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ANALOG MEMORY SYSTEMS

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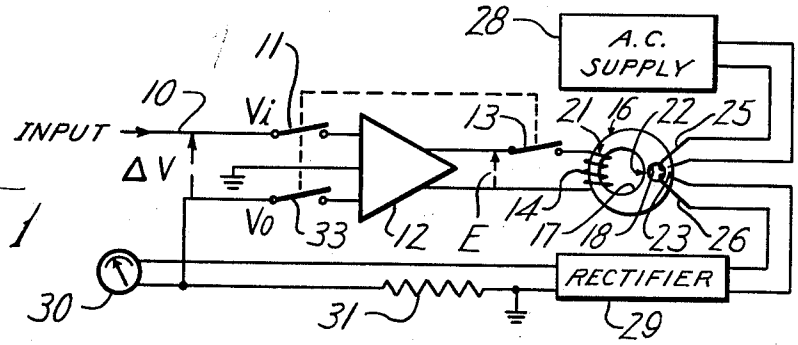


Fig. 1

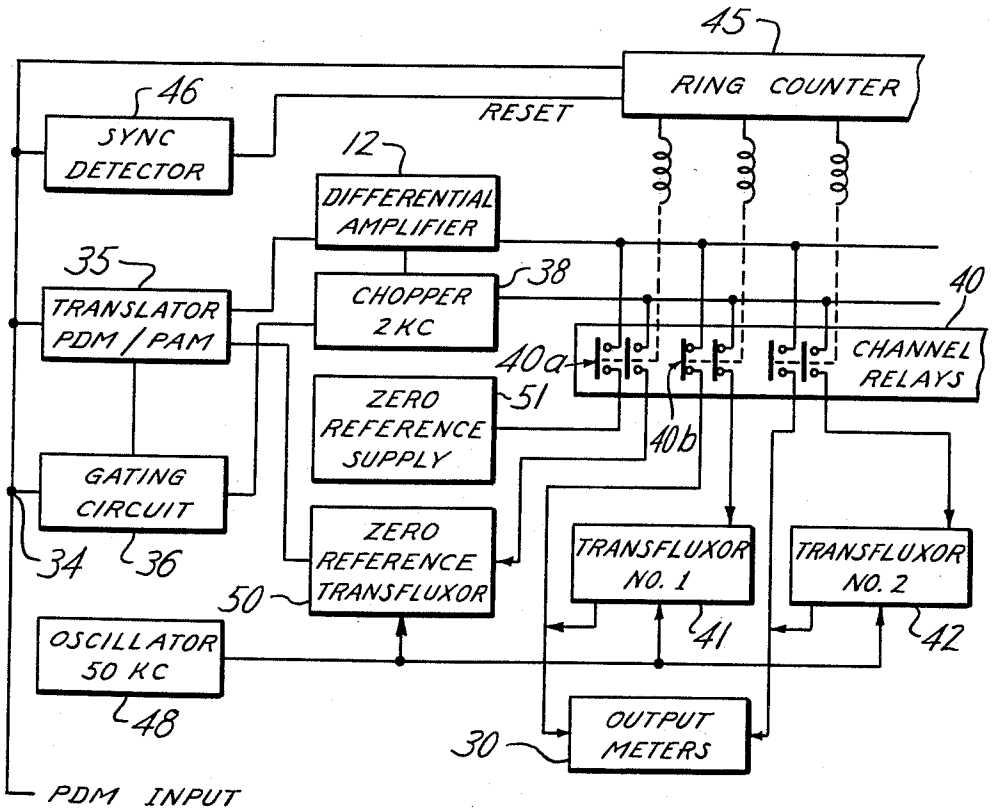


Fig. 2

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ANALOG MEMORY SYSTEMS

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This invention relates to analog memory systems and more particularly to memory systems employing magnetic circuit elements having a generally rectangular hysteresis characteristic.

For purposes of sampling the analog outputs of transducers, particularly for remote telemetering of their outputs, a time multiplexing is often desirable. If continuous indications are to be obtained of these outputs, especially with a moderate sampling rate, storage of a sampled output between successive intervals is necessary. In the past such storage has tended to require relatively complex and expensive apparatus or has been characterized by decay of stored values.

Accordingly, it is an object of the present invention to provide new and improved analog memory systems wherein storage of analog values may be obtained with no decay or loss of stored values.

Another object of the invention is to provide such systems which are highly reliable, require relatively simple and inexpensive apparatus and are adaptable to a wide variety of applications.

