A MAGNETICALLY-CONTROLLED COUNTER UTILIZING THE INTEGRATING PROPERTY OF SQUARE-LOOP CORES

by

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INTRODUCTION

Magnetic cores are widely used in electronic counters. The magnetic counter described in this report has the advantage of core economy over the more conventional type. A basic magnetic shift register would require ten cores to yield an output after ten inputs, while the circuit considered here requires only one core to perform the same function. The savings on money, space, and weight are thereby obvious.

A section on magnetic theory has been included in this report. Such a discussion was felt to be necessary since the basic element used in the counter circuit is the magnetic core. No direct comments on the circuit have been made until the section on the magnetically controlled counter.

THEORY OF MAGNETISM

Magnetic Units

The mks units will be used to define the various magnetic quantities.

The magnetomotive force (abbreviated mmf) is the magnetizing force necessary to create a magnetic field. This mmf is defined by the equation

$$F = NI \text{ amperes}^{1} \qquad (1)$$

[1] F is usually written in engineering references as NI and read as ampere-turns.

where I is the current in the magnetizing conductor in amperes and N is the number of turns of conductor around the magnetic circuit.

A magnetic flux is set up by the mmf, this flux having the units of webers and the symbol ϕ.

The magnetizing force H in a uniform field is

$$H = F/\ell \quad \text{amperes/meter} \tag{2}$$

where F is the mmf in amperes and ℓ is the mean length of the magnetic circuit in meters.

Magnetic flux density in a uniform field is

$$B = \phi/A \quad \text{webers/square meter} \tag{3}$$

where ϕ is the magnetic flux in webers in the area A, and A is the area in square meters perpendicular to the direction of B.

Ferromagnetic Theory

A basic idea used in the description of magnetic phenomena is that of the magnetic moment of an atom. The magnetic moment can best be defined by considering a small current-carrying loop contained in a magnetic field as shown in Fig. 1. A torque T is exerted on the loop which tends to rotate it until it is perpendicular to the magnetic field. The torque is related to the various quantities by the equation

$$T = BIA \sin \theta \quad \text{newton-meters} \tag{4}$$

where θ is the angle between the flux density vector B and the perpendicular to the loop area.

The product IA is defined to be the magnetic moment of the

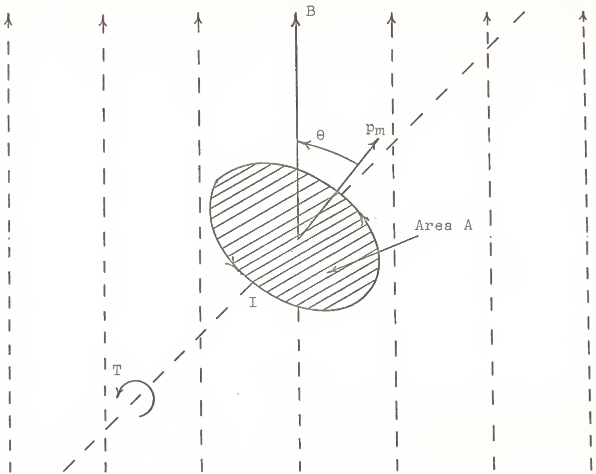


Fig. 1. Magnetic moment of small current-carrying loop.

loop and is denoted by the symbol p_m.

$$p_m = IA \quad \text{ampere-square meters} \tag{5}$$

The magnetic moment is a vector quantity having a direction perpendicular to the plane of the loop and a positive sense determined by the direction that a right-hand screw would advance should it be turned in a direction corresponding to the movement of the current I.

The magnetic moment depends only on the product of A with I and not on the shape of the current path. Magnetic moment is a vector quantity so the resultant of a set of component magnetic moments is their vector sum.

It is to be noted that the torque acting on the loop tends to align the magnetic moment with the direction of the magnetic field. If the loop is free to move, the magnetic moment will indeed rotate into the same direction as the flux density of the applied field.

The electrons surrounding the nucleus of atoms have magnetic moments associated with them. These magnetic moments lead to an explanation of the effects of materials in magnetic fields. An electron has two types of magnetic moments, one associated with the electron in orbit and the other with the electron spin. Drawing a correspondence between the electron in orbit and a current existing in a loop enables one to visualize the orbital magnetic moment. The picture shown in Fig. 2 indicates the spin magnetic moment. Depicting the electron as a sphere spinning on an axis gives rise to a magnetic moment directed along the axis of rotation.

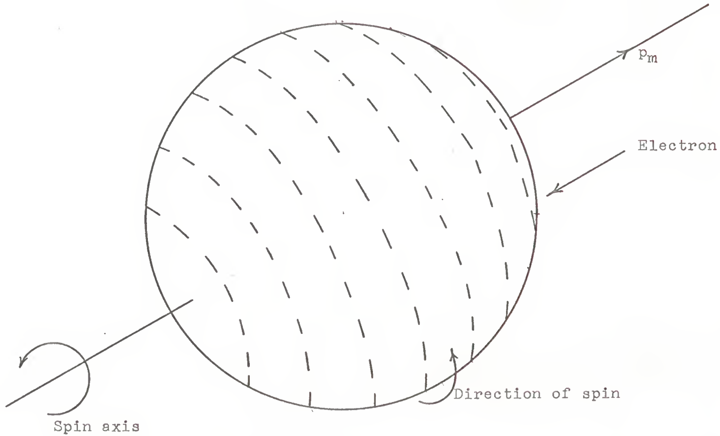


Fig. 2. Magnetic moment of spinning electron.

The orbital magnetic moments are oriented symmetrically about the nucleus and have a near zero resultant. The orbital moment is so small that it is negligible and will not be considered here.

