(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 099 638
A2

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 83303309.5

(22) Date of filing: 08.06.83

(51) Int. Cl.³: E 21 B 47/12
G 08 C 19/28

(30) Priority: 21.07.82 US 400334
22.07.82 US 400804

(43) Date of publication of application:
01.02.84 Bulletin 84/5

(84) Designated Contracting States:
DE GB NL

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(54) **A method and system of data transmission for a borehole logging tool.**

(57) A borehole logging system employs a transmitter of acoustic energy pulses and at least one receiver for producing an analog signal representative of the acoustic pulses traveling from the transmitter to the receiver through the formation adjacent the borehole as the logging system is moved through the borehole. A sample-and-hold unit 21 samples the analog signal and an analog-to-digital converter 23 produces a digital word representative of the sampled analog signal. A plurality of digital data words are stored in a memory 24 and converted to a digital serial word for transmission to the surface of the earth over the logging cable 26.

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A METHOD AND SYSTEM OF DATA TRANSMISSION FOR A BOREHOLE LOGGING TOOL

This invention relates to a borehole logging tool employing data transmission of borehole logging signals to recording equipment on the surface of the earth.

In the exploration for petroleum and other minerals, well logging techniques are employed to determine the character of subsurface formations penetrated by a borehole. One technique of logging these characteristics employs a logging tool including a transmitter of acoustic pulses and a receiver, or receivers, for detecting these acoustic pulses after they have traversed the subsurface formations adjacent the tool. By measuring the traveltime of acoustic energy from the transmitter through the formation to the receiver, an indication of the velocity of acoustic energy through the subsurface formation is obtained and this acoustic velocity is an indication of the character of the subsurface formation. By recording the acoustic velocity in correlation with the depth of the borehole as the tool moves through the borehole, there is obtained a log of the characteristics of the subsurface formations as a function of depth. Such logs are useful, particularly in the exploration for oil-bearing subsurface strata.

In U.S. Patent No. 3,302,166 to Joseph Zemanek, Jr., there is disclosed an acoustic velocity logging system wherein a downhole tool comprises a plurality of transducers including a transmitter and multiple receivers. The receivers are spaced at different distances from the transmitter such that an acoustic pulse from the transmitter arrives at the receivers by way of different travel paths through the formation surrounding the borehole. Upon generation of an acoustic pulse by the transmitter, a transmitter trigger pulse is transmitted uphole by way of a conductor in the logging cable. The analog signals produced by the receivers in response to the arrival of the acoustic pulse at the receivers are also transmitted uphole by way of conductors within the logging cable. The logging system is provided with downhole gating circuits which permit the first acoustic pulse to be detected and an analog signal sent uphole by a first receiver, the second acoustic pulse to be detected and an analog signal sent uphole by a second receiver, the third acoustic pulse to be detected and an analog signal sent uphole by a third receiver, and the fourth acoustic pulse to be detected and an analog signal sent uphole by a fourth receiver. This multiplexing cycle is then repeated with successive acoustic pulses being detected and transmitted uphole. The time interval between the generation of each acoustic pulse and the detection of that pulse at a particular receiver is recorded. These time intervals are combined to provide an indication of acoustic velocity of formations adjacent to the logging tool. In such a system, the influence of variations on the acoustic velocity measurement caused by the borehole medium as the acoustic pulses travel to and from the borehole tool is eliminated so that the measurements are dependent solely upon the character of the subsurface formations surrounding the borehole.

Receiver signals from borehole logging systems such as described in the aforementioned U.S. patent to Zemanek, Jr., have typically been multiplexed, amplified, filtered, and transmitted over several miles of logging cable in analog form. However, state-of-the-art logging cables have relatively poor transmission qualities. Consequently, analog data transmission has reached the upper limit of data quality and dynamic range. Further, analog signals must be transmitted in real time. Simultaneous transmission of many channels of analog information requires multiconductor logging cables that are well shielded against crossfeed effects. The present invention is directed to overcoming the analog transmission difficulties by transmitting the receiver signals over the several miles of variable quality logging cable in digital form so that such signals can be recovered with full fidelity at the surface of the earth. Also, signals from several receivers can be digitally stored in solid state memories and transmitted over a single conductor at optimum intervals to minimize logging runs through the borehole.

