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WESTERN DISTRICT OF WASHINGTON
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UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF WASHINGTON
AT SEATTLE

IP INNOVATION L.L.C. and TECHNOLOGY LICENSING CORPORATION,

Plaintiffs,

vs.

REALNETWORKS, INC., and SNELL & WILCOX, LTD.,

Defendants.

No. C03-2428P

COMPLAINT

JURY DEMAND

03-CV-02428-CMP

Plaintiffs, IP Innovation, L.L.C.("IP Innovation"), and Technology Licensing Corporation ("TLC"), complain of defendants, Snell & Wilcox, Ltd., ("Snell & Wilcox"), and RealNetworks, Inc. ("RealNetworks"), as follows:

ORIGINAL

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Mines
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701 Pike Street
Seattle, Washington 98101-3927
(206) 292-9988

JURISDICTION AND VENUE

1. This is a claim for patent infringement arising under the patent laws of the United States, 35 U.S.C. § 271. This Court has exclusive jurisdiction over the subject matter of this action under 28 U.S.C. § 1338(a).

2. IP Innovation, L.L.C. ("IP Innovation") is a limited liability company, with a principal place of business at 500 Skokie Boulevard, Suite 585, Northbrook, Illinois 60062.

3. TLC is a corporation organized and existing under the laws of the State of California and has a principal place of business at 110 Knowles Drive, Los Gatos, California 95032.

4. IP Innovation and TLC together own and have standing to sue for infringement for United States Patent No. 4,305,091 B2, entitled "Electronic Noise Reducing Apparatus and Method," which issued December 8, 1981, and which was issued a reexamination certificate on February 10, 1998, (the "'091 patent"), for United States Patent No. 4,573,070, entitled "Noise Reduction System For Video Signals," which issued February 25, 1986 (the "'070 patent"), for United States Patent No. 4,723,166, entitled "Noise Adjusted Recursive Filter," which issued February 2, 1988 (the "'166 patent"), and for United States Patent No. 4,803,547, entitled "Adaptive Comb Filter System For Processing Video Signals," which issued February 7, 1989 (the "'547 patent").

5. Snell & Wilcox is a corporation organized and existing under the laws of the United Kingdom, and having its primary place of business at 6 Old Lodge Place, St. Margarets, Twickenham, TW1 1RQ, United Kingdom.

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6. RealNetworks is a corporation organized and existing under the laws of the State of Washington, and having its headquarters at 2601 Elliott Avenue, Suite 1000, Seattle, Washington 98121.

7. Snell & Wilcox and RealNetworks transact business in this judicial district by importing, selling, offering to sell or using video broadcast systems or components thereof having adaptive comb filters for decoding, frame synchronization and noise reduction purposes, that are the subject of at least claims 28 of the '091 patent, at least claims 1, 24, and 42 of the '070 patent, at least claim 1 of the '166 patent, and at least claim 1 of the '547 patent or by practicing methods or selling products produced by practicing methods covered by one or more claims of the patents at issue or by inducing others to infringe the patent through the use of such broadcast systems, or by otherwise conducting other business in this judicial district.

8. On May 13, 2003, IP Innovation and TLC filed suit against RealNetworks and Snell & Wilcox for infringement of the patents listed above in the United States District Court for the Northern District of Illinois, where IP Innovation has its principal place of business. On May 20, 2003 the Honorable Ruben Castillo *sua sponte* dismissed that complaint without prejudice, giving IP Innovation leave until July 30, 2003 to refile the complaint in defendant RealNetworks' home district. Judge Castillo's Minute Order reads as follows:

> After a careful review of this recently filed complaint, said complaint is dismissed without prejudice for failure to establish jurisdiction or appropriate venue in this district. Neither defendants [sic] are citizens of this district and only one of the two plaintiffs reside in this district. None of these parties have any unique contracts [sic] with this district. Therefore venue and jurisdiction appears to be more appropriate in the defendant Realnetworks, Inc.'s home district of Washington. Plaintiffs are given until 7/30/03 to refile this lawsuit in the district of Washington or file a brief and or [sic] an amended complaint which explains why jurisdiction and venue is appropriate in this district[.]

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(See Exhibit E, Plaintiffs' May 13, 2003 complaint, and Exhibit F, Minute Order.)

9. Venue is proper under 28 U.S.C. § 1391 (d) and § 1400(b).

PATENT INFRINGEMENT

10. As set forth above, IP Innovation and TLC together own and have standing to sue for infringement of United States Patent Nos. 4,305,091 B2, 4,573,070, 4,723,166 and 4,803,547. Snell & Wilcox and RealNetworks have infringed at least claims 28 of the '091 patent, at least claims 1, 24, and 42 of the '070 patent, at least claim 1 of the '166 patent, and at least claim 1 of the '547 patent by making, using, importing, selling and offering to sell, and by inducing, aiding and abetting, encouraging and contributing to others' use within the United States of various video broadcast systems or components thereof having adaptive comb filters for decoding, frame synchronization and noise reduction purposes, including but not limited to video broadcast systems or components thereof having adaptive comb filters for decoding, frame synchronization and noise reduction purposes, such as certain IQ Modular Series products.

11. Other products sold or used by the defendants, and not yet identified, are also believed to be covered by the asserted claims of the '091, '070, '166 and '547 patents.

12. Such infringement has injured IP Innovation and TLC and they are entitled to recover damages, under the law, adequate to compensate them for the infringement that has occurred, but in no event less than a reasonable royalty.

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13. Upon information and belief, the defendants' infringement has been willful and wanton with full knowledge of the '091, '070, '166 and '547 patents and without a reasonable investigation or legal advice.

WHEREFORE, plaintiffs, IP Innovation and TLC, respectfully request judgment against the Defendants and their subsidiaries and affiliates as follows:

A. An award of damages adequate to compensate IP Innovation and TLC for the infringement that has occurred, together with prejudgment interest from the date infringement of the '091, '070, '166 and '547 patents began;

B. Any other damages permitted by law, including any for willful infringement, under 35 U.S.C. § 284;

C. A finding that this case is exceptional and an award to IP Innovation and TLC of its attorneys' fees as provided by 35 U.S.C. § 285;

D. An injunction permanently prohibiting the defendants, their customers and all persons in active concert or participation with it, from further acts of infringement of the'166 and/or '547 patents; and

E. Such other and further relief as this Court or a jury may deem proper and just.

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JURY DEMAND

Plaintiffs demand a trial by jury.

DATED this 30th day of July, 2003.

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By Robert F. Lopez
Robert F. Lopez, WSBA #21057

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EXHIBIT A

United States Patent [19]

Cooper

Best Available Copy

[11] **4,305,091**

[45] **Dec. 8, 1981**

[54] **ELECTRONIC NOISE REDUCING APPARATUS AND METHOD**

[76] Inventor: J. Carl Cooper, 1101 Continentals Way #109, Belmont, Calif. 94002

[21] Appl. No.: 30,288

[22] Filed: Apr. 16, 1979

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 763,904, Jan. 31, 1977, abandoned.

[51] Int. Cl.³ H04N 9/535; H04N 5/21; H04B 15/00

[52] U.S. Cl. 358/36; 358/167; 328/165

[58] Field of Search 358/36, 167, 37, 31, 358/166; 328/165, 167; 455/303, 304, 307, 311, 312; 364/515

[56] **References Cited**

U.S. PATENT DOCUMENTS

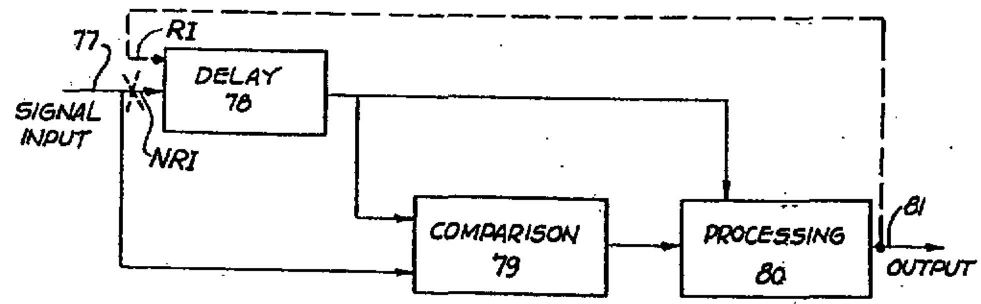
3,009,016	11/1961	Graham	358/167
3,700,812	10/1972	Springett	325/473
3,875,584	4/1975	Fletcher et al.	358/36
3,995,108	11/1976	Morrison	358/162
4,009,334	2/1977	Sypula	358/36
4,058,836	11/1977	Drewery et al.	358/167
4,064,530	12/1977	Kaiser	358/36
4,072,984	2/1978	Kaiser	358/31

Primary Examiner—John C. Martin
Attorney, Agent, or Firm—Woodling, Krost & Rust

[57] **ABSTRACT**

The present disclosure teaches a method and apparatus for reducing noise in an electronic signal. These inventive conceptions include a means for delaying the electronic signal and a comparison means for comparing the delayed signal to the signal in its undelayed condition. Means are provided for processing the signal in response to the comparison means to remove at least part of the noise.

30 Claims, 28 Drawing Figures



EXHIBIT

A

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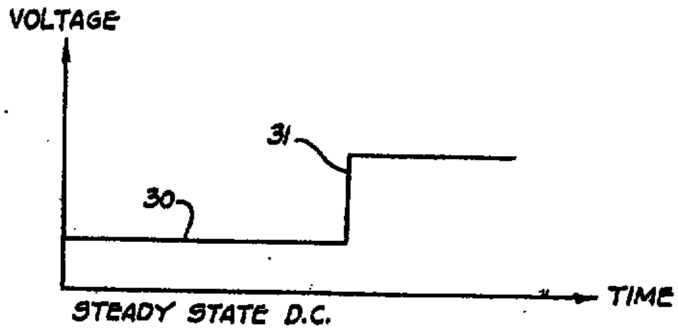