The free atom of an element consists of a nucleus surrounded by a sufficient number of electrons to maintain the atom neutral. These electrons are grouped into shells and subshells and, as indicated earlier, are conceived to be spinning on their own axis. Figure 3 gives a diagram of the positions of the shells and the electrons contained in an atom of iron. Some electrons spin in one direction and others in the opposite. F. Brailsford (2) gives a table, see Fig. 4, which shows the distribution of electrons in the various shells of the ferromagnetic elements of iron, cobalt, and nickel, while the direction of spin is indicated by a plus or minus sign. The atom of each element will have a magnetic moment corresponding to the number of uncompensated spins.

In the metallic state the average distribution of electrons in the 3d subshell, and in the outer shell, is different and the average distribution is given in Fig. 5.

The unbalance of electron spins within a single atom does not bring about over-all ferromagnetic effects if adjacent atoms in a metallic state have counterbalancing forces. There must be a force of interaction acting to hold the magnetic moments of the atoms in alignment. As the atoms are drawn together, the interacting forces become strongly positive and do bring about spin alignment. There exists a critical atomic distance at which

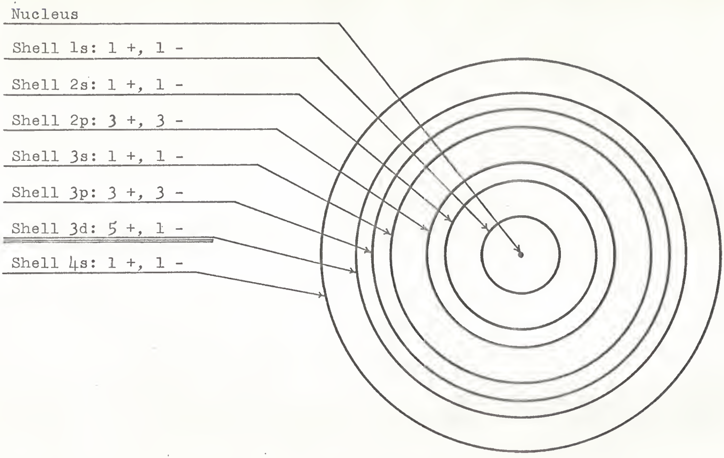


Fig. 3. Idealized iron atom indicating relative shell position, number of electrons per shell and their spin, emphasizing the uncompensated spins in subshell 3d.

Sub-shell	1s	2s	2p	3s	3p	3d	4s	Spin	Number of uncompensated spins
	Number of electrons								
Iron	1	1	3	1	3	5	1	+	4
	1	1	3	1	3	1	1	-	
Cobalt	1	1	3	1	3	5	1	+	3
	1	1	3	1	3	2	1	-	
Nickel	1	1	3	1	3	5	1	+	2
	1	1	3	1	3	3	1	-	

Fig. 4. Distribution of electrons in the free atom.

Sub-shell	3d	4s	Spin	Average number of uncompensated spins per atom
Iron	4.8	0.3	+	2.22
	2.6	0.3	-	
Cobalt	5.0	0.35	+	1.71
	3.3	0.35	-	
Nickel	5.0	0.3	+	0.606
	4.4	0.3	-	

Fig. 5. Average distribution of electrons for the metallic state of some ferromagnetic materials.

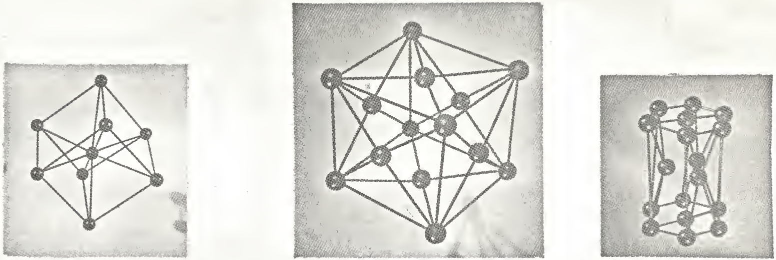
these forces become zero and ferromagnetism ceases to exist. To bring the atoms closer together creates strong negative forces which produce antiparallel electron spins. It is only in the solid metals of iron, cobalt, and nickel that the interacting forces result in alignment of adjacent magnetic moments.

A ferromagnetic material contains microscopic regions in which the magnetic moments of all the atoms may be found aligned in the same direction. Such a group of atoms is called a domain. Each domain will inherently be magnetized to saturation in some direction. With no external field present the direction the domains take corresponds to one of the crystallographic directions of easy magnetization of the single crystal which contains the domain.

The lattice of an iron crystal is cubic in form. The easy directions of magnetization are along the three major axes of the crystal structure. The lattice of a nickel crystal is cubic in form with an atom located in each cube face. The easy directions here are along the cube-diagonal. The cobalt crystal has a hexagonal lattice with the principal axis being the easy direction. A sketch of each unit-cell crystal structure is given in Fig. 6.

B-H Curves

Since each domain is magnetized to saturation, a ferromagnetic material is in a state of internal magnetic saturation even with no external field applied. This internal saturation



(a) Iron

(b) Nickel

(c) Cobalt

Fig. 6. Crystal structures of (a) Iron, (b) Nickel, and (c) Cobalt.

is called intrinsic magnetization. The magnetic moments of the domains occur in a random fashion and no evidence of this internal state is detectable externally. Upon the application of an external field the internal situation changes in such a manner that at least a part of this intrinsic magnetization becomes detectable.

The manner in which the internal magnetization is altered is best shown by plotting magnetic flux density against magnetizing force, i.e., B against H. Applying an external magnetizing force to an initially demagnetized ferromagnetic material and increasing this force from zero to some maximum value gives rise to the B-H curve of the general form shown in Fig. 7. The flux density can be divided into that which would be present even if the material were not ferromagnetic and that which is attributable to the intrinsic magnetization. The flux density due to intrinsic magnetization does not increase indefinitely, but reaches a peak value called the saturation flux density. The total flux density continues to increase slowly due to that part of B which does not depend on the material (extrinsic magnetization).