According to one aspect of the invention there is provided, in a borehole logging system having a transducer assembly including a transmitter for producing bursts of acoustic energy pulses and at least one receiver for producing signals representative of said acoustic pulses traveling from said transmitter to said at least one receiver through the formation adjacent the borehole as the assembly is moved through the borehole, a method for digitally transmitting said signals along a transmission line to recording equipment on the surface of the earth, comprising:

(a) sampling said receiver signals at a select data rate,

(b) producing digital data words representative of the analog values of said sampled receiver signals, and

(c) converting said digital data words into digital serial word signals for transmission to the earth's surface over said transmission line.

In a further aspect, the invention resides in a borehole logging system comprising:

a) a transmitter for producing bursts of acoustic energy pulses,

b) at least one receiver for producing an analog signal representative of said acoustic pulses traveling from said transmitter to said at least one receiver through the formation adjacent the borehole as said logging system is moved through the borehole,

c) means for sampling said analog signal over a first time period,

d) means for converting said sampled analog signals to a digital data word during a second time period,

e) a memory for storing a plurality of said digital data words generated over a plurality of successive second time periods,

f) a digital encoder, and

g) a parallel-to-serial converter for applying a plurality of digital data words from said memory to said encoder in serial format, whereby said digital encoder produces a digital serial word for transmission to the surface of the earth.

In the accompanying drawings:

Figures 1 and 2 are block diagrams of the borehole data acquisition unit according to one example of the present invention,

Figure 3 is a timing diagram useful in understanding the operation of the borehole data acquisition unit of Figures 1 and 2,

Figure 4 is a block diagram of an uphole recording system for use with the borehole data acquisition unit of Figures 1 and 2, and

Figure 5 is an electrical schematic of a portion of the block diagrams of Figures 1 and 2.

Referring to Figure 1, the data acquisition unit of a borehole logging system includes a preamp 20 and a sample and hold (S/H) circuit 21 which receive an analog voltage signal from a receiver in the borehole logging tool. It is desirable to sample the analog receiver signal at a very high rate, preferably at least 100 kilosamples/second. In one embodiment, the cycling rate was selected as 200 kilosamples/second, or every 5 microseconds. A binary gain amplifier (BGA) 22 acts to select and apply a desired gain for each sampled receiver signal. An analog-to-digital converter (ADC) 23 converts the amplified analog signals to a digital data word which is stored in a solid state memory 24. A select number of the stored digital data words may be stacked at 27 to improve the signal-to-noise ratio. Transmission of the stored digital data words is by way of a parallel-to-serial converter 28 and a Manchester encoder 25 which operate to format and convert the digital data words into a digital serial word for telemetry to the surface of the earth over a single conductor 26 of the borehole logging cable.

More particularly, the binary gain amplifier 22 is programmable up to a gain of 128 through the 8 stages of gain as shown in Figure 2. The purpose of such a gain range is to amplify low level receiver signals to a greater extent than the higher level receiver signals so that the analog-to-digital (A/D) converter 23 will always be operating on the highest level signal possible. For example, a very low level receiver signal can receive up to 42 db of gain while a high level signal can be passed on through the amplifier 22 with no gain. Such an amplitude equalization technique permits the A/D converter 23 to provide optimum analog-to-digital conversion of all receiver analog signals.

In one embodiment, A/D converter 23 provides an 8-bit digital data word for each sampling of the analog signal by the sample and hold circuit 21. To identify the gain applied to such analog signal, the amplifier 22 provides an additional 3-bit digital data word to the memory unit 24. The memory 24 combines these 3-bit and 8-bit digital data words to store an 11-bit digital data word characteristic of the sampled and amplified analog signal. The A/D converter 23 provides a dynamic range of 48 db. The total dynamic gain range provided by the combination of the amplifier 22 and A/D converter 23 is 90 db.

