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In This Issue...

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Editorial . . .

WANTED—BULLETIN ARTICLES

by John E. Remich

Manager, Technical Department

The BULLETIN is devoted primarily to the type of article which offers specific technical information and assistance to the field engineer, although it includes timely news articles concerning the latest developments in the electronics art. In other words, the BULLETIN is *your* publication. Obviously, then, most of the material should originate in the field—it should relate directly to the problems encountered in the field and to the methods by which these problems are solved. The BULLETIN is in need of a greater backlog of this type of technical article. From our conversations with visiting field engineers, we find that many fine ideas have been pigeonholed simply because the engineer feels he has no flair for "technical writing." This should not be a deterrent, since the BULLETIN staff can edit the submitted material and, if necessary, add the professional writing touch to put the article in proper form. This editorial, then, is a call for more technical articles from the men in the field.

We are also anxious to receive your comments on the BULLETIN, and any constructive ideas you may have to offer. Probably we are a little too close to the project for accurate stock-taking. We believe that your comments would be objective, and therefore helpful to us in making the BULLETIN more informative and more valuable to our many readers.

TRAINING SLIDES—HOMEMADE

by Bud M. Compton

Philco Coordinator

A discussion of how to make your own training slides. This problem often besets the instructor, especially when commercially prepared slides are not available or local facilities are inadequate.

WHAT WE SEE is retained, according to some authorities, about 500% better than what we hear. That is why visual aids are so much desired in training activities. Training slides, which are one type of visual aid, offer an instructor three important advantages: stimulation of class interest, saving in time, and ease of storage.

Training slides stimulate interest partly because they can be made locally to fit the immediate requirements. When properly made, they are clearer and easier to follow than typical blackboard work. Some of the students may volunteer to help make the training-slide file and thus will take personal pride and interest in the project. Slides go a long way in dressing up the training and making it more "appetizing."

Slides are time savers in that they can be used time and time again, while blackboard diagrams must be redrawn every time it is necessary to retrace steps in the training. One evening of work making up slides will produce as much training material as weeks or months of work preparing wall charts or blackboard drawings. Since slides take up very little space, they are much easier to store than large, bulky wall charts.

In some instances, slides can present information, such as radar scope photos or troubles, jamming, etc., which would be very difficult to display to the students in any other manner. Any subject matter which should be shown in photographic form rather than by blackboard sketches or locally made wall charts is handled best as a slide.

Before a program of slide making is initiated, it is important that an inventory be made of the facilities that are available. A decision must be made as to the type and size of slides that are to be used. Camera and projector facilities will determine this. The most common slide sizes are: (1) the popular 2" x 2" slide, which can be made with a 35-mm. camera, and (2) the 2¼" x 2¼" size, which can be made on 120 or 620 roll film exposed in square frames. Most twin-lens reflex cameras are of this size. While some projectors, such as the one shown in figure 1, can accommodate either size slide, by using an adapter, most projectors will handle only one size. In any event, a 35-mm. projector (for 2" x 2" slides) will probably be available to most instructors. Camera equipment should, of course, be compatible with the projector equipment. However, a larger camera can be used for making smaller-size slides merely by placing the camera at a greater distance from the chart or drawing to be photographed, so that the image on the film is limited to an area, in the center of the frame, corresponding to the size of slide desired. Figure 2 shows a typical array of basic equipment.

In actually making the slides, it is important to limit the amount of detail that is included in each one. Experience

Figure 1. Example of a Typical Slide Projector. (The additional lens has a different focal length, and, while not necessary it will give the advantage of better control over projected-picture size. Examples of glass (2¼" x 2¼") and cardboard (2" x 2") mounts are shown. A choice of glass or cardboard is available in both sizes.)

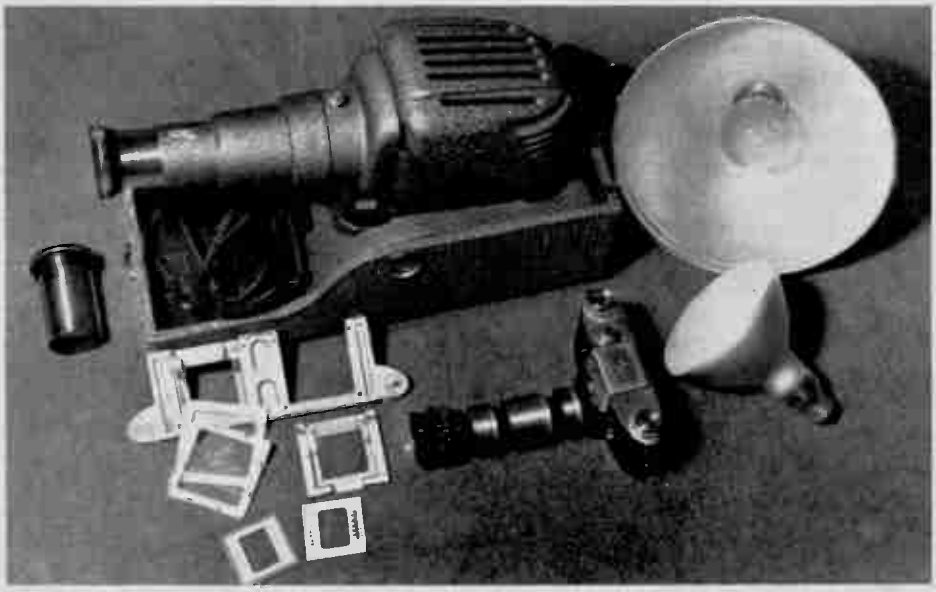


Figure 2. Basic Equipment Used for Making and Projecting Slides. (The projector shown can handle either 2" x 2" or 2¼" x 2¼" slides. The camera is equipped with extension tubes, which allow the making of close-ups. Two types of flood lamps are shown, one with a metal reflector and the other with a built-in reflector.

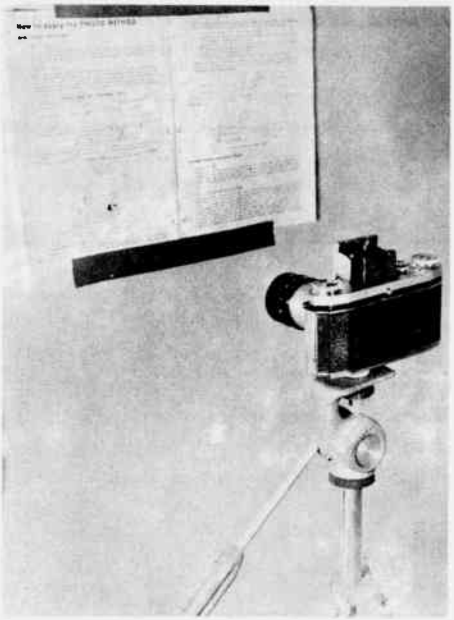


Figure 3. Setup for Photographing Copy. (Simply place the material to be copied against a wall, illuminate, and align and focus the camera. An elevating tripod will save considerable time in getting good alignment. A single-lens reflex camera is first choice for this type of work.)

will serve best in determining just how much detail may be shown on a given-size slide. In case of schematic diagrams, for a 2″ x 2″ slide, three stages are usually optimum for maximum clarity. This number of stages enables the instructor to show the stage under discussion along with the one before it and the one after it. With 2¼″ x 2¼″ slides, four stages can usually be clearly shown. In case of block diagrams, a greater number of stages may be included. Factors that determine the amount of detail a slide can handle are: quality of camera, projector, and screen; technique and method of processing the film; and the resolution limitations of the film.

Material to be copied can be supported against a wall by thumb tacks, gummed tape, etc., as shown in figure 3. The camera is placed on a tripod. (An elevating tripod is ideal as it enables rapid camera alignment with the copy material.) Two flood lamps, one on each side, provide illumination, or an outside wall in natural light will do. As most cameras without attachments are incapable of making close-ups, the use of extension tubes, extension bellows, or supplementary close-up lenses will probably be necessary.

Ordinary film can be used. Of course, such film as contrast pan, process, or litho will give better results for black-and-white line drawings. Color slides may be made where color improves clarity. However, color is more expensive, and, if no local facilities are available for processing, the time element may be undesirable.

The exposed and processed black-and-white film has a negative image, while in most cases, it is desirable that the slide be positive. To make the positive, use the negative to make a contact print on slow-speed contrast film stock such as a litho-type film. The slower the film speed, the easier it is to control the exposure in the contact printer. Even with the slowest of films, the printing time is usually less than a second. To obtain the correct exposure, one must resort to trial and error. Those who are lacking in processing know-how should try to get an experienced person to help with the first few slides.

After the final positive transparency is printed, it is ready to be mounted. Glass mounts are better than simple cardboard types and are recommended for those slides that will be used most. For light service, the cardboard mounts have the advantage of low cost and easy mounting.

Before the time comes to show the slides, make sure the light in the room can be subdued without interfering with the ventilation. It is not necessary nor desirable to have complete darkness. In fact, there should be enough light to permit the students to take notes.

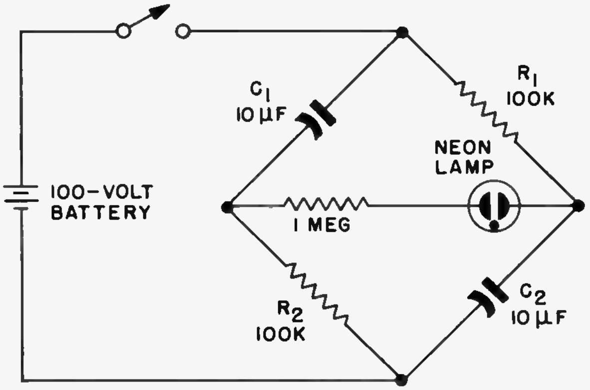
All the slides should be prearranged in the correct sequence, so a trained assistant (usually a member of the class) can operate the projector while the instructor stands near the screen to point out the details as he lectures.

In conclusion, it should be pointed out that there is usually a wealth of photographic reference material in any military or public library.

"What's Your Answer?"

This problem was recently shown to the BULLETIN staff by John Meehan of the Headquarter's Instructional Staff. We found it so interesting that we are passing it along to our readers.

Assume that the neon lamp in the following circuit strikes at 90 volts, extinguishes at 10 volts, and has negligible current drain (for the circuit shown) when it conducts.



