SEP 20 1965

SC-R-65-959

MASTER

Sandia Corporation

REPRINT

A PRECISION ANALOG MEMORY
WITH NONDESTRUCTIVE READOUT
USING MULTIAPERTURE FERRITE CORES

by

Andrew C Wilken

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

August 1965

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Published by
Sandia Corporation,
a prime contractor to the
United States Atomic Energy Commission

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

SANDIA CORPORATION REPRINT

A PRECISION ANALOG MEMORY WITH NONDESTRUCTIVE
READOUT USING MULTIAPERTURE FERRITE CORES

by

Andrew C. Wilken

ABSTRACT

The utilization of a square loop multiaperture ferrite core in conjunction with solid state switches results in a device that is capable of nondestructively interrogating the flux content about the core's minor aperture. The minor aperture flux can be controlled by a signal applied to the major aperture. The minor aperture flux quantity is the frequency controlling element of a readout oscillator which is the interrogator. There is, therefore, an analog input to frequency output which can be easily calibrated.

The circuit can be operated in a completely passive mode at all times except during the interrogation cycle. The information, once stored as a flux reversal in the multiaperture core, can be maintained for an infinite time interval or until reset.

August 1965

A PRECISION ANALOG MEMORY WITH NONDESTRUCTIVE READOUT USING MULTIAPERTURE FERRITE CORES

Introduction

The advantage of using a multiaperture core over a conventional toroid is that, observing certain restrictions, it is possible to ascertain the flux state of the region surrounding the major aperture by interrogating the flux condition of the region surrounding the minor aperture.

The region surrounding the minor aperture appears as a simple toroid when properly connected and driven by prescribed levels of signal. This region contains the flux quantity which cross-couples a pair of transistors to form a magnetic multivibrator. The circuit can be considered to be a modified Royer circuit. (1)

Circuit configurations can be such that, during information insertion, the multiaperture core can either be an integral part of/or completely divorced from the interrogation circuitry.

Any transducer, capable of converting a desired quantity being measured to an electric current in the range that the memory core requires, can be used as an analog generator. Bias currents can be incorporated if desired. The input signal to output frequency transfer function is also controllable, within limits, by the multiaperture core geometry and material composition.

It is imperative that, before a signal is applied to the major aperture, the core be preset to some exact flux condition. In the application, the core is electrically demagnetized. This method produces the flux condition required.

The flux state of the major aperture region can be set by an unknown signal. This flux state can then be interrogated nondestructively by the multivibrator whose frequency is related to this flux condition.

Purpose

The purpose of this paper is to describe the design, construction and operating procedures of the analog memory and associated circuitry. The capability of the memory while exposed to environments such as shock, temperature and radiation is also described. Actual applications and their results will also be elaborated upon.

History of Situation

The requirement existed for a precision analog memory with nondestructive readout capability for many conventional applications and, in particular, the storage of peak currents derived from nonrecurrent sources.

Theory of Operation

The memory package consists of a multiaperture ferrite memory core, an interrogation multivibrator, an input circuit and a reset circuit. These units are shown in Figure 1.

The memory core is a magnesium-manganese ferrite core with two apertures, a major and a minor aperture. The information and reset windings are wound through the major aperture whereas the minor aperture contains the interrogation windings.

The multivibrator utilizes the flux content about the minor aperture as the frequency determining quantity. The equation

$$\text{Frequency} \approx \frac{E}{4N\Phi} \quad (1)$$

describes the various parameter relations. This well-known Faraday's Law derived equation has been adequately covered in previous literature and will not be elaborated upon. A schematic of the multivibrator and memory core is shown in Figure 2.

If the minor aperture is considered to be a simple toroid, then the circuit is similar to the Royer Converter.

The 0.1 percent degree of precision that this device is capable of achieving is dependent on numerous factors. The power supply voltage stability, environmental conditions and the memory core preconditioning are the most important. The latter is accomplished by a procedure called "ringdown." Before applying an analog signal to the major aperture, it is necessary to "reset" the core to an "exact" flux condition. A passive circuit for generating the reset signal is shown in Figure 6. This signal is a damped sinusoidal current and has a decrement rate that is dependent on the "Q" of the inductor, the load value, the capacitor, and its charge value. This ringdown current sets the core in a initial "demagnetized" state. The flux conditions in this demagnetized state are pictorially described by Figure 3a. A laminar distribution of saturated material set in alternating directions radially across the core provides the core conditioning necessary to achieve the prescribed accuracy. This technique is also afforded the minor aperture region and intermediate transformer by placing a large capacitor across the power supply such that when the power supply is turned off, there is an exponential decay which reduces the minor aperture applied signal exponentially. This procedure is required because

FIGURE 1

INFORMATION RESET

MAJOR APERTURE

FIGURE 2

(a)

(b)

(c)

FIGURE 3

the reflected load of the intermediate transformer to the windings of the minor aperture region must appear as a repeatable quantity to the input signal source.

