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TECHNICAL INFORMATION SERIES

Title Page

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TITLE

ASTRAC - SCR CONTROLS FOR MODEL TRAINS

ABSTRACT

A low cost remote control system for model trains employs SCR's. Both transmitter and receiver circuitry are discussed. Multichannel system allows independent simultaneous operation of many trains on one track.

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CONCLUSIONS

The ASTRAC system is an excellent example of the commercial possibilities for SCR's. Low cost and high performance make the remote control features of this system very attractive. Initial market penetrations show excellent consumer acceptance.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

For list of contents—drawings, photos, etc. and for distribution see next page (FN-610-2).

INFORMATION PREPARED FOR W. L. Ferrigno

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JD HARNDEN
K. HOWELL
RH HUEBENTHAL
HB MOORE
J. MUNGENEST

One principle objective of model railroading is realism. Many hours and thousands of dollars have been spent in the perfection of reproductions of railroad equipment. However, until a short time ago, very little had been achieved in the simulation of true train operation. Independent operation of multiple trains on one track had been cumbersome, to say the least. The low speed performance of smaller gauge model trains left quite a bit to be desired. Without complicated and often expensive equipment, headlamps and parlor car lights varied in brightness with the speed of the train. It is obvious that while mechanical realism flourished, operational realism floundered.

Early in 1962, the concept of selective frequency control for multiple train operation was revived. This means of control had been employed as early as the thirties, using thyratron tubes as the motor control element. Consider, if you will, the size and weight of a thyratron control receiver, mounted in a train, complete with two tubes, A, B, and C batteries, coils, capacitors, and the sundry other items necessary for operation. Virtually a whole train was necessary to house this equipment. Additional other problems, such as battery life, hazardous voltages, heat and instability, branded this method of control unsatisfactory.

In principal, selective frequency control is basic. Defining a selective frequency control system, we might list the following parameters:

1. Each train engine would be controlled by a single frequency signal.
2. The signal, applied to the tracks, would be intercepted by a selective receiver in that engine.
3. The signal, processed in the receiver, would be converted to a form whereby it controls the power available to the engine motor, in a proportional manner.
4. The motor power would be supplied from the tracks.

Deviating for a moment, it might be wise to consider the broader aspects of selective frequency remote control, as it might have application to any number of devices and products. A generalized parallel of the above parameters would be:

1. A single frequency signal would be used to control any device requiring power.
2. The signal would be carried by the power conductors to the device and might be introduced at any point on those conductors.
3. The signal, intercepted and processed by a selective receiver, could be used in either a proportional manner, such as motor speed control, or a step function, such as relay actuation.
4. The power utilized by the device would be supplied from a line source.

The ramifications of a selective frequency control for model trains are extensive. The size and weight of the total receiver is limited by consumer demands that it fit either in the engine itself, or one car immediately behind. The receiver must be capable of handling various loads, as presented by the many different engines, trains and motors both on and off the market. Power control must be proportional, not stepped, and very smooth. High motor torque at creep speeds is essential for realistic operation. Other major considerations are stability of tuned circuits, transmitter frequencies and active components, along with variations of track length, line voltage, track voltage, ambient temperature, the number of trains operating on one track at one time, the regulation of the track power transformers, line losses, amount of operation, shock, vibration, detuning by proximity to metals, co-channel interference, component variations, frequency spectrum, and last but certainly not least, radio interference.

At first, the engineering design of a system that meets the above requirements looks difficult. After a subtle hint by the marketing manager that the equipment must be low cost, it looks even worse.

This was 10 months ago. Today, the system is a reality.

At this point, let me introduce you to ASTRAC*, standing for Automatic Simultaneous Train Control.

The ASTRAC system is a breakthrough in the area of realistic control for model trains. Some of the features of the ASTRAC system are:

* Multiple train operation, simultaneously and independently, on the same electrically continuous track.
* Full voltage on the tracks at all times gives constant brilliance to headlamp and parlor cars. Accessories requiring constant voltage can be wired to the nearest track terminals.
* Ultra low speed operation, at increased power. Creep speeds so slow, you can barely see the wheels turn.
* Higher power efficiency from existing power packs by elimination of the rheostat and rectifier.
* AC track voltage allows better balanced multiple track feeds.
* Small receiver size means adaptability to most gauge trains.
* Simplicity of the system allows equally simple installation.
* Low cost for multi-channel - multi-function remote control system.

The heart of this ASTRAC system is the micro-receiver -- tiny, rugged and stable - made possible by Silicon Controlled Rectifiers, better known as SCR's.

SCR's are very new miniature power control devices, capable of handling high power without appreciable loss. Their small size makes them invaluable for this application. The electrical operation of an SCR is quite simple. Basically, an SCR is a type of diode which will allow current to pass through it in one direction only. Also, no current will be allowed through until a small triggering signal is applied to the SCR. Let's look at the way SCR's are utilized in the

ASTRAC receivers. The SCR is in series with the load (a DC motor for model trains) as shown in Figure I. The current that passes through the SCR will also pass through the motor. The power supply to the tracks is in the form of 60 cycle AC voltage from a transformer, as pictured in Figure 2. Here the SCR is shown in its symbolic form. Current can pass through the SCR only in the direction of the arrow (anode to cathode). This means that the circuit of Figure 2 utilizes only the positive half cycles of the AC wave. The current that would flow through the motor under full conduction conditions is shown in Figure 3.

As stated before, current can flow only when a triggering signal is applied to the SCR. The signal is applied between the gate and cathode of the SCR. When the gate becomes strongly enough positive with respect to the cathode, the SCR will fire, and current will flow. The normal means of applying the triggering signal to the gate-cathode is to use some of the transformer voltage, as shown in Figure 4. The voltage necessary to fire the SCR is represented by the dotted line. When the gate-cathode voltage reaches that level, point x, the SCR fires. One might immediately think that the SCR will cease conducting when the gate-cathode voltage reaches the firing level on the way back down, point y. However, an SCR is a device that will remain in conduction until the current through it decreases below a small enough value known as the "maintenance current". Only when the current reaches that point will the device shut off. Lowering, or even removal of the gate-cathode voltage, will not shut off the conducting SCR. The motor current for the circuit of Figure 4, then, has only the first part of the positive half cycle missing.

Controlling the average current through the motor can be accomplished by controlling the point in the half cycle when the SCR is fired, as shown in Figure 5. This is normally termed "phase" control.

In order to bi-directionally control a train motor, both positive and negative current must be available to the motor. The circuit of Figure 4 would allow only positive current to the motor. In the ASTRAC receivers, two SCR's are used in a back-to-back configuration to provide the positive and negative motor current, as shown in Figure 6A. SCR 1 controls the positive current, and SCR 2 controls the negative current. The operation of circuit for "Forward" movement of the train (positive motor current) is shown in Figure 6B, and "Reverse" movement in Figure 6C.

The triggering signals for the SCR's in ASTRAC receivers are in the form of high frequency bursts, as shown in Figure 7. These signals are applied to the gate-cathodes of SCR's through the simplified signal network shown in Figure 8. The signal is passed through a transformer to adjust it to the correct level.

Signal bursts are generated by a control transmitter. The output of the transmitter is connected to the tracks in parallel with the track transformer. See Figure 9. The next point is the key to the ASTRAC control system: the signal bursts from the control transmitter are synchronized to the 60 cycle power line. Therefore, if signal bursts are released every time the line voltage begins a positive half cycle, then these signals will appear on the tracks every time the AC track voltage begins a positive half cycle, providing the track voltage and line voltage are in phase. The signal will be superimposed on the track voltage. See Figure 10.

To produce a forward movement of a train, the synchronized transmitter signal bursts appear on the positive half cycles of the AC track voltage.

Reverse motion requires signal bursts on the negative half cycles. This implies a 180 degree phase shift between the track voltage and transmitter voltage to accomplish direction reversal. This can be accomplished by reversing a line cord plug, or by inserting a double pole -- double throw reversing switch somewhere in the AC supply line, either to the track or to the transmitter.

The transmitter output for the ASTRAC system has the following characteristics:

1. The signal bursts are constant amplitude, but variable width.
2. The width of the burst determines the conduction period of the SCR's in the receivers. The width, then, must be variable from zero to 8.1 milliseconds, or one half cycle of the AC track voltage.
3. The amplitude of the bursts must be sufficient to fire the SCR's.

The only significant portion of the signal burst is the leading edge, since its phase position with respect to the track voltage determines the conduction period of the SCR's. The rest of the signal burst does nothing but contribute to power dissipation in the gate-cathode junction of the SCR's.

Figure 11 shows a block diagram of the ASTRAC transmitter. A power oscillator produces the high frequency signal bursts. The oscillator is turned on and off by a trigger circuit. The trigger is in turn controlled by a line sync circuit. The phase position of the signal burst leading edge is determined by a pulse width control in the sync circuit.

