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1. Magic "T" Ring duplexer

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Editorial

MICROWAVE—THE "HYBRID" OF THE INDUSTRY

By John E. Remich, Manager, Technical Department

An interesting phenomenon has been unfolding during the last three years in the electronics industry—the merging of two distinctly different specialized branches of the profession.

Since well before the recent War, the communications specialists, including design and development engineers as well as installation and maintenance technicians, have considered their activities as almost entirely divorced from the correspondng activities in the field of pulsed equipment such as radar. In fact, there has always been a considerable amount of good-natured rivalry between the two groups, particularly among personnel assigned to installations which incorporate both types of equipment.

Now, however, among personnel involved in the new microwave communications systems, there is no such rivalry, because these systems contain not only the full range of conventional communications circuitry, but also practically all the types of circuits and components included in a typical heavy ground radar.

On the "conventional-communications" side of the system are the audio amplifiers, filters, oscillators, modulators, and mixers used in the frequency-division-multiplex components. In addition, there are the newer multiplex systems, such as the pulse-amplitude-modulation types of equipment, requiring a knowledge of time-base circuits, pulse samplers, wave shapers, and a myriad of other special-purpose circuits. Added to all this, are the components required for the generation, modulation, transmission, reception, and demodulation of microwave energy. Certainly, there are few circuits and few types of components remaining in either the communications or pulsed-equipment fields which lie outside the scope of the qualified microwave-system engineer.

THEORY AND APPLICATION OF THE MAGIC T

By Gail W. Woodward
Headquarters Technical Staff

A basic discussion of some of the uses of the Magic T, with a non-mathematical analysis of the theory of operation.

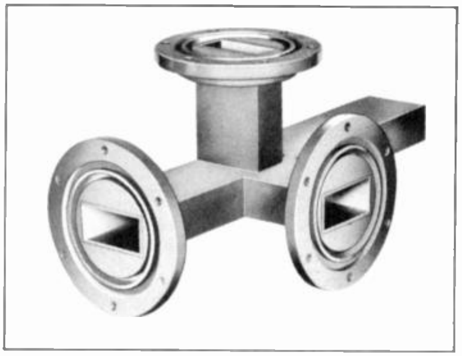

Figure 1. The Magic T

The Magic T, known by our less enthusiastic colleagues as the hybrid junction, has at long last emerged from the laboratory. Its arrival in the field has caused some consternation—due, no doubt, to its unique properties. Applications include such items as radar duplexers, impedance bridges, isolation transformers, standing-wave detectors, and balanced mixers.

In actuality, there is no magic involved—rather, there is a lot of solid research and development behind the production of a commercial unit. While the properties of a Magic T appear to be quite fortuitous on the surface, many hidden problems have had to be resolved before the desirable factors could be utilized.

THEORY OF OPERATION

From its external view, figure 1, the Magic T appears to be a junction of four waveguide sections. The unusual property can be best stated as follows: Power entering any one of the arms will see only two exits.

To understand the action of the Magic T, it is necessary to look first at the action of a simple junction. Figure 3 shows an ordinary H-type T junction with a generator connected to its side arm. Since the side arm is effectively in parallel with the straight section, it is evident that the generator signal will be divided equally at the junction, and two in-phase signals (of equal magnitude) will be propagated to the loads.

In figure 4, the E-type T junction is shown. The main difference between this type and the one shown in figure 3 is found in the fact that the side arm is effectively in series with the straight section. As before, the generator output is divided equally, and two signals are propagated to the respective loads; however, in this case, the two signals are out of phase with respect to each other. This condition can be understood by examining the polarity of an

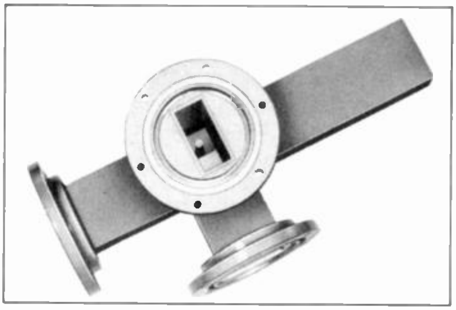

Figure 2. Typical Magic T, Showing Rod for Matching H-Type Arm, and Unsymmetrical Inductive Iris for Matching E-Type Arm

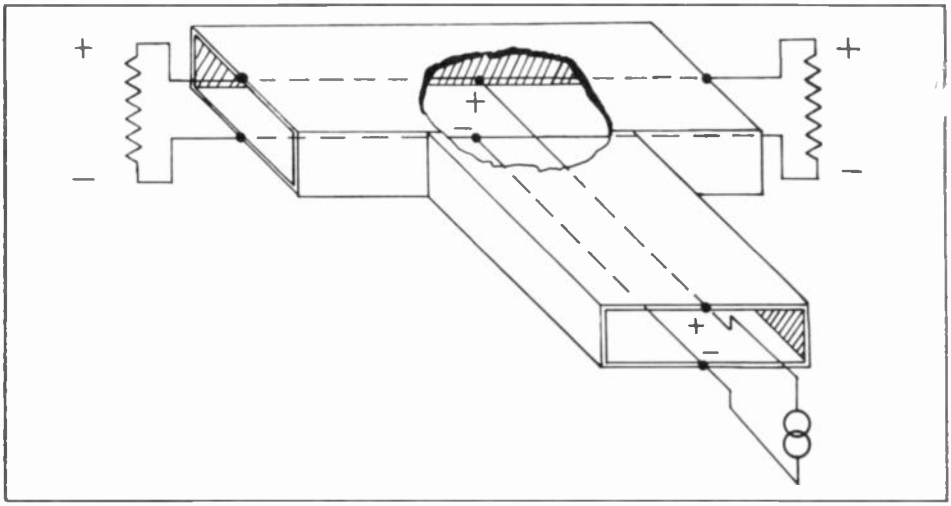

Figure 3. H-Type Waveguide Junction, Showing Phasing

assumed signal at the junction. If the side arm is polarized as shown (plus to the right), the top side of the right-hand section will be positive with respect to the bottom side, and the top of the left-hand section will be negative with respect to the bottom side.

Figure 5 shows the combined E-type and H-type junctions forming a Magic T. Matched loads have been connected to arms A and B, and synchronized generators (of arbitrary phase and equal output) have been connected to arms C and D. Upon inspection it can be seen that energy cannot propagate directly between arms C and D because they are cross

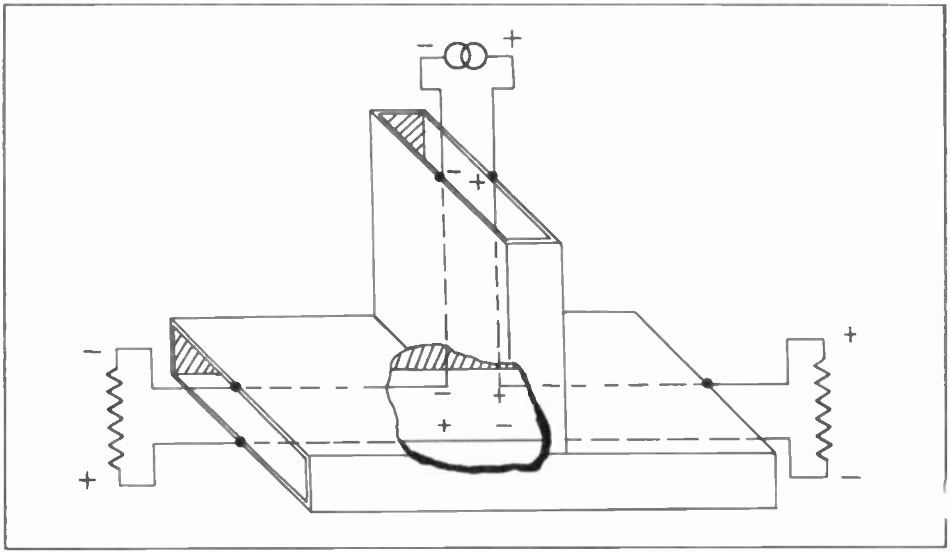

Figure 4. E-Type Waveguide Junction, Showing Phasing

polarized (neither waveguide can support the mode presented by the other).

The arm-C generator will apply a signal to each load as indicated by the dotted arrows (note that the two load signals are out of phase). The arm-D generator also applies a signal to each load as indicated by the solid arrows. The resulting arrows in the arm-A load are in the same direction, indicating phase addition, whereas the resulting arrows in the arm-B load are in opposing directions, indicating phase cancellation.

Here comes the fast one; watch closely. In accordance with the theorem of reciprocity, we replace the two generators with matched loads, and connect the two generators in place of the load at arm A. The generators are phased as indicated by the arrows. The theorem indicates that the foregoing action will cause no change in the circuit conditions at arm B, where it is noted that the resultant signals are out of phase and therefore cancel. Thus, a signal inserted into arm A will produce two cancelling signals at arm B, and no transfer of energy can take place between these two arms.

The action of the Magic T can be summarized as follows (if all legs are considered to be matched):

1. Power entering arm A will divide equally between arms C and D.
2. Power entering arm B will divide equally between arms C and D.
3. Power entering arm C will divide equally between arms A and B (with the two outputs out of phase).
4. Power entering arm D will divide equally between arms A and B (with the two outputs in phase).

If an imaginary plane is thought of as bisecting arms C and D simultaneously, the Magic T is said to have mirror symmetry about this plane. In practice, it can be seen that looking into either arm C or D, a metallic wall will be encountered. Without the addition of some method of matching, this would result in a rather large SWR in these two arms. This factor is one of the major problems encountered in Magic-T design.

Figure 2 shows a typical matching system, where the H-type arm is matched by means of a rod, and the E-type arm is matched by means of an inductive iris. These forms of matching are frequency sensitive, and therefore restrict the useful bandwidth of a practical Magic T.

MAGIC-T MIXER

The basic Magic-T mixer is shown in figure 6. Arm A is connected to a matched load, arm B is connected to a matched crystal-detector section (similar to a standard radar mixer), arm C is connected to the antenna, and arm D is connected to the local oscillator. Because of the coupling characteristics, the crystal detector will receive signals from both the antenna and the local oscillator—thus conversion occurs as in conventional systems. The major advantage is the lack of coupling between the local oscillator and the antenna. This lack of coupling prevents the radiation of

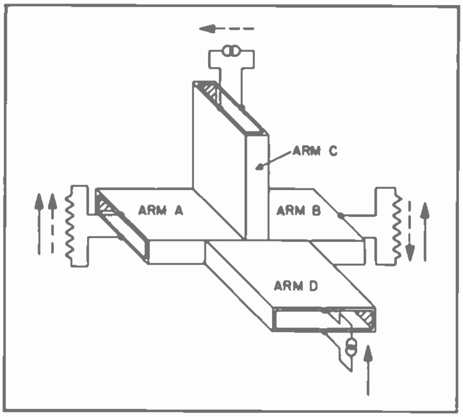

Figure 5. Magic-T, Showing Phasing

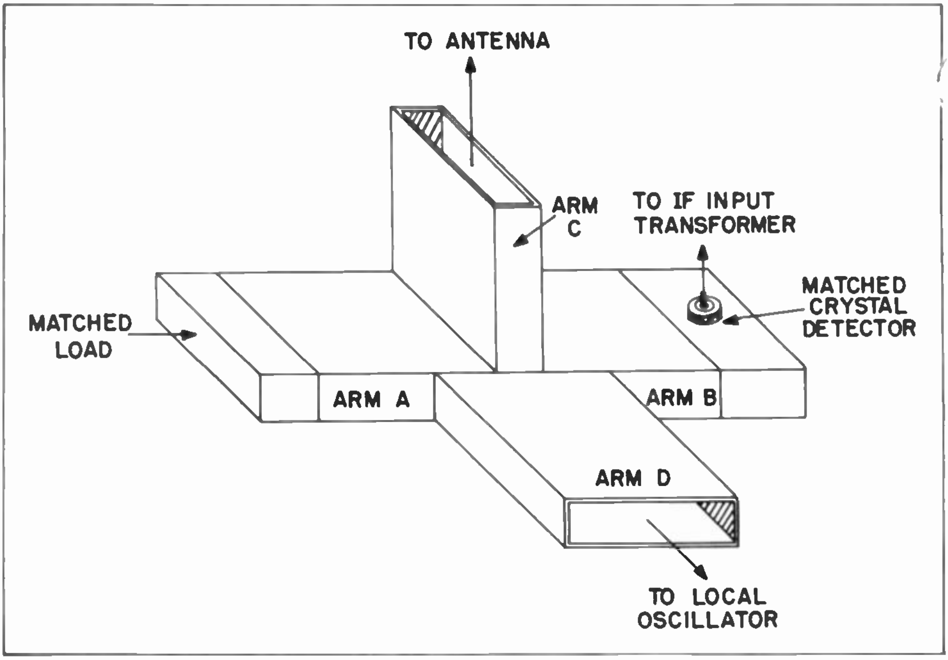

Figure 6. Basic Magic-T Mixer

the local-oscillator signal, and also prevents antenna discontinuities from causing local-oscillator pulling. The major disadvantage is a signal loss of 3 db. This is because the antenna input signal is split equally between the crystal mixer and the matched load—thus the load absorbs one half of the signal.

