RAILWAY SIGNALING AND COMMUNICATIONS

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Applying Ferrites to Signal Systems

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In recent years, static switching devices in the form of ferrite cores have received increasing attention and usage in industrial controls. In this paper, originally presented before the Institution of Railway Signal Engineers (England), the possible use of these devices in signal circuits is explored.

● An important aspect of the design philosophy of railway signaling has been the development of foolproof control mechanisms which make it impossible for a dangerous condition to be set up. Generally speaking, the signal control mechanisms are both "fail safe" and "interlocked." The "fail safe" feature insures against component failure, while the "interlocking" feature insures against human error.

Signal control was based for many years on mechanically interlocked lever frames and mechanical actuation of the signal. During recent years, however, there has been an increasing tendency to replace the mechanical systems by electrically operated devices.

The electrical systems use electromechanical relays as the basic switching unit and interlocking of the relay network is readily achieved. Telephone-type relays are thought to be quite inadequate to provide the desired degree of safety and reliability and other highly reliable relays have been developed. These incorporate large coils, heavy carbon contacts to prevent welding, large spacing between terminals and accurately aligned moving parts. Unfortunately, the cost of these relays is high and they are bulky.

This paper describes some preliminary investigations into the possible use of new electronic components for the signal control duty, the main objectives being:

1. To insure that the alternative switching components will satisfy the safety requirements.
2. To provide a less expensive and less bulky system.
3. To have a high degree of reliability. The new system is expected to be at least as reliable as the present relay circuits, one improvement being the elimination of moving contacts.

Electron tubes do not meet the required standards of safety and reliability; inter-electrode shorts may occur and the accidental removal of the bias could cause the tubes to be switched on, thus giving a false indication. Solid-state devices such as transistors and semiconductor diodes have a very high degree of reliability but, like electron tubes, are subject to both open-circuit and short-circuit types of failure and hence may not be used in the signal control path; they may, however, be used in circuits, described later, where any form of failure would result in the circuits operated by them failing to safety.

Ferrite Cores

It was decided to use ferrite cores exclusively in the signal control circuits because they are entirely passive elements. Transistors are used to provide a power source for the core "gates" to operate. Diodes are used in parts of the circuit which depend upon their rectification property; that is, the diodes must act as rectifiers rather than as bilateral resistors.

The scope of the work presented here is limited to an investigation of some of the possible uses of these new components in railway signaling and does not attempt to present a complete system or one that conforms to all the restrictions and refinements of railway signaling practices.

In general, ferrites are chemical compounds of the form $MFe2O_4$ (where M is a metal) which are pressed and sintered. The ordinary ferrites have a very high magnetic permeability and an extremely high electrical resistivity in all directions. The first property is of value in increasing the coefficient of inductance of electrical circuits. The second property means that eddy current losses are negligible, and therefore ferrites are useful at relatively high frequencies (about 1,000 times higher than the best laminated silicon steel).

"Square Loop" Ferrites

Perhaps a more interesting class of ferrites for the present purpose is the so-called "square loop" class. These ferrites are similar in appearance to the ordinary type. They also have a very high resistivity, but their magnetic properties are much different. Fig. 1 is a graph of flux density as a function of magnetizing force for these materials. The diagram shows that the residual flux density B_r is almost equal to the maximum flux density B_{max}. If the material is in the state which will be arbitrarily called $-B_r$, and a magnetizing force H is applied to reverse the flux direction, it is seen that very little flux change takes place until H_c is reached, at which time the flux promptly reverses to the other extreme. This hysteresis effect is attributed to the particularly strong magnetic dipole of the molecules of the substance.

If a magnetizing force is applied which is not great enough to "switch" the core, then various minor hysteresis

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paths will be followed. Here again the residual flux density will be almost equal to B_{max}. In Fig. 1 if the core is at $-B_r$ and a magnetizing force H_1 is applied and then removed, the flux will follow the path 1-2-3. The ratio of B_r to B_{max} is called the "squareness" ratio of the core and is a criterion of usefulness for applications based upon the switching properties of the core. The temperature at which the cores lose their magnetic properties is about 300 deg C. Square loop cores are manufactured in the form of toroids of various dimensions. For ease of winding in the laboratory one-inch diameter cores have been used.

