

**IN THE UNITED STATES DISTRICT COURT
FOR THE CENTRAL DISTRICT OF CALIFORNIA**



LIGHTSIDE TECHNOLOGIES LLC,

Plaintiff,

v.

TINNOVATE LLC (D/B/A
WESTINGHOUSE ELECTRONICS),

Defendant.

C.A. No. 5:20-cv-00378-CJC-KKx

JURY TRIAL DEMANDED

PLAINTIFF LIGHTSIDE TECHNOLOGIES LLC
SECOND AMENDED COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff Lightside Technologies LLC (“Lightside” or “Plaintiff”) files this Second Amended Complaint for Patent Infringement against Defendant Tinnovate LLC (“Defendant” or “Westinghouse”) based on knowledge to itself and information and belief as to Defendant as follows.

NATURE OF ACTION

1. Pursuant to 35 U.S.C. § 271, this is an action for infringement of U.S. Patent Nos. 5,999,220 (“the ’220 Patent”), 6,370,198 (“the ’198 Patent”), 8,228,979 (“the ’979 Patent”) and 8,842,727 (“the ’727 Patent”) (collectively, the “Patents-in-Suit”).

PARTIES

2. Lightside is a Texas limited liability company with a principal place of business at 700 Lavaca St., Suite 1401, Austin, TX 78701-3101.

3. Defendant Tinnovate LLC (which does business under the name Westinghouse Electronics) is a California company with a regular and established place of business at 6255 Providence Way, Eastvale, CA 92885. Defendant may be served with process via its registered agent, Russell Johnston. Defendant promotes, markets, offers, and sells, *inter alia*, Westinghouse brand televisions in the United States market, including those sold under the Westinghouse and/or Westinghouse Electronics name.

JURISDICTION AND VENUE

4. This action arises under the Patent Act, 35 U.S.C. § 1 *et seq.*

5. Pursuant to 28 U.S.C. §§ 1331 and 1338, this Court has original jurisdiction over the subject matter of this action as it is an action arising under the Patent Laws of the United States.

6. This Court has personal jurisdiction over Defendant as: (i) Defendant conducts business in this Judicial District, directly or through intermediaries; (ii) at least a portion of the alleged infringements occurred in this Judicial District; and (iii) Defendant regularly solicits business, engage in other established and persistent

courses of conduct, or derive revenue from goods and services provided to individuals in this Judicial District.

7. Venue is proper in this Judicial District under 28 U.S.C. § 1400(b) because Defendant has committed acts of infringement within this Judicial District and has an established place of business in this Judicial District.

THE PATENTS-IN-SUIT

8. On December 7, 1999, the USPTO issued the '220 Patent, titled "Wide-Band Multi-Format Audio/Video Production System With Frame-Rate Conversion," to Ken Washino of New Jersey, USA. A true and correct copy of the '220 Patent is provided herewith as Exhibit 1.

9. On April 9, 2002, the USPTO issued the '198 Patent, titled "Wide-Band Multi-Format Audio/Video Production System With Frame-Rate Conversion," to Ken Washino of New Jersey, USA. A true and correct copy of the '198 Patent is provided herewith as Exhibit 2.

10. On July 24, 2012, the USPTO issued the '979 Patent, titled "Wide-Band Multi-Format Audio/Video Production System With Frame-Rate Conversion," to Ken Washino of New Jersey, USA. A true and correct copy of the '979 Patent is provided herewith as Exhibit 3.

11. On September 23, 2014, the USPTO issued the '727 Patent, titled "Wide-Band Multi-Format Audio/Video Production System With Frame-Rate Conversion," to Ken Washino of New Jersey, USA. A true and correct copy of the '727 Patent is provided herewith as Exhibit 4.

12. Plaintiff is the owner and assignee of all substantial rights, title, and interest in the Patents-in-Suit, as evidenced by the recorded assignment submitted herewith as Exhibit 5.

13. The Patents-in-Suit are presumed valid under 35 U.S.C. § 282(a).

BACKGROUND

14. Ken Washino is the inventor of the inventions claimed and disclosed in the Patents-in-Suit.

15. Mr. Washino is the epitome of the ingenious tinkerer who used inventive skills and a deep understanding of the industry to resolve a long-standing problem that succeeded where others had failed.

16. Mr. Washino was born in Aichi Prefecture, Japan, on February 21, 1953. His parents operated a small commercial farm in this rural area. He became interested in communications and electronics at an early age, acquiring an amateur ham radio license by the time he was thirteen years old. During his junior high school and high school years, he built a transmitter and receiver from salvaged parts

of an old tube television. From such experiences, he learned the basics of analog communications.

17. In 1974, Mr. Washino found a position as an audio recording engineer with a Japanese documentary film company working in the U.S. This expanded to other production and post-production tasks. During the years that Mr. Washino worked in this business, he gained a working knowledge of film production and of production and post-production processes.

18. After Mr. Washino returned to Japan, he earned an Electronics Engineering degree from Nihon Kogakuin Technical College in Tokyo in 1979, and in 1981 acquired a first class broadcast engineering license. By that time, Mr. Washino was already working as a camera design engineer for Ikegami, a Japanese manufacturer of high-end video cameras. In 1985, he was appointed Video Field Sales Engineer and sent to the U.S. This experience enabled Mr. Washino to acquire a deep insight into the competitive market for equipment and services and to appreciate the needs of and problems encountered by video professionals. Mr. Washino then decided to establish himself in the U.S. permanently and formed his own video services company, focused on video production, post-production, and video cassette duplication in New York City.

19. By late 1986, Mr. Washino had acquired the market knowledge, technical skills, and financial resources to begin working on some of the ideas he

had to improve efficiency and preserve quality in video field production. He identified the need for a universal camera control system and developed a prototype. Subsequent experimentation with early digital video devices soon led to his 1992 inventions for Video Field Production, Video Monitoring and Conferencing, and PC-Based Audio/Video Production. In 1989, Mr. Washino began working on high-speed video duplication and filed his first patent application in 1993.

20. From then on, Mr. Washino developed a long series of inventions related to video production, post-production and signal distribution that could accommodate the coming digital and High-Definition “multiple format” future.

21. By October 2014, Mr. Washino had been granted twenty U.S. patents on inventions for which he is the inventor or co-inventor, with fourteen foreign equivalents.

22. The Washino '220, '198, '979 and '727 Patents are each and all directed to the field of video production, image processing, and computer graphics. The inventions disclosed in these Patents-in-Suit relates to a multi-format digital video production method and system.

23. The claims of the Patents-in-Suit recite inventive concepts such as the use of specialized high-capacity digital video storage memory and the process of performing frame rate conversion, such as such memory for supporting asynchronous program recording/writing and reproducing/reading capability for

transforming lower pixel dimension (*i.e.*, lower resolution) video programs having lower frequency sampling rates into higher pixel dimension (*i.e.*, high definition and ultra-high definition) video programs having higher frequency sampling rates.

24. Upon information and belief, Defendant made, sold, offered for sale, used, and/or imported products in the United States that implement the inventive concept of the Patents-in-Suit, including UHDTVs and HDTVs, including Westinghouse brand UHDTV/HDTVs with MEMC technology, e.g., Westinghouse Smart 4K Ultra High-Definition (UHD) LED television product lines, and other non-MEMC Westinghouse television product lines, including, but not limited to, Westinghouse WD32HB1120 televisions (referred to as “Accused Products”).

COUNT I
INFRINGEMENT OF U.S. PATENT NO. 5,999,220

25. Plaintiff incorporates by reference each of its foregoing allegations.

26. Without license or authorization and in violation of 35 U.S.C. § 271(a), on information and belief, Defendant directly infringed one or more claims of the '220 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by making, using, selling, offering for sale, and/or importing their Accused Products, and/or induced infringement or engage in contributory infringement by such actions with their Accused Products, that performs all of the limitations of the asserted claims.

27. On information and belief, Defendant has known of the '220 Patent and that use of their Accused Products results in direct infringement of one or more claims of the '220 Patent, and Defendant has engaged in actions which have knowingly resulted in such direct infringement.

28. Without license or authorization and in violation of 35 U.S.C. § 271(b), on information and belief, Defendant infringed one or more claims of the '220 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by actively inducing direct infringement of the '220 Patent via end-user use of their Accused Products, which, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, results in use of a device having all of the limitations of the asserted claims.

29. Without license or authorization and in violation of 35 U.S.C. § 271(c), on information and belief, Defendant indirectly infringed one or more claims of the '220 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, through offers to sell or sales within the United States or imports into the United States of one or more component(s) of an apparatus for use in practicing the methods of the '220 Patent claims and constituting a material part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of the '220 Patent claims, and not an article or commodity

suitable for substantial non-infringing use, wherein Defendant's Accused Products, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, results in use of a device having all of the limitations of the asserted claims.

COUNT II
INFRINGEMENT OF U.S. PATENT NO. 6,370,198

30. Plaintiff incorporates by reference each of its foregoing allegations.

31. Without license or authorization and in violation of [35 U.S.C. § 271\(a\)](#), on information and belief, Defendant directly infringed one or more claims of the '198 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by making, using, selling, offering for sale, and/or importing their Accused Products, and/or induced infringement or engage in contributory infringement by such actions with their Accused Products, that performs all of the limitations of the asserted claims.

32. On information and belief, Defendant has known of the '198 Patent and that use of their Accused Products results in direct infringement of one or more claims of the '198 Patent, and Defendant has engaged in actions which have knowingly resulted in such direct infringement.

33. Without license or authorization and in violation of [35 U.S.C. § 271\(b\)](#), on information and belief, Defendant infringed one or more claims of the '198 Patent in this Judicial District and throughout the United States, literally or under the

doctrine of equivalents, by actively inducing direct infringement of the '198 Patent via end-user use of their Accused Products, which, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, results in such end-users performing all of the limitations of the asserted claims.

34. Without license or authorization and in violation of 35 U.S.C. § 271(c), on information and belief, Defendant indirectly infringed one or more claims of the '198 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, through offers to sell or sales within the United States or imports into the United States of one or more component(s) of an apparatus for use in practicing the methods of the '198 Patent claims and constituting a material part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of the '198 Patent claims, and not an article or commodity suitable for substantial non-infringing use, wherein Defendant's Accused Products, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, result in such end-users performing all of the limitations of the asserted claims.

COUNT III
INFRINGEMENT OF U.S. PATENT NO. 8,228,979

35. Plaintiff incorporates by reference each of its foregoing allegations.

36. Without license or authorization and in violation of 35 U.S.C. § 271(a), on information and belief, Defendant directly infringed one or more claims of the '979 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by making, using, selling, offering for sale, and/or importing their Accused Products, and/or induced infringement or engage in contributory infringement by such actions with their Accused Products, that performs all of the limitations of the asserted claims.

37. On information and belief, Defendant has known of the '979 Patent and that use of their Accused Products results in direct infringement of one or more claims of the '979 Patent, and Defendant has engaged in actions which have knowingly resulted in such direct infringement.

38. Without license or authorization and in violation of 35 U.S.C. § 271(b), on information and belief, Defendant infringed one or more claims of the '979 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by actively inducing direct infringement of the '979 Patent via end-user use of their Accused Products, which, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, results in such end-users performing all of the limitations of the asserted claims.

39. Without license or authorization and in violation of 35 U.S.C. § 271(c), on information and belief, Defendant indirectly infringed one or more claims of the '979 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, through offers to sell or sales within the United States or imports into the United States of one or more component(s) of an apparatus for use in practicing the methods of the '979 Patent claims and constituting a material part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of the '979 Patent claims, and not an article or commodity suitable for substantial non-infringing use, wherein Defendant's Accused Products, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, result in such end-users performing all of the limitations of the asserted claims.

COUNT IV
INFRINGEMENT OF U.S. PATENT NO. 8,842,727

40. Plaintiff incorporates by reference each of its foregoing allegations.

41. Without license or authorization and in violation of 35 U.S.C. § 271(a), on information and belief, Defendant directly infringed one or more claims of the '727 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by making, using, selling, offering for sale, and/or importing their Accused Products, and/or induced infringement or engage in

contributory infringement by such actions with their Accused Products, that performs all of the limitations of the asserted claims.

42. On information and belief, Defendant has known of the '727 Patent and that use of their Accused Products results in direct infringement of one or more claims of the '727 Patent, and Defendant has engaged in actions which have knowingly resulted in such direct infringement.

43. Without license or authorization and in violation of 35 U.S.C. § 271(b), on information and belief, Defendant infringed one or more claims of the '727 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, by actively inducing direct infringement of the '727 Patent via end-user use of their Accused Products, which, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, results in such end-users performing all of the limitations of the asserted claims.

44. Without license or authorization and in violation of 35 U.S.C. § 271(c), on information and belief, Defendant indirectly infringed one or more claims of the '727 Patent in this Judicial District and throughout the United States, literally or under the doctrine of equivalents, through offers to sell or sales within the United States or imports into the United States of one or more component(s) of an apparatus for use in practicing the methods of the '727 Patent claims and constituting a material

part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of the '727 Patent claims, and not an article or commodity suitable for substantial non-infringing use, wherein Defendant's Accused Products, when used in normal operation and as prescribed by written operational guidance for the Accused Products as provided by Defendant, result in such end-users performing all of the limitations of the asserted claims.

45. Plaintiff reserves the right to modify its infringement theories as discovery progresses in this case; it shall not be estopped for infringement contentions or claim construction purposes by the claim charts that it provides with this Complaint. The claim charts are intended to satisfy the notice requirements of Rule 8(a)(2) of the Federal Rule of Civil Procedure; they do not represent Plaintiff's preliminary or final infringement contentions or preliminary or final claim construction positions.

PRAYER FOR RELIEF

Plaintiff requests the following relief:

A. That this Court enter a Judgment that Defendant has infringed the Patents-in-Suit under 35 U.S.C. § 271;

B. An accounting of all infringing acts including, but not necessarily limited to, those acts presented before this Court;

C. Pursuant to 35 U.S.C. § 284, an Order for an award of damages adequate to compensate Plaintiff for Defendant's infringement, and in no event less than a reasonable royalty, together with interest and costs;

D. Award reasonable attorneys' fees, costs, and expenses incurred by Plaintiff in prosecuting this action, pursuant to 35 U.S.C. § 285; and

E. Award such other and further relief at law or in equity that this Court deems just and proper.

JURY TRIAL DEMAND

Plaintiff demands a trial by jury on all claims and issues so triable under Federal Rule of Civil Procedure 38(b).

Dated: June 23, 2020

Respectfully Submitted,

WEIDE & MILLER, LTD.,

/s/ R. Scott Weide

R. Scott Weide (CA Bar No. 155998)
sweide@weidemiller.com
10655 Park Run Drive, Suite 100
Las Vegas, NV 89144
Tel: 702-382-4804
Fax: 702-382-4805

Counsel for Plaintiff
LIGHTSIDE TECHNOLOGIES, LLC

EXHIBIT 1

EXHIBIT 1

United States Patent [19]

[11] Patent Number: **5,999,220**

Washino

[45] Date of Patent: **Dec. 7, 1999**

- [54] **MULTI-FORMAT AUDIO/VIDEO PRODUCTION SYSTEM WITH FRAME-RATE CONVERSION**
- [76] Inventor: **Kinya Washino**, 750 Huyler St., Peterborough, N.J. 07608
- [21] Appl. No.: **08/834,912**
- [22] Filed: **Apr. 7, 1997**
- [51] Int. Cl.⁶ **H04N 5/46; H04N 7/01**
- [52] U.S. Cl. **348/441; 348/722; 348/445; 348/555; 348/556**
- [58] Field of Search 348/441, 445, 348/448, 426, 432, 454, 558, 568, 555-556, 722, 911, 575; 358/527, 524; H04N 5/46, 7/01, 5/262, 5/253

OTHER PUBLICATIONS

- G. Demos, "An Example of Hierarchy of Formats for HDTV," SMPTE Journal, Sep. 1992, pp. 609-617.
- J.S. Lim, "A Proposal for an HDTV/ATV Standard with Multiple Transmission Formats," SMPTE Journal, Aug. 1993, pp. 699-702.
- W.E. Bretl, "3SNTSC-A 'Leapfrog' Production Standard for HDTV," SMPTE Journal, Mar. 1989, pp. 173-178.
- B. Hunt, G. Kennel, L. DeMarsh, S. Kristy, "High-Resolution Electronic Intermediate System for Motion-Picture Film," SMPTE Journal, Mar. 1991, pp. 156-161.

(List continued on next page.)

Primary Examiner—Vu Le
 Attorney, Agent, or Firm—Gifford, Krass, Groh, Sprinkle, Anderson & Citkowski, PC

[56] References Cited

U.S. PATENT DOCUMENTS

4,633,293	12/1986	Powers	348/441
5,045,932	9/1991	Sharman et al.	358/527
5,243,433	9/1993	Hailey	348/445
5,327,235	7/1994	Richards	348/441
5,331,346	7/1994	Shields et al.	348/441
5,384,598	1/1995	Rodriguez et al.	348/441
5,444,491	8/1995	Lim	348/441
5,519,438	5/1996	Elliott et al.	348/441
5,532,749	7/1996	Hong	348/441
5,537,157	7/1996	Washino et al.	348/722
5,600,377	2/1997	David et al.	348/441
5,608,464	3/1997	Woodham	348/441
5,617,218	4/1997	Rhodes	348/441
5,701,383	12/1997	Russo et al.	386/46
5,724,101	3/1998	Haskin	348/441
5,754,248	5/1998	Faroudja	348/441
5,771,073	6/1998	Lim	348/441
5,812,204	9/1998	Baker et al.	348/441
5,832,085	11/1998	Inoue et al.	348/441
5,835,150	11/1998	Choi	348/441
5,838,381	11/1998	Kasahara et al.	348/441

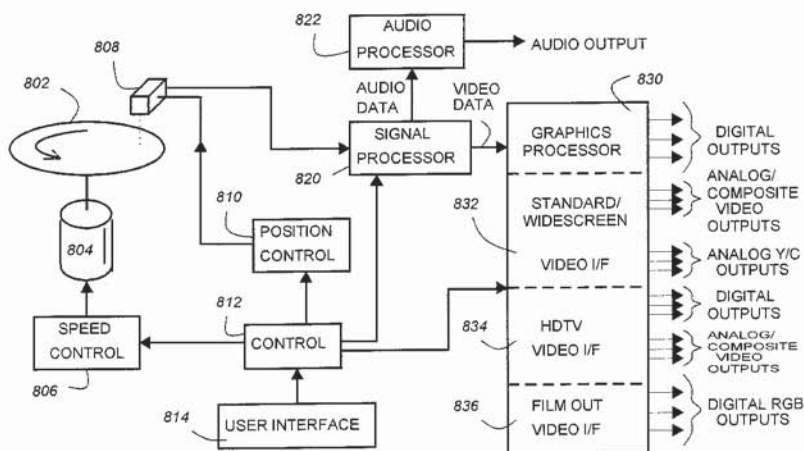
FOREIGN PATENT DOCUMENTS

314873	5/1989	European Pat. Off.	H04N 5/46
514012	11/1992	European Pat. Off.	H04N 7/01
WO93/15586	8/1993	WIPO	H04N 7/01

[57] ABSTRACT

An audio/video production system facilitates professional quality image manipulation and editing. A program input may be translated into any of a variety of graphics or television formats, including NTSC, PAL, SECAM and HDTV, and stored as data-compressed images, using any of several commercially available methods such as Motion JPEG, MPEG, etc. While being processed, the images may be re-sized to produce a desired aspect ratio or dimensions using conventional techniques such as pixel interpolation, and signals within the video data stream optionally may be utilized to control "pan/scan" operations at a receiving video display unit, in case this unit does not have the same aspect ratio as the source signal. Other information may be utilized to restrict playback of the program material based on predetermined regional or geographical criteria. Frame rate conversion to and from conventional formats is performed by using the prevailing techniques employed for film-to-NTSC and film-to-PAL transfers, or by inter-frame interpolation, all well known in the art, or by reproduction of the program at a selected non-standard frame rate, optionally combined with these prevailing techniques. By judicious selection of the optimal digitizing parameters, the system allows a user to establish an inter-related family of aspect ratios, resolutions, and frame rates, yet remain compatible with currently available and planned graphics and television formats.

27 Claims, 9 Drawing Sheets



5,999,220

Page 2

OTHER PUBLICATIONS

A. Kaiser, H. Mahler, R. McMann, "Resolution Requirements for HDTV Based Upon the Performance of 35mm Motion-Picture Films for Theatrical Viewing," SMPTE Journal, Jun. 1985, pp. 654-659.

Y. Ide, M. Sasuga, N. Harada, T. Nishizawa, "A Three-CCD HDTV Color Camera," SMPTE Journal, Jul. 1990, pp. 532-537.

G. Reitmeier, C. Carlson, E. Geiger, D. Westerkamp, "The Digital Hierarchy—A Blueprint for Television in the 21st Century," SMPTE Journal, Jul. 1992, pp. 466-470.

L. Thorpe, T. Hanabusa, "If Progressive Scanning is So Good, How Bad is Interlace?," SMPTE Journal, Dec. 1990, p. 972-86.

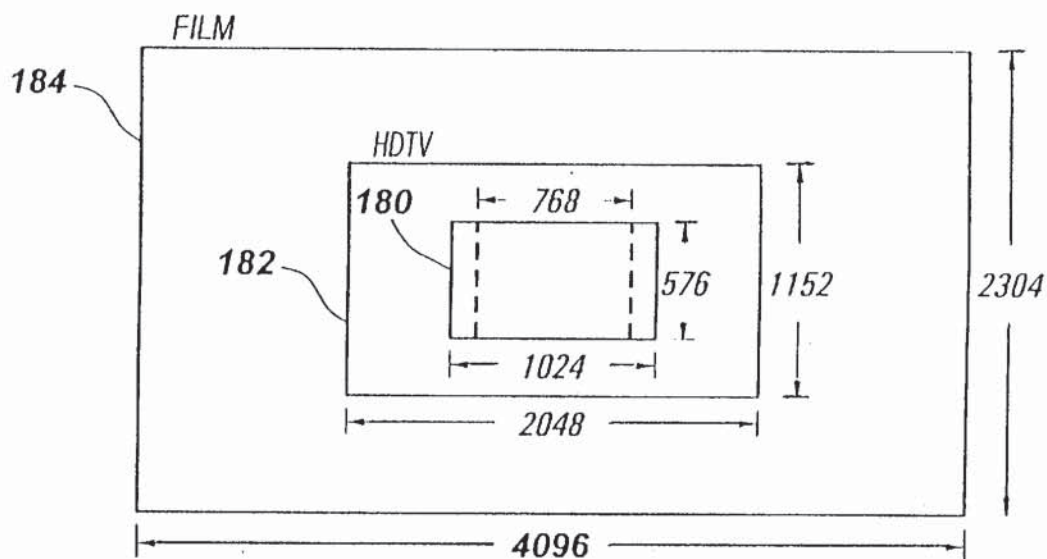


Figure 1a

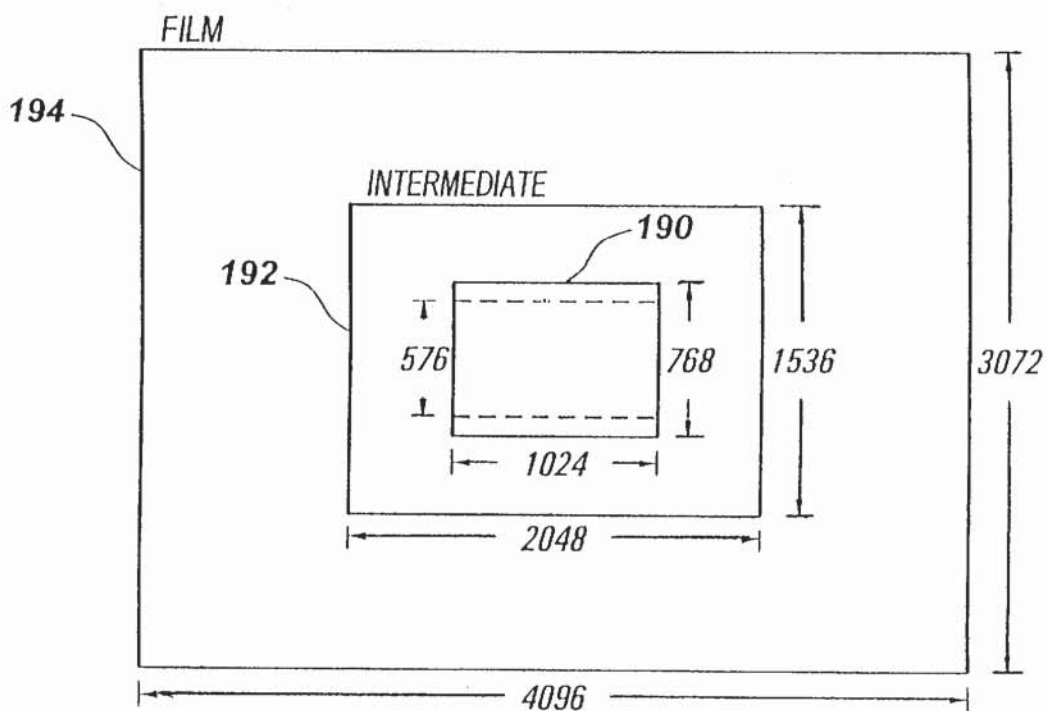


Figure 1b

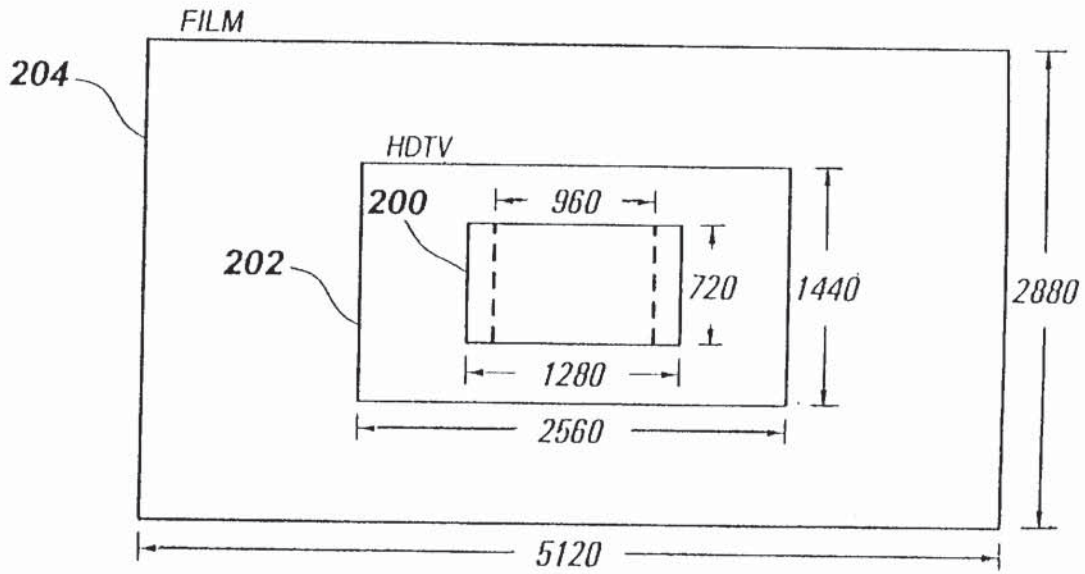


Figure 1c

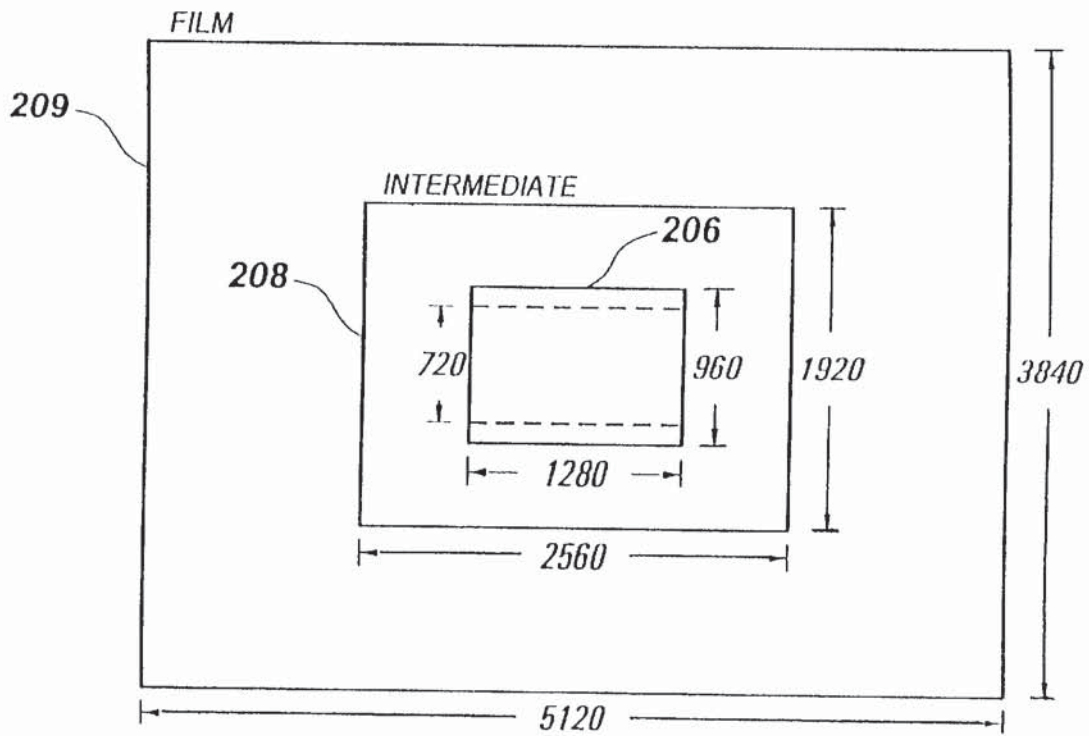


Figure 1d

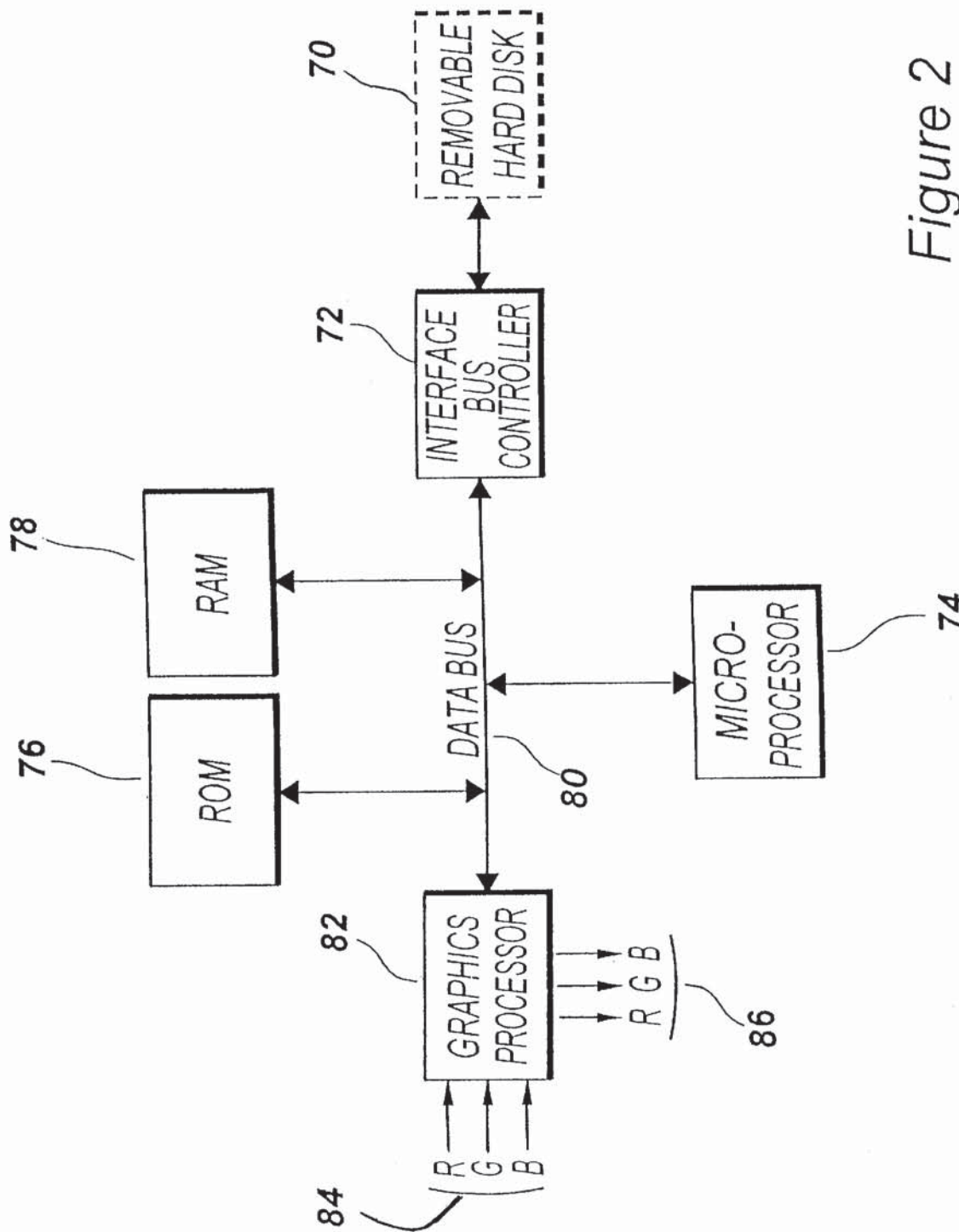


Figure 2

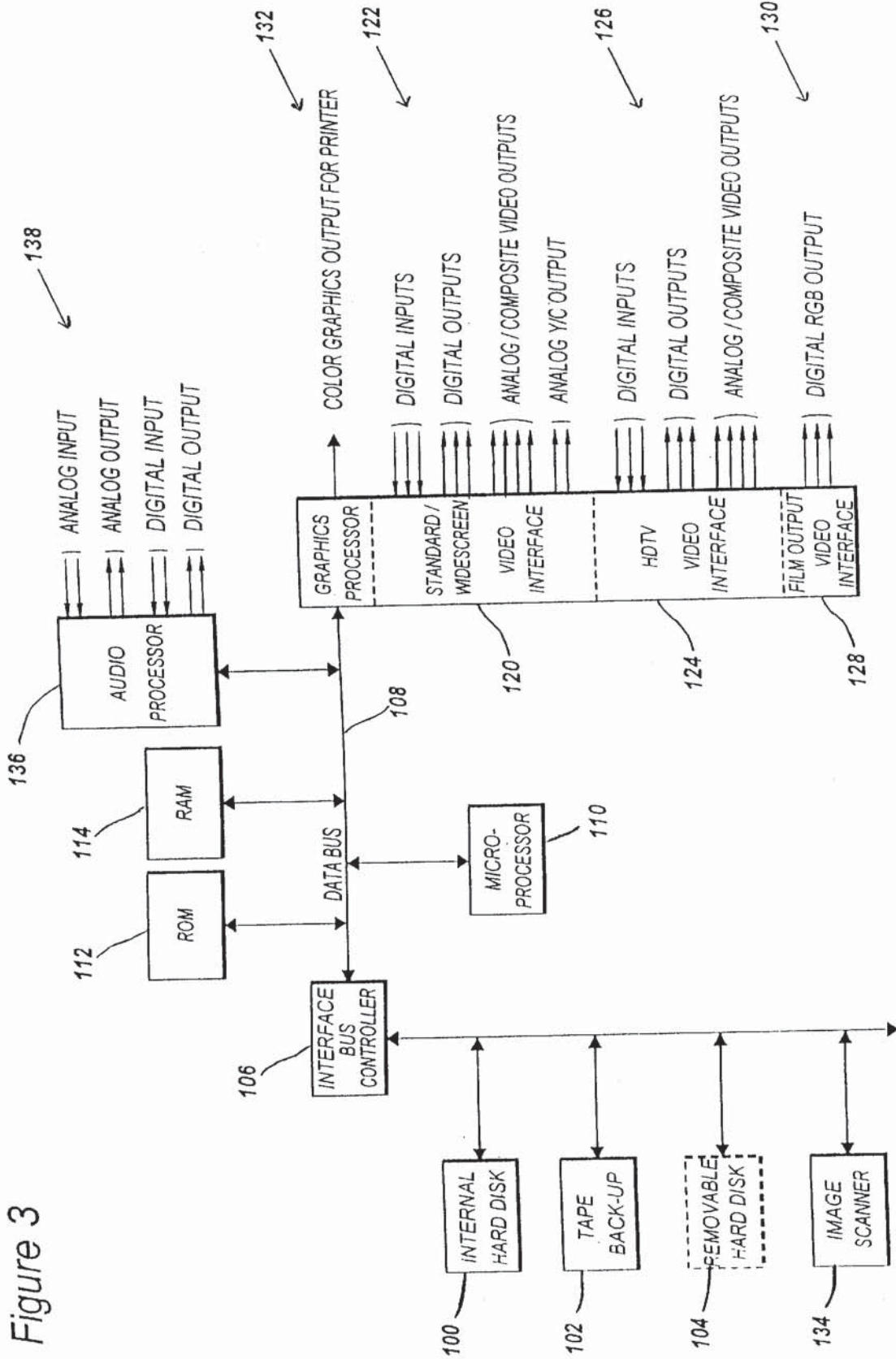


Figure 3

Figure 4

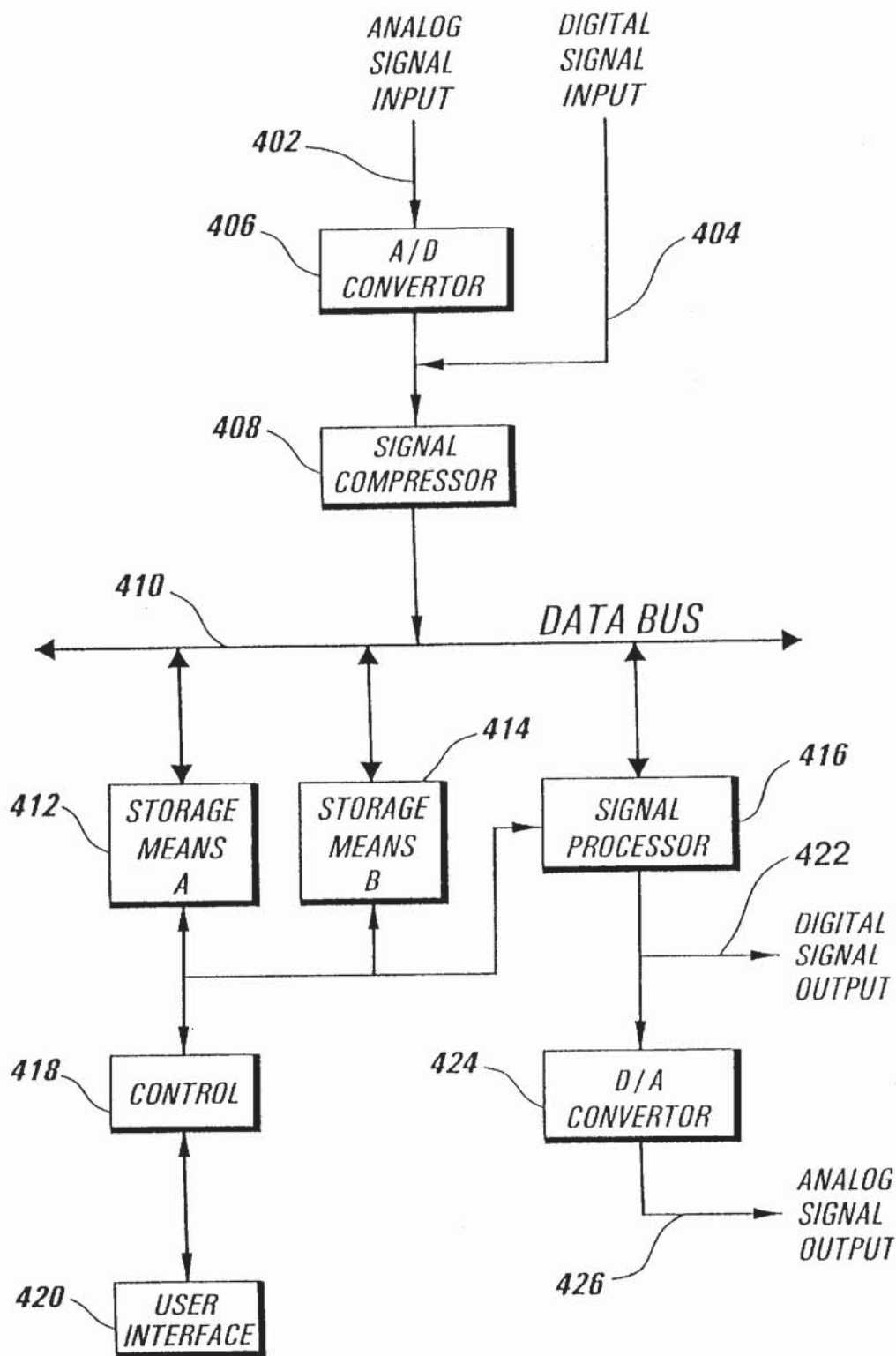


Figure 5

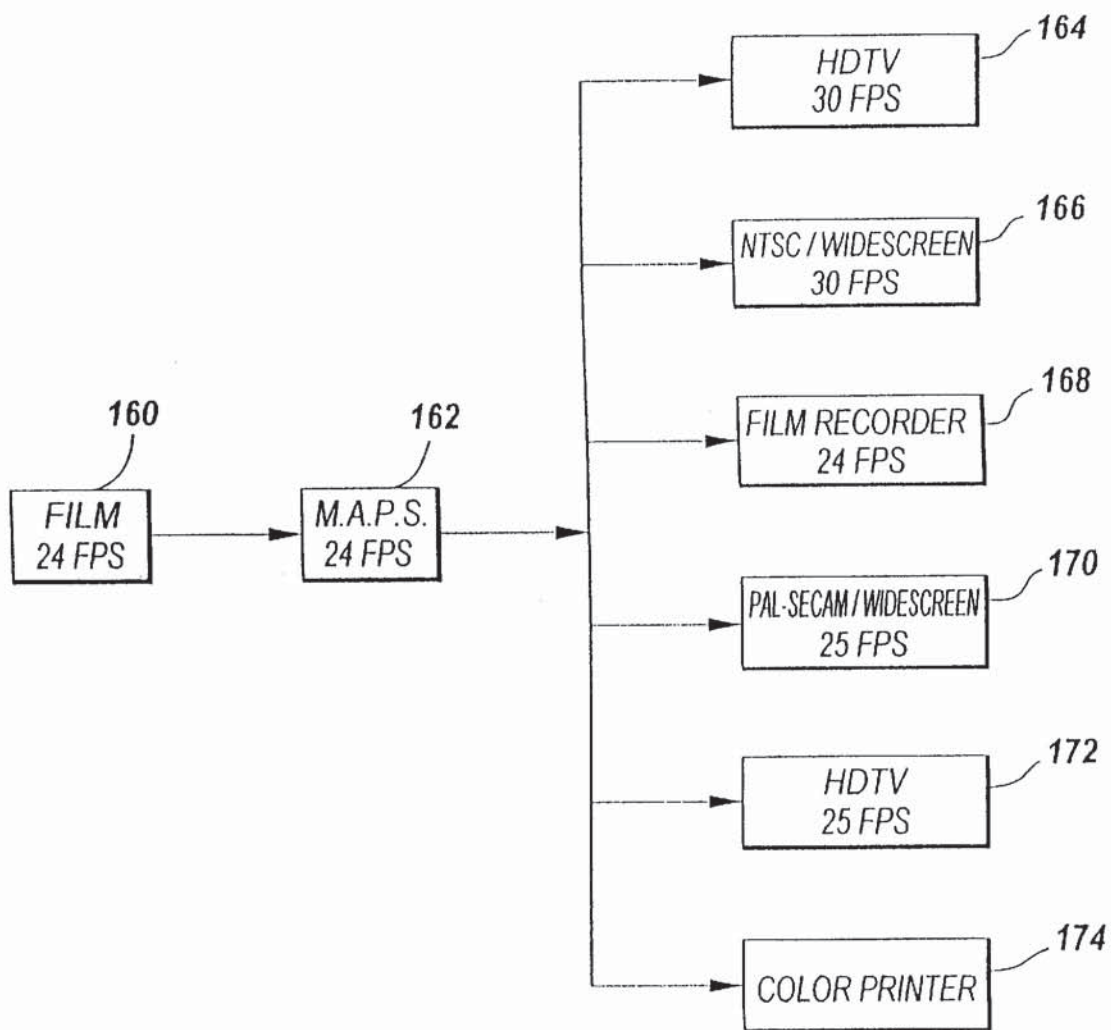


Figure 6

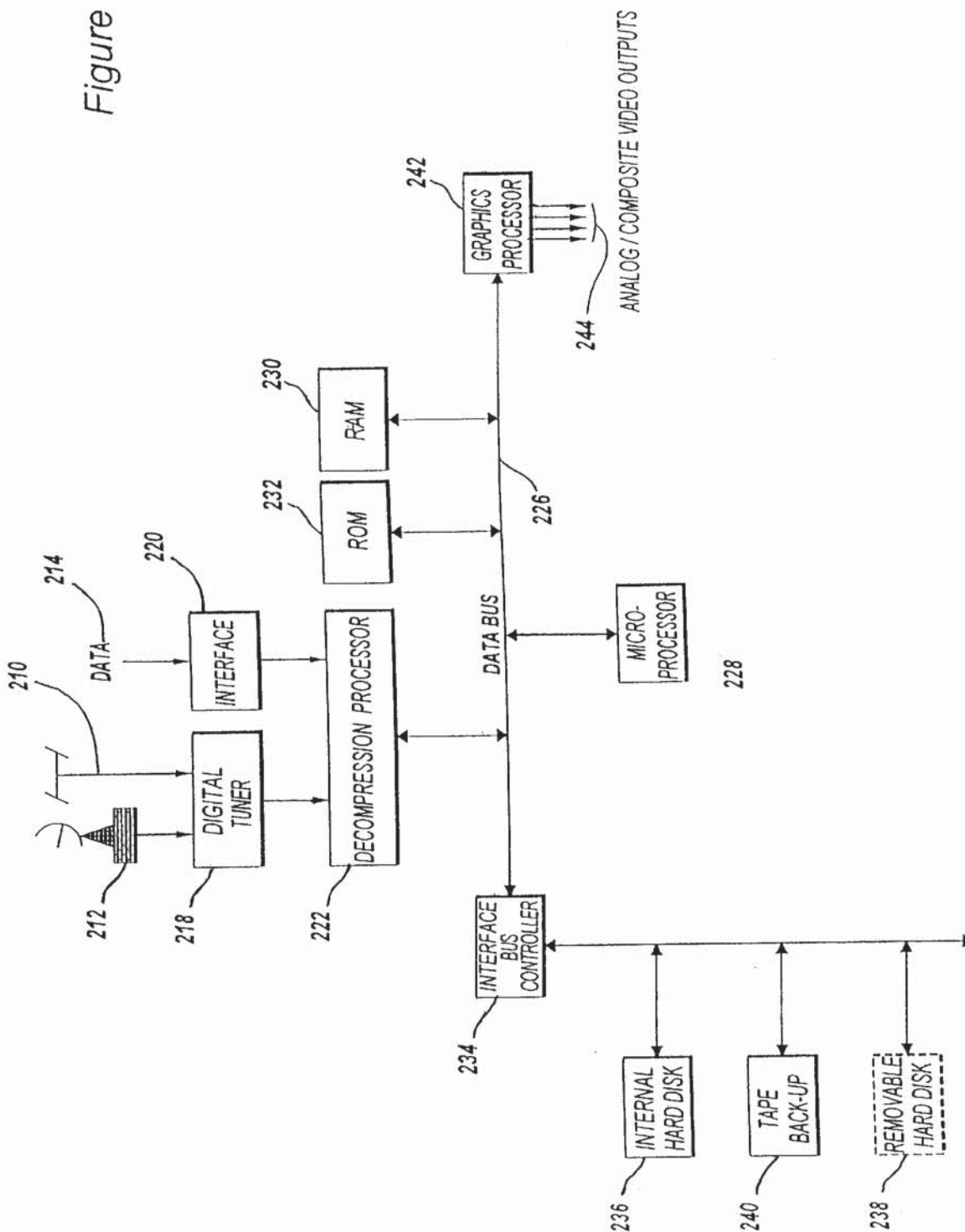
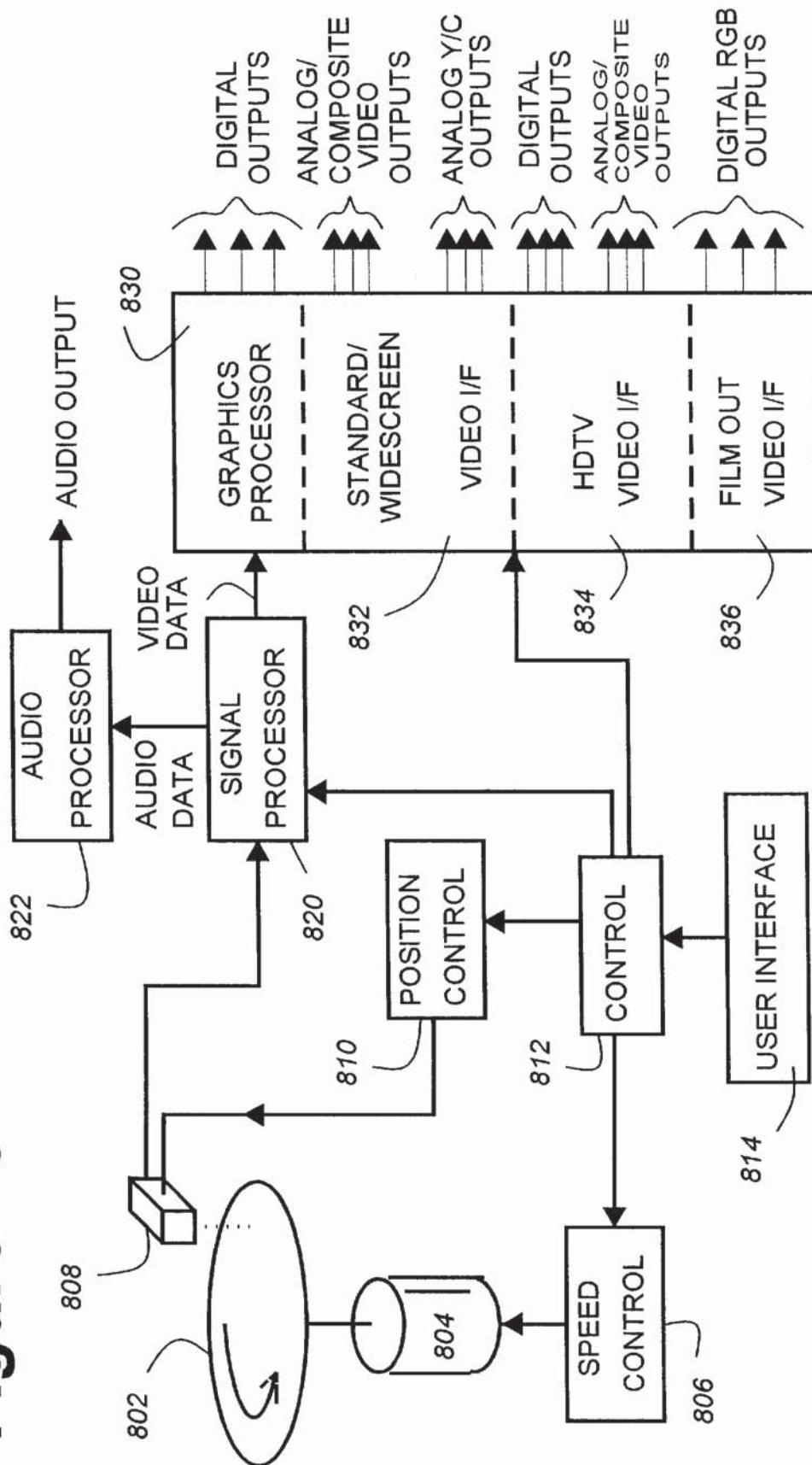


Figure - 7

OUTPUT SOURCE	24	25	30
24	X	SPEED-UP	3:2 PULL-DOWN
25	SLOW-DOWN	X	SLOW-DOWN & 3:2 PULL-DOWN
30	2:3 PULL-DOWN	2:3 PULL-DOWN & SPEED-UP	X

Figure - 8



**MULTI-FORMAT AUDIO/VIDEO
PRODUCTION SYSTEM WITH FRAME-
RATE CONVERSION**

FIELD OF THE INVENTION

This invention relates generally to video production, photographic image processing, and computer graphics design, and, more particularly, to a multi-format video production system capable of professional quality editing and manipulation of images intended for television and other applications, including HDTV programs.

BACKGROUND OF THE INVENTION

As the number of television channels available through various program delivery methods (cable TV, home video, broadcast, etc.) continues to proliferate, the demand for programming, particularly high-quality HDTV-format programming, presents special challenges, both technical and financial, to program producers. While the price of professional editing and image manipulation equipment continues to increase, due to the high cost of research and development and other factors, general-purpose hardware, including personal computers, can produce remarkable effects at a cost well within the reach of non-professionals, even novices. As a result, the distinction between these two classifications of equipment has become less well defined. Although general-purpose PC-based equipment may never allow professional-style rendering of images at full resolution in real-time, each new generation of microprocessors enables progressively faster, higher-resolution applications. In addition, as the price of memory circuits and other data storage hardware continues to fall, the capacity of such devices has risen dramatically, thereby improving the prospects for enhancing PC-based image manipulation systems for such applications.

In terms of dedicated equipment, attention has traditionally focused on the development of two kinds of professional image-manipulation systems: those intended for the highest quality levels to support film effects, and those intended for television broadcast to provide "full 35 mm theatrical film quality," within the realities and economics of present broadcasting systems. Conventional thinking holds that 35 mm theatrical film quality as projected in theaters is equivalent to 1200 or more lines of resolution, whereas camera negatives present 2500 or more lines. As a result, image formats under consideration have been directed towards video systems having 2500 or more scan lines for high-level production, with hierarchies of production, HDTV broadcast, and NTSC and PAL compatible standards which are derived by down-converting these formats. Most proposals employ progressive scanning, although interlace is considered an acceptable alternative as part of an evolutionary process. Another important issue is adaptability to computer-graphics-compatible formats.

Current technology directions in computers and image processing should allow production equipment based upon fewer than 1200 scan lines, with picture expansions to create a hierarchy of upward-converted formats for theatrical projection, film effects, and film recording. In addition, general-purpose hardware enhancements should be capable of addressing the economic aspects of production, a subject not considered in detail by any of the available references.

SUMMARY OF THE INVENTION

The present invention takes advantage of general-purpose hardware where possible to provide an economical multi-

format video production system. In the preferred embodiment, specialized graphics processing capabilities are included in a high-performance personal computer or workstation, enabling the user to edit and manipulate an input video program and produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format is chosen which provides the greatest compatibility with existing and planned formats associated with standard and widescreen television, high-definition television, and film. For compatibility with film, the frame rate of the internal production format is preferably 24 fps. Images are re-sized by the system to larger or smaller dimensions so as to fill the particular needs of individual applications, and frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions; simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) of playback; or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities.

The invention comprises a plurality of interface units, including a standard/widescreen interface unit operative to convert the video program in the input format into an output signal representative of a standard/widescreen formatted image, and output the signal to an attached display device. A high-definition television interface unit is operative to convert the video program in the input format into an output signal representative of an HDTV-formatted image, and output the signal to the display device. A centralized controller in operative communication with the video program input, the graphics processor, and an operator interface, enables commands entered by an operator to cause the graphics processor to perform one or more of the conversions using the television interfaces. The present invention thus encourages production at relatively low pixel dimensions to make use of lower-cost general-purpose hardware and to maintain high signal-to-noise, then subsequently expands the result into a higher-format final program. This is in contrast to competing approaches, which recommend operating at higher resolution, then down-sizing, if necessary, to less expensive formats, which has led to the expensive dedicated hardware, the need for which the present invention seeks to eliminate. In addition, the flexible storage and playback facilities allow extensive control of the playback of the program material, enabling frame rate adjustments and alterations, and providing for time-shifting of the start and end points of the program reproduction in those cases wherein direct control of the source material frame rate is not practical, due to physical separation of the equipment or multiple reception points simultaneously producing outputs at different frame rates from the same source signal playback data stream. In commercial implementations, the invention readily accepts and processes enhanced information, such as pan/scan information or identification information to restrict viewing based on regional or geographical marketing plans.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D show the preferred and alternative image aspect ratios in pixels;

FIG. 2 shows a functional diagram for disk-based video recording;

FIG. 3 shows the components comprising the multi-format audio/video production system;

FIG. 4 is a block diagram of an alternative embodiment of video program storage means incorporating asynchronous reading and writing capabilities to carry out frame-rate conversions;

FIG. 5 shows the inter-relationship of the multi-format audio/video production system to many of the various existing and planned video formats;

FIG. 6 shows the implementation of a complete television production system, including signals provided by broadcast sources, satellite receivers, and data-network interfaces;

FIG. 7 shows the preferred methods for conversion between several of the most common frame-rate choices; and

FIG. 8 shows a block diagram of an embodiment of a universal playback device for multi-format use.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is primarily concerned with the conversion of disparate graphics or television formats, including requisite frame-rate conversions, to establish an inter-related family of aspect ratios, resolutions, and frame rates, while remaining compatible with available and future graphics/TV formats. These formats include images of pixel dimensions capable of being displayed on currently available multi-scan computer monitors, and custom hardware will be described whereby frames of higher pixel-count beyond the capabilities of these monitors may be viewed. Images are re-sized by the system to larger or smaller dimensions so as to fill the particular needs of individual applications, and frame rates are adapted by inter-frame interpolation or by traditional schemes such as using "3:2 pull-down" (for 24 to 30 frame-per-second film-to-NTSC conversions) or by speeding up the frame rate itself (as for 24 to 25 fps for PAL television display). The re-sizing operations may involve preservation of the image aspect ratio, or may change the aspect ratio by "cropping" certain areas, by performing non-linear transformations, such as "squeezing" the picture, or by changing the vision center for "panning," "scanning" and so forth. Inasmuch as film is often referred to as "the universal format," (primarily because 35-mm film equipment is standardized and used throughout the world), the preferred internal or "production" frame rate is preferably 24 fps. This selection also has an additional benefit, in that the 24 fps rate allows the implementation of cameras having greater sensitivity than at 30 fps, which is even more critical in systems using progressive scanning (for which the rate will be 48 fields per second vs. 60 fields per second in some other proposed systems).

The image dimensions chosen allow the use of conventional CCD-type cameras, but the use of digital processing directly through the entire signal chain is preferred, and this is implemented by replacing the typical analog RGB processing circuitry with fully digital circuitry. Production effects may be conducted in whatever image size is appropriate, and then re-sized for recording. Images are recorded by writing the digital data to storage devices employing removable hard-disk drives, disk drives with removable media, optical or magneto-optical based drives, tape-based drives, or semiconductor-based memory devices, preferably in compressed-data form. As data rates for image processing and reading-from- or writing-to- disk drives increase, many processes that currently require several seconds will soon become attainable in real-time; this will eliminate the need to record film or video frames at slower rates. Other production effects, such as slow-motion or fast-motion may be incorporated, and it is only the frame-processing-rate of these effects that is limited in any way by the technology of the day. In particular, techniques such as non-linear-editing, animation, and special-effects will ben-

efit from the implementation of this system. In terms of audio, the data rate requirements are largely a function of sound quality. The audio signals may be handled separately, as in an "interlocked" or synchronized system for production, or the audio data may be interleaved within the video data stream. The method selected will depend on the type of production manipulations desired, and by the limitations of the current technology.