The problem is to describe how the neon lamp will act after the switch is thrown. (Assume that the capacitors have no initial charge.)

(Solution next issue)

THEVENIN EQUIVALENTS FOR VACUUM-TUBE CIRCUITS

by Fred Pfifferling and Richard Rojas

Philco Government and Industrial Division

A simplified method of vacuum-tube circuit analysis using Thevenin equivalents. The general rules and approach are covered so that the reader can apply the method to any circuit.

(Editor's Note: All rights to this article have been reserved by the authors; therefore, no portion of it may be extracted, reprinted, or reproduced in any form, without written permission.)

THE PURPOSE OF THIS ARTICLE is to derive a set of rules which will permit the engineer to write down the equivalent circuits of commonly encountered amplifiers at sight. Although the results derived are not original, the systematic application of these rules is something which has not been presented before. Armed with this set of rules, the engineer can quickly determine the output impedance and gain of amplifiers, and thus acquire new insight into circuit design and analysis.

As a first approach, the general case of an amplifier with current degeneration in the cathode will be examined. (See figure 1.) To derive the Thevenin equivalent circuit, we proceed in the conventional manner to obtain the equivalent circuit looking into the plate and cathode. From part A of figure 1, it can be seen that:

$$E_{gk} = E - i_b R_k \qquad (1)$$

For the closed loop formed in the equivalent circuit shown in part B of the figure, it can be seen that:

$$\mu E_{gk} = i_b (R_L + R_k + r_p) \qquad (2)$$

Combining equations (1) and (2), and solving for i_b, the following relationship is obtained:

$$i_b = \frac{\frac{\mu}{\mu + 1} \cdot E}{R_k + \frac{r_p + R_L}{\mu + 1}} = \frac{\mu E}{r_p + R_L + (\mu + 1) R_k} \qquad (3)$$

From equation (3) the two equivalent circuits shown in figure 2 may be obtained.

The following set of rules can be deduced from figure 2:

1. To transfer a voltage from grid to plate, multiply by μ.

2. To transfer a voltage from plate to cathode, divide by $\mu + 1$.

3. To transfer a voltage from cathode to plate, multiply by $\mu + 1$.

4. To transfer a resistance from plate to cathode, divide by $\mu + 1$.

5. To transfer a resistance from cathode to plate, multiply by $\mu + 1$.

6. A resistance appearing in the grid circuit does not appear in the equivalent circuit because it draws no current.

7. To transfer a voltage from grid to cathode, first transfer it to the plate and

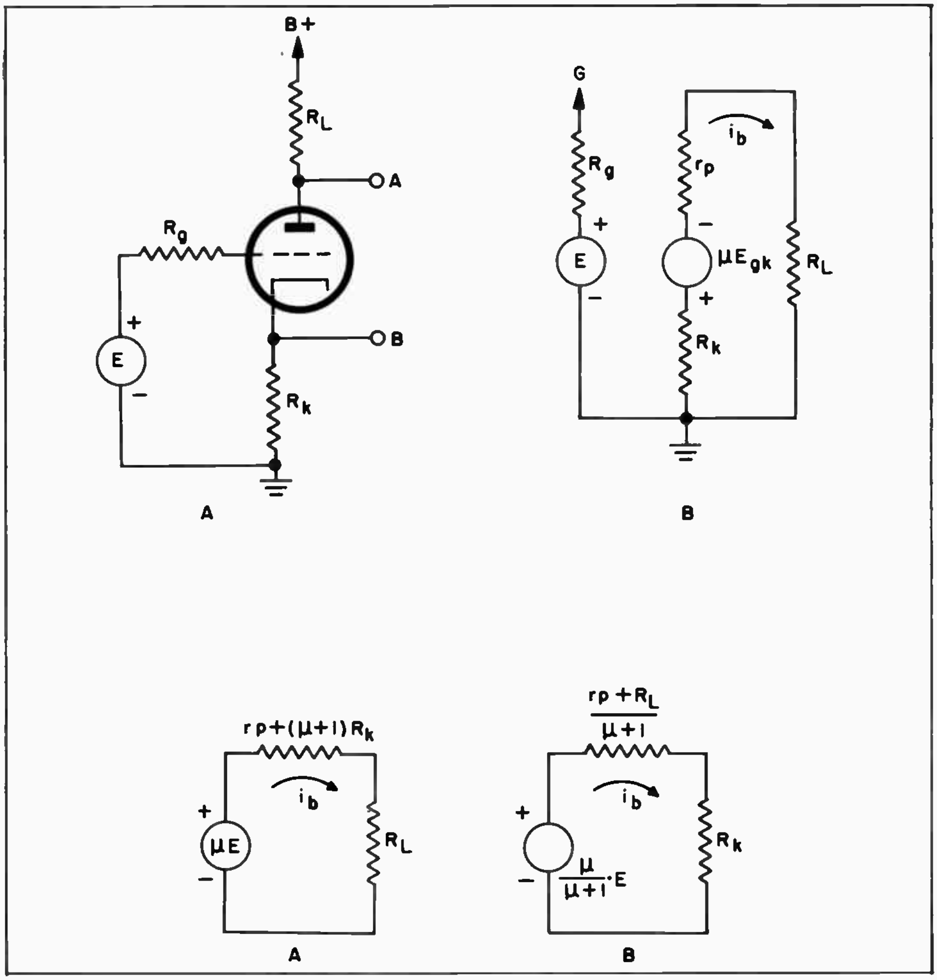


Figure 2. Equivalent Circuits of Figure 1
A. Looking Into the Plate Circuit
B. Looking Into the Cathode Circuit

then apply rule 2; if preferred, multiply the voltage by

$$\frac{\mu}{\mu + 1}$$

Either R_k or R_L may be zero, as in the case of grounded-cathode and cathode-follower amplifiers. The same rules will still apply even in these special cases.

The second case to be discussed is that of an amplifier with plate to grid feedback as shown in part A of figure 3. This amplifier has shown a host of uses in recent years.

In this type of amplifier the input terminals are grid and ground, and the output terminals are plate and ground. Feedback is obtained by connecting an impedance between plate and grid, while the external voltage is applied to the input terminals in series with an impedance (source impedance). In the following derivation it is assumed that no grid current is drawn. From the equivalent circuit it can be seen that:

$$I = I_g + I_2 = \frac{E_i}{R_g} + \frac{E_i - E_o}{R_2} \qquad (4)$$

and

$$E_o = KE_i \qquad (5)$$

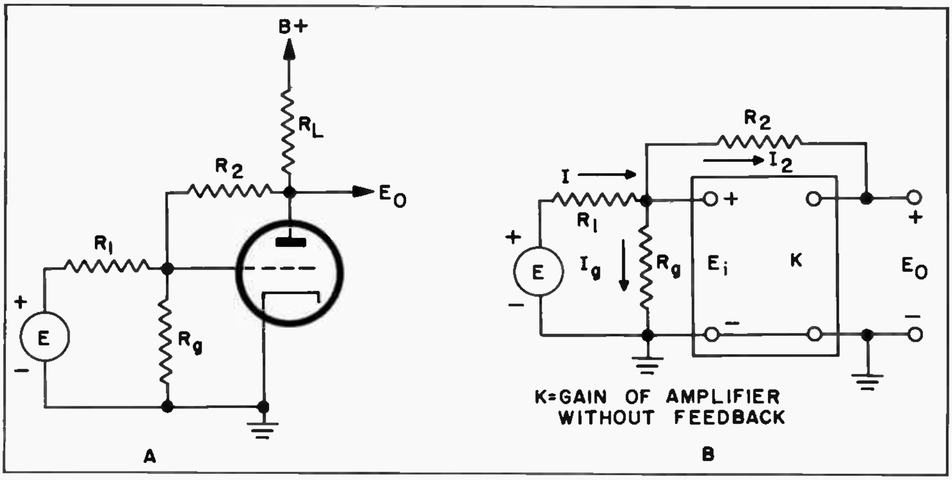


Figure 3. Amplifier with Plate to Grid Feedback
A. Schematic Diagram
B. Equivalent Circuit

Therefore, combining equations (4) and (5), the equation for the current becomes:

$$I = \frac{E_i}{R_g} + \frac{E_i\,(1-K)}{R_2} = \frac{E_i}{R_g} + \frac{E_i}{\dfrac{R_2}{1-K}} \qquad (6)$$

From equation (6) another equivalent circuit may be obtained which has the same input current, input voltage, and output voltage as shown in figure 4.

Thus any impedance between plate and grid may be placed between grid and ground in the input circuit by simply dividing this impedance by (1−K). Therefore, another useful rule is obtained. Since $\frac{R_2}{1-K}$ is usually small compared with R_g, and since K is large, the parallel combination is essentially $\frac{R_2}{1-K}$. The voltage which appears at the input of the amplifier is simply:

$$E_i = \frac{R_2}{R_2 + (1-K)R_1} \cdot E \qquad (7)$$

Now using the rules previously derived, this voltage when transferred to the plate is multiplied by μ, and the circuit shown in figure 5 is obtained look-

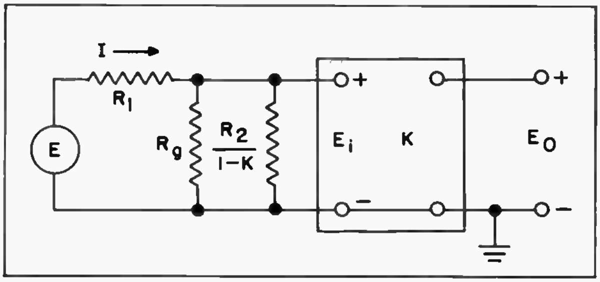


Figure 4. Alternate Equivalent Circuit of Figure 3

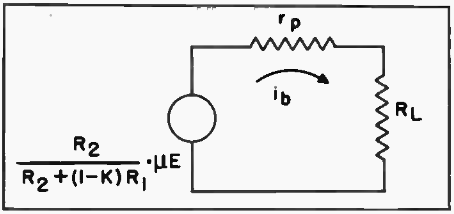


Figure 5. Equivalent Circuit of Figure 3, Looking Into the Plate Circuit

ing into the plate. The plate current is given by the equation:

$$i = \frac{\dfrac{R_2}{R_2 + (1 - K)R_1} \cdot \mu E}{r_p + R_L} \tag{8}$$

The gain with feedback, K_f, is given by:

$$K_f = \frac{E_o}{E} = \frac{\mu R_L R_2}{(R_L + r_p)\ [R_2 + (1 - K)R_1]} \tag{9}$$

