

# PHILCO

## TECHREP DIVISION BULLETIN

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**PHILCO**  
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# *Editorial . . .*

## **AUTOMATION**

*by John E. Remich*  
*Manager, Technical Department*

Automation—"the new technology" that is as modern as tomorrow. It is so modern that it is an extremely difficult subject to define; however, the generally accepted definition is the application of automatic procedures to various fabrication and business processes. Automation is not to be confused with mechanization. The mechanized era began when man first used a machine to ease his labor, whereas the automation era is just beginning.

In a past editorial, a brief mention was made to this subject with reference to project "Tinkertoy." Project "Tinkertoy" appears to be the first full-scale attempt at automation in the field of electronic equipment production. Since then many advances have been made, and the future holds even greater and more important advances. Today a major part of the circuitry of many electronic devices is produced by automatic machinery.

All of us in the electronics field should be interested in the progress of automation, since most of the new techniques developed in the future in this field will probably be electronic in nature. It must be realized, however, that a knowledge of mechanics as well as electronics is necessary when dealing with automatic machinery, since mechanical movement is always involved in producing the end product. Already automation is causing a tremendous increase in the complexity of machines for fabrication and business, and this, in turn, is reflected in a corresponding increase in the complexity of the electronic circuits that are needed to control them.

Needless to say, the broad experience of the Philco TechRep Field Engineer in complex electronics systems and mechanisms will enable him to play a key role in this new technology.

# SHIELDED ENCLOSURES

Reprinted from material submitted by  
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*(Editor's Note: In the May 1952 issue of the BULLETIN appeared an article entitled "Screen-Room Construction" which was well received by our readers. Since this time, advances have been made in this field and it was felt that a follow-up article was required. This article is intended, among other things, to show the current trends in the construction of screen rooms.)*

COMMERCIAL SHIELDED ENCLOSURES for suppressing radio-frequency interference are still quite new to the industrial scene. Their ever-widening application in recent years is due to the tremendous increase in the use of electronic equipment plus the phenomenal rise in the number of home television receivers installed since World War II. This multiplicity of operating electronic devices has made radio-frequency interference such an acute problem that the Federal Communications Commission has had to tighten up its frequency regulations by public notice. This notice deals mostly with interference energy created by manufacturers' r-f equipment. It was the need, however, for preventing undesirable radio-frequency energy from interfering with tests of sensitive equipment that originally gave birth to the shielded enclosure. Interference signals that introduced errors in measuring devices, or in some cases even blanketed the operation of electronic equipment, had to be eliminated as much as possible.

Test equipment designed to meet the high standards of science, industry, and the military was housed in "home-made" test rooms or "cells" which acted as a barrier to the passage of undesired r-f energy. In some cases these home-made rooms did the job; but at best, they were make-shift rigs, expensive and time-consuming to construct and, when constructed, could seldom be moved to a new location.

## HOW THE MODERN SCREEN ROOM CAME TO BE

Development of a truly effective enclosure dates back to the "cell-type" construction as reported by the Rensselaer Polytechnic Institute for shielding diathermy equipment. Later, an improved cell-type enclosure was designed by the U.S. Naval Air Development Center; it incorporated double serrated phosphor-bronze door fingers, waveguide type attenuators to accommodate the filter installation, decoupling filters used as input and output barriers, and redesign of the floor section to permit ready access to all bolts.

## DEVELOPMENT OF NEW ENCLOSURE TYPES

By far the most important structural change in recent years has been the introduction of a solid-panel sheet-copper or galvanized sheet and plated steel framing design. This type of enclosure is shown in figure 1. Answering a definite need for strength and permanence, this enclosure can be entirely weather-proofed for outdoor or indoor use, can be safely transported by truck from one location to another without disassembling, and can be completely air-conditioned to provide maximum comfort for engineers and technicians.

Recently, a third important type of enclosure has been introduced that utilizes galvanized screening material. This economical enclosure is specifically designed to satisfy the requirements of

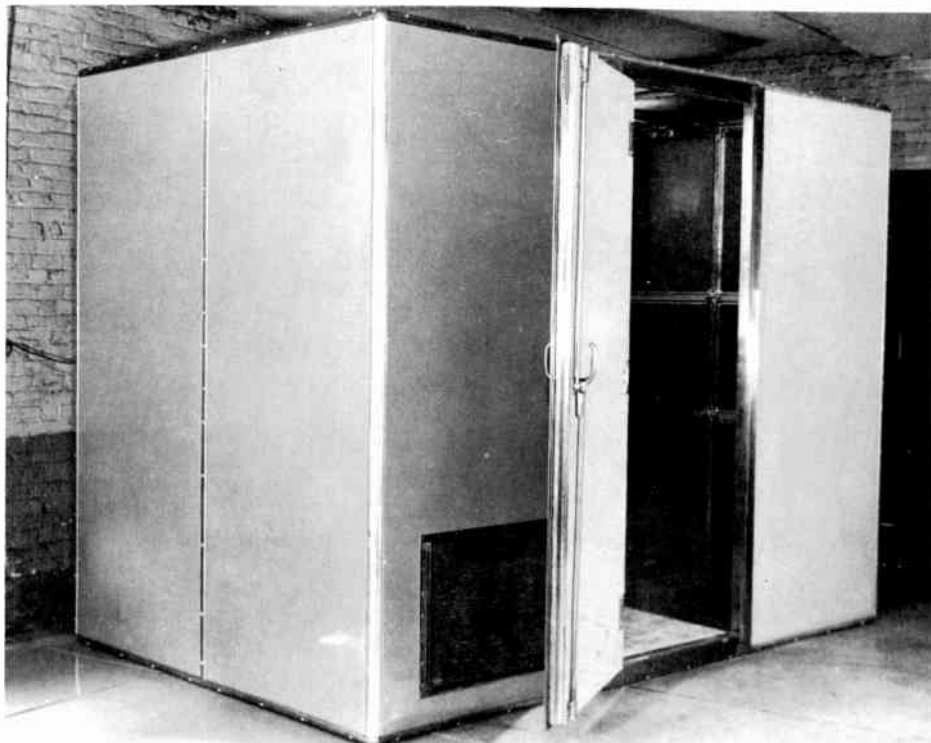


Figure 1. Solid-Panel Type Shielded Enclosure

general industry, packaging firms, and the medical profession. In these applications, the enclosure suppresses r-f energy created by housed equipment such as induction heaters, dielectric sealing units, diathermy machines, etc. All energy that might interfere with television and radio reception in the area is suppressed to within prescribed F.C.C. limits.

### EVALUATING SHIELDED ENCLOSURES\*

#### Attenuation vs Insertion Loss

The need for standard nomenclature in the specifications of shielded enclosures is nowhere better illustrated than in the rating of enclosure performance. This rating as usually given purports to be in terms of *attenuation*, but the manufacturer may actually mean either

*attenuation* or *insertion loss*. Thus, the user who wishes to compare the relative merits of several enclosures may unwittingly compare the attenuation characteristics of one enclosure with the insertion-loss characteristics of another. That these two terms are not interchangeable is readily apparent from the definitions given below and from the explanatory diagrams shown in figures 2 and 3.

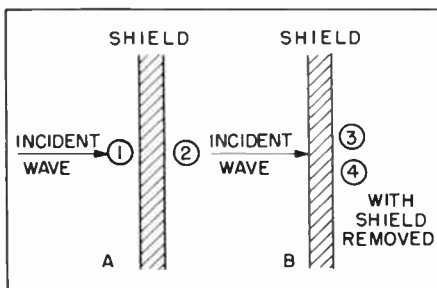


Figure 2. Location of Points for Measuring Attenuation (in Part A) and Insertion Loss (in Part B)

\*A large percentage of the material under this subject heading appears through the courtesy of TELE-TECH and ELECTRONIC INDUSTRIES, Caldwell-Clements, Inc.

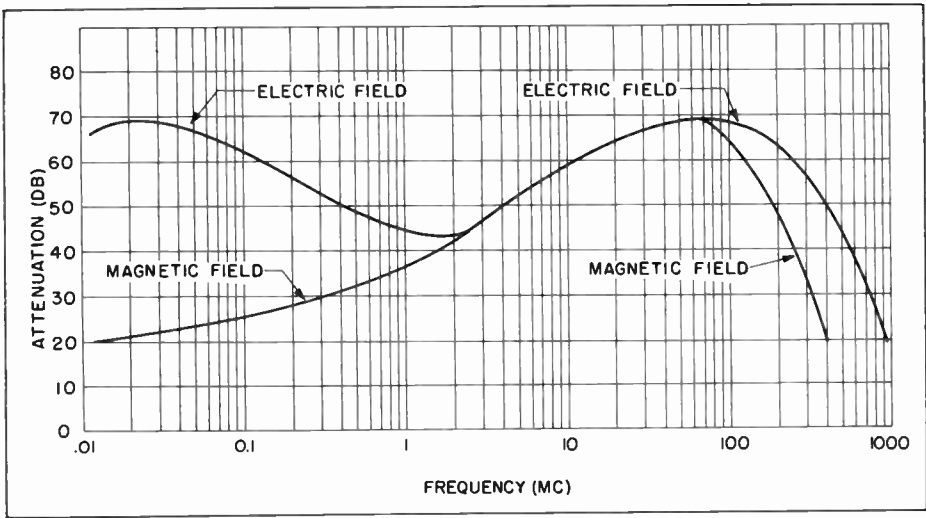


Figure 3. Shielding Effect of Galvanized Iron Shielded Enclosures

Attenuation of a periodic wave is the decrease in amplitude with distance in the direction of wave propagation, expressed in db.

Insertion loss at a given frequency, caused by the insertion of apparatus (wall of a shielded enclosure) in a transmission system (air), is the ratio, expressed in db, of the power (delivered to that part of the system beyond the point of insertion) before insertion to the power after insertion.

The applicability of these terms to the measurement of the performance of a shielded enclosure is readily apparent from the following discussion.

### Attenuation

In accordance with the definition, a measurement should be made of the power associated with the wave at points 1 and 2 in part A of figure 2, and the ratio of these measurements should be expressed in db. Instead, it is common practice to measure only the electric field intensities,  $E_1$  and  $E_2$ , at these points and to use the expression:

$$\text{Attenuation (db)} = 20 \log (E_1/E_2)$$

For a plane wave striking the shield at normal incidence, a correct measurement may be obtained only where there is negligible reflection to point 2 from

other surfaces of the enclosure. However, it is practically impossible to meet plane-wave conditions at the lower radio frequencies in use today, and reflections inside shielded enclosures are generally large.

### Insertion Loss

A measurement of insertion loss is based upon the illustration in part B of figure 2. Here, the two measurements indicated as 3 and 4 are made at the same point, but respectively without and with the shielding barrier in place. The power ratio of these measurements should be taken and expressed in db, but again, it is common practice to use only the electric field intensities for "attenuation," although occasionally magnetic field intensities are used.

If the measurement at point 2 or 3 is within the shielded enclosure, the presence of reflections causes the wave impedance (ratio of electric to magnetic field intensities) to differ considerably from that of free space, and radically different results may be obtained for attenuation and insertion loss. On the other hand, if point 2 is outside the shielded enclosure, it is practically impossible to obtain an incident wave which is plane and the results will

again be widely different. Figure 3 illustrates this difference for measurements made upon an experimental galvanized iron screened room of single-shield construction. Induction field effects are evident below 2.5 mc., and leakage at joints is evident above 100 mc. Obviously the terms *attenuation* and *insertion loss* should not be used interchangeably.