Although a wide variety of video formats and apparatus configurations are applicable to the present invention, the system will be described in terms of the alternatives most compatible with currently available equipment and methods. FIG. 1A illustrates one example of a compatible system of image sizes and pixel dimensions. The selected frame rate is preferably 24 per second (2:1 interlaced), for compatibility with film elements; the selected picture dimension in pixels is preferably 1024x576 (0.5625 Mpxl), for compatibility with the 16:9 "wide-screen" aspect ratio anticipated for HDTV systems, and the conventional 4:3 aspect ratio used for PAL systems [768x576 (0.421875 Mpxl)]. All implementations preferably rely on square pixels, though other pixel shapes may be used. Re-sizing (using the well known, sophisticated sampling techniques available in many image-manipulation software packages or, alternatively, using hardware circuitry described herein below) to 2048x1152 (2.25 Mpxl) provides an image suitable for HDTV displays or even theatrical projection systems, and a further re-sizing to 4096x2304 (9.0 Mpxl) is appropriate for even the most demanding production effects. Images may be data compressed 5:1 for 16:9 "wide-screen" TV frames, or 10:1 for HDTV; the data files may then be stored on conventional disk drives, requiring only approximately 8.1 MB/sec for wide-screen frames in RGB, and only 16.1 MB/sec for HDTV frames in RGB.

An alternative embodiment of the invention is shown in FIG. 1B. In this case, the user would follow a technique commonly used in film production, in which the film is exposed as a 4:3 aspect ratio image. When projected as a wide-screen format image, the upper and lower areas of the frame may be blocked by an aperture plate, so that the image shows the desired aspect ratio (typically 1.85:1 or 1.66:1). If the original image format were recorded at 24 frames per second, with a 4:3 ratio and with a dimension in pixels of 1024x768, all image manipulations would preserve these dimensions. Complete compatibility with the existing formats would result, with NTSC and PAL images produced directly from these images by re-scaling, and the aforementioned wide-screen images would be provided by excluding 96 rows of pixels from the top of the image and 96 rows of pixels from the bottom of the image, resulting in the 1024x576 image size as disclosed above. The data content of each of these frames would be 0.75 Mpxls, and the data storage requirements disclosed above would be affected accordingly.

Another embodiment of the invention is depicted in FIG. 1C. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats under consideration by the Advanced Television Study Committee of the Federal Communications Commission. The format to be adopted is expected to assume a wide-screen image having dimensions of 1280x720 pixels. Using these image dimensions (but at 24 fps with 2:1 interlace), compatibility with the existing formats would be available, with NTSC and PAL images derived from this frame size by excluding 160 columns of pixels from each side of the image, thereby resulting in an image having a dimension in pixels of 960x720. This new image would then

5,999,220

5

be re-scaled to produce images having pixel dimensions of 640×480 for NTSC, or 768×576 for PAL; the corresponding wide-screen formats would be 854×480 and 1024×576, respectively. In this case, an image having a dimension in pixels of 1280×720 would contain 0.87890625 Mpxl, with 1,000 TV lines of resolution; furthermore, the systems under evaluation by the ATSC of the FCC also assume a decimation of the two chrominance signals, with detail of only 640×360 pixels retained. The data storage requirements disclosed above would be affected accordingly. The development path to 24 fps with progressive scanning is both well-defined and practical, as is the use of the previously described methods to produce images having a dimension in pixels of 2048×1152.

A further alternative embodiment of the invention is shown in FIG. 1D. As with the system described with reference to FIG. 1B, the user follows the technique commonly used in film production, wherein the film is exposed as a 4:3 aspect ratio image. When projected as a wide-screen format image, the upper and lower areas of the frame area again blocked by an aperture plate, so that the image shows the desired aspect ratio (typically 1.85:1 or 1.66:1). For an original image format recorded at 24 frames per second, with 4:3 ratio and with pixel dimensions of 1280×960, all image manipulations preserve these dimensions. Complete compatibility with the existing formats results, with NTSC and PAL images produced directly from these images by resealing, and the aforementioned wide-screen images are provided by excluding 120 rows of pixels from the top of the image and 120 rows of pixels from the bottom of the image, thereby resulting in the 1280×720 image size as described above. The data content of each of these frames is 0.87890625 Mpxls, and the data storage requirements disclosed above are affected accordingly.

In each of the cases described herein above, a positioning or image centering signal may be included within the data stream, so as to allow the inclusion of information which may be utilized by the receiving unit or display monitor to perform a "pan/scan" operation, and thereby to optimize the display of a signal having a different aspect ratio than that of the display unit. For example, a program transmitted in a wide-screen format would include information indicating the changing position of the image center, so that a conventional (4:3 aspect ratio) display unit would automatically pan to the proper location. For the display of the credits or special panoramic views, the monitor optionally could be switched to a full "letter-box" display, or the image could be centered and rescaled to include information corresponding to an intermediate situation, such as halfway between full-height (with cropped sides) and letter-box (full-width, but with blank spaces above and below the image on the display). This positioning/rescaling information would be determined under operator control (as is typical for pan/scan operations when performing film transfers to video) so as to maintain the artistic values of the original material, within the limitations of the intended display format.

Conventional CCD-element cameras produce images of over 800 TV Lines horizontal Luminance (Y) resolution, with a sensitivity of 2,000 lux at f8, and with a signal-to-noise ratio of 62 dB. However, typical HDTV cameras, at 1,000 TV Lines resolution and with similar sensitivity, produce an image with only a 54 dB signal-to-noise ratio, due to the constraints of the wideband analog amplifiers and the smaller physical size of the CCD-pixel-elements. By employing the more conventional CCD-elements in the camera systems of this invention, and by relying upon the computer to create the HDTV-type image by image

6

re-sizing, the improved signal-to-noise ratio is retained. In the practical implementation of cameras conforming to this new design approach, there will be less of a need for extensive lighting provisions, which in turn, means less demand upon the power generators in remote productions, and for AC-power in studio applications.

In CCD-based cameras, it is also a common technique to increase the apparent resolution by mounting the red and blue CCD-elements in registration, but offsetting the green CCD-element by one-half pixel width horizontally. In this case, picture information is in-phase, but spurious information due to aliasing is out-of-phase. When the three color signals are mixed, the picture information is intact, but most of the alias information will be canceled out. This technique will evidently be less effective when objects are of solid colors, so it is still the usual practice to include low-pass optical filters mounted on each CCD-element to suppress the alias information. In addition, this technique cannot be applied to computer-based graphics, in which the pixel images for each color are always in registration. However, in general-use video, the result of the application of this spatial-shift offset is to raise the apparent Luminance (Y) horizontal resolution to approximately 800 television lines.

The availability of hard-disk drives of progressively higher capacity and data transmission rates is allowing successively longer program duration and higher resolution image displays in real-time. At the previously cited data rates, wide-screen frames would require 486 MB/min, so that currently available 10 GB disk drives will store more than 21 minutes of video. When the anticipated 100 GB disk drives (2.5-inch or 3.5-inch disks using Co—Cr, barium ferrite, or other high-density recording magnetic materials) become available, these units will store 210 minutes, or 3 ½ hours of video. For this application, a data storage unit is provided to facilitate editing and production activities, and it is anticipated that these units would be employed in much the same way as video cassettes are currently used in Betacam and other electronic news gathering (ENG) cameras and in video productions. This data storage unit may be implemented by use of a magnetic, optical, or magneto-optical disk drive with removable storage media, by a removable disk-drive unit, such as those based on the PCMCIA standards, or by semiconductor-based memory. Although PCMCIA media are 1.8-inches in dimension, alternative removable media storage units are not restricted to this limit, and could employ larger media, such as 2.5-inch or 3.5-inch disks; this, in turn, will lead to longer duration program data storage, or alternatively this storage capacity could be applied to lower ratios of data compression or higher-pixel-count images, within the limits of the same size media.

FIG. 2 shows the functional diagram for the storage-device-based digital recorder employed in the video camera, or separately in editing and production facilities. As shown, a removable hard disk drive 70 is interfaced through a bus controller 72; in practice, alternative methods of storage such as optical or magneto-optical drives could be used, based on various interface bus standards such as SCSI-2 or PCMCIA. This disk drive system currently achieves data transfer rates of 20 MB/sec, and higher rates on these or other data storage devices, such as high-capacity removable memory modules, is anticipated. The microprocessor 74 controls the 64-bit or wider data bus 80, which integrates the various components. Currently available microprocessors include the Alpha 21064 by Digital Equipment Corporation, or the MIPS R4400 by MIPS Technologies, Inc.; future implementations would rely on the P6 by Intel Corp. or the

PowerPC 620, which is capable of sustained data transfer rates of 100 MB/sec. Up to 256 MB of ROM, shown at **76**, is anticipated for operation, as is 256 MB or more of RAM, shown at **78**. Current PC-based video production systems are equipped with at least 64 MB of RAM, to allow sophisticated editing effects. The graphics processor **82** represents dedicated hardware that performs the various manipulations required to process the input video signals **84** and the output video signals **86**; although shown using an RGB format, either the inputs or outputs could be configured in alternative signal formats, such as Y/R-Y/B-Y, YIQ, YUV or other commonly used alternatives. In particular, while a software-based implementation of the processor **82** is possible, a hardware-based implementation is preferred, with the system employing a compression ratio of 5:1 for the conventional/widescreen signals (“NTSC/PAL/Widescreen”), and a 10:1 compression ratio for HDTV signals (2048×1152, as described herein above). An example of one of the many available options for this data compression is the currently available Motion-JPEG system. Image re-sizing alternatively may be performed by dedicated microprocessors, such as the gm865X1 or gm833X3 by Genesis Microchip, Inc. Audio signals may be included within the data stream, as proposed in the several systems for digital television transmission already under evaluation by the Federal Communications Commission, or by one of the methods available for integrating audio and video signals used in multi-media recording schemes, such as the Microsoft “AVI” (Audio/Video Interleave) file format. As an alternative, an independent system for recording audio signals may be implemented, either by employing separate digital recording provisions controlled by the same system and electronics, or by implementing completely separate equipment external to the camera system described herein above.

FIG. 3 shows the components that comprise a multi-format audio/video production system. As in the case of the computer disk-based recording system of FIG. 2, an interface bus controller **106** provides access to a variety of storage devices, preferably including an internal hard-disk drive **100**, a tape-back-up drive **102**, and a hard-disk drive with removable media or a removable hard-disk drive **104**; other possible forms of high-capacity data storage (not shown) utilizing optical, magneto-optical, or magnetic storage techniques may be included, as appropriate for the particular application. The interface bus standards implemented could include, among others, SCSI-2 or PCMCIA. Data is transmitted to and from these devices under control of microprocessor **110**. Currently, data bus **108** would operate as shown as 64-bits wide, employing microprocessors such as those suggested for the computer-disk-based video recorder of FIG. 3; as higher-powered microprocessors become available, such as the PowerPC 620, the data bus may be widened to accommodate 128 bits, and the use of multiple parallel processors may be employed, with the anticipated goal of 1,000 MIPS per processor. Up to 256 MB of ROM **112** is anticipated to support the requisite software, and at least 1,024 MB of RAM **114** will allow for the sophisticated image manipulations, inter-frame interpolation, and intra-frame interpolation necessary for sophisticated production effects, and for conversions between the various image formats.

A key aspect of the system is the versatility of the graphics processor shown generally as **116**. Eventually, dedicated hardware will allow the best performance for such operations as image manipulations and re-scaling, but it is not a requirement of the system that it assume these functions.

Three separate sections are employed to process the three classifications of signals. Although the video input and output signals described herein below are shown, by example, as RGB, any alternative format for video signals, such as Y/R-Y/B-Y, YIQ, YUV, or other alternatives may be employed as part of the preferred embodiment. One possible physical implementation would be to create a separate circuit board for each of the sections as described below, and manufacture these boards so as to be compatible with existing or future PC-based electrical and physical interconnect standards.

A standard/widescreen video interface **120**, intended to operate within the 1024×576 or 1024×768 image sizes, accepts digital RGB signals for processing and produces digital RGB outputs in these formats, as shown generally at **122**. Conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, including analog RGB signals and composite video signals. These outputs may optionally be supplied to either a conventional multi-scan computer video monitor or a conventional video monitor having input provisions for RGB signals (not shown). A third set of outputs supplies analog Y/C video signals. The graphics processor may be configured to accept or output these signals in the standard NTSC, PAL, or SECAM formats, and may additionally be utilized in other formats as employed in medical imaging or other specialized applications, or for any desired format for computer graphics applications. Conversion of these 24 frame-per-second images to the 30 fps (actually, 29.97 fps) NTSC and 25 fps PAL formats may be performed in a similar manner to that used for scanned film materials, that is, to NTSC by using the conventional 3:2 “pull-down” field-sequence, or to PAL by reproducing the images at the higher 25 fps rate. For other HDTV frame rates, aspect ratios, and line rates, intra-frame and inter-frame interpolation and image conversions may be performed by employing comparable techniques well known in the art of computer graphics and television.

An HDTV video interface **124**, intended to operate within the 2048×1152 or 2048×1536 image sizes (with re-sizing as necessary), accepts digital RGB (or alternative) signals for processing and produces digital outputs in the same image format, as shown generally at **126**. As is the case for the Standard/Widescreen interface **120**, conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, for analog RGB signals and composite video signals.

The third section of the graphics processor **116** shown in FIG. 3 is the film output video interface **128**, which comprises a special set of video outputs **130** intended for use with devices such as laser film recorders. These outputs are preferably configured to provide a 4096×2304 or 4096×30.72 image size from the image sizes employed internally, using re-sizing techniques discussed herein as necessary for the format conversions. Although 24 fps is the standard frame rate for film, some productions employ 30 fps (especially when used with NTSC materials) or 25 fps (especially when used with PAL materials), and these alternative frame rates, as well as alternative image sizes and aspect ratios for internal and output formats, are anticipated as suitable applications of the invention, with “3:2-pull-down” utilized to convert the internal 24 fps program materials to 30 fps, and 25 fps occurring automatically as the film projector runs the 24 fps films at the 25 fps rate utilized for PAL-type materials.

Several additional features of this system are disclosed in FIG. 3. The graphics processor includes a special output 132 for use with a color printer. In order to produce the highest quality prints from the screen display it is necessary to adjust the print resolution to match the image resolution, and this is automatically optimized by the graphics processor for the various image sizes produced by the system. In addition, provisions are included for an image scanner 134, which may be implemented as a still image scanner or a film scanner, thereby enabling optical images to be integrated into the system. An optional audio processor 136 includes provisions for accepting audio signals in either analog or digital form, and outputting signals in either analog or digital form, as shown in the area generally designated as 138. For materials including audio intermixed with the video signals as described herein above, these signals are routed to the audio processor for editing effects and to provide an interface to other equipment.

It is important to note that although FIG. 3 shows only one set of each type of signal inputs, the system is capable of handling signals simultaneously from a plurality of sources and in a variety of formats. Depending on the performance level desired and the image sizes and frame rates of the signals, the system may be implemented with multiple hard disk or other mass-storage units and bus controllers, and multiple graphics processors, thereby allowing integration of any combination of live camera signals, prerecorded materials, and scanned images. Improved data compression schemes and advances in hardware speed will allow progressively higher frame rates and image sizes to be manipulated in real-time.

Simple playback of signals to produce PAL output is not a serious problem, since any stored video images may be replayed at any frame rate desired, and filmed material displayed at 25 fps is not objectionable. Indeed, this is the standard method for performing film-to-tape transfers used in PAL- and SECAM-television countries. Simultaneous output of both NTSC and film-rate images may be performed by exploiting the 3:2 field-interleaving approach: $5 \times 24 = 120 = 2 \times 60$; that is, two film frames are spread over five video fields. This makes it possible to concurrently produce film images at 24 fps and video images at 30 fps. The difference between 30 fps and the exact 29.97 fps rate of NTSC may be palliated by slightly modifying the system frame rate to 23.976 fps. This is not noticeable in normal film projection, and is an acceptable deviation from the normal film rate.

The management of 25 fps (PAL-type) output signals in a system configured for 24 fps production applications (or vice versa) presents technical issues which must be addressed, however. One alternative for facilitating these and other frame-rate conversions is explained with reference to FIG. 4. A digital program signal 404 is provided to a signal compression circuit 408; if the input program signal is provided in analog form 402, then it is first processed by A/D converter 406 to be placed in digital form. The signal compressor 408 processes the input program signal so as to reduce the effective data rate, utilizing any of the commonly implemented data compression schemes, such as motion-JPEG, MPEG-1, MPEG-2, etc. well known in the art. As an alternative, the digital program signal 404 may be provided in data-compressed form. At this point, the digital program signal is provided to data bus 410. By way of example, several high-capacity digital storage units, designated as "storage means A" 412 and "storage means B" 414, are included for storing the digital program signals presented on data bus 410, under management by controller 418. The two

storage means 412 and 414 may be used in alternating fashion, with one storing the source signal until it reaches its full capacity. At this point, the other storage means would continue storing the program signal until it, too, reached its full capacity. The maximum program storage capacity for the program signals will be determined by various factors, such as the input program signal frame rate, the frame dimensions in pixels, the data compression rate, the total number and capacities of the various storage means, and so forth. When the available storage capacity has been filled, this data storage scheme automatically will result in previously-recorded signals being overwritten; as additional storage means are added, the capacity for time-delay and frame rate conversion is increased, and there is no requirement that all storage means be of the same type, or of the same capacity. In practice, the storage means would be implemented using any of the commonly available storage techniques, including, for example, magnetic disks, optical or magneto-optical discs, or semiconductor memory.

When it is desired to begin playback of the program signal, signal processor 416, under management by controller 418 and through user interface 420, retrieves the stored program signals from the various storage means provided, and performs any signal conversions required. For example, if the input program signals were provided at a 25 fps rate (corresponding to a 625-line broadcast system), the signal processor would perform image resizing and inter-frame interpolation to convert the signal to 30 fps (corresponding to a 525-line broadcast system). Other conversions (such as color encoding system conversion from PAL-format to NTSC, etc., or frame dimension or aspect-ratio conversion) will be performed as necessary. The output of the signal processor is then available in digital form as 422, or may be processed further, into analog form 426 by D/A converter 424. In practice, a separate data bus (not shown) may be provided for output signals, and/or the storage means may be implemented by way of dual-access technology, such as dual-port RAM utilized for video-display applications, or multiple-head-access disk or disc storage units, which may be configured to provide simultaneous random-access read and write capabilities. Where single-head storage means are implemented, suitable input buffer and output buffer provisions are included, to allow time for physical repositioning of the record/play head.

In utilizing program storage means including synchronous recording and reprogram capabilities of the types just described, if it is known that a program will be stored in its entirety before the commencement of playback, that is, with no time-overlap existing between the occurrence of the input and output signal streams, it typically will be most efficient to perform any desired frame conversion on the program either before or after initial storage, depending upon which stored format would result in the least amount of required memory. For example, if the program is input at a rate of 24 frames per second, it probably will be most efficient to receive such a program and store it at that rate, and perform a conversion to higher frame rates upon output. In addition, in situations where a program is recorded in its entirety prior to conversion into a particular output format, it is most efficient to store the program either on a tape-based format or a format such as the new high-capacity DVD discs, given the reduced cost, on a per-bit basis, of these types of storage. Of course, conventional high-capacity disk storage also may be used, and may become more practical as storage capacities continue to increase and costs decrease. If it is known that a program is to be output at a different frame rate while it is being input or stored, it is most preferable to use disk

storage and to perform the frame rate conversion on an ongoing basis, using one of the techniques described above. In this case, the high-capacity video storage means, in effect, assumes the role of a large video buffer providing the fastest practical access time. Again, other memory means (types) may be used, including all solid-state and semiconductor types, depending upon economic considerations, and so forth.

As an example of an alternative embodiment, the storage means **100** or **104** of the multi-format audio/video production system would be equipped with dual-head playback facilities and a second set of graphics processing hardware (not shown) analogous in function to the normal graphics processing hardware (identical to the standard hardware shown as **120**, **124**, and **128**), and having analogous signal output facilities (identical to the standard provisions shown as **122**, **126**, **130**, and **132**). In this case, the two heads would be driven independently, to provide simultaneous, asynchronous playback at different frame rates; that is, one head would be manipulated so as to provide a data stream corresponding to a first frame rate (for example, 25 fps), while the second head would be manipulated so as to provide a data stream corresponding to a second frame rate (for example, 24 fps, which, in turn, may be converted to 30 fps, using the "3:2-pull-down" technique). Evidently, both the storage means and also the internal bus structure of the system would have to support the significantly increased data rate for providing both signal streams simultaneously, or, as an alternative, a second, separate data bus would be provided.

In some applications, a more sophisticated conversion scheme is required. For example, in frame rate conversion systems of conventional design, if an input program signal having a 24 fps rate format is to be displayed at a 25 fps rate, it is customary to simply speed up the source signal playback, so as to provide the signals at a 25 fps rate. This is the procedure utilized for performing a conversion of 24-fps-film-material for 25 fps PAL-format video usage. However, implementation of this method requires that the user of the output signal must have control over the source-signal playback. In a wide-area distribution system (such as direct-broadcast-satellite distribution) this is not possible. While a source signal distributed at 24 fps readily could be converted to 30 fps (utilizing the familiar "3-2-pull-down" technique), the conversion to 25 fps is not as easily performed, due to the complexity and expense of processing circuitry required for inter-frame interpolation over a 24-frame sequence. However, utilizing the system disclosed in FIG. 4, the conversion is straightforward. If, for example, a 24 fps program lasting 120 minutes is transmitted in this format, there are a total of 172,800 frames of information (24 frames/second \times 60 seconds/minute \times 120 minutes); display of this program in speeded-up fashion at 25 fps would mean that the input frame rate falls behind the output frame rate by one frame per second, or a total of 7,200 frames during the course of the program. At a 24 fps transmission rate, this corresponds to 300 seconds transmission time; in other words, for the input program (at 24 fps) and the output program (at 25 fps) to end together, the input process would have to commence 300 seconds before the output process begins. In order to perform this process, then, it is necessary for the storage means to have the capacity to retain 300 seconds of program material, in effect serving as a signal buffer. As an example, for the systems disclosed herein (in which the compressed-data rates range from 8.1 MB/sec for 24 fps standard/widescreen RGB-based TV formats, using 5:1 data compression such as MPEG or motion-JPEG) to

16.2 MB/sec (for 24 fps HDTV RGB-based formats, using 10:1 data compression such as MPEG or motion-JPEG), it may be necessary to store as much as 4.7 GBytes of data, which is readily available by way of multiple disks or discs utilizing conventional storage technology. In practice, the transmission simply would begin 300 seconds before the playback begins, and once the playback starts, the amount of buffered signal would decrease by one frame per second of playback until the last signal is passed through as soon as it is received.

A mirror of this situation arises in the case of a 25 fps signal to be displayed at 24 fps, or some other data rate readily provided by conversion from 24 fps (such as 30 fps). In this case, the source signal is provided at a higher frame rate than the output signal, so that a viewer watching a program from the onset of the transmission would fall behind the source signal rate, and the storage means would be required to hold frames of the program to be displayed at a time after the source signal arrival time; in the case of the 120 minute program described above, the viewing of the source program would conclude 300 seconds after the source signal itself had concluded, and comparable calculations are applied for the storage means. In this case, the extra frames would be accumulated as the buffer contents increased, until, after the transmission has completed, the last 300 seconds would be replayed directly from the storage means.

The conversion of frame rates from 30 fps to 24 fps or to 25 fps is more complicated, because some form of inter-frame interpolation is required. In one case, a multi-frame storage facility would allow this type of interpolation to be performed in a relatively conventional manner, as typically is utilized in NTSC-to-PAL conversions (30 fps to 25 fps). At this point, a 25 fps to 24 fps conversion could be performed, in accordance with the methods and apparatus described herein above.

It should be noted that if, for example, a DVD-R-type of storage media is selected, then the implementation of the significantly higher data compression rates of MPEG-2 coding techniques will result in the ability to record an entire program of 120 minutes or more in duration. In this manner, the complete program is held in the disc/buffer, thereby enabling the user to perform true time-shifting of the program, or allowing the program rights owner to accomplish one form of software distribution, in accordance with the invention.

An alternative method to carry out this frame rate conversion is to perform, in effect, the reverse of the "3:2 pull-down" procedure. If one were to select every fifth field and delete it from the signal sequence, the resultant ratio of 5:4 of the remaining fields would result in the desired conversion of 30 fps to 24 fps. In this case, it is necessary to re-interlace the image signal, by reversing the field identity (i.e., from odd to even, or from even to odd) of each of the four following fields, so that the signal stream continues to alternate between odd and even fields. The next four fields would be retained, then the fifth field deleted, and the next four again would have their field identity reversed. This pattern would be continued throughout the program. If the original source material were from 24 fps (for example, film), then if the repeated fields (i.e., the "3" field of the 3:2 sequence) were identified at the time of conversion; then the removal of these fields would simply return the material to its original form. If the desired conversion is to be from 30 fps to 25 fps, then an equivalent procedure would be performed using the storage-based frame-conversion method described herein above, or, alternatively, every sixth

field could be deleted, in accordance with the method described for 30 fps to 24 fps. Depending on the original source material frame rate and intermediate conversions, the user would select the method likely to present the least amount of image impairment.

In the case in which the user is able to exercise control over the frame rate of the source program material, an alternative method is available. Just as film-to-video transfers for PAL-format (25 fps) presentations utilize a speeded-up playback of the 24 fps film materials to source them at the 25 fps rate (thereby matching the intended output frame rate), the reverse of this process enables a user to utilize materials originated at 25 fps to produce playback at 24 fps. As disclosed herein above, conversions of 24 fps materials are handled easily in conventional methods (such as the "3:2-pull-down" method), and therefore the operator control of the source material enables the user to utilize materials originating from conventional or widescreen PAL format sources for editing and production, then replaying the resulting program at 24 fps for conversion to either standard or widescreen NTSC output materials, or even to HDTV format materials, all at 30 fps, by performing the "3:2-pull-down" process.

In these applications, the presence of the storage means allows the viewer to control the presentation of a program, utilizing a user interface 420 to control the playback delay and other characteristics of the signal while it is being stored or thereafter. In practice, a wide range of alternatives for input frame rates and output frame rate conversions are made available through this system, by selecting the most appropriate of the various methods for altering the frame rate of a signal described herein.

FIG. 5 shows the inter-relationship of the various film and video formats compatible with the invention, though not intended to be inclusive of all possible implementations. In-typical operations, the multi-format audio/video production system 162 would receive film-based elements 160 and combine them with locally produced materials already in the preferred internal format of 24 frames-per-second. In practice, materials may be converted from any other format including video at any frame rate or standard. After the production effects have been performed, the output signals may be configured for any use required, including, but not limited to, HDTV at 30 fps shown as 164, NTSC/widescreen at 30 fps shown as 166, PAL-SECAM/widescreen at 25 fps shown as 170, or HDTV at 25 fps shown as 172. In addition, output signals at 24 fps are available for use in a film-recording unit 168.

FIG. 6 shows an implementation involving one possible choice for image sizes, aspect ratios, and frame rates to provide a universal television production system. As shown, signals are provided from any of several sources, including conventional broadcast signals 210, satellite receivers 212, and interfaces to a high bandwidth data network 214. These signals would be provided to the digital tuner 218 and an appropriate adapter unit 220 for the data network or "information superhighway" before being supplied to the decompression processor 222. The processor 222 provides any necessary data de-compression and signal conditioning for the various signal sources, and preferably is implemented as a plug-in circuit board for a general-purpose computer, though the digital tuner 218 and the adapter 220 optionally may be included as part of the existing hardware.

The output of processor 222 is provided to the internal data bus 226. The system microprocessor 228 controls the data bus, and is provided with 16 to 64 MB of RAM 230 and

up to 64 Mb of ROM 232. This microprocessor could be implemented using one of the units previously described, such as the PowerPC 604 or PowerPC 620. A hard disk drive controller 234 provides access to various storage means, including, for example, an internal hard disk drive unit 236, a removable hard disk drive unit 238, or a tape drive 240; these storage units also enable the PC to function as a video recorder, as described above. A graphic processor 242, comprising dedicated hardware which optionally be implemented as a separate plug-in circuit board, performs the image manipulations required to convert between the various frame sizes (in pixels), aspect ratios, and frame rates. This graphics processor uses 16 to 32 MB of DRAM, and 2 to 8 MB of VRAM, depending on the type of display output desired. For frame size of 1280x720 with an aspect ratio 16:9, the lower range of DRAM and VRAM will be sufficient, but for a frame size of 2048x1152, the higher range of DRAM and VRAM is required. In general, the 1280x720 size is sufficient for conventional "multi-sync" computer display screens up to 20 inches, and the 2048x1152 size is appropriate for conventional "multi-sync" computer display screens up to 35 inches. Analog video outputs 244 are available for these various display units. Using this system, various formats may be displayed, including (for 25 fps, shown by speeding up 24 fps signals) 768x576 PAL/SECAM, 1024x576 wide-screen, and 2048x1152 HDTV, and (for 30 fps, shown by utilizing the well-known "3:2 pull-down" technique, and for 29.97 fps, shown by a slight slow-down in 30 fps signals) 640x480 NTSC and 854x480 wide-screen, and 1280x720 USA and 1920x1080 NHK (Japan) HDTV. While most NTSC monitors will synchronize to a 30 fps signal, possibly requiring that the color subcarrier frequency be adjusted, many PAL and SECAM monitors will not accept a 24 fps signal. In this case, more sophisticated frame-rate conversion techniques, such as those described herein above, may be required for viewing live broadcasts, since the 24 fps input signal rate cannot keep pace with the 25 fps display rate. However, in practice it is anticipated that future television sets will incorporate "multi-sync" designs that eliminate this potential problem.

It will be appreciated by the skilled practitioner of the art that most of the highest quality program material has been originated on 24 fps 35-mm film, and therefore conversions that rely on reconstituting the signal material from 25 fps or 30 fps materials into 24 fps material do not entail any loss of data or program material. In addition, signals that have been interlaced from a lower or equivalent frame rate source signal in any of the currently available means (24 fps to 25 fps via speed-up; 24 fps to 30 fps via "3:2-pull-down") may be de-interlaced and reconstituted as progressive-scan frames without introducing any signal artifacts, provided that the original frames are recreated from properly matched fields. These techniques are summarized in FIG. 7.

FIG. 8 shows one possible implementation of a universal playback device, in accordance with the invention. By way of example, a DVD-type video disc 802 is rotatably driven by motor 804 under control of speed-control unit 806. One or more laser read- or read/write-heads 808 are positioned by position control unit 810. Both the speed control unit and the position control unit are directed by the overall system controller 812, at the direction of the user interface 814. It should be noted that the number and configuration of read-or read/write-heads will be determined by the choice of the techniques employed in the various embodiments disclosed herein above. The signals recovered from the laser heads is delivered to signal processor unit 820, and the data stream is split into an audio data stream (supplied to audio processor

unit **822**) and a video data stream (supplied to video graphics processor unit **830**).

During the audio recovery process, the alteration of the playback frame rate (for example, from 24 fps to 25 fps, accomplished by speed control adjustment) may suggest the need for pitch-correction of the audio material. This procedure, if desired, may be implemented either as part of the audio processor **822**, or within a separate, external unit (not shown), as offered by a number of suppliers, such as Lexicon.

The video data stream may undergo a number of modifications within the graphics processor, shown generally at **830**, depending on the desired final output format. Assuming that the output desired is NTSC or some other form of wide-screen or HDTV signal output at a nominal frame rate of 30 fps, a signal sourced from the disc at 24 fps would undergo a "3:2-pull-down" modification as part of the conversion process (as explained herein above); if the signal as sourced from the disk is based on 25 fps, then it would undergo an preliminary slowdown to 24 fps before the "3:2-pull-down" processing is applied. It should be noted that the 0.1% difference between 30 fps and 29.97 fps only requires the buffering of 173 frames of video over the course of a 120-minute program, and at a data rate of 8.1 MB/sec, this corresponds to approximately 57 MB of storage (for Standard/widescreen) or 115 MB of storage (for HDTV), which readily may be implemented in semiconductor-based memory. In any event, a signal supplied to the graphics processor at a nominal 24 fps simultaneously may be output at both 30 fps and 29.97 fps, in image frames compatible with both NTSC and NTSC/widescreen (the Standard/Widescreen Video Interface **832**), and HDTV (HDTV Video Interface **834**), in accordance with the invention as described herein above. As disclosed above, an optional Film Output Video Interface **836** may be included, with digital video outputs for a film recorder. Overall, the outputs for the Graphics processor **830** parallel those of the Multi-Format Audio/Video Production System as shown in FIG. 5 and disclosed herein above. In addition, for signals to be output in a format having a different aspect ratio than that of the source signal, it may be necessary to perform a "pan/scan" function in order to assure that the center of action in the source program material is presented within the scope of the output frame. This function may be implemented within the graphics processor by utilizing a "tracking" signal associated with the source program material, for example, as part of the data stream for each frame, or, alternatively, through a listing identifying changes that should be applied during the presentation of the source material. Where no "tracking" information is available, the image frame would be trimmed along the top and bottom, or the sides, as necessary in order to fit the aspect ratio of the source material to the aspect ratio of the output frame. This latter technique is explained herein above, with reference to FIGS. 1A-1D. In addition, the program material may include security information, such as regional or geographical information directed towards controlling the viewing of the program material within certain marketing areas or identifiable classes of equipment (such as hardware sold only in the United States or in the German market). This information, as has been disclosed for use with other disc- and tape-based systems, often relates to issues such as legal licensing agreements for software materials; it may be processed in a way similar to the detection and application of the "pan/scan" tracking signal, and the signal processor **820**, under the direction of controller **812** may act to enforce these restrictions.

Alternatively, if output at 25 fps is desired, it is a simple matter to configure the various components of this system to

replay the video information of the disc **802** at this higher frame rate. The controller will configure the speed control unit **806** (if necessary) to drive the motor **804** at a greater rotational speed to sustain the increased data rate associated with the higher frame rate. The audio processor **822**, if so equipped, will be configured to correct for the change in pitch associated with the higher frame rate, and the Graphics processor will be configured to provide all output signals at the 25 fps frame rate.

As yet another alternative, materials produced at 25 fps and stored on the disc-based mass storage means of this example could originate from conventional standard or widescreen PAL format signals. Utilizing the slow-down method, these signals are readily converted to 24 fps frame rate, from which conversion to various 30 fps formats is implemented, as disclosed herein above. This feature has significance in the commercial development of HDTV, as the ability to utilize more-or-less conventional PAL format equipment greatly facilitates the economical production and origination of materials intended for HDTV markets.

It will be appreciated that a wide range of output frame rates may be made available through combination of the techniques of speed-up, slow-down, "3-2-pull-down," and other related field-rearrangement techniques as disclosed herein above with respect to FIG. 4, and these various combinations and approaches should be considered to be within the scope of the invention. In addition, these techniques may be combined with hardware and/or software which perform image manipulations such as line-doubling, deinterlacing, etc., such that the display device will be capable of providing smoother apparent motion, by increasing the display rate without increasing the actual data/information rate. One example would be to process the 24 fps signal from the internal format to convert it into a 48 fps signal, using field-doubling techniques such as deinterlacing and line doubling; then, the process would employ frame-store techniques to provide a frame-doubled output at a rate of 96 fps. These types of display-related improvements, in conjunction with the instant invention, should also be considered to be within the scope of the invention as disclosed herein.

Having described the invention, I claim:

1. A multi-format audio/video production system adapted for use with a display device, comprising:

an input to receive a signal representative of an audio/video program in one of a plurality of display formats; high-capacity video storage means including an asynchronous program recording and reproducing capability; an operator control; and

a graphics processor in communication with the input, the high-capacity video storage means, and the operator control, enabling a user to perform the following functions:

- (a) convert the display format of the audio/video program received through the input into an intermediate production format,
- (b) perform a frame-rate conversion of the audio/video program received through the input means using the asynchronous recording and reproducing capability associated with the high-capacity video storage means, and
- (c) output a program having a display format or frame rate different than that of the audio/video program received through the input.

2. The multi-format audio/video production system of claim 1, wherein the graphics processor is operative to

output a program in a standard television format regardless of the display format of the input program.

3. The multi-format audio/video production system of claim 1, wherein the graphics processor is operative to output a program in a widescreen format regardless of the display format of the input program.

4. The multi-format audio/video production system of claim 1, wherein the graphics processor is operative to output a program in an enhanced-definition format regardless of the display format of the input program.

5. The multi-format audio/video production system of claim 4, wherein the enhanced-definition format is an HDTV format.

6. The multi-format audio/video production system of claim 1, wherein the graphics processor is operative to output a program in a film-compatible format regardless of the display format of the input program.

7. The multi-format audio/video production system of claim 1, wherein the graphics processor is further operative to perform a pan/scan operation with respect to the program received through the input.

8. The multi-format audio/video production system of claim 1, wherein the graphics processor is further operative to perform an interpolation operation with respect to the program received through the input so as to expand the number of pixels associated with the production format as compared to the input display format.

9. The multi-format audio/video production system of claim 1, wherein the graphics processor is further operative to perform an interpolation operation with respect to the program received through the input so as to reduce the number of pixels associated with the production format as compared to the input display format.

10. The multi-format audio/video production system of claim 1, wherein the high-capacity video storage means includes sufficient capacity to store at least 120 minutes of program material to perform the frame-rate conversion.

11. The multi-format audio/video production system of claim 1, including high-capacity video storage means in the form of a removable medium.

12. The multi-format audio/video production system of claim 1, further including means for performing a data compression operation on a program prior to storing the program in the high-capacity video storage means.

13. The multi-format audio/video system of claim 1, wherein the intermediate production format is based upon a frame rate of 24 frames per second.

14. A multi-format audio/video production system forming part of a general-purpose computer platform having a user input and a color display, the system comprising:

means to receive an input video program in one of a plurality of input formats;

high-capacity video storage means;

means to convert the input program into a 24 frames-per-second (fps) production format, if necessary, for storage within the high-capacity video storage means and for review on the color display;

means to convert the production format into one or more of the following output formats, either directly from the input receiving means or from the storage means:

NTSC at 30 fps,

PAL/SECAM at 25 fps,

HDTV at 25 fps,

HDTV at 30 fps,

film-compatible video at 24 fps, and

film-compatible video at 30 fps; and

asynchronous program recording and reproducing capabilities to provide a program in an output format having a frame rate greater than 24 per second.

15. The multi-format audio/video production system of claim 14, wherein the means to convert the production format into one or more of the output formats further includes interpolation means to expand the number of pixels associated with the production format.

16. The multi-format audio/video production system of claim 14, wherein the asynchronous program recording and reproducing capabilities are used to increase the frame rate from the 24 fps production format frame rate to a 25 fps output frame rate.

17. The method of claim 16, wherein the step of manipulating the video program in the production format further includes the step of performing an interpolation operation on a received so as to expand the number of pixels associated with the production format as compared to the input format.

18. The method of claim 16, wherein the step of manipulating the video program in the production format further includes the step of performing an interpolation operation on a received so as to reduce the number of pixels associated with the production format as compared to the input format.

19. The method of claim 16, wherein the step of manipulating the video program in the production format includes the step of panning and scanning the vision center of the displayed program.

20. The method of claim 16, wherein the step of manipulating the video program in the production format includes the step of providing predetermined criteria used to restrict the viewing of the program.

21. In an enhanced personal computer having a color monitor, the method of producing a video program, comprising the steps of:

receiving an input video program;

converting the input video program into a production format having a predetermined frame rate and image dimension in pixels;

providing a high-capacity video storage means equipped with an asynchronous program recording and reproducing capability to perform a frame-rate conversion; manipulating the video program in the production format using the high-capacity video storage means on a selective basis to output an edited version of the program having a desired frame rate and image dimensions in pixels which may be different from those of the production format.

22. The method of claim 21, further including the step of interpolating the video program in the production format to output an edited version of the program having pixel dimensions greater than that of the production format.

23. The method of claim 21, further including the step of controlling pan/scan operations relative to the received input video program.

24. The method of claim 21, wherein the high-capacity video storage means includes sufficient capacity to store at least 120 minutes of program material.

25. The method of claim 21, further including the step of providing a removable high-capacity video storage medium.

26. The method of claim 21, further including the step of data compressing the video program in the production format.

27. The method of claim 21, wherein the predetermined frame rate is 24 frames per second.

EXHIBIT 2

EXHIBIT 2

(12) **United States Patent**
Washino

(10) **Patent No.: US 6,370,198 B1**
 (45) **Date of Patent: Apr. 9, 2002**

(54) **WIDE-BAND MULTI-FORMAT AUDIO/VIDEO PRODUCTION SYSTEM WITH FRAME-RATE CONVERSION**

5,838,381 A * 11/1998 Kasahara et al. 348/458
 5,999,220 A * 12/1999 Washino 348/441

* cited by examiner

(76) Inventor: **Kinya Washino**, 80 Hamilton St., Dumont, NJ (US) 07624

Primary Examiner—Vu Le
 (74) *Attorney, Agent, or Firm—Gifford, Krass, Groh, Sprinkle, Anderson & Citkowski, PC*

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(57) **ABSTRACT**

A multi-format digital video production system enables a user to process an input video program to produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format of 24 fps is preferably chosen to provide the greatest compatibility with existing and planned formats associated with HDTV standard 4:3 or widescreen 16:9 high-definition television, and film. Images are re-sized horizontally and vertically by pixel interpolation, thereby producing larger or smaller image dimensions so as to fill the particular needs of individual applications. Frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions. Simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) for playback, or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities. The step of converting the signal to a HDTV format is preferably performed using a modified upconversion process for wideband signals (utilizing a higher sampling clock frequency) and a resizing to HDTV format frame dimensions in pixels. The present invention thus encourages production at relatively low pixel dimensions to make use of lower-cost general-purpose technology and to maintain high signal-to-noise ratio, and then subsequently expands the resultant image into a so-called up-converted program. This is in contrast to alternative approaches, which recommend operating at HDTV-type resolution, then down-converting, as necessary, to smaller image formats.

(21) Appl. No.: **09/305,953**

(22) Filed: **May 6, 1999**

Related U.S. Application Data

(63) Continuation-in-part of application No. 08/834,912, filed on Apr. 7, 1997, now Pat. No. 5,999,220.

(60) Provisional application No. 60/084,522, filed on May 7, 1998.

(51) **Int. Cl.**⁷ **H04N 7/12; H04N 5/46; H04N 7/01**

(52) **U.S. Cl.** **375/240.26; 348/441; 348/445; 348/555; 348/556; 348/722**

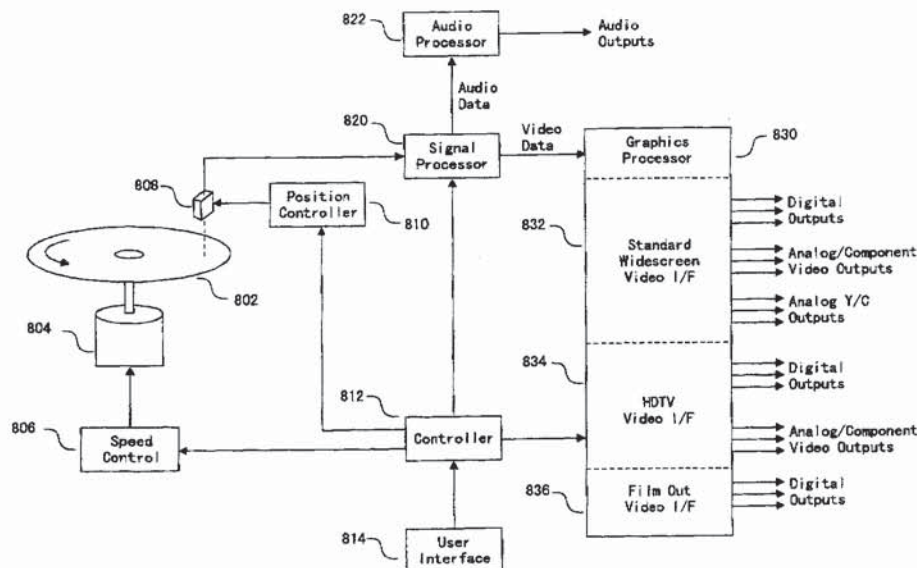
(58) **Field of Search** 348/441, 445, 348/448, 426, 432, 454, 558, 568, 555-556, 722, 911, 575; 358/527, 524; 375/240.26, 240.29

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,327,235 A	7/1994	Richards	.....	348/441
5,444,491 A	* 8/1995	Lim	.....	348/441
5,532,749 A	* 7/1996	Hong	.....	348/449
5,537,157 A	7/1996	Washino et al.	.....	348/722
5,608,464 A	3/1997	Woodham	.....	348/578
5,724,101 A	* 3/1998	Haskin	.....	348/441
5,754,248 A	* 5/1998	Faroudja	.....	348/474
5,812,204 A	* 9/1998	Baker et al.	.....	348/453

