United States Patent [19]

Ciesielka

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[45] **Nov. 13, 1973**

[54] **METHOD AND ARRANGEMENT FOR SETTING THE REMANENT FLUX DENSITY IN MAGNETIC CIRCUITS AND EQUALIZER UTILIZING SAME**

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[51] **Int. Cl.**..... **H04b 3/04,** H01f 13/00

[58] **Field of Search**..... 333/17, 18, 16; 307/101, 309; 317/123; 330/52, 132, 144

[56] **References Cited**

UNITED STATES PATENTS

2,908,873	10/1959	Bogert	333/18
3,257,628	6/1966	Kaenel	307/309 X
3,359,511	12/1967	Varnell, Jr.	330/52 X
3,458,769	7/1969	Stampfli	317/123

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[57] **ABSTRACT**

The remanent flux density in a selected portion of a magnetic circuit is precisely set to a desired value by comparing the flux density in the selected portion to a predetermined reference, generating an error signal based on the comparison, integrating the error signal, and inducing an H field in the magnetic circuit in accordance with the integrated error signal. Integration of the error signal is performed only when the flux density has a substantially remanent value, i.e., only when the H field in the magnetic circuit is substantially zero. Thus, error in setting the flux density due to imperfect remanence in the magnetic circuit is substantially eliminated.

In an illustrative embodiment of the invention, the magnetic circuit comprises a magnetic core having an air gap, and is advantageously employed in a transmission cable equalizer. The remanent flux density in the air gap is utilized to precisely set the resistance value of a magnetoresistor, which in turn determines the gain of the equalizer.

