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In This Issue...

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Editorial . . .

by John E. Remich

Manager, Technical Department

A NEW CHALLENGE— TRANSISTORIZED EQUIPMENT MAINTENANCE

Much has recently been written concerning the future potentialities of the transistor in the electronic industry. While the future of the transistor is very bright indeed, it might be pointed out that its importance in today's electronics should not be underestimated.

The transistor has arrived as a useful component of everyday electronic equipment, and many of its "future potentialities" are actually being used *today.* This fact is evidenced by the large number of new equipments, both military and civilian, which are currently making their appearance. For example, the superior qualifications of transistors for low-power receiver applications have dictated their use in many of the new receivers appearing on the market, especially those in the portable category, such as the new Philco T-7 Transistor Cordless Radio which operates for several hundred hours on a pair of ordinary flashlight cells.

The performance, stability, and reliability of the transistor have been steadily improved since its inception in 1948; as a result, we have, today, a whole new family of these solid state devices from which the circuit designer may choose.

With the advent of practical transistorized electronic equipments have come new maintenance problems. It is anticipated that the reliability of transistorized equipments will be high, but it is obvious that this equipment will develop malfunctions which will require correction. This fact is of immediate concern to all TechRep field engineers. In order that efficient maintenance may be performed upon this new equipment, electronics maintenance personnel in all branches of the field must prepare themselves now by learning as much as possible about the practical aspects of maintaining transistorized circuitry. The preparation must certainly include the special maintenance techniques peculiar to the transistor and to the associated miniaturized circuitry which accompanies it. Careful and thorough preparation to meet this new maintenance challenge will ensure the continued performance of equipment vitally important to our defense.

LETTERS TO THE EDITORS

During the year we receive many letters which contain worth-while suggestions, comments, and information concerning the BULLETIN and the electronics field in general. In the past we have retained this information for our own use and for those who have specifically requested it; however, we have decided that wider dissemination should be given information of this type. In line with this decision, we began a new feature called The Tech Info Mail Bag in the May-June issue of the BULLETIN, and with this issue we begin the Letters to the Editors column.

The following excerpts were obtained from letters received recently by the Technical Information Section.

"I shall look for each issue of the BULLETIN with even greater anticipation because of the new feature, The Tech Info Mail Bag. . . .

"With specific reference to the diesel generator load described in this item, one of the AC&W squadrons in OCAMA's service area built a similar load, but out of harder wire. Their experience was that as the wire coils heated, air currents were set up that caused irregular cooling and fluctuations in resistance, making the load resistance unstable. This effect was particularly noticeable when there was a gusty wind, making it impossible to adjust a governor—about the only reason for having a load bank. Apparently the use of lower-resistance soft iron wire has solved that phase of the problem. With that much of it solved, I'm sure that many in the field would like to know how the load was connected to the generator, considering the fact that it would be necessary to use the panel instruments."

Thomas E. Arnold
Lt. Colonel, USAF Retired

(It is our understanding that the load, as described in the May-June BULLETIN, was sufficiently stable for use in adjusting governors. The load was connected to the tech bus by means of locally installed switches so that the meters installed on the panel could be used to monitor the performance of the generator. Ed.)

"The TechRep Division BULLETIN always creates a great deal of interest here, and someone always wants to borrow my copy before I have finished with it. As an example, the last issue had an item on constructing a dummy load for a diesel power unit. This problem is one that we have been trying to solve for some time and the method given may be our answer."

Kenneth E. Flein
Doyle E. Woodward
Wallace H. Jacobsen
Philco TechRep Field Engineers

(In The Tech Info Mail Bag column in this issue you will find another dummy load idea. Ed.)

"I would like to suggest that each issue of the BULLETIN contain a physical and electrical description, with pictures, of some of the newer types of test gear in use in the services. A brief rundown on the capabilities and limitations of the equipment would also be helpful to the TechReps in the field."

Walter J. Sampson
Philco Field Supervisor

(This sounds like a mighty fine idea, but here again we need the support of the BULLETIN readers to put the idea across. How about it? Ed.)

"I would like to obtain information concerning procurement of the IRE Directory and the AIEE Directory."

Winston S. Burdick
Philco Field Interviewer

(The 1955 IRE Directory is available at a cost of $15.00 per copy. There has been no AIEE Directory since 1953. The next one is due in the fall of 1956. By writing directly to the AIEE, 33 West 39th Street, New York 18, New York, you can obtain the 1953 Directory free of charge. Ed.)

"The bomb-nav. section has a problem concerning the TR tubes in their radar set. They want to know the difference between a 1B63A and a 6334 . . . are they interchangeable? According to the Field Engineers' Data Handbook, both tubes have the same characteristics except that the 6334 is designed for use in balanced duplexers, and the 6334 is the tube recommended for use in this equipment."

Troy K. Bailey, Jr.
Philco TechRep Field Engineer

(The 6334, Bomac designation BL-27, is a dual TR tube consisting essentially of two matched 1B63A tubes in one package. The 6334 has been designed specifically, as you mentioned, for use in balanced duplexers where a dual tube is required. The characteristics of each section of the 6334 are identical to those of a 1B63A, but the two tubes are naturally not interchangeable. Ed.)

ELECTRICAL OPERATION OF THE 15-J-1-c (AN/UPS-T4)

by Robert D. Hunter
Headquarters Technical Staff

This article describes the electrical operation of the Moving Radar Target Generator 15-J-1-c, alternately known as the AN/UPS-T4. The operation of the major part of the associated mechanical equipment was discussed in the January-February issue of the BULLETIN under the title "Mechanical Troubles in the Standard Target Course Generator 15-J-4-p."

INTRODUCTION

As POINTED OUT in the previous article on the course generator (see above), the position of the radar target to be simulated is represented in rectangular coordinates, with the radar system as the origin, by the voltages obtained from the E-W and N-S potentiometers. These potentiometers are precision ten-turn units whose outputs are either in phase or out of phase with an excitation voltage referred to as the reference phase.

Since conventional radar sets "see" their targets in polar coordinates, i.e., the position of a target is represented by an angle (azimuth) and a distance (radar range), the rectangular coordinates of the target position must be transformed into polar coordinates. This transformation is accomplished in a quadrature addition circuit, which produces an a-c voltage whose amplitude is proportional to the target range and whose phase, with respect to the reference phase, represents the azimuth of the target.

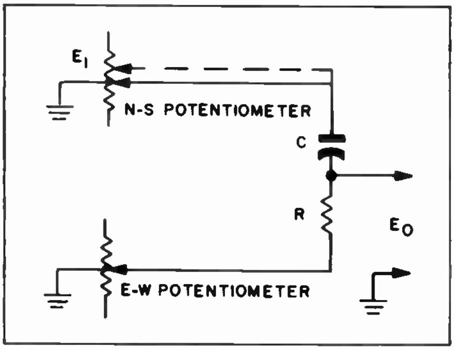

Figure 1. Potentiometer and Quadrature Addition Circuit for Case 1

QUADRATURE CIRCUIT OPERATION

The E-W and N-S potentiometers are connected to the transformer of the power amplifier, so that the center of each potentiometer is at a-c ground potential, as indicated in figure 1. In figure 1, capacitor C represents capacitor C1 of card 227,* and resistor R represents the series combination of resistors R1 and R2. A calculation shows that the reactance of C1 at 1020 c.p.s. is roughly 230,000 ohms. Note that the combined resistance of R1 and R2 can be made exactly equal to this reactance. Also observe that the series combination of R and C constitutes a negligible shunt on the two potentiometers connected to it.

For explanation purposes, the quadrature circuit will be explained in the following manner: The characteristics of the output voltage (E_0) between the junction of C and R and ground will be determined when a separate voltage is impressed on the circuit first by one potentiometer and then by the other. Then the characteristics of the output voltage will be determined when voltages are

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*The circuitry of this equipment is constructed on removable plastic cards which are numbered. This numbering system is used in this article to facilitate reference to the equipment.

impressed by both potentiometers simultaneously.

First, assume that the center arm of the E-W potentiometer is at ground potential, and that only the N-S potentiometer impresses a voltage (E_1) on the circuit. For this case (Case 1) it may be seen from figure 1 that

$$E_O = E_R \tag{1}$$

Assuming that $X_c = R$,

$$I = \frac{E_1}{R - jR} \tag{2}$$

and

$$E_R = IR = \left(\frac{E_1}{R - jR}\right) R = \frac{E_1}{1 - j}$$

$$= \frac{E_1}{1 - j} \cdot \frac{1 + j}{1 + j} = \frac{E_1 + jE_1}{2} . \tag{3}$$

From figure 2 the amplitude (A) is

$$A = \sqrt{\left(\frac{E_1}{2}\right)^2 + \left(\frac{E_1}{2}\right)^2} = 0.707\,E_1 , \tag{4}$$

and the phase, ϕ, of the output voltage with respect to the input voltage is

$$\phi = \tan^{-1}\left(\frac{\frac{E_1}{2}}{\frac{E_1}{2}}\right) = \tan^{-1}(1) = 45^\circ. \tag{5}$$
(leading)

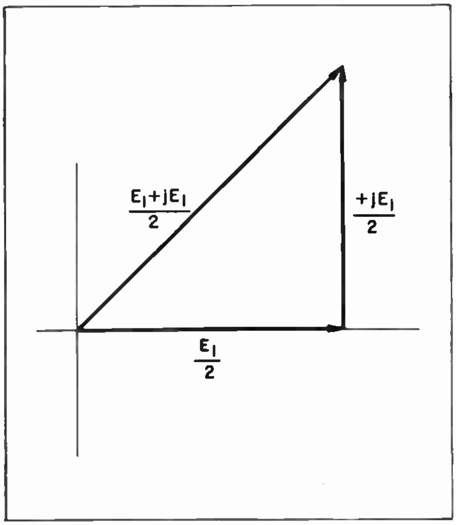


Figure 2. Output of Quadrature Addition Circuit for Case 1

It is apparent, therefore, that the output voltage resulting from E_1 *leads* E_1 by 45 degrees.

Next, assume that the center arm of the N-S potentiometer is at ground potential, and that only the E-W potentiometer impresses a voltage (E_2) on the circuit. For this case (Case 2), it can be seen from figure 3 that the output voltage with respect to a-c ground is

$$E_o = E_C \tag{6}$$

and as before,

$$I = \frac{E_2}{R - jR} \tag{7}$$

and

$$E_C = IX_c = \left(\frac{E_2}{R - jR}\right)(-jR) = \frac{-jE_2}{1 - j}$$

$$= \frac{-jE_2}{1 - j} \cdot \frac{1 + j}{1 + j} = \frac{E_2 - jE_2}{2} . \tag{8}$$

As before the amplitude (A) is

$$A = \sqrt{\left(\frac{E_2}{2}\right)^2 + \left(\frac{E_2}{2}\right)^2} = 0.707\,E_2 \tag{9}$$

and from figure 4, the phase of the output voltage with respect to the input voltage is

$$\phi = \tan^{-1}\left(\frac{-\frac{E_2}{2}}{\frac{E_2}{2}}\right) = \tan^{-1}(-1) = -45^\circ. \tag{10}$$

Hence, the output voltage in this case *lags* the input voltage by 45 degrees.

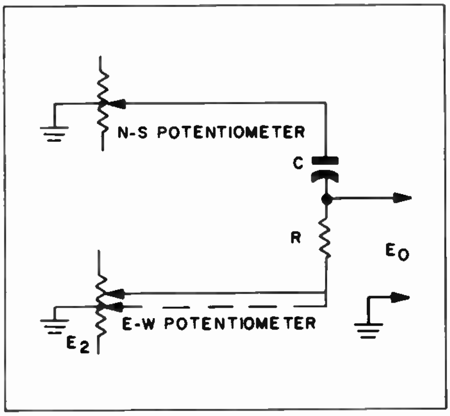


Figure 3. Potentiometer and Quadrature Addition Circuit for Case 2

In the preceding discussion, it has been shown that when the N-S potentiometer supplies voltage the output is shifted 45 degrees in one direction, and that when the E-W potentiometer supplies voltage the output is shifted 45 degrees in the opposite direction. It is now time to consider the case (Case 3) when both potentiometers supply voltages simultaneously.

It must be remembered that the voltages of the two potentiometers, representing the rectangular coordinates of the target position, are to be converted by card 227 into a single voltage whose amplitude is proportional to the target range, and whose phase is proportional to the target azimuth. The expressions for the amplitude and phase of the quadrature-added voltages have been written to illustrate this operation.

Regardless of which side of center the arms of the potentiometers occupy, each potentiometer may be considered to be an a-c generator with one terminal grounded. Both potentiometers acting together are equivalent to two generators in series with their common connection grounded as shown in figure 5.