29 Claims, 14 Drawing Sheets



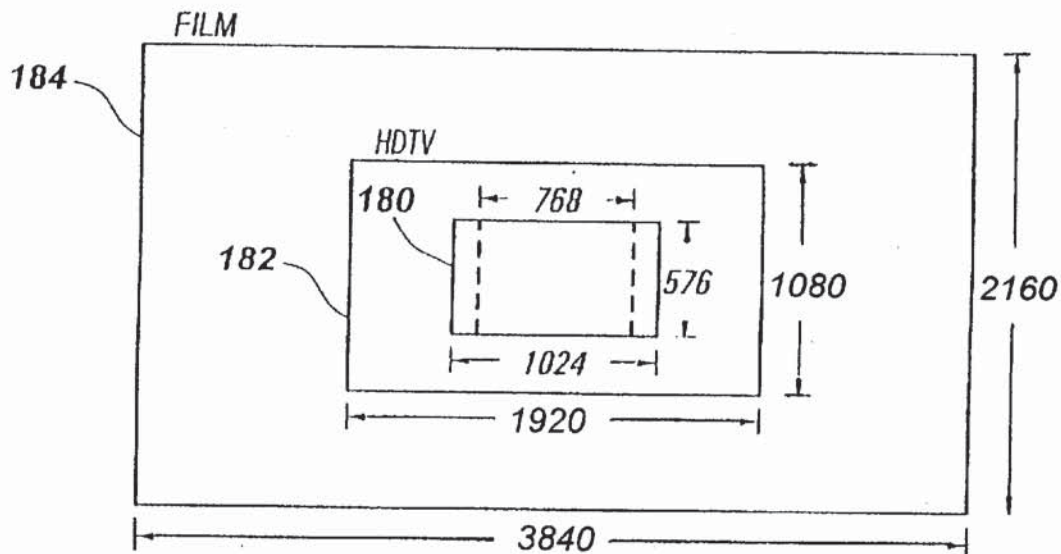


Figure 1a

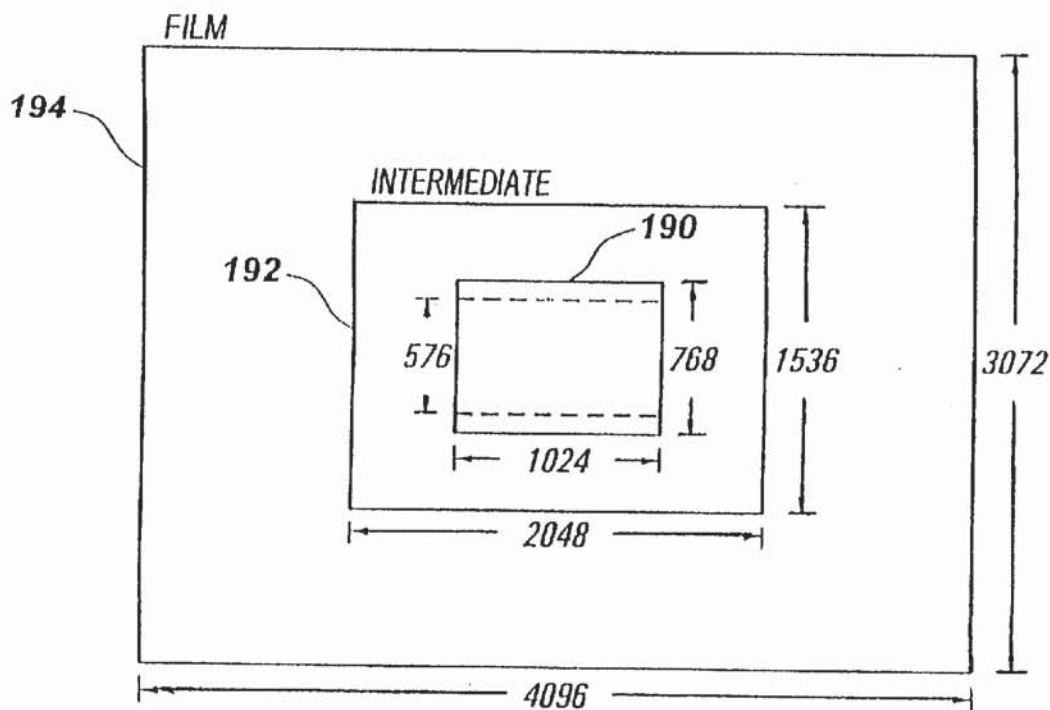


Figure 1b

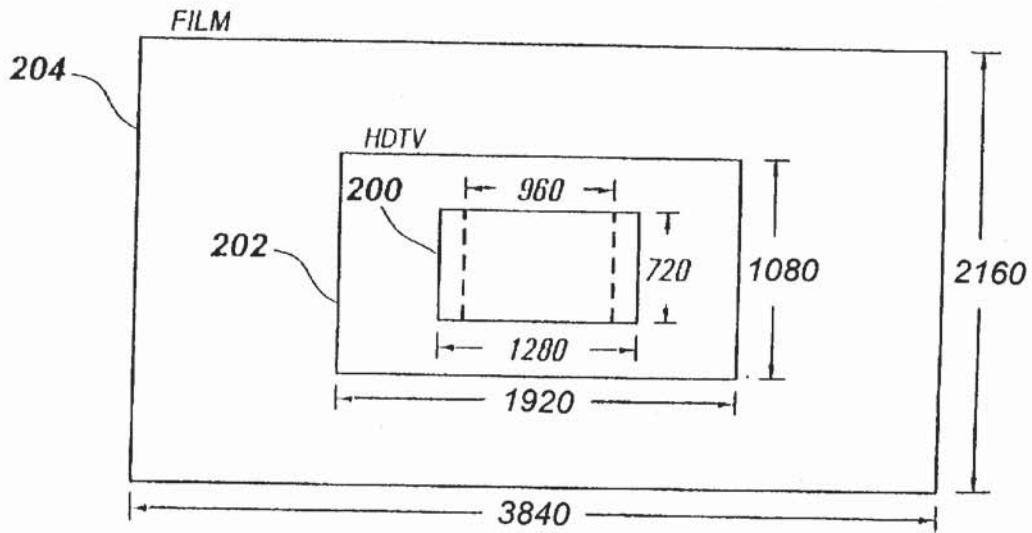


Figure 1c

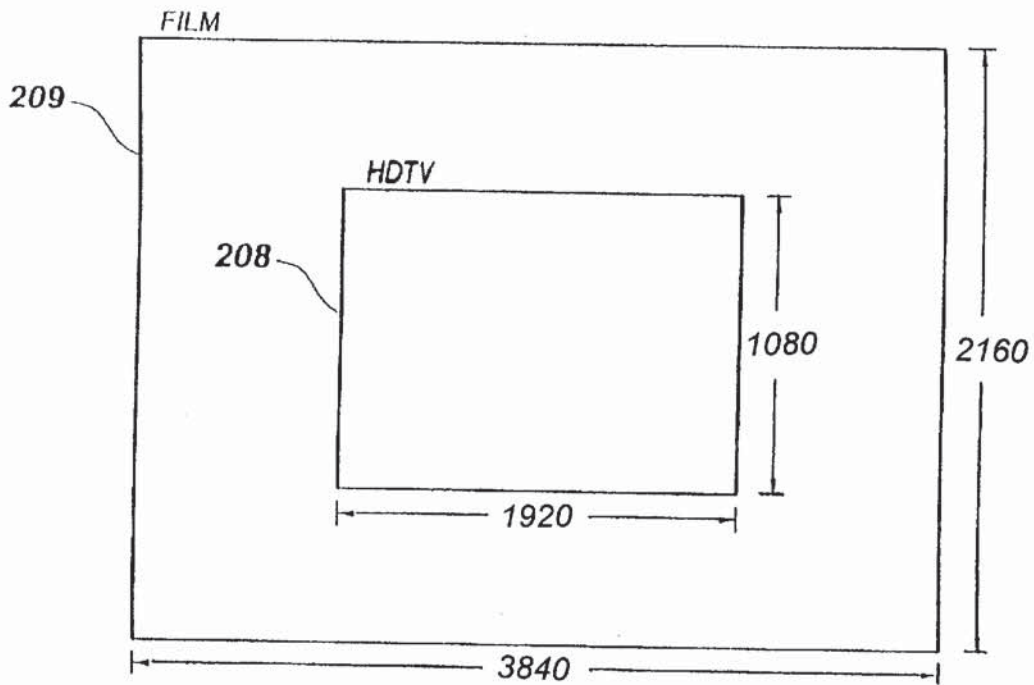


Figure 1d

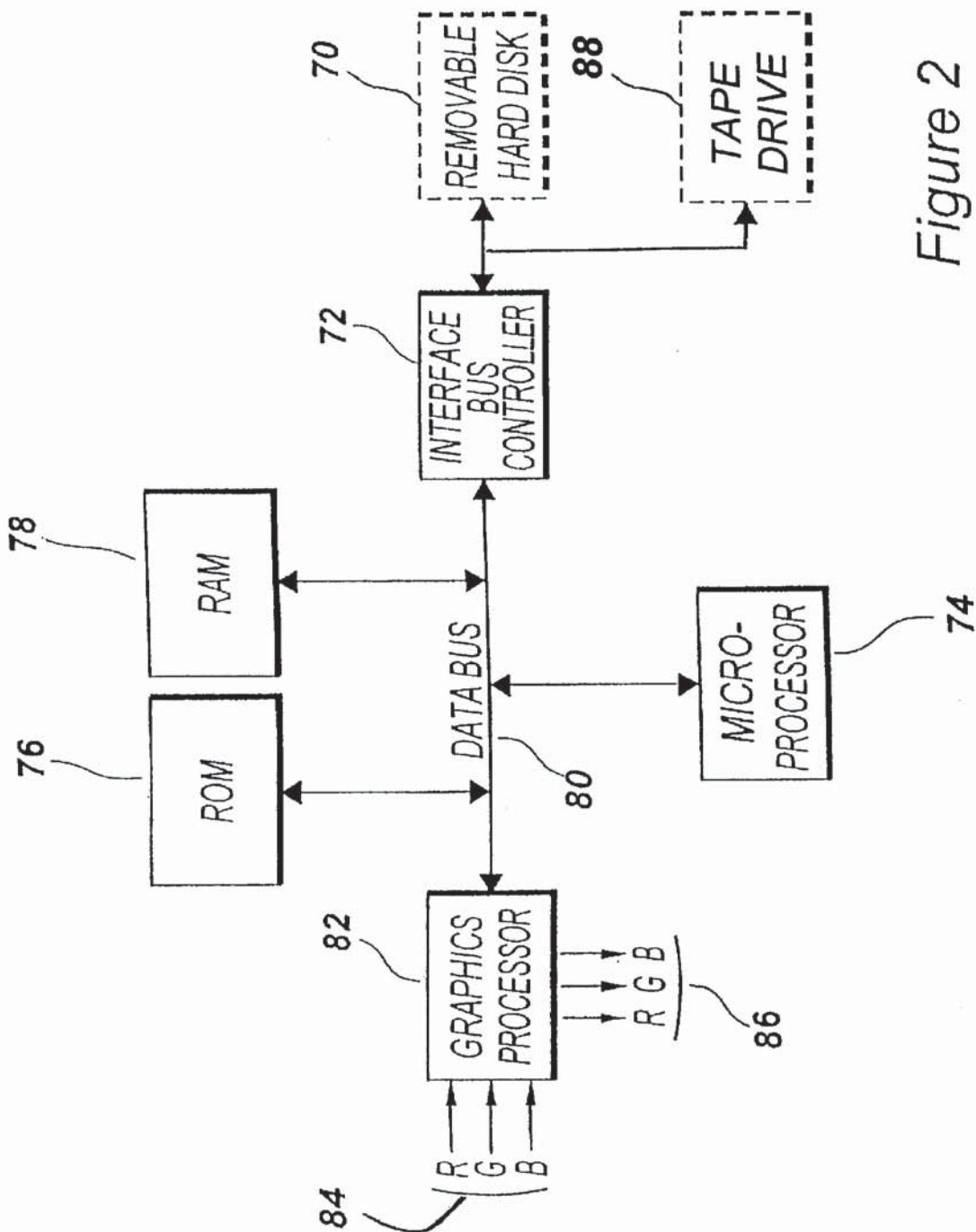


Figure 2

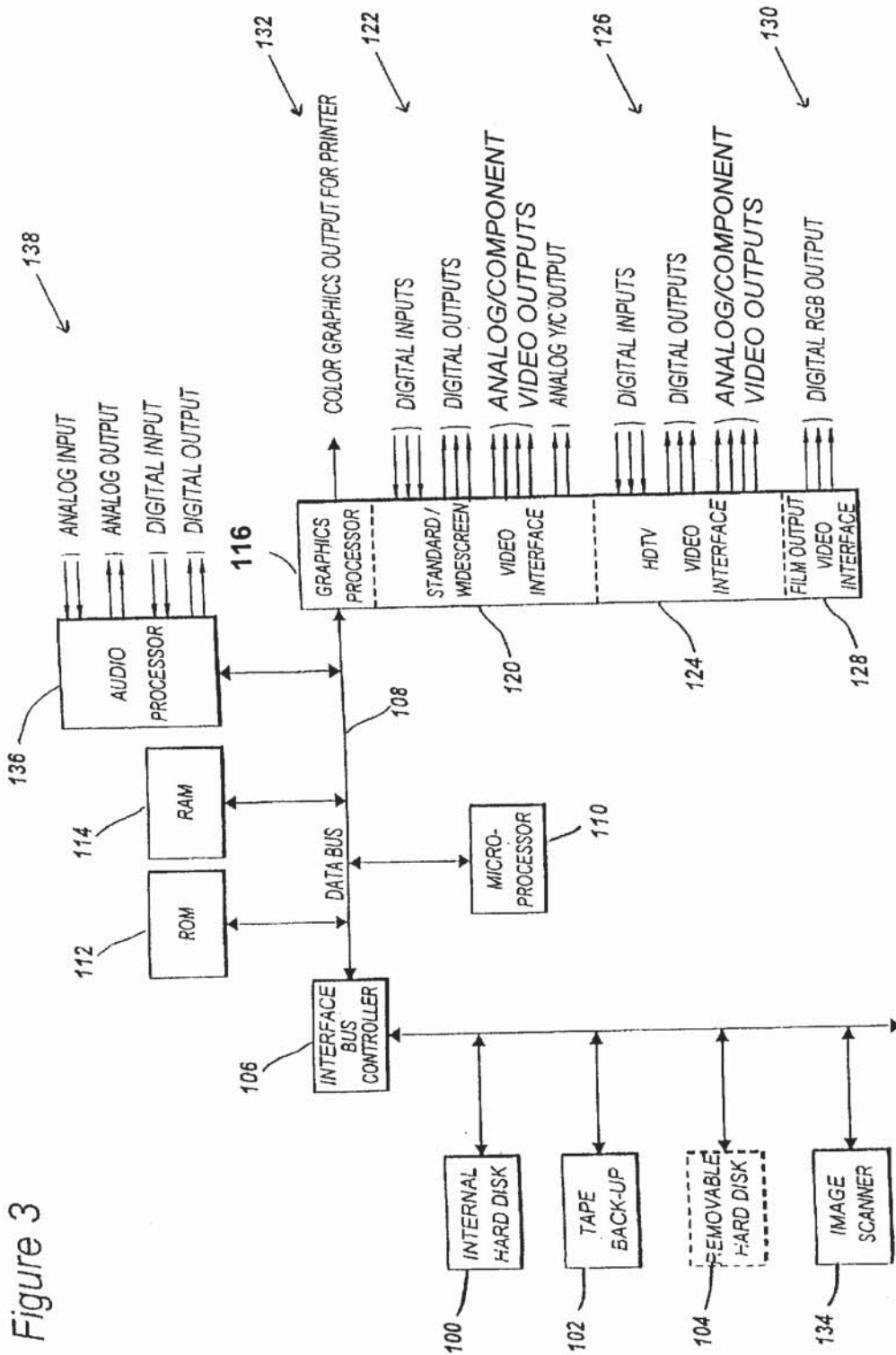


Figure 3

Figure 4

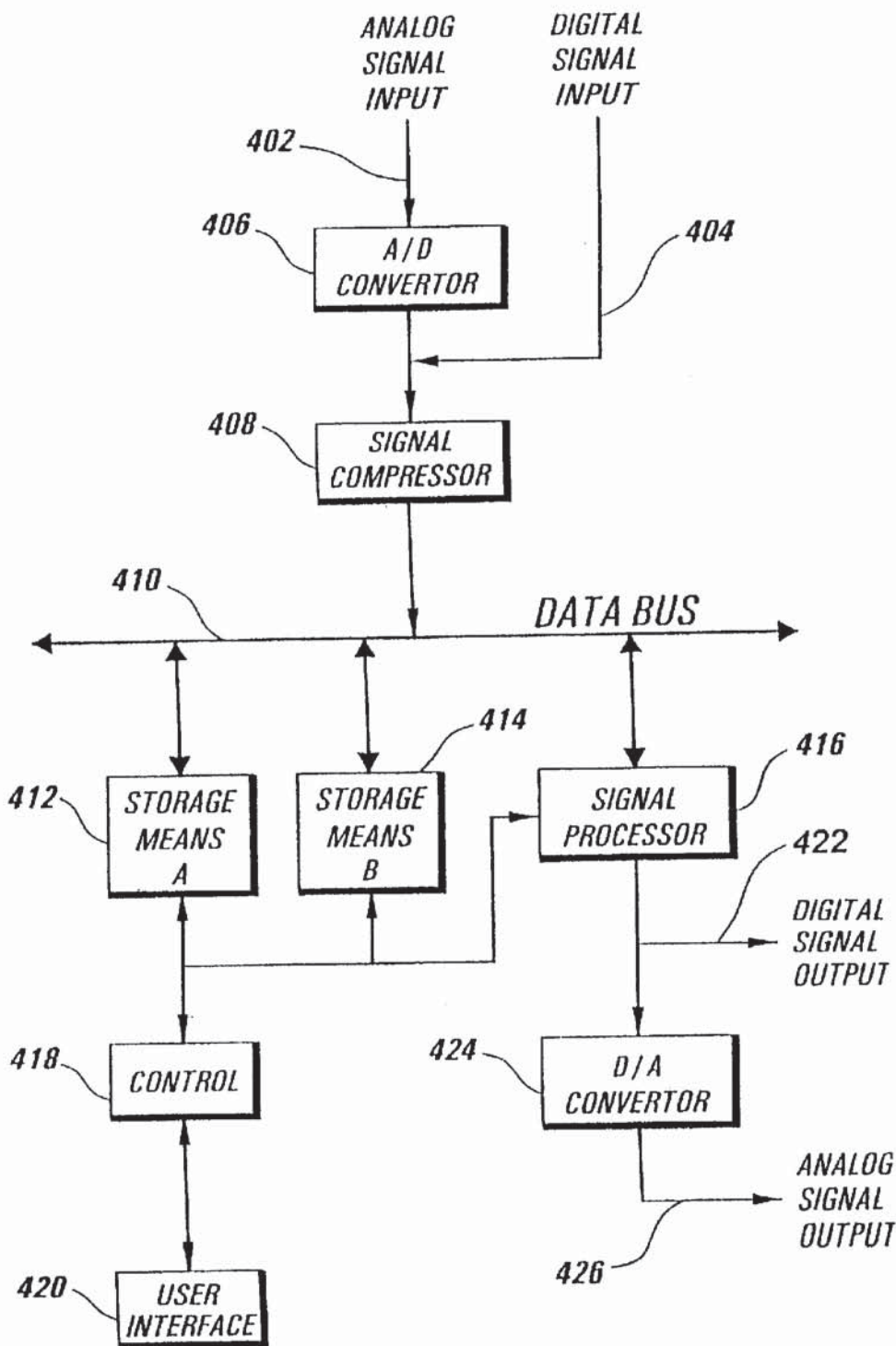


Figure 5

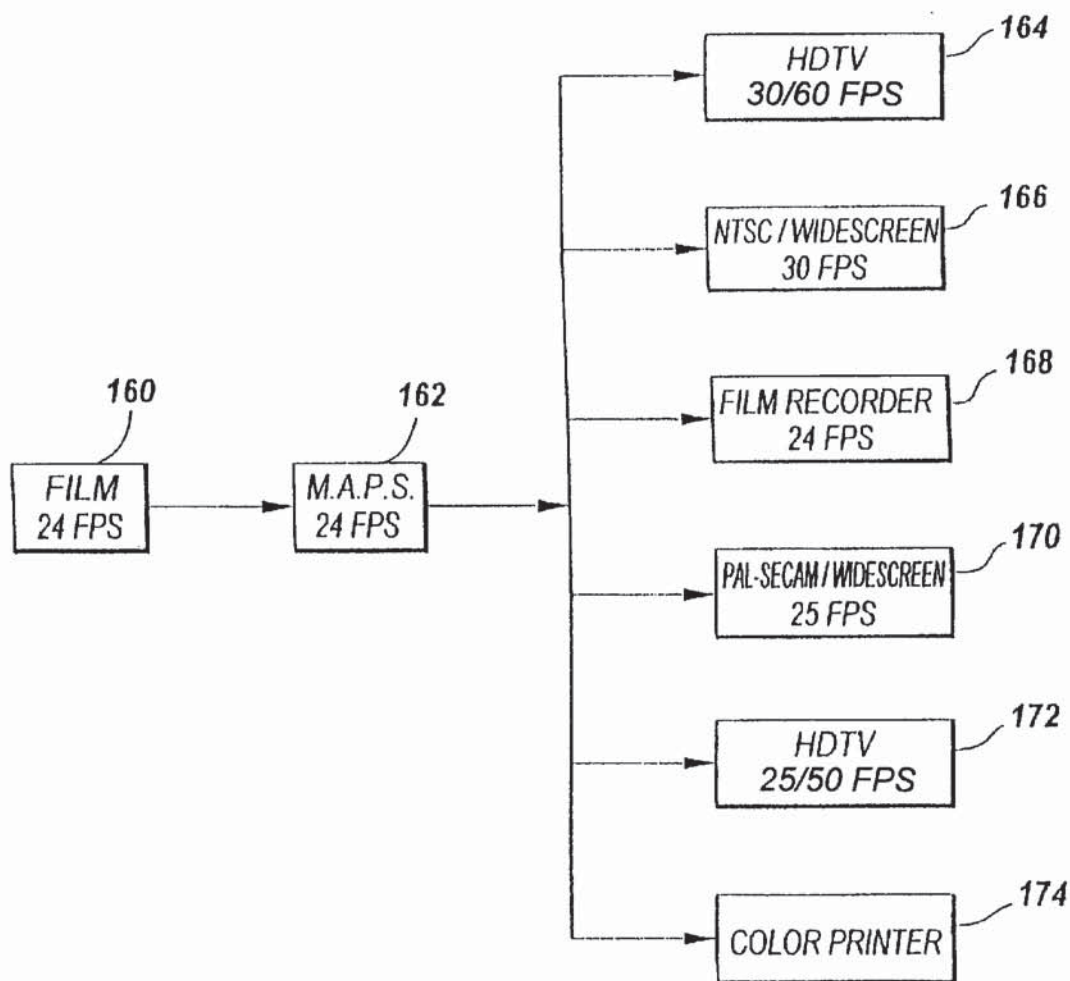


Figure 6

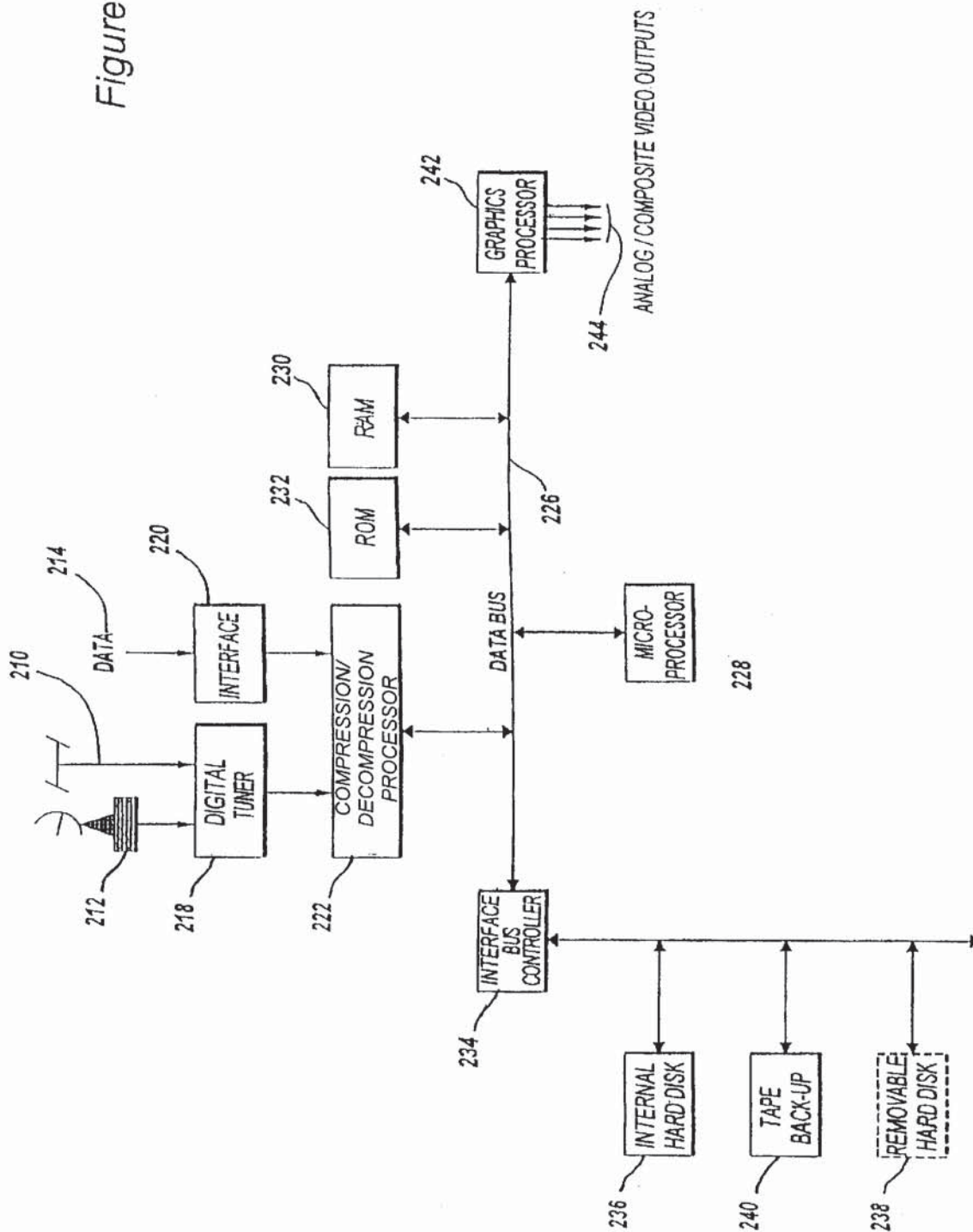


FIGURE 7A

Output Source	24 fps Interlace (24fps I)	24fps Progress. (24fps P)	25fps Interlace (25fps I)	25fps Progress. (25fps P)	30fps Interlace (30fps I)	30fps Progress. (30fps P)	48fps Progress. (48fps P)	50fps Progress. (50fps P)	60fps Progress. (60fps P)	96fps Progress. (96fps P)
24fps Interlace (24fps I)	—	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (1)	2:1 Frame Reduction From 50fps P (3)	Interlace & discard From 60fps P (3)	2:1 Frame Reduction From 60fps P (3)	De-Interlace From 24fps I (1)	De-Interlace From 25fps I (2)	4 th Frame Repeat From 48fps P (2)	Repeat From 48fps P (2)
24fps Progress. (24fps P)	Interlace From 24fps P (1)	—	Speed-up From 24fps I (2)	Speed-up From 24fps P (1)	3:2 Pull-down From 24fps I (2)	2:1 Frame Reduction From 60fps P (2)	Repeat From 24fps P (1)	Repeat From 25fps P (2)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (2)
25fps Interlace (25fps I)	Slow-Down From 25fps I (1)	2:1 Frame Reduction From 48fps P (3)	—	2:1 Frame Reduction From 50fps P (2)	Interlace & discard From 60fps P (4)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (2)	De-Interlace From 25fps I (1)	4 th Frame Repeat From 48fps P (3)	Repeat From 48fps P (3)
25fps Progress. (25fps P)	Interlace From 24fps P (2)	Slow-down From 25fps P (1)	Interlace From 25fps P (1)	—	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (3)	Repeat From 25fps P (1)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (3)
30fps Interlace (30fps I)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 48fps P (3)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 50fps P (3)	—	2:1 Frame Reduction From 60fps P (2)	De-Interlace From 24fps I (3)	De-Interlace From 25fps I (3)	De-Interlace From 30fps I (1)	Repeat From 48fps P (3)

FIGURE 7A (CONT)

30fps Progress. (30fps P)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 50fps P (4)	Interlace From 30fps P (1)	—	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (3)	Repeat From 30fps P (1)	Repeat From 48fps P (4)
48fps Progress. (48fps P)	Interlace From 24fps P (2)	2:1 Frame Reduction From 48fps P (1)	Interlace From 25fps P (3)	Speed-up From 24fps P (2)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (2)	—	De- Interlace From 25fps I (4)	De- Interlace From 30fps I (4)	Repeat From 48fps P (1)
50fps Progress. (50fps P)	Interlace From 24fps P (3)	Slow-down From 25fps P (2)	Interlace & discard From 50fps P (1)	2:1 Frame Reduction From 50fps P (1)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (3)	De- Interlace From 24fps I (4)	—	3:2 Frame Repeat From 24fps P (3)	Repeat From 48fps P (2)
60fps Progress. (60fps P)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (1)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (1)	2:1 Frame Reduction From 50fps P (4)	Interlace From 60fps P (1)	2:1 Frame Reduction From 60fps P (1)	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (2)	—	Repeat From 48fps P (4)
96fps Progress. (96fps P)	Interlace From 24fps P (3)	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (4)	Speed-up From 24fps P (3)	3:2 Pull-Down From 24fps I (4)	2:1 Frame Reduction From 60fps P (3)	2:1 Frame Reduction From 96fps P (1)	De- Interlace From 25fps I (5)	4 th Frame Repeat From 48fps P (2)	—

Figure 7b

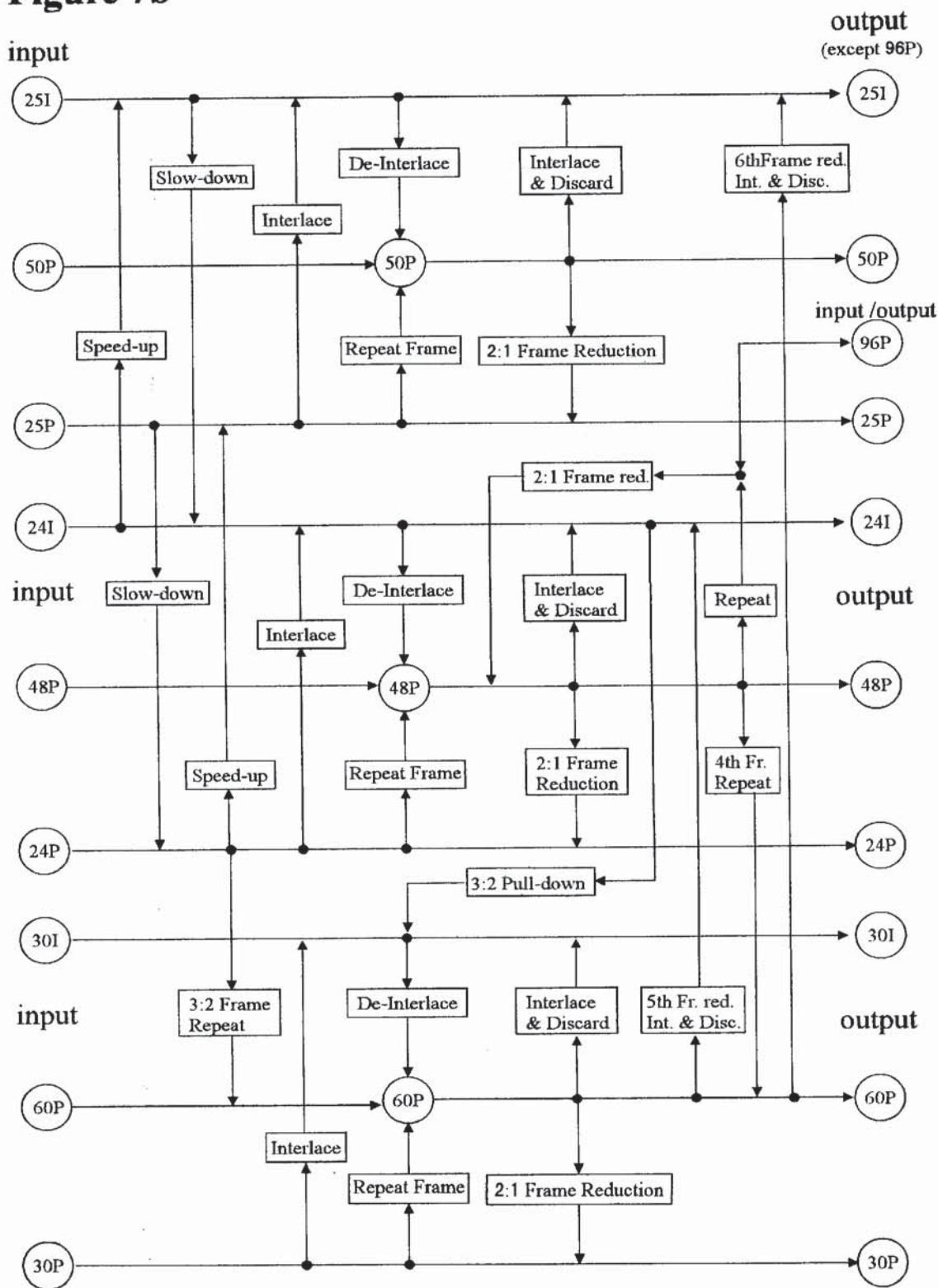


Figure 7c 3 : 2 Pull-Down
(24 fps P to 30 fps I)

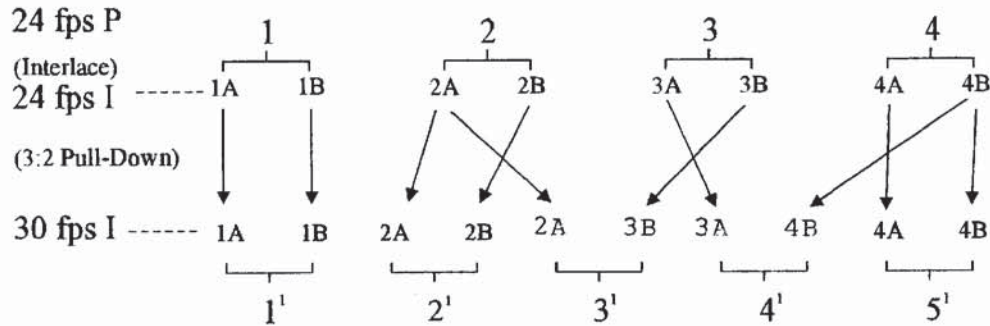


Figure 7e 4th & 7th Field Repeat plus Re-Interlace
(24 fps I to 30 fps I)

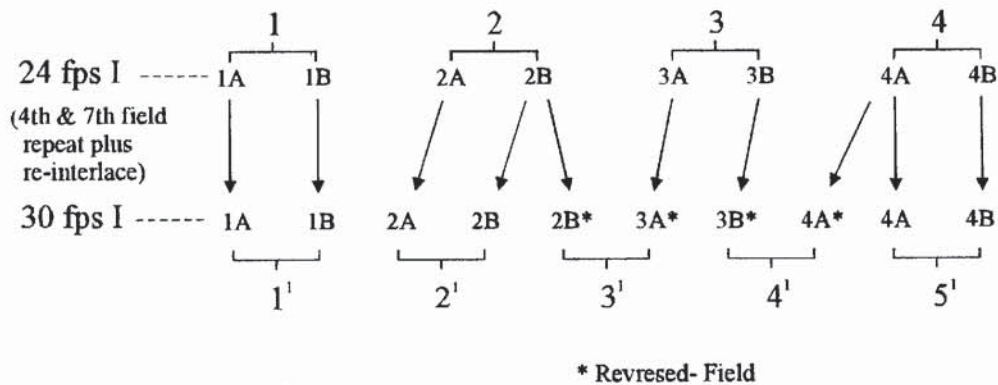


Figure 7g 3 : 2 Frame Repeat (24 fps P to 60fps P)

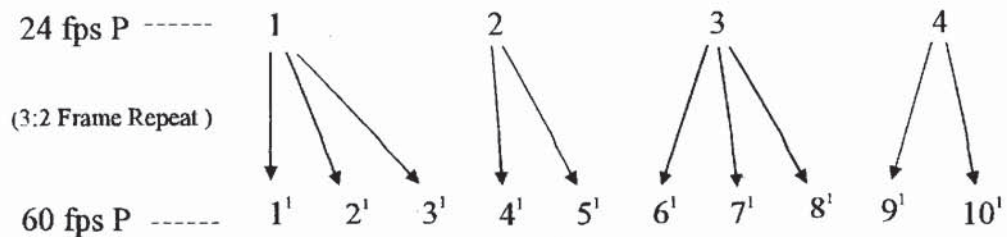


Figure 7d 25 fps Interlace to 30 fps Interlace Conversion
(from PAL CCD camera source to NTSC out)

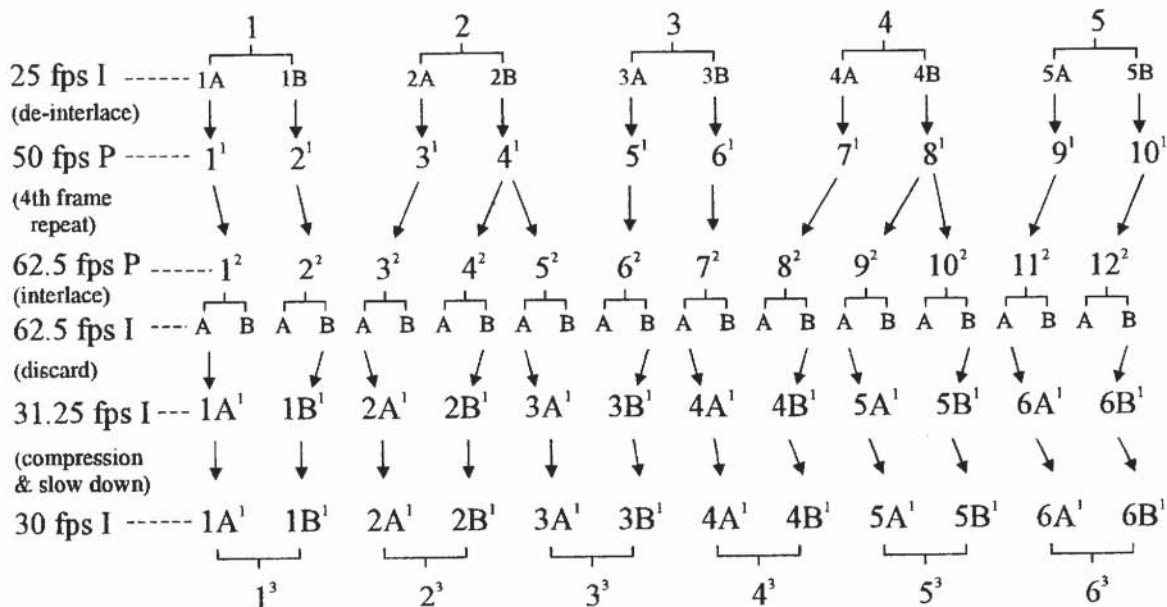


Figure 7f 4th Frame Repeat (24fps I to 30fps I)

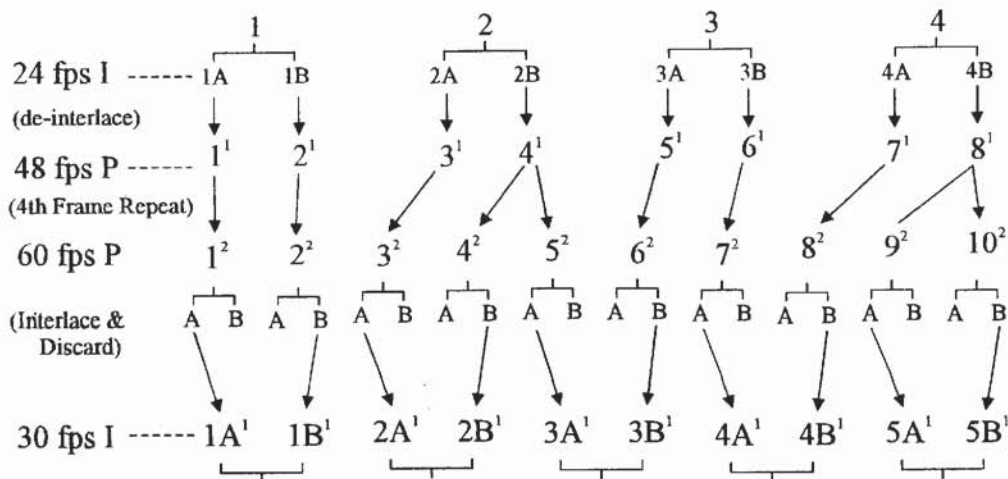


Figure 7h 6th Frame Reduction (30fps I to 25fps I)

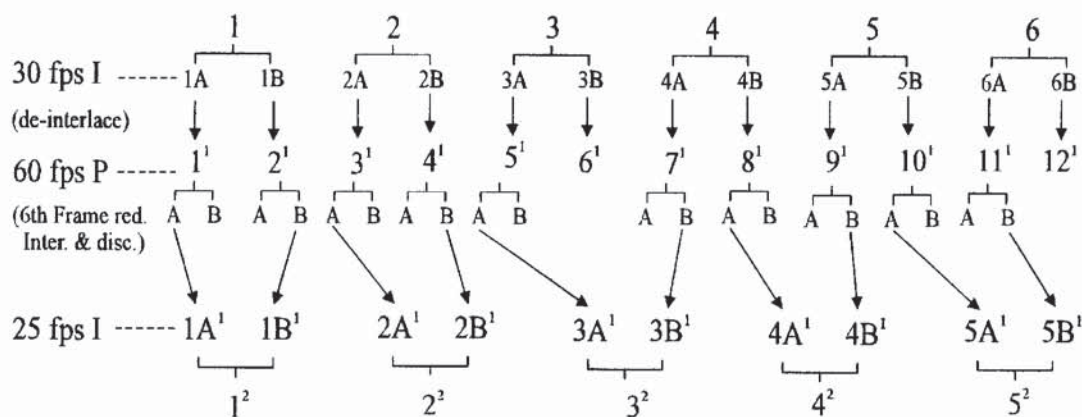


Figure 7i 5th Frame Reduction (30fps I to 24fps I)

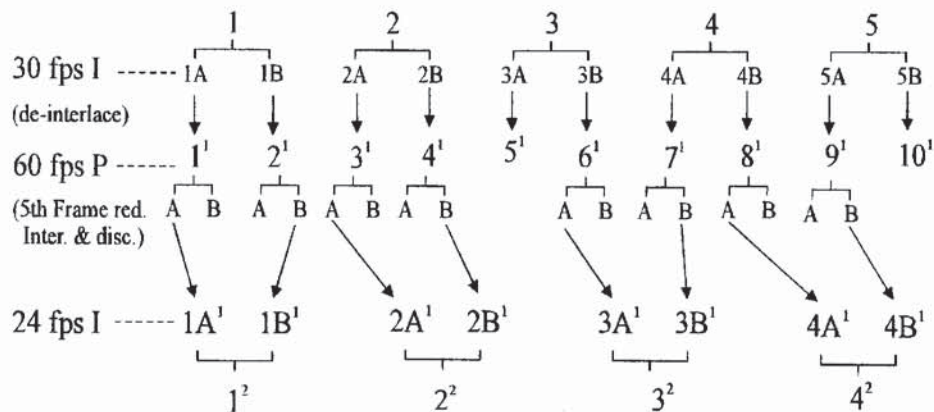
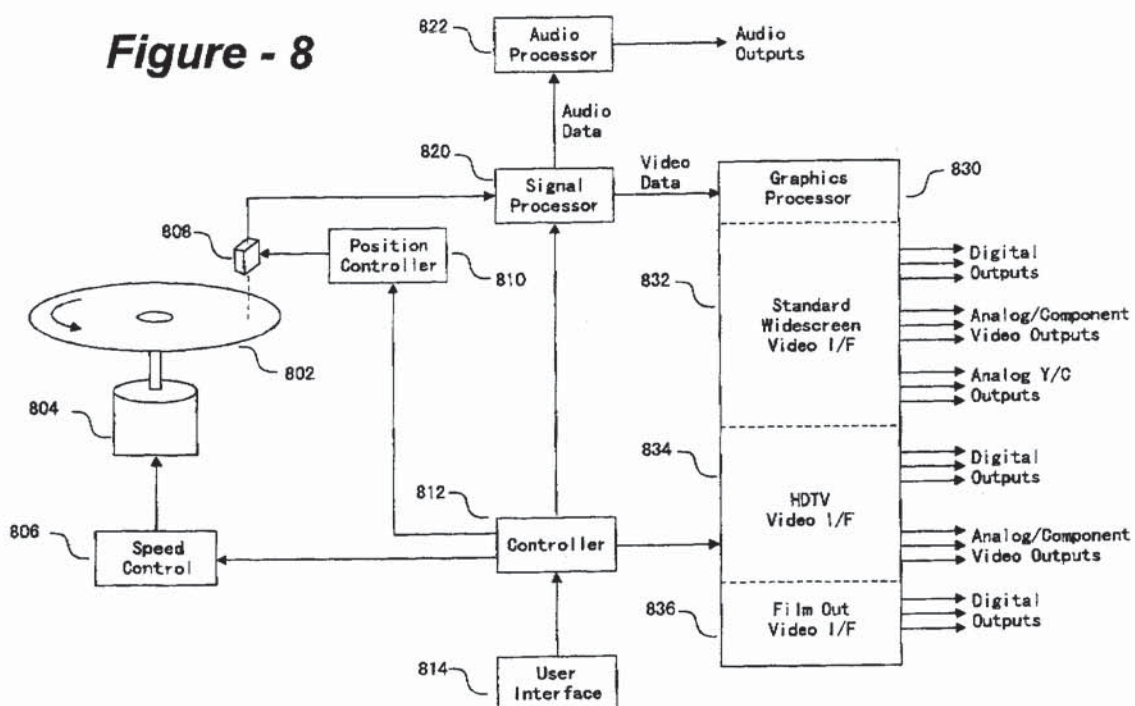


Figure - 8



US 6,370,198 B1

1

**WIDE-BAND MULTI-FORMAT
AUDIO/VIDEO PRODUCTION SYSTEM
WITH FRAME-RATE CONVERSION**

REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 08/834,912, filed Apr. 7, 1997, and also claims priority of U.S. Provisional Patent Application Serial No. 60/084,522, filed May 7, 1998. Both of these prior applications are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

This invention relates generally to video production, photographic image processing, and computer graphics, and, more particularly, to a multi-format digital video production system capable of maintaining the full bandwidth resolution of the subject material, while providing professional quality editing and manipulation of images intended for digital television and other applications, including digital HDTV programs.

BACKGROUND OF THE INVENTION

As the number of television channels available through various program delivery methods digital TV (DTV) broadcasting, cable TV, home video, broadcast, etc. continues to proliferate, the demand for programming, particularly high-quality HDTV-format programming, presents special challenges, both technical and financial, to program producers. While the price of professional editing and image manipulation equipment continues to increase, due to the high cost of research and development and other factors, general-purpose hardware, including personal computers, can produce remarkable effects at a cost well within the reach of non-professionals, even novices. As a result, the distinction between these two classifications of equipment has become less well defined. Although general-purpose PC-based equipment may never allow professional-style rendering of images at full resolution in real-time, each new generation of microprocessors enables progressively faster, higher-resolution applications. In addition, as the price of memory circuits and other data storage hardware continues to fall, the capacity of such devices has risen dramatically, thereby improving the prospects for enhancing PC-based image manipulation systems for such applications.

In terms of dedicated equipment, attention has traditionally focused on the development of two kinds of professional image-manipulation systems: those intended for the highest quality levels to support film effects, and those intended for television broadcast to provide "full 35 mm theatrical film quality," within the realities and economics of present broadcasting systems. Conventional thinking holds that 35 mm theatrical film quality as projected in theaters is equivalent to 1200 or more lines of resolution, whereas camera negatives provide 2500 or more lines. As a result, image formats under consideration have been directed towards video systems having 2500 or more scan lines for high-level production, with hierarchies of production, HDTV broadcast, and NTSC and PAL compatible standards which are derived by down-converting these formats. Most proposals employ progressive scanning, although interlace is considered an acceptable alternative as part of an evolutionary process. Another important issue is adaptability to computer-graphics-compatible formats.

Current technology directions in computers and image processing should allow production equipment based upon

2

fewer than 1200 scan lines, with picture expansions to create a hierarchy of upward-converted formats for theatrical projection, film effects, and film recording. In addition, general-purpose hardware enhancements should be capable of addressing the economic aspects of production, a subject not considered in detail by any of the available references.

For the first fifty years of television in the United States, the history shows continuous development and improvement of a purely analog-based system for video production broadcasting. The nature of the NTSC system is to limit the video bandwidth to 4.2 MHz, which corresponds to approximately 340 TV-lines of resolution. In countries where PAL or SECAM systems are employed, the bandwidth is 5.5 MHz, which corresponds to approximately 440 TV-lines of resolution.

During the past ten years, digital processing has become the standard for video production equipment. However, to preserve compatibility with existing equipment and standards, the video bandwidth typically has been limited to 4–6 MHz (for NTSC and PAL applications, respectively). This also has tended to reduce the apparent generation loss during video production steps.

In the past five years or so, digital image compression technology has matured greatly. Furthermore, there are many incompatible standards, such as the different forms of JPEG systems, the Quick-Time system, MPEG-1, and the numerous forms of the MPEG-2 standard. In addition, the latest recording formats for video production have introduced a new set of variations, including the ¼-inch DVC-formats from Sony and Matsushita. While the signal deterioration characteristics of multi-generation analog-based production systems are well known, those imperfections resulting from diverse-format digital video compression and the conversions between these formats can be just as troublesome and unpredictable. In practice, these repeated steps of analog-to-digital (A/D) conversion and digital-to-analog (D/A) conversion, as well as data compression and decompression, introduce many signal artifacts and various forms of signal noise. Although digital video production promises multiple-step production processes free of generation losses, the reality is different, due to the repeated steps of A/D and D/A conversions, as well as data compression and decompression, present when utilizing the various incompatible image data compression formats.

Meanwhile, during the last twenty years, camera technology has advanced to a point far surpassing the performance of traditional production equipment. The video bandwidth capability has increased from 4.2 MHz (corresponding to 340 TV-lines of resolution) to approximately 12 MHz (corresponding to nearly 1000 TV-lines of resolution). Because of the limitations of conventional broadcast and production equipment, most of the detail information produced by today's high-performance camera systems is lost.

For HDTV systems, one goal is to produce images having approximately 1000 TV-lines of resolution per picture height, which requires a bandwidth of approximately 30 MHz. This, in turn, raises a new problem in terms of signal-to-noise ratio. While conventional broadcast cameras can produce signals having a S/N ratio of 65 dB, utilizing 10-bit digital processing, HDTV cameras typically produce signals having a S/N ratio of 54 dB, and utilize only 8-bit digital processing. In addition, the typical HDTV camera utilizes a 2 Megapixel CCD, in which the elements are approximately one-quarter the size of conventional broadcast cameras. This translates into a much lower sensitivity (a loss corresponding to 1–2 lens f-stops), higher levels of "smearing", and lower highlight compression ratios.

Analog-based HDTV systems, such as the Japanese MUSE system, do not approach the design goal of 1000 TV-lines. In reality, only one quarter of the picture information is transmitted. Although the nominal reduced luminance bandwidth of 20 MHz provides approximately 600 TV-lines of resolution per picture height in static program material, this resolution is drastically reduced to only 450 TV-lines where motion is occurring. The chrominance bandwidth is even further reduced by the sub-sampling scheme, to 280 TV-lines for the I-signal and 190 TV-lines for the Q-signal (in static scenes), and to 140 TV-lines for the I-signal and 50 TV-lines for the Q-signal (in moving scenes). Although this system provides a wide-screen aspect ratio of 16:9, it does not really qualify as a High-Definition Television System.

Because of the aforementioned compatibility issues, it is clear that conventional video recorders cannot match the technical performance of modern camera systems. Although "D-6 format" digital recorders are available, the cost and complexity of such equipment place these units beyond the means of the vast majority of broadcast stations. Furthermore, the capability of conventional switchers and other production equipment still fail to match that of available camera systems.

Other recorders have been produced, such as the one-half-inch portable recorder ("Uni-HI"), but this system only achieves 42 dB signal-to-noise ratio, and records in the analog domain. These specifications render this unit unsuitable for multi-generation editing applications. Furthermore, the luminance bandwidth is only 20 MHz, corresponding to approximately 600 TV-lines of resolution.

W-VHS ("Wideband-VHS") recorders provide a wide aspect-ratio image, but only 300 TV-lines of resolution, which also renders this unit unsuitable for any professional applications. Other distribution formats (such as D-VHS) require the application of high compression ratios to limit the data-rate to be recorded, so these formats only achieve W-VHS quality (less than 400 TV-lines of resolution).

The newly-introduced HD Digital Betacam format (HDCAM) video recorder utilizes a 3:1:1 digital processing system rather than the 4:2:2 processing. However, it has a 24 MHz luminance bandwidth corresponding to 700 TV-lines of resolution, and a narrower chrominance bandwidth. Although this system is clearly superior to any existing analog HDTV recording system, it still falls short of delivering the full resolution produced by an HDTV digital camera. Because of its proprietary image data compression format, the production process results in repeated data compression and decompression steps, as well as A/D and D/A conversions, which, in turn, results in many signal artifacts and various forms of signal noise.

In summary, the conventional technology for these markets utilizes professional cameras having a 30 MHz bandwidth, and capable of 1000 TV-lines of resolution. However, they produce quality levels more characteristic of consumer-grade equipment (in terms of resolution and signal-to-noise ratio). In addition, the price of these systems is cost-prohibitive both on an absolute and also a cost/benefit basis, employing digital systems which produce only analog-type performance.

SUMMARY OF THE INVENTION

The present invention takes advantage of available general-purpose technology, where possible, in order to provide an economical multi-format digital video production system. In the preferred embodiment, specialized graph-

ics processing capabilities are included in a high-performance personal computer or workstation, enabling the user to edit and manipulate an input video program and produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format is chosen which provides the greatest compatibility with existing and planned formats associated with HDTV standard 4:3 or widescreen 16:9 high-definition television, and film. For compatibility with film, the frame rate of the internal production format preferably is 24 fps (for program materials originated in film format) and 48 fields-per-second (for live program materials such as sporting events). Images are re-sized horizontally and vertically by pixel interpolation, thereby producing larger or smaller image dimensions so as to fill the particular needs of individual applications. Frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions. Simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) for playback, or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities. The step of converting the signal to a HDTV format is performed by a modified upconversion process for wideband signals (utilizing a higher sampling clock frequency) and a resizing to HDTV format frame dimensions in pixels.

The invention preferably incorporates one or more interface units, including a standard/widescreen interface unit operative to convert the video program in the input format into an output signal representative of a standard/widescreen formatted image, and output the signal to an attached display device. A high-definition television interface unit is operative to convert the video program in the input format into an output signal representative of an HDTV-formatted image, and output the signal to the display device. A centralized controller in operative communication with the video program input, the graphics processor, and an operator interface, enables commands entered by an operator to cause the graphics processor to perform one or more of the conversions using the television interfaces. The present invention thus encourages production at relatively low pixel dimensions to make use of lower-cost general-purpose technology and to maintain high signal-to-noise ratio, and then subsequently expands the resultant image into a so-called up-converted program. This is in contrast to alternative approaches, which recommend operating at HDTV-type resolution, then down-converting, as necessary, to smaller image formats. This has led to the use of expensive dedicated hardware, the need for which the present invention seeks to eliminate. In addition, the flexible storage and playback facilities allow extensive control of the playback of the program material, enabling frame rate adjustments and alterations, and providing for time-shifting of the start and end points of the program reproduction in those cases wherein direct control of the source material frame rate is not practical, due to physical separation of the equipment or multiple reception points simultaneously producing outputs at different frame rates from the same source signal playback data stream. In commercial implementations, the invention readily accepts and processes enhanced information, such as pan/scan information or identification information to restrict viewing based on regional or geographical marketing plans.

The method and associated technology provide for maintaining the original high bandwidth of conventional cameras (up to 15 MHz, which corresponds to more than 600 TV-lines of resolution-per picture height for 16:9 aspect ratio) and provide optimized compression techniques to

fully utilize the available capacity of general storage media, such as the commercially available Panasonic DVCPRO, DVCPRO50, Sony DVCAM, JVC Digital-S, and Sony Betacam SX recorders. The system preferably employs a consistent compression scheme utilizing only intra-frame compression (such as Motion-JPEG-type systems, systems used in DV-format recorders, MPEG-2 4:2:2P@ML) throughout the entire production process. This avoids many signal artifacts, ensures high signal-to-noise ratios, and provides for editing the program material in data-compressed format. This enables the system to preserve the original camera capability of 600+ TV-lines of resolution per picture height, and with 4:2:2 processing provides a chrominance bandwidth of up to 7.5 MHZ. Utilizing 10-bit processing results in 65 dB signal-to-noise performance and improved camera sensitivity (rating of f-11). In contrast, available and proposed systems for HDTV are based on 8-bit processing, and offer performance of less than 54 dB signal-to-noise ratio and camera sensitivity rating of only f-8.

The invention provides for optimization of the available storage media as well. Utilizing hard-disks, optical discs (such as DVD, DVD-R, and DVD-RAM), magneto-optical discs, or digital tapes (such as DAT-format, DVC, DVCPRO, DVCPRO50, DVCAM, Digital-S, or 8-mm format) the data-rate to be recorded is nearly one-quarter that of conventional HDTV systems, and consumes only 20 GB of storage space to record more than 60 minutes in the Production Format compression scheme, which utilizes a data-rate of 50 Mb per second or less, which is well within the capabilities of certain conventional recording devices. Horizontal and vertical pixel-interpolation techniques are utilized to quadruple the image size, preferably resulting in an image frame size of 1920x1080 pixels. The resulting program information may then be distributed in a conventional compression format, such as MPEG-2.

Three alternative image frame sizes preferably are suggested, depending on the intended application. For general usage, an image frame size of 1024x576 is recommended. As an option, a frame size of either 1280x720 or 1920x1080 may be utilized, at 24 frames-per-second. A sampling frequency of up to 74.25 MHZ for luminance is utilized for 1920x1080. Sampling frequencies of up to 37 MHZ are preferably are utilized for 1024x576 and 1280x720. Chrominance components preferably are sampled consistent with a 4:2:2 system, and 10-bit precision is preferred.

The technology of display devices and methodology has progressed as well, offering alternative features such as conversion of interlaced signals to progressive scan, line doubling, pixel quadrupling, and improved general techniques for horizontal and vertical pixel interpolation. Availability of these features as part of display devices will simplify the process of implementing multi-format digital production.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A–1D show the preferred and alternative image aspect ratios in pixels;

FIG. 2 shows a functional diagram for disk/tape-based video recording;

FIG. 3 shows the components comprising the multi-format audio/video production system;

FIG. 4 is a block diagram of an alternative embodiment of video program storage means incorporating asynchronous reading and writing capabilities to carry out frame-rate conversions;

FIG. 5 shows the inter-relationship of the multi-format audio/video production system to many of the various existing and planned video formats;

FIG. 6 shows the implementation of a complete television production system, including signals provided by broadcast sources, satellite receivers, and data-network interfaces;

FIGS. 7A–7B show the preferred methods for conversion between several of the most common frame-rate choices;

FIGS. 7C–7I show details of possible methods for frame rate conversion processes; and

FIG. 8 shows a block diagram of an embodiment of a universal playback device for multi-format use.

DETAILED DESCRIPTION OF THE INVENTION

The present invention resides in the conversion of disparate graphics or television formats, including requisite frame-rate conversions, to establish an inter-related family of aspect ratios, resolutions, and frame rates, while remaining compatible with available and future graphics/TV formats, including images of pixel dimensions capable of being displayed on currently available multi-scan computer monitors. Custom hardware is also disclosed whereby frames of higher pixel-count beyond the capabilities of these monitors may be viewed. Images are re-sized by the system to larger or smaller dimensions so as to fill the particular needs of individual applications, and frame rates are adapted by inter-frame interpolation or by traditional schemes such as using “3:2 pull-down” (such as 24 frame-per-second (fps) Progressive to 30 fps interlace shown in FIG. 7C or 48 fps Progressive to 60 fps Progressive, as would be utilized for film-to-NTSC conversions) or by speeding up the frame rate itself (such as for 24 to 25 fps for PAL television display) The re-sizing operations may involve preservation of the image aspect ratio, or may change the aspect ratio by “cropping” certain areas, by performing non-linear transformations, such as “squeezing” the picture, or by changing the vision center for “panning,” “scanning” and so forth. Inasmuch as film is often referred to as “the universal format,” (primarily because 35-mm film equipment is standardized and used throughout the world), the preferred internal or “production” frame rate is preferably 24 fps. This selection also has an additional benefit, in that the 24 fps rate allows the implementation of cameras having greater sensitivity than at 30 fps, which is even more critical in systems using progressive scanning (for which the rate will be 48 fields per second interlaced (or 24 fps Progressive) vs. 60 fields per second interlaced in some other proposed systems).

The image dimensions chosen allow the use of conventional CCD-type cameras, but the use of digital processing directly through the entire signal chain is preferred, and this is implemented by replacing the typical analog RGB processing circuitry with fully digital circuitry. Production effects may be conducted in whatever image size is appropriate, and then re-sized for recording. Images are recorded by writing the digital data to storage devices employing internal or removable hard-disk drives, disk drives with removable media, optical or magneto-optical based drives, DVD-R or DVD-RAN type drives, tape-based drives, or semiconductor-based memory devices, preferably in compressed-data form.

As data rates for image processing and reading from, is or writing to, disk drives increase, many processes that currently require several seconds will soon become attainable in real-time. This will eliminate the need to record film or video frames at slower rates. Other production effects, such as slow-motion or fast-motion may be incorporated, and it is only the frame-processing-rate of these effects that is limited

in any way by the technology of the day. In particular, techniques such as non-linear-editing, animation, and special-effects will benefit from the implementation of this system. In terms of audio, the data rate requirements are largely a function of sound quality. The audio signals may be handled separately, as in an "interlocked" or synchronized system for production, or the audio data may be interleaved within the video data stream. The method selected will depend on the type of production manipulations desired, and by the limitations of the current technology.

Although a wide variety of video formats and apparatus configurations are applicable to the present invention, the system will be described in terms of the alternatives most compatible with currently available equipment and methods. FIG. 1A illustrates one example of a compatible system of image sizes and pixel dimensions. The selected frame rate is preferably 24 per second progressive (for compatibility with film elements), or 48 fields per second interlaced (for live program material such as sporting events). The selected picture dimension in pixels is preferably 1024x576 (0.5625 Mpxl), for compatibility with the Standard Definition TV (SDTV) 16:9 "wide-screen" aspect ratio anticipated for HDTV systems, and the conventional 4:3 aspect ratio used for PAL systems [768x576 (0.421875 Mpxl)] or NTSC systems [640x480 (0.3072 Mpxl)]. All implementations preferably rely on square pixels, though other pixel shapes may be used. Re-sizing (using the well known, sophisticated sampling techniques available in many image-manipulation software packages or, alternatively, using horizontal and vertical pixel interpolation hardware circuitry described herein below) either to 1280x720 (0.922 Mpxl) or else to 1920x1080 (2.14 Mpxl) provides an image suitable for HDTV displays or even theatrical projection systems, and a further re-sizing to 3840x2160 (8.3 Mpxl) is appropriate for even the most demanding production effects. Images may be data compressed, preferably 5:1 with Motion-JPEG-type compression such as utilized in DV-format equipment, or preferably 10:1 with MPEG-2 4:2:2P@ML compression.

In order to preserve the full bandwidth of this high-resolution signal, a higher sampling frequency is required for encoding, preferably approximately 20 MHZ, for 1024x576 at 24 fps, which results in 1250 samples per total line, with 625 total lines per frame. This sampling rate allows processing a 10 MHZ bandwidth luminance signal, which corresponds to approximately 600 TV lines of resolution per picture height. In contrast, traditional SDTV digital component systems employ a sampling frequency of 13.5 MHZ, which provides a luminance bandwidth of 5 to 6 MHZ (approximately 300 to 360 TV lines of resolution per picture height). These wide-band data files may then be stored on conventional magnetic or optical disk drives, or tape-based storage units, requiring only approximately 5.5 MB/sec for SDTV wide-screen frames in Y/R-Y/B-Y (assuming a 4:2:2 system at 8 bits per sample). The resultant data rate for this system is less than 50 Megabits per second, which is within the capabilities of currently available video recording equipment, such as the Betacam SX, DVCPRO50 or Digital S50. If a higher data-compression ratio is applied, then other units may be used, such as DVC, DVCPRO or DVCAM; Betacam SX, DVCPRO50 or Digital S50 may be used to allow sampling to 10-bit precision rather than 8-bit precision.

An alternative aspect of the invention is shown in FIG. 1B. In this case, the user follows a technique commonly used in film production, in which the film is exposed as a 4:3 aspect ratio image. When projected as a wide-screen format image, the upper and lower areas of the frame may be

blocked by an aperture plate, so that the image shows the desired aspect ratio (typically 1.85:1 or 1.56:1) If the original image format were recorded at 24 frames per second, with a 4:3 ratio and with a dimension in pixels of 1024x768, all image manipulations would preserve these dimensions. Complete compatibility with the existing formats would result, with NTSC and PAL images produced directly from these images by re-scaling, and the aforementioned wide-screen images would be provided by excluding 96 rows of pixels from the top of the image and 96 rows of pixels from the bottom of the image, resulting in the 1024x576 image size as disclosed above. The data content of each of these frames would be 0.75 Mpxls, and the data storage requirements disclosed above would be affected accordingly.

Another aspect of the invention is depicted in FIG. 1C. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimensions of 1280x720 pixels. Using these image dimensions (but at 24 fps progressive), compatibility with the existing formats would be available, with NTSC and PAL images derived from this frame size by excluding 160 columns of pixels from each side of the image, thereby resulting in an image having a dimension in pixels of 960x720. This new image would then be re-scaled to produce images having pixel dimensions of 640x480 for NTSC, or 768x576 for PAL. The corresponding wide-screen formats would be 854x480 and 1024x576, respectively. Utilizing a 4:2:2 sampling scheme, the 1280x720 image will require 1.85 MB when sampled at a precision of 8-bits, and 2.3 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 4.44 MB. per second (35.5 megabits per second) or 5.55 MB per second (44.4 megabits per second).

In order to preserve the full 5 MHZ bandwidth of this high-resolution signal, a sampling frequency of approximately 30 MHZ is required for encoding, which results in 1650 samples per total line, with 750 total lines per frame for a 1280x720 image at 24 frames-per-second. In contrast, typical high definition systems require sampling rates of 74 MHZ to provide a bandwidth of 30 MHZ). In this case, an image having a dimension in pixels of 1280x720 would contain 0.87890625 Mpxl, with 720 TV lines of resolution. Furthermore, the systems under evaluation by the ATSC of the FCC all assume a decimation of the two chrominance signals, with detail of only 640x360 pixels retained. Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 50 megabits per second. This is within the capabilities of currently available video recording equipment, such as Betacam SX, the DVCPRO50 or Digital S50. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. The development path to 24 fps progressive is both well-defined and practical, as is the use of the previously described methods to produce images having a dimension in pixels of 1920 x1080.

A third embodiment of the invention is depicted in FIG. 1D. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimen-

sions of 1920×1080 pixels (2.1 megapixels), but at 24 frames-per-second Progressive. Utilizing a 4:2:2 sampling scheme, this 1920×1080 image will require 4.2 MB when sampled at a precision of 8-bits, and 5.2 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 10 MB per second (80 Megabits per second) or 12.5 MB per second (96 megabits per second). In order to preserve the full bandwidth of this high-resolution signal, a sampling frequency of 74.25 MHZ is required for encoding, which results in 2750 samples per total line, with 1125 total lines per frame. In this case, an image having these dimensions would have over 1,200 TV lines of resolution per picture height, representing over 30 MHZ luminance bandwidth. The chrominance bandwidth (as R-Y/B-Y) would be 15 MHZ. In contrast, HDTV with 1920×1080 and 30 fps Interlace only produces 1,000 TV lines (200 lines less than above) of resolution per picture height from same sampling frequency of 74.25 MHZ.

Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 100 Megabits per second. This is within the capabilities of video recording equipment, such as the Panasonic DVCPRO100 or JVC Digital S100, which will be available in the near future. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. These images may be resized into frames as large as 7680×4320, which would allow use of the system for special optical effects, or with other, specialized film formats, such as IMAX and those employing 65 mm. Camera negatives. In addition, conversions processes are available, as described herein below, to produce other HDTV formats (such as 1280×720 Progressive at 24 fps, 1920×1080 Interlaced at 25 fps, 1920×1080 Progressive at 50 fps, 1920×1080 Interlaced at 30 fps, and 1920×1080 Progressive at 60 fps), or to alternative SDTV formats, (such as 1024×576 at fps, 768×576 at 25 fps, 853×480 at 30 fps, or 640×480 at 30 fps).

In each of the cases described herein above, a positioning or image centering signal may be included within the data stream, so as to allow the inclusion of information which may be utilized by the receiving unit or display monitor to perform a “pan/scan” operation, and thereby to optimize the display of a signal having a different aspect ratio than that of the display unit. For example, a program transmitted in a wide-screen format would include information indicating the changing position of the image center, so that a conventional (4:3 aspect ratio) display unit would automatically pan (horizontally and/or vertically) to the proper location. For the display of the credits or special panoramic views, the monitor optionally could be switched to a full “letter-box” display, or the image could be centered and rescaled to include information corresponding to an intermediate situation, such as halfway between full-height (with cropped sides) and letter-box (full-width, but with blank spaces above and below the image on the display). This positioning/resealing information would be determined under operator control (as is typical for pan/scan operations when performing film transfers to video) so as to maintain the artistic values of the original material, within the limitations of the intended display format.

Conventional CCD-element cameras produce images of over 900 TV Lines horizontal Luminance (Y) resolution, with a sensitivity of 2,000 lux at f-11, and with a signal-to-

noise ratio of 65 dB. However, typical HDTV cameras, at 1,000 TV Lines resolution and with sensitivity ratings of f-8, produce an image with only a 54 dB signal-to-noise ratio, due to the constraints of the wideband analog amplifiers and the smaller physical size of the CCD-pixel-elements. By employing the more conventional CCD-elements in the camera systems of this invention, and by relying upon the computer to create the HDTV-type image by image re-sizing, the improved signal-to-noise ratio is retained. In the practical implementation of cameras conforming to this new design approach, there will be less of a need for extensive lighting provisions, which in turn, means less demand upon the power generators in remote productions, and for AC-power in studio applications.

In CCD-based cameras, it is also a common technique to increase the apparent resolution by mounting the red and blue CCD-elements in registration, but offsetting the green CCD-element by one-half pixel width horizontally and in some application vertically. In this case, picture information is in-phase, but spurious information due to aliasing is out-of-phase. When the three color signals are mixed, the picture information is intact, but most of the alias information will be canceled out. This technique will evidently be less effective when objects are of solid colors, so it is still the usual practice to include low-pass optical filters mounted on each CCD-element to suppress the alias information. In addition, this technique cannot be applied to computer-based graphics, in which the pixel images for each color are always in registration. However, for Y/R-Y/B-Y video, the result of the application of this spatial-shift offset is to raise the apparent Luminance (Y) horizontal resolution to approximately 900 television lines (a 4:3 aspect ratio utilizing 1200 active pixels per line), and the apparent vertical resolution is increased by 50–100+ lines.

During the transition period to implement 24 fps recording as a new production standard, conventional 16:9 widescreen-capable CCD cameras (running in 25 or 30 fps Interlaced mode) may be utilized to implement the wideband recording method so as to preserve the inherent wideband capability of these cameras, in accordance with the invention. By abandoning the requirement for square pixels, sampling frequencies of up to 30 MHZ for luminance (15 MHZ for chrominance) preferably are utilized, which frequencies are less than half the typical sampling rate of 74 MHZ utilized for typical HDTV luminance signals in alternative systems. Chrominance components preferably are sampled consistent with a 4:2:2 system. This wideband data stream is then compressed 10:1, utilizing MPEG-2 4:2:2P@ML at 10-bit. The resultant data rate is still less than 50 Megabits per second. With a straightforward modification to increase the data compression rate to 10:1, this signal may be recorded utilizing any of several conventional recording devices, including Panasonic DVCPRO50, JVC Digital-S, and Sony Betacam SX, thereby preserving the wideband signal (up to 800 TV lines of resolution per picture height). By utilizing the appropriate techniques for image resizing and frame rate conversion as described herein, video systems may be supported consistent with 1280×720 60 fps progressive, 1280×720 24 fps Progressive, 1920×1080 25 fps Interlace, 1920×1080 30 fps Interlace, 1920×1080 50 fps progressive, 1920×1080 60 fps progressive, in accordance with the invention.

The availability of hard-disk drives of progressively higher capacity and data transmission rates is allowing successively longer program duration and higher resolution image displays in real-time. At the previously cited data rates, wide-screen frames (1024×576 pixel, 24 fps, 4:2:2

process, 8bits precision and 5:1 compression) would require 330 MB/min, so that currently available 10 GB disk drives will store more than 30 minutes of video. When the anticipated 50 GB disk drives (5.25-inch disks) become available from Seagate within the year, these units will store 150 minutes, or 2½ hours of video. For this application, a data storage unit is provided to facilitate editing and production activities, and it is anticipated that these units would be employed in much the same way as video cassettes are currently used in Betacam SP and other electronic news gathering (ENG) cameras and in video productions. This data storage unit may be implemented by use of a magnetic, optical (such as DVD-R or DVD-RAM) discs, or magneto-optical disk drive with removable storage media, by a removable disk-drive unit, such as those based on the PCMCIA standards, by tape-based storage means, or by semiconductor-based memory. Future advances in storage technology will lead to longer duration program data storage. Alternatively, this storage capacity could be applied to lower ratios of data compression, higher sampling precision (10 bits or more) or higher-pixel-count images, within the limits of the same size media.