The following electrical circuit properties of coils wound on square loop ferrites are used as the basis of design for the new system:

1. A small flux change, as occurs when the core flux moves along the line $-B_r$ to $-B_{max}$ or $+B_r$ to $+B_{max}$ will produce only a very small voltage on any of the linking windings. If, however, the flux change is from $-B_r$ to $+B_{max}$ or from $+B_r$ to $-B_{max}$, then a relatively large voltage will be produced. This follows from Faraday's Law of Induction.

2. The cores are current defining devices, that is, so long as saturation is not reached, they will allow only a constant value of current i_c to flow through the winding, regardless of the voltage applied. The current i_c corresponds to the magnetizing force H_c in Fig. 1.*

3. If less current than i_c is forced through, the core flux will not move around the B – H loop. From property (1) it can be seen that in such a case, very little voltage will be developed on any other winding.*

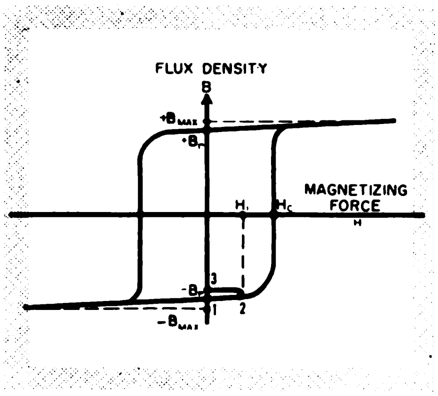

Figure 1: Ferrite core hysteresis curve.

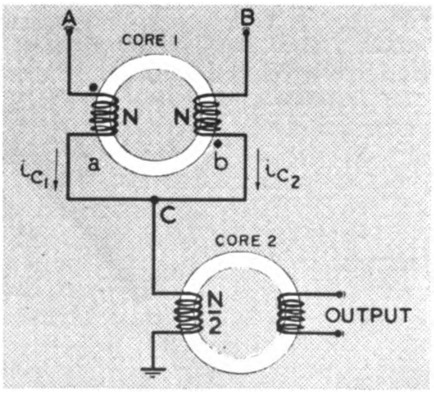

Figure 2: A two-input "AND" gate.

Gates

Using the three relations stated in the last section we are now in a position to construct a two input "and" gate. This is simply a device with two inputs and one output; both inputs must be energized at the same time to get an output. Fig. 2 shows such a circuit. Core 1 has two winding of N turns with relative polarities as shown. (The dotted terminal convention is used, that is, "currents into dotted terminals cause fluxes that add," or alternatively, "dotted terminals have the same instantaneous polarity.") Points A and B are the two input terminals with respect to earth. Here and throughout the rest of the paper a 30 kc square wave of 20 volts amplitude has been adopted as the power source. The reasons for this voltage form will be given subsequently. This voltage will be referred to simply as E (meaning the instantaneous bus voltage). Then, if E is applied to point A, and point B left uncompleted, a current i_{c1} will flow through coil "a" down to the $\frac{N}{2}$ winding of core 2. Since i_{c1} will correspond to H_c for core 1, this core will cycle around its BH loop; but i_{c1} is exactly half the necessary current required to cycle core 2 since it has $\frac{N}{2}$ turns. Since core 2 does not cycle, no output voltage will be developed on its output winding. If now point B is connected to E, then core 1 will stop cycling since the two input currents are in opposite senses, thus causing no net magnetizing force in the core. Therefore core 2 will cycle, since point C is at E, and an output will result.

In this type of gate the input terminals (A and B) are either connected to E or open circuited. This is not always possible in practice and so a gate whose input terminals are either E or O volts is useful. In Fig. 3, if point A is at E and point B at zero, then i_{c1} flows into the winding of core 3. This is insufficient to cycle it, hence there is no output voltage. If now, point B is raised to E, an additional current i_{c2} is available.

