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(54) **REDUCING LOCATION-DEPENDENT DESTRUCTIVE INTERFERENCE IN DISTRIBUTED ANTENNA SYSTEMS (DASS) OPERATING IN MULTIPLE-INPUT, MULTIPLE-OUTPUT (MIMO) CONFIGURATION, AND RELATED COMPONENTS, SYSTEMS, AND METHODS**

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,365,865 A 12/1982 Stiles
4,449,246 A 5/1984 Seiler et al.

(Continued)

FOREIGN PATENT DOCUMENTS

AU 645192 B 10/1992
AU 731180 B2 3/1998

(Continued)

OTHER PUBLICATIONS

Sheldon, et al., "A 60GHz line-of-sight 2x2 MIMO link operating at 1.2Gbps," Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE, vol., No., pp. 1-4, Jul. 5-11, 2008.

(Continued)

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(58) **Field of Classification Search**

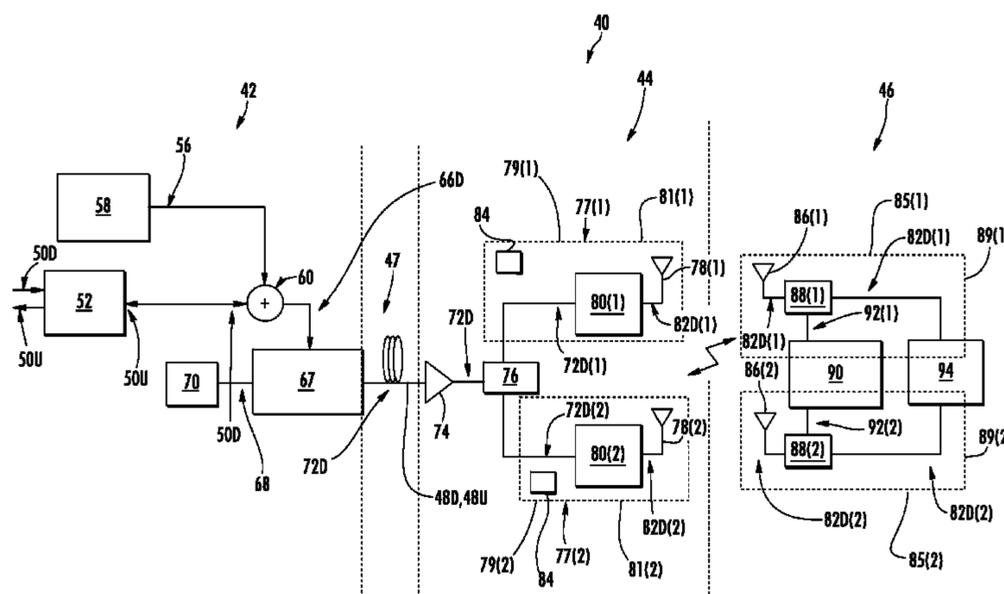
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See application file for complete search history.

(57) **ABSTRACT**

Components, systems, and methods for reducing location-dependent destructive interference in distributed antenna systems operating in multiple-input, multiple-output (MIMO) configuration are disclosed. Interference is defined as issues with received MIMO communications signals that can cause a MIMO algorithm to not be able to solve a channel matrix for MIMO communications signals received by MIMO receivers in client devices. These issues may be caused by lack of separation (i.e., phase, amplitude) in the received MIMO communications signals. Thus, to provide amplitude separation of received MIMO communications signals, multiple MIMO transmitters are each configured to employ multiple transmitter antennas, which are each configured to transmit in different polarization states. In certain embodiments, one of the MIMO communications signals is amplitude adjusted in one of the polarization states to provide amplitude separation between received MIMO communications signals. In other embodiments, multiple trans-

(Continued)



mitter antennas in a MIMO transmitter can be offset to provide amplitude separation.

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- (56) **References Cited**

U.S. PATENT DOCUMENTS

4,573,212 A	2/1986	Lipsky	5,682,256 A	10/1997	Motley et al.
4,665,560 A	5/1987	Lange	5,694,232 A	12/1997	Parsay et al.
4,867,527 A	9/1989	Dotti et al.	5,703,602 A	12/1997	Casebolt
4,889,977 A	12/1989	Haydon	5,708,681 A	1/1998	Malkemes et al.
4,896,939 A	1/1990	O'Brien	5,726,984 A	3/1998	Kubler et al.
4,916,460 A	4/1990	Powell	5,765,099 A	6/1998	Georges et al.
4,939,852 A	7/1990	Brenner	5,774,789 A	6/1998	van der Kaay et al.
4,972,346 A	11/1990	Kawano et al.	5,790,536 A	8/1998	Mahany et al.
5,039,195 A	8/1991	Jenkins et al.	5,790,606 A	8/1998	Dent
5,042,086 A	8/1991	Cole et al.	5,793,772 A	8/1998	Burke et al.
5,056,109 A	10/1991	Gilhousen et al.	5,802,173 A	9/1998	Hamilton-Piercy et al.
5,059,927 A	10/1991	Cohen	5,802,473 A	9/1998	Rutledge et al.
5,125,060 A	6/1992	Edmundson	5,805,975 A	9/1998	Green, Sr. et al.
5,159,479 A	10/1992	Takagi	5,805,983 A	9/1998	Naidu et al.
5,187,803 A	2/1993	Sohner et al.	5,809,395 A	9/1998	Hamilton-Piercy et al.
5,189,718 A	2/1993	Barrett et al.	5,809,422 A	9/1998	Raleigh et al.
5,189,719 A	2/1993	Coleman et al.	5,809,431 A	9/1998	Bustamante et al.
5,206,655 A	4/1993	Caille et al.	5,812,296 A	9/1998	Tarusawa et al.
5,208,812 A	5/1993	Dudek et al.	5,818,619 A	10/1998	Medved et al.
5,210,812 A	5/1993	Nilsson et al.	5,818,883 A	10/1998	Smith et al.
5,260,957 A	11/1993	Hakimi	5,821,510 A	10/1998	Cohen et al.
5,263,108 A	11/1993	Kurokawa et al.	5,825,651 A	10/1998	Gupta et al.
5,267,122 A	11/1993	Glover et al.	5,828,658 A	10/1998	Ottersten et al.
5,268,971 A	12/1993	Nilsson et al.	5,832,379 A	11/1998	Mallinckrodt
5,278,690 A	1/1994	Vella-Coleiro	5,835,857 A	11/1998	Otten
5,278,989 A	1/1994	Burke et al.	5,838,474 A	11/1998	Stilling
5,280,472 A	1/1994	Gilhousen et al.	5,839,052 A	11/1998	Dean et al.
5,299,947 A	4/1994	Barnard	5,852,651 A	12/1998	Fischer et al.
5,301,056 A	4/1994	O'Neill	5,854,986 A	12/1998	Dorren et al.
5,325,223 A	6/1994	Bears	5,859,719 A	1/1999	Dentai et al.
5,339,058 A	8/1994	Lique	5,862,460 A	1/1999	Rich
5,339,184 A	8/1994	Tang	5,867,485 A	2/1999	Chambers et al.
5,343,320 A	8/1994	Anderson	5,867,763 A	2/1999	Dean et al.
5,377,035 A	12/1994	Wang et al.	5,881,200 A	3/1999	Burt
5,379,455 A	1/1995	Koschek	5,883,882 A	3/1999	Schwartz
5,381,459 A	1/1995	Lappington	5,896,568 A	4/1999	Tseng et al.
5,396,224 A	3/1995	Dukes et al.	5,903,834 A	5/1999	Wallstedt et al.
5,400,391 A	3/1995	Emura et al.	5,910,776 A	6/1999	Black
5,420,863 A	5/1995	Taketsugu et al.	5,913,003 A	6/1999	Arroyo et al.
5,424,864 A	6/1995	Emura	5,917,636 A	6/1999	Wake et al.
5,444,564 A	8/1995	Newberg	5,930,682 A	7/1999	Schwartz et al.
5,457,557 A	10/1995	Zarem et al.	5,936,754 A	8/1999	Ariyavisitakul et al.
5,459,727 A	10/1995	Vannucci	5,943,372 A	8/1999	Gans et al.
5,469,523 A	11/1995	Blew et al.	5,946,622 A	8/1999	Bojeryd
5,502,446 A	3/1996	Denninger	5,949,564 A	9/1999	Wake
5,519,830 A	5/1996	Opoczynski	5,953,670 A	9/1999	Newson
5,543,000 A	8/1996	Lique	5,959,531 A	9/1999	Gallagher, III et al.
5,546,443 A	8/1996	Raith	5,960,344 A	9/1999	Mahany
5,557,698 A	9/1996	Gareis et al.	5,969,837 A	10/1999	Farber et al.
5,574,815 A	11/1996	Kneeland	5,983,070 A	11/1999	Georges et al.
5,583,517 A	12/1996	Yokey et al.	5,987,303 A	11/1999	Dutta et al.
5,598,288 A	1/1997	Collar	5,995,832 A	11/1999	Mallinckrodt
5,606,725 A	2/1997	Hart	6,005,884 A	12/1999	Cook et al.
5,615,034 A	3/1997	Hori	6,006,069 A	12/1999	Langston et al.
5,627,879 A	5/1997	Russell et al.	6,006,105 A	12/1999	Rostoker et al.
5,640,678 A	6/1997	Ishikawa et al.	6,011,980 A	1/2000	Nagano et al.
5,644,622 A	7/1997	Russell et al.	6,014,546 A	1/2000	Georges et al.
5,648,961 A	7/1997	Ebihara	6,016,426 A	1/2000	Bodell
5,651,081 A	7/1997	Blew et al.	6,023,625 A	2/2000	Myers, Jr.
5,661,582 A	8/1997	Kintis et al.	6,037,898 A	3/2000	Parish et al.
5,668,562 A	9/1997	Cutrer et al.	6,049,705 A	4/2000	Xue
5,677,974 A	10/1997	Elms et al.	6,061,161 A	5/2000	Yang et al.
			6,069,721 A	5/2000	Oh et al.
			6,088,381 A	7/2000	Myers, Jr.
			6,112,086 A	8/2000	Wala
			6,118,767 A	9/2000	Shen et al.
			6,122,529 A	9/2000	Sabat, Jr. et al.
			6,127,917 A	10/2000	Tuttle
			6,128,470 A	10/2000	Naidu et al.
			6,128,477 A	10/2000	Freed
			6,148,041 A	11/2000	Dent
			6,150,921 A	11/2000	Werb et al.
			6,157,810 A	12/2000	Georges et al.
			6,192,216 B1	2/2001	Sabat, Jr. et al.
			6,194,968 B1	2/2001	Winslow
			6,198,432 B1	3/2001	Janky
			6,212,397 B1	4/2001	Langston et al.
			6,222,503 B1	4/2001	Gietema
			6,223,201 B1	4/2001	Reznak

(56)

