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BUSHIPS Electron

A MONTHLY MAGAZINE FOR RADIO TECHNICIANS

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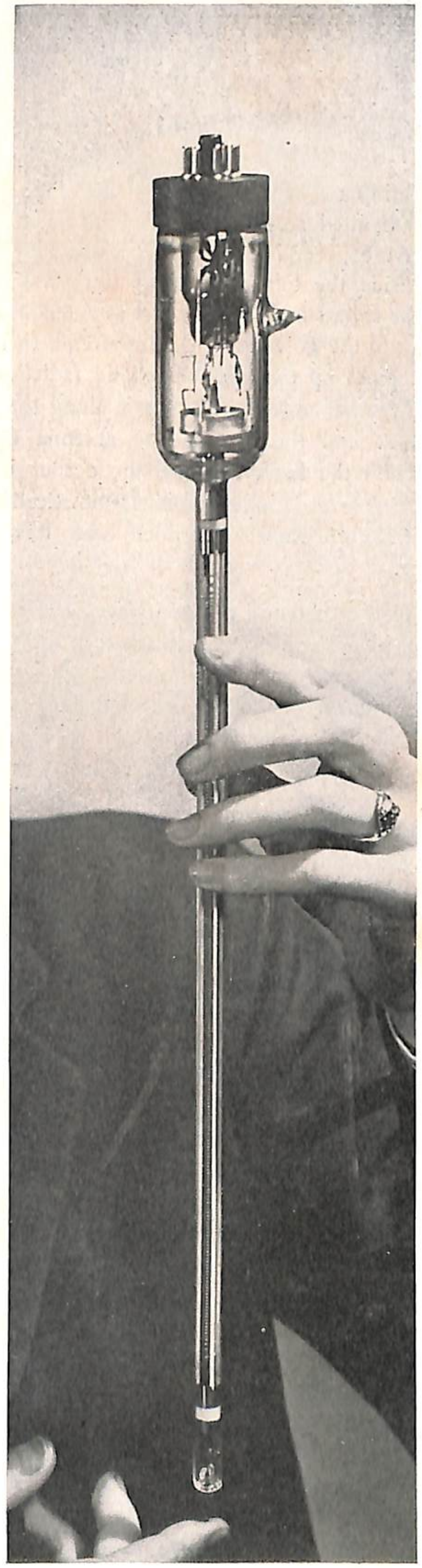
BUREAU OF SHIPS — NAVY DEPARTMENT

THE BEAM TRAVELLING-WAVE TUBE



The recent release of the first information on the beam travelling-wave tube has aroused keen interest in the communications field. It has opened up many new possibilities by making it possible, for the first time, to build a practical vacuum-tube amplifier for use in the region of 4000 Mc without the use of sharply-resonant circuits. The importance of such a device cannot be overestimated. It will open the way to the development of extremely broad band transmissions of highly directional beams which can handle high-fidelity television circuits as well as an extremely large number of simultaneous telephone, facsimile, teletype, or similar services. Following is the first detailed technical information released by the Bell Telephone Laboratories on this important contribution to the art of communications.

■ In developing broad-band communication such as television it has been difficult to obtain adequate amplification over the wide frequency ranges required. With the amplifier tubes most suitable for microwave frequencies, such as disk-seal triodes and klystrons, high gain can be secured only by narrowing the band. If an amplifier with a bandwidth of 10 megacycles were required, a gain of perhaps 10 db per stage could be obtained. Were such an amplifier readjusted to give a 20-megacycle band the gain would fall from 10 db to 4 db, and for a 32-megacycle band the gain would be 0 db, and the amplifier would be completely useless.

The recent development by the Bell Telephone Laboratories of the beam traveling-wave tube promises to overcome this limitation. An unprecedentedly high gain has been attained with a bandwidth about eighty times as great as has been practicable with other microwave tubes. Further, the nature of this new tube is such that the band can be broadened even more without sacrificing gain.

The beam traveling-wave amplifier has in common with other vacuum tubes an evacuated envelope and a stream of electrons, but it differs widely from more familiar types in appearance, construction, and operation. Electrons are accelerated from a hot cathode by a high-voltage electrode and shoot down the axis of the tube in a narrow beam, focused and guided by magnetic fields. No grids are employed, and the electrons striking the anode do not carry the amplified output, since the amplifying action has been completed before the electrons reach the anode.

