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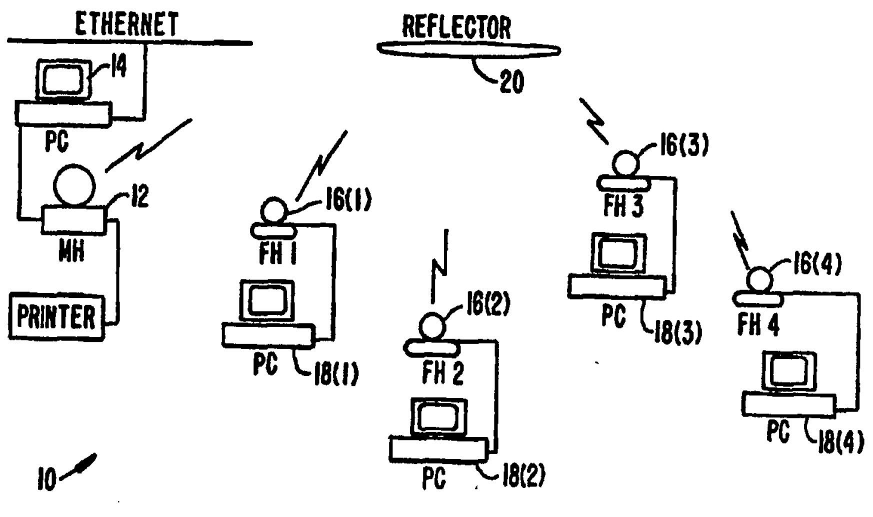

(57) Abstract

An infrared LAN (10) provides direct full-duplex TDM links between a main hub (12) and field hubs (16) in the LAN (10). A reflector (20) facilitates non-line-of-sight communication between the main hub (12) and the field hubs (16). Communication between the hubs (12, 16) is effected in error coded data packets. Pseudo-random code spectrum spreading is utilized to decrease transmission interference.

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INFRARED LOCAL AREA NETWORK

BACKGROUND OF THE INVENTION

Local area networks (LANs) are increasingly being used to couple computers and peripherals, generically referred to a data terminal equipment (DTE), to facilitate communication and interactions. Such communication requires a communication medium which may be copper cables, fiber optic cables, sound waves, or electromagnetic radiation in the radio frequency (rf), microwave, and optical spectra. Each medium has advantages and disadvantages and must be evaluated for its suitability for a particular application.

Copper cables are presently most commonly used in office environments and have the advantage of reliability, reasonably low cost, and familiarity. However, the disadvantages of cables are well known and include the need to reconnect cabling every time a DTE is added or removed from the system, the physical space taken up the cables, the unsightliness of cables running through the office, and susceptibility to interference from electromagnetic radiation. The cost of recabling is about the same as the original cable installation.

LANs utilizing infrared radiation (IR) have been developed which utilize CSMA (Carrier Sense Multiple Access) as an access protocol for the various stations in the LAN. In these systems transmitted data packets include sender and receiver ID information and control information to establish sender/receiver pairs. The high overhead required for handshaking reduces the available bandwidth for information transfer.

Another problem inherent is IR LANs is possible mutual interference between the signals sent by different transmitters. In many systems collisions of packets require retransmission of the data further reducing data transfer rates.

SUMMARY OF THE INVENTION

The present invention is an IR wireless communication network that includes a multi-point main hub (MH) and a plurality of single-point field hubs (FH) that communicate in TDM (time division multiplex) format. Time frames for TDM are established by the MH so that data packets do not require handshaking information and the bandwidth available for information transfer is increased.

According to one aspect of the invention, full-duplex communication is supported between two hubs during each TDM frame.

According to a further aspect of the invention, adaptive echo cancellation cancels the interference between reflected transmitted signals and signals received from another hub.

According to a still further aspect of the invention, mutual interference from IR transmissions outside the network are minimized by utilizing pseudo-random frequency spreading modulation and demodulation techniques.

According to a still further aspect of the invention, access an Ethernet protocol LAN is provided to each FH via the MH.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an IR communication network;

Fig. 2 is schematic diagram of a Link Data Frame Format;

Fig. 3 is a schematic diagram of time/frame alignment for full duplex TDM communication;

Fig. 4 is a block diagram depicting the time/frame alignment for an IR link;

Fig. 5 is a block diagram of a transmitter;

Fig. 6 is a block diagram of an Extended Golay Encoder utilized in the transmitter;

Fig. 7 is a block diagram of a receiver;

Fig. 8 is a block diagram of an Extended Golay Decoder utilized in the receiver;

Fig. 9 is a series of graphs illustrating the auto-correlation properties of the Gold Code;

Fig. 10 is a schematic diagram depicting an echo path;

Fig. 11 is a block diagram of an adaptive echo cancellation system utilized in the transmitter;

Figs. 12A and B are a flow charts of the TDM protocol;

Fig. 13 is a flow chart of the clock synchronization procedure;

Fig. 14 is a flow chart of the energy search procedure; and

Fig. 15 is a schematic diagram depicting full duplex communication.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a block diagram of an embodiment of the IR communication network 10 of the present invention. In Fig. 1, a main hub (MH) 12 is coupled to a DTE 14 configure as a PC interconnected to an IEEE802 standard LAN, such as ETHERNET. Four field hubs (FHs) 16(1-4) are each coupled to an associated DTE 18(1-4). An optional reflector 20 can be utilized to increase the efficiency of non-line-of-sight transmissions, to minimize variations in dynamic range, and to provide beam dispersion to increase the view angle of the receiver in each hub.

In the system depicted in Fig. 1, the IR communication network 10 forms a wireless LAN for the DTEs 14 and 18(1-4). Each FH 16 can access the ETHERNET LAN or another FH 16 via the MH 12. The MH 12 functions as a network server and all communications are routed through it.

First, an overview of the TDM communication protocol of the system will be described with reference to Figs. 2-4. Next, a the operation of the transmitter and receiver will be described with reference to Figs. 5-9. The operation of the adaptive echo cancellation subsystem will then be described with reference to Figs. 10 and 11. Finally, a detailed description of the TDM format will be described with reference to Figs. 12A and B and 15.

Turning now to Figs. 2-4, the Link Data Frame Format utilized in the TDM is depicted in Fig. 2. The ideal time/frame alignment for full duplex TDM communication is depicted in Fig. 3. Ideally, the frames transmitted from the MH 12 to the FHs 16 and the frames received from the FHs 16 at the MH 12 are perfectly aligned relative to the clock at the MH 12.

Fig. 4 schematically depicts the aligning of the received frames relative to the clock at the MH 12. Each link between an FH 16 and the MH 12 is characterized by an associated link delay caused by lack of synchronization between the clocks at the MH 12 and FHs 16 and delays caused by the IR channel. These delays are determined and compensated for so that the received frames are aligned relative to the clock at the MH 12.