Figure 12 is a schematic diagram of the oscillator. Basically, it is a simple tickler coil oscillator. The main design considerations are power output, and the shaping of the signal bursts. A high beta, high alpha cutoff PNP transistor, with a 50 volt V_{ce} rating, is currently being used. The fundamental frequency of the signal bursts, 100Kc to 255Kc, imposes the alpha cutoff requirement. The beta spec determines to a large degree the shape of the signal burst. The oscillator is a low output impedance device, and is heavily damped. Feedback is much heavier than the minimum required for oscillation. This is to compensate for varying track loads. C_4 is a DC blocking capacitor in the feedback circuit. C_3 is the emitter bypass capacitor, and C_8 is the tank capacitor. The oscillator has a high-C tank circuit for optimum temperature stability. R_7 and

R_8 are base bias resistors. R_9 is the emitter swamping and current limiting resistor. R_{10} is a damping resistor, to "bleed" the oscillator output, and maintain a fairly low impedance load.

The input signal to the oscillator is a variable width square wave. The amplitude, once again, is constant. The amplitude is sufficient to hold the transmitter in a conducting state. This square wave is produced by the trigger circuit, comprised as shown in Figure 13. R_5 is the collector load. R_6 is a current limiting and isolation resistor for the base of TR_2. R_4 is a negative voltage limiter for the base-emitter junction of TR-1. When a negative voltage appears at the input, it is divided between the back resistance of the diode, D_2, and the parallel combination of R_4 and the back resistance of the base-emitter junction. R_4 is effectively ten times less than either back resistance and serves to protect the base-emitter junction from reverse voltage breakdown.

The sync circuit drives the trigger circuit into heavy conduction to initiate a pulse burst. The sync circuit, in its simplest form, is shown in Figure 14.

Line frequency voltage is applied to the input. On negative half cycles, C_1 charges very rapidly through D_1. C_1 discharges through R_2 and R_1 on positive half cycles. If the discharge time constant is large enough, then C_1 will never completely lose its negative charge. This is shown in Figure 15A. T_D, the discharge time is greater than 16.2 milliseconds, or one cycle of 60cps. Never seeing a positive voltage, TR_1 of the trigger circuit remains cutoff.

Reducing the value of R_1, the pulse width control, produces a faster discharge. At some point, T_D will be less than 16.2 ms and C_1 will charge positively on the positive half cycle of input voltage. See Figure 15B. Diode D_2 and the base-emitter junction of TR_1 in the trigger circuit will be biased positively, and TR_1 will conduct heavily. The current flow through the base-emitter of TR_1 limits the positive charge on C_1.

R_8 are base bias resistors. R_9 is the emitter swamping and current limiting resistor. R_{10} is a damping resistor, to "bleed" the oscillator output, and maintain a fairly low impedance load.

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With R_1 equal to zero, diode D_2 of the trigger circuit is driven by raw AC from the line. TR_1 will now conduct for the full positive half cycle. See Figure 15C.

Refinements to the sync circuit are shown in Figure 16. R_2 and R_3 comprise a voltage divider to stabilize the discharge path through TR_1. C_2 and R_{11} are a simple looking addition but are the product of long hours of investigation.

In actual operation, the motion of a train was noted to be jerky as though the quiescent SCR was firing sporadically. This misfiring was first attributed to a poor signal to noise ratio, since motor brush noise and wheel transients were extremely high. The receiver did not misfire on a resistive load, adding to the noise theory. However, capacitors across motor brushes, and high Q signal circuits in the receiver did not markedly improve performance. Oscillographs of the track voltage showed the transmitter signals to be in sync with the track voltage. If the transmitter signal bursts were hanging over past polarity reversal of the line voltage, the situation would have been explained. It then occurred that the motor presented an inductive load to the circuit. The resulting phase shift across the load proved to be just enough to cause signal hangover. This was augmented by the forward anode-cathode bias on the quiescent SCR caused by the back emf of the motor. This is graphically illustrated in Figure 17.

An obvious solution would be to stop the signal burst long before polarity reversal of the line voltage. This could be done by a phase shift in the transmitter. However, a fixed phase shift could limit the minimum conduction angle of the SCR's. Therefore, a variable phase shift was introduced, made up of C_2 and R_{11} of Figure 16. As the resistance of R_1 is reduced, the phase shift of the current through C_1 increases. This causes the negative half cycle to reset TR_1 into cutoff much ahead of a line polarity reversal on the track at maximum burst width, when motor back emf is highest. At narrower burst widths, and lower back emf's, it was found that misfiring was not so prevalent and less phase shift was needed for correction.

The phase shift mechanism is based on the fact that the transmitter will stop when the voltage on C_1 becomes negative. If the voltage on C_1 precedes the line voltage in phase, then the desired effect would occur. The phase shifting components, C_2 and R_{11}, are in the positive charge circuit. When the positive voltage goes to zero, TR_1 resets. The turn-on point is determined largely by the minimum resistance of R_1 and R_{11} in series in the C_1 positive charge path. Considering R_1 reducible to zero, then the size of R_{11} will determine the maximum width of signal burst. R_{11} and C_2 are adjusted to produce optimum phase shift and minimum burst width compression.

The full schematic of the receiver is shown in Figure 18. L_1 and C_1 form a series resonant circuit which is connected directly across the tracks. Maximum current flows through L_1 at resonance, inducing maximum voltage in its secondaries. The secondaries are connected across the gate-cathode junctions of the SCR's through current limiting resistors R_1 and R_2. R_3 and R_4 shunt the gate-cathodes and serve to hold the input impedance of the SCR's to a nominal value. R_1 and R_3 form a voltage divided as do R_2 and R_4. This was done to reduce the amount of noise getting to the SCR's. Of course, the signal was reduced by a like amount. The signal reduction was compensated by an increase in the transmitter output.

The SCR's used in the receiver are 2N1595's having a 50-volt PIV, a 10 mil gate and a 1.6 rms ampere rating. This current and voltage rating is sufficient to handle most smaller gauge train motors.

The obtainable Q of the resonant input circuit determined, to a large extent, the layout of the frequency spectrum used in the system. The frequencies chosen were: 100Kc, 140Kc, 180Kc, 220Kc and 255Kc. The upper limit was set at 255Kc to keep the second harmonic out of the broadcast band, minimizing radio interference.

The extra frequency spread at the low end of the spectrum has to do with SCR sensitivities. SCR's are sorted, before use, into sensitivity categories. The more sensitive units are used in the upper frequency receivers where total receiver sensitivity is controlled by the resistors in the firing circuit, the transmitter output amplitude being held constant. Because of circuit Q and tuning considerations, co-channel interference would occur if the co-channel quiescent receiver were too sensitive or the transmitter badly mistuned.

The firing circuit resistors are adjusted for the lower frequency receivers to make use of the lower sensitivity SCR's. Yield in the sorting process is not a problem since the higher sensitivity SCR's can also be used in the lower frequency receivers. Total receiver sensitivity could be much greater than that of an upper frequency receiver. This is no problem insofar as co-channel interference is concerned as the lower channel frequency spread is adequate.

L_1 is built into a 3/8" by 3/8" miniature shield can. It has an adjustable ferrite core for tuning. The design of L_1 for this size can is an extremely difficult task. At resonance, the voltage across L_1 is in the order of 250 volts, the product of the transmitter output and the circuit Q. This voltage and the resonant circuit impedance of L_1 and C_1 causes a high current to flow through L_1.

Problems in core saturation occur, causing a loss in firing voltage to the SCR's. Operating in this high current region, the permeability and the inductance of the coil change with signal amplitude. This problem manifests itself in the change in receiver resonant frequency with a change in signal amplitude. The result can be misfiring or loss of firing altogether if signal amplitude is too large. Signal amplitude varies with the line voltage to the transmitter and regulation of the transmitter oscillator power supply. The system must operate on line voltages from 90 to 135 volts if it is for consumer use. This further complicates the problem of L_1 design. One solution to this problem is to use a construction with a relatively large air gap. High LC ratios have also proved helpful in reducing resonant frequency change with signal amplitude.

The total receiver, once assembled, is encapsulated in LTV-602*, a clear silicone rubber compound. The primary purpose of encapsulation is heat sinking the SCR's. LTV-602 is far inferior to a highly loaded epoxy, although it is ten times better than still air. The choice of LTV-602 was based on other considerations such as optical clarity (requested by Industrial Design), low durometer for shock proofing, insulation, and the ease with which the consumer might trim the receiver to fit his particular train.

Mass production handling of receivers makes LTV-602 a natural since it is easily mixed, has a reasonable pot life and cures in a short time at room temperatures. Chipped edges can be repaired without noticeable lines and with high bonding strength.