As H is decreased from some maximum value the flux density does not follow the curve for increasing H. As indicated in Fig. 8, the flux density remains at some value even when H reaches zero, this value being referred to as the residual magnetism. The applied magnetizing force must be reversed and increased to a value called the coercive force in order to remove the residual magnetism entirely. If H is then increased to a

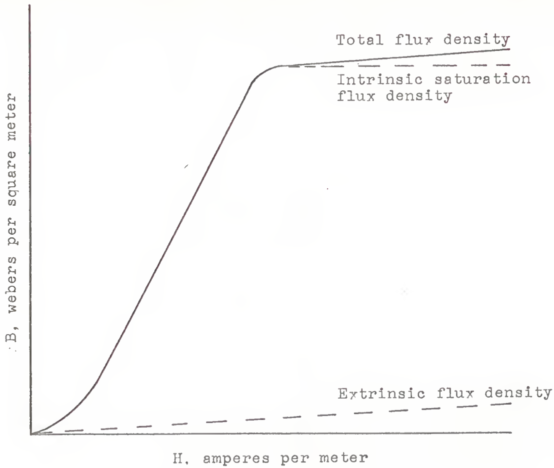


Fig. 7. B-H curve.

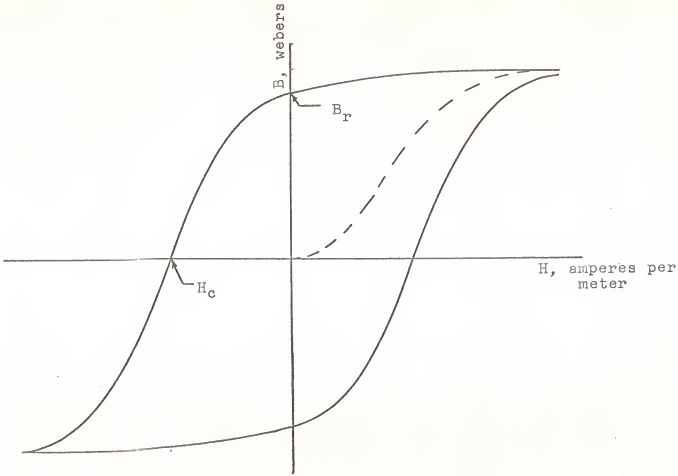


Fig. 8. Hysteresis curve.

maximum, decreased to zero, reversed once again and increased back to its original positive maximum, the flux density will be slightly below the previous positive maximum. Upon cycling H a number of times, the B-H curve will close on itself.

The appearance of the B-H curve depends upon the rate of changing the magnetizing force, i.e., the frequency of operation. Eddy-current effects become more pronounced as the frequency increases. Eddy currents are currents induced in the magnetic material by the changing magnetic field which give rise to an increased energy requirement as a result of I^2R loss. Figure 9 demonstrates the change in the B-H curve as a result of this power loss.

Temperature also has a definite effect on the magnetic characteristics of ferromagnetic material. The change in characteristic depends on the type of material involved.

It is instructive to explain the appearance of the B-H curve by utilizing the previously described magnetic domains. Brailsford offers an explanation in which he considers the B-H curve to consist of four parts. Figure 10 is used to indicate how magnetization takes place from the demagnetized condition up to saturation. As mentioned previously, the domains will initially lie parallel to certain crystal axis. This is indicated by the arrows shown in Fig. 10. Initially the magnetic moments of the domains are such that the resultant magnetization is zero. Upon applying a small field the resultant field in the direction of H is caused to increase by a small movement of the domain boundaries which move so that domains in which the

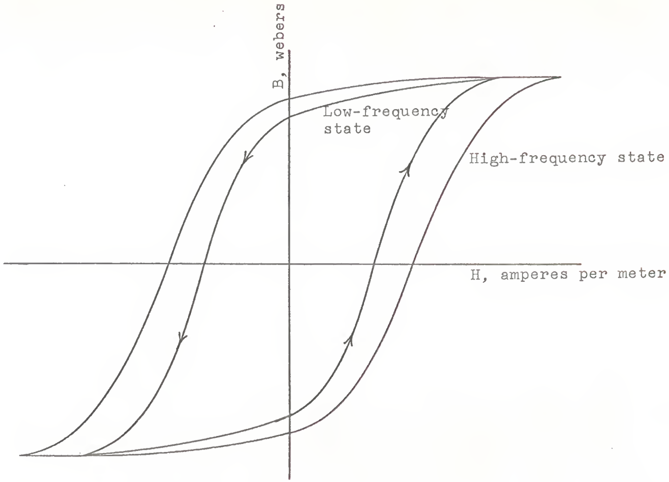


Fig. 9. Hysteresis curves showing effect of frequency.

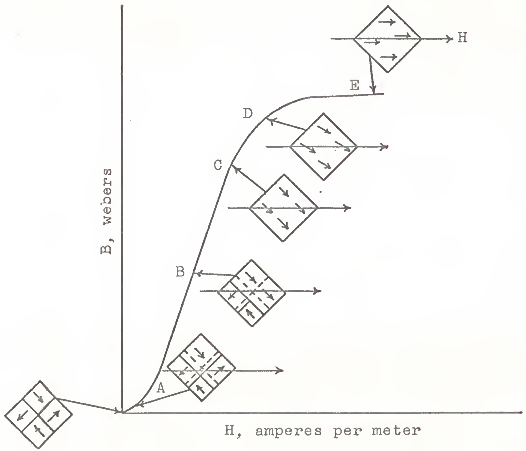


Fig. 10. B-H curve showing domain movement with increasing H. (Brailsford, 2)

saturation magnetization vector is favorably directed with respect to H, grow in volume at the expense of the remainder. This is illustrated at A. As the field is further increased a sudden swing of one domain vector after another takes place from an unfavorable to a favorable direction. These sudden direction changes are called Barkhausen jumps and are indicated at B. These jumps will be about complete for a relatively low field strength at some point C. Beyond C the magnetization occurs more slowly as H is increased, the process now being one in which the saturation magnetization of the domains is gradually pulled into the field direction as H increased. When this process is complete, intrinsic saturation is reached as indicated at E, this having the same value as that in the individual domains.