15 Claims, 3 Drawing Figures

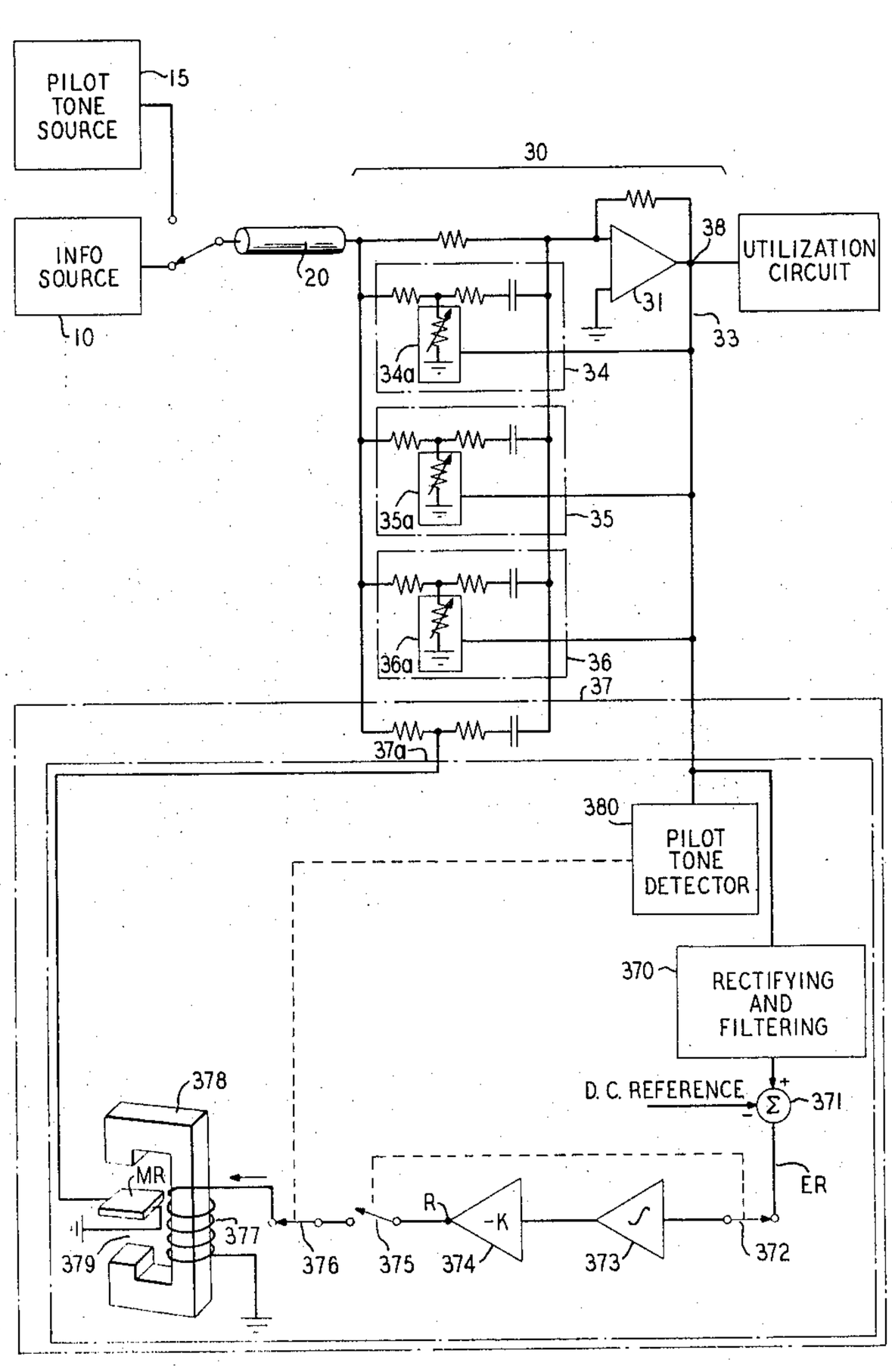
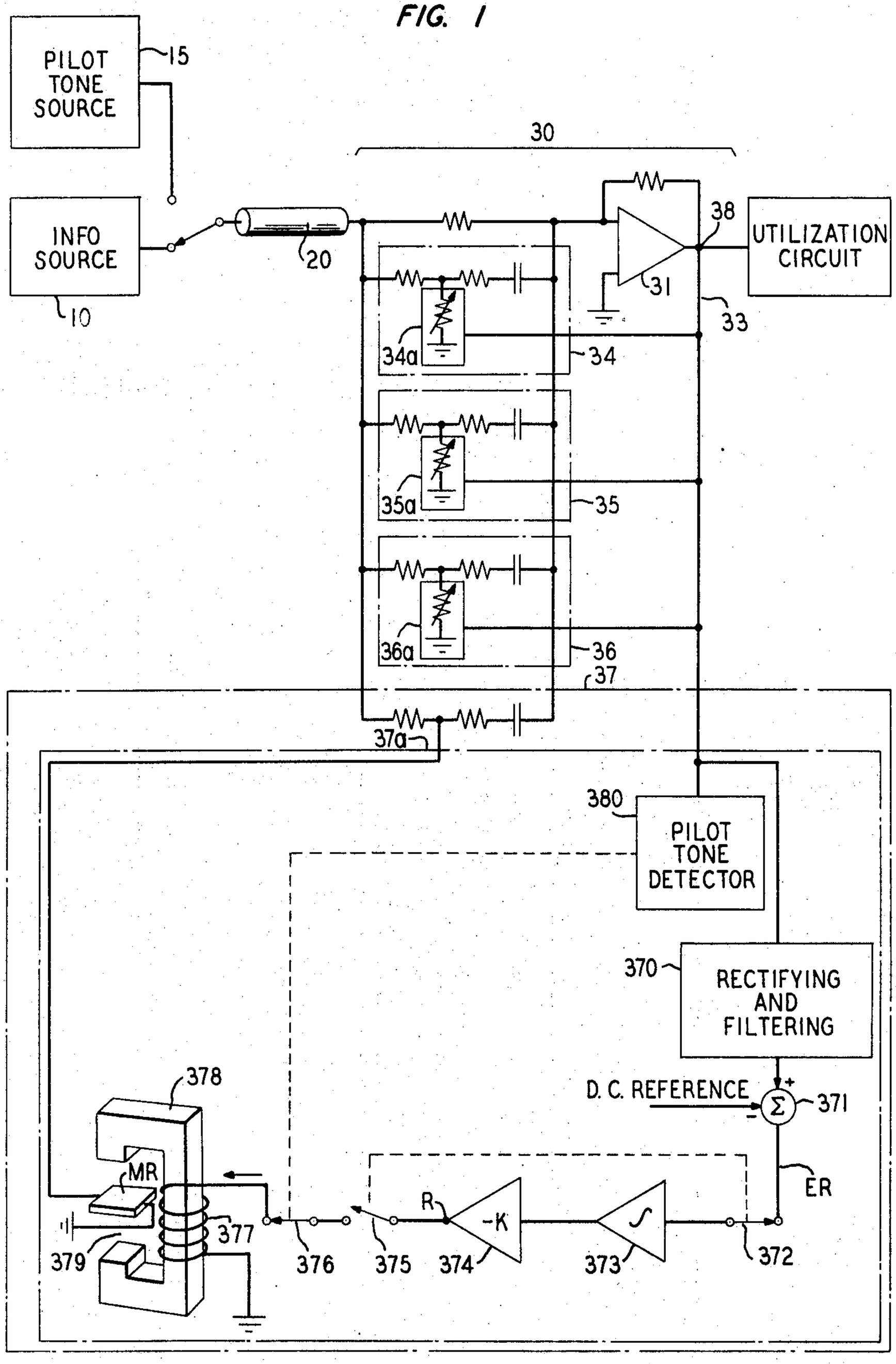