An improved version of the Magic-T mixer is shown in figure 7. Here, a balanced version of the mixer is used to eliminate the 3-db loss found in the basic circuit. A second crystal detector, identical to the first one, is used to replace the matched load used in the basic mixer on arm A. The crystal output circuits are connected, by means of a balance-to-unbalance transformer, in such a manner that the i-f signals produced are combined in phase. As was pointed out earlier, arms C and D have the characteristic of producing signals in phase opposition in arms A and B. Therefore, if arm-C signals produce in-phase, i-f signals, arm-D signals must produce out-of-phase, i-f signals which would cancel. It is well known that the local oscillators of X-Band and K-Band radars contribute to the receiver noise figure—since this mixer cancels the local-oscillator signal (as far as the i.f. is concerned), this source of noise is eliminated. In practice, the sensitivity of an X-Band radar can be increased by at least 2 db (10% increase in air-search range), and the sensitivity of a K-Band radar can be increased by as much as 5 db (25% increase in air-search range). Of course the advantages thus gained are lost unless maintenance personnel make sure that the crystal balance is not allowed to deterioriate.

ISOLATION

The Magic-T mixer is also an excellent means of isolating microwave signal sources. If two oscillators are coupled into the same waveguide, one will tend to pull the other into synchronism. In fact it is very difficult to prevent pulling of one of the two oscillators, even with a frequency separation of several megacycles.

The solution to this problem is to feed one oscillator into arm C of the Magic T (figure 5), and to feed the second oscillator into arm D. A matched load terminates arm A, while the two-signal output appears at arm B. Of course a 3-db signal loss is incurred for each signal, but the two oscillators are well isolated (and the pulling tendency is thereby minimized).*

MICROWAVE BRIDGE

Figure 8 shows the Magic T connected as a microwave impedance (or SWR) bridge. It is important that the load, generator, and detector be accurately matched (reflectionless). If the device under test is a perfect match, it can be seen that the generator output will be divided between arms A and B, whereupon complete absorption will result. The detector will, of course, receive zero power under these conditions, and the indicator will read zero. (This corresponds to an SWR of 1:1.) If the device under test is a complete reflector, all the power incident in arm B is reflected back to the junction, where it will be equally divided between arms C and D. The detector will therefore receive one fourth of the total generator output. If the generator output is calibrated to 1 mw., an indicator reading of 0.25 mw. indicates complete reflection at arm B. (This corresponds to an SWR of infinity.) Thus, the indicator could easily be calibrated in terms of the device under test for impedance, SWR, or VSWR. However, the indicator will read only magnitude—the phase of the reflection cannot be determined. This inability proves to be a minor factor in circuit adjustment.

To simplify measurements, the signal generator can be pulsed at

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*This is the method used to isolate the Philco CLR-6 microwave units when two or more are used with the same antenna.

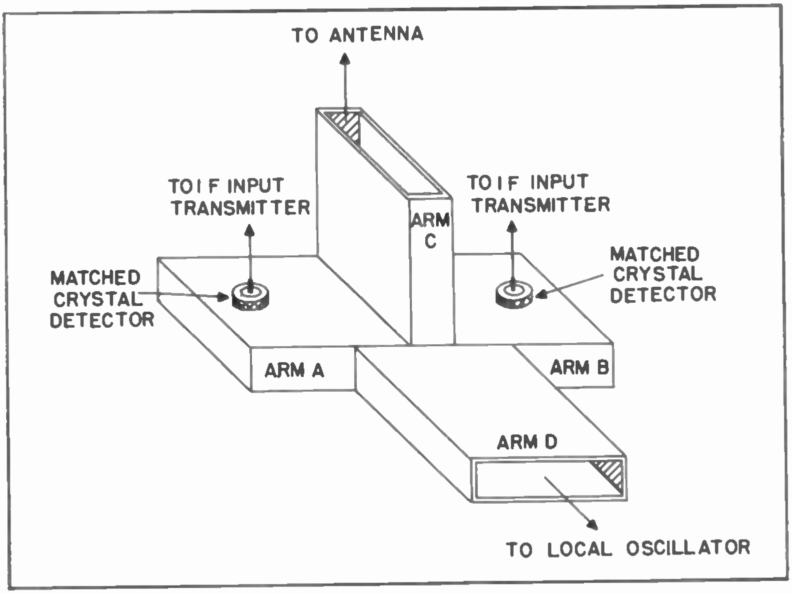

Figure 7. Balanced Magic-T Mixer

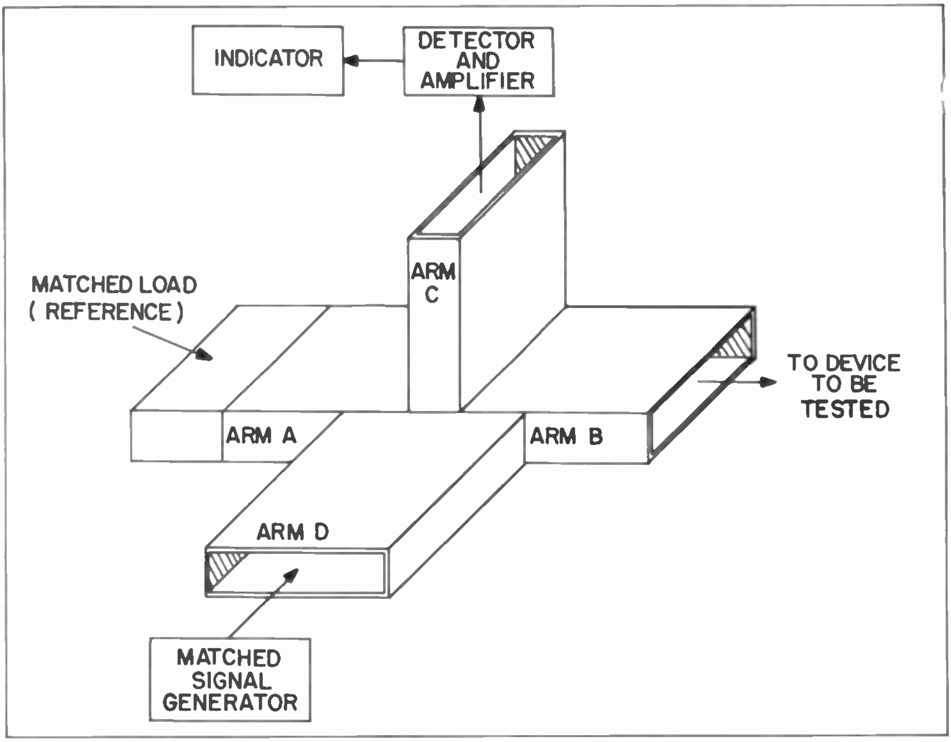

Figure 8. Magic-T Microwave Bridge

three or more different frequencies on a recurrent sequence basis. The indicator is replaced by an oscilloscope which is swept in synchronism with the recurrent pulses. Each signal-generator frequency will be represented by a pulse on the oscilloscope —pulse height being the index of measurement. If three frequencies are used, a device can be simultaneously tested at its center frequency as well as the upper and lower limits of operation. In fact, adjustments can be performed so that the device meets SWR requirements over its operating band.

MICROWAVE DISCRIMINATOR

The Magic T forms the circuitry required for frequency discrimination by the device shown in figure 9. In this device, the Magic T is used as a bridge to compare the reflection of a resonant cavity to the reflection of a shorted section of waveguide one-eighth wavelength long. Since both arms A and B are almost complete reflectors, the eighth-wavelength line provides an additional travel of one-quarter wavelength in arm B—thus quadrature-phased signals are obtained.

Power is applied to arm D through a directional coupler (or other suitable isolating device). Magic-T action applies the input (arm D) equally to arms A and B, where virtually complete reflection occurs. The reflected signals are then returned to the crystal detectors in arms C and D. If the reflected signals in arms A and B are in phase, they will only propagate to arm D, whereas if the two signals are reflected out of phase, they will only propagate to arm C. The quadrature phase relationship, being halfway between in and out of phase, will cause equal propagation of the reflected signals through arms C and D. Thus the crystal detectors will receive equal signals. The crystal output circuit, which is connected to read the *difference* in crystal output, will indicate zero.

This zero-output condition will occur at the resonant frequency of the cavity, and also at frequencies far removed from resonance, because the cavity will appear essentially resistive for these conditions. However, in the region of resonance, the cavity will cause the phase of reflection in arm A to advance or retard, depending upon the sign of the reactance presented by the cavity. Thus, if a slight change of frequency causes the phase in arm A to retard, the reflected signals become more nearly in phase, causing the crystal in arm C to receive less signal, and the crystal in arm D to receive more signal. Since the output consists of the difference, the output of the arm-D crystal will predominate. A change in frequency in the opposite direction will cause a phase advance in arm A, and the output conditions will be reversed.

It can be seen that this circuit will act as a conventional discriminator, with the polarity of the output-voltage-versus-frequency curve being determined by the polarity of the crystal-detector connections. If the resonant cavity is made variable, the crossover frequency can be varied over fairly wide limits.

Aside from the more obvious applications, the microwave discriminator provides a very reliable source of frequency stabilization for klystron signal sources. This action can be accomplished by connecting a high-gain, stabilized, d-c amplifier between the klystron repeller and the discriminator output. A small portion of the klystron output is used to activate the discriminator. The circuit will tend to maintain the klystron frequency at the resonant frequency of the cavity. The degree of frequency-stability improvement is determined by the overall gain (or tightness) of the control system—this factor can be as high as 600 to 1 in present microwave circuits.

The use of the directional coupler as an isolating device means that a coupling loss of at least 20 db must occur. To overcome this loss, a second Magic T can be used as an isolating device, with a resultant overall coupling loss of only 6 db (3 db per T). A practical version of a double Magic-T microwave discriminator is shown in figure 10.

Power enters at arm A′ and is subjected to a 3-db loss by an equal division between arms C′ and D′ (the half entering arm C′ is dissipated in the load). The D′ arm is connected to the D arm of a Magic T similar to the one shown in figure 8. However, any signal reflected by discriminator action back into arm D, is coupled through arm D′ and suffers a second split between arms A′ and B′. The energy which enters arm B′ drives the second crystal detector. The two power splits represent an overall 6-db loss between input and crystal output. Since the arm-C crystal receives a signal 3 db higher than the arm-B′ crystal, in attenuator is inserted into arm C. If all circuit elements were perfect, this attenuator would be set for a 3-db loss—however, in practice, the attenuator would be adjusted for overall balance, and would tend to compensate for any other circuit inperfections.