Square-loop Material

Upon considering the domain theory it becomes evident that should the crystals of a magnetic material all be initially parallel to the applied force the corners of the B-H curve would be square as shown in Fig. 11. When the domains swing into a favorable magnetization direction they will immediately be aligned with the direction of H. Since no further domain rotation will then be called for, the "knee" of the B-H curve will be quite sharp.

Square-loop core materials are produced in two different ways. One obvious method is to orient the crystals in such a

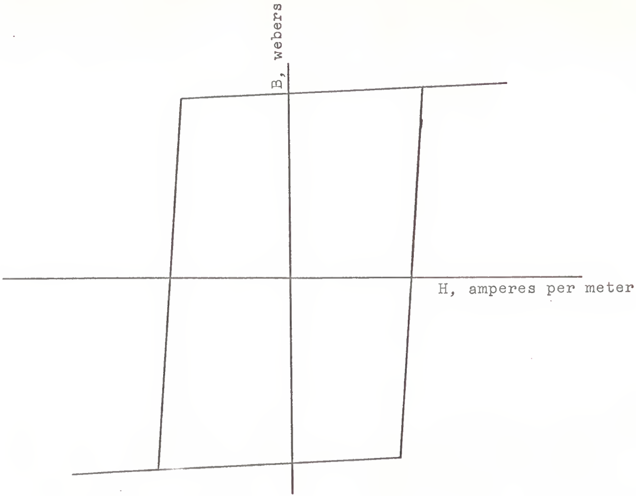


Fig. 11. Square hysteresis loop.

manner that an axis direction of easy magnetization exists parallel to the applied force. This is brought about by a series of cold reductions and heat treatments. The other method does not necessarily require the crystals to be aligned. This is accomplished by cooling certain materials through the Curie point at a slow rate in a magnetic field. The Curie point is that temperature at which a material ceases to be ferromagnetic. This procedure affects magnetic properties by orientation of the domains. Here the desirable magnetic properties are developed without regard to the rolling direction during processing.

A MAGNETICALLY-CONTROLLED COUNTER

General Background

The magnetically-controlled counter described in this report utilizes the integrating property of rectangular hysteresis loop magnetic material cores. This property can best be seen upon considering Faraday's law, $e = d(N\phi)/dt$, along with the circuit and B-H curve in Fig. 12.

When a voltage pulse of magnitude e and duration Δt is applied to a core wound with a fixed number of turns, the resultant change in flux is given by Faraday's law to be

$$\Delta \phi = 1/N \int_{\Delta t} e\,dt \qquad (6)$$

To change the core from the negative remanent state to positive saturation in one step, an applied pulse must have a

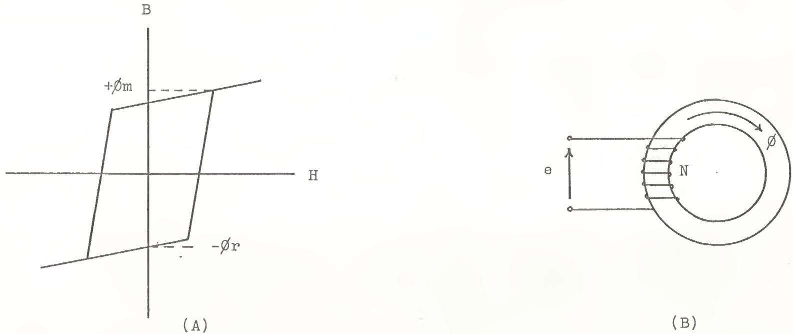


Fig. 12. (A), Rectangular hysteresis loop;
(B), Basic core circuit.

volt-time area equal to $N(\phi m - \phi r)$. Assuming an ideal core, a total of k pulses of area $N(\phi m - \phi r)/k$ would be required to change the flux from $-\phi r$ to $+\phi m$. This "stepping" process is pictured in Fig. 13.

If a means were devised for resetting the core to negative remanence once it reaches positive saturation, a block of k pulses used in the stepping process could be counted. The reset mode could then be detected and one pulse outputted after k input pulses.

A value of 10 for k was chosen only for illustrative purposes here since by controlling the volt-time integral of each input pulse or the number of turns on the core, this number can be changed. There is, of course, an upper limit to the number of pulses for a reliable count. As the count increases and the flux steps grow smaller, the effect of changes in circuit parameters, voltage, or temperature on the count becomes more pronounced.

The utilization of the integration principle in a counter circuit reduces itself to the construction of two circuits: (1) a source which delivers pulses of constant volt-time area; (2) a counter core along with a reset device. A circuit of this sort was introduced by F. G. Pittman (3) in 1955. A greatly modified and more modern version is given here.

Circuitry

The block diagram of Fig. 14 illustrates the two basic

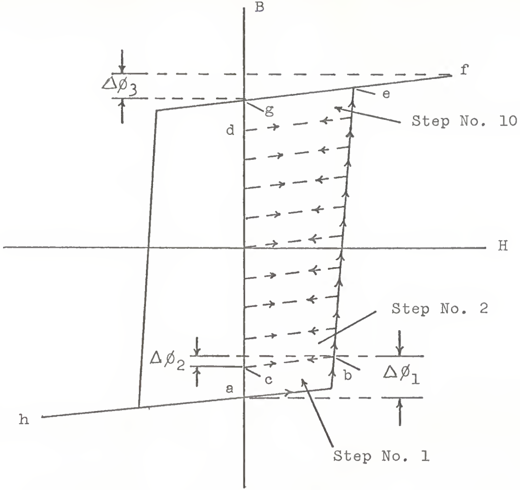


Fig. 13. Hysteresis loop showing ten flux steps.