These and other objects are achieved, in accordance with the invention, by the use of a variable transformer, referred to herein as a transfluxor, comprising a core of substantially rectangular hysteresis material having at least two apertures defining three legs. A first leg carries a control winding and a third leg carries primary and secondary windings having an inductive coupling dependent upon flux density and direction in the intermediate or second leg. Periodic current from a reference supply is applied to the primary winding, and an output signal is obtained from the secondary winding dependent upon the coupling established by the passage of current through the control winding.

By controlling the current momentarily applied to the control winding by an excitation circuit as a function of a data input signal (and preferably also in degenerative relation to the output signal applied to the excitation circuit by way of a feed-back loop), the output signal is reset to a value corresponding to said data signal.

When the data signal is time multiplexed, separate transfluxors may be driven continuously by a common reference supply for the primary windings and sequentially by a common excitation circuit for the control windings.

The invention, together with others of its objectives and advantages, will be more fully understood from the following detailed description, taken in conjunction with the drawing, in which:

FIGURE 1 is a block diagram of apparatus embodying the invention; and

FIGURE 2 is a block diagram representing a modification of the apparatus of FIGURE 1, suitable for multi-channel applications.

In FIGURE 1 an input signal voltage V_i is applied at terminal 10 via switch 11 to one input terminal of a balance or differential amplifier 12, with respect to a ground or reference point. Across the output terminals of the amplifier 12 is connected a switch 13 and a control winding 14 in series. The amplifier thus applies a control signal voltage E to the control winding 14 of what is termed a transfluxor, when the switch 13 is closed.

The transfluxor is described more particularly in an article by Rajchman and Lo entitled "The Transfluxor" appearing in the "Proceedings of the IRE," March 1956.

For purposes of the present invention, however, the transfluxor may be understood as a variable transformer comprising a magnetic core 16 composed of material such as ferrite having a substantially rectangular hysteresis characteristic. The core 16 may be of relatively thin cylindrical form having an excentered main aperture 17 and a secondary smaller aperture 18 offset from the main aperture in a direction opposite from the direction of excentering of the main aperture so as to define a first leg 21, a second leg 22, and a third leg 23. Preferably the cross sectional area of the first leg on the excentering diameter is equal to the sum of the cross sections of legs 22 and 23, the latter being substantially equal. Hence an inner annular flux path encircles main aperture 17 via legs 21 and 22 when current is passed through control winding 14, and another flux path is provided by legs 22 and 23 encircling aperture 18 for purposes of inductively coupling a primary winding 25 and a secondary winding 26 carried by leg 23.

A periodic reference signal of constant value, such as an alternating current at 50 kc., is applied to primary winding 25 by A.C. supply 28. Such current is of an amplitude less than that which would produce saturation in the flux path about aperture 18. The terminals of the secondary winding are connected to a rectifier 29 which may, for example, comprise an emitter-follower rectifying amplifier operating in Class "C" and a resistance-capacitance low-pass filter circuit of suitable time constant for respectively rectifying and filtering the 50 kc. signal induced in the output winding. To obtain indications of the rectified output winding signal corresponding in value to the input signal V_i, there is connected across the output terminal of rectifier 29 an output meter 30 which may be in series with a suitable resistor 31 across which the output voltage V_o to be measured is developed.

Because the transfer characteristic between the control winding 14 and the output winding 26 varies non-linearly and as a function of such variables as the ambient temperature, the exact characteristics of the core material, and the physical dimensions of the core itself, it is difficult to provide a calibration of the output which is independent of the particular core and ambient conditions. Hence, there is provided, in accordance with the invention, a feedback loop from the ungrounded side of the output resistor 31 through a switch 33 to the other input terminal of differential amplifier 12. Accordingly, the differential amplifier is responsive to $\Delta V = V_i - V_o$ or the error signal between the output and input applied whenever switches 11 and 33 are closed in common.

It may be noted that Class "C" operation of the rectifying amplifier results in a D.C. current output which is exactly comparable to the input signal at the instant of sampling. Also, while a common connection has been shown for concurrent closure of switches 11, 13 and 33, switch 13 need not be closed for the full interval for which both switches 11 and 33 are closed. Depending upon the rate at which switch 13 is actuated, it may be desirable to encircle leg 14 with a closed single-turn damping winding to prevent overshoot of the flux adjustment effected by control winding 14.