Measurements were made to determine the value of LTV-602 potting. It was found that temperature rise, measured at the bottom of the SCR case for maximum load current, was 50% less in the potted receiver as compared to a receiver in still air. Shock loads, equivalent to two large trains colliding head on at 150 scale mph, did absolutely nothing to a potted receiver.

The FCC is very specific about radiation interference at ASTRAC operating frequencies. Power line conduction of the transmitter signal is also specified. However, since both the transmitter and the tracks are transformer coupled to the line, no problem exists in this area. Radiation from the tracks is minimum because the parallel conductors of the track resemble a transmission line. Extensive measurements at worse conditions show the radiation to be well within FCC limits.

* General Electric Company, Silicone Products Department

Prudent design of the ASTRAC units has produced a highly-acceptable cost picture. The manufacturer's selling price of the receivers is in the order of five dollars, which includes material, manufacturing, overhead, advertising, administrative allocation, engineering, tooling and, of course, profit. A single transmitter with a five frequency selector switch has a manufacturer's selling price of about twelve dollars. This boils down to the fact that a double function (forward-reverse) carrier current remote control system, comprised of a transmitter and a receiver, could be made with extremely low costs. Adaptability of this system to specific areas, and products within the company might be highly desirable. Parameters of the system such as operating voltages, frequency, etc. are flexible and can be modified to fit the need.

These SCR's are going to market in model trains, and I am confident that they will soon be appearing in many more applications.