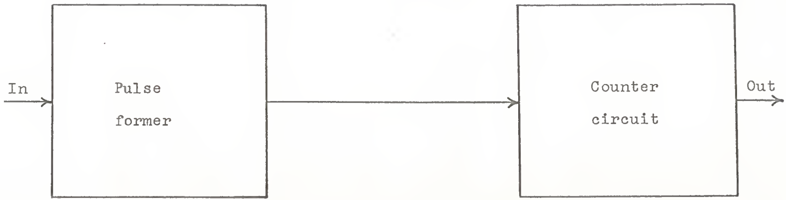


Fig. 14. Block diagram of decade counter.

sections of the circuit. The operation of each section will be described and selection of parameter values will be discussed. This circuit was designed to yield an output signal for every ten input pulses. It is assumed that the input signal is periodic in nature although this is not necessary. The cores used are 1/4 mil, 4-79 supermalloy tape toroids produced by the Arnold Engineering Co., Marengo, Illinois. All transistors are Texas Instrument Type 2N718A while the silicon-controlled rectifier is an SA-1304.

The Pulse Former. Since the input pulse amplitudes and their duration may be random in nature, we require a buffer to insure that the counter circuit input pulses be of constant volt-time area. The pulse former shown in Fig. 15 serves this purpose.

To observe the circuit operation, assume that the capacitor C1 is initially charged to the nominal supply voltage of 20 volts. A positive voltage pulse applied to Terminal 3 will cause the silicon-controlled rectifier Q2 to turn on. Capacitor C1 will then have a discharge path through the diode CR1, Q2, and the primary winding of the square-loop transformer T1. This current will cause the core to shift from one remanent state to the other which results in a pulse of voltage across the secondary coil. When the capacitor has discharged to a low value it will be unable to deliver sufficient current to maintain Q2 in a conducting state. The SCR will then open and the capacitor will begin to charge through the transistor Q1. The charge path includes the primary coil of T1. This current switches the

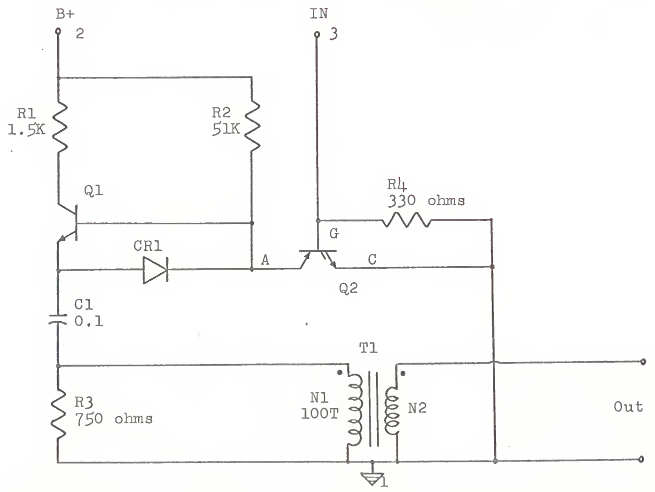


Fig. 15. Pulse former circuit diagram.

transformer to the opposite magnetic state, produces a pulse of voltage across the secondary coil of opposite polarity to that above, and sets the core in a position ready to deliver a second output pulse. The core is forced to be initially in its "positive" remanent state, whereupon the positive input pulse at Terminal 3 forces it into its negative remanent state, resulting in a negative output pulse from the secondary coil. Once the capacitor has charged to the supply voltage level, Q1 will no longer conduct and the circuit will wait to receive the next input pulse.

Resistor R2 serves as a base current path for transistor Q1. With a supply as low as 10 volts, a value of 51K for R2 will yield a turn on base current of 197 microamperes which will put Q1 well into saturation. When Q2 is conducting and the supply voltage is 40 volts, a current of 40/51K 0.8 milliampere will be insufficient to hold Q2 on. The SCR should, of course, be held conducting only by the capacitor C1.

The period of the input signal for which the circuit was designed is one millisecond. The capacitor C1 should therefore charge to full voltage in less than one millisecond. The time constant will be effectively R1 x C1 since R3 will be shunted by a very low impedance during most of the charge cycle. With the values for R1 and C1 chosen as 1.5K and 0.1 microfarads respectively, the capacitor will be virtually fully charged in five time constants, or $(5)\ (1.5)\ (10^3)\ (0.1)\ (10^{-6}) = 0.75$ millisecond.

The resistor R4 was determined to be 330 ohms from the manufacturer's data on the SCR. This resistor tends to reduce the voltage difference between the gate and cathode due to capacitive coupling between the anode and gate which would lead to erratic firing of the SCR.

During part of the discharge cycle of C1 the impedance of the primary winding of T1 is relatively high. Should this impedance become sufficiently large, the current through Q2 could drop below that required to maintain conduction. The 750-ohm resistor in parallel with the primary coil insures that this will not happen.

The number of turns on the primary of T1 was set at 100 to satisfy the requirements of available current and existing core dimensions. It is desirable that the pulse former circuit have a low output impedance in order that the output voltage will not vary significantly with changes in load. In keeping with this idea the secondary coil was allowed 30 turns. This was changed to 36 turns as determined experimentally and is discussed later.