BALANCED MODULATOR

The inherent properties of the Magic T can also be applied to the

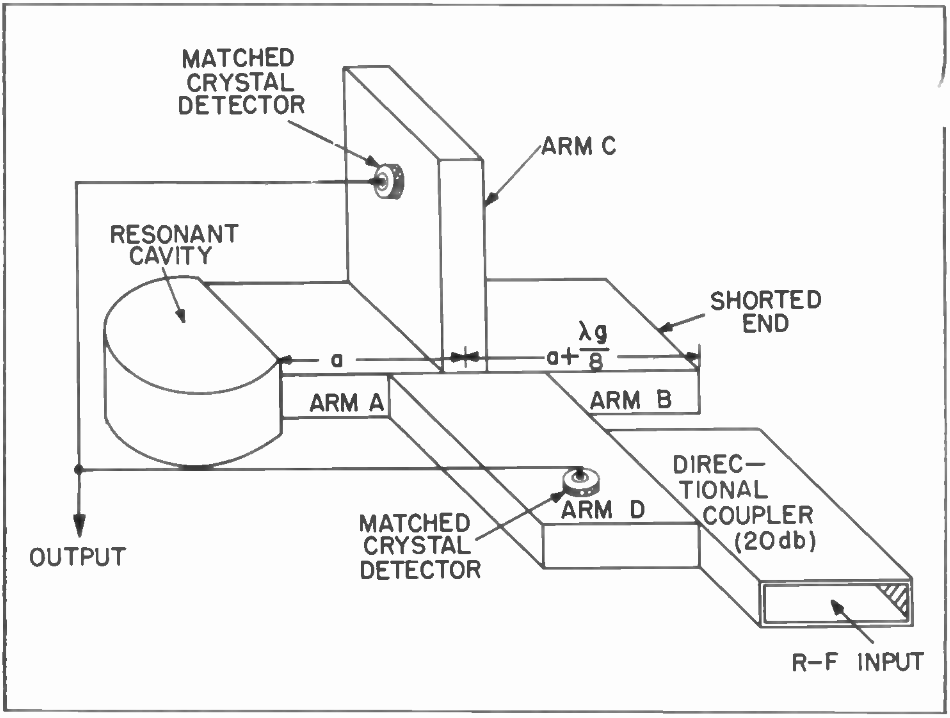

Figure 9. Magic-T Microwave Discriminator, with Directional-Coupler Input

balanced modulator, as shown in figure 11. The object of this circuit is to produce only the upper sidebands of a modulated signal. This application is very useful in measuring incremental frequencies. If F represents some microwave frequency, and f represents an accurately known increment, then the output of this circuit is at a frequency equal to F + f.

Since the oscillator F is coupled to arm C, and since the crystals match arms A and B, it is obvious that F will not appear at arm D. However, since F is fed simultaneously to both crystals along with the signal from oscillator f, each crystal will generate a sum frequency (F + f), and a difference frequency (F − f). These sideband signals will then be radiated by the crystals (which now act as generators) back toward the junction. As was discussed earlier, in-phase components from arms A and B will couple to arm D, while out-of-phase components will couple to arm C. The additional eighth wavelength of arm B and the 90° phase-shift element are inserted in such a manner that the upper sideband energy (F + f) couples to arm D, while the lower sideband energy (F − f) couples to arm C, where the matched input absorbs it. (The carrier, F, is absorbed by the crystals, and appears as crystal current.)

Thus the Magic T can also be used to produce single-sideband, suppressed-carrier signals. For example, suppose that F is a c-w transmitter in a c-w, MTI radar. By tuning f to the receiver i.f., a coherent local-oscillator signal would be produced.

THE RAT RACE

Thus far, only the conventional Magic T has been discussed—this

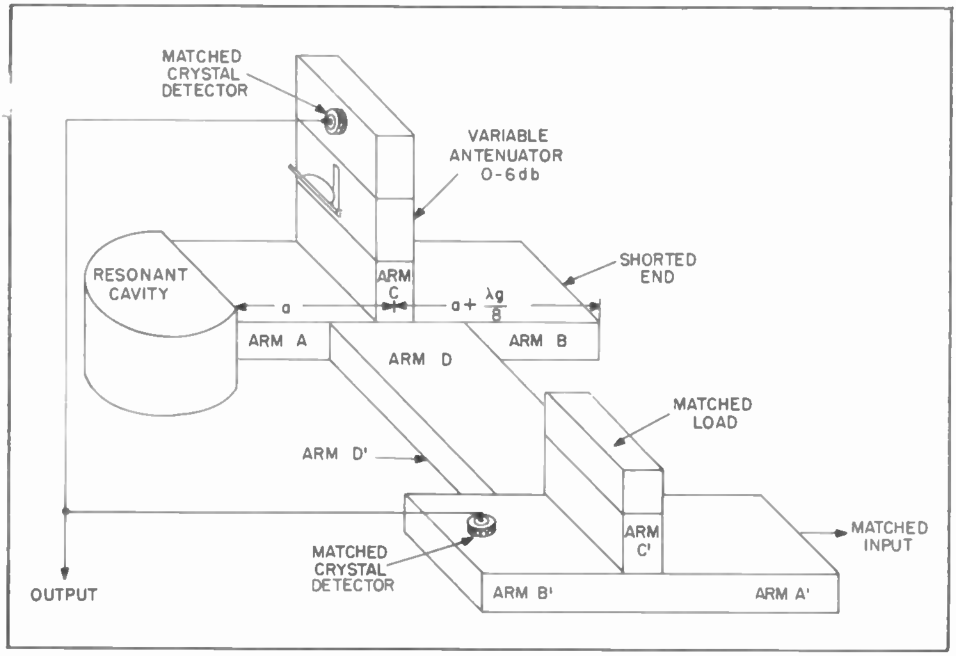

Figure 10. Double Magic-T Microwave Discriminator

does not mean that other forms do not exist. Actually there are a great many different types of the hybrid junction. Some are made up entirely of coaxial lines; others are made up of waveguides only; still others utilize both coaxial lines and waveguides.

A good example of an early form of hybrid junction is found in the "rat race" (the inference should be obvious from the drawing) shown in figure 12. The device shown is fairly simple, with the critical dimensions identified in terms of waveguide wavelength. The waveguide construction should be such that the narrow dimension of the side arms is about 40% greater than that of the ring itself. (This is because an equal power split will result in a voltage equal to 1/52 times the original voltage.) To show the method of analysis, only one entry will be considered. However each entry could easily be analyzed in a like fashion.

Incident power in arm A will divide equally between the two halves of the ring. Three possible exits are considered as follows:

1. Arm B will receive two energy components—one which has traveled one quarter wavelength, and the other which has traveled five quarter wavelengths. The difference is one full wavelength, which results in an in-phase condition, and propagation is possible.
2. Arm C will receive two components—one which has a path of two quarter wavelengths, and the other which has a path of four quarter wavelengths. The difference is one-half wavelength, which produces cancellation and prevents propagation in this arm.
3. The path lengths to arm D are the same and propagation to this arm can occur.

As was the case with the Magic T, input through one arm of the rat race results in propagation to only two other arms. However, in this instance, resonant lengths are used rather than

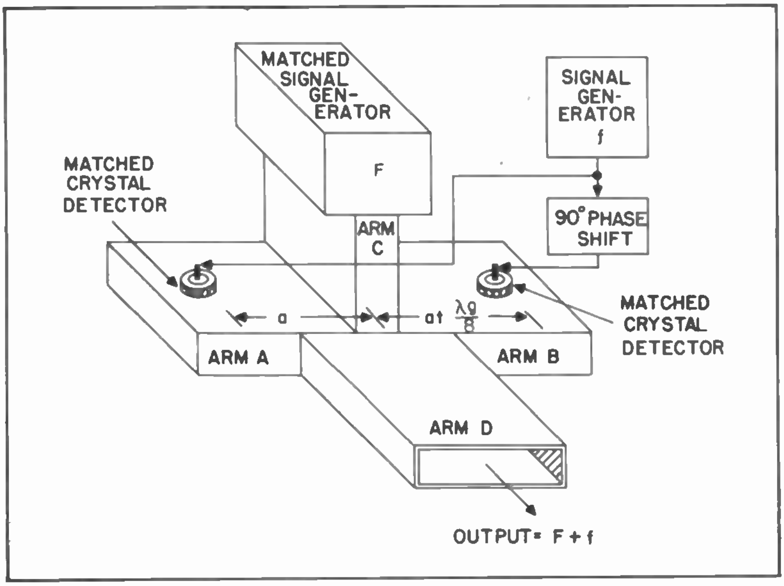

Figure 11. Magic-T Balanced Modulator Providing Single-Sideband, Suppressed-Carrier Output

cross polarization.

Since polarization is not involved, it is a simple matter to replace the waveguide sections of the rat race with equivalent lengths of coaxial line.

MAGIC-T BALANCED DUPLEXER

Figure 13 shows two Magic T's used in a balanced version of a radar duplexer. This duplexer has several advantages which are very desirable.

During transmission, the transmitter arm couples energy into legs A and B, thereby causing the TR tubes to fire. As a result, each TR presents a short circuit to transmitted energy which is then reflected back to the transmitter junction. Since the travel in leg A is two quarter wavelengths longer than the travel in leg B, the reflected signals arrive back at the transmitter junction out of phase, and are therefore coupled to the antenna arm (E junction). Since the overall lengths of legs A and B are the same, any leakage energy that arrives at the receiver junction will appear in phase, and will couple to the matched load where it is absorbed. Thus, the TR leakage energy is not coupled to the receiver, and greater crystal protection is afforded.

During reception, the antenna signal is coupled out of phase to legs A and B by virtue of the E-type T junction. Since legs A and B are equal in length, the two signals will arrive at the receiver junction out of phase, and will couple only to the receiver arm. No energy is coupled from the

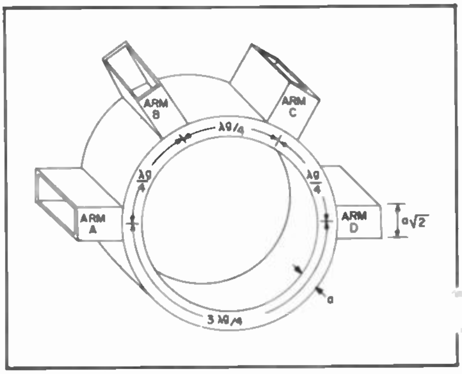

Figure 12. The Rat Race

antenna to the transmitter—thus no ATR assembly is needed.

This arrangement provides a high degree of crystal-mixer protection, but this factor cannot be used to reduce TR requirements because complete cancellation could only occur in the event of identical TR boxes and perfect symmetry (a case rarely met in practice). However, crystal burnout from TR leakage would be rare in such a duplexer.

CONCLUSION

The selective properties of the Magic T are as useful as they are fascinating. This article has presented a few of the many possible applications, but the future will no doubt bring to light many more such applications, and further improvement of the device will result in much wider field use.