Turning to Figs. 5-9, a block diagram of the transmitter 50 is depicted in Fig. 5. A microprocessor or DSP (digital signal processor) 51 is coupled to a PC/Peripheral Interface 52, a Transmit Bit Synchronizer 54, and a Transmit Gain Controller 56 by a processor bus 58. The Interface 52 receives data to be transmitted from a DTE 18 and transmits a block of data to a Block Error Code Encoder 60 which has its output coupled to the data input of a PN (pseudo-random noise) Spreader 62. A Transmit Gold Code generator 64 has a timing input coupled to the output of the Transmit Bit Synchronizer 54 and a data output coupled to a control input of the PN Spreader 62. A data output of the PN Spreader 62 is coupled to the input of the Transmit Gain Controller 56 which has its output coupled to an LED 68.

Fig. 6 depicts the Block Error Code Encoder 60 which, in this embodiment, utilizes an extended Golay code. The raw data from the interface 52 is transferred to the data inputs of a Parity Block Generator 70 and a Raw Data Holding Register 72 which have their outputs coupled to the inputs of a MUX 74. The output of the MUX 72 is the Golay encoded raw data which is transferred to a Parallel to Serial Convertor 76, routed through an Odd/Even Parity Generator 78 and transferred to the PN Spreader 62.

Fig. 7 is a block diagram depicting the receiver 80. A microprocessor or DSP 81 is coupled to Early, Punctual, and Late Auto Correlators (EAC, PAC, LAC) 82, 84, and 86, a Block Error Code Decoder 88, and a PC/Peripheral Interface 90 by a processor bus 92. Incoming IR radiation is received by a Photo-detector 94 serially coupled to an LNA w/ Filter 96 and a Digitizer w/ Echo Cancellation 98. The output of the Digitizer 98 is coupled to a first input of a Matched Filter & PN Despreader and the first data input of the Early, Punctual, and Late Auto-Correlators 82, 84, and 86. A Bit Synchronizer 102 has a control input coupled to the Processor 80 and a timing output coupled to a timing input of a Gold Code Generator 104. A first output of the Gold Code Generator is coupled to second inputs of the Matched Filter & PN Despreader 100 and Punctual Auto-Correlator 84 and a second output is coupled to the second input of the Early and Late Auto-Correlators 82 and 86. The output of the Matched Filter & PN Despreader 100 is coupled to the data input of the Block Error Code Decoder 88.

Fig. 8 is a block diagram of the receiver Block Error Code Decoder 88. The received data from the PN Despreader 100 is coupled to serially connected Syndrom Generator 120, Error Locator Polynomial Generator 122, Chien Search Error Detector 124, and Error Status Register 126 and also coupled to a Receive Data Holding Register 128. The output of the Error Detector 124 is coupled the input of an Error Locator Number Generator 126. An Error Corrector 128 has its inputs coupled to the outputs of the Received Data Holding Register 128 and the Number Generator 127 and has a data output coupled to the processor bus 92.

The syndrom generator 120 indicates whether errors are present in the received frame and the Chien search circuit 124 indicates whether the errors are correctable. If the data is not correctable then a flag is set in the status register

126 and AQRs (Automatic Repeat Requests) are made under control of the receiver processor 81.

The auto-correlation property of a PN sequence, of which the Gold code is a subset, and the use of the Early and Late Auto-Correlators 82 and 86 to compute the timing and code offset between the code received at the receiver and the code generated by the receiver will now be described with reference to Figs. 7 and 9.

In Fig. 9, graph 9A depicts the magnitude of the auto-correlation signal at a receiver 80 as a function of the time offset of the received and generated codes. The magnitude is greatest when there is no time offset and becomes zero for a time offset of magnitude T in the positive (late) or negative (early) direction.

Graph 9B depicts the magnitude of the auto-correlation signal at the Early and Late Auto-Correlators 82 and 86. The Gold code generated at the receiver is supplied to the EAC 82 at T/2 seconds before it is supplied to the PAC 84 and to the LAC 86 at T/2 seconds after it is supplied to the PAC 84. Accordingly, the magnitude at the EAC is a maximum when the received code is received T/2 seconds in advance of the generated code provided to the PAC 84 and is a maximum at the LAC when the received code is received T/2 seconds behind the generated code provided to the PAC 84.

Graphs 9C and 9D depict the difference and sum of the EAC and LAC magnitudes and graph 9E depicts the ratio of difference to the sum. Note from graph 9E that the ratio is zero when there is no time offset.

The Processor 80 in the receiver utilizes the outputs of EAC, PAC, and LAC to and the properties depicted in Fig. 9 to calculate the code offset between the received and generated codes.

The receive data is despread by the same Gold code utilized to spread the data at the transmitter. For a first group of FHs serviced by an MH, each FH receiver generates the same Gold code generated by the MH transmitter and each FH transmitter generates a different Gold code which is generated by the MH receiver. A different group of FHs serviced by a different MH uses different Gold codes. Thus, the signals from the different group would have very low energy after demodulation and would not increase the signal to noise ratio in the receivers of the first group and mutual interference between transmitters of different groups is reduced.

The operation of the adaptive echo cancellation function of the receiver will now be described with reference to Figs. 10 and 11. In Fig. 10 a first source 200 transmits a signal xmt1 modulated by a transmit Gold code (TGC) and a second source 210 transmits a signal xmt2 modulated by a receive Gold code (RGC). The first source 200 receives a signal which is a equal to the sum of Rxmt1 + xmt2 where R is a complex number encoding a phase change due to the delay between the transmission and reception of the reflected part of xmt1 and a magnitude less than 1 indicating the attenuation of the received reflected signal compared to the transmitted signal.

In Fig. 11 the received signal is coupled to the input of the receiver auto-correlator 84, an echo correlator 240, and a the first input of a subtractor 242. The echo correlator 240, which may be the PAC 84, is coupled to the transmit Gold code generator 64 and correlates the received signal with the transmit Gold code. A multiplier 244 has a first input coupled to the output of the PN Spreader 62, a second input coupled to an Adaptive Coefficient register 246 and an output coupled to a second input of the subtractor 242. The output of the subtractor 242 is coupled to the matched filter 100.

The processor 81 utilizes the techniques described with reference to Fig. 9 to determine the offset time and attenuation of the reflected xmt1 signal and loads an adaptive coefficient equal to the R coefficient of the reflected xmt1 signal into register 246. The stored spread transmit data is multiplied by the R coefficient and subtracted from the received signal to cancel the reflected xmt1 signal from the received signal to improve the signal to noise ratio.

