

[54] **FLUXGATE MAGNETOMETER DRIVE
CIRCUIT INCLUDING A SENSOR
DEMAGNETIZER**

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Related U.S. Application Data

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1968, Pat. No. 3,509,424.

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307/270

[51] Int. Cl.G01r 33/02, H01f 13/00

[58] Field of Search.....317/148.5, 157.5; 324/43 R

[56] **References Cited**

UNITED STATES PATENTS

3,509,424 4/1970 Inouye.....317/148.5

3,093,774 6/1963 Christianson et al.317/157.5

Primary Examiner—Lee T. Hix

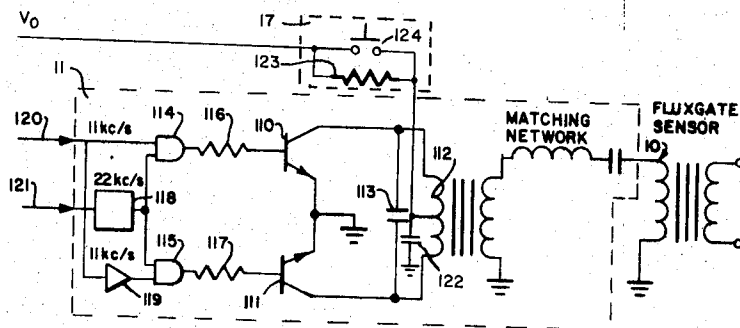
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Oser

[57]

ABSTRACT

A drive circuit for a fluxgate magnetometer including a demagnetizing system for the fluxgate sensor. The drive circuit is arranged to minimize the second harmonic frequency of the drive frequency in the drive signal to reduce interference with the signal output from the magnetometer at the second harmonic frequency. The circuit draws current only half the time to conserve power and consequently reduce the weight of the power source. The drive voltage is derived from a crystal oscillator having a frequency four times that of the desired frequency and which is connected to the drive circuit through a pair of series connected divide-by-two flip-flops to develop a square wave. Demagnetization is achieved by momentarily increasing the current in the fluxgate sensor and then allowing it to decay back exponentially to a lower value.