In said one embodiment, the memory 24 has a storage capability of up to 2048 samples of digital data words of 11 bits each. The data acquisition time to complete the memory is 2048 samples times 5 microseconds per sample, or 10.24 milliseconds. When the memory is filled, the Manchester encoder 25 converts the 2048 digital data words into serial format for telemetry to the surface of the earth at a data rate above 100 kilobits per second and preferably at a data rate of 150 kilobits per second or over a time period of 200 milliseconds. This can best be seen by reference to the timing diagram of Figure 3.

Referring again to Figure 1, multiplexer 29 permits the selection of the stacker 27 output or the memory 24 output. Stacking permits the signal-to-noise ratio of the telemetered digital data to be enhanced by stacking a select number of digital data words from each sampling, for example, 2 to 8 of the 11 bit digital data words stored in memory 24 may be applied to the stacker 27 prior to encoding for telemetry by the parallel-to-serial converter 28 and the Manchester encoder 25.

Referring now to Figure 4, there is shown uphole circuitry for receiving and recording the digital serial data words as telemetered over the several miles of logging cable 26. Uphole reception is by way of a Manchester decoder 30 which converts the serial stream of digital data back into individual 11 bit digital data words for either storage on a digital storage device 31, such as a digital tape transport, or for conversion back into analog format by the digital-to-analog converter 32 for viewing on a suitable display device 33.

Referring now to Figure 5, there will be described in more detail the operation of the binary gain amplifier 22. The analog receiver signal, after passing through the preamplifier 20, is applied to the sample and hold 21. The analog signal is sampled for about 500 nanoseconds, for example, and then the sampled voltage is held constant for about 4.5 microseconds, for example. It is during this holding period that the analog-to-digital conversion takes place within the A/D converter 23. The sampled voltage is converted to an 8 bit digital data word by A/D converter 23 and applied by way of the latch 41 to the memory 42 which is a programmable read only memory (PROM). The memory 42 is programmed in conventional look-up table format so as to select a desired dynamic gain based upon the voltage level of the sampled analog receiver signal. As the signal level decreases, the desired gain increases in 6 db steps with amplifications x2, x4, x8, x16, x32, x64 and x128. Likewise, the same gain selection process is carried out for negative voltage levels.

The output of the memory 42 is a 3 bit binary gain word representing the particular gain selection. This binary gain word is applied to the analog switch 43 which selects the particular amplifier in the bank of amplifiers 44 which gives the selected amount of 2^N amplification to the sampled analog receiver signal stored in the sample and hold 21. The analog modified voltage output signal (AMVO) from the selected amplifier is then passed on by switch 43 to the A/D converter 23 for digitization while the 3 bit binary gain word (BGW) from the memory 42 is passed on to the memory 24 for inclusion in the 11 bit digital data word generated therein.

It is to be understood that the foregoing described circuit elements are merely representative of one embodiment of the present invention. Various other types and values of circuit components may be utilized. In accordance with the preferred embodiment, the following table sets forth specific types and values of the circuit elements.

TABLE

Reference Designation	Description
Serial-to-parallel converter 28	74 LS165 (Texas Instruments)
Manchester encoder 25	HD15530 (Harris)
Memory 24	8108(16x2K) (Fujitsu)
Preamp 20	OP27 (Precision Monolithic)
Sample and Hold 21	MN346 T/H (Micro Networks)
Analog-to-digital converters 23 & 40	MN 5132 (Micro Networks)
Manchester decoder 30	HD 15530 (Harris)
Digital-to-analog converter 32	MN 3020 (Micro Networks)
Latch 41	74 LS 374 (Texas Instruments)
Memory 42	HM-7611 (Harris)
Switch 43	HI-1818 CMOS (Harris)
Amplifier 44	OP 27 (Precision Monolithic)