The sum of $i_{c1} + i_{c2}$ is just sufficient to cycle core 3, giving an output.

The output of a two-input "And gate" can be fed into another such gate and thus "And gate" of any number of inputs can be built up.

Amplifiers

The voltage wave form degenerates after passing through several gates and it is necessary to regenerate it occasionally. For this purpose a regenerative or amplifier circuit is necessary. Fig. 4 shows the circuit of such an amplifier. Cores 1 and 2 are connected in such a way that there is no net voltage around the loop composed of the "a" coils, that is, the control circuit. Core 3 will thus have only half current flowing into the winding. Core 4 is an input transformer and core 5 is a series inductance to filter out switching transients. The diode and condenser impose an average dc current in the control loop if there is a signal present at the input terminal. This dc control current will saturate cores 1 and 2 and core 3 will then receive the full bus voltage and develop an output at the terminal marked "+ output." The extra winding on core 3 is a so-called "negation" output. With no input voltage at the input terminal core 3 will not cycle, therefore no voltage will be developed across any of its windings, thus the terminal marked "– output" will be at E by conduction through the coil up to the bus. When an input voltage is applied, core 3 is cycled, a voltage equal to E is developed across each of its windings and the potential at "– output" disappears because of the relative polarities of the coils.

This outline is quite standard magnetic amplifier practice except for one very important feature. The square loop output core gives the amplifier a threshold characteristic. For no input there is no output. As the input voltage is increased the output stays at zero until a certain threshold is reached, thereafter the output goes up very rapidly. The threshold input level can be designed to have a large range of values. The threshold effect means that amplifiers can be cascaded without an accumulative "leak-on" effect. Typical amplifiers have the following characteristics: Input 20 volts at 15 ma giving an output of approximately 20 volts at 150 to 200 ma.

The threshold effect mentioned in the last section enables the modifica-

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* The authors' mathematical proofs for these statements have been omitted here.

tion of the amplifier circuit to a bistable unit, that is, a unit whose output is normally zero, but if turned on, will remain on. This unit is analogous to a relay which when picked up holds itself.

Fig. 5 shows such a circuit. The output is normally zero. If a voltage is applied at the terminal marked "Trigger," the output becomes equal to the bus voltage (E). The output remains E when the trigger voltage is removed, and until the bus voltage is interrupted. Thereafter it remains zero until re-triggered.

Inhibiting Gate

It is sometimes necessary to simulate the "back" contacts on a relay. The unit of Fig. 6, when connected to the negation output of an amplifier, is used for this purpose. The gate itself is similar to the amplifier circuit except that it has no output coil. It does not have an output voltage of its own, but rather acts as a variable impedance between its output and input terminals. Normally with no voltage applied at the terminal marked "control," there is approximately 400 ohms impedance between "input" and "output" terminals. With a voltage applied at the control terminal the transfer impedance drops to approximately 5 to 10 ohms. These values of impedance are typical of the present circuits; these circuits can be designed to give other values if required. It was explained in a previous section that the negation output of an amplifier is zero if the amplifier is "on," and E if the amplifier is "off." Thus in Fig. 6, with a signal into the amplifier, its positive output terminal is at E volts, its negative terminal is at zero, hence the control terminal of the inhibiting gate is at zero and the gate is in its "closed" or high impedance state. With no input to the amplifier the inhibiting gate is open. If the wire connecting the amplifier and the inhibiting gate opens for any reason, it is seen that the inhibiting gate will revert to its high impedance or "closed" state.