In an exemplary operation of the system of FIG. 1, the analog signal voltage V_i is applied to terminal 10, while switches 11, 13, 33 are momentarily closed. If there is any difference ΔV between the then existing output voltage V_o and the applied input voltage V_i, the error signal voltage E, representing an amplified version of this difference, is applied to control winding 14 to pass a corresponding current through it.

Assuming that the core 16 was, prior to the application of voltage E to the control winding, in a state of saturation in the positive or clockwise direction, and that the magneto-motive force developed by circulation

of current in winding 14 is in the negative sense, it is clear that the existing condition of saturation may be partially or entirely removed, or even reversed. When the intermediate or second leg 22 as well as the third leg 23 are saturated, no additional flux can be developed about aperture 18 for linking the primary and secondary windings by coupling through the core material. The coupling and consequently the output voltage V_o will then be at a minimum. Hence, any change away from the condition of saturation will allow output voltage V_o to be increased toward V_i. Actually, since the flux path circulating the main aperture 17 is the shortest and hence most responsive to excitation of winding 14, the range of flux density variations between saturation and non-saturation is effectively accomplished in the intermediate leg 22 with preferred operation.

A suitably large current in control winding 14 is then able to produce such a change from the saturated condition in leg 22 that the output voltage V_o is increased toward the input voltage V_i. As the output and input approach equality, the error signal goes towards zero and the core is left in the remanent state, which is required for a flux coupling between the primary and secondary windings sufficient to produce such output voltage. When switches 11, 13, 33 are then opened, the output voltage V_o remains constant indefinitely at the set value, so long as the reference signal from the supply 28 remains constant. During a succeeding interval, the input signal may be again sampled and the remanent state of the core reset by application of the error signal until the output voltage again is brought into correspondence with the sampled input voltage. In this manner a continuous reading may be obtained from output meter 30 representing the last sampled value of the input signal, regardless of time elapsed since the sampling operation.

It will be appreciated that adjustment of the residual flux density in the intermediate leg 22 of the core may be in a positive or negative sense depending upon whether the error signal is positive or negative, so that the output voltage may be in exact correspondence with the sampled input voltage in the zero to full scale range. It has been found that the core will remain in a desired condition of remanence when excitation of the control winding by the amplifier is terminated following a sample interval, where such interval is relatively short. Hence, the switch 13 may be closed at a rate of, say, 2 kc. Also, if desired, the control winding may be shorted at all times except during a sampling interval to preclude any change in magnetic state of the core due to switching transients. If desired, a shorting switch across coil 14 may be substituted for series switch 13 and closed at alternate times. Of course, switches 11, 33 need be closed only for such time as is required to effect the necessary change in magnetic state of the core. For a full scale change, 25–50 milliseconds has been found suitable.

In FIG. 2 there is shown a multichannel embodiment of the invention wherein a pulse duration modulated (PDM) input signal is translated to obtain continuous indications of the channel values. To obtain an analog representation of the input signal channel values for application to one input of the differential amplifier 12, a translator 35 is connected between system input terminal 34 and the differential amplifier. Translator 35 provides a pulse amplitude modulated (PAM) output, and for this purpose, may comprise an inverted ramp generator providing a decreasing voltage ramp which is initiated by the leading edge of the PDM pulses and locked substantially for the duration of the channel interval at the lower value existing upon arrival of the trailing edge. In addition translator 35 may have a gated output for fixing the output duration of the error voltage at the locked value. To gate the output of the translator, as well as to reset it just prior to the end of the channel interval, a gating circuit 36 may be provided which is responsive to the leading edges of the PDM input to provide delayed gate pulses to the translator.

In lieu of switch 13, there is provided a chopper 38 which chops the error signal output of the differential amplifier to zero at a rate of, say, 2 kc. The chopper may be gated on during the successive channel intervals when the amplitude modulated pulses are applied to amplifier 12 by a suitable connection to gating circuit 36. The output of chopper 38 is applied in common to error signal poles of channel relays 40 in parallel relation, each relay being of the double pole type and only one relay being closed during any sampling or data channel interval. As illustrated, for example, the contacts of relay 40*b* are closed to connect chopper 38 to the control winding input of transfluxor 41 for channel No. 1. Sequential closing of the relays is controlled by ring counter 45 which is stepped by leading edges of the PDM input and reset for synchronization with the transmitter-source of the PDM input by synchronization detector 46. For example, detector 46 may be selectively responsive to a double channel sync pulse and may comprise a Schmitt trigger for providing a reset pulse to the ring counter.