The protocol utilized to establish full duplex TDM communication between the hubs will now be described in more detail with reference to the flow charts of Figs. 12A and B.

Referring to Figs. 12A and B, during a standby mode the MH 12 transmits a polling packet to the FHs including its synchronization pattern to maintain a lock with each FH 16. This synchronization pattern is the bits of the MH transmit Gold code included in the preamble of each frame. The MH 12 tests whether the ETHERNET LAN is free and indicates same by reversing the bits of its synchronization pattern also transmitting a control field so indicating. When a given FH acquires data from its host DTE to send to the MH it requests channel acquisition to the MH by sending an ACK signal including its ID number and status information in an allocated time slot. The MH then grants links to the requesting FHs. The FH transmits its data to the MH and sends an End_of-XFER signal when the data transfer is complete.

The alignment of the frames received at the MH to the time slots as depicted in Fig. 3 will now be described with reference to the flow chart of Fig. 13.

Referring to Fig. 13, the FH transmits a frame, including a synch pattern in the preamble, during its allocated time slot. The MH measures the time and code offset utilizing the EAC and LAC 82 and 86 and the energy of the received frame. If the energy for a given FH is too high the MH transmits a frame including control information commanding the given FH to reduce its power and also including the time offset. The FH utilizes this control information to adjust its clock so that its transmitted frames are received at the MH in alignment with its time frames and the power of each frame received at the MH from different FHs is the same.

The step of locking the FH clocks to the MH 300 will now be described with reference to the flow chart of Fig. 14. The receiver bit synchronizer includes a Numerical Controlled Oscillator (NCO) and a Clock Add/Swallow (CAS). The processor utilizes the properties of PN sequence described with reference to Fig. 9 to compute the time and code offset and adjusts its local clock utilizing the bit synchronizer. The

CAS is used to control coarse acquisition and the NCO is for fine acquisition.

Referring to Fig. 14, the FH correlates data every 128 bits, instead of every frame, during energy search to increase the search speed by a factor of 31. The CAS delays the FH clock a chirp and tests to see whether energy is detected. When energy is detected the NCO synchronizes the local clock to the received data.

Fig. 15 depicts the formation of a full duplex link and Fig. 2 depicts the link format. Referring to those figures, the MH transits code and offset errors and data at the CONTROL 1 and DATA sectors of a given frame to FH2 while concurrently receiving control and data information from FH1 during the CONTROL1 and DATA sectors of the given frame. If data with correctable errors is received at the MH then the MH transmits an ACK signal to FH1 during the CONTROL2 sector of the given frame and if data with correctable errors is received at FH2 then FH2 transmits an ACK signal to the MH during the CONTROL2 sector of the given frame.

Thus, the communication between an MH/FH during a given frame is half-duplex but the communication between the MH and a pair of FHs is full duplex.

The invention has now been described with reference to the preferred embodiments. Alternatives and substitutions will now be apparent to persons of skill in the art. For example, although the Gold and Golay codes have been described as the pseudo-random spreading and error correction codes other well-known codes could be substituted. Accordingly, it is not intended to limit the scope of the application except as provided by the appended claims.

<u>WHAT IS CLAIMED IS</u>:

1. A wireless communication network for communicating information between a plurality of data terminal equipment (DTEs) comprising:

a single multi-point hub (MH);

a plurality of single-point field hubs (FHs);

means at each of said hubs for transmitting and receiving digital information modulated onto an IR carrier; and

means for forming full duplex IR indirect communication links between selected pairs of FHs through said MH and a direct link between said MH and any FH in a time-division multiplexed format.

2. The network of claim 1 wherein said MH further comprises:

means for assembling said digital information in the form of transmission packets including preamble, data, and control portions;

a DTE coupled to a non-IR local area network (LAN); and interface means for transferring data between the non-IR LAN and the data portion of said data packet.

3. The network of claim 1 further comprising:

a reflector for facilitating non-line-of-sight communication between said MH and said FHs.

4. The network of claim 1 wherein said means for forming further comprises:

means for assembling said digital information in the form of transmission packets including preamble, data, and control portions;

a FH local clock at each FH and an MH local clock at said MH;

means, at said MH, for measuring the time offset from the MH local clock of a received packet transmitted by a given FH;

means at said MH for transmitting the measured time offset in the control portion of a transmitted packet; and

means at said given FH, coupled to receive said transmitted measured time offset, for adjusting its local FH clock so that its transmitted packets are received at said MH in synchronism with the local clock at said MH.

5. The network of claim 1 further wherein, for a given hub, said means for transmitting further comprises:

means for assembling said digital information in the form of transmission packets having a predetermined signal strength and including preamble, data, and control portions;

means for generating a first pseudo-random code, where said means for forming is coupled to said means for generation to form a first data packet having a preamble comprising said first pseudo-random code;

and wherein said transmitter transmits said first data packet at a predetermined signal strength and said means for receiving further comprises:

a echo correlator for correlating a received packet with said first pseudo-random code to measure the delay and strength of an echoed part of said first transmitted packet; and

adaptive means for adjusting the signal strength of said first packet according to the ratio of the measured strength of said echoed part to said predetermined signal strength and adjusting phase according to the measured delay to form a correction data packet;

means, coupled to said adaptive means, for subtracting said correction data packet from said received data packet to cancel said echoed part of said transmitted packet from said received packet.

6. The network of claim 1 further comprising:

a first group of FHs, each FH in said first group including:

means for assembling said digital information in the form of transmission packets including preamble, data, and control portions;

means for generating a first pseudo-random code;

means, coupled to said means for assembling and said means for generation, for spreading the data and control portions of said transmission packets with said first pseudo-random code to form a spread data packet;

a second group of FHs, each FH in said second group including:

means for assembling said digital data in the form of transmission packets including preamble, data, and control portions;

means for generating a second pseudo-random code;

means, coupled to said means for assembling and said means for generating, for spreading the data and control portions of said transmission packets with said second pseudo-random code to form a spread data packet;

a first MH including:

means for generating said first pseudo-random sequence;

despreading means, coupled to said means for generating, for despreading a received data packet according to said first pseudo-random sequence thereby discriminating data packets transmitted by FHs in said first group from data packets transmitted by FHs in said second group.

7. The network of claim 1 wherein said means for transmitting further comprises:

means for error encoding a digital information in the form of a transmitted data packet;

and wherein said means for receiving further comprises:

means for error decoding a received digital information in the form of a data packet;

error detecting means, coupled to said means for decoding, for indicating whether said received data packet included more than a predetermined number of errors; and

means, coupled to said error encoding means, for generating control information requesting that said received packet be retransmitted when said error detecting means indicated that said received data packet includes more than said predetermined number of errors.