Fail-Safe Features

All the circuits described so far have one thing in common, namely, if the circuit is opened at any point the result will be the loss of output voltage. In the gate circuits this can be readily appreciated because of the extreme simplicity of these circuits. The amplifier circuit has two other components in it, a diode and a condenser, and the result of failure in these components on the amplifier circuit as a

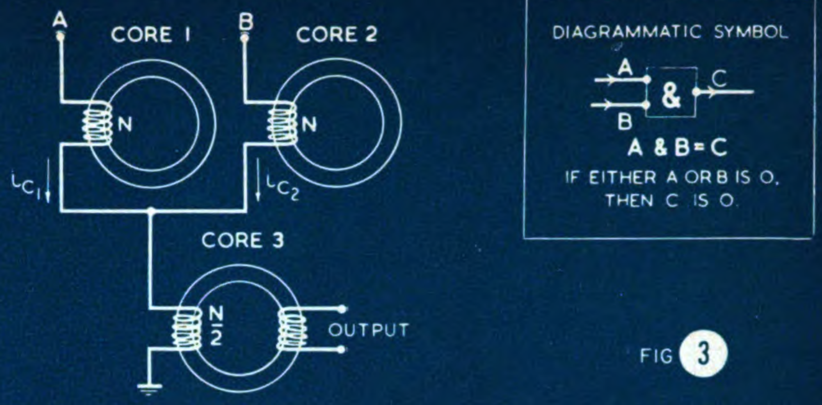

FIG 3

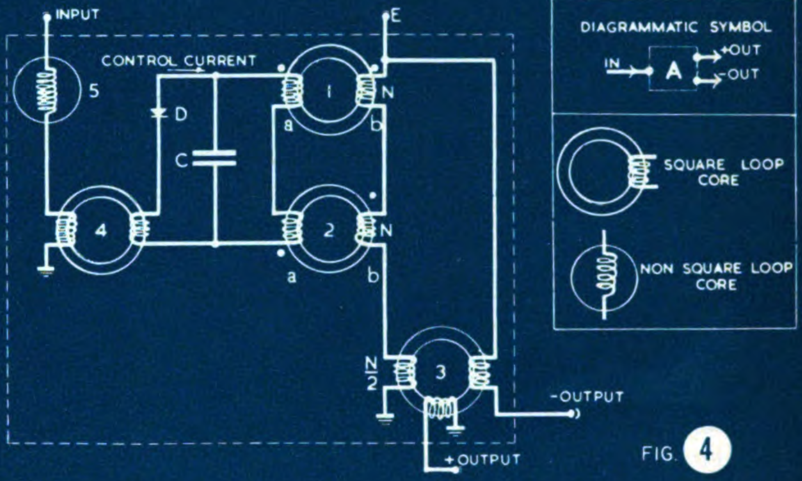

FIG. 4

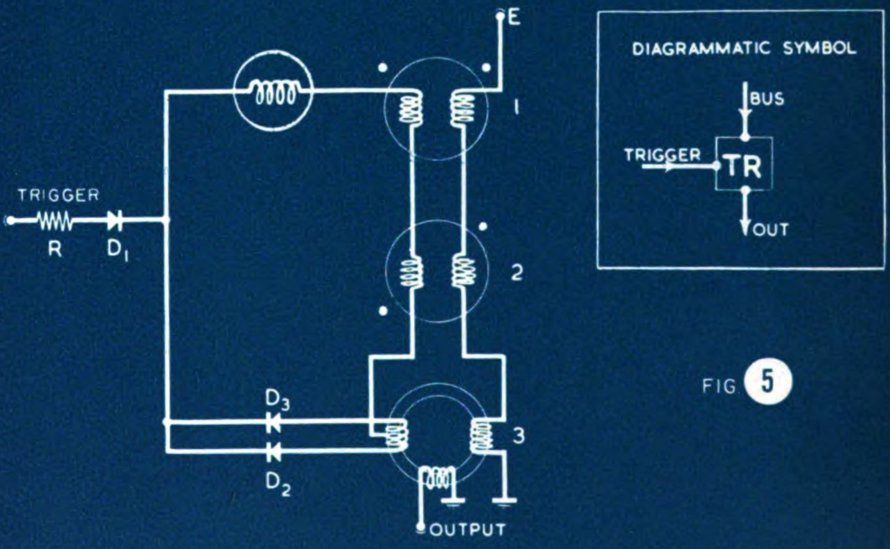

FIG 5

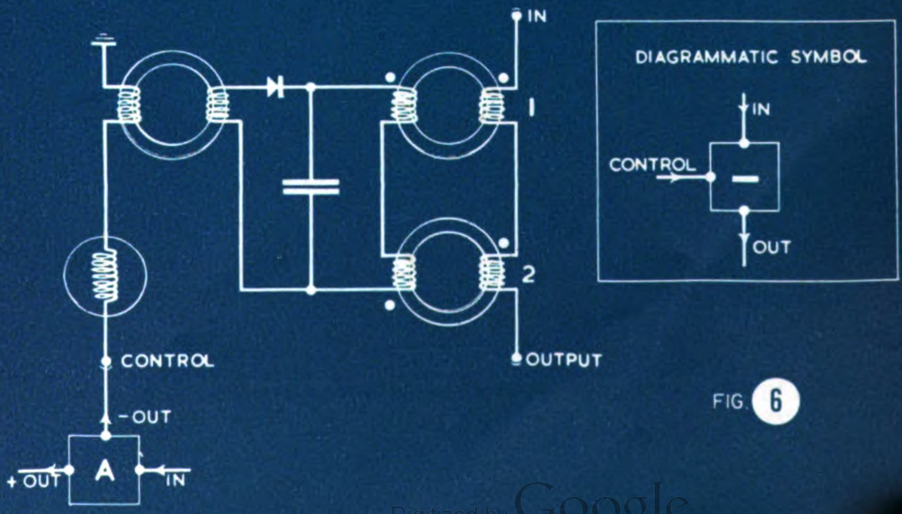

FIG. 6

whole may not be entirely obvious. From Fig. 4, in order for cores 1 and 2 to pass enough current to core 3 to cause it to develop an output voltage, they must have an average dc current flowing in the "a" coils, or control circuit. An ac current flowing in the control circuit results in no output. Thus if the diode "opens," there will be no current in the control loop, and hence no output voltage. If the diode "shorts," there will be ac current in the control loop and hence again, no output voltage. If the condenser "shorts," there will be no control voltage. If the condenser "opens," the magnitude of the dc current in the control loop will be so reduced that the amplifier will have either no output whatever, or a very small output when it would otherwise be "on" fully. The diode and condenser do not occur indiscriminately in the circuits but only in the way just described. The same arguments apply also in the case of the bistable unit and inhibiting gate.

In general, it can be said that all forms of circuit failure are safe except an insulation failure in some coils. Several suggestions for rendering insulation failure less of an objection are considered later.

Simple Switching Example