### **Plane-Wave Attenuation**

The measurement of plane-wave attenuation reveals much more clearly than insertion loss the quality or lack of quality of a shielded enclosure. This is also the characteristic which is of most value to a person conducting tests on sensitive equipment within the shielded enclosure. On the other hand, insertion loss gives a reasonable description of performance in cases where the enclosure surrounds a generator of radio interference which must not escape from the room, provided the test incident wave is similar in nature to that of the r-f generator. Because of the less universal applicability of insertion loss and certain practical difficulties in measurements which are generally much greater than for attenuation, it is recommended that the engineering usage of attenuation be adopted as standard by the shielded room industry.

### **Methods of Measuring Attenuation**

Among the most frequently used methods for the measurement of attenuation are the following:

*Free-Field Method*—This method requires a plane wave of sufficient intensity to permit the measurements indicated by figure 2. In practice it has been found expedient to use the radiation fields of powerful broadcasting stations (10 to 50 kw.) for this purpose. The shielded enclosure is generally mounted upon a truck so that it may be placed in fields of adequate strength, but out of the induction field, at the various frequencies to be measured. This method most closely approaches ideal theoretical conditions but has many practical disadvan-

tages. Among these disadvantages are: the enclosure must be small enough to be portable, and broadcasting stations must be available at the frequencies of interest. Stations are rarely available for very-high-frequency and extremely-low-frequency measurements. At low frequencies it is difficult to obtain the high field strengths required and still be outside the induction field of the transmitting antenna.

*Military Method*—This method makes use of lower-power sources of signal, approximately 2 to 10 watts. All measurements below the fairly high frequencies are made in the induction field region. Measurements are of the rod-to-rod or dipole-to-dipole type in the induction field except for an additional loop-to-loop measurement at low frequency. The military method was originally proposed as a production check on the performance of shielded enclosures for military use. Results obtained by this method are not directly comparable with those of the free-field method, but are useful for comparison with other results obtained by the military method. It is believed that, wherever measurements are made in the induction field region, attenuation to both the electric field and the magnetic field components should be separately stated. While the military method produces results difficult to support by mathematical theory, which is also complicated, it lends itself fairly well to practical use in the field.

### **Methods of Measuring Insertion Loss**

Insertion-loss measurements are frequently attempted by one of the following methods:

*Uniform-Field Method*—This method requires a plane wave of sufficient intensity to permit the measurement indicated by figure 3. The practical execution of this method and its advantages and disadvantages are similar to those for the measurement of free-field attenuation.

**Induction-Field Method**—This method is similar to the military method for measurement of attenuation except that ideally the shielded enclosure must be removable from between the fixed source and the receiver of energy. In practice, the room is left in place but both the source and the receiver are moved to a new location, where the distance between the two is kept the same as with the presence of the shielded enclosure. It is important that the measurement indicated at 4 in part B of figure 2 be performed in a region free from reflection of r-f energy. Generally, adequate care is not given to see that this is true, and the measurement therefore suffers in accuracy.

**Open/Closed Door Method**—In this method, removal of the shielded enclosure from between the source and the receiver is supposedly accomplished by opening the access (door) to the enclosure. Since a significant amount of loss may be sustained even with an open door, results are quite misleading and almost always indicate a value lower than the actual insertion loss. Fortunately, this method is vanishing from current usage.

### **Need For Standard**

Each method of measuring insertion loss has some inherent disadvantages sufficiently serious to keep it from being recommended as a standard method. Considerable work has yet to be accomplished in devising a standard method that will have universal acceptance, but choice of an interim standard would certainly be helpful to industry.

### **Filter Performance**

In addition to the field measurements mentioned, it is also necessary to know to what extent interference conducted along power lines will be attenuated as it passes through the power-line filter. It is almost universal practice to provide this information on the basis of insertion loss in a 50-ohm line, and it is recommended that this practice be adhered to as standard. The insertion loss re-

quired of a power-line filter depends, not only upon the shielding attenuation, but also upon many other non-predictable factors, such as length and proximity of power lines to sources of interference. The rule-of-thumb requirement usually observed is that the filter have as much insertion loss as the shielded room itself provides attenuation, although in specific applications this requirement may be much more, or possibly less, than necessary.

### **Classification of Shielded Enclosures**

Commercial shielded enclosures are available in three different basic types of design. The simplest and cheapest of these is the *single-shield* screen cloth type which employs only one envelope of shielding material to encompass the enclosure.

The second type is the *cell* type enclosure which is also constructed with screen cloth but using two thicknesses. This enclosure is constructed of panels formed in the following manner: Two rectangular wooden frames are formed with one having bolt holes jig-drilled for ease of erection. Each frame is faced on one side with 22-mesh, .015-inch-diameter copper wire, allowing enough overlap to cover the edges. The frames are fastened together in such a manner that the screen cloth layers are separated by the thickness of one frame. The wire covering the edges is fastened down, to form an electrically bonded, two-ply overlap on the frame periphery. The separation between the layers of screen cloth thus forms a cell.

The screen room shown in figure 4 is representative of either the single-shield or cell screen cloth type, since it is difficult to distinguish the difference between them except by close inspection.

The third type is the *solid* single shield enclosure. This type is composed of die-formed solid sheets of either galvanized steel or copper, utilizing as its framework, M and U channels and tensioners. This type of construction, shown in fig-



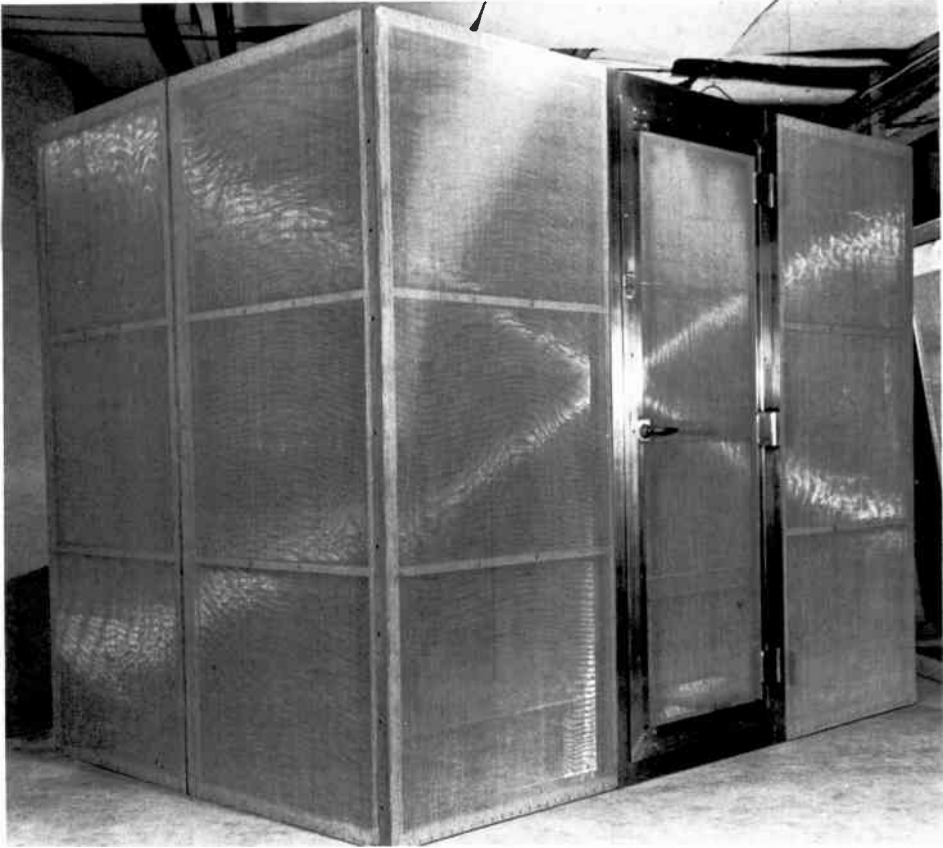


Figure 4. Screen Cloth Type Shielded Enclosure

ure 1, permits high attenuation over the frequency range, without the necessity of using two layers of shielding materials. Figure 5 shows some of the construction details of this type enclosure.

### **SCREEN ROOM DESIGN CONSIDERATIONS**

#### **Shielding Materials**

Today's rapidly growing shielded room industry makes it possible to buy commercial shielded enclosures of room size from \$500 to upwards of \$40,000. What is being paid for when buying shielded rooms? One obvious item is the shielding material itself. Solid sheet materials are generally better performers than their woven or screening counter-

parts. In addition, enclosures made of solid sheet materials can be transported on a truck without disassembly, and can be exposed to the weather in virtually any climate with no detrimental effects. Of individual metals, copper is generally far superior to, and more expensive than, all others commonly used, although iron is particularly useful at low frequencies. Plain iron and aluminum are seldom used because of the difficulty in making adequate electrical contact along the peripheries of adjacent pieces of material.

Of the composite metals, *galvannealed* iron is occasionally used to provide improved seam contacts, but an enclosure of this material requires frequent clean-

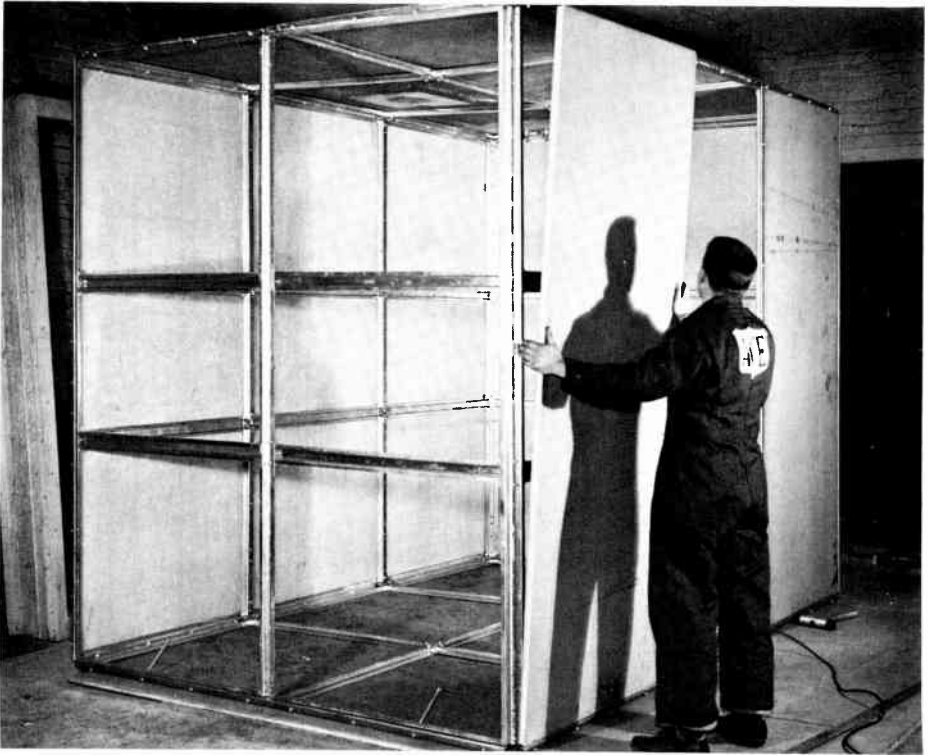


Figure 5. Construction Details of the Solid Type Shielded Enclosure

ing of all contacting surfaces in corrosive atmospheres. The best composite material of all is iron completely clad with copper. This material combines the natural advantages of both copper and iron with an additional bonus in shielding action due to the reflection of waves at copper-steel interfaces. As one might suspect, this material is slightly more expensive than solid copper.