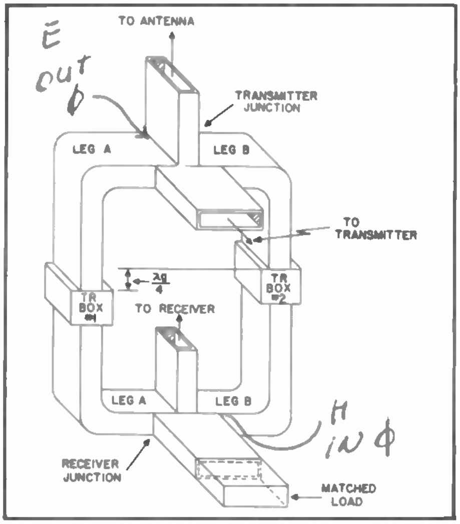

Figure 13. Magic-T Balanced Duplexer

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In Coming Issues

If you've ever found difficulty in explaining why the plate tank of a t-p-t-g oscillator should be tuned slightly inductive, or why triodes don't make good wideband video amplifiers, then a new article by Gail W. Woodward, titled "The Miller Effect," will be of great interest to you. Many other aspects of the subject are also covered in the article, including a number of circuits in which the Miller effect is used to advantage.

John W. Adams has written another BULLETIN article too—this one the first of a series on multiplex theory and techniques. The series will ultimately embrace all currently known practical methods of creating and separating composited signals.

RADAR INTERPRETATION IN THE NORTHLAND

By Bud Compton

Philco Field Engineer

A discussion of the effects of arctic weather conditions upon X-Band radar reflections.

Editor's Note: The author has spent 28 months in Alaska, and has travelled most of the northern territory including the north pole. Spare time "bush" flights have augmented duty with the 58th Recon. Sqdn., in the arctic. All "scope" photos are by courtesy of the 58th Strategic Reconnaissance Sq. (M) Wea.

Throbbing engines and whistling jets are heard in increasing numbers in the north country, and radar eyes are accomplishing a navigational need demanded by operations over vast trackless expanses. The remoteness of operations is attested by 24-hour operation of CAA rotating beacon lights at such places as Bettles, Alaska.

When the intrepid bush pilot pushes the nose of his small craft into the winter arctic, the flight level is at about 100 feet, and even this low altitude permits only a vague sight of tundra or ice. Everything seems to be swallowed in a dimensionless bottle of milk. Faster, long-range aircraft must fly at a much higher altitude, and therefore must depend heavily upon radar to "see" through the shrouded arctic twilight.

Radar observers, unfamiliar with arctic operations, find several departures from their past experiences. Seasonal changes send the mercury from as low as minus 80° to plus 90° (F). It is easy to appreciate how this will affect the electrical properties (as well as the mechanical texture) of reflecting terrain. The radar-scope shots in figures 1 and 2 illustrate the difference between summer and spring reflection characteristics around the Point Barrow area. During winter, the ice pack makes a shore line indistinguishable,

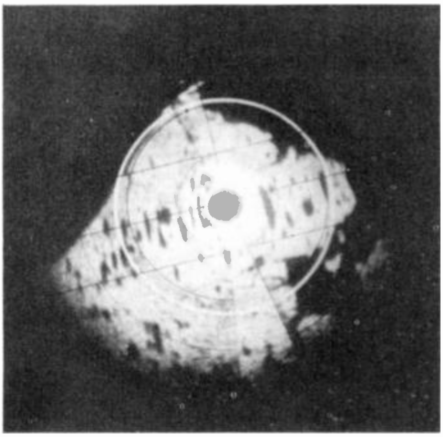

Figure 1. Scattered Unfrozen Lakes Around the Point Barrow Area

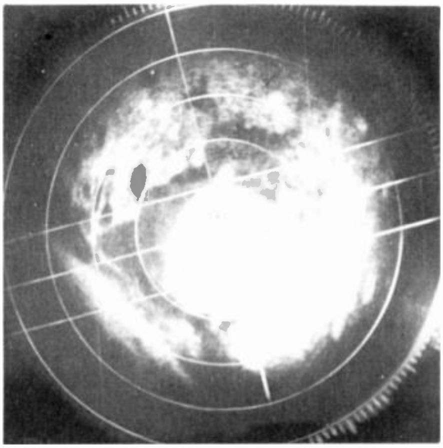

Figure 2. Scattered Frozen Lakes Around the Point Barrow Area

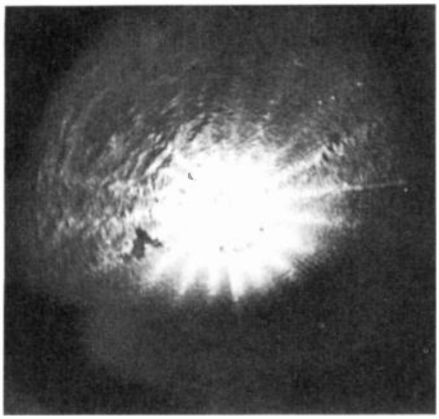

Figure 3. Lake Minchumina, Frozen (11 December 1950)

and some lakes paint bright while others remain dark. Surface texture accounts for the difference. If wind causes the ice to freeze rough, enough reflection returns to the radar to cause the lake to paint bright—but where a lake is protected from wind during freeze-up (such as Lake Minchumina, in figure 3), a smooth ice cover is produced, and the lake continues to paint dark. There are also a few confusion factors tossed in. Figure 4 shows how a sand area, which paints dark throughout the year, could easily be misinterpreted as a lake. Experience and familiarity are a must for reliable scope interpretation.

Table I indicates nominal values of conductivity and relative permittivity.[*]

The absorption index of ice at freezing is approximately ten times greater than at minus 50° C.

Not only do the larger bodies of water manifest seasonal variations, but rivers are also affected. Large, broad-valley rivers, such as the Yukon, display changes similar to those of lakes (where surface roughness is the main factor). Mountain rivers are

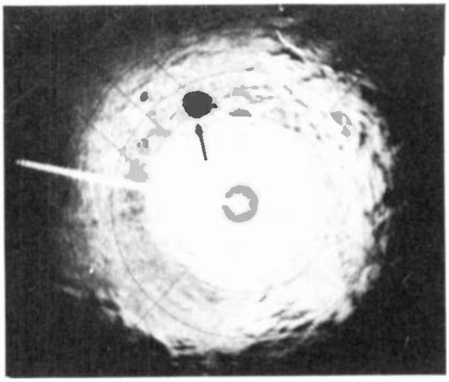

Figure 4. Sand Area

Table I. Relative Conductivity and Permittivity of Various Types of Terrain

Material	Conductivity mhos/meter	Relative Permittivity (dielectric constant)
Sea Water	3 to 5	80
Lake Water	10^{-2} to 10^{-3}	80
Wet Earth	10^{-2} to 10^{-3}	5 to 15
Dry Earth	10^{-4} to 10^{-5}	2 to 5
Glass	10^{-12}	5 to 10
Ice at 0°C.	8×10^{-4}	3
Ice at −40°C.	10^{-4}	3
Wood (dry)	6×10^{-5}	1.75 to 2.05

[*] **References:** ***Theory and Application of Microwaves*, Bronwell and Beam; New York: McGraw-Hill Book Company, Inc., 1947.**
***Radio Wave Propagation*, Burrows and Attwood; Consolidated Technical Report of the Committee on Propagation of the N.D.R.C.; New York: Academic Press, Inc., 1949.**

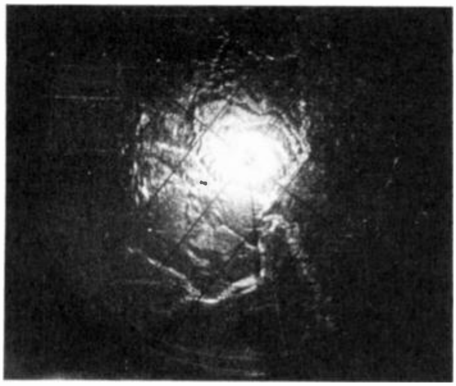

Figure 5. Colville River Area in Winter (16 February 1952)

further modified by changing run-off volume. Furthermore, river-bed and bank conditions are important because of water-depth changes. A fast-running stream is very likely to freeze rough so that it paints bright when frozen. (See figure 5.)

The question of how winter's snow blanket affects radar detection has often been raised. In actual tests conducted by the author with X-Band radar, negligible attenuation was found to be caused by cold, loosely packed snow. Only when the snow is wet and packed does it produce significant effects. In the arctic, this means that snow coverage will be of concern to the radar observer for only a few weeks during spring.

Varying in thickness from generally four to twelve feet, the polar ice pack is steadily moving, opening, cracking, and breaking. These varying surface conditions provide a radar picture that sometimes resembles a surface having rivers, lakes, and mixed objects. The famous exploitation of ice island "T-3"[*] would have been practically impossible without radar. Only occasionally do airborne observers see the ice pack. Even then, atmospheric haze, angle of the sun, and altitude of the aircraft make it extremely difficult to identify specific formations such as the ice islands. However, with radar, these formations are clearly outlined, as can be seen in the scope photo of "T-3," figure 6. By using "Doppler Drift" with radar, or by time-tracking a point of high contrast across the scope, the aircraft's drift and ground speed are readily determined. With this knowledge, the navigator can not only breathe easier, but can also direct his flight more accurately.

With meager printed information, and with many erroneous ideas extant, radar use in the arctic continues to be fascinating for those who desire to pioneer and conquer.

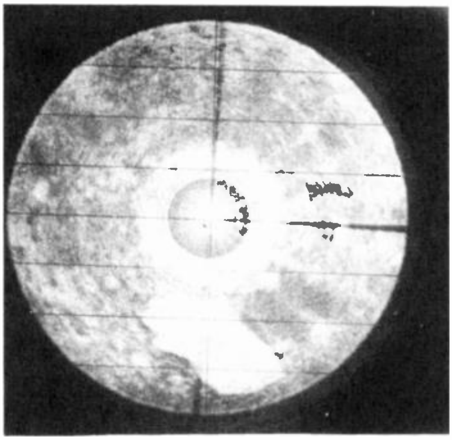

Figure 6. Famous Ice Island T-3 (4 December 1950)

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[*] Col. Joseph O. Fletcher and Major Lawrence S. Koening, "Floating Ice Islands," SPL Report No. 5, 15 Sept. 1951.

A RADAR INTERFERENCE BLANKER

By BULLETIN Staff

A radar interference blanker which solves the problem of blanking without the necessity for a connection to the offending radar.

(Editor's Note: This novel interference blanker was designed and built by Philco Field Engineer Cleve G. Cleveland. The results were so encouraging that we are publishing this article in the hope that more field engineers will try the circuit, and that constructive improvement of the basic idea will be forthcoming.).

When two or more radar sets operate in the same frequency band, and in the same general locality, mutual interference becomes a problem which increases in complexity with the number of radars. The problem is further complicated when the radars are separated sufficiently to make it impracticable to interconnect each radar to the other. (This is a requirement of standard blankers.)

The interference blanker to be described has a basic feature of requiring no interconnection between radars. However, the principle used requires the fulfillment of two basic conditions, both of which are generally likely; these conditions are:

(1) That the interfering radar is not operating at exactly the same frequency as the radar being affected.

(2) That no more than two other radars are close enough to the operating frequency to cause interference.

To illustrate, assume an operating frequency of 1000 mc., and a nearby radar operating at 1001 mc. The 1-mc. separation is not sufficient to prevent interference because the selectivity of modern radar circuits is not sharp enough to discriminate between such signals. If the radar uses a 30-mc.