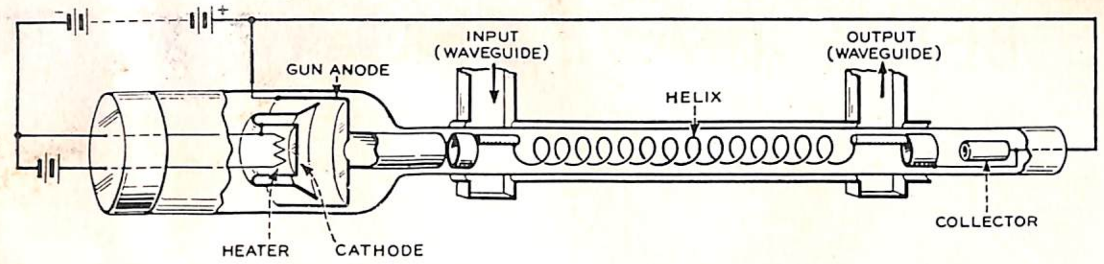


FIGURE 1—*Cross-section of beam traveling-wave tube showing arrangement of the elements.*

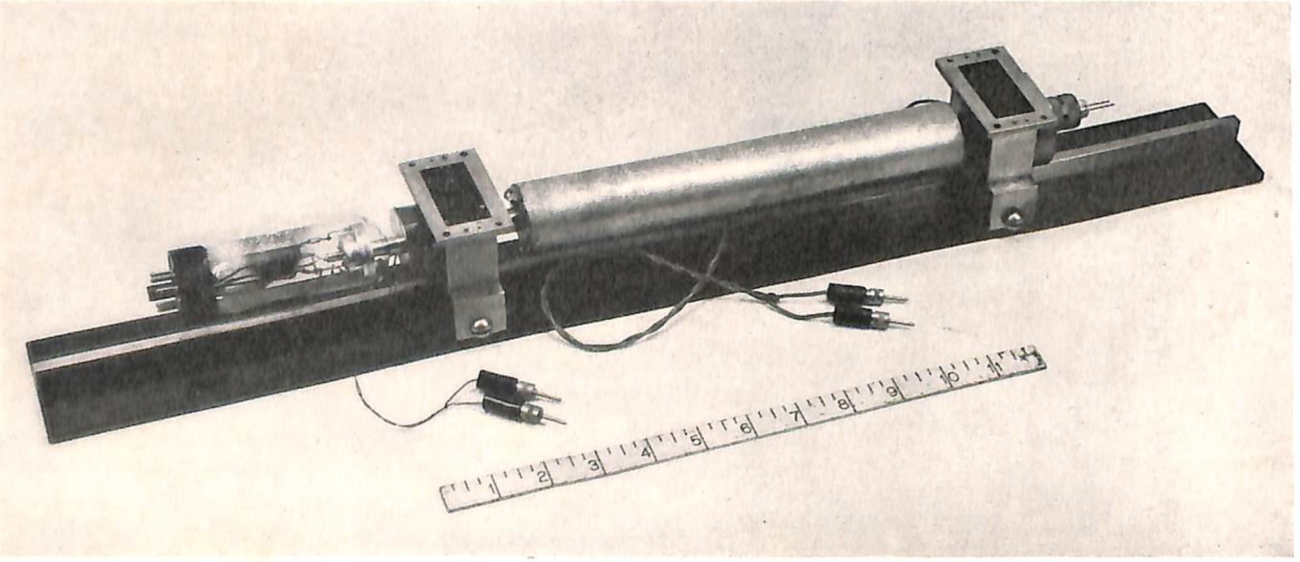
Surrounding the electron beam for nearly a foot of its length down the tube there is a closely wound helix of wire which carries the signal current. The signal current produces electric and magnetic fields, and indeed the signal progresses down the helix as an electromagnetic wave. This wave tends to go along the wire at about the speed of light, and as the wire itself is roughly thirteen times as long as the wound spiral, the wave travels down the helix about one-thirteenth as fast as light. The electron stream travels through the helix a little faster than the wave.