#### **Structural Considerations**

The structural arrangement of the shielded enclosure is another important item. Framing is made of selected, kiln-dried white pine, which has been preservative treated, and is used because it maintains the structural stability required for good, permanent contact at joints of the shielding material where pressure-type contacts are used. In order to secure good contacts between pre-

fabricated panels, it is necessary to maintain extremely close tolerances in the woodwork—a requirement which adds to the cost. In addition, application of shielding material to the structure is generally arranged so that there is no accidental contact between construction nails and the shielding material; however, *short* staples are commonly used without a soldered bond to the shielding material, since the dipole moment of the antenna effect of the staple cannot become important at commonly used frequencies.

Until recently, all screened enclosures were bolted together from the outside. This method presented a disadvantage because a clearance of at least two feet was necessary at each side and the top of the room to permit tightening the bolts. Screen rooms are now available

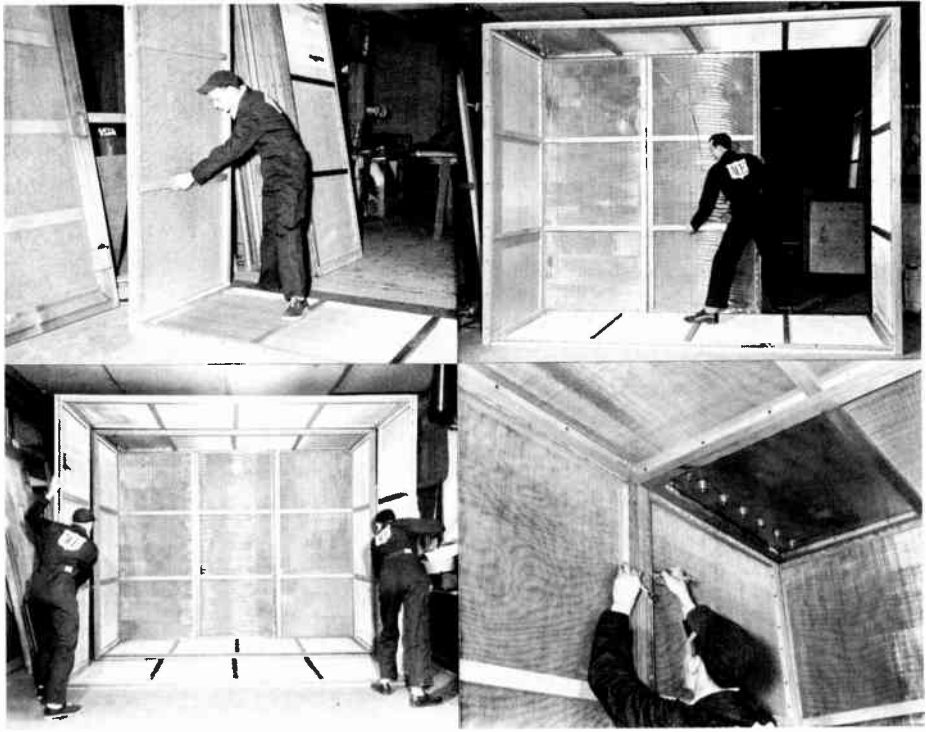


Figure 6. Some Phases of Screen Enclosure Construction

using inside bolting, to afford maximum use of available space. Figure 6 shows a series of four photographs which illustrate a few phases in the construction of a screened enclosure.

Another recent structural innovation is the enclosure comprised of interchangeable panels. Using *only two* standard sizes of prefabricated panels for *all* wall, floor, and ceiling sections, it provides the utmost in convenience and versatility, together with all the other advantages of standard cell-type enclosures. Purchasers need order or stock only the two sizes of panels to erect or enlarge, in both width and in length, screen rooms of any size, anywhere, without making a specific order out of each need. Moreover, an existing room can easily be reassembled in a different

size or shape to suit a new location.

#### Contacting of Components

The matter of continuous electrical contacting of successive pieces of shielding is extremely important to the overall performance of the shield. Hence, manufacturers are generally careful to secure good contacts between doors and jambs by means of one or two rows of phosphor-bronze contacting fingers. Figure 7 is a photo of the inside of a door showing the phosphor-bronze contacting fingers and the door latch.

#### Filters

Electrical power is generally brought into the room through power-line filters which freely permit the entry of electrical energy at power frequencies but reject it at radio frequencies. A large

variety of such filters are available because of the widely different requirements of operating voltage, current, and frequency range of attenuation. It is to the economic advantage of the user to specify the least stringent requirements satisfactory for his operation. Commonly used frequency ranges are 150 kilocycles to 400 megacycles and 14 kilocycles to 1000 megacycles.

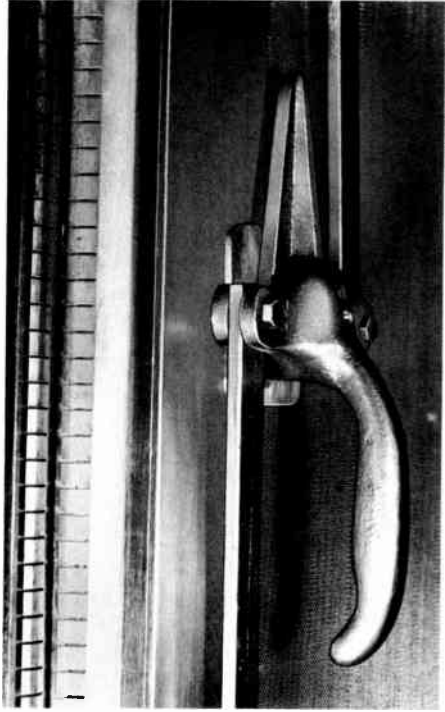
#### **Air Inlets**

Some shielded rooms are available with copper honeycomb cores set in the shield. These cores permit the passage of forced air for air-conditioning but, because they act as parallel waveguides operated below the cutoff frequency, they prevent the passage of radio-frequency energy. It is generally desirable to air-condition any enclosure in which personnel must work, whether the enclosure be of solid or screen material. This is essential for solid material, but it also applies to screening material in which the mesh is so fine that considerable resistance is offered to the normal flow of air.

#### **CONCLUSION**

The growth in the use of shielded enclosures has been so rapid that today finds one in practically every electronic manufacturing firm, electronic military installation, and major hospital. A shielded enclosure can no longer be considered only as an engineering re-

search implement. New shielding uses created by fields such as microwave testing, radiation, electroencephalography, ultrasonics, etc., are spreading the application of shielded enclosures over a larger and larger segment of American industry.



*Figure 7. Details of Phosphor-Bronze Contacting Fingers and Door Latch*

# RADAR RECEIVER A-F-C SYSTEMS

## PART 4

by H. W. Merrihew  
Headquarters Technical Staff

This is the fourth and final article on radar a-f-c systems. The first three articles dealt with the theory of operation of a-f-c systems and appeared in the three previous issues of the BULLETIN.

### A-F-C CIRCUIT TESTING AND ALIGNMENT

#### I-F Amplifier

In order to adjust the bandwidth of an i-f amplifier, either of two methods may be used—FM or CW. In the FM method, a signal capable of sweeping a wider band of frequencies than the desired i-f bandwidth is applied to the i-f amplifier by an FM signal generator. This scheme is shown in figure 1.

The FM signal generator is an electronically or mechanically swept oscillator. The oscilloscope shown in figure 1 may be an integral part of the generator or external to it. The detector may be housed in a probe or, as is sometimes

done, built into the a-f-c chassis for test purposes. The FM generator must include an absorption wavemeter in order to indicate the half-power frequencies. The pattern observed on the oscilloscope will be the response curve of the i-f amplifier, as shown in figure 2. The wavemeter absorption pip can be varied between the half-power frequencies  $f_1$  and  $f_2$ , and the i-f amplifier can be adjusted for the correct bandwidth. At the same time it should be determined that the center frequency (peak response) is located about halfway between the half-power points.

It is important to keep the amplitude of the FM generator low enough to

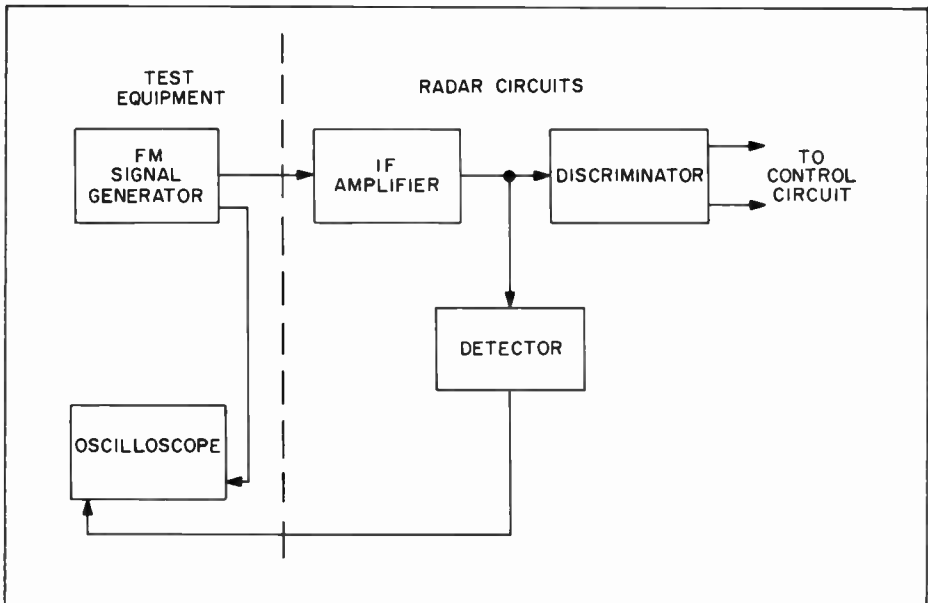
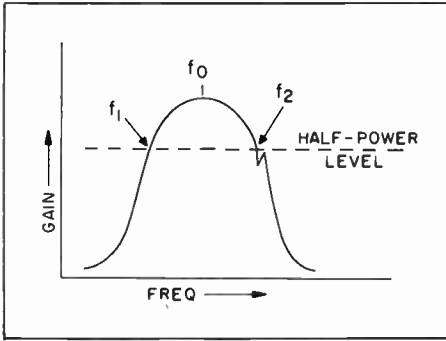


Figure 1. FM Generator Test Setup for I-F Amplifier



**Figure 2. Center Frequency and Half-Power Points of I-F Amplifier Response**

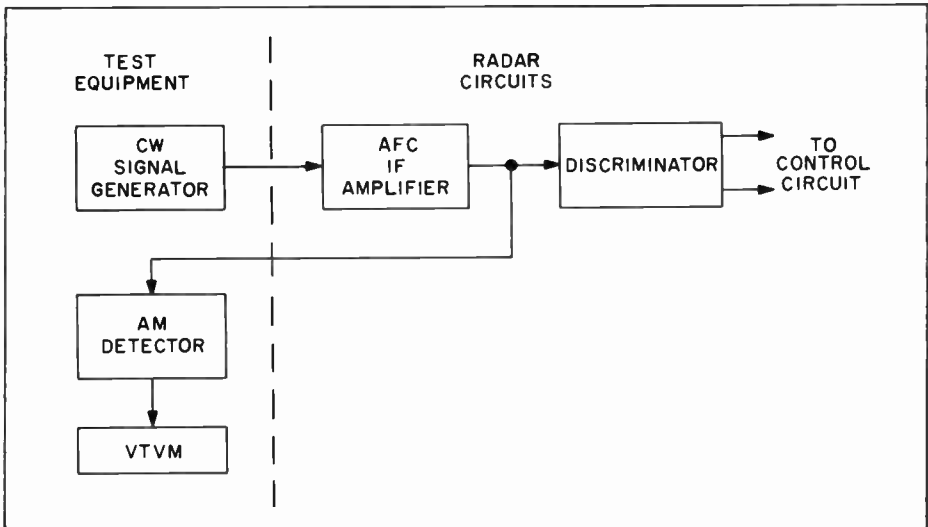
prevent limiting of the signal by the i-f amplifier. Limiting is easily detected by observing the change in the output of the i-f amplifier as the signal-generator output is increased. Limiting is indicated by little or no change in amplitude and by an increase in the bandwidth as the output is increased. For accurate determination of the bandwidth and center frequency of the i-f amplifier, the output of the signal generator should be placed below the level at which limiting occurs.