FIG. 2 shows the functional diagram for the storage-device-based digital recorder employed in the video camera, or separately in editing and production facilities. As shown, a removable hard disk drive 70 is interfaced through a bus controller 72. In practice, alternative methods of storage such as optical drives (such as DVD-R or DVD-RAM units) or magneto-optical drives could be used, based on various interface bus standards such as SCSI-2. This disk drive system currently achieves data transfer rates of 40 MB/sec, and higher rates on these or other data storage devices, such as high-capacity removable memory modules, is anticipated. If a digital tape-based format is selected, a tape drive 88 is interfaced through the bus controller 72. Currently available digital tape-based formats include DVCPRO, DVCPRO50, DVCAM, Betacam SX, Digital S50, and others. These units typically offer storage capacities in the range of 30 to 50 GigaBytes. The microprocessor 74 controls the 64-bit or wider data bus 80, which integrates the various components. Currently available microprocessors include the Alpha 21164 by Digital Equipment Corporation, or the MIPS processor family by MIPS Technologies, Inc. Future implementations would rely on the Pentium™ series by Intel Corp. or the PowerPC G3, which is capable of sustained data transfer rates of 100 MB/sec.

Up to 256 MB of ROM, shown at 76, is anticipated for operation, as is 256 MB or more of RAM, shown at 78. Current PC-based video production systems are equipped with at least 64 MB of RAM, to allow sophisticated editing effects. The graphics processor 82 represents dedicated hardware that performs the various manipulations required to process the input video signals 84 and the output video signals 86. Although shown using an RGB format, either the inputs or outputs could be configured in alternative signal formats, such as Y/R-Y/B-Y, YIQ, YUV or other commonly used alternatives. In particular, while a software-based implementation of the processor 82 is possible, a hardware-based implementation is preferred, with the system employing a compression ratio of 5:1 for the conventional/widescreen signals ("NTSC/PAL/Widescreen"), and a 10:1 compression ratio for HDTV signals (1280x720 or 1920x1080, as described herein above). Example of the many available options for this data compression include the currently available Motion-JPEG system and the MPEG systems. Image re-sizing alternatively may be performed by dedicated microprocessors, such as the gm865x1 or

gm833x3 by Genesis Microchip, Inc. Audio signals may be included within the data stream, as proposed in the several systems for digital television transmission considered by the Federal Communications Commission, or by one of the methods available for integrating audio and video signals used in multi-media recording schemes, such as the Microsoft "AVI" (Audio/Video Interleave) file format. As an alternative, an independent system for recording audio signals may be implemented, either by employing separate digital recording provisions controlled by the same system and electronics, or by implementing completely separate equipment external to the camera system described herein above.

FIG. 3 shows the components that comprise a multi-format audio/video production system according to the invention. As in the case of the computer disk- or tape-based recording system of FIG. 2, an interface bus controller 106 provides access to a variety of storage devices, preferably including an internal hard-disk drive 100, a tape-drive 102, and a hard-disk drive with removable media or a removable hard-disk drive 104. Other possible forms of high-capacity data storage (not shown) utilizing optical, magneto-optical, or magnetic storage techniques may be included, as appropriate for the particular application. The interface bus standards implemented could include, among others, SCSI-2. Data is transmitted to and from these devices under control of microprocessor 110. Currently, data bus 108 would operate as shown as 64-bits wide, employing microprocessors such as those suggested for the computer-disk-based video recorder of FIG. 3. As higher-powered microprocessors become available, such as the PowerPC G3, the data bus may be widened to accommodate 128 bits, and the use of multiple parallel processors may be employed, with the anticipated goal of 1,000 MIPS per processor. Up to 256 MB of ROM 112 is anticipated to support the requisite software, and at least 1,024 MB of RAM 114 will allow for the sophisticated image manipulations, inter-frame interpolation, and intra-frame interpolation necessary for sophisticated production effects, and for conversions between the various image formats.

A key aspect of the system is the versatility of the graphics processor shown generally as 116. Eventually, dedicated hardware will allow the best performance for such operations as image manipulations and re-scaling, but it is not a requirement of the system that it assume these functions, or even that all of these functions be included in the graphics processor in every configuration of the system. Three separate sections are employed to process the three classifications of signals. Although the video input and output signals described herein below are shown, by example, as RGB, any alternative format for video signals, such as Y/R-Y/B-Y, YIQ, YUV, or other alternatives may be employed as part of the preferred embodiment. One possible physical implementation would be to create a separate circuit board for each of the sections as described below, and manufacture these boards so as to be compatible with existing or future PC-based electrical and physical interconnect standards.

A standard/widescreen video interface 120, intended to operate within the 1024x576, 1280x720, 1024x768, 854x480, 640x480 or 1280x960 image sizes, accepts digital RGB or Y/R-Y/B-Y signals for processing and produces digital RGB or Y/R-Y/B-Y outputs in these formats, as shown generally at 122. Conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, including analog RGB or Y/R-Y/B-Y signals and composite video signals. These outputs may optionally be

supplied to either a conventional multi-scan computer video monitor or a conventional video monitor having input provisions for RGB or Y/R-Y/B-Y signals (not shown). A third set of outputs supplies analog Y/C video signals. The graphics processor may be configured to accept or output these signals in the standard NTSC, PAL, or SECAM formats, and may additionally be utilized in other formats as employed in medical imaging or other specialized applications, or for any desired format for computer graphics applications. Conversion of these 24 frame-per-second progressive images to the 30 fps Interlaced (actually, 29.97 fps) NTSC and 25 fps PAL formats may be performed in a similar manner to that used for scanned film materials, that is, to NTSC by using the conventional 3:2 "pull-down" field-sequence, or to PAL by reproducing the images at the higher 25 fps rate.

If the source signal is 24 fps interlaced, these images first are de-interlaced to 48 fps progressive, which can be performed by dedicated microprocessors such as the gmVLD8 or gmVLD10 by Genesis Microchips, and then converted to 60 fps progressive by utilizing a "Fourth Frame Repeat" process (which repeats the fourth frame in every sequence). Next, the signal is interlaced to produce 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced (as disclosed in FIG. 7F). If the source format is 25 fps interlaced video (as would result from using conventional PAL-type equipment, or PAL-type equipment as modified in accordance with the invention), the first step is to slow down the frame rate by replaying the signal at 24 fps Interlaced. Next, the signal is de-interlaced to 48 fps progressive (as described herein above), and the Fourth Frame Repeat process is utilized to convert the signal to 60 fps progressive. In the last step, the signal is interlaced to produce 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced. Alternatively, if the source signal is 24 fps progressive, the 60 fps progressive signal may be produced directly from a "3:2 Frame Repeat" process shown in FIG. 7G (which is analogous to the conventional "3:2 pull-down" field-sequencing process previously described). For other HDTV frame rates, aspect ratios, and line rates, intra-frame and inter-frame interpolation and image conversions may be performed by employing comparable techniques well known in the art of computer graphics and television.

An HDTV video interface **124**, Intended to operate within the 1920x1080 or other larger image sizes (with re-sizing as necessary), accepts digital RGB or Y/R-Y/B-Y (or alternative) signals for processing and produces digital outputs in the same image format, as shown generally at **126**. As is the case for the standard/widescreen interface **120**, conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, for analog RGB signals and composite video signals. In alternative embodiments, this function may be performed by an external upconverter, which will process the wideband signal of the instant invention. A modification of currently available upconvertors is required, to increase the frequency of the sampling clock in order to preserve the full bandwidth of this signal, in accordance with the invention. In this case, frequency of the sampling clock is preferably adjustable to utilize one of several available frequencies.

The third section of the graphics processor **116** shown in FIG. 3 is the film output video interface **128**, which comprises a special set of video outputs **130** intended for use with devices such as laser film recorders. These outputs are preferably configured to provide a 3840x2160 or other

larger image size from the image sizes employed internally, using re-sizing techniques discussed herein as necessary for the format conversions. Although 24 fps is the standard frame rate for film, some productions employ 30 fps (especially when used with NTSC materials) or 25 fps (especially when used with PAL materials), and these alternative frame rates, as well as alternative image sizes and aspect ratios for internal and output formats, are anticipated as suitable applications of the invention, with "3:2-pull-down" utilized to convert the internal 24 fps program materials to 30 fps, and 25 fps occurring automatically as the film projector runs the 24 fps films at the 25 fps rate utilized for PAL-type materials.

Several additional optional features of this system are disclosed in FIG. 3. The graphics processor preferably also includes a special output **132** for use with a color printer. In order to produce the highest quality prints from the screen display it is necessary to adjust the print resolution to match the image resolution, and this is automatically optimized by the graphics processor for the various image sizes produced by the system. In addition, provisions may be included for an image scanner **134**, which may be implemented as a still image scanner or a film scanner, thereby enabling optical images to be integrated into the system. An optional audio processor **136** includes provisions for accepting audio signals in either analog or digital form, and outputting signals in either analog or digital form, as shown in the area generally designated as **138**. For materials including audio intermixed with the video signals as described herein above, these signals are routed to the audio processor for editing effects and to provide an interface to other equipment.

It is important to note that although FIG. 3 shows only one set of each type of signal inputs, the system is capable of handling signals simultaneously from a plurality of sources and in a variety of formats. Depending on the performance level desired and the image sizes and frame rates of the signals, the system may be implemented with multiple hard disk or other mass-storage units and bus controllers, and multiple graphics processors, thereby allowing integration of any combination of live camera signals, prerecorded materials, and scanned images. Improved data compression schemes and advances in hardware speed will allow progressively higher frame rates and image sizes to be manipulated in real-time.

Simple playback of signals to produce PAL output is not a serious problem, since any stored video images may be replayed at any frame rate desired, and filmed material displayed at 25 fps is not objectionable. Indeed, this is the standard method for performing film-to-tape transfers used in PAL- and SECAM-television countries. Simultaneous output of both NTSC and film-rate images may be performed by exploiting the 3:2 field-interleaving approach: $5 \times 24 = 120 = 2 \times 60$. That is, two film frames are spread over five video fields. This makes it possible to concurrently produce film images at 24 fps and video images at 30 fps. The difference between 30 fps and the exact 29.97 fps rate of NTSC may be palliated by slightly modifying the system frame rate to 23.976 fps. This is not noticeable in normal film projection, and is an acceptable deviation from the normal film rate.

The management of 25 fps (PAL-type) output signals in a signal distribution system configured for 24 fps production applications (or vice versa) presents technical issues which must be addressed, however. One alternative for facilitating these and other frame-rate conversions is explained with reference to FIG. 4. A digital program signal **404** is provided to a signal compression circuit **408**. If the input program

signal is provided in analog form **402**, then it is first processed by A/D converter **406** to be placed in digital form. The signal compressor **408** processes the input program signal so as to reduce the effective data rate, utilizing any of the commonly implemented data compression schemes, such as motion-JPEG, MPEG-1, MPEG-2, etc. well known in the art. As an alternative, the digital program signal **404** may be provided in data-compressed form. At this point, the digital program signal is provided to data bus **410**. By way of example, several high-capacity digital storage units, designated as "storage means A" **412** and "storage means B" **414**, are included for storing the digital program signals presented on data bus **410**, under management by controller **418**.

The two storage means **412** and **414** may be used in alternating fashion, with one storing the source signal until it reaches its full capacity. At this point, the other storage means would continue storing the program signal until it, too, reached its full capacity. The maximum program storage capacity for the program signals will be determined by various factors, such as the input program signal frame rate, the frame dimensions in pixels, the data compression rate, the total number and capacities of the various storage means, and so forth. When the available storage capacity has been filled, this data storage scheme automatically will result in previously-recorded signals being overwritten. As additional storage means are added, the capacity for time-delay and frame rate conversion is increased, and there is no requirement that all storage means be of the same type, or of the same capacity. In practice, the storage means would be implemented using any of the commonly available storage techniques, including, for example, magnetic disks, optical (such as DVD-RAM discs) or magneto-optical discs, or semiconductor memory.

When it is desired to begin playback of the program signal, signal processor **416**, under management by controller **418** and through user interface **420**, retrieves the stored program signals from the various storage means provided, and performs any signal conversions required. For example, if the input program signals were provided at a 25 fps rate (corresponding to a 625-line broadcast system), the signal processor would perform image resizing and inter-frame interpolation to convert the signal to 30 fps (corresponding to a 525-line broadcast system). Other conversions (such as color encoding system conversion from PAL-format to NTSC, etc., or frame dimension or aspect-ratio conversion) will be performed as necessary. The output of the signal processor is then available in digital form as **422**, or may be processed further, into analog form **426** by D/A converter **424**. In practice, a separate data bus (not shown) may be provided for output signals, and/or the storage means may be implemented by way of dual-access technology, such as dual-port RAM utilized for video-display applications, or multiple-head-access disk or disk storage units, which may be configured to provide simultaneous random-access read and write capabilities. Where single-head storage means are implemented, suitable input buffer and output buffer provisions are included, to allow time for physical repositioning of the record/play head.

In utilizing program storage means including synchronous recording and playback capabilities of the types just described, if it is known that a program will be stored in its entirety before the commencement of playback, that is, with no time-overlap existing between the occurrence of the input and output signal streams, it typically will be most efficient to perform any desired frame conversion on the program either before or after initial storage, depending upon which

stored format would result in the least amount of required memory. For example, if the program is input at a rate of 24 frames per second, it probably will be most efficient to receive such a program and store it at that rate, and perform a conversion to higher frame rates upon output. In addition, in situations where a program is recorded in its entirety prior to conversion into a particular output format, it is most efficient to store the program either on a tape-based format or a format such as the new high-capacity DVD-type discs, given the reduced cost, on a per-bit basis, of these types of storage. Of course, conventional high-capacity disk storage also may be used, and may become more practical as storage capacities continue to increase and costs decrease. If it is known that a program is to be output at a different frame rate while it is being input or stored, it is most preferable to use disk storage and to perform the frame rate conversion on an ongoing basis, using one of the techniques described above. In this case, the high-capacity video storage means, in effect, assumes the role of a large video buffer providing the fastest practical access time. Again, other memory means (types) may be used, including all solid-state and semiconductor types, depending upon economic considerations, and so forth.

As an example of an alternative embodiment, the storage means **100** or **104** are equipped with dual-head playback facilities and a second set of graphics processing hardware (not shown) analogous in function to the normal graphics processing hardware (identical to the standard hardware shown as **120**, **124**, and **128**), and having analogous signal output facilities (identical to the standard provisions shown as **122**, **126**, **130**, and **132**). In this case, the two heads would be driven independently, to provide simultaneous, asynchronous playback at different frame rates. That is, one head would be manipulated so as to provide a data stream corresponding to a first frame rate (for example, 25 fps), while the second head would be manipulated so as to provide a data stream corresponding to a second frame rate (for example, 24 fps, which, in turn, may be converted to 30 fps, using the "3:2-pull-down" technique). In this case, both the storage means and also the internal bus structure of the system would have to support the significantly increased data rate for providing both signal streams simultaneously, or, as an alternative, a second, separate data bus would be provided.

In some applications, a more sophisticated conversion scheme is required. For example, in frame rate conversion systems of conventional design, if an input program signal having a 24 fps rate format is to be displayed at a 25 fps rate, it is customary to simply speed up the source signal playback, so as to provide the signals at a 25 fps rate. This is the procedure utilized for performing A conversion of 24-10 fps-film-material for 25 fps PAL-format video usage. However, implementation of this method requires that the user of the output signal must have control over the source-signal playback. In a wide-area distribution system (such as direct-broadcast-satellite distribution) this is not possible. While a source signal distributed at 24 fps readily could be converted to 30 fps (utilizing the familiar "3-2-pull-down" technique), the conversion to 25 fps is not as easily performed, due to the complexity and expense of processing circuitry required for inter-frame interpolation over a 24-frame sequence. However, utilizing the system disclosed in FIG. 4, the conversion is straightforward. If, for example, a 24 fps program lasting 120 minutes is transmitted in this format, there are a total of 172,800 frames of information (24 frames/second×60 seconds/minute×120 minutes). Display of this program in speeded-up fashion at 25 fps would

mean that the input frame rate falls behind the output frame rate by one frame per second, or a total of 7,200 frames during the course of the program. At a 24 fps transmission rate, this corresponds to 300 seconds transmission time. In other words, for the input program (at 24 fps) and the output program (at 25 fps) to end together, the input process would have to commence 300 seconds before the output process begins. In order to perform this process, then, it is necessary for the storage means to have the capacity to retain 300 seconds of program material, in effect serving as a signal buffer. As an example, for the systems disclosed herein in which the compressed-data rates range from 5.5 MB/sec (for 24 fps standard/widescreen Y/R-Y/B-Y-based TV formats, using 5:1 data compression such as MPEG or motion-JPEG and 4:2:2 processing with 8-bit precision) to 10 MB/sec (for 24 fps HDTV Y/R-Y/B-Y-based formats, using 10:1 data compression such as MPEG or motion-JPEG and 4:2:2 processing with 8-bit precision), it may be necessary to store as much as 3.3 GBytes of data, which is readily available by way of multiple disks or discs utilizing conventional storage technology. In practice, the transmission simply would begin 300 seconds before the playback begins, and once the playback starts, the amount of buffered signal would decrease by one frame per second of playback until the last signal is passed through as soon as it is received.

A mirror of this situation arises in the case of a 25 fps signal to be displayed at 24 fps, or some other data rate readily provided by conversion from 24 fps (such as 30 fps). In this case, the source signal is provided at a higher frame rate than the output signal, so that a viewer watching a program from the onset of the transmission would fall behind the source signal rate, and the storage means would be required to hold frames of the program to be displayed at a time after the source signal arrival time. In the case of the 120 minute program described above, the viewing of the source program would conclude 300 seconds after the source signal itself had concluded, and comparable calculations are applied for the storage means. In this case, the extra frames would be accumulated as the buffer contents increased, until, after the transmission has completed, the last 300 seconds would be replayed directly from the storage means.

The conversion of frame rates from 30 fps to 24 fps or to 25 fps is more complicated, because some form of inter-frame interpolation is required. In one case, a multi-frame storage facility would allow this type of interpolation to be performed in a relatively conventional manner, as typically is utilized in NTSC-to-PAL conversions (30 fps to 25 fps). At this point, a 25 fps to 24 fps conversion could be performed, in accordance with the methods and apparatus described herein above.

It should be noted that if, for example, a DVD-R-type, DVD-RAM-type, or some form of removable magnetic storage media is selected, then the implementation of the significantly higher data compression rates of MPEG-2 coding techniques will result in the ability to record an entire program of 120 minutes or more in duration. In this manner, the complete program is held in the disk/buffer, thereby enabling the user to perform true time-shifting of the program, or allowing the program rights owner to accomplish one form of software distribution, in accordance with the invention.

An alternative method to carry out this frame rate conversion is carried out utilizing the following process. The 30 fps interlaced signal is first de-interlaced to 60 fps Progressive. Then, every fifth frame is deleted from the sequence, producing a 48 fps progressive signal stream. Next, these

remaining frames are converted to 24 fps interlaced, as disclosed in FIG. 7I ("5th Frame Reduction"). If the original source material were from 24 fps (for example, film), then if the repeated fields (i.e., the "3" field of the 3:2 sequence) were identified at the time of conversion, then the removal of these fields would simply return the material to its original form. If the desired conversion is to be from 30 fps to 25 fps, then an equivalent procedure would be performed using the storage-based frame-conversion method described herein above. As an alternative, the 30 fps interlaced signal would first be de-interlaced to 60 fps progressive; then, every sixth frame would be deleted from the sequence ("6th Frame Reduction"). The remaining frames are re-interlaced to produce 25 fps interlaced, as disclosed in FIG. 7H. Depending on the original source material frame rate and intermediate conversions, the user would select the method likely to present the least amount of image impairment.

In the case in which the user is able to exercise control over the frame rate of the source program material, an alternative method is available. Just as film-to-video transfers for PAL-format (25 fps) presentations utilize a speeded-up playback of the 24 fps film materials to source them at the 25 fps Progressive rate (thereby matching the intended output frame rate), the reverse of this process enables a user to utilize materials originated at 25 fps Progressive to produce playback at 24 fps. As disclosed herein above, conversions of 24 fps progressive materials are handled easily by way of conventional methods (such as the "3:2-pull-down" method), and therefore the operator control of the source material enables the user to utilize materials originating from conventional or widescreen PAL format sources for editing and production, then replay the resulting program at 24 fps for conversion to either standard or widescreen NTSC output materials, or even to HDTV format materials, all at 30 fps Interlaced, by performing the "3:2-pull-down" process.

If the source format is 25 fps interlaced video (as would result from using conventional PAL-type CCD widescreen camera), an alternative method for producing a 30 fps Interlaced signal is available. Instead of performing a slow-down to produce a 24 fps interlaced signal, the 25 fps Interlaced signal is first de-interlaced to 50 fps progressive. Next, a "4th Frame Repeat" process is applied, which results in a 62.5 fps progressive signal. This signal is then converted to 62.5 fps interlaced, and after half of the fields are discarded, to produce 31.25 fps interlaced. After data compression, the signal undergoes a slow-down process, resulting in a 30 fps interlaced signal which now has a compressed-data-rate of less than 10 Mbytes per second, as disclosed in FIG. 7D. By using this procedure, the entire process from the CCD camera to the final conversion to 30 fps Interlaced only one data compression step is employed. Alternatively, if the output of the camera is already in data compressed form, then this signal must be decompressed before applying the listed conversion steps. In order to ensure accurate conversion, interlace and de-interlace processes should only be applied to de-compressed signals. Conversely, speed-up and slow-down procedures are preferably applied with compressed data, as the raw data rate for uncompressed video, depending on the image dimensions in pixels and frame rate, will be in the range of 30 to 100 MB per second, which is not practical for current technology storage devices.

A variety of conversions between formats (both interlaced and progressive) having differing frame rates, and some of these possible conversion paths are indicated in FIGS. 7A through 7I. While extensive, these listings are not intended

to represent a complete listing of all alternatives, as in many cases there is more than one combination of methods which may effect an equivalent conversion. Depending on the particular application, different paths may be selected, and these differing paths may produce more, or less, effective results.

The various alternatives utilize several techniques not previously applied to these types of conversions. For example, conversions of 60 fps progressive signals to 30 fps Progressive may be effected by simply dropping alternate frames. On the other hand, a "3:2 Frame Repetition" method consists of repeating a first frame a second and a third time, then repeating the next frame a second time, thereby converting two frames into five frames (as depicted in FIG. 7G).

Depending on whether the source material is 24 fps progressive or 24 fps interlaced, different approaches are utilized for conversion to 30 fps interlaced. In the first case, the 24 fps progressive signal is first converted to 24 fps Interlaced. A set of four consecutive frames may be indicated as 1A1B, 2A2B, 3A3B, 4A4B. By recombining these fields (but outputting them at a 30 fps rate) the following field sequence is obtained: 1A1B, 1A2B, 2A3B, 3A4B, 4A4B. This sequence repeats for every four input frames, which is to say, for every five output frames (as depicted in FIG. 7C).

Alternatively, for a signal which originates at 24 fps Interlaced, the original four-frame sequence is identical. However, the situation is more complicated because the absolute time-sequence of frames must be preserved. For this reason, it is necessary to reverse the field identification of alternate groups of fields in order to preserve the proper interlace relationship between the fields. In effect, every fourth and seventh field in the eight-field (24 fps interlaced) sequence is repeated, but with reversed field identification (as disclosed in FIG. 7E). When the fourth input field has had its identification reversed (to produce the fifth output field), then the next two input fields (corresponding to the sixth and seventh output field) in the sequence also will require field reversal, in order to preserve the correct sequence for proper interlace. Furthermore, when the seventh input field is repeated, the first time it will appear in reversed-field-identity from as the eighth output field. For this procedure, the resulting field sequence will be 1A1B, 2A2B, 2B*3A*, 3B*4A*, 4A4B (wherein a field having reversed field identification is denoted by a * symbol). This sequence repeats for every four input frames, which is to say, for every five output frames.

In addition, the reversal of the field identity of the fourth input field (when repeated) results in information that previously was displayed on the second scan line now being displayed on the first scan line. Therefore, it is necessary to discard the first line of the next reversed-field, so that the information displayed on the second scan line of the new field will be the information previously displayed on the third line of the next (reversed) field. After the seventh input field has been reversed (to produce the eighth output field, the following fields are once again in the proper line order without any further adjustments of this kind (as disclosed in FIG. 7E).

For image manipulations entirely within the internal storage format, there is no issue as to interlacing, as the graphics processor is only manipulating a rectangular array of image pixels, not individual scan lines. As such, identification of fields is derived solely from the location of the image pixels on either odd-numbered lines or even-numbered lines. The interlacing field identification adjustments are made only at

the time of output to the display device. In these applications, the presence of the storage means allows the viewer to control the presentation of a program, utilizing a user interface 420 to control the playback delay and other characteristics of the signal while it is being stored or thereafter. In practice, a wide range of alternatives for input frame rates and output frame rate conversions are made available through this system, by selecting the most appropriate of the various methods for altering the frame rate of a signal described herein.

FIG. 5 shows the inter-relationship of the various film and video formats compatible with the invention, though not intended to be inclusive of all possible implementations. In typical operations, the multi-format audio/video production system 162 would receive film-based elements 160 and combine them with locally produced materials already in the preferred internal format of 24 frames-per-second. In practice, materials may be converted from any other format including video at any frame rate or standard. After the production effects have been performed, the output signals may be configured for any use required, including, but not limited to, HDTV at 30/60 fps shown as 164, widescreen at 30 fps shown as 166, widescreen at 25 fps shown as 170, or HDTV at 25/50 fps shown as 172. In addition, output signals at 24 fps are available for use in a film-recording unit 168.

In FIG. 6, signals are provided from any of several sources, including conventional broadcast signals 210, satellite receivers 212, and interfaces to a high bandwidth data network 214. These signals would be provided to the digital tuner 218 and an appropriate adapter unit 220 for access to a high-speed data network before being supplied to the decompression processor 222. As an option, additional provisions for data compression would provide for transmission of signals from the local system to the high bandwidth data network 214. The processor 222 provides any necessary data de-compression and signal conditioning for the various signal sources, and preferably is implemented as a plug-in circuit board for a general-purpose computer, though the digital tuner 218 and the adapter 220 optionally may be included as part of the existing hardware.

The output of processor 222 is provided to the internal data bus 226. The system microprocessor 228 controls the data bus, and is provided with 32 to 128 MB of RAM 230 and Up to 64 Mb of ROM 232. This microprocessor could be implemented using one of the units previously described, such as the PowerPC 604, PowerPC G3, Pentium-series, or other processors. A hard disk drive controller 234 provides access to various storage means, including, for example, an internal hard disk drive unit 236, a removable hard disk drive unit 238, a unit utilizing removable magnetic, optical, or magneto-optical media (not shown), or a tape drive 240. These storage units also enable the PC to function as a video recorder, as described above. A graphic processor 242, comprising dedicated hardware which optionally be implemented as a separate plug-in circuit board, performs the image manipulations required to convert between the various frame sizes (in pixels), aspect ratios, and frame rates. This graphics processor uses 16 to 32 MB of DRAM, and 2 to 8 MB of VRAM, depending on the type of display output desired. For frame size of 1280x720 with an aspect ratio 16:9, the lower range of DRAM and VRAM will be sufficient, but for a frame size of 1920x1080, the higher range of DRAM and VRAM is required. In general, the 1280x720 size is sufficient for conventional multi-sync, computer display screens up to 20 inches, and the 1920x1080 size is appropriate for conventional multi-sync, computer display screens up to 35 inches. Analog video outputs

244 are available for these various display units. Using this system, various formats may be displayed, including (for 25 fps, shown by speeding up 24 fps signals) 768x576 PAL/SECAM, 1024x576 wide-screen, and 1280x720/1920x1080 HDTV, and (for 30 and 60 fps, shown by utilizing the well-known "13:2 pull-down" technique, and for 29.97 fps, shown by a slight slow-down in 30 fps signals) 640x480 NTSC and 854x480 wide-screen, and 1920x1080 NHK (Japan) HDTV.

It will be appreciated by the skilled practitioner that most of the highest quality program material has been originated on 24 fps 35-mm film, and therefore conversions that rely on reconstituting the signal material from 25 fps or 30 fps materials into 24 fps material do not entail any loss of data or program material. In addition, signals that have been interlaced from a lower or equivalent frame rate source signal in any of the currently available means (24 fps to 25 fps via speed-up; 24 fps to 30 fps via "3:2-pull-down") may be de-interlaced and reconstituted as progressive-scan frames without introducing any signal artifacts, provided that the original frames are recreated from properly matched fields. If it is desired to produce 24 fps interlaced, 25 fps Interlaced, or 30 fps interlaced signals from higher frame rate progressive signals (such as 48 fps Progressive, 50 fps progressive, or 60 fps progressive signals, respectively), these may be obtained by interlacing these signals and discarding the redundant data. Alternatively, if it is desired to produce 24 fps progressive, 25 fps progressive, 30 fps Progressive, or 48 fps progressive signals from higher frame rate progressive signals (such as 48 fps progressive, 50 fps progressive, 60 fps progressive, or 96 fps progressive signals, respectively), these may be obtained by applying a 2:1 frame reduction. These techniques are summarized in FIG. 7A, with conversion charts showing typical process flow charts in FIGS. 7B and 7C.

FIG. 8 shows one possible implementation of a universal playback device, in accordance with the invention. By way of example, a DVD-type video disk 802 is rotatably driven by motor 804 under control of speed-control unit 806. One or more laser read- or read/write-heads 808 are positioned by position control unit 810. Both the speed control unit and the position control unit are directed by the overall system controller 812, at the direction of the user interface 814. It should be noted that the number and configuration of read-or read/write-heads will be determined by the choice of the techniques employed in the various embodiments disclosed herein above. The signals recovered from the laser heads is delivered to signal processor unit 820, and the data stream is split into an audio data stream (supplied to audio processor unit 822) and a video data stream (supplied to video graphics processor unit 830). During the audio recovery process, the alteration of the playback frame rate (for example, from 24 fps to 25 fps, accomplished by speed control adjustment) may suggest the need for pitch-correction of the audio material. This procedure, if desired, may be implemented either as part of the audio processor 822, or within a separate, external unit (not shown), as offered by a number of suppliers, such as Lexicon.

The video data stream may undergo a number of modifications within the graphics processor, shown generally at 830, depending on the desired final output format. Assuming that the output desired is NTSC or some other form of wide-screen or HDTV signal output at a nominal frame rate of 30 fps, a signal sourced from the disk at 24 fps would undergo a "3:2-pull-down" modification as part of the conversion process (as explained herein above). If the signal is sourced from the disk is based on 25 fps, then it would undergo an preliminary slowdown to 24 fps before the "3:2-pull-down" processing is applied. It should be noted that the 0.1% difference between 30 fps and 29.97 fps only

requires the buffering of 173 frames of video over the course of a 120-minute program, and at a data rate of 5.5 MB/sec, this corresponds to approximately 39 MB of storage (for standard/widescreen) or 79 MB of storage (for HDTV), which readily may be implemented in semiconductor-based memory. In any event, a signal supplied to the graphics processor at a nominal 24 fps simultaneously may be output at both 30 fps and 29.97 fps, in image frames compatible with both NTSC and NTSC/widescreen (the standard/widescreen video interface 832), and HDTV (HDTV video interface 834), in accordance with the invention as described herein above.

As disclosed above, an optional film output video interface 836 may be included, with digital video outputs for a film recorder. Overall, the outputs for the graphics processor 830 parallel those of the Multi-Format Audio/Video Production System as shown in FIG. 5 and disclosed herein above. In addition, for signals to be output in a format having a different aspect ratio than that of the source signal, it may be necessary to perform a horizontal and/or vertical "pan/scan" function in order to assure that the center of action in the source program material is presented within the scope of the output frame. This function may be implemented within the graphics processor by utilizing a "tracking" signal associated with the source program material, for example, as part of the data stream for each frame, or, alternatively, through a listing identifying changes that should be applied during the presentation of the source material. Where no "tracking" information is available, the image frame would be trimmed along the top and bottom, or the sides, as necessary in order to fit the aspect ratio of the source material to the aspect ratio of the output frame. This latter technique is explained herein above, with reference to FIGS. 1A-1D. In addition, the program material may include security information, such as regional or geographical information directed towards controlling the viewing of the program material within certain marketing areas or identifiable classes of equipment (such as hardware sold only in the United States or in the German market). This information, as has been disclosed for use with other disk-and tape-based systems, often relates to issues such as legal licensing agreements for software materials. It may be processed in a way similar to the detection and application of the "pan/scan" tracking signal, and the signal processor 820, under the direction of controller 812 may act to enforce these restrictions.

Alternatively, if output at 25 fps is desired, it is a simple matter to configure the various components of this system to replay the video information of the disk 802 at this higher frame rate. The controller will configure the speed control unit 806 (if necessary) to drive the motor 804 at a greater rotational speed to sustain the increased data rate associated with the higher frame rate. The audio processor 822, if so equipped, will be configured to correct for the change in pitch associated with the higher frame rate, and the graphics processor will be configured to provide all output signals at the 25 fps frame rate. As Alternate method for audio pitch correction, additional audio data can be stored in disk which is already corrected. When the frame rate is changed, the corresponding audio data is selected in accordance with the invention.

As yet another alternative, materials produced at 25 fps and stored on the disk-based mass storage means of this example could originate from conventional standard or widescreen PAL format signals. Utilizing the slow-down method, these signals are readily converted to 24 fps frame rate, from which conversion to various 30 fps formats is implemented, as disclosed herein above. This feature has significance in the commercial development of HDTV, as the ability to utilize more-or-less conventional PAL format equipment greatly facilitates the economical production and origination of materials intended for HDTV markets.

A wide range of output frame rates may be made available through combination of the techniques of speed-up, slow-down, "3-2-pull-down," and other related field-rearrangement, de-interlacing, interlacing/de-interlacing, frame repetition, and frame reduction techniques, as disclosed herein above with respect to FIG. 4 and FIGS. 7A-7E, and these various combinations and approaches should be considered to be within the scope of the invention. In addition, these techniques may be combined with hardware and/or software which perform image manipulations such as line-doubling, line-quadrupling, deinterlacing, etc., such that the display device will be capable of providing smoother apparent motion, by increasing the display rate without increasing the actual data/information rate. One example would be to process the 24 fps signal from the internal format to convert it into a 48 fps signal, using field-doubling techniques such as deinterlacing and line doubling. Then, the process would employ frame-store techniques to provide a frame-repeated output at a rate of 96 fps. These types of display-related improvements, in conjunction with the instant invention, should also be considered to be within the scope of the invention as disclosed herein. Examples of these various combinations and conversion methods are included in the table of FIG. 7A and the chart of FIG. 7B.

In general, the features as described need not all be provided in a single unit, but rather may be distributed through various external units (such as external data-recorders or display units). In addition, particular configurations of the system may include only the graphics capabilities required for that application (such as the use of 25 fps PAL outputs, but not 30 fps NTSC) and may even exclude certain options (such as printer outputs), and these variations should be considered to be within the scope of the invention.

I claim:

1. A method of producing a video program, comprising the steps of:

receiving an input video program in an input format;
 converting the input video program into a digital production format by sampling the input program at a sampling frequency in excess of 18 megahertz;
 providing high-capacity digital video storage means equipped with an asynchronous program recording and reproducing capability to perform a frame-rate conversion; and
 processing the video program in the production format using the high-capacity video storage means on a selective basis to output a version of the video program having a desired frame rate and image dimensions in pixels.

2. The method of claim 1, wherein the production format uses a frame rate of 24 frames per second.

3. The method of claim 1, wherein the step of processing the video program in the production format includes the use of pixel interpolation.

4. The method of claim 1, wherein the output version of the program has image dimensions pixels of 1024x576; 1280x720; or 1920x1080.

5. The method of claim 4, using a sampling frequency of up to 37 Mhz at the image dimensions of 1024x576 and 1280x720.

6. The method of claim 4, using a sampling frequency of up to 74.25 Mhz at the image dimension of 1920x1080.

7. The method of claim 1, wherein the input video program is standard or widescreen NTSC or PAL.

8. The method of claim 1, wherein the output version of the program is standard or widescreen NTSC or PAL.

9. The method of claim 1, wherein the step of receiving an input video program includes receiving the program from a camera having 600 or more lines of resolution.

10. The method of claim 1, further including the step of storing the program in data-compressed form.

11. The method of claim 10, wherein the compression scheme is MPEG-2.

12. The method of claim 1, wherein the step of processing the video program in the production format includes the use of 4:2:2 10-bit processing.

13. The method of claim 1, wherein the frame rate of the output version of the program is higher than one or both of the input and production formats.

14. The method of claim 1, wherein the frame rate of the output version of the program is lower than one or both of the input and production formats.

15. The method of claim 1, wherein the high-capacity digital video storage means includes an asynchronous read/write capability used to perform a frame-rate conversion.

16. The method of claim 1, wherein the step of processing the video program in the production format includes the use of line doubling or quadrupling.

17. A method of producing an enhanced definition video program, comprising the steps of:

receiving a standard definition television (SDTV) program from a source having a resolution capability of 600 or more lines;

converting the input video program into a digital production format by sampling the input program at a sampling frequency in excess of 18 megahertz;

providing high-capacity digital video storage means equipped with an asynchronous program recording and reproducing capability to perform a frame-rate conversion;

storing the program in data compressed form; and

processing the program in the production format to output an enhanced definition version of the program having a desired frame rate and image dimensions in pixels.

18. The method of claim 17, wherein the production format uses a frame rate of 24 frames per second.

19. The method of claim 17, wherein the SDTV program is standard or widescreen NTSC or PAL.

20. The method of claim 17, wherein the enhanced definition version of the program has image dimensions in pixels of 1024x576; 1280x720; or 1920x1080.

21. The method of claim 20, using a sampling frequency of up to 37 Mhz at image dimensions of 1024x576 and 1280x720.

22. The method of claim 20, using a sampling frequency of up to 74.25 Mhz at an image dimension of 1920x1080.

23. The method of claim 17, wherein the source is a video camera.

24. The method of claim 17, wherein the compression scheme is MPEG-2.

25. The method of claim 17, wherein the step of processing the video program in the production format includes the use of 4:2:2 10-bit processing.

26. The method of claim 17, wherein the frame rate of the enhanced definition version of the program is higher than one or both of the input and production formats.

27. The method of claim 17, wherein the frame rate of the enhanced definition version of the program is lower than one or both of the input and production formats.

28. The method of claim 17, wherein the step of processing the video program in the production format includes the use of pixel interpolation.

29. The method of claim 17, wherein the step of processing the video program in the production format includes the use of line doubling or quadrupling.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,370,198 B1
DATED : April 9, 2002
INVENTOR(S) : Kinya Washino

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5,

Line 42, replace "are utilized" with -- utilized --.

Column 7,

Line 50, replace "height." with -- height). --.

Column 8,

Line 2, replace "1.56:1)" with -- 1.66:1) --.

Line 38, replace "5" with -- 5 --.

Line 44, replace "30 MHZ)" with -- 30MHz --.

Column 9,

Line 34, replace "mm. Camra" with -- MM camera --.

Line 40, replace "fps" with -- 25 fps --.

Column 13,

Lines 23 and 34, replace "produced" with -- produce --.

Column 16,

Line 51, replace "a" with -- A --.

Line 52, replace "24-10 fps" with -- 24 - fps --.

Column 18,

Line 58, replace "slow-sown" with -- slow-down --.

Column 19,

Line 43, replace "from" with -- form --.

Column 20,

Line 44, replace "Up" with -- up --.

Column 21,

Line 6, replace "13:2" with -- 3:2 --.

Line 65, replace "an preliminary" with -- a preliminary --.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,370,198 B1
DATED : April 9, 2002
INVENTOR(S) : Kinya Washino

Page 2 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 22,

Line 38, replace "disk-and" with -- disk- and --.

Line 53, replace "Alternate" with -- alternate --.

Signed and Sealed this

Fourteenth Day of January, 2003

A handwritten signature in black ink, appearing to read "James E. Rogan", with a horizontal line underneath.

JAMES E. ROGAN

Director of the United States Patent and Trademark Office

EXHIBIT 3

EXHIBIT 3



(12) **United States Patent**
Washino

(10) **Patent No.:** **US 8,228,979 B2**
(45) **Date of Patent:** **Jul. 24, 2012**

(54) **WIDE-BAND MULTI-FORMAT AUDIO/VIDEO PRODUCTION SYSTEM WITH FRAME-RATE CONVERSION**

(75) Inventor: **Kinya Washino**, Little Ferry, NJ (US)

(73) Assignee: **Multi-Format, Inc.**, Little Ferry, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/348,804**

(22) Filed: **Jan. 5, 2009**

(65) **Prior Publication Data**
US 2009/0174813 A1 Jul. 9, 2009

Related U.S. Application Data

(63) Continuation of application No. 10/117,496, filed on Apr. 5, 2002, now Pat. No. 7,474,696, which is a continuation of application No. 09/305,953, filed on May 6, 1999, now Pat. No. 6,370,198, which is a continuation-in-part of application No. 08/834,912, filed on Apr. 7, 1997, now Pat. No. 5,999,220.

(60) Provisional application No. 60/084,522, filed on May 7, 1998.

(51) **Int. Cl.**
H04B 1/66 (2006.01)
H04N 7/01 (2006.01)

(52) **U.S. Cl.** **375/240.01**; 348/446

(58) **Field of Classification Search** 348/555, 348/556, 722, 441, 445, 448, 426, 432, 454, 348/558, 568, 446; 375/240.26, 240.29, 375/240.01, 240.16, 240.24

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,633,293 A 12/1986 Powers
(Continued)

FOREIGN PATENT DOCUMENTS

EP 314873 5/1989
(Continued)

OTHER PUBLICATIONS

G Demos, "An Example of Hierarchy of Formats for HDTV," SMPTE Journal, Sep. 1992, pp. 609-617.

(Continued)

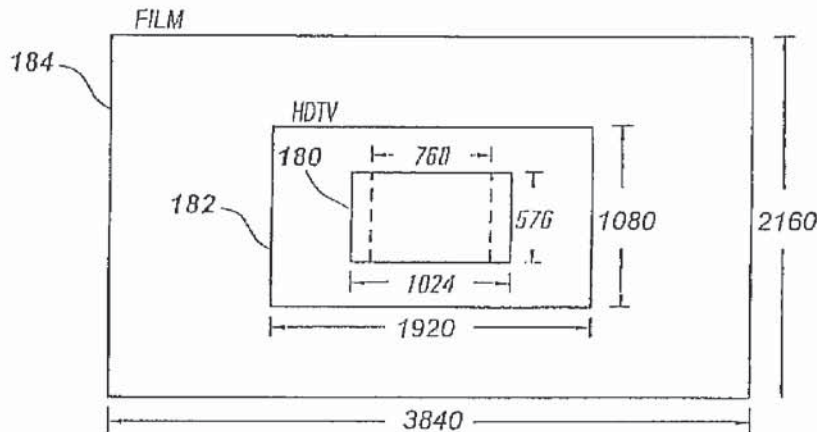
Primary Examiner — Behrooz Senfi

(74) *Attorney, Agent, or Firm* — Gifford, Krass, Sprinkle, Anderson & Citkowski, P.C.

(57) **ABSTRACT**

A multi-format digital video production system enables a user to process an input video program to produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format of 24 fps is preferably chosen to provide the greatest compatibility with existing and planned formats associated with HDTV standard 4:3 or widescreen 16:9 high-definition television, and film. Images are re-sized horizontally and vertically by pixel interpolation, thereby producing larger or smaller image dimensions so as to fill the particular needs of individual applications. Frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions. Simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) for playback, or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities. The step of converting the signal to a HDTV format is preferably performed using a modified upconversion process for wideband signals (utilizing a higher sampling clock frequency) and a resizing to HDTV format frame dimensions in pixels.

14 Claims, 14 Drawing Sheets



US 8,228,979 B2

Page 2

U.S. PATENT DOCUMENTS

5,045,932 A 9/1991 Sharman et al.
 5,243,433 A 9/1993 Hailey et al.
 5,327,235 A 7/1994 Richards et al.
 5,329,309 A * 7/1994 Dorricott et al. 348/97
 5,331,346 A 7/1994 Shields et al.
 5,335,013 A * 8/1994 Faber 348/104
 5,384,598 A 1/1995 Rodriguez et al.
 5,444,491 A * 8/1995 Lim 348/441
 5,444,492 A * 8/1995 Kihara 348/445
 5,519,438 A 5/1996 Elliott et al.
 5,532,749 A 7/1996 Hong et al.
 5,537,157 A 7/1996 Washino et al.
 5,600,377 A 2/1997 David et al.
 5,608,464 A 3/1997 Woodham et al.
 5,617,218 A 4/1997 Rhodes
 5,701,383 A 12/1997 Russo et al.
 5,706,290 A 1/1998 Shaw et al.
 5,724,101 A 3/1998 Haskin
 5,754,248 A * 5/1998 Faroudja 348/474
 5,771,073 A 6/1998 Lim
 5,812,204 A 9/1998 Baker et al.
 5,832,085 A 11/1998 Inoue et al.
 5,835,150 A 11/1998 Choi et al.
 5,838,381 A 11/1998 Kasahara et al.
 5,999,220 A * 12/1999 Washino 348/441
 6,356,945 B1 3/2002 Shaw et al.
 6,370,198 B1 * 4/2002 Washino 375/240.26
 6,542,198 B1 4/2003 Hung et al.
 6,549,240 B1 * 4/2003 Reitmeier 348/459

6,656,945 B2 12/2003 Campbell et al.
 6,906,687 B2 * 6/2005 Werner 345/8
 7,864,865 B2 * 1/2011 Hatti et al. 375/240.25
 2002/0118296 A1 * 8/2002 Schwab et al. 348/441

FOREIGN PATENT DOCUMENTS

EP 514012 11/1992
 WO WO-9315586 8/1993

OTHER PUBLICATIONS

J.S. Lim, "A Proposal for an HDTV/ATV Standard with Multiple Transmission Formats," SMPTE Journal, Aug. 1993, pp. 699-702.
 W.E. Bretl, "3SNTSC-A 'Leapfrog' Production Standard for HDTV," SMPTE Journal, Mar. 1989, pp. 173-178.
 B. Hunt, G. Kennel, L. DeMarsh, S. Kristy, "High-Resolution Electronic Intermediate System for Motion-Picture Film," SMPTE Journal, Mar. 1991, pp. 156-161.
 A. Kaiser, H. Mahler, R., McMann, "Resolution Requirements for HDTV Based Upon the Performance of 35mm Motion-Picture Films for Theatrical Viewing," SMPTE Journal, Jun. 1985, pp. 654-659.
 Y. Ide, M. Sasuga, N. Harada, T. Nishizawa, "A Three-CCD HDTV Color Camera," SMPTE Journal, Jul. 1990, pp. 532-537.
 G. Reitmeier, C. Carlson, E. Geiger, D. Westerkamp, "The Digital Hierarchy—A Blueprint for Television in the 21st Century," SMPTE Journal, Jul. 1992, pp. 466-470.
 L. Thorpe, T. Hanabusa, "If Progressive Scanning is So Good, How Bad is Interlace?," SMPTE Journal, Dec. 1990, p. 972-86.