A desirable feature of using a magnetic core in the pulse former is that the volt-time area of the output pulses will remain relatively constant with changes in power supply voltage. For higher voltages the pulse amplitude will increase but pulse width will decrease due to faster switching time. For lower voltages, the reverse is true.

The Counter Stage. The circuit diagram for the counter stage is given in Fig. 16. The operation of this circuit proceeds as follows. Each negative input pulse turns the coupling

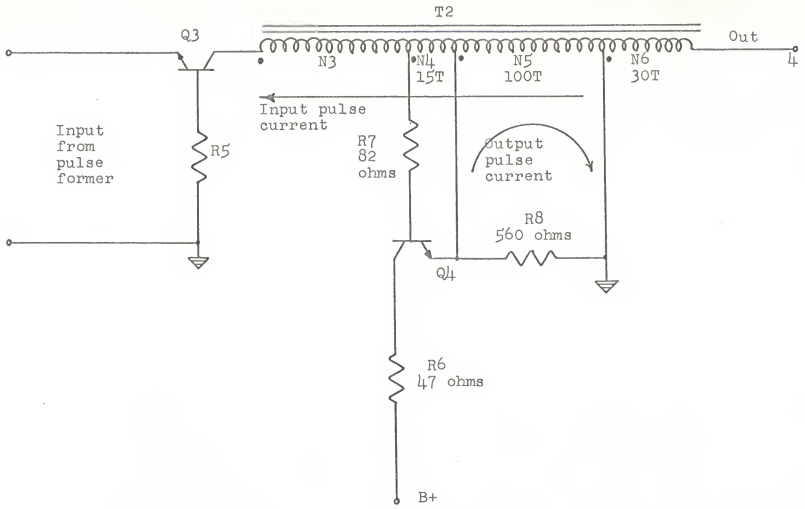


Fig. 16. Counter circuit.

transistor Q3 on and steps the counter core one-tenth of the way from negative remanence to positive saturation as indicated by moving from a to b on Fig. 13. Any positive input pulse will be blocked by Q3.

The change in flux $\Delta\phi_1$ will produce a small positive voltage pulse on the output winding N6. As the input goes to zero the flux will fall from b to c. The change in flux $\Delta\phi_2$ experienced here will yield a very small negative output pulse. This flux change will also result in a positive voltage from the base to emitter of transistor Q4. This voltage, however, is below that required to turn Q4 on. After the ninth input pulse has passed the flux will have been driven to point d. At some time during the tenth input the flux will rise to e. At that point positive saturation is reached, the load on the pulse former increases considerably, and the core is driven far into saturation out to point f. As the tenth input pulse disappears, the flux decreases to g. The flux change $\Delta\phi_3$ is much larger than that obtained when moving, typically, from b to c and will produce a positive voltage across N4 (base to emitter on Q4) which is sufficiently large to turn Q4 on. As Q4 begins to conduct the current through N5 produces a voltage which is magnetically coupled to N4. This further increases conduction so the process is regenerative. The current in N5 drives the core flux to point h. It is this large flux change that yields the output counting pulse. The negative saturation state results in the base voltage of Q4 being reduced to a value insufficient to hold the transistor on. With Q4 in the nonconducting state the flux will shift from h back to point a and be ready to go through the 10-count cycle once again.

The most critical phase in the design of this circuit is the choice of turns for N3, N4, and N5. The total turns $N = N3 + N4 + N5$ must be such that one input pulse increases the flux a little more than one-tenth of the total from negative remanence to positive saturation. For the core being used the flux change from $-\phi r$ to $+\phi m$ is about 120×10^{-8} weber. This yields an input pulse with a volt-time area of $N_2 \Delta\phi =$ $(30)\ (120)\ (10^{-8}) = 36 \times 10^{-6}$ volt-seconds. Due to temperature considerations to be discussed later, it is desirable that the ninth step almost reach positive saturation.

This, along with the fact that the flux falls off a little upon the removal of each input pulse, would call for an incremental flux change $\Delta\phi_1$ in the neighborhood of 15×10^{-8} to 16×10^{-8} weber. Therefore the turns required for N would be

$$N = \frac{(N_2 \Delta\phi)}{15.5} \times 10^8 = \frac{(36)(10^{-6})(10^8)}{15.5} = 232 \qquad (7)$$

The nominal value of N was set at 230 turns. The combination of N5 and N6 goes to make up the output transformer of the counter circuit. Should the counter stage be used to drive a second identical counting circuit, an output pulse would necessarily have to look like an input pulse. Because of this, N5 and N6 were set equal to N1 and N2 respectively. The number of turns for N4 is fairly restricted. If too many turns are used the intermediate positive pulses on the base of Q4 might be sufficient to turn the transistor on. This would result in a premature reset. On the other hand, if N4 is too small, the larger positive pulse obtained when the flux returns from positive saturation could be insufficient to cause Q4 to conduct, the result being that the circuit would not reset.

It was estimated that the flux returns to points c and g of Fig. 13 in a period of time equal to the fall time of the input voltage. This fall time was experimentally determined to be one microsecond. From the B-H curve for the core it was estimated that $\Delta\phi_2 = 3 \times 10^{-8}$ weber and $\Delta\phi_3 = 10 \times 10^{-8}$ weber. For the transistor used a voltage of 0.45 volt or below is too small to turn Q4 on. A maximum number of turns would therefore be

$$N4 = \frac{\Delta t}{\Delta\phi_2} E_{base} = \frac{(10^{-6})(0.45)(10^{8})}{3} = 15 \text{ turns} \qquad (8)$$

The flux change $\Delta\phi_3$, with N4 equal to 15 turns, would result in a base voltage of

$$e_b = N4 \frac{\Delta\phi_3}{\Delta t} = \frac{(15)(10)(10^{-8})}{10^{-6}} = 1.5 \text{ volts} \qquad (9)$$

This is sufficiently large to turn Q4 on. With N4 fixed at 15 and N5 at 100, which leaves 115 turns for N3.