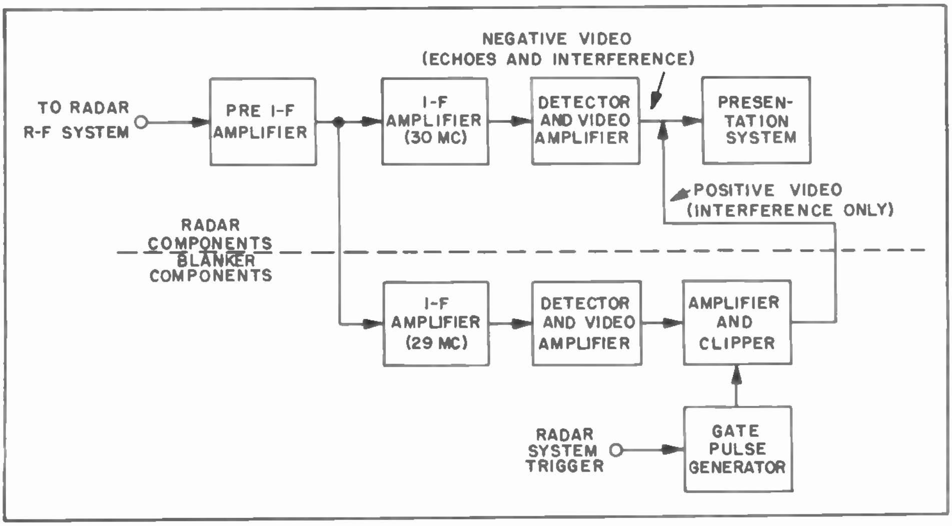


Figure 1. Simplified Block Diagram of Blanking System

intermediate frequency, the interfering signal will cause the production of either a 29-mc. or 31-mc. i.f.

Figure 1 shows a simplified block diagram of the blanker circuit (the upper half of the figure shows the conventional radar components). Since the pre-i.f. amplifier of the radar is relatively broadbanded, there is little discrimination between 29-mc., 30-mc., or 31-mc. signals at the i.f.-amplifier input. An added i-f amplifier, tuned to either 29 mc. or 31 mc., provides the blanking-signal path. The amplifier should have a bandwidth of from 0.5 mc. to 1 mc., at the half-power points. It can be seen that the blanking circuit will pass the interfering signals more readily than it will pass regular echo signals. Thus, the video amplifier output of the blanker will contain high-amplitude interference signals and low-amplitude echo signals.

The amplifier-and-clipper section is designed to pass only high-amplitude signals and to clip any low-amplitude signals. Therefore, the output of the blanking section contains only the interfering pulses.

The polarity of the output of the blanking section is designed to be opposite to that of the radar video output. If the blanking output is equal in amplitude to the amplitude of the interference in the radar at the point of connection, the two signals will cancel. However, since the normal echos are eliminated from the blanker portion of the circuit, no cancellation of echos will occur.

The gate-pulse generator acts to prevent the blanker from functioning

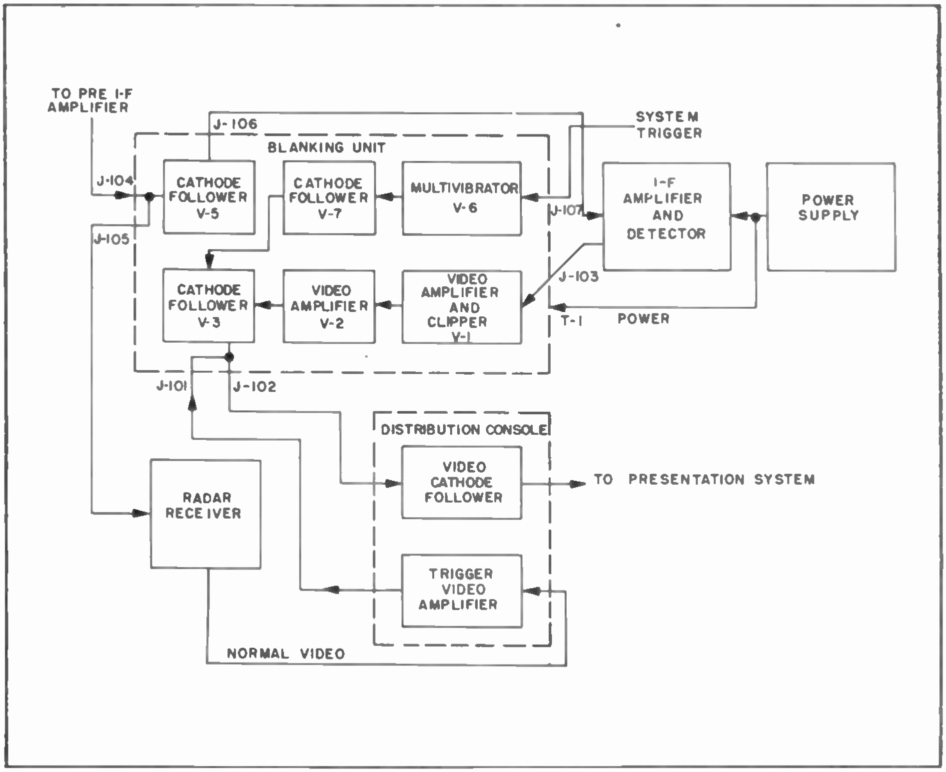


Figure 2. Detailed Block Diagram of Interference Blanker

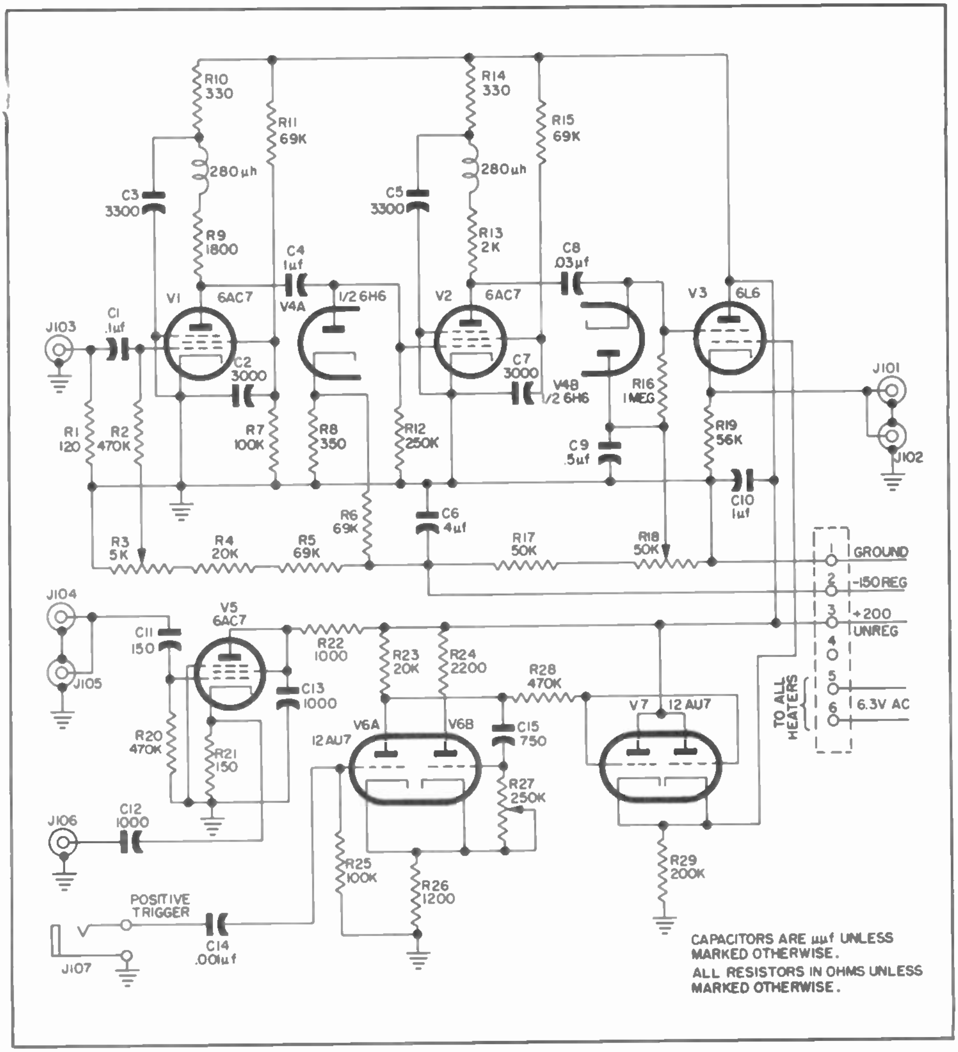


Figure 3. Schematic Diagram of Blanker Circuits Used in Original Model

during the main bang of the local transmitter.

Figure 2 show a detailed block diagram of the interference blanker designed by Mr. Cleveland. The signal which is normally fed to the radar receiver is also fed to an isolating cathode follower, V_5, which provides i-f signal to the blanker i-f section. The output from the blanker i-f section is fed to a two-stage video amplifier, one section of which is biased so as to clip all but strong signals. (The strong signals, in this case, are produced by the interfering signals because the blanker i-f section is tuned to accept the interference.) Thus, the output of V_2 will contain only interfering signals. V_3, a cathode follower, acts as an impedance-matching device, and allows the interfering signals to be fed into the radar video section at the proper level.

It was found that if cancellation of the local-transmitter main bang were attempted, the blanker output would contain excessive jitter. This effect is eliminated by the inclusion of a suppression pulse that prevents blanker action during the main bang. The suppression pulse is generated by V_6 upon application of the system trigger. V_6 produces a negative output pulse which is applied to the screen grid of V_3 by way of V_7 (an isolating cathode follower).

V_4 is a dual clipper which established the proper reference bias for V_2 and V_3, regardless of signal amplitude.

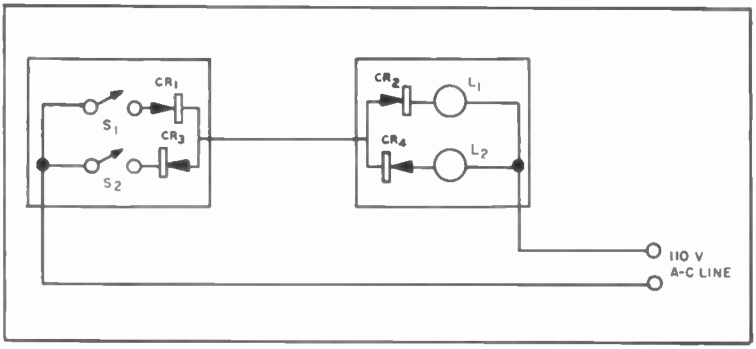
Figure 3 shows the schematic of the special blanker circuits used in the original model. It was found that a considerable reduction of the interfering signal was possible, and it appears that the system has merit.

Solution to . . .

Last Month's "What's Your Answer?"

Two selenium rectifiers are added to each box as shown. Thus, S_1 will light L_1 through CR_1 and CR_2, while S_2 will light L_2 through CR_3 and CR_4.

Of course, there are more complex solutions involving vacuum tubes, relays, etc., but we feel that this is the simplest solution.



PHYSICAL CONSTANTS FOR TELEVISION WIDE-BAND ANTENNAS

By John Carnuccio

Headquarters Technical Staff

A practical discussion of the characteristics of various types of TV antennas, with emphasis on element configuration, dimensions, and spacing.

To cover all VHF television channels, it is recommended that a low-frequency antenna be used for the low channels, and that a separate high-frequency antenna be used for the high-frequency channels. The formula $\lambda/4 = 234/f$ (mc.) can be used to calculate the length in feet of the $\lambda/4$ section of an antenna when the center frequency of a channel is used. Table I gives the actual lengths needed for the quarter-wavelength elements (figure 1). The dimensions for the low-band and high-band antennas are given in the last two columns. (The number 234 takes into account 5% for end effect.)