Fig. 1

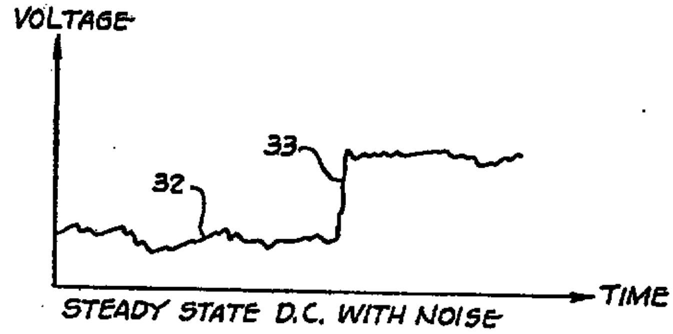


Fig. 2

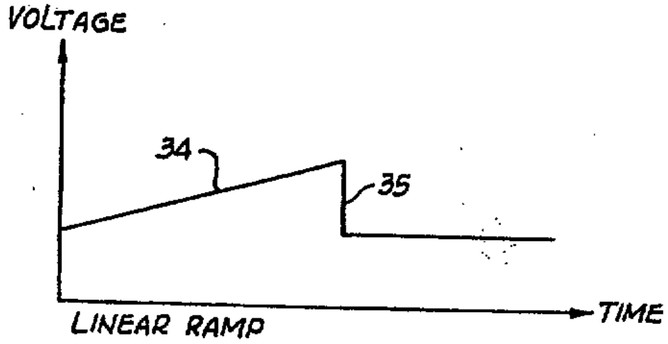


Fig. 3

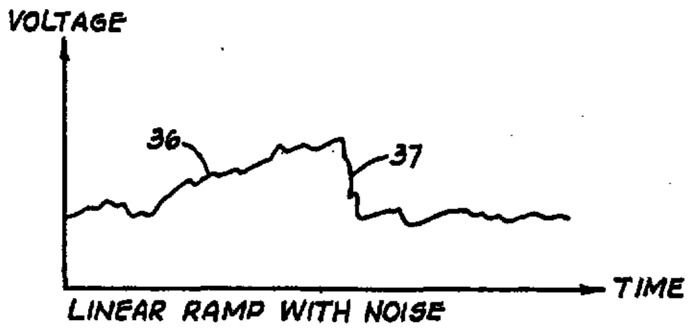


Fig. 4

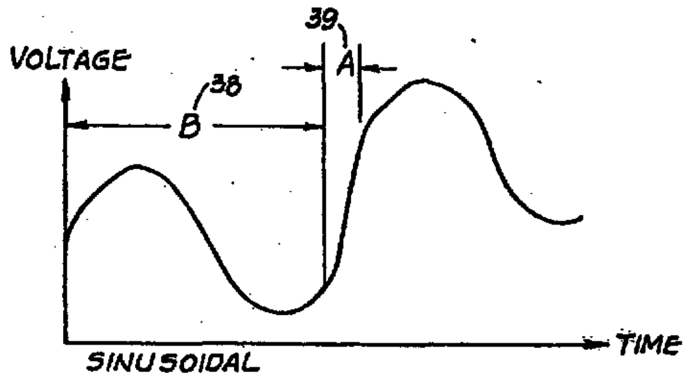


Fig. 5

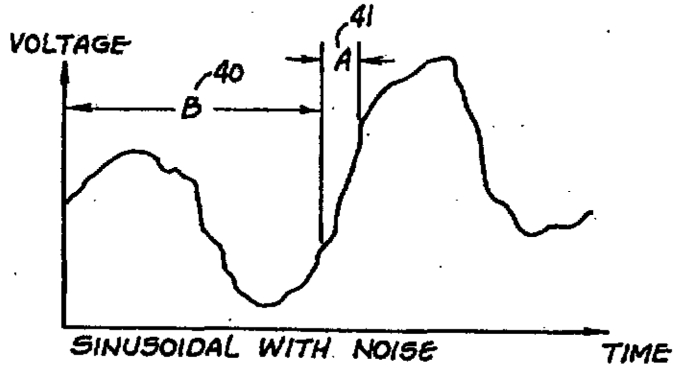


Fig. 6

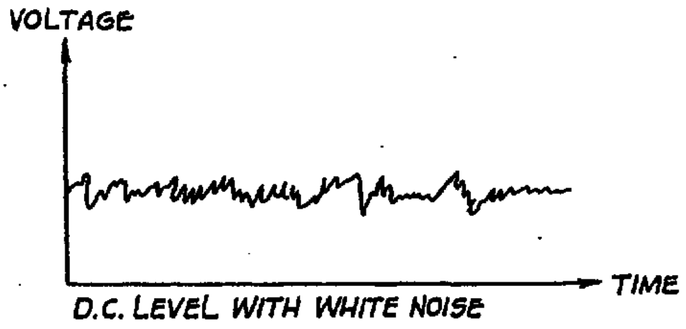

VOLTAGE
TIME
D.C. LEVEL WITH WHITE NOISE

Fig. 7

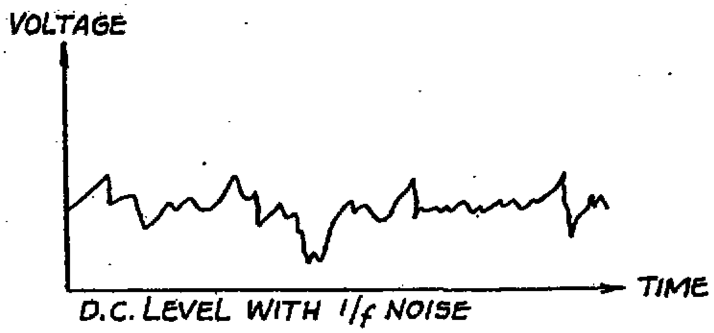

VOLTAGE
TIME
D.C. LEVEL WITH 1/f NOISE

Fig. 8

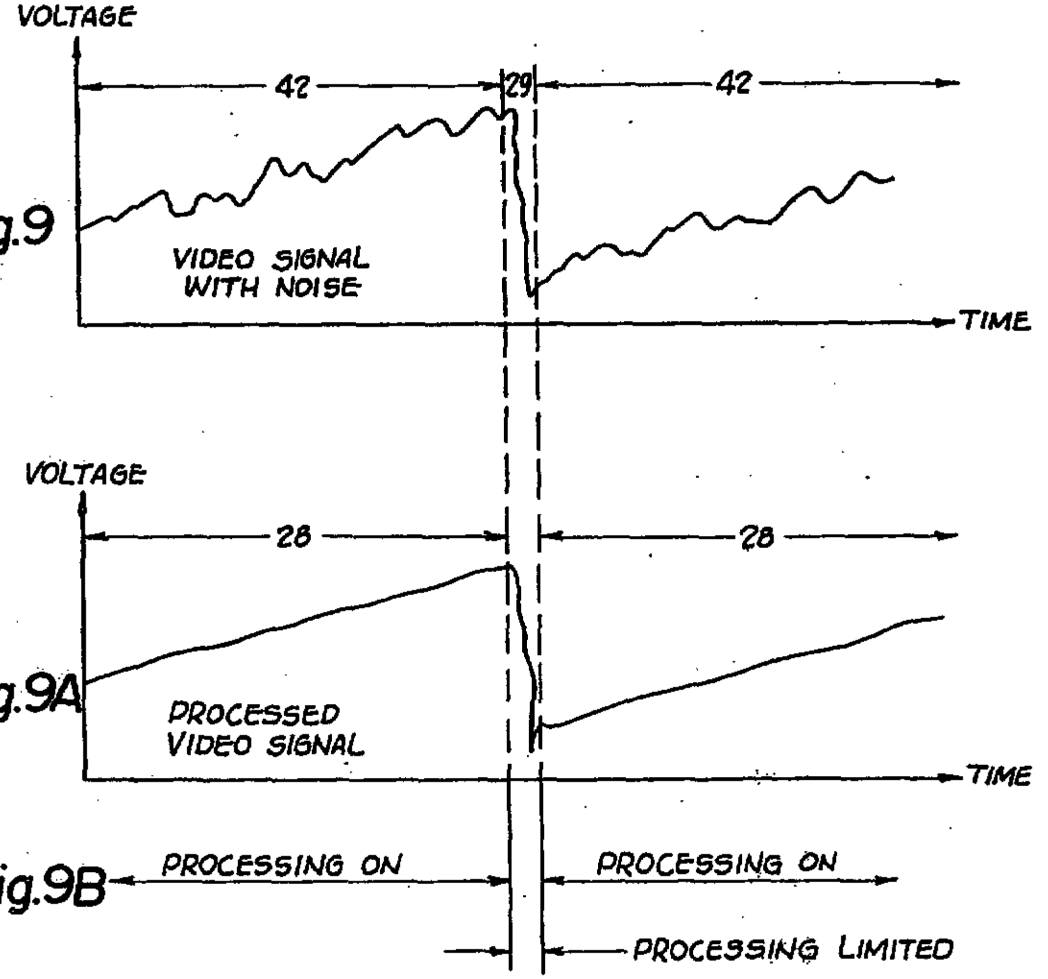


Fig.9

Fig.9A

Fig.9B

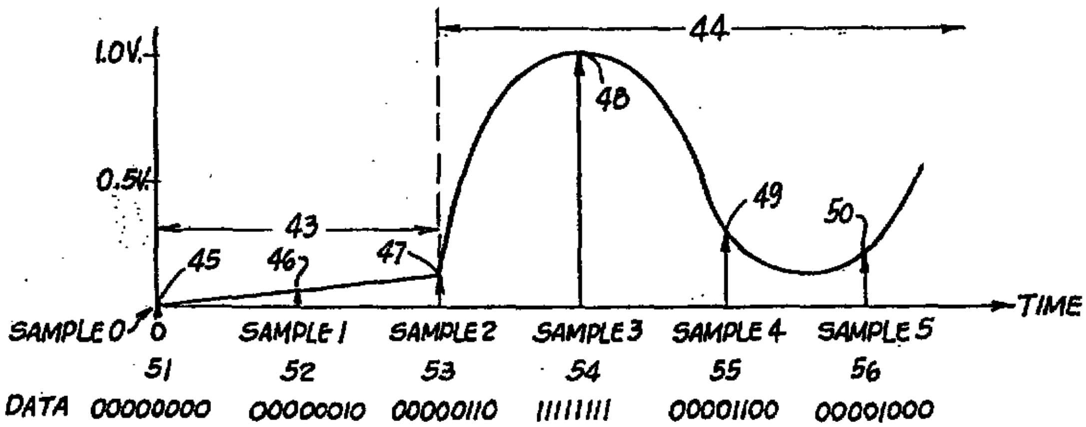


Fig.10

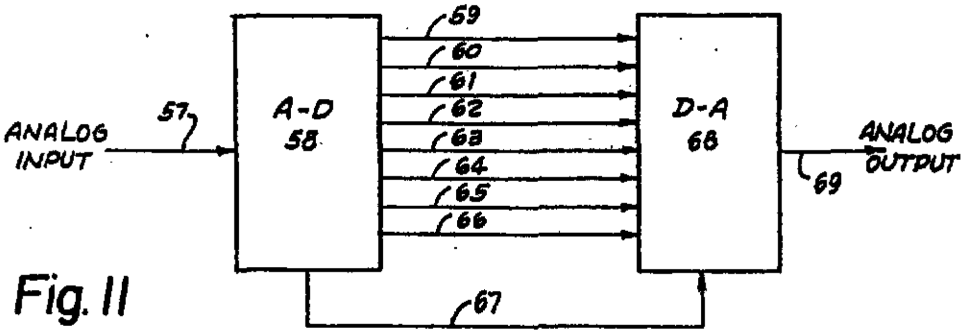


Fig. 11

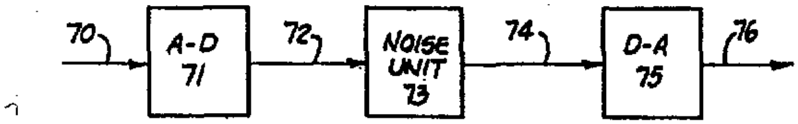


Fig. 12

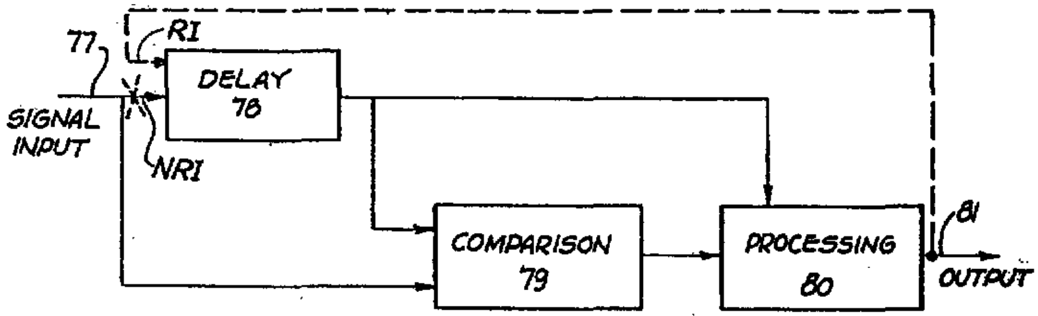


Fig. 13

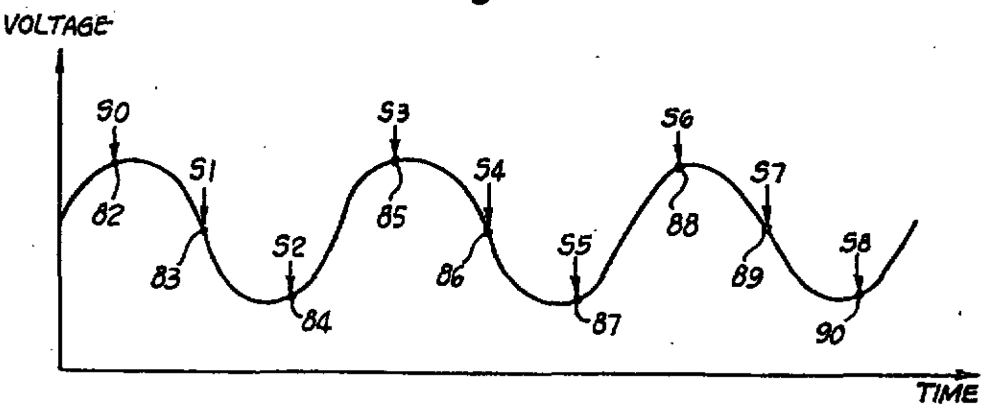


Fig. 14

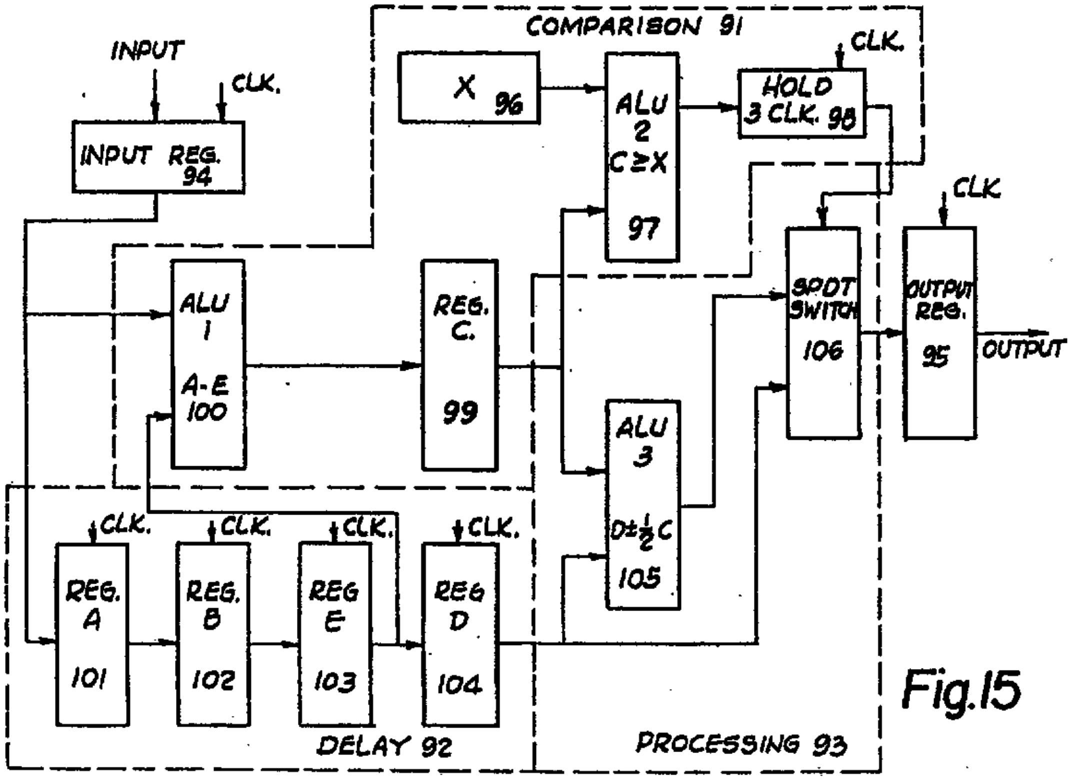

COMPARISON 91
INPUT
CLK.
INPUT REG. 94
X 96
ALU 2 C≥X 97
HOLD 3 CLK. 98
SPDT SWITCH 106
OUTPUT REG. 95
OUTPUT
ALU 1 A-E 100
REG. C. 99
ALU 3 D±½C 105
REG. A 101
REG. B 102
REG E 103
REG D 104
DELAY 92
PROCESSING 93

Fig.15

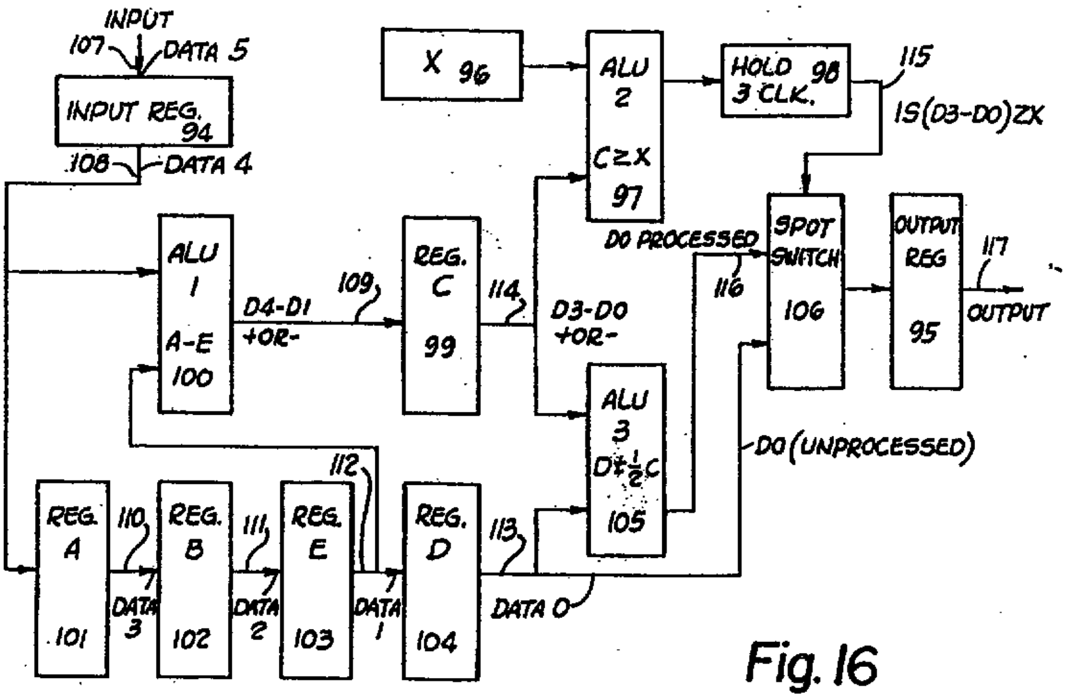

INPUT
107
DATA 5
INPUT REG. 94
108
DATA 4
X 96
ALU 2 C≥X 97
HOLD 3 CLK. 98
115
IS(D3-D0)≥X
SPOT SWITCH 106
OUTPUT REG 95
117
OUTPUT
D0 PROCESSED
116
ALU 1 A-E 100
D4-D1 +OR-
109
REG. C 99
114
D3-D0 +OR-
ALU 3 D±½C 105
D0 (UNPROCESSED)
112
REG. A 101
110
DATA 3
REG. B 102
111
DATA 2
REG. E 103
DATA 1
REG. D 104
113
DATA 0

Fig. 16

7404 INVERTER

INPUT IS INVERTED AND APPEARS AT THE OUTPUT.

Fig. 17

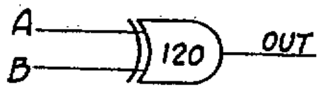
7400 NAND

Fig. 18

OUTPUT OBEYS THE FOLLOWING TRUTH TABLE.

A	B	OUT
0	0	1
0	1	1
1	0	1
1	1	0

IF LINE A IS HIGH THE OUTPUT BECOMES LINE B INVERTED



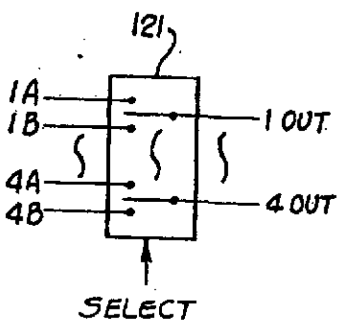
7486 EXCLUSIVE OR

Fig. 19

OUTPUT OBEYS THE FOLLOWING TRUTH TABLE.

A	B	OUT
0	0	0
0	1	1
1	0	1
1	1	0

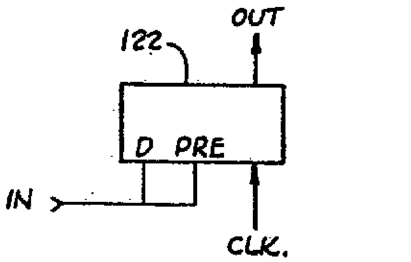
IF A IS LOW THE OUTPUT IS THE SAME AS B. IF A IS HIGH THE OUTPUT IS OPPOSITE OF B (AN INVERTER THAT CAN BE BYPASSED).



74157 LINE SELECT

AN ELECTRONIC 4 DOUBLE THROW SWITCH CONTROLLED BY A SELECT INPUT. THE OUTPUT IS SWITCHED TO ONE OR THE OTHER INPUT BY THE SELECT LINE.

Fig. 20

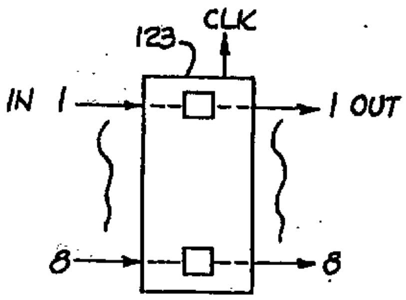


7474 D TYPE FLIP FLOP

FUNCTIONAL BLOCK

USED TO PASS ANY LOW SIGNAL FROM INPUT TO OUTPUT IMMEDIATELY. DELAYS ANY HI INPUT UNTIL CLK. CHANGES FROM LOW TO HI.

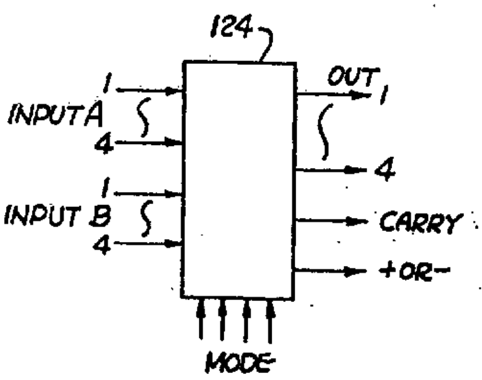
Fig. 21



74198 SHIFT REGISTER

STORES WHAT IS PRESENT AT INPUT AND MAINTAINS THAT DATA AT OUTPUT. STORAGE TAKES PLACE WHEN CLK GOES FROM LOW TO HI AND OUTPUT WILL REMAIN THE SAME EVEN IF INPUT IS REMOVED.

Fig. 22



74181 ARITHMETIC LOGIC UNIT

A.L.U. PREFORMS ADDITION, SUBTRACTION, ETC. ON 2,4 BIT BINARY NUMBERS- FUNCTION (ADD, SUB., ETC.) IS CONTROLLED BY 4 MODE CONTROL LINES. A CARRY OUTPUT IS PROVIDED AND UNITS MAY BE CASCADED TO COMPUTE NUMBERS LARGER THAN 4 BITS. IN SUBTRACTION THE CARRY OUTPUT INDICATES WHETHER THE OUTPUT IS INVERTED OR NORMAL. EXTERNAL INVERTERS (7486) MUST BE SWITCHED IN OR OUT IN ORDER TO CORRECT THE INVERSION, AN EXTRA OUTPUT TELLS WHETHER THE DIFFERENCE IS + OR - (TELLS WHETHER A>B).