References Cited

U.S. PATENT DOCUMENTS

6,232,870 B1	5/2001	Garber et al.	6,636,747 B2	10/2003	Harada et al.
6,236,789 B1	5/2001	Fitz	6,640,103 B1	10/2003	Inman et al.
6,236,863 B1	5/2001	Waldroup et al.	6,643,437 B1	11/2003	Park
6,240,274 B1	5/2001	Izadpanah	6,652,158 B2	11/2003	Bartur et al.
6,268,946 B1	7/2001	Larkin et al.	6,654,590 B2	11/2003	Boros et al.
6,275,990 B1	8/2001	Dapper et al.	6,654,616 B1	11/2003	Pope, Jr. et al.
6,279,158 B1	8/2001	Geile et al.	6,657,535 B1	12/2003	Magbie et al.
6,286,163 B1	9/2001	Trimble	6,658,269 B1	12/2003	Golemon et al.
6,292,673 B1	9/2001	Maeda et al.	6,665,308 B1	12/2003	Rakib et al.
6,295,451 B1	9/2001	Mimura	6,670,930 B2	12/2003	Navarro
6,301,240 B1	10/2001	Slabinski et al.	6,675,294 B1	1/2004	Gupta et al.
6,307,869 B1	10/2001	Pawelski	6,678,509 B2	1/2004	Skarman et al.
6,308,085 B1	10/2001	Shoki	6,687,437 B1	2/2004	Starnes et al.
6,314,163 B1	11/2001	Acampora	6,690,328 B2	2/2004	Judd
6,317,599 B1	11/2001	Rappaport et al.	6,696,917 B1	2/2004	Heitner et al.
6,323,980 B1	11/2001	Bloom	6,697,603 B1	2/2004	Lovinggood et al.
6,324,391 B1	11/2001	Bodell	6,704,298 B1	3/2004	Matsumiya et al.
6,330,241 B1	12/2001	Fort	6,704,545 B1	3/2004	Wala
6,330,244 B1	12/2001	Swartz et al.	6,710,366 B1	3/2004	Lee et al.
6,334,219 B1	12/2001	Hill et al.	6,714,800 B2	3/2004	Johnson et al.
6,336,021 B1	1/2002	Nukada	6,731,880 B2	5/2004	Westbrook et al.
6,336,042 B1	1/2002	Dawson et al.	6,745,013 B1	6/2004	Porter et al.
6,337,754 B1	1/2002	Imajo	6,758,913 B1	7/2004	Tunney et al.
6,340,932 B1	1/2002	Rodgers et al.	6,763,226 B1	7/2004	McZeal, Jr.
6,353,406 B1	3/2002	Lanzl et al.	6,771,862 B2	8/2004	Karnik et al.
6,353,600 B1	3/2002	Schwartz et al.	6,771,933 B1	8/2004	Eng et al.
6,359,714 B1	3/2002	Imajo	6,784,802 B1	8/2004	Stanescu
6,370,203 B1	4/2002	Boesch et al.	6,785,558 B1	8/2004	Stratford et al.
6,374,078 B1	4/2002	Williams et al.	6,788,666 B1	9/2004	Linebarger et al.
6,374,124 B1	4/2002	Slabinski	6,801,767 B1	10/2004	Schwartz et al.
6,389,010 B1	5/2002	Kubler et al.	6,807,374 B1	10/2004	Imajo et al.
6,400,318 B1	6/2002	Kasami et al.	6,812,824 B1	11/2004	Goldinger et al.
6,400,418 B1	6/2002	Wakabayashi	6,812,905 B2	11/2004	Thomas et al.
6,404,775 B1	6/2002	Leslie et al.	6,823,174 B1	11/2004	Masenten et al.
6,405,018 B1	6/2002	Reudink et al.	6,826,163 B2	11/2004	Mani et al.
6,405,058 B2	6/2002	Bobier	6,826,337 B2	11/2004	Linnell
6,405,308 B1	6/2002	Gupta et al.	6,836,660 B1	12/2004	Wala
6,414,624 B2	7/2002	Endo et al.	6,836,673 B1	12/2004	Trott
6,415,132 B1	7/2002	Sabat, Jr.	6,842,433 B2	1/2005	West et al.
6,421,327 B1	7/2002	Lundby et al.	6,842,459 B1	1/2005	Binder
6,438,301 B1	8/2002	Johnson et al.	6,847,856 B1	1/2005	Bohannon
6,438,371 B1	8/2002	Fujise et al.	6,850,510 B2	2/2005	Kubler
6,448,558 B1	9/2002	Greene	6,865,390 B2	3/2005	Goss et al.
6,452,915 B1	9/2002	Jorgensen	6,873,823 B2	3/2005	Hasarchi
6,459,519 B1	10/2002	Sasai et al.	6,876,056 B2	4/2005	Tilmans et al.
6,459,989 B1	10/2002	Kirkpatrick et al.	6,879,290 B1	4/2005	Toutain et al.
6,477,154 B1	11/2002	Cheong et al.	6,882,311 B2	4/2005	Walker et al.
6,480,702 B1	11/2002	Sabat, Jr.	6,883,710 B2	4/2005	Chung
6,486,907 B1	11/2002	Farber et al.	6,885,344 B2	4/2005	Mohamadi
6,496,290 B1	12/2002	Lee	6,885,846 B1	4/2005	Panasik et al.
6,501,965 B1	12/2002	Lucidarme	6,889,060 B2	5/2005	Fernando et al.
6,504,636 B1	1/2003	Seto et al.	6,895,249 B2	5/2005	Gaal
6,504,831 B1	1/2003	Greenwood et al.	6,909,399 B1	6/2005	Zegelin et al.
6,512,478 B1	1/2003	Chien	6,914,539 B2	7/2005	Hoctor et al.
6,519,395 B1	2/2003	Bevan et al.	6,915,058 B2	7/2005	Pons
6,519,449 B1	2/2003	Zhang et al.	6,915,529 B1	7/2005	Suematsu et al.
6,525,855 B1	2/2003	Westbrook et al.	6,919,858 B2	7/2005	Rofougaran
6,535,330 B1	3/2003	Lelic et al.	6,920,330 B2	7/2005	Caronni et al.
6,535,720 B1	3/2003	Kintis et al.	6,924,997 B2	8/2005	Chen et al.
6,556,551 B1	4/2003	Schwartz	6,930,987 B1	8/2005	Fukuda et al.
6,577,794 B1	6/2003	Currie et al.	6,931,183 B2	8/2005	Panak et al.
6,577,801 B2	6/2003	Broderick et al.	6,931,659 B1	8/2005	Kinemura
6,580,393 B2	6/2003	Holt	6,933,849 B2	8/2005	Sawyer
6,580,402 B2	6/2003	Navarro et al.	6,934,511 B1	8/2005	Lovinggood et al.
6,580,905 B1	6/2003	Naidu et al.	6,934,541 B2	8/2005	Miyatani
6,580,918 B1	6/2003	Leickel et al.	6,941,112 B2	9/2005	Hasegawa
6,583,763 B2	6/2003	Judd	6,946,989 B2	9/2005	Vavik
6,587,514 B1	7/2003	Wright et al.	6,961,312 B2	11/2005	Kubler et al.
6,594,496 B2	7/2003	Schwartz	6,963,289 B2	11/2005	Aljadeff et al.
6,597,325 B2	7/2003	Judd et al.	6,963,552 B2	11/2005	Sabat, Jr. et al.
6,598,009 B2	7/2003	Yang	6,965,718 B2	11/2005	Koertel
6,606,430 B2	8/2003	Bartur et al.	6,967,347 B2	11/2005	Estes et al.
6,615,074 B2	9/2003	Mickle et al.	6,968,107 B2	11/2005	Belardi et al.
6,628,732 B1	9/2003	Takaki	6,970,652 B2	11/2005	Zhang et al.
6,634,811 B1	10/2003	Gertel et al.	6,973,243 B2	12/2005	Koyasu et al.
			6,974,262 B1	12/2005	Rickenbach
			6,977,502 B1	12/2005	Hertz
			7,002,511 B1	2/2006	Ammar et al.
			7,006,039 B2	2/2006	Miyamoto et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,006,465 B2	2/2006	Toshimitsu et al.	7,460,507 B2	12/2008	Kubler et al.
7,013,087 B2	3/2006	Suzuki et al.	7,460,829 B2	12/2008	Utsumi et al.
7,015,826 B1	3/2006	Chan et al.	7,460,831 B2	12/2008	Hasarchi
7,020,473 B2	3/2006	Splett	7,466,925 B2	12/2008	Iannelli
7,020,488 B1	3/2006	Bleile et al.	7,469,105 B2	12/2008	Wake et al.
7,023,382 B1	4/2006	Akano	7,477,597 B2	1/2009	Segel
7,024,166 B2	4/2006	Wallace	7,483,504 B2	1/2009	Shapira et al.
7,035,512 B2	4/2006	Van Bijsterveld	7,483,711 B2	1/2009	Burchfiel
7,035,671 B2	4/2006	Solum	7,496,070 B2	2/2009	Vesuna
7,039,399 B2	5/2006	Fischer	7,496,384 B2	2/2009	Seto et al.
7,043,271 B1	5/2006	Seto et al.	7,505,747 B2	3/2009	Solum
7,047,028 B2	5/2006	Cagenius et al.	7,512,419 B2	3/2009	Solum
7,050,017 B2	5/2006	King et al.	7,522,552 B2	4/2009	Fein et al.
7,053,838 B2	5/2006	Judd	7,539,509 B2	5/2009	Bauman et al.
7,054,513 B2	5/2006	Herz et al.	7,542,452 B2	6/2009	Penumetsa
7,069,577 B2	6/2006	Geile et al.	7,546,138 B2	6/2009	Bauman
7,072,586 B2	7/2006	Aburakawa et al.	7,548,138 B2	6/2009	Kamgaing
7,082,320 B2	7/2006	Kattukaran et al.	7,548,695 B2	6/2009	Wake
7,084,769 B2	8/2006	Bauer et al.	7,551,641 B2	6/2009	Pirzada et al.
7,092,726 B2	8/2006	Shi et al.	7,557,758 B2	7/2009	Rofougaran
7,093,985 B2	8/2006	Lord et al.	7,580,384 B2	8/2009	Kubler et al.
7,103,119 B2	9/2006	Matsuoka et al.	7,586,861 B2	9/2009	Kubler et al.
7,103,377 B2	9/2006	Bauman et al.	7,590,354 B2	9/2009	Sauer et al.
7,106,931 B2	9/2006	Sutehall et al.	7,593,704 B2	9/2009	Pinel et al.
7,110,795 B2	9/2006	Doi	7,599,420 B2	10/2009	Forenza et al.
7,114,859 B1	10/2006	Tuohimaa et al.	7,599,672 B2	10/2009	Shoji et al.
7,123,939 B1	10/2006	Bird et al.	7,610,046 B2	10/2009	Wala
7,127,176 B2	10/2006	Sasaki	7,627,250 B2	12/2009	George et al.
7,142,503 B1	11/2006	Grant et al.	7,630,690 B2	12/2009	Kaewell, Jr. et al.
7,142,535 B2	11/2006	Kubler et al.	7,633,934 B2	12/2009	Kubler et al.
7,142,619 B2	11/2006	Sommer et al.	7,639,982 B2	12/2009	Wala
7,160,032 B2	1/2007	Nagashima et al.	7,646,743 B2	1/2010	Kubler et al.
7,171,244 B2	1/2007	Bauman	7,646,777 B2	1/2010	Hicks, III et al.
7,184,728 B2	2/2007	Solum	7,653,397 B2	1/2010	Pernu et al.
7,190,748 B2	3/2007	Kim et al.	7,668,565 B2	2/2010	Ylänen et al.
7,194,023 B2	3/2007	Norrell et al.	7,675,936 B2	3/2010	Mizutani et al.
7,199,443 B2	4/2007	Elsharawy	7,688,811 B2	3/2010	Kubler et al.
7,200,305 B2	4/2007	Dion et al.	7,693,486 B2	4/2010	Kasslin et al.
7,200,391 B2	4/2007	Chung et al.	7,697,467 B2	4/2010	Kubler et al.
7,228,072 B2	6/2007	Mickelsson et al.	7,697,574 B2	4/2010	Suematsu et al.
7,250,907 B2	7/2007	Krumm et al.	7,715,375 B2	5/2010	Kubler et al.
7,263,293 B2	8/2007	Ommodt et al.	7,715,722 B1	5/2010	Hoke et al.
7,269,311 B2	9/2007	Kim et al.	7,751,374 B2	7/2010	Donovan
7,280,011 B2	10/2007	Bayar et al.	7,751,838 B2	7/2010	Ramesh et al.
7,286,843 B2	10/2007	Scheck	7,760,703 B2	7/2010	Kubler et al.
7,286,854 B2	10/2007	Ferrato et al.	7,768,951 B2	8/2010	Kubler et al.
7,295,119 B2	11/2007	Rappaport et al.	7,773,573 B2	8/2010	Chung et al.
7,310,430 B1	12/2007	Mallya et al.	7,778,603 B2	8/2010	Palin et al.
7,313,415 B2	12/2007	Wake et al.	7,787,823 B2	8/2010	George et al.
7,315,735 B2	1/2008	Graham	7,787,854 B2	8/2010	Conyers et al.
7,324,730 B2	1/2008	Varkey et al.	7,809,012 B2	10/2010	Ruuska et al.
7,343,164 B2	3/2008	Kallstenius	7,812,766 B2	10/2010	Leblanc et al.
7,348,843 B1	3/2008	Qiu et al.	7,812,775 B2	10/2010	Babakhani et al.
7,349,633 B2	3/2008	Lee et al.	7,817,958 B2	10/2010	Scheinert et al.
7,359,408 B2	4/2008	Kim	7,817,969 B2	10/2010	Castaneda et al.
7,359,674 B2	4/2008	Markki et al.	7,835,328 B2	11/2010	Stephens et al.
7,366,150 B2	4/2008	Lee et al.	7,844,273 B2	11/2010	Scheinert
7,366,151 B2	4/2008	Kubler et al.	7,848,316 B2	12/2010	Kubler et al.
7,369,526 B2	5/2008	Lechleider et al.	7,848,731 B1	12/2010	Dianda et al.
7,379,669 B2	5/2008	Kim	7,848,770 B2	12/2010	Scheinert
7,388,892 B2	6/2008	Nishiyama et al.	7,853,234 B2	12/2010	Afsahi
7,392,025 B2	6/2008	Rooyen et al.	7,870,321 B2	1/2011	Rofougaran
7,392,029 B2	6/2008	Pronkine	7,880,677 B2	2/2011	Rofougaran et al.
7,394,883 B2	7/2008	Funakubo et al.	7,881,755 B1	2/2011	Mishra et al.
7,403,156 B2	7/2008	Coppi et al.	7,894,423 B2	2/2011	Kubler et al.
7,409,159 B2	8/2008	Izadpanah	7,899,007 B2	3/2011	Kubler et al.
7,412,224 B2	8/2008	Kotola et al.	7,907,972 B2	3/2011	Walton et al.
7,424,228 B1	9/2008	Williams et al.	7,912,043 B2	3/2011	Kubler et al.
7,429,951 B2	9/2008	Kennedy, Jr. et al.	7,912,506 B2	3/2011	Lovberg et al.
7,442,679 B2	10/2008	Stolte et al.	7,916,706 B2	3/2011	Kubler et al.
7,444,051 B2	10/2008	Tatat et al.	7,917,177 B2	3/2011	Bauman
7,450,853 B2	11/2008	Kim et al.	7,920,553 B2	4/2011	Kubler et al.
7,450,854 B2	11/2008	Lee et al.	7,920,858 B2	4/2011	Sabat, Jr. et al.
7,451,365 B2	11/2008	Wang et al.	7,924,783 B1	4/2011	Mahany et al.
7,454,222 B2	11/2008	Huang et al.	7,929,940 B1	4/2011	Dianda et al.
			7,936,713 B2	5/2011	Kubler et al.
			7,948,897 B2	5/2011	Stuart et al.
			7,949,364 B2	5/2011	Kasslin et al.
			7,957,777 B1	6/2011	Vu et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,962,111 B2	6/2011	Solum	2004/0043764 A1	3/2004	Bigham et al.
7,969,009 B2	6/2011	Chandrasekaran	2004/0047313 A1	3/2004	Rumpf et al.
7,969,911 B2	6/2011	Mahany et al.	2004/0078151 A1	4/2004	Aljadeff et al.
7,990,925 B2	8/2011	Tinnakornsrishuphap et al.	2004/0095907 A1	5/2004	Agee et al.
7,996,020 B1	8/2011	Chhabra	2004/0100930 A1	5/2004	Shapira et al.
8,018,907 B2	9/2011	Kubler et al.	2004/0102196 A1	5/2004	Weckstrom et al.
8,023,886 B2	9/2011	Rofougaran	2004/0105435 A1	6/2004	Morioka
8,027,656 B2	9/2011	Rofougaran et al.	2004/0126068 A1	7/2004	Van Bijsterveld
8,036,308 B2	10/2011	Rofougaran	2004/0126107 A1	7/2004	Jay et al.
8,082,353 B2	12/2011	Huber et al.	2004/0139477 A1	7/2004	Russell et al.
8,086,192 B2	12/2011	Rofougaran et al.	2004/0146020 A1	7/2004	Kubler et al.
8,107,464 B2	1/2012	Schmidt et al.	2004/0149736 A1	8/2004	Clothier
8,174,428 B2	5/2012	Wegener	2004/0151164 A1	8/2004	Kubler et al.
8,274,929 B2	9/2012	Schmidt et al.	2004/0151503 A1	8/2004	Kashima et al.
8,275,265 B2	9/2012	Kobyakov et al.	2004/0157623 A1	8/2004	Splett
8,279,800 B2	10/2012	Schmidt et al.	2004/0160912 A1	8/2004	Kubler et al.
8,310,963 B2	11/2012	Singh	2004/0160913 A1	8/2004	Kubler et al.
8,346,091 B2	1/2013	Kummetz et al.	2004/0162084 A1	8/2004	Wang
8,422,884 B2	4/2013	Mao	2004/0162115 A1	8/2004	Smith et al.
8,467,823 B2	6/2013	Seki et al.	2004/0162116 A1	8/2004	Han et al.
8,548,330 B2	10/2013	Berlin et al.	2004/0164902 A1	8/2004	Karlsson et al.
8,548,526 B2	10/2013	Schmidt et al.	2004/0165568 A1	8/2004	Weinstein
8,583,100 B2	11/2013	Koziy et al.	2004/0165573 A1	8/2004	Kubler et al.
8,599,794 B2	12/2013	Ahmadi	2004/0175173 A1	9/2004	Deas
8,634,766 B2	1/2014	Hobbs et al.	2004/0196404 A1	10/2004	Loheit et al.
8,676,214 B2	3/2014	Fischer et al.	2004/0202257 A1	10/2004	Mehta et al.
8,681,917 B2	3/2014	McAllister et al.	2004/0203703 A1	10/2004	Fischer
8,693,342 B2	4/2014	Uyehara et al.	2004/0203704 A1	10/2004	Ommodt et al.
8,694,034 B2	4/2014	Notargiacomo	2004/0203846 A1	10/2004	Caronni et al.
8,699,982 B2	4/2014	Singh	2004/0204109 A1	10/2004	Hoppenstein
8,737,300 B2	5/2014	Stapleton et al.	2004/0208526 A1	10/2004	Mibu
8,792,933 B2	7/2014	Chen	2004/0208643 A1	10/2004	Roberts et al.
8,873,585 B2	10/2014	Oren et al.	2004/0218873 A1	11/2004	Nagashima et al.
8,908,607 B2	12/2014	Kummetz et al.	2004/0233877 A1	11/2004	Lee et al.
8,913,892 B2	12/2014	Berlin et al.	2004/0258105 A1	12/2004	Spathas et al.
8,948,816 B2	2/2015	Fischer et al.	2005/0041693 A1	2/2005	Priotti
8,958,789 B2	2/2015	Bauman et al.	2005/0052287 A1	3/2005	Whitesmith et al.
8,976,067 B2	3/2015	Fischer	2005/0058451 A1	3/2005	Ross
9,001,811 B2	4/2015	Wala et al.	2005/0068179 A1	3/2005	Roesner
9,130,613 B2	9/2015	Oren et al.	2005/0076982 A1	4/2005	Metcalf et al.
9,258,052 B2	2/2016	George et al.	2005/0078006 A1	4/2005	Hutchins
2001/0036199 A1	11/2001	Terry	2005/0093679 A1	5/2005	Zai et al.
2002/0003645 A1	1/2002	Kim et al.	2005/0099343 A1	5/2005	Asrani et al.
2002/0009070 A1	1/2002	Lindsay et al.	2005/0116821 A1	6/2005	Wilsey et al.
2002/0012495 A1	1/2002	Sasai et al.	2005/0123232 A1	6/2005	Piede et al.
2002/0048071 A1	4/2002	Suzuki et al.	2005/0141545 A1	6/2005	Fein et al.
2002/0051434 A1	5/2002	Ozluturk et al.	2005/0143077 A1	6/2005	Charbonneau
2002/0075906 A1	6/2002	Cole et al.	2005/0147071 A1	7/2005	Karaoguz et al.
2002/0085643 A1	7/2002	Kitchener et al.	2005/0148306 A1	7/2005	Hiddink
2002/0092347 A1	7/2002	Niekerk et al.	2005/0159108 A1	7/2005	Fletcher
2002/0111149 A1	8/2002	Shoki	2005/0174236 A1	8/2005	Brookner
2002/0111192 A1	8/2002	Thomas et al.	2005/0176458 A1	8/2005	Shklarsky et al.
2002/0114038 A1	8/2002	Arnon et al.	2005/0201761 A1	9/2005	Bartur et al.
2002/0123365 A1	9/2002	Thorson et al.	2005/0219050 A1	10/2005	Martin
2002/0126967 A1	9/2002	Panak et al.	2005/0224585 A1	10/2005	Durrant et al.
2002/0128009 A1	9/2002	Boch et al.	2005/0226625 A1	10/2005	Wake et al.
2002/0130778 A1	9/2002	Nicholson	2005/0232636 A1	10/2005	Durrant et al.
2002/0181668 A1	12/2002	Masoian et al.	2005/0242188 A1	11/2005	Vesuna
2002/0190845 A1	12/2002	Moore	2005/0252971 A1	11/2005	Howarth et al.
2003/0002604 A1	1/2003	Fifield et al.	2005/0266797 A1	12/2005	Utsumi et al.
2003/0007214 A1	1/2003	Aburakawa et al.	2005/0266854 A1	12/2005	Niiho et al.
2003/0016418 A1	1/2003	Westbrook et al.	2005/0269930 A1	12/2005	Shimizu et al.
2003/0045284 A1	3/2003	Copley et al.	2005/0271396 A1	12/2005	Iannelli
2003/0078074 A1	4/2003	Sesay et al.	2005/0272439 A1	12/2005	Picciriello et al.
2003/0112826 A1	6/2003	Ashwood Smith et al.	2006/0002326 A1	1/2006	Vesuna
2003/0141962 A1	7/2003	Barink	2006/0014548 A1	1/2006	Bolin
2003/0161637 A1	8/2003	Yamamoto et al.	2006/0017633 A1	1/2006	Pronkine
2003/0165287 A1	9/2003	Krill et al.	2006/0028352 A1	2/2006	McNamara et al.
2003/0174099 A1	9/2003	Bauer et al.	2006/0045054 A1	3/2006	Utsumi et al.
2003/0209601 A1	11/2003	Chung	2006/0046662 A1	3/2006	Moulsley et al.
2004/0001719 A1	1/2004	Sasaki	2006/0056283 A1	3/2006	Anikhindi et al.
2004/0008114 A1	1/2004	Sawyer	2006/0056327 A1	3/2006	Coersmeier
2004/0017785 A1	1/2004	Zelst	2006/0062579 A1	3/2006	Kim et al.
2004/0037565 A1	2/2004	Young et al.	2006/0063494 A1	3/2006	Zhang et al.
2004/0041714 A1	3/2004	Forster	2006/0094470 A1	5/2006	Wake et al.
			2006/0104643 A1	5/2006	Lee et al.
			2006/0120395 A1	6/2006	Xing et al.
			2006/0128425 A1	6/2006	Rooyen
			2006/0159388 A1	7/2006	Kawase et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2006/0182446	A1	8/2006	Kim et al.	2008/0207253	A1	8/2008	Jaakkola et al.
2006/0182449	A1	8/2006	Iannelli et al.	2008/0212969	A1	9/2008	Fasshauer et al.
2006/0189280	A1	8/2006	Goldberg	2008/0219670	A1	9/2008	Kim et al.
2006/0189354	A1	8/2006	Lee et al.	2008/0232799	A1	9/2008	Kim
2006/0203836	A1	9/2006	Kim	2008/0233967	A1	9/2008	Montejo et al.
2006/0217132	A1	9/2006	Drummond-Murray et al.	2008/0247716	A1	10/2008	Thomas
2006/0223439	A1	10/2006	Pinel et al.	2008/0253280	A1	10/2008	Tang et al.
2006/0233506	A1	10/2006	Noonan et al.	2008/0253351	A1	10/2008	Pernu et al.
2006/0239630	A1	10/2006	Hase et al.	2008/0253773	A1	10/2008	Zheng
2006/0262014	A1	11/2006	Shemesh et al.	2008/0260388	A1	10/2008	Kim et al.
2006/0268738	A1	11/2006	Goerke et al.	2008/0261656	A1	10/2008	Bella et al.
2006/0274704	A1	12/2006	Desai et al.	2008/0268766	A1	10/2008	Narkmon et al.
2006/0276227	A1	12/2006	Dravida	2008/0268833	A1	10/2008	Huang et al.
2007/0008939	A1	1/2007	Fischer	2008/0273844	A1	11/2008	Kewitsch
2007/0009266	A1	1/2007	Bothwell	2008/0279137	A1	11/2008	Pernu et al.
2007/0054682	A1	3/2007	Fanning et al.	2008/0280569	A1	11/2008	Hazani et al.
2007/0058978	A1	3/2007	Lee et al.	2008/0291818	A1	11/2008	Leisten
2007/0060045	A1	3/2007	Prautzsch	2008/0291830	A1	11/2008	Pernu et al.
2007/0060055	A1	3/2007	Desai et al.	2008/0292322	A1	11/2008	Daghighian et al.
2007/0071128	A1	3/2007	Meir et al.	2008/0298813	A1	12/2008	Song et al.
2007/0072646	A1	3/2007	Kuwahara et al.	2008/0304831	A1	12/2008	Miller, II et al.
2007/0076649	A1	4/2007	Lin et al.	2008/0310464	A1	12/2008	Schneider
2007/0093273	A1	4/2007	Cai	2008/0310848	A1	12/2008	Yasuda et al.
2007/0099578	A1*	5/2007	Adeney H04B 7/0408 455/69	2008/0311876	A1	12/2008	Leenaerts et al.
2007/0104165	A1	5/2007	Hanaoka et al.	2009/0022304	A1	1/2009	Kubler et al.
2007/0135169	A1	6/2007	Sychaleun et al.	2009/0028087	A1	1/2009	Nguyen et al.
2007/0149250	A1	6/2007	Crozzoli et al.	2009/0028317	A1	1/2009	Ling et al.
2007/0155314	A1	7/2007	Mohebbi	2009/0041413	A1	2/2009	Hurley
2007/0166042	A1	7/2007	Seeds et al.	2009/0047023	A1	2/2009	Pescod et al.
2007/0173288	A1	7/2007	Skarby et al.	2009/0059903	A1	3/2009	Kubler et al.
2007/0182626	A1	8/2007	Samavati et al.	2009/0061796	A1	3/2009	Arkko et al.
2007/0184841	A1	8/2007	Choi et al.	2009/0061939	A1	3/2009	Andersson et al.
2007/0224954	A1	9/2007	Gopi	2009/0073916	A1	3/2009	Zhang et al.
2007/0243899	A1	10/2007	Hermel et al.	2009/0087179	A1	4/2009	Underwood et al.
2007/0248358	A1	10/2007	Sauer	2009/0088071	A1	4/2009	Rofougaran
2007/0253714	A1	11/2007	Seeds et al.	2009/0092073	A1	4/2009	Doppler et al.
2007/0257796	A1	11/2007	Easton et al.	2009/0135078	A1	5/2009	Lindmark et al.
2007/0264009	A1	11/2007	Sabat, Jr. et al.	2009/0141780	A1	6/2009	Cruz-Albrecht et al.
2007/0264011	A1	11/2007	Sone et al.	2009/0149221	A1	6/2009	Liu et al.
2007/0268846	A1	11/2007	Proctor et al.	2009/0154621	A1	6/2009	Shapira et al.
2007/0274279	A1	11/2007	Wood et al.	2009/0169163	A1	7/2009	Abbott, III et al.
2007/0280370	A1	12/2007	Liu	2009/0175214	A1	7/2009	Sfar et al.
2007/0292143	A1	12/2007	Yu et al.	2009/0180407	A1	7/2009	Sabat et al.
2007/0297005	A1	12/2007	Montierth et al.	2009/0218407	A1	9/2009	Rofougaran
2008/0002652	A1	1/2008	Gupta et al.	2009/0218657	A1	9/2009	Rofougaran
2008/0005219	A1	1/2008	Nabar et al.	2009/0237317	A1	9/2009	Rofougaran
2008/0007453	A1	1/2008	Vassilakis et al.	2009/0239521	A1	9/2009	Mohebbi
2008/0008134	A1	1/2008	Satou et al.	2009/0245084	A1	10/2009	Moffatt et al.
2008/0013473	A1	1/2008	Proctor, Jr. et al.	2009/0245153	A1	10/2009	Li et al.
2008/0013909	A1	1/2008	Kostet et al.	2009/0245221	A1	10/2009	Pipponen
2008/0013956	A1	1/2008	Ware et al.	2009/0247109	A1	10/2009	Rofougaran
2008/0013957	A1	1/2008	Akers et al.	2009/0252136	A1	10/2009	Mahany et al.
2008/0014948	A1	1/2008	Scheinert	2009/0252204	A1	10/2009	Shatara et al.
2008/0026765	A1	1/2008	Charbonneau	2009/0252205	A1	10/2009	Rheinfelder et al.
2008/0031628	A1	2/2008	Dragas et al.	2009/0258652	A1	10/2009	Lambert et al.
2008/0043714	A1	2/2008	Pernu	2009/0278596	A1	11/2009	Rofougaran et al.
2008/0056167	A1	3/2008	Kim et al.	2009/0279593	A1	11/2009	Rofougaran et al.
2008/0058018	A1	3/2008	Scheinert	2009/0285147	A1	11/2009	Subasic et al.
2008/0063397	A1	3/2008	Hu et al.	2009/0316609	A1	12/2009	Singh
2008/0070502	A1	3/2008	George et al.	2010/0002626	A1	1/2010	Schmidt et al.
2008/0080863	A1	4/2008	Sauer et al.	2010/0027443	A1	2/2010	LoGalbo et al.
2008/0098203	A1	4/2008	Master et al.	2010/0056200	A1	3/2010	Tolonen
2008/0107202	A1	5/2008	Lee et al.	2010/0080154	A1	4/2010	Noh et al.
2008/0118014	A1	5/2008	Reunamaki et al.	2010/0080182	A1	4/2010	Kubler et al.
2008/0119198	A1	5/2008	Hettstedt et al.	2010/0091475	A1	4/2010	Toms et al.
2008/0124086	A1	5/2008	Matthews	2010/0118864	A1	5/2010	Kubler et al.
2008/0124087	A1	5/2008	Hartmann et al.	2010/0127937	A1	5/2010	Chandrasekaran et al.
2008/0129594	A1	6/2008	Pera et al.	2010/0134257	A1	6/2010	Puleston et al.
2008/0129634	A1	6/2008	Pera et al.	2010/0142598	A1	6/2010	Murray et al.
2008/0134194	A1	6/2008	Liu	2010/0142955	A1	6/2010	Yu et al.
2008/0145061	A1	6/2008	Lee et al.	2010/0144285	A1	6/2010	Behzad et al.
2008/0150514	A1	6/2008	Codreanu et al.	2010/0148373	A1	6/2010	Chandrasekaran
2008/0166094	A1	7/2008	Bookbinder et al.	2010/0156721	A1	6/2010	Alamouti et al.
2008/0194226	A1	8/2008	Rivas et al.	2010/0159859	A1	6/2010	Rofougaran
				2010/0188998	A1	7/2010	Pernu et al.
				2010/0190509	A1	7/2010	Davis
				2010/0202326	A1	8/2010	Rofougaran et al.
				2010/0225413	A1	9/2010	Rofougaran et al.
				2010/0225520	A1	9/2010	Mohamadi et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2010/0225556 A1 9/2010 Rofougaran et al.
 2010/0225557 A1 9/2010 Rofougaran et al.
 2010/0232323 A1 9/2010 Kubler et al.
 2010/0246541 A9 9/2010 Kim
 2010/0246558 A1 9/2010 Harel
 2010/0255774 A1 10/2010 Kenington
 2010/0258949 A1 10/2010 Henderson et al.
 2010/0260063 A1 10/2010 Kubler et al.
 2010/0261501 A1 10/2010 Behzad et al.
 2010/0265874 A1 10/2010 Palanki et al.
 2010/0284323 A1 11/2010 Tang et al.
 2010/0290355 A1 11/2010 Roy et al.
 2010/0309049 A1 12/2010 Reunamäki et al.
 2010/0311472 A1 12/2010 Rofougaran et al.
 2010/0311480 A1 12/2010 Raines et al.
 2010/0329161 A1 12/2010 Ylanen et al.
 2010/0329166 A1 12/2010 Mahany et al.
 2011/0007724 A1 1/2011 Mahany et al.
 2011/0007733 A1 1/2011 Kubler et al.
 2011/0008042 A1 1/2011 Stewart
 2011/0019999 A1 1/2011 George et al.
 2011/0021146 A1 1/2011 Pernu
 2011/0021224 A1 1/2011 Koskinen et al.
 2011/0026932 A1 2/2011 Yeh et al.
 2011/0065450 A1 3/2011 Kazmi
 2011/0066774 A1 3/2011 Rofougaran
 2011/0069668 A1 3/2011 Chion et al.
 2011/0071734 A1 3/2011 Van Wiemeersch et al.
 2011/0086614 A1 4/2011 Brisebois et al.
 2011/0116572 A1 5/2011 Lee et al.
 2011/0122912 A1 5/2011 Benjamin et al.
 2011/0126071 A1 5/2011 Han et al.
 2011/0135308 A1 6/2011 Tarlazzi et al.
 2011/0149879 A1 6/2011 Noriega et al.
 2011/0158298 A1 6/2011 Djadi et al.
 2011/0182230 A1 7/2011 Ohm et al.
 2011/0194475 A1 8/2011 Kim et al.
 2011/0200325 A1 8/2011 Kobayakov et al.
 2011/0201368 A1 8/2011 Faccin et al.
 2011/0204504 A1 8/2011 Henderson et al.
 2011/0206383 A1 8/2011 Chien et al.
 2011/0211439 A1 9/2011 Manpuria et al.
 2011/0215901 A1 9/2011 Van Wiemeersch et al.
 2011/0222415 A1 9/2011 Ramamurthi et al.
 2011/0222434 A1 9/2011 Chen
 2011/0222616 A1 9/2011 Jiang et al.
 2011/0222619 A1 9/2011 Ramamurthi et al.
 2011/0223958 A1 9/2011 Chen et al.
 2011/0223960 A1 9/2011 Chen et al.
 2011/0223961 A1 9/2011 Chen et al.
 2011/0227795 A1 9/2011 Lopez et al.
 2011/0243201 A1 10/2011 Phillips et al.
 2011/0244887 A1 10/2011 Dupray et al.
 2011/0256878 A1 10/2011 Zhu et al.
 2011/0268033 A1 11/2011 Boldi et al.
 2011/0268446 A1 11/2011 Cune et al.
 2011/0274021 A1 11/2011 He et al.
 2011/0281536 A1 11/2011 Lee et al.
 2011/0305284 A1* 12/2011 Mueck H04B 7/0413
 375/260
 2012/0002750 A1 1/2012 Hooli et al.
 2012/0046039 A1 2/2012 Hagerman et al.
 2012/0087670 A1 4/2012 Han et al.
 2012/0140660 A1 6/2012 Kang et al.
 2012/0170542 A1 7/2012 Zangi
 2012/0177026 A1 7/2012 Uyehara et al.
 2012/0208581 A1 8/2012 Ishida et al.
 2012/0213111 A1* 8/2012 Shimezawa H04B 7/063
 370/252
 2012/0243513 A1 9/2012 Fujishima et al.
 2012/0314797 A1 12/2012 Kummetz et al.
 2012/0327800 A1 12/2012 Kim et al.
 2013/0017863 A1 1/2013 Kummetz et al.
 2013/0095875 A1* 4/2013 Reuven H04B 7/10
 455/509

2013/0101005 A1* 4/2013 Aryanfar H04B 5/0025
 375/224
 2013/0150063 A1 6/2013 Berlin et al.
 2013/0195000 A1* 8/2013 Shen H04B 7/024
 370/312
 2013/0235962 A1* 9/2013 O'Keefe H01Q 3/267
 375/371
 2014/0078920 A1* 3/2014 Tandra H04L 25/022
 370/252
 2014/0126914 A1 5/2014 Berlin et al.
 2014/0211875 A1 7/2014 Berlin et al.
 2014/0226698 A1* 8/2014 Negus H04B 7/0486
 375/211
 2014/0269859 A1 9/2014 Hanson et al.
 2014/0314061 A1 10/2014 Trajkovic et al.
 2015/0003565 A1* 1/2015 George H04B 7/0413
 375/299
 2015/0023283 A1 1/2015 Liu et al.
 2015/0098351 A1 4/2015 Zavadsky et al.
 2015/0098372 A1 4/2015 Zavadsky et al.
 2015/0098419 A1 4/2015 Zavadsky et al.