The design of the various gates, amplifiers and bistable units which, when connected together according to some design procedure will control the signals, has been discussed. The logical design of such a system is best shown by taking a simple switching function as an illustration. A simple route consisting of two sections of track only will be considered (see Fig. 7). If the two sections of track are unoccupied, the route may be set by turning the entrance key and pushing the exit button. To make this illustration more complete, it will be assumed that the signal will be cleared only if an associated route, not shown here, is in the normal position.

The system must have at least two gates which will "open," that is, allow power to go through when the track circuits are clear, and an "inhibit" (or negation) gate which will open in the presence of a signal from the associated route showing that it is normal. All three gates require a signal to be present before they will open; this is in accordance with the usual safety precautions which require that a disconnected wire shall produce the same effect as a condition closing the gates.

The route trigger is a bistable unit which remembers that the exit button has been pushed, that is, that the route has been called, and will allow power to go through the rest of the circuit if the above conditions (labeled 1, 2 and 3 in Fig. 7) are satisfied.

If the route cannot be set up due to one or more of the safety conditions not being satisfied, or if, after the signal has cleared it is returned to normal by the passage of a train, the signalman is required to restore the entrance key before he can call the route again; the operation of the exit button alone should not clear the signal. This condition is satisfied by the bistable unit called in the diagram the "button trigger." This unit will interrupt the power to the exit button once the button has been pushed, regardless of whether the route has been obtained or not. The trigger is fed from the negative output terminal of an amplifier unit; that is, power is supplied to the trigger when the amplifier is off.