When the analog memory core is in the condition shown by Figure 3b, the amount of minor aperture switchable flux is maximized and the frequency of the multivibrator minimized. See Equation (1). It should be pointed out that although the microscopic flux patterns may or may not be repeatable from reset to reset, the macroscopic patterns, or net effect, is very repeatable. The actual similarity of the described flux patterns may or may not be as they actually exist but are used only for descriptive convenience.

The intermediate transformer T_1 serves as the coupling transformer and also as a filter in eliminating some of the transients that occur on the semiconductor side of the transformer that could erase minute amounts of information stored as irreversible flux around the major aperture. The output winding, from which a near square wave is derived, is also wound on transformer T_1 . The semiconductor requirements for this circuit are that the betas be sufficient to guarantee that the switches remain in a saturated condition during the total time that flux is being switched around the minor aperture. The transistors should also exhibit low leakage current and low collector to emitter saturation voltage characteristics. Transistor matching of these parameters is also helpful in attaining output waveform symmetry. The power supply voltage must be of sufficient magnitude to guarantee that the flux being switched around the minor aperture is traversing a major Φ -F loop.

A simple method of determining this voltage is to reset the core and vary the power supply voltage. A point will be observed where the frequency reaches a minimum value as the power supply voltage is varied. The supply voltage is then set to a value of approximately 10 percent above the minimum frequency-voltage point. This point varies with temperature and must be selected accordingly.

From Figure 4

- R_0 = inner radius of the major aperture
- R_1 = radius limited by the MMF applied to a winding on the major aperture
- R_2 = separation of the major and minor aperture centers
- R_3 = inner radius of the minor aperture
- Φ_m = the signal controlled flux region
- Φ_f = the frequency dependent flux region
- Φ_{sat} = the flux level at saturation
- S = squareness ratio of material = $(\Phi_{sat} \div \Phi_r)$ = saturation flux $\div$ remanent flux
- h = the material thickness

Since the frequency of the interrogation oscillator is described by the formula $\text{Frequency} = \frac{E}{4N\Phi_f}$, and if E and N are constant values, the Frequency $\approx K \frac{1}{\Phi_f}$.

FIGURE 4

2

$\phi_f = BA$ where B is the flux density of the core material at saturation and is considered to be constant. The parameter A is the cross-sectional area of the core within which the interrogation unit is switching flux.

The following equation explains this.

$$\phi_f = \left[(R_2 - R_3) - R_1 \right] hB + (1-S)\phi_{sat} \quad (2)$$

The signal controlled flux is described by:

$$\phi_m = (R_1 - R_0) hB \quad (3)$$

These equations are related to one another by the parameter R_1 .

To determine the relationship, one must solve Equation (3) for R_1 and substitute the result into Equation (2) yielding

$$\phi_f = hB \left[(R_2 - R_3) - R_0 \right] - \phi_m + (1-S)\phi_{sat} \quad (4)$$

To properly describe the input-output transfer function, the input signal must be defined. In this case, it is assumed to be a pulse of current that has a rise time that exceeds that of the minimum switching time of the core. This means that the flux switched in the core is able to track and record the peak current applied to the core as an irreversible flux change.

To simplify the explanation, it is assumed that the B-H point properties throughout the core material are similar.

It can be said, therefore, that the threshold field H_t , is a constant value along a radial path

Thus,

$$H_t = \frac{NI}{\ell} \quad (5)$$

H_t = threshold field

N = number of turns

I = current in amperes

ℓ = $2\pi R_1$ = radial path length

The field necessary to switch flux in the core to a radius R_1 (Figure 4) is:

$$H_t = \frac{NI}{2\pi R_1} \quad (6)$$

and

$$\frac{I}{R_1} = \frac{2\pi H_t}{N} \quad (7)$$

Since H_t is a material constant, then:

$$\frac{I}{R_1} = K \quad (8)$$

It can be seen from Equation 8 that to attain the required threshold field H_t at radius R_1 , or any other radius within the core, a current must flow sufficient to maintain the required constant K . A change in Current I will, therefore, result in a corresponding change in the radius R_1 and consequently the signal controlled flux ϕ_m .

Define ϕ_f in terms of the input Current I .