FIG. 1


PILOT TONE SOURCE
15
INFO SOURCE
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20
30
38
UTILIZATION CIRCUIT
31
33
34a
34
35a
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36a
36
37
37a
380
PILOT TONE DETECTOR
370
RECTIFYING AND FILTERING
D. C. REFERENCE
371
ER
378
MR
377
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375
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373
372
R
-K

FIG. 2A

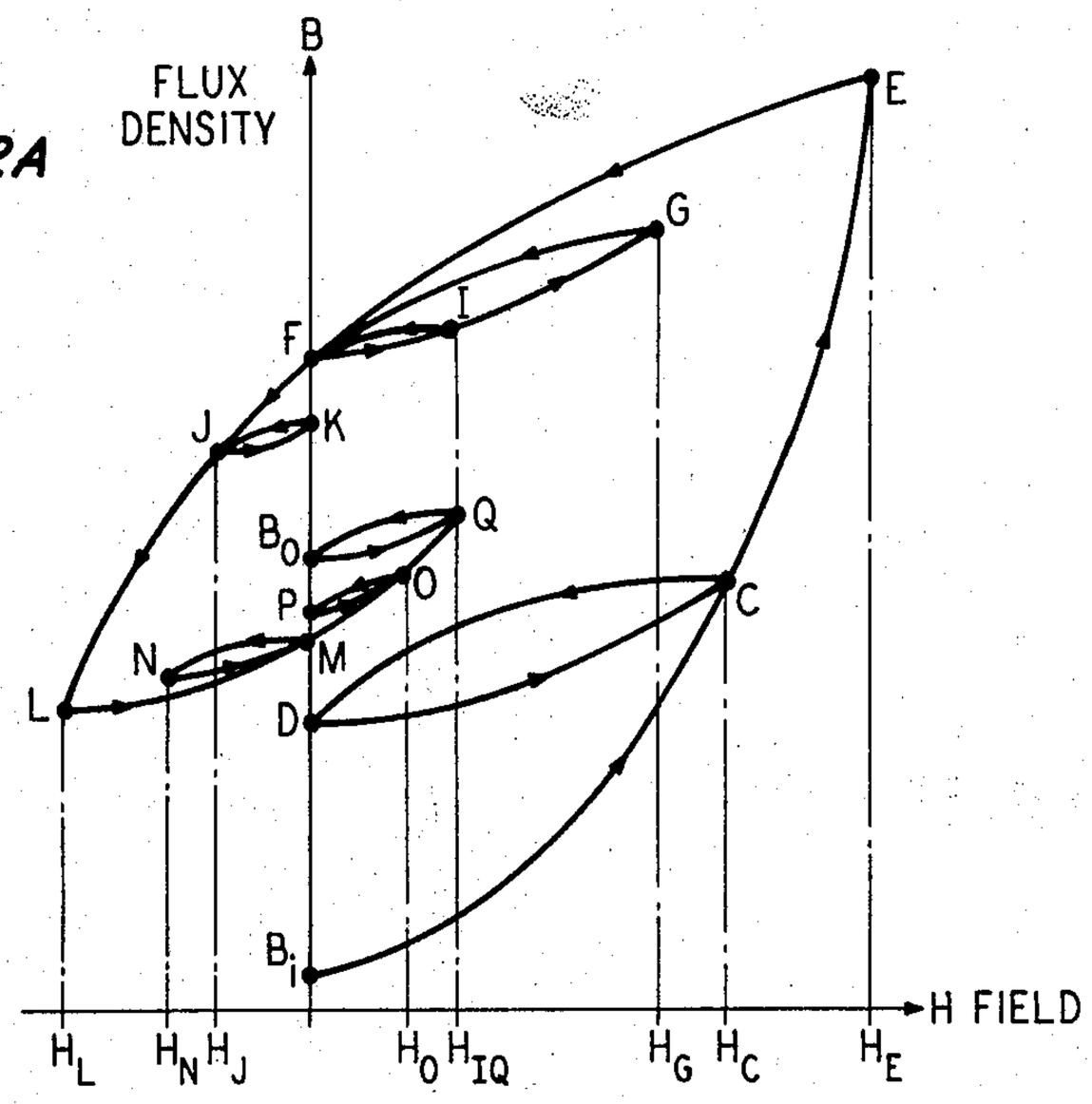
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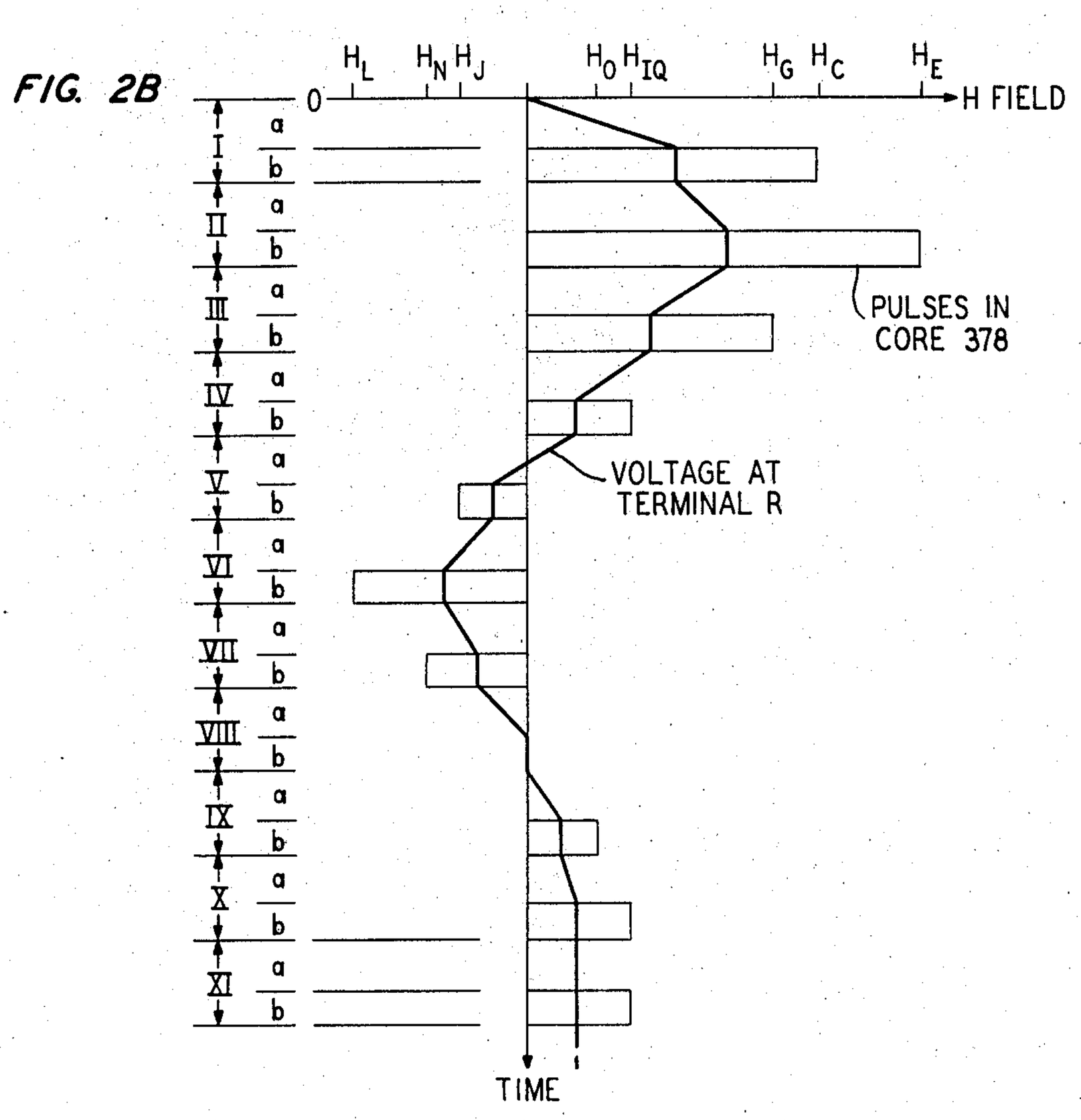
FIG. 2B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I
II
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VII
VIII
IX
X
XI
a
b
PULSES IN CORE 378
VOLTAGE AT TERMINAL R
TIME