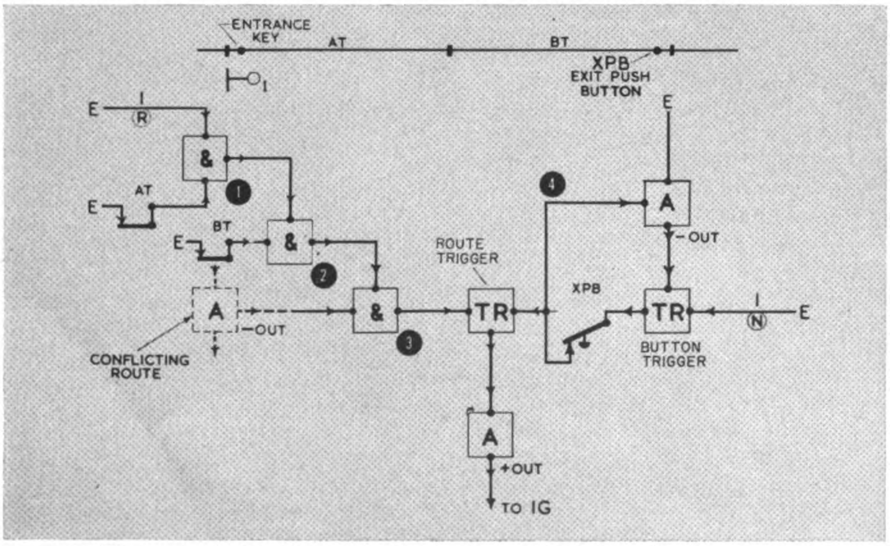

Figure 7: This example illustrates how ferrite cores could be used in signaling.

The trigger is turned on by means the normal contacts of the entran key, and will remain on irrespective the position of the entrance key. Pow is now available at the exit button. turning the key and operating the e button, the route trigger will or w not come on, depending on wheth the conditions 1, 2 and 3 are satisfi or not; at the same time, the amplifi is turned on; thus there is no pow at the negative output terminal a the "button trigger" is turned off, i terrupting the power to the exit bu ton. This switches off the amplifi and restores the power to the trigge which remains off until the restoratio of the entrance key. In other word the operation of the exit button caus the power to it to be interrupted r gardless of the state of the route tri ger, until the entrance key has be restored.

This unit is not fail-safe since di connecting the lead (4) from the ex button to the amplifier would result the power to the exit button not bei interrupted on operation of the ex button. However, this does not affect the safety of the circuit as a whole. since the necessity to restore the entrance key once the exit button has been pushed is dictated by convention and not by safety considerations.

The amplifier increases the power available to the value required to operate the signal lamps. The negative output from the amplifier unit is used to operate the "inhibit" gate of the conflicting route. This output is present only when the amplifier itself is producing no output, that is, when the route is not set.

Thus it can be seen that this "logical" switch system simulates exactly the behavior of relay systems.

Interlocking Example

It was decided to instrument a model of a double track junction, the symbolic diagram of which is shown in Fig. 8. Several of the refinements usually found in standard signaling practice (route-locking, for instance) have been left out of this model for purposes of simplification. It must be emphasized, however, that these omissions do not imply any inherent limitations of the circuit approach presented. In fact, at this stage of the investigations, no reason has been found to prevent these new circuits from performing all the functions of the present relay system. It is felt that the existing model is sufficiently complex to demonstrate the possibilities of the system.