The current through the R-C combination is

$$I = \frac{E_1 + E_2}{R - jR} \qquad (11)$$

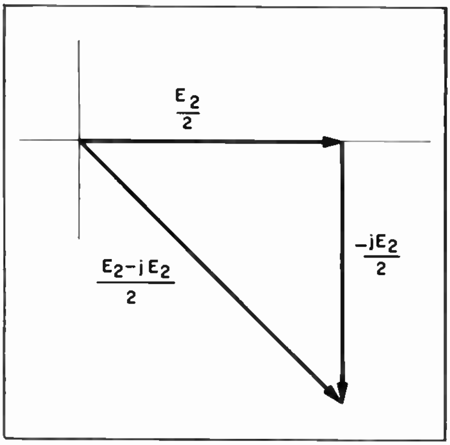


Figure 4. Output of Quadrature Addition Circuit for Case 2

where it is understood that E_1 and E_2 can be added algebraically, since they are either in phase or 180 degrees out of phase. The voltage across the resistor E_R will then be

$$E_R = IR = \left(\frac{E_1 + E_2}{R - jR}\right) R = \frac{E_1 + E_2}{1 - j} \qquad (12)$$

For the simple series circuit,

$$E_1 + E_2 = E_R + E_C \qquad (13)$$

where E_R and E_C are written in the rectangular complex form. A rearrangement of this equation gives

$$E_2 - E_R = E_C - E_1 . \qquad (14)$$

The potential from the junction of R and C to ground may now be determined by adding E_C and E_1 or by adding E_2 and E_R according to equation (14). To find E_0 then by using E_2 and E_R:

$$\begin{aligned} E_0 = E_2 - E_R &= E_2 - \frac{E_1 + E_2}{1 - j} \\ &= \frac{E_2 - jE_2 - E_1 - E_2}{1 - j} \\ &= \frac{-jE_2 - E_1}{1 - j} \cdot \frac{1 + j}{1 + j} \\ &= \frac{-jE_2 - E_1 + E_2 - jE_1}{2} \\ &= \frac{E_2(1 - j) - E_1(1 + j)}{2} . \qquad (15) \end{aligned}$$

This result shows that E_1 and E_2 are added at right angles to each other (in quadrature), as shown in figure 6. Figure 7 shows the vectors for the cases E_1 greater than E_2, and E_2 greater than E_1.

From the facts just illustrated it can be seen that the resultant voltage can

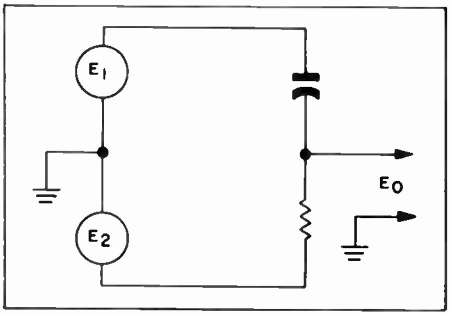


Figure 5. Potentiometer and Quadrature Addition Circuit for Case 3

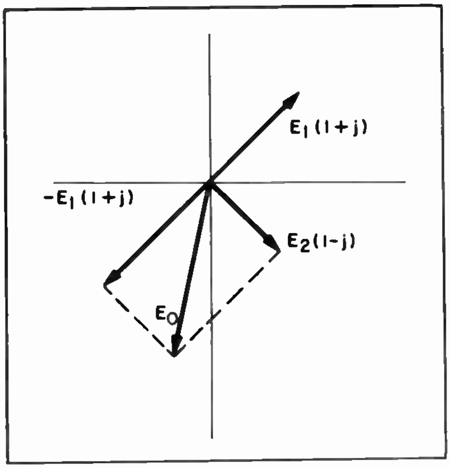


Figure 6. Typical Combination of Potentiometer Voltages for Case 3

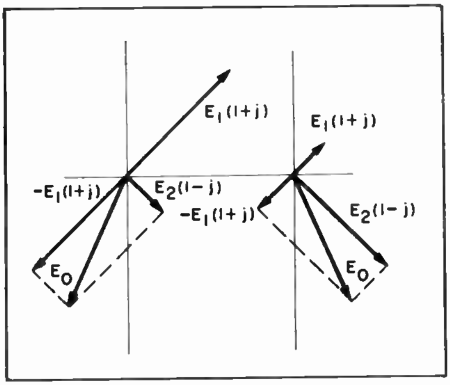


Figure 7. Combination of Potentiometer Voltages for One-Quadrant Coverage

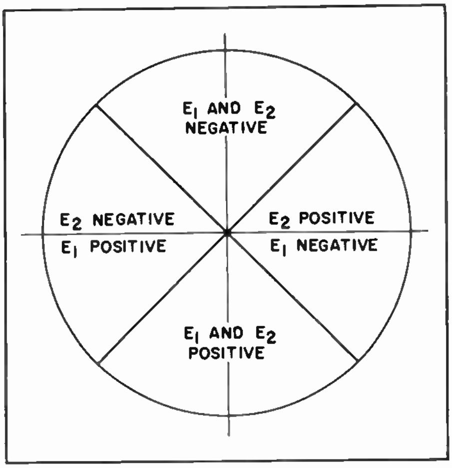


Figure 8. Potentiometer-Voltage Combinations for Four-Quadrant Coverage

cover one quadrant for a given phase relationship between E_1 and E_2. Since there are four possible phase relationships for E_1 and E_2 with respect to the reference voltage, the same argument may be extended to show that the resultant voltage can cover all four quadrants. The possible phase relationships for E_1 and E_2 are as follows: E_1 and E_2 may be in phase with each other and (1) out of phase with the reference voltage, or (2) in phase with the reference voltage. E_1 and E_2 may be out of phase with each other (3) while E_1 is in phase with the reference voltage, or (4) while E_2 is in phase with the reference voltage. From figure 6 the amplitude A of the output voltage is

$$A = \sqrt{\left(\frac{E_1}{\sqrt{2}}\right)^2 + \left(\frac{E_2}{\sqrt{2}}\right)^2} \qquad (16)$$

and the phase angle ϕ with respect to the positive X axis is

$$\phi = -45^\circ - \tan^{-1}\left(\frac{E_1}{E_2}\right) \qquad (17)$$

Figure 8 shows how all four quadrants can be covered by the four possible combinations of E_1 and E_2. The polarities shown describe the phase relationship for a given arbitrary instant.

Results identical to those above will be obtained if E_C is added to E_1 according to equation (14). Note that the vector addition in figure 6 is accomplished by reversing the direction of the vector $E_1\ (1 + j)/2$, and then adding this vector to $E_2\ (1 - j)/2$.

The phase-shifting process described above applies equally well to the operation of the Autosyns and cards 126 and 135 in the IFF and radar antenna azimuth circuits. The potentiometers are replaced by the Autosyn stator windings, whose outputs are either in phase or 180 degrees out of phase. The series R-C grid

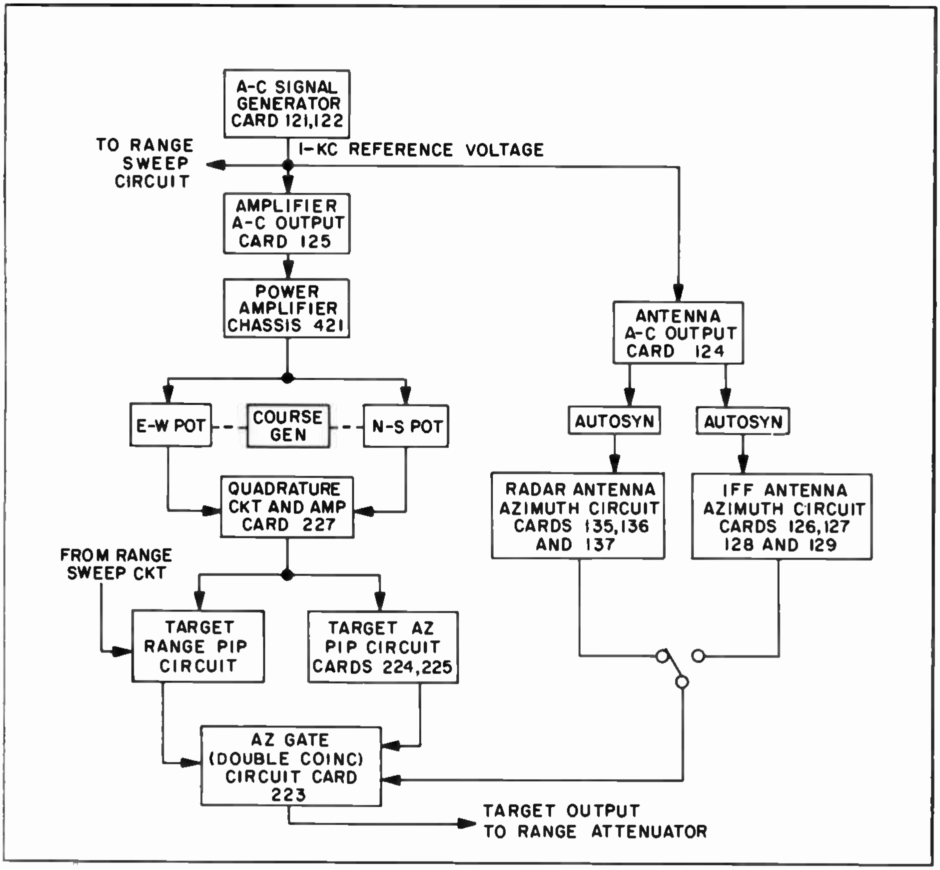


Figure 9. Simplified Block Diagram of Part of Target Generator

circuits are the same as those found on the No. 227 cards.

As can be seen from the discussion above, proper operation of the quadrature addition circuit is essential to the satisfactory operation of the target generator. This is especially true in those installations where the programming unit is used to accurately reproduce a given flight path for operations training and evaluation. For proper operation of the quadrature circuit, it is essential that R be adjusted to exactly equal X_C and that the frequency of the "1-kc. Oscillator" (1020 ± 5 c.p.s.) remain constant. The accuracy with which the reset dials can be easily read tends to limit the accuracy of the quadrature adjustment, which is made by separately adjusting the N-S and E-W output voltages at the quadrature circuit to the same value for given readings of the reset dials [see the quadrature circuit alignment procedure given in NAVEXOS P-1027, and "A New Reset Dial for 15-J-1-c" in the February 1955 C&E Digest (ADC)].

SYSTEM PHASE RELATIONS FOR THE 1-KC. SIGNAL

Refer to the simplified block diagram of the target generator shown in figure 9. The object of the following discussion is to show how phase coincidence occurs at the azimuth gate circuit (card 223) for the target azimuth pip and the antenna azimuth pip from either the radar or the IFF antenna azimuth circuits.

The 1-kc. outputs of the a-c signal generator (cards 121 and 122) to the amplifier a-c output (card 125) and the antenna a-c output (card 124) are in phase with each other since they are isolated only by a cathode follower in card 122. For convenience, these outputs will be referred to as the reference voltage, and successive phase shifts with respect to this voltage will be designated by ϕ. It will be shown that the phase shift of the target azimuth signal and the phase shift of the antenna signal are the same upon the arrival of the signals at the azimuth gate circuit (card 223).

Card 125 consists of a cathode follower; hence, the phase shift for this circuit is zero. The outputs of the push-pull stages of the power amplifier (Chassis 421) are either in phase or 180 degrees out of phase with the reference voltage. For this discussion, assume that the phase shift through the power amplifier is zero. In a similar manner, assume that the phase shift of the potentiometer outputs is zero. In the quadrature circuit and amplifier (card 227), the phase shift ϕ will be 45 degrees (leading) if the N-S potentiometer voltage is acting alone. The output of card 227 passes through a cathode follower in card 226 enroute to the target azimuth pip circuit; therefore, the additional phase shift introduced is zero. Two inversions of the signal occur in card 225; hence, the phase shift here is also zero. In card 224, a negative-going pip is produced which is coincident with the negative-going axis crossing of the signal. This negative-going pip is applied to the azimuth gate (double coincidence) circuit (card 223). It may be seen, therefore, that the total phase shift ϕ of the target azimuth signal with respect to the reference signal is 45 degrees, the amount that occurred in the quadrature circuit.

The phase shift of the reference signal by the antenna a-c output circuit (card 124) is zero, because this circuit is essentially a cathode follower. The 1-kc. signal is then passed to the Autosyn. The rotor of the Autosyn is rotated synchronously with the radar antenna by means of a servo system in the target generator. The Autosyn has two outputs, one proportional to the sine of the radar antenna azimuth angle and one proportional to the cosine of this angle. These two voltages are added in quadrature by the quadrature addition circuit of card 135 (identical to the quadrature addition circuit of card 227); the resultant voltage has a constant amplitude, and its phase with respect to the reference voltage depends upon the pointing angle of the radar antenna. When the radar antenna is pointing north, the case of interest for a simulated target due north, the phase shift ϕ of the reference signal produced by the Autosyn and the quadrature addition circuit of card 135 is 45 degrees (leading), the same as that produced by the N-S potentiometer and the quadrature circuit of card 227. This voltage is inverted three times in card 135 and once in card 136 without any additional shift in phase. The antenna azimuth pip produced by these circuits is positive-going, however, while the target azimuth pip is negative-going at the same time, or phase. The signal from the radar antenna azimuth circuits is therefore inverted by an amplifier in the azimuth gate circuit (card 223) so that both pips are negative-going at the same time (phase) at the comparison point in the azimuth gate circuit. Thus it may be seen that the phase shift ϕ of the reference voltage in the antenna azimuth circuit is the same as that in the target azimuth circuit. Note that this phase coincidence occurs for only one position of the Autosyn rotor, i.e., when the radar antenna is pointing at the target azimuth. In like manner, it may be shown how phase coincidence occurs for a target at any azimuth.