METHOD AND ARRANGEMENT FOR SETTING THE REMANENT FLUX DENSITY IN MAGNETIC CIRCUITS AND EQUALIZER UTILIZING SAME

BACKGROUND OF THE INVENTION

My invention relates generally to magnetic circuits and, more particularly, to a method and arrangement for precisely setting remanent flux density in magnetic circuits.

As herein defined, a magnetic circuit is an arrangement in which magnetic flux is produced in response to an applied magnetic field. A particular magnetic circuit may include one or more paths of magnetic material and a coil for applying the magnetic field thereto. The magnetic circuit may also include an air gap or gaps in one or more of the paths. The flux density in a particular path or portion of the circuit is determined principally by the circuit geometry, the strength of the applied magnetic field and the previous magnetic history of the circuit.

In the prior art, the flux density, or B field, in a selected portion of a magnetic circuit is generally set to a desired value by inducing a magnetic field, or H field, in the circuit such that the desired flux density is attained. Many magnetic materials, for example, ferromagnetic materials, exhibit substantial remanence, so that the H field in the magnetic circuit can be reduced to zero without the flux density being reduced to zero as well. Advantageously, then, a nonzero flux density can be permanently established in a selected portion of a magnetic circuit (for example, an air gap or a section of magnetic material) without expending energy to maintain same.