Fig. 8 shows a block diagram of the

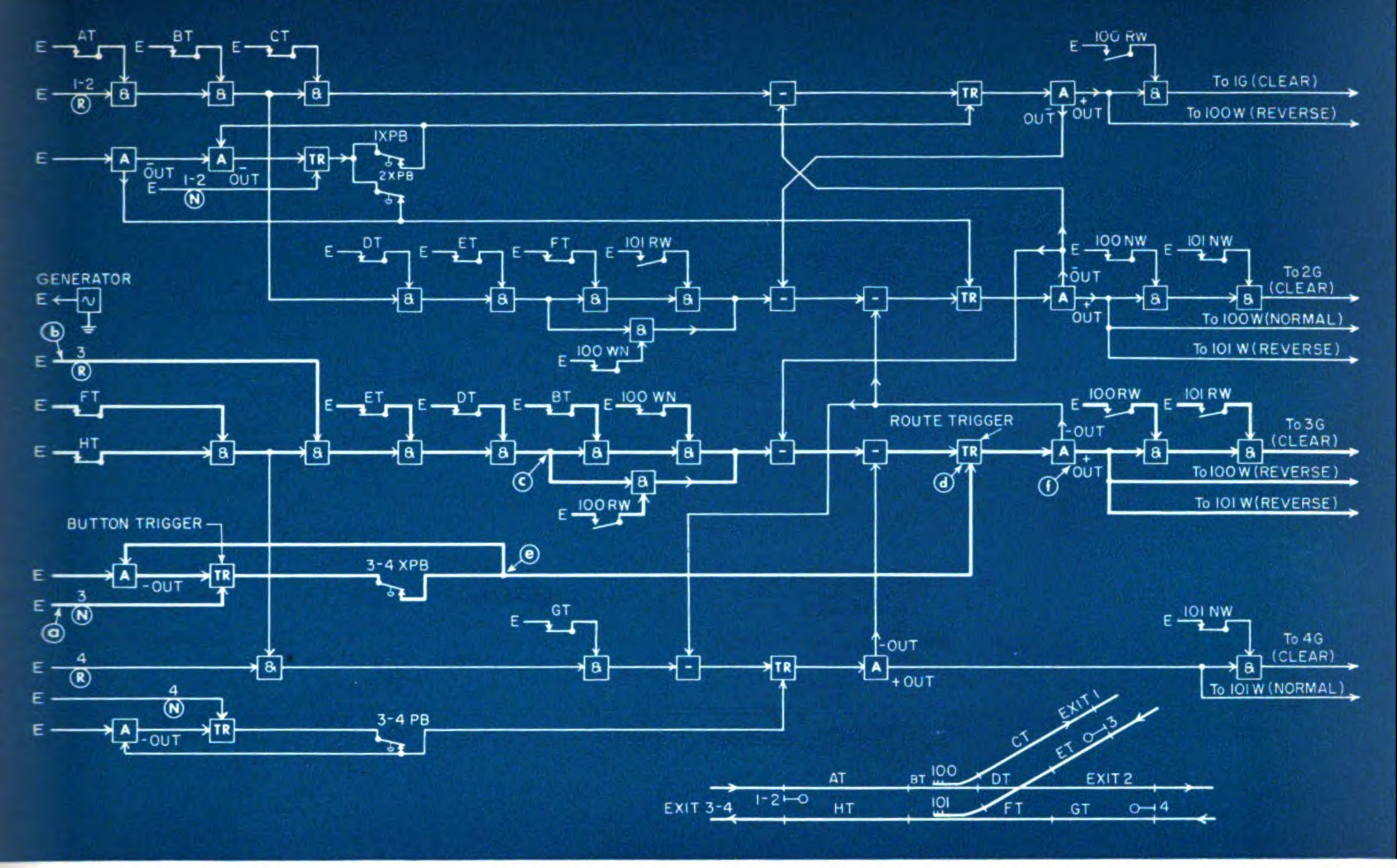

Figure 8: Circuits such as this interlocking example may be used to perform all the functions of the present relay system.

circuits involved. The diagram is somewhat simplified to facilitate its interpretation. Several design short-cuts have been used in the development of the circuits since all units are not yet compatible. The achievement of compatibility between all units will require more circuit development. Relays have been used to start the model switch machine motors. These relays are analogous to contactors in present switch machines.

The power source generator is shown as the box marked "Generator." It consists of several power transistors in a saturation controlled oscillator followed by current amplifiers. The output transistors act as switches making and breaking the connection from the output terminal of the generator to a dc source. This is a "fail-safe" circuit since failure of a transistor will inevitably result in no output from the generator, which is transformer coupled to the bus. The basic repetition rate is 30 kc per second. This frequency was chosen by consideration of the physical size of the core. E was chosen as 20 volts, and 50 turns as the smallest number of turns on any core (to limit heat dissipation).