Fig. 23

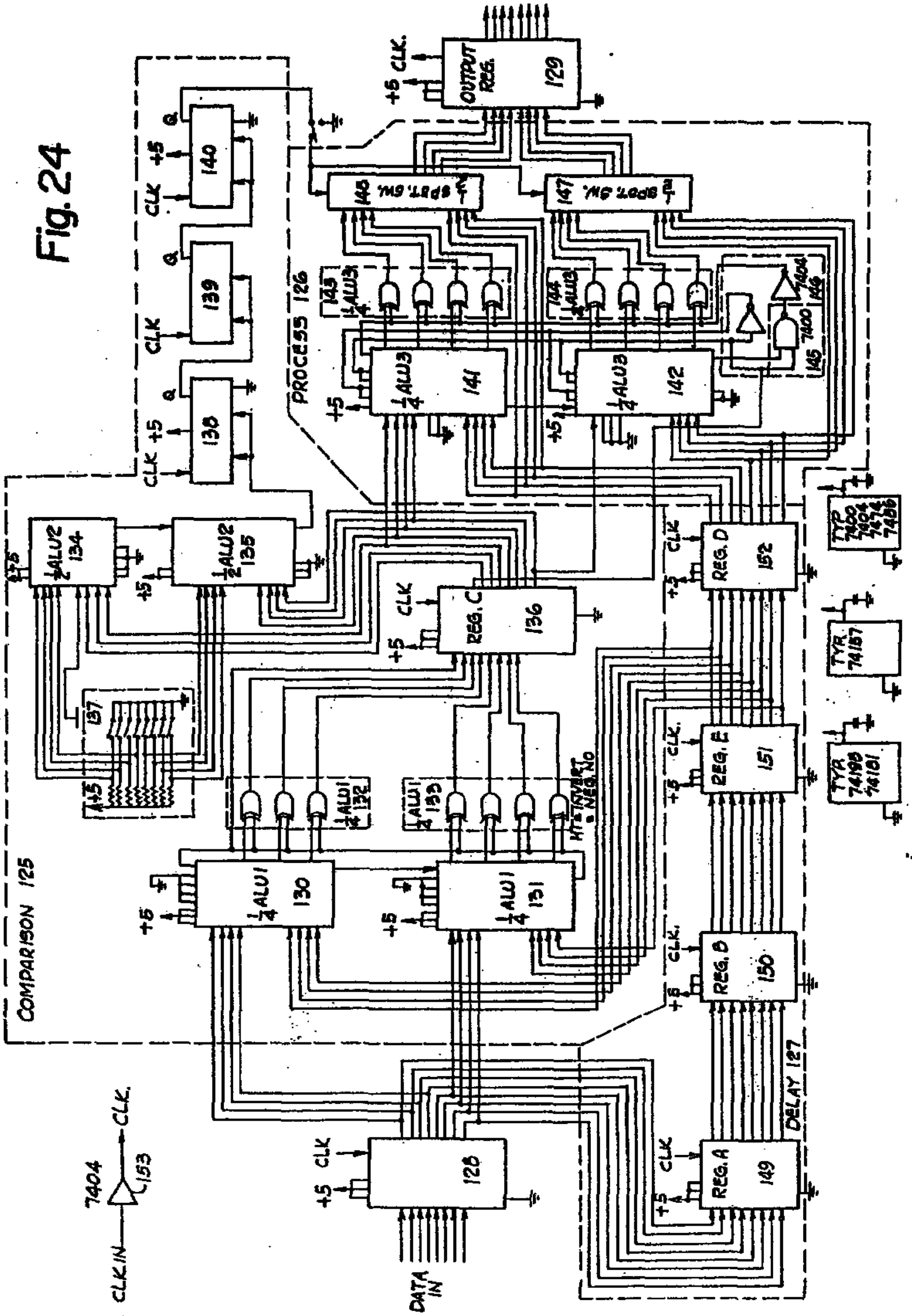

OUTPUT REG. 129
CLK
+5
140
139
138
Q
SPST. SW. 146
SPST. SW. 147
PROCESS 126
¼ ALU3 141
¼ ALU3 142
¼ ALU3 143
¼ ALU3 144
7404
7400
145
146
½ ALU2 134
½ ALU2 135
REG. C 136
REG. D 152
REG. E 151
REG. B 150
REG. A 149
137
¼ ALU1 130
¼ ALU1 131
¼ ALU1 132
¼ ALU1 133
COMPARISON 125
DELAY 127
128
DATA IN
CLK IN
153
TYP. 7400 7404 7474 7486
TYP. 74187
TYP. 74198 74181

Fig. 24

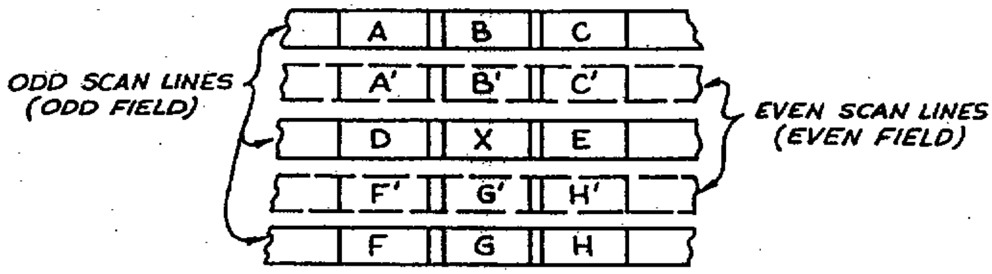

ODD SCAN LINES
(ODD FIELD)
A
B
C
A'
B'
C'
D
X
E
F'
G'
H'
F
G
H
EVEN SCAN LINES
(EVEN FIELD)

FIG. 25

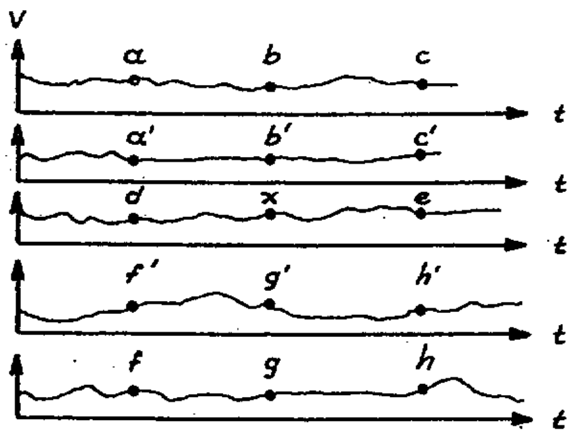

V
a
b
c
t
a'
b'
c'
d
x
e
f'
g'
h'
f
g
h

FIG. 26

ELECTRONIC NOISE REDUCING APPARATUS AND METHOD

This application is a continuation in part of my U.S. Pat. Application Ser. No. 763,904 filed Jan. 31, 1977 entitled "Electronic Noise Reducing Apparatus And Method", now abandoned.

Electronic Noise is a physical property which is at times most troublesome to electronic circuitry. In practical applications, unwanted noise is added or increased in a wanted electronic signal every time that signal passes through any resistance. Since all electronic devices contain some resistance, they are noise producers, and when amplification is added to these devices, the noise is amplified along with the wanted signals. While it is possible to design electronic circuitry to minimize the effects of noise on the wanted electronic signal, it is impossible to completely eliminate these effects. As the wanted signal passes through more and more stages of circuitry, the unwanted noise will always increase, i.e. the signal to noise ratio (S/N) will decrease until at some point, no matter how well designed the circuitry, the signal will become unacceptable because of the noise. In order to improve on this situation, it is obvious that the noise on the electronic signal must be removed at some stage in order to prevent the eventual destruction of the signal. In order to demonstrate the problem and its solution, I have selected television video signals.

Other objects and a fuller understanding of this invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a typical steady state D.C. electronic signal graph with detail 31;

FIG. 2 is a typical steady state D.C. signal 32 with detail 33 as in FIG. 1, after noise has been impressed on said signal and detail;

FIG. 3 is a typical electronic linear ramp signal 34 with detail 35;

FIG. 4 is a typical electronic linear ramp signal 36 with detail 37 as in FIG. 3 after noise has been impressed on said signal and detail;

FIG. 5 is a typical sinusoidal electronic signal 38 with detail 39;

FIG. 6 is a typical sinusoidal electronic signal 40 with detail 41 as in FIG. 5 after noise has been impressed on said signal and detail;

FIG. 7 is a typical D.C. electronic signal with noise of even power distribution throughout frequency domain (white noise). Refer to Motchenbacher and Fitchen "Low Noise Electronic Design" ©1973 John Wiley & Sons, Inc., New York, N.Y. for further explanation.

FIG. 8 is a typical D.C. electronic signal with noise having an inverse power distribution with respect to frequency (1/f noise). Refer to Motchenbacher and Fitchen "Low Noise Electronic Design" for further explanation.

FIG. 9 is a graph of a typical video signal 42 with detail 29 with said signal and detail having noise impressed on them;

FIG. 9A is a graph of a typical video signal as in FIG. 9 with noise removed from signal areas 28 which do not contain detail;

FIG. 9B is an indication of time durations during which processing is turned on, and limited, in noise removal circuitry. Note that FIGS. 9, 9A and 9B share a common time axis;

FIG. 10 is a graph of a typical signal containing a linear ramp 43 and a sinusoid wave 44, including typical sample points in sequence 45-50 used by an A-D converter and 8 bit binary data words 51-56 which are the output of the A-D which correspond to the voltage of the analog signal at the sample points 45-50 in sequence.

FIG. 11 is a block diagram of a typical 8 binary bit analog to digital to analog conversion set. The set is composed of an input 57 for the analog signal which is to be converted, the analog to digital converter 58, the output of the A-D comprised of 8 binary data lines 59-66 inclusive, the clock output 67, the digital to analog (D-A) converter 68, which converts the series of digital data words on lines 59-66, utilizing the clock on *line 67, to an analog circuit 69. The analog output 69* will correspond to the analog input 57 if the digital data on lines 59-66 is not changed or modified;

FIG. 12 is a block diagram of a typical digital noise *reducer unit which utilizes an A-D, D-A conversion set* for ease of operation. The reducer is composed of analog input 70 which corresponds to 57. FIG. 11; data lines and clock line 72 which correspond to 59-67 of FIG. 11, the actual noise reduction circuitry 73, data and clock outputs 74 from the noise reduction circuitry, similar to 59-67 of FIG. 11, D-A unit 75, which corresponds to 68 of FIG. 11, and analog output 76 which corresponds to 69 of FIG. 11.

FIG. 13 is a block diagram of noise reduction unit with the circuit input 77, the data delay block 78, the comparison block 79, the processing block 80 and the circuit output 81. Dashed line RI indicates the recursive input connection and NRI the nonrecursive connection for the delay block 78. For a nonrecursive system NRI is connected and RI is removed. For a recursive system NRI is disconnected and RI is connected.

FIG. 14 is a graph of a typical sinusoidal color subcarrier such as that in the National Television Standards Committee (NTSC) Color Television System, with A-D sample points 50-58 labeled 82-90 respectively;

FIG. 15 is a block diagram of prototype noise reduction unit having components grouped into 3 blocks, comparison block 91, including components 96, 97, 98, 99, 100, delay block 92 including components 101, 102, 103, 104, processing block 93 including components 105, 106, and output register 95 and input register 94 *shown for clarity. Parts listed are:*

- Number 96 identifies a binary number also known as the detail threshold, which may be set by a series of switches.
- Number 97 identifies an arithmetic logic unit similar to that in FIG. 23 set to determine if one input number is larger than another.
- Number 98 identifies a storage circuit for the output of 97, having a storage time 3 clock pulses, similar to that described in FIG. 21.
- Number 99 identifies a shift register for the output of 100 similar to that in FIG. 22.
- Number 100 identifies an arithmetic logic unit, set to subtract one number from another similar to that described in FIG. 23.
- Numbers 101-104 identify shift registers similar to that described in FIG. 22.
- Number 105 identifies an arithmetic logic unit set to add or subtract two numbers depending on a command from one of its inputs, similar to that described in FIG. 23.

Number **106** identifies an eight pole double throw electronic switch also known as a line selector similar to that described in FIG. 20.

FIG. 16 is the same block diagram as FIG. 15, showing the location of data words and internal calculations, at points 107–117, in a specific example;

FIG. 17 is a schematic symbol for a digital inverter 118 and an explanation of its function. For further details consult manufacturers information for a type 7404 Integrated Circuit (I.C.);

FIG. 18 is a schematic symbol 119 for a digital Nand gate and an explanation of its function. For further details consult manufacturers information for a type 7400 I.C.;

FIG. 19 is a schematic symbol 120 for a digital exclusive or gate with a brief explanation of its function. For further detail consult manufacturers information for a type 7486 I.C.;

FIG. 20 is a schematic symbol 121 for a digital line selector with a brief explanation of its function. For further details consult manufacturers information for a type 74157 I.C.;

FIG. 21 is a schematic symbol 122 for a digital D type flip flop with a brief explanation of its use. For further details consult manufacturers information for a type 7474 I.C.;

FIG. 22 is a schematic diagram 123 for a digital shift register (SR) with a brief explanation of its function. For further details refer to manufacturers specifications for a type 74198 I.C.;

FIG. 23 is a schematic diagram 124 for a digital arithmetic logic unit (ALU) with a brief explanation of its function. For further details refer to manufacturers specifications for a type 74181 I.C.;

FIG. 24 is a schematic diagram for prototype noise reduction circuit composed of comparison block 125 including ALU-1 130, 131, 132, 133, register C 136, ALU-2, 134, 135, number set switches 137, 3 clock delay 138, 139, 140 process block 126 composed of ALU-3 141, 142, 143, 144, 145, 146, and SPST switch 147, 148, delay block 127, composed of shift registers 149, 150, 151, 152, input register 128 and output register 129, and clock inverter 153. Components are:

Numbers 128, 136, 129, 149, 150, 151, 152 identify a 74198 shift register. See FIG. 22.

Numbers 130, 131, 134, 135, 141, 142 identify a 74181 ALU. See FIG. 23.

Numbers 153, 146 identify an inverter. See FIG. 17.

Numbers 132, 133, 143, 144 identify an Exclusive Or. See FIG. 19.

Numbers 147, 148 identify an SPST switch. See FIG. 20.

Number 145 identifies a NAND gate. See FIG. 18.

Numbers 138, 139, 140 identify a flip flop. See FIG. 21.

FIG. 25 is a representation of five scan lines taken at any point in a television raster and as viewed on a television CRT; and

FIG. 26 is a representation of the video waveforms which correspond to the scan lines of FIG. 25.

NOISE ESSAY

A study of noise which is prevalent in a video signal is necessary before one may attempt to reduce this noise. A great many engineers have devoted much time to the design of low noise circuitry in television cameras, video tape recorders, and video processing equipment; however, relatively few engineers have devoted their work to removing noise which has already been generated. It is believed that this lack of attention is primarily due to the common belief that once noise is generated, it cannot be removed, except by bandwidth limiting, which in its simple form eliminates or reduces resolution or detail. The present invention has come about after an in depth study and analysis of noise in video and audio signals over the past several years utilizing several different approaches. Among the methods used are spectrum analysis, waveform analysis, vector analysis (for phase encoded color signals) and observation of CRT displays. Most observations confirm the standard noise models which are discussed by Motchenbacher and Fitchen in their book *Low Noise Electronic Design*. Observation of noise on a video waveform which has been recorded, and replayed in a frozen time mode reveals a property of noise in the detail in that signal that is not commonly known. This property will be discussed later.

A steady state D.C. signal is shown in FIGS. 1, 2, 7 and 8 of the drawings, which exhibit normal noise, in white and 1/f domains. Bandwidth reduction will effectively decrese this noise, and if the reduction is severe enough, the noise will be virtually eliminated. See *Low Noise Electronic Design* for further details.

Noise on a linear or approximately linear ramp can be treated approximately the same as that of a steady state D.C. signal, except that bandwidth limiting cannot be as severe since it is necessary to pass the D.C. shift. See FIGS. 3 and 4. Noise anaylsis of a sine wave is somewhat more complex. See FIGS. 5 and 6. Most high frequency noise (primarily white and popcorn noise) can be effectively removed by band limiting above the frequency of the signal sine wave; however, 1/f noise can be especially troublesome in this mode. If the bandwidth is lowered further to suppress 1/f noise, then the signal will also be suppressed. Since color information in a National Television Standards Committee (NTSC) video signal is a sine wave which is phase and amplitude modulated, variations will be subjectively observed as color hue and saturation variations. These variations are very annoying to most observers; therefore, it is especially critical to preserve this sine wave formation. The mechanism for reducing noise on this signal must therefore be an averaging process, coupled with a band limiting process. The average would sample the sine wave in different spots, compute an average amplitude and phase and then correct the sine wave to these average values. Bandwidth limiting would reduce noise above the frequency of the sine wave. The averaging process also works well on low frequency noise and linear ramp signals, which could be treated as sinusoidal waves having no sinusoidal amplitude.

Analysis of recorded noise reveals that the subjective or visual noise in the color subcarrier is primarily dominated by noise of those frequencies near and far below subcarrier. The noise above subcarrier frequency is not seen as color noise because of the band pass effects of all state-of-the art color demodulators; this high frequency noise is observed as luminance noise. This luminance noise (with the color subcarrier spectrum removed) appears to be the same as the linear ramp noise of FIG. 4 and may be removed by band limiting or averaging.

For video signals, analysis and observation of all three signal cases in FIGS. 1–6 reveals that noise is visually most noticeable on low bandwidth portions (horizontal waveform portions of a video signal). This implies once again the an averaging process is needed to remove the noise, since averaging works better than bandlimiting at low frequencies.

Noise which has been impressed on a fast signal risetime such as in FIG. 6, component 41, tends only to modify the rise time and phase of the signal and are not readily visually apparent to the viewer.

While these statements may appear at first glance to be relatively unimportant, careful thought reveals that in the process of noise reduction, it is relatively unimportant to try to correct the noise in fast risetimes, such as FIG. 2, 33, FIG. 6,41. Therefore, noise in high frequency video components is not as important as that in low frequency components.

Noise in the slow risetime components such as in FIG. 4, item 36, tend to modify the amplitude of the signal causing readily apparent visual annoyance, therefore, this noise should be of prime concern to a designer who is involved in reducing visual noise effects. Since color information is both phase and amplitude encoded in an NTSC system, phase variations of the color subcarrier are also of concern. With an averaging technique this would be corrected.

THEORY OF NOISE REDUCTION

First, a plan for noise reduction of steady state D.C. and linear ramps is disclosed. Processing such as, but not limited to, averaging and bandwidth limiting to a low frequency for these waveforms will give a proportional decrease in white noise and a restricted decrease in excess, *1/f and other types of noise for these signals.* The amount of reduction can be rather dramatic since virtually all of the noise can be limited if the upper frequency of the bandwidth is severely limited. In video, any noise below 15kh$_z$ would appear as a line to line brightness change and any noise above 15kh$_z$ would be eliminated with sufficient processing. Obviously, with flat 15kh$_z$ filtering, there would be no signal data or information passed, so it is necessary to determine when high frequency signal information is present and remove, restrict, or turn off the processing during the *time this information is present. As discussed previously,* noise has a small visual effect on high frequency signal information, so that restricting the processing during this time to preserve the high frequency signal will have little visual effect on this portion of the signal. A graphic example of the above is given in FIGS. 9, 9A, 9B.

In order to process the video waveform, it is easiest to first convert the analog waveform to a digital representative of the waveform. This will make it easier to perform the mathematical averaging function. The conversion equipment, (See FIGS. 10 and 11), known as an analog to digital converter or A-D is commercially available and will not be discussed extensively. A representative input waveform to the A-D with a linear ramp 43 (FIG. 10) and a sinusoidal waveform 44 is shown. The A-D samples, 45–50, occur on the waveform at a frequency which is exactly 3 times the frequency of the color subcarrier. The output of the A-D is a series of 8 bit binary data words (FIG. 10, items 51–56) which occur at a rate which is exactly 3 times (3×) the color subcarrier frequency of the NTSC video signal. The individual data word is a binary number whose magnitude is directly related to the magnitude (voltage) of the incoming video waveform which it represents. In addition to these 8 bits of data, (FIG. 11, items 59–66), there is also available a square wave clock pulse (FIG. 11,67) whose negative to positive transition corresponds to the time when the 8 data bits may be stored or transferred with the assurance that they are valid and stable. This clock is provided because between sample points there is a period of uncertainty when the data is changing. There will be one clock pulse for each data word. A-D conversion techniques are by no means limited to 8 bits or 3× subcarrier nor is processing limited to NTSC video signals. Arithmetic operations such as addition which change the binary data, will change the analog waveform correspondingly, when the binary data is converted back to analog, in a digital to analog converter (D-A) FIG. 11, 68. For example, if all the data words are multiplied by 2, the analog output will be doubled. In order to utilize the digital domain to do the noise reduction, the actual digital circuitry to perform the arithmetic functions, such as comparing and averaging, is inserted in the binary data line between the A-D and D-A as in FIG. 12. The continual stream of 8 bit data words from the A-D is fed via a transmission line 72 to the noise unit 73 where the noise unit stores, compares and processes the data, then the data which has been processed is fed via a transmission line 74 to the D-A 75 where the digital data is converted back to analog data and applied to the output 76. A further discussion and detailed description of analog to digital and digital to analog conversion may be found by referring to U.S. Pat. No. 3,860,952. This patent covers the Consolidated Video Corp. Model No. 504A. Digital Time-base Corrector, utilizes the A-D to D-A process to facilitate time-base correction of a video signal. The A-D converter of this device was utilized to implement the invention herein disclosed.