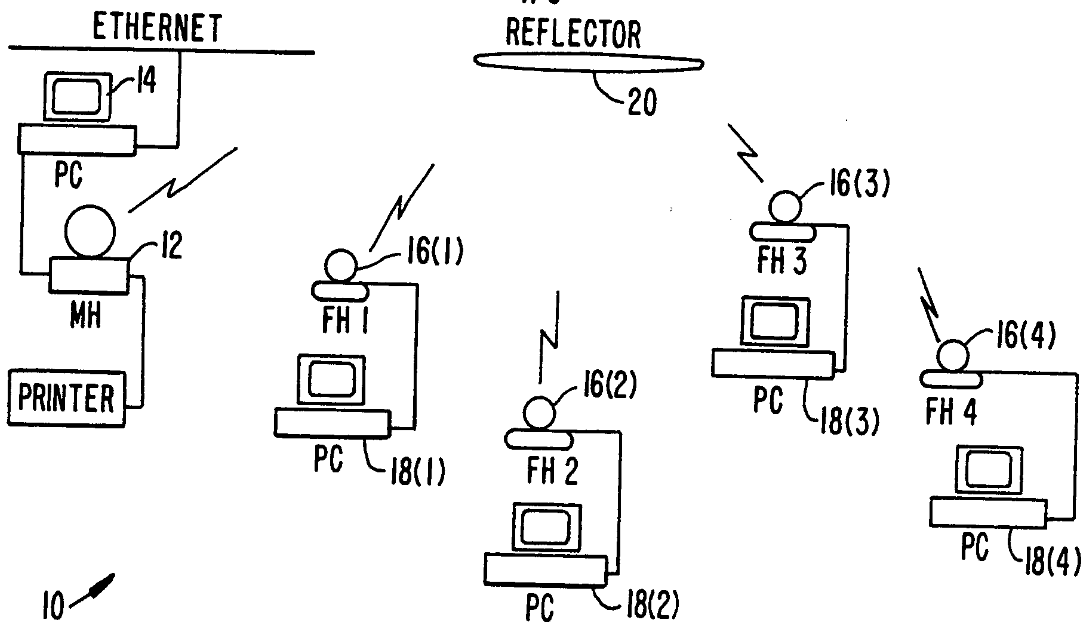


FIG. 1.

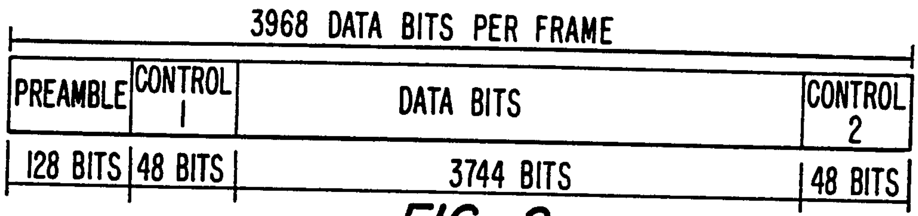


FIG. 2.

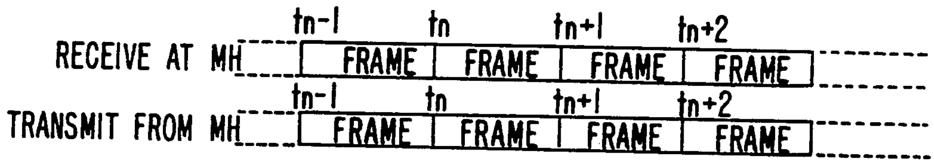


FIG. 3.

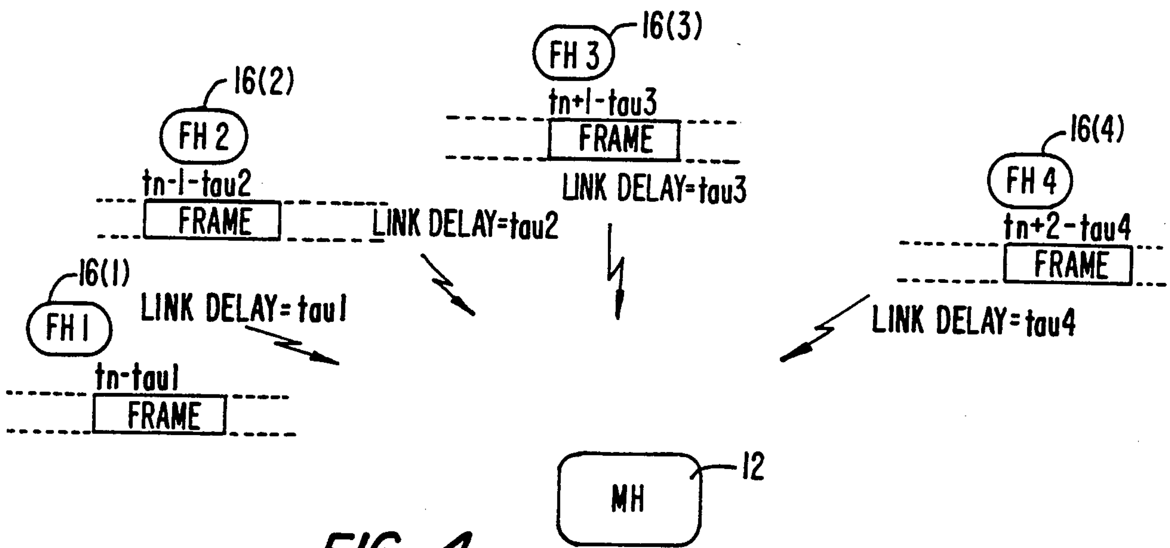
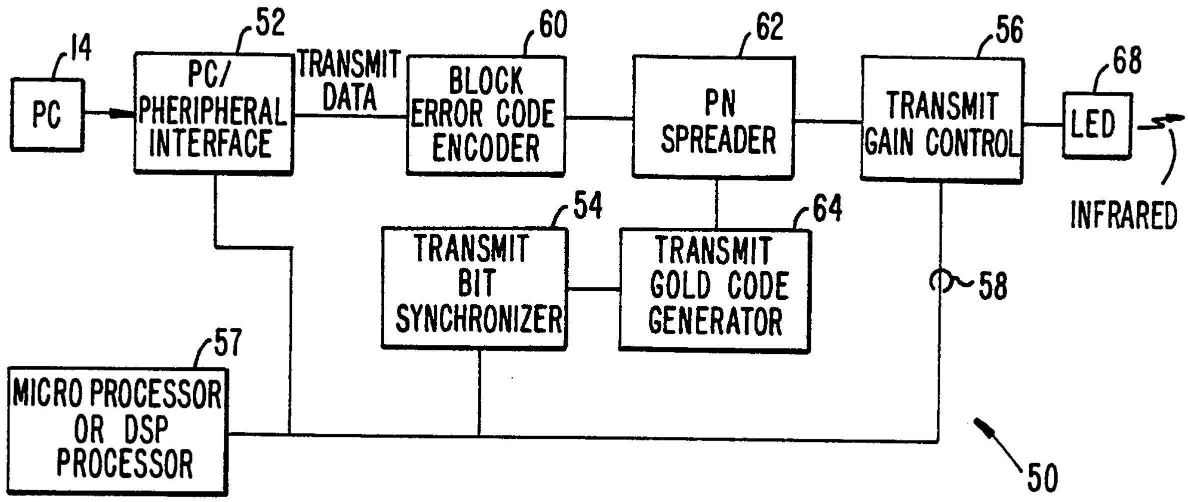