For radar equipments that employ separate mixers for the signal and a-f-c channels, it is very important that the

i-f center frequency of the signal channel and the i-f center frequency of the a-f-c channel be identical. In order to ensure this condition, the center frequency of the signal channel should be checked prior to the alignment of the a-f-c circuit.

The testing procedure described above may be carried out with a CW generator, an AM detector, and a vacuum-tube voltmeter. The block diagram of this layout is shown in figure 3. The signal-generator frequency is set to the desired i-f center frequency and the i-f amplifier adjusted for a maximum output. The higher-frequency half-power point may be determined by increasing the frequency of the signal generator until the voltmeter reading is reduced to 0.7 of the center-frequency value. The lower half-power point may be similarly determined. The bandwidth is the frequency interval between the half-power points.

Most a-f-c circuits do not use stagger tuning; hence, tuning of the individual i-f amplifier stages to specific frequencies is usually not necessary. It is desirable, however, to definitely determine that the a-f-c i-f amplifier is not stagger tuned.



**Figure 3. CW Generator Test Setup for I-F Amplifier**

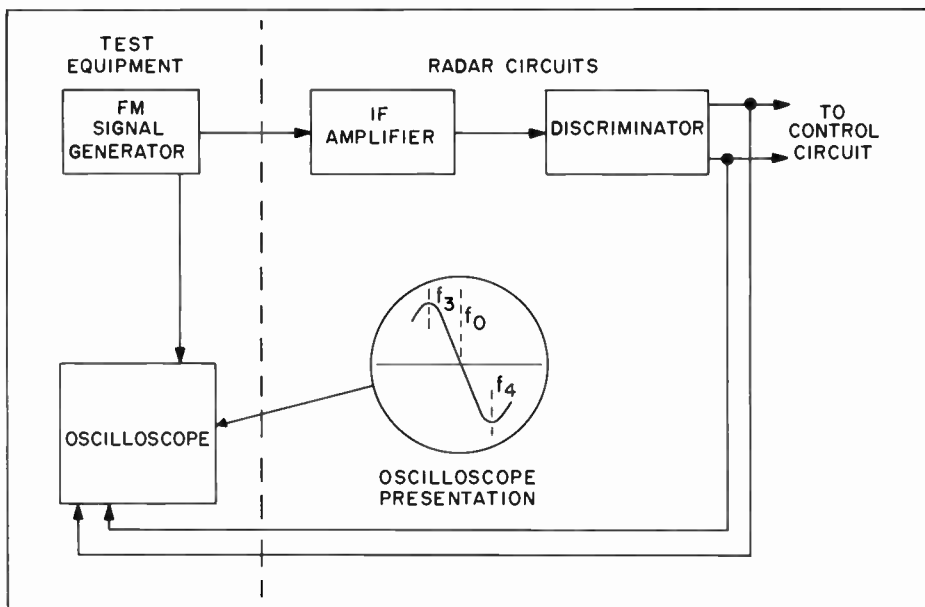


Figure 4. Test Setup and Oscilloscope Presentation for Discriminator Response

### Discriminator

Following the i-f alignment, the discriminator must be tuned. Again an FM or CW signal method can be used. The major advantage of the FM method is that it gives an integrated, visual presentation of the alignment results. Various readings must be taken to obtain the same information when using the CW method. Generally, either method will give reasonably good results.

The FM method is illustrated in figure 4. The output S-curve of the discriminator is observed on the oscilloscope, and the primary and secondary windings (of a Foster-Seely type) are tuned to produce an S-curve which is symmetrical and which has the desired bandwidth. The amplitude of the curve above the horizontal center line should be exactly equal to the amplitude below the center line, and the frequency between points  $f_3$  and  $f_4$  should be the desired bandwidth.

The CW method is shown in figure 5. A vacuum-tube voltmeter is connected across the discriminator output, and the CW signal generator is set to the i-f center frequency. The voltmeter

should read zero volts. When the CW signal frequency is changed above and then below the center frequency by equal amounts, the voltage readings produced should be equal but opposite in polarity. A center-reading voltmeter is desirable for this operation. Adjustment of the primary and secondary windings of the discriminator transformer is made to give the desired bandwidth and linearity.

The procedure used in aligning the discriminator depends upon the type discriminator and will not be discussed here because of the detailed explanation involved.

### Control Circuits

In most a-f-c circuits for klystrons, the control circuits have very few adjustments. To test for search action, turn the transmitter off and observe the a-f-c or signal-mixer crystal current. The crystal current meter reading will rise and fall periodically as the searching takes place. This effect is due to the variation of the repeller voltage through a mode of oscillation for the klystron. To determine whether the tuning of the a-f-c circuit

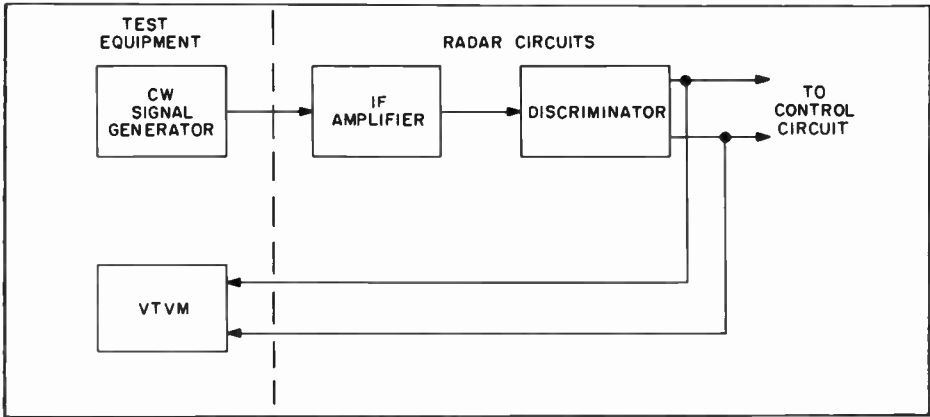


Figure 5. CW Generator Test Setup for Discriminator Response

is correct, tune the local oscillator manually for maximum signal return, and then switch to a-f-c operation. If the video signal does not change in amplitude, the circuit is properly tuned. If a variable-frequency magnetron is available, the transmitter frequency may be changed and the following action of the a-f-c circuit observed. In the alignment of a servo type a-f-c system, the i-f amplifier and discriminator adjustment is the same as that already outlined. The adjustment of the servo may be checked by applying an input signal to the a-f-c system at the i-f center frequency and checking the servo with an oscilloscope for zero output. A slight deviation of the signal-generator frequency below the i-f center frequency should produce an output voltage 180 degrees out of phase with the output voltage produced by a slight deviation above the center frequency. Hunting of the servo may be stopped by reducing the servo gain.

Difficulties due to a-f-c lock-in at a subharmonic may occasionally be encountered. For example, a 30-mc. i-f signal may be produced by the second harmonics of the transmitter and local-oscillator signals when they are only 15 mc. apart at their fundamental frequencies. The local oscillator could, in this case, lock in at a frequency separated from the transmitter frequency by only 15 mc. This sometimes happens when

the a-f-c amplifier gain is too high. Lock-in at a subharmonic, which is accompanied by a loss of video, may be detected by measuring the transmitter and local-oscillator frequencies.

Another case of false lock-in may occur when the local oscillator is set up to lock in only below the transmitter frequency. In this case, if the klystron frequency should exceed the transmitter frequency by an amount greater than 30 mc., the signals coming from the discriminator will continue to raise the klystron frequency until the discriminator output is zero. This condition is illustrated in figure 6.

In the testing of a-f-c circuits, FM or CW signals may be injected at the r-f rather than the i-f frequency, although in this case frequency differences are not indicated as accurately on the signal generator.

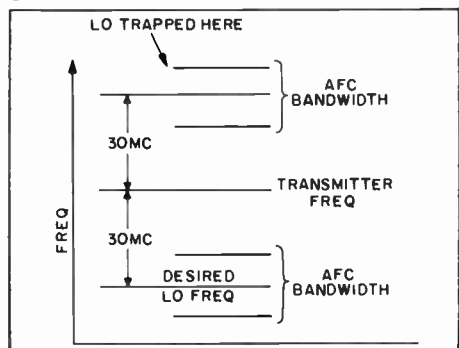


Figure 6. Illustration of False Lock-in Point



# MECHANICAL TROUBLES IN THE STANDARD TARGET COURSE GENERATOR 15-J-4-p

by Robert D. Hunter  
Headquarters Technical Staff

This article deals with the cause and cure of some common mechanical troubles in the 15-J-4-p which can seriously reduce the effectiveness of the Moving Radar Target Generator equipment used to simulate radar targets for training purposes.

PROPER OPERATION of Radar Moving Target Generator 15-J-1-c, also known as the AN/UPS-T4, depends upon many factors, one of which is the proper operation of Standard Target Course Generator 15-J-4-p. In this article the 15-J-4-p is referred to as the "course generator."

The function of the course generator is to position two 10-turn precision potentiometers so that the output voltages from the arms of these potentiometers will represent the rectangular coordinates of the target position in two dimensions. A target motion is then resolved into two components, an X component (east-west) and a Y component (north-south), as indicated in figure 1. Thus two precision potentiometers are referred to as the "east-west" and the "north-south" potentiometers.

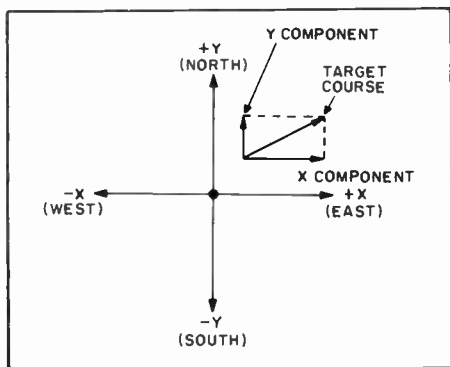


Figure 1. Resolution of a Target Course Into Its X and Y Components

An initial target position in rectangular coordinates is determined by manual adjustment of the positions of these potentiometers. The subsequent motion of the target position is produced when the course generator mechanically drives the potentiometers from their initial positions to new positions which depend upon the target course and speed being simulated.