However, remanence in magnetic materials is not perfect and the flux density does not remain precisely at a desired, originally set value once the H field is removed. Rather, the flux density drops somewhat, retaining on the order of 80 to 90 percent of its original value. In certain applications, an error of this magnitude may be tolerable. In others, more precise flux density control is necessary.

One known arrangement for precisely setting flux density in a magnetic circuit maintains an H field in the circuit at all times. This arrangement precludes advantageous utilization of magnetic remanence, as described above. Moreover, a failure in the H field supply will change the flux density from the desired value.

Another prior arrangement utilizes so-called square hysteresis loop materials which have remanences typically on the order of 98 percent. These materials are relatively expensive and thus not commercially viable for many applications.

Moreover, in certain magnetic circuit applications, an error of even several percent in a flux density setting may be intolerable. For example, a magnetic circuit comprising a magnetic core having an air gap interrupting its continuity, can be utilized in an arrangement for controlling the gain of a transmission cable equalizer. A magnetoresistor is positioned in the air gap, its resistance value thus being determined by the remanent flux density in the gap. The equalizer gain is determined by the resistance value of the magnetoresistor. Thus, precise control of the equalizer gain requires that the remanent flux density in the air gap be precisely set.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention is to provide

a method and arrangement for precisely setting remanent flux density in magnetic circuits.

A more specific object of the invention is to provide a method and arrangement for precisely setting the remanent flux density in an air gap in a magnetic circuit.

A further object of the invention is to provide a method and arrangement for precisely setting the flux density in the air gap of a magnetic core and thus the resistance value of a magnetoresistor positioned in the gap.

Another object of the invention is to provide a method and arrangement for precisely setting the flux density in the air gap of a magnetic core to precisely set the resistance value of a magnetoresistor to, in turn, precisely set the gain of a transmission cable equalizer.

These and other objects are achieved by comparing the flux density in a selected portion of a magnetic circuit to a predetermined reference, generating an error signal based on that comparison, integrating the error signal, and inducing an H field in the magnetic circuit in accordance with the integrated error signal to thereby change the flux density in the selection portion. In accordance with the invention, integration of the error signal is performed only when the flux density has substantially a remanent value; that is, only when substantially no H field is being induced in the magnetic circuit. In this way, the invention substantially eliminates error in setting the flux density due to imperfect magnetic remanence. In the prior art, as described above, a desired flux density is established while some H field is being induced in the magnetic circuit so that subsequent reduction of the H field to zero causes an unwanted change in the flux density.

An important feature of the invention is that the above-mentioned integrating and field inducing steps are performed independently in sequence; when the error signal is being integrated, no H field is induced in the magnetic circuit and when the H field is being induced in the magnetic circuit, no integration of the error signal is performed. The sequence of integrating and field inducing is performed repetitively until the flux density in the selected portion of the magnetic circuit attains the desired value.

An illustrative embodiment of the invention precisely sets the flux density in the air gap of a magnetic core. The flux density is sensed by a magnetoresistor positioned in the gap, and the resistance value of the magnetoresistor establishes the amplitude of a control signal. The above-mentioned error signal is generated by determining the difference between the control signal and the above-mentioned predetermined reference.

In the illustrative embodiment, the magnetoresistor is advantageously utilized as a gain-determining element in a transmission cable equalizer. A pilot frequency tone is transmitted down the cable to be equalized, and is thereby extended to the input of an amplifier included in the equalizer. The pilot tone, detected at the equalizer output, is rectified and filtered to provide the above-mentioned control signal. A subtractor determines the difference between the control signal and a predetermined reference voltage proportional to that value of air gap flux density which provides a predetermined equalizer output amplitude. The resultant error signal is processed in accordance with the invention, as described above, to set the remanent flux density in the air gap, by which the resistance value of the magnetoresistor and hence the gain of the equalizer are set.

BRIEF DESCRIPTION OF THE DRAWING

A clear understanding of the invention and of the preceding and other objects and features thereof may be gained from a consideration of the following detailed description and accompanying drawing in which:

FIG. **1** depicts an arrangement according to the invention, illustratively employed in a transmission cable equalizer; and

FIGS. **2A** and **2B** show graphs useful in describing the operation of the arrangement of FIG. **1.**

DETAILED DESCRIPTION

FIG. **1** depicts a magnetic circuit comprising a magnetic core **378,** an air gap **379** interrupting the continuity thereof, and core windings **377.** FIG. **1** further depicts circuitry in accordance with the invention for precisely setting the remanent flux density in a selected portion of the magnetic circuit, viz. gap **379.** The magnetic circuit is utilized illustratively in an automatic transmission cable equalizer **30** which includes an operational amplifier **31.** As described in detail hereinafter, the magnitude of the flux density in gap **379** determines the gain of amplifier **31** and hence of equalizer **30** for a predetermined pilot frequency. Thus the present invention, by providing precise setting of the flux density in gap **379,** assures precise setting of the gain of equalizer **30** at that pilot frequency.