It is the interaction of the electrons with the electric field of the helix which produces the amplification; the greater the electron current or the longer the helix, the greater is the gain. No tuned circuit is used in any part of the path; the helix acts throughout as a smooth line capable of transmitting a broad band of frequencies, and thus bandwidth limitations are almost absent. Were better means provided for getting the signal onto and off of the helix, bands of greater than 800 megacycles could probably be attained. As it is, the present 800-megacycle band far exceeds existing needs, and little effort has been directed toward broadening the band further.

In the present amplifier two waveguides, one carrying the weak input signal and the other the amplified output signal, are fitted around the tube near the ends of the helix. At each end the helix is fastened to a metal collar inside the tube, and short straight sections between the collars and the helix act as antennas to couple the helix to the guides. At the input end, the receiving antenna picks up the electromagnetic radiation coming down the input guide and sends it along the helix; at the output end the transmitting antenna directs the power from the helix out into the output waveguide. This arrangement is indicated diagrammatically in figure 1, while figure 2 shows a complete beam traveling-wave amplifier.

Besides the tube and the two waveguide connections, two coils which can be seen in figure 2 are required in forming the electron flow into a narrow beam and in guiding it down the tube. The electrodes surrounding the cathode are so shaped as to send the electrons into the tube in nearly parallel paths. The narrow coil just to the left of the input waveguide in figure 2 provides a final adjustment before the beam enters the helix, and the long coil covering the tube between the two waveguides keeps the beam from spreading in its passage through the helix.

FIGURE 2—*An experimental model of a beam traveling-wave tube showing waveguide connections.*



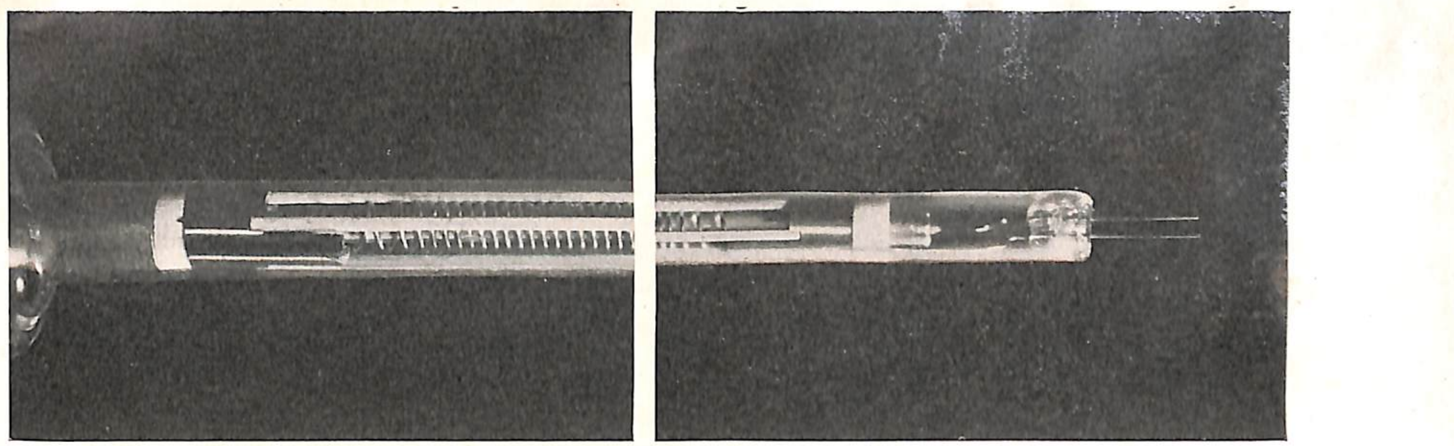


FIGURE 3—*At each end of the tube the helix is attached to a projection from a metal ring. These narrow projecting fingers act as small antennas in coupling the helix to the waveguide. The photographs show the cathode and collector ends of the tube, the left-hand picture being of the cathode end.*

The construction of the experimental tube can be seen more clearly in figure 3, which shows enlarged views of the two ends. Four slender ceramic rods which run the length of the tube between the helix and the inner surface of the glass hold the helix accurately centered in the envelope. The ends of these rods are held in four slots placed ninety degrees apart in the metal collars to which the helix is connected. The connection of the helix to each collar is made at the end of a narrow projecting finger which acts as an antenna in coupling the helix to the waveguide. Thus, the ends of the helix are fastened to the high voltage ends of two antennas.