THEORY OF OPERATION FOR COLOR PHOTOTYPE

In order to process color properly in the NTSC system, care must be taken to ensure that comparisons and computations are made only on samples of successive corresponding parts of the color subcarrier waveform (S.C.). Refer to FIG. 14 where a sine wave subcarrier is *shown with A-D sample spots (S0-S8)82–90 indicated* occurring at a 3 time S.C. rate. If comparisons are made between successive samples or data bits S0, S1, S2, etc., the difference in the value of these bits would be affected by both noise on the signal and the normal displacement due to the sinusoidal waveform. Obviously, it would be difficult to compute the amount of noise present by first correcting the bits to remove, or compensate for, the amount of color subcarrier present. Now consider the case where every bit is compared to the one 3 bits before i.e. S1 and S4, S2 and S5, etc. Clearly, in a steady signal, these bits will differ only by the noise difference between the two bits being compared. It is possible to average these samples to determine the average value of the samples and correct these subcarrier samples accordingly to remove the variation. Refer to FIGS. 15, 16 and FIG. 24 (FIGS. 15 and 16 are block diagrams of FIG. 24).

In order to analyze the operation of the noise reduction circuitry first assume that data word 1 (D1) (Refer specifically to FIG. 15) which corresponds to sample 1 (S1) is present at the input register when the first clock pulse arrives. Data word 1 (D1) will be transferred to the inputs of register A, 101 and ALU1, 100. The input register 94 is not necessary to the operation of the unit but does serve to minimize reflections on interconnecting lines. In a similar manner, at the next clock pulse, data word 1 will pass through Register B, 102, and with successive clock pulses, will pass through Register E, 103 and Register D, 104 and it will then appear at the input of ALU-3,105. In a similar manner, data words 2, 3, and 4 will also propagate through this string. Registers A, B, E, and D make up the delay block of the circuit. Now consider the time period just after clock pulse 4 when we have the situation shown in FIG. 16. We earlier assumed the output of register 94, point 108 is applied to the input of ALU-1,100. ALU-1 performs a subtraction function, subtracting Data Word 1 from Data Word 4. An output of ALU-1, point 109 gives the result of the subtraction and a second output from ALU-1 indicates whether the answer is positive or negative. This information is stored in Register C, 99 at the next clock pulse. We may assume that Register C already has stored the difference of the previous subtraction which was D3-DO. We may also assume that Register D has Data DO already stored. ALU-3,105 averages DO with the difference of D3 and DO from Register C according to the formula X=DO±(D3−DO)/2. The previously stored sign (+ or −) information for the quanity (D3−DO) is used by the ALU-3 in order to perform the plus or minus function so that if D3 is greater than DO, (D3−DO)/2 is added to DO and if D3 is smaller, (D3−DO)/2 is subtracted from DO. Since the difference between D3 and DO is the low frequency noise impressed on the waveform, the output of ALU-3 will be DO with ½ of the noise removed by this averaging process. This noise averaging process will continue indefinitely, processing every bit of information in the waveform. Now assume the case where the subcarrier has a long term D.C. shift in either a positive or negative direction. Since the difference in data is only corrected by a factor of 0.50, 3 clock pulses after the shift appeared at input point 108, the shift will appear at the output of ALU-3, 116, offset by ½ of the D.C. shift over the 3 clock period, but having the same slope as the input. For most applications, this shift is not noticeable to a viewer watching a picture monitor; if it were, further circuitry could compensate for it. Next assume the case where there is a step function or a large D.C. shift in the input waveform. This is where ALU-2,97 and the switch 106 come into operation. As soon as the new level and old level are subtracted by ALU-1, and subsequently clocked through Register C, the difference at point 114 is presented to the input of ALU-2. ALU-2 compares this difference to a fixed number X,96 which is set by a series of switches. If this difference is greater than the number X (detail threshold) ALU-2 sends a signal via point 115 to the switch, which switches it from the averaged output of ALU-3 to the uncorrected output of Register D. This effectively bypasses the processing action for the duration of the large level shift and preserves the detail of the risetime. The delay 98 between ALU-2 and the switch passes a switch off command instantly and delays the following switch on command for 3 clock pulses. This allows the detail to clock through the Register chain 101-104 to the output. ALU-1, REG C, ALU-2, X, the 3 CLK hold and their associated component make up the comparison block of the circuit. ALU-3 and the SPDT switch make up the processing block of the circuit. The output register 95 is not necessary to the operations but was included in order to minimize transmission line reflections in the prototype. The net effect of these three actions is that the noise on color subcarrier will be reduced by a factor of ½ for both steady state subcarrier and for slowly shifting color subcarrier, this will give an improvement of the signal in these areas. Those areas which are of fast risetime or high detail are bypassed. This preserves the detail, but no noise limiting will take place. Since noise is not as noticeable on these high detail areas, there would be little visual improvement of the signal anyway.

The overall effect of the processing, as viewed on the picture monitor will be that of a much more pleasing image which still has its original detail but has lost much of the objectionable graininess. The foregoing circuit was designed primarily to demonstrate the principle of noise reduction of an electronic signal. With a little study one sees that by adding more delay to increase the time between compared pulses to a single or one horizontal line, the net effect is to compare successive vertical picture elements. Also, it would be advantageous to compare several different adjacent picture elements so that comparisons could be made in a plane and make the bandwidth limiting and averaging more exacting. These methods would, of course, require much more circuitry to implement but can be accomplished under the teachings of the present invention.

The above analysis may be expanded to include processing of a television video signal. It will be seen that the comparison of adjacent picture elements, as described above, will be most useful. Referring to FIG. 25, one sees a representation of five scan lines which may be taken from any point in the television raster, as viewed on a television CRT. The scan lines are adjacent in location on the CRT but will not necessarily be sequential in time, depending on the type of television system used.

The lines in FIG. 25 are broken into segments A through H, A', B', C', F', G', H', and X which represent picture elements and may be equated to the digital samples which were previously discussed. By envisioning the picture elements of FIG. 25 as being segments or pixels of an actual display of a television scene, one may understand that elements D and E will be very similar to element X. The video waveforms which correspond to these scan lines might look like those in FIG. 26 where pixel A corresponds to voltage a, A' to a', etc. As previously discussed, in a noisy signal, by averaging pixels D and X a better approximation of the true noise free value of the waveform in the area around pixel X is obtained. Statistically, it can be shown that the greater the number of pixels which are compared to pixel X, and used to determine a new approximated value for the true value of pixel X before noise was added, the better that approximation will be.

This process of approximating or predicting the true value for a series of pixels, which have noise impressed on them, is called noise reduction. In a simple low cost form the circuitry used to accomplish noise reduction would compare pixel X to pixel D or E and if these pixels were approximately the same, the two would be averaged, giving a new value for pixel X. If the pixels were very different, no average would take place. The next pixel would then undergo the same process thus making the system continuous. This is the theory of operation of the device which has been previously described. An imporvement to this system would be to weight the averaging so that as the pixels get farther and farther apart in magnitude, the comparison pixel (D) would affect the prediction less and less. A formula which would accomplish this is $(1-Z)\times D+Z\times X$ where Z is the weighting factor and $Z=0.5$ for $D=X$

and increases as the magnitude of D−X increases until Z=1 where D≈−X.

Another logical improvement on this system is to use several adjacent pixels with each pixel being compared to X and then averaged with X according to some weighted averaging process. Of course, instead of an actual sum and divide type of average the hardware would operate more efficiently if a prediction of the amount of noise on pixel X were computed by inspecting the adjacent pixels with respect to pixel X, and this amount of noise subtracted from pixel X.

In the actual hardware implementation of a scheme where several adjacent pixels are compared to an input pixel, there are many considerations to be made. Referring again to FIG. 25 and assuming a NTSC system, those pixels which are truly adjacent to pixel X are A', B', C', D, E, F', G' and H'. Since pixels D and E are very close to pixel X in time, there is a good probability that any low frequency noise on pixel X will also be spread over pixels D and E. An average of pixels D and E to provide a reference for determining an estimate of the true value of X will be of limited use for low frequency noise. Pixels A', B', C', F', G' and H' are physically adjacent to X but in time are quite separate from X and therefore both low frequency and high frequency noise impressed on these adjacent pixels would be very random with respect to X. One may assume that pixels A', B' and C' may however contain different amounts of high frequency picture information or detail, so it would be wise to select only the one of the three that is closest in magnitude to X or to average all 3 of these pixels to remove or reduce this high frequency detail before computing a reference. A similar technique may be used for pixels F', G' and H', to provide another reference for comparison to pixel X.

In the NTSC system, in order to have the adjacent pixels A', B', C', F', G', and H' available for comparison at the same time as pixel X, a large delay or memory of approximately 1 field must be used. Large delays, with current techniques, are very costly. In order to reduce this cost, it would be possible to use pixels A, B, C, F, G, and H, which are taken from the same field as X, in place of those truly adjacent pixels which would come from the previous field. These pixels from the same field would still be relatively similar to pixel X and would have random noise impressed on them. A very good cost/performance tradeoff can be expected by using pixels which are not adjacent to the input pixel X, but are close to it, such as those pixels to the left and right of pixels D and E respectively.

In the previous discussion, no mention has been made of the order of processing the various pixels with respect to time. One variation of note relates to pixels which happened in time before the pixel which is currently being input to the system. Referring to FIG. 25, in the NTSC system, pixels A, B, C, and D as well as A', B', C', F', G', and H' would have happened before input pixel X, if one assumes pixel X is in the second field. It should be obvious that it would be quite easy to derive a recursive type of system so that those pixels which are used for a reference for estimating the true value of X have also been previously processed in order to remove part of the noise from them. This process would be easily accomplished by delaying the output of the device and using the output of the delay as the reference for the comparison to the input. Referring to FIG. 13, and assuming connection NR1 is deleted and R1 is connected to form a recursive system, the comparison block will now compare the delayed output signal to the input signal. The delay d output signal is a noise reduced version of the input signal which allows the input picture element to be compared to a noise reduced picture element which was previously input to the system. For example, in FIG. 25, any of the pixels A, B, C, D, A', B', C', F', G', or H' can be compared to pixel X with these pixels having been previously noise reduced, if it is assumed that pixel X is in the second field. It should be noted that in actual practice the signal delays through the processing means will contribute to the delay time between the two inputs to the comparison means, thus this delay must be subtracted from the delay means. This and other changes necessary to convert the noise reduction system from a nonrecursive to a recursive system are very similar to classic textbook treatment of digital filters. The processing means is so constructed that whenever the difference between the input signal and the delayed output signal is below a given threshold it provides an average of the input and delayed output signals. Otherwise it provides the equivalent of the input signal.

The principle of comparing two or more points on an electronic signal and mathematically processing the signal to remove the random noise on that signal is by no means limited to the field of television. Any electronic signal which has information of a periodic or predictable nature can be processed in this manner by selecting the delays such that signal elements having some predictable relationship can be compared to determine how well these elements fit their predicted value. For example, Radar signal elements which correspond to the same area of the display CRT on different sweeps could be compared. In the audio domain, most wanted audio is composed of repetitive bursts of frequencies. For any given frequency in the audio spectrum, a wanted piece of information will contain several cycles of this frequency. A random noise at this frequency would be composed of a very few cycles or less than one cycle. By comparing the signal to a point or several points which are integral cycle lengths apart at the frequency being processed, a prediction can be made as to how much noise a given cycle of information has on it. The number of other intelligent signals to which variations of this technique can be applied to are almost endless.

Actual electronic circuitry to accomplish these functions is shown in FIG. 24. This circuitry is typical of state of the art digital electronics and utilizes large scale integration components which are standard manufactured parts. A short functional explanation for each of these components is included in FIGS. 17–23. Manufacturers data sheets may be consulted for further information. It will be seen that the circuitry follows very closely the block diagrams given previously and the operational description given for the block diagram FIGS. 15 and 16 is the same as for the circuit of FIG. 24.

Actual circuit construction was made using computer type wire wrap techniques; however, printed circuit, hand wiring or any type of construction should work equally as well.

As used previously in these descriptions, the word Noise is meant to mean any unwanted disturbances superimposed upon a useful electronic signal that tends to obscure the information content of said electronic signal. Data shall refer to any signal to which intelligence may be assigned, and Detail shall refer to any element of a data signal which differs significantly from those elements which surround it. NTSC or National Television Standards Committe is at present an inactive organization which previously set up the television system currently in use in the U.S.

Although this invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. Apparatus for reducing noise on an input electronic signal, including in combination, delay means for delaying said input electronic signal to produce a delayed input signal, comparison means responsive to said input electronic signal and said delayed input signal which has the same bandwidth as said input electronic signal which comparison means may always determine if the difference between said signals is greater than a reference and processing means responsive to said comparison means and said delayed input signal to generate an output signal which is either an average of said input and delayed signals when said difference is less than said reference or said delayed signal otherwise, as determined by said comparison means.

2. Apparatus as claimed in claim 1 including means to determine the presence of detail in said input electronic signal as part of said comparison means.

3. Apparatus as claimed in claim 1 including means to remove detail in said delayed input signal as part of said comparison means.

4. Apparatus as claimed in claim 1 wherein said processing means operates in response to said comparison means to allow detail in said input electronic signal to be present on said output signal.

5. Apparatus for reducing noise on an input electronic signal which noise has a peak to peak amplitude which is less than the peak to peak amplitude of said input electronic signal, to a level lower than that at the input of said noise reducing apparatus, with said apparatus requiring no special processing of said input electronic signal before noise is added, including in combination delay means for delaying said input electronic signal to provide a delayed input signal, comparison means for comparing said delayed input signal to said input electronic signal to determine the difference thereof and comparing said difference to a reference which may allow the larger of said reference or said difference to always be determined, and processing means responsive to said comparison means and the full amplitude of said delayed input signal to select as the output signal either an average of said input electronic signal and said delayed signal if said difference is less than said reference or said delayed signal otherwise which selection is in response to said comparison means.

6. Apparatus as described in claim 5 whereby said comparison means operates to determine the presence of detail in said input electronic signal.

7. Apparatus as set forth in claim 5 wherein said comparison means includes means to remove detail from said input electronic signal.

8. Apparatus as set forth in claim 5 wherein digital representation of said input electronic signal is utilized.

9. Apparatus as set forth in claim 5 wherein said input electronic signal is a television video signal and said delay means allows said signals input to said comparison means to correspond to different locations on the television raster.

10. Apparatus as set forth in claim 9, including in combination, means for processing color subcarrier of said television signal.

11. Apparatus as set forth in claim 9, including in combination, means for comparing corresponding parts of NTSC video color subcarrier and means responsive to said subcarrier comparison for processing said NTSC color video subcarrier to reduce noise in said television video signal.

12. Apparatus for generating a noise reduced version of an input electronic signal which has been derived by scanning a spatial image, including in combination delay means for delaying the output signal which is output from said apparatus which output signal represents a noise reduced version of the electronic signal previously input to said apparatus, comparison means for comparing at least one element of said input electronic signal to at least one element of said delayed output signal to determine the difference in said input and said delayed output signal elements and to perform a threshold comparison to determine if said difference is greater than a threshold, said elements corresponding to different points on the scanned image, and processing means responsive to said difference and said threshold comparison of said comparison means and at least one element of said output signal which has been delayed to generate said output signal which represents an average of said input electronic signal and said delayed output signal when said difference is less than said threshold and with said output signal being equivalent to said input electronic signal otherwise.

13. Apparatus as set forth in claim 12 wherein said input electronic signal is a television video signal with said input and delayed output elements being picture elements and said delay means utilizes a delay that is less than one television frame and allows said delayed output signal picture element or elements to be adjacent to the picture element of the input electronic signal which is being input to said comparison means where said picture element or picture elements which are from said delayed output signal are derived from the same field as or the field previous to said input electronic signal picture element.

14. Apparatus as set forth in claim 12 wherein said input electronic signal is a television video signal with said input and delayed output elements being picture elements and said delay means utilizes a delay that is greater than one television frame and allows said delayed output signal picture element or elements to be adjacent to the picture element of the input electronic signal which is being input to said comparison means where said picture element or picture elements from said delayed output signal are derived from a field or fields which occurred previous to the field containing said input electronic signal picture element.

15. Apparatus as set forth in claim 13 wherein said delayed output and input elements are substantially close but not adjacent to each other in the television frame.

16. Apparatus as set forth in claim 12 wherein said delayed output and input elements are multiple elements which are selected from a rectangular area within a television frame.

17. Apparatus for removing noise from an input video signal which is a color television video signal, including in combination, delay means for delaying said input

video signal to provide a delayed input video signal corresponding to a point on the raster different from said input video signal, comparison means responsive to said delayed input video signal and said input video signal to determine the difference thereof for all signal conditions and comparing said difference to a reference to determine if said difference is less than said reference, and processing means responsive to said comparison means to construct a noise reduced version of said input video signal which version is an average of said input and delayed input video signals if said difference is less than said reference with said processing means responsive to said delayed input video signal and said comparison means to output said delayed input video signal if said difference is not less than said reference.

18. Apparatus as set forth in claim 17 wherein said color television video signal is represented in digital form.

19. Apparatus as set forth in claim 17 including in combination, digital shift registers or digital memories which comprise said delay means.

20. Apparatus as set forth in claim 17 including in combination, digital arithmetic circuitry as part of said comparison means and processing means.

21. Apparatus as set forth in claim 17, including in combination, digital shift registers as part of said delay means, digital logic circuitry as part of said processing means and digital logic circuitry as part of said comparison means.

22. Apparatus as set forth in claim 18, including in combination, digital arithmetic logic means and digital memory means as part of said processing means.