6 Claims, 4 Drawing Figures



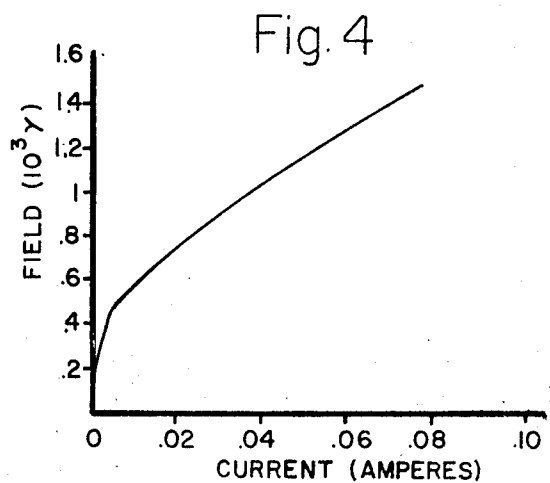
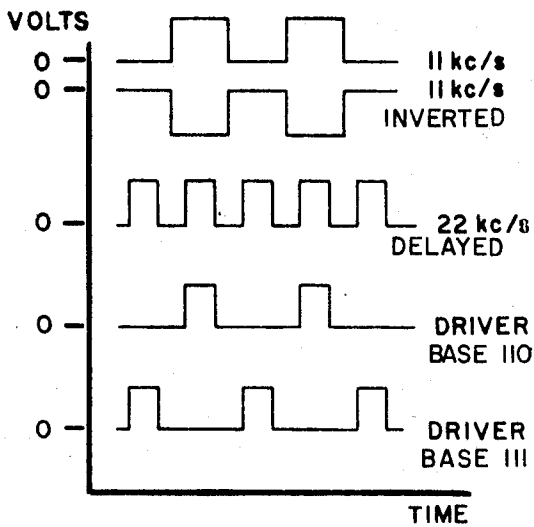
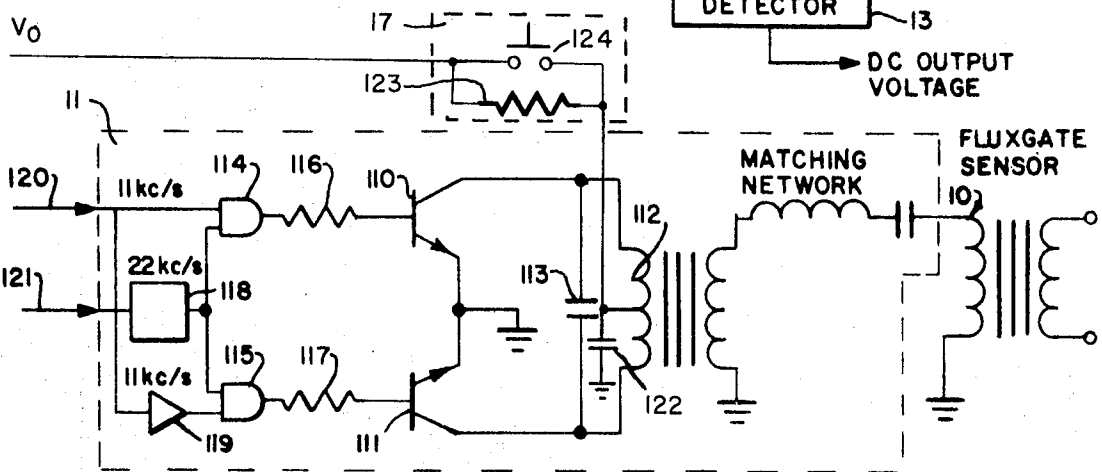
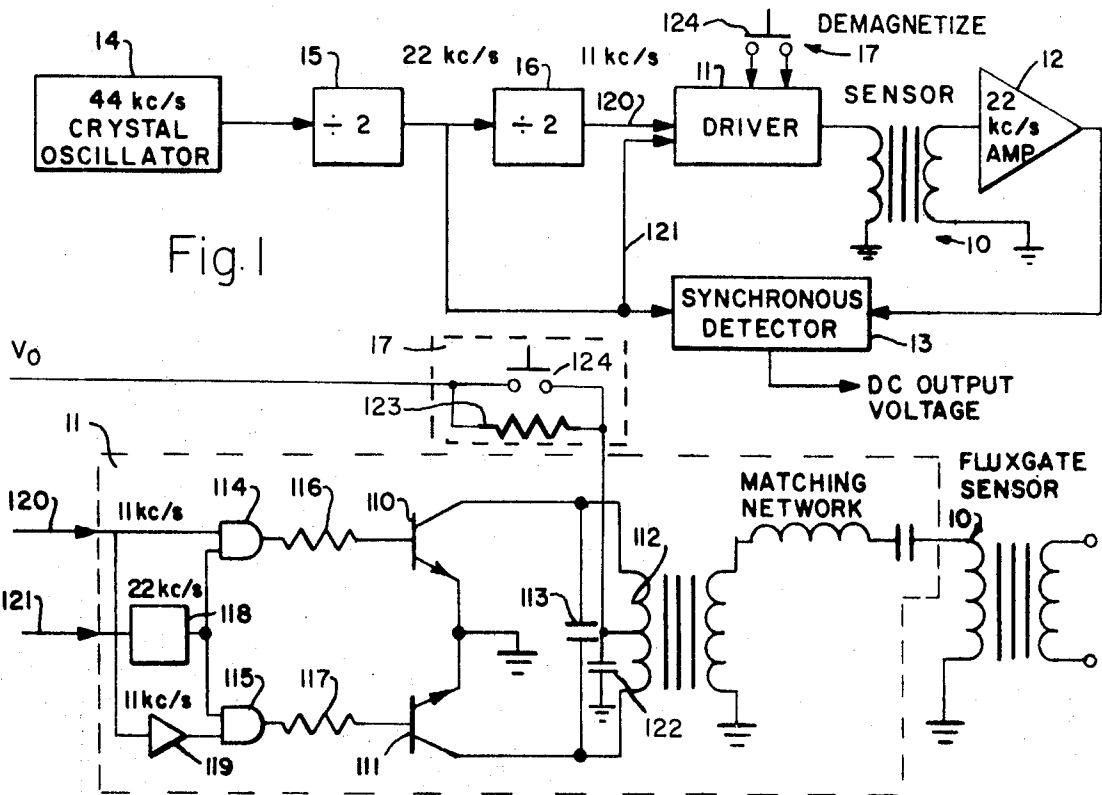


Fig. 3

Fig. 4

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FLUXGATE MAGNETOMETER DRIVE CIRCUIT INCLUDING A SENSOR DEMAGNETIZER

CROSS-REFERENCES TO RELATED APPLICATIONS

This is a continuation-in-part of application Ser. No. 700,396, filed Jan. 25, 1968 which will issue as U.S. Pat. No. 3,509,424 on Apr. 28, 1970.