CLAIMS:

1. In a borehole logging system having a transducer assembly including a transmitter for producing bursts of acoustic energy pulses and at least one receiver for producing signals representative of said acoustic pulses traveling from said transmitter to said at least one receiver through the formation adjacent the borehole as the assembly is moved through the borehole, a method for digitally transmitting said signals along a transmission line to recording equipment on the surface of the earth, comprising:

(a) sampling said receiver signals at a select data rate,

(b) producing digital data words representative of the analog values of said sampled receiver signals, and

(c) converting said digital data words into digital serial word signals for transmission to the earth's surface over said transmission line.

2. The method of claim 1 further including storing a plurality of said digital data words prior to conversion into said digital serial word signals and stacking a select number of said stored digital data words to enhance signal-to-noise ratio.

3. The method of claim 1 or claim 2 wherein said sampling is carried out at a rate of at least 100 kilosamples/sec.

4. The method of any preceding claim wherein said digital serial word signals for a select time period are sequentially transmitted over a single transmission line.

5. The method of any preceding claim further comprising:

a) receiving said transmitted digital serial word signals at the earth's surface,

b) reproducing the digital data words representative of the analog values of said sampled receiver signals, and

c) recording said reproduced digital data words.

6. A borehole logging system comprising:

a) a transmitter for producing bursts of acoustic energy pulses,

b) at least one receiver for producing an analog signal representative of said acoustic pulses traveling from said transmitter to said at least one receiver through the formation adjacent the borehole as said logging system is moved through the borehole,

c) means for sampling said analog signal over a first time period,

d) means for converting said sampled analog signals to a digital data word during a second time period,

e) a memory for storing a plurality of said digital data words generated over a plurality of successive second time periods,

f) a digital encoder, and

g) a parallel-to-serial converter for applying a plurality of digital data words from said memory to said encoder in serial format, whereby said digital encoder produces a digital serial word for transmission to the surface of the earth.