23. Apparatus as set forth in claim 17, including in combination, said processing means utilizing mathematical altering of said delayed input video signal and the difference of said input and said delayed input video signals, with said processing means operating in response to said comparison means, with said comparison means performing comparisons of said input video signal and said delayed input video signal to determine the presence of detail in said input video signal.

24. Apparatus as set forth in claim 17 including said delay means which utilizes a delay of substantially one television pixel, or one television horizontal line or one television field or a combination of pixels, lines, or fields to enable said comparison means to compare at least one pixel of said delayed input video signal to at least one pixel of said input video signal with said pixels being adjacent to each other as viewed on a television screen.

25. Apparatus as set forth in claim 24 including said processing means having binary mathematical formulas to modify said input video signal.

26. Apparatus as set forth in claim 25 whereby said formulas may be changed to suit the amount of noise of said input video signal.

27. Apparatus as set forth in claim 26 whereby said formulas operate relative to constants which may be changed to suit said input video signal.

28. The method of removing noise on an input color television signal including the steps of delaying said input video signal to provide a delayed input video signal corresponding to a point in the raster different from said input video signal, comparing the delayed input video signal to the input video signal in its undelayed condition to determine the difference thereof under all signal conditions and to compare said difference to a reference to determine the larger thereof and processing the delayed input video signal and said difference in direct response to the aforementioned comparison to said reference to produce an output signal which is either an average of said input and delayed input video signal when said difference is less than said reference, or is equal to said input video signal.

29. The method of generating a noise reduced version of an input electronic signal including the steps of delaying said input electronic signal to produce a delayed input signal having the same bandwidth as said input electronic signal, comparing said input electronic signal to said delayed input signal to determine the difference thereof and comparing said difference to a reference which may allow the larger of said difference or said reference to always be determined, and processing said delayed input signal in response to said comparisons to generate a signal which may be changed from an average of said input and delayed input electronic signals to a signal equivalent to said input electronic signal in response to said comparisons.

30. The method of generating an output electronic signal which is a noise reduced version of an input electronic signal which has been derived by scanning a spatial image, including the steps of delaying said output electronic signal, comparing at least one element of said delayed output electronic signal to at least one element of said input electronic signal to determine the difference to said elements and comparing said difference to a reference to determine the larger thereof, said elements corresponding to different points on the scanned image, and processing said delayed output electronic signal with said difference in direct response to the aforementioned comparison of said difference and said reference to generate said output signal which is an average of said delayed output and input electronic signals when said difference is less than said reference or is equivalent to said input signal otherwise.

* * * * *

REEXAMINATION CERTIFICATE (400th)

United States Patent [19]

[11] **B1 4,305,091**

Cooper

[45] Certificate Issued **Oct. 8, 1985**

[54] **ELECTRONIC NOISE REDUCING APPARATUS AND METHOD**

[76] Inventor: **J. Carl Cooper**, 1101 Continentals Way #109, Belmont, Calif. 94002

Reexamination Reqsst:
No. 90/000,504, Feb. 15, 1984
No. 90/000,674, Dec. 3, 1984

Reexamination Certificate for:

Patent No.:	**4,305,091**
Issued:	**Dec. 8, 1981**
Appl. No.:	**30,288**
Filed:	**Apr. 16, 1979**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 763,904, Jan. 31, 1977, abandoned.

[51] **Int. Cl.**[4] H04N 9/535; H04N 5/21; H04B 15/00

[52] **U.S. Cl.** 358/36; 358/167; 328/165

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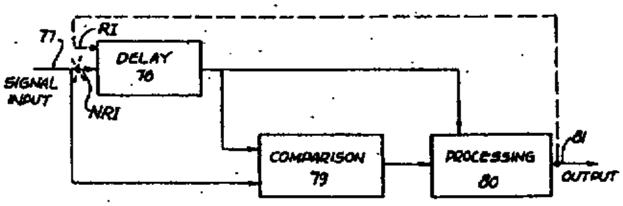
Primary Examiner—Michael A. Masinick

[57] **ABSTRACT**

The present disclosure teaches a method and apparatus for reducing noise in an electronic signal. These inventive conceptions include a means for delaying the electronic signal and a comparison means for comparing the delayed signal to the signal in its undelayed condition. Means are provided for processing the signal in response to the comparison means to reprove at least a part of the noise.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

NO AMENDMENTS HAVE BEEN MADE TO THE PATENT

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims 1–30 is confirmed.

* * * * *

US004305091B1

REEXAMINATION CERTIFICATE (3438th)

United States Patent [19] [11] B2 4,305,091

Cooper [45] Certificate Issued Feb. 10, 1998

[54] ELECTRONICS NOISE REDUCING APPARATUS AND METHOD

[76] Inventor: J. Carl Cooper, 1101 Continentals Way #109, Belmont, Calif. 94002

Reexamination Request:
No. 90/002,107, Aug. 13, 1990

Reexamination Certificate for:

Patent No.:	4,305,091
Issued:	Dec. 8, 1981
Appl. No.:	30,288
Filed:	Apr. 16, 1979

Reexamination Certificate B1 4,305,091 issued Oct. 8, 1985

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 763,904, Jan. 31, 1977, abandoned.

[51] Int. Cl.[6] H04N 5/21; H04N 9/00

[52] U.S. Cl. 348/619; 327/552; 348/607

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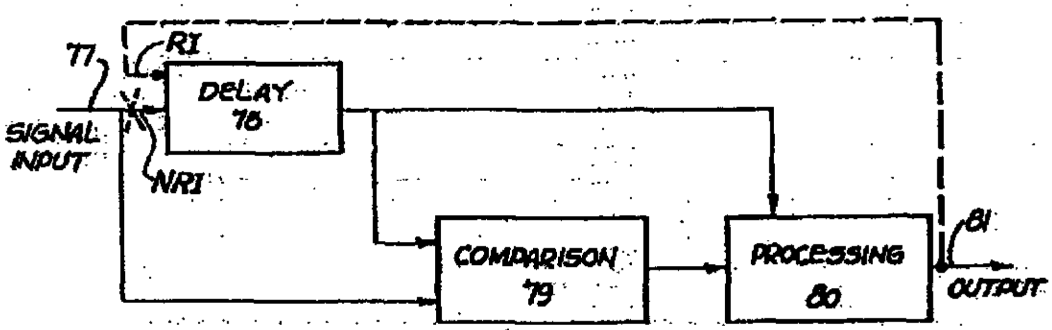
What Is Signal Averaging? (Hewlett Packard Journal), Apr., 1968.

Primary Examiner—Donald Hajec

[57] ABSTRACT

The present disclosure teaches a method and apparatus for reducing noise in an electronic signal. These inventive conceptions include a means for delaying the electronic signal and a comparison means for comparing the delayed signal to the signal in its undelayed condition. Means are provided for processing the signal in response to the comparison means to remove at least part of the noise.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **2, 3, 6, 7, 10–16, 23, 25–28** and **30** is confirmed.

Claims **1, 4, 5, 8, 9, 17–22, 24** and **29** are cancelled.

New claims **31–39** are added and determined to be patentable.

31. The method as claimed in claim 28, 29, or 30 wherein said difference is combined with said delayed signal to generate said equivalent to said input video signal when said difference is greater than said reference.

32. The method as claimed in claim 28, 29, or 30 wherein a portion of said difference is combined with said delayed signal to generate said average when said difference is less than said reference.

33. The method as claimed in claim 28, 30, or 39 wherein said comparison of delayed and undelayed signals involves adjacent elements.

34. The method as claimed in claim 28, 30, or 39 wherein said comparison of delayed and undelayed signals involves non-adjacent but close elements.

35. The method as claimed in claim 28, 30, or 39 wherein said comparison of delayed and undelayed signals involves points which are integral cycle lengths apart.

36. The method as claimed in claim 28, 29, or 30 wherein said delayed signal has been previously noise reduced.

37. The method as claimed in claim 28, 29, or 30 wherein said delayed video signal has been previously compared before said delaying.

38. The method as claimed in claim 28, 29, or 30 wherein said average is an average wherein the weighting thereof is responsive to said difference.

39. The method of generating a noise reduced version of an input electronic color television signal including the steps of delaying said input electronic video signal to produce a delayed input video signal having the same bandwidth as said input electronic video signal and corresponding to a point in the raster different from said input electronic video signal, comparing said input electronic video signal in its undelayed condition to said delayed input video signal to determine the difference thereof under all signal conditions and comparing said difference to a reference to allow the larger of said difference or said reference to always be determined, and processing said delayed input video signal and said difference in direct response to said comparisons to said reference to generate an output signal which is either an average of said input and delayed input electronic video signals when said difference is less than said reference, or is a signal equal to said input electronic video signal in response to said comparisons.

* * * * *

EXHIBIT B

United States Patent [19]
Cooper

[11] **Patent Number: 4,573,070**
[45] **Date of Patent: Feb. 25, 1986**

[54] **NOISE REDUCTION SYSTEM FOR VIDEO SIGNALS**

[76] Inventor: **J. Carl Cooper, 1373 Sydney Dr., Sunnyvale, Calif. 94087**

[21] Appl. No.: **615,666**

[22] Filed: **May 31, 1984**

Related U.S. Application Data

[63] Continuation of Ser. No. 268,870, Jun. 1, 1981, abandoned, which is a continuation-in-part of Ser. No. 30,288, Apr. 16, 1979, Pat. No. 4,305,091, which is a continuation-in-part of Ser. No. 763,904, Jan. 31, 1977, abandoned.

[51] Int. Cl.[4] H04N 9/64
[52] U.S. Cl. 358/36; 358/167; 358/37; 358/166
[58] Field of Search 358/167, 166, 162, 36, 358/37, 163, 170, 160, 213; 364/515; 382/50, 51, 54

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Primary Examiner—Michael A. Masinick
Attorney, Agent, or Firm—Woodling, Krost, Rust & Hochberg

[57] **ABSTRACT**

Noise reduction on a video signal is achieved by an adaptive filter system which is capable of automatic changes in filter parameters. This inventive concept includes an automatic method of independently changing both the width and center frequency of the teeth of a comb type bandpass envelope of the filter, as well as adjusting the amplitude response of the filter, independent of the bandpass characteristics, in order to closely match the filter bandpass response to the power spectrum of the video signal being processed, thus rejecting noise in those portions of the spectrum not being used by the video signal. The filter system herein disclosed also provides an adaptive spatial processing of the video signal thus further improving said signal by enhancing detail in the image and by smoothing low amplitude noise in relatively detail free areas of the picture.