FOREIGN PATENT DOCUMENTS

CA 2065090 C 2/1998
 CA 2242707 A1 1/1999
 DE 20104862 U1 8/2001
 DE 10249414 A1 5/2004
 EP 0355328 A2 2/1990
 EP 0477952 A2 4/1992
 EP 0477952 A3 4/1992
 EP 0709974 A1 5/1996
 EP 0461583 B1 3/1997
 EP 851618 A2 7/1998
 EP 0687400 B1 11/1998
 EP 0938204 A1 8/1999
 EP 0993124 A2 4/2000
 EP 1037411 A2 9/2000
 EP 1085684 A2 3/2001
 EP 1179895 A1 2/2002
 EP 1267447 A1 12/2002
 EP 1347584 A2 9/2003
 EP 1363352 A1 11/2003
 EP 1391897 A1 2/2004
 EP 1443687 A1 8/2004
 EP 1455550 A2 9/2004
 EP 1501206 A1 1/2005
 EP 1503451 A1 2/2005
 EP 1530316 A1 5/2005
 EP 1511203 B1 3/2006
 EP 1267447 B1 8/2006
 EP 1693974 A1 8/2006
 EP 1742388 A1 1/2007
 EP 1227605 B1 1/2008
 EP 1954019 A1 8/2008
 EP 1968250 A1 9/2008
 EP 1056226 B1 4/2009
 EP 1357683 B1 5/2009
 EP 2219310 A1 8/2010
 GB 2313020 A 11/1997
 GB 2323252 A 9/1998
 GB 2399963 A 9/2004
 GB 2428149 A 1/2007
 JP H4189036 A 7/1992
 JP 05252559 A 9/1993
 JP 05260018 A 10/1993
 JP 05327569 A 12/1993
 JP 05327576 A 12/1993
 JP 09083450 A 3/1997
 JP 09162810 A 6/1997
 JP 09200840 A 7/1997
 JP 11068675 A 3/1999
 JP 2000152300 A 5/2000
 JP 2000341744 A 12/2000
 JP 2002264617 A 9/2002
 JP 2002353813 A 12/2002
 JP 2003148653 A 5/2003
 JP 2003172827 A 6/2003

(56)

References Cited

FOREIGN PATENT DOCUMENTS

JP 2004172734 A 6/2004
 JP 2004245963 A 9/2004
 JP 2004247090 A 9/2004
 JP 2004264901 A 9/2004
 JP 2004265624 A 9/2004
 JP 2004317737 A 11/2004
 JP 2004349184 A 12/2004
 JP 2005018175 A 1/2005
 JP 2005087135 A 4/2005
 JP 2005134125 A 5/2005
 JP 2007228603 A 9/2007
 JP 2008172597 A 7/2008
 KR 20010055088 A 7/2001
 KR 20110087949 A 8/2011
 WO 9603823 A1 2/1996
 WO 9613102 A1 5/1996
 WO 9804054 A1 1/1998
 WO 9810600 A1 3/1998
 WO 0042721 A1 7/2000
 WO 0072475 A1 11/2000
 WO 0178434 A1 10/2001
 WO 0184760 A1 11/2001
 WO 0186755 A2 11/2001
 WO 0221183 A1 3/2002
 WO 0230141 A1 4/2002
 WO 02091618 A1 11/2002
 WO 02102102 A1 12/2002
 WO 03024027 A1 3/2003
 WO 03098175 A1 11/2003
 WO 2004030154 A2 4/2004
 WO 2004047472 A1 6/2004
 WO 2004056019 A1 7/2004
 WO 2004059934 A1 7/2004
 WO 2004086795 A2 10/2004
 WO 2004093471 A2 10/2004
 WO 2004107783 A1 12/2004
 WO 2005062505 A1 7/2005
 WO 2005069203 A2 7/2005
 WO 2005073897 A1 8/2005
 WO 2005079386 A2 9/2005
 WO 2005101701 A2 10/2005
 WO 2005111959 A2 11/2005
 WO 2006011778 A1 2/2006
 WO 2006018592 A1 2/2006
 WO 2006019392 A1 2/2006
 WO 2006039941 A1 4/2006
 WO 2006046088 A1 5/2006
 WO 2006051262 A1 5/2006
 WO 2006060754 A2 6/2006
 WO 2006094441 A1 9/2006
 WO 2006105185 A2 10/2006
 WO 2006133609 A1 12/2006
 WO 2006136811 A1 12/2006
 WO 2007048427 A1 5/2007
 WO 2007075579 A2 7/2007
 WO 2007077451 A1 7/2007
 WO 2007088561 A1 8/2007
 WO 2007091026 A1 8/2007
 WO 2007133630 A2 11/2007
 WO 2008008249 A2 1/2008
 WO 2008027213 A2 3/2008
 WO 2008033298 A2 3/2008
 WO 2008039830 A2 4/2008
 WO 2008116014 A2 9/2008
 WO 2009100395 A1 8/2009
 WO 2009100396 A1 8/2009
 WO 2009100397 A2 8/2009
 WO 2009100398 A2 8/2009
 WO 2010087919 A2 8/2010
 WO 2010090999 A1 8/2010
 WO 2010132739 A1 11/2010
 WO 2011005162 A1 1/2011
 WO 2011043172 A1 4/2011
 WO 2011100095 A1 8/2011
 WO 2011112373 A1 9/2011

WO 2011139939 A1 11/2011
 WO 2011158302 A1 12/2011
 WO 2011160117 A1 12/2011
 WO 2012024345 A2 2/2012
 WO 2012054553 A1 4/2012
 WO 2012148256 A1 11/2012
 WO 2012148938 A1 11/2012
 WO 2012148940 A1 11/2012
 WO 2012170865 A2 12/2012
 WO 2013009283 A1 1/2013
 WO 2013009835 A1 1/2013
 WO 2014070236 A1 5/2014
 WO 2014082070 A1 5/2014
 WO 2014082072 A1 5/2014
 WO 2014082075 A1 5/2014
 WO 2014144314 A1 9/2014
 WO 2015054162 A1 4/2015
 WO 2015054164 A1 4/2015
 WO 2015054165 A1 4/2015

OTHER PUBLICATIONS

Lee, et al., "Evaluation of 60 GHz MIMO Channel Capacity in the Conference Room STA-STA Scenario," Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, vol., No., pp. 1-5, May 15-18, 2011.

Shu-Hao, et al., "Spectrally Efficient 60-GHz xy-MIMO Data Transport over a Radio-Over-Fiber System for Gigabit Wireless Local Area Networks," GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference, vol., No., pp. 1-4, Dec. 6-10, 2010.

Arredondo, Albedo et al., "Techniques for Improving In-Building Radio Coverage Using Fiber-Fed Distributed Antenna Networks," IEEE 46th Vehicular Technology Conference, Atlanta, Georgia, Apr. 28-May 1, 1996, pp. 1540-1543, vol. 3.

Bakaul, M., et al., "Efficient Multiplexing Scheme for Wavelength-Interleaved DWDM Millimeter-Wave Fiber-Radio Systems," IEEE Photonics Technology Letters, Dec. 2005, vol. 17, No. 12, pp. 2718-2720.

Cho, Bong Youl et al. "The Forward Link Performance of a PCS System with an AGC," 4th CDMA International Conference and Exhibition, "The Realization of IMT-2000," 1999, 10 pages.

Chu, Ta-Shing et al. "Fiber optic microcellular radio," IEEE Transactions on Vehicular Technology, Aug. 1991, pp. 599-606, vol. 40, Issue 3.

Cooper, A.J., "Fiber/Radio for the Provision of Cordless/Mobile Telephony Services in the Access Network," Electronics Letters, 1990, pp. 2054-2056, vol. 26.

Cutrer, David M. et al., "Dynamic Range Requirements for Optical Transmitters in Fiber-Fed Microcellular Networks," IEEE Photonics Technology Letters, May 1995, pp. 564-566, vol. 7, No. 5.

Dolmans, G. et al. "Performance study of an adaptive dual antenna handset for indoor communications", IEE Proceedings: Microwaves, Antennas and Propagation, Apr. 1999, pp. 138-144, vol. 146, Issue 2.

Ellinger, Frank et al., "A 5.2 GHz variable gain LNA MMIC for adaptive antenna combining", IEEE MTT-S International Microwave Symposium Digest, Anaheim, California, Jun. 13-19, 1999, pp. 501-504, vol. 2.

Fan, J.C. et al., "Dynamic range requirements for microcellular personal communication systems using analog fiber-optic links", IEEE Transactions on Microwave Theory and Techniques, Aug. 1997, pp. 1390-1397, vol. 45, Issue 8.

Gibson, B.C., et al., "Evanescent Field Analysis of Air-Silica Microstructure Waveguides," The 14th Annual Meeting of the IEEE Lasers and Electro-Optics Society, 1-7803-7104-4/01, Nov. 12-13, 2001, vol. 2, pp. 709-710.

Huang, C., et al., "A WLAN-Used Helical Antenna Fully Integrated with the PCMCIA Carrier," IEEE Transactions on Antennas and Propagation, Dec. 2005, vol. 53, No. 12, pp. 4164-4168.

Kojucharow, K., et al., "Millimeter-Wave Signal Properties Resulting from Electrooptical Upconversion," IEEE Transaction on Microwave Theory and Techniques, Oct. 2001, vol. 49, No. 10, pp. 1977-1985.

(56)

References Cited

OTHER PUBLICATIONS

- Monro, T.M., et al., "Holey Fibers with Random Cladding Distributions," *Optics Letters*, Feb. 15, 2000, vol. 25, No. 4, pp. 206-208.
- Moreira, J.D., et al., "Diversity Techniques for OFDM Based WLAN Systems," *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Sep. 15-18, 2002, vol. 3, pp. 1008-1011.
- Niiho, T., et al., "Multi-Channel Wireless LAN Distributed Antenna System Based on Radio-Over-Fiber Techniques," *The 17th Annual Meeting of the IEEE Lasers and Electro-Optics Society*, Nov. 2004, vol. 1, pp. 57-58.
- Author Unknown, "ITU-T G.652, Telecommunication Standardization Sector of ITU, Series G: Transmission Systems and Media, Digital Systems and Networks, Transmission Media and Optical Systems Characteristics—Optical Fibre Cables, Characteristics of a Single-Mode Optical Fiber and Cable," ITU-T Recommendation G.652, International Telecommunication Union, Jun. 2005, 22 pages.
- Author Unknown, "ITU-T G.657, Telecommunication Standardization Sector of ITU, Dec. 2006, Series G: Transmission Systems and Media, Digital Systems and Networks, Transmission Media and Optical Systems Characteristics—Optical Fibre Cables, Characteristics of a Bending Loss Insensitive Single Mode Optical Fibre and Cable for the Access Network," ITU-T Recommendation G.657, International Telecommunication Union, 20 pages.
- Opatic, D., "Radio over Fiber Technology for Wireless Access," *Ericsson*, Oct. 17, 2009, 6 pages.
- Paulraj, A.J., et al., "An Overview of MIMO Communications—A Key to Gigabit Wireless," *Proceedings of the IEEE*, Feb. 2004, vol. 92, No. 2, 34 pages.
- Pickrell, G.R., et al., "Novel Techniques for the Fabrication of Holey Optical Fibers," *Proceedings of SPIE*, Oct. 28-Nov. 2, 2001, vol. 4578, 2001, pp. 271-282.
- Roh, W., et al., "MIMO Channel Capacity for the Distributed Antenna Systems," *Proceedings of the 56th IEEE Vehicular Technology Conference*, Sep. 2002, vol. 2, pp. 706-709.
- Schweber, Bill, "Maintaining cellular connectivity indoors demands sophisticated design," *EDN Network*, Dec. 21, 2000, 2 pages, <http://www.edn.com/design/integrated-circuit-design/4362776/Maintaining-cellular-connectivity-indoors-demands-sophisticated-design>.
- Seto, I., et al., "Antenna-Selective Transmit Diversity Technique for OFDM-Based WLANs with Dual-Band Printed Antennas," *2005 IEEE Wireless Communications and Networking Conference*, Mar. 13-17, 2005, vol. 1, pp. 51-56.
- Shen, C., et al., "Comparison of Channel Capacity for MIMO-DAS versus MIMO-CAS," *The 9th Asia-Pacific Conference on Communications*, Sep. 21-24, 2003, vol. 1, pp. 113-118.
- Wake, D. et al., "Passive Picocell: A New Concept in Wireless Network Infrastructure," *Electronics Letters*, Feb. 27, 1997, vol. 33, No. 5, pp. 404-406.
- Windyka, John et al., "System-Level Integrated Circuit (SLIC) Technology Development for Phased Array Antenna Applications," *Contractor Report 204132, National Aeronautics and Space Administration*, Jul. 1997, 94 pages.
- Winters, J., et al., "The Impact of Antenna Diversity on the Capacity of Wireless Communications Systems," *IEEE Transactions on Communications*, vol. 42, No. 2/3/4, Feb./Mar./Apr. 1994, pp. 1740-1751.
- Yu et al., "A Novel Scheme to Generate Single-Sideband Millimeter-Wave Signals by Using Low-Frequency Local Oscillator Signal," *IEEE Photonics Technology Letters*, vol. 20, No. 7, Apr. 1, 2008, pp. 478-480.
- Second Office Action for Chinese patent application 20078002293.6 mailed Aug. 30, 2012, 10 pages.
- International Search Report for PCT/US2010/022847 mailed Jul. 12, 2010, 3 pages.
- International Search Report for PCT/US2010/022857 mailed Jun. 18, 2010, 3 pages.
- Decision on Appeal for U.S. Appl. No. 11/451,237 mailed Mar. 19, 2013, 7 pages.
- Decision on Rejection for Chinese patent application 200780022093.6 mailed Feb. 5, 2013, 9 pages.
- International Search Report and Written Opinion for International patent application PCT/US2007/013802 mailed May 8, 2008, 12 pages.
- Attygalle et al., "Extending Optical Transmission Distance in Fiber Wireless Links Using Passive Filtering in Conjunction with Optimized Modulation," *Journal of Lightwave Technology*, vol. 24, No. 4, Apr. 2006, 7 pages.
- Bo Zhang et al., "Reconfigurable Multifunctional Operation Using Optical Injection-Locked Vertical-Cavity Surface-Emitting Lasers," *Journal of Lightwave Technology*, vol. 27, No. 15, Aug. 2009, 6 pages.
- Chang-Hasnain, et al., "Ultrahigh-speed laser modulation by injection locking," Chapter 6, *Optical Fiber Telecommunication V A: Components and Subsystems*, Elsevier Inc., 2008, 20 pages.
- Cheng Zhang et al., "60 GHz Millimeter-wave Generation by Two-mode Injection-locked Fabry-Perot Laser Using Second-Order Sideband Injection in Radio-over-Fiber System," *Conference on Lasers and Electro-Optics and Quantum Electronics, Optical Society of America*, May 2008, 2 pages.
- Chrostowski, "Optical Injection Locking of Vertical Cavity Surface Emitting Lasers," Fall 2003, PhD dissertation University of California at Berkeley, 122 pages.
- Dang et al., "Radio-over-Fiber based architecture for seamless wireless indoor communication in the 60GHz band," *Computer Communications*, Elsevier B.V., Amsterdam, NL, vol. 30, Sep. 8, 2007, pp. 3598-3613.
- Hyuk-Kee Sung et al., "Optical Single Sideband Modulation Using Strong Optical Injection-Locked Semiconductor Lasers," *IEEE Photonics Technology Letters*, vol. 19, No. 13, Jul. 1, 2007, 4 pages.
- Lim et al., "Analysis of Optical Carrier-to-Sideband Ratio for Improving Transmission Performance in Fiber-Radio Links," *IEEE Transactions of Microwave Theory and Techniques*, vol. 54, No. 5, May 2006, 7 pages.
- Lu H H et al., "Improvement of radio-on-multimode fiber systems based on light injection and optoelectronic feedback techniques," *Optics Communications*, vol. 266, No. 2, Elsevier B.V., Oct. 15, 2006, 4 pages.
- Pleros et al., "A 60 GHz Radio-Over-Fiber Network Architecture for Seamless Communication With High Mobility," *Journal of Lightwave Technology*, vol. 27, No. 12, IEEE, Jun. 15, 2009, pp. 1957-1967.
- Reza et al., "Degree-of-Polarization-Based PMD Monitoring for Subcarrier-Multiplexed Signals Via Equalized Carrier/Sideband Filtering," *Journal of Lightwave Technology*, vol. 22, No. 4, IEEE, Apr. 2004, 8 pages.
- Zhao, "Optical Injection Locking on Vertical-Cavity Surface-Emitting Lasers (VCSELs): Physics and Applications," Fall 2008, PhD dissertation University of California at Berkeley, pp. 1-209.
- Advisory Action for U.S. Appl. No. 12/712,758 mailed Sep. 16, 2013, 3 pages.
- Final Office Action for U.S. Appl. No. 12/712,758 mailed May 24, 2013, 17 pages.
- Non-final Office Action for U.S. Appl. No. 12/712,758 mailed Jan. 10, 2012, 14 pages.
- Examination Report for European patent application 07835803.3 mailed Aug. 13, 2013, 6 pages.
- Extended European Search Report for patent application 10014262.9 mailed Mar. 14, 2011, 6 pages.
- International Search Report and Written Opinion for PCT/US2012/034853 mailed Aug. 6, 2012, 12 pages.
- International Search Report and Written Opinion for PCT/US2012/034855 mailed Jul. 26, 2012, 10 pages.
- Written Opinion of the International Searching Authority for European patent application 11701916.6 mailed Sep. 21, 2012, 10 pages.
- International Search Report for PCT/US2011/021799 mailed Apr. 6, 2011, 4 pages.
- Examination Report for European patent application 10702806.0 mailed Sep. 12, 2013, 11 pages.

(56)

References Cited

OTHER PUBLICATIONS

Non-final Office Action for U.S. Appl. No. 13/194,429 mailed Mar. 1, 2013, 22 pages.

Notice of Allowance for U.S. Appl. No. 13/194,429 mailed Jul. 9, 2013, 9 pages.

International Search Report for PCT/US2011/043405 mailed Apr. 25, 2012, 4 pages.

Non-final Office Action for U.S. Appl. No. 11/958,062 mailed Nov. 6, 2013, 16 pages.

Chowdhury et al., "Multi-service Multi-carrier Broadband MIMO Distributed Antenna Systems for In-building Optical Wireless Access," Presented at the 2010 Conference on Optical Fiber Communication and National Fiber Optic Engineers Conference, Mar. 21-25, 2010, San Diego, California, IEEE, pp. 1-3.

International Search Report and Written Opinion for PCT/US2007/025855 mailed Mar. 19, 2008, 14 pages.

International Preliminary Report on Patentability for PCT/US2007/025855 mailed Jul. 2, 2009, 9 pages.

Bahl et al. "Enhancements to the RADAR User Location and Tracking System," Microsoft Research Technical Report, Feb. 2000, pp. 1-13.

Frikel et al., "A Robust Mobile Positioning Algorithm," EURASIP Proceedings, ISCCSP 2006, pp. 1-4.

Pahlavan et al., "An Overview of Wireless Indoor Geolocation Techniques and Systems," LNCS 1818, pp. 1-13, 2000.

Wann et al., "Hybrid TDOA/AOA Indoor Positioning and Tracking Using Extended Kalman Filters," 63rd IEEE VTC 2006, pp. 1058-1062.

Ibernon-Fernandez, R., et al., "Comparison Between Measurements and Simulations of Conventional and Distributed MIMO System," IEEE Antennas and Wireless Propagation Letters, vol. 7, Aug. 2008, pp. 546-549.

Tarlazzi L., et al., "Characterization of an Interleaved F-DAS MIMO Indoor Propagation Channel," Loughborough Antennas & Propagation Conference, Nov. 2010, Loughborough, United Kingdom, IEEE, pp. 505-508.

Tolli, Antti, "Resource Management in Cooperative MIMO-OFDM Cellular Systems," Academic Dissertation—ACTA Universitatis Ouluensis, No. C Technica 296, Apr. 11, 2008, pp. 1-198.

Vitucci, E.M., et al., "Analysis of the Performance of LTE Systems in an Interleaved F-DAS MIMO Indoor Environment," Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP), Apr. 11-15, 2011, Rome, Italy, IEEE, pp. 2184-2186.

Wei, Xinning, et al., "Cooperative communication with partial channel-state information in multiuser MIMO systems," International Journal of Electronics and Communications, vol. 65, No. 4, Apr. 2011 (available online May 15, 2010), Elsevier GmbH, pp. 349-360.

International Search Report for PCT/US2013/070489 mailed Feb. 24, 2014, 4 pages.

Biton et al., "Challenge: CeTV and Ca-Fi—Cellular and Wi-Fi over CATV," Proceedings of the Eleventh Annual International Conference on Mobile Computing and Networking, Aug. 28-Sep. 2, 2005, Cologne, Germany, Association for Computing Machinery, 8 pages.

Hansryd, Jonas et al., "Microwave capacity evolution," Ericsson Review, Jun. 21, 2011, 6 pages.

Seto et al., "Optical Subcarrier Multiplexing Transmission for Base Station With Adaptive Array Antenna," IEEE Transactions on Microwave Theory and Techniques, vol. 49, No. 10, Oct. 2001, pp. 2036-2041.

Examination Report for European Patent Application No. 11733965.5 mailed Oct. 10, 2014, 6 pages.

International Search Report for PCT/US2013/034328 mailed Jul. 3, 2013, 5 pages.

International Preliminary Report on Patentability for PCT/US2013/034328 mailed Oct. 1, 2014, 8 pages.

Non-final Office Action for U.S. Appl. No. 13/598,078 mailed Dec. 22, 2014, 7 pages.

Non-Final Office Action for U.S. Appl. No. 14/078,949 mailed Sep. 10, 2015, 29 pages.

Notice of Allowance for U.S. Appl. No. 13/598,078 mailed May 12, 2015, 8 pages.

Non-final Office Action for U.S. Appl. No. 14/148,908 mailed May 22, 2015, 20 pages.

Notice of Allowance for U.S. Appl. No. 14/242,139 mailed Oct. 22, 2014, 12 pages.

Diehm, et al., "The Futon Prototype: Broadband Communication through Coordinated Multi-Point using a Novel integrated Optical/Wireless Architecture," Presented at Globecom Workshops, Dec. 6-10, 2010, Miami, Florida, IEEE, pp. 757-762.

Fan, Shu-Hao et al., "Spectrally Efficient 60-GHz xy-MIMO Data Transport over a Radio-Over-Fiber System for Gigabit Wireless Local Area Networks," Presented at IEEE Global Telecommunications Conference, Dec. 6-10, 2010, Miami, Florida, IEEE, 4 pages.

Lee et al., "Evaluation of 60 GHz MIMO Channel Capacity in the Conference Room STA-STA Scenario," Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, pp. 1-5, May 15-18, 2011.

Sheldon, C. et al., "A 60GHz Line-of-Sight 2x2 MIMO Link Operating at 1.2 Gbps," Presented at Antennas and Propagation Society International Symposium, Jul. 5-11, 2008, San Diego, California, IEEE, 4 pages.

Written Opinion for European Patent Application No. 13798863.0 mailed Aug. 6, 2015, 10 pages.

Non-final Office Action for U.S. Appl. No. 14/487,232 mailed Jun. 23, 2015, 15 pages.

Notice of Allowance for U.S. Appl. No. 14/227,108 mailed Nov. 18, 2015, 8 pages.

Final Office Action for U.S. Appl. No. 14/487,232 mailed Oct. 15, 2015, 7 pages.

Notice of Allowance for U.S. Appl. No. 14/078,949 mailed Feb. 3, 2016, 9 pages.

Non-final Office Action for U.S. Appl. No. 14/721,357, mailed Jan. 4, 2016, 10 pages.

Heath, Robert, et al., "Multiuser MIMO in Distributed Antenna Systems with Out-of-Cell Interference," IEEE Transactions on Signal Processing, vol. 59, Issue 10, Oct. 2011, IEEE, 4885-4899.

Non-final Office Action for U.S. Appl. No. 14/079,977 mailed Mar. 4, 2016, 21 pages.

Notice of Allowance for U.S. Appl. No. 14/079,977 mailed Apr. 29, 2016, 8 pages.

Final Office Action for U.S. Appl. No. 14/721,357 mailed Mar. 1, 2016, 12 pages.

Advisory Action for U.S. Appl. No. 14/721,357, mailed Jun. 30, 2016, 3 pages.

Notice of Allowance for U.S. Appl. No. 14/721,357, mailed Aug. 16, 2016, 7 pages.