A mathematical analysis of the operation of the tube has been carried out. This agrees with measurements of the field along the helix in showing that near the input end, where the electron stream is shot in as a smooth unvarying flow, the signal level remains nearly constant for a short distance. In this region the signal acts on the electron stream, gradually producing fluctuations in velocity and density. Then, when these fluctuations become large enough, the electron stream begins to give up energy to the electric field, and finally there is a long region in which the signal increases the same number of db for each inch of travel.

The detailed behavior of the field and of the electrons in the region near the input end of the tube is quite complicated. It is found, however, that this complication can be resolved into a simple picture of three different waves, excited nearly equally by the input signal and traveling down the helix quite independently and without mutual interaction. In the absence of the electron stream there is only one sort of wave, of a unique speed and attenuation, which can travel on the helix; it can, of course, travel in either direction. When the electron stream is present, however, it is found that there are three different sorts of waves that can travel in the direction of electron motion. Two of these are attenuated with distance, and are present only near the input end of the tube, accounting for the complicated behavior in that region. The third wave has the unusual property of negative attenuation; that is, it grows stronger as it travels instead of weaker. It is this wave which, increasing with travel while the other two waves are attenuated and become negligible, accounts for the linear increase in the signal level with distance in the later part of the tube.

The mechanism leading to the increase of this negative attenuation wave can be likened roughly to the building up of water waves as a wind blows past them. In the beam traveling-wave tube, the electrons move faster than the increasing wave and form a sort of "electron wind" which gives energy to the wave as it moves along. A mechanical analogy of this action is illustrated in figure 4, which shows a representation of the electric field as it would be seen by an observer moving along the helix with the speed of the wave. The electric field is represented as a series of hills and valleys, increasing slightly in height from left to right, the direction in which the wave is traveling, and the electrons are represented as frictionless balls rolling up and down over the hills. It can be shown that when the electrons move to the right past the wave, and when the hills grow higher with time (as they do for an observer moving with the growing wave), the electrons will go slower on the up slopes than on the down slopes. Hence, the electrons will crowd together in regions of retarding field, where they are going slowest, and where they are giving up energy to the wave.

In the past a number of studies have been made at these Laboratories and elsewhere of the interaction of electrons with traveling waves. During the war, R. Kompfner and others at the Claredon Laboratory,

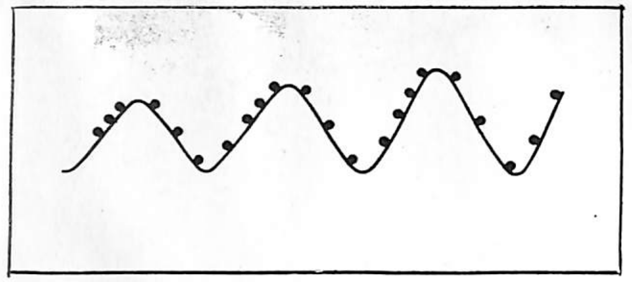


FIGURE 4—*The bunching of the electrons may be likened to the action of balls rolling up and down hills of increasing height.*

Oxford, England, showed that amplification was possible with a device consisting of an electron stream and a helix. In Bell Telephone Laboratories, Dr. John R. Pierce and Dr. L. M. Field, with F. R. Best handling the mechanical design and construction problems have been successful in producing amplifiers with the astonishingly high gain and broad band already mentioned, and further development should lead to tubes for various broad-band microwave communication systems.

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POLYSTYRENE WINDOWS FOR SV RADARS

As a matter of information to the submarine fleet, attention is invited to the fact that the polystyrene windows used in the waveguide flange of SV and SV-1 radar equipments are interchangeable. They are listed in the spare parts section of the instruction books as Item #746, contractor's drawing number BL-53196 for the SV, and Item #1003, contractor's drawing number BL-53198 for the SV-1. An ample supply of SV-1 equipment tender and stock spares is available. The rectangular polystyrene windows used in the projectors of the SV and SV-1 radar equipments and listed as Items #776 and #1026, respectively, are also interchangeable.