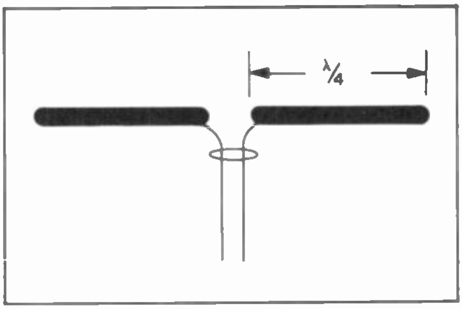


Figure 1. Dipole Antenna

MATCHED SINGLE DIPOLE

The following data is based on the standard television-receiver input impedance of 300 ohms and a single dipole impedance of 73 ohms. The dipole can be effectively matched to the impedance of the line by means of a Q-Bar matching section, as shown in figure 2. The Q-Bar consists of a quarter-wavelength section of 150-ohm line.

A properly matched dipole has a higher "Q" than one which is not matched, and therefore has a narrower bandwidth; thus it will operate best on one channel. The response to adjacent channels can be improved, however, by using large diameter elements (at least ½ inch in diameter). In regions of low signal strength or high noise, it is advisable to match the line both to the dipole and to the receiver input. The dimensions of the matching section are given in Table II. $D = 245/f$ (mc.) is the formula used to find the length of

Table I. Dimensions of Single-Dipole Antenna

TV CHANNEL	2	3	4	5	6	7	8	9	10	11	12	13	LO	HI
CENTER FREQ.	57	63	69	79	85	177	183	189	195	201	207	213	66	195
LENGTH OF $\lambda/4$ ELEMENT (Ft.)	4.1	3.6	3.4	3.0	2.8	1.32	1.28	1.24	1.2	1.16	1.13	1.1	3.5	1.2

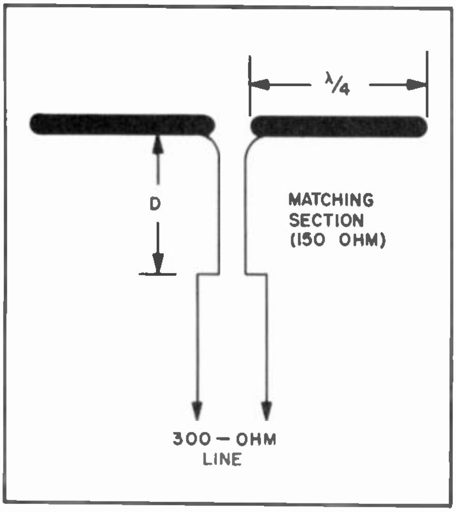


Figure 2. Dipole Antenna with Q-Bar Matching Section

the matching section in feet.

FOLDED DIPOLE

The bandwidth of an antenna system can be increased, without changing its sensitivity, by increasing the resistive component of its impedance. (The increase in antenna resistance decreases the "Q" of the dipole.) The increase in resistance can be obtained by folding a full wavelength into a dipole as shown in figure 3. The spacing should be 1/64 of a wavelength or less. The resistance of such an antenna is approximately four times that of a single dipole, and therefore matches a 300-ohm line. The dimensions for a folded-dipole antenna for each of the different channels, as well as those for a low-band antenna and for a high-band antenna, are given in Table III. The two parts of the folded dipole can be made from tubing of different diameters. Decreasing the diameter of the fed element, i.e., the dipole part, increases the resistance and the bandwidth. Increasing the diameter of the fed element decreases the antenna resistance and bandwidth.

Table II. Dimensions of Q-Bar Matching Section for Coupling 73-Ohm Antenna to 300-Ohm Transmission Line (K refers to propagation constant of line used.)

CHANNEL	LENGTH OF SECTION
2	5.3K
3	4.3K
4	3.9K
5	3.56K
6	2.94K
7	1.98K
8	1.92K
9	1.86K
10	1.8K
11	1.74K
12	1.7K
13	1.65K

SPECIAL FOLDED DIPOLES

For temporary installations or experimental work, the folded dipole illustrated in figure 4 can be used. It is constructed from 300-ohm twin lead, and is a half wavelength long. However, since the 300-ohm line usually has a propagation constant (K) of about 86%, each end of the dipole is shortened an equal amount by joining the two wires on each half of the dipole at points 7% of a half wavelength from the end. The dipole in figure 5 is constructed of three half-wave elements, and has nine times

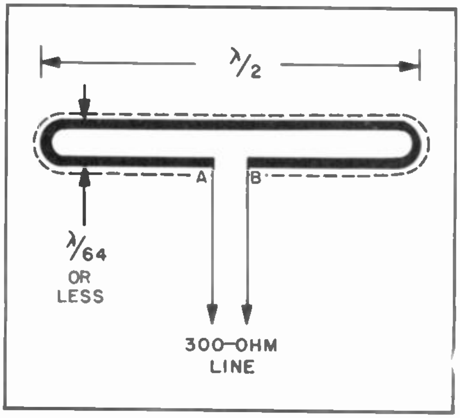


Figure 3. Folded-Dipole Antenna

Table III. Dimensions of Folded-Dipole Antenna for Various Channels (See figure 3)

CHANNEL	2	3	4	5	6	7	8	9	10	11	12	13	LO	HI
λ IN FT. (A TO B)	16.4	14.4	13.6	12.0	11.2	5.28	5.12	4.96	4.8	4.64	4.52	4.4	14.4	4.8
$\lambda/64$ IN FT.	.54	.5	.45	.4	.36	.18	.17	.165	.16	.155	.15	.145	.47	.16
$\lambda/2$ IN FT.	8.2	7.2	6.8	6.0	5.6	2.64	2.56	2.48	2.4	2.32	2.26	2.2	7.2	2.4

the impedance of a single dipole. It is characterized by low Q and wide bandwidth.

FOLDED DIPOLE WITH DIRECTOR AND REFLECTOR

The gain and horizontal directivity of a TV antenna can be improved by the use of directors and reflectors, as shown in figure 6. This procedure will also reduce noise pickup and ghosts. The reflector is located about a quarter wavelength behind the main dipole, and is made 5% longer than the dipole element. The director is positioned a quarter wavelength ahead of the dipole element, and is 4% shorter than the driven element. The use of a director and reflector with a simple dipole is not recom-

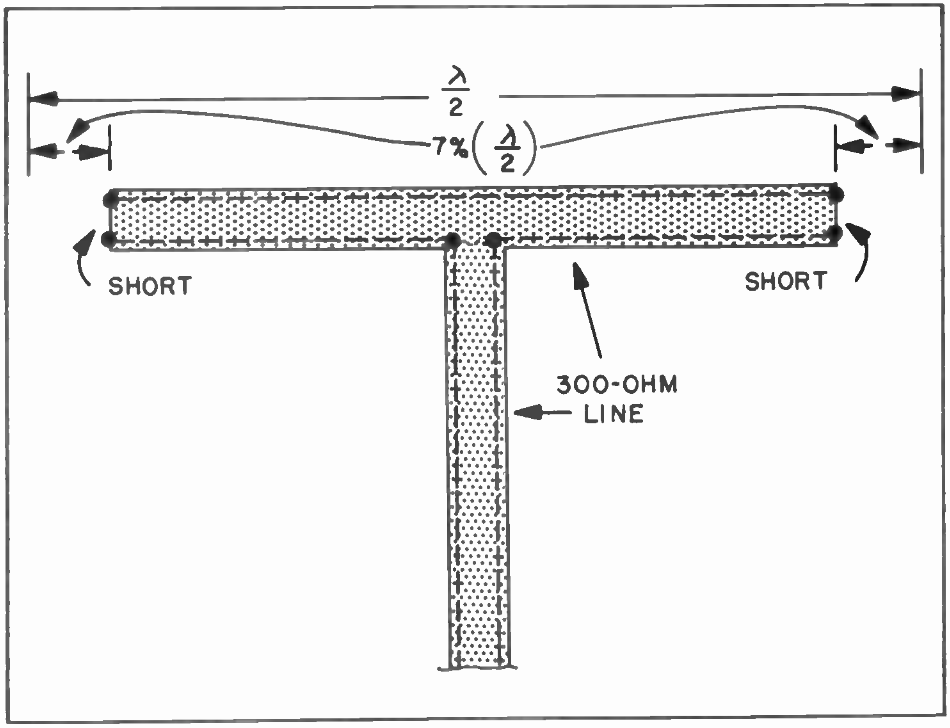


Figure 4. Construction of Folded-Dipole Antenna using 300-Ohm Ribbon Line

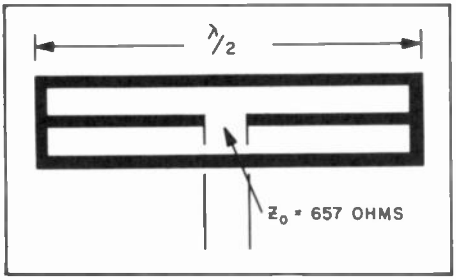


Figure 5. Folded-Dipole Antenna using Three Half-Wavelength Elements

mended because of the resulting reduction in bandwidth. For television requirements, it is best to employ a folded dipole with director and reflector. The dimensions for this type of antenna for each of the different channels, and for the low band and the high band are given in Table IV. A director or reflector spaced a quarter wavelength behind or ahead, respectively, of the dipole (or folded dipole) will cause the antenna resistance to decrease approximately 10% to 20%. Since this effect is not great, the antenna will still match the transmission-line impedance. If the director or the reflector is moved closer to the dipole than a quarter wavelength, the antenna gain will rise somewhat, but the antenna resistance (and therefore the bandwidth) will decrease considerably. A simple dipole with closely spaced parasitic elements will have an excessively narrow bandwidth for TV use.

A folded dipole, with its greater resistance and lower "Q," could be used with closely spaced parasitic elements, and would give wideband characteristics. Moving the director or reflector closer to the dipole than a quarter wavelength will decrease the antenna impedance, and therefore a transmission line of lower impedance must be used to match the antenna. The director spacing in most modern antennas is .15 wavelength instead of a quarter wavelength. Addition of a parasitic element spaced .15 wavelength from the dipole cuts the antenna impedance to one-half of its previous value; thus, the line must have that impedance. Notice

Table IV. Dimensions for Folded-Dipole Antenna with Reflector and Director (See figure 6)

CHANNEL	2	3	4	5	6	7	8	9	10	11	12	13	LO	HI
FOLDED DIPOLE LENGTH IN FEET (A TO B) = 936/f (mc.)	16.4	14.4	13.6	12.0	11.2	5.28	5.12	4.96	4.8	4.64	4.52	4.4	14.0	4.8
REFLECTOR LENGTH IN FEET = 492/f (mc.)	8.5	7.8	7.1	6.2	5.8	2.78	2.69	2.6	2.52	2.45	2.37	2.31	7.5	2.52
DIRECTOR LENGTH IN FEET = 450/f (mc.)	7.9	7.1	6.5	5.7	5.3	2.54	2.46	2.38	2.31	2.23	2.17	2.11	6.8	2.31
λ/4 SPACING IN FEET = 246/f (mc.)	4.3	3.9	3.56	3.15	2.94	1.98	1.92	1.86	1.8	1.74	1.7	1.65	3.72	1.8

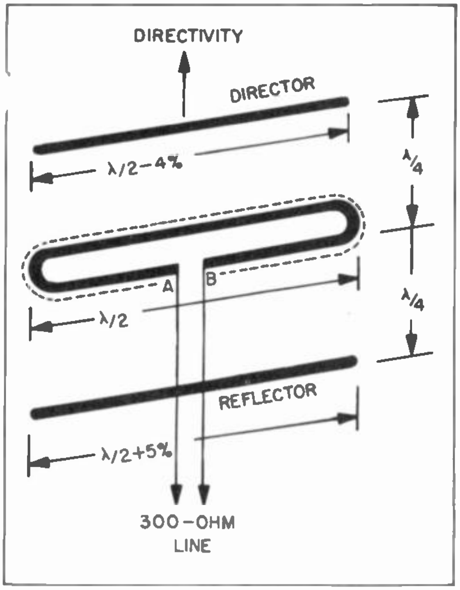


Figure 6. Folded Dipole with Director and Reflector

that the antenna impedance and the transmission-line impedance required can be varied by changing the spacing of the parasitic element.