Repeating Equation (2)

$$\begin{aligned} \phi_f &= hB \left[(R_2 - R_3) - R_1 \right] + (1-S)\phi_{sat} \\ \phi_f &= hB \left[(R_2 - R_3) - \frac{NI}{2\pi H_t} \right] + (1-S)\phi_{sat} \\ \phi_f &= -hB \frac{NI}{2\pi H_t} + hB(R_2 - R_3) + (1-S)\phi_{sat} \end{aligned} \quad (9)$$

Since N , h , B , 2π , H_t , R_2 , R_3 , S , and ϕ_{sat} are constant values

$$\phi_f = K_1(I) + K_2 \quad (10)$$

$$K_1 = - \frac{N h B}{2\pi H_t}$$

$$K_2 = hB(R_2 - R_3) + (1-S)\phi_{sat}$$

A curve which describes the input signal MMF versus the multivibrator output frequency is shown in Figure 5.

FIGURE 5

There is a region of linearity which has been measured to be less than 1 percent. The linear region is, of course, dependent on the desired dynamic range. When high linearity and small dynamic range are the desired qualities, extreme care must be taken to guarantee maximum stability and repeatability of the analog memory and interrogator combination. Through practice it has been discovered that the following operating procedure tends to optimize these quantities:

1. Multivibrator "off"
2. Apply reset signal
3. Multivibrator "on" and then "off," resetting the minor aperture
4. Apply analog signal
5. Interrogate the memory core.

There is another mode of readout which might be utilized where a higher speed of interrogation is required. The multivibrator output might be used to gate a high frequency clock, thus making a period rather than a frequency measurement.

The system resolution can be maintained if a proper clock frequency is selected. The transfer function curve will exhibit linearity in the region where $\frac{1}{\phi_f}$ is linear. In previous applications all readout methods have utilized the frequency readout on a conventional event per unit time meter.

The memory core can be a completely passive device during memory insertion and then be mated with the interrogator for readout. Remote operation or operation in severe environments lend themselves quite well to this device.

The memory cores have been able to maintain their memory characteristics while being subjected to nuclear radiation levels up to 2×10^{16} neutrons per square centimeter, and, with proper packaging, shock levels in excess of 5000 G.

Circuit variations have included the use of tunnel diodes as the multivibrator switches. The advantage of this is a simplified circuit with a greater immunity to radiation but at the expense of smaller output signals. Single core multivibrators were also constructed but the stability and repeatability of the described system was not achieved.

Core geometry variations have been utilized in an attempt to control either the transfer function or other parameters such as minor aperture to major aperture discrimination, a particular frequency range, or to compensate for physical parameters such as weight or size.

Core materials are presently under investigation in an attempt to minimize the effects of temperature without the usual compromise in sensitivity as is the case when lithium nickel ferrite cores are used. The temperature sensitivity with the present system is about 50 cycles per degree Fahrenheit with about 25 cycles due to variations in flux density and the other 25 cycles due to variations in the threshold field requirements of the core.

The analog memory system described has been used in various applications. An instrument used for digitizing a single shot phenomenon utilizes the analog memory to "store" a peak current after it has been properly manipulated by preceding circuitry. Another application was to store peak information in the

analog memory with the core separated from the interrogation unit. The units were mated for readout with time intervals, from the time information was inserted to readout, typically a week or longer.

Summary

This paper has been an attempt to furnish insight to the regions concerning the utilization of multiaperture ferrite cores as an analog storage medium and to the associated circuitry required such that a high degree of accuracy is attained by such a system.

K_1 MERCURY RELAY - CLARE - HGSM - 1011
 R_1 100 K
 C_1 1 MFD.
 L_1 .5 HY - HIGH "Q" HQB - 5

FIGURE 6

LIST OF REFERENCES

1. Royer, G. H., "A Switching Transistor DC to AC Converter Having An Output Frequency Proportional to the DC Input Voltage," Trans. AIEE, Part I, July 1955
2. Barker, R. C. (Sandia Corporation Consultant) Analog Oscillator, (Unpublished)
3. Sherin, R. J., "Transfluxor Oscillator Gives Drift-Free Operation," Electronics, March 1960, Volume 33, No. 10, Pages 48-49
4. Meyerhoff, A. J., Digital Applications of Magnetic Devices, John Wiley & Sons, Inc., New York, 1960
5. Rajchman, J. A., and Lo, A. W., "The Transfluxor," Proc. IRE, March 1956, Volume 44, Pages 321-332.
6. Wilken, A. C., Interim Report on a Multivibrator Flux Interrogator With Memory, SCTM 46-63(24), Sandia Corporation, Albuquerque, New Mexico