It is necessary to place a resistor in the base lead of transistor Q3 to protect the transistor and to avoid loading the pulse transformer to the point where the input voltage will fall off. Even for the smallest negative input pulse and for any load Q3 should act as a closed switch. This requires the base current to be sufficiently large to drive the transistor into saturation. This in turn limits the maximum value which can be chosen for R5. With R5 set at 82 ohms and the input as low as 2 volts, the base current will be

$$I_b = \frac{V_{in} - V_{be}}{R5} = \frac{2 - 1.3}{82} = 8.5 \text{ ma} \qquad (10)$$

This is more than enough to keep the transistor saturated even when the core saturates, i.e., when the load impedance is quite low. Resistor R7 is used in a manner identical to R5 so the resistance values were chosen equally. R5 was subsequently changed to 500 ohms as will be seen in the section on count trimming.

The purpose of R6 is to protect transistor Q4 during that part of the reset cycle when the core is saturated. The coil impedance is then quite low so with no resistance in the collector lead all the supply voltage would be dropped across Q4. Even with 40 volts supply the peak pulse current drawn by Q4 will be less than one ampere with R6 set at 47 ohms.

The flux change $\Delta\phi_2$ shown in Fig. 13 induces a small positive voltage across N4. Although not large enough to turn Q4 fully on, this voltage does cause slight conduction. This small current is large enough to cause sufficient drop across N5 to bring about regeneration and the consequential full conduction of Q4. Resistor R8 was placed in parallel with N5 to provide a relatively low impedance path for this current and thus avoid reset after the first input pulse. A value of 560 ohms for R8 was found to be sufficiently small to eliminate the premature reset, yet large enough to allow normal reset to take place at the end of the tenth input pulse.

The Complete Circuit. The complete circuit is shown in Fig. 17. Some additions and modifications which will be explained presently have been made to the circuit.

Count Trimming

Experience has shown that the magnetic properties of cores cannot be assumed to be uniform from one core to another. Such an assumption would be erroneous even among cores from a given manufacturer which have been produced during the same production run. The variation can be high as a result of the cores being constructed during different production runs and by different manufacturers. These core differences make it necessary to "trim" the count, i.e., to experimentally adjust the appropriate circuit parameters to bring about a count of 10. The most obvious way to change the count is to vary the number of turns on N3 of Fig. 17. This method is quite accurate but undesirable from a production point of view.

A more desirable trimming method is to fix the number of turns for N3 and vary the volt-time area of the input pulse to the count circuit. This can be done by an appropriate choice of the resistor R9. Resistor R9 was allowed a range of 0 to 160 ohms in 5-ohm steps. Resistor R5 was increased to 500 ohms to enhance the fine trimming characteristics of R9. If R5 were left at 82 ohms up to roughly two-thirds of the input voltage could be dropped across R9. This would bring about a drastic change in count. With R5 set at 500 ohms, no more than one-

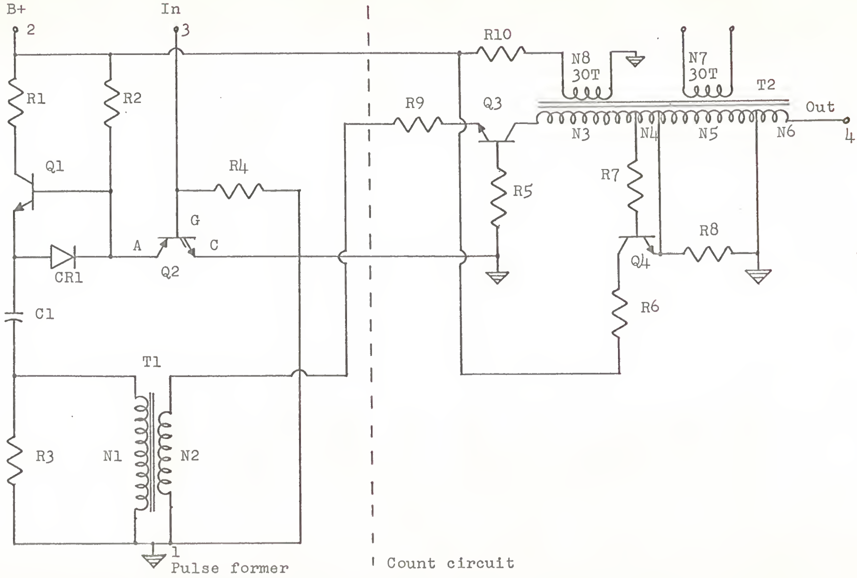


Fig. 17. Complete circuit.

fourth of the input can be dropped across R9. It was found that 100 turns for N3 allowed correct trimming of most cores. The presence of R9 in series with the core windings could possibly limit the peak current which drives the core into positive saturation. This in turn could reduce $\Delta \phi_3$ of Fig. 13 to a value below that required to turn the reset transistor on. The maximum value of 160 ohms was found to cause no reset problem.

The trimming procedure settled on proceeds as follows. The supply voltage is set at 40 volts and R9 is chosen so that the count is at the 10 to 9 changeover point, as shown in Fig. 18.

The value for R9 is determined with the bias winding N8 connected to the supply. It was experimentally determined that the temperature range over which a ten count could be achieved was increased by including the bias current. Temperature considerations force one to trim this 10 to 9 changeover. As temperature increases or decreases, the core saturates at a higher flux value than it does around 25 degrees C. The change of the incremental steps is negligible. With the core trimmed as indicated in Fig. 7, the saturation flux must increase by an amount equal to $\Delta \phi$ before the count changes to 11. Forty volts was chosen as the supply level to allow for the inherent decrease in volt-time area of the input pulses as the supply voltage decreases. Over ten input pulses this volt-time change would have to result in a total flux decrease of $\Delta \phi$ before the count goes to 11. This trimming procedure has yielded a reliable count for a range of 10 to 40 volts supply over the required temperature range.