BACKGROUND OF THE INVENTION

This invention relates to fluxgate magnetometer drive circuits which may, for example, be used in magnetometers of the type described in a book entitled, *Methods and Techniques in Geophysics*, edited by S. K. Runcorn and published in 1960 by Interscience Publishers Inc. of New York. Reference is particularly made to pages 139 through 147 of this book and more generally to all of the article entitled, *Measurement of the Geomagnetic Elements* by K. Whitham, beginning on page 104. Both the field of invention and the relevant prior art are well set forth therein.

In a particular application the objective of the fluxgate magnetometer drive circuit is to generate a sinusoidal current of approximately 80 milliamperes peak to peak in the drive coil of the fluxgate sensor. Typically, the drive frequency may be 11 kilocycles and the waveform should not contain any second harmonic components since this is the signal frequency in the output of the magnetometer which contains the information as to the magnitude and direction of the magnetic field being measured. The manner in which this second harmonic component of the output signal is analyzed for such measurement is clearly set forth in the above-noted text.

One problem associated with a fluxgate sensor is that it may acquire a "perm" or an offset bias of unpredictable magnitude of the order of several gamma on exposure to fields on the ground having a magnitude of one or two gauss.

A solution to the "perm" problem is to obtain a measure of this offset, and then subtract it from the fluxgate reading. Several experimenters have added mechanical devices to their fluxgate sensors to periodically mechanically reverse the orientation of the sensors by 180°. This reversal permits extraction of the offset by averaging the fluxgate readings before and after reversal. Mechanical reversers, however, add unnecessary weight and complexity to the magnetometer.

Another approach to the "perm" or offset problem is to demagnetize the fluxgate sensor to eliminate the "perm." In the normal demagnetization process such as is used for demagnetizing magnetic tapes, watches or spacecraft, the object to be demagnetized is subjected to an alternating magnetic field having an envelope which decreases from a large value to zero at a rate which is much slower than the alternating field. The peak amplitude of the envelope should be larger than the field which originally magnetized the object. The ambient magnetic field should be cancelled out.

In the case of the fluxgate magnetometer, the high-permeability cores are already subject to a large oscillating field of several tens of gauss at the sensor drive frequency. If the field were increased and then reduced to zero to cause demagnetization, the fluxgate sensor would be inoperable during the period of reduced field.

It is desirable, therefore, to have a means for demagnetizing the fluxgate sensor without rendering it inoperable during the period of demagnetization. It has been found that if the magnetic field is increased momentarily, and then allowed to decay back to the previous level, fluxgate sensor demagnetization will occur without an interruption in the operation of the fluxgate sensor.

SUMMARY

In accordance with an example of a preferred embodiment of the present invention, a fluxgate driver is designed to minimize the second harmonic content, operate on reduced power, and demagnetize the fluxgate sensor without interrupting its operation.

In order to minimize the second harmonic content, the drive waveform is derived from a divide-by-two flip-flop which is driven by a 22-kilocycle waveform. A 44-kilocycle crystal oscillator is normally used as the primary frequency source to eliminate frequency variations which would cause undesired phase shifts within the instrument. A 22-kilocycle reference frequency signal is derived from a first divide-by-two flip-flop and is applied to one input of a synchronous detector and to a second divide-by-two flip-flop. The output of the second divide-by-two flip-flop is an 11-kilocycle signal which is applied to the drive circuit of the magnetometer sensor. The second harmonic output of the sensor provides the other input for the synchronous detector. Normally, the drive circuit operates as a push-pull Class B amplifier with an input which is a push-pull square wave and with an output transformer tuned to 11 kc. The secondary of the transformer matches the sensor drive coil. In the present circuit, both the 22 kilocycle and the 11-kilocycle square wave signals are combined and are applied to the drive circuit in a manner described below such that current is drawn only one-half of the time, thereby conserving on the power consumption of the instrument.