43 Claims, 16 Drawing Figures

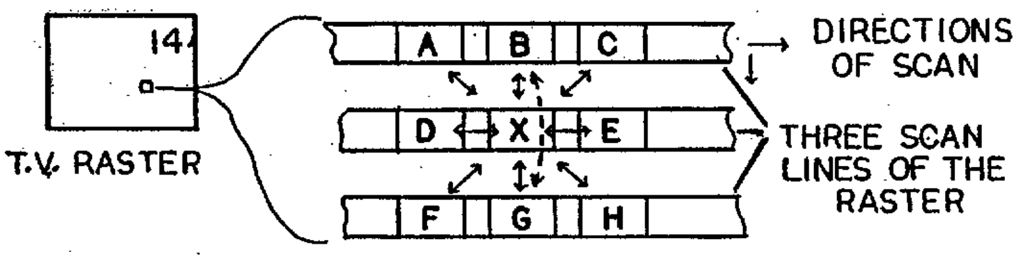


EXHIBIT
B

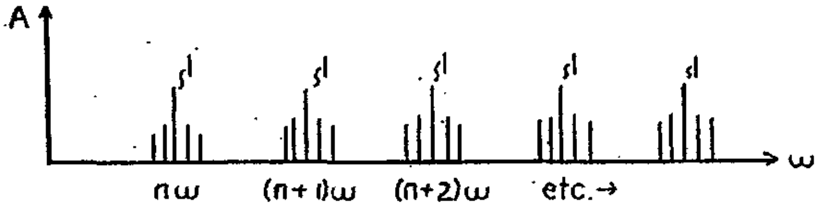


FIG. 1

FIG. 2

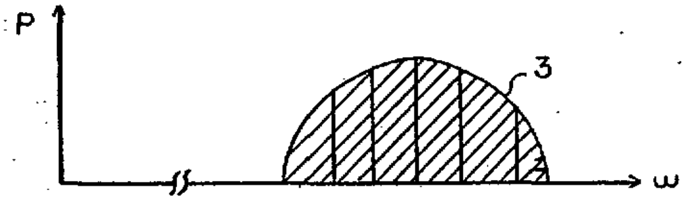


FIG. 3

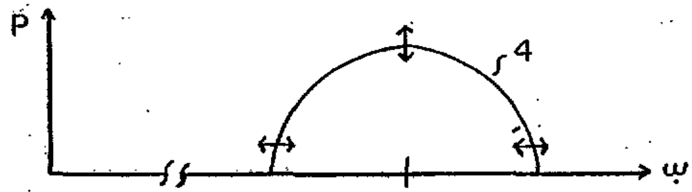


FIG. 4

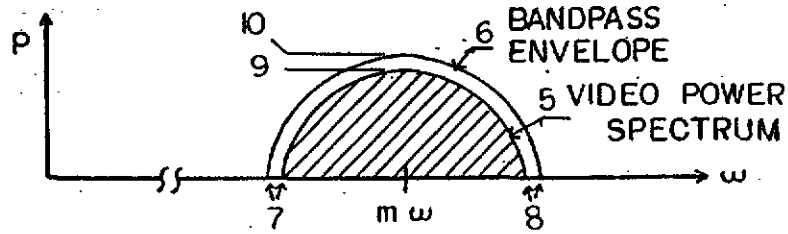


FIG. 5

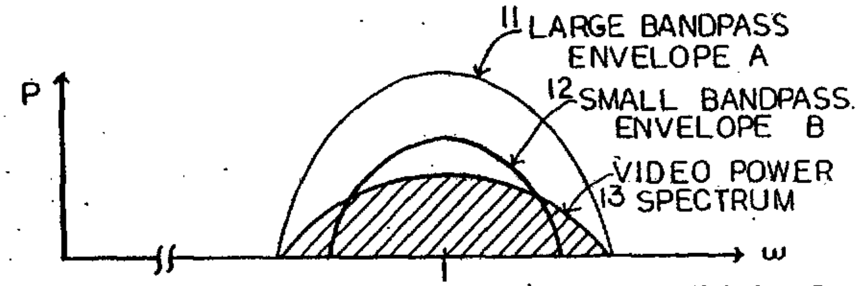


FIG. 6

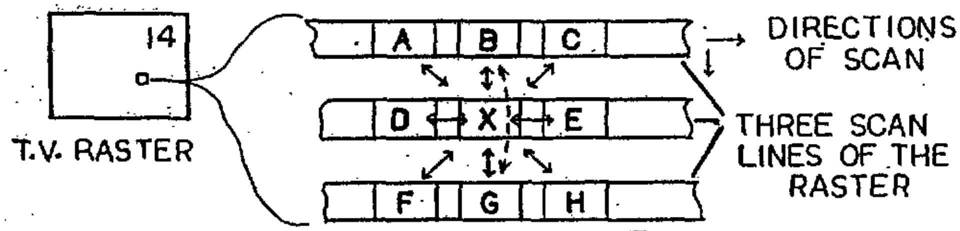


FIG. 7

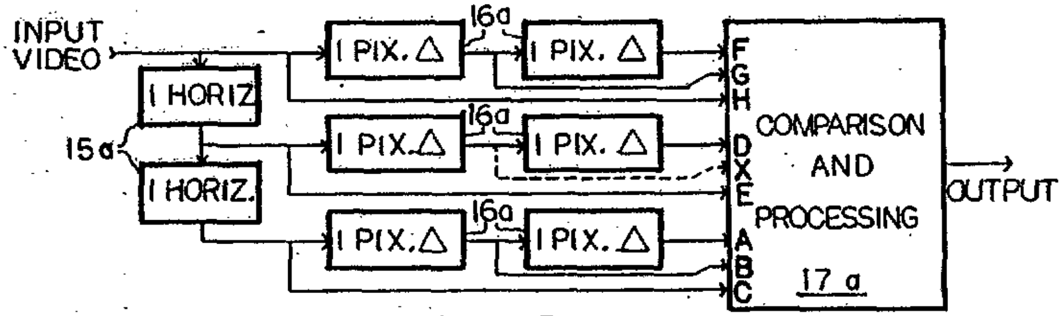


FIG. 8

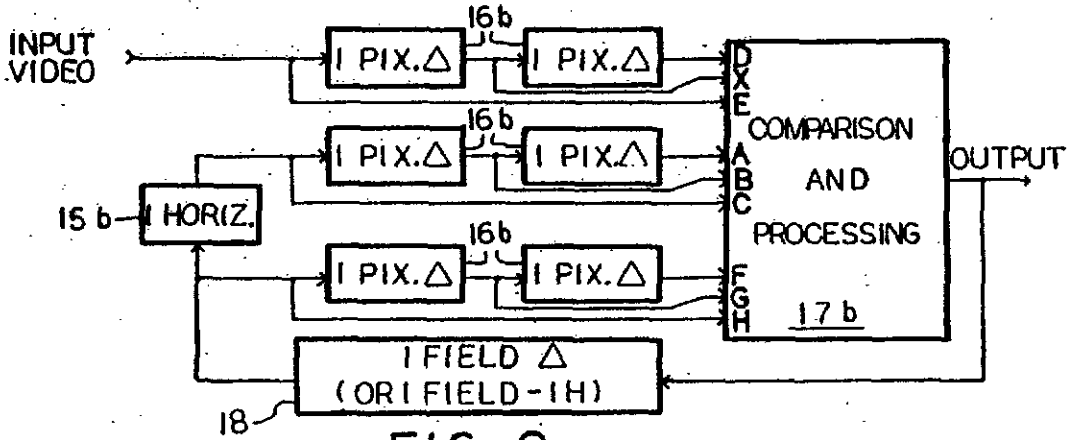


FIG. 9

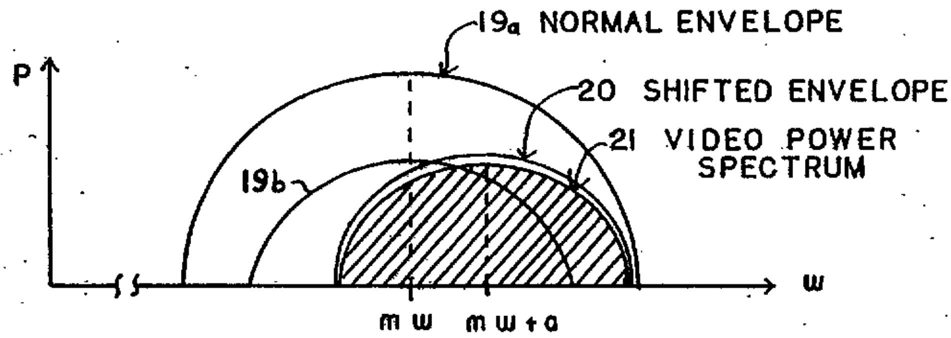


FIG. 10

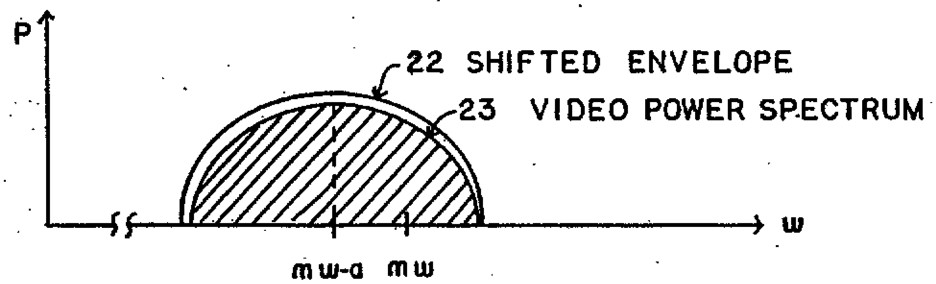


FIG. 11

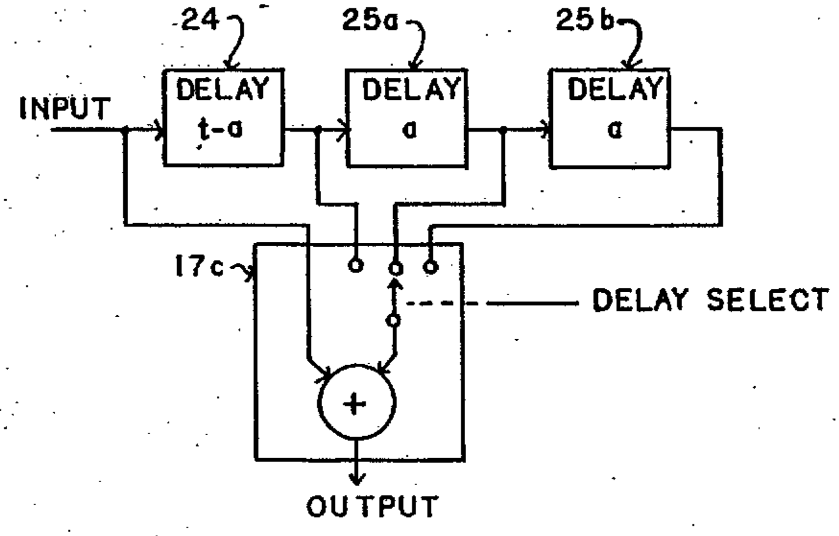
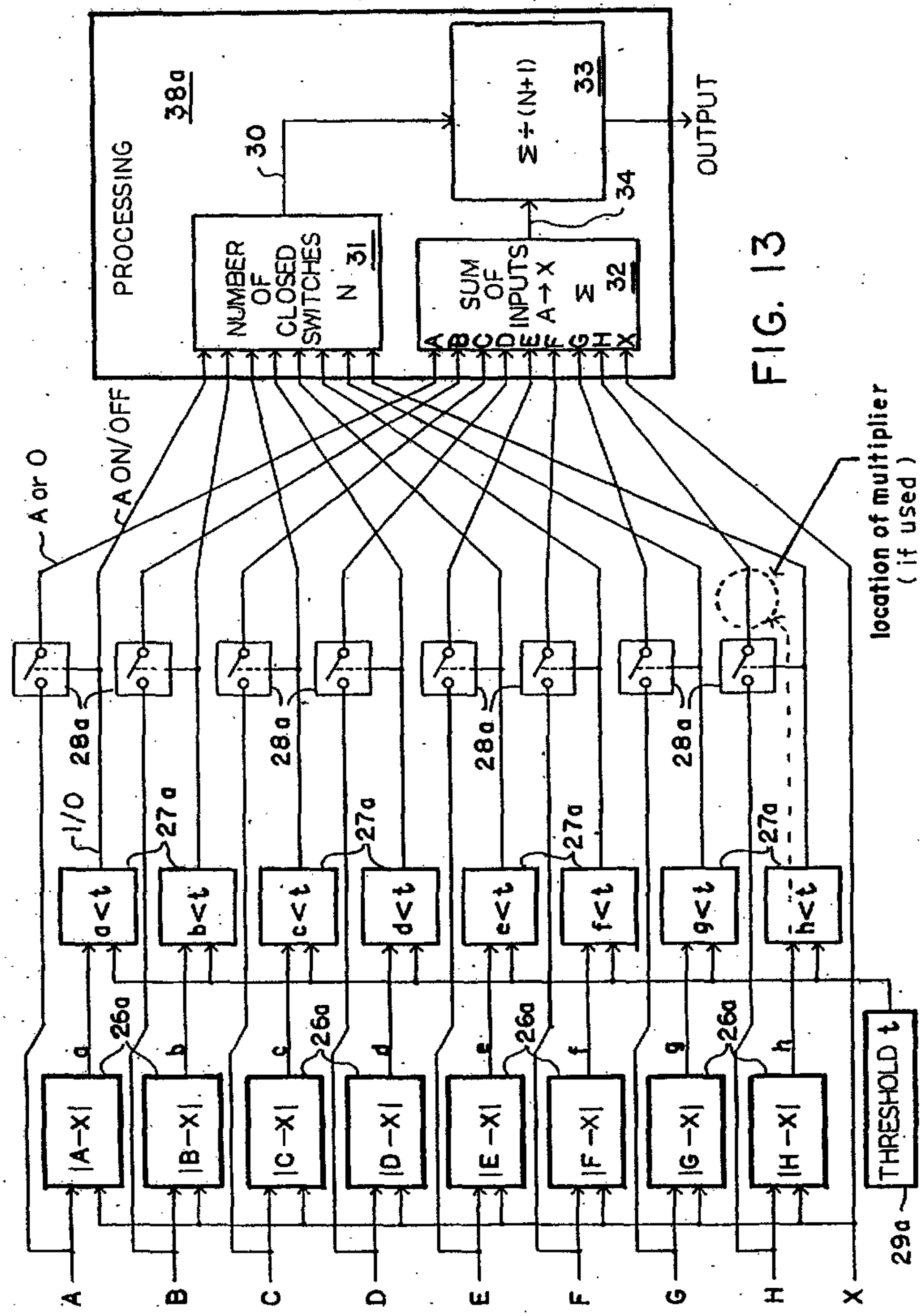


FIG. 12



PROCESSING
38a
NUMBER OF CLOSED SWITCHES
N 31
30
Σ ÷ (N+1)
33
OUTPUT
34
SUM OF INPUTS A → X
Σ 32
A ON/OFF
A or O
location of multiplier
(if used)
28a
1/O
27a
26a
a<t
b<t
c<t
d<t
e<t
f<t
g<t
h<t
|A−X|
|B−X|
|C−X|
|D−X|
|E−X|
|F−X|
|G−X|
|H−X|
THRESHOLD t
29a
A
B
C
D
E
F
G
H
X

FIG. 13

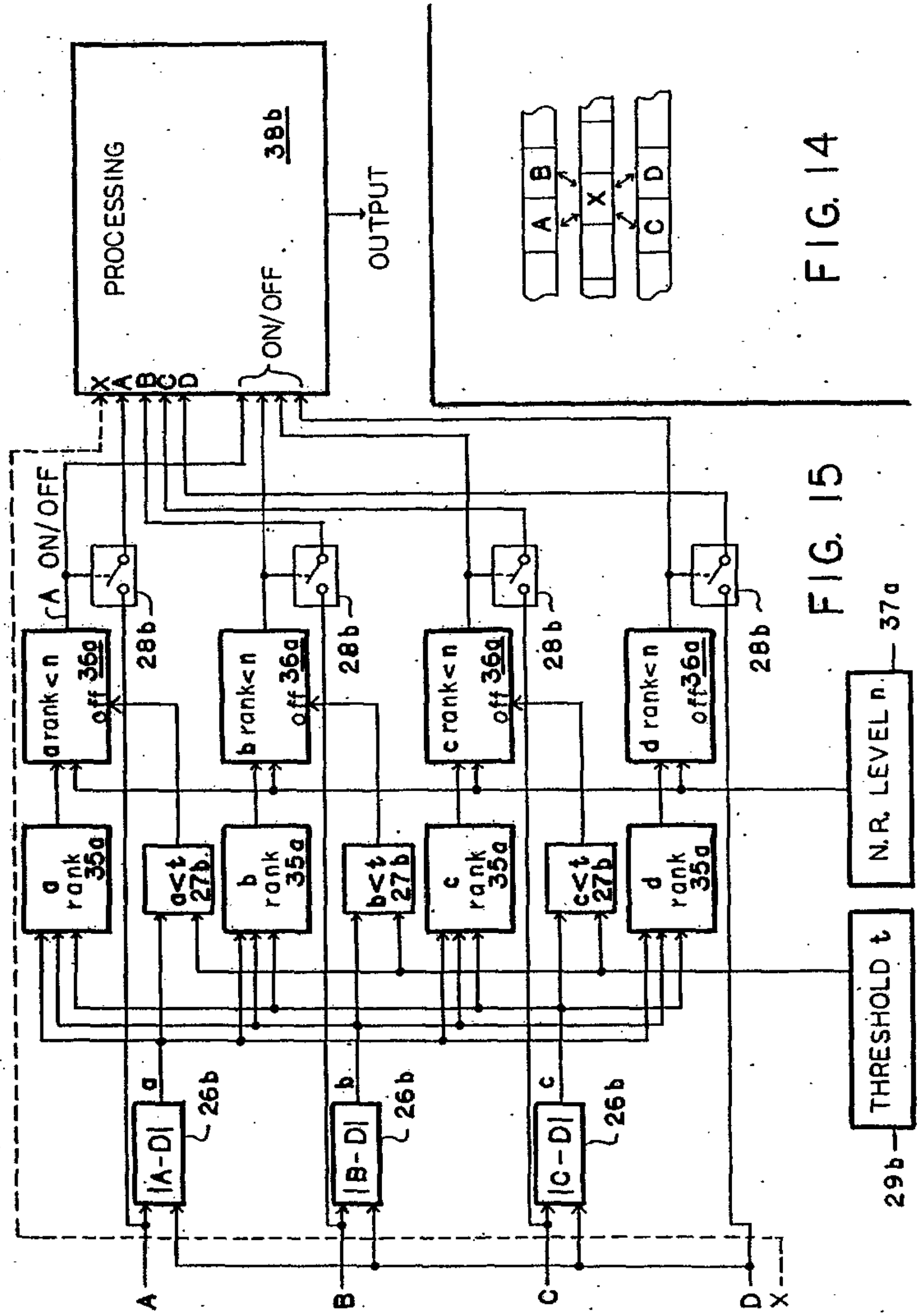

PROCESSING
38b
OUTPUT
ON/OFF
X
A
B
C
D
A ON/OFF
a rank<n
off 36a
b rank<n
c rank<n
d rank<n
28b
a rank 35a
b rank 35a
c rank 35a
d rank 35a
a<t 27b
b<t 27b
c<t 27b
|A-D|
|B-D|
|C-D|
26b
N.R. LEVEL n
37a
THRESHOLD t
29b

FIG. 14

FIG. 15

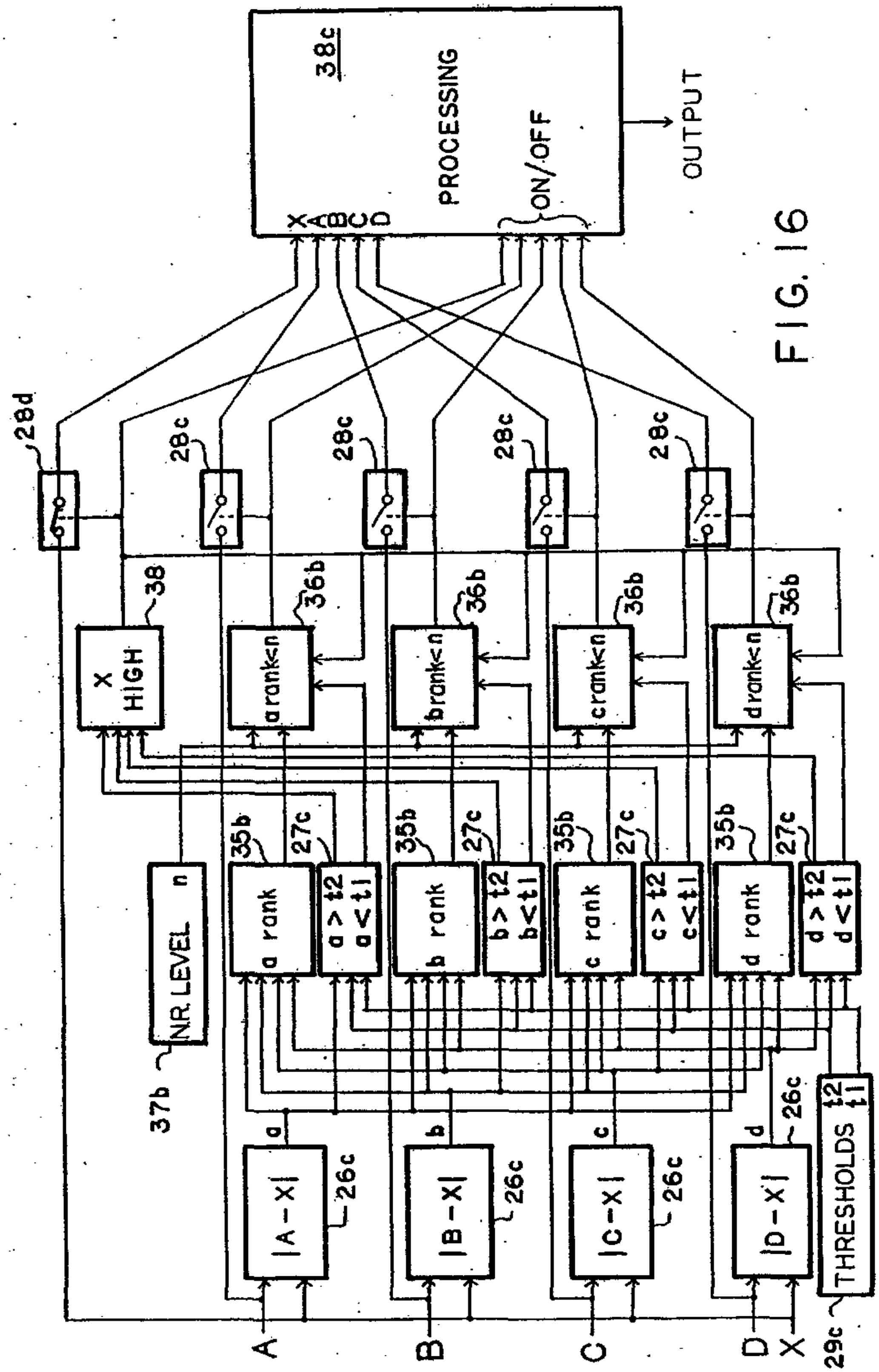

38c
PROCESSING
ON/OFF
OUTPUT
X A B C D
28d
28c
38
36b
X HIGH
a rank<n
b rank<n
c rank<n
d rank<n
35b
27c
NR LEVEL n
a rank
b rank
c rank
d rank
a > t2 a < t1
b > t2 b < t1
c > t2 c < t1
d > t2 d < t1
37b
|A - X|
|B - X|
|C - X|
|D - X|
26c
THRESHOLDS t2 t1
29c
A
B
C
D
X

FIG. 16

NOISE REDUCTION SYSTEM FOR VIDEO SIGNALS

This application is a continuation of Ser. No. 268,870, filed 06-01-81, now abandoned and a continuation-in-part of U.S. patent application Ser. No. 30,288 filed Apr. 16, 1979 now U.S. Pat. No. 4,305,091 entitled "Electronic Noise Reducing Apparatus and Method", which application in turn is a continuation-in-part of U.S. patent application, Ser. No. 763,904 filed Jan. 31, 1977, now abandoned, entitled "Electronic Noise Reducing Apparatus and Method."

Noise on video signals and in particular low amplitude random noise is a very troublesome problem in television systems. Several methods of removing this noise have been developed which include coreing, comb filters, and recursive temporal integration systems. Coreing systems are generally unacceptable because along with the noise a large amount of detail is lost. Line type comb filters have long been used for chroma separation, with a small signal to noise improvement, and now large scale digital noise reducers which utilize frame delays to implement recursive temporal integration or time averages, are available. Two such devices are described in detail in U.S. Pat. Nos. 4,058,836 Drewery et al. and 4,064,530 Kaiser et al. These recursive time integration systems do a fairly good job of noise reduction, but always introduce an artifact known as motion effect due to the infinite impulse response characteristic of recursive filters, and the problem of frame to frame video differences. The motion effect problem in general prevents the cascading of devices, and limits the amount of useful noise reduction of an individual unit.

It is the object of this invention to provide a high level of noise reduction similar to the temporal integration systems without the inherent motion effect artifacts, or loss of detail as in coreing systems. This is accomplished with a filter operating on picture elements in a continuous analog system, or a discrete sample time system such as would be provided in a digital or charge coupled device system, in either a recursive or non-recursive configuration. Because the filters delay times may be changed automatically in response to the motion of elements in the video, and because the number of coefficients of the filter may also be changed automatically, the bandpass characteristics of the filter may be automatically adjusted to fit the input video signal to a close degree.