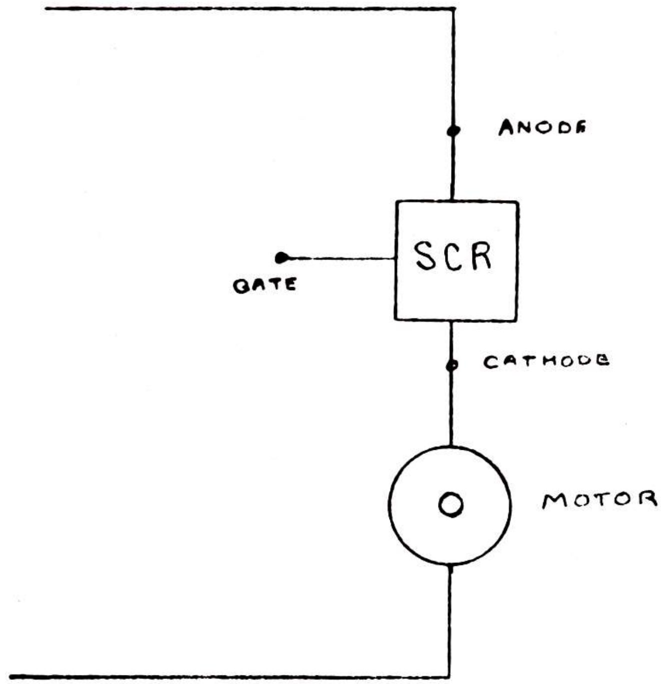


FIGURE 1

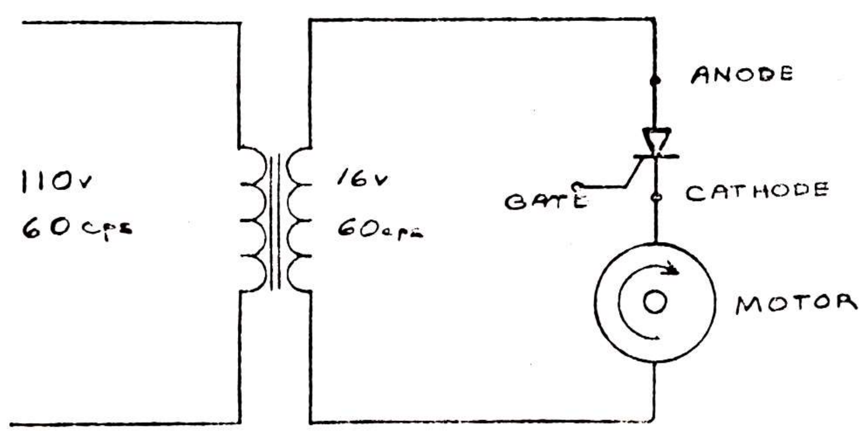


FIGURE 2

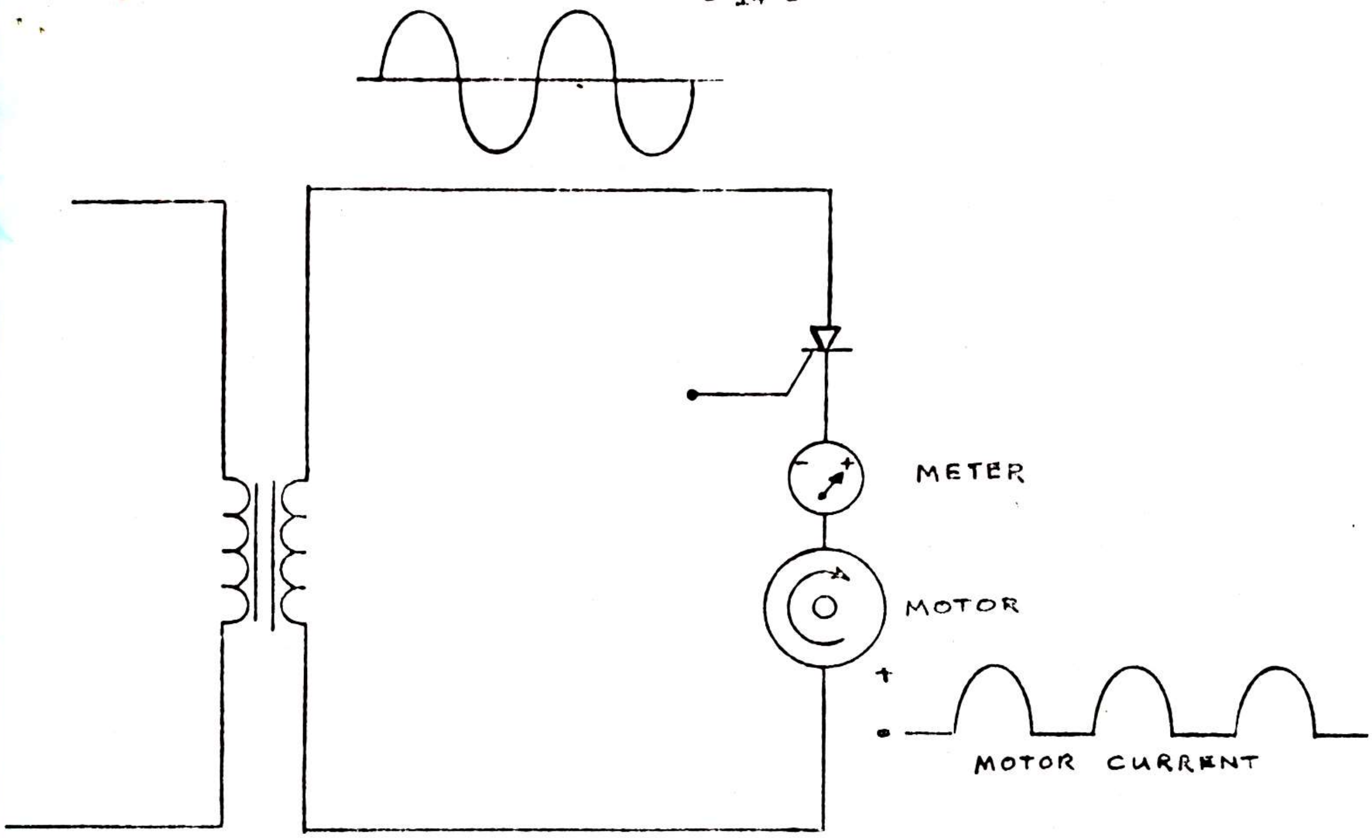


FIGURE 3

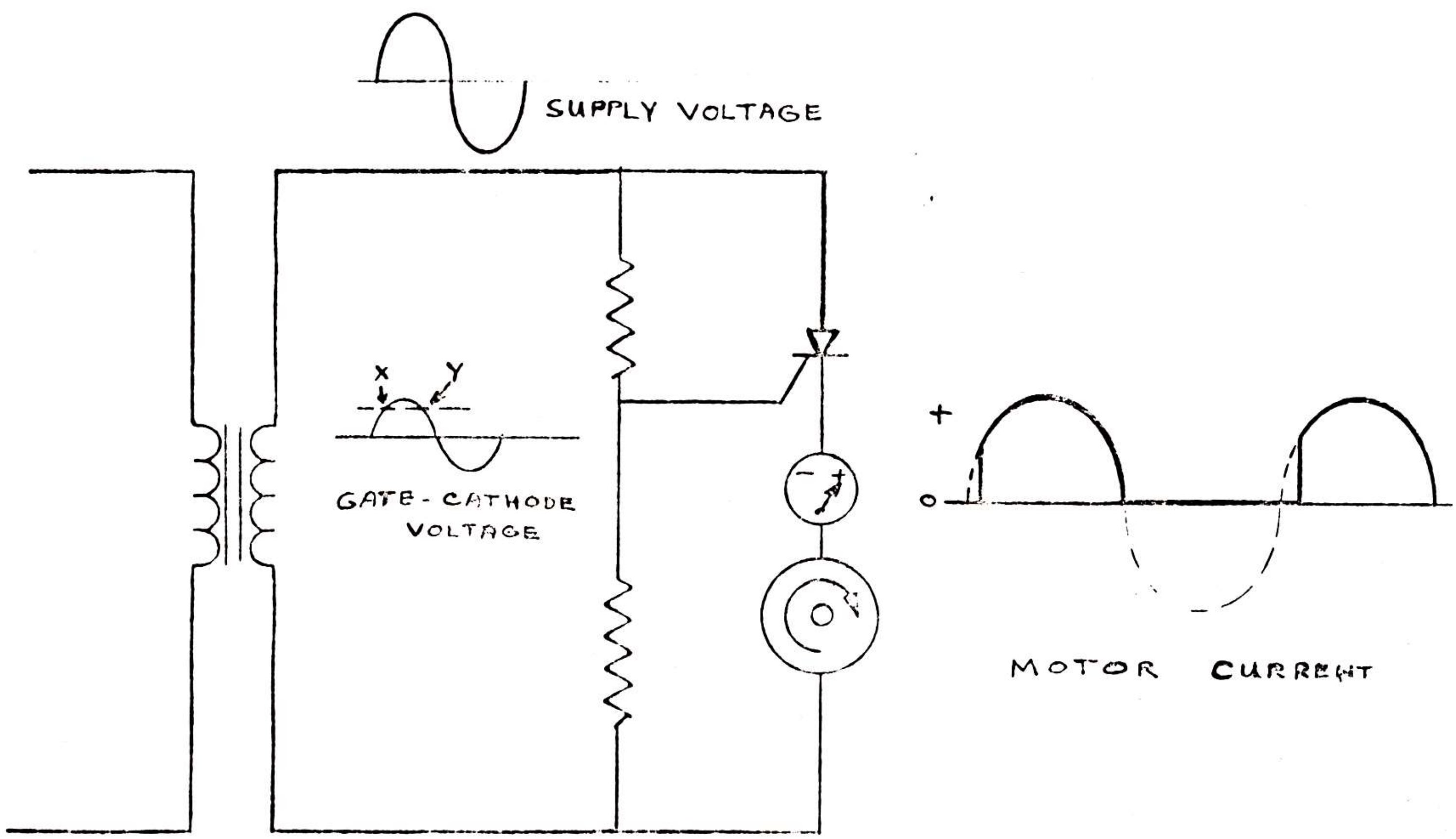


FIGURE 4

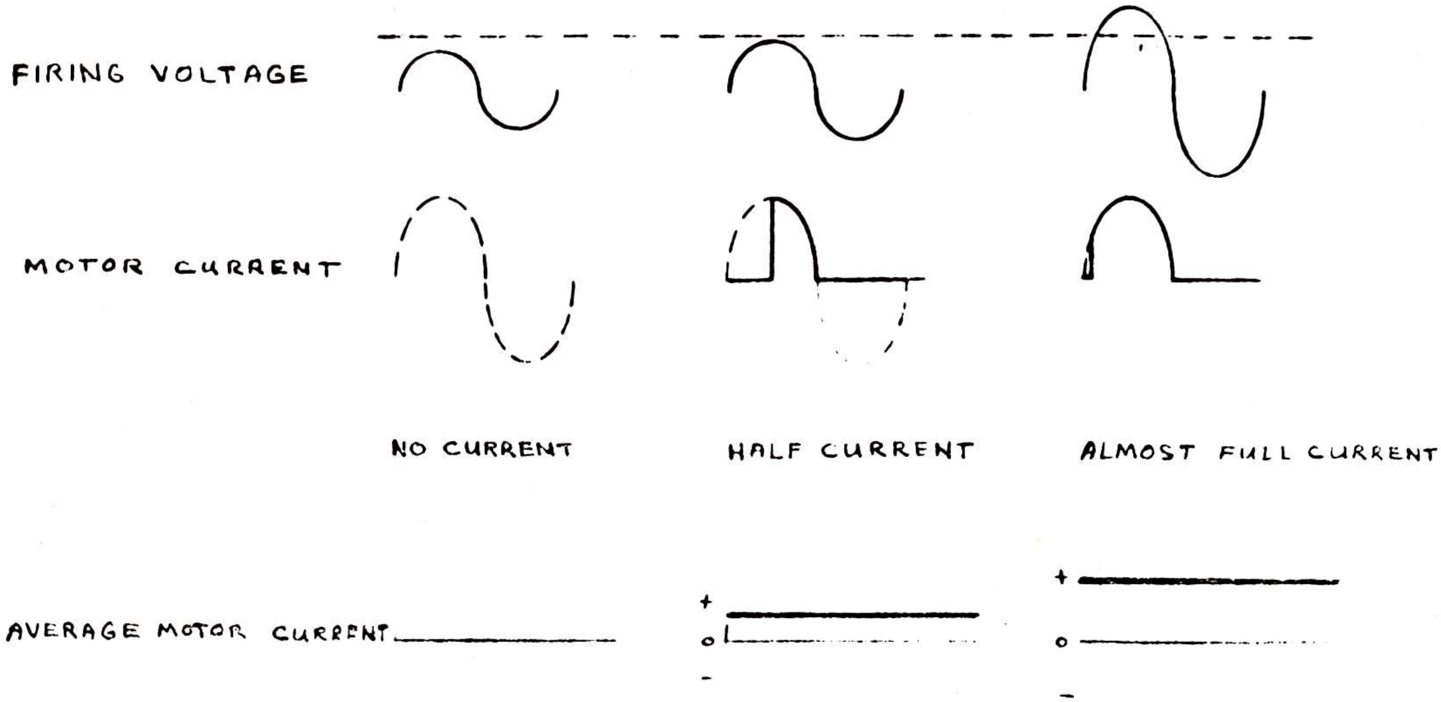