Since $K >> 1$, and $KR_1 >> R_2$, the equation above becomes:

$$K_f = - \frac{\mu R_L R_2}{(R_L + r_p)KR_1} \tag{10}$$

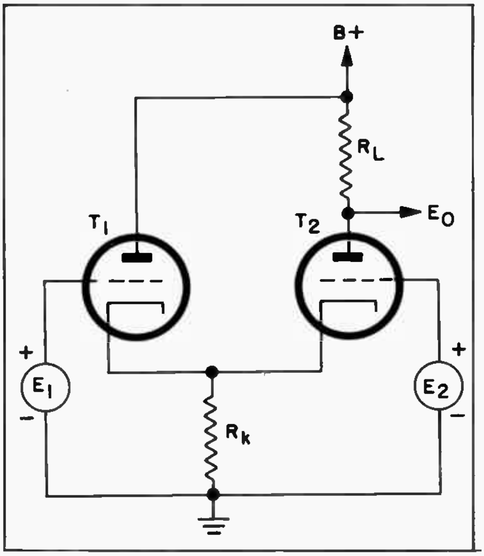


Figure 6. Schematic Diagram of Differential Amplifier

but since

$$K = \frac{\mu R_L}{R_L + r_p}$$

$$K_f = - \frac{R_2}{R_1} \tag{11}$$

As an example of the use of the derived rules, the case of a common differential amplifier, shown in figure 6, will be examined. The advantages of these rules will become apparent.

Looking into the cathode of T_1 and applying rules 4 and 7, the equivalent circuit shown in figure 7 is obtained.

Note that the equivalent circuit obtained is simply that of a cathode follower. The output impedance, R_o, of the cathode follower, T_1, is R_k in parallel with $\frac{r_{p_1}}{\mu_1 + 1}$, or:

$$R_o = \frac{r_{p_1}}{(\mu_1 + 1) + \dfrac{r_{p_1}}{R_k}} \tag{12}$$

and the voltage across R_k due to E_1 is:

$$E_k = \frac{\mu_1 E_1}{(\mu_1 + 1) + \dfrac{r_{p_1}}{R_k}} \tag{13}$$

It now remains to bring R_o and E_k into the plate of T_2 by using rules 3 and

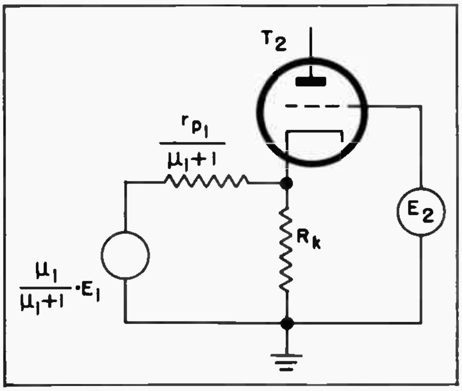


Figure 7. Equivalent Circuit of Figure 6, Looking Into the Cathode of T_1

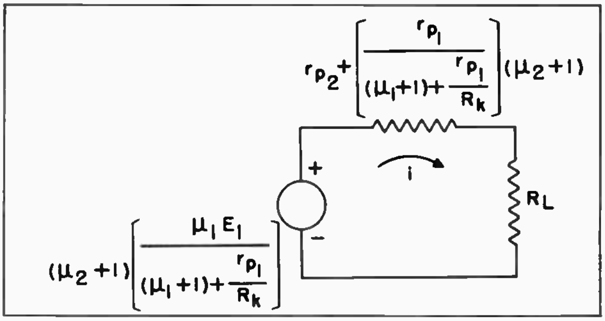


Figure 8. Final Equivalent Circuit of Figure 6

5, to obtain the final equivalent circuit shown in figure 8.

Note that this circuit is drawn with respect to E_1. The voltage gain with respect to E_1 is easily determined in the above circuit and can be shown to be given by the following equation:

Gain =

$$\frac{(\mu_2+1)\left\{\frac{\mu_1}{(\mu_1+1)+\frac{r_{p_1}}{R_k}}\right\}R_L}{R_L+r_{p_2}+(\mu_2+1)\left\{\frac{r_{p_1}}{(\mu_1+1)+\frac{r_{p_1}}{R_2}}\right\}} \qquad (14)$$

A similar analysis for E_2 can be made by this method, but this task is left to the reader as an exercise in using the foregoing rules.

All the rules are summarized in the table shown in figure 9. These results apply only to these cases for which the linear equivalent tube circuit is applicable. Many circuits lend themselves to analysis by this method. Among others the conventional Wallman and the cathode-coupled Wallman circuits immediately come to mind. It is hoped that these rules will prove useful to engineers involved in vacuum-tube circuit analysis and design.

QUANTITY TO BE TRANSFERED	VALUE OF QUANTITY AFTER TRANSFER TO		
	PLATE	CATHODE	GRID TO GROUND
—(E)— GRID GENERATOR	μE	$\frac{\mu}{\mu+1}\cdot E$	
—(E)— CATHODE GENERATOR	$(\mu+1)E$		
—(E)— PLATE GENERATOR		$\frac{1}{\mu+1}\cdot E$	
R GRID RESISTOR	0	0	
R CATHODE RESISTOR	$R(\mu+1)$		
R PLATE RESISTOR		$\frac{R}{\mu+1}$	
R PLATE-TO-GRID RESISTOR			$\frac{R}{1-K}$

Figure 9. Table Summarizing the Rules for Equivalent Circuits

THE ENGINEERING REPORT

by Frank G. Kear

One important link between the engineer and his professional and commercial associates is the Engineering Report. Its significance and helpfulness are often underestimated, and its preparation is occasionally and regrettably neglected. Many readers of these *Proceedings* will accordingly benefit from the following helpful analysis of report preparation by a Fellow of the Institute of Radio Engineers, who is a consulting engineer and a member of Kear & Kennedy, of Washington, D. C.

(Editor's Note: This article originally appeared in the May 1954, issue of **Proceedings of the I.R.E.,** ***and is being reprinted here with permission. The material applies so well to the Field Engineer, that we felt our readers would appreciate it.)***

THE TRADEMARK of the engineer is, by common acceptance, the slide rule, an instrument also generally assumed to be his most important tool. There is, however, a tool even more basic to an engineer, but one which is frequently neglected: this is the Engineering Report.

From the beginning of his professional education, the engineer receives training in the writing of reports. Many of these are in the nature of laboratory reports on specific tests, but a large number cover the investigation of more general problems. Familiarity with the framework of these reports is vital to clear, organized thinking, and only by means of such reports can the engineer adequately present the results of his work. Upon completion of his formal education, the engineer is often prone to overlook the continuing need for using the report framework as part and parcel of his thinking, with the result that much effort and time expended in performing work is lost to industry because of failure to prepare an adequate and complete presentation. Unless an engineer can convey to his management or his client a correct and adequate presentation of the work which he has performed, he has failed in his obligations.

Since the *Proceedings* of the *I.R.E.* constitutes the medium whereby engineering information is disseminated within the profession, it seems appropriate that it include in its pages a reminder of the importance of the proper use of the engineering report.

The basic report outline is simple enough, having only five subdivisions—(1) the statement of the problem, (2) the facts bearing upon the problem, (3) an analysis and discussion of these facts, (4) the conclusions drawn therefrom, and (5) recommendations. Let us consider these.

(1) Formulation of a correct statement of the problem presented is obviously fundamental, yet frequently overlooked. The engineer must take ample time to determine exactly what is required of him in order that no time is

wasted on issues which are not relevant. The statement should be reduced to writing before any work is begun.

(2) The facts bearing upon the problem should be carefully marshalled, and great care taken to include every pertinent fact which the engineer will use. By so doing it becomes a simple matter at a later date to look back and determine the reasons for a recommended course of action. Frequently an engineer finds it advisable to change his recommendations materially because of the discovery of facts not originally considered. Reference to the original report will immediately disclose the absence of those new facts, the inclusion of which would justify the change in recommended action.

(3) The analysis and discussion of the facts will vary greatly in size and format, depending on the type of problem. It could run into several notebooks full of pertinent information and data, or it might be a mere paragraph. If the analysis is lengthy, it should be reduced to summary form for inclusion in the exposition.

(4) The conclusions reached after completion of the analysis should be stated concisely and clearly, pointing out the line of reasoning employed in reaching these conclusions and, of course making certain that this reasoning is substantiated by the preceding portions of the report. This subdivision must be carefully limited to the conclusions of the engineer making the report. It should not contain any new material previously undisclosed, nor should it duplicate material which will be included in the fifth subdivision. Many engineering reports will close at this point. The average paper published in the *Proceedings* customarily contains these four subdivisions.

(5) The last and most important subdivision, although (as in the case of a paper for the *Proceedings*) it is not always required, is the one containing recommendations. The person or group to whom this report is made is usually interested only in this last paragraph. It must contain clear and concise recommendations as to the proper course of action to be taken as a result of the engineering work which has been performed. Brevity is desirable. The recommendations should not be confused by quotations from previous portions of the report. The ability to present this paragraph properly represents the dividing line between the technician and the professional engineer. When an engineer is assigned a task, the presumption is that he is competent to perform this task. Accordingly, he should not waste time and space in establishing this competency. The recipient of the report merely wants to know what he should do and how he should do it. The recommendations, therefore, should be limited to simple, clearly worded sentences, avoiding multiple or conflicting recommendations unless the writer clearly indicates the relative merits of each.

If the engineer follows carefully the foregoing outline in each problem presented to him, he will find his work is simplified, his reports present a permanent record of the project, and management or the client will have the necessary information on which to base their action.

* * *

A VOICE-OPERATED RELAY

by Murray Elson
Philco Field Engineer

A construction item that can perform a multitude of useful functions in communications systems.

OCCASIONALLY, the field engineer finds it necessary to construct a voice-operated relay (VOR) in order to provide automatic control, by voice, of important circuit functions. Such a relay has several applications. It may be used in conjunction with a receiver to turn on a warning light, to start a recorder at the beginning of a radiotelephone transmission, to switch a series of alarms, and to perform other functions suitable for control by voice.