Other objects and a fuller understanding of this invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a typical video power spectrum with characteristic power clusters 1;

FIG. 2 is a more detailed drawing of one of the power clusters with typical 30 hz. separated sidebands 2;

FIG. 3 is a typical video power cluster envelope 3;

FIG. 4 is a typical video power cluster envelope 4 which depicts characteristic envelope shape changes;

FIG. 5 is a typical video power cluster spectrum 5 having a peak amplitude 9, with an upper band edge at 8 and a lower band edge at 7, and a typical comb filter bandpass envelope 6 having a peak allowable amplitude 10 and having upper and lower band edges also at 8 and 7;

FIG. 6 is a spread video power spectrum 13 with comb filter bandpass envelopes 11 and 12;

FIG. 7 is a drawing of 3 scan lines from some random point in a television raster, showing the location of 9 picture elements A thru H and X;

FIG. 8 is a drawing of a typical delay configuration for the non-recursive form of the noise reducer, having 1 horizontal line delays 15*a*, 1 pixel delays 16*a* and comparison and processing circuit 17*a*;

FIG. 9 is a drawing of a typical delay configuration for the recursive form of the noise reducer having 1 horizontal line delay 15*b*, 1 pixel delays 16*b*, 1 field delay 18 and comparison and processing circuit 17*b*;

FIG. 10 is a shifted video power spectrum 21 with shifted bandpass envelope 20 and noise reducer bandpass envelopes 19*a* and 19*b*;

FIG. 11 is a shifted video power spectrum 23 with shifted bandpass envelope 22;

FIG. 12 is an adaptable nonrecursive filter having delays 24, 25*a*, 25*b* and processing circuit 17*c*;

FIG. 13 is a detailed block diagram of a comparison and processing circuit having inputs A thru H and X, absolute value difference computers 26*a*, magnitude comparators 27*a*, video switches 28*a*, threshold number 29*a*, processing circuit 38*a* composed of coefficient adder 31 with output 30, pixel summer 32 with output 34 and divider 33;

FIG. 14 is a drawing of 3 scan lines from a random point in a television raster showing the locations of pixels A thru D and X;

FIG. 15 is a detailed block diagram of a comparison and processing circuit having inputs A thru D and X with absolute value difference computers 26*b*, threshold number 29*b*, rank computers 35*a*, magnitude comparators 27*b*, rank magnitude comparators 36*a*, video switches 28*b*, processing circuit 38*b* and noise reduction level 37*a*;

FIG. 16 is a detailed block diagram of a comparison and processing block having absolute value difference computers 26*c*, rank computers 35*b*, dual magnitude comparators 27*c*, rank magnitude comparators 36*b*, video switches 28*c* and 28*d*, processing circuit 38*c*, X high computer 38, noise reduction number 37*b* and threshold numbers 29*c*.

It is the object of video noise reduction systems developed as comb filters to provide a bandpass characteristic which matches the spectrum of the video signal to be improved thus rejecting the noise which is contained in the unused spectrum. The merit of these systems may be understood by inspecting the power versus frequency spectrum of video signals, which are shown in simplified graphic examples in FIGS. 1-4. In FIG. 1 a typical power spectrum is shown with the characteristic power clusters 1 at harmonics of the horizontal scanning frequency w. FIG. 2 is a more detailed drawing of one of the harmonics nw, showing the sidebands 2 of each cluster which are spaced a nominal 30 hz apart in frequency for complex changing video. The 30 hz offset is a result of the frame repetition rate used and would be 25 hz for 50 cycle European systems. If one considers a single picture element, it is obvious that the lowest frequency component of the video signal corresponding to that element, if it is stationary, is the frame rate. In a static video signal, i.e., one scanning a non-changing scene, the amplitude and number of the 30 hz sidebands associated with a given harmonic power spectrum will vary according to the line to line changes in picture detail, and for this purely static signal any given sideband group of a horizontal harmonic has no amplitude modulation or frequency modulation components with respect to time. In a normal video scene having motion and changing images, any of these 30 hz sidebands, 2 of FIG. 2, will have time changing amplitude and frequency components which will take up a part or all of the spectrum around the horizontal harmonic, this spectrum may be depicted as the envelope 3 shown in FIG. 3. The width and amplitude of the envelope will of course be independently changing with the scene information, as is shown by envelope 4 in FIG. 4. For the purpose of the following disclosure, reference to power and bandpass envelopes are in relation to one or more given horizontal harmonic power clusters within the video bandwidth.

In this high performance noise reduction device, the object is to model a comb filter such that the bandpass envelope of the teeth of the filter fit the expected video power clusters at the horizontal harmonics. A diagram of a video power envelope 5 and a comb filter bandpass envelope or tooth 6, for one of the 30 hz sideband groups is shown in a simplified graphic example in FIG. 5. In actual practice, the envelopes of FIGS. 3–6 would be much more complex if viewed on a spectrum analyzer or plotted with a high degree of accuracy, however these drawings will still serve to illustrate the important concepts relating to this invention. Obviously, the closer the bandpass envelope 6 fits the video power envelope 5 with respect to their upper and lower cutoff frequencies 8 and 7, the better the rejection of out of band noise and thus noise reduction of the signal will be. If the bandpass envelope also limits the video amplitude 9 to a level slightly higher than that needed to pass the video information as is shown by 10, thus high amplitude noise spikes will also be limited. Both envelopes 5 and 6 in FIG. 5 are representations of complex series of 30 hz elements. The devices in the previously mentioned Drewery and Kaiser patents operate to adjust the width of the bandpass envelope, i.e., changing the allowable number of the 30 hz elements within the bandpass envelope so that the entire video power envelope may be passed, while keeping the distance between upper and lower cutoff frequencies, or width of the bandpass envelope 6 as small as possible, however it is not possible to adjust the cutoff frequencies and width independently. In the device described by Kaiser et al. the coefficients of the input and delayed signals are changed in order to vary the noise reduction levels which causes the size of the bandpass envelope to change. It should be noted that by changing these coefficients that it is not possible to modify the shape of the bandpass envelope, i.e., to change the width independent of the amplitude, or to change the center frequency of the envelope of the 30 hz components. As shown in FIG. 6, when the video power spectrum 13 broadens due to changing video, the bandpass envelope may be increased as is shown in 11 to pass all of the video spectrum with very little noise reduction, or a compromise is set such as 12 which achieves moderate noise reduction and some loss of video information. As a result of the limited control over the shape, and position of the 30 hz components within the bandpass envelope, serious mismatching of the bandpass and power envelopes can occur, such as in FIG. 6.

The noise reduction system for electronic signals disclosed herein operates on a spatial technique in which each picture element within a television raster 14 is compared to the elements surrounding it such as X and A thru H respectively, as shown in solid line typically in FIG. 7, with said picture element being selectively combined with those surrounding elements which are similar to the central element in a product, a sum, a mean, a weighted average or similar mathematical process. The actual mathematical process used is relatively unimportant from a noise performance standpoint since all average and mean type processes give approximately the same level of noise reduction, however other image processes may be combined in this function as will be discussed later. It is important to note that for removing low amplitude noise the surrounding picture elements are not compared with each other, but only with the central element and there is no need to compute any two dimensional measure of the surface deviation or flexure about the central element. As was disclosed previously the surrounding elements do not have to be truly adjacent or symmetrically patterned, however experimental results indicate that the adjacent symmetrically patterned elements are best. Note, however, that surrounding elements can be directly compared as shown for example in dotted line in FIG. 7. The area covered by these the examined elements may be referred to as the inspection area. For the purpose of the following disclosure it will be assumed that these elements are discrete time elements such as samples in a digital system, however the disclosed concepts will apply equally to any continuous analog system where the elements are continuous and not broken or sampled into individual units. This may be effected in hardware by replacing all memories or shift registers used by digital systems with analog delay lines. Analog delay lines are of course available in either fixed delay length and variable delay length configurations.

The above process may take on either a recursive or nonrecursive form and may operate on a varying number of surrounding elements depending on the desired cost versus performance and complexities involved. The sampling system used and as a result the alignment of the sampled elements from line to line will also affect the number of elements used and delay structure to arrive at those elements. One should note that the elements shown in FIG. 7 are aligned vertically and those of FIG. 14 are offset from line to line showing 2 common systems which may be used. The particular considerations of sampling schemes will be obvious to one skilled in the art and will not be discussed further. A typical nonrecursive system would look like that of FIG. 8 and a recursive system like that of FIG. 9. The dotted line FIG. 8 recognizes that the element x can be omitted from the comparison and processing of the signals. FIGS. 13, 15 and 16 disclose various embodiments of the comparison and processing circuitry of FIGS. 8 and 9. The object and operation of the comparison and processing circuits are the same for any system; only the configuration of the delays 15, 16 and 18 used to generate the central and surrounding picture elements X and A through H respectively is changed in order to optimize the system for a particular application. The changes from non-recursive to recursive systems are essentially the same as for textbook digital filters and will not be extensively discussed. Inputs to the comparison and processing circuit 17*a* in FIG. 8 and 17*b* of FIG. 9 are labeled A thru F and X corresponding to where these elements appear in the raster as shown in FIG. 7.

As was previously mentioned, the video 30 hz sideband shape is a result of both the line to line detail changes and frame to frame detail changes. A special case where a displayed image changes in its raster position from frame to frame while the image itself remains relative unchanged frequently occurs in video. An example of this would be where a camera pans a fixed scene with little detail around the edges of the frame. The effect of this type of changing video is to greatly broaden and frequency shift the 30 hz components of the video power envelope while the amplitude remains relatively constant such as shown in FIGS. 10 and 11. If one considers a given pixel which is moving in the frame, that element's lowest frequency component is no longer the frame rate that it was when stationary, but has been changed by the amount of motion. If the element were to move 2 scan lines up per frame, the lowest frequency component would be 1 frame less 2 H, thus giving a positive frequency shift by an amount a to the video power spectrum such as is shown by 21 in FIG. 10. This situation gives rise to the mismatching of envelopes similar to that previously mentioned, and is shown by 19*b* and 21 of FIG. 10. If the picture elements were to move down in the frame a negative frequency shift such as shown by 23 of FIG. 11 would be created. Because the envelope center frequency cannot be shifted the two options available to a temporal integration noise reducer such as those previously discussed are to increase the bandpass envelope like 19*a* of FIG. 10 to broaden the allowable number of 30 hz components to pass all of the components of the video information but provide little noise reduction, or to set a compromise position such as shown by 19*b* of FIG. 10 which provides moderate noise reduction, and some loss of video information. Unfortunately, in most state of the art noise reducers, the smaller envelope 19*b* will be used and most of the video information which is lost contains frame to frame detail information. In a recursive type of system this lost detail is accentuated due to the infinite impulse response characteristic, giving a smear effect on the edges of moving images which is known in the industry as motion effect. The primary reason for motion effect is the lack of ability of noise reducers to change the shape and frequency position of the bandpass envelope, independent of the allowable amplitude characteristic to match the video envelope adequately. The mechanism needed to accomplish this is an adaptive time delay system which can track moving picture elements from frame to frame or field to field.

A simple diagram of such an adaptive system is shown in FIG. 12. If the 3 position switch of 17*c* is in the middle position the filter will have bandpass teeth at some frequency spacing w which is determined by the length of delays 24 and 25*a*. If one assumes 24 is a delay of t−a, and 25*a* and *b* each have a delay of a with t being much larger than a, then the 3 position switch will be able to select delays of t−a, t and t+a. The switch selection will then have the effect of shifting the bandpass envelope in frequency by a small amount determined by a. The bandpass envelope will look like 20 and 22 of FIGS. 10 and 11 and one can see that by selecting the proper switch position the filter's frequency characteristic can be made to closely match the video power spectrum. The operation of the filter may be simply explained by assuming that the delay t is equal to the repetition period, i.e., 1/frequency of a sine wave signal to be passed by the filter. The middle switch position will be selected and the input signal will be summed with the input signal which has been delayed by t or one

wave length thus giving an output equal to twice the input. If another signal is input which has a wave length of 2t there will be no output since the input will be combined with the signal delayed by t, which corresponds to a 180° phase shift, i.e., two signals of exact opposite phase are added with a sum of 0. If the wanted signal now shifts either up or down in frequency by an amount 1/a a different switch position may be selected to adjust the filter bandpass characteristic accordingly. Thus for a signal having a repetition period of t+2a the right switch position would need to be selected to give the optimum delay, and for a signal having a repetition period of t the left switch would be selected. In general for this type of filter the delay should be selected to match the repetition period of the wanted signal. The method of determining what delay length is to be used is a nontrivial matter, and is one of the inventive concepts of this device and method, as will be discussed later in this disclosure. One skilled in the art can envision a system where the three delays and switch would be replaced with a single variable length delay such as a CCD device clocked with a variable frequency clock.

Referring to FIG. 13, the least complex comparison and processing system, each of the pixels from the delays is input to an arithmatic block 26*a* along with pixel X, where the absolute value of the difference between X and the respective pixel is computed. Each of these absolute value differences, a for pixel A, b for B, etc. is compared to a threshold t, 29*a*, in blocks 27*a* to determine if the difference is less than the threshold 29*a*. If the difference is less than the threshold, a switch 28*a* is closed which allows the corresponding pixel to be input to the processing circuit 38*a*, otherwise the switch 28*a* is opened which inputs a zero, this action allows only picture elements which are similar to X to be input to the processing circuit 38*a*. For the purpose of this explanation the threshold is assumed to be a fixed number, however one skilled in the art recognize that it would be useful to make the threshold automatically variable in response to the signal to noise ratio of the incoming video signal, or to the video content of said signal. The threshold would be adjusted to a relatively small value for good S/N ratios, and a large value for poor S/N ratios. In section 32 the processing circuit sums all of the pixels including pixel X, which are input to it. Section 31 adds the coefficients of the elements input to the processing circuit at section 32, either by summing all the coefficients of the switches (one or zero) or alternately by adding multiplier coefficients as discussed later, and section 33 divides 34, the sum of the picture elements by the total of coefficients of picture elements summed 30, thus computing the average of those elements. Alternately the root mean square, product or other combination could be used to generate a replacement value or output for element x. This average is the normalized noise reduced signal which is output from the device. Of course each of the switch functions 28*a* could be replaced with or supplemented by a multiplier (or divider) as shown in the H signal path in FIG. 13, to perform a weighted average such as a gaussian weighted response of the elements selected. Such a system might perform the weighting function in a fixed on/off mode or the weighting might be adjusted according to the computed difference A thru H of FIG. 13, or alternately according to the rank which will be discussed later. For example the weighting given to element A might be (1−a') where the function is defined by A(1−a') where A is the value of element A, a' is the normalized value of a, i.e., a÷(2× maximum allowable value of A). The multiplier could also be used in order to provide weighting of each element to perform other image operations such as unsharp masking, lag reduction and spatial enhancement, or as a replacement for the switch 28a. The coefficient of the multiplier (or divider) would be controlled by the difference computed in 26a or the threshold comparison output from 27a. Typical noise reduction results output from the processing means would then be like $(A+B+C+D+E+F+G+H+X)\div 9$ where all differences are less than t, or $(A+B+C+X)\div 4$ where only differences a, b and c are less than t or only X where all differences are greater than t. For spatial enhancement one typical output would be $(jA+kB+jC+kD+kE+jF+kG+jH+X)\div m$ where the coefficients j and k are fixed multiplier constants, or zero as determined by 26a and 27a, and m is the normalization number, i.e., the sum of the absolute value of the coefficients +1, corresponding to 30. The actual weighting function and values used would depend on the quality of the video signal being processed. If the signal were soft due to the use of a low quality camera for origination, spatial enhancements would be used to sharpen the video images to a more pleasing level, if the video contained lag due to low light conditions a lag reduction operation could be performed. Actual coefficients to accomplish these functions have been developed by computer image processing devices which operate on still pictures, and a study of computer image processing will reveal actual coefficients which can be used to correct video image defects. A typical set of values for a high pass (detail enhancement) filter would be $j=-0.25$ and $k=-0.5$. If A, B, and C had differences less than t the output would then be $[(-0.25A)+(-0.5B)+(-0.25C)+X]\div 2$.

In FIG. 15 a more complex processing and comparison system for a five element scheme such as is shown in FIG. 14, is illustrated. FIG. 15 contains the same difference computing arithmetic block, 26b, corresponding to 26a for each element, the same threshold comparison system, 29b and 27b corresponding to 29a and 27a respectively, the same picture element switches, 28b, corresponding to 28a and the same processing circuit 38b corresponding to 38a to average the selected pixels as does the system of FIG. 13. FIG. 15 does differ by the addition of a rank computers 35a and rank to noise reduction level comparison 36a for each difference. It is the function of the rank computers 35a to compare each difference a thru d to all of the other differences to determine how many of the other differences it is greater than. Each difference is given a rank from 0 to N where N is one less than the total number of differences, in this instance N=3. For example, if the differences had magnitudes of: a=3, b=4, c=9, d=5, the ranks would be a=0, since a is larger than none of the other differences, b=1, c=3, d=2. It is of course possible for two or more differences to have the same rank, if they had the same difference value. Each difference's rank is in turn compared to the noise reduction level 37a in 36a, if the rank is smaller than the N.R. level 37a and if the difference is smaller than the threshold t, 29b, the corresponding switch 28b for that element is closed inputting said element to the processing circuit 38b. Switch 28b could be replaced or augmented by a multiplier or other operation as in the previous example. As with the threshold 29a of the previous example, the N.R. level 37a could be adjustable in response to input

video. Since any difference greater than 29b will probably have a high rank it also would be possible to delete 29b and 27b at a sacrifice in performance, and small cost savings. The processing circuit will compute the average of all elements input to it as in the system 38a of FIG. 13. If either the difference for an element is larger than the threshold t, 29b, or the rank of that difference is larger than the N.R. level, 37a, then the switch 28b or multiplier for that element is forced to input a zero to the processing circuit 38b. Of course individual thresholds or N.R. levels could be used for each element, which would give preference to the direction of elements averaged and the switch 28b could be replaced with or augmented by a multiplier as discussed previously.

If one assumes that in the area of inspection the picture had moved 1 vertical line up in the past field of time, then element X which is currently input to the device would be from the same point on the televised image as that which is output from the memory corresponding to the area immediately below X, on the line from the preceding field. This point is represented by the junction between pixels C and D of FIG. 14 (or pixel G of FIG. 7). These elements would then have a very low rank, since they correspond to approximately the same point on the image as x, and would be input to the processing block. The filter will have tracked the movement causing the time delay to be adjusted accordingly, by the process of rank selection of pixels. One can see that it would be wise to use enough elements in this system to cover all of the possible locations that an input pixel could move to or from within a one field (or alternatively 1 frame) amount of time, in order for the filter to track any possible motion in the input video signal. Referring to FIG. 16. It will be seen that the system of FIG. 16 is similar to that of FIG. 15, except that 2 thresholds are output from 29c, 2 comparisons are made in each of the magnitude comparators 27c, an extra circuit, the X high circuit 38 has been added which controls a video switch 28d in the X video line input to the processing circuit 38c. In the previously discussed circuits of FIG. 13 and FIG. 15 it has been assumed that pixel X would always be averaged with the other elements input to the processing circuit.