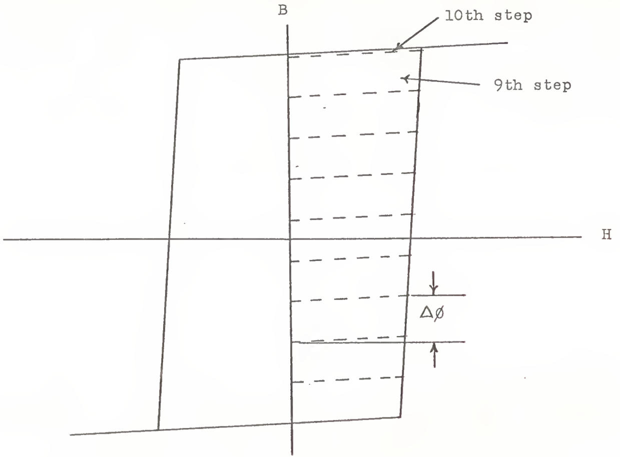


Fig. 18. B-H curve showing trim point.

Experimental Data

Five count-by-ten circuits were constructed and subjected to temperature tests. The 10-count supply voltage range for each circuit is listed in Fig. 19. All units were count trimmed for a 9 to 10 changeover at 40 volts supply at room temperature.

The output voltage was photographed with the oscilloscope sweep set to time scales of five microseconds per centimeter and two milliseconds per centimeter. Sketches of these pictures are shown in Fig. 20.

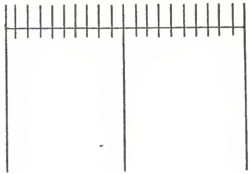
Extensions and Additions

In timing applications it would be necessary to insure that the count started from the negative remanent point. The coil N7 of Fig. 17 is included for this purpose. By applying a 28-volt pulse to N7, with positive polarity on the dotted terminal, the core is driven into negative saturation. This "zero sets" the core and readies it for the count cycle. The zero set winding can also be used to externally pre-set a given number of steps into the core before the count starts.

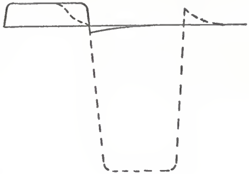
A count-by-1000 circuit can be easily constructed by cascading three count-by-ten stages. The pulse former need only be used on the input while no modification need be made to the 10-count circuit described here. The trimming resistor will, of course, vary from one stage to another to account for core differences.

Circuit number	10-count voltage range		
	$-55^{o}C$	$25^{o}C$	$+75^{o}C$
1	12.0 - 40.0	8.5 - 40.0	7.2 - 38.6
2	12.1 - 40.0	9.1 - 40.0	7.8 - 38.9
3	12.3 - 40.0	8.3 - 40.0	7.2 - 40.0
4	12.2 - 40.0	8.8 - 40.0	7.6 - 40.0
5	12.2 - 40.0	9.0 - 40.0	7.7 - 41.2

Fig. 19. Temperature test data for five count by 10 circuits.



Two milliseconds per centimeter



Five microseconds per centimeter

Fig. 20. Output voltage from count-by-10 circuit.

If a count of much below 10 is desired, the number of turns required on the counter core falls below N4 + N5 = 115. For a count of three, the total turns called for is around 85. It would be necessary to change the reset and pulse former circuits should the sum of N4 and N5 be reduced below 115 turns. This can be avoided by simply grounding one end of N3, as shown in Fig. 21.

The circuit which has been described in this report can be used in many applications which require the measurement of long time intervals. The accuracy of this measurement depends for the most part on the accuracy of the oscillator producing the input pulses. Time was not available to determine the effect of shock and vibration on the circuit operation. As indicated previously, the circuit was found to operate reliably under extreme temperature and supply voltage variations.

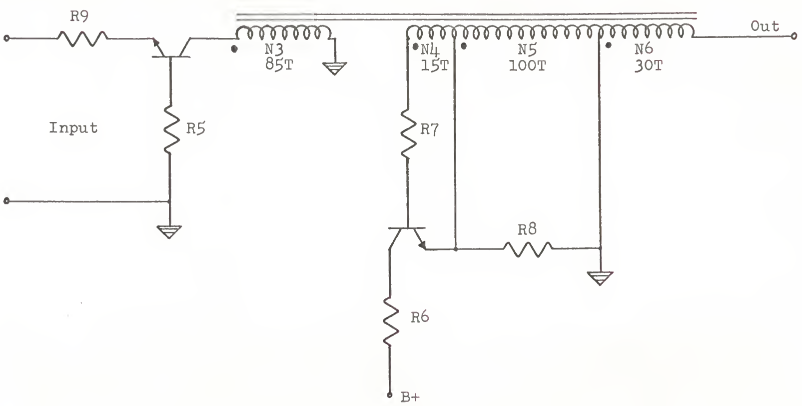


Fig. 21. Count-by-3 circuit.

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A MAGNETICALLY-CONTROLLED COUNTER UTILIZING
THE INTEGRATING PROPERTY OF SQUARE-
LOOP CORES

by

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B. S., Iowa State University, 1959

AN ABSTRACT OF
A MASTER'S REPORT

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This report deals with a multi-state device incorporating a magnetic core of rectangular hysteresis loop material as a counter. Provisions are made to adjust the number of counts from one to ten with automatic reset after each complete count cycle. Test data indicating the operation of the circuit over extreme temperature and supply voltage variations is included. Since the basic element used in the circuit is the magnetic core, a section on the theory of ferromagnetism is also included.