APPLICATION

The VOR described in this article was specifically designed to control the operation of a recorder used to record radiotelephone transmissions, and in this capacity, it has given excellent service. Its sensitivity, stability, and overall performance has been very satisfactory. The unit is relatively simple to construct, and with minor circuit modification and adjustment, it can easily be adapted to other applications. To aid the field engineer in making such adaptations, a brief description of the theory and operation of the circuit is included.

THEORY OF OPERATION

In most applications of the VOR the length of time required for the unit to accomplish its switching function after the input signal is applied or removed is very important, and must be carefully evaluated in consideration of the circuit that is to be controlled. In general, the time required for energizing the VOR should be as short as possible compatible with the requirements of the controlled circuit, and the holding time after the input signal is removed should be somewhat longer than the time between successive utterances. In addition, the VOR should be positive acting, and it should be easily adjusted to accept different level input signals.

Figure 1 shows a simplified block diagram of the setup for controlling the recording of radiotelephone transmissions using the VOR. Figure 2 shows the schematic diagram of the VOR circuit.

Referring to the schematic diagram, it can be seen that the VOR consists of a clamping circuit (V_1), a bias supply (V_2), and a thyratron relay control circuit (V_3).

The clamping circuit, employing both sections of a 6H6 duodiode, V_1, clamps

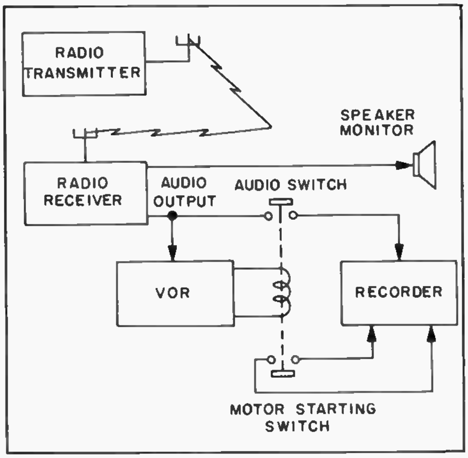


Figure 1. Simplified Block Diagram of Setup for Automatic Control of a Recorder with a Voice-Operated Relay

the negative extremity of the input-signal waveform at the fixed-bias level established for the thyratron relay control tube, V_3, so that the input signal varies only in a positive direction with respect to the bias level. Thus the peak-to-peak voltage of the signal, rather than merely the peak voltage, is effective in triggering the thyratron, thereby rendering the circuit more sensitive than it would be if clamping were not used. The input signal is applied to the cathodes of clamping tube V_1 through the input circuit consisting of coupling capacitor C_1, resistor R_1, connected from the cathodes to the plates of the tube, and capacitor C_2, connected from the junction of the plates and resistor R_1 to ground. The clamped output is fed directly from the cathodes of V_1 to the control grid of V_3.

The bias supply, using both sections of a 6X5 rectifier, V_2, and connected for half-wave rectification, provides the necessary bias voltages for the thyratron tube, V_3. A-c voltage for the supply is obtained from the 115-volt, a-c power source to which the VOR is connected. After the negative rectified output is filtered by the R-C filter consisting of resistor R_4 and capacitors C_3 and C_4 a portion of the voltage is supplied through potentiometer R_3 to the plates of V_1 and thence through resistor R_1 to the control grid of V_3. This potentiometer is usually set for a voltage, at the plates of V_1 slightly greater than minus 5 volts, which is the firing point of the thyratron.

The thyratron relay control circuit employs a type 2050 gas tetrode, V_3 to control the operation of a double-pole, single-throw plate relay, K_1, which accomplishes the switching functions provided by the VOR. A-c plate voltage for the thyratron is supplied from the sec-

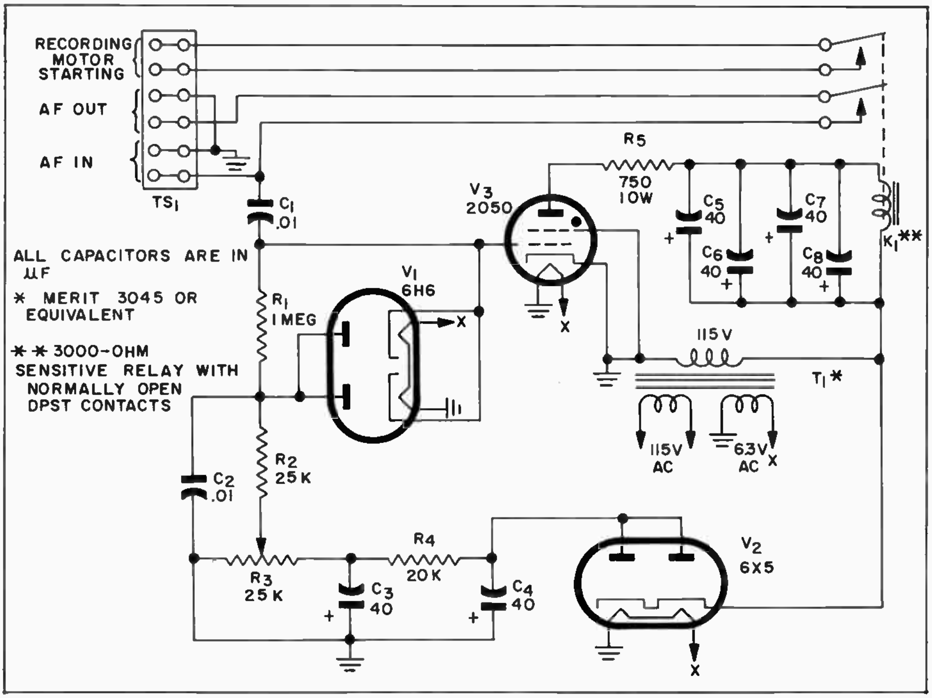


Figure 2. Schematic Diagram of Voice-Operated Relay

ondary of transformer T_1 through the relay coil and current limiting resistor R_5. With no signal applied to the control grid, V_3 is held below the firing potential by the bias voltage, and the relay is unenergized. When the thyratron is triggered by an input signal, the tube ionizes, and the flow of rectified plate current through current limiting resistor R_5 rapidly charges capacitors C_5, C_6, C_7, and C_8, connected in parallel with the relay coil. After a very short delay, the charge on the capacitors becomes great enough to provide the 1-ma. current required to energize the relay, and after the additional delay inherent in the relay, the relay is activated, giving a total elapsed time of approximately 2 milliseconds following the firing of the thyratron. As the relay activates, one set of contacts applies power to the recorder motor, and the other set connects the audio output of the communications receiver to the recorder circuits.

Since the thyratron plate voltage is a.c., the length of time required for the tube to fire after the application of an input signal will vary, depending upon the amplitude and polarity of the plate voltage at the instant the input signal is applied. Assuming that the VOR is connected to a 60-cycle source and that the thyratron fires at the positive peak of the a-c cycle, the maximum possible delay time before firing occurs is approximately 17 milliseconds, the period of one a-c cycle. It can be seen therefore, that the maximum possible delay time from the time of arrival of the input signal to the time the relay is activated is approximately 19 milliseconds (17 + 2). Of course, more rapid operation is possible if the VOR is connected to a 400-cycle power source, but a 19 millisecond delay cannot be detected by the human ear.

When the input signal is removed from the control grid of V_3, the thyratron becomes deionized on the following negative half cycle of primary power and ceases to conduct. Relay K_1, however, is maintained in an activated condition by the slow discharge of capacitors C_5, C_6, C_7 and C_8 through the relay coil. With a total capacitance of 160 to 200 μf. in the circuit, the relay will remain activated for 3 to 4 seconds before the current decreases below the 0.5-ma. drop-out value of the relay. The length of time that the relay holds after V_3 stops conducting is a function of the time constant of the four capacitors and the relay coil, relay characteristics and the leakage of the capacitors. It should be noted that the holding time will decrease with aging of the capacitors; hence, the capacitors should be replaced about every 18 months.

In case it is desirable to use a sensitive relay that has characteristics different from the one described in this article, it is merely necessary to alter the value of shunt capacitance to a value that results in the desired holding interval.

Careful adjustment of the bias with potentiometer P_3 is required to prevent unwanted closure of the relay when noise is present at the input of the VOR. This is especially true with intermittent noise such as the ignition type.

CONCLUSION

Operation of the VOR may be initiated not only by audio signals but also by higher-frequency signals and even by a d-c voltage. In the case of the recorder application described above, this fact can be used to advantage to prevent loss of the first part of the transmission during the interval (about ¼ second) required for the recorder motor to reach recording speed. By connecting the VOR to the receiver so that it is carrier-operated rather than voice-operated, the recorder motor will be turned on as soon as a carrier appears, and the recorder will be ready for recording by the time the transmission starts.

SERVICING SYNCHROS AND SERVOMECHANISMS

PART 3 OF A SERIES

by *J. J. Mills*

Philco Field Engineer

The third installment of a popular series devoted to synchro and servomechanism practices. Part 3 explores the theory and operation of dual-speed positioning systems as well as the electronic circuitry associated with them.

THE FIRST INSTALLMENT of this series (May-June, 1954, BULLETIN) covered the theory, operation, and construction of synchro transmitters, followers, and differentials. Part 2 of the series (July-August, 1954, BULLETIN) continued with a study of the synchro control transformer and its operation as a null device in single-speed servomechanisms. In this installment, the author deals with dual-speed servomechanisms and explains the importance of crossover networks, anti-stickoff voltages, and other circuit refinements necessary for satisfactory servomechanism performance.