FIG. 4.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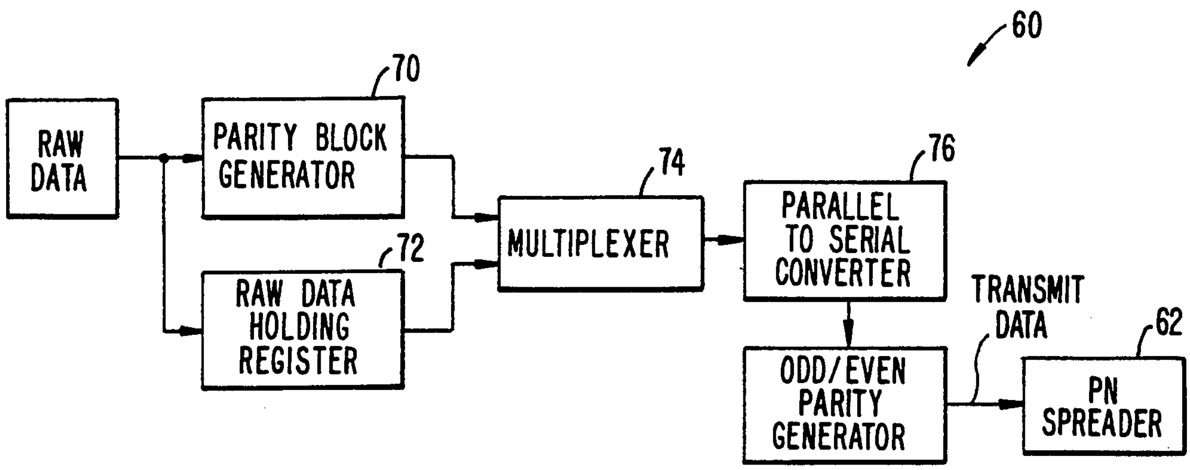
PC
52
PC/
PHERIPHERAL
INTERFACE
TRANSMIT
DATA
60
BLOCK
ERROR CODE
ENCODER
62
PN
SPREADER
56
TRANSMIT
GAIN CONTROL
68
LED
INFRARED
54
TRANSMIT
BIT
SYNCHRONIZER
64
TRANSMIT
GOLD CODE
GENERATOR
58
57
MICRO PROCESSOR
OR DSP
PROCESSOR
50

FIG. 5.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GENERATOR
72
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HOLDING
REGISTER
74
MULTIPLEXER
76
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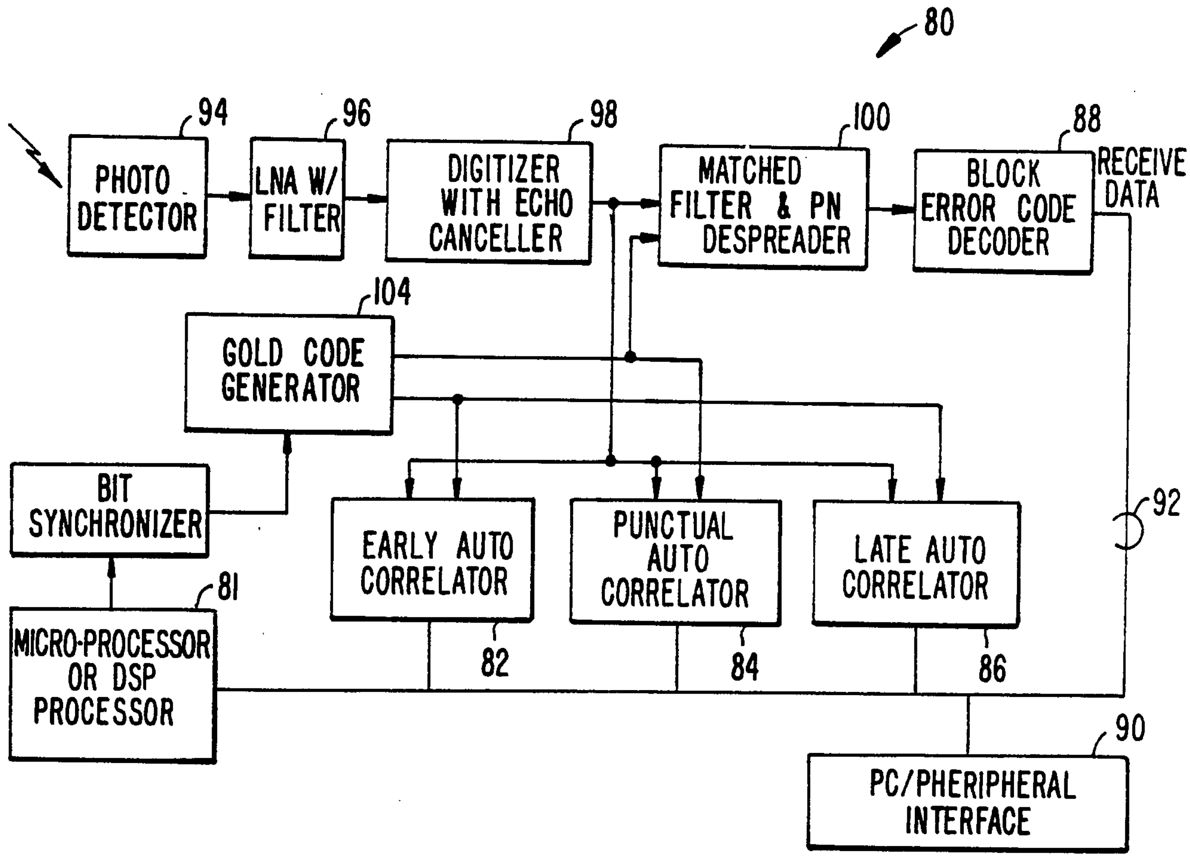
CONVERTER
ODD/EVEN
PARITY
GENERATOR
TRANSMIT
DATA
62
PN
SPREADER

FIG. 6.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94
PHOTO DETECTOR
96
LNA W/ FILTER
98
DIGITIZER WITH ECHO CANCELLER
100
MATCHED FILTER & PN DESPREADER
88
BLOCK ERROR CODE DECODER
RECEIVE DATA
104
GOLD CODE GENERATOR
BIT SYNCHRONIZER
92
EARLY AUTO CORRELATOR
PUNCTUAL AUTO CORRELATOR
LATE AUTO CORRELATOR
81
MICRO-PROCESSOR OR DSP PROCESSOR
82
84
86
90
PC/PHERIPHERAL INTERFACE

FIG. 7.