To cause demagnetization of the fluxgate sensor, the current in the sensor is momentarily increased, which in turn increases the field of the sensor. The increased field magnetometer allowed to decay exponentially back to its previous level. The increase in the field and its subsequent decrease causes sufficient demagnetization of the sensor for most purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an example of a fluxgate magnetometer including a fluxgate sensor demagnetizer according to the present invention;

FIG. 2 is a circuit diagram for the driver circuit of the magnetometer and for the demagnetizing circuit;

FIG. 3 is a graph illustrating voltage waveforms which occur in the drive circuit of FIG. 2 as a function of time; and

FIG. 4 is a graph of the axial field of the fluxgate sensor as a function of the sensor current.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning to FIG. 1, there is shown a block diagram of a typical fluxgate magnetometer as described in greater detail in the above-referenced book by Runcorn. The magnetometer includes a sensor 10 which is a magnetizable core which is driven in and out of saturation by a driver 11. In the absence of any component of ambient magnetic field, the peaks detected in the output voltage from sensor 10 will be uniform. In the presence of a magnetic field, the peaks vary in a manner which is well understood in the art and which is measured by applying the output voltage through an output amplifier 12 to one input of a synchronous detector circuit 13.

The other input to synchronous detector 13 is derived from a crystal oscillator 14 through a divide-by-two flip-flop 15 which has its output connected to the second input of synchronous detector 13 and also through a second divide-by-two flip-flop 16 to driver circuit 11. The flip-flop 16 develops a square wave which is impressed on driver circuit 11. Such a square wave has only odd harmonics, and hence, minimizes the second harmonic frequency of the drive frequency. The output of synchronous detector 13 is a DC voltage which affords a measure of the ambient field sensed by the core of sensor 10.

The magnetometer also includes a fluxgate sensor demagnetizer 17. When a pushbutton 124 is depressed, the current in sensor 10 is increased momentarily by approximately 50 percent. The increased current is then allowed to decay exponentially to its previous value. The increase in current momentarily increases the envelope of the magnetic field surrounding sensor 10. The envelope decreases as the current decays back to the value prior to increase. The decreasing magnetic field envelope demagnetizes sensor 10, thus reducing the effect of ambient magnetic fields.

In the example shown, it will be noted that crystal oscillator 14 is tuned to a 44-kilocycle frequency so that the output of first flip-flop 15 is at 22 kc. It is this 22-kilocycle voltage which is applied to one side of synchronous detector 13 and also to the second dividing flip-flop 16. The output of flip-flop 16 is an 11-kilocycle voltage which is applied through driver circuit 11 to sensor 10. Thus, the fundamental frequency at which sensor 10 is driven alternatively in and out of saturation is 11 kc. As has been noted above, the information with respect to the ambient magnetic field is contained in the second harmonic of this fundamental frequency to which amplifier 12 is tuned. This second harmonic is, of course, 22 kc. which is the operating frequency of synchronous detector 13.

In FIG. 2 there is shown a detailed circuit diagram of driver circuit 11 and demagnetizing circuit 17. Driver 11, it will be seen, consists of a pair of transistors 110 and 111 which may be of the NPN-type as shown and which are connected to operate as a push-pull Class B amplifier with the primary winding 112 of an output transformer driver, and tuned to the 11-kilocycle fundamental drive frequency. Tuning may readily be achieved by capacitor 113. This output transformer is connected through a matching network to match impedances to the drive coil of the fluxgate sensor 10.

Drive circuit 11 may be energized by a battery having its negative terminal grounded and its positive terminal, V_0 , connected to the midpoint of the primary winding 112 via a resistor 123. A capacitor 122 is connected from the midpoint of primary 112 to ground.

The push-pull-connected transistor amplifiers 110-111 are driven through respective gate circuits 114 and 115 which have output resistors 116 and 117 connected from the gate output to the base of transistors 110 and 111, respectively. The gate circuits 114 and 115 may be any logical AND gate circuit, many types of which are well known in the art.

The inputs to driver circuit 11 (which is shown enclosed in the dash line block in FIG. 2) are derived over input lines 120 and 121. As can be seen by comparing FIGS. 1 and 2, line 120 carries the 11-kilocycle output of flip-flop 16, whereas line 121 carries the 22-kilocycle output of flip-flop 15. Line 120 is connected directly to one input of first AND-gate 114 and is connected through an inverter amplifier 119 to one input of second AND-gate 115. The 22-kilocycle voltage on input line 121 is connected through a 90° phase shifter 118 and thence to the second input of each of AND-gate circuits 114 and 115. The effect of this type of connection is illustrated graphically in the waveforms of FIG. 3.