FIGURE 5

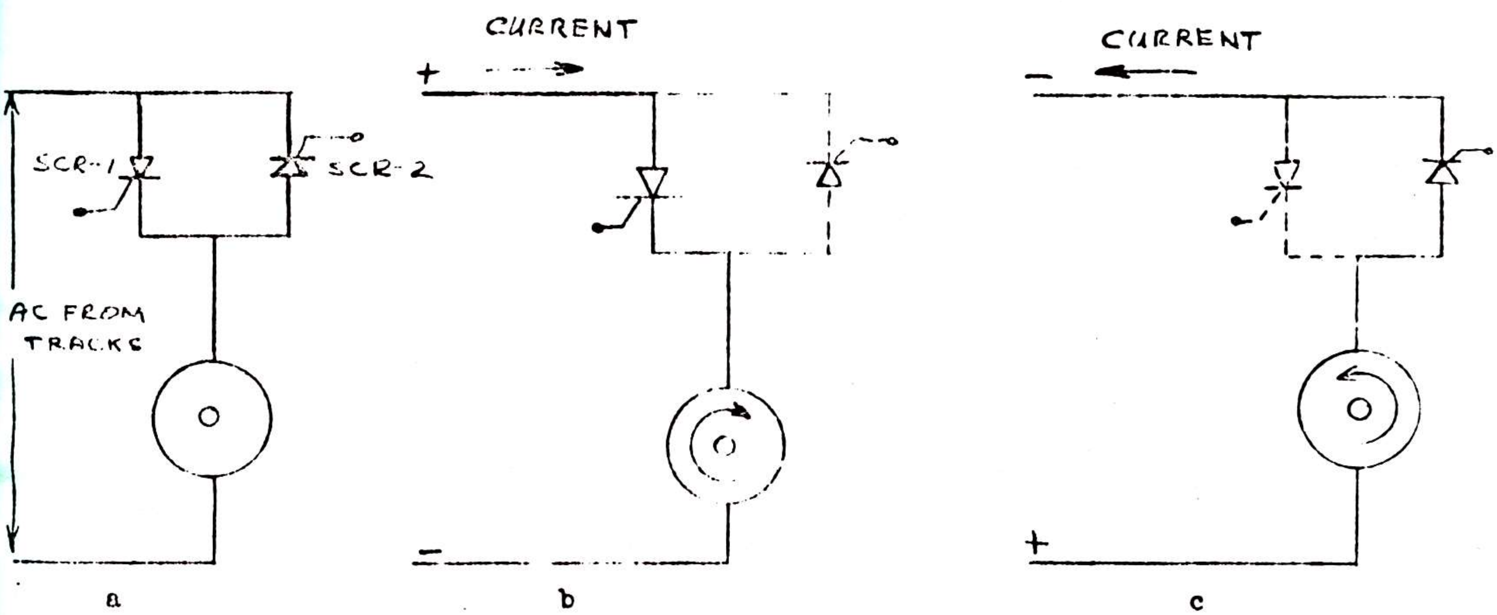


FIGURE 6

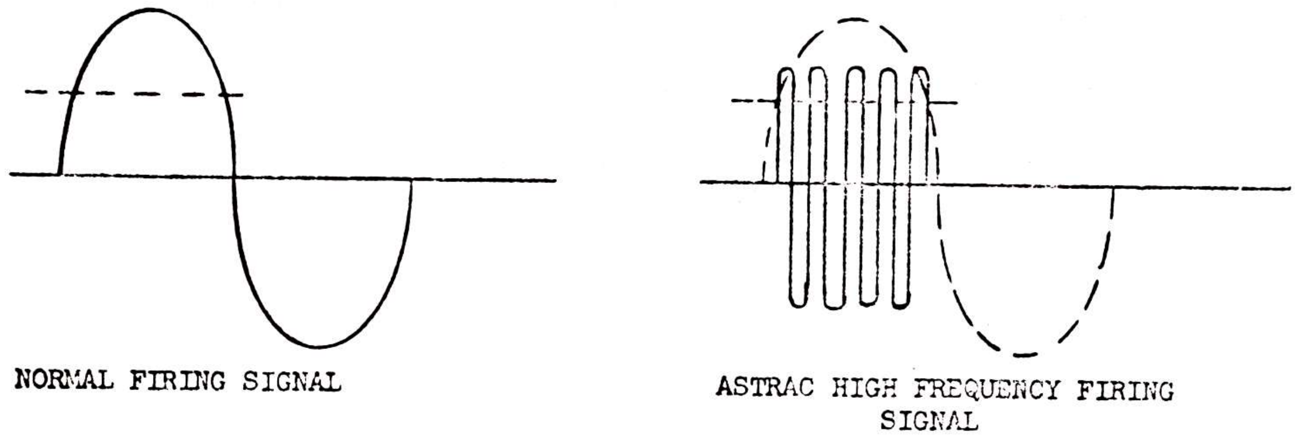


FIGURE 7

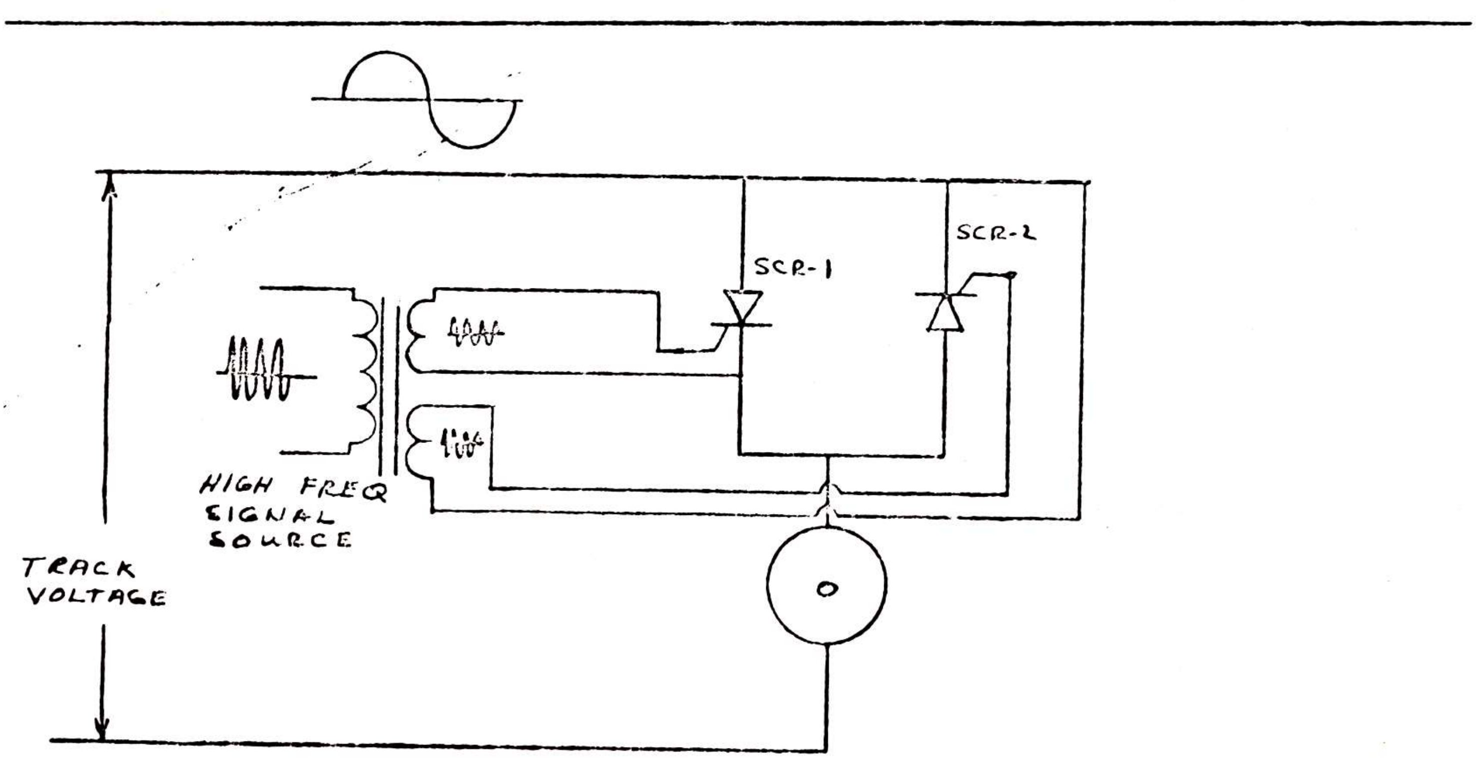


FIGURE 8

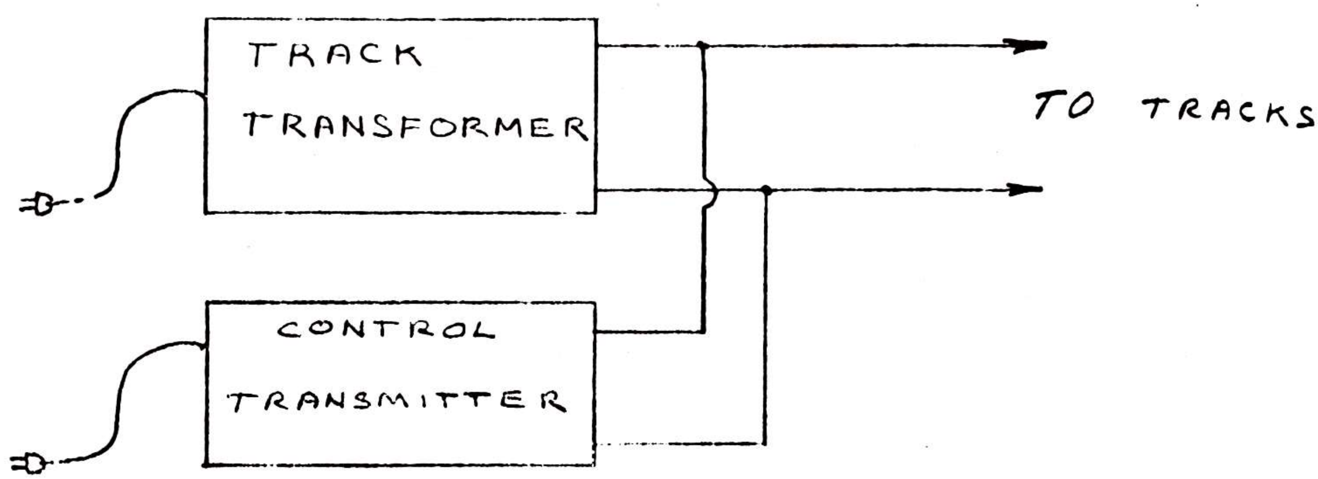