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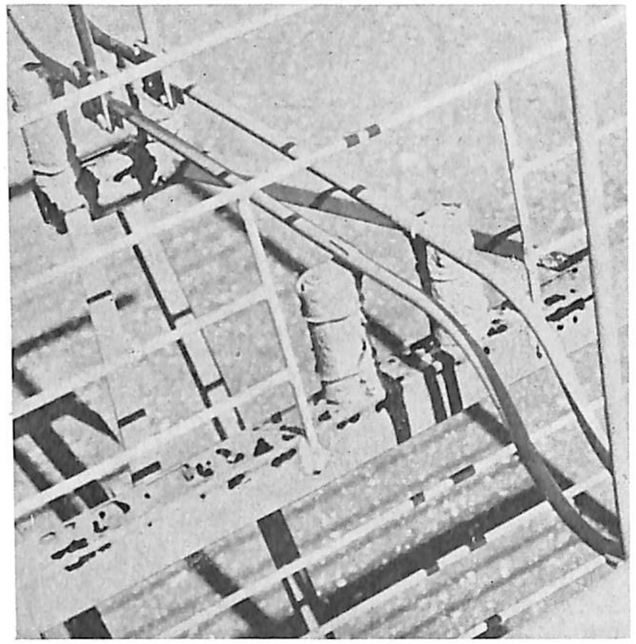
SPARE LOCAL OSCILLATORS FOR SP RADARS

Spare local oscillator pre-amplifier and AFC units are now available for all Model SP Radar equipped ships that desire them for equipment spares. Quantities of these units have been distributed to Electronics Officers at Naval Shipyards as indicated below. Ships having SP equipments and desiring one of these spare units should contact the nearest of these activities:

10	Mare Island Naval Shipyard
10	Puget Sound Naval Shipyard
10	San Diego Naval Repair Base
20	Oakland, California, Naval Supply Depot
10	Norfolk Naval Shipyard
10	New York Naval Shipyard
10	Boston Naval Shipyard
20	Bayonne, N. J., Naval Supply Depot

CONCEALED DETERIORATION

Say Mac, don't you think it's about time to give your antenna a good inspection? If there is any doubt in your mind take a look at the SC-1 antenna in the accompanying photograph. It was apparently in fairly good condition when removed from the AM-62. There were three or four places where the paint was slightly discolored from rust but, outside of these, there were no other outward signs of deterioration. However, when the old paint and rust were cleaned off by sandblasting, the illustrated condition was found. Well what do you think now? Yep, its just about time for antenna inspection.



Deterioration of an SC-1 antenna assembly. Note the many holes where rust has eaten all the way through the metal.

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SENSITIVITY OF RCH RECEIVERS

It has frequently been reported that the model RCH receiving equipment is found insensitive upon installation or shortly thereafter. If the trouble is a lack of c-w sensitivity on all bands, investigation has disclosed that a defective gain control is usually responsible. A lack of both c-w and mcw sensitivity on bands 4 and 5 is usually caused by misalignment of the high-frequency oscillator. This means that the oscillator is adjusted to a frequency lower than the signal frequency, rather than higher.

Activities may restore the equipment to its proper operating condition by replacing the gain control, should the c-w sensitivity prove low on all bands, or by re-adjusting the high-frequency oscillator to the high side of the signal frequency if the sensitivity is low on bands 4 and/or 5 only.