In FIG. 3, there is shown a graph in which volts on the vertical axis are plotted as a function of time on the horizontal axis for various waveforms in the circuit of FIG. 2, each of which has its own separate zero level as indicated on the voltage axis. Starting at the upper waveform in FIG. 3, the 11-kilocycle voltage applied to input line 120 is first depicted. The next waveform is the inverted 11-kilocycle voltage which is derived as the output of inverter 119. Next there is shown the 22-kilocycle voltage which is derived as the output from the phase shifter or delay network 118, which is preferably used to introduce a small delay such as 90° in the voltage applied over input line 121 in order to avoid exact coincidence of the leading edges of the 11 and 22-kilocycle inputs applied to AND-gate circuits 114 and 115. Finally, the next waveform represents the output of AND-gate 114, which is applied to the base of driver 110, and the lower waveform represents the output of AND-gate 115 which is applied to the base of driver 111.

Demagnetizing circuit 17 is part of the energizing circuit for driver 11. A pushbutton 124 is shunted across resistor 123. Voltage V_0 , which supplies driver circuit 16, likewise controls the current flowing in fluxgate sensor 10. Resistor 123 reduces voltage V_0 and the current flowing in fluxgate sensor 10 to a "desired" level. When pushbutton 124 is momentarily depressed, the current flowing in fluxgate sensor 10 is increased. The increased current enlarges the magnetic field envelope surrounding sensor 10 as shown in FIG. 4. The increased current in sensor 10 then decays back to the "desired" level exponentially.

Assume the fluxgate sensor 10 is wound with 0.0035-inch diameter wire, which would create a field of 141 oersted per ampere if wound in a single large solenoid. In a first test performed to measure the offset caused by exposure to high fields, the solenoid creating the field around the sensor inside the fluxtank also "permed" the fluxtank itself to the extent of 10 gamma as measured by the sensor after it was demagnetized. The net sensor "perm" was about ± 1 gamma for a $\pm 100,000$ -gamma exposure, and doubled to ± 2 gamma for a $\pm 200,000$ -gamma exposure.

A second test performed was to decrease the peak-demagnetizing current from 0.16 ampere until the effectiveness was degraded for the 2-gauss magnetization. About 0.10 ampere was found to be the minimum current required.

A third test measured the effect of a fixed field created by the fluxtank solenoid while degaussing with a 0.12-ampere peak current. The results were as follows:

Perming field (γ)	Offset (γ)
300	>1
600	1
1,000	2
2,000	3
3,000	3
5,000	4
7,000	4
9,000	4
11,000	4
21,000	3
40,000	2
80,000	2
110,000	1

The offset thus has a broad peak of 4 gamma for perming fields between 5,000 and 10,000 gamma.

The results of these tests show it is possible to demagnetize the fluxgate sensor in the magnetic field environment in which it is making measurements, and still be sufficiently effective to reduce any offset to less than a few tenths of a percent of the ambient field. This order of accuracy is sufficient for the uses to which magnetometers are put. The fact that the magnetometer can make measurements while the sensor is undergoing demagnetization is a decided advantage.

Since the peak power needed to cause demagnetization is only momentarily needed, power dissipation in driver circuit 11 is inconsequential. However, transistors 110 and 111 and the other components of the driver should be designed to withstand the increased voltages to prevent breakdown.

It will be noted that the 22-kilocycle voltage is in effect used to gate a portion of both the original and the inverted 11-kilocycle signal so that the push-pull arrangement is driven during only half of the total time duration of these respective signals. Since each excursion of the 22-kilocycle square wave has a width or time duration only half that of the 11-kilocycle signal, it follows that this must necessarily be so by virtue of the operation of the AND gates in the circuit shown. Thus, in this manner, the 22-kilocycle and the 11-kilocycle square wave signals are combined so that current is drawn only one-half of the time, thereby conserving on the power consumption of the instrument.