FIGURE 9

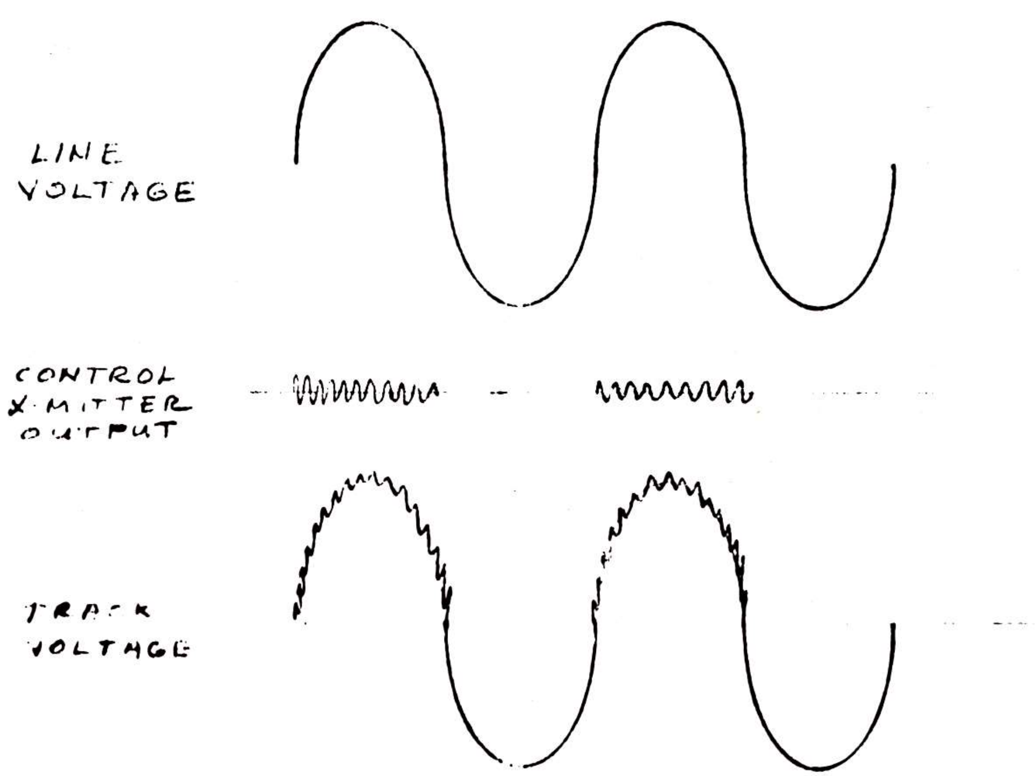


FIGURE 10

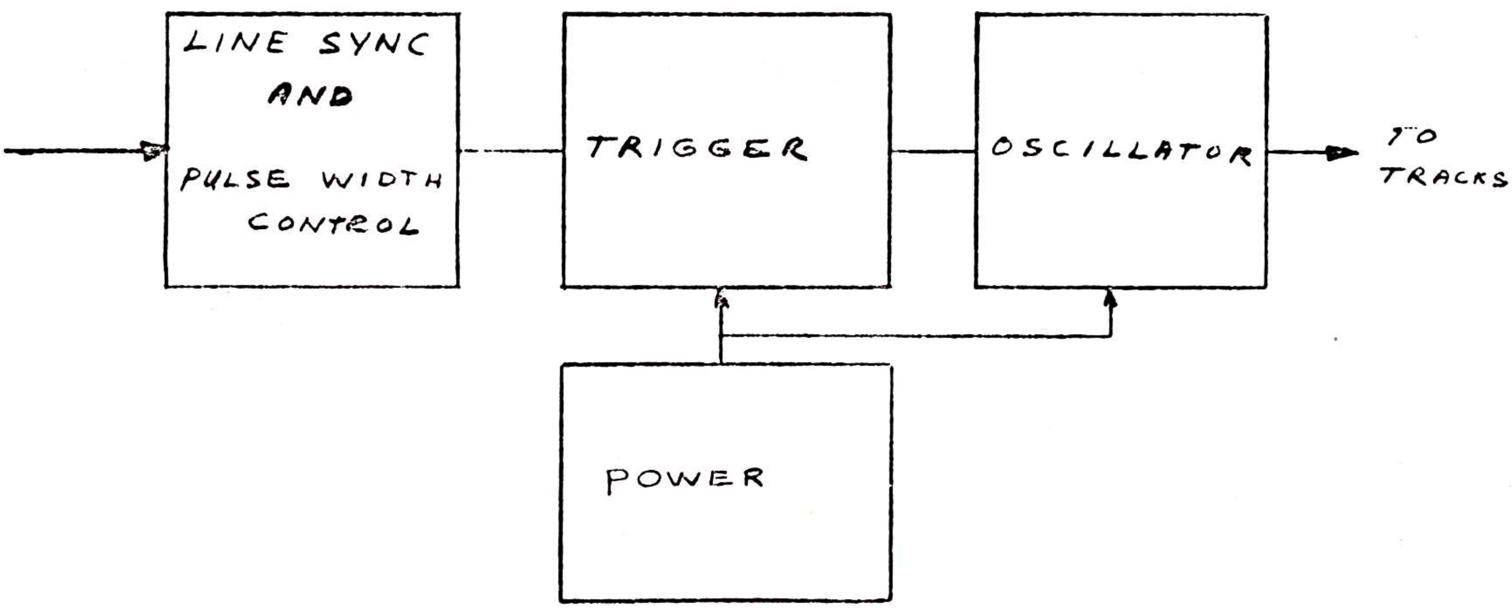

LINE SYNC
AND
PULSE WIDTH
CONTROL
TRIGGER
OSCILLATOR
TO
TRACKS
POWER

FIGURE 11

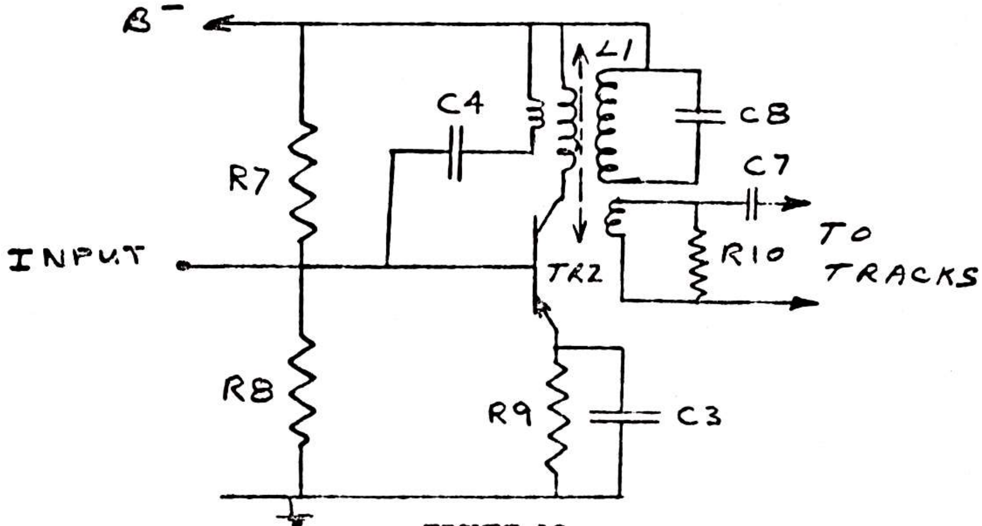


FIGURE 12