DUAL-SPEED SYNCHRO POSITIONING SERVOMECHANISMS

The combined static accuracy of the single-speed positioning servo, described in the last installment, is limited chiefly

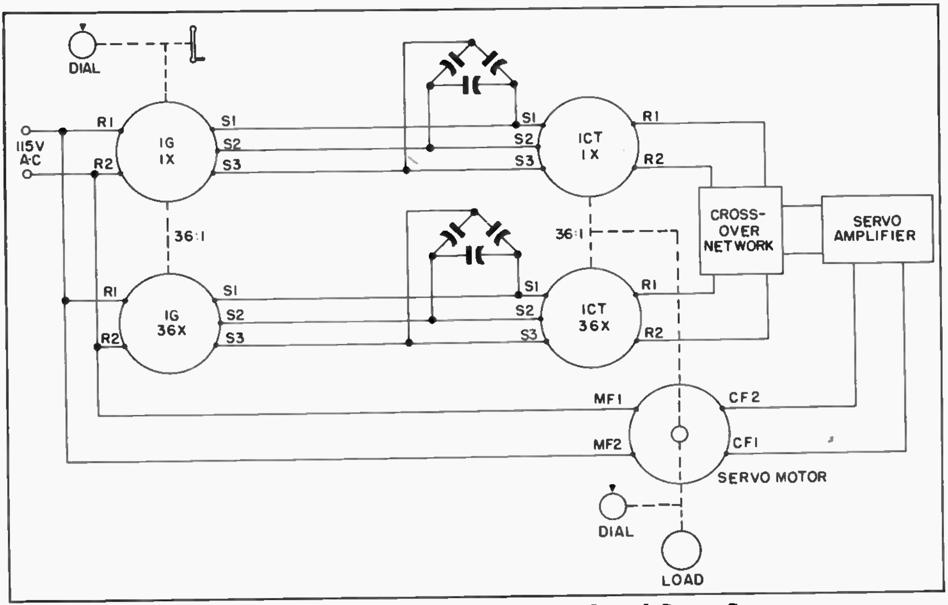


Figure 1. Components of Simple Two-Speed Servo System

by the static accuracy of the synchros involved. The combined static errors of a 1G and a 1CT run as high as 1° or more. In order to reduce this static error, dual-speed data transmission systems are frequently used.

A typical dual-speed positioning servo is shown in block diagram form in figure 1. It may be seen that the only components added to the single-speed servomechanism are:

1. A 1G, geared to the data transmitter dial and the single-speed 1G at a 36:1 ratio.
2. A 1CT, geared to the follow-up system dial and to the single-speed 1CT at a 36:1 ratio.
3. A crossover network, which determines whether the single-speed (1X) rotor voltage or the 36X rotor voltage is fed to the servo amplifier.

If the combined static error of a 1G and a 1CT is 1° of mechanical rotation, and if these synchros are geared to their respective dials and mechanisms at a 36:1 ratio, they will still have a combined static error of 1° of mechanical rotation, but 1° of their mechanical rotation now means only 1/36th of a degree of dial error. Hence, the dial-indication accuracy of this system is considerably greater than that of a single-speed system.

Another advantage of the high-speed system is that it increases the "gain" of the data transmission system (in volts per degree of error angle), and therefore the "stiffness" of positioning the mechanism. For example, for an error angle of .25° (neglecting static errors), a voltage will be induced in the 1X CT rotor equal to 55 sin .25°, or about .25 volt. However, the voltage induced in the 36X CT rotor will be equal to 55 sin 9°, or about 9 volts. Thus, the 36X system will provide more sensitive, more accurate, and more rapid positioning of the mechanism because its higher rotor voltage, when amplified, will drive the servomotor and associated CT's to a lower error-angle position than could be attained using the 1X system alone.

The 36X synchros make a complete revolution, and therefore have true zero positions, for every 10° rotation of their dials. A 36X positioning system by itself, then, would have 35 false zeros. Therefore, the 1X system must be retained in order to ensure that the remote mechanism will not be displaced 10° or some multiple thereof from the data transmitter.

The Crossover Network

The crossover network determines whether the 1X or the 36X CT rotor voltage will be fed to the servo amplifier and, therefore, which of these voltages will control the positioning of the mechanism at any given error angle. When the error angle is large, the 1X system must be in control so as to prevent the mechanism from locking in on one of the 36X false zeros; when the error angle is small, it is desirable to have the 36X system in control in order to position the mechanism stiffly and accurately. In general, in a 1- and 36-speed system, the crossover network (sometimes called a synchronizing circuit) is designed so that the 36X system is put in control for error angles less than 2.5° (an error angle of 2.5° corresponds to a maximum 36X CT induced rotor voltage, the closest maximum to zero-degree error angle).

A widely used crossover system is illustrated in figure 2. The relay is normally de-energized and the 36X system is in control. Voltage induced in the 1X CT rotor, caused by an error angle, is amplified and fed to the vacuum-tube relay circuit. The gain of V_1 or the bias of V_2 is set so that when the error angle between the output shaft and the

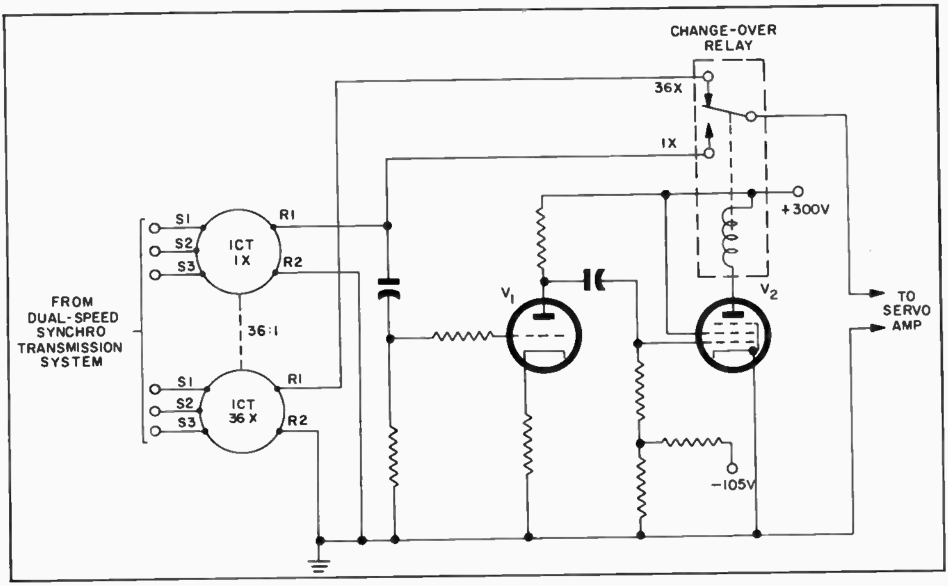


Figure 2. Change-Over System, Relay Type

data transmitter exceeds 2.5° (corresponding to an induced 1X CT rotor voltage of 55 sin 2.5°, or about 2.5 volts), the relay will be energized, placing the 1X CT in control of positioning the mechanism until the error angle becomes less than 2.5°, at which point the relay drops out, permitting the 36X system to position the mechanism accurately to a zero-degree error angle.

Another type of crossover network frequently used is shown in figure 3. This system eliminates the relay and is smooth and trouble-free in its performance characteristics. In operation, the

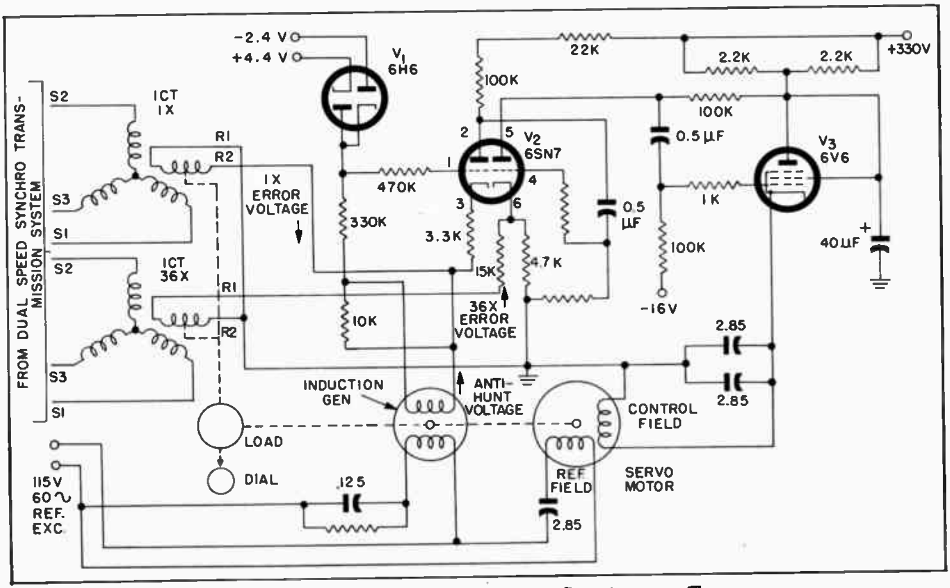


Figure 3. Change-Over System, Continuous Type

current through the first section of V_2 and the total cathode resistance are such that a 1-volt bias appears at R2 of the 1X CT. A twin diode, V_1, is connected to the grid circuit in such a manner as to limit grid signals to values between plus 4.4 volts and minus 2.4 volts. Neglecting the damping voltage introduced into the circuit by the induction generator, the 1-volt bias of the signal source (1X CT) means that limiting occurs for source voltages in excess of 3.4 volts. As stated previously, the r-m-s value of the 1X CT error voltage is related to the error angle by the equation:

$$E_{r.m.s.} = 55 \sin \Theta$$

Where Θ is the error angle between the remotely positioned mechanism and the data transmitter.

The maximum instantaneous (peak) value of the error voltage is, then,

$$e_i = \sqrt{2}(55) \sin \Theta$$

The error voltage of the 1X CT reaches a value of 3.4 volts when the error angle, Θ, is such that

$$e_i = \sqrt{2}(55) \sin \Theta = 3.4$$

Then,

$$\sin \Theta = \frac{3.4}{\sqrt{2}(55)} = 2.5°$$

In solving the above equation and obtaining a value for Θ of 2.5°, it is seen that limiting does not occur for error angles less than 2.5°. With no limiting, the cathode and grid signals are identical, and negligible output appears at the first anode (pin 2) of V_2. About one fourth of the 36X CT rotor voltage, introduced at the second cathode (pin 6) of V_2, is amplified and will be in control of positioning the mechanism.

When the error angle exceeds 2.5°, the signal at the first cathode (pin 3) can increase to a maximum r-m-s value of 55 volts (at 90° error angle). The signal at the first grid (pin 1) however, is constrained to the values previously stated. A voltage difference between grid and cathode, therefore, is established during those portions of the signal excursions when the amplitude exceeds plus or minus 3.4 volts. Such portions of the signal are amplified and appear at the second grid (pin 4) with a gain of 10.