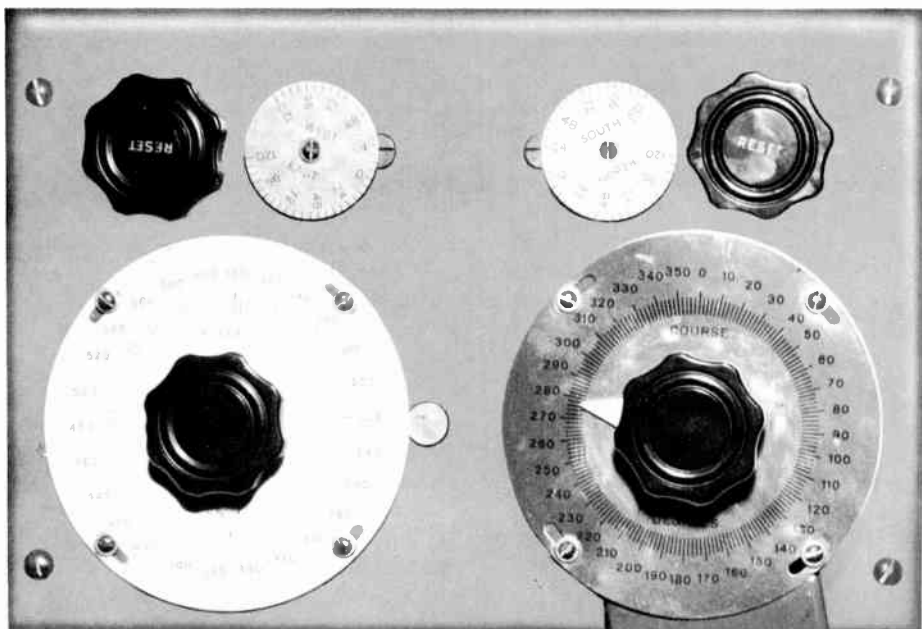
In general, two types of trouble may occur in the course generator, "course wander" (a deviation of the target course from that desired), and "speed error."

## PERFORMANCE TESTING THE COURSE GENERATOR

The usual training equipment contains six or more course generators. The following procedure has been found useful for simultaneously checking the operation of the entire bank of course generators:

Set the north-south reset dial on each course generator at 72 miles north\* (refer to figure 2). Set the east-west reset dial at 72 miles west. Place the speed control on each course generator at 800 knots, and the course control on all units at 135 degrees. For these conditions the simulated target position is

\* When the 120-mile reset dials are in use, the performance test of the course generator can be accomplished by placing the initial target position at 36 miles north, 36 miles west, and setting the speed control to 400 knots. The remainder of the procedure is the same as that given.

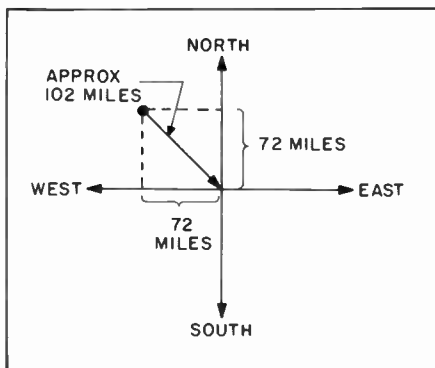


*Figure 2. Front View of Course Generator*

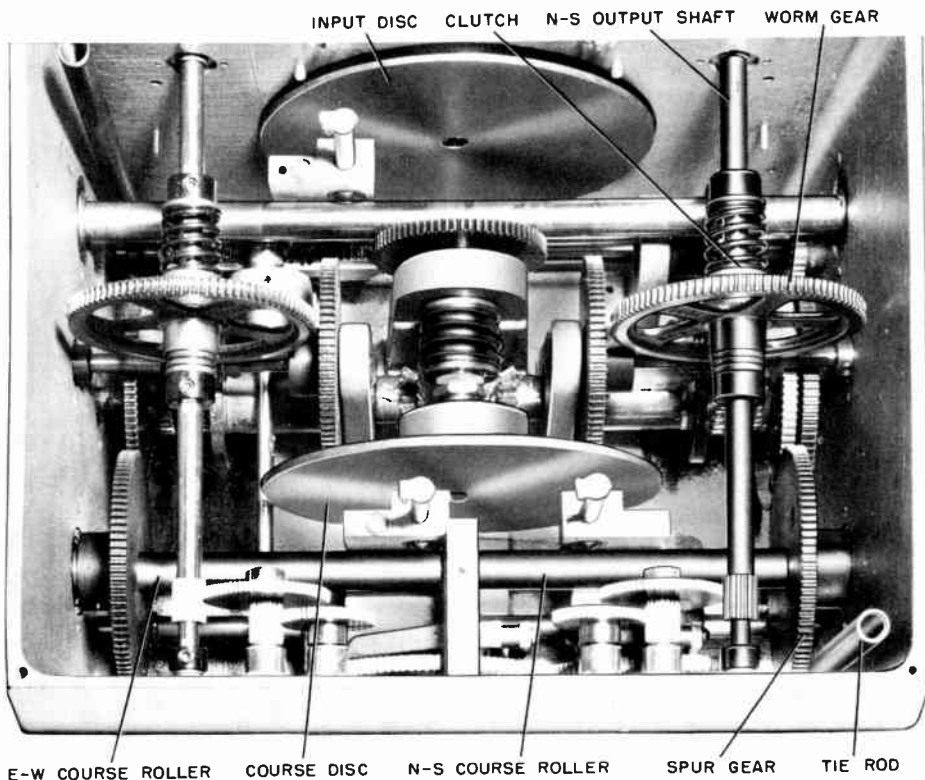
approximately 102 miles northwest of the origin, as indicated in figure 3. Using a watch with a sweep second hand to time the test, run the drive bases for exactly  $7\frac{1}{2}$  minutes and stop them. If the controls have all been properly aligned, and the performance of the course generators is satisfactory, all of the reset dials should now read zero. If one of the dial readings on one of the course generators is substantially different from zero, a course error is indicated. If the readings of both reset dials on one course generator are the same but are not zero, a speed error is indicated. These conclusions are based on the assumption that there is little error in the calibration of the course dial. This assumption may be checked by removing the top of the course generator (see figure 4) and observing the east-west and north-south differentials. With the drive base unit in operation, the east-west differential should remain stationary if the course control is set to zero degrees, and the north-south differential should remain stationary if the course control is set to 90 degrees. The course

control dial should be adjusted, by means of its mounting screws, to obtain this condition.

This procedure is useful for determining whether the fault is in the mechanical or the electrical units of the equipment. If the position of the simulated target is always in agreement with its coordinates, as displayed on the reset dial, any fault in the operation of that target must be mechanical. If this condition is not obtained, the trouble must



*Figure 3. Target Positioning for the Performance Test of the Course Generator*



**Figure 4. Top View of Course Generator 15-J-4-p With Cover Removed**

be electrical. Course wander, for example, may be caused by improper alignment of the quadrature circuit in the Six Target Generator Unit for that target. Errors in speed or course should not exceed 2 percent or 2 degrees, respectively.

#### **SPEED ERROR**

Speed error is usually found to be the result of the wrong gear ratio at the drive base unit (15-J-4-t), improper speed output from the drive base unit, or a failure of the speed changer mechanism in the course generator. The latter trouble may be due to a flattened ball or balls, or insufficient spring pressure on the input disk of the DBR (disk ball roller) assembly (refer to figure 4). The spring pressure on the input disk should be 20 pounds, and may be measured and adjusted by the procedure given in publication NAVEXOS P-976,

which covers the course generator. The proper output gear ratio may be obtained by adjusting the output gearing in accordance with manual NAVEXOS P-953, which covers the drive base unit.

#### **COURSE WANDER**

Excessive course wander may be caused by one of several things, among which are a flat ball in the course DBR assembly and insufficient spring pressure on the course disk. These troubles and their remedies are rather obvious, and are discussed in the handbook. In addition, course wander may be caused by interference of the worm gear (see figure 4) with the cover of the course generator. This condition is evidenced by a pair of scratch marks on the underside of the course generator cover at the point of contact, and may be remedied by grinding a small recess into the cover at these points.

Course wander may be due to the binding of the spur gear (see figure 4), associated with the north-south course roller, by the tie rod. (The tie rod secures the stack of units, consisting of three course generators and three turn rate units on a drive base unit.) This trouble may usually be alleviated by turning the stack to the left (as viewed from above) as far as the play in the tie rods will permit. The play in the tie rods can be increased by removing the straps from the top course generators in each stack.

A misalignment of the potentiometer shaft and output shaft may also cause course wander by partially or completely stalling the friction drive of the output shaft. The coupler that connects the potentiometer shaft to the output shaft can compensate for only small misalignments without binding. In some cases binding in this coupling may be relieved by filing the bottom of the slot in one side of the coupler with a small, thin file. The sides of the slot must not be filed because this would produce backlash in the system which would make it

inaccurate. The two halves of the coupling should have sufficient separation to ensure against interference between the coupling halves.

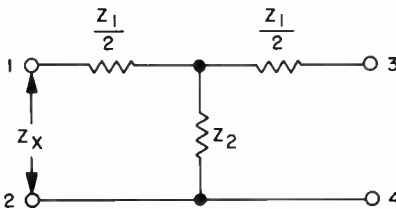
Course wander may also be caused by a misalignment of the course disk with respect to the two course rollers. This condition is noticeable during replacement of the balls in the course DBR, but little can be done about it, since the mounting bolts on the bottom of the unit cannot be repositioned to any extent. If one of the course rollers is misaligned, the ball bearings which support that course roller should be checked for play and ease of turning.

During the routine maintenance of the course generator, special attention should be given to the condition of the disks, balls, and rollers, and replacements made when necessary. In general, the clutch tension should be great enough to insure reliable driving of the output shafts without making the reset knobs hard to turn. Any operation which is noisy or rough should be promptly remedied.

### “What’s Your Answer?”

Although the solution of this “What’s Your Answer?” problem is obtained in a somewhat straightforward manner, it was selected because of the type of solution which can be obtained.

Show that the characteristic impedance of the transmission line shown in the illustration is given by the formula  $Z_x = \sqrt{Z_{oc} Z_{sc}}$ , where  $Z_{sc}$  is the impedance that appears between terminals 1 and 2 with terminals 3 and 4 shorted, and  $Z_{oc}$  is the impedance that appears between terminals 1 and 2 when terminals 3 and 4 are open.



(Solution next issue ...)

## NEW PHILCO SILICON TRANSISTOR

Philco has developed a new type of transistor known as the silicon-alloy transistor. It is the first practical, precision made, high-speed silicon transistor.

The new transistor offers both the advantage of silicon for high-temperature applications and the Philco precision process of transistor manufacture developed in connection with the Surface-Barrier Transistor. It is the result of more than two years of intensive research in the Philco laboratories.

The Philco silicon-alloy transistor has numerous advantages over the best type germanium transistors thus far developed. In particular, it will operate at temperatures as high as 150 degrees centigrade—well above the 85-degree limit typical of germanium transistors. This property greatly expands the number of uses for transistors in both military and civilian equipment. It is the first silicon transistor capable of operating with full performance at flashlight battery voltage levels.

The silicon-alloy transistor will find its first applications in military computers and communications systems, both on the ground and in the air, in which temperatures may rise considerably above 100 degrees centigrade. The high-frequency range of the silicon-alloy transistor suits it ideally to uses in computers having repetition rates up to one-half megacycle.

For guided missiles, the silicon-alloy transistor has other special advantages, including small size, rugged construction, and low-power requirements.

# THE STATDUCT ALIGNER

by Joseph R. Gober  
Philco TechRep Field Engineer

A Tuning Aid for the AN/GRC-27 which was designed and constructed by the author.