* cited by examiner

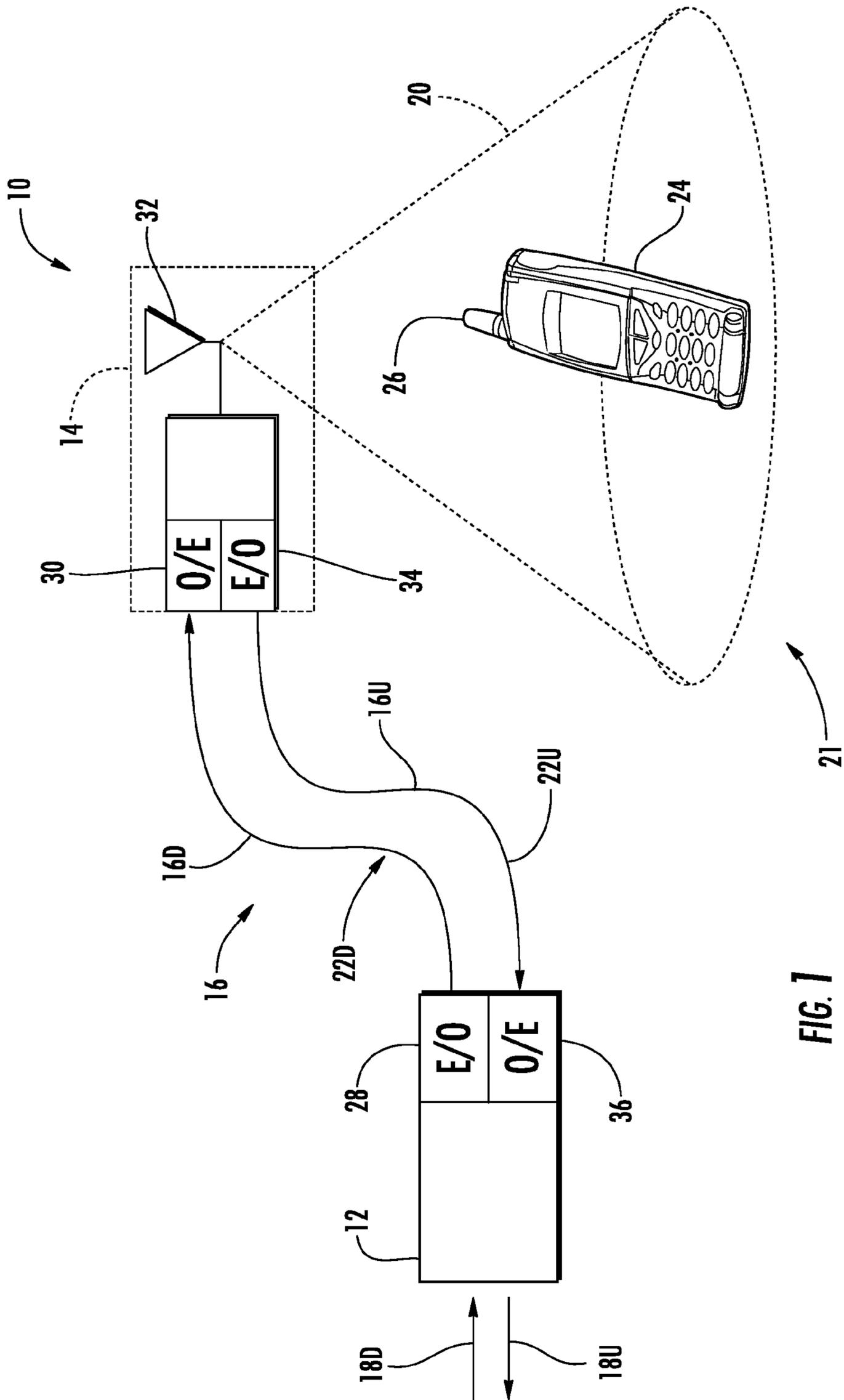


FIG. 1

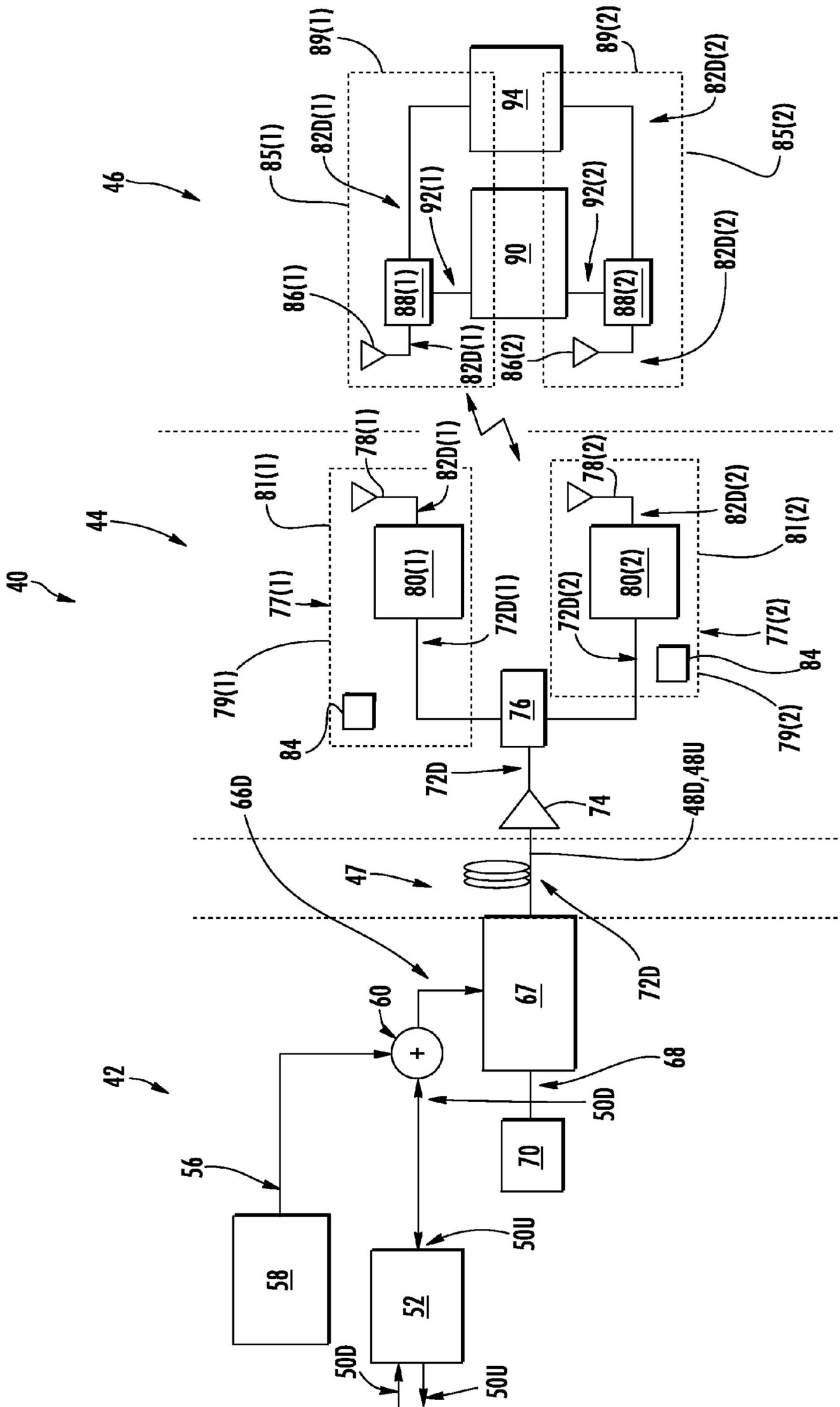


FIG. 2

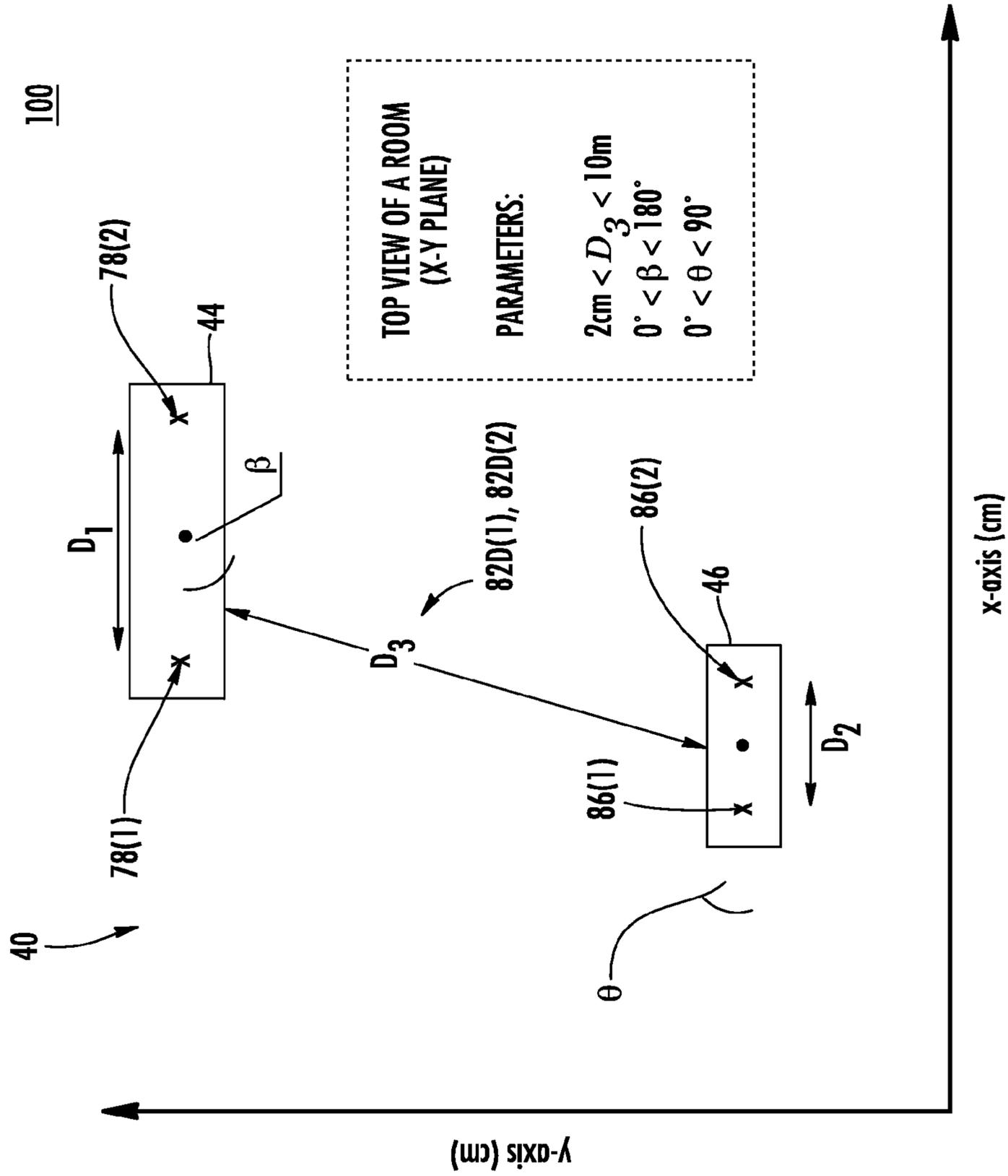


FIG. 3A

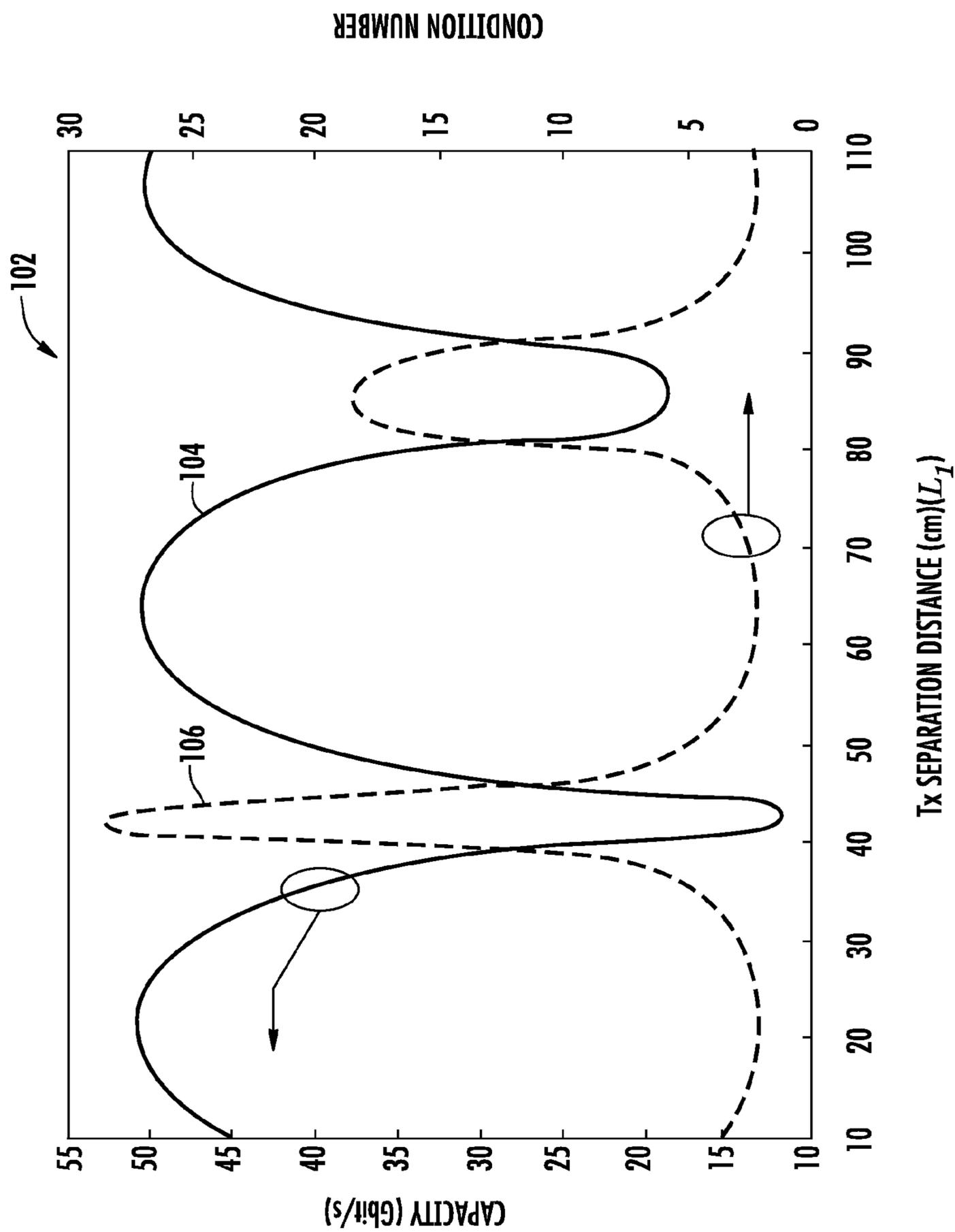


FIG. 3B

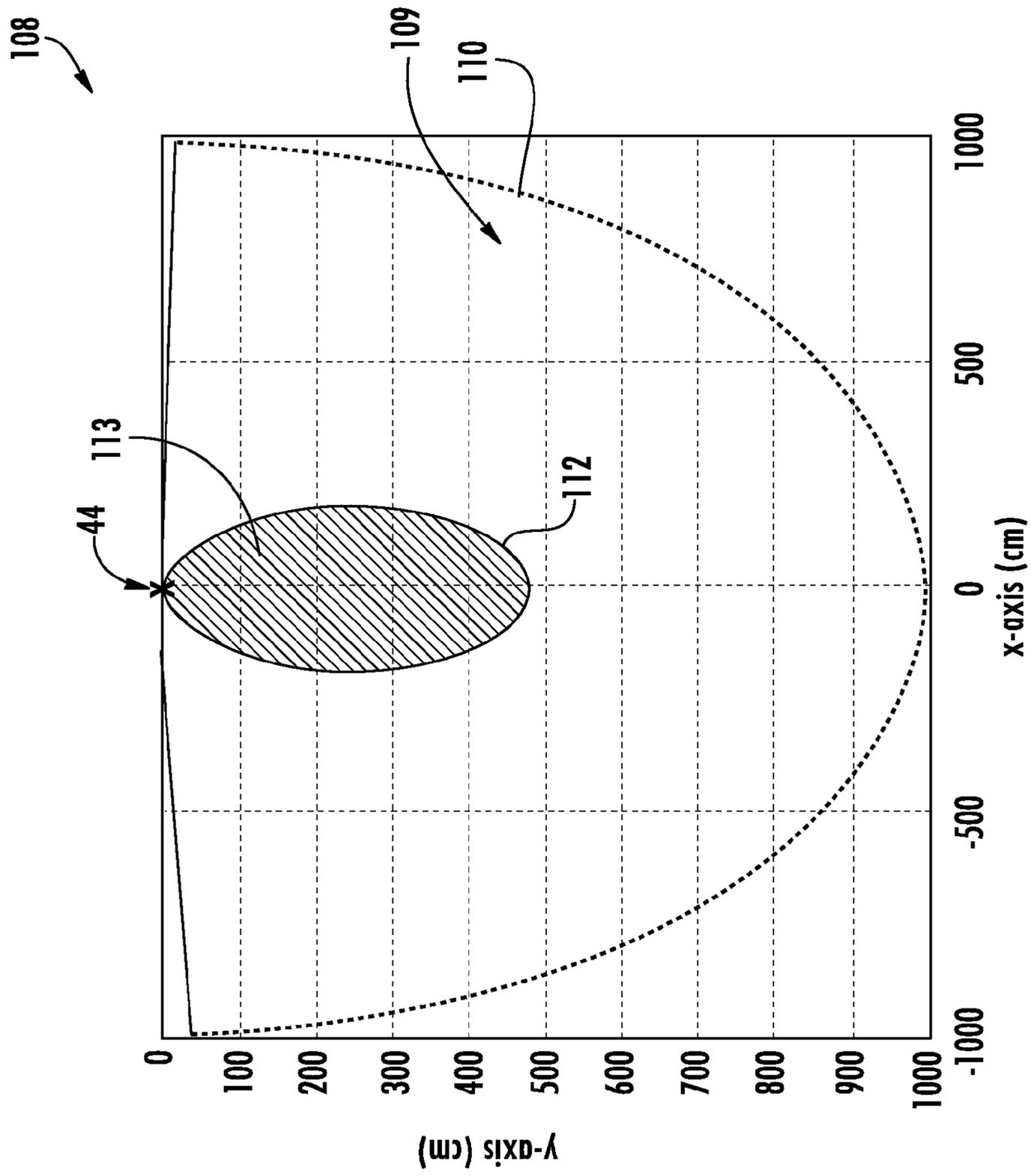


FIG. 3C

120

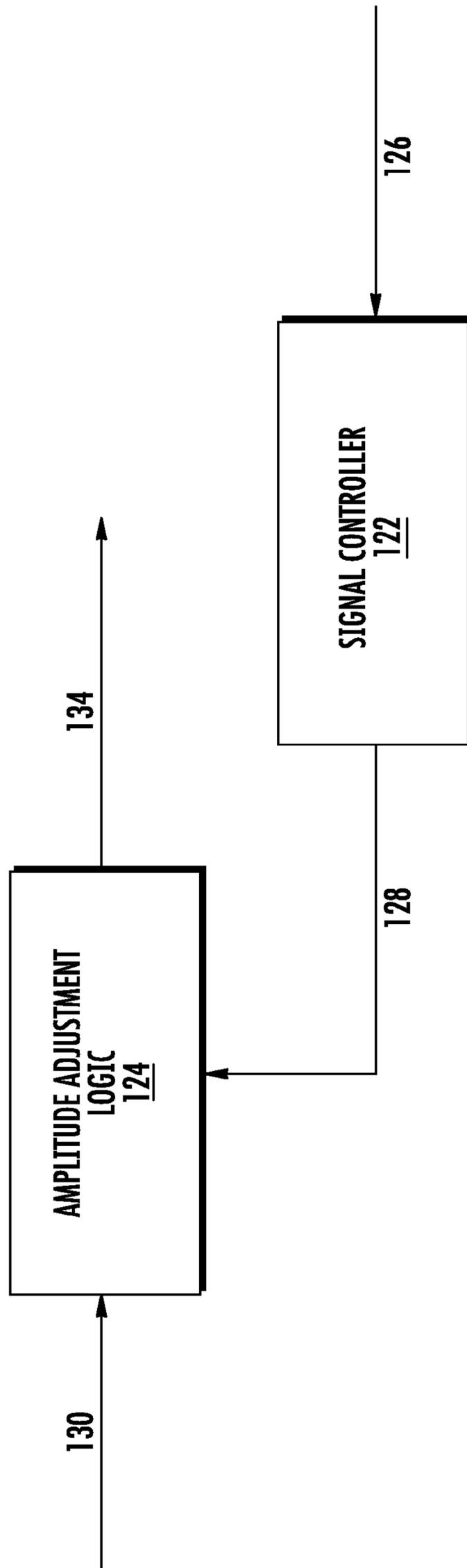


FIG. 4

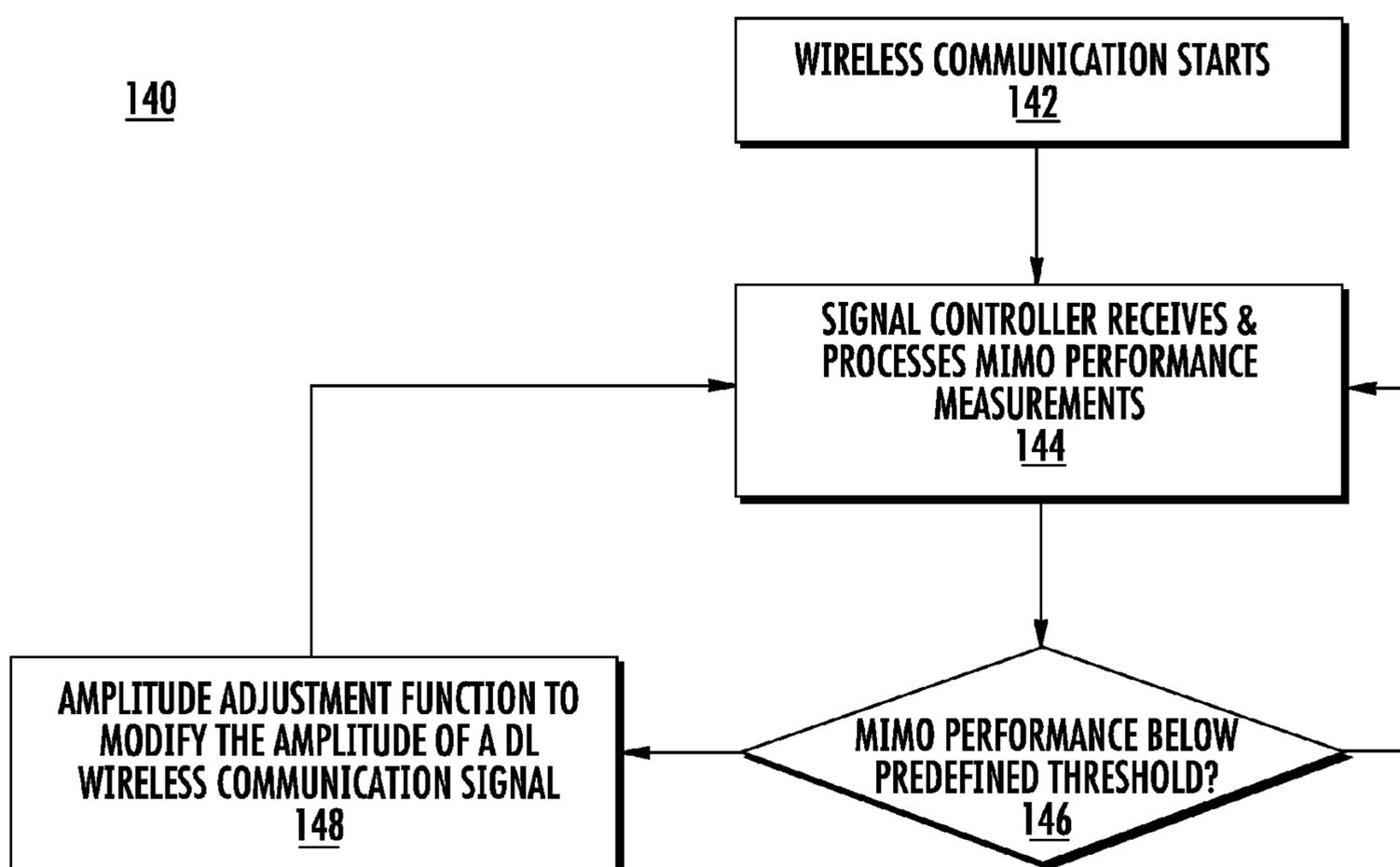


FIG. 5

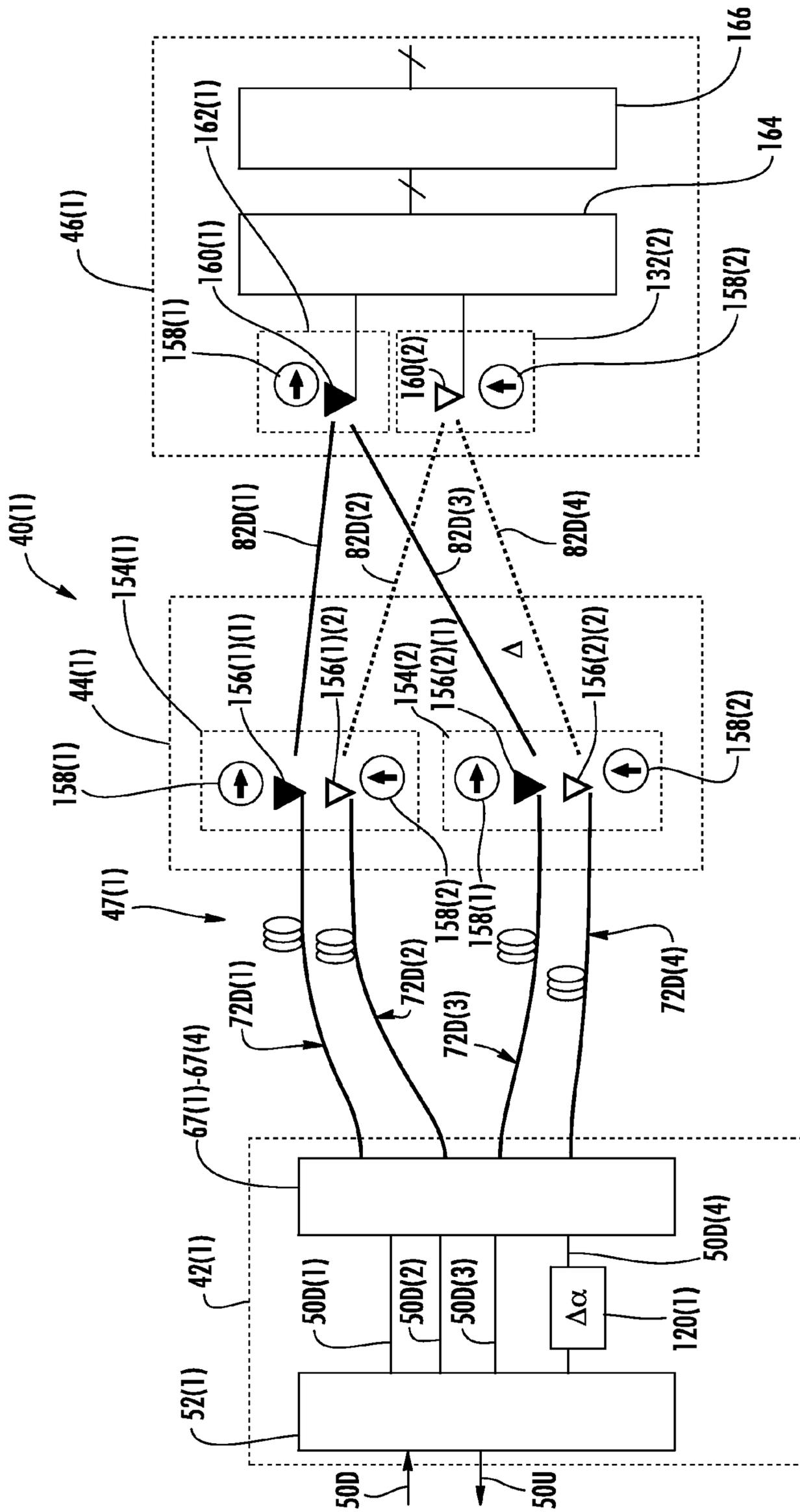


FIG. 6A

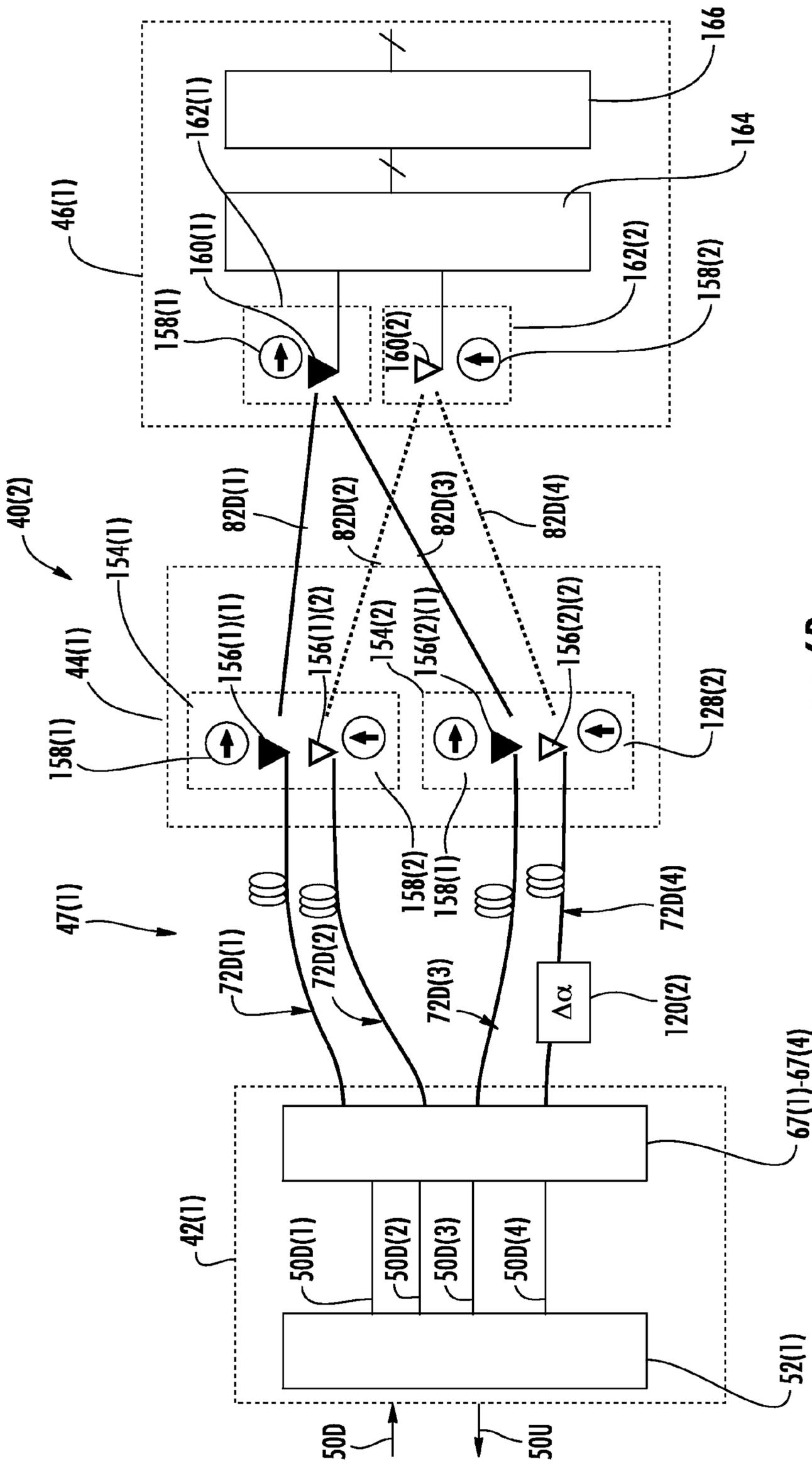


FIG. 6B