The gain of equalizer **30** is a function of input frequency and is adjusted at each of (illustratively) four pilot frequencies f_1, f_2, f_3 and f_4 (which are distributed across the frequency band over which equalizer **30** is to operate) by adjusting the impedance of one of four equalizer input networks **34–37.** For this purpose, networks **34–37** include variable resistances **34***a*–**37***a*, respectively. Equalizer **30** is adapted for equalizing a transmission path comprising transmission cable **20** over which signals are extended from an information source **10** to a utilization circuit. The frequency-dependent gain characteristic of equalizer **30** is adjusted to correspond to frequency-dependent attenuation in cable **20.** Thus, the frequency characteristic of signals from source **10** is substantially preserved at the input of the utilization circuit. When equalizer **30** is to be aligned, that is, when its gain characteristic is to be adjusted in accordance with the frequency-dependent attenuation in cable **20,** tones at each of the above-mentioned pilot frequencies are transmitted down cable **20** from a pilot tone source **15.** The impedances of networks **34–37** are adjusted by adjusting variable resistances **34***a*–**37***a*, respectively such that the signal at output terminal **38** of amplifier **31** has a predetermined amplitude at each pilot frequency. Advantageously, this adjustment of variable resistances **34***a*–**37***a* is effected automatically. For this purpose, connections between terminal **38** and each variable resistance are provided via taps off lead **33.**

Each of the variable resistances **34***a*–**37***a* comprises a magnetic core having an air gap, circuitry in accordance with the invention for precisely setting the flux density in the air gap, and a magnetoresistor positioned in the air gap. The magnetoresistor in each variable resistor comprises the resistive element thereof while the magnetic core and its associated circuitry control the resistance value of the magnetoresistor.

Thus, variable resistance **37***a*, for example, includes magnetic core **378,** magnetoresistor MR positioned in gap **379,** and circuitry for setting the flux density in gap **379.** The latter comprises rectifying and filtering circuit **370,** subtractor **371,** error signal lead ER, switch **372,** integrator **373,** amplifier **374,** switches **375** and **376** all connected in series in the order named. Switch **376** is connected to core windings **377.** Variable resistance **37***a* also includes a pilot tone detector **380** which is coupled to output terminal **38** of equalizer **30,** as is rectifying and filtering circuit **370.** Detector **380** closes switch **376** when a tone at pilot frequency f_4 is present at terminal **38.**

Setting the flux density in gap **379** in accordance with the above-discussed prior art can be illustrated by assuming that when cable **20** is being equalized at pilot frequency f_4, switches **372** and **375** are both closed. Circuit **370** provides a d.c. control signal proportional to the amplitude of the a.c. pilot signal (of frequency f_4) at output terminal **38.** Subtractor **371** determines the difference between the control signal and a predetermined d.c. reference. The resultant error signal is extended along lead ER to integrator **373** and therefore to amplifier **374.** The voltage at output terminal R of amplifier **374** generates a current in windings **377.** The H field induced in windings **377** and thus in core **378** adjusts the flux density in gap **379,** thus the resistance value of magnetoresistor MR and thus the gain of equalizer **30** at pilot frequency f_4.

The gain of amplifier **374** is chosen, based on the parameters of the other components of variable resistance **37***a* to ensure that the system is stable and that the error signal on lead ER will converge to zero. At that time, equalization of cable **20,** i.e. alignment of equalizer **30** at pilot frequency f_4, is complete. The signal at terminal R and, accordingly, the H field induced in core **378** become constant.

Thus, in the prior art, when the flux density in gap **379** and the resistance value of magnetoresistor MR are such that cable **20** is equalized at pilot frequency f_4, the H field in core **378** is not zero. If the H field in core **378** is thereafter reduced to zero to take advantage of the magnetic remanence of core **378,** the flux density in gap **379** drops (assuming first quadrant operation) somewhat because the remanence in core **378** is not perfect. This, of course, lowers the resistance value of magnetoresistor MR and destroys the equalization. The remanence even of so-called square hysteresis loop materials, is generally too imperfect for precise equalization.