*(Editor's Note: It is assumed that anyone who is interested in this article will already be familiar with the usual method of tuning the AN/GRC-27; therefore, many of the tuning details have been omitted from this discussion.)*

BEFORE PROCEEDING with the electrical alignment of the transmitter or receiver components of the AN/GRC-27, it is essential that the mechanical alignment of all tunable circuits be complete and exact. In the alignment of the subchassis containing the UHF tuner tanks, it is important that all tuners be in perfect synchronization. When the subchassis containing these tuners are in their respective positions within the component main frame, it is difficult to determine when the short stator bar is directly in line with the movable inductance bar. These tuners can be aligned with some degree of accuracy visually, but an exact alignment is almost impossible without disassembling the subchassis, because of the angle at which these bars must be observed during the alignment process.

The aligner described herein was constructed to fit the tuner tanks of the driver subchassis without removing them. All references in this article to tuner tanks will be to the driver type.

## USE OF ALIGNER

The Statduct aligner is constructed so that it may be quickly and securely fastened to the tuner tank to be aligned or checked. To show how the aligner mounts on the tuner (refer to figure 1), it was necessary to remove the unit from the equipment. To mount the aligner, however, does not require removal of the unit. It is only necessary to take off the rear cover plate of the chassis subassembly, remove the 2C39 tube from its socket, fasten the aligner to the ceramic end plate, and attach the "U" clip to the inductance bar, as shown in figures 1 and 2. An examination of figure

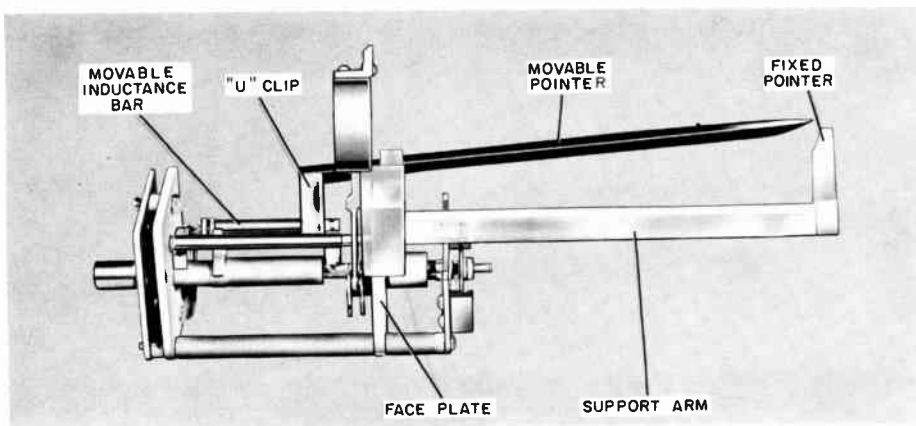
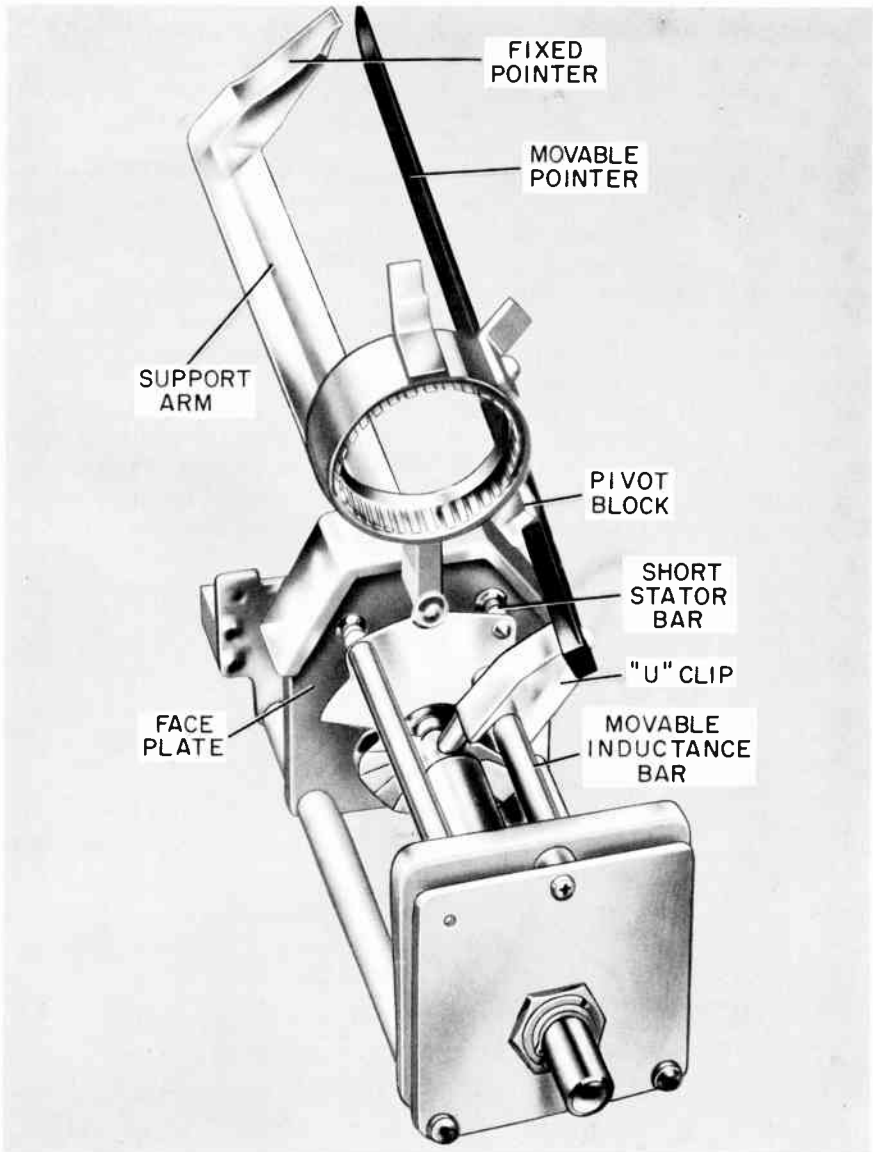


Figure 1. Side View of the Statduct Aligner Mounted on a Tuner Tank



*Figure 2. End View of the Statduct Aligner Mounted on a Tuner Tank*

2 will reveal how the "U" clip moves about its mounting and about the pivot point to follow the movement of the inductance bar. The movement of the "U" clip is registered as an amplified deviation of the movable pointer. The fixed pointer, attached by its support

arm to the aligner face plate, is the alignment marker to which the movable pointer must align itself when the stator and movable inductance bars are opposite each other in proper alignment. The aligner should be calibrated prior to use; this initial calibration is all that is

generally required, provided that the pointers are not bumped or distorted during storage periods.

The rotating shafts of the tuners in the AN/GRC-27 driver subchassis have been known to bind partially or completely, inhibiting the free rotation of the tuners, and thus cause detuning of the associated stage. Realignment of these tuners by conventional methods is often time consuming and therefore expensive. Realignment is important because the decrease in power-amplifier grid drive resulting from detuning increases the PA plate currents and consequently shortens tube life. With the aid of the Statduct aligner, the tuner shafts can be realigned quickly, and the alignment is so accurate that very little tab bending is required, assuming that the initial alignment was accurately executed.

Furthermore, use of this aligner will permit tuner tank checks to be incorporated in the maintenance check list, so that misalignment conditions can be detected before failure occurs.

### ALIGNER CONSTRUCTION DETAILS

The aligner is composed of six separate parts, as follows:

1. Face plate
2. Fixed pointer
3. Fixed pointer support arm
4. Movable pointer
5. Pivot block
6. Inductance bar "U" clip

The face plate, as shown in figure 3, is cut  $\frac{1}{8}$  inch larger than the ceramic end plate of the tuner onto which it is to be mounted. To this  $\frac{1}{8}$ -inch overhang are glued the plastic strips shown by the dotted lines. Indentations are first

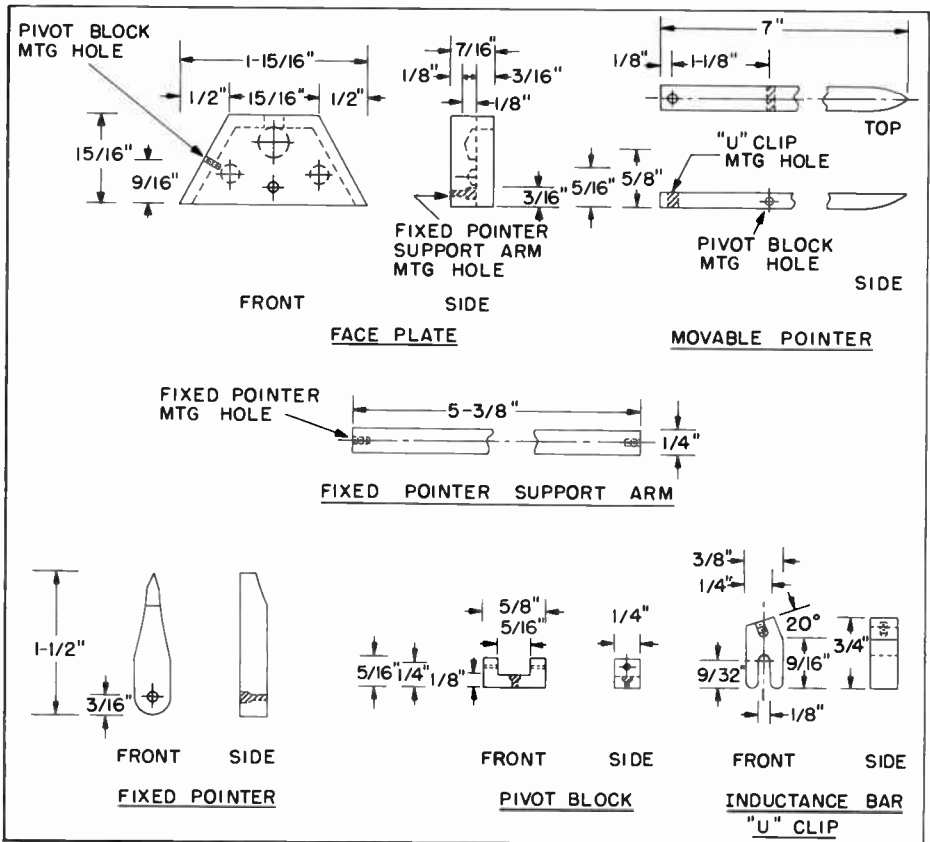


Figure 3. Drawing of Parts of the Statduct Aligner



drilled into the face plate as shown so that it can fit flat against the ceramic end plate of the tuner. It is necessary to drill these indentations somewhat larger than the diameter of the protrusions on the ceramic end plate, because of the irregularities found in different tuners. *It is very important that the face plate fit solidly against the ceramic end plate of the tuner.* To ensure a snug fit, the face plate should be held against the ceramic end plate of a tuner while the  $\frac{1}{8}$ -inch strips are being cemented to it.

A hole is drilled in the fixed pointer to receive a 3-56 x  $\frac{1}{2}$ -inch machine screw. If the hole is not countersunk, it is recommended that a machine screw slightly longer than  $\frac{1}{2}$  inch be used. The diameter of this hole should be approximately the diameter of the screw. A snug fit is more desirable than a loose fit. Attaching the pointer by this method permits adjustment of the pointer when calibrating the aligner prior to using it. The fixed pointer is attached to the support arm, which in turn is fastened to the face plate, by using a similar mounting arrangement.

The movable pointer was constructed of bakelite. This material was selected because it did not warp when heated by the cutting tool and was found to be more durable than plastic when cut to

a  $\frac{1}{8}$ -inch thickness. The diameter of the pivot hole depends on the type of pivot material used. The straight portion of a paper clip was used for the pivot in the pilot model.