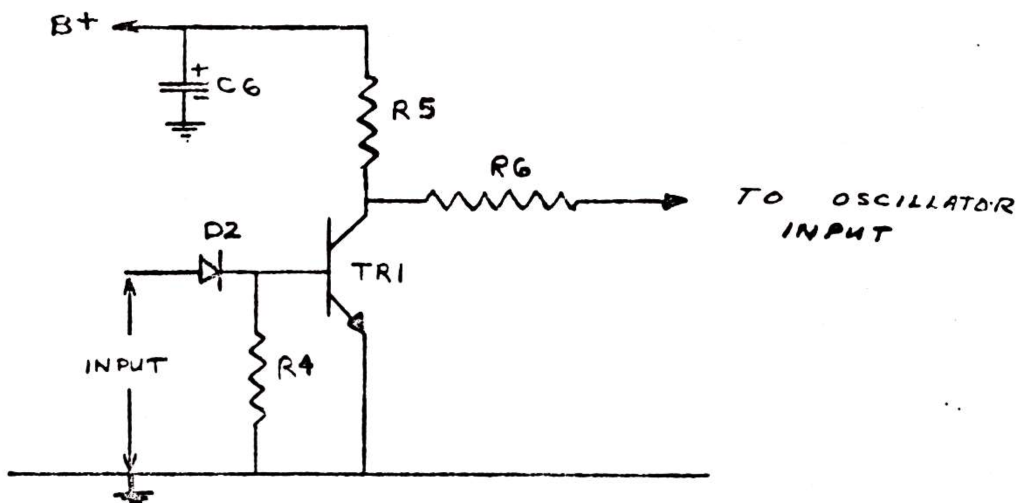


FIGURE 13

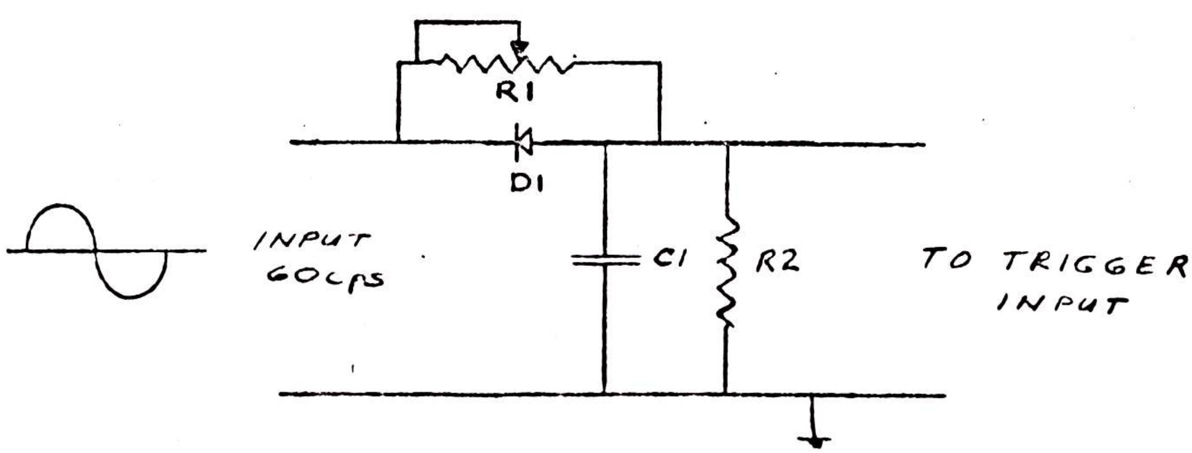
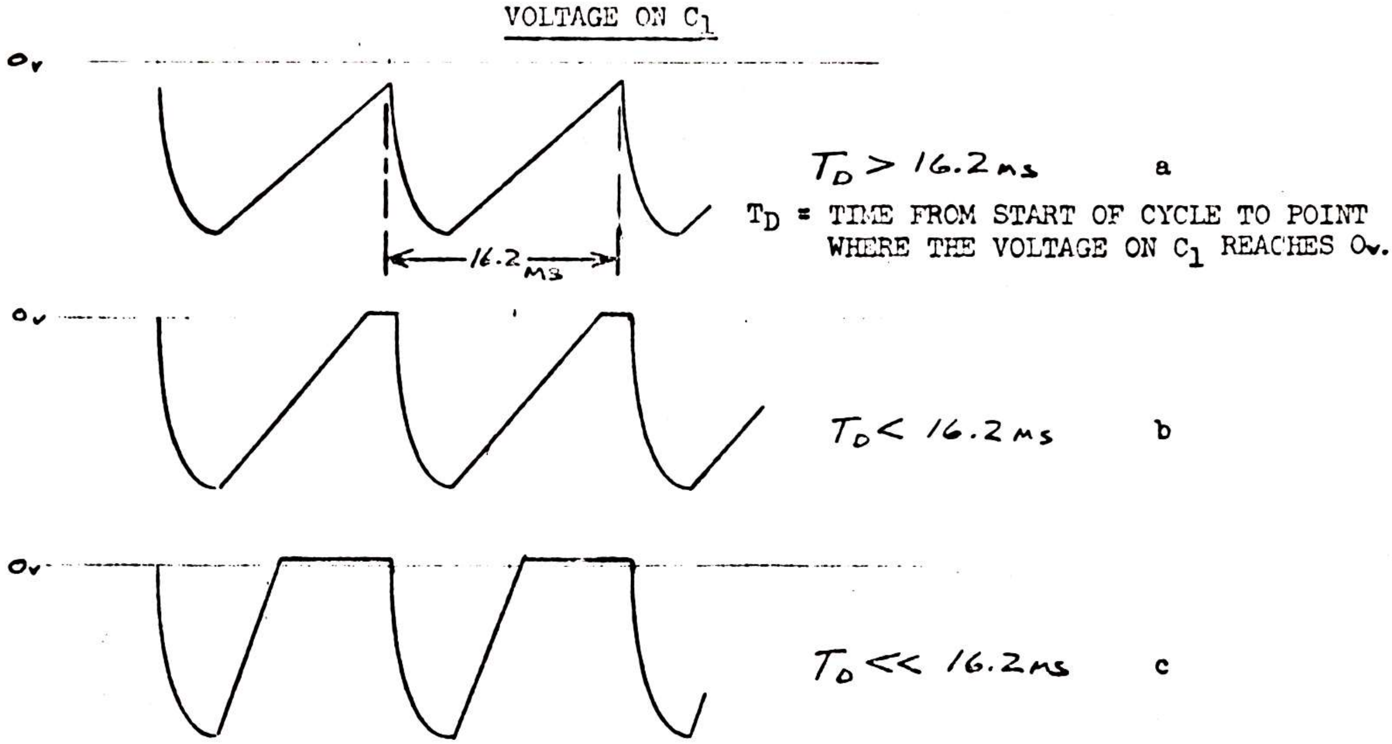


FIGURE 14



T_D = TIME FROM START OF CYCLE TO POINT WHERE THE VOLTAGE ON C_1 REACHES 0v.