STACKED ARRAYS

A stacked array can be used to increase antenna sensitivity to signals which arrive at low vertical angles. The use of a director or reflector concentrates the antenna sensitivity in one horizontal direction, and reduces noise pickup from the rear and from both sides. A stacked system will reduce noise pickup from top and bottom, and will thus improve antenna sensitivity in the desired direction. Such stacked arrays are valuable when the receiver is located a great distance from the television transmitter.

Figure 7 shows a stacked system which is composed of two dipole elements spaced a half wavelength vertically, and connected in phase. A signal arriving from the proper direction will induce in-phase voltages in the dipoles, which add in the transmission line. Noise signals arriving from top or bottom induce out-of-phase voltages which cancel at the transmission line. The increase in signal-to-noise ratio results in improved picture reception.

STACKED DIPOLES WITH TRANSPOSED FEED

In the transposed feeder system shown in figure 8, the signal from the top dipole appears, in phase, at the bottom element, where the transmission line is connected. The in-phase condition is produced by the combined action of the transposition and the half-wave line section. For this reason, the spacing is critical, and must be exactly one-half wavelength. Therefore, this method will supply in-phase voltages only over a very narrow band of frequencies. However, it can be used over several channels provided that the losses on adjacent channels can be tolerated. The antenna impedance is half that of the single dipole, or about 37 ohms.

STACKED FOLDED DIPOLES WITH PARASITIC ELEMENTS

Addition of a reflector and/or a director will increase the horizontal directivity of the antenna, and stacking two folded dipoles with parasitic elements will increase the vertical

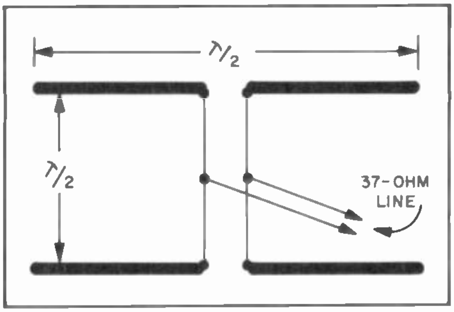


Figure 7. Stacked Dipoles with Center Feed

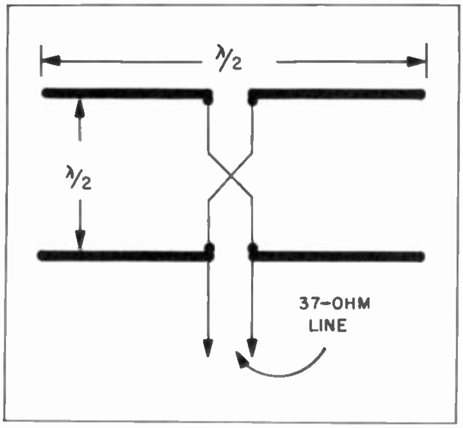


Figure 8. Stacked Dipoles with Transposed Feed

directivity. It should be remembered, however, that stacking two antennas will cut down the antenna impedance to half the value of one of the antennas. The stacked folded dipole (figure 9), shown with reflectors, will match a 150-ohm line. If the receiver has a 300-ohm input only, always use a 300-ohm line and let the mismatch occur at the antenna where it will do the least damage. Table V gives the length of the reflectors, each of which is spaced one-quarter wavelength from the corresponding folded dipole, and one-half wavelength from each other.

Table V. Length of Reflector Elements for Antenna Illustrated in Figure 9

CHANNEL	LENGTH OF REFLECTOR (FT.)
2	8.5
3	7.8
4	7.1
5	6.2
6	5.8
7	2.78
8	2.69
9	2.6
10	2.52
11	2.45
12	2.37
13	2.31
LO	7.5
HI	2.52

THE FANNED ANTENNA

The fanned antenna illustrated in figure 10 is a full wavelength long, and requires a large amount of space;

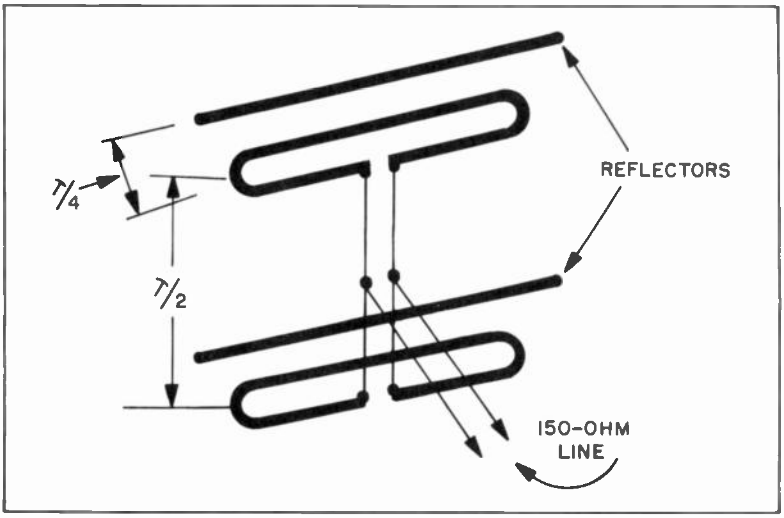


Figure 9. Stacked Folded Dipoles with Reflectors

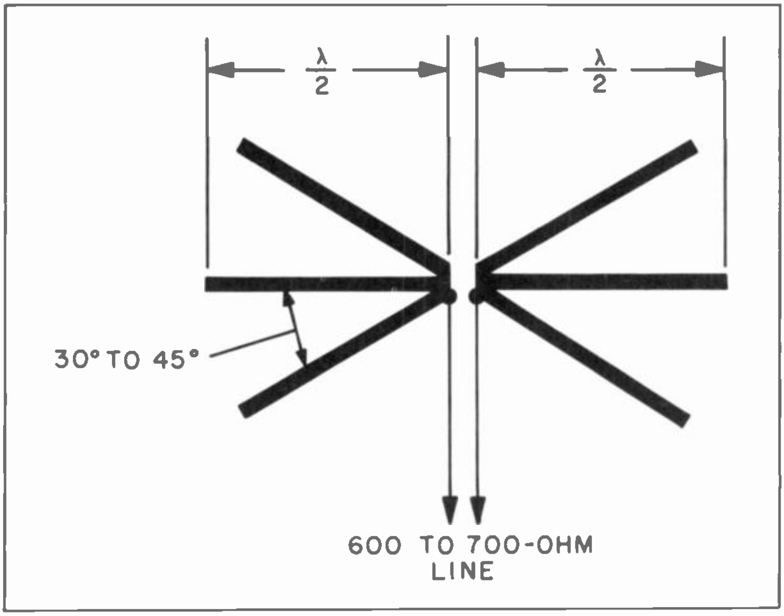


Figure 10. Fanned Antenna

however, it has high resistance and exceptional bandwidth characteristics. The simple fanned antenna consists of three half-wavelength rods on each side of the center-feed point. The rods are spaced from 30° to 45° from each other. Since the full-wave antenna is center-fed, it is fed at a high-impedance point (usually around 600 to 700 ohms). Two of these stacked in an array would provide high gain and an effective impedance of 300 ohms which would match the usual receiver input. The fans are mounted in a vertical plane, and to increase the horizontal gain, a set of reflectors can be mounted in back or a set of directors in front. Such a fanned antenna, cut for the center of the low-band channels, will present a good match over the entire set of low-band channels, while a shorter fanned antenna will provide reception over the high-band TV channels.

CONICAL ANTENNAS

The conical antenna, shown in figure 11, is one of the most effective broadband antennas for TV use. It has a high resistance and a linear response over a wide band of frequencies. The length of each side is made 0.365 wavelength. An important advantage of the conical antenna is that it can be made to match any line impedance by properly choosing the angle of revolution. As the angle of revolution is varied, the impedance of the antenna varies. To match a 300-ohm line, the angle of revolution should be 15 degrees, as shown in figure 11. The length of each element for low-band channels is 5.4 ft., while for the high-band channels, each element should be 1.84 ft., as calculated by the formula: $L = 359/f$ (mc.). The optimum dimension for such an antenna cut for operation on all TV channels is 2.76 ft.

The conical antenna can be constructed from sheet metal, copper screening, or about 12 lengths of #14 wire spaced equidistantly. The antenna is lighter when constructed of

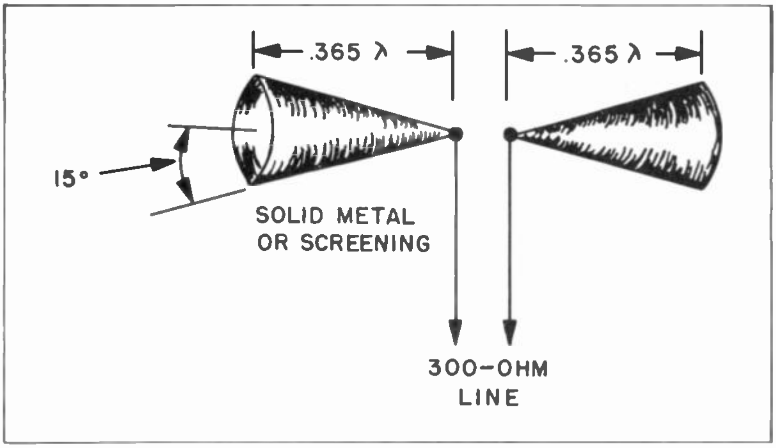


Figure 11. Conical Antenna

screening rather than sheet metal.

LONG-WIRE AND RHOMBIC ANTENNAS

A long-wire (or aperiodic) antenna, as shown in figure 12, is not critical in length, provided it is several wavelengths long. Long-wire antennas can be highly directional, with the directivity increasing with the number of wavelengths. A single long wire is highly directional off its end if it is 10 wavelengths in length or more. (The tilt angle becomes smaller as the number of wavelengths increases.) This too is a high-impedance line and must match a high-input-impedance receiver. For television purposes, the most common long-wire antennas are the rhombic and the V antenna. The V antenna (figure 13) is made of two lengths of wire, fed at the apex of the V. Maximum directivity is in a line passing through the center of the V. It is bidirectional unless terminated at the open end.

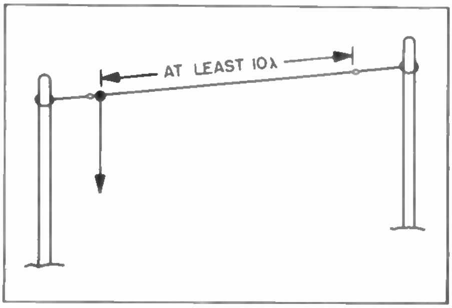


Figure 12. Long-Wire Antenna

A rhombic antenna (figure 14A) is formed by extending the V into a diamond-shaped antenna. The rhombic has greater horizontal directivity and a lower vertical angle, but requires more space. Like the V antenna, it is bidirectional when it is not terminated. It can be made unidirectional by terminating the end with an 800-ohm, noninductive resistor, as shown in figure 14B. Since the input impedance of the rhombic antenna is about 800 ohms, it requires an 800-ohm line, or it can be used with a 300-ohm line with the proper matching section. Since the rhombic and V antennas are sharply directional, they must be laid out with a compass before construction. The angle between antenna legs is important, and must be carefully established. Tilt angle (figure 14C) is the angle between the antenna wire and the direction of wave propagation. For satisfactory television service, this tilt angle is best con-

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Upon receiving his discharge in May, 1946, he entered the Radio and Television Institute, in Philadelphia. This was followed by a three-year course at the American Television Institute of Technology, in Chicago, from which he received the degree of Bachelor of Science in Television Engineering, in November, 1949.