Additional transfluxors may be provided, such as 42, for additional channels, as well as for calibration purposes. Like transfluxor 41, their primary windings are connected in common (series) with the output of oscillator 43 (corresponding to A.C. supply 28) and their secondary windings are connected via respective channel relay contacts to a common junction with the remaining input terminal of differential amplifier 12 to apply rectified feedback thereto. The boxes representing transfluxors 41 and 42 will be understood to include rectifiers corresponding to rectifier 29. Their rectified outputs are supplied to corresponding output meters 30'.

For purposes of calibration the zero reference channel relay connects chopper 38 with a transfluxor 50 having its primary connected to oscillator 43 and its secondary coupled through a rectifier to a zero reference adjusting circuit in translator 35. For example, the initial value of the ramp voltage may be responsive to the output of transfluxor 50 to provide automatic zero calibration when a zero reference pulse is received at the input. The translator output corresponding to the width of the zero reference pulse is compared with a zero reference voltage from regulated supply 51. Similarly, a full scale transfluxor may be connected through a channel relay in suitable sequence for adjusting the slope of the ramp employed in the translator 35, when a full scale pulse is received.

In general, the operation of the system shown in FIGURE 2 corresponds to that of FIGURE 1 but with a periodicity slaved to the incoming PDM signal. By the synchronous operation of channel relays 40, the magnetic states of the respective transfluxors are periodically reset by the error signal between the corresponding outputs and PAM inputs so that each output meter accurately and continuously indicates a proper channel value. When the zero or full scale values are applied to the differential amplifier, any difference between such values and the voltages derived from the zero or full scale reference supplies, respectively, will result in automatic adjustment of calibration. By actuating chopper 38 only when both the PAM and feedback inputs are applied to the differential amplifier 12, any false resetting of the transfluxors will be avoided.

It will be understood that the invention is susceptible to a wide variety of modifications and adaptations in many different applications. Accordingly, the invention is not to be limited to the embodiments illustrated and described, but is of a scope defined in the appended claims.

What is claimed is:

1. An analog storage system comprising a plurality

of transfluxor units each having a multi-apertured core of rectangular hysteresis material, primary and secondary windings carried by a first portion of said core linking one aperture and a control winding carried by a second portion of said core linking a second aperture to adjust flux density in a core portion intermediate said apertures, means for passing regulated alternating current through each said primary winding to develop an output signal in the corresponding output winding dependent upon flux coupling developed about said one aperture, a differential amplifier having one input to which the analog signal to be stored is applied, signal rectifying means coupled to the output windings of said transfluxor units to develop a rectified version of the corresponding output signal for application to a second input of said differential amplifier, and switch means for synchronously coupling the output winding of each successive transfluxor unit with the second input of said differential amplifier in sequence with coupling the output of said amplifier with the control winding of such successive transfluxor units.

2. An analog storage system in accordance with claim 1 further comprising means for periodically reducing the output of said differential amplifier to zero at a frequency lower than said alternating current asynchronously with respect to said switch means.

3. A system for storing in analog form data transmitted in successive channels of a PDM signal having a calibration channel, comprising means for translating said PDM signal into a PAM signal and including a circuit responsive to a calibration signal for correcting the correspondence between said PAM signal and said PDM signal, a plurality of transfluxor units each having a multi-apertured core of rectangular hysteresis material, primary and secondary windings carried by a first portion of said core linking one aperture and a control winding carried by a second portion of said core linking

a second aperture to adjust flux density in a core portion intermediate said apertures, means for passing regulated alternating current through each said primary winding to develop an output signal in the corresponding output winding dependent upon flux coupling developed about said one aperture, a differential amplifier having one input to which said PAM signal is applied, signal rectifying means coupled to the output windings of said transfluxor units to develop a rectified version of the corresponding output signal for application to a second input of said differential amplifier, a reference supply for providing a calibration voltage, and switch means synchronized by said PDM signal for coupling said calibration voltage to the second input of said differential amplifier while coupling the output of said amplifier with the control winding of one of said transfluxor units to develop in its output winding a calibration signal for application to the correcting circuit of said translating means when the calibration channel of said PDM signal is applied thereto, and for sequentially coupling the output winding of other of said transfluxor units with the second input of said differential amplifier while successively coupling the output of said amplifier with the control winding of said other transfluxor units, whereby the PAM signal output of said translating means is corrected for calibration and said differential amplifier sets said other transfluxor units in accordance with the data transmitted in respective channels of said PDM signal.

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