The fact that current is drawn only half of the time is an obvious advantage. Furthermore, the power dissipated in the driver transistors is small because the collectors are shorted to the emitters when current is being drawn. Because they are used in a switching mode, the tolerances on the transistor parameters are relaxed. Since the drive circuit power consumption is a major portion of the power required in the total instrument, this saving is a great advantage for airborne instruments where weight considerations place a limit on available power.

It is possible to combine the 44-kilocycle drive in addition to the 22- and 11-kilocycle drive signals to thereby further reduce the power consumption by drawing current only during one-fourth of the 11-kilocycle signal waveform. Such an extension is by straightforward analogy to that illustrated herein. Since the 22-kilocycle and 44-kilocycle signals are al-

ready available in the circuit as originally designed, the only additional circuitry required for such a power-saving arrangement are the gating logic stages which are available in a single integrated circuit component.

What is claimed is:

1. In a fluxgate magnetometer of the type wherein the sensor is driven by a fixed oscillator, the improvement comprising means for demagnetizing said fluxgate sensor including:
 - means for momentarily increasing the drive current flowing in said fluxgate sensor and for allowing said increased current to decay back exponentially to the value prior to increase; so that
 - said fluxgate is demagnetized without interrupting its ability to make measurements.
2. An improvement for a fluxgate magnetometer as claimed in claim 1 wherein the means for momentarily increasing the drive current flowing in the fluxgate sensor and for allowing it to decay back exponentially to the value prior to increase comprises:
 - a load resistor in series with the current supply to the fluxgate sensor; and
 - pushbutton means shorting said resistor to increase the drive current flowing in the fluxgate sensor whenever said pushbutton is depressed.
3. A fluxgate magnetometer drive circuit comprising:
 - push-pull power amplifier means connected to apply a drive signal to the drive coil of the sensor of said magnetometer;
 - means for demagnetizing said fluxgate sensor including:
 - means for momentarily increasing the drive current flowing in said fluxgate sensor and for allowing said increased current to decay back exponentially to the value prior to increase, so that
 - said fluxgate is demagnetized without interrupting its ability to make measurements;
 - first and second gate circuit means connected to control said push-pull amplifier;
 - first control means to apply a signal of the fundamental drive frequency of said sensor to a first of said gate cir-

cuits and means to apply a signal of the same frequency but inverted phase to a second of said gate circuits; and second control means to apply to each of said gate circuits a control signal to alternately open and close said gate circuits at a frequency which is an even harmonic of said fundamental drive frequency.

4. A fluxgate magnetometer drive circuit as claimed in claim 3 wherein said means for momentarily increasing the drive current flowing in the fluxgate sensor and for allowing it to decay back exponentially to the value prior to increase comprises:

a load resistor in series with the current supply to the fluxgate sensor; and

pushbutton means shorting said resistor to increase the drive current flowing in the fluxgate sensor whenever said pushbutton is depressed.

5. A fluxgate magnetometer drive circuit as claimed in claim 3 wherein:

said push-pull power amplifier means comprises a pair of transistors connected to form said amplifier;

said outputs of said first and second gate circuit means are connected to the base electrodes of said transistors; and said gate circuits each comprise logical AND gates.

6. A fluxgate magnetometer drive circuit as claimed in claim 3 wherein:

said first control means comprises a crystal controlled oscillator stabilized at a frequency which is a harmonic of said fundamental drive frequency and the output from which is applied through at least one divide-by-two flip-flop in order to derive said signal of said fundamental drive frequency which is applied to said gate circuits; and

said second control means comprises circuitry to apply a signal of one of said harmonic frequencies generated by said first control means through phase shifting means to control each of said gate circuit means to permit application of said signal of said fundamental drive frequency through said gate means only during a fraction of the time duration of said fundamental frequency signal.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,638,074 Dated January 25, 1972

Inventor(s) George T. Inouye

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 24, the sentence should read --
The increased field is allowed to decay exponentially back to its previous level. --.

Column 4, lines 20 through 30 should read:

Perming field (γ)	Offset (γ)
300	<1
600	1
1,000	2
2,000	3
3,000	3
5,000	4
7,000	4
9,000	4
11,000	4
21,000	3
40,000	2
80,000	2
110,000	1

Signed and sealed this 29th day of August 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Signed and sealed this 29th day of August 1972.

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EDWARD M. FLETCHER, JR.
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ROBERT GOTTSCHALK
Commissioner of Patents