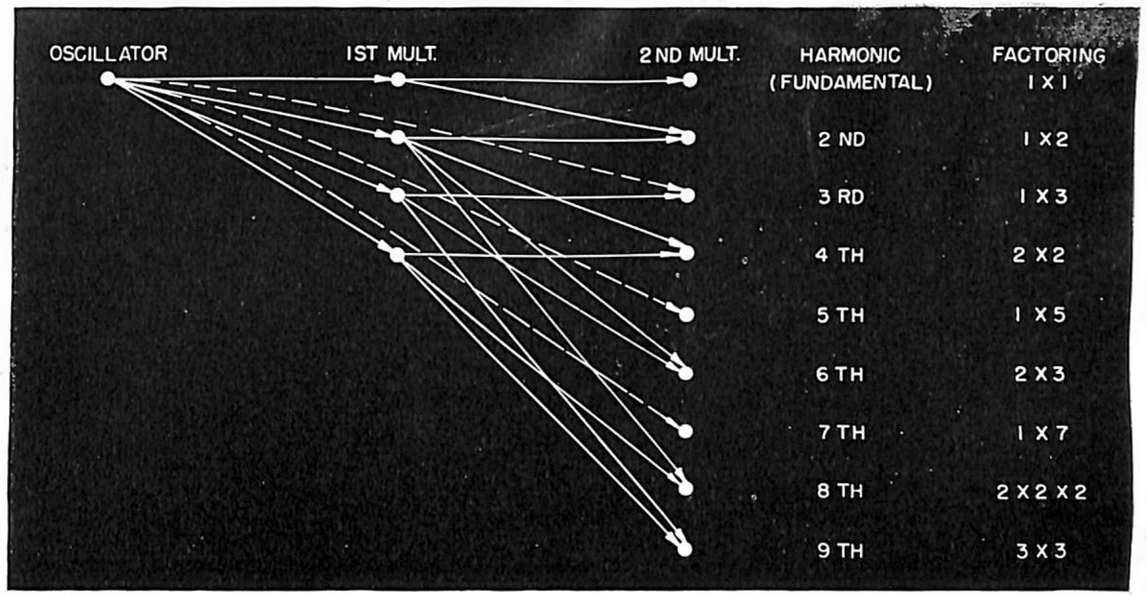


FIGURE 1—*Diagram illustrating possible harmonics produced in the output after passing through two stages utilizing different combinations of frequency multiplication.*

SPURIOUS TRANSMITTER RADIATION

By COMDR. E. H. CONKLIN, *Navy Department*

■ It has long been generally recognized and accepted that radio transmitters will radiate at frequencies which are harmonics of the final output frequency of the transmitter. But there are often other spurious radiations from a transmitter, and responses in a receiver, which are not generally recognized. These radiations may be caused by harmonics of the oscillator, and their frequencies are usually closer to or actually below the desired operating frequency. When an oscillator frequency is multiplied in order to arrive at the correct final frequency, it is easily possible that some harmonics of the master oscillator frequency will be produced in unauthorized ranges, both above and below the desired output frequency.

When the final amplifier is modulated, it is not always possible to identify the station which is radiating on spurious frequencies. Transmitters in which the oscillator is keyed, however, are frequently cited for radiating on incorrect frequencies.

It is widely assumed that frequency multiplication produces only the desired output from each stage. This is an incorrect assumption which makes no allowance for the possibility that new frequencies, not expected to be produced by the multiplier, may appear in the output of the final stage. This may be the result of undesired coupling between the oscillator and final amplifier, or between other stages. To illustrate this point, consider a transmitter having a total frequency multiplication of 16 (that is, 2 × 2 × 2 × 2). It would be possible for the adjacent 17th harmonic of the master oscillator to appear in the output, although it might not be expected because it can be obtained only by a large multiplication of the frequency of the master oscillator (1 × 17). However, if r-f energy from the master oscillator leaks into the final amplifier, it may very possibly modulate the output of the final amplifier. This would produce an output on both the adjacent master oscillator harmonics which would be the 15th and 17th.

An investigation of some of the characteristics of frequency multipliers may help to understand this situation better. If the frequency multiplication in a stage is greater than two, undesired harmonics of the driving stage are relatively close to the desired frequency and the tuned circuit presents sufficient impedance to enable the generation of appreciable power. If a multiplier doubles, the nearest undesired harmonics are the 3rd, which is 50% higher in frequency, and the fundamental, which is 50% lower. If a total multiplication of 6 is desired, this doubler might be followed by a tripler. The doubled output of the first tube is then amplified in the second tube, whose output circuit is tuned to present a high impedance to the 6th harmonic of the master oscillator. Close study will show that the second tube may also have in its output the 4th and 8th harmonics of the master oscillator by also doubling and quadrupling its input.

The grid of the tube following the second multiplier, described above, will have on it the output of the second multiplier, together with any of the second-harmonic input which reaches it. These may intermodulate just as in a mixer tube, to produce the 6th harmonic plus and minus the 2nd harmonic, creating 4th and 8th harmonic power.

Before going further, let us examine the harmonic spectrum from the first tube. Its 5th harmonic relative to the oscillator frequency should have been greatly attenuated by its tuned circuit. However, the second tube is a relatively efficient straight-through amplifier for this frequency inasmuch as its plate circuit, tuned to the 6th harmonic, is resonant at a frequency which is only 1/5 higher than this 5th harmonic.