The pivot block must be drilled accurately. The vertical and horizontal pivot points must be snug to the point that no play is evident in the pointer movement, yet free enough to permit pointer movement. The accuracy of the aligner is dependent on the proper functioning of these two pivot points.

The inductance bar "U" clip is attached to the movable arm by means of a 3-56 x  $\frac{1}{2}$ -inch machine screw, so that it too may pivot when the inductance bar is rotated small distances, and to facilitate attaching the clip.

Clear plastic was selected as the principal material for construction because it was available, it is light in weight and fairly durable, and wood-working tools can be used for cutting and shaping the parts. A piece of  $\frac{1}{4}$ -inch plastic material, six inches long and three inches wide will furnish more than enough material to complete the project. The 3-56 machine screws used in the model were selected because a drill and tap of that size were available. Machine screws of any small size can be used satisfactorily.

# D-C ANALOG COMPUTERS

## PART I

by Allen J. MacKinnon  
*Philco TechRep Field Engineer*

Electronic digital computers were discussed in a series of five articles which appeared in the BULLETIN during 1952 and 1953. This is the first installment of a similar series of articles which will deal with d-c analog computers, their uses, and the circuits commonly used in them. This type of computer has found considerable use in both military and industrial applications.

### INTRODUCTION

PERHAPS THE FIRST ITEM on the agenda in any discussion of computers is to distinguish between the analog-type and the digital-type computers. The information applied to a digital computer is separated into and handled in discrete, measurable steps (digits) within the computer, whereas the information applied to an analog computer may be used as continuously variable quantities within the computer, and is not restricted to digital values. Most of the mathematical operations of a digital computer are performed by repeated addition, while different methods are used to perform these operations in analog computers. Digital computers are, in general, capable of greater accuracy, but are ordinarily much more complicated and more difficult to operate in the solution of many physical problems, than are the analog type.

Analog computers may be classified into either of two general groups, mechanical or electrical, depending on the types of inputs used to represent certain quantities. The slide rule, for instance, is a mechanical analog computer since it involves the mechanical manipulation of a slide. Many radar system computers, on the other hand, employ electrical inputs and thus are classified as electrical computers. If an electrical computer utilizes a slowly varying a-c or d-c voltage as an input, it is called a d-c analog computer.

A d-c analog computer is capable of solving complex problems by means of such simple circuits as d-c amplifiers and potentiometers. A d-c voltage may represent information about a particular item. For example, a sawtooth voltage could easily represent the acceleration of an airplane. The slope of the sawtooth could represent the magnitude of the acceleration, the starting level of the slope representing the initial velocity, and the final level of the slope representing the final velocity of the airplane.

### FEEDBACK IN COMPUTER AMPLIFIERS

D-c analog computers frequently employ negative feedback circuits. Negative feedback is required primarily because vacuum tubes are unstable devices. The transconductance, amplification factor, and plate resistance of a tube vary with the applied voltage, and hence cause the circuit amplification to vary with the supply voltage. Tube parameters are not held to close tolerances in manufacture, and the replacement of a tube may considerably change the circuit characteristics. In addition, oscillations may occur at the natural resonant frequencies of the circuit. One way to overcome these unstable conditions is to employ negative feedback.

When a part of the output voltage of an amplifier is fed back to its input in such a manner as to oppose the input signal, it is called negative feedback; on the other hand, if the voltage fed back

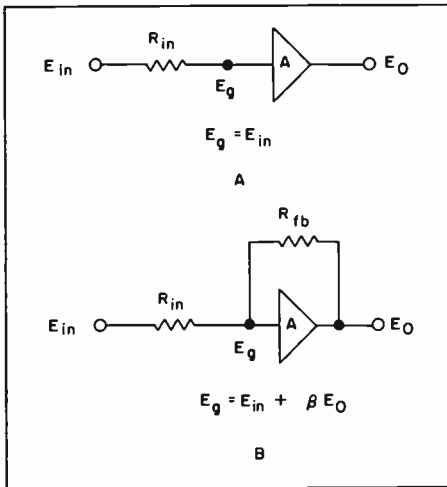


Figure 1. Line Diagram of an Amplifier Without Feedback (Part A) and With Feedback (Part B)

aids the input signal, it is called positive feedback. Oscillators use positive feedback to sustain oscillations, whereas negative feedback is used to suppress oscillations. An equation known as the feedback equation can be used to determine whether a circuit is using positive or negative feedback. To derive this equation it need only be known that the output voltage of an amplifier without feedback is equal to the input voltage multiplied by the gain of the amplifier. In part A of figure 1 is shown a line diagram of an amplifier without negative feedback, and in part B of the figure is shown an amplifier with negative feedback. The input voltages ( $E_{in}$ ) applied to both amplifiers are equal, and both amplifiers have the same gain ( $A$ ); however, it will be shown that the output voltages ( $E_o$ ) are not the same.

In part A of figure 1, the voltage ( $E_g$ ) applied to the grid is equal to the input voltage ( $E_{in}$ ). The gain ( $A$ ) of the amplifier without feedback is equal to the quotient of the output voltage ( $E_o$ ) and the grid voltage ( $E_g$ ) or, since the grid voltage is equal to the input voltage ( $E_{in}$ ), the gain is equal to the quotient of the output voltage and the input voltage.

In part B of figure 1, the input voltage is the same as in part A of figure 1, but the grid voltage is not the same since a portion of the output voltage is fed back to the input so as to add algebraically to the grid voltage. Let  $\beta$  represent a fraction which is proportional to the amount of output voltage that is fed back to the input, so that the product  $\beta E_o$  is equal to the feedback voltage. It can be seen that the grid voltage in part B of figure 1 is equal to the input voltage plus the feedback voltage, or

$$E_g = E_{in} + \beta E_o. \quad (1-1)$$

The output voltage is equal to the product of the gain of the stage and the grid voltage, or

$$E_o = (E_{in} + \beta E_o) A.$$

By performing the indicated multiplication on the right side of the latter equation, transposing the terms  $E_o$  and  $AE_{in}$ , and factoring out  $E_o$ , this equation becomes

$$E_o(1 - A\beta) = AE_{in}. \quad (1-2)$$

Dividing equation (1-2) by  $E_{in}(1 - A\beta)$  gives

$$\frac{E_o}{E_{in}} = \frac{A}{1 - A\beta} \quad (1-3)$$

Equation (1-3) is known as the feedback equation, and the product  $A\beta$  is referred to as the feedback factor. If the denominator of equation (1-3) is less than one, the feedback is positive, and if the denominator is greater than one, the feedback is negative. If the gain  $A$  of the amplifier is made large enough, so that the product  $A\beta$  is much greater than one, equation (1-3) reduces to

$$\frac{E_o}{E_{in}} = -\frac{1}{\beta} \quad (1-4)$$

so that the actual gain of the circuit with feedback is nearly a function of the feedback network alone and is practically independent of tube variations.

To understand the operation of a d-c amplifier with negative feedback, consider the circuit shown in part A of figure 2. Here a generator with negligible internal impedance supplies a variable d-c input voltage. The tube should be biased so as to operate near the center

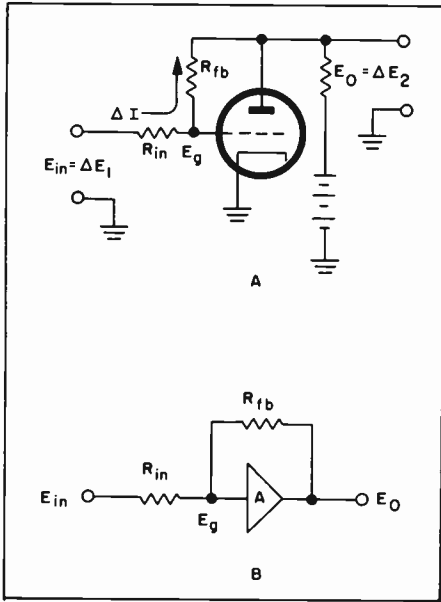


Figure 2. Schematic Diagram of a D-C Amplifier With Negative Feedback (Part A), and Its Line Diagram Representation (Part B)

of its linear range if the input voltage is to increase or decrease from its quiescent value. The "signal" voltages then are actually the changes in the input voltage  $E_{in}$  and the output voltage  $E_o$ , and are represented by  $\Delta E_1$  and  $\Delta E_2$ , respectively. Since nearly all of the change in the output voltage appears across the feedback resistor,  $R_{fb}$ , the grid voltage will be near ground potential *and will change only a very small amount during normal operation when the input signal varies, provided that the gain of the amplifier is very high.* This occurs because the feedback voltage tends to prevent any change in the grid voltage. The amplifier, represented here by one tube, can actually consist of any odd number of tubes (most such d-c amplifiers contain three tubes) with this method of supplying negative feedback.

For this situation, assuming zero grid current, it is seen that the same current must flow through both  $R_{in}$  and  $R_{fb}$ . As a result, the voltages  $\Delta E_1$  and  $\Delta E_2$  are given by

$$\Delta E_1 = \Delta I R_{in} \quad (1-5)$$

$$-\Delta E_2 = \Delta I R_{fb}, \quad (1-6)$$

where the minus sign for  $-\Delta E_2$  indicates the voltage inversion in the amplifier which is symbolic of negative feedback. Dividing (1-6) by (1-5) gives

$$\frac{-\Delta E_2}{\Delta E_1} = \frac{R_{fb}}{R_{in}}$$

or in terms of  $E_{in}$  and  $E_o$ ,

$$\frac{-E_o}{E_{in}} = \frac{R_{fb}}{R_{in}} \quad (1-7)$$

where it is understood that  $E_{in}$  and  $E_o$  are changes in voltage. It should be emphasized that the higher the gain of the amplifier, the more nearly this condition holds. A line diagram of this circuit is shown in part B of figure 2.

It has been shown that the higher the gain of a feedback amplifier, the more dependent the output voltage will be upon the feedback network. The following numerical example shows how an increase in gain will increase the accuracy of the reproduction of the input voltage  $E_{in}$  in the output voltage  $E_o$ . A line diagram of a d-c amplifier having a gain (if no feedback circuit were used) of 100 is shown in part A of figure 3. Suppose that  $E_{in}$  is 102 volts, and that  $R_{in}$  and  $R_{fb}$  are equal. When  $E_{in}$  is initially applied, the potential at the grid ( $E_g$ ) tends to rise toward 102 volts. As soon as the first small change in potential is felt at the grid, it is amplified by a factor of  $-100$  (minus because of the inversion in the amplifier), and a portion of the output voltage is fed back to the grid, thus reducing  $E_g$ . This decrease in  $E_g$  is in turn amplified by a factor of  $-100$ , and a portion of the output voltage is fed back to raise the grid voltage toward its original level. This process continues to repeat until a stable operating point is reached (the point of stable operation is reached almost instantly). At this time, 101 volts is dropped across each of the resistors,  $R_{in}$  and  $R_{fb}$ , and the output voltage  $E_o$  is  $-100$  volts, an approximation to the input voltage  $E_{in}$ . An equivalent circuit for this condition is shown in part B of figure 3.