* cited by examiner

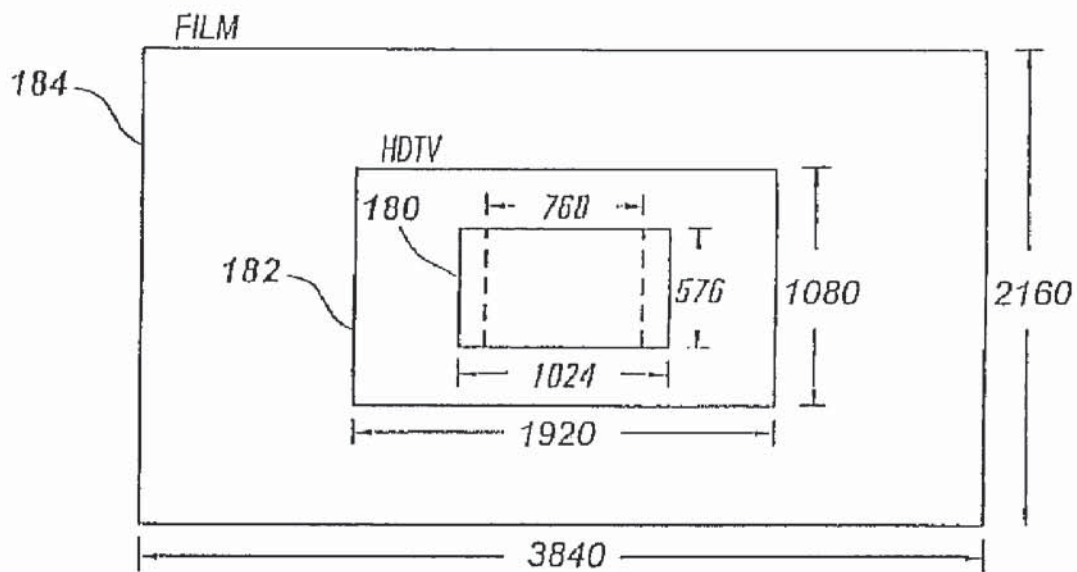


Figure 1a

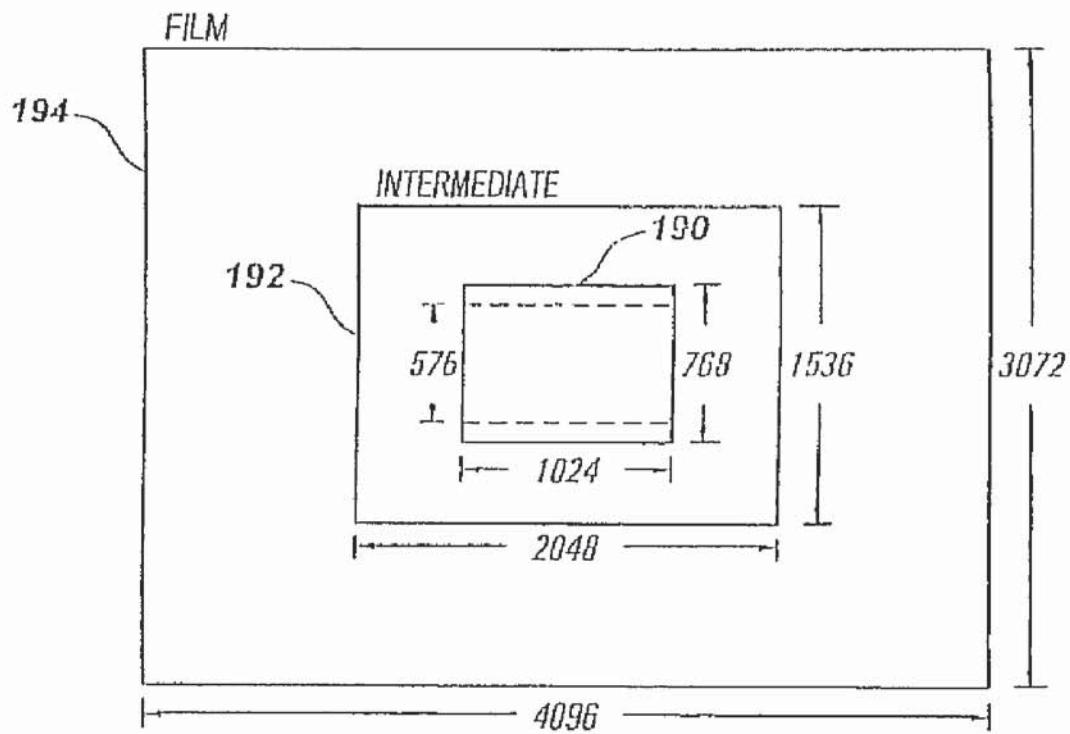


Figure 1b

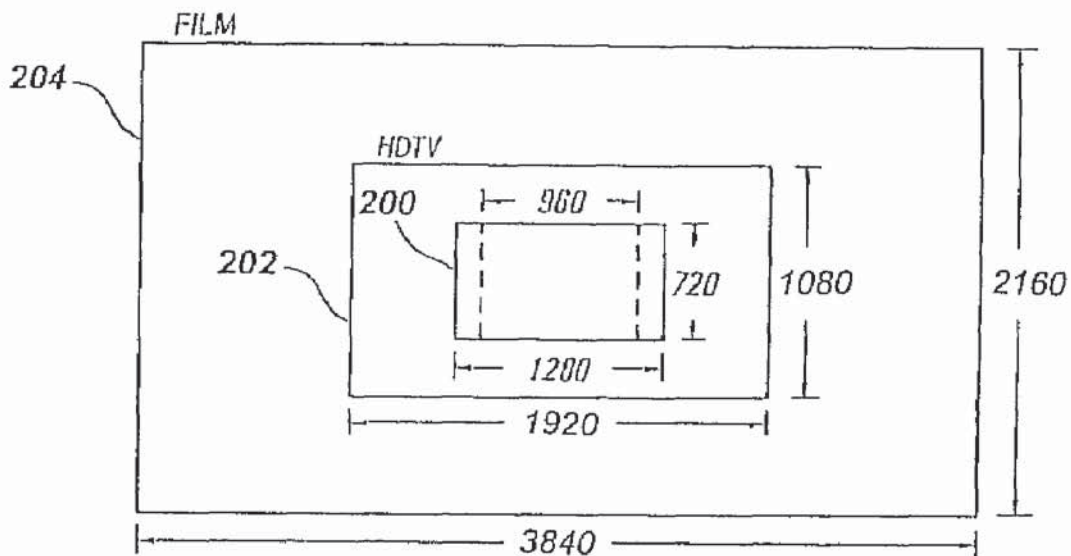


Figure 1c

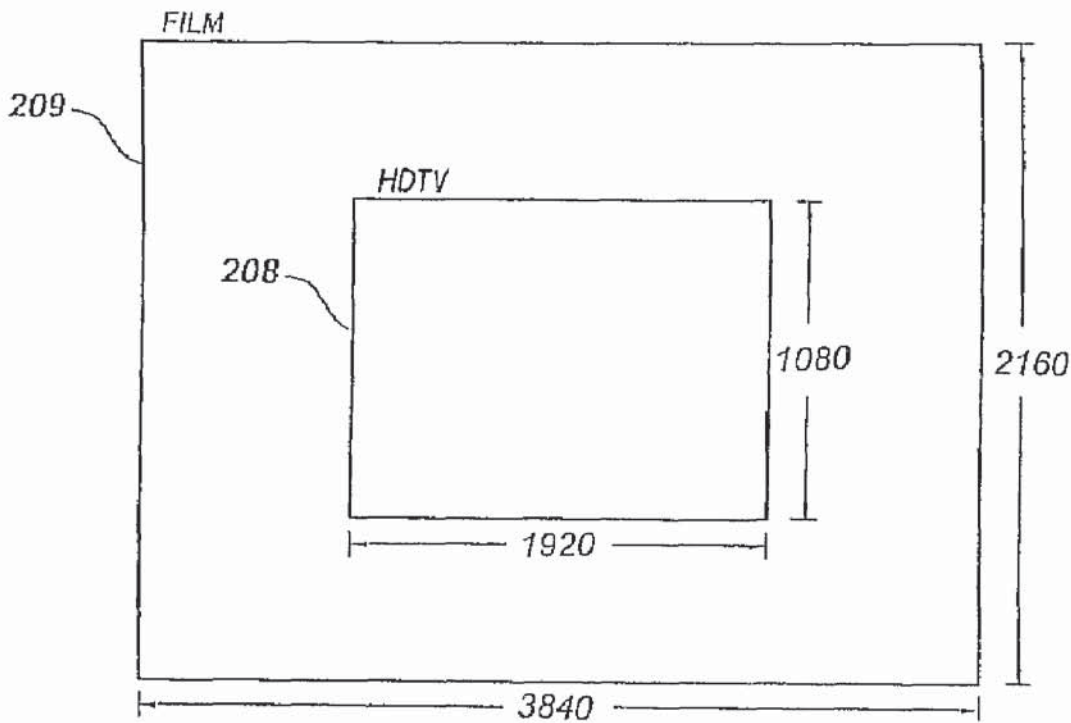


Figure 1d

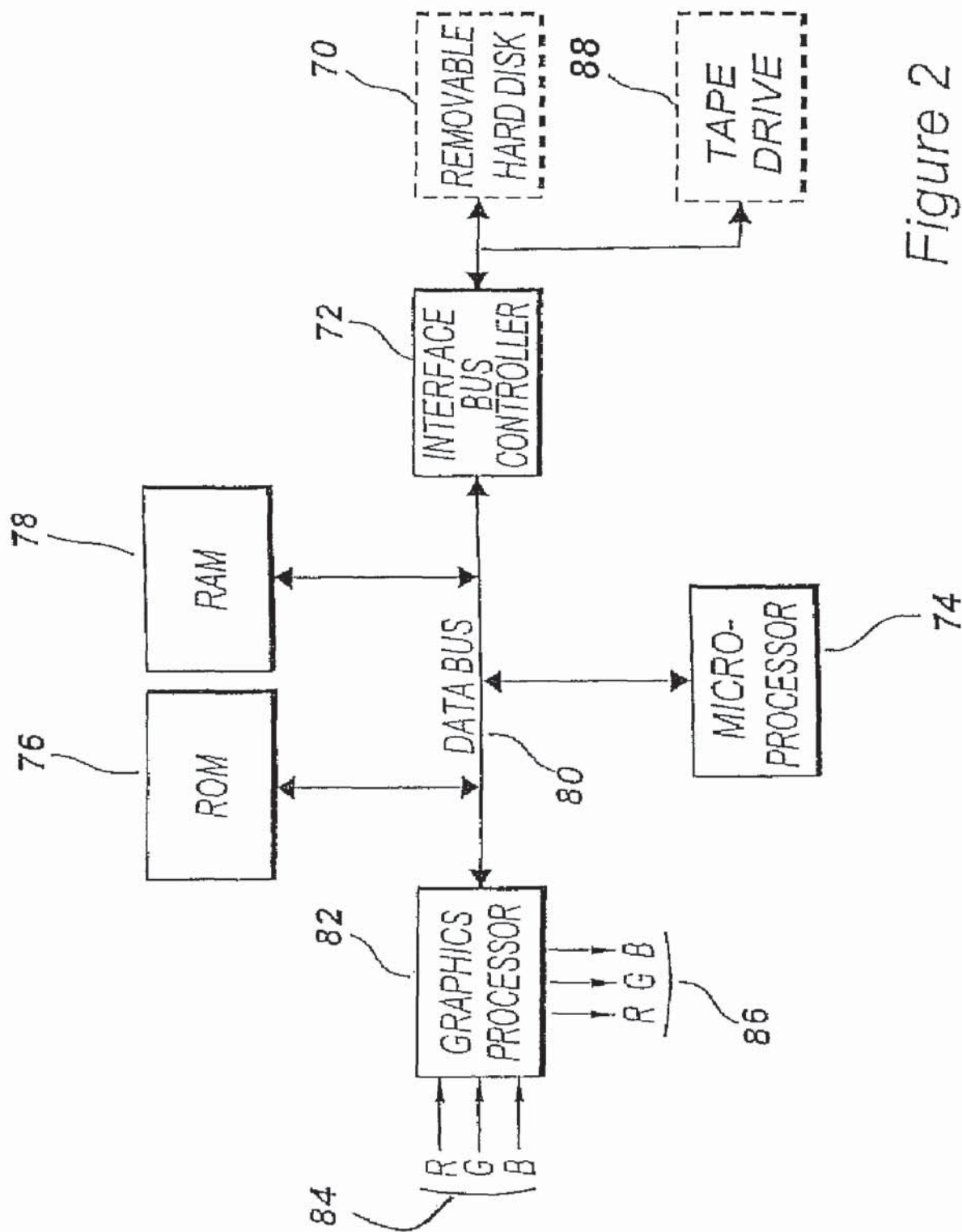


Figure 2

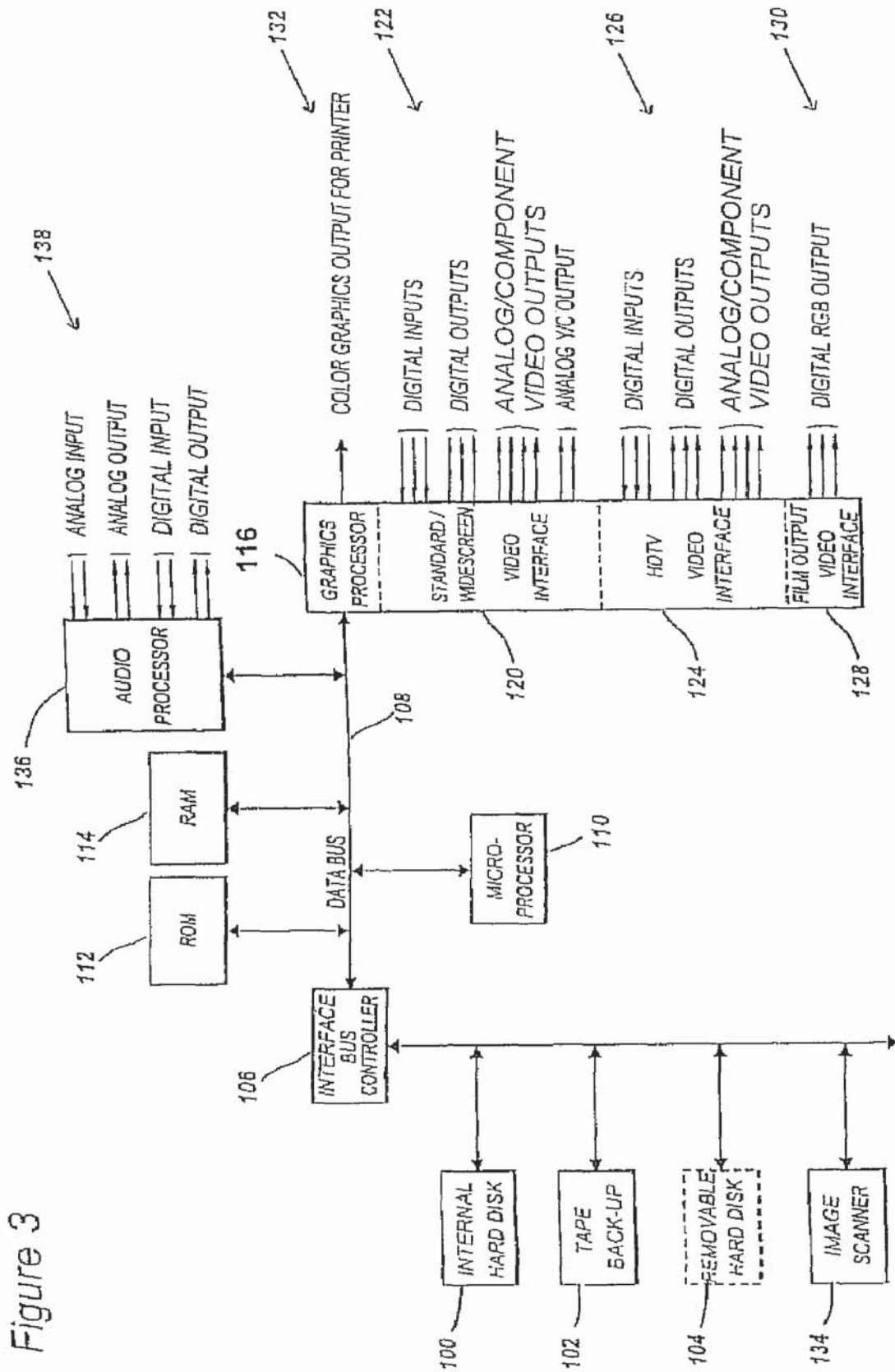


Figure 3

Figure 4

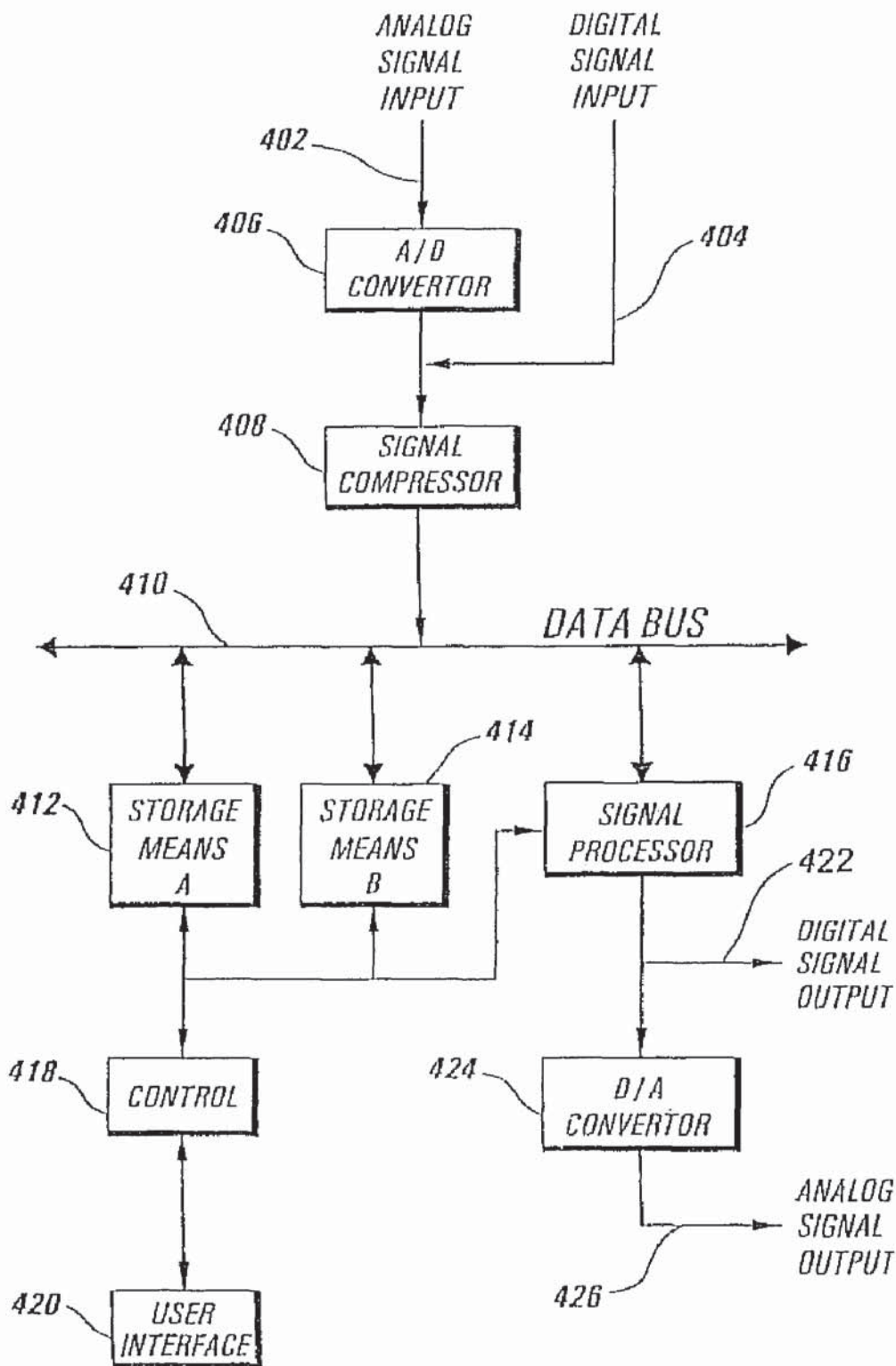


Figure 5

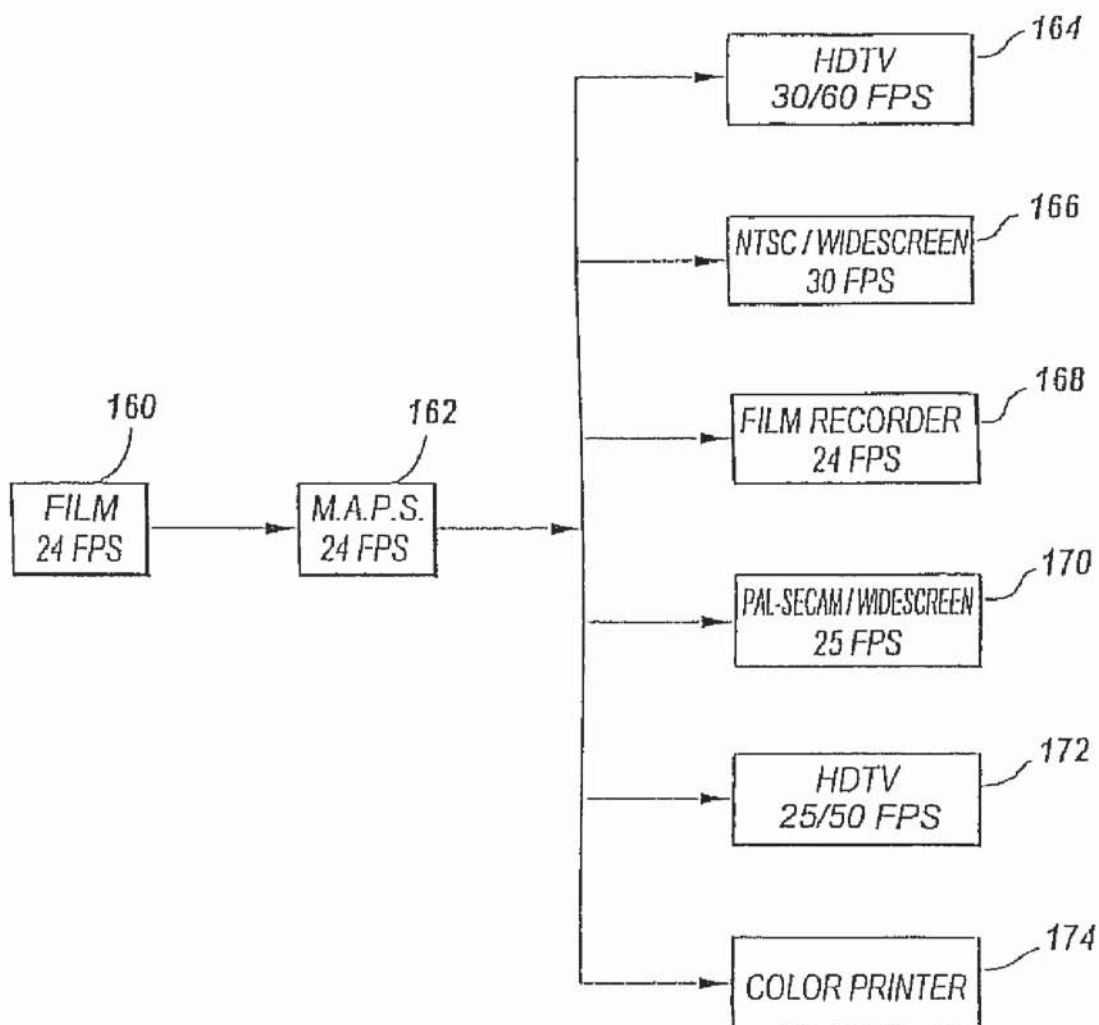


Figure 6

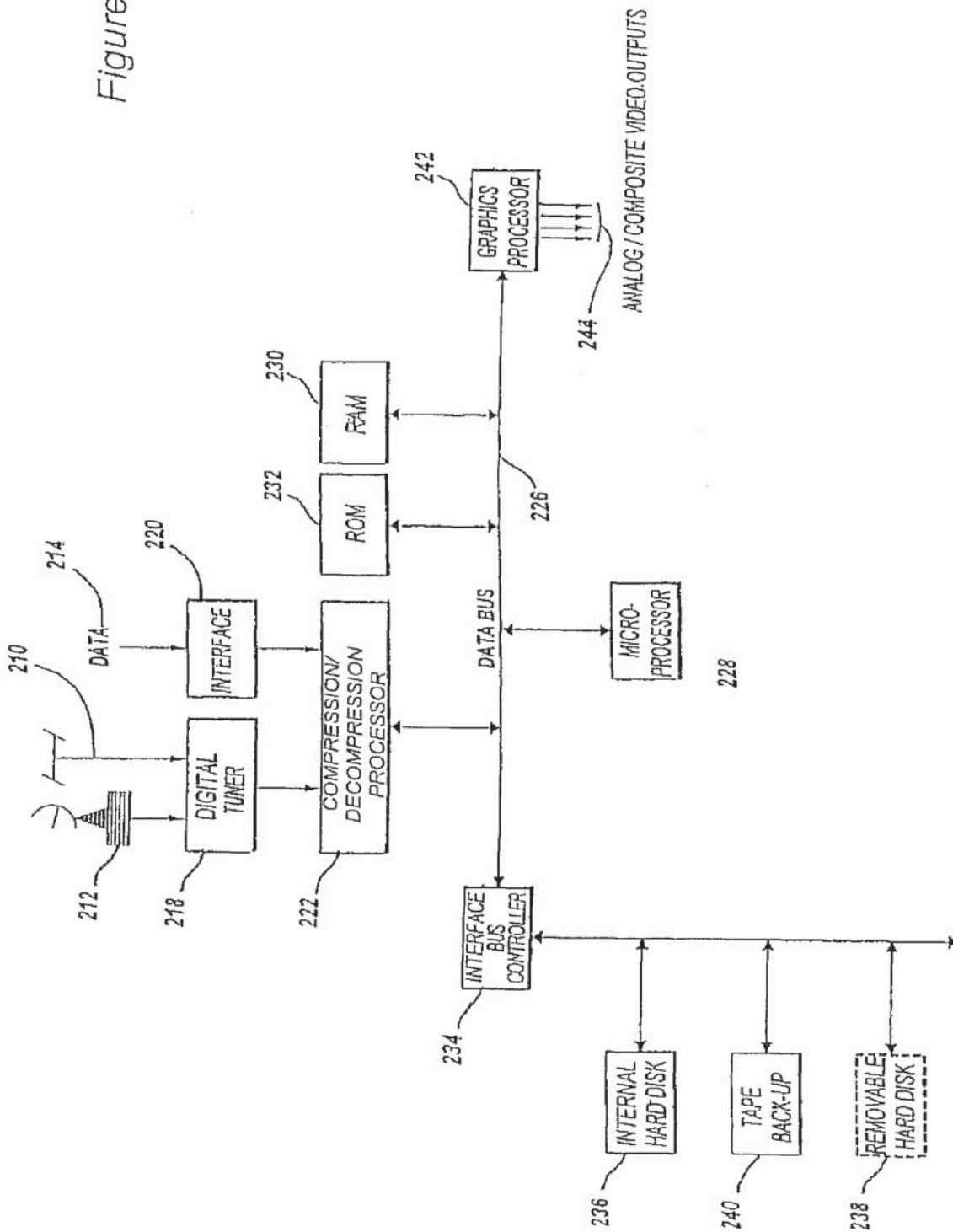


FIGURE 7A

Output Source	24 fps Interlace (24fps I)	24fps Progress. (24fps P)	25fps Interlace (25fps I)	25fps Progress. (25fps P)	30fps Interlace (30fps I)	30fps Progress. (30fps P)	48fps Progress. (48fps P)	50fps Progress. (50fps P)	60fps Progress. (60fps P)	96fps Progress. (96fps P)
24fps Interlace (24fps I)	—	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (1)	2:1 Frame Reduction From 50fps P (3)	Interlace & discard From 60fps P (3)	2:1 Frame Reduction From 60fps P (3)	De-Interlace From 24fps I (1)	De-Interlace From 25fps I (2)	4th Frame Repeat From 48fps P (2)	Repeat From 48fps P (2)
24fps Progress. (24fps P)	Interlace From 24fps P (1)	—	Speed-up From 24fps I (2)	Speed-up From 24fps P (1)	3:2 Pull-down From 24fps I (2)	2:1 Frame Reduction From 60fps P (2)	Repeat From 24fps P (1)	Repeat From 25fps P (2)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (2)
25fps Interlace (25fps I)	Slow-Down From 25fps I (1)	2:1 Frame Reduction From 48fps P (3)	—	2:1 Frame Reduction From 50fps P (2)	Interlace & discard From 60fps P (4)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (2)	De-Interlace From 25fps I (1)	4th Frame Repeat From 48fps P (3)	Repeat From 48fps P (3)
25fps Progress. (25fps P)	Interlace From 24fps P (2)	Slow-down From 25fps P (1)	Interlace From 25fps P (1)	—	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (3)	Repeat From 25fps P (1)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (3)
30fps Interlace (30fps I)	5th Fr. red., Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 48fps P (3)	6th Fr. red. Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 50fps P (3)	—	2:1 Frame Reduction From 60fps P (2)	De-Interlace From 24fps I (3)	De-Interlace From 25fps I (3)	De-Interlace From 30fps I (1)	Repeat From 48fps P (3)

FIGURE 7A (CONT)

30fps Progress. (30fps P)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 50fps P (4)	Interlace From 30fps P (1)	—	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (3)	Repeat From 30fps P (1)	Repeat From 48fps P (4)
48fps Progress. (48fps P)	Interlace From 24fps P (2)	2:1 Frame Reduction From 48fps P (1)	Interlace From 25fps P (3)	Speed-up From 24fps P (2)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (2)	De- Interlace From 25fps I (4)	De- Interlace From 25fps I (4)	De- Interlace From 30fps I (4)	Repeat From 48fps P (1)
50fps Progress. (50fps P)	Interlace From 24fps P (3)	Slow-down From 25fps P (2)	Interlace & discard From 50fps P (1)	2:1 Frame Reduction From 50fps P (1)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (3)	De- Interlace From 24fps I (4)	—	3:2 Frame Repeat From 24fps P (3)	Repeat From 48fps P (2)
60fps Progress. (60fps P)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (1)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (1)	2:1 Frame Reduction From 50fps P (4)	Interlace & discard From 60fps P (1)	2:1 Frame Reduction From 60fps P (1)	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (2)	—	Repeat From 48fps P (4)
96fps Progress. (96fps P)	Interlace From 24fps P (3)	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (4)	Speed-up From 24fps P (3)	3:2 Pull-Down From 24fps I (4)	2:1 Frame Reduction From 60fps P (3)	2:1 Frame Reduction From 96fps P (1)	De- Interlace From 25fps I (5)	4 th Frame Repeat From 48fps P (2)	—

Figure 7b

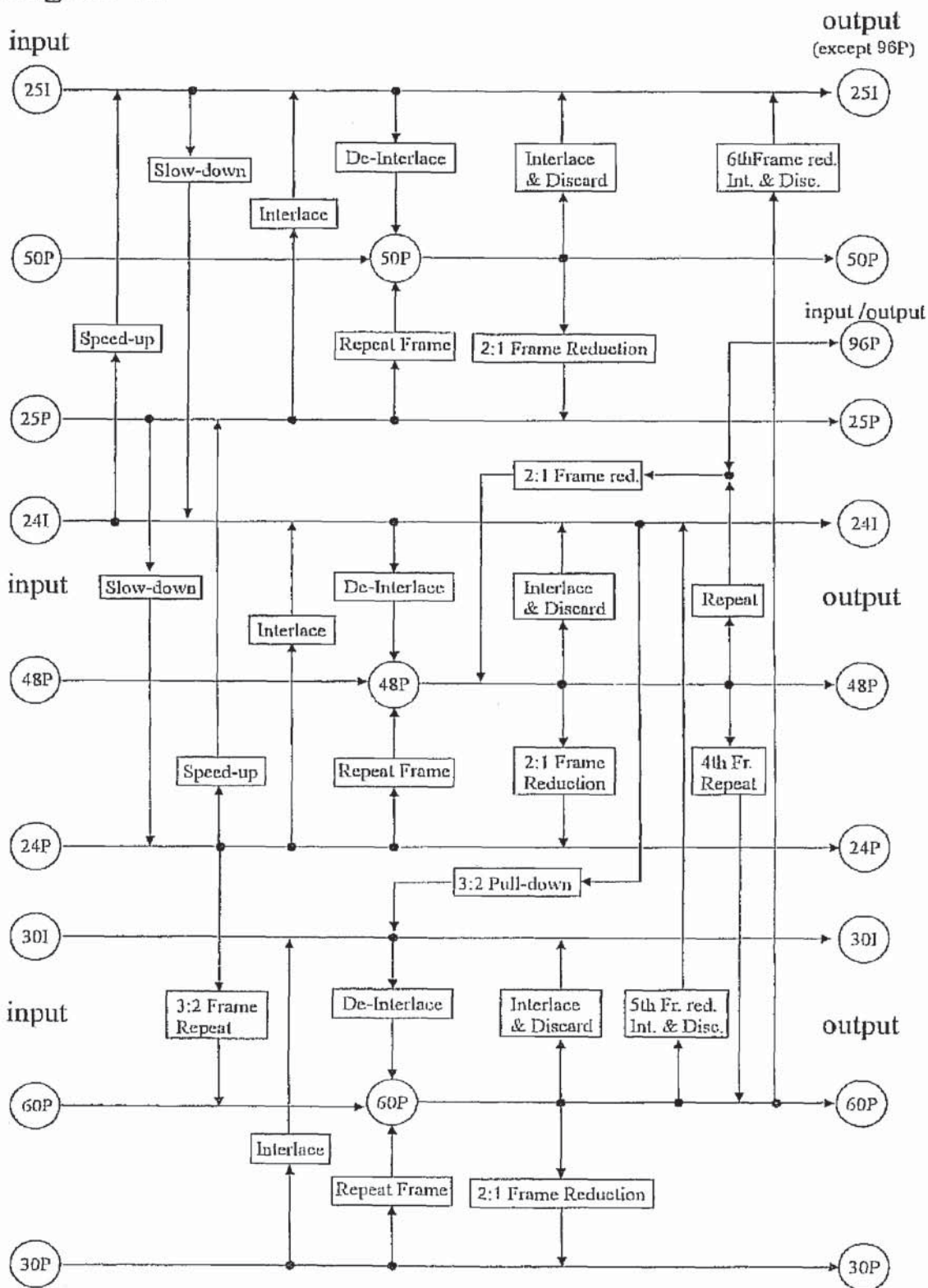


Figure 7c 3 : 2 Pull-Down
(24 fps P to 30 fps I)

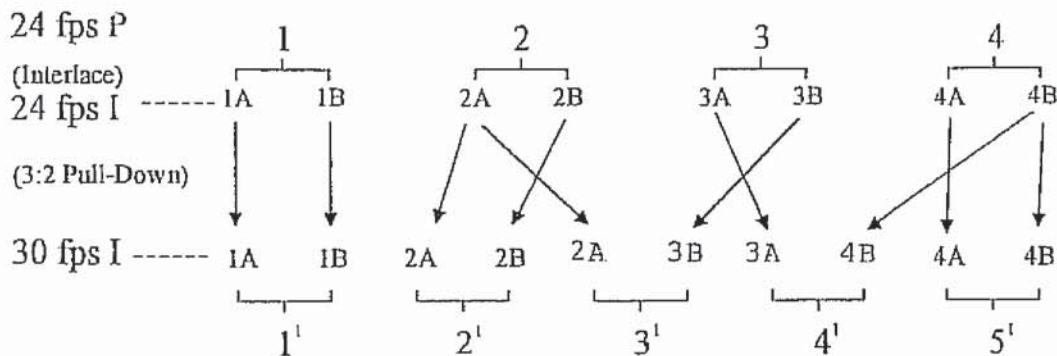


Figure 7e 4th & 7th Field Repeat plus Re-Interlace
(24 fps I to 30 fps I)

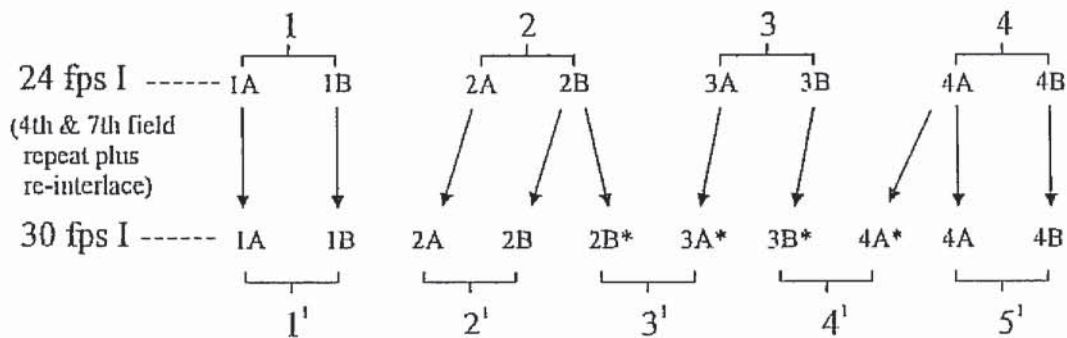


Figure 7g 3 : 2 Frame Repeat (24 fps P to 60fps P)

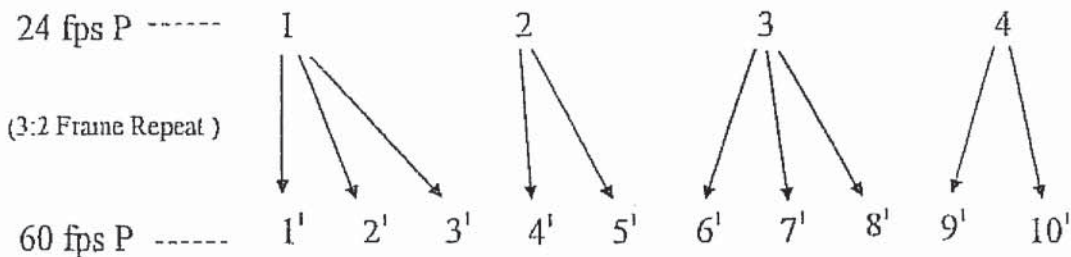


Figure 7d 25 fps Interlace to 30 fps Interlace Conversion
(from PAL CCD camera source to NTSC out)

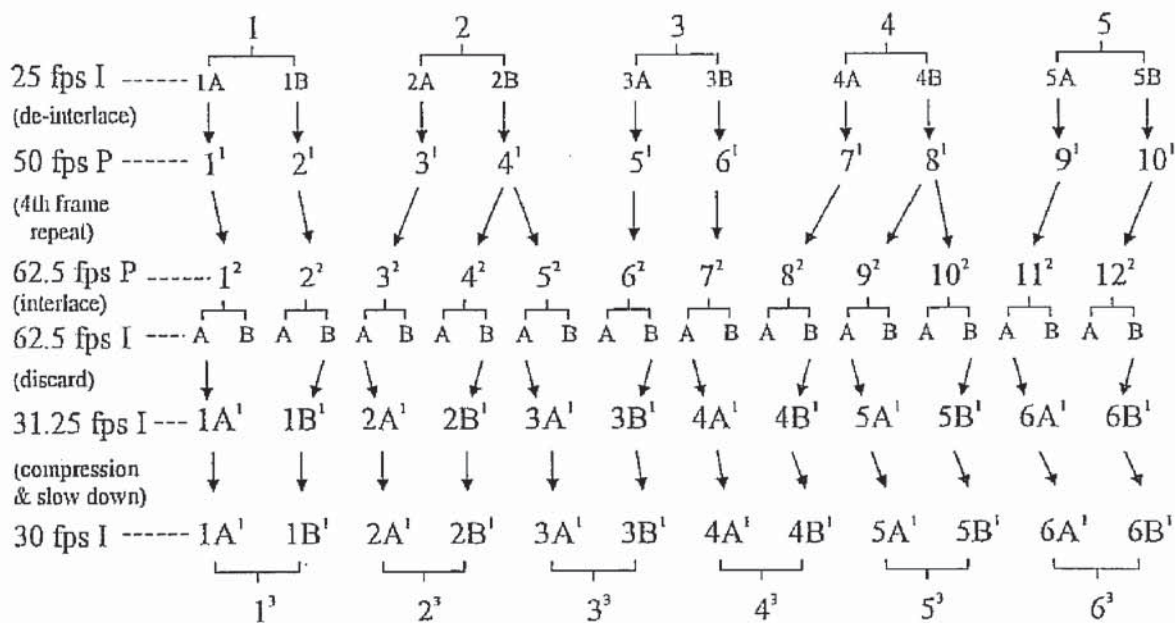


Figure 7f 4th Frame Repeat (24fps I to 30fps I)

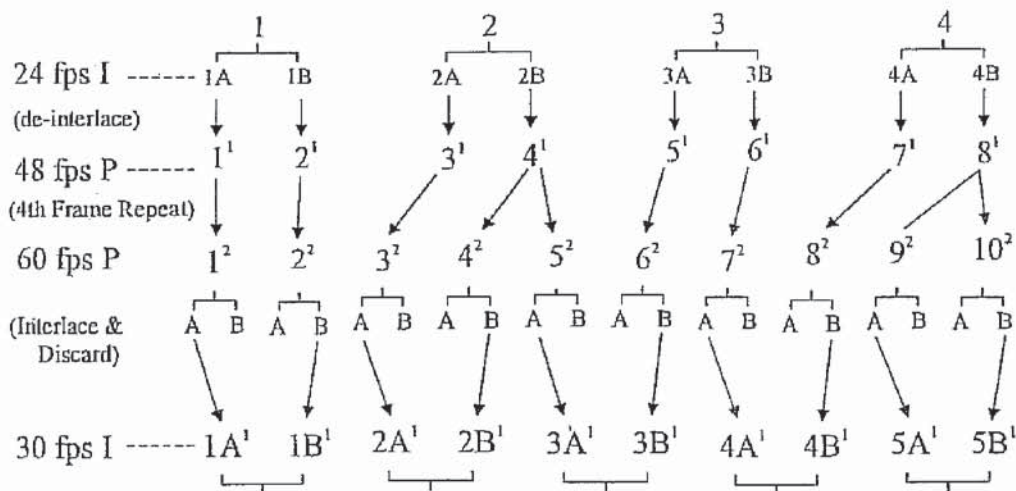


Figure 7h 6th Frame Reduction (30fps I. to 25fps I)

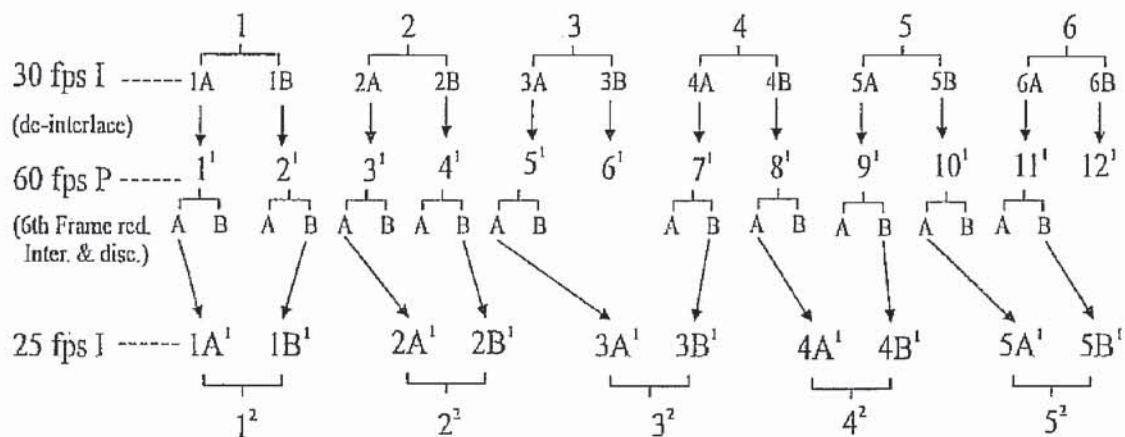
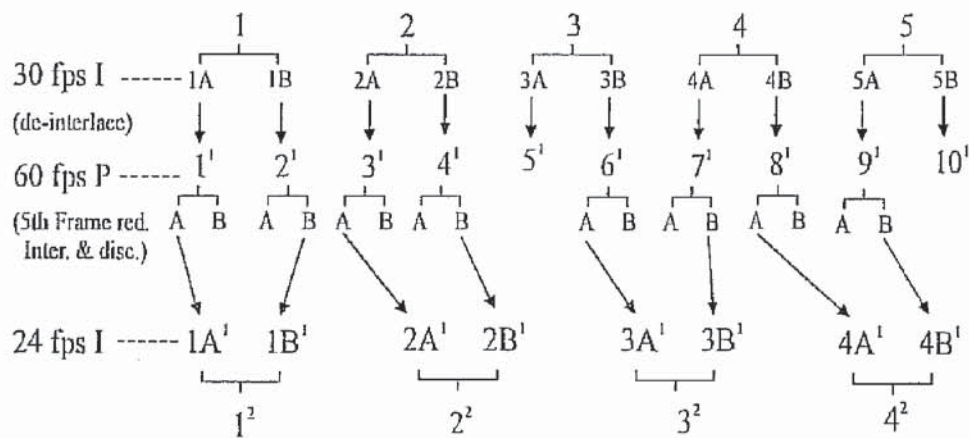


Figure 7i 5th Frame Reduction (30fps I to 24fps I)



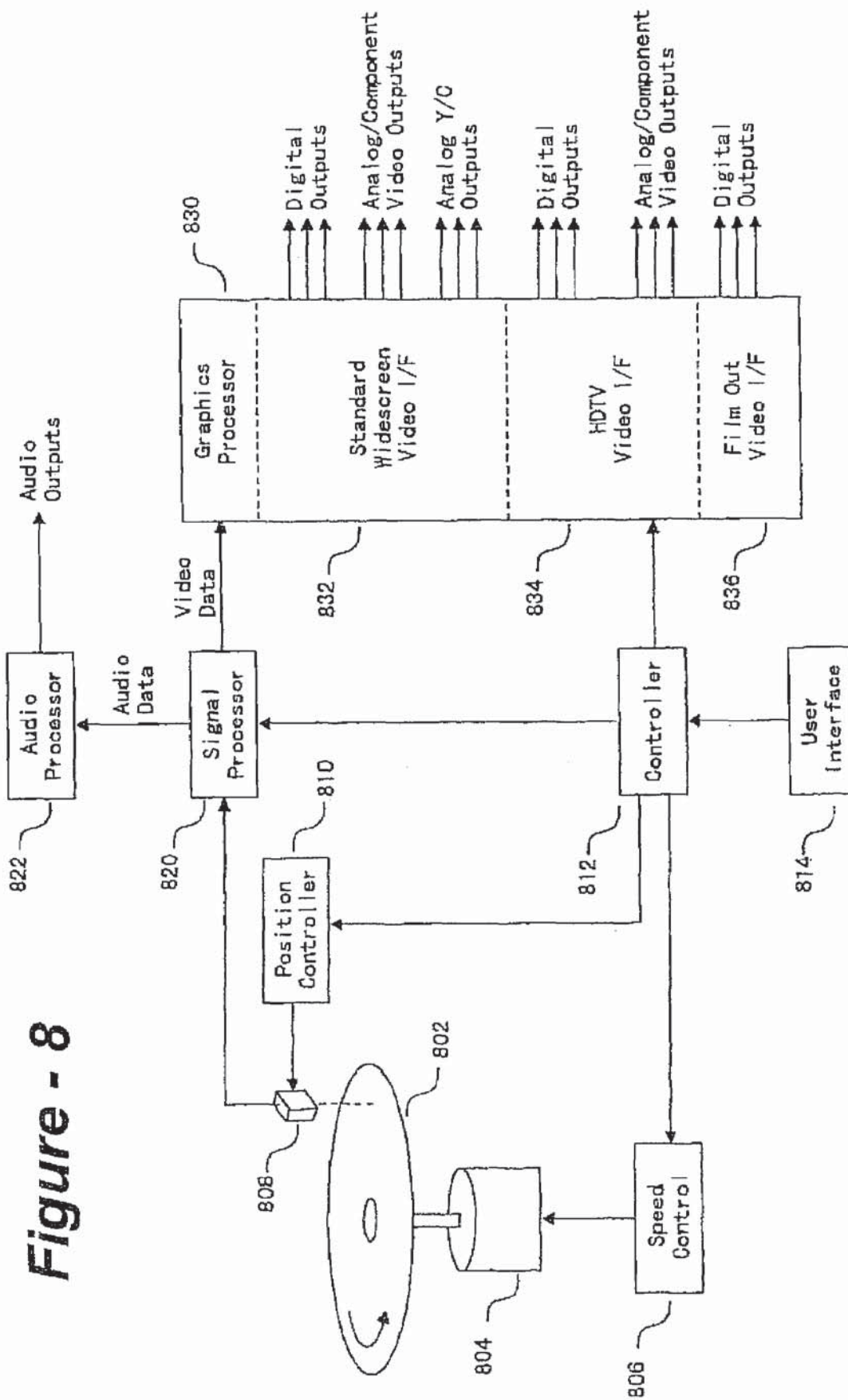


Figure - 8

US 8,228,979 B2

1

**WIDE-BAND MULTI-FORMAT AUDIO/VIDEO
PRODUCTION SYSTEM WITH FRAME-RATE
CONVERSION**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 10/117,496 filed Apr. 5, 2002; which is a continuation of U.S. patent application Ser. No. 09/305,953 filed May 6, 1999, now U.S. Pat. No. 6,370,198; which is a continuation-in-part of U.S. patent application Ser. No. 08/834,912, filed Apr. 7, 1997, now U.S. Pat. No. 5,999,220; and also claims priority of U.S. Provisional Patent Application Ser. No. 60/084,522, filed May 7, 1998. All of these prior applications are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

This invention relates generally to video production, photographic image processing, and computer graphics, and, more particularly, to a multi-format digital video production system capable of maintaining the full bandwidth resolution of the subject material, while providing professional quality editing and manipulation of images intended for digital television and other applications, including digital HDTV programs.

BACKGROUND OF THE INVENTION

As the number of television channels available through various program delivery methods digital TV (DTV) broadcasting, cable TV, home video, broadcast, etc. continues to proliferate, the demand for programming, particularly high-quality HDTV-format programming, presents special challenges, both technical and financial, to program producers. While the price of professional editing and image manipulation equipment continues to increase, due to the high cost of research and development and other factors, general-purpose hardware, including personal computers, can produce remarkable effects at a cost well within the reach of non-professionals, even novices. As a result, the distinction between these two classifications of equipment has become less well defined. Although general-purpose PC-based equipment may never allow professional-style rendering of images at full resolution in real-time, each new generation of microprocessors enables progressively faster, higher-resolution applications. In addition, as the price of memory circuits and other data storage hardware continues to fall, the capacity of such devices has risen dramatically, thereby improving the prospects for enhancing PC-based image manipulation systems for such applications.

In terms of dedicated equipment, attention has traditionally focused on the development of two kinds of professional image-manipulation systems: those intended for the highest quality levels to support film effects, and those intended for television broadcast to provide "full 35 mm theatrical film quality," within the realities and economics of present broadcasting systems. Conventional thinking holds that 35 mm theatrical film quality as projected in theaters is equivalent to 1200 or more lines of resolution, whereas camera negatives provide 2500 or more lines. As a result, image formats under consideration have been directed towards video systems having 2500 or more scan lines for high-level production, with hierarchies of production, HDTV broadcast, and NTSC and PAL compatible standards which are derived by down-converting these formats. Most proposals employ progressive

2

scanning, although interlace is considered an acceptable alternative as part of an evolutionary process. Another important issue is adaptability to computer-graphics-compatible formats.

5 Current technology directions in computers and image processing should allow production equipment based upon fewer than 12200 scan lines, with picture expansions to create a hierarchy of upward-converted formats for theatrical projection, film effects, and film recording. In addition, general-purpose hardware enhancements should be capable of addressing the economic aspects of production, a subject not considered in detail by any of the available references.

10 For the first fifty years of television in the United States, the history shows continuous development and improvement of a purely analog-based system for video production broadcasting. The nature of the NTSC system is to limit the video bandwidth to 4.2 MHz, which corresponds to approximately 340 TV-lines of resolution. In countries where PAL or SECAM systems are employed, the bandwidth is 5.5 MHz, which corresponds to approximately 440 TV-lines of resolution.

15 During the past ten years, digital processing has become the standard for video production equipment. However, to preserve compatibility with existing equipment and standards, the video bandwidth typically has been limited to 4-6 MHz (for NTSC and PAL applications, respectively). This also has tended to reduce the apparent generation loss during video production steps.

20 In the past five years or so, digital image compression technology has matured greatly. Furthermore, there are many incompatible standards, such as the different forms of JPEG systems, the-Quick-Time system, MPEG-1, and the numerous forms of the MPEG-2 standard. In addition, the latest recording formats for video production have introduced a new set of variations, including the 1/4-inch DVC-formats from Sony and Matsushita. While the signal deterioration characteristics of multi-generation analog-based production systems are well known, those imperfections resulting from diverse-format digital video compression and the conversions between these formats can be just as troublesome and unpredictable. In practice, these repeated steps of analog-to-digital (A/D) conversion and digital-to-analog (D/A) conversion, as well as data compression and decompression, introduce many signal artifacts and various forms of signal noise. Although digital video production promises multiple-step production processes free of generation losses, the reality is different, due to the repeated steps of A/D and D/A conversions, as well as data compression and decompression, present when utilizing the various incompatible image data compression formats.

25 Meanwhile, during the last twenty years, camera technology has advanced to a point far surpassing the performance of traditional production equipment. The video bandwidth capability has increased from 4.2 MHz (corresponding to 340 TV-lines of resolution) to approximately 12 MHz (corresponding to nearly 1000 TV-lines of resolution). Because of the limitations of conventional broadcast and production equipment, most of the detail information produced by today's high-performance camera systems is lost.

30 For HDTV systems, one goal is to produce images having approximately 1000 TV-lines of resolution per picture height, which requires a bandwidth of approximately 30 MHz. This, in turn, raises a new problem in terms of signal-to-noise ratio. While conventional broadcast cameras can produce signals having a S/N ratio of 65 dB, utilizing 10-bit digital processing, HDTV cameras typically produce signals having a S/N ratio of 54 dB, and utilize only 8-bit digital processing. In addition, the typical HDTV camera utilizes a 2 Megapixel

US 8,228,979 B2

3

CCD, in which the elements are approximately one-quarter the size of conventional broadcast cameras. This translates into a much lower sensitivity (a loss corresponding to 1-2 lens f-stops), higher levels of "smearing", and lower highlight compression ratios.

Analog-based HDTV systems, such as the Japanese MUSE system, do not approach the design goal of 1000 TV-lines. In reality, only one quarter of the picture information is transmitted. Although the nominal reduced luminance bandwidth of 20 MHz provides approximately 600 TV-lines of resolution per picture height in static program material, this resolution is drastically reduced to only 450 TV-lines where motion is occurring. The chrominance bandwidth is even further reduced by the sub-sampling scheme, to 280 TV-lines for the I-signal and 190 TV-lines for the Q-signal (in static scenes), and to 140 TV-lines for the I-signal and 50 TV-lines for the Q-signal (in moving scenes). Although this system provides a wide-screen aspect ratio of 16:9, it does not really qualify as a High-Definition Television System.

Because of the aforementioned compatibility issues, it is clear that conventional video recorders cannot match the technical performance of modern camera systems. Although "D-6 format" digital recorders are available, the cost and complexity of such equipment place these units beyond the means of the vast majority of broadcast stations. Furthermore, the capability of conventional switchers and other production equipment still fail to match that of available camera systems.

Other recorders have been produced, such as the one-half-inch portable recorder ("Uni-HI"), but this system only achieves 42 dB signal-to-noise ratio, and records in the analog domain. These specifications render this unit unsuitable for multi-generation editing applications. Furthermore, the luminance bandwidth is only 20 MHz, corresponding to approximately 600 TV-lines of resolution.

W-VHS ("Wideband-VHS") recorders provide a wide aspect-ratio image, but only 300 TV-lines of resolution, which also renders this unit unsuitable for any professional applications. Other distribution formats (such as D-VHS) require the application of high compression ratios to limit the data-rate to be recorded, so these formats only achieve W-VHS quality (less than 400 TV-lines of resolution).

The newly-introduced HD Digital Betacam format (HD-CAM) video recorder utilizes a 3:1:1 digital processing system rather than the 4:2:2 processing. However, it has a 24 MHz luminance bandwidth corresponding to 700 TV-lines of resolution, and a narrower chrominance bandwidth. Although this system is clearly superior to any existing analog HDTV recording system, it still falls short of delivering the full resolution produced by an HDTV digital camera. Because of its proprietary image data compression format, the production process results in repeated data compression and decompression steps, as well as A/D and D/A conversions, which, in turn, results in many signal artifacts and various forms of signal noise.

In summary, the conventional technology for these markets utilizes professional cameras having a 30 MHz bandwidth, and capable of 1000 TV-lines of resolution. However, they produce quality levels more characteristic of consumer-grade equipment (in terms of resolution and signal-to-noise ratio). In addition, the price of these systems is cost-prohibitive both on an absolute and also a cost/benefit basis, employing digital systems which produce only analog-type performance.

SUMMARY OF THE INVENTION

The present invention takes advantage of available general-purpose technology, where possible, in order to provide an

4

economical multi-format digital video production system. In the preferred embodiment, specialized graphics processing capabilities are included in a high-performance personal computer or workstation, enabling the user to edit and manipulate an input video program and produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format is chosen which provides the greatest compatibility with existing and planned formats associated with HDTV standard 4:3 or widescreen 16:9 high-definition television, and film. For compatibility with film, the frame rate of the internal production format preferably is 24 fps (for program materials originated in film format) and 48 fields-per-second (for live program materials such as sporting events). Images are re-sized horizontally and vertically by pixel interpolation, thereby producing larger or smaller image dimensions so as to fill the particular needs of individual applications. Frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions. Simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) for playback, or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities. The step of converting the signal to a HDTV format is performed by a modified upconversion process for wideband signals (utilizing a higher sampling clock frequency) and a resizing to HDTV format frame dimensions in pixels.

The invention preferably incorporates one or more interface units, including a standard/widescreen interface unit operative to convert the video program in the input format into an output signal representative of a standard/widescreen formatted image, and output the signal to an attached display device. A high-definition television interface unit is operative to convert the video program in the input format into an output signal representative of an HDTV-formatted image, and output the signal to the display device. A centralized controller in operative communication with the video program input, the graphics processor, and an operator interface, enables commands entered by an operator to cause the graphics processor to perform one or more of the conversions using the television interfaces. The present invention thus encourages production at relatively low pixel dimensions to make use of lower-cost general-purpose technology and to maintain high signal-to-noise ratio, and then subsequently expands the resultant image into a so-called up-converted program. This is in contrast to alternative approaches, which recommend operating at HDTV-type resolution, then down-converting, as necessary, to smaller image formats. This has led to the use of expensive dedicated hardware, the need for which the present invention seeks to eliminate. In addition, the flexible storage and playback facilities allow extensive control of the playback of the program material, enabling frame rate adjustments and alterations, and providing for time-shifting of the start and end points of the program reproduction in those cases wherein direct control of the source material frame rate is not practical, due to physical separation of the equipment or multiple reception points simultaneously producing outputs at different frame rates from the same source signal playback data stream. In commercial implementations, the invention readily accepts and processes enhanced information, such as pan/scan information or identification information to restrict viewing based on regional or geographical marketing plans.

The method and associated technology provide for maintaining the original high bandwidth of conventional cameras (up to 15 MHz, which corresponds to more than 600 TV-lines of resolution-per picture height for 16:9 aspect ratio) and provide optimized compression techniques to fully utilize the

US 8,228,979 B2

5

available capacity of general storage media, such as the commercially available Panasonic DVCPRO, DVCPRO50, Sony DVCAM, JVC Digital-S, and Sony Betacam SX recorders. The system preferably employs a consistent compression scheme, utilizing only intra-frame compression (such as Motion-JPEG-type systems, systems used in DV-format recorders, MPEG-2 4:2:2 P@ML) throughout the entire production process. This avoids many signal artifacts, ensures high signal-to-noise ratios, and provides for editing the program material in data-compressed format. This enables the system to preserve the original camera capability of 600+ TV-lines of resolution per picture height, and with 4:2:2 processing provides a chrominance bandwidth of up to 7.5 MHz. Utilizing 10-bit processing results in 65 dB signal-to-noise performance and improved camera sensitivity (rating of f-11). In contrast, available and proposed systems for HDTV are based on 8-bit processing, and offer performance of less than 54 dB signal-to-noise ratio and camera sensitivity rating of only f-8.

The invention provides for optimization of the available storage media as well. Utilizing hard-disks, optical discs (such as DVD, DVD-R, and DVD-RAM), magneto-optical discs, or digital tapes (such as DAT-format, DVC, DVCPRO, DVCPRO50, DVCAM, Digital-S, or 8-mm format) the data-rate to be recorded is nearly one-quarter-that of conventional HDTV systems, and consumes only 20 GB of storage space to record more than 60 minutes in the Production Format compression scheme, which utilizes a data-rate of 50 Mb per second or less, which is well within the capabilities of certain conventional recording devices. Horizontal and vertical pixel-interpolation techniques are utilized to quadruple the image size, preferably resulting in an image frame size of 1920x1080 pixels. The resulting program information may then be distributed in a conventional compression format, such as MPEG-2.

Three alternative image frame sizes preferably are suggested, depending on the intended application. For general usage, an image frame size of 1024x576 is recommended. As an option, a frame size of either 1280x720 or 1920x1080 may be utilized, at 24 frames-per-second. A sampling frequency of up to 74.25 MHz for luminance is utilized for 1920x1080. Sampling frequencies of up to 37 MHz are preferably are utilized for 1024x576 and 1280x720. Chrominance components preferably are sampled consistent with a 4:2:2 system, and 10-bit precision is preferred.

The technology of display devices and methodology has progressed as well, offering alternative features such as conversion of interlaced signals to progressive scan, line doubling, pixel quadrupling, and improved general techniques for horizontal and vertical pixel interpolation. Availability of these features as part of display devices will simplify the process of implementing multi-format digital production.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D show the preferred and alternative image aspect ratios in pixels;

FIG. 2 shows a functional diagram for disk/tape-based video recording;

FIG. 3 shows the components comprising the multi-format audio/video production system;

FIG. 4 is a block diagram of an alternative embodiment of video program storage means incorporating asynchronous reading and writing capabilities to carry out frame-rate conversions;

6

FIG. 5 shows the inter-relationship of the multi-format audio/video production system to many of the various existing and planned video formats;

FIG. 6 shows the implementation of a complete television production system, including signals provided by broadcast sources, satellite receivers, and data-network interfaces;

FIGS. 7A-7B show the preferred methods for conversion between several of the most common frame-rate choices;

FIGS. 7C-7I show details of possible methods for frame rate conversion processes; and

FIG. 8 shows a block diagram of an embodiment of a universal playback device for multi-format use.

DETAILED DESCRIPTION OF THE INVENTION

The present invention resides in the conversion of disparate graphics or television formats, including requisite frame-rate conversions, to establish an inter-related family of aspect ratios, resolutions, and frame rates, while remaining compatible with available and future graphics/TV formats, including images of pixel dimensions capable of being displayed on currently available multi-scan computer monitors. Custom hardware is also disclosed whereby frames of higher pixel-count beyond the capabilities of these monitors may be viewed. Images are re-sized by the system to larger or smaller dimensions so as to fill the particular needs of individual applications, and frame rates are adapted by inter-frame interpolation or by traditional schemes such as using "3:2 pull-down" (such as 24 frame-per-second (fps) Progressive to 30 fps interlace shown in FIG. 7C or 48 fps Progressive to 60 fps Progressive, as would be utilized for film-to-NTSC conversions) or by speeding up the frame rate itself (such as for 24 to 25 fps for PAL television display). The re-sizing operations may involve preservation of the image aspect ratio, or may change the aspect ratio by "cropping" certain areas, by performing non-linear transformations, such as "squeezing" the picture, or by changing the vision center for "panning," "scanning" and so forth. Inasmuch as film is often referred to as "the universal format," (primarily because 35-mm film equipment is standardized and used throughout the world), the preferred internal or "production" frame rate is preferably 24 fps. This selection also has an additional benefit, in that the 24 fps rate allows the implementation of cameras having greater sensitivity than at 30 fps, which is even more critical in systems using progressive scanning (for which the rate will be 48 fields per second interlaced (or 24 fps Progressive) vs. 60 fields per second interlaced in some other proposed systems).

The image dimensions chosen allow the use of conventional CCD-type cameras, but the use of digital processing directly through the entire signal chain is preferred, and this is implemented by replacing the typical analog RGB processing circuitry with fully digital circuitry. Production effects may be conducted in whatever image size is appropriate, and then re-sized for recording. Images are recorded by writing the digital data to storage devices employing internal or removable hard-disk drives, disk drives with removable media, optical or magneto-optical based drives, DVD-R or DVD-RAM type drives, tape-based drives, or semiconductor-based memory devices, preferably in compressed-data form.

As data rates for image processing and reading from, or writing to, disk drives increase, many processes that currently require several seconds will soon become attainable in real-time. This will eliminate the need to record film or video frames at slower rates. Other production effects, such as slow-motion or fast-motion may be incorporated, and it is only the frame-processing-rate of these effects that is limited in any way by the technology of the day. In particular, techniques

US 8,228,979 B2

7

such as non-linear-editing, animation, and special-effects will benefit from the implementation of this system. In terms of audio, the data rate requirements are largely a function of sound quality. The audio signals may be handled separately, as in an "interlocked" or synchronized system for production, or the audio data may be interleaved within the video data stream. The method selected will depend on the type of production manipulations desired, and by the limitations of the current technology.

Although a wide variety of video formats and apparatus configurations are applicable to the present invention, the system will be described in terms of the alternatives most compatible with currently available equipment and methods. FIG. 1A illustrates one example of a compatible system of image sizes and pixel dimensions. The selected frame rate is preferably 24 per second progressive (for compatibility with film elements), or 48 fields per second interlaced (for live program material such as sporting events). The selected picture dimension in pixels is preferably 1024×576 (0.5625 Mpxl), for compatibility with the Standard Definition TV (SDTV) 16:9 "wide-screen" aspect ratio anticipated for HDTV systems, and the conventional 4:3 aspect ratio used for PAL systems [768×576 (0.421875 Mpxl)] or NTSC systems [640×480 (0.3072 Mpxl)]. All implementations preferably rely on square pixels, though other pixel shapes may be used. Re-sizing (using the well known, sophisticated sampling techniques available in many image-manipulation software packages or, alternatively, using horizontal and vertical pixel interpolation hardware circuitry described herein below) either to 1280×720 (0.922 Mpxl) or else to 1920×1080 (2.14 Mpxl) provides an image suitable for HDTV displays or even theatrical projection systems, and a further re-sizing to 3840×2160 (8.3 Mpxl) is appropriate for even the most demanding production effects. Images may be data compressed, preferably 5:1 with Motion-JPEG-type compression such as utilized in DV-format equipment, or preferably 10:1 with MPEG2 4:2:2 P@ML compression.

In order to preserve the full bandwidth of this high-resolution signal, a higher sampling frequency is required for encoding, preferably approximately 20 MHz, for 1024×576 at 24 fps, which results in 1250 samples per total line, with 625 total lines per frame. This sampling rate allows processing a 10 MHz bandwidth luminance signal, which corresponds to approximately 600 TV lines of resolution per picture height. In contrast, traditional SDTV digital component systems employ a sampling frequency of 13.5 MHz, which provides a luminance bandwidth of 5 to 6 MHz (approximately 300 to 360 TV lines of resolution per picture height). These wide-band data files may then be stored on conventional magnetic or optical disk drives, or tape-based storage units, requiring only approximately 5.5 MB/sec for SDTV wide-screen frames in Y/R-Y/B-Y (assuming a 4:2:2 system at 8 bits per sample). The resultant data rate for this system is less than 50 Megabits per second, which is within the capabilities of currently available video recording equipment, such as the Betacam SX, DVCPRO50 or Digital S50. If a higher data-compression ratio is applied, then other units may be used, such as DVC, DVCPRO or DVCAM; Betacam SX, DVCPRO50 or Digital S50 may be used to allow sampling to 10-bit precision rather than 8-bit precision.

An alternative aspect of the invention is shown in FIG. 1B. In this case, the user follows a technique commonly used in film production, in which the film is exposed as a 4:3 aspect ratio image. When projected as a wide-screen format image, the upper and lower areas of the frame may be blocked by an aperture plate, so that the image shows the desired aspect ratio (typically 1.85:1 or 1.66:1). If the original image format were

8

recorded at 24 frames per second, with a 4:3 ratio and with a dimension in pixels of 1024×768, all image manipulations would preserve these dimensions. Complete compatibility with the existing formats would result, with NTSC and PAL images produced directly from these images by re-scaling, and the aforementioned wide-screen images would be provided by excluding 96 rows of pixels from the top of the image and 96 rows of pixels from the bottom of the image, resulting in the 1024×576 image size as disclosed above. The data content of each of these frames would be 0.75 Mpxls, and the data storage requirements disclosed above would be affected accordingly.

Another aspect of the invention is depicted in FIG. 1C. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimensions of 1280×720 pixels. Using these image dimensions (but at 24 fps progressive), compatibility with the existing formats would be available, with NTSC and PAL images derived from this frame size by excluding 160 columns of pixels from each side of the image, thereby resulting in an image having a dimension in pixels of 960×720. This new image would then be re-scaled to produce images having pixel dimensions of 640×480 for NTSC, or 768×576 for PAL. The corresponding wide-screen formats would be 854×480 and 1024×576, respectively. Utilizing a 4:2:2 sampling scheme, the 1280×720 image will require 1.85 MB when sampled at a precision of 8-bits, and 2.3 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 4.44 MB per second (35.5 megabits per second) or 5.55 MB per second (44.4 megabits per second).

In order to preserve the full 15 MHz bandwidth of this high-resolution signal, a sampling frequency of approximately 30 MHz is required for encoding, which results in 1650 samples per total line, with 750 total lines per frame for a 1280×720 image at 24 frames-per-second. In contrast, typical high definition systems require sampling rates of 74 MHz to provide a bandwidth of 30 MHz). In this case, an image having a dimension in pixels of 1280×720 would contain 0.87890625 Mpxl, with 720 TV lines of resolution. Furthermore, the systems under evaluation by the ATSC of the FCC all assume a decimation of the two chrominance signals, with detail of only 640×360 pixels retained. Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 50 megabits per second. This is within the capabilities of currently available video recording equipment, such as Betacam SX, the DVCPRO50 or Digital S50. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. The development path to 24 fps progressive is both well-defined and practical, as is the use of the previously described methods to produce images having a dimension in pixels of 1920×1080.

A third embodiment of the invention is depicted in FIG. 1D. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimensions of 1920×1080 pixels (2.1 megapixels), but at 24 frames-per-second Progressive. Utilizing a 4:2:2 sampling scheme, this 1920×1080 image will require 4.2 MB when sampled at a

US 8,228,979 B2

9

precision of 8-bits, and 5.2 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 10 MB per second (80 Megabits per second) or 12.5 MB per second (96 megabits per second). In order to preserve the full bandwidth of this high-resolution signal, a sampling frequency of 74.25 MHz is required for encoding, which results in 2750 samples per total line, with 1125 total lines per frame. In this case, an image having these dimensions would have over 1,200 TV lines of resolution per picture height, representing over 30 MHz luminance bandwidth. The chrominance bandwidth (as R-Y/B-Y would be 15 MHz. In contrast, HDTV with 1920x1080 and 30 fps Interlace only produces 1,000 TV lines (200 lines less than above) of resolution per picture height from same sampling frequency of 74.25 MHz.

Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 100 Megabits per second. This is within the capabilities of video recording equipment, such as the Panasonic DVCPRO100 or JVC Digital S100, which will be available in the near future. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. These images may be resized into frames as large as 7680x4320, which would allow use of the system for special optical effects, or with other, specialized film formats, such as IMAX and those employing 65 mm. Camera negatives. In addition, conversions processes are available, as described herein below, to produce other HDTV formats (such as 1280x720 Progressive at 24 fps, 1920x1080 Interlaced at 25 fps, 1920x1080 Progressive at 50 fps, 1920x1080 Interlaced at 30 fps, and 1920x1080 Progressive at 60 fps), or to alternative SDTV formats, (such as 1024x576 at 25 fps, 768x576 at 25 fps, 853x480 at 30 fps, or 640x480 at 30 fps).