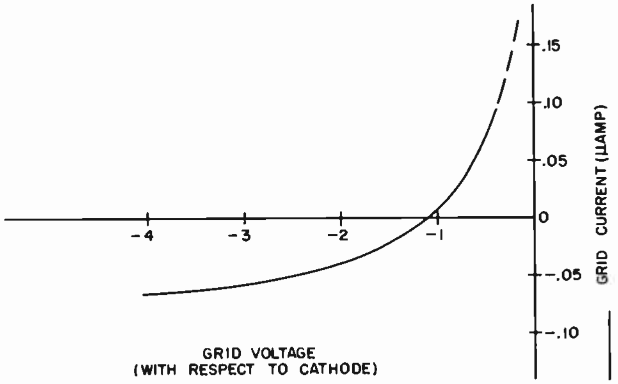
The target range pip circuit extracts the range information (amplitude) from the 1-kc. output signal of card 227 and produces a series of range pulses, each of which has the proper time relationship to the radar system trigger. These range pulses pass through the azimuth gate circuit when the target and antenna azimuth gates coincide, and are sent through the range attenuator to the PPI of the radar.

Solution to May-June "What's Your Answer?"

The positive voltage with respect to ground observed at the grid is the result of *negative* grid current, that is, a flow of electrons toward the grid through the grid resistor. This current flow is made possible by a number of causes including the combination of positive gas ions with electrons at the grid (called ionic grid current), and the emission of electrons from the grid. Grid emission depends mostly upon the temperature of the grid and the extent to which its surface may have been contaminated with oxides from the cathode. Ionic grid current increases with higher plate voltages because of the increased ionization by collision of the gas atoms in the tube; hence, the input stage in some high-gain d-c amplifiers is operated at lower-than-normal plate voltage to reduce the magnitude of this effect. A plot of the grid current (in microamperes) versus the grid voltage (in volts) for a typical triode operating at a constant plate current is shown in the accompanying figure.

As the grid-to-cathode voltage nears zero, the grid current becomes *positive,* rising sharply, because the grid intercepts increasing numbers of the electrons emitted by the cathode. In many cases of low-frequency and d-c operation, the flow of grid current sets a practical limit on the input impedance obtainable in a vacuum-tube amplifier. A survey of the causes and effects of grid current in vacuum tubes is given in WADC Technical Report 55-1 (October, 1955).

Grid current can be a source of trouble in audio amplifiers having a high value of grid resistor. Here the loss of normal bias resulting from the increase in grid potential can increase distortion to undesirable levels or even make the stage completely inoperative. This trouble usually does not appear when the set is first turned on, but becomes noticeable when the grid temperature has increased sufficiently to encourage emission.



PHILCO COLOR TELEVISION TEXTBOOK

THE PHILCO CORPORATION'S Electronic Education Unit has recently published a textbook entitled Color Television, which is the finest of its type available today. This book consists of over 150 pages and has 288 illustrations, many of which are in full color. It was edited by Donald G. Fink, former editor of *Electronics* magazine and now Director of Research, Philco Corporation. The book is subdivided into nine major subject headings as follows:

1. Review of Black and White Television
2. Colorimetry
3. Transmission and Reception—Methods and Standards
4. Circuit Description
5. Color Cathode Ray Tube Assembly and Associated Circuits
6. Color Cathode Ray Tube and Receiver Adjustments
7. Color Television Receiver Alignment
8. Servicing Procedures
9. Installing the Color Television Receiving System

The special price of this deluxe edition is $3.50, and a check or money order for this amount should be made payable to Philco Corporation. Send requests to:

PHILCO CORPORATION
P.O. Box 9817
Philadelphia 40, Penna.

THE TECH INFO MAIL BAG

The following problem and its solution were obtained from the Site Engineer's Report submitted by Billy D. Bridges.

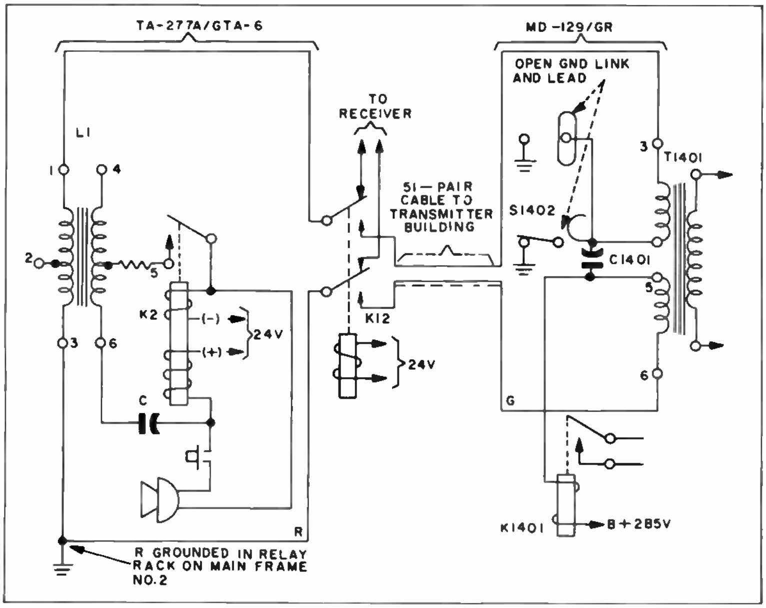
Recently when Telephone Equipment AN/GTA-3 was replaced by Telephone Equipment AN/GTA-6A, it was naturally assumed that the original circuits used for keying and modulating the T-217A/GR transmitting equipments would still be adequate. (In the past, only one pair of telephone lines was used for each transmitter circuit in this application. One of these lines was used for keying and the other to carry the modulation, with earth ground utilized as a common return.) However, after the AN/GTA-6A equipment was installed, cross modulation was experienced whenever two or more transmitters were keyed simultaneously. The cross modulation was evidenced by the modulation of each keyed transmitter modulating all the keyed transmitters, and resulted in the transmission of badly scrambled information from all the transmitters. After due consideration, the conclusion reached was that the signal applied remotely to transformer T1401 in the modulator unit (MD-129/GR) of the

AN/GRC-27 equipment was being applied to the same transformer in the other modulator units through the common earth-ground return and the ground links at terminal 4 of the transformer. That this was the case was proven when individual pairs of wires were used for modulation and keying purposes, thus eliminating the common earth ground. The solution to the problem appeared complete; however, there were not enough conductors in the existing cable to accomplish modulation and keying of all transmitters over separate wire pairs. Moreover, it was not feasible to install an additional cable for this purpose. What could be done?

Here is the solution to the problem that Frank Cammack, Philco TechRep Field Engineer, used:

A method of keying and applying audio to the remote transmitter using a single pair of conductors was devised. This was accomplished by opening the ground link connected to terminal 4 of transformer T1401 and by removing the connection to switch S1402 which is also connected to terminal 4. The modulation is thus applied through both conductors of the pair, with the signal now isolated from ground at T1401. The keying circuit was completed by connecting the lead labeled R in main frame 2 to ground. This connection allows keying to be accomplished through one of the audio legs and ground, and at the same time prevents interference when two or more transmitters are keyed simultaneously.

Can you think of a better solution?



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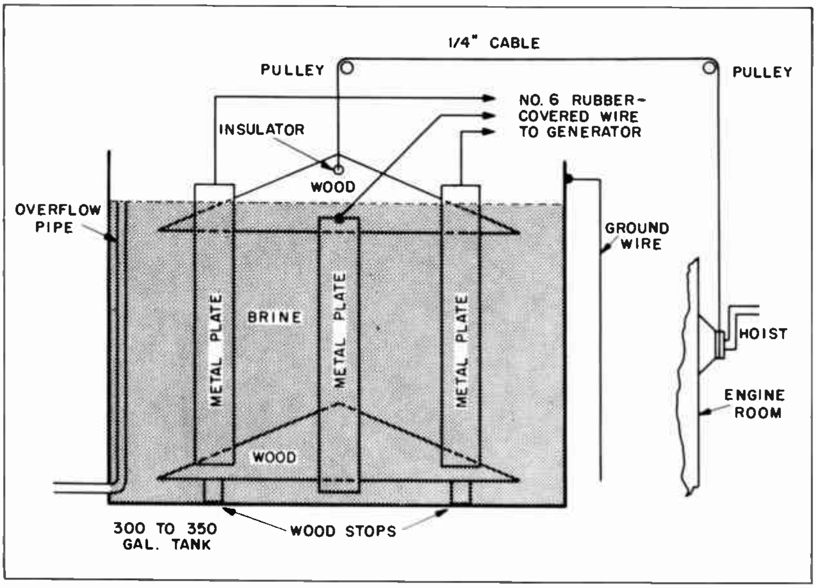
Here is another solution to the dummy load problem of the Tech Info Mail Bag (May-June issue of the BULLETIN). In this solution, a suitable dummy load for the generator is provided by means of the brine tank illustrated in the accompanying figure. This suggestion was submitted by Albert Biehl, Philco TechRep Field Engineer, 680th AC&W Squadron, Bonners Ferry, Idaho. If desired, a selector switch box may be used to connect the load to either the base or tech bus (this feature would be a distinct advantage at some sites). The load is continuously adjustable. Apparently, the primary disadvantages of this type of load are that it requires a certain amount of attention during operation and that it must be refilled occasionally. However, if a ready supply of salt water is available, such as at locations near an ocean or salt lake, a brine load may be a very practical expedient.

In regard to the drawing, the metal plates may be made of either iron or copper plate. These plates are ½ inch thick by 6 inches wide, and their length is determined by the size of the tank used. They are attached to the wooden (or other insulating material) triangles as shown in the figure. The triangles are made of 2-inch by 6-inch lumber, and their length is also determined by the tank size. Wooden stops are used to prevent the metal plates from coming into contact with the tank (if a metal tank is used). It is recommended that the dummy load be located as close to the switchboard as possible.



(Editor's Note: The exact load that can be supplied by this arrangement was not specified and will depend upon many variables; however, the safe continuous load for the No. 6 wire called for in the figure would be at least 25 kw and short-duration loads of higher value could be tolerated.)

D-C ANALOG COMPUTERS

PART 4

by Robert D. Hunter
Headquarters Technical Staff

In the three previous installments it has been shown how a high-gain d-c amplifier may be used, with the appropriate circuitry, to perform the mathematical operations of summation, multiplication by a constant, differentiation, and integration. The object of this article, which is the final article of the series, is to show how these basic computing circuits may be combined to produce an electronic calculating machine.

DIFFERENTIAL ANALYZER

THE NAME "DIFFERENTIAL ANALYZER" has been given to calculating machines which are capable of solving differential equations. The earliest of these machines was a mechanical computer and used a mechanical integrator. To construct an electronic differential analyzer capable of solving a homogeneous linear differential equation with constant coefficients requires only the circuitry to perform the functions of integration, summation, the attendant sign changing (inversion), and multiplication by a constant. This type of machine is quite simple and has the advantage of high-speed operation together with operating simplicity and flexibility. Fairly inexpensive machines of this type may have solution accuracies of 5% or better, which is often sufficient for investigative purposes. Exploring the effects of parameter changes in a physical system may be very conveniently carried out with such a computer.

EXAMPLE PROBLEM

As an example problem, consider the simple series LCR circuit shown in figure 1. Suppose that the problem is to determine the current flowing in this circuit at any time (t) after the closing of the switch at time t = 0. (It is assumed that the charge on the capacitor (C) is zero at time t = 0.) The voltage across the resistor at any given instant is Ri, that across the capacitor is $\frac{Q}{C}$, and that across the coil is $L\frac{di}{dt}$, where $\frac{di}{dt}$ is the instantaneous rate of change of current (i) with time (t). Kirchoff's voltage law for this circuit is:

$$L\frac{di}{dt} + Ri + \frac{1}{C}Q = E(t), \qquad (4\text{-}1)$$

where E(t) is the applied voltage as a function of time. Since $i = \frac{dq}{dt}$, differentiating this equation and dividing both sides by L gives:

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LR}i = \frac{1}{L}\frac{d}{dt}E(t). \qquad (4\text{-}2)$$

If the applied voltage E(t) has a constant value (suppose it is produced by a battery), then $\frac{d}{dt}E(t) = 0$, and equation (4-2) becomes the homogeneous equation

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LC}i = 0, \qquad (4\text{-}3)$$

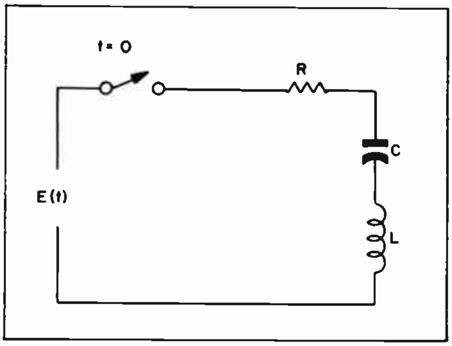


Figure 1. A Simple Circuit Involving a Second-Order Differential Equation

which is the sample equation to be solved by the use of the computer.