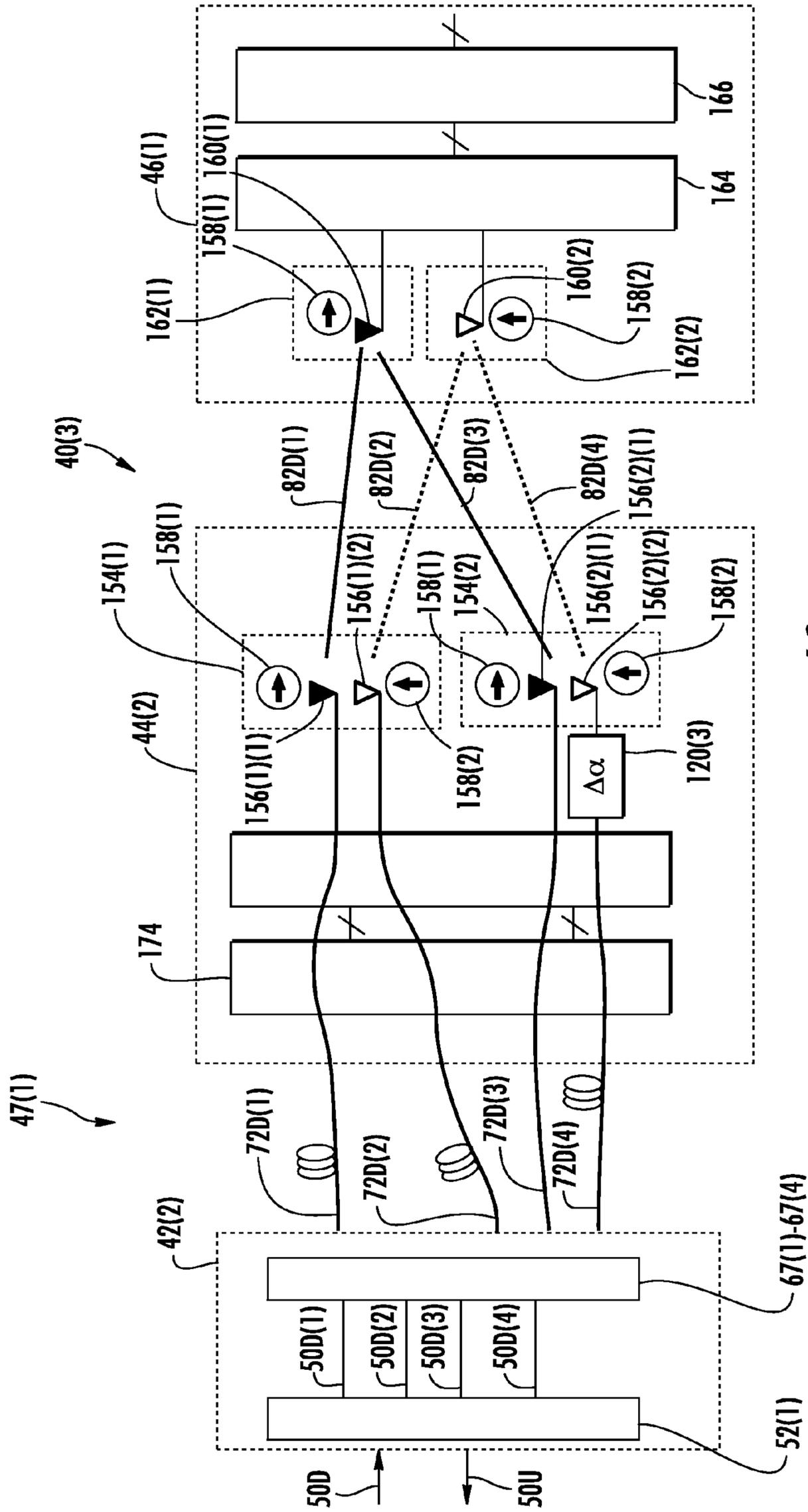


FIG. 6C

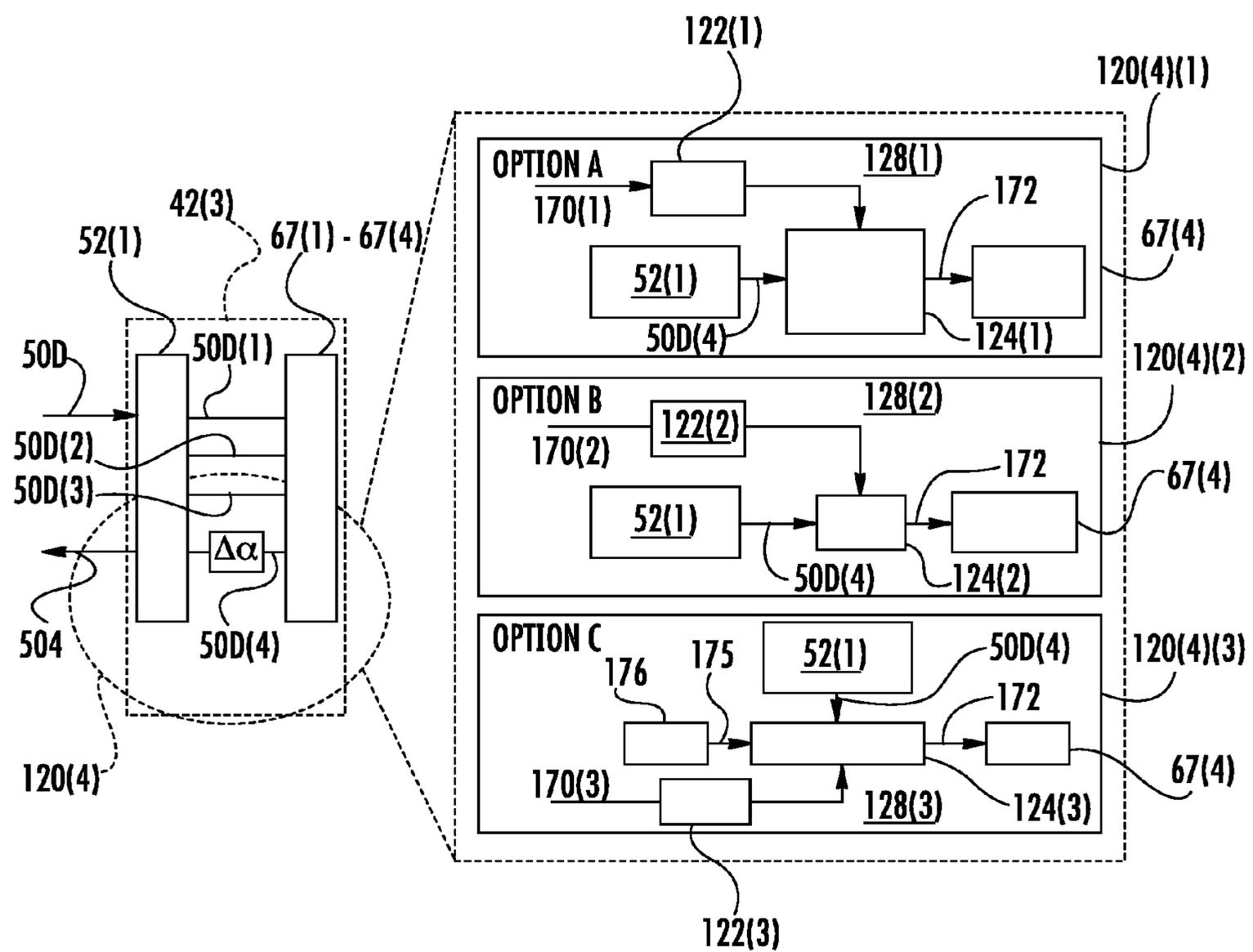


FIG. 7

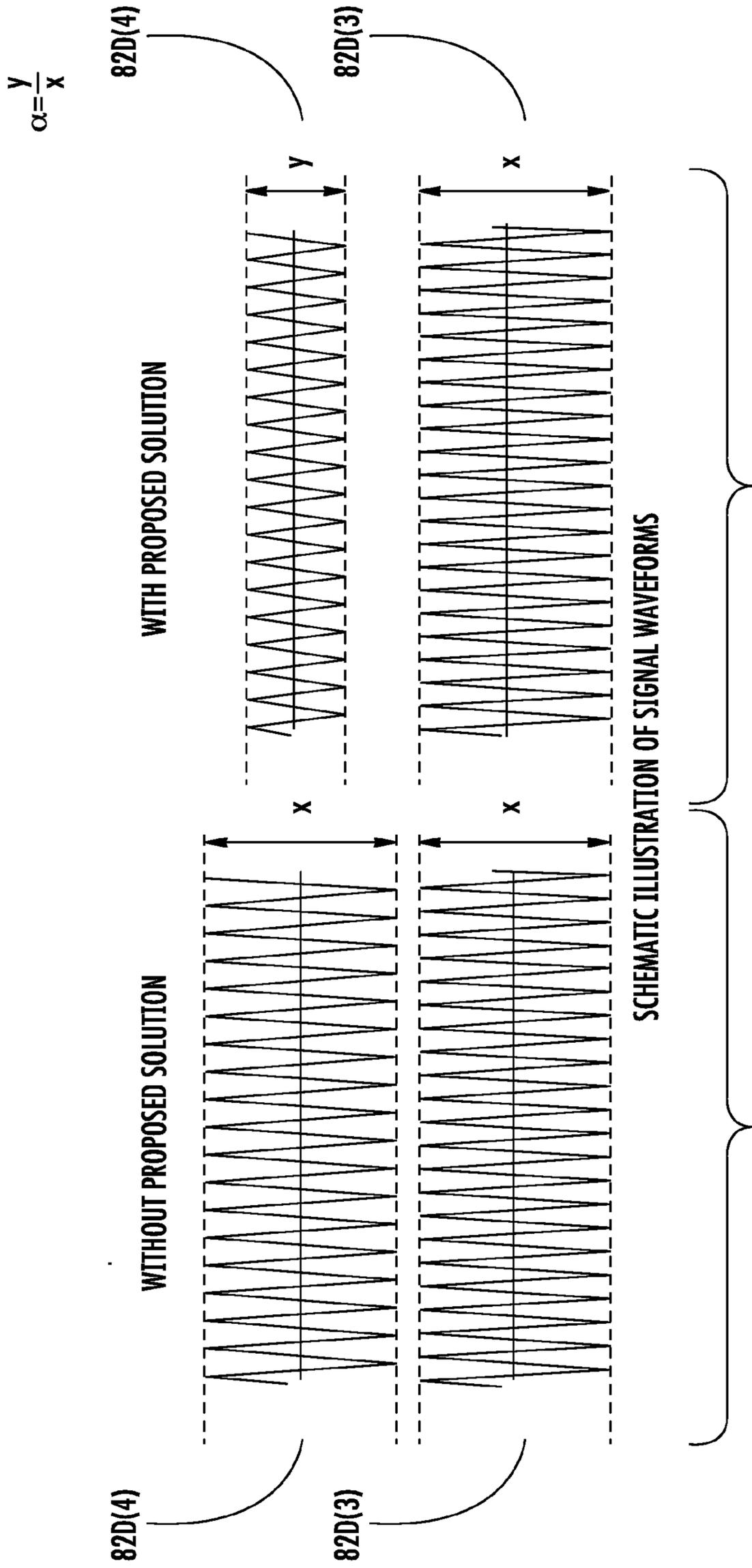


FIG. 8A

FIG. 8B

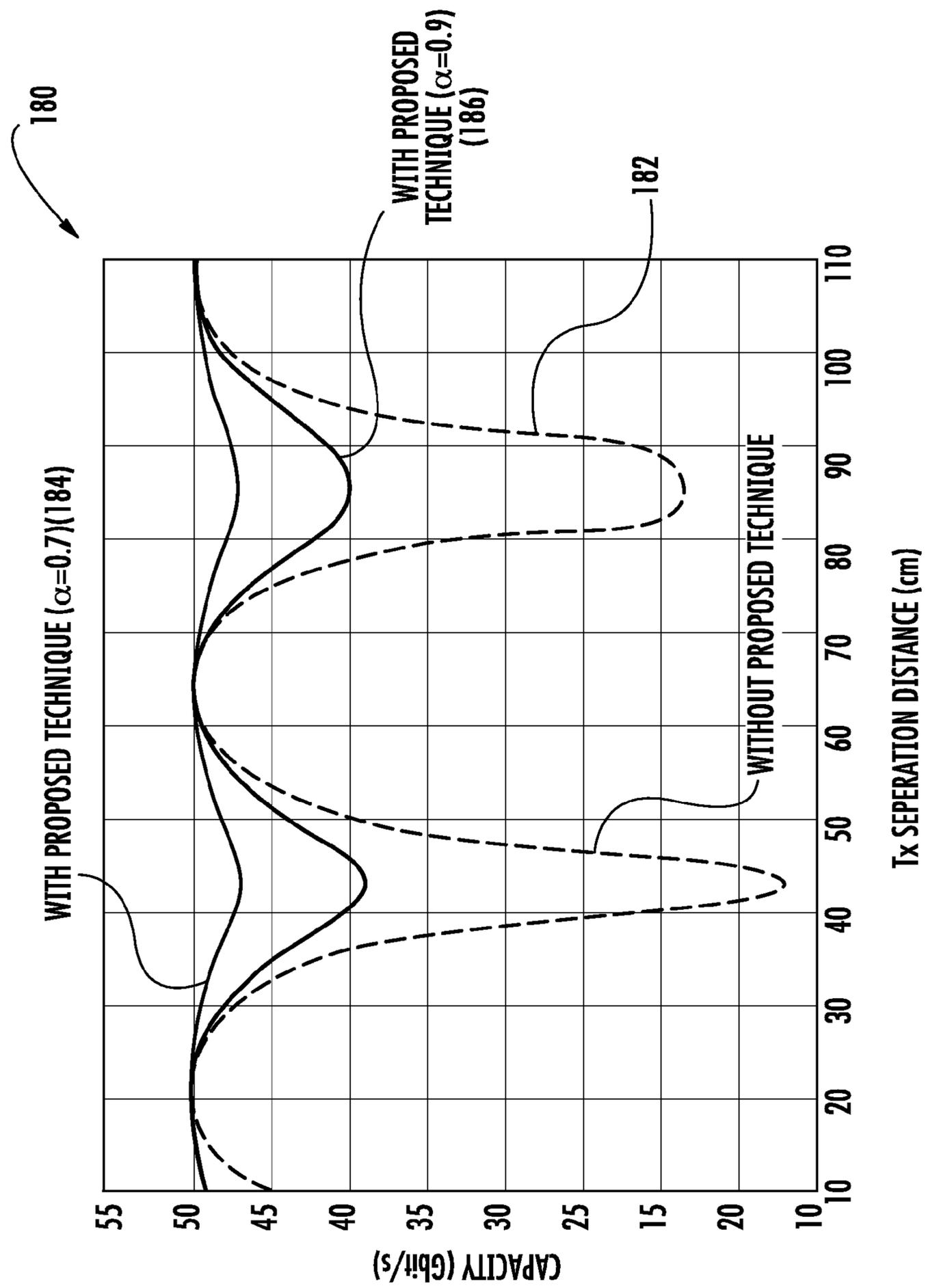


FIG. 8C

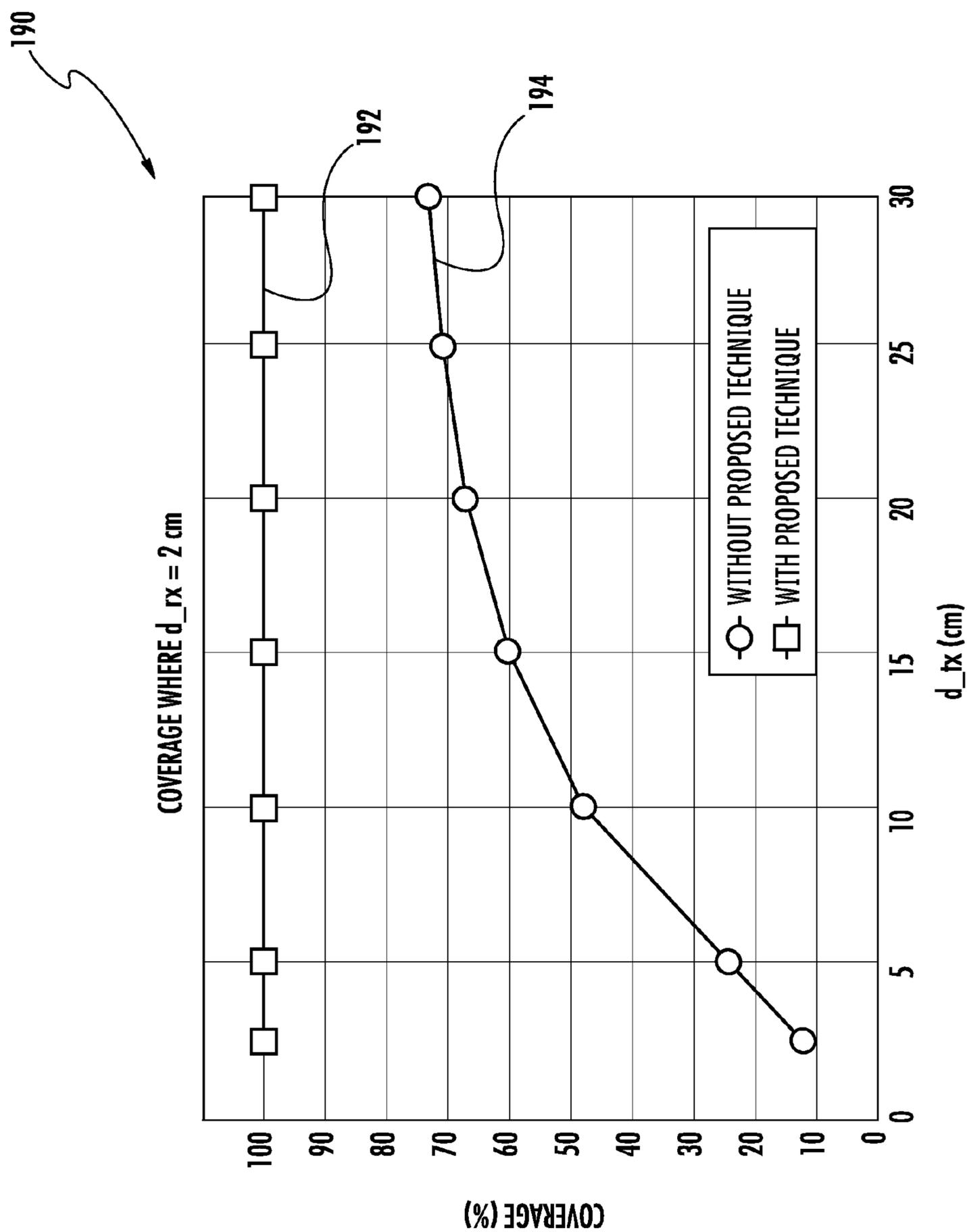


FIG. 8D

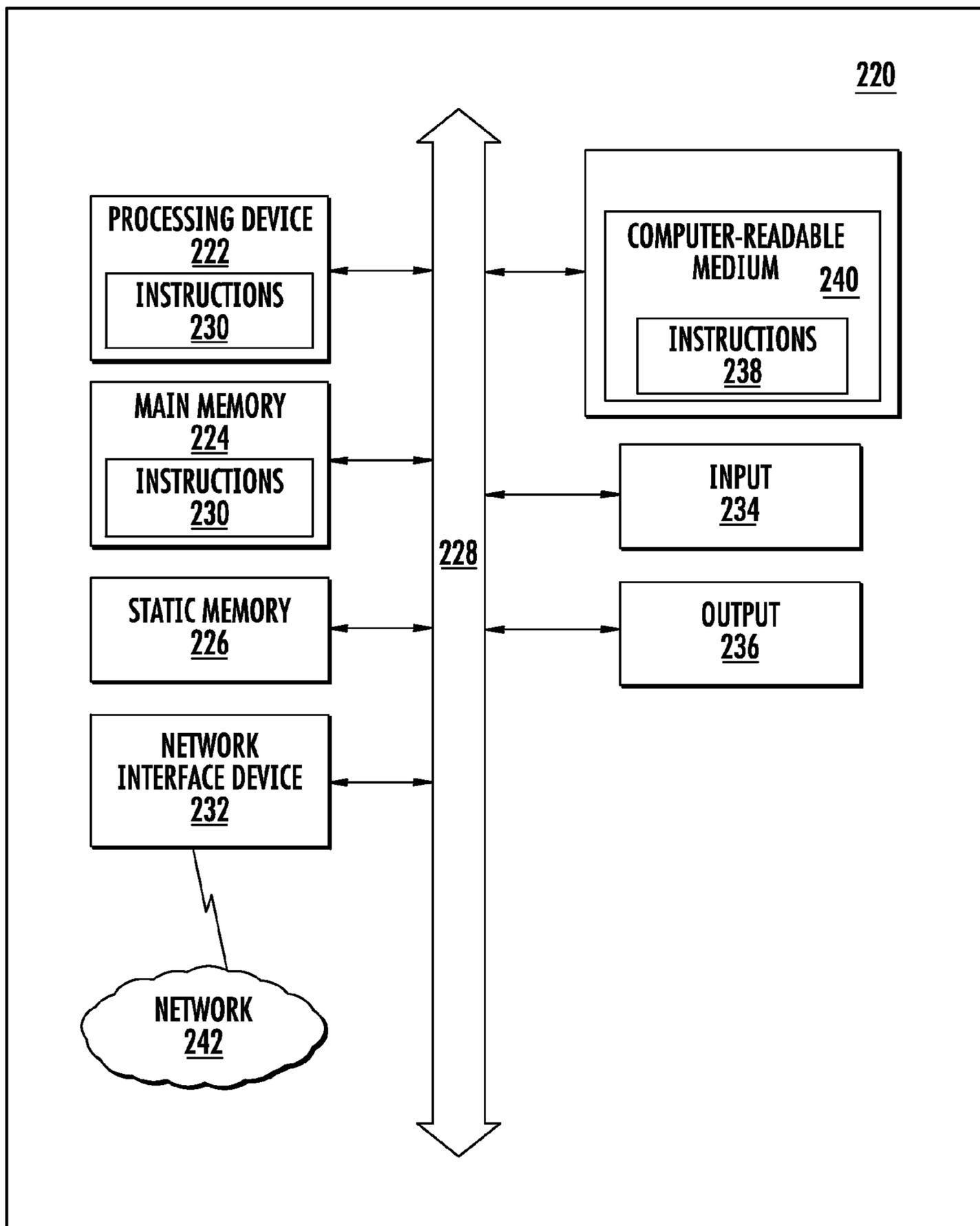


FIG. 9

1

**REDUCING LOCATION-DEPENDENT
DESTRUCTIVE INTERFERENCE IN
DISTRIBUTED ANTENNA SYSTEMS (DASS)
OPERATING IN MULTIPLE-INPUT,
MULTIPLE-OUTPUT (MIMO)
CONFIGURATION, AND RELATED
COMPONENTS, SYSTEMS, AND METHODS**