It is interesting to note the behavior of this system at various error angles between 0° and 10°. When the error angle is less than 2.5°, only the 36X signal is amplified. For error angles between 2.5° and 5°, both the 1- and 36-speed signals are amplified in the second section of V_2, but they are both of similar phase and tend to drive the motor in the same direction. At an error angle of 5°, the 36X rotor voltage is zero, and only the 1X CT rotor voltage is amplified and fed to the control field of the servomotor. At error angles between 5° and 10°, the phase of the 36X CT rotor voltage is such (180° out of phase with the 1X CT) as to drive the servomotor to an error angle of 10°, whereas the 1X CT rotor voltage is still of a phase that tends to drive the mechanism to a 0° error angle. Consequently, it might be said that for error angles between 5° and 10°, the 1- and 36-speed systems fight for control of the direction of servomotor rotation. This effect is most pronounced at an error angle of 7.5°, since the induced rotor voltage of the 36X CT is at a maximum at that error angle and its phase is in the wrong direction. It is necessary, therefore, that the combined voltages at the second anode of V_2 be such that the 1X rotor signal may override the 36X rotor signal when the latter is in the 7.5° position. Since the gear ratio is 36:1, if a linear relationship is assumed (for small angles), the 36X rotor voltage will rise at a rate 36 times faster than that of the 1X rotor voltage. Therefore, it appears that the 1X signal gain must be made more than 36 times that of the 36X signal (if it were exactly 36, the input to

V_3 would be zero volts at a 7.5° error angle). In the system described, the 1X signal is amplified by a factor of 10, while the 36X signal is attenuated by a factor of 4. Effectively, then, the 1X signal has a gain of 40, which fulfills the requirements satisfactorily.

The foregoing analysis is important to the field engineer as well as to the design engineer; in systems using this type of crossover network, the possibility that a mechanism may lock out by a 7.5° error angle must be considered. The field engineer must accomplish the system checkout with this fact in mind. If the synchros in the system are not quite mutually zeroed, or if the circuit components have changed somewhat in value, it frequently happens that the mechanism will lock out 7° or 8° away from zero error angle. This possibility may be checked by turning off the equipment and setting the remote mechanism to an 8° or 10° error angle, then turning on the equipment again and checking to see that the mechanism does not encounter too much difficulty in getting past the 7.5° error angle on its way to 0° error angle. Another good check is made by turning the data transmitter through at least 20° of rotation to a zero dial reading from *each* direction since, if the synchros are not mutually zeroed, the mechanism will tend to lock out more easily in one direction than in the other.

It will be noted that the power output stage of the servo amplifier is connected as a cathode follower, the output load consisting of the control field of the servomotor, shunted by 5.7 μf. of capacitance. This arrangement eliminates the need for an output transformer, provides some damping, and smooths the output waveform so that the harmonic content of the signal at the grid of V_3 has negligible effect on the servomotor's operation.

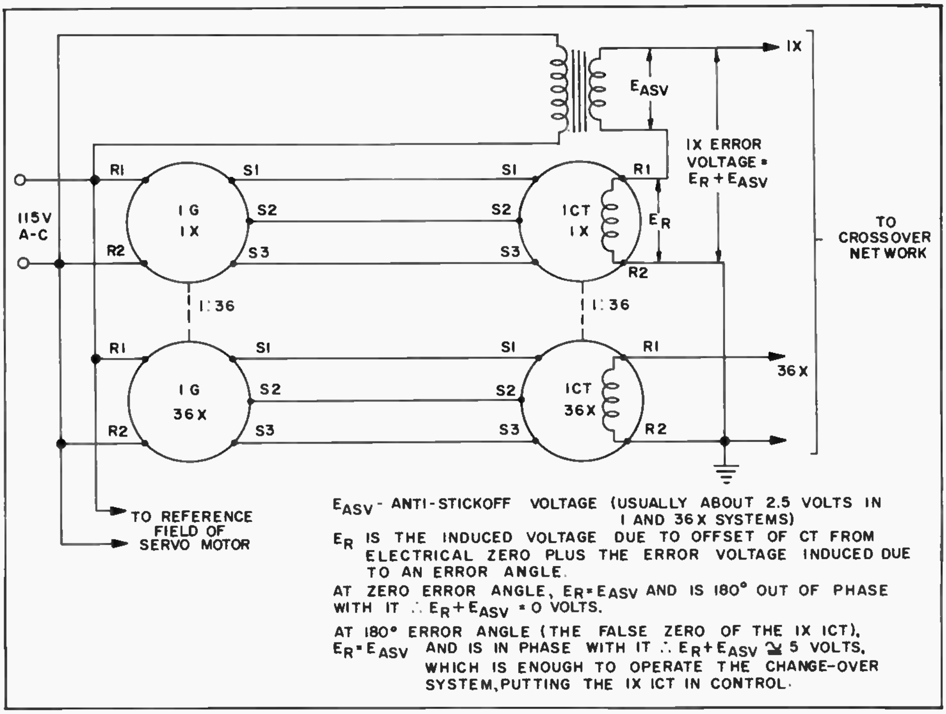
Further damping is provided by the induction generator, the rotor of which is mounted on the servomotor shaft. One coil of the generator is excited by 82 volts, 60 cycles. Voltage is induced in the other coil by the rotating action of the induction-cup rotor, an output voltage of about 6 volts being generated at a speed of 1000 r.p.m. One disadvantage of a large damping factor is that it limits the top running speed of the mechanism. In this system, this disadvantage is overcome by feeding back the induction generator voltage to the servo controller at a point where it does not take effect except at small error angles, where the top running speed is not of prime importance. The phase of the induction generator output voltage is controlled in design by the phase-shifting network in series with the excitation winding of the generator, so that the induction generator output is 180° out of phase with the 1X CT rotor voltage. It is introduced across the 10K resistor between the grid and cathode of the first section of V_2. When the error angle is *greater* than 2.5°, limiting occurs at the grid of the first section of V_2, and the grid-cathode potential difference is caused principally by the 1X CT rotor voltage at the cathode. For this condition, the induction generator voltage has little effect on the signal at pin 1 of V_2. When the error angle is *less* than 2.5°, the grid-cathode potential difference may be attributed chiefly to the induction generator output, because the rotor voltage of the 1X CT is less than 3.4 volts. Since the signal at pin 1 of V_2 may now effectively be considered as the output of the generator, and since this damping voltage is of such a phase as to tend to reverse the direction of the motor, it will, when combined with the 36X order in the second section of V_2 limit the speed of the mechanism as it approaches zero error angle, and aid considerably in bringing the mechanism to a smooth stop with no overshoot. Thus, it is seen that the function of the crossover network is to eliminate the possibility that the mechanism will lock out at some multiple of 10° error angle.

Anti-Stickoff Voltages

Another ambiguity that must be overcome in dual-speed positioning servomechanisms is the possibility that the mechanism will lock out at a 180° error angle. At this error angle both the 1X and 36X CT rotor voltages are zero. The 1X CT rotor is at a false zero; the 36X CT rotor is at a true zero, since it goes through a true zero every ten degrees. If the 1X system were in control, any transient would cause the mechanism to position itself quickly to zero error angle. However, if the error angle should be within 2.5° of 180° when the system is first turned on, the 36X system is in control, and remains in control unless a large transient should cause the mechanism to lag more than 182.5°, at which time the crossover network would allow the 1X system to take control (for example, this might occur when slewing the data transmitter). However, it can be seen that with the 36X system in control, the mechanism will remain 180° away from its correct position.

This ambiguity can be overcome by placing an anti-stickoff voltage in series with the rotor voltage of the 1X CT. The amplitude of this voltage must be large enough to operate the crossover network, but not so large that the 1X false zero must be displaced enough to approach the next stable null of the high-speed (36X) system. In a 1- and 36-speed system, the r-m-s value of the anti-stickoff voltage is usually about 2.5 volts.

Figure 4 illustrates the use of an anti-stickoff voltage in a dual-speed system.



E_{ASV} - ANTI-STICKOFF VOLTAGE (USUALLY ABOUT 2.5 VOLTS IN 1 AND 36X SYSTEMS)

E_R IS THE INDUCED VOLTAGE DUE TO OFFSET OF CT FROM ELECTRICAL ZERO PLUS THE ERROR VOLTAGE INDUCED DUE TO AN ERROR ANGLE.

AT ZERO ERROR ANGLE, $E_R = E_{ASV}$ AND IS 180° OUT OF PHASE WITH IT $\therefore E_R + E_{ASV} = 0$ VOLTS.

AT 180° ERROR ANGLE (THE FALSE ZERO OF THE 1X 1CT), $E_R = E_{ASV}$ AND IS IN PHASE WITH IT $\therefore E_R + E_{ASV} \cong 5$ VOLTS, WHICH IS ENOUGH TO OPERATE THE CHANGE-OVER SYSTEM, PUTTING THE 1X 1CT IN CONTROL.

Figure 4. Introduction of Anti-Stickoff Voltage in Two-Speed System

The 1X CT must be offset from its electrical zero position by an amount necessary to make the sum of the anti-stickoff voltage and the 1X CT rotor voltage zero when a zero error angle exists between the remote mechanism and the data transmitter. The direction of offset, of course, must be such that the two voltages are 180° out of phase. If the anti-stickoff voltage is 2.5 volts, the 1X CT must be offset approximately 2.5°, since for small error angles the CT error voltage is about 1 volt per degree of error angle. If, at a zero degree error angle, these two voltages are made equal and 180° out of phase, they will be equal and *in phase* at an error angle of 180°. Their sum at this angle will be 5 volts, enough to permit the one-speed system to take over and position the mechanism to zero error angle, thus preventing the mechanism from locking out at an error angle of 180°.

Lead Reversals

If the remote mechanism rotates in the wrong direction, the reversal of a stator lead to one or both CT's is indicated. If the mechanism is positioned 180° from its correct position, several defects are possible:

1. The 1X synchro generator or control transformer may be zeroed 180° out.
2. The 1X CT rotor leads may be reversed.
3. The leads to the reference field of the servomotor may be reversed.
4. If no anti-stickoff voltage is present, the mechanism may be locked out on a false zero of the 1X system.

Zeroing Dual-Speed CT-Positioned Mechanisms

Instructions for zeroing the synchros and the remote mechanisms in a dual-speed servo system generally call for the following procedure:

1. Secure the system.
2. Set the data transmitter on zero, and set the synchro generators or DG's geared to the data transmitter to their electrical zero positions (using the jumper method previously described) by loosening the stator clamps and moving the synchro barrels.
3. Set the remote mechanism so that its dial reads zero.
4. Block the mechanism in position by means of soft wooden blocks.
5. Zero the control transformers geared to the mechanism by the jumper method.