7. The system of claim 6 and further including means for stacking a plurality of said stored digital data words.

8. The system of claim 6 or claim 7 wherein said digital encoder employs a Manchester encoding technique.

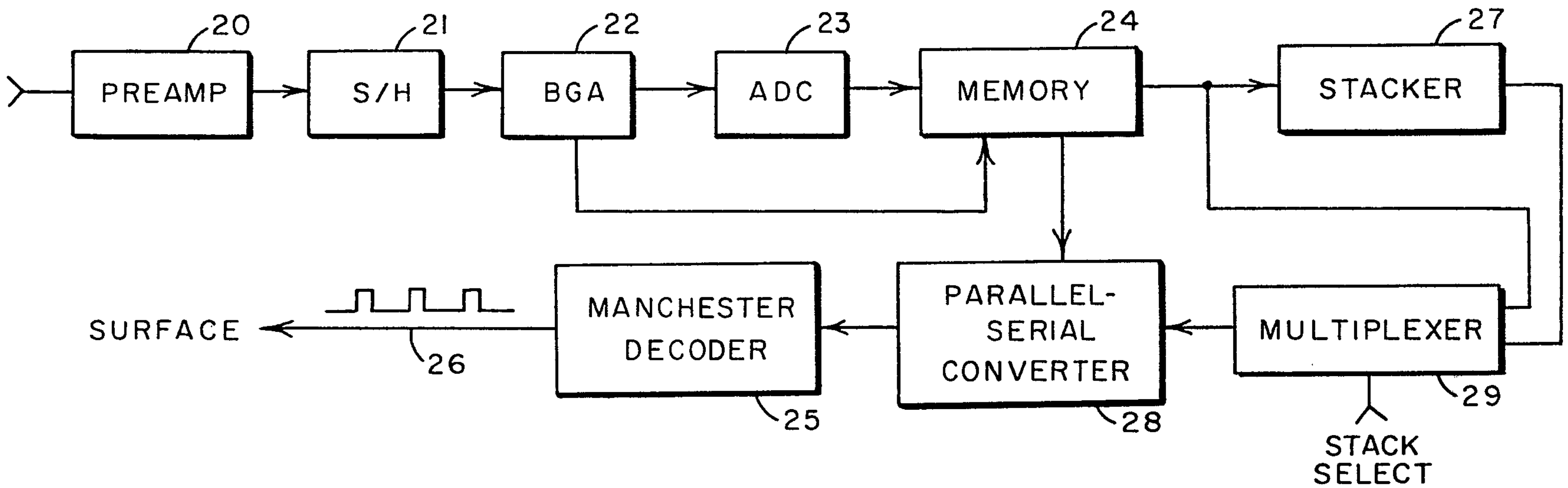

RECEIVER
ANALOG
SIGNAL
PREAMP
20
S/H
21
BGA
22
ADC
23
MEMORY
24
STACKER
27
MANCHESTER
DECODER
25
PARALLEL-
SERIAL
CONVERTER
28
MULTIPLEXER
29
STACK
SELECT
SURFACE
26