BACKGROUND

The disclosure relates generally to distribution of data (e.g., digital data services and radio-frequency communications services) in a distributed antenna system (DAS) and more particularly to multiple-input, multiple-output MIMO technology, which may be used in the DAS.

Wireless customers are demanding digital data services, such as streaming video signals. Concurrently, some wireless customers use their wireless devices in areas that are poorly served by conventional cellular networks, such as inside certain buildings or areas where there is little cellular coverage. One response to the intersection of these two concerns has been the use of distributed antenna systems. Distributed antenna systems can be particularly useful to be deployed inside buildings or other indoor environments where client devices may not otherwise be able to effectively receive radio-frequency (RF) signals from a source. Distributed antenna systems include remote units (also referred to as “remote antenna units”) configured to receive and wirelessly transmit wireless communications signals to client devices in antenna range of the remote units. Such distributed antenna systems may use Wireless Fidelity (WiFi) or wireless local area networks (WLANs), as examples, to provide digital data services.

Distributed antenna systems may employ optical fiber to support distribution of high bandwidth data (e.g., video data) with low loss. Even so, WiFi and WLAN-based technology may not be able to provide sufficient bandwidth for expected demand, especially as HD video becomes more prevalent. WiFi was initially limited in data rate transfer to 12.24 Mb/s and is provided at data transfer rates of up to 54 Mb/s using WLAN frequencies of 2.4 GHz and 5.8 GHz. While interesting for many applications, WiFi bandwidth may be too small to support real time downloading of uncompressed HD television signals to wireless client devices.

MIMO technology can be employed in distributed antenna systems to increase the bandwidth up to twice the nominal bandwidth, as a non-limiting example. MIMO is the use of multiple antennas at both a transmitter and receiver to increase data throughput and link range without additional bandwidth or increased transmit power. However, even doubling bandwidth alone may not be enough to support high bandwidth data to wireless client devices, such as the example of real time downloading of uncompressed high definition (HD) television signals.

The frequency of wireless communications signals could also be increased in a MIMO distributed antenna system to provide larger channel bandwidth as a non-limiting example. For example, an extremely high frequency (EHF) in the range of approximately 30 GHz to approximately 300 GHz could be employed. For example, the sixty GHz (60 GHz) spectrum is an EHF that is an unlicensed spectrum by the Federal Communications Commission (FCC). EHF's could be employed to provide for larger channel bandwidths. However, higher frequency wireless signals are more easily attenuated and/or blocked from traveling through walls, building structures, or other obstacles where distributed antenna systems are commonly installed. Higher frequency

2

wireless signals also provide narrow radiation patterns. Thus, remote units in distributed antenna systems may be arranged for line-of-sight (LOS) communications to allow for higher frequencies for higher bandwidth. However, if remote units are provided in a LOS configuration and the remote units are also configured to support MIMO, multiple spatial streams received by multiple receiver antennas in the remote units may be locked into a relative phase and/or amplitude pattern. This can lead to multiple received spatial streams periodically offsetting each other when the spatial streams are combined at MIMO receivers, leading to performance degradation and reduced wireless coverage.

No admission is made that any reference cited herein constitutes prior art. Applicant expressly reserves the right to challenge the accuracy and pertinency of any cited documents.

SUMMARY

Components, systems, and methods for reducing location-dependent destructive interference in distributed antenna systems (DASS) operating in multiple-input, multiple-output (MIMO) configuration are disclosed. The DASS include remote units employing MIMO transmitters configured to transmit multiple data streams in MIMO configuration to MIMO receivers in wireless client devices. Destructive interference in a MIMO system can occur when two or more spatial streams transmitted from multiple MIMO antennas are locked into a relative phase and/or amplitude pattern, causing periodic destructive interferences when the two or more spatial streams are combined at MIMO receivers in client devices. These issues can occur due to lack of separation (i.e., phase, amplitude) in the received MIMO communications signals, especially with closely located MIMO transmitters configured for line-of-sight (LOS) communications. Thus, to provide spatial separation of MIMO communications signals received by MIMO receivers in client devices, multiple MIMO transmitters in a remote unit in a DAS are each configured to employ multiple transmitter antennas, which are each configured to transmit in different polarization states. In certain embodiments, the amplitude of one of the MIMO communications signals is modified in one of the polarization states to further provide amplitude separation between the MIMO communications signals received by the MIMO receivers.

The components, systems, and methods for reducing location-dependent periodic destructive interference in distributed antenna systems operating in MIMO configuration may significantly improve high-data rate wireless coverage without significant dependence on transmitter and/or receiver placement. This may allow for LOS communications to be more easily achieved between MIMO transmitters and MIMO receivers, especially for higher frequency communications where LOS communications may be required to reduce destructions to higher frequency signals by obstacles on the transmission path. High antenna isolation is not required in the MIMO receivers. No additional hardware component is required in the MIMO transmitters or receivers as well. The improved MIMO performance and increased coverage area can also allow higher frequency bands (e.g., 60 GHz) to be used efficiently to provide multi-gigabit per second (Gbps) data access to client devices in indoor and outdoor environments.

One embodiment of the disclosure relates to a MIMO remote unit configured to wirelessly distribute MIMO communications signals to wireless client devices in a distributed antenna system. The MIMO remote unit comprises a

first MIMO transmitter comprising a first MIMO transmitter antenna configured to transmit MIMO communications signals in a first polarization and a second MIMO transmitter antenna configured to transmit MIMO communications signals in a second polarization different from the first polarization. The MIMO remote unit also comprises a second MIMO transmitter comprising a third MIMO transmitter antenna configured to transmit MIMO communications signals in the first polarization and a fourth MIMO transmitter antenna configured to transmit MIMO communications signals in the second polarization. The first MIMO transmitter is configured to receive a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium, and transmit the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over the first MIMO transmitter antenna in the first polarization. The first MIMO transmitter is also configured to receive a second downlink MIMO communications signal at the first amplitude over a second downlink communications medium, and transmit the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over the second MIMO transmitter antenna in the second polarization. The second MIMO transmitter is configured to receive a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium, and transmit the third downlink MIMO communications signal wirelessly as a third electrical downlink MIMO communications signal over the third MIMO transmitter antenna in the first polarization. The second MIMO transmitter is also configured to receive a fourth downlink MIMO communications signal over a fourth downlink communications medium, and transmit the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth electrical downlink MIMO communications signal over the fourth MIMO transmitter antenna in the second polarization.

An additional embodiment of the disclosure relates to a method of transmitting MIMO communications signals to wireless client devices in a distributed antenna system is provided. The method includes receiving a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium. The method also includes transmitting the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over a first MIMO transmitter antenna in a first polarization. The method also includes receiving a second downlink MIMO communications signal at the first amplitude over a second downlink communications medium. The method also includes transmitting the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over a second MIMO transmitter antenna in a second polarization. The method also includes receiving a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium. The method also includes transmitting the third downlink MIMO communications signal wirelessly as a third electrical downlink MIMO communications signal over a third MIMO transmitter antenna in the first polarization. The method also includes receiving a fourth downlink MIMO communications signal over a fourth downlink communications medium. The method also includes transmitting the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth

electrical downlink MIMO communications signal over a fourth MIMO transmitter antenna in the second polarization.

An additional embodiment of the disclosure relates to a distributed antenna system for distributing MIMO communications signals to wireless client devices. The distributed antenna system comprises a central unit. The central unit comprises a central unit transmitter configured to receive a downlink communications signal. The central unit transmitter is also configured to transmit the received downlink communications signal as a first downlink MIMO communications signal over a first downlink communications medium, a second downlink MIMO communications signal over a second downlink communications medium, a third MIMO downlink communications signal over a third downlink communications medium, and a fourth downlink MIMO communications signal over a fourth downlink communications medium.

This distributed antenna system also comprises a remote unit. The remote unit comprises a first MIMO transmitter comprising a first MIMO transmitter antenna configured to transmit MIMO communications signals in a first polarization and a second MIMO transmitter antenna configured to transmit MIMO communications signals in a second polarization different from the first polarization. The remote unit also comprises a second MIMO transmitter comprising a third MIMO transmitter antenna configured to transmit MIMO communications signals in the first polarization and a fourth MIMO transmitter antenna configured to transmit MIMO communications signals in the second polarization. The first MIMO transmitter is configured to receive a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium, and transmit the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over the first MIMO transmitter antenna in the first polarization. The first MIMO transmitter is also configured to receive a second downlink MIMO communications signal at the first amplitude over a second downlink communications medium, and transmit the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over the second MIMO transmitter antenna in the second polarization. The second MIMO transmitter is configured to receive a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium, and transmit the third downlink MIMO communications signal wirelessly as a third electrical downlink MIMO communications signal over the third MIMO transmitter antenna in the first polarization. The second MIMO transmitter is also configured to receive a fourth downlink MIMO communications signal over a fourth downlink communications medium, and transmit the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth electrical downlink MIMO communications signal over the fourth MIMO transmitter antenna in the second polarization. The remote unit also comprises at least one amplitude adjustment circuit configured to amplitude adjust the fourth downlink MIMO communications signal to the second amplitude.

The distributed antenna systems disclosed herein can be configured to support one or more radio-frequency (RF)-based services and/or distribution of one or more digital data services. The remote units in the distributed antenna systems may be configured to transmit and receive wireless communications signals at one or more frequencies, including but not limited to extremely high frequencies (EHF) (i.e., approximately 30 GHz—approximately 300 GHz). The dis-

tributed antenna systems may include, without limitation, wireless local area networks (WLANs). Further, as a non-limiting example, the distributed antenna systems may be an optical fiber-based distributed antenna system, but such is not required. An optical fiber-based distributed antenna system may employ Radio-over-Fiber (RoF) communications. The embodiments disclosed herein are also applicable to other remote antenna clusters and distributed antenna systems, including those that include other forms of communications media for distribution of communications signals, including electrical conductors and wireless transmission. For example, the distributed antenna systems may include electrical and/or wireless communications mediums between a central unit and remote units in addition or in lieu of optical fiber communications medium. The embodiments disclosed herein may also be applicable to remote antenna clusters and distributed antenna systems and may also include more than one communications media for distribution of communications signals (e.g., digital data services, RF communications services). The communications signals in the distributed antenna system may or may not be frequency shifted.

Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the embodiments as described in the written description and the claims hereof, as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understand the nature and character of the claims. The accompanying drawings are included to provide a further understanding and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiments, and together with the description serve to explain principles and operation of the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of an exemplary distributed antenna system;

FIG. 2 is a schematic diagram of an exemplary multiple-input, multiple-output (MIMO) optical fiber-based distributed antenna system;

FIG. 3A is a top view diagram of a room having an exemplary MIMO antenna system comprising two (2) MIMO transmitter antennas in line-of-sight (LOS) with two (2) MIMO receiver antennas to illustrate periodic destructive interference in MIMO communications signals received in the same frequency channel by the MIMO receiver antennas;

FIG. 3B is a graph illustrating exemplary measured periodic performance degradations for a given placement distance between the MIMO transmitter antennas in the MIMO antenna system in FIG. 3A;

FIG. 3C is a graph illustrating an exemplary effective antenna coverage area in proximity to the MIMO transmitter antennas in FIG. 3A;

FIG. 4 is a schematic diagram of an exemplary amplitude adjustment circuit for amplitude adjusting a downlink (DL) MIMO communications signal transmitted by a MIMO transmitter antenna in FIG. 2;

FIG. 5 is a flowchart illustrating an exemplary amplitude adjustment process performed by the exemplary amplitude adjustment circuit in FIG. 4 for amplitude adjusting a

downlink (DL) MIMO communications signal transmitted by a MIMO transmitter antenna in FIG. 2;

FIG. 6A is a schematic diagram of an exemplary MIMO optical fiber-based distributed antenna system employing a central unit employing a MIMO transmitter configured to electrically amplitude adjust at least one transmitted MIMO electrical downlink communications signal received and transmitted by a remote unit employing multiple MIMO transmitters each configured with multiple MIMO transmitter antennas configured to transmit in different polarization states;

FIG. 6B is a schematic diagram of an exemplary MIMO optical fiber-based distributed antenna system employing an amplitude adjustment circuit of FIG. 4 in an optical downlink communications medium configured to provide amplitude adjustment to at least one transmitted MIMO electrical downlink communications signal received and transmitted by a remote unit employing multiple MIMO transmitters each configured with multiple MIMO transmitter antennas configured to transmit in different polarization states;

FIG. 6C is a schematic diagram of an exemplary MIMO optical fiber-based distributed antenna system employing remote units employing multiple MIMO transmitters each employing multiple MIMO transmitter antennas configured to transmit in different polarization states, wherein one of the MIMO electrical downlink communications signals transmitted by one of the MIMO transmitters in a polarization state is electrically amplitude adjusted;

FIG. 7 is a schematic diagram illustrating exemplary implementation options of an amplitude adjustment circuit in FIG. 4 in a central unit in FIGS. 6A-6C;

FIG. 8A is a graph illustrating exemplary MIMO communications signal waveforms transmitted by a first MIMO transmitter antenna and a second MIMO transmitter antenna of a MIMO transmitter in a remote unit in FIGS. 6A-6C without amplitude adjustment;

FIG. 8B is a graph illustrating exemplary MIMO communications signal waveforms transmitted by a first MIMO transmitter antenna and a second MIMO transmitter antenna of a MIMO transmitter in a remote unit in FIGS. 6A-6C with amplitude adjustment;

FIG. 8C is a graph illustrating exemplary measured periodic performance degradation for a given placement distance between MIMO transmitter antennas in a MIMO transmitter in a remote unit in the distributed antenna system in FIGS. 6A-6C, when employing and not employing amplitude adjustment of at least one transmitted downlink communications signals;

FIG. 8D is a graph illustrating an exemplary effective antenna coverage versus placement distance between MIMO transmitter antennas in a MIMO transmitter in a remote unit in the distributed antenna system in FIGS. 6A-6C, for a given placement distance between MIMO receiver antennas, when employing and not employing amplitude adjustment of at least one transmitted downlink communications signal; and

FIG. 9 is a schematic diagram of a generalized representation of an exemplary controller that can be included in any central unit, remote units, wireless client devices, and/or any other components of distributed antenna systems to reduce or eliminate issues of periodic destructive interference in transmitted MIMO electrical downlink communications signals, wherein the exemplary computer system is adapted to execute instructions from an exemplary computer readable medium.

DETAILED DESCRIPTION

Components, systems, and methods for reducing location-dependent destructive interference in distributed antenna

systems (DASs) operating in multiple-input, multiple-output (MIMO) configuration are disclosed. The DASs include remote units employing MIMO transmitters configured to transmit multiple data streams in MIMO configuration to MIMO receivers in wireless client devices. Destructive interference in a MIMO system can occur when two or more spatial streams transmitted from multiple MIMO antennas are locked into a relative phase and/or amplitude pattern, causing periodic destructive interferences when the two or more spatial streams are combined at MIMO receivers in client devices. These issues can occur due to lack of separation (i.e., phase, amplitude) in the received MIMO communications signals, especially with closely located MIMO transmitters configured for line-of-sight (LOS) communications. Thus, to provide spatial separation of MIMO communications signals received by MIMO receivers in client devices, multiple MIMO transmitters in a remote unit in a DAS are each configured to employ multiple transmitter antennas, which are each configured to transmit in different polarization states. In certain embodiments, the amplitude of one of the MIMO communications signals is modified in one of the polarization states to further provide amplitude separation between the MIMO communications signals received by the MIMO receivers. Various embodiments will be explained by the following examples.

Before discussing examples of components, systems, and methods for reducing location-dependent destructive interference in distributed antenna systems operating in MIMO configuration starting at FIG. 4, an exemplary distributed antenna system is described in regard to FIGS. 1-3C. In this regard, FIG. 1 is a schematic diagram of a conventional distributed antenna system 10. The distributed antenna system 10 is an optical fiber-based distributed antenna system. The distributed antenna system 10 is configured to create one or more antenna coverage areas for establishing communications with wireless client devices located in the radio frequency (RF) range of the antenna coverage areas. In an exemplary embodiment, the distributed antenna system 10 may provide RF communication services (e.g., cellular services). As illustrated, the distributed antenna system 10 includes a central unit 12, one or more remote units 14, and an optical fiber 16 that optically couples the central unit 12 to the remote unit 14. The central unit 12 may also be referred to as a head-end unit. The remote unit 14 is a type of remote communications unit, and may also be referred to as a "remote antenna unit." In general, a remote communications unit can support wireless communications or wired communications, or both. The central unit 12 is configured to receive communications over downlink electrical RF signals 18D from a source or sources, such as a network or carrier as examples, and provide such communications to the remote unit 14. The central unit 12 is also configured to return communications received from the remote unit 14, via uplink electrical RF signals 18U, back to the source or sources. In this regard, in this embodiment, the optical fiber 16 includes at least one downlink optical fiber 16D to carry signals communicated from the central unit 12 to the remote unit 14 and at least one uplink optical fiber 16U to carry signals communicated from the remote unit 14 back to the central unit 12.

One downlink optical fiber 16D and one uplink optical fiber 16U could be provided to support multiple full-duplex channels each using wave-division multiplexing (WDM), as discussed in U.S. patent application Ser. No. 12/892,424, entitled "Providing Digital Data Services in Optical Fiber-based Distributed Radio Frequency (RF) Communications Systems, And Related Components and Methods," incorpo-

rated herein by reference in its entirety. Other options for WDM and frequency-division multiplexing (FDM) are also disclosed in U.S. patent application Ser. No. 12/892,424, any of which can be employed in any of the embodiments disclosed herein. Further, U.S. patent application Ser. No. 12/892,424 also discloses distributed digital data communications signals in a distributed antenna system which may also be distributed in the distributed antenna system 10 either in conjunction with the RF communications signals or not.

The distributed antenna system 10 has an antenna coverage area 20 that can be disposed around the remote unit 14. The antenna coverage area 20 of the remote unit 14 forms an RF coverage area 21. The central unit 12 is adapted to perform or to facilitate any one of a number of Radio-over-Fiber (RoF) applications, such as RF identification (RFID), wireless local-area network (WLAN) communication, or cellular phone service. Shown within the antenna coverage area 20 is a client device 24 in the form of a mobile device, which may be a cellular telephone as an example. The client device 24 can be any device that is capable of receiving RF communications signals. The client device 24 includes an antenna 26 (e.g., a wireless card) adapted to receive and/or send electromagnetic RF signals.

With continuing reference to FIG. 1, to communicate the electrical RF signals over the downlink optical fiber 16D to the remote unit 14, to in turn be communicated to the client device 24 in the antenna coverage area 20 formed by the remote unit 14, the central unit 12 includes a radio interface in the form of an electrical-to-optical (E/O) converter 28. The E/O converter 28 converts the downlink electrical RF signals 18D to downlink optical RF signals 22D to be communicated over the downlink optical fiber 16D. The remote unit 14 includes an optical-to-electrical (O/E) converter 30 to convert the received downlink optical RF signals 22D back to electrical RF signals to be communicated wirelessly through an antenna 32 of the remote unit 14 to the client device 24 located in the antenna coverage area 20.

Similarly, the antenna 32 is also configured to receive wireless RF communications from the client device 24 in the antenna coverage area 20. In this regard, the antenna 32 receives wireless RF communications from the client device 24 and communicates electrical RF signals representing the wireless RF communications to an E/O converter 34 in the remote unit 14. The E/O converter 34 converts the electrical RF signals into uplink optical RF signals 22U to be communicated over the uplink optical fiber 16U. An O/E converter 36 provided in the central unit 12 converts the uplink optical RF signals 22U into uplink electrical RF signals, which can then be communicated as uplink electrical RF signals 18U back to a network or other source.

As noted, one or more of the network or other sources can be a cellular system, which may include a base station or base transceiver station (BTS). The BTS may be provided by a second party such as a cellular service provider, and can be co-located or located remotely from the central unit 12.

In a typical cellular system, for example, a plurality of BTSs is deployed at a plurality of remote locations to provide wireless telephone coverage. Each BTS serves a corresponding cell and when a mobile client device enters the cell, the BTS communicates with the mobile client device. Each BTS can include at least one radio transceiver for enabling communication with one or more subscriber units operating within the associated cell. As another example, wireless repeaters or bi-directional amplifiers could also be used to serve a corresponding cell in lieu of a

BTS. Alternatively, radio input could be provided by a repeater, picocell, or femtocell, as other examples. In a particular exemplary embodiment, cellular signal distribution in the frequency range from 400 MHz to 2.7 GHz is supported by the distributed antenna system **10**.

Although the distributed antenna system **10** in FIG. **1** allows for distribution of radio frequency (RF) communications signals; the distributed antenna system **10** is not limited to distribution of RF communications signals. Data communications signals, including digital data signals, for distributing data services could also be distributed in the distributed antenna system **10** in lieu of or in addition to RF communications signals. Also note that while the distributed antenna system **10** in FIG. **1** discussed below includes distribution of communications signals over optical fiber, the distributed antenna system **10** is not limited to distribution of communications signals over optical fiber. Distribution media could also include, but are not limited to, coaxial cable, twisted-pair conductors, wireless transmission and reception, and any combination thereof. Also, any combination can be employed that also involves optical fiber for portions of the distributed system.