Returning to Philadelphia, he acquired practical experience doing radio and television service work for City Television Company, of Camden, N. J. He joined Philco in September, 1950, in the Research Department of the Lansdale Tube Company, Lansdale, Pa., where he engaged in the design and construction of circuits for the testing of transmitting and receiving tubes. He transferred to the TechRep Division in June, 1951, to serve as an instructor in the Navy Television Training Course, and since completion of that course has been assigned to the training of Philco Field Engineers, on heavy ground radar.

structed by making the length of each antenna leg a half wavelength longer than a line which starts at the apex and is stepped off toward the station to a point (P) where a right-angle line will meet the other ends of the antenna legs (see figure 15). Therefore, the longer each leg of the antenna is in wavelengths, the smaller the tilt angle.

The long-wire antennas have exceptional bandwidth, and a single antenna will function on all television channels if it is made at least three wavelengths per leg, at the lowest channel frequency. However, rhombic antennas do require considerable space. They are used principally for long-range reception, and for television-relay systems.

CONSTRUCTION OF A RHOMBIC

In the construction of a rhombic, the first step is to estimate how many wavelengths per leg can be erected in the allotted space. The more wavelengths that can be used, the sharper and more sensitive the antenna will be. Next, lay off a string line from the receiver end to the end in the direction of the station. If it has been decided to use 5 wavelengths per

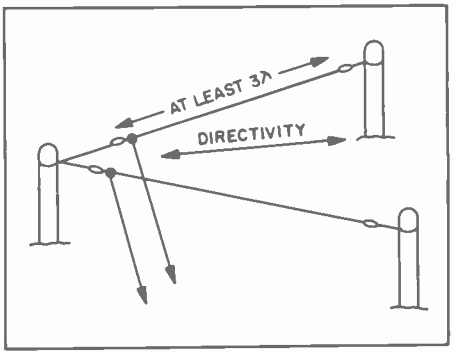


Figure 13. V Antenna

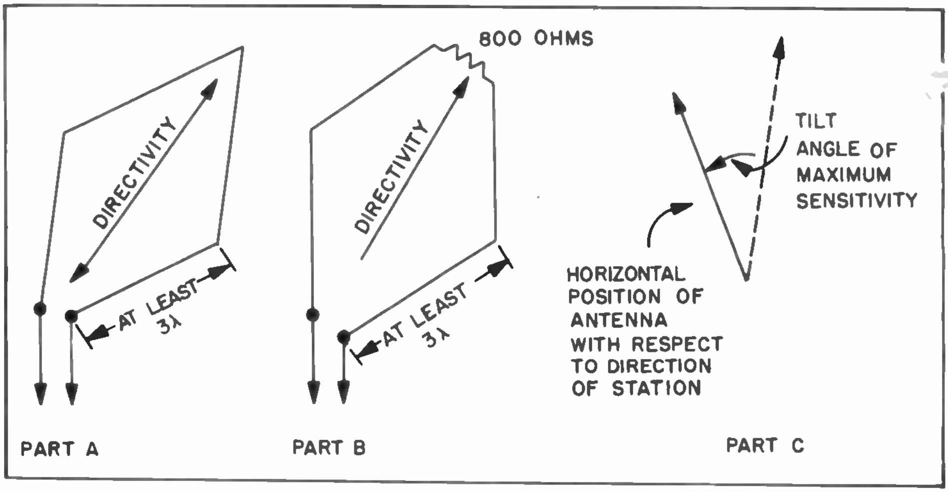


Figure 14. A—Bidirectional Rhombic Antenna
B—Unidirectional Rhombic Antenna (Terminated)
C—Tilt-Angle of Rhombic Antenna

side, step off 4½ wavelengths along the line in the direction of the station. At the 4½ wavelengths point (the center of the rhombic), lay out a line perpendicular to the string line. The proper tilt angle is established when the free end of a 5-wavelength section of line attached to the receiver end coincides with this perpendicular. Two points on the diamond have now been located. A similar procedure can be used to locate the third point. The fourth point is another 4½ wavelengths down the station-direction line from the point at which the perpendicular crosses the station-direction line.

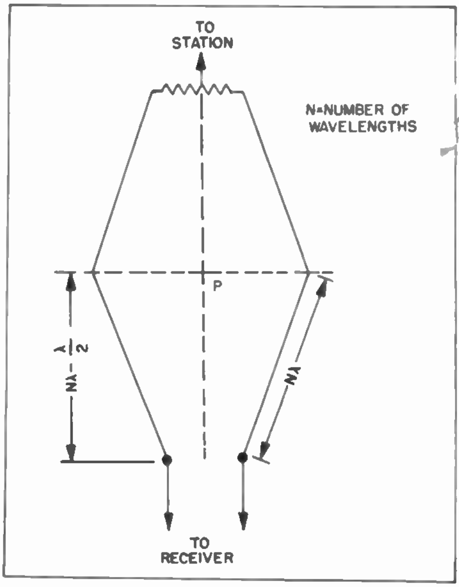


Figure 15. Dimensions of Rhombic Antenna for Proper Tilt Angle

ERRATUM

April issue, page 7—Equation 10 should read:

$$C_c = \frac{R_{G\ out}(C_{g\text{-}k})}{R_{C\ out}}$$

TESTING 2C39 TUBES FOR USE IN THE TDZ TRANSMITTER

It is highly desirable that a means of testing 2C39 tubes be made available at all installations using the TDZ transmitter, because carefully matched tubes allow greatly increased power output adjustments without danger of exceeding the grid or cathode currents recommended in C.E.M.B.'s. Furthermore, it is believed that much longer tube life can be expected with matched tubes. Although no exact record of numbers of hours of operation are available, the U.S.S. Sicily has some 2C39 tubes which have been in use for over 18 months.

The 2C39 tube may be tested in any of the series-OD tube testers, by means of an adapter constructed from a spare 2C39 socket from the TDZ equipment spare parts. The adapter is wired so that a 1500-ohm, ½-watt resistor is placed in series with the grid lead to prevent oscillations.

The 2C39 is tested as follows:

1. Adjust grid voltage to 1 volt.
2. Adjust plate voltage to 300 volts.
3. Adjust filament voltage to 6.3 volts.
4. Adjust hum control to provide minimum grid current. This adjustment is necessary because the cathode is connected to one side of the filament. The position of the hum control will be either completely CCW or completely CW. Once set, this control should be left in the same position for all further tests.
5. Record plate current.
6. Raise grid voltage to two volts, readjust plate voltage to 300 volts, and record the new plate current.
7. The transconductance may now be computed by means of the formula:

$$G_m = \frac{\Delta I_p}{\Delta E_g} \quad (E_p \text{ constant})$$

8. Using the values specified, the G_m may be computed very rapidly, because a change of 1 ma. in plate current is equal to a G_m of 1000 μmhos.
9. Check for reverse grid current by raising the grid voltage to a high value and holding the grid-current-meter switch in the 15-μA. position. A tube that shows reverse grid current is usually worthless.

If desired, the range of the OD checker may be increased by use of a shunt composed of two 10-μf. capacitors and a 2200-ohm resister. (The capacitors are paralleled, with the resistor placed in series with *one* capacitor.) This shunt increases the range of the meter from 6,000 μmhos to 30,000 μmhos. If this shunt is installed the 2C39 may be tested under dynamic conditions instead of by the static test described above. (The tester settings prescribed under steps 1 through 4 should be used, as before.)

The tubes should be matched both for transconductance and for plate current. A new 2C39 should exhibit a G_m of 13,000 μmhos, but out of approximately 100 new tubes checked by the writer, only two had a G_m which closely approached this figure. A suggested method of grading tubes is to use those with G_m's of 12,000 μmhos or higher in the power-amplifier stage of the TDZ, while those with G_m's of from 9,000 μmhos to 12,000 µmhos may be used in the tripler stage.

The tubes should be replaced in pairs, because the characteristics of a new tube change somewhat after several hours of operation. The defective tube should be discarded, and the good tube which was removed should be tested and rematched with another of similar characteristics.

E. E. Adams
Philco Field Engineer

A Note On
TRANSISTOR DEVELOPMENT

It has recently been announced that the transistor will shortly replace vacuum tubes in a wide variety of applications. Based upon the specifications of the units available in 1949, this statement appeared fantastic, because only in a very few limited applications could the transistor show improved performance over vacuum tubes. However, in the two years following the first transistors, great strides were made in terms of improvement of characteristics. For example, current gain was improved by a factor of 10 to 1, the class-A gain was increased from 18 db to 45 db, the 1000-c.p.s. noise figure was reduced from 60 db to only 10 db, maximum frequency was increased from only 5 mc. to 50 mc., class A power output was increased from ½ watt to 2 watts, and the available photocurrent ratio was increased by a factor of 10 to 1.

These improvements were obtained in only two years, and we didn't even mention the improvements in uniformity and reproducibility. All factors considered, it is a real possibility that the great majority of vacuum-tube functions *will* be replaced by transistors in the very near future.

A very interesting comparison of transistor power ratings recently appeared in a letter written to and published by the editors of TELE-TECH magazine. Mr. R. L. Wallace, Jr., of Bell Telephone Laboratories, shows how "one lazy flea power" can actuate a transistor. If a one-milligram flea jumps 50 centimeters once per minute (which proves that he is lazy), the average energy represents almost one erg per second (or about one ten-billionth of one horsepower). Yet this energy level will operate a junction-type transistor.

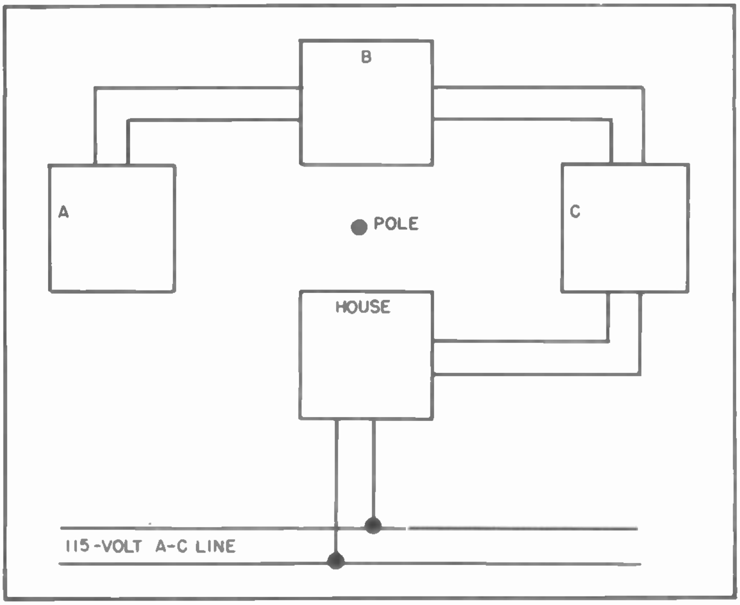
WHAT'S YOUR ANSWER?

Our growing list of switch problems gets a lift this month from John Hicks, Philco Field Engineer. We think this one is a clever twist to an old problem.

A farmer who has just received power-line service decides to wire his house and three outbuildings (A, B, and C) for lights. After running lines as shown, and connecting 115-volt lights in each building, he places a pole in the middle of the yard for the purpose of mounting a yard light.

Without affecting the operation of the lights in any of the four buildings, a switch must be mounted in each building and wired so that any switch will turn the yard light on if it is off or off if it is on.

Any type or types of switches may be used, but only one switch may be used in each building for yard-light control. Only two wires may be run to the pole, and no new lines may be run from building to building. No other equipment may be used.



(Solution next month)

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