It must be kept in mind, in the following, that the current i in this problem and its derivatives with respect to time will be represented by *voltages* in the computer. These voltages are labeled in figure 2 with the same notation used to represent the variables in equation (4-3). In the formal solution of this simple problem, the two arbitrary constants which appear in the general solution are evaluated by using the initial conditions; that is, the current i is zero at time t = 0, and $\frac{di}{dt}$ is equal to $\frac{E}{L}$ at time t = 0. These initial conditions (frequently abbreviated IC) are also used in the solution of the problem by the computer, as will be shown shortly.

COMPUTER SETUP

A computer setup for the solution of equation (4-3) is shown in figure 2, where, as before, the triangles represent high-gain d-c amplifiers. A useful procedure for determining the computer setup, frequently referred to as the mechanization of the equation, is to solve the given equation (4-3) for the highest order derivative:

$$\frac{d^2i}{dt^2} = -\left(\frac{R}{L}\frac{di}{dt} + \frac{1}{LC}i\right) \qquad (4\text{-}4)$$

If it is then assumed that this quantity is known, it may be used as an input to successive integrators to obtain the lower order derivatives and the independent variable (i in this case) itself. The quantity $\frac{d^2i}{dt^2}$ shown at the right-hand side of the diagram in figure 2, is applied to the integrator at the left-hand side of the diagram.

Here the voltage representing $\frac{d^2i}{dt^2}$ is integrated with respect to time to obtain $-\frac{di}{dt}$. This new voltage, representing

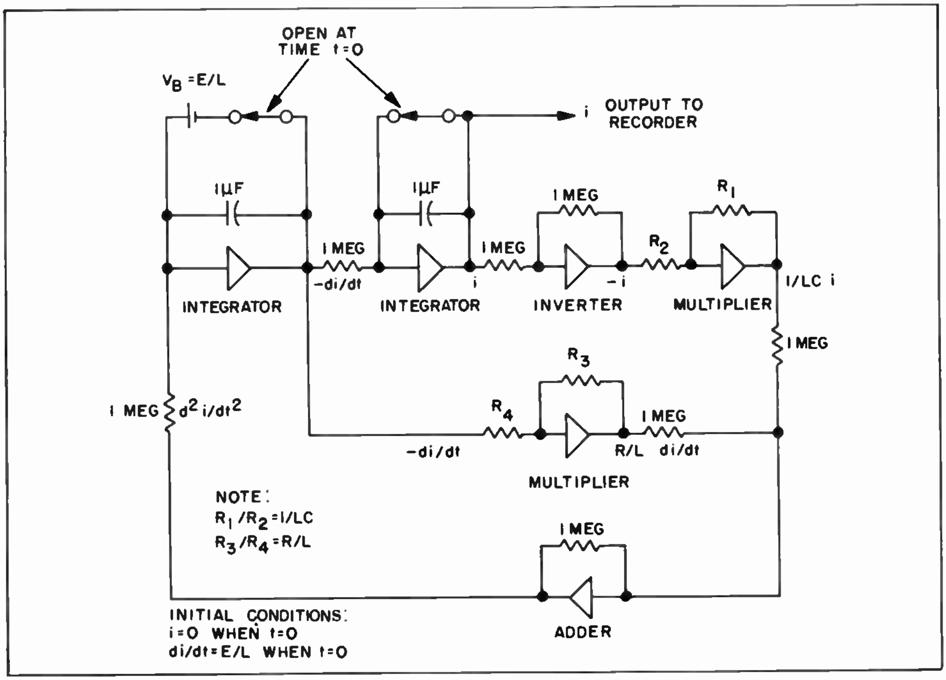


Figure 2. Computer Connection for Solving the Equation

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LC}i = 0$$

$-\frac{di}{dt}$, is applied to a multiplier which multiplies it by $\frac{R}{L}$, and inverts the polarity to produce a voltage representing the quantity $\frac{R}{L}\frac{di}{dt}$. The voltage representing $-\frac{di}{dt}$ is also applied to another integrator and the output is i (another inversion of sign takes place in this integrator), which is the dependent variable being sought. The voltage representing i is applied to an inverter to obtain a voltage representing $-$ i, which is then multiplied by $\frac{1}{LC}$ in the multiplier that follows. The result is a voltage representing $\frac{1}{LC}i$. It may now be seen that the inputs to the summing circuit (adder) of figure 2 are $\frac{R}{L}\frac{di}{dt}$ and $\frac{1}{LC}i$. The output of the adder with these inputs will be, as shown previously, the negative of the sum of the inputs, thus satisfying equations (4-4) and (4-3). Since the voltage across the capacitor of the first integrator represents, at any time t, the value of $-\frac{di}{dt}$, the initial condition $\frac{di}{dt}(0) = \frac{E}{L}$ is set into the computer by charging this capacitor to this voltage prior to the beginning of the computation cycle. For the same reason, the capacitor in the second integrator is shorted by a switch until $t = 0$, to ensure that the voltage across it is zero as is required by the other initial condition. This interconnection of computer circuitry to satisfy equations (4-4) and (4-3) is known as the implicit function technique. It will be seen that the computer is, in reality, an analog (a rather elaborate one in this case) of the original system shown in figure 1, and that the voltages in the computer have no choice but to vary in the same manner as the variables that they represent in the original system.

SCALE FACTOR AND COMPUTING TIME

In the simple problem example above, a unity scale factor has been assumed; that is, 1 volt of the machine variable (voltage) is equivalent to 1 ampere of the original variable. In most problems, a scale factor other than unity must be assigned to the machine variables in order to accomplish the following: limit the machine variables to the dynamic operating range of the computer; make the machine variables of interest large enough so that the resolution of the variables and the solution is sufficient to obtain accurate results. In addition, the example problem just discussed was computed on the basis of actual time, the variations of voltage with time in the machine being synchronous with the variations of the corresponding variables in the physical system being investigated (the RC time constant of the integrators is 1 second). In many cases, it is desirable to compute on "fast time" in order to speed the computation or on "slow time" in order to increase the accuracy of the solution (these are conflicting requirements since fast-time computing requires that the computing components have a greater bandwidth). For example, if fast-time computation in the ratio of 10:1 was desirable, the integrating capacitors could be reduced in value from 1 μf. to 0.1 μf. This reduction would decrease the RC time constant to 0.1 second, and the change that previously took place in 1 second would then take place in 0.1 second.

In the type of computer under consideration, it will be seen that the independent variable is inevitably time. Although this fact poses some restrictions on the computation, many of the problems of physics and chemistry are described by equations having time as the independent variable; hence, this type of computer seems suitable for use in attacking such problems. To emphasize the fact that the variables in the computer are actually voltages, which are operated on by the computer components in accordance with a machine equation, the original equation to be solved is frequently written in terms of another variable, say X. If successive time derivatives of this machine variable X are indicated by $\dot{X}$, $\ddot{X}$, . . . , equation (4-3) may be transformed (with the scale factor still unity) to:

$$\ddot{X} + \frac{R}{L}\dot{X} + \frac{1}{LC}X = 0. \qquad (4\text{-}5)$$

The result is the machine equation actually solved by the computer.

SETUP USING DIFFERENTIATORS

The machine setup for the solution of the simple example problem shown in figure 2 is not the simplest one available. There are other setups that can be used to accomplish the same solution. For an example of a simple setup which could be used to solve the same equation, solve the machine equation (4-5) for X to obtain:

$$X = -(LC\ddot{X} + RC\dot{X}). \qquad (4\text{-}6)$$

Again treating X as if it were already known, the voltage representing X is applied to a differentiator (see figure 3), the output of which is $=\dot{X}$. This quantity is applied to an inverter-multiplier, to obtain a change in polarity and a multiplication by the constant RC. Also, the voltage $-\dot{X}$ is applied to another differentiator, which produces $\ddot{X}$ (another change in polarity takes place in this differentiator). If the product LC is less than unity (which would be the case in most circuits), a potentiometer may be used to multiply the voltage $\ddot{X}$ by LC, since it was shown in a previous article that potentiometers were capable of multiplication by a quantity less than unity. Here, the initial condition that X = 0, corresponding to the initial condition i = 0 for equation (4-3), is easily inserted by connecting a switch to ground out this voltage until computation begins. The initial condition that $\dot{X} = \frac{E}{L}$ is met by using a battery to supply a voltage equal to $\frac{E}{L}$. This battery is connected across the resistor of the differentiator that produces $-\dot{X}$, until the computation begins.

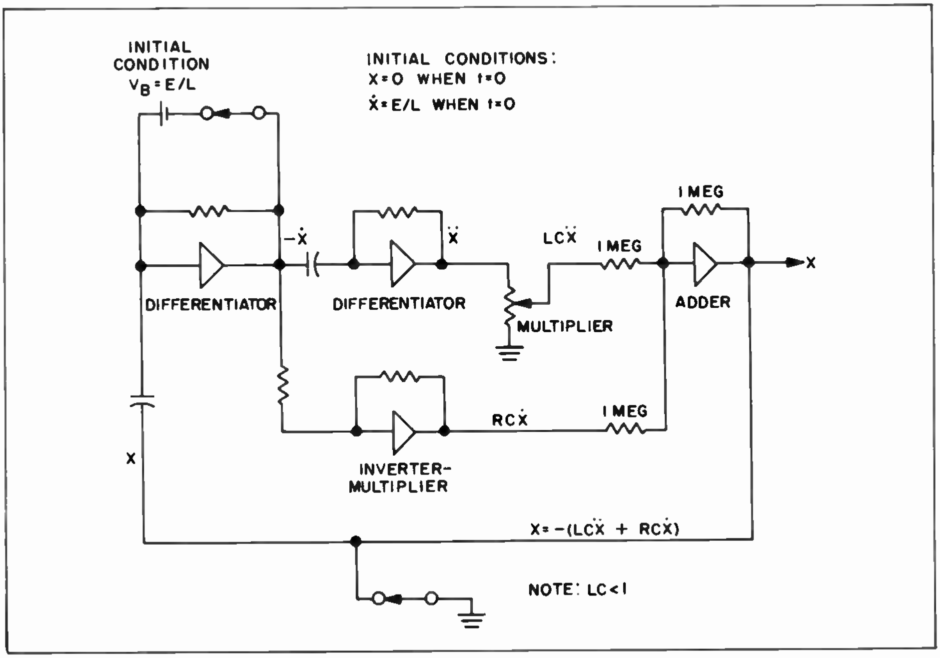


Figure 3. A Differential Analyzer Connection Using Differentiators Rather Than Integrators for Solving Problem in Figure 2

In practice, differential analyzers are seldom constructed using differentiators, because these circuits tend to emphasize the high-frequency and noise components of the computer voltages. Differentiators find greater use in special purpose computers such as fire control computers. It can be seen from the foregoing discussion that the actual computer setup used for the solution of a given problem may well depend upon the problem constants, as well as upon the general type of equation being solved.

AN ECONOMICAL SETUP

If machine equation (4-5) is solved for $\ddot{X}$, the result is:

$$\ddot{X} = -\left(\frac{R}{L}\dot{X} + \frac{1}{LC}X\right). \qquad (4\text{-}7)$$

Integrating both sides of this equation with respect to time gives $\dot{X}$ implicitly as a function of itself and X,

$$\dot{X} = -\int\left(\frac{R}{L}\dot{X} + \frac{1}{LC}X\right)dt \ , \qquad (4\text{-}8)$$

subject to the initial conditions as they determine $\ddot{X}(0)$. To determine $\ddot{X}(0)$, the given values of $X = 0$, $\dot{X} = \frac{E}{L}$, when $t = 0$, are substituted into equation (4-7) to give:

$$\ddot{X}(0) = -\left[\frac{R}{L}\left(\frac{E}{L}\right) + \frac{1}{LC}(0)\right] = -\frac{RE}{L^2}.$$

Equation (4-8) may be mechanized as shown in figure 4. It may be seen that the output of the first integrator is the $\dot{X}$ on the left-hand side of the equation. This quantity is required for the input to the integrator, as shown in equation (4-8); hence, the output of this integrator is connected to its input through a suitable resistance (the first integrator is a summation circuit in addition to being an integrator). The other required input to the first integrator-adder is the quantity X, which is obtained from an inverter (sign changer), the input to which is $-X$. The output of the first integrator ($\dot{X}$) is applied to the input of the second integrator so that the quantity $-X$ is obtained in the output of the latter circuit. Since equation (4-8) was derived subject to the condition on $\ddot{X}$, the value of $\ddot{X}(0) = -\frac{RE}{L^2}$ must be supplied to the first integrator-adder at the time $t = 0$.