FIG. 1

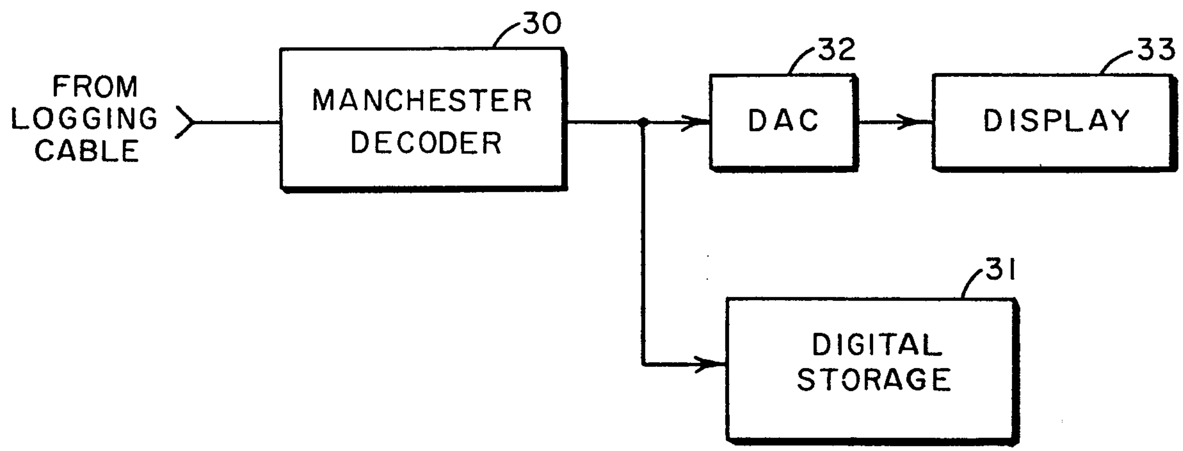
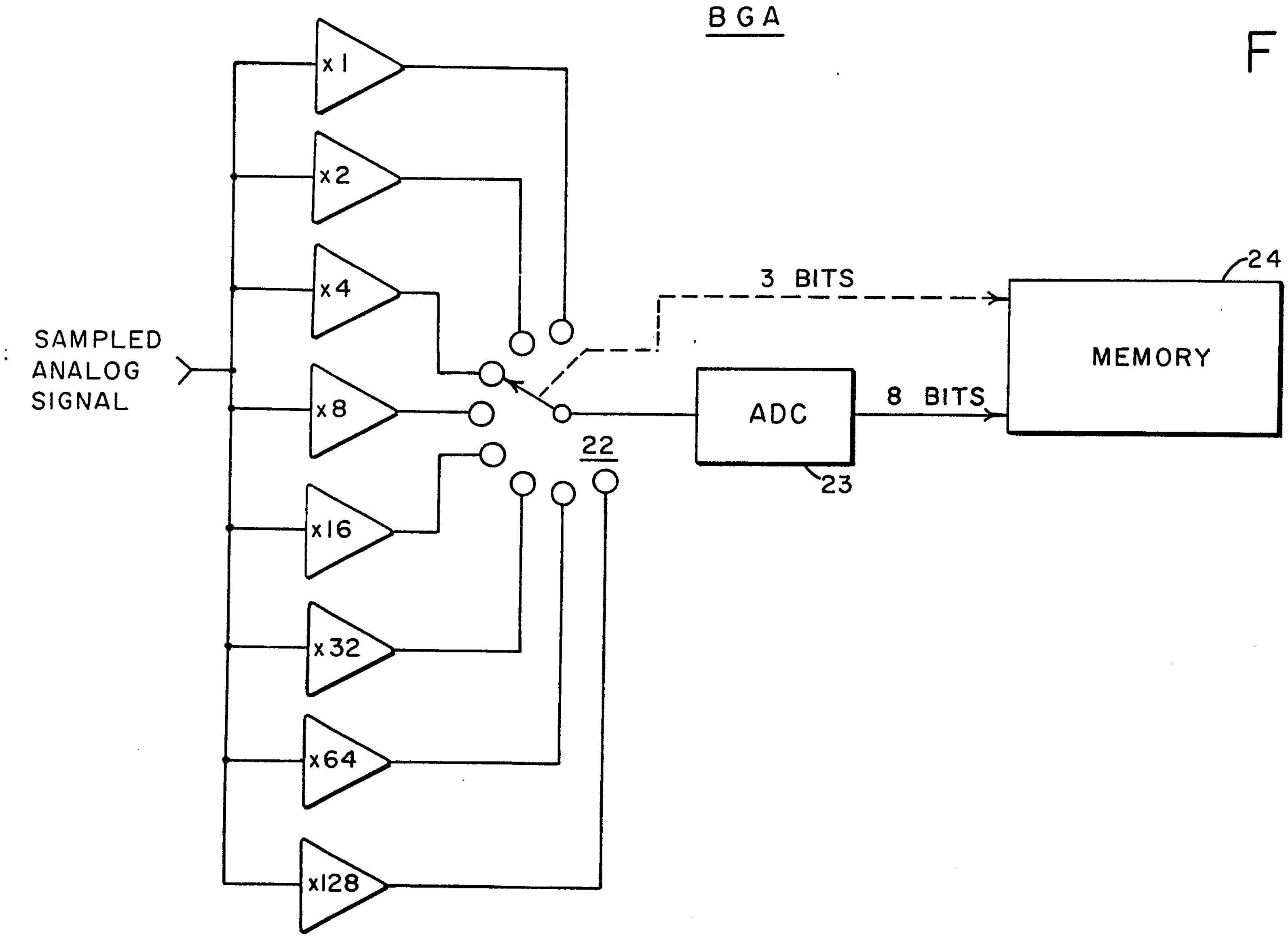