A distributed antenna system, including the distributed antenna system **10** in FIG. **1**, can be configured in MIMO configuration for MIMO operation. In this regard, FIG. **2** illustrates a schematic diagram of an exemplary MIMO optical fiber-based distributed antenna system **40** (hereinafter referred to as “MIMO distributed antenna system **40**”). The MIMO distributed antenna system **40** is configured to operate in MIMO configuration. MIMO technology involves the use of multiple antennas at both a transmitter and receiver to improve communication performance. In this regard, a central unit **42** is provided that is configured to distribute downlink communications signals to one or more remote units **44**. FIG. **2** only illustrates one remote unit **44**, but note that a plurality of remote units **44** is typically provided. The remote units **44** are configured to wirelessly communicate the downlink communication signals to one or more client devices **46** that are in communication range of the remote unit **44**. The remote units **44** may also be referred to as “remote antenna units **44**” because of their wireless transmission over antenna functionality. The remote unit **44** is also configured to receive uplink communication signals from the client devices **46** to be distributed to the central unit **42**. In this embodiment, an optical fiber communications medium **47** comprising at least one downlink optical fiber **48D** and at least one uplink optical fiber **48U** is provided to commutatively couple the central unit **42** to the remote units **44**. The central unit **42** is also configured to receive uplink communication signals from the remote units **44** via the optical fiber communications medium **47**, although more specifically over the at least one uplink optical fiber **48U**. The client device **46** in communication with the remote unit **44** can provide uplink communication signals to the remote unit **44** which are then distributed over the optical fiber communications medium **47** to the remote unit **44** to be provided to a network or other source, such as a base station for example.

With continuing reference to FIG. **2**, more detail will be discussed regarding the components of the central unit **42**, the remote unit **44**, and the client device **46** and the distribution of downlink communications signals. The central unit **42** is configured to receive electrical downlink MIMO communication signals **50D** from outside the MIMO distributed antenna system **40** in a signal processor **52** and provide electrical uplink communications signals **50U** received from client devices **46**, to other systems. The signal

processor **52** is configured to provide the electrical downlink communication signals **50D** to a mixer **60**, which may be an IQ signal mixer in this example. The mixer **60** in this embodiment is configured to convert the electrical downlink MIMO communication signals **50D** to IQ signals. The mixer **60** is driven by a frequency signal **56** that is provided by a local oscillator **58**. Frequency conversion is optional. In this embodiment, it is desired to up-convert the frequency of the electrical downlink MIMO communication signals **50D** to a higher frequency to provide electrical downlink MIMO communication signals **66D** to provide for a greater bandwidth capability before distributing the electrical downlink MIMO communications signals **66D** to the remote units **44**. For example, the up-conversion carrier frequency may be provided as an extremely high frequency (e.g. approximately 30 GHz to 300 GHz).

With continuing reference to FIG. **2**, because the communication medium between the central unit **42** and the remote unit **44** is the optical fiber communications medium **47**, the electrical downlink MIMO communication signals **66D** are converted to optical signals by an electro-optical converter **67**. The electro-optical converter **67** includes components to receive a light wave **68** from a light source **70**, such as a laser. The light wave **68** is modulated by the frequency oscillations in the electrical downlink MIMO communication signals **66D** to provide optical downlink MIMO communication signals **72D** to be communicated over the downlink optical fiber **48D** to the remote unit **44**. The electro-optical converter **67** may be provided so that the electrical downlink MIMO communication signals **66D** are provided as radio-over-fiber (RoF) communications signals over the downlink optical fiber **48D**.

With continuing reference to FIG. **2**, the optical downlink MIMO communication signals **72D** are received by an optical bi-directional amplifier **74**, which is then provided to a MIMO splitter **76** in the remote unit **44**. The MIMO splitter **76** is provided so that the optical downlink MIMO communication signals **72D** can be split among two separate communication paths **77(1)**, **77(2)** to be radiated over two separate MIMO transmitter antennas **78(1)**, **78(2)** provided in two separate MIMO transmitters **79(1)**, **79(2)** configured in MIMO configuration. The MIMO splitter **76** in the remote unit **44** is an optical splitter since the received optical downlink MIMO communication signals **72D** are optical signals. In each communication path **77(1)**, **77(2)**, optical-to-electrical converters **80(1)**, **80(2)** are provided to convert the optical downlink MIMO communication signals **72D** to electrical downlink MIMO communication signals **82D(1)**, **82D(2)**. In this embodiment, as will be discussed in more detail below, an amplitude adjustment circuit **84** is provided in one of the transmission paths **77(1)**, **77(2)** to provide amplitude adjustment in one of the optical downlink MIMO communication signals **72D(1)**, **72D(2)** transmitted over one of the MIMO transmitter antennas **78(1)**, **78(2)** to help reduce or eliminate periodic destructive interferences when received electrical downlink MIMO communication signals **82D** are combined at the client device **46**.

A destructive interference occurs when the electrical downlink MIMO communication signals **82D(1)**, **82D(2)** are locked into a relative phase and/or amplitude pattern, causing them to cancel each other when combined at MIMO receivers **85(1)**, **85(2)**. Because the electrical downlink MIMO communication signals **82D(1)**, **82D(2)** are periodic radio frequency waves, the destructive interference also becomes periodic as result. When physical obstacles (e.g., buildings, walls, trees, vehicles, etc.) standing in radio transmission paths between the MIMO transmitter antennas

78(1), 78(2) and the MIMO receiver antennas 86(1), 86(2), the electrical downlink MIMO communication signals 82D(1), 82D(2) transmitted by the MIMO transmitter antennas 78(1), 78(2) typically arrive at the MIMO receiver antennas 86(1), 86(2) from different directions and/or angles (also known as “multipath”) due to reflections from the physical obstacles. Due to multipath effect, the electrical downlink MIMO communication signals 82D(1), 82D(2) transmitted by the MIMO transmitter antennas 78(1), 78(2) may arrive at the MIMO receiver antennas 86(1), 86(2) with slight delays among each other, resulting in natural phase shifts between the electrical downlink MIMO communication signals 82D(1), 82D(2). Further, the amplitudes of the electrical downlink MIMO communication signals 82D(1), 82D(2) may also be modified due to different reflection angles caused by different obstacles along different transmission paths. In this regard, multipath acts to break up the locked-in phase and/or amplitude pattern among the electrical downlink MIMO communication signals 82D(1), 82D(2) transmitted by the MIMO transmitter antennas 78(1), 78(2) and, thus, helps mitigate periodic destructive interferences at MIMO receivers 85(1), 85(2). However, when a millimeter wave radio frequency band (e.g., 60 GHz) is employed as the carrier frequency between the MIMO transmitter antennas 78(1), 78(2) and the MIMO receiver antennas 86(1), 86(2), there cannot be any physical obstacle stand in the radio transmission path. This is because higher frequency signals like a 60 GHz signal are inherently incapable of penetrating or bouncing off physical obstacles. To prevent millimeter wave radio frequency signals from being blocked by physical obstacles, the MIMO transmitter antennas 78(1), 78(2) and the MIMO receiver antennas 86(1), 86(2) must be configured in a line-of-sight (LOS) arrangement, which is further elaborated in FIGS. 3A-3C. With the LOS arrangement, multipath becomes non-existent between the MIMO transmitter antennas 78(1), 78(2) and the MIMO receiver antennas 86(1), 86(2). Therefore, periodic destructive interferences often occur when the electrical downlink MIMO communication signals 82D(1), 82D(2) are combined at the MIMO receivers 85(1), 85(2).

With continuing reference to FIG. 2, the client device 46 includes two MIMO receivers 85(1), 85(2) that include MIMO receiver antennas 86(1), 86(2) also configured in MIMO configuration. The MIMO receiver antennas 86(1), 86(2) are configured to receive the electrical downlink MIMO communication signals 82D(1), 82D(2) wirelessly from the remote unit 44. Mixers 88(1), 88(2) are provided and coupled to the MIMO receiver antennas 86(1), 86(2) in the client device 46 to provide frequency conversion of the electrical downlink MIMO communication signals 82D(1), 82D(2). In this regard, a local oscillator 90 is provided that is configured to provide oscillation signals 92(1), 92(2) to the mixers 88(1), 88(2), respectively, for frequency conversion. In this embodiment, the electrical downlink MIMO communications signals 82D(1), 82D(2) are down converted back to their native frequency as received by the central unit 42. The down converted electrical downlink MIMO communication signals 82D(1), 82D(2) are then provided to a signal analyzer 94 in the client device 46 for any processing desired.

FIG. 3A illustrates a top view of a room 100 employing the exemplary MIMO distributed antenna system 40 in FIG. 2 to discuss performance of MIMO communications as affected by antenna placement. As illustrated in FIG. 3A, the two MIMO transmitter antennas 78(1), 78(2) of the remote unit 44 are shown as being located in the room 100. Similarly, a client device 46 is shown with its two MIMO

receiver antennas 86(1), 86(2) configured to receive the electrical downlink MIMO communication signals 82D(1), 82D(2) from the two MIMO transmitters 81(1), 81(2) (shown in FIG. 2) in MIMO configuration. The two MIMO transmitter antennas 78(1), 78(2) and two MIMO receiver antennas 86(1), 86(2) are placed according to the LOS arrangement. The LOS arrangement ensures that the electrical downlink MIMO communication signals 82D(1), 82D(2) from the two MIMO transmitters 81(1), 81(2) are directed towards the two MIMO receiver antennas 86(1), 86(2), even if the electrical downlink MIMO communication signals 82D(1), 82D(2) are reflected on the downlink propagation path. In other words, the LOS arrangement does not stop the two MIMO receiver antennas 86(1), 86(2) from receiving reflected signals. The MIMO transmitter antennas 78(1), 78(2) in the MIMO transmitters 81(1), 81(2) in the remote unit 44 are separated by a distance D_1 . The MIMO receiver antennas 86(1), 86(2) in the client device 46 are separated by a distance D_2 . In absence of multipath due to the LOS arrangement, issues can arise, due to destructive interference, with MIMO algorithm being able to solve the channel matrix for received electrical downlink MIMO communication signals 82D(1), 82D(2) at the client device 46 as a function of the distance D_1 between the MIMO transmitter antennas 78(1), 78(2) in the remote unit 44, the distance D_2 between MIMO receiver antennas 86(1), 86(2) in the client device 46, and the distance D_3 between remote unit 44 and the client device 46. These issues are also referred to herein as location-dependent destructive interference issues.

Location-dependent destructive interference for the received electrical downlink MIMO communication signals 82D(1), 82D(2) can negatively affect MIMO communications performance. These issues with electrical downlink MIMO communication signals 82D(1), 82D(2) received by the MIMO receiver antennas 86(1), 86(2) can occur due to lack of separation (e.g., phase, amplitude) in the received electrical downlink MIMO communication signals 82D(1), 82D(2), especially in LOS communications. To illustrate the effect of these issues, FIG. 3B illustrates a graph 102 illustrating the exemplary measured performance degradation for a given placement distance between the MIMO transmitter antennas 78(1), 78(2) in FIG. 3A. The graph 102 in FIG. 3B illustrates the capacity on the y-axis in Gigabits per second (Gbps) versus the MIMO transmitter antennas 78(1), 78(2) separation distance D_1 in centimeters. As illustrated in the graph 102, at separation distances D_1 of approximately 42 centimeters (cm) and 85 cm, the communications capacity illustrated by a capacity curve 104 is periodically degraded due to periodic destructive interferences between the received electrical downlink MIMO communication signals 82D(1), 82D(2). Similarly, a MIMO condition number curve 106 in FIG. 3B also illustrates the effect periodic destructive interferences between the received electrical downlink MIMO communication signals 82D(1), 82D(2), which is complementary to the capacity curve 104.

FIG. 3C illustrates a graph 108 representing an exemplary effective communication coverage area provided by the MIMO distributed antenna system 40 in FIG. 2 according to the MIMO transmitter antennas 78(1), 78(2), separation distance D_1 , the MIMO receiver antennas 86(1), 86(2), separation distance D_2 in FIG. 3A, and distance D_3 therebetween. As illustrated in FIG. 3C, a desired antenna coverage area 109 is shown as being provided by the area formed inside a boundary line 110. However, an actual communication coverage area 113 for the remote unit 44 is provided

inside the boundary line **112**, illustrating the effect in reduction communication range of the remote unit **44**.

To address these issues, FIGS. **4-8D** are provided to illustrate exemplary distributed antenna systems configured to reduce location-dependent destructive interference in distributed antenna systems operating in MIMO configuration. In these embodiments, to provide spatial separation of MIMO communication signals received by MIMO receivers in client devices, multiple MIMO transmitters in a remote unit are each configured to employ multiple transmitter antennas. The multiple transmitter antennas are each configured to transmit communications signals in different polarization states. In certain embodiments, one of the MIMO communications signals is amplitude adjusted in one of the polarization states to provide amplitude separation between MIMO communication signals received by the MIMO receivers.

In this regard, FIG. **4** illustrates an exemplary amplitude adjustment circuit for amplitude adjusting a DL MIMO communication signal transmitted by a MIMO transmitter antenna **78** in FIG. **2**. The exemplary amplitude adjustment circuit **120** comprises a signal controller **122** and an amplitude adjustment logic **124**. As a non-limiting example, the amplitude adjustment logic **124** may be implemented by a hardware component, a software function, or a combination of both. In another non-limiting example, the signal controller **122** may be a digital baseband processor, a digital signal processor, a MIMO controller, or a general-purpose processor (e.g., central processing unit (CPU)). The signal controller **122** receives a MIMO performance measurement **126** on an uplink reception path (not shown). The signal controller **122** is configured to compare the MIMO performance measurement **126** with a pre-determined MIMO performance threshold. If the MIMO performance measurement **126** indicates a MIMO performance level is below the pre-determined MIMO performance threshold, the signal controller **122** is further configured to provide an amplitude adjustment signal **128** to the amplitude adjustment logic **124** to perform amplitude adjustment on a downlink MIMO communication signal **130**. The amplitude adjustment logic **124** in turn performs amplitude adjustment on the downlink communication signal **130** received from a downlink transmission path (not shown). The amplitude adjustment circuit thus produces an amplitude-adjusted downlink communication signal **134** that is sent to a MIMO transmitter antenna on the downlink transmission path (not shown). In a non-limiting example, if the DL MIMO communication signal **130** has an original amplitude x , the amplitude adjustment logic **124** may produce a modified amplitude y that is different from the original amplitude x for the amplitude-adjusted downlink communication signal **134**.

With continuing reference to FIG. **4**, FIG. **5** illustrates an exemplary amplitude adjustment process performed by the exemplary amplitude adjustment circuit in FIG. **4**. FIGS. **2** and **4** are referenced in connection with FIG. **5** and will not be re-described herein. The amplitude adjustment process **140** is invoked when wireless communication starts (block **142**). The signal controller **122** receives and processes a MIMO performance measurement (block **144**) and compares the MIMO performance measurement with a pre-determined threshold (block **146**). If the MIMO performance measurement is above the pre-determined threshold, it indicates that the MIMO transmitter antennas **78** are performing as expected. In this case, the signal controller **122** will not take any action and awaits a next MIMO performance measurement. If, however, the MIMO performance measurement is below the pre-determined threshold,

it is an indication that the MIMO transmitter antennas **78** are not performing as expected. Under such circumstance, the signal controller **122** will instruct the amplitude adjustment logic **124** to modify the amplitude of the downlink MIMO communication signal **130** (block **148**). The amplitude adjustment process **140** repeats the step of comparing MIMO performance measurement against the pre-determined threshold (block **146**) and the step of amplitude adjustment (block **148**) until the next MIMO performance measurement is above the pre-determined threshold.

In this regard, FIGS. **6A-6C** illustrate alternative MIMO distributed antenna systems **40(1)-40(3)** similar to the MIMO distributed antenna system **40** in FIG. **2**. FIGS. **6A-6C** respectively illustrate three (3) different downlink signal processing stages in the MIMO distributed antenna systems **40(1)-40(3)** wherein the amplitude adjustment circuit **120** may be provided. The MIMO distributed antenna systems **40(1)-40(3)** in FIGS. **6A-6C** are configured to reduce or eliminate periodic destructive interferences between received downlink communication signals at a MIMO receiver in a client device so as to reduce or eliminate performance degradation such as shown in FIGS. **3B** and **3C** above. The MIMO distributed antenna systems **40(1)-40(3)** may include the same components in the MIMO distributed antenna system **40** in FIG. **2** unless otherwise noted in FIGS. **6A-6C**. Elements of FIG. **4** are referenced in connection with FIGS. **6A-6C** and will not be re-described herein.

With reference to FIG. **6A**, a central unit **42(1)** is configured to receive the electrical downlink MIMO communications signals **50D** as discussed in regard to FIG. **2**. However, a signal processor **52(1)** is configured to split the electrical downlink MIMO communications signals **50D** into four (4) electrical downlink MIMO communications signals **50D(1)-50D(4)** over four separate channels. As a first option, an amplitude adjustment circuit **120(1)** is provided in the central unit **42(1)** to amplitude adjust at least one of the electrical downlink MIMO communications signals **50D**. Note that although the electrical downlink MIMO communications signal **50D(4)** is amplitude adjusted in this example, any other(s) downlink MIMO communications signal(s) **50D(1)-50D(3)** could be amplitude adjusted as well. The amplitude adjustment circuit **120(1)** may be programmed or controlled by the signal controller **122** to provide a pre-determined level of amplitude adjustment, if desired. Turning back to the central unit **42(1)**, electro-optical converters **67(1)-67(4)** are provided to convert the electrical downlink MIMO communications signals **50D(1)-50D(4)** into optical downlink MIMO communications signals **72D(1)-72D(4)** provided over optical fiber communications medium **47(1)**.

With continuing reference to FIG. **6A**, the remote unit **44(1)** includes two MIMO transmitters **154(1)**, **154(2)** in MIMO configuration. However, the MIMO transmitters **154(1)**, **154(2)** each include two MIMO transmitter antennas **156(1)(1)**, **156(1)(2)**, and **156(2)(1)**, **156(2)(2)**. The first MIMO transmitter **154(1)** includes the first MIMO transmitter antenna **156(1)(1)** configured to radiate the first electrical downlink MIMO communications signals **82D(1)** (after conversion from optical to electrical signals) in a first polarization **158(1)**. The first MIMO transmitter **154(1)** also includes the second MIMO transmitter antenna **156(1)(2)** configured to radiate the second electrical downlink MIMO communications signal **82D(2)** in a second polarization **158(2)** different from the first polarization **158(1)**. In this manner, the first and second electrical downlink MIMO communications signals **82D(1)**, **82D(2)** can be received by

two different MIMO receiver antennas **160(1)**, **160(2)** in MIMO receivers **162(1)**, **162(2)**, respectively, each configured to receive signals in different polarizations **158(1)**, **158(2)** among the first and second polarizations **158(1)**, **158(2)** without experiencing periodic destructive interferences. Thus, the MIMO receivers **162(1)**, **162(2)** can receive the first and second electrical downlink MIMO communications signal **82D(1)**, **82D(2)** in different polarizations **158(1)**, **158(2)**, respectively, from the first MIMO transmitter **154(1)** so that a MIMO algorithm can solve the channel matrix for the first and second electrical downlink MIMO communications signal **82D(1)**, **82D(2)**. In this embodiment, the first polarization **158(1)** is configured to be orthogonal to the second polarization **158(2)** to maximize spectral efficiency and minimize cross talk between the electrical downlink MIMO communications signals **82D(1)**, **82D(2)** at the MIMO receivers **162(1)**, **162(2)**, but this configuration is not required.

With continuing reference to FIG. 6A, the second MIMO transmitter **154(2)** in the remote unit **44(1)** includes a third MIMO transmitter antenna **156(2)(1)** configured to radiate the third electrical downlink MIMO communications signals **82D(3)** (after conversion from optical to electrical signals) in the first polarization **158(1)**. The second MIMO transmitter **154(2)** also includes the fourth MIMO transmitter antenna **156(2)(2)** configured to radiate the fourth electrical downlink MIMO communications signal **82D(4)** in the second polarization **158(2)** different from the first polarization **158(1)**. In this manner, the third and fourth electrical downlink MIMO communications signals **82D(3)**, **82D(4)** can also be received by the two different MIMO receiver antennas **160(1)**, **160(2)** in MIMO receivers **162(1)**, **162(2)**, respectively, each configured to receive signals in different polarizations **158(1)**, **158(2)** among the first and second polarizations **158(1)**, **158(2)**. Thus, the MIMO receivers **162(1)**, **162(2)** can receive the third and fourth electrical downlink MIMO communications signal **82D(3)**, **82D(4)** in different polarizations, respectively, from the second MIMO transmitter **154(2)** between the third and fourth electrical downlink MIMO communications signal **82D(3)**, **82D(4)**. The electrical downlink MIMO communications signals **82D(1)**-**82D(4)** are received by the MIMO receivers **162(1)**, **162(2)** and provided to a signal processor **164** and a MIMO processor **166** for processing.

As previously discussed above, the amplitude adjustment circuit **120(1)** is provided in the central unit **42(1)** to amplitude adjust the electrical downlink MIMO communications signal **50D(4)**. The amplitude adjustment in the above example in turn causes the second and fourth electrical downlink MIMO communications signals **82D(2)**, **82D(4)** to be received by the second MIMO receiver antennas **160(2)** to have a small but sufficient amplitude difference. Further, the second and fourth electrical downlink MIMO communications signals **82D(2)**, **82D(4)** are also received by the second MIMO receiver antenna **160(2)** in the second polarization **158(2)**, which is different from the first and third electrical downlink MIMO communications signals **82D(1)**, **82D(3)** received by the first MIMO receiver **162(1)** in the first polarization **158(1)**. This combination of amplitude adjustment and MIMO transmitter antenna polarization can reduce or eliminate periodic destructive interferences between the first and the third electrical downlink MIMO communications signals **82D(1)**, **82D(3)** being received by the first MIMO receiver **162(1)** and between the second and the fourth electrical downlink MIMO communications signals **82D(2)**, **82D(4)** being received by the second MIMO receiver **162(2)**.

As previously stated above, the amplitude adjustment circuit **120** can be provided in other downlink signal processing stages of the MIMO distributed antenna system **40** other than in the central unit, as provided in the MIMO distributed antenna system **40(1)** in FIG. 6A. In this regard, FIG. 6B is a schematic diagram of another MIMO optical fiber-based distributed antenna system **40(2)** (“MIMO distributed antenna system **40(2)**”) employing an amplitude adjustment circuit **120(2)** in the optical fiber communications medium **47(1)**. The amplitude adjustment circuit **120(2)** can be tunable to allow for the amplitude adjustment to be controlled and tuned. The amplitude adjustment circuit **120(2)** may be an optical attenuator or amplifier that makes the amplitude of the optical downlink MIMO communications signal **72D(1)** smaller or larger, respectively, than the other downlink optical fibers of the optical fiber communications medium **47(1)**. Common elements between the MIMO distributed antenna system **40(1)** in FIG. 6A and the MIMO distributed antenna system **40(2)** in FIG. 6B are noted with common element numbers and will not be re-described. In this embodiment, the amplitude adjustment circuit **120(2)** is configured to optically amplitude adjust the optical downlink MIMO communications signal **72D(4)** received and transmitted by the second MIMO transmitter **154(2)** to the client device **46(1)**. The central unit **42(2)** in FIG. 6B does not include the amplitude adjustment circuit **120(1)** to amplitude shift downlink electrical communications signals like provided in the central unit **42(1)** in FIG. 6A.

As previously discussed above with regard to FIGS. 6A and 6B, the amplitude adjustment circuit **120** can be provided in the central unit **42(1)** and/or the optical fiber communications medium **47(1)** to amplitude adjust the electrical downlink MIMO communications signal **50D(4)**. In this regard, FIG. 6C is a schematic diagram of another MIMO optical fiber-based distributed antenna system **40(3)** (“MIMO distributed antenna system **40(3)**”) employing an amplitude adjustment circuit **120(3)** in the form of an antenna power attenuator or amplifier in the remote unit **44(2)**. Common elements between the MIMO distributed antenna system **40(3)** in FIG. 6C and the MIMO distributed antenna systems **40(1)**, **40(2)** in FIGS. 6A and 6B are noted with common element numbers and will not be re-described. In this embodiment, a signal processor **174** in the remote unit **44(2)** receives the optical downlink MIMO communications signals **72D(1)**-**72D(4)** and converts these signals into electrical downlink MIMO communications signals **82D(1)**-**82D(4)** in an optical-to-electrical converter. The amplitude adjustment circuit **120(3)** is configured to electrically amplitude adjust the electrical downlink MIMO communications signal **82D(4)** received and transmitted by the second MIMO transmitter **154(2)** in the remote unit **44(2)** to the client device **46(1)** so that periodic destructive interferences resulting from LOS arrangement can be reduced or eliminated at the MIMO receivers **162(1)**, **162(2)**.

With reference back to FIG. 4, the amplitude adjustment circuit **120** includes the amplitude adjustment logic **124** configured to make amplitude adjustment on the DL MIMO communication signal **130** based on the amplitude adjustment signal **128** received from the signal controller **122**. Also with reference back to FIG. 6A, the amplitude adjustment circuit **120(1)** is provided in the central unit **42(1)** of the MIMO distributed antenna system **40(1)** to electronically amplitude adjust at least one of the electrical downlink MIMO communications signals **50D(4)**. The amplitude adjustment circuit **120(1)** may be configured to provide

amplitude adjustment in a plurality of ways depending on how the amplitude adjustment logic **124** is implemented. In this regard, FIG. 7 illustrates exemplary implementation options of the amplitude adjustment circuit **120(1)** in the central unit **42(1)**. Elements of FIGS. 4 and 6A are referenced in connection with FIG. 7 and will not be re-described herein. Common elements between the central unit **42(1)** in FIG. 6A and the central unit **42(3)** in FIG. 7 are noted with common element numbers and will not be re-described.