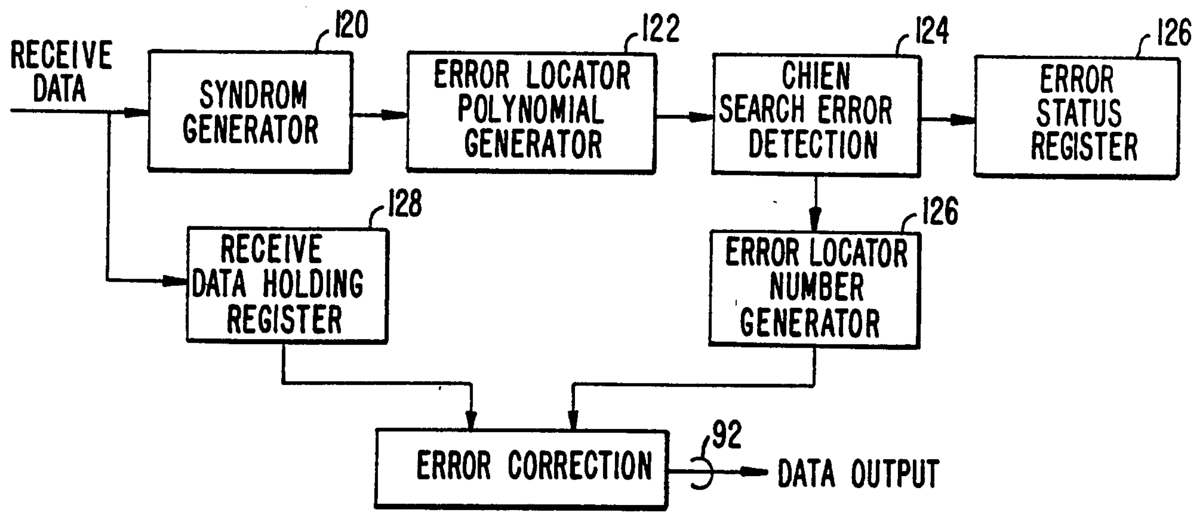
RECEIVE DATA
120
SYNDROM GENERATOR
122
ERROR LOCATOR POLYNOMIAL GENERATOR
124
CHIEN SEARCH ERROR DETECTION
126
ERROR STATUS REGISTER
128
RECEIVE DATA HOLDING REGISTER
126
ERROR LOCATOR NUMBER GENERATOR
ERROR CORRECTION
92
DATA OUTPUT

FIG. 8.

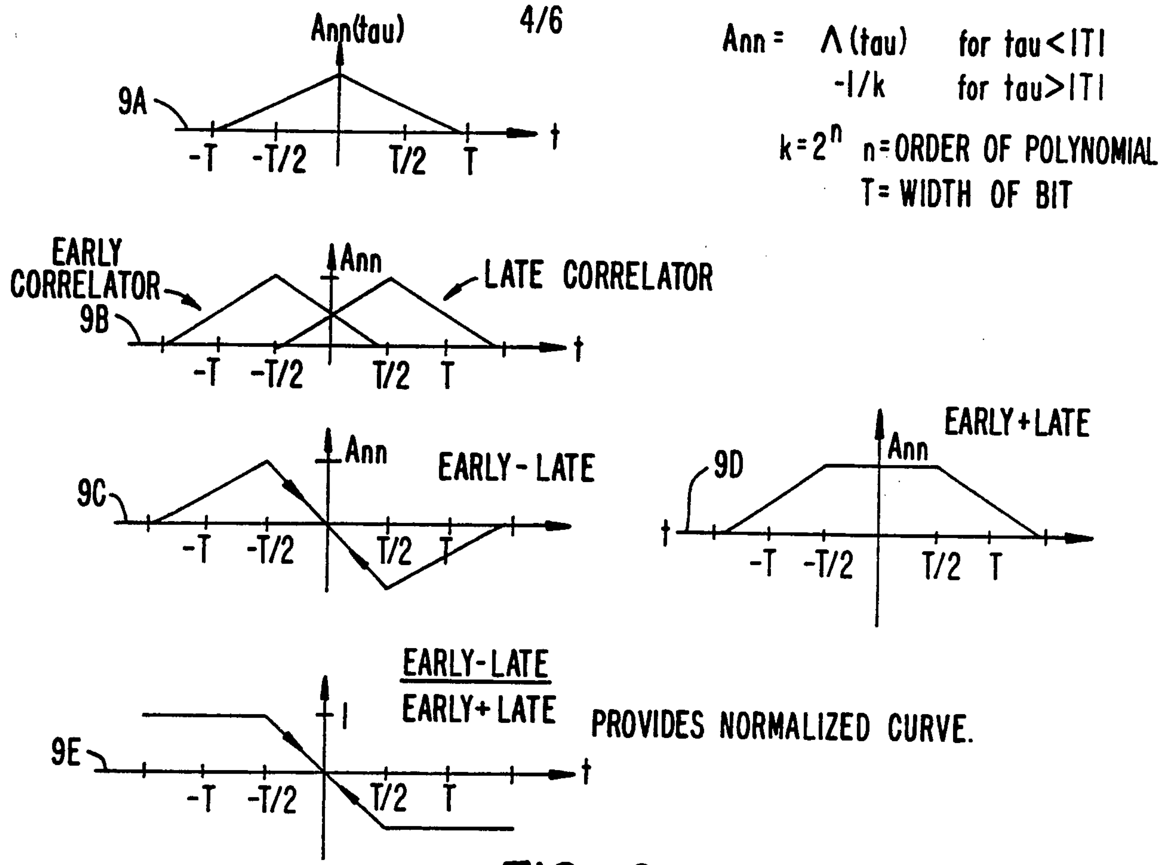

FIG. 9.