In each of the cases described herein above, a positioning or image centering signal may be included within the data stream, so as to allow the inclusion of information which may be utilized by the receiving unit or display monitor to perform a "pan/scan" operation, and thereby to optimize the display of a signal having a different aspect ratio than that of the display unit. For example, a program transmitted in a wide-screen format would include information indicating the changing position of the image center, so that a conventional (4:3 aspect ratio) display unit would automatically pan (horizontally and/or vertically) to the proper location. For the display of the credits or special panoramic views, the monitor optionally could be switched to a full "letter-box" display, or the image could be centered and resealed to include information corresponding to an intermediate situation, such as halfway between full-height (with cropped sides) and letter-box (full-width, but with blank spaces above and below the image on the display). This positioning/resealing information would be determined under operator control (as is typical for pan/scan operations when performing film transfers to video) so as to maintain the artistic values of the original material, within the limitations of the intended display format.

Conventional CCD-element cameras produce images of over 900 TV Lines horizontal Luminance (Y) resolution, with a sensitivity of 2,000 lux at f-11, and with a signal-to-noise ratio of 65 dB. However, typical HDTV cameras, at 1,000 TV Lines resolution and with sensitivity ratings of f-8, produce an image with only a 54 dB signal-to-noise ratio, due to the constraints of the wideband analog amplifiers and the smaller physical size of the CCD-pixel-elements. By employing the more conventional CCD-elements in the camera systems of

10

this invention, and by relying upon the computer to create the HDTV-type image by image re-sizing, the improved signal-to-noise ratio is retained. In the practical implementation of cameras conforming to this new design approach, there will be less of a need for extensive lighting provisions, which in turn, means less demand upon the power generators in remote productions, and for AC-power in studio applications.

In CCD-based cameras, it is also a common technique to increase the apparent resolution by mounting the red and blue CCD-elements in registration, but offsetting the green CCD-element by one-half pixel width horizontally and in some application vertically. In this case, picture information is in-phase, but spurious information due to aliasing is out-of-phase. When the three color signals are mixed, the picture information is intact, but most of the alias information will be canceled out. This technique will evidently be less effective when objects are of solid colors, so it is still the usual practice to include low-pass optical filters mounted on each CCD-element to suppress the alias information. In addition, this technique cannot be applied to computer-based graphics, in which the pixel images for each color are always in registration. However, for Y/R-Y/B-Y video, the result of the application of this spatial-shift offset is to raise the apparent Luminance (Y) horizontal resolution to approximately 900 television lines (a 4:3 aspect ratio utilizing 12200 active pixels per line), and the apparent vertical resolution is increased by 50-100+ lines.

During the transition period to implement 24 fps recording as a new production standard, conventional 16:9 widescreen-capable CCD cameras (running in 25 or 30 fps Interlaced mode) may be utilized to implement the wideband recording method so as to preserve the inherent wideband capability of these cameras, in accordance with the invention. By abandoning the requirement for square pixels, sampling frequencies of up to 30 MHz for luminance (15 MHz for chrominance) preferably are utilized, which frequencies are less than half the typical sampling rate of 74 MHz utilized for typical HDTV luminance signals in alternative systems. Chrominance components preferably are sampled consistent with a 4:2:2 system. This wideband data stream is then compressed 10:1, utilizing MPEG2 4:2:2 P@ML at 10-bit. The resultant data rate is still less than 50 Megabits per second. With a straightforward modification to increase the data compression rate to 10:1, this signal may be recorded utilizing any of several conventional recording devices, including Panasonic DVCPRO50, JVC Digital-S, and Sony Betacam SX, thereby preserving the wideband signal (up to 800 TV lines of resolution per picture height). By utilizing the appropriate techniques for image resizing and frame rate conversion as described herein, video systems may be supported consistent with 1280x720 60 fps progressive, 1280x720 24 fps Progressive, 1920x1080 25 fps Interlace, 1920x1080 30 fps Interlace, 1920x1080 50 fps progressive, 1920x1080 60 fps progressive, in accordance with the invention.

The availability of hard-disk drives of progressively higher capacity and data transmission rates is allowing successively longer program duration and higher resolution image displays in real-time. At the previously cited data rates, wide-screen frames (1024x576 pixel, 24 fps, 4:2:2 process, 8 bits precision and 5:1 compression) would require 330 MB/min, so that currently available 10 GB disk drives will store more than 30 minutes of video. When the anticipated 50 GB disk drives (5.25-inch disks) become available from Seagate within the year, these units will store 150 minutes, or 2½ hours of video. For this application, a data storage unit is provided to facilitate editing and production activities, and it is anticipated that these units would be employed in much the

US 8,228,979 B2

11

same way as video cassettes are currently used in Betacam SP and other electronic news gathering (ENG) cameras and in video productions. This data storage unit may be implemented by use of a magnetic, optical (such as DVD-R or DVD-RAM) discs, or magneto-optical disk drive with removable storage media, by a removable disk-drive unit, such as those based on the PCMCIA standards, by tape-based storage means, or by semiconductor-based memory. Future advances, in storage technology will lead to longer duration program data storage. Alternatively, this storage capacity could be applied to lower ratios of data compression, higher sampling precision (10 bits or more) or higher-pixel-count images, within the limits of the same size media.

FIG. 2 shows the functional diagram for the storage-device-based digital recorder employed in the video camera, or separately in editing and production facilities. As shown, a removable hard disk drive 70 is interfaced through a bus controller 72. In practice, alternative methods of storage such as optical drives (such as DVD-R or DVD-RAM units) or magneto-optical drives could be used, based on various interface bus standards such as SCSI-2. This disk drive system currently achieves data transfer rates of 40 MB/sec, and higher rates on these or other data storage devices, such as high-capacity removable memory modules, is anticipated. If a digital tape-based format is selected, a tape drive 88 is interfaced through the bus controller 72. Currently available digital tape-based formats include DVCPRO, DVCPRO50, DVCAM, Betacam SX, Digital S50, and others. These units typically offer storage capacities in the range of 30 to 50 GigaBytes. The microprocessor 74 controls the 64-bit or wider data bus 80, which integrates the various components. Currently available microprocessors include the Alpha 21164 by Digital Equipment Corporation, or the MIPS processor family by MIPS Technologies, Inc. Future implementations would rely on the Pentium™ series by Intel Corp. or the PowerPC G3, which is capable of sustained data transfer rates of 100 MB/sec.

Up to 256 MB of ROM, shown at 76, is anticipated for operation, as is 256 MB or more of RAM, shown at 78. Current PC-based video production systems are equipped with at least 64 MB of RAM, to allow sophisticated editing effects. The graphics processor 82 represents dedicated hardware that performs the various manipulations required to process the input video signals 84 and the output video signals 86. Although shown using an RGB format, either the inputs or outputs could be configured in alternative signal formats, such as Y/R-Y/B-Y, YIQ, YUV or other commonly used alternatives. In particular, while a software-based implementation of the processor 82 is possible, a hardware based implementation is preferred, with the system employing a compression ratio of 5:1 for the conventional/widescreen signals ("NTSC/PAL/Widescreen"), and a 10:1 compression ratio for HDTV signals (1280×720 or 1920×1080, as described herein above). Example of the many available options for this data compression include the currently available Motion-JPEG system and the MPEG systems. Image re-sizing alternatively may be performed by dedicated microprocessors, such as the gm865X1 or gm833X3 by Genesis Microclip, Inc. Audio signals may be included within the data stream, as proposed in the several systems for digital television transmission considered by the Federal Communications Commission, or by one of the methods available for integrating audio and video signals used in multi-media recording schemes, such as the Microsoft "AVI" (Audio/Video Interleave) file format. As an alternative, an independent system for recording audio signals may be implemented, either by employing separate digital recording provisions controlled

12

by the same system and electronics, or by implementing completely separate equipment external to the camera system described herein above.

FIG. 3 shows the components that comprise a multi-format audio/video production system according to the invention. As in the case of the computer disk- or tape-based recording system of FIG. 2, an interface bus controller 106 provides access to a variety of storage devices, preferably including an internal hard-disk drive 100, a tape-drive 102, and a hard-disk drive with removable media or a removable hard-disk drive 104. Other possible forms of high-capacity data storage (not shown) utilizing optical, magneto-optical, or magnetic storage techniques may be included, as appropriate for the particular application. The interface bus standards implemented could include, among others, SCSI-2. Data is transmitted to and from these devices under control of microprocessor 110. Currently, data bus 108 would operate as shown as 64-bits wide, employing microprocessors such as those suggested for the computer-disk-based video recorder of FIG. 3. As higher-powered microprocessors become available, such as the PowerPC G3, the data bus may be widened to accommodate 128 bits, and the use of multiple parallel processors may be employed, with the anticipated goal of 1,000 MIPS per processor. Up to 256 MB of ROM 112 is anticipated to support the requisite software, and at least 1,024 MB of RAM 114 will allow for the sophisticated image manipulations, inter-frame interpolation, and intra-frame interpolation necessary for sophisticated production effects, and for conversions between the various image formats.

A key aspect of the system is the versatility of the graphics processor shown generally as 116. Eventually, dedicated hardware will allow the best performance for such operations as image manipulations and re-scaling, but it is not a requirement of the system that it assume these functions, or even that all of these functions be included in the graphics processor in every configuration of the system. Three separate sections are employed to process the three classifications of signals. Although the video input and output signals described herein below are shown, by example, as RGB, any alternative format for video signals, such as Y/R-Y/B-Y, YIQ, YUV, or other alternatives may be employed as part of the preferred embodiment. One possible physical implementation would be to create a separate circuit board for each of the sections as described below, and manufacture these boards so as to be compatible with existing or future PC-based electrical and physical interconnect standards.

A standard/widescreen video interface 120, intended to operate within the 1024×576, 1280×720, 1024×768, 854×480, 640×480 or 1280×960 image sizes, accepts digital RGB or Y/R-Y/B-Y signals for processing and produces digital RGB or Y/R-Y/B-Y outputs in these formats, as shown generally at 122. Conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, including analog RGB or Y/R-Y/B-Y signals and composite video signals. These outputs may optionally be supplied to either a conventional multi-scan computer video monitor or a conventional video monitor having input provisions for RGB or Y/R-Y/B-Y signals (not shown). A third set of outputs supplies analog Y/C video signals. The graphics processor may be configured to accept or output these signals in the standard NTSC, PAL, or SECAM formats, and may additionally be utilized in other formats as employed in medical imaging or other specialized applications, or for any desired format for computer graphics applications. Conversion of these 24 frame-per-second progressive images to the 30 fps Interlaced (actually, 29.97 fps) NTSC and 25 fps PAL formats may be

US 8,228,979 B2

13

performed in a similar manner to that used for scanned film materials, that is, to NTSC by using the conventional 3:2 “pull-down” field-sequence, or to PAL by reproducing the images at the higher 25 fps rate.

If the source signal is 24 fps interlaced, these images first are de-interlaced to 48 fps progressive, which can be performed by dedicated microprocessors such as the gmVLD8 or gmVLD10 by Genesis Microchips, and then converted to 60 fps progressive by utilizing a “Fourth Frame Repeat” process (which repeats the fourth frame in every sequence). Next, the signal is interlaced to produced 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced (as disclosed in FIG. 7F). If the source format is 25 fps interlaced video (as would result from using conventional PAL-type equipment, or PAL-type equipment as modified in accordance with the invention), the first step is to slow down the frame rate by replaying the signal at 24 fps Interlaced. Next, the signal is de-interlaced to 48 fps progressive (as described herein above), and the Fourth Frame Repeat process is utilized to convert the-signal to 60 fps progressive. In the last step, the signal is interlaced to produced 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced. Alternatively, if the source signal is 24 fps progressive, the 60 fps progressive signal may be produced directly from a “3:2 Frame Repeat” process shown in FIG. 7G (which is analogous to the conventional “3:2 pull-down” field-sequencing process previously described). For other HDTV frame rates, aspect ratios, and line rates, intra-frame and inter-frame interpolation and image conversions may be performed by employing comparable techniques well known in the art of computer graphics and television.

An HDTV video interface 124, intended to operate within the 1920x1080 or other larger image sizes (with re-sizing as necessary), accepts digital RGB or Y/R-Y/B-Y (or alternative) signals for processing and produces, digital outputs in the same image format, as shown generally at 126. As is the case for the standard/widescreen interface 120, conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, for analog RGB signals and composite video signals. In alternative embodiments, this function may be performed by an external upconverter, which will process the wideband signal of the instant invention. A modification of currently available upconverters is required, to increase the frequency of the sampling clock in order to preserve the full bandwidth of this signal, in accordance with the invention. In this case, frequency of the sampling clock is preferably adjustable to utilize one of several available frequencies.

The third section of the graphics processor 116 shown in FIG. 3 is the film output video interface 128, which comprises a special set of video outputs 130 intended for use with devices such as laser film recorders. These outputs are preferably configured to provide a 3840x2160 or other larger image size from the image sizes employed internally, using re-sizing techniques discussed herein as necessary for the format conversions. Although 24 fps is the standard frame rate for film, some productions employ 30 fps (especially when used with NTSC materials) or 25 fps (especially when used with PAL materials), and these alternative frame rates, as well as alternative image sizes and aspect ratios for internal and output formats, are anticipated as suitable applications of the invention, with “3:2-pull-down” utilized to convert the internal 24 fps program materials to 30 fps, and 25 fps occurring automatically as the film projector runs the 24 fps films at the 25 fps rate utilized for PAL-type materials.

14

Several additional optional features of this system are disclosed in FIG. 3. The graphics processor preferably also includes a special output 132 for use with a color printer. In order to produce the highest quality prints from the screen display it is necessary to adjust the print resolution to match the image resolution, and this is automatically optimized by the graphics processor for the various image sizes produced by the system. In addition, provisions may be included for an image scanner 134, which may be implemented as a still image scanner or a film scanner, thereby enabling optical images to be integrated into the system. An optional audio processor 136 includes provisions for accepting audio signals in either analog or digital form, and outputting signals in either analog or digital form, as shown in the area generally designated as 138. For materials including audio intermixed with the video signals as described herein above, these signals are routed to the audio processor for editing effects and to provide an interface to other equipment.

It is important to note that although FIG. 3 shows only one set of each type of signal inputs, the system is capable of handling signals simultaneously from a plurality of sources and in a variety of formats. Depending on the performance level desired and the image sizes and frame rates of the signals, the system may be implemented with multiple hard disk or other mass-storage units and bus controllers, and multiple graphics processors, thereby allowing integration of any combination of live camera signals, prerecorded materials, and scanned images. Improved data compression schemes and advances in hardware speed will allow progressively higher frame rates and image sizes to be manipulated in real-time.

Simple playback of signals to produce PAL output is not a serious problem, since any stored video images may be replayed at any frame rate desired, and filmed material displayed at 25 fps is not objectionable. Indeed, this is the standard method for performing film-to-tape transfers used in PAL- and SECAM-television countries. Simultaneous output of both NTSC and film-rate images may be performed by exploiting the 3:2 field-interleaving approach: $5 \times 24 = 120 = 2 \times 60$. That is, two film frames are spread over five video fields. This makes it possible to concurrently produce film images at 24 fps and video images at 30 fps. The difference between 30 fps and the exact 29.97 fps rate of NTSC may be palliated by slightly modifying the system frame rate to 29.976 fps. This is not noticeable in normal film projection, and is an acceptable deviation from the normal film rate.

The management of 25 fps (PAL-type) output signals in a signal distribution system configured for 24 fps production applications (or vice versa) presents technical issues which must be addressed, however. One alternative for facilitating these and other frame-rate conversions is explained with reference to FIG. 4. A digital program signal 404 is provided to a signal compression circuit 408. If the input program signal is provided in analog form 402, then it is first processed by A/D converter 406 to be placed in digital form. The signal compressor 408 processes the input program signal so as to reduce the effective data rate, utilizing any of the commonly implemented data compression schemes, such as motion-JPEG, MPEG1, MPEG2, etc. well known in the art. As an alternative, the digital program signal 404 may be provided in data-compressed form. At this point, the digital program signal is provided to data bus 410. By way of example, several high-capacity digital storage units, designated as “storage means A” 412 and “storage means B” 414, are included for storing the digital program signals presented on data bus 410, under management by controller 418.

15

The two storage means **412** and **414** may be used in alternating fashion, with one storing the source signal until it reaches its full capacity. At this point, the other storage means would continue storing the program signal until it, too, reached its full capacity. The maximum program storage capacity for the program signals will be determined by various factors, such as the input program signal frame rate, the frame dimensions in pixels, the data compression rate, the total number and capacities of the various storage means, and so forth. When the available storage capacity has been filled, this data storage scheme automatically will result in previously-recorded signals being overwritten. As additional storage means are added, the capacity for time-delay and frame rate conversion is increased, and there is no requirement that all storage means be of the same type, or of the same capacity. In practice, the storage means would be implemented using any of the commonly available storage techniques, including, for example, magnetic disks, optical (such as DVD-RAM discs) or magneto-optical discs, or semiconductor memory.

When it is desired to begin playback of the program signal, signal processor **416**, under management by controller **418** and through user interface **420**, retrieves the stored program signals from the various storage means provided, and performs any signal conversions required. For example, if the input program signals were provided at a 25 fps rate (corresponding to a 625-line broadcast system), the signal processor would perform image resizing and inter-frame interpolation to convert the signal to 30 fps (corresponding to a 525-line broadcast system). Other conversions (such as color encoding system conversion from PAL-format to NTSC, etc., or frame dimension or aspect-ratio conversion) will be performed as necessary. The output of the signal processor is then available in digital form as **422**, or may be processed further, into analog form **426** by D/A converter **424**. In practice, a separate data bus (not shown) may be provided for output signals, and/or the storage means may be implemented by way of dual-access technology, such as dual-port RAM utilized for video-display applications, or multiple-head-access disk or disk storage units, which may be configured to provide simultaneous random-access read and write capabilities. Where single-head storage means are implemented, suitable input buffer and output buffer provisions are included, to allow time for physical repositioning of the record/play head.

In utilizing program storage means including synchronous recording and playback capabilities of the types just described, if it is known that a program will be stored in its entirety before the commencement of playback, that is, with no time-overlap existing between the occurrence of the input and output signal streams, it typically will be most efficient to perform any desired frame conversion on the program either before or after initial storage, depending upon which stored format would result in the least amount of required memory. For example, if the program is input at a rate of 24 frames per second, it probably will be most efficient to receive such a program and store it at that rate, and perform a conversion to higher frame rates upon output. In addition, in situations where a program is recorded in its entirety prior to conversion into a particular output format, it is most efficient to store the program either on a tape-based format or a format such as the new high-capacity DVD-type discs, given the reduced cost, on a per-bit basis, of these types of storage. Of course, conventional high-capacity disk storage also may be used, and may become more practical as storage capacities continue to increase and costs decrease. If it is known that a program is to be output at a different frame rate while it is being input or stored, it is most preferable to use disk storage and to perform the frame rate conversion on an ongoing basis, using one of

16

the techniques described above. In this case, the high-capacity video storage means, in effect, assumes the role of a large video buffer providing the fastest practical access time. Again, other memory means (types) may be used, including all solid-state and semiconductor types, depending upon economic considerations, and so forth.

As an example of an alternative embodiment, the storage means **100** or **104** are equipped with dual-head playback facilities and a second set of graphics processing hardware (not shown) analogous in function to the normal graphics processing hardware (identical to the standard hardware shown as **120**, **124**, and **128**), and having analogous signal output facilities (identical to the standard provisions shown as **122**, **126**, **130**, and **132**). In this case, the two heads would be driven independently, to provide simultaneous, asynchronous playback at different frame rates. That is, one head would be manipulated so as to provide a data stream corresponding to a first frame rate (for example, 25 fps), while the second head would be manipulated so as to provide a data stream corresponding to a second frame rate (for example, 24 fps, which, in turn, may be converted to 30 fps, using the "3:2-pull-down" technique). In this case, both the storage means and also the internal bus structure of the system would have to support the significantly increased data rate for providing both signal streams simultaneously, or, as an alternative, a second, separate data bus would be provided.

In some applications, a more sophisticated conversion scheme is required. For example, in frame rate conversion systems of conventional design, if an input program signal having a 24 fps rate format is to be displayed at a 25 fps rate, it is customary to simply speed up the source signal playback, so as to provide the signals at a 25 fps rate. This is the procedure utilized for performing a conversion of 24-fps-film-material for 25 fps PAL-format video usage. However, implementation of this method requires that the user of the output signal must have control over the source-signal playback. In a wide-area distribution system (such as direct-broadcast-satellite distribution) this is not possible. While a source signal distributed at 24 fps readily could be converted to 30 fps (utilizing the familiar "3-2-pull-down" technique), the conversion to 25 fps is not as easily performed, due to the complexity and expense of processing circuitry required for inter-frame interpolation over a 24-frame sequence. However, utilizing the system disclosed in FIG. 4, the conversion is straightforward. If, for example, a 24 fps program lasting 120 minutes is transmitted in this format, there are a total of 172,800 frames of information (24 frames/second \times 60 seconds/minute \times 120 minutes). Display of this program in speeded-up fashion at 25 fps would mean that the input frame rate falls behind the output frame rate by one frame per second, or a total of 7,200 frames during the course of the program. At a 24 fps transmission rate, this corresponds to 300 seconds transmission time. In other words, for the input program (at 24 fps) and the output program (at 25 fps) to end together, the input process would have to commence 300 seconds before the output process begins. In order to perform this process, then, it is necessary for the storage means to have the capacity to retain 300 seconds of program material, in effect serving as a signal buffer. As an example, for the systems disclosed herein in which the compressed-data rates range from 5.5 MB/sec (for 24 fps standard/widescreen Y/R-Y/B-Y-based TV formats, using 5:1 data compression such as MPEG or motion-JPEG and 4:2:2 processing with 8-bit precision) to 10 MB/sec (for 24 fps HDTV Y/R-Y/B-Y-based formats, using 10:1 data compression such as MPEG or motion-JPEG and 4:2:2 processing with 8-bit precision), it may be necessary to store as much as 3.3 GBytes of data,

which is readily available by way of multiple disks or discs utilizing conventional storage technology. In practice, the transmission simply would begin 300 seconds before the playback begins, and once the playback starts, the amount of buffered signal would decrease by one frame per second of playback until the last signal is passed through as soon as it is received.

A mirror of this situation arises in the case of a 25 fps signal to be displayed at 24 fps, or some other data rate readily provided by conversion from 24 fps (such as 30 fps). In this case, the source signal is provided at a higher frame rate than the output signal, so that a viewer watching a program from the onset of the transmission would fall behind the source signal rate, and the storage means would be required to hold frames of the program to be displayed at a time after the source signal arrival time. In the case of the 120 minute program described above, the viewing of the source program would conclude 300 seconds after the source signal itself had concluded, and comparable calculations are applied for the storage means. In this case, the extra frames would be accumulated as the buffer contents increased, until, after the transmission has completed, the last 300 seconds would be replayed directly from the storage means.

The conversion of frame rates from 30 fps to 24 fps or to 25 fps is more complicated, because some form of inter-frame interpolation is required. In one case, a multi-frame storage facility would allow this type of interpolation to be performed in a relatively conventional manner, as typically is utilized in NTSC-to-PAL conversions (30 fps to 25 fps). At this point, a 25 fps to 24 fps conversion could be performed, in accordance with the methods and apparatus described herein above.

It should be noted that if, for example, a DVD-R-type, DVD-RAM-type, or some form of removable magnetic storage media is selected, then the implementation of the significantly higher data compression rates of MPEG-2 coding techniques will result in the ability to record an entire program of 120 minutes or more in duration. In this manner, the complete program is held in the disk/buffer, thereby enabling the user to perform true time-shifting of the program, or allowing the program rights owner to accomplish one form of software distribution, in accordance with the invention.

An alternative method to carry out this frame rate conversion is carried out utilizing the following process. The 30 fps interlaced signal is first de-interlaced to 60 fps Progressive. Then, every fifth frame is deleted from the sequence, producing a 48 fps progressive signal stream. Next, these remaining frames are converted to 24 fps interlaced, as disclosed in FIG. 7I ("5th Frame Reduction"). If the original source material were from 24 fps (for example, film), then if the repeated fields (i.e., the "3" field of the 3:2 sequence) were identified at the time of conversion, then the removal of these fields would simply return the material to its original form. If the desired conversion is to be from 30 fps to 25 fps, then an equivalent procedure would be performed using the storage-based frame-conversion method described herein above. As an alternative, the 30 fps interlaced signal would first be de-interlaced to 60 fps progressive; then, every sixth frame would be deleted from the sequence ("6th Frame Reduction"). The remaining frames are re-interlaced to produce 25 fps interlaced, as disclosed in FIG. 7H. Depending on the original source material frame rate and intermediate conversions, the user would select the method likely to present the least amount of image impairment.

In the case in which the user is able to exercise control over the frame rate of the source program material, an alternative method is available. Just as film-to-video transfers for PAL-format (25 fps) presentations utilize a speeded-up playback of

the 24 fps film materials to source them at the 25 fps Progressive rate (thereby matching the intended output frame rate), the reverse of this process enables a user to utilize materials originated at 25 fps Progressive to produce playback at 24 fps. As disclosed herein above, conversions of 24 fps progressive materials are handled easily by way of conventional methods (such as the "3:2-pull-down" method), and therefore the operator control of the source material enables the user to utilize materials originating from conventional or widescreen PAL format sources for editing and production, then replay the resulting program at 24 fps for conversion to either standard or widescreen NTSC output materials, or even to HDTV format materials, all at 30 fps Interlaced, by performing the "3:2-pull-down" process.

If the source format is 25 fps interlaced video (as would result from using conventional PAL-type CCD widescreen camera), an alternative method for producing a 30 fps Interlaced signal is available. Instead of performing a slow-down to produce a 24 fps interlaced signal, the 25 fps Interlaced signal is first de-interlaced to 50 fps progressive. Next, a "4th Frame Repeat" process is applied, which results in a 62.5 fps progressive signal. This signal is then converted to 62.5 fps interlaced, and after half of the fields are discarded, to produce 31.25 fps interlaced. After data compression, the signal undergoes a slow-down process, resulting in a 30 fps interlaced signal which now has a compressed-data-rate of less than 10 Mbytes per second, as disclosed in FIG. 7D. By using this procedure, the entire process from the CCD camera to the final conversion to 30 fps Interlaced only one data compression step is employed. Alternatively, if the output of the camera is already in data compressed form, then this signal must be decompressed before applying the listed conversion steps. In order to ensure accurate conversion, interlace and de-interlace processes should only be applied to de-compressed signals. Conversely, speed-up and slow-down procedures are preferably applied with compressed data, as the raw data rate for uncompressed video, depending on the image dimensions in pixels and frame rate, will be in the range of 30 to 100 MB per second, which is not practical for current technology storage devices.

A variety of conversions between formats (both interlaced and progressive) having differing frame rates, and some of these possible conversion paths are indicated in FIGS. 7A through 7I. While extensive, these listings are not intended to represent a complete listing of all alternatives, as in many cases there is more than one combination of methods which may effect an equivalent conversion. Depending on the particular application, different paths may be selected, and these differing paths may produce more, or less, effective results.

The various alternatives utilize several techniques not previously applied to these types of conversions. For example, conversions of 60 fps progressive signals to 30 fps Progressive may be effected by simply dropping alternate frames. On the other hand, a "3:2 Frame Repetition" method consists of repeating a first frame a second and a third time, then repeating the next frame a second time, thereby converting two frames into five frames (as depicted in FIG. 7G).

Depending on whether the source material is 24 fps progressive or 24 fps interlaced, different approaches are utilized for conversion to 30 fps interlaced. In the first case, the 24 fps progressive signal is first converted to 24 fps Interlaced. A set of four consecutive frames may be indicated as 1A1B, 2A2B, 3A3B, 4A4B. By recombining these fields (but outputting them at a 30 fps rate) the following field sequence is obtained: 1A1B, 1A2B, 2A3B, 3A4B, 4A4B. This sequence repeats for every four input frames, which is to say, for every five output frames (as depicted in FIG. 7C).

Alternatively, for a signal which originates at 24 fps Interlaced, the original four-frame sequence is identical. However, the situation is more complicated because the absolute time-sequence of frames must be preserved. For this reason, it is necessary to reverse the field identification of alternate groups of fields in order to preserve the proper interlace relationship between the fields. In effect, every fourth and seventh field in the eight-field (24 fps interlaced) sequence is repeated, but with reversed field identification (as disclosed in FIG. 7E). When the fourth input field has had its identification reversed (to produce the fifth output field), then the next two input fields (corresponding to the sixth and seventh output field) in the sequence also will require field reversal, in order to preserve the correct sequence for proper interlace. Furthermore, when the seventh input field is repeated, the first time it will appear in reversed-field-identity from as the eighth output field. For this procedure, the resulting field sequence will be 1A1B, 2A2B, 2B*3A*, 3B*4A*, 4A4B (wherein a field having reversed field identification is denoted by a * symbol). This sequence repeats for every four input frames, which is to say, for every five output frames.

In addition, the reversal of the field identity of the fourth input field (when repeated) results in information that previously was displayed on the second scan line now being displayed on the first scan line. Therefore, it is necessary to discard the first line of the next reversed-field, so that the information displayed on the second scan line of the new field will be the information previously displayed on the third line of the next (reversed) field. After the seventh input field has been reversed (to produce the eighth output field, the following fields are once again in the proper line order without any further adjustments of this kind (as disclosed in FIG. 7E).

For image manipulations entirely within the internal storage format, there is no issue as to interlacing, as the graphics processor is only manipulating a rectangular array of image pixels, not individual scan lines. As such, identification of fields is derived solely from the location of the image pixels on either odd-numbered lines or even-numbered lines. The interlacing field identification adjustments are made only at the time of output to the display device. In these applications, the presence of the storage means allows the viewer to control the presentation of a program, utilizing a user interface 420 to control the playback delay and other characteristics of the signal while it is being stored or thereafter. In practice, a wide range of alternatives for input frame rates and output frame rate conversions are made available through this system, by selecting the most appropriate of the various methods for altering the frame rate of a signal described herein.

FIG. 5 shows the inter-relationship of the various film and video formats compatible with the invention, though not intended to be inclusive of all possible implementations. In typical operations, the multi-format audio/video production system 162 would receive film-based elements 160 and combine them with locally produced materials already in the preferred internal format of 24 frames-per-second. In practice, materials may be converted from any other format including video at any frame rate or standard. After the production effects have been performed, the output signals may be configured for any use required, including, but not limited to, HDTV at 30/60 fps shown as 164, widescreen at 30 fps shown as 166, widescreen at 25 fps shown as 170, or HDTV at 25/50 fps shown as 172. In addition, output signals at 24 fps are available for use in a film-recording unit 168.

In FIG. 6, signals are provided from any of several sources, including conventional broadcast signals 210, satellite receivers 212, and interfaces to a high bandwidth data network 214. These signals would be provided to the digital

tuner 218 and an appropriate adapter unit 220 for access to a high-speed data network before being supplied to the decompression processor 222. As an option, additional provisions for data compression would provide for transmission of signals from the local system to the high bandwidth data network 214. The processor 222 provides any necessary data decompression and signal conditioning for the various signal sources, and preferably is implemented as a plug-in circuit board for a general-purpose computer, though the digital tuner 218 and the adapter 220 optionally may be included as part of the existing hardware.

The output of processor 222 is provided to the internal data bus 226. The system microprocessor 228 controls the data bus, and is provided with 32 to 128 MB of RAM 230 and up to 64 Mb of ROM 232. This microprocessor could be implemented using one of the units previously described, such as the PowerPC 604, PowerPC G3, Pentium-series, or other processors. A hard disk drive controller 234 provides access to various storage means, including, for example, an internal hard disk drive unit 236, a removable hard disk drive unit 238, a unit utilizing removable magnetic, optical, or magneto-optical media (not shown), or a tape drive 240. These storage units also enable the PC to function as a video recorder, as described above. A graphic processor 242, comprising dedicated hardware which optionally be implemented as a separate plug-in circuit board, performs the image manipulations required to convert between the various frame sizes (in pixels), aspect ratios, and frame rates. This graphics processor uses 16 to 32 MB of DRAM, and 2 to 8 MB of VRAM (depending on the type of display output desired. For frame size of 1280x720 with an aspect ratio 16:9, the lower range of DRAM and VRAM will be sufficient, but for a frame size of 1920x1080, the higher range of DRAM and VRAM is required. In general, the 1280x720 size is sufficient for conventional "multi-sync" computer display screens up to 20 inches, and the 1920x1080 size is appropriate for conventional "multi sync" computer display screens up to 35 inches. Analog video outputs 244 are available for these various display units. Using this system, various formats may be displayed, including (for 25 fps, shown by speeding up 24 fps signals) 768x576 PAL/SECAM, 1024x576 wide-screen, and 1280x720/1920x1080 HDTV, and (for 30 and 60 fps, shown by utilizing the well-known "3:2 pull-down" technique, and for 29.97 fps, shown by a slight slow-down in 30 fps signals) 640x480 NTSC and 854x480 wide-screen, and 1920x1080 NHK (Japan) HDTV.

It will be appreciated by the skilled practitioner that most of the highest quality program material has been originated on 24 fps 35-mm film, and therefore conversions that rely on reconstituting the signal material from 25 fps or 30 fps materials into 24 fps material do not entail any loss of data or program material. In addition, signals that have been interlaced from a lower or equivalent frame rate source signal in any of the currently available means (24 fps to 25 fps via speed-up; 24 fps to 30 fps via "3:2-pull-down") may be deinterlaced and reconstituted as progressive-scan frames without introducing any signal artifacts, provided that the original frames are recreated from properly matched fields. If it is desired to produce 24 fps interlaced, 25 fps Interlaced, or 30 fps interlaced signals from higher frame rate progressive signals (such as 48 fps Progressive, 50 fps progressive, or 60 fps progressive signals, respectively) these may be obtained by interlacing these signals and discarding the redundant data. Alternatively, if it is desired to produce 24 fps progressive, 25 fps progressive, 30 fps Progressive, or 48 fps progressive signals from higher frame rate progressive signals (such as 48 fps progressive, 50 fps progressive, 60 fps progressive, or 96

US 8,228,979 B2

21

fps progressive signals, respectively), these may be obtained by applying a 2:1 frame reduction. These techniques are summarized in FIG. 7A, with conversion charts showing typical process flow charts in FIGS. 7B and 7C.

FIG. 8 shows one possible implementation of a universal playback device, in accordance with the invention. By way of example, a DVD-type video disk 802 is rotatably driven by motor 804 under control of speed-control unit 806. One or more laser read- or read/write-heads 808 are positioned by position control unit 810. Both the speed control unit and the position control unit are directed by the overall system controller 812, at the direction of the user interface 814. It should be noted that the number and configuration of read- or read/write-heads will be determined by the choice of the techniques employed in the various embodiments disclosed herein above. The signals recovered from the laser heads is delivered to signal processor unit 820, and the data stream is split into an audio data stream (supplied to audio processor unit 822) and a video data stream (supplied to video graphics processor unit 830). During the audio recovery process, the alteration of the playback frame rate (for example, from 24 fps to 25 fps, accomplished by speed control adjustment) may suggest the need for pitch-correction of the audio material. This procedure, if desired, may be implemented either as part of the audio processor 822, or within a separate, external unit (not shown), as offered by a number of suppliers, such as Lexicon.

The video data stream may undergo a number of modifications within the graphics processor, shown generally at 830, depending on the desired final output format. Assuming that the output desired is NTSC or some other form of widescreen or HDTV signal output at a nominal frame rate of 30 fps, a signal sourced from the disk at 24 fps would undergo a "3:2-pull-down" modification as part of the conversion process (as explained herein above). If the signal as sourced from the disk is based on 25 fps, then it would undergo an preliminary slowdown to 24 fps before the "3:2-pull-down" processing is applied. It should be noted that the 0.1% difference between 30 fps and 29.97 fps only requires the buffering of 173 frames of video over the course of a 120-minute program, and at a data rate of 5.5 MB/sec, this corresponds to approximately 39 MB of storage (for standard/widescreen) or 79 MB of storage (for HDTV), which readily may be implemented in semiconductor-based memory. In any event, a signal supplied to the graphics processor at a nominal 24 fps simultaneously may be output at both 30 fps and 29.97 fps, in image frames compatible with both NTSC and NTSC/widescreen (the standard/widescreen video interface 832), and HDTV (HDTV video interface 834), in accordance with the invention as described herein above.

As disclosed above, an optional film output video interface 836 may be included, with digital video outputs for a film recorder. Overall, the outputs for the graphics processor 830 parallel those of the Multi-Format Audio/Video Production System as shown in FIG. 5 and disclosed herein above. In addition, for signals to be output in a format having a different aspect ratio than that of the source signal, it may be necessary to perform a horizontal and/or vertical "pan/scan" function in order to assure that the center of action in the source program material is presented within the scope of the output frame. This function may be implemented within the graphics processor by utilizing a "tracking" signal associated with the source program material, for example, as part of the data stream for each frame, or, alternatively, through a listing identifying changes that should be applied during the presentation of the source material. Where no "tracking" information is available, the image frame would be trimmed along the

22

top and bottom, or the sides, as necessary in order to fit the aspect ratio of the source material to the aspect ratio of the output frame. This latter technique is explained herein above, with reference to FIGS. 1A-1D. In addition, the program material may include security information, such as regional or geographical information directed towards controlling the viewing of the program material within certain marketing areas or identifiable classes of equipment (such as hardware sold only in the United States or in the German market). This information, as has been disclosed for use with other disk-n and tape-based systems, often relates to issues such as legal licensing agreements for software materials. It may be processed in a way similar to the detection and application of the "pan/scan" tracking signal, and the signal processor 820, under the direction of controller 812 may act to enforce these restrictions.

Alternatively, if output at 25 fps is desired, it is a simple matter to configure the various components of this system to replay the video information of the disk 802 at this higher frame rate. The controller will configure the speed control unit 806 (if necessary) to drive the motor 804 at a greater rotational speed to sustain the increased data rate associated with the higher frame rate. The audio processor 822, if so equipped, will be configured to correct for the change in pitch associated with the higher frame rate, and the graphics processor will be configured to provide all output signals at the 25 fps frame rate. As Alternate method for audio pitch correction, additional audio data can be stored in disk which is already corrected. When the frame rate is changed, the corresponding audio data is selected in accordance with the invention.

As yet another alternative, materials produced at 25 fps and stored on the disk-based mass storage means of this example could originate from conventional standard or widescreen PAL format signals. Utilizing the slow-down method, these signals are readily converted to 24 fps frame rate, from which conversion to various 30 fps formats is implemented, as disclosed herein above. This feature has significance in the commercial development of HDTV, as the ability to utilize more-or-less conventional PAL format equipment greatly facilitates the economical production and origination of materials intended for HDTV markets.

A wide range of output frame rates may be made available through combination of the techniques of speed-up, slow-down, "3-2-pull-down," and other related field-rearrangement, de-interlacing, interlacing/de-interlacing, frame repetition, and frame reduction techniques, as disclosed herein above with respect to FIG. 4 and FIGS. 7A-7E, and these various combinations and approaches should be considered to be within the scope of the invention. In addition, these techniques may be combined with hardware and/or software which perform image manipulations such as line-doubling, line-quadrupling, deinterlacing, etc., such that the display device will be capable of providing smoother apparent motion, by increasing the display rate without increasing the actual data/information rate. One example would be to process the 24 fps signal from the internal format to convert it into a 48 fps signal, using field-doubling techniques such as deinterlacing and line doubling. Then, the process would employ frame-store techniques to provide a frame-repeated output at a rate of 96 fps. These types of display-related improvements, in conjunction with the instant invention, should also be considered to be within the scope of the invention as disclosed herein. Examples of these various combinations and conversion methods are included in the table of FIG. 7A and the chart of FIG. 7E.

US 8,228,979 B2

23

In general, the features as described need not all be provided in a single unit, but rather may be distributed through various external units (such as external data-recorders or display units). In addition, particular configurations of the system may include only the graphics capabilities required for that application (such as the use of 25 fps PAL outputs, but not 30 fps NTSC) and may even exclude certain options (such as printer outputs), and these variations should be considered to be within the scope of the invention.

I claim:

1. A method of processing an audio/video program to output a modified version of the program at a desired display rate, comprising the steps of:

providing a computer including RAM, ROM and a processor;

the computer receiving an input video program in a first interlaced format having no added redundant frames or fields;

the computer de-interlacing the input video program to generate a video program in a first progressive format comprising a sequence of progressive frames, each progressive frame being derived from a respective one, and only one, of the fields in the first interlaced format;

the computer removing or repeating some of the frames of the video program in the first progressive format to generate a program in a second progressive format; and

the computer outputting the program in the second progressive format, wherein the display rate of the program is at least 48 frames-per-second, and is an integer multiple of substantially 24, 25, or 30 frames-per-second.

2. The method of claim 1, wherein the first interlaced format is PAL or HDTV at 25 fps.

3. The method of claim 1, wherein the first interlaced format is NTSC or HDTV at 30 fps.

4. A method of processing an audio/video program to output a modified version of the program at a desired display rate, comprising the steps of:

providing a computer including RAM, ROM and a processor;

the computer receiving an input video program in a first progressive format having no added redundant frames;

the computer repeating each frame of the first progressive format to generate a program in an intermediate progressive format having a frame rate exactly twice that of the first progressive format;

the computer removing or repeating some of the frames of the video program in the intermediate progressive format to generate a program in a second progressive format; and

the computer outputting the program in the second progressive format, wherein the display rate of the program is at least 48 frames-per-second, and is an integer multiple of substantially 24, 25, or 30 frames-per-second.

5. The method of claim 4, wherein the first progressive format is at 24, 25 or 30 fps.

6. The method of claim 4, wherein the second progressive format is re-interlaced to generate an interlaced output format comprising a sequence of interlaced fields, each interlaced field being derived from a respective one, and only one, of the frames in the second progressive format prior to outputting the program.

7. The method of claim 6, wherein the interlaced format is NTSC or HDTV at 30 fps.

24

8. The method of claim 6, wherein the interlaced format is PAL or HDTV at 25 fps.

9. A method of processing an audio/video program to output a modified version of the program at a desired display rate, comprising the steps of:

providing a computer including RAM, ROM and a processor;

the computer receiving an input video program in a first format having no added redundant frames or fields, and having a frame rate that is an integer multiple of 24 fps;

the computer determining if the input video program is in an interlaced format, the computer de-interlacing the input video program to generate a video program in a first progressive format comprising a sequence of progressive frames, each progressive frame being derived from a respective one, and only one, of the fields in the first format;

the computer removing or repeating some of the frames of the video program in the first progressive format to generate a program in an intermediate progressive format at a frame rate of at least 48 frames per second, if not already in that format; and

the computer outputting the program in the intermediate progressive format wherein the display rate is an integer multiple of substantially 24, 25, or 30 frames-per-second and is greater than or equal to 48 frames per second.

10. A method of processing an audio/video program to output a modified version of the program at a desired display rate, comprising the steps of:

providing a computer including RAM, ROM and a processor;

the computer receiving an input video program in a first format having no added redundant frames or fields, and having a frame rate that is an integer multiple of 25 fps;

the computer determining if the input video program is in an interlaced format, the computer de-interlacing the input video program to generate a video program in a first progressive format comprising a sequence of progressive frames, each progressive frame being derived from a respective one, and only one, of the fields in the first format;

the computer removing or repeating some of the frames of the video program in the first progressive format to generate a program in an intermediate progressive format at a frame rate of at least 50 frames per second, if not already in that format; and

the computer outputting the program in the intermediate progressive format wherein the display rate is an integer multiple of substantially 24, 25, or 30 frames-per-second and is greater than or equal to 48 frames per second.

11. The method of claim 1 further including the step of displaying the program on a display device following outputting of the program.

12. The method of claim 4 further including the step of displaying the program on a display device following outputting of the program.

13. The method of claim 9 further including the step of displaying the program on a display device following outputting of the program.

14. The method of claim 9 further including the step of displaying the program on a display device following outputting of the program.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,228,979 B2
APPLICATION NO. : 12/348804
DATED : July 24, 2012
INVENTOR(S) : Kinya Washino

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification:

At column 1, line number 32, After methods Insert -- , --

At column 4, line number 24, Delete “a” Insert -- an --

At column 5, line number 19, After sensitivity Insert -- (--

At column 5, line number 20, After f-8 Insert --) --

At column 5, line number 44, After preferably Delete “are”

At column 7, line number 48, After height Insert --) --

At column 8, line number 41, After MHZ Delete “)”

At column 9, line number 30, Delete “conversions” Insert -- conversion --

At column 10, line number 12, Delete “application” Insert -- applications --

At column 13, line number 45, Delete “upeonvertors” Insert -- upconverters --

At column 20, line number 25, Before be Insert -- may --

At column 21, line number 36, Delete “an” Insert -- a --

At column 22, line number 28, Delete “as” and Insert -- An --

Signed and Sealed this
Nineteenth Day of February, 2013



Teresa Stanek Rea
Acting Director of the United States Patent and Trademark Office

EXHIBIT 4

EXHIBIT 4



US008842727B2

(12) **United States Patent**
Washino

(10) **Patent No.:** **US 8,842,727 B2**
(45) **Date of Patent:** ***Sep. 23, 2014**

(54) **WIDE-BAND MULTI-FORMAT AUDIO/VIDEO PRODUCTION SYSTEM WITH FRAME-RATE CONVERSION**

G11B 27/031 (2006.01)
H04N 5/781 (2006.01)
H04N 5/46 (2006.01)

(75) Inventor: **Kinya Washino**, Dumont, NJ (US)

(52) **U.S. Cl.**

(73) Assignee: **Kinya Washino**, Dumont, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

CPC **H04N 5/91** (2013.01); *G11B 2220/2516* (2013.01); *G11B 2220/20* (2013.01); **H04N 5/222** (2013.01); *H04N 7/0122* (2013.01); **G11B 27/105** (2013.01); *H04N 5/772* (2013.01); *H04N 9/7925* (2013.01); **G11B 27/034** (2013.01); *H04N 5/85* (2013.01); **H04N 7/0125** (2013.01); *G11B 27/031* (2013.01); **H04N 7/011** (2013.01); *H04N 5/781* (2013.01); **H04N 9/7921** (2013.01); *G11B 2220/218* (2013.01); **H04N 7/0112** (2013.01); **H04N 7/01** (2013.01); **H04N 5/2228** (2013.01); *G11B 2220/2545* (2013.01); *H04N 5/46* (2013.01)

(21) Appl. No.: **13/547,150**

(22) Filed: **Jul. 12, 2012**

USPC **375/240.01**; 348/448

(65) **Prior Publication Data**

US 2013/0010188 A1 Jan. 10, 2013

(58) **Field of Classification Search**

Related U.S. Application Data

(63) Continuation of application No. 12/348,804, filed on Jan. 5, 2009, now Pat. No. 8,228,979, which is a continuation of application No. 10/117,496, filed on Apr. 5, 2002, now Pat. No. 7,474,696, which is a continuation of application No. 09/305,953, filed on May 6, 1999, now Pat. No. 6,370,198, which is a continuation-in-part of application No. 08/834,912, filed on Apr. 7, 1997, now Pat. No. 5,999,220.

CPC *G11B 2220/20*; *G11B 2220/218*; *G11B 2220/2516*; *G11B 2220/2545*; *G11B 27/031*; *G11B 27/034*; *G11B 27/105*; *H04N 5/222*; *H04N 5/2228*; *H04N 5/46*; *H04N 5/772*; *H04N 5/781*; *H04N 5/85*; *H04N 5/91*; *H04N 7/01*; *H04N 7/011*; *H04N 7/0112*; *H04N 7/0122*; *H04N 7/0125*; *H04N 9/7921*; *H04N 9/7925*
USPC 348/555, 556, 722, 441, 445, 448, 426, 348/452, 454, 558, 568, 446; 375/240.01-240.26

(60) Provisional application No. 60/084,522, filed on May 7, 1998.

(56)

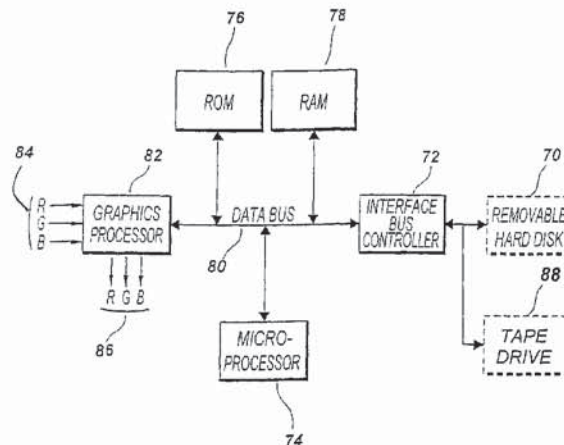
References Cited

(51) **Int. Cl.**

H04B 1/66 (2006.01)
H04N 5/222 (2006.01)
G11B 27/10 (2006.01)
G11B 27/034 (2006.01)
H04N 5/91 (2006.01)
H04N 7/01 (2006.01)
H04N 5/77 (2006.01)
H04N 9/79 (2006.01)
H04N 5/85 (2006.01)

U.S. PATENT DOCUMENTS

4,633,293 A 12/1986 Powers
5,045,932 A 9/1991 Sharman et al.
5,243,433 A 9/1993 Hailey et al.
5,327,235 A 7/1994 Richards et al.
5,331,346 A 7/1994 Shields et al.
5,384,598 A 1/1995 Rodriguez et al.
5,444,491 A 8/1995 Lim
5,519,438 A 5/1996 Elliott et al.
5,532,749 A 7/1996 Hong et al.
5,537,157 A 7/1996 Washino et al.
5,600,377 A 2/1997 David et al.



US 8,842,727 B2

Page 2

5,608,464	A	3/1997	Woodham et al.	
5,617,218	A	4/1997	Rhodes	
5,701,383	A	12/1997	Russo et al.	
5,706,290	A	1/1998	Shaw et al.	
5,724,101	A	3/1998	Haskin	
5,754,248	A	5/1998	Faroudja	
5,771,073	A	6/1998	Lim	
5,812,204	A	9/1998	Baker et al.	
5,832,085	A	11/1998	Inoue et al.	
5,835,150	A	11/1998	Choi et al.	
5,838,381	A	11/1998	Kasahara et al.	
5,999,220	A *	12/1999	Washino	348/441
6,356,945	B1	3/2002	Shaw et al.	
6,370,198	B1	4/2002	Washino	
6,542,198	B1	4/2003	Hung et al.	
6,656,945	B2	12/2003	Campbell et al.	
8,228,979	B2 *	7/2012	Washino	375/240.01
2002/0118296	A1 *	8/2002	Schwab et al.	348/441

FOREIGN PATENT DOCUMENTS

EP	314873	5/1989
EP	514012	11/1992
WO	9315586	8/1993

OTHER PUBLICATIONS

G Demos, "An Example of Hierarchy of Formats for HDTV," SMPTE Journal, Sep. 1992, pp. 609-617.
 J.S. Lim, "A Proposal for an HDTV/ATV Standard with Multiple Transmission Formats," SMPTE Journal, Aug. 1993, pp. 699-702.
 W.E. Brett, "3SNTSC-A 'Leapfrog' Production Standard for HDTV," SMPTE Journal, Mar. 1989, pp. 173-178.
 B. Hunt, G. Kennel, L. DeMarsh, S. Kristy, "High-Resolution Electronic Intermediate System for Motion-Picture Film," SMPTE Journal, Mar. 1991, pp. 156-161.
 A. Kaiser, H. Mahler, R. McMann, "Resolution Requirements for HDTV Based Upon the Performance of 35mm Motion-Picture Films for Theatrical Viewing," SMPTE Journal, Jun. 1985, pp. 654-659.

Y. Ide, M. Sasuga, N. Harada, T. Nishizawa, "A Three-CCD HDTV Color Camera," SMPTE Journal, Jul. 1990, pp. 532-537.
 G. Reitmeier, C. Carlson, E. Geiger, D. Westerkamp, "The Digital Hierarchy—A Blueprint for Television in the 21st Century," SMPTE Journal, Jul. 1992, pp. 466-470.
 L. Thorpe, T. Hanabusa, "If Progressive Scanning is So Good, How Bad is Interlace?," SMPTE Journal, Dec. 1990, p. 972-986.

* cited by examiner

Primary Examiner — Behrooz Senfi
 (74) *Attorney, Agent, or Firm* — Law Office of R. Alan Burnett, PS; R. Alan Burnett

(57) **ABSTRACT**

A system for processing an audio/video program to output at a desired display rate includes a computer including RAM, ROM and a processor. The system has an input receiving an input video program in a first interlaced format. The computer has hardware or software functioning to: storing the input program, at least temporarily, in the first format; de-interlacing the input video program to generate a video program in a first progressive format having progressive frames, each progressive frame being derived from a respective one, and only one, of the fields in the first interlaced format; removing or repeating some of the frames of the video program in the first progressive format generating a program in a second progressive format; outputting the program in the second progressive format, wherein the display rate of the program is at least 48 frames-per-second.