In some video applications, in particular digital applications, a noise situation exists which corresponds to a digital bit error which will cause a gross amplitude change in an individual pixel. An example of this would be in an application using a solid state RAM or in a digital data transmission channel where a MSB bit is defective due to noise. In the circuits of FIGS. 13 and 15 this gross amplitude change occurring on pixel X would cause all of the magnitude comparators to sense differences greater than the threshold t, thus effectively passing pixel X to the output unaveraged. In the circuit of FIG. 16 the magnitude comparators essentially compare the differences to two thresholds, t1 and t2. Threshold t1 can be assumed to have the same value and effect as does t of FIGS. 13 and 15. Threshold t2 is a much higher threshold used to detect gross amplitude differences. The t2 threshold comparison for each difference is input to the X high circuit 38. If a number of differences, nominally two or more, have exceeded the t2 threshold, 38 opens the video switch 28d for pixel X and forces the other rank comparators to close their respective video switches thus inputting all pixels except X into the processing circuit 38c. In the simplest configuration, processing circuit 38c will average all the pixels input to it, thus outputting this value for the noise reduced value of X.

Experimental results have shown the above processing system adequate for occasional random gross amplitude errors, however when these gross amplitude errors increase in frequency it may be desirable to average only a small number of surrounding pixels, those which are closest in magnitude to each other. These close magnitude pixels represent the minimum brightness gradient or the surface contour having the least amount of deflection or change within the area under inspection, and their average statistically represents the highest probability of the true noise free value of X. For the pixels within the area of FIG. 7 the minimum gradient would be the smallest magnitude of A-H, B-G, C-F or D-E which would be determined with difference circuits like *26b* operating on each pair of elements and rank computer *35a* of FIG. 15, i.e., the minimum gradient would also have the smallest rank. The output of the processing system would be the average of those two pixels having the smallest difference if X was determined to have a gross error. The circuitry which would need to be added to the processing circuit of FIG. 16 to accomplish a minimum gradient average is minimal and would be an elementary design task to one skilled in the art. Similar minimum brightness gradient circuitry was also discussed by Graham in U.S. Pat. No. 3,009,016. It should be noted however that if pixel X does not suffer from gross amplitude noise, and has a difference less than threshold t, the system of either FIG. 15 or 16 will inherently compute an average of pixels because of the operation of the rank computers and rank threshold comparison, as was previously discussed.

In many systems which operate on digital video signals there is circuitry included to detect bit or gross errors as part of such systems. In these systems it would be unnecessary to include the X high circuitry 38 and the associated threshold t2 and comparison circuitry since errors on pixel X have already been detected. The external system error detector would merely need to be coupled to the rank computers *36b*, the X video switch *28d* and processing means *38c* as was the X high circuit 38.

The element x need not be used in the treatment of normal television signals (element x containing very little information not present in neighboring pixels) or in defective television images (wherein the neighboring pixels statistically have a high probability of representing the true noise free value of x). The neighboring pixels could thus be directly compared with the results used to replace a different pixel. A mathematical process to do this could be accomplished by deleting element x from the processing means in FIGS. 15 and 16, using a different subtrahend in FIG. 13, or otherwise.

The operation of the noise reduction device has been discussed in relation to FIGS. 13, 15 and 16 in order to clearly explain how the device functions, however it will be clear to one skilled in the art that several of the functions could be combined or implemented in a different fashion as is convenient in order to optimize the design to meet a particular set of goals such as low cost, portability or high performance. It is considered obvious that the hardware used to implement any of the various functions such as the delays *15a*, *b* and 18 could be shared with another device, such as would be the case if this invention were constructed as a secondary feature or option of another device such as a television frame synchronizer, or that the video signal could be

output from the main memory via a different port thus giving the video output a variable delay and essentially the ability to perform a timebase corrector or synchronizer capability.

Of particular interest for state of the art television systems is the recursive system shown in FIG. 9 because of its unique and efficient relationship when used in a 2:1 interlace system. In the arrangement of FIG. 9 the input video picture element X is compared to those surrounding it (see FIG. 7). However it may be noted that by carefully selecting the length of the large delay 18, so that it provides at its output the line above the input line, (which may require a change in delay length to compensate for interlace on even or odd fields) elements ABCFG and H will be from the field previous to element X. This situation has the requirement of approximately a 1 field delay for 18, rather than a 1 frame delay which is most often used in recursive temporal average systems, with the obvious cost advantage. By combining the system configuration of FIG. 9 with the processing and comparison system of FIG. 15 or FIG. 16, which has been expanded to handle 9 total elements, a very good cost vs. performance ratio is achieved. One can see that by the previously described system of FIG. 15 or FIG. 16 of selecting pixels which surround X to average together in this recursive scheme of FIG. 9, a form of adaptive recursive comb filter is effected. It is most important to note that the delay used is variable by the amounts controlled by the selection of the surrounding elements. For example, in FIG. 9, if pixel C is selected the delay is 1 H more than if pixel H is selected. Referring to the previous discussion Line relating to the shape of the bandpass envelope one should understand that it is this variable delay arrangement which coupled with averaging variable numbers of pixels, which may have variable weighting, can cause both the width and allowable amplitude of, as well as the position of 30 hz components of the bandpass envelope to change independently and automatically in order to provide a close fit to the video power spectrum envelope, as well as providing spatial image processing.

The above described system which utilizes a field delay proves in practice to be extremely cost effective and of high performance when compared to frame recursive devices which are currently commercially available. To one skilled in the art it should be obvious that there are many variations of this system which may be constructed to fit a given need. In particular a much more elegant system could be built which utilizes a full frame delay thus allowing an input pixel to be compared with those pixels surrounding it in both the previous field and the previous frame. Less or more than the suggested nine elements could also be used with a group of central elements being compared to a group of surrounding elements. A system could also be built which allows the comparison of one or more input pixels to a number of the pixels surrounding it, but from the previous frame or a multiple number of frames or fields. It may be noted that in all cases the delayed element corresponding to input element X i.e. that element corresponding to the same point on the raster as X need not be used if a sufficient number of surrounding elements are used, since it is reasonable to assume that the delayed element corresponding to X contains very little information not already contained in those pixels which surround it, for normal television scenes.

What is claimed is:

1. Apparatus for reducing noise on an input televison video signal which apparatus contains a comparison circuit means responsive to said input video signal to compare a central picture element of said video signal to at least one of the surrounding picture elements of said video signal to determine the difference thereof and to further compare said difference to a threshold, said threshold adjusted automatically in response to said input television video signal, and a processing circuit responsive to said picture elements and said comparison to sum portions of said surrounding element and said central element if said difference corresponding to said surrounding element is less than said threshold, with said portion of *surrounding element being decreased* otherwise, which decreased portion may be zero and which sum is the noise reduced value substituted for said central element by said processing circuit before said signal is output from said apparatus.

2. Apparatus for reducing noise on an input televison video signal which apparatus contains a comparison circuit means responsive to said input video signal to compare a central picture element of said video signal to at least one of the surrounding picture elements of said video signal to determine the difference thereof and to further compare said difference to a threshold, a processing circuit responsive to said picture elements and said comparison to sum portions of said surrounding element and said central element if said difference corresponding to said surrounding element is less than said threshold, with said portion of said surrounding element being decreased otherwise, which decreased portion may be zero and which sum is the noise reduced value substituted for said central element by said processing circuit before said signal is output from said apparatus, a second comparison circuit responsive to differences from multiple surrounding elements *wherein said differences* are compared to each other allowing said multiple surrounding elements to be ranked according to their respective differences with only a number of said surrounding elements which have the smallest differences being summed with said central element which number of surrounding elements may be a number set by an operator or may be responsive to said input video signal in either delayed or undelayed form.

3. Apparatus as claimed in claim 2 wherein the number of said surrounding elements combined is responsive to the amount of noise on said input video signal in delayed or undelayed form.

4. Apparatus as claimed in claim 2 wherein the number of said surrounding elements combined is responsive to the information content of said input television video signal in delayed or undelayed form.

5. A method for reducing noise on a video signal which noise may result from errors occurring in a video signal system with said method containing a comparison step to compare a central video element of said video signal to two or more of the video elements surrounding said central element as viewed on the television raster to determine the difference thereof, and a processing step responsive to said comparison to determine if said difference is greater than a threshold and to replace a noisy central video element with a combination of at least two surrounding elements which may be the same or different elements as said compared elements with said replacement ocuring when said central video element differs from said two or more of the compared surrounding elements by more than said threshold.

6. A method as claimed in claim 5 wherein said two combined surrounding samples have a difference which is less than the difference of any two other surrounding samples as determined by a further comparison step.

7. A method as claimed in claim 5 wherein said two combined surrounding samples are adjacent to said noisy central video sample and constitute the minimum brightness gradient across said noisy video sample as determined by said further comparison step.

8. The method of claim 5 wherein the surrounding video elements of the combination are from the scan line above and scan line below the central video element and from the same field.

9. A method for reducing noise on a set of pixels derived from an optical image including the steps of comparing two pixels to determine the difference thereof, comparing said difference to a reference to determine the larger thereof and replacing a given pixel with a combination of other pixels in response to said comparison to said reference, said combination representing a noise reduced given pixel.

10. The method for reducing noise of claim 9 wherein the two pixels being compared to determine the difference thereof are different than the given pixel replaced.

11. The method for reducing noise of claim 10 wherein the given pixel is used in the combination of pixels.

12. The method of claim 9 wherein the given pixel is located between two compared pixels.

13. The method of claim 9 wherein the given pixel and compared pixels are each on a separate scan line from the same field and are aligned in a straight line on the raster.

14. The method of claim 9 wherein the given pixel and compared pixels are from the same point on the raster but each located in a different frame.

15. A method for reducing noise on a video signal comprising the steps of comparing a given pixel to other pixels to determine whether the difference between each of such other pixels and the given pixel is less than a reference threshold level, combining said given pixel and those other pixels that are within said reference threshold level of said given pixel, the total number of pixel signals used in this combining varying and outputing the combination, this combination increasing the apparent signal to noise ratio of the video signal.

16. Method as claimed in claim 15 wherein said combinations includes summing said given pixel and those other pixels within said reference threshold of said given pixel and dividing said sum by the total number of pixels summed.

17. A method for reducing noise on an electronic signal derived by scanning a image comprising the steps of comparing a given element of said signal to each of two or more other elements of said signal to determine the difference thereof, comparing each difference to the other differences to determine which of said other elements has the smallest corresponding difference and combining the element having the smallest corresponding difference with at least said given element to provide a noise reduced element which may be substituted for said given element.

18. A method for reducing noise on a signal derived by scanning an image comprising the steps of establishing a reference threshold level, comparing a central pixel to adjacent pixels to determine whether the absolute value of the difference between each of such adjacent pixels and the central pixel is less than said refer-

ence threshold level, and computing an average of said central pixel and those adjacent pixels that are within said reference threshold level of said central pixel, the total number of pixel signals used in computing this average varying and outputing this average as the value of said central pixel, this averaging increasing the apparent signal to noise ratio of the video signal.

19. A method for reducing noise on a signal derived by scanning an image comprising the steps of establishing a reference threshold level, comparing the level of a central pixel to the levels of a plurality of the surrounding pixels to determine whether the absolute value of the difference between each of such surrounding pixels and the central pixel is less than said reference threshold level, computing the sum of the levels of said surrounding pixels that are within said threshold reference level of said level of said central pixel plus the level of said central pixel, computing the number of pixels summed, dividing said sum by said number to determine an average value for the levels of similar pixels, and outputing said value for said central pixel, this process increasing the apparent signal to noise ratio of the video signal.

20. A method for reducing noise on a video signal comprising the steps of establishing a reference threshold level, comparing the level of a first pixel to the levels of a plurality of the adjacent pixels to determine whether the absolute value of the difference between each of the compared adjacent pixels and said first pixel is less than said reference threshold level, computing the sum of the levels of said compared adjacent pixels that are within said threshold reference level of said level of said first pixel plus the level of said first pixel, computing the number of pixels summed, dividing said sum by said number to determine a value for the levels of similar pixels, and outputing said value for said first pixel, this process reducing the apparent noise of the video signal.

21. A method for reducing noise on a video signal comprising the steps of comparing the level of a given pixel to the level of neighboring pixels to determine whether the difference between each of said neighboring pixels and said given pixel is less than a reference threshold level, computing the sum of the levels of said neighboring pixels that are within said threshold reference level of said level of said given pixel plus the level of said given pixel, computing the number of pixels summed, dividing said sum by said number to determine a value for the levels of similar pixels, and outputing said value for said given pixel, this process increasing the apparent signal to said noise ratio of the video signal.

22. An apparatus for reducing noise on a series of pixels derived from a video signal, said apparatus comprising means to compare a given pixel to other pixels to determine whether or not the difference between each of such other pixels and the given pixel is less than a reference threshold level, and means to compute an average of said given pixel with those other pixels that are within said reference threshold level of said given pixel, the total number of pixel signals used in computing this average varying and means to output the average as the value of said given pixel, this averaging increasing the apparent signal to noise ratio of the video signal.

23. An apparatus for reducing noise on a series of pixels derived from a video signal comprising means of establishing a reference threshold level, means of comparing a central pixel to surrounding pixels to determine whether the difference between each of such surrounding pixels and the central pixel is less than said reference threshold level, means to average said central pixel and those surrounding pixels that are within said reference threshold level of said central pixel, the total number of pixel signals used in this average varying and means to output this average as the value of said central pixel, this averaging increasing the apparent signal to noise ratio of the video signal.

24. Apparatus for reducing noise on a group of pixels derived from a video signal including in combination means responsive to the difference between a given pixel and at least one other pixel to compare said difference to two threshold levels to determine the greater of said difference and each of said threshold levels and means for substituting a combination of two or more pixels for said given pixel in response to said comparisons.

25. A method for reducing noise on a set of pixels derived from an optical image including the steps of comparing two neighboring pixels to determine the difference thereof, comparing said difference to a reference to determine the larger thereof and replacing a third neighboring pixel located between said first two neighboring pixels with a combination including neighboring pixels in response to said comparison to said reference, said combination representing a noise reduced third pixel.

26. Method of claim 25 where first two pixels are chosen so that they have the same color subcarrier phase.

27. The method for reducing noise of claim 25 wherein the two neighboring pixels are combined to produce the combination of the neighboring pixels used to replace the third pixel.

28. The method for reducing noise of claim 27 wherein the third neighboring pixel is also used in the combination of the neighboring pixels.

29. The method for reducing noise of claim 25 wherein the reference is a percentage of signal type reference.

30. The method of claim 25 wherein said set of pixels consists of three pixels taken from three consecutive scan lines from the same field of an NTSC video signal with said third neighboring pixel being from the central scan line of said three scan lines and with one said compared neighboring pixel being from one of the other of the three scan lines and the other said compared neighboring pixel being from the third scan line.

31. The method of claim 25 wherein said combination of pixels is made such that noise is reduced on the color subcarrier.

32. The method of claim 25 wherein determining said difference includes subtracting a first pixel from a second pixel, and further including taking the absolute value of the result.

33. The method of claim 25 wherein said pixels include the color subcarrier of an NTSC video signal.

34. The method of claim 25 wherein said pixels are represented in digital form.

35. The method of claim 25 wherein said pixels are represented in analog form.

36. A method for reducing noise on a video signal comprising the steps of selecting neighboring picture elements from the signal, examining said elements to determine their respective levels, ranking said elements according to their respective levels, combining all said elements within a chosen rank to produce a replacement

value and outputing said replacement value in the place of one of said elements within chosen rank, this processing increasing the apparent signal to noise ratio of the video signal.

37. A method for reducing noise on a video signal comprising the steps of selecting a first and neighboring picture elements from the signal, examining said first and neighboring elements to determine their respective levels, setting a threshold, examining the levels of said neighboring elements to determine whether the level of any of said neighboring elements are within the level of said threshold of the level of said first element, ranking said neighboring elements within said threshold of said first element, combining all said within threshold neighboring elements within a chosen rank and outputing said combination of all said within threshold neighboring elements within said chosen rank in the place of said first element, this process increasing the apparent signal to noise ratio of the video signal.

38. A method for reducing noise on a video signal comprising the steps of selecting neighboring picture elements from the signal, selecting a reference, examining the levels of said elements to determine whether the level of any of said elements are within said reference of the other of said elements, combining said elements that are within said reference to each other, to produce a replacement value and outputing said replacement value of said elements that are within said reference of each other in place of one of said element that is within said reference of each other, this increasing the apparent signal to noise ratio of the video signal.

39. A method for reducing noise on a video signal comprising the steps of selecting a first and neighboring picture elements from the signal, examining said elements to determine their respective levels, setting a threshold, comparing the levels of said neighboring elements to determine whether the level of any of said neighboring elements are within said threshold of said first element, combining said neighboring elements that are within said threshold of said first element, and outputing said combination of said neighboring elements that are within said threshold of said first element in place of said first element, this process increasing the apparent signal to noise ratio of the video signal.

40. A method for reducing noise on a video signal comprising the steps of selecting neighboring picture elements from the signal, selecting a reference, comparing the levels of said elements to determine whether any

of said elements are dissimilar by more than said reference from the others of said elements, combining some of said elements that are within said reference of each other, to produce a replacement value and outputing said replacement value of some of said elements that are within said reference of each other in place of one of said elements that is dissimilar by more than said reference of the others of said elements, this process increasing the apparent signal to noise ratio of the video signal.

41. A method for reducing noise on a video signal comprising the steps of selecting a first and neighboring elements from the signal, setting a threshold, comparing the levels of said neighboring elements to the level of said first element to determine whether the level of all of said neighboring elements are dissimilar by more than said threshold from said first element, and if all of said neighboring elements are dissimilar by more than said threshold from said first element then combining said neighboring elements and outputing said combination of said neighboring elements in place of said first element, this process increasing the apparent signal to noise ratio of the video signal.

42. The method of preserving detail in a noise reduced video signal wherein noise reduction is performed by combining a group of three or more pixels and substituting said combination for one pixel of said group, including the step of comparing two or more pixels of said group to determine the difference thereof, comparing said difference to a reference to determine the larger thereof, and inhibiting said substitution when said difference exceeds said reference.

43. The method of preserving detail in a noise reduced video signal which is the chroma subcarrier portion of an NTSC television video signal wherein noise reduction is performed by combining a first element and two neighboring elements of the input NTSC television video signal, said combination being the noise reduced value substituted for said first element, including the step of comparing two of said elements which are normally combined to determine if they are similar within a threshold value of each other, the step allowing said substitution to be made if said compared elements are similar within said threshold and inhibiting said substitution if said compared elements are not similar within said threshold thereby outputing said first element uncombined.

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