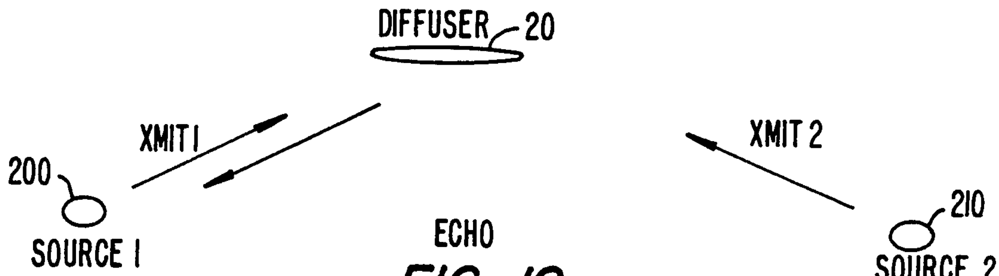

FIG. 10.

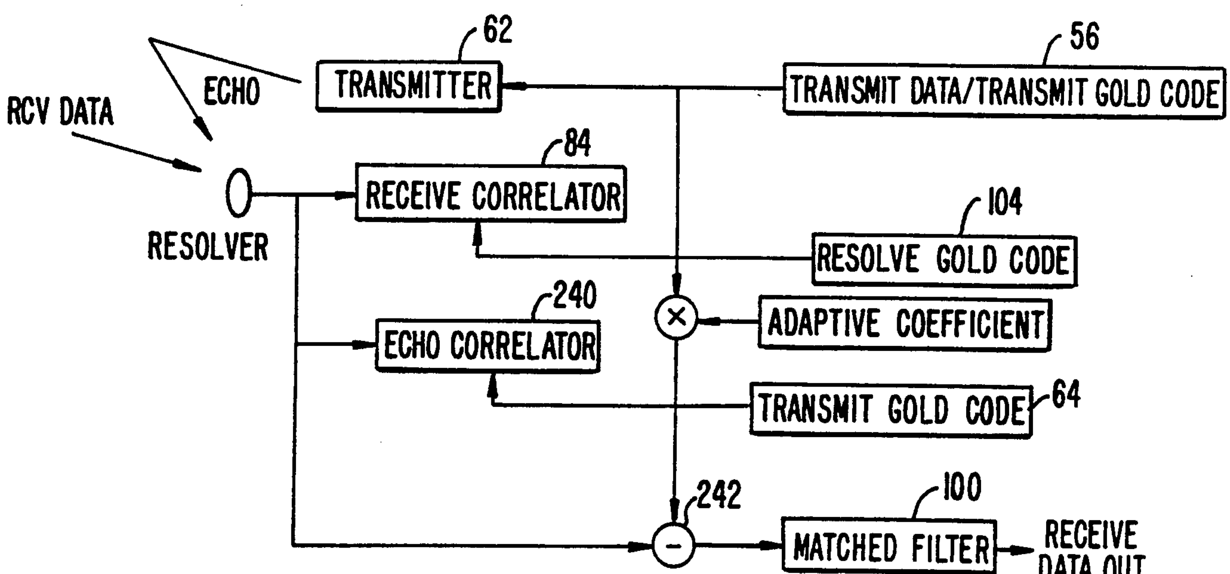

FIG. 11.

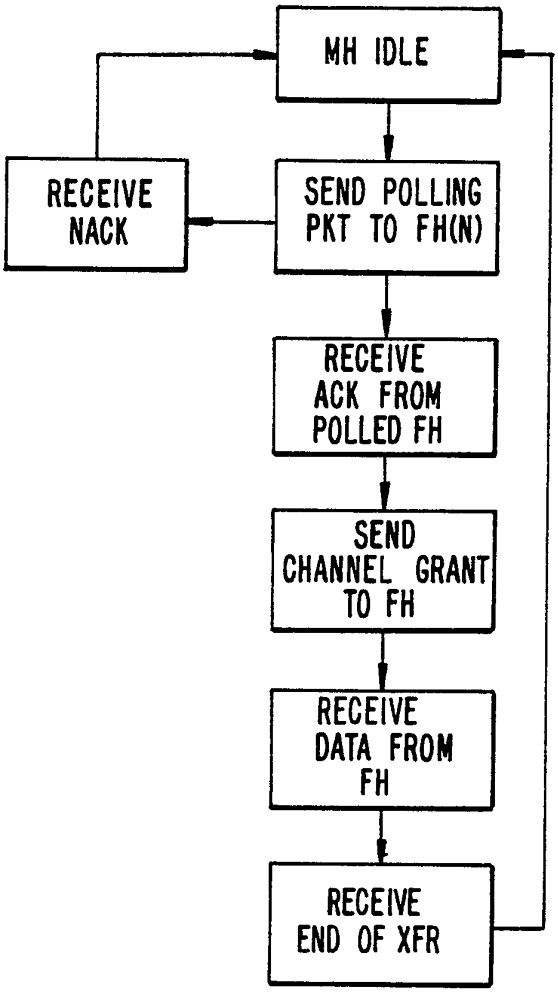

FIG. 12A.

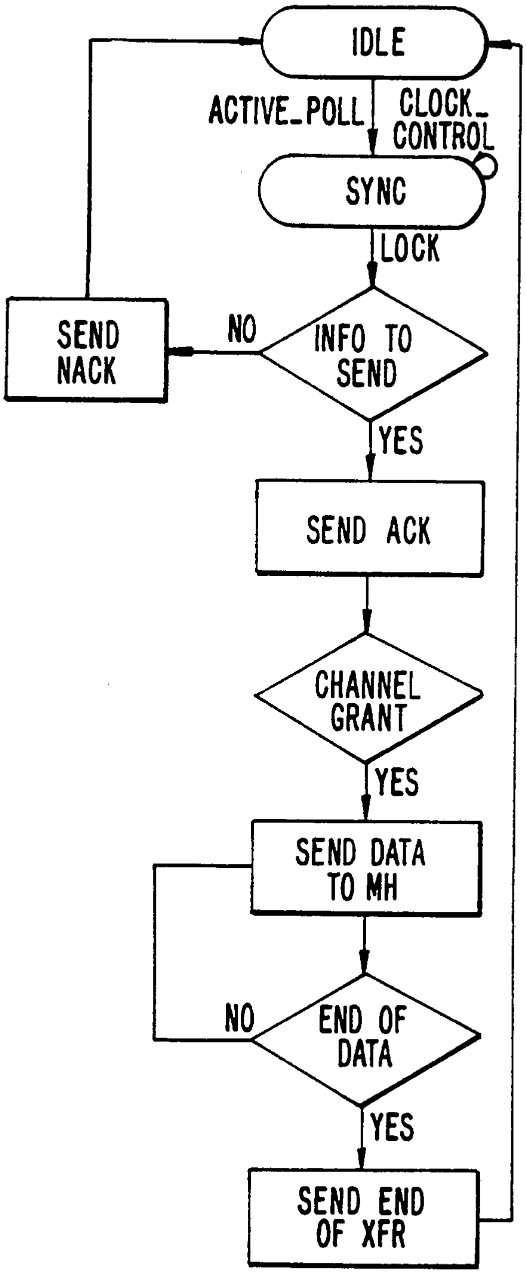

FIG. 12B.