28 Claims, 14 Drawing Sheets

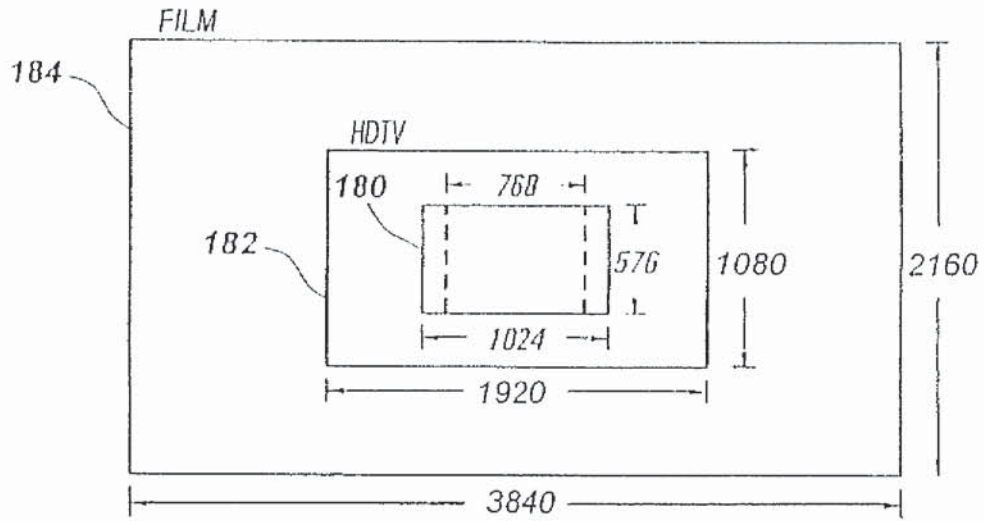


Figure 1a

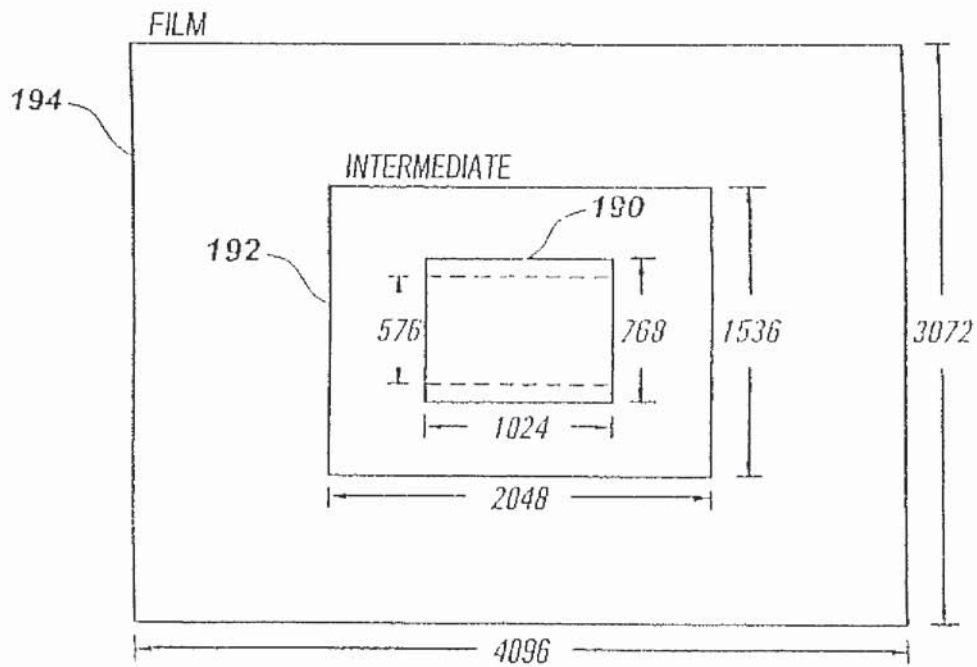


Figure 1b

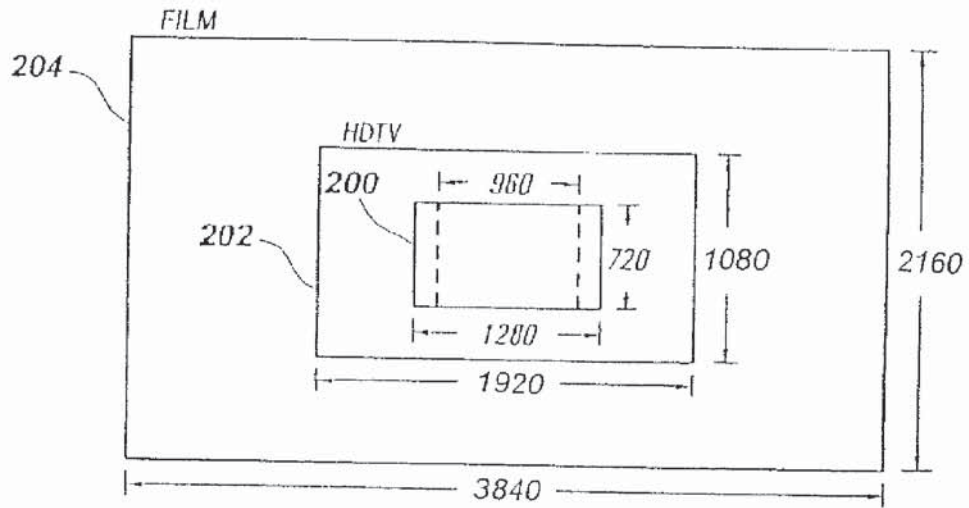


Figure 1c

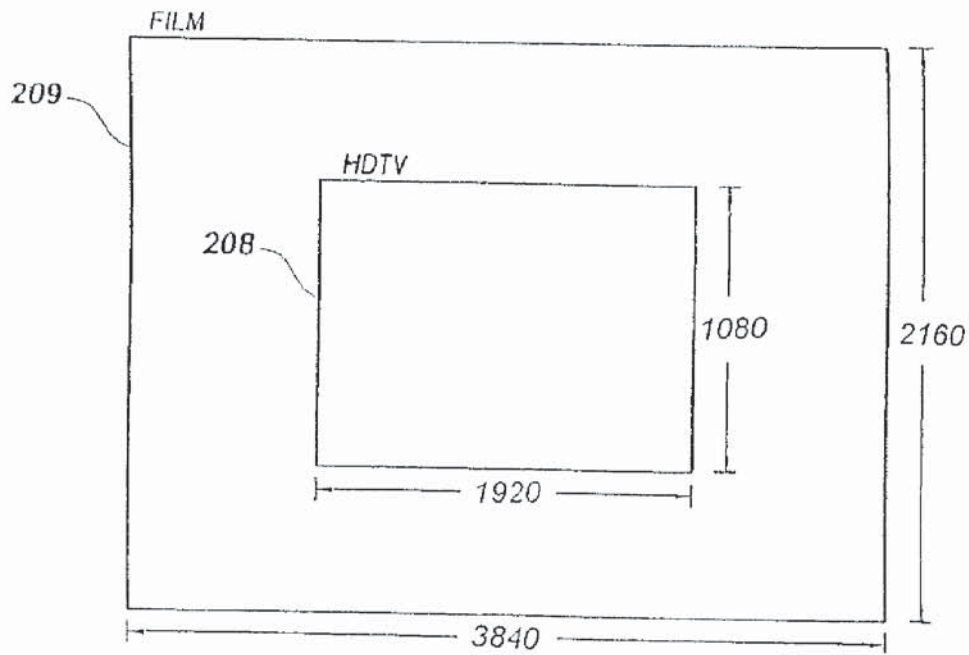


Figure 1d

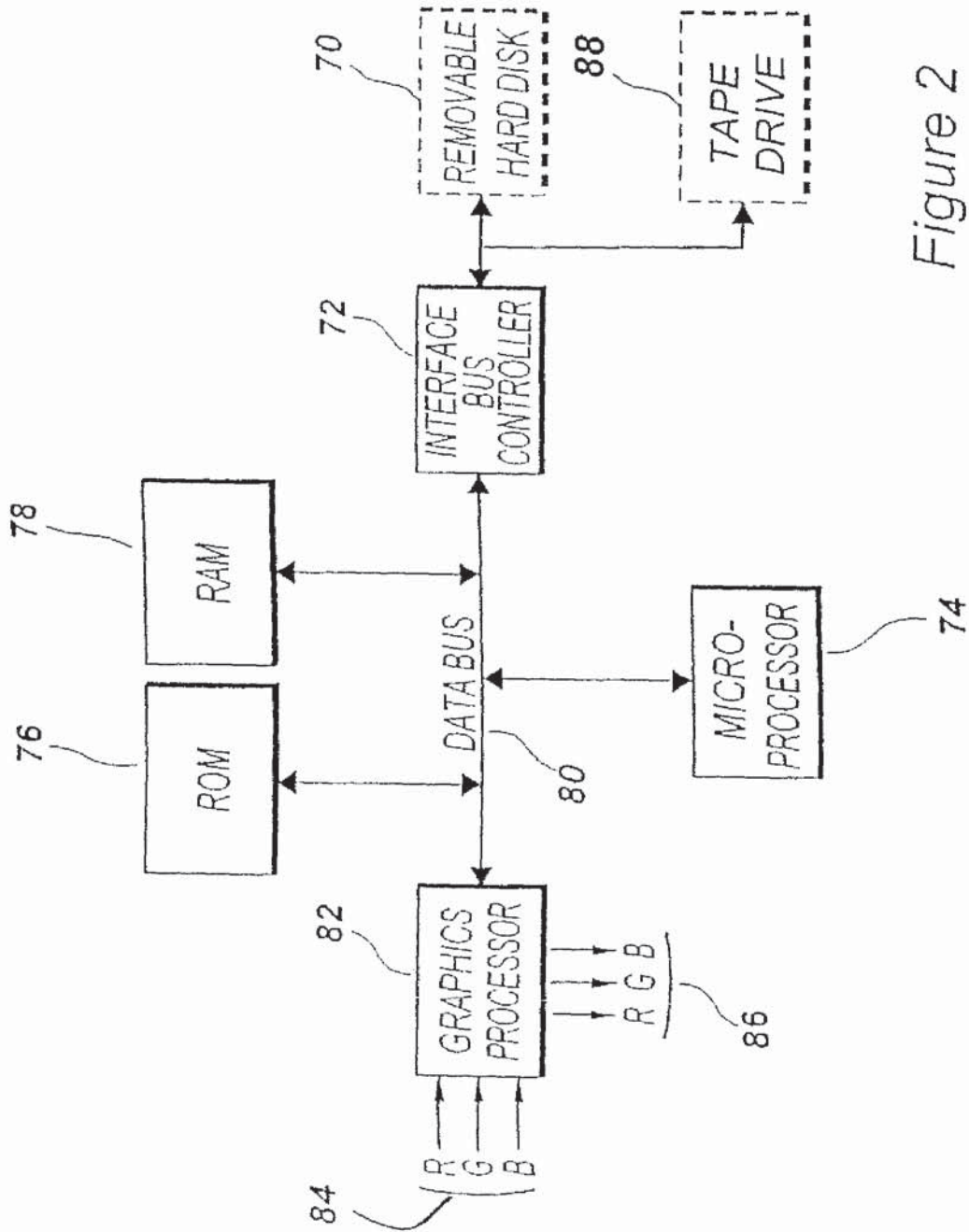


Figure 2

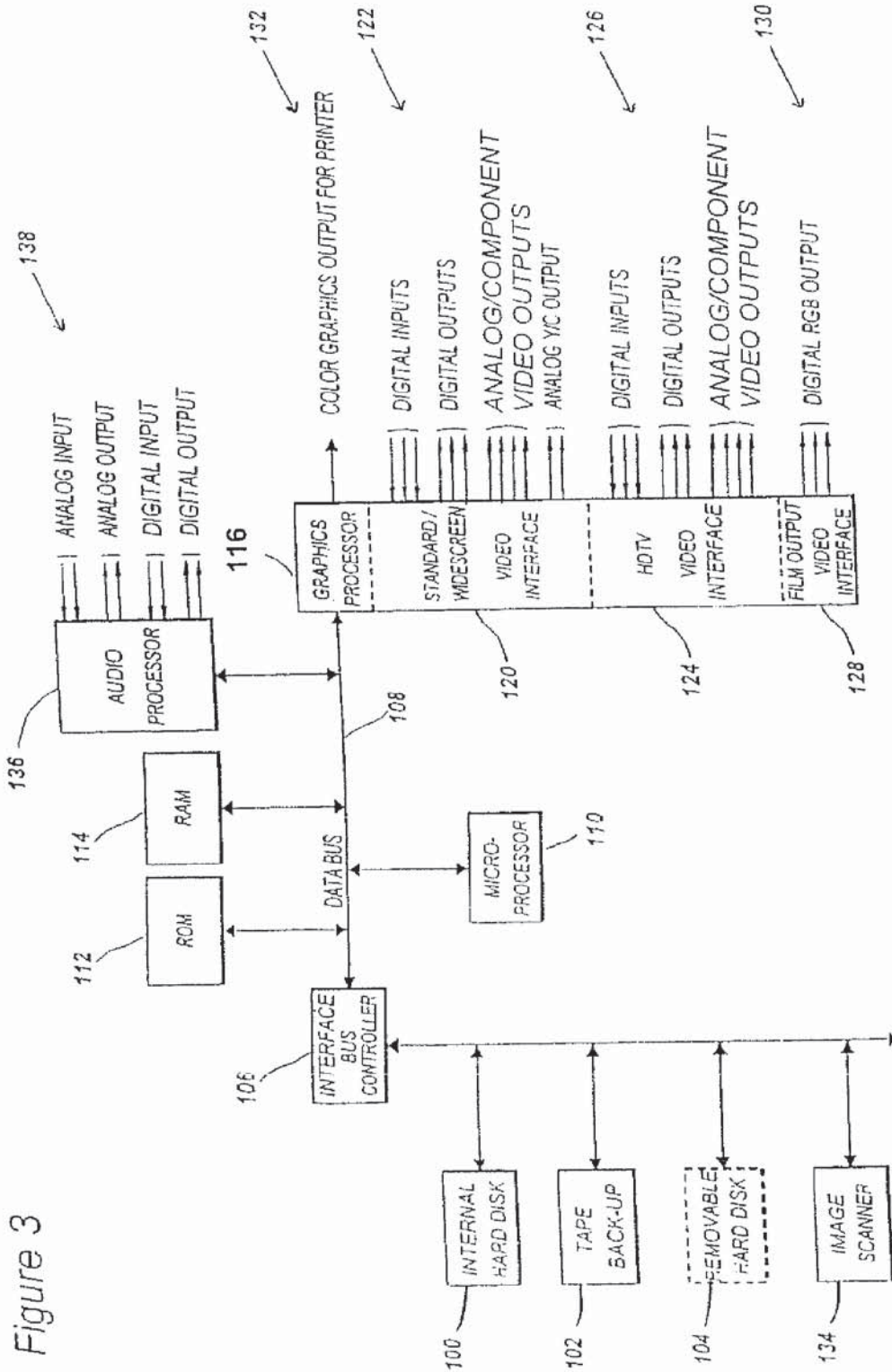


Figure 3

Figure 4

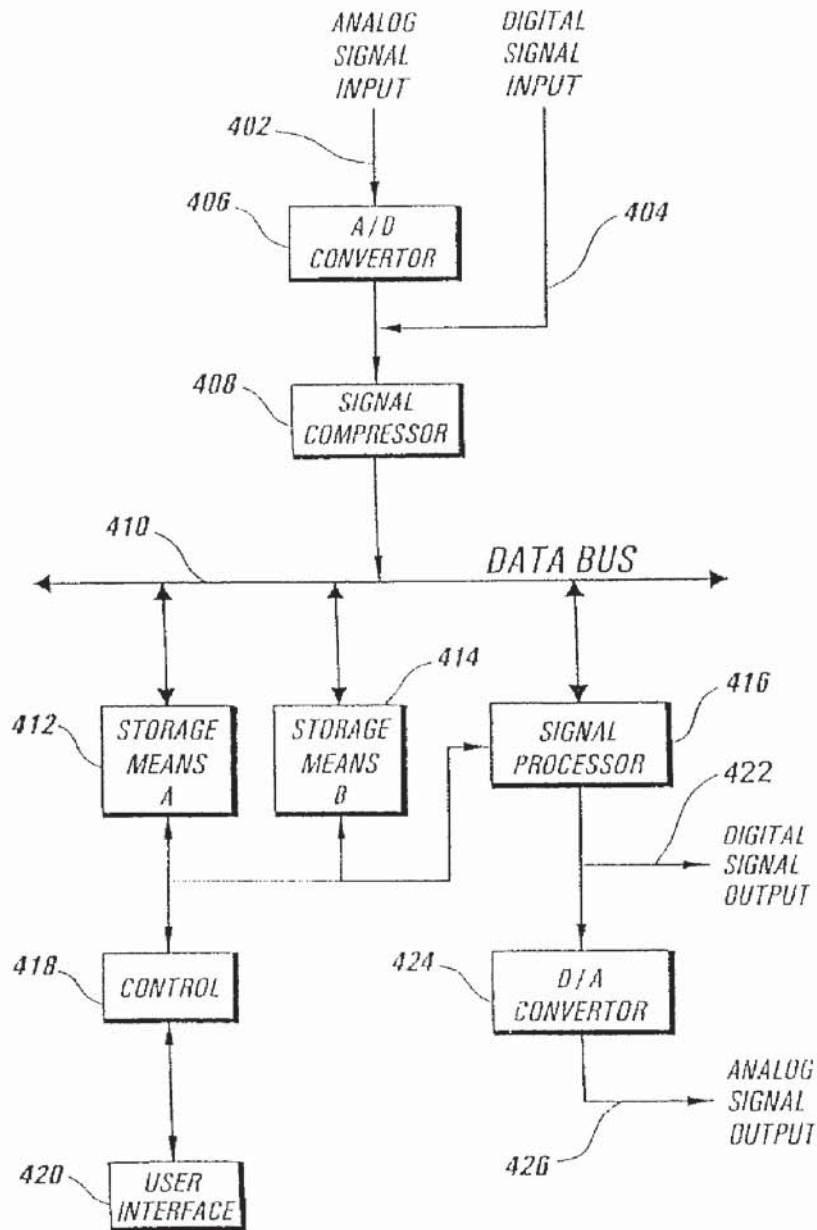


Figure 5

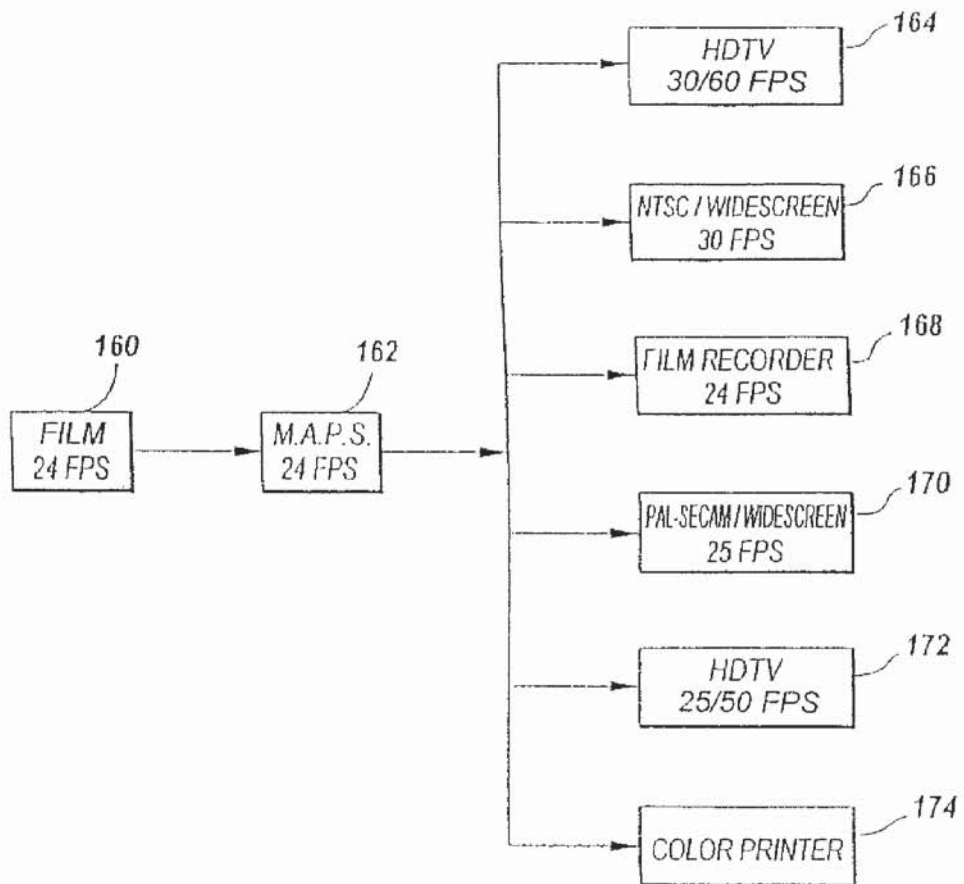


Figure 6

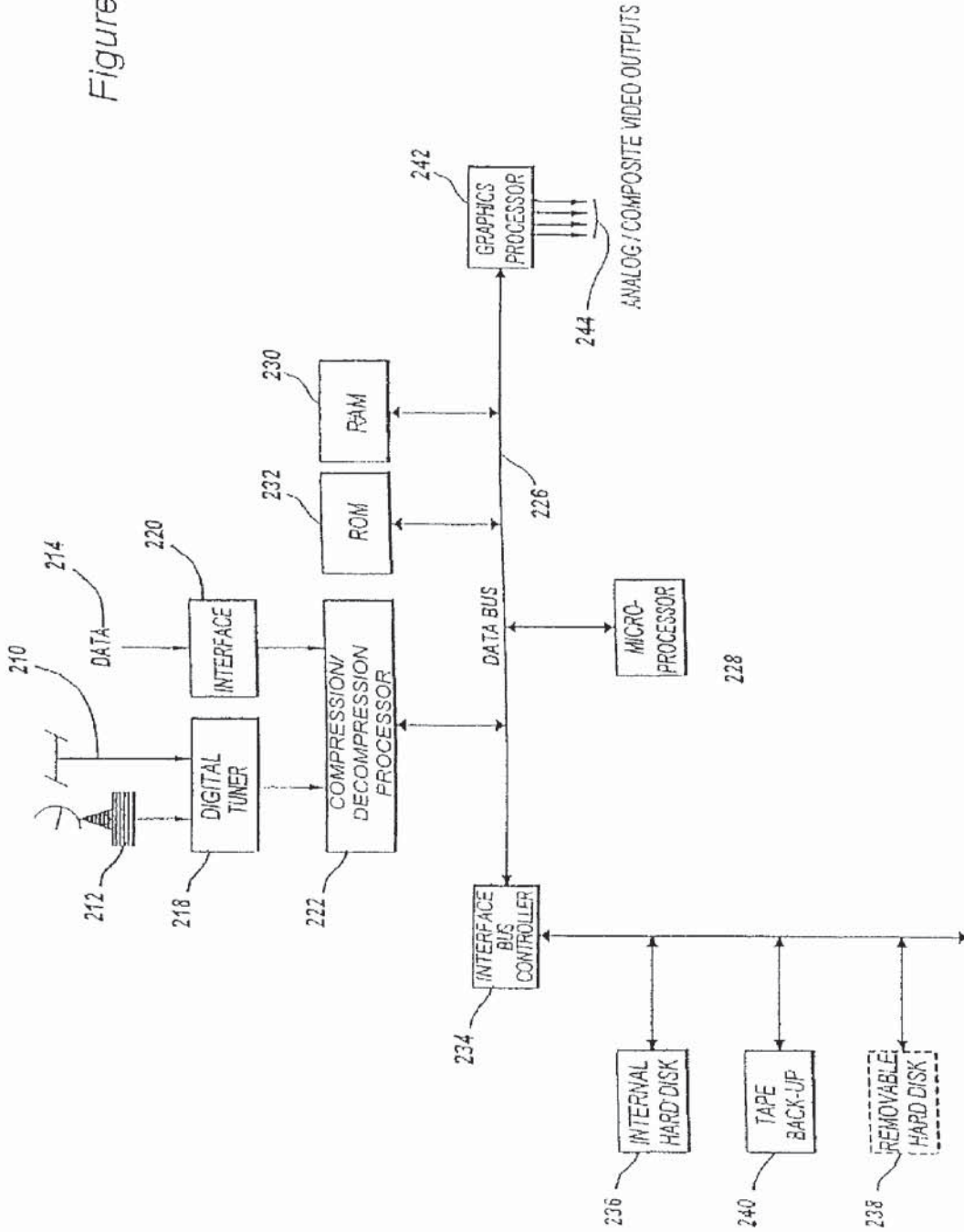


FIGURE 7A

Output Source	24 fps Interlace (24fps I)	24fps Progress. (24fps P)	25fps Interlace (25fps I)	25fps Progress. (25fps P)	30fps Interlace (30fps I)	30fps Progress. (30fps P)	48fps Progress. (48fps P)	50fps Progress. (50fps P)	60fps Progress. (60fps P)	96fps Progress. (96fps P)
24fps Interlace (24fps I)	—	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (1)	2:1 Frame Reduction From 50fps P (3)	Interlace & discard From 60fps P (3)	2:1 Frame Reduction From 60fps P (3)	De-Interlace From 24fps I (1)	De-Interlace From 25fps I (2)	4 th Frame Repeat From 48fps P (2)	Repeat From 48fps P (2)
24fps Progress. (24fps P)	Interlace From 24fps P (1)	—	Speed-up From 24fps I (2)	Speed-up From 24fps P (1)	3:2 Pull-down From 24fps I (2)	2:1 Frame Reduction From 60fps P (2)	Repeat From 24fps P (1)	Repeat From 25fps P (2)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (2)
25fps Interlace (25fps I)	Slow-Down From 25fps I (1)	2:1 Frame Reduction From 48fps P (3)	—	2:1 Frame Reduction From 50fps P (2)	Interlace & discard From 60fps P (4)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (2)	De-Interlace From 25fps I (1)	4 th Frame Repeat From 48fps P (3)	Repeat From 48fps P (3)
25fps Progress. (25fps P)	Interlace From 24fps P (2)	Slow-down From 25fps P (1)	Interlace From 25fps P (1)	—	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (4)	De-Interlace From 24fps I (3)	Repeat From 25fps P (1)	3:2 Frame Repeat From 24fps P (2)	Repeat From 48fps P (3)
30fps Interlace (30fps I)	5 th Fr. red., Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 48fps P (3)	6 th Fr. red. Interlace & Disc. Frm. 60fps P (2)	2:1 Frame Reduction From 50fps P (3)	—	2:1 Frame Reduction From 60fps P (2)	De-Interlace From 24fps I (3)	De-Interlace From 25fps I (3)	De-Interlace From 30fps I (1)	Repeat From 48fps P (3)

FIGURE 7A (CONT'D)

30fps Progress. (30fps P)	5 th Fr. red., Interlace & Disc. Frm. From 60fps P (2)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. From 60fps P (2)	2:1 Frame Reduction From 50fps P (4)	Interlace From 30fps P (1)	—	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (3)	Repeat From 30fps P (1)	Repeat From 48fps P (4)
48fps Progress. (48fps P)	Interlace From 24fps P (2)	2:1 Frame Reduction From 48fps P (1)	Interlace From 25fps P (3)	Speed-up From 24fps P (2)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (2)	—	De- Interlace From 25fps I (4)	De- Interlace From 30fps I (4)	Repeat From 48fps P (1)
50fps Progress. (50fps P)	Interlace From 24fps P (3)	Slow-down From 25fps P (2)	Interlace & discard From 50fps P (1)	2:1 Frame Reduction From 50fps P (1)	3:2 Pull-down From 24fps I (3)	2:1 Frame Reduction From 60fps P (3)	De- Interlace From 24fps I (4)	—	3:2 Frame Repeat From 24fps P (3)	Repeat From 48fps P (2)
60fps Progress. (60fps P)	5 th Fr. red., Interlace & Disc. Frm. From 60fps P (1)	2:1 Frame Reduction From 48fps P (4)	6 th Fr. red. Interlace & Disc. Frm. From 60fps P (1)	2:1 Frame Reduction From 50fps P (4)	Interlace & discard From 60fps P (1)	2:1 Frame Reduction From 60fps P (1)	De- Interlace From 24fps I (3)	De- Interlace From 25fps I (2)	—	Repeat From 48fps P (4)
96fps Progress. (96fps P)	Interlace From 24fps P (3)	2:1 Frame Reduction From 48fps P (2)	Speed-up From 24fps I (4)	Speed-up From 24fps P (3)	3:2 Pull-Down From 24fps I (4)	2:1 Frame Reduction From 60fps P (3)	2:1 Frame Reduction From 96fps P (1)	De- Interlace From 25fps I (5)	4 th Frame Repeat From 48fps P (2)	—

Figure 7c 3 : 2 Pull-Down
(24 fps P to 30 fps I)

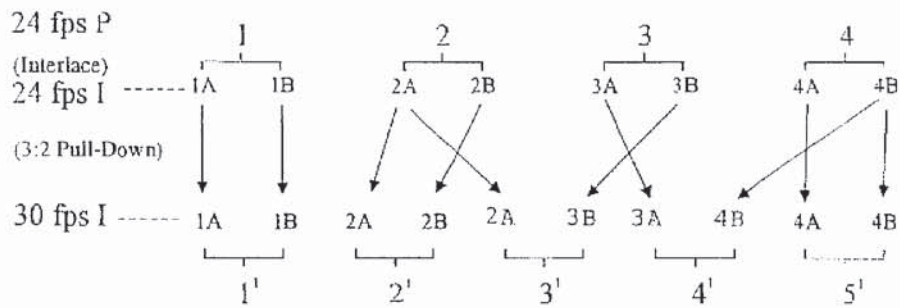


Figure 7e 4th & 7th Field Repeat plus Re-Interlace
(24 fps I to 30 fps I)

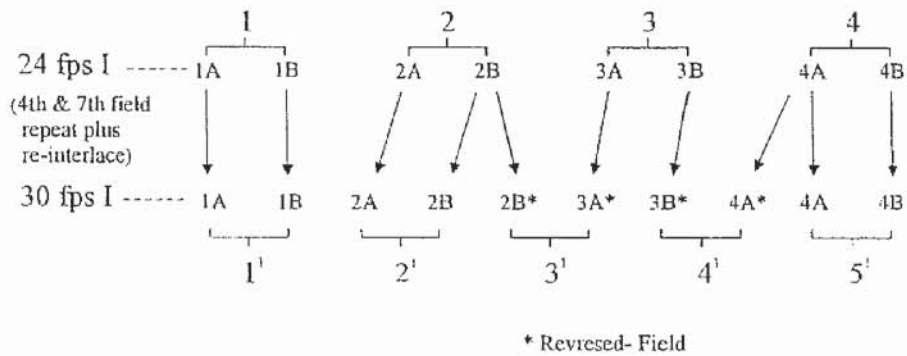


Figure 7g 3 : 2 Frame Repeat (24 fps P to 60fps P)

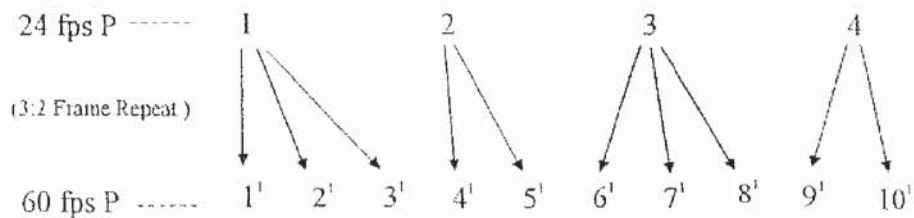


Figure 7d 25 fps Interlace to 30 fps Interlace Conversion
(from PAL CCD camera source to NTSC out)

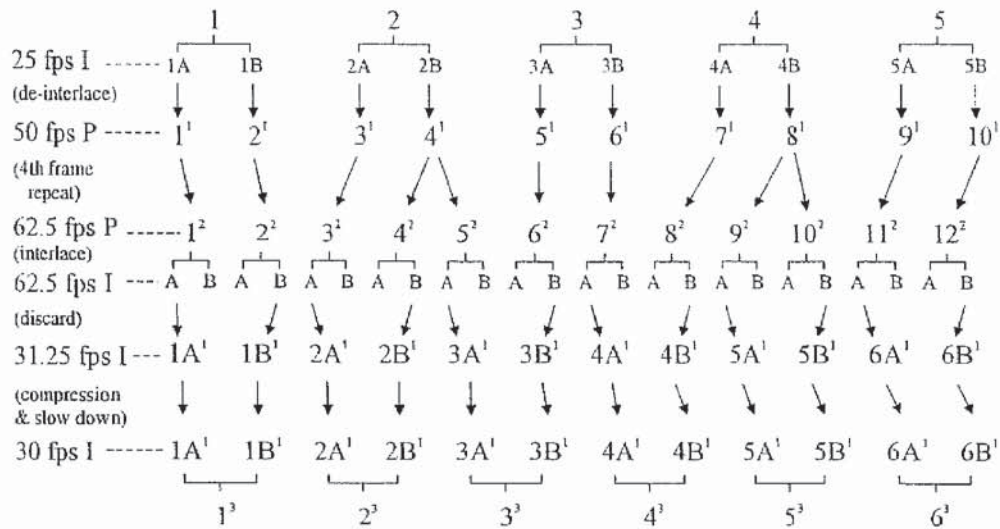


Figure 7f 4th Frame Repeat (24fps I to 30fps I)

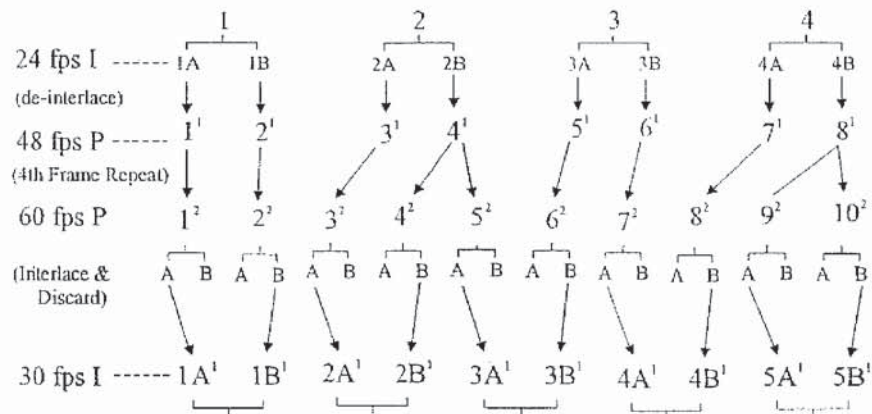


Figure 7h 6th Frame Reduction (30fps I to 25fps I)

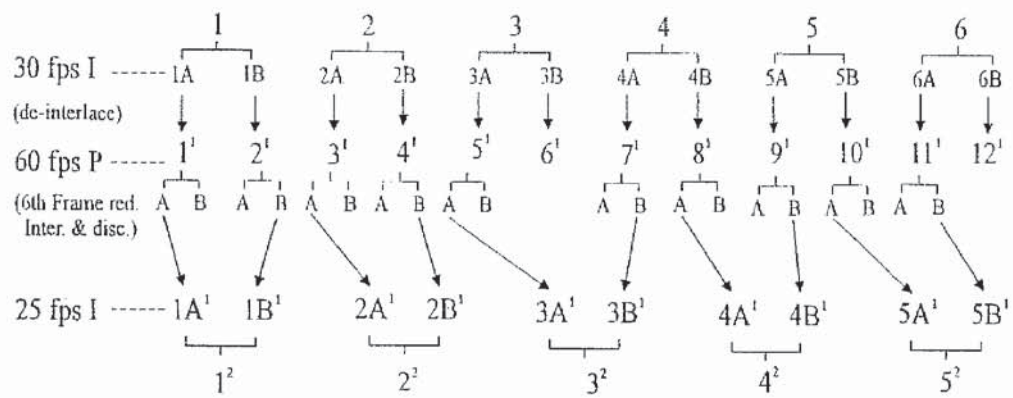
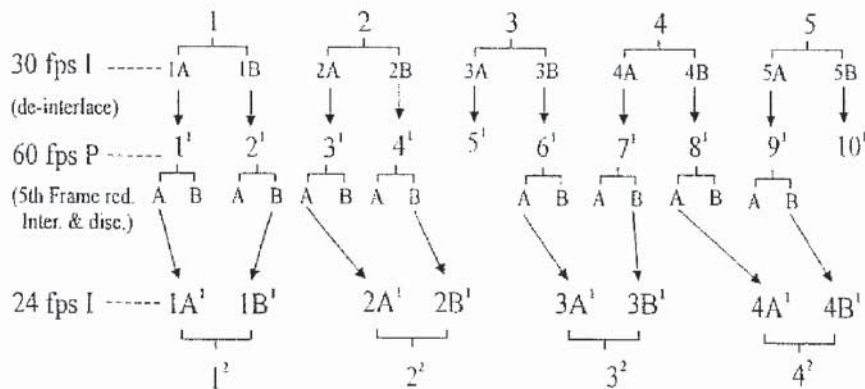


Figure 7i 5th Frame Reduction (30fps I to 24fps I)



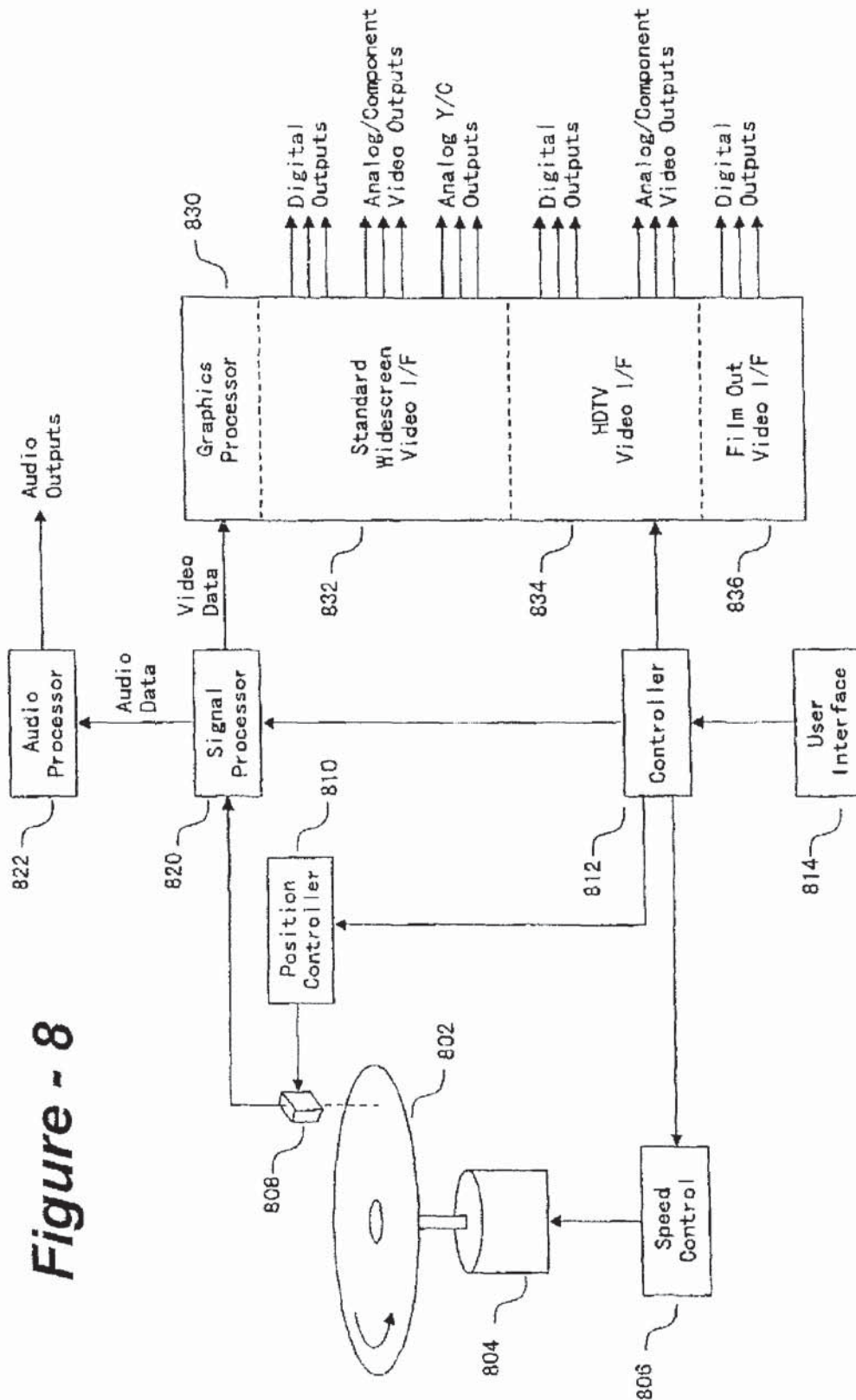


Figure - 8

US 8,842,727 B2

1

**WIDE-BAND MULTI-FORMAT AUDIO/VIDEO
PRODUCTION SYSTEM WITH FRAME-RATE
CONVERSION**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/348,804, filed Jan. 5, 2009 which application is a continuation of U.S. patent application Ser. No. 10/117,496 filed Apr. 5, 2002; which is a continuation of U.S. patent application Ser. No. 09/305,953 filed May 6, 1999, now U.S. Pat. No. 6,370,198; which is a continuation-in-part of U.S. patent application Ser. No. 08/834,912, filed Apr. 7, 1997, now U.S. Pat. No. 5,999,220; and also claims priority of U.S. Provisional Patent Application Ser. No. 60/084,522, filed May 7, 1998. All of these prior applications are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

This invention relates generally to video production, photographic image processing, and computer graphics, and, more particularly, to a multi-format digital video production system capable of maintaining the full bandwidth resolution of the subject material, while providing professional quality editing and manipulation of images intended for digital television and other applications, including digital HDTV programs.

BACKGROUND OF THE INVENTION

As the number of television channels available through various program delivery methods digital TV (DTV) broadcasting, cable TV, home video, broadcast, etc. continues to proliferate, the demand for programming, particularly high-quality HDTV-format programming, presents special challenges, both technical and financial, to program producers. While the price of professional editing and image manipulation equipment continues to increase, due to the high cost of research and development and other factors, general-purpose hardware, including personal computers, can produce remarkable effects at a cost well within the reach of non-professionals, even novices. As a result, the distinction between these two classifications of equipment has become less well defined. Although general-purpose PC-based equipment may never allow professional-style rendering of images at full resolution in real-time, each new generation of micro-processors enables progressively faster, higher-resolution applications. In addition, as the price of memory circuits and other data storage hardware continues to fall, the capacity of such devices has risen dramatically, thereby improving the prospects for enhancing PC-based image manipulation systems for such applications.

In terms of dedicated equipment, attention has traditionally focused on the development of two kinds of professional image-manipulation systems: those intended for the highest quality levels to support film effects, and those intended for television broadcast to provide "full 35 mm theatrical film quality," within the realities and economics of present broadcasting systems. Conventional thinking holds that 35 mm theatrical film quality as projected in theaters is equivalent to 1200 or more lines of resolution, whereas camera negatives provide 2500 or more lines. As a result, image formats under consideration have been directed towards video systems having 2500 or more scan lines for high-level production, with hierarchies of production, HDTV broadcast, and NTSC and

2

PAL compatible standards which are derived by down-converting these formats. Most proposals employ progressive scanning, although interlace is considered an acceptable alternative as part of an evolutionary process. Another important issue is adaptability to computer-graphics-compatible formats.

Current technology directions in computers and image processing should allow production equipment based upon fewer than 12200 scan lines, with picture expansions to create a hierarchy of upward-converted formats for theatrical projection, film effects, and film recording. In addition, general-purpose hardware enhancements should be capable of addressing the economic aspects of production, a subject not considered in detail by any of the available references.

For the first fifty years of television in the United States, the history shows continuous development and improvement of a purely analog-based system for video production broadcasting. The nature of the NTSC system is to limit the video bandwidth to 4.2 MHz, which corresponds to approximately 340 TV-lines of resolution. In countries where PAL or SECAM systems are employed, the bandwidth is 5.5 MHz, which corresponds to approximately 440 TV-lines of resolution.

During the past ten years, digital processing has become the standard for video production equipment. However, to preserve compatibility with existing equipment and standards, the video bandwidth typically has been limited to 4-6 MHz (for NTSC and PAL applications, respectively). This also has tended to reduce the apparent generation loss during video production steps.

In the past five years or so, digital image compression technology has matured greatly. Furthermore, there are many incompatible standards, such as the different forms of JPEG systems, the-Quick-Time system, MPEG-1, and the numerous forms of the MPEG-2 standard. In addition, the latest recording formats for video production have introduced a new set of variations, including the 1/4-inch DVC-formats from Sony and Matsushita. While the signal deterioration characteristics of multi-generation analog-based production systems are well known, those imperfections resulting from diverse-format digital video compression and the conversions between these formats can be just as troublesome and unpredictable. In practice, these repeated steps of analog-to-digital (A/D) conversion and digital-to-analog (D/A) conversion, as well as data compression and decompression, introduce many signal artifacts and various forms of signal noise. Although digital video production promises multiple-step production processes free of generation losses, the reality is different, due to the repeated steps of A/D and D/A conversions, as well as data compression and decompression, present when utilizing the various incompatible image data compression formats.

Meanwhile, during the last twenty years, camera technology has advanced to a point far surpassing the performance of traditional production equipment. The video bandwidth capability has increased from 4.2 MHz (corresponding to 340 TV-lines of resolution) to approximately 12 MHz (corresponding to nearly 1000 TV-lines of resolution). Because of the limitations of conventional broadcast and production equipment, most of the detail information produced by today's high-performance camera systems is lost.

For HDTV systems, one goal is to produce images having approximately 1000 TV-lines of resolution per picture height, which requires a bandwidth of approximately 30 MHz. This, in turn, raises a new problem in terms of signal-to-noise ratio. While conventional broadcast cameras can produce signals having a S/N ratio of 65 dB, utilizing 10-bit digital processing, HDTV cameras typically produce signals having a S/N

ratio of 54 dB, and utilize only 8-bit digital processing. In addition, the typical HDTV camera utilizes a 2 Megapixel CCD, in which the elements are approximately one-quarter the size of conventional broadcast cameras. This translates into a much lower sensitivity (a loss corresponding to 1-2 f-stops), higher levels of "smearing", and lower highlight compression ratios.

Analog-based HDTV systems, such as the Japanese MUSE system, do not approach the design goal of 1000 TV-lines. In reality, only one quarter of the picture information is transmitted. Although the nominal reduced luminance bandwidth of 20 MHz provides approximately 600 TV-lines of resolution per picture height in static program material, this resolution is drastically reduced to only 450 TV-lines where motion is occurring. The chrominance bandwidth is even further reduced by the sub-sampling scheme, to 280 TV-lines for the I-signal and 190 TV-lines for the Q-signal (in static scenes), and to 140 TV-lines for the I-signal and 50 TV-lines for the Q-signal (in moving scenes). Although this system provides a wide-screen aspect ratio of 16:9, it does not really qualify as a High-Definition Television System.

Because of the aforementioned compatibility issues, it is clear that conventional video recorders cannot match the technical performance of modern camera systems. Although "D-6 format" digital recorders are available, the cost and complexity of such equipment place these units beyond the means of the vast majority of broadcast stations. Furthermore, the capability of conventional switchers and other production equipment still fail to match that of available camera systems.

Other recorders have been produced, such as the one-half-inch portable recorder ("Uni-HI"), but this system only achieves 42 dB signal-to-noise ratio, and records in the analog domain. These specifications render this unit unsuitable for multi-generation editing applications. Furthermore, the luminance bandwidth is only 20 MHz, corresponding to approximately 600 TV-lines of resolution.

W-VHS ("Wideband-VHS") recorders provide a wide aspect-ratio image, but only 300 TV-lines of resolution, which also renders this unit unsuitable for any professional applications. Other distribution formats (such as D-VHS) require the application of high compression ratios to limit the data-rate to be recorded, so these formats only achieve W-VHS quality (less than 400 TV-lines of resolution).

The newly-introduced HD Digital Betacam format (HD-CAM) video recorder utilizes a 3:1:1 digital processing system rather than the 4:2:2 processing. However, it has a 24 MHz luminance bandwidth corresponding to 700 TV-lines of resolution, and a narrower chrominance bandwidth. Although this system is clearly superior to any existing analog HDTV recording system, it still falls short of delivering the full resolution produced by an HDTV digital camera. Because of its proprietary image data compression format, the production process results in repeated data compression and decompression steps, as well as A/D and D/A conversions, which, in turn, results in many signal artifacts and various forms of signal noise.

In summary, the conventional technology for these markets utilizes professional cameras having a 30 MHz bandwidth, and capable of 1000 TV-lines of resolution. However, they produce quality levels more characteristic of consumer-grade equipment (in terms of resolution and signal-to-noise ratio). In addition, the price of these systems is cost-prohibitive both on an absolute and also a cost/benefit basis, employing digital systems which produce only analog-type performance.

SUMMARY OF THE INVENTION

The present invention takes advantage of available general-purpose technology, where possible, in order to provide an

economical multi-format digital video production system. In the preferred embodiment, specialized graphics processing capabilities are included in a high-performance personal computer or workstation, enabling the user to edit and manipulate an input video program and produce an output version of the program in a final format which may have a different frame rate, pixel dimensions, or both. An internal production format is chosen which provides the greatest compatibility with existing and planned formats associated with HDTV standard 4:3 or widescreen 16:9 high-definition television, and film. For compatibility with film, the frame rate of the internal production format preferably is 24 fps (for program materials originated in film format) and 48 fields-per-second (for live program materials such as sporting events). Images are re-sized horizontally and vertically by pixel interpolation, thereby producing larger or smaller image dimensions so as to fill the particular needs of individual applications. Frame rates are adapted by inter-frame interpolation or by traditional schemes, including "3:2 pull-down" for 24-to-30 fps conversions. Simple speed-up (for 24-to-25 conversions) or slow-down (for 25-to-24 conversions) for playback, or by manipulating the frame rate itself using a program storage facility with asynchronous reading and writing capabilities. The step of converting the signal to a HDTV format is performed by a modified upconversion process for wideband signals (utilizing a higher sampling clock frequency) and a resizing to HDTV format frame dimensions in pixels.

The invention preferably incorporates one or more interface units, including a standard/widescreen interface unit operative to convert the video program in the input format into an output signal representative of a standard/widescreen formatted image, and output the signal to an attached display device. A high-definition television interface unit is operative to convert the video program in the input format into an output signal representative of an HDTV-formatted image, and output the signal to the display device. A centralized controller in operative communication with the video program input, the graphics processor, and an operator interface, enables commands entered by an operator to cause the graphics processor to perform one or more of the conversions using the television interfaces. The present invention thus encourages production at relatively low pixel dimensions to make use of lower-cost general-purpose technology and to maintain high signal-to-noise ratio, and then subsequently expands the resultant image into a so-called up-converted program. This is in contrast to alternative approaches, which recommend operating at HDTV-type resolution, then down-converting, as necessary, to smaller image formats. This has led to the use of expensive dedicated hardware, the need for which the present invention seeks to eliminate. In addition, the flexible storage and playback facilities allow extensive control of the playback of the program material, enabling frame rate adjustments and alterations, and providing for time-shifting of the start and end points of the program reproduction in those cases wherein direct control of the source material frame rate is not practical, due to physical separation of the equipment or multiple reception points simultaneously producing outputs at different frame rates from the same source signal playback data stream. In commercial implementations, the invention readily accepts and processes enhanced information, such as pan/scan information or identification information to restrict viewing based on regional or geographical marketing plans.

The method and associated technology provide for maintaining the original high bandwidth of conventional cameras (up to 15 MHz, which corresponds to more than 600 TV-lines of resolution-per picture height for 16:9 aspect ratio) and provide optimized compression techniques to fully utilize the

US 8,842,727 B2

5

available capacity of general storage media, such as the commercially available Panasonic DVCPRO, DVCPRO50, Sony DVCAM, JVC Digital-S, and Sony Betacam SX recorders. The system preferably employs a consistent compression scheme, utilizing only intra-frame compression (such as Motion-JPEG-type systems, systems used in DV-format recorders, MPEG-2 4:2:2P@ML) throughout the entire production process. This avoids many signal artifacts, ensures high signal-to-noise ratios, and provides for editing the program material in data-compressed format. This enables the system to preserve the original camera capability of 600+ TV-lines of resolution per picture height, and with 4:2:2 processing provides a chrominance bandwidth of up to 7.5 MHz. Utilizing 10-bit processing results in 65 dB signal-to-noise performance and improved camera sensitivity (rating of f-11). In contrast, available and proposed systems for HDTV are based on 8-bit processing, and offer performance of less than 54 dB signal-to-noise ratio and camera sensitivity rating of only f-8.

The invention provides for optimization of the available storage media as well. Utilizing hard-disks, optical discs (such as DVD, DVD-R, and DVD-RAM), magneto-optical discs, or digital tapes (such as DAT-format, DVC, DVCPRO, DVCPRO50, DVCAM, Digital-S, or 8-mm format) the data-rate to be recorded is nearly one-quarter-that of conventional HDTV systems, and consumes only 20 GB of storage space to record more than 60 minutes in the Production Format compression scheme, which utilizes a data-rate of 50 Mb per second or less, which is well within the capabilities of certain conventional recording devices. Horizontal and vertical pixel-interpolation techniques are utilized to quadruple the image size, preferably resulting in an image frame size of 1920x1080 pixels. The resulting program information may then be distributed in a conventional compression format, such as MPEG-2.

Three alternative image frame sizes preferably are suggested, depending on the intended application. For general usage, an image frame size of 1024x576 is recommended. As an option, a frame size of either 1280x720 or 1920x1080 may be utilized, at 24 frames-per-second. A sampling frequency of up to 74.25 MHz for luminance is utilized for 1920x1080. Sampling frequencies of up to 37 MHz are preferably are utilized for 1024x576 and 1280x720. Chrominance components preferably are sampled consistent with a 4:2:2 system, and 10-bit precision is preferred.

The technology of display devices and methodology has progressed as well, offering alternative features such as conversion of interlaced signals to progressive scan, line doubling, pixel quadrupling, and improved general techniques for horizontal and vertical pixel interpolation. Availability of these features as part of display devices will simplify the process of implementing multi-format digital production.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D show the preferred and alternative image aspect ratios in pixels;

FIG. 2 shows a functional diagram for disk/tape-based video recording;

FIG. 3 shows the components comprising the multi-format audio/video production system;

FIG. 4 is a block diagram of an alternative embodiment of video program storage means incorporating asynchronous reading and writing capabilities to carry out frame-rate conversions;

6

FIG. 5 shows the inter-relationship of the multi-format audio/video production system to many of the various existing and planned video formats;

FIG. 6 shows the implementation of a complete television production system, including signals provided by broadcast sources, satellite receivers, and data-network interfaces;

FIGS. 7A-7B show the preferred methods for conversion between several of the most common frame-rate choices;

FIGS. 7C-7I show details of possible methods for frame rate conversion processes; and

FIG. 8 shows a block diagram of an embodiment of a universal playback device for multi-format use.

DETAILED DESCRIPTION OF THE INVENTION

The present invention resides in the conversion of disparate graphics or television formats, including requisite frame-rate conversions, to establish an inter-related family of aspect ratios, resolutions, and frame rates, while remaining compatible with available and future graphics/TV formats, including images of pixel dimensions capable of being displayed on currently available multi-scan computer monitors. Custom hardware is also disclosed whereby frames of higher pixel-count beyond the capabilities of these monitors may be viewed. Images are re-sized by the system to larger or smaller dimensions so as to fill the particular needs of individual applications, and frame rates are adapted by inter-frame interpolation or by traditional schemes such as using "3:2 pull-down" (such as 24 frame-per-second (fps) Progressive to 30 fps interlace shown in FIG. 7C or 48 fps Progressive to 60 fps Progressive, as would be utilized for film-to-NTSC conversions) or by speeding up the frame rate itself (such as for 24 to 25 fps for PAL television display). The re-sizing operations may involve preservation of the image aspect ratio, or may change the aspect ratio by "cropping" certain areas, by performing non-linear transformations, such as "squeezing" the picture, or by changing the vision center for "panning," "scanning" and so forth. Inasmuch as film is often referred to as "the universal format," (primarily because 35-mm film equipment is standardized and used throughout the world), the preferred internal or "production" frame rate is preferably 24 fps. This selection also has an additional benefit, in that the 24 fps rate allows the implementation of cameras having greater sensitivity than at 30 fps, which is even more critical in systems using progressive scanning (for which the rate will be 48 fields per second interlaced (or 24 fps Progressive) vs. 60 fields per second interlaced in some other proposed systems).

The image dimensions chosen allow the use of conventional CCD-type cameras, but the use of digital processing directly through the entire signal chain is preferred, and this is implemented by replacing the typical analog RGB processing circuitry with fully digital circuitry. Production effects may be conducted in whatever image size is appropriate, and then re-sized for recording. Images are recorded by writing the digital data to storage devices employing internal or removable hard-disk drives, disk drives with removable media, optical or magneto-optical based drives, DVD-R or DVD-RAM type drives, tape-based drives, or semiconductor-based memory devices, preferably in compressed-data form.

As data rates for image processing and reading from, or writing to, disk drives increase, many processes that currently require several seconds will soon become attainable in real-time. This will eliminate the need to record film or video frames at slower rates. Other production effects, such as slow-motion or fast-motion may be incorporated, and it is only the frame-processing-rate of these effects that is limited in any way by the technology of the day. In particular, techniques

US 8,842,727 B2

7

such as non-linear-editing, animation, and special-effects will benefit from the implementation of this system. In terms of audio, the data rate requirements are largely a function of sound quality. The audio signals may be handled separately, as in an "interlocked" or synchronized system for production, or the audio data may be interleaved within the video data stream. The method selected will depend on the type of production manipulations desired, and by the limitations of the current technology.

Although a wide variety of video formats and apparatus configurations are applicable to the present invention, the system will be described in terms of the alternatives most compatible with currently available equipment and methods. FIG. 1A illustrates one example of a compatible system of image sizes and pixel dimensions. The selected frame rate is preferably 24 per second progressive (for compatibility with film elements), or 48 fields per second interlaced (for live program material such as sporting events). The selected picture dimension in pixels is preferably 1024×576 (0.5625 Mpxl), for compatibility with the Standard Definition TV (SDTV) 16:9 "wide-screen" aspect ratio anticipated for HDTV systems, and the conventional 4:3 aspect ratio used for PAL systems [768×576 (0.421875 Mpxl)] or NTSC systems [640×480 (0.3072 Mpxl)]. All implementations preferably rely on square pixels, though other pixel shapes may be used. Re-sizing (using the well known, sophisticated sampling techniques available in many image-manipulation software packages or, alternatively, using horizontal and vertical pixel interpolation hardware circuitry described herein below) either to 1280×720 (0.922 Mpxl) or else to 1920×1080 (2.14 Mpxl) provides an image suitable for HDTV displays or even theatrical projection systems, and a further re-sizing to 3840×2160 (8.3 Mpxl) is appropriate for even the most demanding production effects. Images may be data compressed, preferably 5:1 with Motion-JPEG-type compression such as utilized in DV-format equipment, or preferably 10:1 with MPEG2 4:2:2P@ML compression.

In order to preserve the full bandwidth of this high-resolution signal, a higher sampling frequency is required for encoding, preferably approximately 20 MHz, for 1024×576 at 24 fps, which results in 1250 samples per total line, with 625 total lines per frame. This sampling rate allows processing a 10 MHz bandwidth luminance signal, which corresponds to approximately 600 TV lines of resolution per picture height. In contrast, traditional SDTV digital component systems employ a sampling frequency of 13.5 MHz, which provides a luminance bandwidth of 5 to 6 MHz (approximately 300 to 360 TV lines of resolution per picture height). These wide-band data files may then be stored on conventional magnetic or optical disk drives, or tape-based storage units, requiring only approximately 5.5 MB/sec for SDTV wide-screen frames in Y/R-Y/B-Y (assuming a 4:2:2 system at 8 bits per sample). The resultant data rate for this system is less than 50 Megabits per second, which is within the capabilities of currently available video recording equipment, such as the Betacam SX, DVCPRO50 or Digital S50. If a higher data-compression ratio is applied, then other units may be used, such as DVC, DVCPRO or DVCAM; Betacam SX, DVCPRO50 or Digital S50 may be used to allow sampling to 10-bit precision rather than 8-bit precision.

An alternative aspect of the invention is shown in FIG. 1B. In this case, the user follows a technique commonly used in film production, in which the film is exposed as a 4:3 aspect ratio image. When projected as a wide-screen format image, the upper and lower areas of the frame may be blocked by an aperture plate, so that the image shows the desired aspect ratio (typically 1.85:1 or 1.66:1). If the original image format were

8

recorded at 24 frames per second, with a 4:3 ratio and with a dimension in pixels of 1024×768, all image manipulations would preserve these dimensions. Complete compatibility with the existing formats would result, with NTSC and PAL images produced directly from these images by re-scaling, and the aforementioned wide-screen images would be provided by excluding 96 rows of pixels from the top of the image and 96 rows of pixels from the bottom of the image, resulting in the 1024×576 image size as disclosed above. The data content of each of these frames would be 0.75 Mpxls, and the data storage requirements disclosed above would be affected accordingly.

Another aspect of the invention is depicted in FIG. 1C. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimensions of 1280×720 pixels. Using these image dimensions (but at 24 fps progressive), compatibility with the existing formats would be available, with NTSC and PAL images derived from this frame size by excluding 160 columns of pixels from each side of the image, thereby resulting in an image having a dimension in pixels of 960×720. This new image would then be re-scaled to produce images having pixel dimensions of 640×480 for NTSC, or 768×576 for PAL. The corresponding wide-screen formats would be 854×480 and 1024×576, respectively. Utilizing a 4:2:2 sampling scheme, the 1280×720 image will require 1.85 MB when sampled at a precision of 8-bits, and 2.3 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 4.44 MB per second (35.5 megabits per second) or 5.55 MB per second (44.4 megabits per second).

In order to preserve the full 15 MHz bandwidth of this high-resolution signal, a sampling frequency of approximately 30 MHz is required for encoding, which results in 1650 samples per total line, with 750 total lines per frame for a 1280×720 image at 24 frames-per-second. In contrast, typical high definition systems require sampling rates of 74 MHz to provide a bandwidth of 30 MHz). In this case, an image having a dimension in pixels of 1280×720 would contain 0.87890625 Mpxl, with 720 TV lines of resolution. Furthermore, the systems under evaluation by the ATSC of the FCC all assume a decimation of the two chrominance signals, with detail of only 640×360 pixels retained. Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 50 megabits per second. This is within the capabilities of currently available video recording equipment, such as Betacam SX, the DVCPRO50 or Digital S50. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. The development path to 24 fps progressive is both well-defined and practical, as is the use of the previously described methods to produce images having a dimension in pixels of 1920×1080.

A third embodiment of the invention is depicted in FIG. 1D. In this alternative, the system would follow the image dimensions suggested in several proposed digital HDTV formats considered by the Advanced Television Study Committee of the Federal Communications Commission. The format adopted assumes a wide-screen image having dimensions of 1920×1080 pixels (2.1 megapixels), but at 24 frames-per-second Progressive. Utilizing a 4:2:2 sampling scheme, this 1920×1080 image will require 4.2 MB when sampled at a

precision of 8-bits, and 5.2 MB when sampled at a precision of 10-bits. When these signals are data-compressed utilizing a compression ratio of 10:1 for recording, the two image sizes require data rates of 10 MB per second (80 Megabits per second) or 12.5 MB per second (96 megabits per second). In order to preserve the full bandwidth of this high-resolution signal, a sampling frequency of 74.25 MHz is required for encoding, which results in 2750 samples per total line, with 1125 total lines per frame. In this case, an image having these dimensions would have over 1,200 TV lines of resolution per picture height, representing over 30 MHz luminance bandwidth. The chrominance bandwidth (as R-Y/B-Y) would be 15 MHz. In contrast, HDTV with 1920x1080 and 30 fps Interlace only produces 1,000 TV lines (200 lines less than above) of resolution per picture height from same sampling frequency of 74.25 MHz.

Overall, the data rate for this system, utilizing 4:2:2 sampling with 10-bit precision, is less than 100 Megabits per second. This is within the capabilities of video recording equipment, such as the Panasonic DVCPRO100 or NC Digital S100, which will be available in the near future. Because expensive, high data-rate recorders (such as the Toshiba D-6 format, the HDCAM, and D-5 format), are not required for applications utilizing the instant invention, the cost of the equipment and production systems for these applications is drastically reduced. These images may be resized into frames as large as 7680x4320, which would allow use of the system for special optical effects, or with other, specialized film formats, such as IMAX and those employing 65 mm. Camera negatives. In addition, conversions processes are available, as described herein below, to produce other HDTV formats (such as 1280x720 Progressive at 24 fps, 1920x1080 Interlaced at 25 fps, 1920x1080 Progressive at 50 fps, 1920x1080 Interlaced at 30 fps, and 1920x1080 Progressive at 60 fps), or to alternative SDTV formats, (such as 1024x576 at 25 fps, 768x576 at 25 fps, 853x480 at 30 fps, or 640x480 at 30 fps).

In each of the cases described herein above, a positioning or image centering signal may be included within the data stream, so as to allow the inclusion of information which may be utilized by the receiving unit or display monitor to perform a "pan/scan" operation, and thereby to optimize the display of a signal having a different aspect ratio than that of the display unit. For example, a program transmitted in a wide-screen format would include information indicating the changing position of the image center, so that a conventional (4:3 aspect ratio) display unit would automatically pan (horizontally and/or vertically) to the proper location. For the display of the credits or special panoramic views, the monitor optionally could be switched to a full "letter-box" display, or the image could be centered and resealed to include information corresponding to an intermediate situation, such as halfway between full-height (with cropped sides) and letter-box (full-width, but with blank spaces above and below the image on the display). This positioning/resealing information would be determined under operator control (as is typical for pan/scan operations when performing film transfers to video) so as to maintain the artistic values of the original material, within the limitations of the intended display format.

Conventional CCD-element cameras produce images of over 900 TV Lines horizontal Luminance (Y) resolution, with a sensitivity of 2,000 lux at f-11, and with a signal-to-noise ratio of 65 dB. However, typical HDTV cameras, at 1,000 TV Lines resolution and with sensitivity ratings of f-8, produce an image with only a 54 dB signal-to-noise ratio, due to the constraints of the wideband analog amplifiers and the smaller physical size of the CCD-pixel-elements. By employing the more conventional CCD-elements in the camera systems of

this invention, and by relying upon the computer to create the HDTV-type image by image re-sizing, the improved signal-to-noise ratio is retained. In the practical implementation of cameras conforming to this new design approach, there will be less of a need for extensive lighting provisions, which in turn, means less demand upon the power generators in remote productions, and for AC-power in studio applications.