If the setup of figure 4 is compared with that of figure 2, the following facts

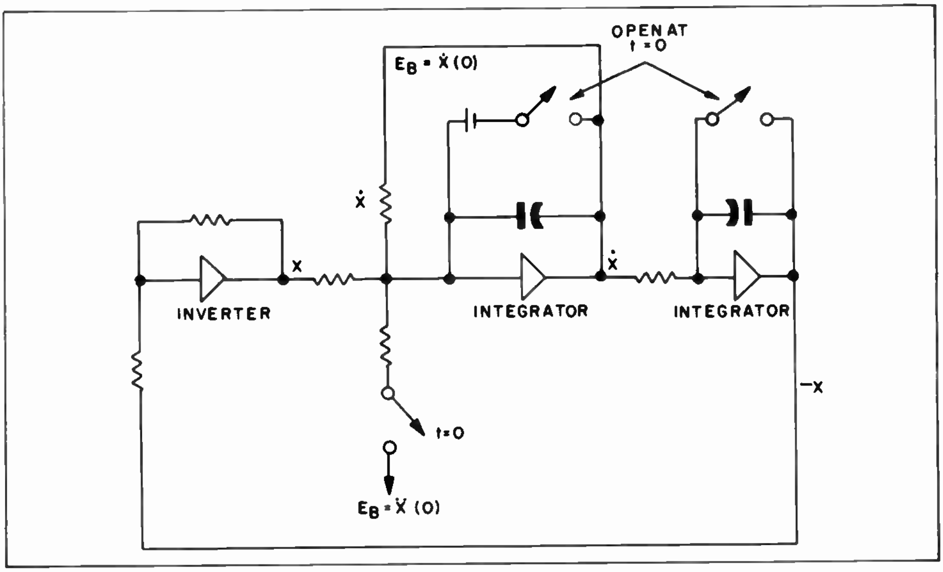


Figure 4. Another Machine Setup for the Solution of Equation (4-5)

will be observed. The setup of figure 4 requires only three computing amplifiers, while that of figure 2 requires six computing amplifiers. The variable $\ddot{X}$ is not available anywhere as a voltage in the setup of figure 4—a condition that would represent a disadvantage if it were desired to record and investigate this variable for a given problem. Furthermore, some extra computation of the values of the resistors to be used in the summing integrator must be done for the setup in figure 4 (this computation is not given here). It should be pointed out that, in general, the setup employing the fewest components (such as amplifiers, etc.), will produce the most accurate solutions, because the accumulation of errors will be smaller in a smaller number of components. Note also that the setup of figure 4 utilizes only integrators, which are preferable to differentiators as previously stated. The initial conditions $X(0) = 0$ and $\dot{X}(0) = \frac{E}{L}$, when $t = 0$, are entered into the integrators of the machine setup as shown in figure 4 by charging the capacitors of the first and second integrators to 0 volts and $\frac{E}{L}$ volts, respectively, and disconnecting these capacitors from the IC power supplies (batteries) at $t = 0$.

Referring again to the original problem, equation (4-3), it may be seen that the "driving function" is zero; hence, there is no "drive" applied directly to the computer during the computation. Actually, the driving voltage for the computer connected as shown in figure 2 appears across the capacitor of the first integrator in the form of the initial condition $\frac{di}{dt} = \frac{E}{L}$, when $t = 0$. The initial conditions are similarly applied to the computer connected as in figure 4, with the addition of the $\ddot{X}(0)$ voltage as noted above. In the circuit of figure 3, the same initial conditions are inserted into the computer by the application of the voltage at the input of the second differentiator, the input capacitor of this circuit being the source of the drive in this case.

FUNCTION GENERATION

The solution of a nonhomogeneous equation on a computer of this type requires that a function generator be available to connect to the machine. Such a function generator could be connected to the adder of the circuit shown in figure 2. An ordinary audio oscillator with a reasonably pure sine-wave output will serve as a function generator if a sinusoidal driving function is required. Differentiating and integrating circuits (preferably integrators) may be employed in conjunction with various voltage waveform generators to produce other driving functions, having short time durations. For example, the rectangular output of a multivibrator may be integrated to obtain a sawtooth voltage, a sawtooth voltage may be integrated to obtain a parabolic voltage, etc. Arbitrary functions may be approximated by the use of diode function generators using the segmented-curve technique. The function represented in part A of figure 5 ($I = kE^n$, where k and n are constants) may be approximated rather closely by the circuit shown in part B of the figure. The approximation method is based on the mathematical principle of approximating a curve by using a series of straight-line segments to join a number of selected points on the curve. In a linear conductance, the relationship between the applied voltage and the current through the conductance is a linear function; hence, in the circuit shown in part B of figure 5, I increases linearly between $E = 0$ and $E = E_1$, because current flows only through R_1. When the applied voltage E exceeds the bias battery voltage E_1, current flows through R_2 as well as R_1, the conductance of the circuit now being $\frac{1}{R_1} + \frac{1}{R_2 + R_C}$, where R_C is the resistance of the crystal diode or tube as the case may be. Thus an additional shunt branch is added to the circuit at

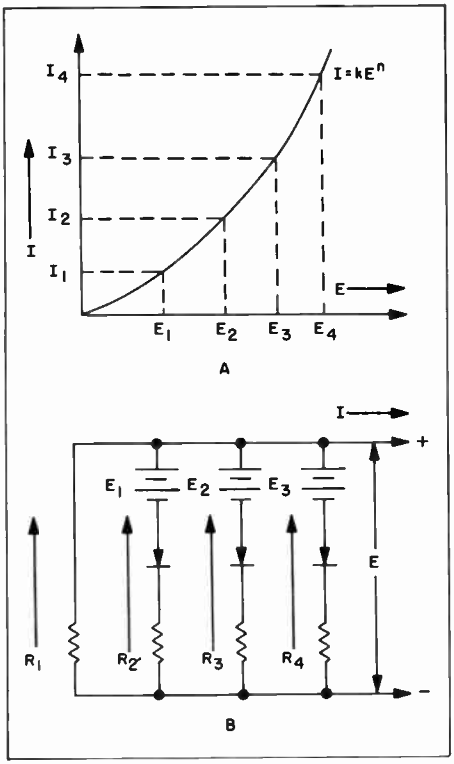


Figure 5. Generation of Arbitrary Function by Means of Diode Function Generator

each of the "break points" E_2, E_3, and E_4. Simple curves may be approximated to a good degree of accuracy with diode function generators of this type employing a reasonable number of segments. This type of function generator is particularly applicable to slow computers which are working toward higher accuracy, since long duration waveforms of the types mentioned above are not easily generated to the required accuracy. The current from the diode generator may be converted to a voltage in a proportional manner by connecting the circuit to the input of a high-gain d-c amplifier.

Other arbitrary function generators include simple resistive networks employing ordinary potentiometers and specially wound potentiometers to provide voltages that represent various functions.

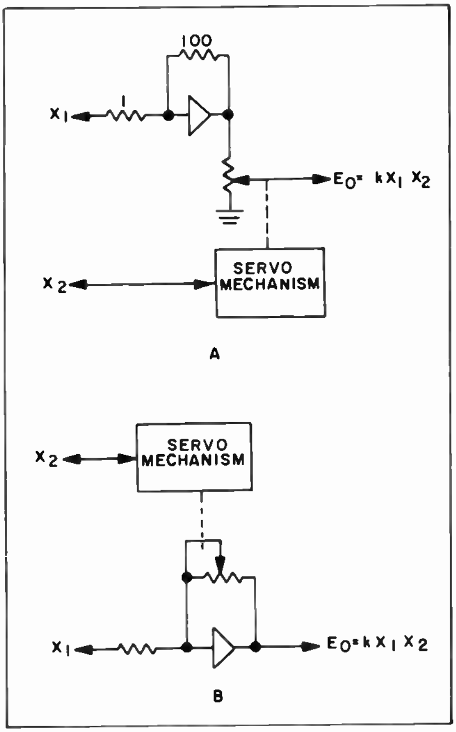


Figure 6. Servo Multiplier for Electronic Analog Computer

MULTIPLIERS

If differential equations with variable coefficients are to be solved using an electronic differential analyzer, a means of multiplying voltages must be provided. It was pointed out earlier that a simple potentiometer is capable of accurate multiplication but that this multiplication must be by a factor less than unity. This disadvantage may be easily eliminated by using a high-gain d-c amplifier to multiply one of the factors by a fixed ratio and then applying the resulting voltage across a precision potentiometer. The voltage representing the other factor is used to control a servomechanism which positions the arm of the precision potentiometer to accomplish the multiplication of the two voltages. Such an arrangement is shown in part A of figure 6. It can be seen that the constant scale factor k may be made equal to unity if the servomechanism is

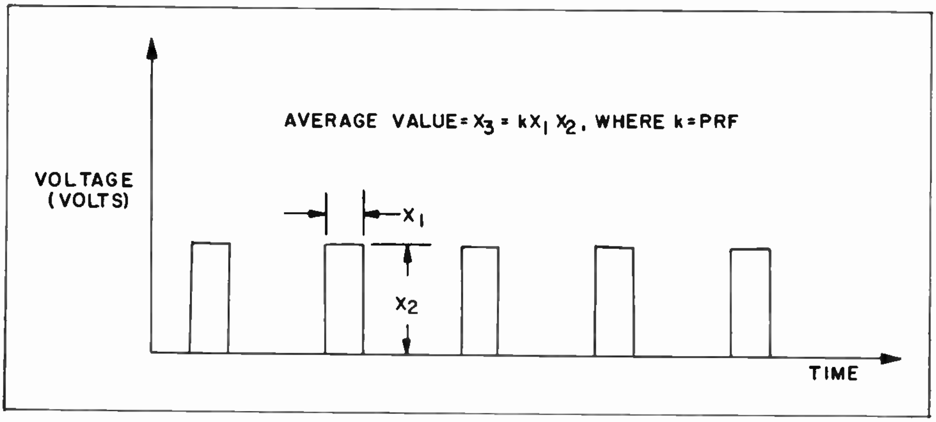


Figure 7. Principle of Operation of One Type of Electronic Multiplier

adjusted so that the output voltage is equal to X_1 when the input voltage X_2 is equal to 1 volt. An alternate scheme for using a servomechanism for multiplication is shown in part B of figure 6. In this arangement, the output voltage is equal to the ratio of R_1 to R_2 multiplied by the input voltage X_1 (where R_1 is the value of the unshorted resistance of the potentiometer). As before, a unity scale factor will result if the servo is adjusted so that $R_1 = R_2$ when the input voltage X_2 is equal to 1 volt. In either of these arrangements, additional potentiometers may be mechanically connected to the servomechanism if other products involving X_2 as a factor are required.

Although servo multipliers are capable of great static accuracy, their dynamic accuracy is severely limited by the speed of response of the mechanical servomechanism which drives the arms of the potentiometers. Therefore, it is highly desirable to obtain an all-electronic multiplier, in order to obtain faster computer operation (and more accurate multiplication at high computing speeds).

A number of all-electronic schemes for multiplication are in use. One such scheme is based on the fact that the average value of a series of rectangular pulses is proportional to the product of the width of the pulses and the height of the pulses. If one of the voltage factors is used to control the width of a series of pulses at a fixed repetition rate and the other voltage factor used to control the amplitude of these pulses, the average value of the pulse train is proportional to the product of the two voltages. The principle of operation of this type of multiplier is shown in figure 7. Another all-electronic multiplier is based on the quarter-squares principle. A calculation will show that

$$X_1X_2 = \frac{1}{4}[(X_1 + X_2)^2 - (X_1 - X_2)^2]. \tag{4-9}$$

In this scheme, the X_1 and X_2 voltages are summed with conventional summing circuits, and their sum and difference squared by diode squaring circuits. The difference of the squares is then obtained by means of a third summing amplifier, which provides a voltage proportional to the product X_1X_2. A number of other all-electronic multipliers have been developed and are in use.

The variables in many physical problems are, for various reasons, limited to certain values. To produce an accurate analog of such a situation, it is necessary to likewise limit the excursion of the corresponding variables in the analog computer. This limiting can readily be accomplished by means of conventional shunt limiters.

COMPUTER OPERATION

The choice of fast-time, real-time, or slow-time operation for an analog computer depends upon the particular problem being solved, the solution accuracy required (as mentioned previously), and the speed of the computing equipment available, especially that of the recorder. If an electromechanical recorder is used with the computer, the limit on its speed of response may limit the operating speed of the computer. If the computer is equipped for fast-time operation, the solution of the equations being solved may be presented on a cathode-ray oscilloscope. This form of presentation usually requires that the equation be solved at least 30 times per second (called repetitive operation). The scope presentation of the solution of equation (4-5) would appear like that shown in figure 8. One of the primary advantages of the use of the oscilloscope for a solution recorder in repetitive operation is that it greatly facilitates the investigation of the effects of parameter changes in the system being studied. The operator of the computer may change the parameters of the system at will while observing the effects of these changes on the scope. In certain boundary value problems (problems requiring the determination of the boundary values for which a given solution is valid), this technique is especially useful.