If the system can be energized, a simpler and more effective zeroing procedure can be used. After setting the data transmitter to zero, check its synchro generators or DG's for electrical zero by using a test synchro in conjunction with a voltmeter, using the latter for a fine check of the S1-S3 voltage (or the R1-R3 voltage, in the case of a DG).

Remembering that the 1X CT returns the mechanism to within about 2.5° of zero error angle, and that the 36X system then takes over to position the mechanism to a very small error angle, it is only necessary to perform the following:

1. Disconnect the ungrounded rotor lead of the 36X CT, and turn the 1X CT barrel until the remote mechanism dial reads zero.

2. Reconnect the 36X CT rotor lead, disconnect the ungrounded 1X CT rotor lead, and turn the 36X CT barrel until the dial reads 0°, 10°, or some multiple of 10°.

The method outlined above has many advantages:

1. It takes considerably less time than any other method.

2. It provides a *separate* "power-on" check of the 1X system and the 36X system. Each speed is thus checked to see that it will do its part in positioning the mechanism to zero error angle.

3. The operation of the crossover network can be checked while the 1X CT rotor lead is disconnected. This may be done by securing the system, and setting the remote mechanism at an error angle of 10° or more. With the 1X CT rotor lead disconnected, and with the power again turned on, the mechanism should turn to the nearest multiple of 10° error angle. Touching the 1X CT rotor lead to its terminal should then operate the crossover network, causing the 1X system to take over until the error angle decreases to 2.5°, at which time the 36X system should again take over for the stiff positioning of the mechanism to a zero error angle.

4. The direction of rotation produced by each system can be checked separately.

5. No special arrangement need be used in the zeroing procedure when an anti-stickoff voltage is used in the system. (In some equipments, accurately spaced scribed marks are used to indicate the offset required to compensate for the anti-stickoff voltage.) The only requirement is that the 1X CT be offset by an amount such that the sum of the 1X CT rotor voltage and the anti-stickoff voltage is equal to zero at zero-degree error angle. Since, with the power on, the CT is driven to a "zero sum" position, the offset is set in automatically by the "power-on" method of zeroing.

6. It makes an excellent demonstration for on-the-job training. The electronic technician can much more readily perceive the operation of the various components of the system by seeing this method in use than he can by seeing a mass of jumpers, wooden blocks, etc., which mean nothing to him so far as the actual operation of each major component is concerned.

A few qualifying statements should be made concerning the "power-on" method of zeroing. When zeroing the 1X CT with the 36X CT rotor lead disconnected (step 1), it will be observed that the stiffness of positioning is very poor. Moreover, if a relay-type crossover system is used, and set to operate at a 2.5° error angle, obviously there will be no torque at all for 2.5° either side of zero error angle. This slight disadvantage can be overcome by turning the 1X CT until the dial is close to zero, setting the remote mechanism to zero dial reading by hand (making sure that it stays there), and slightly adjusting the CT to a zero rotor voltage, or to a "zero sum" voltage if an anti-stickoff voltage is present.

The Positioned Load

The load which is positioned by servomechanisms can, of course, be anything that is rotatable. In most simple electronic systems, the only use of a servomechanism is in positioning such elements as a radar antenna or a sonar transducer. In the more complex and integrated systems, however, servomechanisms are required to position many types of components, such as resolvers, linear potentiometers, synchro transmitter, one side of a mechanical differential, etc. When working with such systems, it is helpful in on-the-job training to emphasize strongly the difference between the *positioning* elements and the *positioned* elements of the mechanism, since, in many instances, this is not too apparent. In most systems, for example, control transformers are used in conjunction with a servo amplifier and motor as the positioning elements of the system, but many other types of null

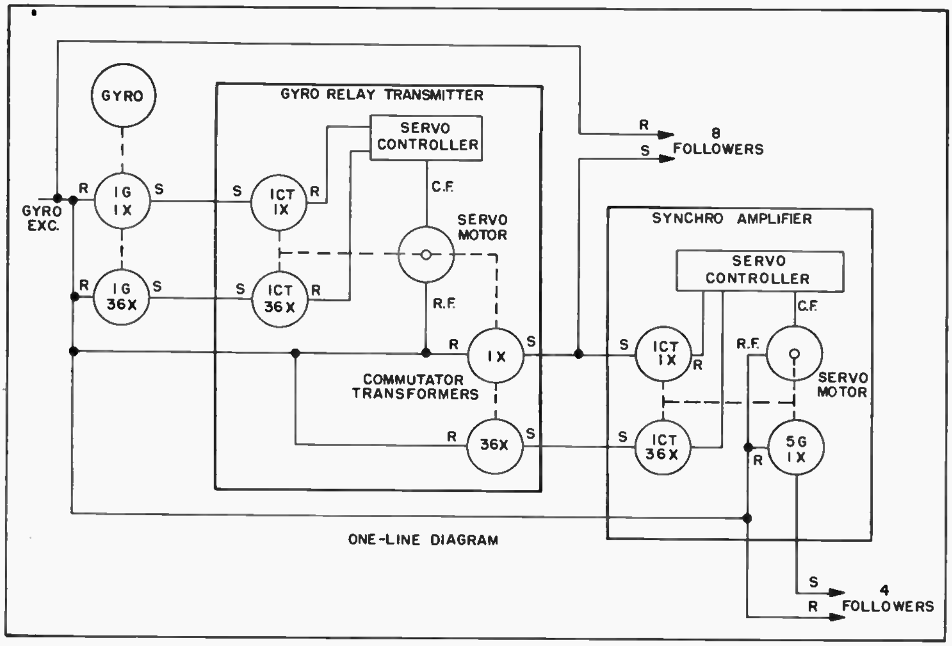


Figure 5. Synchro Amplifier

devices are in use today. In some computers, a resolver is used as a null positioning device in a mechanism that positions synchro transmitters, while in one computer (now obsolete) a control transformer is employed in the usual manner as a positioning null device in a mechanism which positions another control transformer as the load. These and other computing mechanisms will be discussed in detail in a future installment of this series.

Synchro Amplifiers

A control transformer presents a much more desirable load to a synchro transmitter than does a synchro follower, because the CT has a much higher impedance than a follower, and therefore draws much less current from the transmitter. Furthermore, no voltage unbalance can be fed back from the control transformer to the synchro transmitter, as it could be from a follower whose dial, for example, was binding mechanically. For these reasons, servomechanisms called synchro amplifiers are frequently used aboard ship.

Figure 5 illustrates the use of a synchro amplifier to increase the allowable load of followers on the synchro transmission system of a gyrocompass. Assume that the gyro transmission system was designed to accommodate 12 repeaters, but that some time later, it was found necessary to install four additional units. The 1X and 36X CT's of the synchro amplifier present negligible load to the gyro transmission system. It is seen that the synchro amplifier is nothing more than a dual-speed positioning servomechanism which positions as its load a size 5 synchro transmitter. The 5G will position, without being overloaded, the four additional followers required in the system.

The synchro amplifier can be zeroed easily in the following manner:

1. Set the gyrocompass to zero.
2. Check the voltage at the synchro amplifier's CT stator terminals to

be sure a zero order is actually applied.

3. Disconnect the 36X CT rotor lead, and turn the 1X CT barrel until the dial reads zero.
4. Reconnect the 36X CT rotor lead, disconnect the 1X CT rotor lead, and turn the 36X CT until the dial reads zero or some multiple of 10°.
5. With the dial on zero, zero the 5G with a test synchro, or by the jumper method.

Synchro amplifiers are also frequently used as "converters." It is sometimes desired to feed information from a 60-cycle data transmission system to a 400-cycle servomechanism. In this case, the synchro amplifier consists of 60-cycle 1X and 36X CT's, a 60-cycle servo amplifier and motor, and 1X and 36X 400-cycle synchro transmitters.

Troubles in Dual-Speed Positioning Systems

All the troubles that occur in single-speed systems are encountered in dual-speed systems. In addition, other troubles, most of them having to do with inaccurate positioning, are encountered in dual-speed systems:

1. Non-mutual zeroing of synchros can cause hunting. If, when the 36X CT rotor voltage is zero, the 1X CT rotor voltage is 4 volts, the 4 volts will energize the change-over relay, putting the 1X CT in control. The 1-speed CT will position the mechanism to a point corresponding to approximately zero 1X CT rotor voltage, at which time the relay will drop out, placing the 36X CT again in control. The hunting cycle will then start again. In other types of crossover systems, non-mutual synchro zeroing frequently produces erratic inaccuracies in positioning.

2. Depending on design (i.e., on the relative gain of the 1X and 36X systems, the type of crossover network used, etc.), stator lead reversals will produce positioning inaccuracies of various types. Stator lead reversals can be detected easily by rotating the data transmitter with first the 1X CT and then the 36X CT rotor lead disconnected, in order to determine whether each speed system positions the mechanism in the proper direction.

3. Malfunctioning crossover networks can be detected by methods previously described.

All of these possibilities should be checked in a complete synchro system checkout, especially in those systems which have only an index mark for a calibrating dial. Even if a dial is provided, errors often occur at odd dial readings at which checks would not ordinarily be made.

MOTION SYSTEMS

It is frequently desired to rotate certain remote mechanisms at a given rotational rate. Since positioning ambiguities are of no consequence in such applications, a 36X system only can adequately provide the required motion. In general, motion systems require no zeroing.

A basic aided-tracking system for target bearing is illustrated in figure 6. The rate-of-change of target bearing is dependent on several quantities, such as bearing, range, ship's course and speed, and target course and speed. Some of these quantities are fed to the computer, others are calculated by the computer. In addition, the computer determines the rate-of-change of bearing; in a linkage computer, the final element in this computation is usually a mechanical integrator. The output shaft of the integrator turns at 36 times the rate of bearing change, and geared to this shaft is a synchro transmitter. As seen in figure 6, the synchro transmitter (No.