This problem in the prior art is alleviated in accordance with the present invention by integrating the error signal only when the flux density in the air gap has a remanent value; that is, only when the H field in the core is substantially zero. Thus, integration of the error signal on lead ER and induction of an H field in core **378** on the basis of the signal at terminal R, are performed independently in sequence in two distinct steps. During the first step, switch **372** is closed and switch **375** is opened so that a voltage proportional to the error signal on lead ER, and thus to the equalization error, is built up at terminal R with no current flowing in windings **377.** During the second step, switch **372** is opened and switch **375** is closed so that current flows in windings **377** proportional to the equalization error that obtained when the flux density in gap **379** was at its last remanent value. The resultant H field induced in core **378** changes the flux density in gap **379,** thereby

adjusting the resistance value of magnetoresistor MR and reducing the equalization error.

This two-step cycle of integration and induction, hereinafter referred to as a "magnetization cycle", is performed repetitively until the desired flux density is achieved. Once the error signal on lead ER is zero at the start of a cycle, i.e. with switch **375** open, the flux density in gap **379** is assured to have the desired remanent value which provides alignment of equalizer **30** at pilot frequency f_4. In the prior art, this same value of flux density would be attained with some nonzero H field induced in core **378.** Thus it is seen that, advantageously, the present invention substantially eliminates equalization error due to imperfect remanence in core **378.**

Although switches **372** and **375** are illustratively shown in FIG. **1** as mechanical elements, other known arrangements, for example, electronic switches, as well as circuitry for operating them in the manner described above, will be apparent to those skilled in the art.

FIGS. **2A** and **2B** show graphs exemplifying the operation of equalizer **30** and, in particular, of variable resistance **37***a*, during alignment of the former at pilot frequency f_4. FIG. **2A** depicts variations in the gap **379** flux density in response to H field pulses induced in core **378** via windings **377.** FIG. **2B** depicts a time graph of those H pulses, as well as the signal at terminal R which generates them. The H scale along the ordinate of FIG. **2B** is aligned with the H scale along the abscissa of FIG. **2A.**

As seen from FIGS. **2A** and **2B**, the voltage at terminal R is initially zero and the flux density in gap **379** is B_t. Assumptively, the flux density necessary to equalize cable **20** at pilot frequency f_4 is B_o.

In the example of FIGS. **2A** and **2B**, ten magnetization cycles, designated I, II...X, are needed to change the remanent flux density in gap **379** from B_t to B_o. The integration steps of cycles I, II...X are performed in time periods designated I*a*, II*a*...X*a*, respectively. The induction steps are performed in time periods designated I*b*, II*b*,...X*b*, respectively. During periods I*a*, II*a*,...X*a*, switches **372** and switches **375** are closed and opened, respectively. During periods I*b*, II*b*,...X*b*, the opposite relationship obtains.

Since B_t is less than B_o (the d.c. reference provided to subtractor **371** corresponding to the latter), the error signal on lead ER is negative during period I*a* and a positive ramp is generated at terminal R. In period I*b*, then, positive current (as indicated by an arrow) flows into windings **377,** inducing an H field pulse of magnitude H_C in core **378.**

Although the rise time of the H field pulses in FIG. **2B** are shown as substantially zero to simplify illustration, some nonzero rise time elapses before the pulses attain their full magnitude. It will be appreciated that this rise time is not an important consideration as long as periods I*b*, II*b*...X*b* have sufficient duration.

As seen in FIG. **2A**, the flux density in gap **379** rises to point C in response to the H field pulse of period I*b*. Since core **378** has imperfect remanence, the flux density in gap **379** falls back to point D when switch **375** opens at the start of period II*a*. The flux density at point D is less than B_o so that the error signal on lead ER is still negative. Thus, the voltage at terminal R further increases during period II*a*. In period II*b* a pulse of magnitude H_E is induced in windings **377,** driving the flux density in gap **379** to point E.

The flux density falls back to point F as period III*a* begins. The flux density is now greater than B_o so that the error signal on lead ER is positive and the voltage at terminal R decreases during period III*a*. The pulse induced during period III*b* has magnitude H_G, the flux density rising to point G but dropping back to point F as period IV*a* begins.

During period IV*a*, the terminal R voltage drops still further. The flux density rises to point I during period IV*b* and drops back to point F as period V*a* begins.

In period V*a* the voltage at terminal R becomes negative and a negative H field pulse of magnitude H_J is induced in windings **377** during period V*b*. This reduces the flux density in gap **379** to point J. Due to imperfect remanence in core **378,** the flux density rises to point K as period VI*a* begins. The flux density is reduced to point L during period VI*b*.

As period VII*a* begins, the flux density rises to point M at which point the flux density is again less than B_o and the error signal on lead ER is again negative.

Accordingly, the voltage at terminal R increases during period VII*a*. The flux density thus goes to point N in period VII*b*, returns to and remains at point M during cycle VIII and rises to point O in cycle IX, from which it falls back to point P and finally rises to point Q in cycle X.