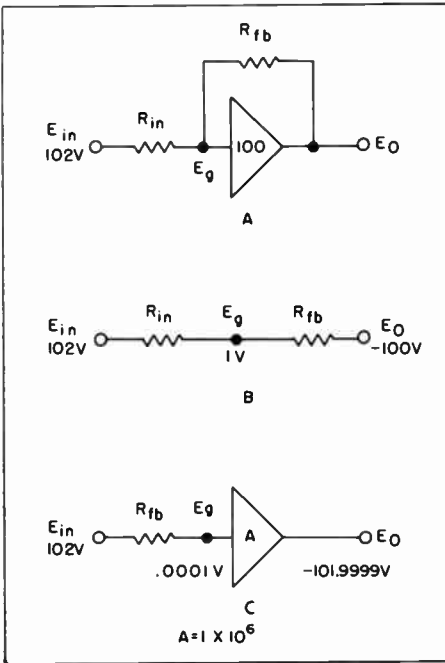


Figure 3. Line Diagram of an Amplifier With Gain of  $-100$  (Part A), Its Equivalent (Part B), and a Line Diagram of an Amplifier With a Gain of One Million (Part C)

An amplifier with a gain of 1 million is shown in part C of figure 3. Again  $E_{in}$  is 102 volts, but the output voltage  $E_o$  is found to be  $-101.9999$  volts. This is nearly a perfect reproduction of the input signal, but with reverse polarity, and is accurate enough for most computer purposes.

It is apparent from the foregoing that the negative feedback amplifier under discussion produces no voltage gain. In practical circuits, the feedback amplifier may or may not produce a voltage gain depending upon its specific application. The following circuit discussions will show how this type of negative feedback amplifier is used for many purposes in a d-c analog computer.

### COMPUTING AND SPECIAL CIRCUITS

The d-c amplifiers in d-c analog computers are used in conjunction with computing and special circuits to perform certain mathematical operations.

Any circuit that performs the operation of addition, subtraction, multiplication, or division is referred to here as a computing circuit, while circuits that perform other operations are referred to as special circuits.

### SUMMING CIRCUIT

Before discussing the summing networks used with computer amplifiers, it may be advantageous to consider the operation and limitations of the simple summing circuit shown in figure 4. If the resistance values are properly chosen, this circuit will produce an output voltage  $E_o$  which is proportional to the sum of the input voltages  $E_1$ ,  $E_2$ , and  $E_3$ . The primary requirement for such a summing device is that  $R_4$  must be much smaller than either of  $R_1$ ,  $R_2$ , or  $R_3$  in order that each of the input voltages may independently establish a current in  $R_4$ . Inaccuracies are introduced even when this condition is met.

In the circuit of figure 4, a voltage  $E_1$  produces a current  $I_1$  through  $R_1$ ,  $E_2$  produces a current  $I_2$  through  $R_2$ , and  $E_3$  produces a current  $I_3$  through  $R_3$ . Since  $R_4$  is small, most of these currents will flow through  $R_4$  and produce an output voltage  $E_o$ . An approximate expression for  $E_o$  would therefore be the total current,  $I_1$ , flowing through  $R_4$  times the resistance value of  $R_4$  ( $E_o = I_1 R_4$ ).

Some sample calculations for this cir-

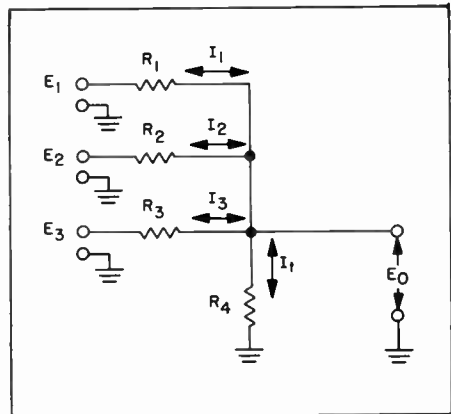


Figure 4. A Simple Adding Circuit

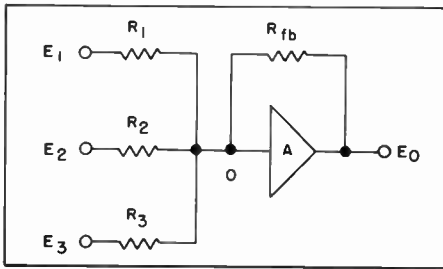


Figure 5. Line Diagram of a Summing Amplifier

cuit are shown in examples 1, 2, and 3 below:

Example 1	Example 2	Example 3
$E_1 = 10 \text{ v}$	$E_1 = 20 \text{ v}$	$E_1 = 20 \text{ v}$
$E_2 = 10 \text{ v}$	$E_2 = 20 \text{ v}$	$E_2 = -20 \text{ v}$
$E_3 = 20 \text{ v}$	$E_3 = 40 \text{ v}$	$E_3 = 40 \text{ v}$
$R_1 = R_2 = R_3 = 1 \text{ meg}$	$R_1 = R_2 = R_3 = 1 \text{ meg}$	$R_1 = R_2 = R_3 = 1 \text{ meg}$
$R_4 = 1000 \text{ ohms}$	$R_4 = 1000 \text{ ohms}$	$R_4 = 1000 \text{ ohms}$
$E_0 = .04 \text{ v}$	$E_0 = .08 \text{ v}$	$E_0 = .04 \text{ v}$

Examples 1 and 2 illustrate that doubling all of the input voltages, while keeping the resistances constant, doubles the output voltage. The same circuit can subtract voltages (algebraic addition) as indicated in example 3 where the output voltage is proportional to the algebraic sum of the input voltages. It can be seen from these examples that the accomplishment of true summation in this case requires that the output voltages be multiplied by an amplifier having a gain of 1000. This type of summing network is not desirable in analog computing since an amplifier with an exact gain is required.

To overcome the disadvantages of the simple summing network described above, a computing amplifier is used in conjunction with a summing network. A voltage output that is almost exactly equal to the sum of the inputs is obtained from the type of circuit shown in figure 5. The application of an input voltage  $E_1$  (considering the effect of each input voltage separately) will cause a current to flow through  $R_1$ . Suppose that the voltage at point 0 tends to increase; then this first small change in voltage is immediately amplified and appears in

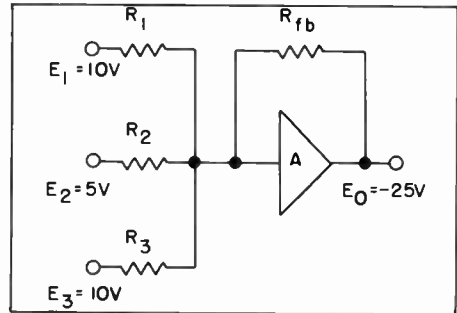


Figure 6. Line Diagram of a Summing Amplifier With Inputs and Outputs as Shown

the output circuit, where a portion of it is fed back to the input so as to decrease the input voltage. The resulting decrease in input voltage is amplified and fed back so as to again increase the amplitude of the input voltage. This process continues until the amplifier reaches a point of stable operation. If  $R_1$  and  $R_{fb}$  are equal, the output voltage is equal to the input voltage except that the polarity is reversed (as before, this amplifier contains an odd number of stages).

If three voltages,  $E_1$ ,  $E_2$ ,  $E_3$ , are present at the input terminals of this summing network, the current through  $R_{fb}$  is the algebraic sum of the currents through  $R_1$ ,  $R_2$ , and  $R_3$ . The voltage drop across  $R_{fb}$  (essentially the output voltage) will then be equal to the algebraic sum of the input voltages. The equations for this circuit are:

$$I_1 = \frac{-E_0}{R_{fb}} \quad (1-8)$$

$$\frac{-E_0}{R_{fb}} = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3} \quad (1-9)$$

If  $R_{fb} = R_1 = R_2 = R_3$ , then  $E_0 = -(E_1 + E_2 + E_3)$ . (1-10) Figure 6 illustrates the action of this summing circuit when the inputs are those given.

## Solution to November-December "What's Your Answer?"

It has been suggested that the difficulty attending the problem of November-December may be due to the incorrect polarity shown on generator  $V_2$ . Such is not the case, however, as the problem may be solved using the same mathematical principles regardless of the polarity on  $V_2$ . Reversing the polarity merely affects the numerical value obtained for  $R_x$ .

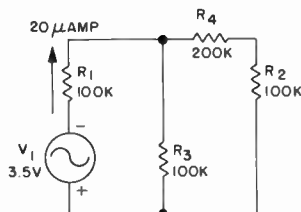
The first step in finding the value of  $R_x$  is to find the amount and the direction of current flowing through  $V_1$ . The two equivalent circuits shown below illustrate the use of the superposition method in determining that current. Note that the polarity on  $V_2$  in part B has been corrected to conform with the stated problem.

From the two equivalent circuits, it can be seen that the net current flowing through  $R_1$ , and therefore through  $V_1$ , is  $110 \mu\text{amps}$  ( $20 \mu\text{amps}$  in part A and  $90 \mu\text{amps}$  in part B). The total impedance across  $V_1$  must then equal  $3.5\text{v}$  divided by  $110 \mu\text{amps}$ , or  $31,818 \text{ ohms}$ . Since the total impedance across  $V_1$  consists of  $R_1$  and  $R_x$  (which is the combination of  $R_3$ ,  $R_4$ , and  $R_2$ ) in series, it follows that the value of  $R_x$  must be either  $-68,182 \text{ ohms}$  or  $-131,818 \text{ ohms}$ . The correct value,  $-68,182 \text{ ohms}$ , can be deduced from the fact that the current flow through  $V_1$  is in such a direction that  $V_1$  is supplying energy to the circuit. (If the value of  $R_x$  were  $-131,818 \text{ ohms}$ , the same current would flow through  $V_1$ , but in the opposite direction, indicating that  $V_1$  was receiving energy from the circuit.)

Physically,  $R_x$  can be regarded as an energy source, rather than as a load. Its nature as a source is due to the feedback from  $V_2$  to  $V_1$  through  $R_4$ . The two possible values of  $R_x$  result because it, like any source, can be connected either series-aiding or series-opposing with respect to  $V_1$ . In this particular circuit,  $R_x$  is recognized as being connected series-aiding with respect to  $V_1$ . It should also be noted that  $V_1$  sees an impedance considerably less than its own internal impedance as a consequence of the feedback through  $R_4$ .

By the use of the circuit with the correct polarities, it is possible to begin an explanation of the Miller effect and to demonstrate, in simple terms, the loading produced because of it. If the resistors in the original problem are correctly replaced by the actual impedances encountered, other consequences of the Miller effect can be developed.

Incidentally, if the problem is solved using the polarity originally indicated on  $V_2$ , the resultant value of  $R_x$  is  $-150,000 \text{ ohms}$ .

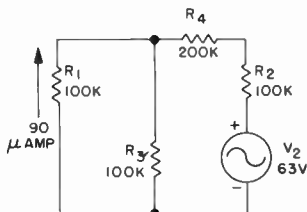


$$R_T = 175\text{K}$$

$$I_T = 20 \mu\text{AMP}$$

$$I_1 = 20 \mu\text{AMP}$$

A



$$R_T = 350\text{K}$$

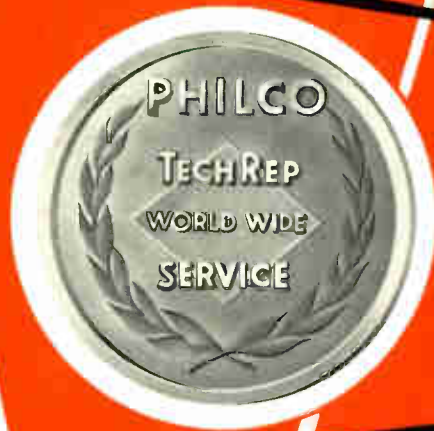
$$I_T = 180 \mu\text{AMP}$$

$$I_1 = 90 \mu\text{AMP}$$

B

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