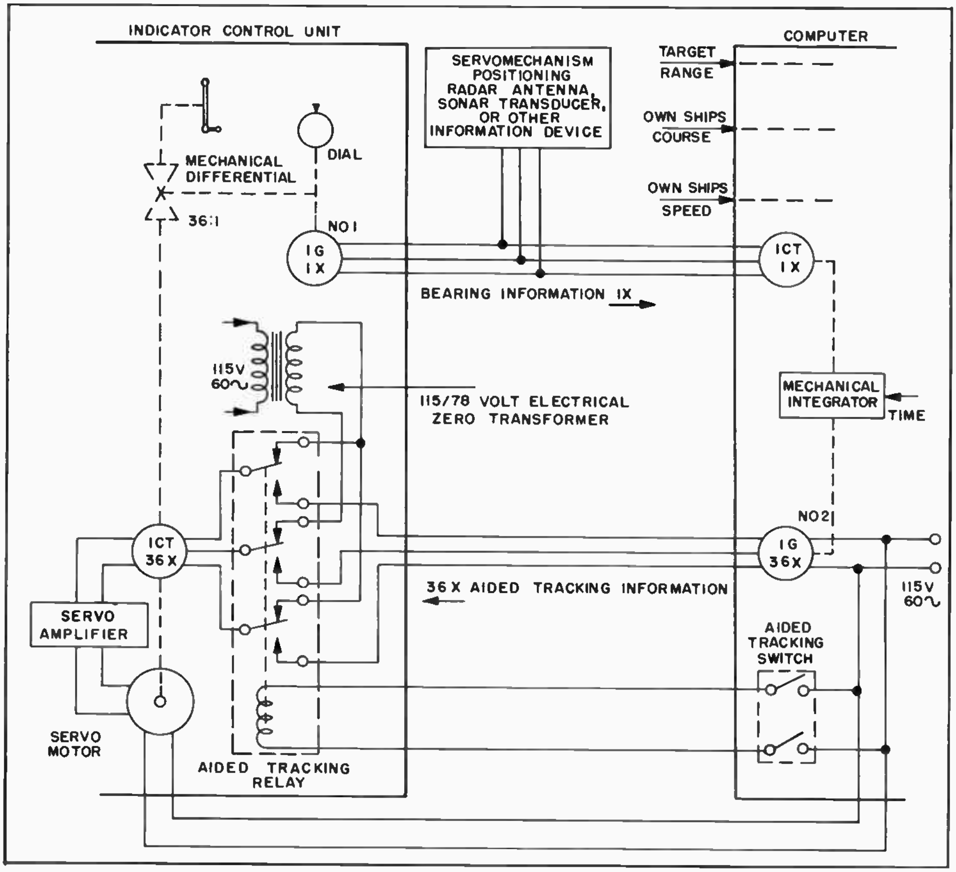


Figure 6. Aided Tracking System

2) feeds its changing stator voltages to a 36X CT which is geared to one side of a mechanical differential in the bearing data transmitter. The CT will cause motion of the data transmitter in exact synchronism with the integrator shaft (i.e., at a 36:1 ratio with the integrator shaft). Once the bearing rate computation is completed, the operator can theoretically sit back and relax until the target changes course and speed. Note that aided tracking provides a closed loop between the data transmitter and the computer. Bearing data and other information are fed to the computer, the computer solves for rate-of-change of bearing, feeds it back to the data transmitter, which re-positions the computer bearing mechanism, etc.

Figure 6 shows that an electrical zero lock is applied to the CT stator terminals when the aided-tracking switch is off. The application of this lock is necessary in order to ensure positive positioning of the data transmitter with the knob; otherwise, at least part of the knob motion would back up through the differential. However, the use of the zero lock produces an important operating defect in the system of which the operator should be aware. Assume that the attack has proceeded far enough for the computer to provide a stable solution for rate-of-change of bearing, and that the aided-tracking switch is thrown at the instant the stator voltages of transmitter No. 2 represent a rotation of 180 electrical degrees (5 mechanical

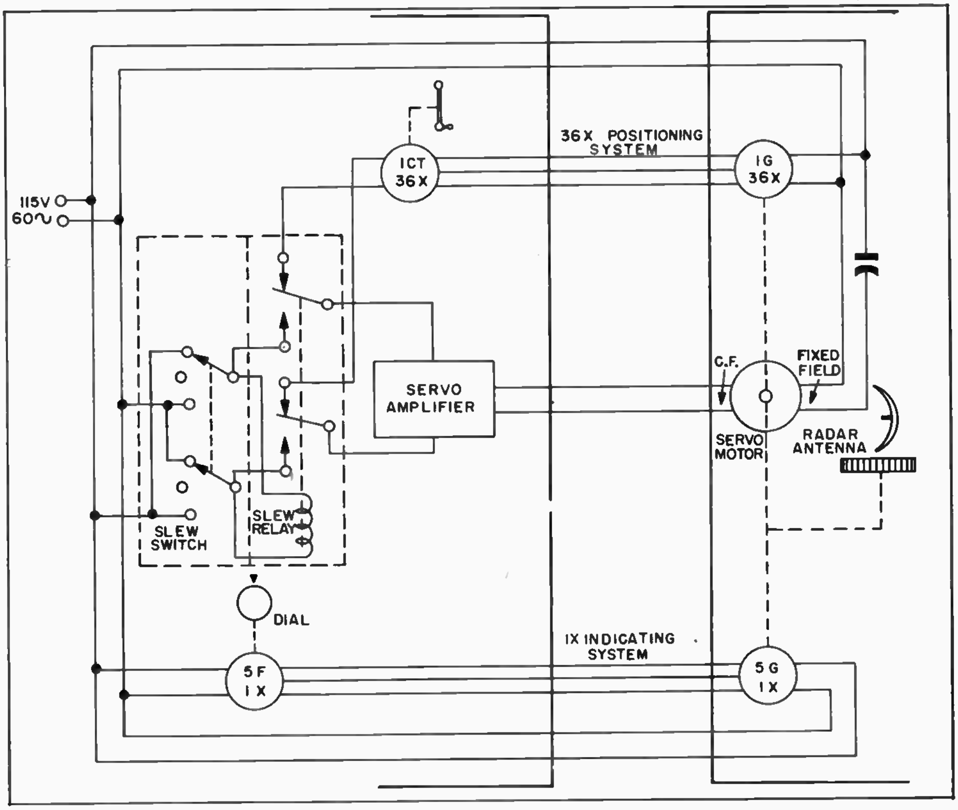


Figure 7. Positioning Mechanism for Radar Antenna

degrees) from electrical zero. Under these conditions the data transmitter will jump 5° and nullify the computer solution. Therefore, the operator should throw the aided-tracking switch early in the attack, so that in case the computer solution is nullified, there will be sufficient time for the computer to reach another stable solution before zero time to fire.

Another frequent use of the motion system is illustrated in figure 7. The radar antenna is positioned by a 36X motion system which requires no zeroing. The position of the antenna is indicated to the operator by the dial geared to the 5F.

An obvious requirement of the servomechanism in a motion system is that its top speed and response be adequate to follow fast rates; otherwise, the mechanism will drop behind in 10° steps. In the system illustrated in figure 7, for example, when the knob is spun, unless the response is very good, the CT rotor voltage will go through a complete cycle before the mechanism really gets moving. Therefore, a slewing voltage is provided for faster positioning rates, as shown.

The step-by-step system, a discontinuous d-c type, is sometimes used in motion transmission. This system is shown in figure 8. The step-by-step transmitter is simply a three-way switch, usually of the cam-operated type, with the cam shaft driven by the motion-producing device. The step-by-step motor consists of six coils mounted around a soft-iron armature, connected as

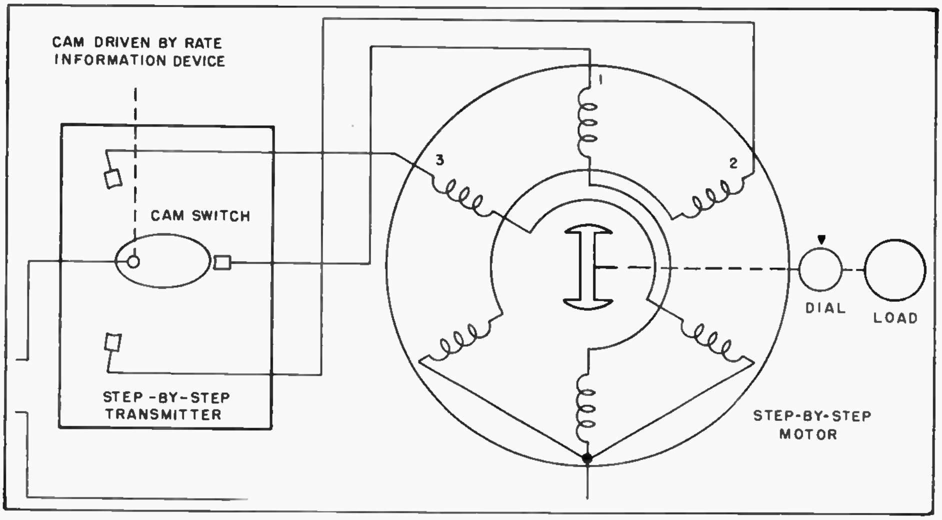


Figure 8. Step-by-Step Motion System

shown in the figure. When the voltage is applied to the No. 1 coils, the armature will align itself with these coils. When the switch reaches the No. 2 position, the armature will align itself with the No. 2 coils, etc. Consequently, the motor armature will follow the motion and run at the same rotational rate as the cam shaft. The step-by-step system is gradually falling into disuse.

(*to be continued*)

Solution to . . . July-August **"What's Your Answer?"**

The extra power results from an increase in the plate efficiency of the r-f amplifier during modulation. The plate efficiency of a class-B linear amplifier is given by the formula,

$$\text{Plate efficiency} = \frac{\pi}{4}\left(1 - \frac{E_{min.}}{E_B}.\right)$$

where $E_{min.}$ is the instantaneous minimum plate voltage during an r-f cycle. and E_B is the power supply voltage. From this formula it can be seen that if the instantaneous minimum plate voltage is decreased, the fraction $\frac{E_{min.}}{E_B}$ becomes smaller and the plate efficiency increases. For 100% modulation, the maximum amplitude of the modulated carrier is double that of the unmodulated carrier. Hence, when modulation is applied, the instantaneous minimum plate voltage of the amplifier is reduced to only one-half the value that exists for the carrier alone. Therefore, the amplifier plate efficiency is increased, and since the average input power to the plate is constant, extra output power is salvaged from the power that is dissipated in the tube with an unmodulated signal. That this is true is shown by the fact that the red glow often visible around the plates of a linear class B amplifier diminishes when modulation is applied.

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