SOLVING SYSTEMS OF DIFFERENTIAL EQUATIONS

Physical systems in which coupling takes place may be described mathematically by systems of differential equations. The technique for handling these equations on an electronic analog computer is similar to that described for single equations. Each equation of the system is solved for a different one of the highest order derivatives. These derivatives are then successively integrated to obtain the lower order derivatives and the independent variables themselves in the same manner as for the single equations discussed previously. The circuits used for this purpose are then interconnected so that all of the same dependent variables and their derivatives are connected together to solve the system. In this manner, large systems of differential equations, which are difficult to solve analytically, may be conveniently solved with a comparatively small amount of equipment.

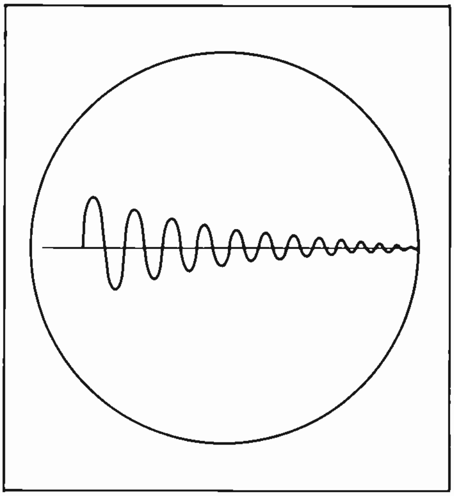


Figure 8. Appearance of Repetitive Solution of Equation (4-5) on an Oscilloscope

COMMERCIAL COMPUTERS

The manufacturers of some commercial electronic analog computers provide overload indicators and removable patch boards to enhance the usefulness of their machines. For overload indication, a light lights and/or a bell rings if any of the amplifiers in the computer become overloaded (are driven outside of their linear range) in the course of the computation. When an overload occurs, a change of scale factor must usually be made, to remedy this situation. The removable patch boards provide a convenient means of interconnecting the computing components, and thus greatly facilitate the programming of a large machine where the interconnection of the computer circuits may become rather involved.

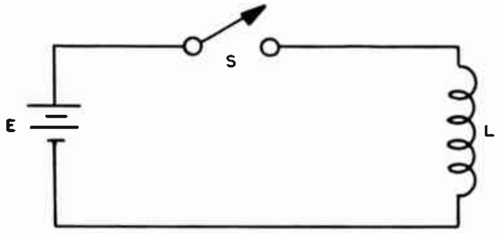
SIMULATION

It has long been noticed that the differential equations describing different physical systems fall into certain classes. Thus the second-order differential equation with constant coefficients describes a system undergoing simple oscillation. Advantageous use may be made of this similarity of equations in the synthesis of analogs, that is, the production of a realistic working model of a system. If a differential equation which accurately describes the behavior of a physical system has been formulated, the relatively unimportant factors in the problem have already been eliminated; hence, the construction of a reasonably accurate analog of the system requires only a computer for the continuous solution of the given equation. This does not, by any means, require that the differential equation of a system must be formulated in order to produce an analog; it merely indicates the convenience in simulation afforded by the use of the equation. As a result of this situation, an electronic analog computer is often found to be the heart of a simulator. Modern simulators are able to simulate the dynamic characteristics of complex servo systems, airplanes in flight, guided missiles (including their complex control systems), and atomic reactors, to mention but a few. Since human beings operate in real time, any simulator used for training operating personnel is inherently a real-time computer. In like manner, the dynamic testing of the new system components of a missile or weapons system must be carried out in real time on a computer-simulator. On the other hand, if a system is being represented completely by the simulator, system studies may be carried out with the computer operating on fast time or slow time, whichever is the most desirable.

"What's Your Answer?"

The problem this time is a relatively simple one but perhaps the explanation of the answer will be considerably more difficult.

The circuit shown below contains an idealized inductance (one which has no resistance) and a battery having an internal resistance which is zero. This circuit, of course, is not a practical circuit as it stands, but serves to illustrate the conditions that exist when the inductance is very much greater than either the resistance of the coil or the impedance of the voltage source. The problem is to draw and explain the waveform representing current variation with time, beginning at the time switch S is closed.



A TESTER FOR SIMPLIFYING CABLE TESTING

by Robert E. Fritsch
Philco TechRep Field Engineer

(Editor's Note: The tester described in this article makes it possible to perform routine cable tests in a considerably shorter period of time than would otherwise be possible. It is simple and easy to construct from readily available materials, and is valuable wherever routine tests are performed on a large number of cables.)

Four common types of cables are used to connect the various components of Ordnance fire control systems; these are 19-conductor, 21-conductor, 28-conductor, and 38-conductor cables. Checking these cables for such defects as short circuits, open circuits, and low values of insulation resistance, either in the field as a part of preventive maintenance or in Ordnance depots during the rebuilding of cable systems, is a very time-consuming job when the only tools employed are an ohmmeter and a megger. Each conductor of a cable first must be checked for opens and shorts, and then must be checked against ground and against every other conductor for specified values of insulation resistance. A complete check of insulation resistance alone on a 38-conductor cable involves 816 different measurements, for which a crank-operated megger is normally used.

The use of the cable tester shown in figures 1, 2 and 3 simplifies these measurements and reduces by more than 80% the number of man-hours required. The tester consists of a box (a salvaged housing of an M47 Tank master junction box was available) on which are mounted male and female plugs for the four types of cables, four rotary switches, a 500-volt power supply, an indicator lamp, binding posts for connecting a

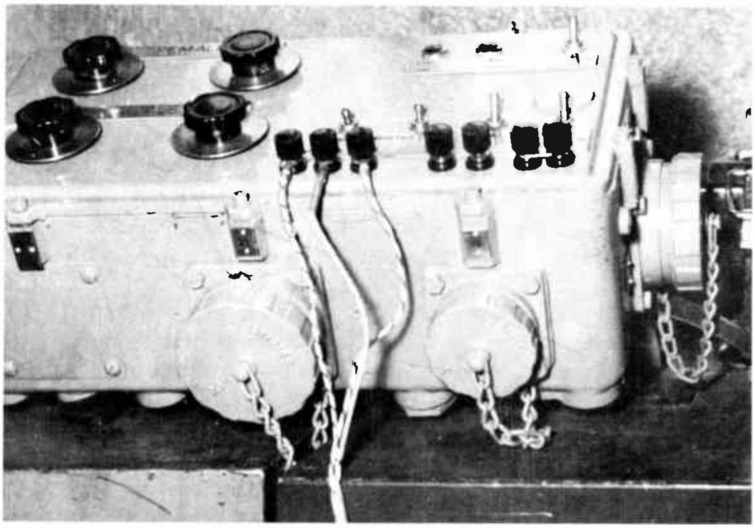


Figure 1. Photograph of Cable Tester, Showing Megger Leads Connected

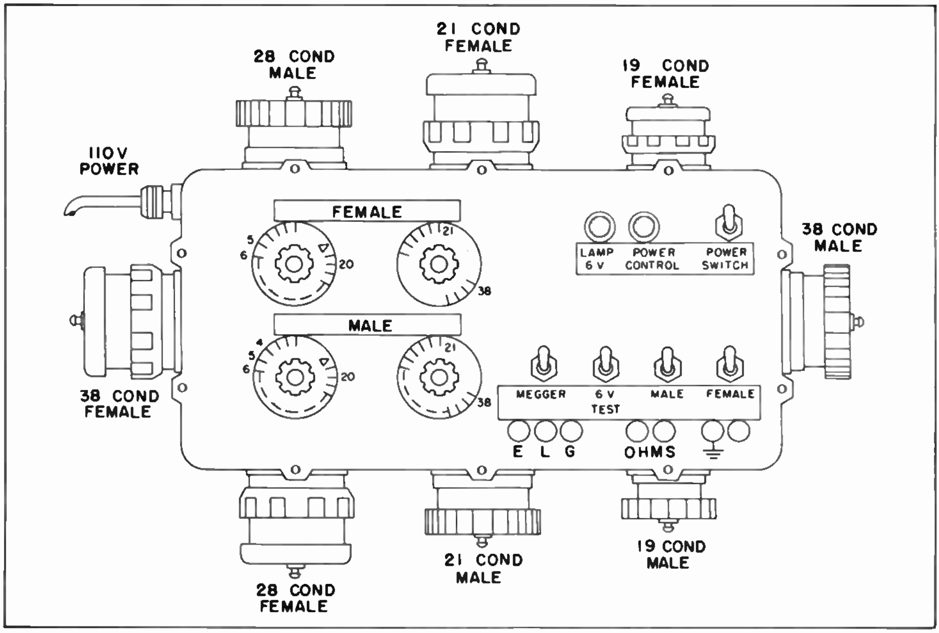


Figure 2. Outline Drawing of Cable Tester, Top View, Showing Placement of Connectors, Switches, Lamps, and Terminals

megger and an ohmmeter, terminal strips, and several control switches. Figure 3 shows a partial wiring diagram of the tester. To simplify the presentation, only the 21-pin male and female connectors are shown. The other connectors are connected in parallel with these (pin 1 of all four male plugs connected to terminal 1M, pin 1 of all four female plugs connected to terminal 1F, and so on). Also for simplicity, only a few of the terminals are shown in figure 3, since they are all identical. The 500-volt power supply, shown in figure 4, is included as a source of meggering voltage, to eliminate the necessity of turning the megger crank for each reading. A switch is added to the megger so that the crank-operated generator can be disconnected when the megger is used with the tester, and reconnected when the megger is required for other purposes. If a megger is available to be incorporated as a permanent part of the tester, the generator can be disconnected internally.

PROCEDURE IN USING TESTER

1. Continuity—Plug both ends of the cable to be tested into the proper receptacles on the box. Turn power switch S1 and 6v test switch S2 to the ON positions. Rotate switches F_1 and M_1 together from position 1 through the number of conductors to be tested. If more than 20 conductors are to be checked, continue with F_2 and M_2, leaving F_1 and M_1 at position 20. The test lamp indicates continuity when lit. A simplified diagram of the tester used as a continuity checker is shown in figure 5.

2. Resistance of conductors—This check follows the same procedure as the continuity check except that an ohmmeter is connected between terminals C_1 and C_2 and the 6v test switch S2 is placed in the OFF position. The simplified diagram of the tester circuits for this check is also shown in figure 5.