FROM
LOGGING
CABLE
MANCHESTER
DECODER
30
DAC
32
DISPLAY
33
DIGITAL
STORAGE
31

FIG. 4

FIG. 2


BGA
SAMPLED ANALOG SIGNAL
x1
x2
x4
x8
x16
x32
x64
x128
22
ADC
23
3 BITS
8 BITS
MEMORY
24

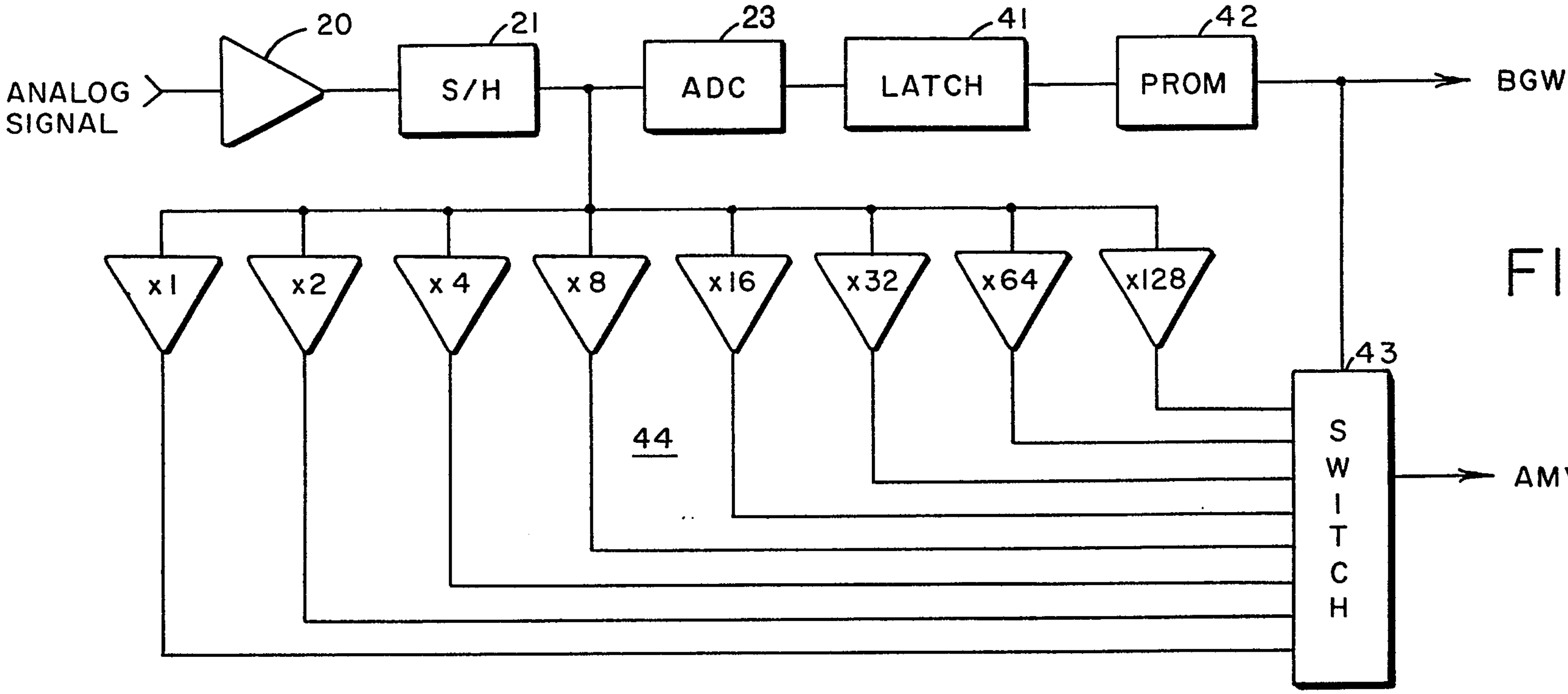
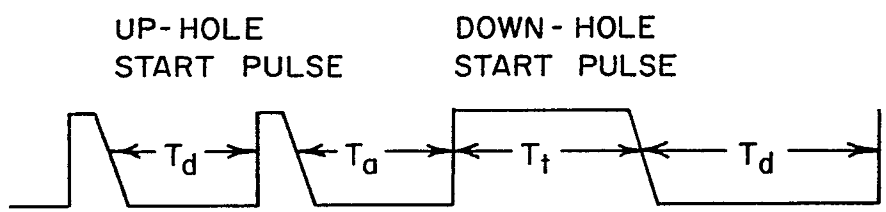


FIG. 5

FIG. 3



T_d ≐ CABLE DELAY

T_a ≐ ACQUISITION PERIOD

T_t = TRANSMISSION PERIOD