With reference to FIG. 7, an amplitude adjustment circuit **120(4)** in the central unit **42(3)** may be implemented in three different options **120(4)(1)**, **120(4)(2)**, and **120(4)(3)**. An amplitude adjustment option **120(4)(1)** comprises a signal controller **122(1)** configured to receive a control signal **170(1)** from a baseband signal processing module (not shown) and provide an amplitude adjustment signal **128(1)** to an amplitude adjustment logic **124(1)**. In response to receiving the amplitude adjustment signal **128(1)**, the amplitude adjustment logic **124(1)** performs amplitude adjustment on a downlink MIMO communications signal **50D(4)** received from a signal processor **52(1)**. The amplitude adjustment logic **124(1)**, in this non-limiting example, is a tunable attenuator or a variable gain amplifier (VGA) that may be electronically controlled by the signal controller **122(1)** to reduce or increase amplitude of the downlink MIMO communications signal **50D(4)**. An amplitude adjusted downlink MIMO communications signal **172** is received by an electrical/optical converter **67(4)** and converted into an optical downlink MIMO communications signal **72D(4)** (not shown) for transmission over the fiber communication medium **47(1)** (not shown). Note that although the electrical downlink MIMO communications signal **50D(4)** is amplitude adjusted in this example, any other(s) downlink MIMO communications signal(s) **50D(1)**-**50D(3)** could be amplitude adjusted in the same way as the downlink MIMO communications signal **50D(4)**. Alternatively, an amplitude adjustment option **120(4)(2)** comprises an amplitude adjustment logic **124(2)** configured to provide amplitude adjustment on the downlink MIMO communications signal **50D(4)** received from the signal processor **52(1)** by adjusting bias signal of a laser diode. Common elements between the amplitude adjustment option **120(4)(1)** and the amplitude adjustment option **120(4)(2)** are noted with common element numbers and will not be re-described.

With continuing reference to FIG. 7, a third amplitude adjustment option **120(4)(3)** comprises an amplitude adjustment logic **124(3)** that is an optical modulator. In a non-limiting example, the amplitude adjustment logic **124(3)** may be a Mach-Zehnder modulator (MZM) or an electro-absorption modulator (EAM). A bias voltage signal **175** is provided to the amplitude adjustment logic **124(3)** from a laser diode **176**. Biasing in electronic circuits is a method of establishing various pre-determined voltage or current points to provide proper operating conditions in the amplitude adjustment logic **124(3)**. In a typical EAM, for example, a 0.3 volt (V) variation in bias signal results in approximately three (3) decibel (dB) amplitude variation in an output signal. Thus, by providing the bias voltage signal **175** to the amplitude adjustment logic **124(3)**, the amplitude of the downlink MIMO communications signal **50D(4)** received from the signal processor **52(1)** may be adjusted. Other common elements among the amplitude adjustment circuit **120(4)(1)**, **120(4)(2)**, **120(4)(3)** are noted with common element numbers and will not be re-described.

To help visualize the concept of amplitude adjustment, FIGS. 8A-8B are provided. Elements of FIGS. 6A-6C are referenced in connection with FIGS. 8A-8B and will be

re-described herein. FIG. 8A is a graph illustrating exemplary MIMO communication signal waveforms transmitted by MIMO transmitter antennas **156(2)(1)**, **156(2)(2)** in a remote unit **44(1)** without amplitude adjustment. As shown in FIG. 8A, when amplitude adjustment is not provided to the MIMO transmitter antennas **156(2)(1)**, **156(2)(2)** in FIG. 6A, the downlink MIMO communications signals **82D(3)**, **82D(4)** both have the same first amplitudes x . FIG. 8B is a graph illustrating exemplary MIMO communication signal waveforms transmitted by MIMO transmitter antennas **156(2)(1)**, **156(2)(2)** in a remote unit **44(1)** when amplitude adjustment is provided to the MIMO transmitter antenna **156(2)(2)**. As can be seen in FIG. 8B, a second amplitude y of the downlink MIMO communications signal **82D(4)** is smaller than the first amplitude x of the downlink MIMO communications signal **82D(3)**. An amplitude adjustment factor α is computed as the ratio between y and x ($\alpha=y/x$). For example, the amplitude adjustment factor $\alpha=0.7$ indicates that the second amplitude y is 70% of the first amplitude x . As previously described in FIGS. 6A-6C, such amplitude difference, in conjunction with different polarization states **158(1)**, **158(2)**, can help reduce or eliminate periodic destructive interferences between the downlink MIMO communications signals **82D(3)**, **82D(4)** at the MIMO receivers **162**. Note that although in FIG. 8B, the amplitude y of the downlink MIMO communications signal **82D(4)** is shown to be smaller than the amplitude x of the downlink MIMO communications signal **82D(3)**, it is possible to amplify the amplitude y of the downlink MIMO communications signal **82D(4)** to be larger than the amplitude x of the downlink MIMO communications signal **82D(3)**. Further, although the downlink MIMO communications signals **82D(4)** in FIGS. 8A and 8B are shown to have the same phase, it is also possible to simultaneously phase shift and amplitude adjust the downlink MIMO communications signal **82D(4)**.

To illustrate the performance improvements provided by the amplitude adjustment circuits **120(1)**-**120(3)** in the MIMO distributed antenna systems **40(1)**-**40(3)** in FIGS. 6A-6C, FIG. 8C illustrates a graph **180** illustrating exemplary performance degradation curves for a given placement distance between the MIMO transmitters **154(1)**, **154(2)**. Similar to graph **102** in FIG. 3B, FIG. 8C illustrates MIMO distributed antenna systems **40(1)**-**40(3)** capacity on the y-axis in units of Gigabits per second (Gbps) versus MIMO transmitter antennas **78(1)**, **78(2)** separation distance on the x-axis in units of centimeters (cm). The capacity degradation curve **182** in FIG. 8C, which is equivalent to the capacity curve **104** in FIG. 3B, illustrates severe periodic capacity dips resulting from periodic destructive interference when amplitude adjustment techniques described above for MIMO distributed antenna systems **40(1)**-**40(3)** are not employed. As shown in the graph **180**, for a given transmitter antenna separation distance and a given wireless distance (e.g., a distance between a wireless transmitter and a wireless receiver), a capacity degradation curve **184** and a capacity degradation curve **186** illustrate different degrees of capacity degradations when amplitude adjustment techniques described above for MIMO distributed antenna systems **40(1)**-**40(3)** are employed. In this non-limiting example, the capacity degradation curves **184** and **186** are associated with amplitude adjustment factors $\alpha=0.7$ and $\alpha=0.9$, respectively. As can be seen in the capacity degradation curves **184**, **186**, periodic capacity dips, although not completely eliminated, do become more moderate as result of reduced periodic destructive interference provided by

amplitude adjustment techniques described above for MIMO distributed antenna systems 40(1)-40(3).

FIG. 8D is a graph 190 illustrating an exemplary effective antenna coverage versus placement distance between MIMO transmitters 154(1), 154(2) in the distributed antenna systems 40(1)-40(3) in FIGS. 6A-6C, for a two (2) cm placement distance between the MIMO receivers 162(1), 162(2). When the amplitude adjustment techniques described above for the MIMO distributed antenna systems 40(1)-40(3) are employed, coverage curve 192 illustrates consistent 100% antenna coverage regardless of placement distance between MIMO transmitters 154(1), 154(2) in the distributed antenna systems 40(1)-40(3) in FIGS. 6A-6C. When the amplitude adjustment techniques described above for the MIMO distributed antenna systems 40(1)-40(3) are not employed, coverage curve 194 illustrates inconsistent antenna coverage dependent upon placement distance between MIMO transmitters 154(1), 154(2) in the distributed antenna systems 40(1)-40(3) in FIGS. 6A-6C.

It may also be desired to provide high-speed wireless digital data service connectivity with remote units in the MIMO distributed antenna systems disclosed herein. One example would be WiFi. WiFi was initially limited in data rate transfer to 12.24 Mb/s and is now provided at data transfer rates of up to 54 Mb/s using WLAN frequencies of 2.4 GHz and 5.8 GHz. While interesting for many applications, WiFi has proven to have too small a bandwidth to support real time downloading of uncompressed high definition (HD) television signals to wireless client devices. To increase data transfer rates, the frequency of wireless signals could be increased to provide larger channel bandwidth. For example, an extremely high frequency in the range of 30 GHz to 300 GHz could be employed. For example, the sixty (60) GHz spectrum is an EHF that is an unlicensed spectrum by the Federal Communications Commission (FCC) and that could be employed to provide for larger channel bandwidths. However, high frequency wireless signals are more easily attenuated or blocked from traveling through walls or other building structures where distributed antenna systems are installed.

Thus, the embodiments disclosed herein can include distribution of extremely high frequency (EHF) (i.e., approximately 30—approximately 300 GHz), as a non-limiting example. The MIMO distributed antenna systems disclosed herein can also support provision of digital data services to wireless clients. The use of the EHF band allows for the use of channels having a higher bandwidth, which in turn allows more data intensive signals, such as uncompressed HD video to be communicated without substantial degradation to the quality of the video. As a non-limiting example, the distributed antenna systems disclosed herein may operate at approximately sixty (60) GHz with approximately seven (7) GHz bandwidth channels to provide greater bandwidth to digital data services. The distributed antenna systems disclosed herein may be well suited to be deployed in an indoor building or other facility for delivering of digital data services.

It may be desirable to provide MIMO distributed antenna systems, according to the embodiments disclosed herein, that provide digital data services for client devices. For example, it may be desirable to provide digital data services to client devices located within a distributed antenna system. Wired and wireless devices may be located in the building infrastructures that are configured to access digital data services. Examples of digital data services include, but are not limited to, Ethernet, WLAN, WiMax, WiFi, DSL, and LTE, etc. Ethernet standards could be supported, including

but not limited to, 100 Mb/s (i.e., fast Ethernet) or Gigabit (Gb) Ethernet, or ten Gigabit (10 G) Ethernet. Examples of digital data services include, but are not limited to, wired and wireless servers, wireless access points (WAPs), gateways, desktop computers, hubs, switches, remote radio heads (RRHs), baseband units (BBUs), and femtocells. A separate digital data services network can be provided to provide digital data services to digital data devices.

FIG. 9 is a schematic diagram representation of additional detail illustrating components that could be employed in any of the components or devices disclosed herein, but only if adapted to execute instructions from an exemplary computer-readable medium to perform any of the functions or processing described herein. In this regard, such component or device may include a computer system 220 within which a set of instructions for performing any one or more of the location services discussed herein may be executed. The computer system 220 may be connected (e.g., networked) to other machines in a LAN, an intranet, an extranet, or the Internet. While only a single device is illustrated, the term “device” shall also be taken to include any collection of devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein. The computer system 220 may be a circuit or circuits included in an electronic board card, such as, a printed circuit board (PCB), a server, a personal computer, a desktop computer, a laptop computer, a personal digital assistant (PDA), a computing pad, a mobile device, or any other device, and may represent, for example, a server or a user’s computer.

The exemplary computer system 220 in this embodiment includes a processing device or processor 222, a main memory 224 (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM), such as synchronous DRAM (SDRAM), etc.), and a static memory 226 (e.g., flash memory, static random access memory (SRAM), etc.), which may communicate with each other via a data bus 228. Alternatively, the processing device 222 may be connected to the main memory 224 and/or static memory 226 directly or via some other connectivity means. The processing device 222 may be a controller, and the main memory 224 or static memory 226 may be any type of memory.

The processing device 222 represents one or more general-purpose processing devices, such as a microprocessor, central processing unit, or the like. More particularly, the processing device 222 may be a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or other processors implementing a combination of instruction sets. The processing device 222 is configured to execute processing logic in instructions 230 for performing the operations and steps discussed herein.

The computer system 220 may further include a network interface device 232. The computer system 220 also may or may not include an input 234, configured to receive input and selections to be communicated to the computer system 220 when executing instructions. The computer system 220 also may or may not include an output 236, including but not limited to a display, a video display unit (e.g., a liquid crystal display (LCD) or a cathode ray tube (CRT)), an alphanumeric input device (e.g., a keyboard), and/or a cursor control device (e.g., a mouse).

The computer system 220 may or may not include a data storage device that includes instructions 238 stored in a computer-readable medium 240. The instructions 238 may

also reside, completely or at least partially, within the main memory 224 and/or within the processing device 222 during execution thereof by the computer system 220, the main memory 224 and the processing device 222 also constituting computer-readable medium. The instructions 238 may further be transmitted or received over a network 242 via the network interface device 232.

While the computer-readable medium 240 is shown in an exemplary embodiment to be a single medium, the term “computer-readable medium” should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term “computer-readable medium” shall also be taken to include any medium that is capable of storing, encoding, or carrying a set of instructions for execution by the processing device and that cause the processing device to perform any one or more of the methodologies of the embodiments disclosed herein. The term “computer-readable medium” shall accordingly be taken to include, but not be limited to, solid-state memories, optical and magnetic medium, and carrier wave signals.

The embodiments disclosed herein include various steps. The steps of the embodiments disclosed herein may be formed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software.

The embodiments disclosed herein may be provided as a computer program product, or software, that may include a machine-readable medium (or computer-readable medium) having stored thereon instructions, which may be used to program a computer system (or other electronic devices) to perform a process according to the embodiments disclosed herein. A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes: a machine-readable storage medium (e.g., ROM, random access memory (“RAM”), a magnetic disk storage medium, an optical storage medium, flash memory devices, etc.); a machine-readable transmission medium (electrical, optical, acoustical, or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.)); and the like.

Unless specifically stated otherwise and as apparent from the previous discussion, it is appreciated that throughout the description, discussions utilizing terms such as “processing,” “computing,” “determining,” “displaying,” or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data and memories represented as physical (electronic) quantities within the computer system’s registers into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatuses to perform the required method steps. The required structure for a variety of these systems will appear from the description above. In addition, the embodiments described herein are not described with reference to any particular programming language. It will be appreciated that a variety of

programming languages may be used to implement the teachings of the embodiments as described herein.

Those of skill in the art will further appreciate that the various illustrative logical blocks, modules, circuits, and algorithms described in connection with the embodiments disclosed herein may be implemented as electronic hardware, instructions stored in memory or in another computer-readable medium and executed by a processor or other processing device, or combinations of both. The components of the distributed antenna systems described herein may be employed in any circuit, hardware component, integrated circuit (IC), or IC chip, as examples. Memory disclosed herein may be any type and size of memory and may be configured to store any type of information desired. To clearly illustrate this interchangeability, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. How such functionality is implemented depends on the particular application, design choices, and/or design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present embodiments.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or other programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. Furthermore, a controller may be a processor. A processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

The embodiments disclosed herein may be embodied in hardware and in instructions that are stored in hardware, and may reside, for example, in RAM, flash memory, ROM, Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a remote station. In the alternative, the processor and the storage medium may reside as discrete components in a remote station, base station, or server.

It is also noted that the operational steps described in any of the exemplary embodiments herein are described to provide examples and discussion. The operations described may be performed in numerous different sequences other than the illustrated sequences. Furthermore, operations described in a single operational step may actually be performed in a number of different steps. Additionally, one or more operational steps discussed in the exemplary embodiments may be combined. Those of skill in the art will also understand that information and signals may be represented using any of a variety of technologies and techniques.

For example, data, instructions, commands, information, signals, bits, symbols, and chips, that may be references throughout the above description, may be represented by voltages, currents, electromagnetic waves, magnetic fields, or particles, optical fields or particles, or any combination thereof.

Further and as used herein, it is intended that terms “fiber optic cables” and/or “optical fibers” include all types of single mode and multi-mode light waveguides, including one or more optical fibers that may be upcoated, colored, buffered, ribbonized, and/or have other organizing or protective structure in a cable such as one or more tubes, strength members, jackets, or the like. The optical fibers disclosed herein can be single mode or multi-mode fibers. Likewise, other types of suitable optical fibers include bend-insensitive optical fibers, or any other expedient of a medium for transmitting light signals. An example of a bend-insensitive, or bend resistant, optical fiber is ClearCurve® Multimode fiber, commercially available from Corning Incorporated. Suitable fibers of this type are disclosed, for example, in U.S. Patent Application Publication Nos. 2008/0166094 and 2009/0169163, the disclosures of which are incorporated herein by reference in their entireties.

Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit or scope of the invention. Since modifications combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and their equivalents.

What is claimed is:

1. A multiple-input, multiple-output (MIMO) remote unit configured to wirelessly distribute MIMO communications signals to wireless client devices in a distributed antenna system, comprising:

a first MIMO transmitter comprising: a first MIMO transmitter antenna configured to transmit MIMO communications signals in a first polarization and a second MIMO transmitter antenna configured to transmit MIMO communications signals in a second polarization different from the first polarization;

a second MIMO transmitter comprising a third MIMO transmitter antenna configured to transmit MIMO communications signals in the first polarization and a fourth MIMO transmitter antenna configured to transmit MIMO communications signals in the second polarization;

the first MIMO transmitter configured to:

receive a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium, and transmit the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over the first MIMO transmitter antenna in the first polarization; and

receive a second downlink MIMO communications signal at the first amplitude over a second downlink

communications medium, and transmit the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over the second MIMO transmitter antenna in the second polarization;

the second MIMO transmitter configured to:

receive a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium, and transmit the third downlink MIMO communications signal wirelessly as a third electrical downlink MIMO communications signal over the third MIMO transmitter antenna in the first polarization; and

receive a fourth downlink MIMO communications signal over a fourth downlink communications medium, and transmit the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth electrical downlink MIMO communications signal over the fourth MIMO transmitter antenna in the second polarization.

2. The remote unit of claim 1, wherein:

the first MIMO transmitter is further configured to transmit the first downlink MIMO communications signal and second downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client; and the second MIMO transmitter is configured to transmit the third MIMO communications signal and fourth downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client.

3. The remote unit of claim 1, further comprising at least one amplitude adjustment circuit configured to amplitude adjust the fourth downlink MIMO communications signal at the second amplitude.

4. The remote unit of claim 3, wherein the at least one amplitude adjustment circuit is further configured to be electronically tunable to adjust the fourth downlink MIMO communications signal at the second amplitude.

5. The remote unit of claim 3, wherein the amplitude adjustment circuit is configured to attenuate the fourth downlink MIMO communications signal at the second amplitude.

6. The remote unit of claim 3, wherein the amplitude adjustment circuit is configured to amplify the fourth downlink MIMO communications signal at the second amplitude.

7. The remote unit of claim 3, wherein the amplitude adjustment circuit is configured to adjust bias signal of a laser diode to provide amplitude adjustment.

8. The remote unit of claim 3, wherein the amplitude adjustment circuit is configured to adjust a bias signal of an optical modulator to amplitude adjust the fourth downlink MIMO communications signal at the second amplitude.

9. The remote unit of claim 1, wherein the second MIMO transmitter is configured to receive the fourth downlink MIMO communications signal at the second amplitude as a result of an amplitude adjustment of the fourth downlink MIMO communications signal in a central unit.

10. The remote unit of claim 1, wherein the second MIMO transmitter is configured to receive the fourth downlink MIMO communications signal in the second amplitude as a result of an amplitude adjustment of the fourth downlink MIMO communications signal in the fourth downlink communications medium.

11. The remote unit of claim 1, wherein:

the first downlink MIMO communications signal further comprises a first optical downlink MIMO communications signal;

25

the second downlink MIMO communications signal further comprises a second optical downlink MIMO communications signal;

the third downlink MIMO communications signal further comprises a third optical downlink MIMO communications signal; and

the fourth downlink MIMO communications signal further comprises a fourth optical downlink MIMO communications signal.

12. The remote unit of claim **11**, wherein

the first MIMO transmitter further comprises:

a first optical-to-electrical (O/E) converter configured to convert the first optical downlink MIMO communications signal to the first electrical downlink MIMO communications signal; and

a second optical-to-electrical (O/E) converter configured to convert the second optical downlink MIMO communications signal to the second electrical MIMO downlink communications signal; and

the second MIMO transmitter further comprises:

a third optical-to-electrical (O/E) converter configured to convert the third optical downlink MIMO communications signal to the third electrical downlink MIMO communications signal; and

a fourth optical-to-electrical (O/E) converter configured to convert the fourth optical downlink MIMO communications signal to the fourth electrical downlink MIMO communications signal.

13. The remote unit of claim **1**, wherein at least one of the first electrical downlink MIMO communications signal, the second electrical downlink MIMO communications signal, the third electrical downlink MIMO communications signal, and the fourth electrical downlink MIMO communications signal include a carrier frequency having an extremely high frequency (EHF) between approximately 30 GHz and approximately 300 GHz.

14. A method of transmitting multiple-input, multiple-output (MIMO) communications signals to wireless client devices in a distributed antenna system, comprising:

receiving a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium;

transmitting the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over a first MIMO transmitter antenna in a first polarization; and

receiving a second downlink MIMO communications signal at the first amplitude over a second downlink communications medium;

transmitting the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over a second MIMO transmitter antenna in a second polarization;

receiving a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium;

transmitting the third downlink MIMO communications signal wirelessly as a third electrical downlink MIMO communications signal over a third MIMO transmitter antenna in the first polarization;

receiving a fourth downlink MIMO communications signal over a fourth downlink communications medium; and

transmitting the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth electrical downlink

26

MIMO communications signal over a fourth MIMO transmitter antenna in the second polarization.

15. The method of claim **14**, further comprising: transmitting the first downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client;

transmitting the second downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client;

transmitting the third downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client; and

transmitting the fourth downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client.

16. The method of claim **14**, further comprising amplitude adjusting the fourth downlink MIMO communications signal at the second amplitude.

17. The method of claim **16**, further comprising receiving the fourth downlink MIMO communications signal at the second amplitude modified from the first amplitude in a central unit.

18. The method of claim **16**, further comprising receiving the fourth downlink MIMO communications signal at the second amplitude modified from the first amplitude in the fourth downlink communications medium.

19. The method of claim **16**, comprising amplitude adjusting the fourth downlink MIMO communications signal at the second amplitude in the second MIMO transmitter antenna.

20. A distributed antenna system for distributing multiple-input, multiple-output (MIMO) communications signals to wireless client devices, comprising:

a central unit comprising a central unit transmitter configured to receive a downlink communications signal, and transmit the received downlink communications signal as a first downlink MIMO communications signal over a first downlink communications medium, a second downlink MIMO communications signal over a second downlink communications medium, a third downlink MIMO communications signal over a third downlink communications medium, and a fourth downlink MIMO communications signal over a fourth downlink communications medium; and

a remote unit, comprising:

a first MIMO transmitter comprising a first MIMO transmitter antenna configured to transmit MIMO communications signals in a first polarization and a second MIMO transmitter antenna configured to transmit MIMO communications signals in a second polarization different from the first polarization;

a second MIMO transmitter comprising a third MIMO transmitter antenna configured to transmit MIMO communications signals in the first polarization and a fourth MIMO transmitter antenna configured to transmit MIMO communications signals in the second polarization;

the first MIMO transmitter configured to:

receive a first downlink MIMO communications signal at a first amplitude over a first downlink communications medium, and transmit the first downlink MIMO communications signal wirelessly as a first electrical downlink MIMO communications signal over the first MIMO transmitter antenna in the first polarization; and

receive a second downlink MIMO communications signal at the first amplitude over a second down-

27

link communications medium, and transmit the second downlink MIMO communications signal wirelessly as a second electrical downlink MIMO communications signal over the second MIMO transmitter antenna in the second polarization; 5

the second MIMO transmitter configured to:

receive a third downlink MIMO communications signal at the first amplitude over a third downlink communications medium, and transmit the third downlink MIMO communications signal wire- 10

lessly as a third electrical downlink MIMO communications signal over the third MIMO transmitter antenna in the first polarization; and

receive a fourth downlink MIMO communications 15

signal over a fourth downlink communications medium, and transmit the fourth downlink MIMO communications signal at a second amplitude modified from the first amplitude, wirelessly as a fourth electrical downlink MIMO communica-

28

tions signal over the fourth MIMO transmitter antenna in the second polarization; and

at least one amplitude adjustment circuit configured to amplitude adjust the fourth downlink MIMO communications signal to the second amplitude.

21. The distributed antenna system of claim **20**, wherein: the first MIMO transmitter is further configured to transmit the first downlink MIMO communications signal and second downlink MIMO communications signal wirelessly to a line-of-sight (LOS) wireless client; and the second MIMO transmitter is configured to transmit the third downlink MIMO communications signal and fourth downlink MIMO communication signals wire- lessly to a line-of-sight (LOS) wireless client.

22. The distributed antenna system of claim **20**, wherein the at least one amplitude adjustment circuit is disposed in the fourth downlink communications medium.

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