A typical route, route 3, in Fig. 8, will now be considered in detail. With the entrance key in the normal position and the exit button released, power is available at the "button trigger" which is switched on by the normal contacts of the key (a). On operating the key, the "button trigger" remains on, and, if track relays E, D, F and H, are energized the bus voltage proceeds through the E, D, F and H gates (b). Then, with switch 100 reversed, the bus voltage passes through the corresponding gate. If the switch is normal and the detector circuit, BT, is unoccupied, an alternative path is established by gates "BT" and "100 WN" (c). The two inhibiting gates then follow. These gates will only be open if routes 2 and 4 are not lined. This is fail-safe since an opening of the connection to the "control" terminal will close the gates, as described previously. Power is now available at the input of the route trigger (d), which may be switched on by pressing the exit button (e). This action also causes the button trigger to be switched off, via its amplifier, thus interrupting the power to the button. The route trigger controls the amplifier (f), which provides an inhibiting condition for routes 2 and 4, and an output to actuate the signal. That is, following down from "+out" terminal of the amplifier (f), if switches 100 and 101 are normal, they will be reversed. The power can then proceed through the two gates "100 RW" and "101 RW" to the signal light.

The route trigger (d) is holding through all the necessary gates. Interruption at any point will turn it off and a new route setting will be required. This can only be obtained by first resetting the key, since no power is available at the exit button until this is done.

Conclusions

The preceding circuits do not solve all the problems encountered in railway signaling. Such refinements as approach control and locking and timing circuits have not been included. However, it can be said that their inclusion would not present a major problem. The work has in fact shown that a system as safe as and in all probability more reliable than the present electro-mechanical relay system, can be designed at a cost remarkably lower than the relay systems. Preliminary estimates would indicate a reduction in cost by a factor of the order of ten.

One-inch diameter cores were chosen for ease of winding in the laboratory. One of the first improvements that come to mind is a reduction in core size. This measure, together with an increase in the power source frequency would lead to a more efficient system and to the need for less turns in the coils. It is conceivable that the number of turns would be so small that each turn would be physically separated from its neighbor, thus eliminating insulation problems. "Potting" the units in resin would render them entirely weatherproof and shockproof.

(*Continued on page 48*)

FERRITE CORES IN SIGNALING

(*Continued from page 23*)

The design of entirely compatible units, that is, units that could be connected together indiscriminately would be the next step. At present, the amplifier unit is the only one that is entirely compatible, that is, it can have any other unit as input or output. Finally, to facilitate wiring and reduce wiring costs, the design of the basic circuits as "plug in" units seems to be indicated.

The present investigation has been carried out in close collaboration with the British Transport Commission who placed a contract with the Electrical Engineering Department of the Imperial College for the equipment required.

ACCIDENT REPORT

(*Continued from page 27*)

ern enginemen were injured.

Under the rules of both carriers a reverse movement within the limits of an interlocking, or a forward movement after making a reverse movement, must not be made without the proper interlocking signal indication or permission from the operator. In the instant case, the forward movement to the crossing, after a reverse movement, was made without permission of the interlocking operator.

The investigation also disclosed that the interlocking was maintained and operated by the Southern, and that the CofG track circuit extended eastward in the interlocking to a point 17.6 ft west of signal 20, instead of to this home signal as required under the Commission's rules, standards and instructions governing interlockings. If the CofG track circuit had extended throughout the interlocking as required, the locomotive of Extra 141 West would have occupied this track circuit when it stopped after the coupling was made to the cars on the pick-up track. The interlocking operator would thereby have been unable to cause signal 2-4 to indicate Proceed for the movement of First 153 through the interlocking, and the accident would probably have been averted. In this case, the Commission has taken appropriate action to obtain compliance with its rule requiring track circuits and route locking to be provided throughout interlocking limits.