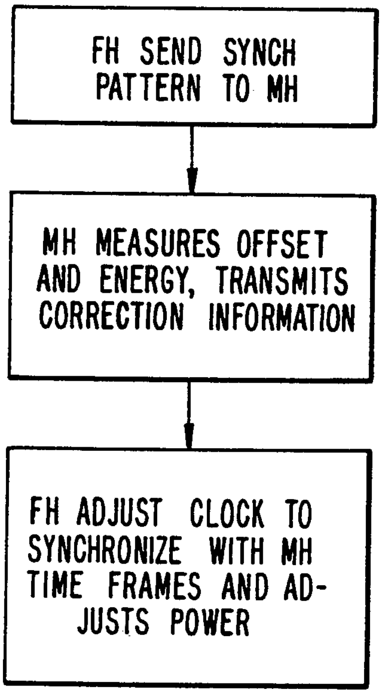

FIG. 13.

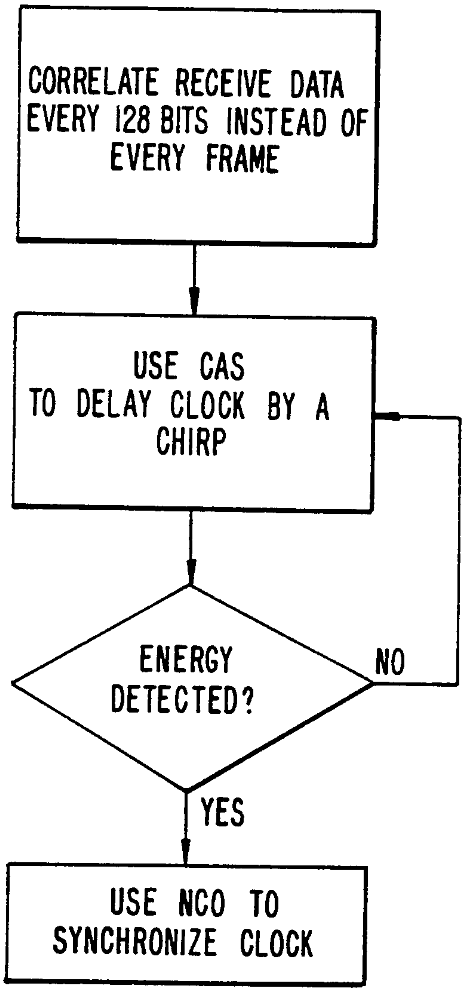

FIG. 14.

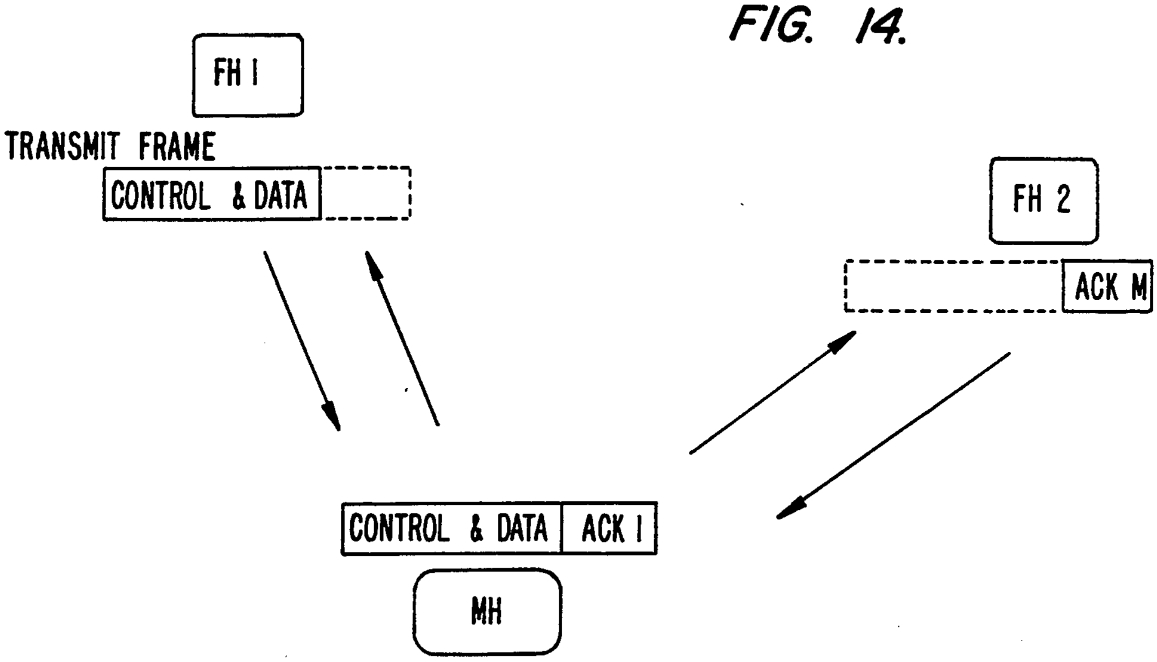

FIG. 15.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/13881

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 10/00; H04L 12/28; H04L 12/56; H04B 15/00; H04B 1/69
US CL :370/94.1, 100.1; 375/1, 118; 359/118, 135; 455/53.1, 69
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/18, 24, 32.1, 79, 94.1, 95.1, 95.3, 100.1, 110.1; 375/1, 107, 109, 118; 359/113, 118, 135, 172; 455/53.1, 54.1, 63, 69; 371/2.1, 3, 32, 48

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P ----- Y,P	US, A, 5,321,542 (FREITAS ET AL) 14 June 1994, col. 3, line 34 through col. 7, line 27.	1-2 ----- 3, 7
Y	US, A, 4,977,618 (ALLEN) 11 December 1990, col. 5, lines 3-11.	3
Y	US, A, 4,939,731 (REED ET AL) 03 June 1990, claim 1.	7
A	US, A, 4,809,257 (GANTENBEIN ET AL) 28 February 1989, entire document.	1
A	US, A, 4,472,802 (PIN ET AL) 18 September 1984, entire document.	1
A	US, A, 4,977,619 (CRIMMINS) 11 December 1990, entire document.	1

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search: 01 FEBRUARY 1995

Date of mailing of the international search report: 03 APR 1995

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/13881

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,099,346 (LEE ET AL) 24 March 1992, entire document.	1
A,P	US, A, 5,280,498 (TYMES ET AL) 18 January 1994, entire document.	2, 4-7