At the end of cycle X the flux density in gap **379** falls to B_o. Thereafter, the error signal on lead ER is zero when switches **372** and **375** are closed and open, respectively, and accordingly, the voltage at terminal R stays constant. Thus, the flux density oscillates between points Q and B_o during any magnetization cycles which follow cycle X, such as cycle XI. Generally, the number of magnetization cycles which will be needed to attain a particular remanent flux density, such as B_o, is not known beforehand, and some number of magnetization cycles corresponding to an anticipated maximum will occur during alignment at each pilot frequency.

The above described arrangement is merely illustrative of the invention. Thus, although use of the invention in conjunction with a particular magnetic circuit is disclosed herein, it will be appreciated that the invention can be utilized to set the remanent flux density in any magnetic circuit, whether or not it has an air gap, as long as the circuit has provision for detecting the flux density in the portion of the circuit of interest. An example of such a magnetic circuit is the transfluxor, described for example by J. A. Rajchman and A. W. Lo in *Proceedings of the IRE*, Vol. 44, page 321, March 1956.

It is to be understood therefore that numerous and other varied arrangements in accordance with the principles of the invention may be devised by those skilled in the art without departing from the spirit and scope thereof.

I claim:

1. A method for setting the flux density in a selected portion of a magnetic circuit comprising the steps of,

generating an error signal corresponding to the difference between the flux density in said selected portion and a desired value therefor,

integrating said error signal, and

inducing an H field in said circuit in accordance with the integrated error signal,

characterized in that said integrating step is performed only when the flux density in said selected portion has substantially a remanent value.

2. A method in accordance with claim 1 wherein said integrating and inducing steps are performed independently in sequence.

3. A method in accordance with claim 2 wherein said generating step comprises the steps of,

sensing the flux density in said selected portion,

providing a control signal having an amplitude proportional to the sensed flux density,

providing a reference signal corresponding to said desired flux density value, and

determining the difference between said control signal and said reference signal to generate said error signal.

4. A method in accordance with claim 3 wherein said selected portion is an air gap and wherein said sensing step is performed using a magnetoresistor positioned in said air gap.

5. A method in accordance with claim 4 wherein said control signal providing step comprises the steps of extending a predetermined signal to the input of an amplifier and adjusting the gain of said amplifier based on the resistance value of said magnetoresistor, said control signal being derived from the output signal of said amplifier.

6. An arrangement for setting the flux density in a selected portion of a magnetic circuit comprising, means for generating an error signal corresponding to the difference between the flux density in said selected portion and a desired value therefor, means operative for integrating said error signal, and means operative for inducing an H field in said magnetic circuit in accordance with the integrated error signal, the improvement comprising means for operating said integrating means only when the flux density in said selected portion has substantially a remanent value.

7. An arrangement in accordance with claim 6 wherein said last-mentioned means comprises means for operating said integrating means and said inducing means independently in sequence.

8. An arrangement in accordance with claim 7 wherein said generating means comprises means for sensing the flux density in said selected portion, means for providing a control signal having an amplitude proportional to the sensed flux density, means for providing a reference signal corresponding to said desired flux density value, and means for determining the difference between said control signal and said reference signal to generate said error signal.

9. An arrangement in accordance with claim 8 wherein said selected portion is an air gap and wherein said sensing means includes a magnetoresistor positioned in said air gap.

10. An arrangement in accordance with claim 9 wherein said control signal providing means comprises an amplifier, means for extending a predetermined signal to the input of said amplifier and means for adjusting the gain of said amplifier in accordance with the resistance value of said magnetoresistor, said control signal being derived from the output of said amplifier.

11. In an equalizer including circuit means adapted for insertion into a transmission path and operative for varying the gain of said path the combination comprising, a magnetic core having an air gap interrupting its continuity and providing remanent magnetic flux in said air gap, means for operating said circuit means in accordance with the density of magnetic flux in said air gap, means coupled to said circuit means for detecting a pilot signal applied to said path, means for comparing the detected pilot signal to a predetermined reference signal and for generating an error signal based on the comparison, means operative for integrating said error signal only when the flux density in said gap has substantially a remanent value, and means operative for applying a magnetic field to said core to adjust the density of the flux in said air gap, said magnetic field being proportional to the output of said integrating means.

12. An equalizer in accordance with claim 11 wherein said last-mentioned means comprises means for operating said integrating means and said applying means independently in sequence.

13. An equalizer in accordance with claim 12 wherein said means for operating said circuit means includes magnetoresistive means positioned in said air gap.

14. An equalizer in accordance with claim 13 wherein said detecting means includes means for providing a d.c. control signal proportional to said detected pilot signal and where said comparing means includes means for determining the difference between said control signal and said error signal.

15. An equalizer in accordance with claim 14 further comprising means for amplifying the output of said integrating means, said magnetic field being proportional to the output of said amplifying means.

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