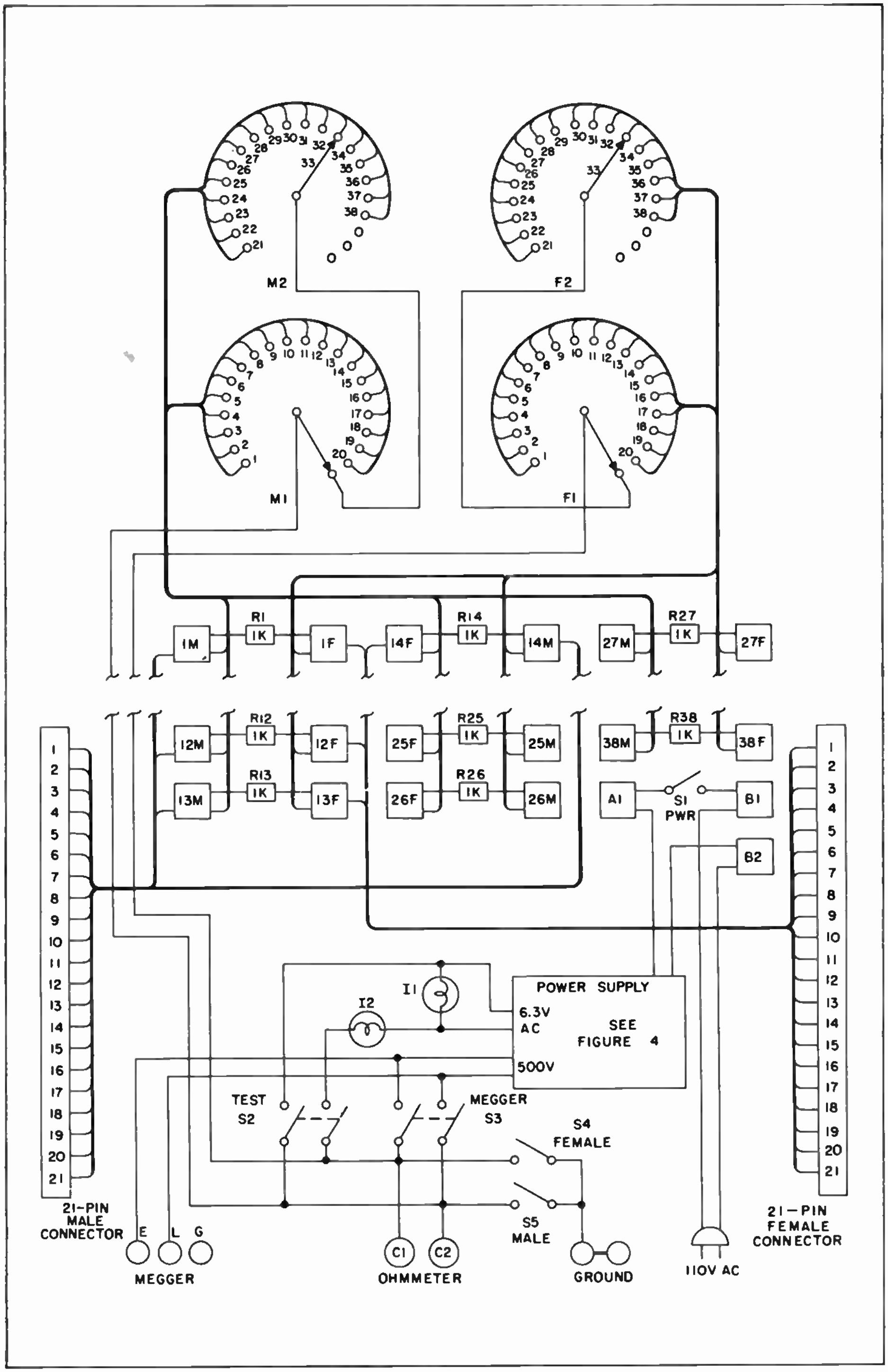


Figure 3. Partial Wiring Diagram of Cable Tester

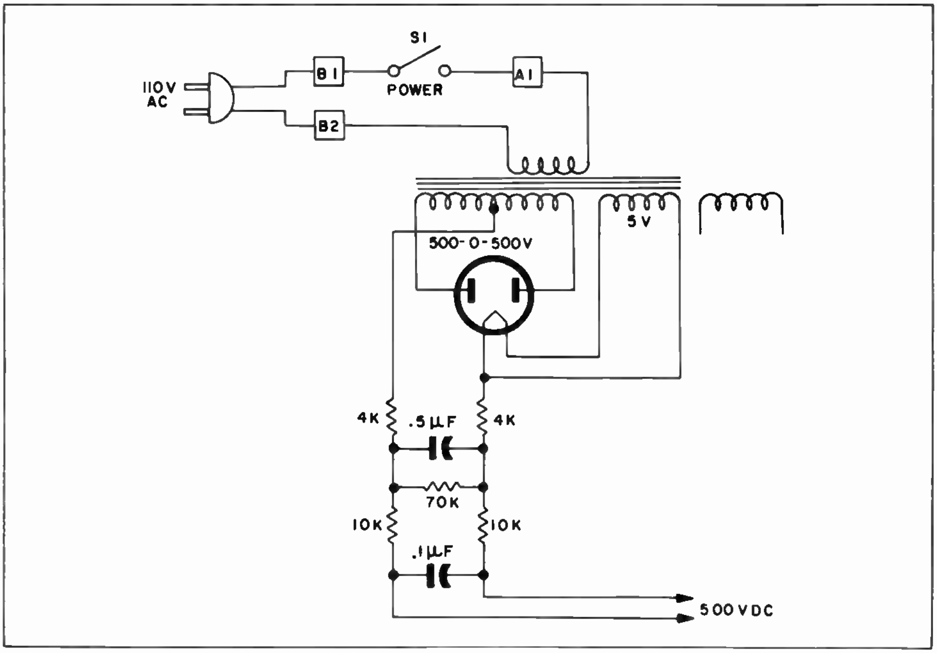


Figure 4. Schematic Diagram of Power Supply

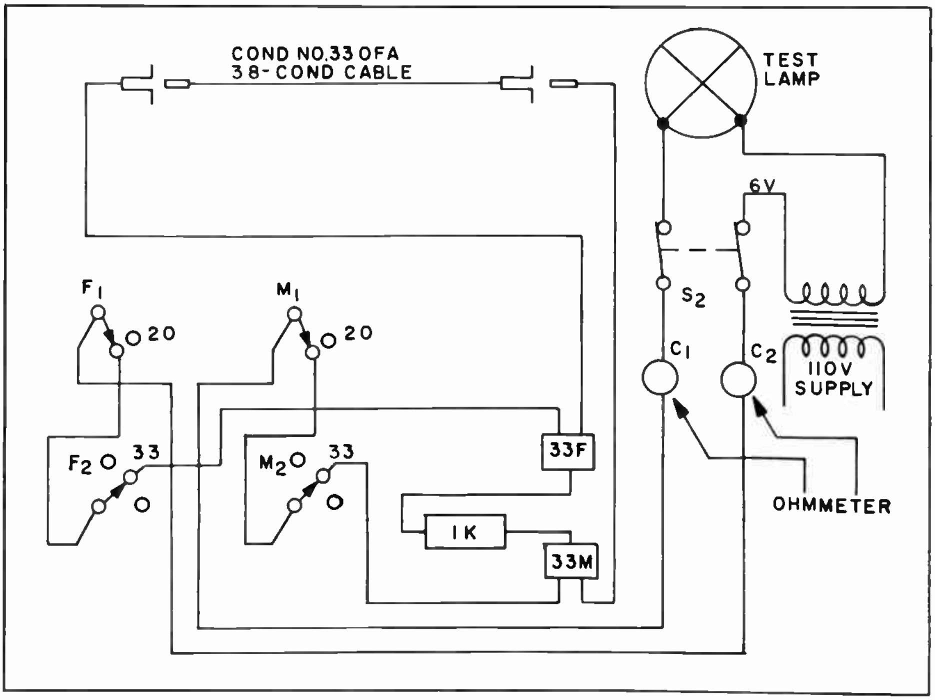


Figure 5. Simplified Schematic Diagram, Showing Circuit Used in Checking for Continuity, Short Circuits, and Lead Resistance

3. Short circuits—Turn 6v test switch S2 to ON. Place switch F_1 in position 1, and rotate M_1 and M_2 through all positions except position 1. The test lamp should not light. Proceed, using position 2 of F_1, position 3 of F_1, and so on. The simplified diagram of the tester circuits for this check is also shown in figure 5.

4. Insulation resistance to ground—Turn megger switch S3 to ON. Plug in and check the male and female ends of the cable separately. When the male plug is being meggered, connect terminal L of the megger to ground by closing switch S5 (marked MALE). When the female plug is being meggered, connect terminal E of the megger to ground by closing switch S4 (marked FEMALE). Each line is independently checked by rotating the appropriate rotary switch.

5. Insulation resistance between leads—Proceed in the same manner as for short circuits except close megger switch S3 and switch S5. Figure 6 illustrates this test.

Provision is also made to test insulation resistance between leads of components containing only one plug or receptacle, as illustrated in figure 7. For this check, a 1000-ohm resistor is placed between each of the F terminals and its corresponding M terminal, to complete the connection for meggering between leads. Since the 1000-ohm resistor is in series with the insulation resistance, it has negligible effect upon the values obtained. The resistor has no effect upon the continuity testing of cables, because in continuity tests it is in parallel with the conductor resistance. An alternate method would have required additional rotary switches and would have made the tester more complicated.

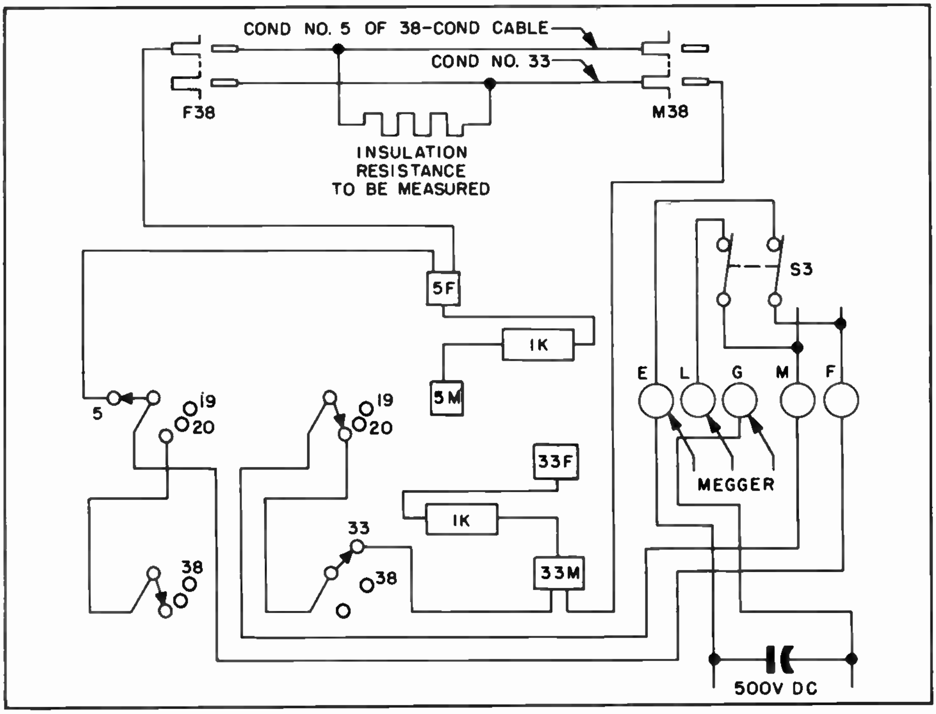


Figure 6. Simplified Schematic Diagram, Showing Circuits Used in Testing Insulation Resistance When Both Ends of Cable Can Be Connected

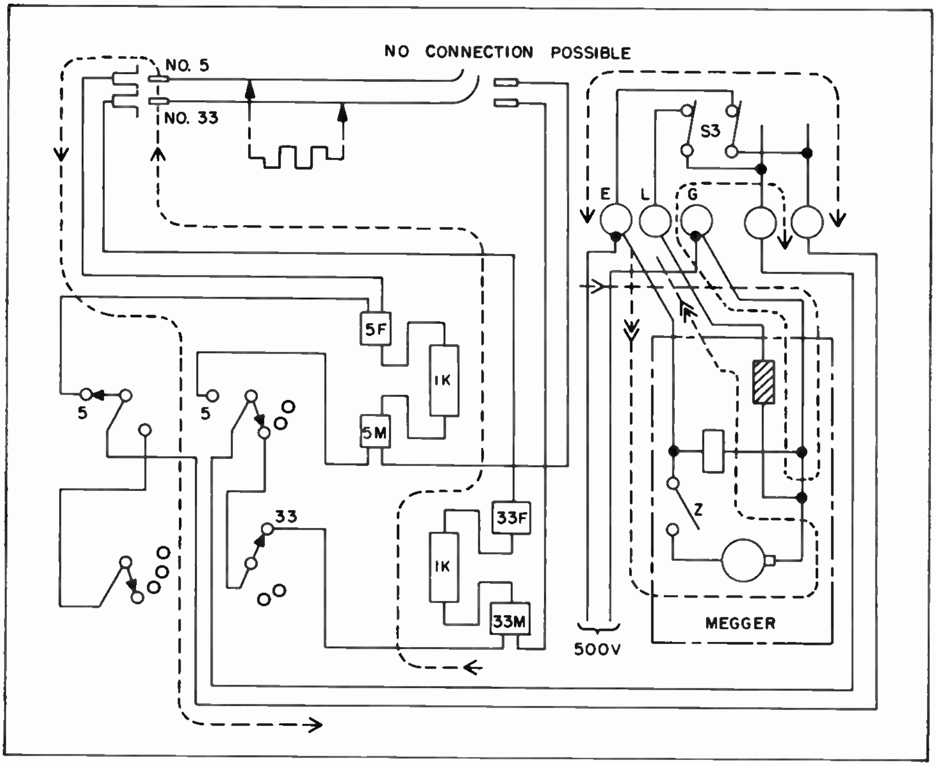


Figure 7. Simplified Schematic Diagram, Showing Circuits Used in Checking Insulation Resistance When Only One End of Cable Can Be Connected

Care should be taken in constructing the box, and only high quality components having high values of insulation resistance should be used. Upon completion, the box should be baked until all insulation resistance values become constant, sprayed inside and out with moisture- and fungi-proofing varnish, air-dried for 30 minutes, and then baked again at 170° F. until dry.

PRF, PULSE-SHAPE, AND PULSE-WIDTH CHECKER SETUP

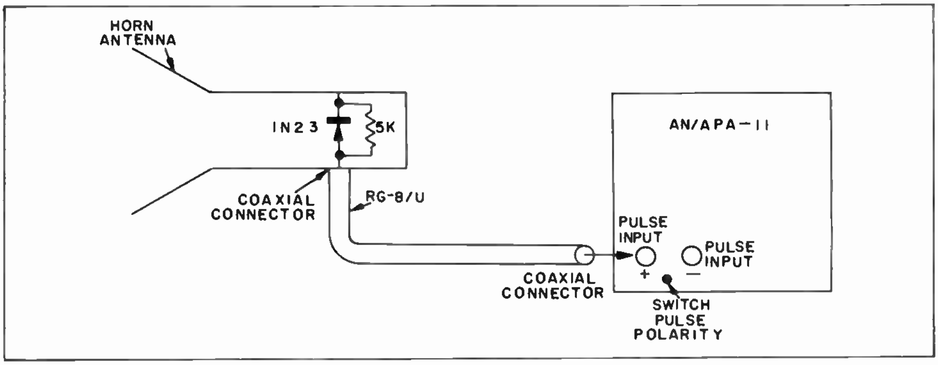
An easily prepared setup for checking the PRF, pulse shape, and pulse width of a search radar. This setup was originally used to provide a bench-check of these items on the APS-15 radar. It can easily be adapted for use also with S-band radar.