The result is that multipliers produce power of different amounts at essentially all harmonics of the original oscillator frequency. This is illustrated in figure 1, which shows that harmonics present in the oscillator itself may also reach the final output circuit by spurious coupling or through the multipliers. The oscillator harmonics may be amplified, and appear through more than one combination of multiplications. Obviously, the 5th and 7th harmonics should be weak since they are either leakage products of the harmonics of the oscillator, or are generated in the final output by the modulation of the 4th, 6th, or 8th harmonics by oscillator frequency energy which has reached the circuit through spurious coupling.

Several means for reducing the power developed at the undesired frequency can be incorporated into the design of the equipment. In general, it would appear to be best to select an arrangement in which the output frequency may be factored into a number of small digits. That is, multipliers of 16 or 32 might be desirable because they may be reached by successive multiplications by two, without requiring multiplication by three or a larger number. For example, a multiplication of 15 could be obtained by 5 × 3, but probably would be less desirable than 16 which could be reached by 2 × 2 × 2 × 2, inasmuch as 15 is normally weak and 16 is normally strong.

Ordinarily, multipliers are designed for the production of maximum power on the desired output frequency. Where the production of spurious frequencies is to be reduced to a minimum, however, the number of tuned circuits, loading, and selectivity also become important because they control the power produced by undesired multiplications.

Unfortunately, inasmuch as all harmonics of the oscillator may appear in the multiplied output, large multiplications are undesirable because they offer less opportunity to suppress all but the intended output frequency. This is because, on a percentage basis, adjacent harmonics are close in the case of a higher multiplier. For example, if the 4th harmonic of the oscillator is desired as the output frequency, the adjacent 3rd and 5th are 25% away in frequency. On the other hand, if the 32nd harmonic of the oscillator is desired, the 31st and 33rd are only about 3% removed in frequency. Also, large multiplications in individual stages limit the number of selective circuits available to suppress the undesired harmonics.

Table I shows the measured output from a frequency-modulated Army VHF transmitter which uses high multiplication of a low-frequency oscillator. In attempting to improve the situation, the first step was to use a much higher oscillator frequency, with less multiplication. This provided a wider separation between the desired harmonics and those next adjacent above and below the output frequency, and resulted in improved attenuation through the normal selectivity of the multiplier tuned circuits. The table also shows the measured attenuation of the undesired harmonics using several types of multipliers. In this instance, 4 × 1 × 2 produced better attenuation than 2 × 2 × 2, presumably because the *buffer* (straight-through) stage allowed the use of the same number of tuned circuits and was not over-biased, which may have tended to reduce the harmonic content of the power passing through it. Undesired coupling in the set will account for other peculiarities.

It is generally expected that the harmonics of the final amplifier or last multiplier stage will be strong. Other expected harmonics of the oscillator may or may not be strong, depending upon the stray coupling within the multiplier; some expected frequencies may be very strong whereas others may be weak, depending on whether the stray coupling aids or bucks the power coming directly through the multiplier tubes.

So-called "push-push" amplifiers are frequently used for doubling and quadrupling. They give the tuned circuit an impulse twice in the same direction for each input cycle; therefore, they tend to suppress the odd-harmonic output. Similarly, ordinary push-pull multipliers may be used as triplers, in which case, if the output from each tube is carefully balanced, the impulse from the second tube tends to cancel power from the first tube on the even harmonics, such as the second and fourth. These types of multipliers will be found in several of the new 225-400 Mc communication equipments, such as the Model MAY pack set.

Crystal-controlled and a few other types of receivers use multiplication from a low-frequency oscillator in order to obtain mixer injection voltage. Because of the presence of undesired harmonics of the original oscillator frequency, aggravated by a tendency to over-drive the mixer, such receivers are likely to respond effectively to frequencies other than the one to which the receiver is tuned, unless the r-f stages and shielding are very effective in preventing such frequencies from reaching the mixer stage.