In CCD-based cameras, it is also a common technique to increase the apparent resolution by mounting the red and blue CCD-elements in registration, but offsetting the green CCD-element by one-half pixel width horizontally and in some application vertically. In this case, picture information is in-phase, but spurious information due to aliasing is out-of-phase. When the three color signals are mixed, the picture information is intact, but most of the alias information will be canceled out. This technique will evidently be less effective when objects are of solid colors, so it is still the usual practice to include low-pass optical filters mounted on each CCD-element to suppress the alias information. In addition, this technique cannot be applied to computer-based graphics, in which the pixel images for each color are always in registration. However, for Y/R-Y/B-Y video, the result of the application of this spatial-shift offset is to raise the apparent Luminance (Y) horizontal resolution to approximately 900 television lines (a 4:3 aspect ratio utilizing 12200 active pixels per line), and the apparent vertical resolution is increased by 50-100+ lines.

During the transition period to implement 24 fps recording as a new production standard, conventional 16:9 widescreen-capable CCD cameras (running in 25 or 30 fps Interlaced mode) may be utilized to implement the wideband recording method so as to preserve the inherent wideband capability of these cameras, in accordance with the invention. By abandoning the requirement for square pixels, sampling frequencies of up to 30 MHz for luminance (15 MHz for chrominance) preferably are utilized, which frequencies are less than half the typical sampling rate of 74 MHz utilized for typical HDTV luminance signals in alternative systems. Chrominance components preferably are sampled consistent with a 4:2:2 system. This wideband data stream is then compressed 10:1, utilizing MPEG2 4:2:2P@ML at 10-bit. The resultant data rate is still less than 50 Megabits per second. With a straightforward modification to increase the data compression rate to 10:1, this signal may be recorded utilizing any of several conventional recording devices, including Panasonic DVCPRO50, JVC Digital-S, and Sony Betacam SX, thereby preserving the wideband signal (up to 800 TV lines of resolution per picture height). By utilizing the appropriate techniques for image resizing and frame rate conversion as described herein, video systems may be supported consistent with 1280x720 60 fps progressive, 1280x720 24 fps Progressive, 1920x1080 25 fps Interlace, 1920x1080 30 fps Interlace, 1920x1080 50 fps progressive, 1920x1080 60 fps progressive, in accordance with the invention.

The availability of hard-disk drives of progressively higher capacity and data transmission rates is allowing successively longer program duration and higher resolution image displays in real-time. At the previously cited data rates, wide-screen frames (1024x576 pixel, 24 fps, 4:2:2 process, 8 bits precision and 5:1 compression) would require 330 MB/min, so that currently available 10 GB disk drives will store more than 30 minutes of video. When the anticipated 50 GB disk drives (5.25-inch disks) become available from Seagate within the year, these units will store 150 minutes, or 2½ hours of video. For this application, a data storage unit is provided to facilitate editing and production activities, and it is anticipated that these units would be employed in much the

US 8,842,727 B2

11

same way as video cassettes are currently used in Betacam SP and other electronic news gathering (ENG) cameras and in video productions. This data storage unit may be implemented by use of a magnetic, optical (such as DVD-R or DVD-RAM) discs, or magneto-optical disk drive with removable storage media, by a removable disk-drive unit, such as those based on the PCMCIA standards, by tape-based storage means, or by semiconductor-based memory. Future advances, in storage technology will lead to longer duration program data storage. Alternatively, this storage capacity could be applied to lower ratios of data compression, higher sampling precision (10 bits or more) or higher-pixel-count images, within the limits of the same size media.

FIG. 2 shows the functional diagram for the storage-device-based digital recorder employed in the video camera, or separately in editing and production facilities. As shown, a removable hard disk drive 70 is interfaced through a bus controller 72. In practice, alternative methods of storage such as optical drives (such as DVD-R or DVD-RAM units) or magneto-optical drives could be used, based on various interface bus standards such as SCSI-2. This disk drive system currently achieves data transfer rates of 40 MB/sec, and higher rates on these or other data storage devices, such as high-capacity removable memory modules, is anticipated. If a digital tape-based format is selected, a tape drive 88 is interfaced through the bus controller 72. Currently available digital tape-based formats include DVCPRO, DVCPRO50, DVCAM, Betacam SX, Digital S50, and others. These units typically offer storage capacities in the range of 30 to 50 GigaBytes. The microprocessor 74 controls the 64-bit or wider data bus 80, which integrates the various components. Currently available microprocessors include the Alpha 21164 by Digital Equipment Corporation, or the MIPS processor family by MIPS Technologies, Inc. Future implementations would rely on the Pentium™ series by Intel Corp. or the PowerPC G3, which is capable of sustained data transfer rates of 100 MB/sec.

Up to 256 MB of ROM, shown at 76, is anticipated for operation, as is 256 MB or more of RAM, shown at 78. Current PC-based video production systems are equipped with at least 64 MB of RAM, to allow sophisticated editing effects. The graphics processor 82 represents dedicated hardware that performs the various manipulations required to process the input video signals 84 and the output video signals 86. Although shown using an RGB format, either the inputs or outputs could be configured in alternative signal formats, such as Y/R-Y/B-Y, YIQ, YUV or other commonly used alternatives. In particular, while a software-based implementation of the processor 82 is possible, a hardware based implementation is preferred, with the system employing a compression ratio of 5:1 for the conventional/widescreen signals ("NTSC/PAL/Widescreen"), and a 10:1 compression ratio for HDTV signals (1280×720 or 1920×1080, as described herein above). Example of the many available options for this data compression include the currently available Motion-WEG system and the MPEG systems. Image re-sizing alternatively may be performed by dedicated microprocessors, such as the gm865X1 or gm833X3 by Genesis Microchip, Inc. Audio signals may be included within the data stream, as proposed in the several systems for digital television transmission considered by the Federal Communications Commission, or by one of the methods available for integrating audio and video signals used in multi-media recording schemes, such as the Microsoft "AVI" (Audio/Video Interleave) file format. As an alternative, an independent system for recording audio signals may be implemented, either by employing separate digital recording provisions controlled

12

by the same system and electronics, or by implementing completely separate equipment external to the camera system described herein above.

FIG. 3 shows the components that comprise a multi-format audio/video production system according to the invention. As in the case of the computer disk- or tape-based recording system of FIG. 2, an interface bus controller 106 provides access to a variety of storage devices, preferably including an internal hard-disk drive 100, a tape-drive 102, and a hard-disk drive with removable media or a removable hard-disk drive 104. Other possible forms of high-capacity data storage (not shown) utilizing optical, magneto-optical, or magnetic storage techniques may be included, as appropriate for the particular application. The interface bus standards implemented could include, among others, SCSI-2. Data is transmitted to and from these devices under control of microprocessor 110. Currently, data bus 108 would operate as shown as 64-bits wide, employing microprocessors such as those suggested for the computer-disk-based video recorder of FIG. 3. As higher-powered microprocessors become available, such as the PowerPC G3, the data bus may be widened to accommodate 128 bits, and the use of multiple parallel processors may be employed, with the anticipated goal of 1,000 MIPS per processor. Up to 256 MB of ROM 112 is anticipated to support the requisite software, and at least 1,024 MB of RAM 114 will allow for the sophisticated image manipulations, inter-frame interpolation, and intra-frame interpolation necessary for sophisticated production effects, and for conversions between the various image formats.

A key aspect of the system is the versatility of the graphics processor shown generally as 116. Eventually, dedicated hardware will allow the best performance for such operations as image manipulations and re-scaling, but it is not a requirement of the system that it assume these functions, or even that all of these functions be included in the graphics processor in every configuration of the system. Three separate sections are employed to process the three classifications of signals. Although the video input and output signals described herein below are shown, by example, as RGB, any alternative format for video signals, such as Y/R-Y/B-Y, YIQ, YUV, or other alternatives may be employed as part of the preferred embodiment. One possible physical implementation would be to create a separate circuit board for each of the sections as described below, and manufacture these boards so as to be compatible with existing or future PC-based electrical and physical interconnect standards.

A standard/widescreen video interface 120, intended to operate within the 1024×576, 1280×720, 1024×768, 854×480, 640×480 or 1280×960 image sizes, accepts digital RGB or Y/R-Y/B-Y signals for processing and produces digital RGB or Y/R-Y/B-Y outputs in these formats, as shown generally at 122. Conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, including analog RGB or Y/R-Y/B-Y signals and composite video signals. These outputs may optionally be supplied to either a conventional multi-scan computer video monitor or a conventional video monitor having input provisions for RGB or Y/R-Y/B-Y signals (not shown). A third set of outputs supplies analog Y/C video signals. The graphics processor may be configured to accept or output these signals in the standard NTSC, PAL, or SECAM formats, and may additionally be utilized in other formats as employed in medical imaging or other specialized applications, or for any desired format for computer graphics applications. Conversion of these 24 frame-per-second progressive images to the 30 fps Interlaced (actually, 29.97 fps) NTSC and 25 fps PAL formats may be

US 8,842,727 B2

13

performed in a similar manner to that used for scanned film materials, that is, to NTSC by using the conventional 3:2 “pull-down” field-sequence, or to PAL by reproducing the images at the higher 25 fps rate.

If the source signal is 24 fps interlaced, these images first are de-interlaced to 48 fps progressive, which can be performed by dedicated microprocessors such as the gmVLD8 or gmVLD10 by Genesis Microchips, and then converted to 60 fps progressive by utilizing a “Fourth Frame Repeat” process (which repeats the fourth frame in every sequence). Next, the signal is interlaced to produce 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced (as disclosed in FIG. 7F). If the source format is 25 fps interlaced video (as would result from using conventional PAL-type equipment, or PAL-type equipment as modified in accordance with the invention), the first step is to slow down the frame rate by replaying the signal at 24 fps Interlaced. Next, the signal is de-interlaced to 48 fps progressive (as described herein above), and the Fourth Frame Repeat process is utilized to convert the signal to 60 fps progressive. In the last step, the signal is interlaced to produce 60 fps interlaced, and half of the fields are discarded to produce 30 fps interlaced. Alternatively, if the source signal is 24 fps progressive, the 60 fps progressive signal may be produced directly from a “3:2 Frame Repeat” process shown in FIG. 7G (which is analogous to the conventional “3:2 pull-down” field-sequencing process previously described). For other HDTV frame rates, aspect ratios, and line rates, intra-frame and inter-frame interpolation and image conversions may be performed by employing comparable techniques well known in the art of computer graphics and television.

An HDTV video interface 124, intended to operate within the 1920x1080 or other larger image sizes (with re-sizing as necessary), accepts digital RGB or Y/R-Y/B-Y (or alternative) signals for processing and produces, digital outputs in the same image format, as shown generally at 126. As is the case for the standard/widescreen interface 120, conventional internal circuitry comprising D/A converters and associated analog amplifiers are employed to convert the internal images to a second set of outputs, for analog RGB signals and composite video signals. In alternative embodiments, this function may be performed by an external upconverter, which will process the wideband signal of the instant invention. A modification of currently available upconverters is required, to increase the frequency of the sampling clock in order to preserve the full bandwidth of this signal, in accordance with the invention. In this case, frequency of the sampling clock is preferably adjustable to utilize one of several available frequencies.

The third section of the graphics processor 116 shown in FIG. 3 is the film output video interface 128, which comprises a special set of video outputs 130 intended for use with devices such as laser film recorders. These outputs are preferably configured to provide a 3840x2160 or other larger image size from the image sizes employed internally, using re-sizing techniques discussed herein as necessary for the format conversions. Although 24 fps is the standard frame rate for film, some productions employ 30 fps (especially when used with NTSC materials) or 25 fps (especially when used with PAL materials), and these alternative frame rates, as well as alternative image sizes and aspect ratios for internal and output formats, are anticipated as suitable applications of the invention, with “3:2-pull-down” utilized to convert the internal 24 fps program materials to 30 fps, and 25 fps occurring automatically as the film projector runs the 24 fps films at the 25 fps rate utilized for PAL-type materials.

14

Several additional optional features of this system are disclosed in FIG. 3. The graphics processor preferably also includes a special output 132 for use with a color printer. In order to produce the highest quality prints from the screen display it is necessary to adjust the print resolution to match the image resolution, and this is automatically optimized by the graphics processor for the various image sizes produced by the system. In addition, provisions may be included for an image scanner 134, which may be implemented as a still image scanner or a film scanner, thereby enabling optical images to be integrated into the system. An optional audio processor 136 includes provisions for accepting audio signals in either analog or digital form, and outputting signals in either analog or digital form, as shown in the area generally designated as 138. For materials including audio intermixed with the video signals as described herein above, these signals are routed to the audio processor for editing effects and to provide an interface to other equipment.

It is important to note that although FIG. 3 shows only one set of each type of signal inputs, the system is capable of handling signals simultaneously from a plurality of sources and in a variety of formats. Depending on the performance level desired and the image sizes and frame rates of the signals, the system may be implemented with multiple hard disk or other mass-storage units and bus controllers, and multiple graphics processors, thereby allowing integration of any combination of live camera signals, prerecorded materials, and scanned images. Improved data compression schemes and advances in hardware speed will allow progressively higher frame rates and image sizes to be manipulated in real-time.

Simple playback of signals to produce PAL output is not a serious problem, since any stored video images may be replayed at any frame rate desired, and filmed material displayed at 25 fps is not objectionable. Indeed, this is the standard method for performing film-to-tape transfers used in PAL- and SECAM-television countries. Simultaneous output of both NTSC and film-rate images may be performed by exploiting the 3:2 field-interleaving approach: $5 \times 24 = 120 = 2 \times 60$. That is, two film frames are spread over five video fields. This makes it possible to concurrently produce film images at 24 fps and video images at 30 fps. The difference between 30 fps and the exact 29.97 fps rate of NTSC may be palliated by slightly modifying the system frame rate to 29.976 fps. This is not noticeable in normal film projection, and is an acceptable deviation from the normal film rate.

The management of 25 fps (PAL-type) output signals in a signal distribution system configured for 24 fps production applications (or vice versa) presents technical issues which must be addressed, however. One alternative for facilitating these and other frame-rate conversions is explained with reference to FIG. 4. A digital program signal 404 is provided to a signal compression circuit 408. If the input program signal is provided in analog form 402, then it is first processed by A/D converter 406 to be placed in digital form. The signal compressor 408 processes the input program signal so as to reduce the effective data rate, utilizing any of the commonly implemented data compression schemes, such as motion-JPEG, MPEG1, MPEG2, etc. well known in the art. As an alternative, the digital program signal 404 may be provided in data-compressed form. At this point, the digital program signal is provided to data bus 410. By way of example, several high-capacity digital storage units, designated as “storage means A” 412 and “storage means B” 414, are included for storing the digital program signals presented on data bus 410, under management by controller 418.

US 8,842,727 B2

15

The two storage means **412** and **414** may be used in alternating fashion, with one storing the source signal until it reaches its full capacity. At this point, the other storage means would continue storing the program signal until it, too, reached its full capacity. The maximum program storage capacity for the program signals will be determined by various factors, such as the input program signal frame rate, the frame dimensions in pixels, the data compression rate, the total number and capacities of the various storage means, and so forth. When the available storage capacity has been filled, this data storage scheme automatically will result in previously-recorded signals being overwritten. As additional storage means are added, the capacity for time-delay and frame rate conversion is increased, and there is no requirement that all storage means be of the same type, or of the same capacity. In practice, the storage means would be implemented using any of the commonly available storage techniques, including, for example, magnetic disks, optical (such as DVD-RAM discs) or magneto-optical discs, or semiconductor memory.

When it is desired to begin playback of the program signal, signal processor **416**, under management by controller **418** and through user interface **420**, retrieves the stored program signals from the various storage means provided, and performs any signal conversions required. For example, if the input program signals were provided at a 25 fps rate (corresponding to a 625-line broadcast system), the signal processor would perform image resizing and inter-frame interpolation to convert the-signal to 30 fps (corresponding to a 525-line broadcast system).

Other conversions (such as color encoding system conversion from PAL-format to NTSC, etc., or frame dimension or aspect-ratio conversion) will be performed as necessary. The output of the signal processor is then available in digital form as **422**, or may be processed further, into analog form **426** by D/A converter **424**. In practice, a separate data bus (not shown) may be provided for output signals, and/or the storage means may be implemented by way of dual-access technology, such as dual-port RAM utilized for video-display applications, or multiple-head-access disk or disk storage units, which may be configured to provide simultaneous random-access read and write capabilities. Where single-head storage means are implemented, suitable input buffer and output buffer provisions are included, to allow time for physical repositioning of the record/play head.

In utilizing program storage means including synchronous recording and playback capabilities of the types just described, if it is known that a program will be stored in its entirety before the commencement of playback, that is, with no time-overlap existing between the occurrence of the input and output signal streams, it typically will be most efficient to perform any desired frame conversion on the program either before or after initial storage, depending upon which stored format would result in the least amount of required memory. For example, if the program is input at a rate of 24 frames per second, it probably will be most efficient to receive such a program and store it at that rate, and perform a conversion to higher frame rates upon output. In addition, in situations where a program is recorded in its entirety prior to conversion into a particular output format, it is most efficient to store the program either on a tape-based format or a format such as the new high-capacity DVD-type discs, given the reduced cost, on a per-bit basis, of these types of storage. Of course, conventional high-capacity disk storage also may be used, and may become more practical as storage capacities continue to increase and costs decrease. If it is known that a program is to be output at a different frame rate while it is being input or stored, it is most preferable to use disk storage and to perform

16

the frame rate conversion on an ongoing basis, using one of the techniques described above. In this case, the high-capacity video storage means, in effect, assumes the role of a large video buffer providing the fastest practical access time. Again, other memory means (types) may be used, including all solid-state and semiconductor types, depending upon economic considerations, and so forth.

As an example of an alternative embodiment, the storage means **100** or **104** are equipped with dual-head playback facilities and a second set of graphics processing hardware (not shown) analogous in function to the normal graphics processing hardware (identical to the standard hardware shown as **120**, **124**, and **128**), and having analogous signal output facilities (identical to the standard provisions shown as **122**, **126**, **130**, and **132**). In this case, the two heads would be driven independently, to provide simultaneous, asynchronous playback at different frame rates. That is, one head would be manipulated so as to provide a data stream corresponding to a first frame rate (for example, 25 fps), while the second head would be manipulated so as to provide a data stream corresponding to a second frame rate (for example, 24 fps, which, in turn, may be converted to 30 fps, using the "3:2-pull-down" technique). In this case, both the storage means and also the internal bus structure of the system would have to support the significantly increased data rate for providing both signal streams simultaneously, or, as an alternative, a second, separate data bus would be provided.

In some applications, a more sophisticated conversion scheme is required. For example, in frame rate conversion systems of conventional design, if an input program signal having a 24 fps rate format is to be displayed at a 25 fps rate, it is customary to simply speed up the source signal playback, so as to provide the signals at a 25 fps rate. This is the procedure utilized for performing a conversion of 24-fps-film-material for 25 fps PAL-format video usage. However, implementation of this method requires that the user of the output signal must have control over the source-signal playback. In a wide-area distribution system (such as direct-broadcast-satellite distribution) this is not possible. While a source signal distributed at 24 fps readily could be converted to 30 fps (utilizing the familiar "3-2-pull-down" technique), the conversion to 25 fps is not as easily performed, due to the complexity and expense of processing circuitry required for inter-frame interpolation over a 24-frame sequence. However, utilizing the system disclosed in FIG. 4, the conversion is straightforward. If, for example, a 24 fps program lasting 120 minutes is transmitted in this format, there are a total of 172,800 frames of information (24 frames/second \times 60 seconds/minute \times 120 minutes). Display of this program in speeded-up fashion at 25 fps would mean that the input frame rate falls behind the output frame rate by one frame per second, or a total of 7,200 frames during the course of the program. At a 24 fps transmission rate, this corresponds to 300 seconds transmission time. In other words, for the input program (at 24 fps) and the output program (at 25 fps) to end together, the input process would have to commence 300 seconds before the output process begins. In order to perform this process, then, it is necessary for the storage means to have the capacity to retain 300 seconds of program material, in effect serving as a signal buffer. As an example, for the systems disclosed herein in which the compressed-data rates range from 5.5 MB/sec (for 24 fps standard/widescreen Y/R-Y/B-Y-based TV formats, using 5:1 data compression such as MPEG or motion-PEG and 4:2:2 processing with 8-bit precision) to 10 MB/sec (for 24 fps HDTV Y/R-Y/B-Y-based formats, using 10:1 data compression such as MPEG or motion-PEG and 4:2:2 processing with 8-bit precision), it

may be necessary to store as much as 3.3 GBytes of data, which is readily available by way of multiple disks or discs utilizing conventional storage technology. In practice, the transmission simply would begin 300 seconds before the playback begins, and once the playback starts, the amount of buffered signal would decrease by one frame per second of playback until the last signal is passed through as soon as it is received.

A mirror of this situation arises in the case of a 25 fps signal to be displayed at 24 fps, or some other data rate readily provided by conversion from 24 fps (such as 30 fps). In this case, the source signal is provided at a higher frame rate than the output signal, so that a viewer watching a program from the onset of the transmission would fall behind the source signal rate, and the storage means would be required to hold frames of the program to be displayed at a time after the source signal arrival time. In the case of the 120 minute program described above, the viewing of the source program would conclude 300 seconds after the source signal itself had concluded, and comparable calculations are applied for the storage means. In this case, the extra frames would be accumulated as the buffer contents increased, until, after the transmission has completed, the last 300 seconds would be replayed directly from the storage means.

The conversion of frame rates from 30 fps to 24 fps or to 25 fps is more complicated, because some form of inter-frame interpolation is required. In one case, a multi-frame storage facility would allow this type of interpolation to be performed in a relatively conventional manner, as typically is utilized in NTSC-to-PAL conversions (30 fps to 25 fps). At this point, a 25 fps to 24 fps conversion could be performed, in accordance with the methods and apparatus described herein above.

It should be noted that if, for example, a DVD-R-type, DVD-RAM-type, or some form of removable magnetic storage media is selected, then the implementation of the significantly higher data compression rates of MPEG-2 coding techniques will result in the ability to record an entire program of 120 minutes or more in duration. In this manner, the complete program is held in the disk/buffer, thereby enabling the user to perform true time-shifting of the program, or allowing the program rights owner to accomplish one form of software distribution, in accordance with the invention.

An alternative method to carry out this frame rate conversion is carried out utilizing the following process. The 30 fps interlaced signal is first de-interlaced to 60 fps Progressive. Then, every fifth frame is deleted from the sequence, producing a 48 fps progressive signal stream. Next, these remaining frames are converted to 24 fps interlaced, as disclosed in FIG. 7I ("5th Frame Reduction"). If the original source material were from 24 fps (for example, film), then if the repeated fields (i.e., the "3" field of the 3:2 sequence) were identified at the time of conversion, then the removal of these fields would simply return the material to its original form. If the desired conversion is to be from 30 fps to 25 fps, then an equivalent procedure would be performed using the storage-based frame-conversion method described herein above. As an alternative, the 30 fps interlaced signal would first be de-interlaced to 60 fps progressive; then, every sixth frame would be deleted from the sequence ("6th Frame Reduction"). The remaining frames are re-interlaced to produce 25 fps interlaced, as disclosed in FIG. 7H. Depending on the original source material frame rate and intermediate conversions, the user would select the method likely to present the least amount of image impairment.

In the case in which the user is able to exercise control over the frame rate of the source program material, an alternative method is available. Just as film-to-video transfers for PAL-

format (25 fps) presentations utilize a speeded-up playback of the 24 fps film materials to source them at the 25 fps Progressive rate (thereby matching the intended output frame rate), the reverse of this process enables a user to utilize materials originated at 25 fps Progressive to produce playback at 24 fps. As disclosed herein above, conversions of 24 fps progressive materials are handled easily by way of conventional methods (such as the "3:2-pull-down" method), and therefore the operator control of the source material enables the user to utilize materials originating from conventional or widescreen PAL format sources for editing and production, then replay the resulting program at 24 fps for conversion to either standard or widescreen NTSC output materials, or even to HDTV format materials, all at 30 fps Interlaced, by performing the "3:2-pull-down" process.

If the source format is 25 fps interlaced video (as would result from using conventional PAL-type CCD widescreen camera), an alternative method for producing a 30 fps Interlaced signal is available. Instead of performing a slow-down to produce a 24 fps interlaced signal, the 25 fps Interlaced signal is first de-interlaced to 50 fps progressive. Next, a "4th Frame Repeat" process is applied, which results in a 62.5 fps progressive signal. This signal is then converted to 62.5 fps interlaced, and after half of the fields are discarded, to produce 31.25 fps interlaced. After data compression, the signal undergoes a slow-down process, resulting in a 30 fps interlaced signal which now has a compressed-data-rate of less than 10 Mbytes per second, as disclosed in FIG. 7D. By using this procedure, the entire process from the CCD camera to the final conversion to 30 fps Interlaced only one data compression step is employed. Alternatively, if the output of the camera is already in data compressed form, then this signal must be decompressed before applying the listed conversion steps. In order to ensure accurate conversion, interlace and de-interlace processes should only be applied to de-compressed signals. Conversely, speed-up and slow-down procedures are preferably applied with compressed data, as the raw data rate for uncompressed video, depending on the image dimensions in pixels and frame rate, will be in the range of 30 to 100 MB per second, which is not practical for current technology storage devices.

A variety of conversions between formats (both interlaced and progressive) having differing frame rates, and some of these possible conversion paths are indicated in FIGS. 7A through 7I. While extensive, these listings are not intended to represent a complete listing of all alternatives, as in many cases there is more than one combination of methods which may affect an equivalent conversion. Depending on the particular application, different paths may be selected, and these differing paths may produce more, or less, effective results.

The various alternatives utilize several techniques not previously applied to these types of conversions. For example, conversions of 60 fps progressive signals to 30 fps Progressive may be effected by simply dropping alternate frames. On the other hand, a "3:2 Frame Repetition" method consists of repeating a first frame a second and a third time, then repeating the next frame a second time, thereby converting two frames into five frames (as depicted in FIG. 7G).

Depending on whether the source material is 24 fps progressive or 24 fps interlaced, different approaches are utilized for conversion to 30 fps interlaced. In the first case, the 24 fps progressive signal is first converted to 24 fps Interlaced. A set of four consecutive frames may be indicated as 1A1B, 2A2B, 3A3B, 4A4B. By recombining these fields (but outputting them at a 30 fps rate) the following field sequence is obtained: 1A1B, 1A2B, 2A3B, 3A4B, 4A4B. This sequence repeats for

every four input frames, which is to say, for every five output frames (as depicted in FIG. 7C).

Alternatively, for a signal which originates at 24 fps Interlaced, the original four-frame sequence is identical. However, the situation is more complicated because the absolute time-
5 sequence of frames must be preserved. For this reason, it is necessary to reverse the field identification of alternate groups of fields in order to preserve the proper interlace relationship between the fields. In effect, every fourth and seventh field in the eight-field (24 fps interlaced) sequence is repeated, but
10 with reversed field identification (as disclosed in FIG. 7E). When the fourth input field has had its identification reversed (to produce the fifth output field), then the next two input fields (corresponding to the sixth and seventh output field) in the sequence also will require field reversal, in order to pre-
15 serve the correct sequence for proper interlace. Furthermore, when the seventh input field is repeated, the first time it will appear in reversed-field-identity from as the eighth output field. For this procedure, the resulting field sequence will be 1A1B, 2A2B, 2B*3A*, 3B*4A*, 4A4B (wherein a field hav-
20 ing reversed field identification is denoted by a * symbol). This sequence repeats for every four input frames, which is to say, for every five output frames.

In addition, the reversal of the field identity of the fourth input field (when repeated) results in information that previ-
25 ously was displayed on the second scan line now being displayed on the first scan line. Therefore, it is necessary to discard the first line of the next reversed-field, so that the information displayed on the second scan line of the new field will be the information previously displayed on the third line
30 of the next (reversed) field. After the seventh input field has been reversed (to produce the eighth output field, the following fields are once again in the proper line order without any further adjustments of this kind (as disclosed in FIG. 7E).

For image manipulations entirely within the internal storage format, there is no issue as to interlacing, as the graphics processor is only manipulating a rectangular array of image
35 pixels, not individual scan lines. As such, identification of fields is derived solely from the location of the image pixels on either odd-numbered lines or even-numbered lines. The interlacing field identification adjustments are made only at the time of output to the display device. In these applications, the presence of the storage means allows the viewer to control the presentation of a program, utilizing a user interface 420 to control the playback delay and other characteristics of the signal while it is being stored or thereafter. In practice, a wide
40 range of alternatives for input frame rates and output frame rate conversions are made available through this system, by selecting the most appropriate of the various methods for altering the frame rate of a signal described herein.

FIG. 5 shows the inter-relationship of the various film and video formats compatible with the invention, though not intended to be inclusive of all possible implementations. In
45 typical operations, the multi-format audio/video production system 162 would receive film-based elements 160 and combine them with locally produced materials already in the preferred internal format of 24 frames-per-second. In practice, materials may be converted from any other format including video at any frame rate or standard. After the production effects have been performed, the output signals may
50 be configured for any use required, including, but not limited to, HDTV at 30/60 fps shown as 164, widescreen at 30 fps shown as 166, widescreen at 25 fps shown as 170, or HDTV at 25/50 fps shown as 172. In addition, output signals at 24 fps are available for use in a film-recording unit 168.

In FIG. 6, signals are provided from any of several sources, including conventional broadcast signals 210, satellite

receivers 212, and interfaces to a high bandwidth data network 214. These signals would be provided to the digital
tuner 218 and an appropriate adapter unit 220 for access to a high-speed data network before being supplied to the decom-
5 pression processor 222. As an option, additional provisions for data compression would provide for transmission of signals from the local system to the high bandwidth data network 214. The processor 222 provides any necessary data de-com-
pression and signal conditioning for the various signal sources, and preferably is implemented as a plug-in circuit
10 board for a general-purpose computer, though the digital tuner 218 and the adapter 220 optionally may be included as part of the existing hardware.

The output of processor 222 is provided to the internal data bus 226. The system microprocessor 228 controls the data bus, and is provided with 32 to 128 MB of RAM 230 and up to 64 Mb of ROM 232. This microprocessor could be imple-
15 mented using one of the units previously described, such as the PowerPC 604, PowerPC G3, Pentium-series, or other processors. A hard disk drive controller 234 provides access to various storage means, including, for example, an internal hard disk drive unit 236, a removable hard disk drive unit 238, a unit utilizing removable magnetic, optical, or magneto-
20 optical media (not shown), or a tape drive 240. These storage units also enable the PC to function as a video recorder, as described above. A graphic processor 242, comprising dedicated hardware which optionally be implemented as a separate plug-in circuit board, performs the image manipulations required to convert between the various frame sizes (in pixels), aspect ratios, and frame rates. This graphics processor uses 16 to 32 MB of DRAM, and 2 to 8 MB of VRAM
25 (depending on the type of display output desired. For frame size of 1280×720 with an aspect ratio 16:9, the lower range of DRAM and VRAM will be sufficient, but for a frame size of 1920×1080, the higher range of DRAM and VRAM is required. In general, the 1280×720 size is sufficient for conventional “multi-sync” computer display screens up to 20 inches, and the 1920×1080 size is appropriate for conventional “multi-sync” computer display screens up to 35 inches.
30 Analog video outputs 244 are available for these various display units. Using this system, various formats may be displayed, including (for 25 fps, shown by speeding up 24 fps signals) 768×576 PAL/SECAM, 1024×576 wide-screen, and 1280×720/1920×1080 HDTV, and (for 30 and 60 fps, shown by utilizing the well-known “3:2 pull-down” technique, and for 29.97 fps, shown by a slight slow-down in 30 fps signals) 640×480 NTSC and 854×480 wide-screen, and 1920×1080 NHK (Japan) HDTV.

It will be appreciated by the skilled practitioner that most of
50 the highest quality program material has been originated on 24 fps 35-mm film, and therefore conversions that rely on reconstituting the signal material from 25 fps or 30 fps materials into 24 fps material do not entail any loss of data or program material. In addition, signals that have been interlaced from a lower or equivalent frame rate source signal in any of the currently available means (24 fps to 25 fps via speed-up; 24 fps to 30 fps via “3:2-pull-down”) may be de-
55 interlaced and reconstituted as progressive-scan frames without introducing any signal artifacts, provided that the original frames are recreated from properly matched fields. If it is desired to produce 24 fps interlaced, 25 fps Interlaced, or 30 fps interlaced signals from higher frame rate progressive signals (such as 48 fps Progressive, 50 fps progressive, or 60 fps progressive signals, respectively) these may be obtained by
60 interlacing these signals and discarding the redundant data. Alternatively, if it is desired to produce 24 fps progressive, 25 fps progressive, 30 fps Progressive, or 48 fps progressive

US 8,842,727 B2

21

signals from higher frame rate progressive signals (such as 48 fps progressive, 50 fps progressive, 60 fps progressive, or 96 fps progressive signals, respectively), these may be obtained by applying a 2:1 frame reduction. These techniques are summarized in FIG. 7A, with conversion charts showing typical process flow charts in FIGS. 7B and 7C.

FIG. 8 shows one possible implementation of a universal playback device, in accordance with the invention. By way of example, a DVD-type video disk 802 is rotatably driven by motor 804 under control of speed-control unit 806. One or more laser read- or read/write-heads 808 are positioned by position control unit 810. Both the speed control unit and the position control unit are directed by the overall system controller 812, at the direction of the user interface 814. It should be noted that the number and configuration of read- or read/write-heads will be determined by the choice of the techniques employed in the various embodiments disclosed herein above. The signals recovered from the laser heads is delivered to signal processor unit 820, and the data stream is split into an audio data stream (supplied to audio processor unit 822) and a video data stream (supplied to video graphics processor unit 830). During the audio recovery process, the alteration of the playback frame rate (for example, from 24 fps to 25 fps, accomplished by speed control adjustment) may suggest the need for pitch-correction of the audio material. This procedure, if desired, may be implemented either as part of the audio processor 822, or within a separate, external unit (not shown), as offered by a number of suppliers, such as Lexicon.

The video data stream may undergo a number of modifications within the graphics processor, shown generally at 830, depending on the desired final output format. Assuming that the output desired is NTSC or some other form of wide-screen or HDTV signal output at a nominal frame rate of 30 fps, a signal sourced from the disk at 24 fps would undergo a "3:2-pull-down" modification as part of the conversion process (as explained herein above). If the signal as sourced from the disk is based on 25 fps, then it would undergo an preliminary slowdown to 24 fps before the "3:2-pull-down" processing is applied. It should be noted that the 0.1% difference between 30 fps and 29.97 fps only requires the buffering of 173 frames of video over the course of a 120-minute program, and at a data rate of 5.5 MB/sec, this corresponds to approximately 39 MB of storage (for standard/widescreen) or 79 MB of storage (for HDTV), which readily may be implemented in semiconductor-based memory. In any event, a signal supplied to the graphics processor at a nominal 24 fps simultaneously may be output at both 30 fps and 29.97 fps, in image frames compatible with both NTSC and NTSC/widescreen (the standard/widescreen video interface 832), and HDTV (HDTV video interface 834), in accordance with the invention as described herein above.

As disclosed above, an optional film output video interface 836 may be included, with digital video outputs for a film recorder. Overall, the outputs for the graphics processor 830 parallel those of the Multi-Format Audio/Video Production System as shown in FIG. 5 and disclosed herein above. In addition, for signals to be output in a format having a different aspect ratio than that of the source signal, it may be necessary to perform a horizontal and/or vertical "pan/scan" function in order to assure that the center of action in the source program material is presented within the scope of the output frame. This function may be implemented within the graphics processor by utilizing a "tracking" signal associated with the source program material, for example, as part of the data stream for each frame, or, alternatively, through a listing identifying changes that should be applied during the presen-

22

tation of the source material. Where no "tracking" information is available, the image frame would be trimmed along the top and bottom, or the sides, as necessary in order to fit the aspect ratio of the source material to the aspect ratio of the output frame. This latter technique is explained herein above, with reference to FIGS. 1A-1D. In addition, the program material may include security information, such as regional or geographical information directed towards controlling the viewing of the program material within certain marketing areas or identifiable classes of equipment (such as hardware sold only in the United States or in the German market). This information, as has been disclosed for use with other disk-n and tape-based systems, often relates to issues such as legal licensing agreements for software materials. It may be processed in a way similar to the detection and application of the "pan/scan" tracking signal, and the signal processor 820, under the direction of controller 812 may act to enforce these restrictions.

Alternatively, if output at 25 fps is desired, it is a simple matter to configure the various components of this system to replay the video information of the disk 802 at this higher frame rate. The controller will configure the speed control unit 806 (if necessary) to drive the motor 804 at a greater rotational speed to sustain the increased data rate associated with the higher frame rate. The audio processor 822, if so equipped, will be configured to correct for the change in pitch associated with the higher frame rate, and the graphics processor will be configured to provide all output signals at the 25 fps frame rate. As Alternate method for audio pitch correction, additional audio data can be stored in disk which is already corrected. When the frame rate is changed, the corresponding audio data is selected in accordance with the invention.

As yet another alternative, materials produced at 25 fps and stored on the disk-based mass storage means of this example could originate from conventional standard or widescreen PAL format signals. Utilizing the slow-down method, these signals are readily converted to 24 fps frame rate, from which conversion to various 30 fps formats is implemented, as disclosed herein above. This feature has significance in the commercial development of HDTV, as the ability to utilize more-or-less conventional PAL format equipment greatly facilitates the economical production and origination of materials intended for HDTV markets.

A wide range of output frame rates may be made available through combination of the techniques of speed-up, slow-down, "3-2-pull-down," and other related field-rearrangement, de-interlacing, interlacing/de-interlacing, frame repetition, and frame reduction techniques, as disclosed herein above with respect to FIG. 4 and FIGS. 7A-7E, and these various combinations and approaches should be considered to be within the scope of the invention. In addition, these techniques may be combined with hardware and/or software which perform image manipulations such as line-doubling, line-quadrupling, deinterlacing, etc., such that the display device will be capable of providing smoother apparent motion, by increasing the display rate without increasing the actual data/information rate. One example would be to process the 24 fps signal from the internal format to convert it into a 48 fps signal, using field-doubling techniques such as deinterlacing and line doubling. Then, the process would employ frame-store techniques to provide a frame-repeated output at a rate of 96 fps. These types of display-related improvements, in conjunction with the instant invention, should also be considered to be within the scope of the inven-

US 8,842,727 B2

23

tion as disclosed herein. Examples of these various combinations and conversion methods are included in the table of FIG. 7A and the chart of FIG. 7E.

In general, the features as described need not all be provided in a single unit, but rather may be distributed through various external units (such as external data-recorders or display units). In addition, particular configurations of the system may include only the graphics capabilities required for that application (such as the use of 25 fps PAL outputs, but not 30 fps NTSC) and may even exclude certain options (such as printer outputs), and these variations should be considered to be within the scope of the invention.

I claim:

1. A method performed by a video apparatus, comprising:
 - receiving compressed video content from a source;
 - decompressing the compressed video content to generate uncompressed video content in an internal format having a frame rate of 24 frames per second (fps) comprising progressive frames of pixel image data having an original pixel resolution;
 - buffering progressive frames of pixel image data in a high-capacity memory buffer supporting asynchronous random read and write access;
 - processing the progressive frames of pixel image data in the buffered progressive frames to perform a frame-rate conversion from 24 fps to a higher output frame rate; and
 - outputting a digital HDTV video signal configured to display the video content on an HDTV at the output frame rate, wherein the digital HDTV video signal is a progressive signal having a pixel resolution of at least 1920×1080 pixels.
2. The method of claim 1, wherein the frame-rate conversion comprises repeating each frame in the 24 fps internal production format an integer multiple of times to output a digital HDTV video signal having a frame rate that is an integer multiple of 24 fps.
3. The method of claim 2, wherein the output frame rate is 96 fps.
4. The method of claim 1, further comprising employing pixel interpolation hardware to perform an up-conversion of the original pixel resolution to output a digital HDTV video signal having a pixel resolution of 3840×2160 pixels.
5. The method of claim 1, wherein the original pixel resolution is less than 1920×1080 pixels, the method further comprising employing pixel interpolation hardware to perform an up-conversion of the original pixel resolution to output a digital HDTV video signal having a pixel resolution of 1920×1080 pixels.
6. The method of claim 1, wherein the source comprises one of a cable or satellite broadcast source.
7. The method of claim 1, wherein the source comprises a DVD-type video disk, and the compressed video content is received by reading video content stored on the DVD-type video disk.
8. The method of claim 1, wherein the video apparatus includes a high-capacity storage means providing asynchronous access for recording and reproduction, and the source comprises the high-capacity storage means.
9. The method of claim 1, further comprising performing inter-frame interpolation of progressive frame pixel image data to perform the frame rate conversion.
10. The method of claim 1, wherein the compressed video content has an original frame rate that is different than 24 fps, the method further comprising:
 - decompressing the compressed video content to generate frames of pixel image data; and

24

processing the frames of pixel image data using the memory buffer to perform a frame rate conversion from the original frame rate to 24 fps.

11. A video apparatus, comprising:
 - means for at least one of receiving or retrieving compressed video data;
 - a high-capacity memory buffer supporting asynchronous random read and write access;
 - digital signal processing circuitry; and
 - a graphics processor;
 wherein the apparatus is configured to,
 - decompress compressed video content that is received or retrieved by the apparatus using at least one of the digital signal processing circuitry and the graphics processor to generate uncompressed video content in an internal format having a frame rate of 24 frames per second (fps) comprising progressive frames of pixel image data having an original pixel resolution;
 - buffer progressive frames of pixel image data in the high-capacity memory buffer;
 - process the progressive frames of pixel image data in the buffered progressive frames using at least one of the digital processing circuitry and the graphics processor to perform a frame-rate conversion from 24 fps to a higher output frame rate; and
 - output a digital HDTV video signal configured to display the video content on an HDTV at the output frame rate, wherein the digital HDTV video signal is a progressive signal having a pixel resolution of at least 1920×1080 pixels.
12. The video apparatus of claim 11, wherein the frame-rate conversion comprises repeating each frame in the 24 fps internal production format an integer multiple of times to output a digital HDTV video signal having a frame rate that is an integer multiple of 24 fps.
13. The video apparatus of claim 12, wherein the output frame rate is 96 fps.
14. The video apparatus of claim 11, wherein the apparatus is further configured to perform an up-conversion of the original pixel resolution to output a digital HDTV video signal having a pixel resolution of 3840×2160 pixels.
15. The video apparatus of claim 11, wherein the original pixel resolution is less than 1920×1080 pixels, and the apparatus is further configured to perform an up-conversion of the original pixel resolution to output a digital HDTV video signal having a pixel resolution of 1920×1080 pixels.
16. The video apparatus of claim 11, wherein the means for at least one of receiving or retrieving compressed video data comprises a tuner configured to receive one of a cable or satellite broadcast signal via which compressed video data is received by the video apparatus.
17. The video apparatus of claim 11, wherein the means for at least one of receiving or retrieving compressed video data comprises a DVD-type video disk reading device, and the compressed video content is retrieved by reading video content stored on a DVD-type video disk.
18. The video apparatus of claim 11, wherein the means for at least one of receiving or retrieving compressed video data comprises a high-capacity storage means providing asynchronous access for recording and reproduction, and the compressed video data is retrieved from the high-capacity storage means.
19. The video apparatus of claim 11, wherein the apparatus is configured to employ at least one of the digital processing circuitry and the graphics processor to perform inter-frame interpolation of progressive frame pixel image data buffered in the memory buffer to perform the frame rate conversion.

US 8,842,727 B2

25

20. The video apparatus of claim 11, wherein the compressed video content has an original frame rate that is different than 24 fps, and the apparatus is further configured to: decompress the compressed video content to generate frames of pixel image data; and

process the frames of pixel image data using the memory buffer to perform a frame rate conversion from the original frame rate to 24 fps.

21. An apparatus, comprising:

means for receiving compressed video data from an external source;

at least one high-capacity storage device and means for reading compressed video content from the at least one high-capacity storage device;

high-capacity memory supporting asynchronous random read and write access;

digital signal processing circuitry; and

a graphics processor;

wherein the apparatus is configured to,

decompress first compressed video content that is received from an external source via the means for receiving compressed video data from an external source using at least one of the digital signal processing circuitry and the graphics processor to generate uncompressed video content in a first internal format having a frame rate of 24 frames per second (fps) comprising first progressive frames of pixel image data having a first original pixel resolution;

buffer first progressive frames of pixel image data in the high-capacity memory buffer;

process the first progressive frames of pixel image data in the buffered progressive frames using at least one of the digital processing circuitry and the graphics processor to perform a frame-rate conversion from 24 fps to a first output frame rate;

output a first digital HDTV video signal configured to display the video content on an HDTV at the first output frame rate, wherein the digital HDTV video signal is a progressive signal having a first output pixel resolution of at least 1920×1080 pixels;

decompress second compressed video content that is read from a high-capacity storage device using at least one of the digital signal processing circuitry and the graphics processor to generate uncompressed video content in a second internal format having a frame rate of 24 frames per second (fps) comprising second progressive frames of pixel image data having a second original pixel resolution;

buffer second progressive frames of pixel image data in the high-capacity memory buffer;

process the second progressive frames of pixel image data in the buffered progressive frames using at least one of the digital processing circuitry and the graphics

26

processor to perform a frame-rate conversion from 24 fps to a second output frame rate; and

output a second digital HDTV video signal configured to display the video content on an HDTV at the second output frame rate, wherein the second digital HDTV video signal is a progressive signal having a second output pixel resolution of at least 1920×1080 pixels.

22. The apparatus of claim 21, wherein the formats of the first compressed video content and the second compressed video content are different.

23. The apparatus of claim 21, wherein at least one of: the first and second output frame rates are different; or the first and second output pixel resolutions are different.

24. The apparatus of claim 21, wherein the apparatus is further configured to perform an up-conversion of uncompressed video content having at least one of the first original pixel resolution or the second original pixel resolution to output a digital HDTV video signal having a pixel resolution of 3840×2160 pixels.

25. The apparatus of claim 21, wherein the means for receiving compressed video data from an external source comprises at least one of a:

a cable or satellite broadcast receiver, configured to receive compressed video data from a cable broadcast source or a satellite broadcast source; or

a data network interface, configured to receive compressed video data from a data network.

26. The apparatus of claim 21, wherein the means for receiving compressed video data from an external source comprises:

a cable or satellite broadcast receiver, configured to receive compressed video data from a cable broadcast source or a satellite broadcast source; and

a data network interface, configured to receive compressed video data from a data network.

27. The apparatus of claim 21, wherein the means for receiving compressed video data from an external source comprises a data network interface, configured to receive compressed video data from a data network, and wherein the apparatus includes a high-capacity storage device comprising a DVD-type video disk reading device, and the second compressed video content is retrieved by reading video content stored on a DVD-type video disk.

28. The apparatus of claim 21, wherein the means for receiving compressed video data from an external source comprises a data network interface, configured to receive compressed video data from a data network, and wherein the apparatus includes a first high-capacity storage device comprising a DVD-type video disk reading device, and a second high-capacity storage device comprising a disk drive, and the second compressed video content is retrieved by reading video content stored on either a DVD-type video disk or the disk drive.

* * * * *

EXHIBIT 5

EXHIBIT 5

PATENT ASSIGNMENT COVER SHEET

Electronic Version v1.1
 Stylesheet Version v1.2

EPAS ID: PAT3936883

SUBMISSION TYPE:	NEW ASSIGNMENT	
NATURE OF CONVEYANCE:	ASSIGNMENT	
SEQUENCE:	2	
CONVEYING PARTY DATA		
	Name	Execution Date
	KINYA WASHINO	04/25/2016
RECEIVING PARTY DATA		
Name:	LIGHTSIDE TECHNOLOGIES, LLC	
Street Address:	1400 PRESTON ROAD	
Internal Address:	# 400	
City:	PLANO	
State/Country:	TEXAS	
Postal Code:	75093	
PROPERTY NUMBERS Total: 9		
	Property Type	Number
	Patent Number:	5999220
	Patent Number:	6370198
	Patent Number:	7474696
	Patent Number:	8228979
	Patent Number:	8374253
	Patent Number:	8842727
	Patent Number:	8873640
	Patent Number:	9113021
	Application Number:	14525142
CORRESPONDENCE DATA		
Fax Number:	(786)431-2229	
	<i>Correspondence will be sent to the e-mail address first; if that is unsuccessful, it will be sent using a fax number, if provided; if that is unsuccessful, it will be sent via US Mail.</i>	
Phone:	7864312228	
Email:	AINTERIAN@LEBFIRM.COM	
Correspondent Name:	LIPSCOMB, EISENBERG & BAKER, PL	
Address Line 1:	2 S. BISCAYNE BLVD.	
Address Line 2:	SUITE 3800	
Address Line 4:	MIAMI, FLORIDA 33131	

PATENT

503890234

REEL: 039173 FRAME: 0209

ATTORNEY DOCKET NUMBER:	1753-001
NAME OF SUBMITTER:	ALBERTO INTERIAN III
SIGNATURE:	/ALBERTO INTERIAN III/
DATE SIGNED:	06/27/2016
	This document serves as an Oath/Declaration (37 CFR 1.63).
Total Attachments: 5 source=Washino_MFI_Lightside_Assignment#page1.tif source=Washino_MFI_Lightside_Assignment#page2.tif source=Washino_MFI_Lightside_Assignment#page3.tif source=Washino_MFI_Lightside_Assignment#page4.tif source=Washino_MFI_Lightside_Assignment#page5.tif	

ASSIGNMENT OF PATENT AND ASSOCIATED RIGHTS

This Patent Assignment ("Assignment" or "Agreement") is by and between Kinya Washino of 80 Hamilton Street, Dumont, New Jersey 07624 ("Assignor"), Multi-Format, Inc., a corporation organized and existing under the laws of the state of New Jersey ("Multi-Format"), and Lightside Technologies, LLC ("Assignee"), a limited liability company organized and existing under the laws of state of Texas, and shall be effective as of the date it is last signed by a party hereto.

RECITALS

A. Assignor is the sole owner of the patents and patent applications set forth on Schedule A ("Patents");

B. Assignor is the sole owner of at least some of the Patents by way of assignment from Multi-Format; and

C. Assignor desires to assign to Assignee, and Assignee desires to accept from Assignor, his entire right, title and interest in and to the Patents, and the rights set forth below.

AGREEMENT

NOW THEREFORE, in view of the foregoing recitals, and for other good and valuable consideration, the receipt and sufficiency of which is hereby acknowledged, the parties hereto agree:

1. Assignment. Assignor hereby irrevocably conveys, transfers and assigns to Assignee, its successors and assigns, and Assignee hereby accepts, all of Assignor's rights, titles and interests in, to and under the following:

(a) the Patents and all continuations, continuations-in-part, divisionals, extensions, substitutions, reissues, re-examinations and renewals, of any of the foregoing, and any patents or patent applications from which any of them claim priority or that claim priority from any of them, and all other inventions set forth therein which Assignor possess any rights;

(b) all rights, privileges, and protections of any kind whatsoever of Assignor accruing under any of the Patents provided under the applicable law of any government's jurisdiction, by international treaties and conventions and otherwise throughout the world, including, but not limited to, the right to file foreign patent applications and license recordations, and all rights derived from agreements relating to the Patents granted by Assignor to any third party;

(c) any and all claims and causes of action, with respect to any of the Patents or Licenses, whether accruing before, on or after the Effective Date, including, without limiting the generality of the foregoing, all rights to and claims for damages, restitution and injunctive and other legal and equitable relief for past, present and future infringement, misappropriation, violation, misuse, breach or default.

2. Recordation and Further Actions.

(a) Each of Assignor and Multi-Format authorizes the Commissioner for Patents for the United States Patent and Trademark Office ("USPTO") and the appropriate officers of the USPTO and all other jurisdictions in which any of the Patents are or may be recorded, registered or pending, to record and register this Patent Assignment upon request by Assignee. Each of Assignor and Multi-Format hereby grants Assignee a limited power of attorney to prepare and execute any and all such documents as may be necessary to perfect and record this Assignment with the USPTO, or any other government body or intellectual property registrar. Additionally, if Assignee reasonably believes it is desirable or necessary, each of Assignor and Multi-Format shall execute any and all documents, including assignments, transfers and related powers of attorney, and take all other further actions as may be necessary or reasonably requested by Assignee to effect, record, perfect or enforce the transfers set forth in this Patent Assignment and ensure that all right, title and interest in and to the Patents and all registrations and recordations thereof, are properly assigned to Assignee, its successors and assigns in accordance with this Patent Assignment. Each party shall bear its own costs incurred while performing its obligations under this Section 2(a).

(b) Without limiting any of the foregoing provisions of this Section 2, each of Assignor and Multi-Format hereby warrants and represents that he, it, his or its employees, consultants, directors and agents shall testify in connection with any administrative or legal proceedings affecting any right, title, interest or benefit of Assignee in, to or under the assigned Patents and perform any other acts as Assignee may deem reasonably necessary or desirable to carry out the intents and purposes of this Patent Assignment. Assignee shall reimburse Assignor or Multi-Format for all costs reasonably incurred by Assignor while performing its obligations to testify under this Section 2(b).

(c) Each Assignor and Multi-Format further agrees to: (i) cooperate with Assignee in the enjoyment of the rights transferred herein; (ii) execute, verify, acknowledge and deliver all such further papers, including further instruments of transfer; and (iii) perform such other acts as Assignee lawfully may request to exercise its any or all of its rights, title, or interest acquired under this Agreement.

3. General.

(a) Entire Agreement. This Assignment, together with all related exhibits and schedules, constitute the sole and entire agreement of the parties with respect to the subject matter contained herein and therein, and supercede all prior understandings and agreements, both written and oral, with respect to such subject matter.

(b) Recitals. The recitals set forth above are incorporated herein by reference and made a part of this Agreement.

(c) Successors and Assigns. This Agreement shall be binding upon and shall inure to the benefit of the parties' successors and assigns.

(d) Interpretation. When a reference is made in this Agreement to Sections, Exhibits, Appendices or Schedules, such reference shall be to a Section of or Exhibit, Appendix or

Schedule to this Agreement unless otherwise indicated. The headings contained in this Agreement are for reference purposes only and shall not affect in any way the meaning or interpretation of this Agreement. Whenever the words "include," "includes" or "including" are used in this Agreement, they shall be deemed to be followed by the words "without limitation". The phrases "the date of this Agreement," "the date hereof" and terms of similar import, unless the context otherwise requires, shall be deemed to refer to the Effective Date. Words used herein, regardless of the number and gender specifically used, shall be deemed and construed to include any other number, singular or plural, and any other gender, masculine, feminine, or neuter, as the context requires.

(e) **Reformation and Severability.** If any section or provision of this Agreement is held to be invalid or unenforceable, to the maximum extent permitted by law, the court shall equitably reform the section or provision to give effect to the parties' intents and purposes. Each section or provision of this Agreement constitutes a separate and distinct undertaking. If any such unenforceable section or provision is not reformable, the court shall sever it from this Agreement and give effect to the remaining enforceable sections and provisions.

(f) **Governing Law.** All matters arising out of or relating to this Patent Assignment shall be governed by and construed in accordance with the laws of the United States and the internal laws of the state of Michigan without giving effect to any choice or conflict of law provision or rule (whether of the state of Michigan or any other jurisdiction).

(g) **Jurisdiction and Venue.** Venue for any dispute arising out of this Agreement shall only be proper in courts of competent jurisdiction in Oakland County, Michigan, and each party submits to the jurisdiction of the foregoing courts.

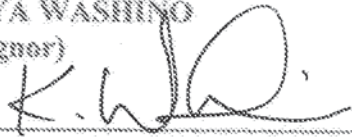
(h) **Representation on Authority of Parties/Signatories.** Each person signing this Agreement represents and warrants that he or she is duly authorized and has legal capacity to execute and deliver this Agreement. Each party represents and warrants to the other that the execution and delivery of the Agreement and the performance of such party's obligations hereunder have been duly authorized and that the Agreement is a valid and legal agreement binding on such party and enforceable in accordance with its terms. Further, each party represents and warrants that it is not prohibited to enter into this agreement, or in any way encumbered in performing such party's obligations hereunder, by any contractual, legal, or other third party or governmental obligation.

(i) **Further Actions.** Each party agrees to take all such other and further actions as may be necessary to carry out the intents and purposes of this Agreement.


[SIGNATURE PAGE TO FOLLOW]

IN WITNESS WHEREOF, the parties set forth their hands below.


KINYA WASHINO
(Assignor)

By: 
Kinya Washino, Individually
Dated: April 25, 2016.

LIGHTSIDE TECHNOLOGIES, LLC
(Assignee)

By: 
Marc Shulman, Managing Member
Dated: April 25, 2016.

MULT-FORMAT, INC
(Multi-Format)

By: 
Kinya Washino, President
Dated: April 25, 2016.

SCHEDULE A

- * 5,999,220 United States (Multi-Format Audio/video Production System with Frame Rate Conversion): Expansion of the US 5,537,157 patent claims to cover asynchronous applications such as Internet movie downloading. Issued 12/7/99. Filed 4/7/97.
- * 6,370,198 United States (Wide Band Multi-Format Audio-Video Production System with Frame Rate Conversion): (A continuation of the 5,999,220). Issued 2/9/02. Filed 5/6/99.
- * 7,474,696 United States (Wide Band Multi-Format Audio-Video Production System with Frame-Rate Conversion) (A continuation of the 5,999,220). Issued 1/06/09. Filed 4/05/02.
- * 8,228,979 United States (Wide Band Multi-Format Audio-Video Production System with Frame-Rate Conversion). (A continuation of the 7,474,696, the 6,370,198, and the 5,999,220). Issued 7/24/12. Filed 01/05/09
- * 8,374,253 United States (Wide Band Multi-Format Audio-Video Production System with Frame-Rate Conversion) (A continuation of the 8,228,979, the 7,474,196, the 6,370,198, and the 5,999,220) Issued 02/12/13. Filed 05/24/11
- * 2,332,049 Canadian version of US 6,370,198 (Wide Band Multi-Format Audio-Video Production System with Frame Rate Conversion): Issued 01/03/06
- * 2,243,859 Canadian (Multi-Format Audio/video Production System with Frame Rate Conversion). Issued 12/27/2005. Filed 01/03/2001.
- * 2,286,194 Canadian version of US 5,999,220 (Multi-Format Audio/video Production System with Frame Rate Conversion). Issued 01/10/06
- * CN 1306724 (also published as CN1127852 C) Chinese version of US 6,370,198 (Wide Band Multi-Format Audio-Video Production System with Frame Rate Conversion). Issued 11/27/2009. Filed 05/07/1999.
- * 8,842,727 United States (Wide-Band Multi-Format Audio-video System with Frame-Rate Conversion) (Continuation of US 8,228,979) Issued 09/23/14. Filed 07/12/12.
- * 8,873,640 United States (Wide-Band Multi-Format Audio-video System with Frame-Rate Conversion) (Continuation of US 8,228,979) Issued 10/28/14. Filed 01/29/13.
- * 9,113,021 United States (Wide-Band Multi-Format Audio/Video Production System with Frame-Rate Conversion) Production System with Frame-Rate Conversion) (Continuation of US 8,842,727) Filed 09/22/14.
- * Pending United States Application 14/525,142 (Wide Band Multi-Format Audio-Video Recording and Production System with Frame-Rate Conversion) (Continuation of US 8,873,640) Filed 10/27/14.
- * Pending European Application 96904562.4, EP publication EP997039 (Multi-Format Audio - Video Production System with Frame-Rate Conversion) (EU version of US 7,474,696) Filed 01/23/96.
- * Pending European Application 99922863.8, EP publication EP1084578 (Wide Band Multi-Format Audio - Video Production System with Frame-Rate Conversion) (EU version of US 6,370,198) Filed 05/07/99.