A CONVENIENT SETUP for checking the PRF, pulse shape, and pulse width of a search radar may be had by using a modified antenna in conjunction with an AN/APA-11 pulse analyzer (now obsolete but available at most shops). The AN/APA-11, which includes a test mockup for airborne ECM equipment, is capable of measuring pulse width, pulse duration, and PRF quite accurately when properly calibrated. If the video gain control is adjusted so that the amplifier is not saturated, the AN/APA-11 may also be used to check pulse shape. The required 400-cycle power input is normally available in airborne electronics shops.

Since the input to the AN/APA-11 is usually the video output from an ECM receiver such as the AN/APR-4, it is necessary to provide some type of detector in place of this receiver. This is done by modifying an X-band horn antenna to include a crystal holder for a 1N23 silicon crystal and a connector for RG-8/U coaxial cable, as shown in the accompanying illustration. A 5k resistor is soldered across the crystal terminals to provide good reproduction of the pulse, because the use of only the back resistance of the crystal would tend to distort the trailing edge of the pulse envelope. The impedance of the RG-8/U cable, together with that of the crystal and resistor, provides an r-f filter which allows only the pulse envelope to appear at the input to the AN/APA-11.

To use the setup described above, the radar antenna is pointed in the general direction of the antenna incorporating the detector unit and the AN/APA-11 is operated in the normal manner. If the pulse appears negative, it is only necessary to connect the coaxial lead to the other input of the AN/APA-11 and reverse the input polarity switch. The proximity of the radar antenna to the detector eliminates any need for extra amplifier stages, such as would normally be provided in the AN/APR-4.

Although only one detector unit was built, a similar device using the same AN/APA-11 could be built for checking S-band radar equipments.



SYNCHRONIZED OPERATION OF AN/FPS-3 AND AN/FPS-8 RADARS

by Fred F. Thomas
Philco TechRep Site Engineer

(Editor's Note: This article was written by the author to describe the procedure for synchronizing the operation of the above named equipments and to describe the results to date. This arrangement has been tried and is currently being tested at the 776th ACW Squadron, Point Arena, California, and was thought to be of considerable interest to BULLETIN readers.)

RECENTLY, UPON APPROVAL from higher headquarters, the trigger signals of the AN/FPS-8 and AN/FPS-3 radars were synchronized. Since the antenna rotation of the two equipments had previously been synchronized, completely synchronized operation was then obtained. The synchronization of these equipments was considered desirable for four reasons, as follows:

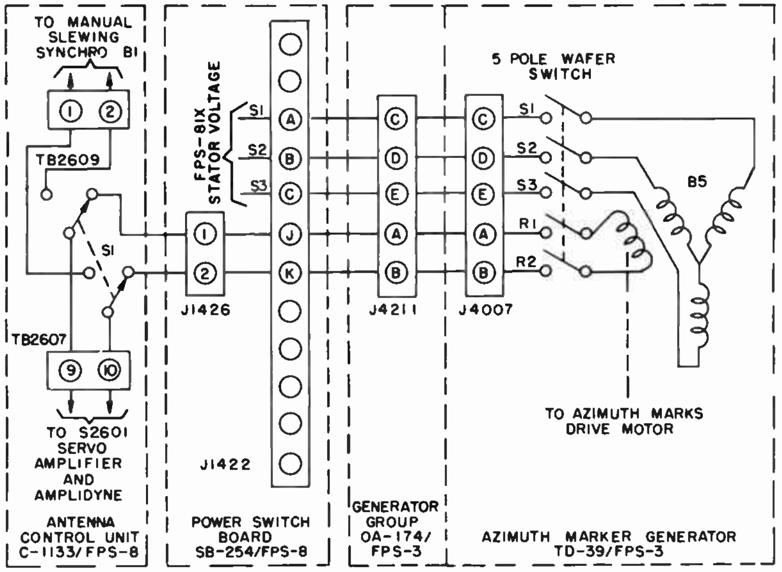
(1) To prevent mutual interference between the two equipments when both are operated at the same time. (2) To provide MTI video to all AN/FPS-3 PPI indicators without increasing the PRF of the AN/FPS-3 and hence sacrificing its long-range capabilities. This is accomplished by applying the MTI video from the AN/FPS-8 to the electronic gate unit of the AN/FPS-3. (3) To provide immediate backup for the output signals of some of the major components of the AN/FPS-3. With complete synchronization it is possible to utilize the range marks, angle marks, etc., of the AN/FPS-3 or AN/FPS-8 in either of the two equipments. For example, in the case of a failure of the upper-beam channel of the AN/FPS-3, the AN/FPS-8 video can be substituted for the upper-beam video of the AN/FPS-3 (this is not possible unless the two radars are synchronized in rotation as well as triggering). (4) To reduce the chance of damage to the crystals of the two equipments by preventing the direct reception by one antenna of the transmitted signal from the other.

SYNCHRONIZATION OF ANTENNAS

As shown in the schematic diagram of figure 1, the synchronization of the two antennas is accomplished by utilizing IFF synchro B5 in Angle Mark Generator TD-39/FPS-3. This synchro, which is geared to the azimuth marker drive motor, is not normally in use but simply rotates in synchronization with the AN/FPS-3 antenna. It is used to provide the "order signal" to the AN/FPS-8 antenna control system by taking the place of manual slewing synchro B1 in the AN/FPS-8 antenna control system.

As shown on the schematic of figure 1, a five-conductor cable is fabricated and connected between connectors J4211 on OA-174/FPS-3 (the IFF synchro connector) and J1422 on SB-254/FPS-8 (a PPI selsyn data and power output connector). This arrangement supplies 1X stator voltage from the AN/FPS-8 radar to IFF synchro B5 in the AN/FPS-3. The rotor error voltage is connected through the five-conductor cable to pins J and K on J1422 in SB-254/FPS-8 (pins J and K are spares on this jack). The power is disconnected from J1426, and jumpers are connected between terminals J and K of J1422 to the two connectors of J1426. This change serves to provide an outlet and cable connector for the error voltage from the rotor of B5 to Antenna Control Unit C-1133/FPS-8. At Antenna Control Unit C-1133/FPS-8 the two lines from manual slewing selsyn B2601 are disconnected from TB2607, and connected to a locally added switch, S1. The two lines from the rotor of B5 are connected to the center set of contacts of the d-p-d-t switch, S1. The remaining pair of contacts on S1 are connected to terminals 9 and 10 of TB2607, in place of the manual slewing selsyn rotor connections. It is then possible to rotate the antennas in synchronism by selecting the error voltage to be applied to the AN/FPS-8 servo amplifier from IFF synchro B5 in the AN/FPS-3. If S1 is placed in the opposite position, normal manual slewing of the AN/FPS-8 antenna may be employed.

A five-pole wafer switch is mounted in Azimuth Marker Generator TD-39/FPS-3 and connected in the stator and rotor leads B5 that connect to J4007, in order to completely isolate the stator windings of B5 from the AN/FPS-8 synchro system when the AN/FPS-8 antenna is not being synchronized with the AN/FPS-3 antenna.



B5	IFF synchro in Azimuth Marker Generator TD-39/FPS-3 (not normally in use)
J4007	Cable connector on TD-39/FPS-3 (for connecting TD-39 to Generator Group Cabinet CY-820/FPS-3)
J4211	IFF synchro cable connector on Cabinet CY-820/FPS-3 (not normally used)
J1422	AN/FPS-8 PPI synchro and power cable connector, J and K spares (not normally in use at this site)
J1426	Utility outlet just above J1422 (reconnected to provide for connection of synchro data from IFF)

Note: S1 and 5-pole wafer switch are added locally.

Figure 1. Connections Required for Synchronizing Rotation of the AN/FPS-3 and AN/FPS-8 Antennas

Isolation is necessary to prevent interaction of the two synchro systems due to the residual magnetism in the rotor of B5. IFF synchro B5 is rotated in its mounting until the pointing of the AN/FPS-8 antenna coincides with that of the AN/FPS-3 antenna.

SYNCHRONIZATION OF TRIGGER

To obtain synchronized trigger operation, the trigger signal of the AN/FPS-8 is used to synchronize the trigger signal of the AN/FPS-3. The AN/FPS-8 is operated at its normal PRF of 360 p.p.s. The AN/FPS-8 trigger is applied to J5013 on Electronic Gate TD-67/FPS-3 to replace the AN/FPS-3 circulating trigger. The free-running blocking oscillator of the AN/FPS-3 is adjusted to approximately 350 p.p.s., and then synchronized at 360 p.p.s. with the AN/FPS-8 trigger. The two-to-one count-down circuit in Electronic Gate TD-67/FPS-3 then provides a trigger at 180 p.p.s. to the AN/FPS-3 system. As a result, every other AN/FPS-8 trigger pulse coincides with the AN/FPS-3 trigger pulse.

Comparison checks of the AN/FPS-3 operating conditions at 200 and at 180 p.p.s. were made. The items checked were the charging wave, r-f pulse amplitude, clipper current, magnetron plate current, peak power, and magnetron spectra. The magnetron plate current was found to be about 4 ma. lower at 180 p.p.s. The spectra of both magnetrons were improved at 180 p.p.s. It appeared that the improvement in the magnetron spectra would at least partially offset the range reduction resulting in the decrease in average power. A comparison of average daily long-range pickup for 17 days at 200 p.p.s. with that for a 10-day operating period at 180 p.p.s. showed a 6-mile increase for the latter operating period. Further testing of the AN/FPS-3 radar performance at 180 p.p.s. is presently underway.

SUMMARY

Among the advantages of the synchronized operation of the AN/FPS-8 and the AN/FPS-3 is the fact that the AN/FPS-8 is utilized to a considerably greater extent than it was previously. The availability of normal and MTI video from the AN/FPS-8, together with the long-range capabilities of the AN/FPS-3, provides for an extremely flexible operating arrangement and ensures greater continuity in the effective operation of the site.

"HANDBOOK OF TUBES AND SEMICONDUCTORS" NOW AVAILABLE

The "Handbook of Tubes and Semiconductors" which was announced in the May-June issue of the BULLETIN is now available. This manual consists of 207 pages of material, and uses a wire-X type of binding. It is being made available to BULLETIN readers at a price of $2.00. Remittance should be in cash, check, or money order payable to Philco Corporation, and requests should be addressed to:

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TECHNICAL SKETCH OF JAMES CLERK MAXWELL
(1831-79)

MAJOR CONTRIBUTION TO ELECTRICAL PROGRESS

In 1864 Maxwell, a Scottish physicist, predicted by mathematical reasoning the existence of electromagnetic waves; however, Maxwell and his contemporaries, at that time, had no way of proving the existence of electric waves by experiment. Twenty-four years elapsed before electrical technology had advanced to the point where an experimental proof could be made. This proof was made by Heinrich Hertz, a German physicist, in a series of brilliant experiments conducted to show the presence of standing waves when incident and reflected waves combine.

Maxwell was a great admirer of Michael Faraday. Using the practical works of Faraday as a basis, Maxwell laid the mathematical structure of electricity and magnetism, terminating in the prediction of the existence of electromagnetic waves and in the unification of the theory of electricity and magnetism on sound mathematical grounds. Maxwell's equations are a generalization of the familiar laws of Ampere and Faraday.

PUBLISHED WORKS

A Treatise on Electricity and Magnetism (1873)—The classic text on the mathematical theory of electricity and magnetism.

Matter and Motion (1876)—An elementary text on physics.

SCIENTIFIC STATURE

Maxwell was the leading scientist of the 19th century, and he ranks with outstanding figures such as Newton and Einstein. A point of interest about the electromagnetic field equations is that they served as an analogue for Einstein's gravitational field equations.

Maxwell investigated color, color blindness, heat, and the kinetic theory of gases. He edited the papers of Henry Cavendish, and the excellence of the result helped make the scientific reputation of the eccentric Cavendish secure.

The unit of magnetic flux is named in Maxwell's honor.

PROFESSIONAL CAREER

Professor at Marischal College, Aberdeen, England
Professor at Kings College, London, England
Professor of Experimental Physics, Cambridge University
Director of the Cavendish Laboratory, Cambridge University

An interesting sidelight on Maxwell is that he delighted in the composition of poetry. The poetry was usually scientific in its tone but well constructed and humorous.

H. W. MERRIHEW
Headquarters Technical Staff

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