FIGURE 15

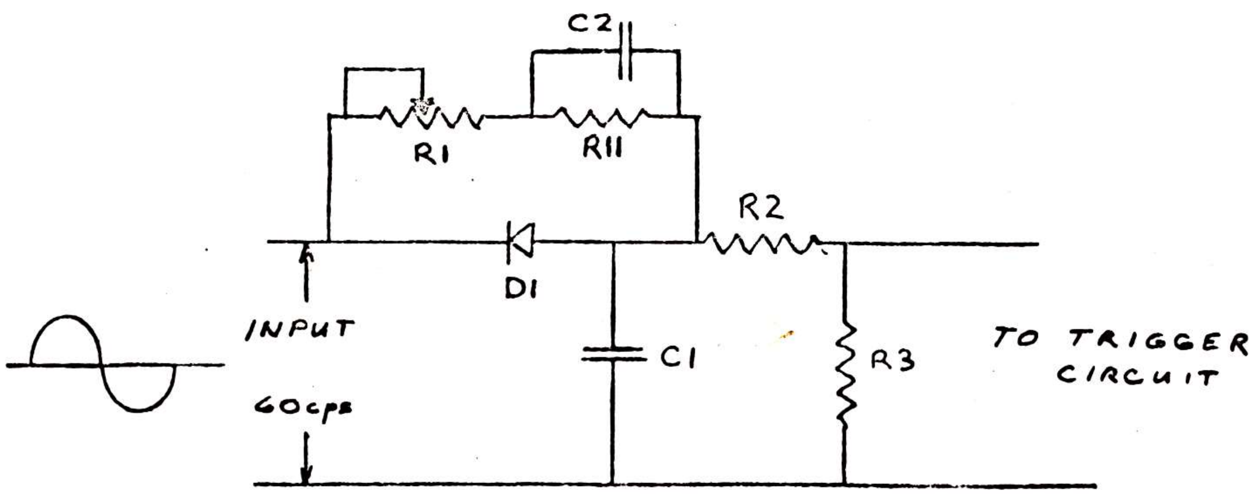


FIGURE 16

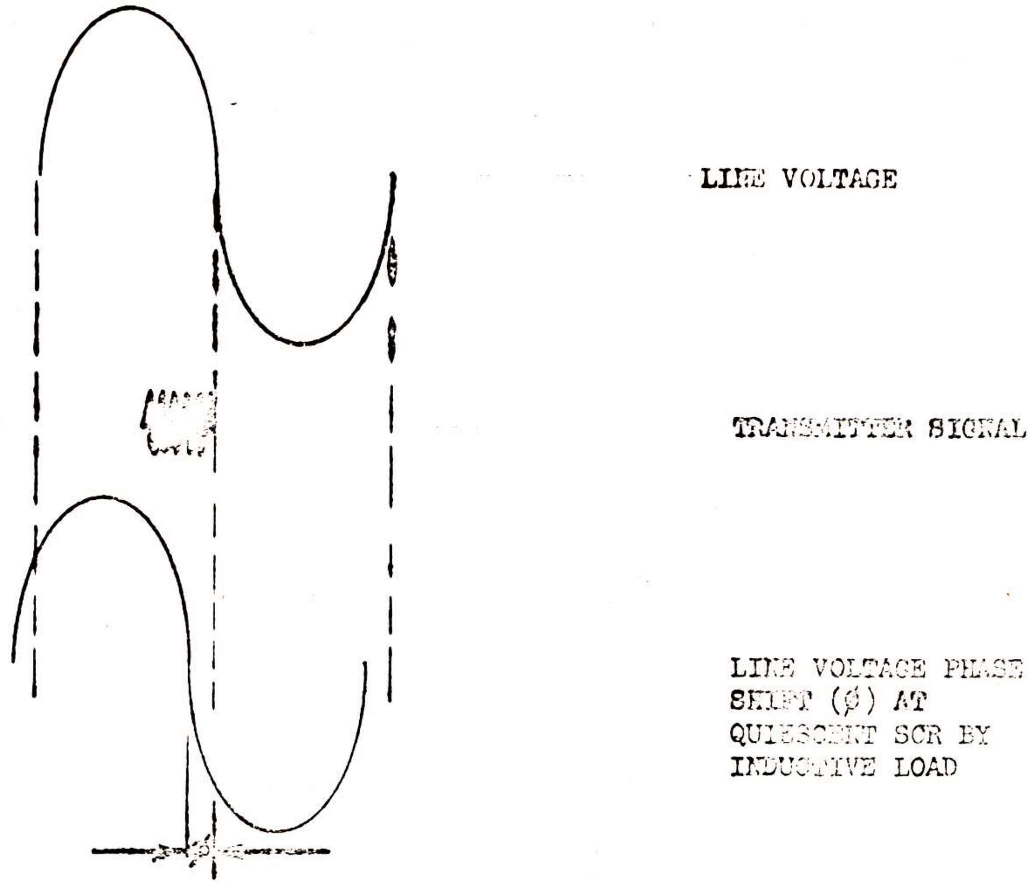


FIGURE 17

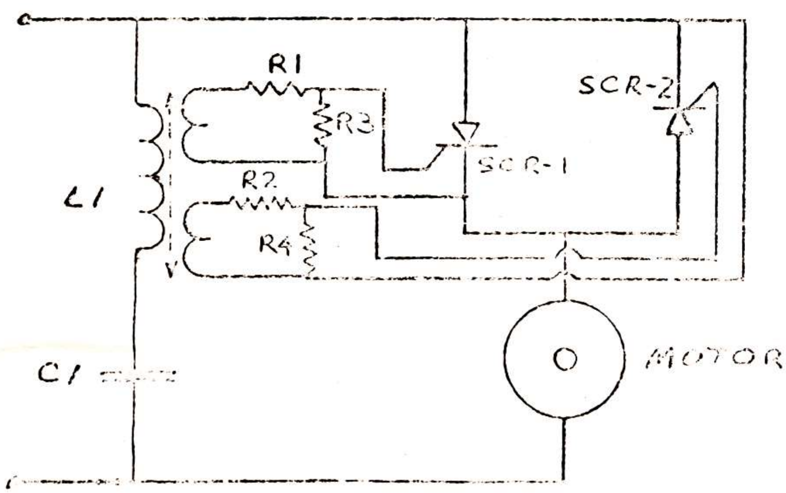


FIGURE 18

GENERAL [illegible] ELECTRIC

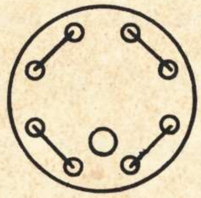
RADIO RECEIVER DEPARTMENT

UTICA, N. Y.

INSTRUCTION SHEET

MODELS K-2, K-4

The Models K-2 and K-4 ASTRAC Dual Control units are each capable of controlling two trains on one electrically continuous track, completely independent of each other. Each unit has two separate speed controls and two separate forward/reverse switches. Model K-2 operates on channels 1 and 5, and Model K-4 operates on channels 2 and 4. Two terminals are provided for track connection wires. The nine-pin socket is for future equipment, and should not be modified in any way. If socket jumpers become disconnected, refer to the diagram below for proper connection.

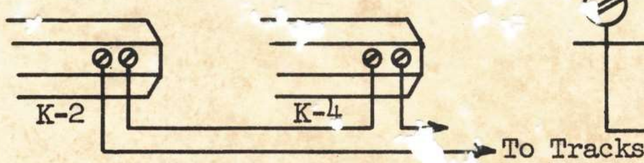


The ASTRAC System utilizes AC voltage on the tracks. This AC can be supplied from the accessory terminals of your present transformer. The DC portion of your transformer is not used. The rheostat can be set at zero and forgotten. If your transformer does not have accessory terminals, you can use any AC transformer having an output voltage in the 16-20 volt range. The ASTRAC receivers can be operated with [illegible] track voltages in the 3-10 volt range. However, 16-20 volts AC is recommended, and will usually produce sufficient maximum speed operation. The AC track voltage is prevented from reaching the DC motor [illegible]re-Receiver. The power supplied to the motor is controlled by the receiver, which in turn is controlled by the transmitter. When operated at creep speeds, [illegible]nes maintain much higher power than that supplied by conventional controls. At creep speeds the motor's armature is not turning fast enough to produce good air circulation; therefore, creep speed operation for extended periods of time will produce slight motor heating, which should be carefully controlled by the operator.

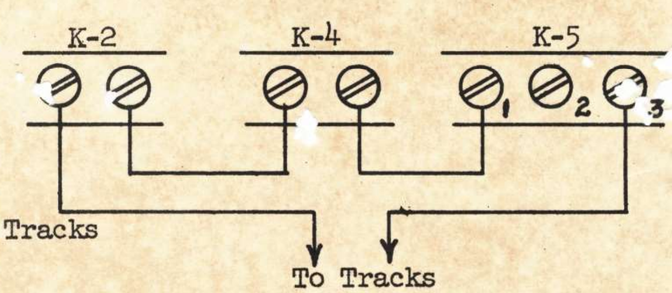
WARNING: Do not attempt to operate an engine <u>without</u> <u>a</u> <u>receiver</u> on tracks carrying AC voltage. AC voltage is harmful to DC motors, and should be avoided completely.

Four trains can be operated simultaneously by jointly using a Model K-2 and a Model K-4. All combinations of transmitter units must be wired in series with each other, as shown below.

4 TRAIN OPERATION



5 TRAIN OPERATION



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-2, K-4

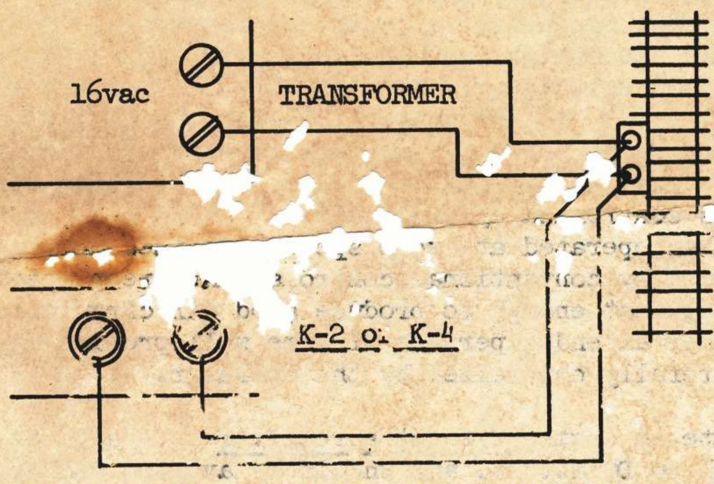
Five trains can be operated by the addition of a Model K-5 transmitter unit. This unit has one speed control and one forward/reverse switch. It also has a five channel selector switch which allows the operator to control any one of the five trains on the track by merely switching to its particular channel. The Model K-5 comes ready to mount in a control panel, and includes a power cord, wire nuts, and all necessary hardware. When used along with a K-2 and a K-4, the K-5 can be used to cover channel 3. Wiring of the K-5 is covered in the K-5 instruction sheet. Installation of Micro-Receivers is covered in the K-10 thru K-50 instruction sheet.

INSTALLATION OF MODEL K-2 or MODEL K-4

1. Disconnect the track wires from the DC terminals of your transformer.

   Re-connect them to the "Accessory" (AC) terminals on the transformer.

2. Connect two wires from the terminals on the back of the Dual Control unit to the track, as shown below.



NOTE: If train runs backwards with switch in forward position, reverse the ...

Questions on the ASTRAC System should be referred to your dealer, or to: ASTRAC, Educational Products Engineering Section, General Electric Co., 1... Broad Street, Utica, New York

April 19, 1971

Dear Harry:

Thanks a lot for the old M/R article by Lynn Wescott. I hadn't read this before.

I am enclosing copy of the original G.E. Technical bulletin which you may keep. Hope your friend can help us out if G.E. doesn't come through in answer to my last letter. The secret to the whole thing is being able to find the right components to make up the individual receivers.

I have solved my problem as to wiring but now believe my engines may be too large, draw too much current, for the SCR's being used. They are rated 1.6 amperes.

Don't worry about the cost of the receiver. I was only too glad that I had one I could send you. Before it's all over one of us my own all or none of the ASTRAC. Sure hope we can find out how to make new receivers.

Best of luck to you and I'll keep in touch

Cordially,
Leo.