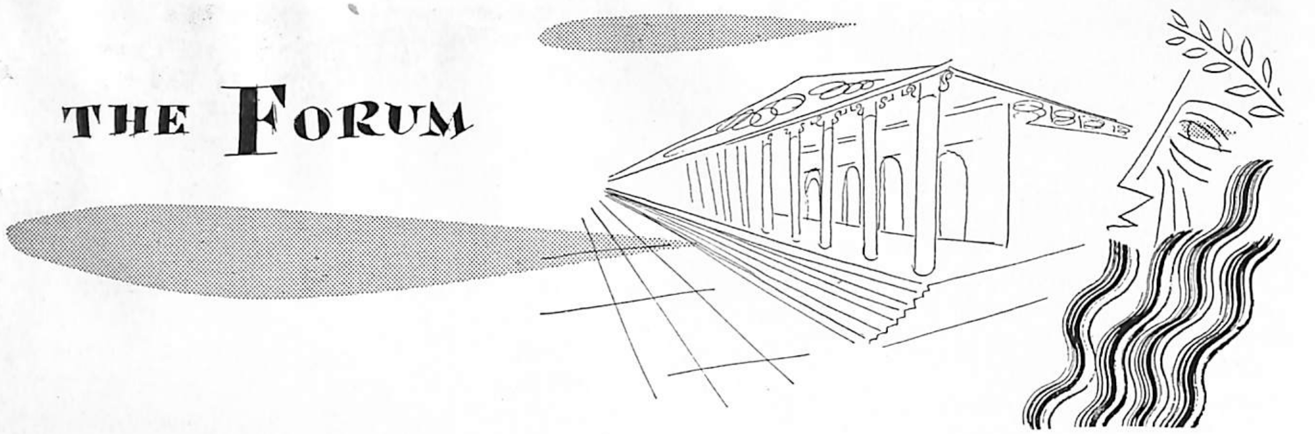
In order to reduce the probability of operation on undesired frequencies, several features should come into consideration by the designers of transmitters and receivers. Some of the more important points which require this special consideration are: 1—Minimum multiplication, using a high frequency oscillator. This is accomplished in Models MAY, RED and AN/ARC-12 which use the type CR-9 harmonic crystal operating up to 50 Mc. 2—The selection of a multiplication which factors into a number of small multipliers. This is done in Model AN/ARC-12 with the new CR-9 crystals, and in Model RDZ with the older CR-7 crystals. 3—The avoidance of multiplication of more than 2 or 3 in a single stage. 4—Using many tuned circuits, each lightly loaded, so as to retain a high degree of selectivity. 5—Reduction of leakage output from the multiplier stages, not only into power lines and other radiating material, but also into the output amplifier itself. An example of this is Model AN/ARC-2, which is a masterpiece of harmonic isolation. 6—Use of push-push or push-pull multiplier stages where applicable, in an attempt to reduce the output in the even or odd harmonics adjacent to the desired multiplication by careful balance between the output of the tubes.

Most of the features listed above are strictly a matter of design; however, the technician can materially aid in suppressing spurious radiation by careful alignment and balance where they apply, provided these factors are made variable. In many cases the technician has no control over any of the above-mentioned points due to the design of the equipment, but knowledge of the basic causes is extremely helpful in solving cases of mutual interference between channels, and in reassigning operating frequencies.

TABLE I — *Spurious-Frequency Power at Transmitter Output Jack (Resistive Termination) in DB Below a Desired Carrier of 40 Mc.*

Frequency	1.25 Mc Crystal		5 Mc Crystal			
	Harmonic	Attenuation	Harmonic	Atten. (4 x 2 Mult.)	Atten. (4 x 1 x 2 Mult.)	Atten. (2 x 2 x 2 Mult.)
33.75	27th	62db				
35.00	28th	51	7th	60	76	70
36.25	29th	52				
37.50	30th	45				
38.75	31st	28				
40.00	**32nd**	**0**	**8th**	**0**	**0**	**0**
41.25	33rd	33				
42.50	34th	53				
43.75	35th	56				
45.00	36th	59	9th	71	84	72
46.25	37th	75				

THE FORUM



BUREAU REPORTS

By JAMES WINTER, RDM, USS *General H. W. Butner* (AP-113)

I have recently been assigned as maintenance man for all electronic equipment on board this ship due to the discharge of our Electronics Technicians Mate. I understand that this job includes the making out and submitting of various reports to the Bureau. I would appreciate information as to any bulletins or publications which will assist me in determining what reports are required, and how to make them.

Bureau Comment: There are two Bureau of Ships reports which are required on all electronic equipment: (1) NBS-383 (Failure Report Form), one of which is required on each and every component and tube failure and, (2) NavShips-2369 (Electronics Field Change Report Card), which is submitted for each authorized Navy Field Change when completed. Information on NBS-383 and NavShips-2369 can be found in either the Radar Maintenance Bulletin, the Communication Equipment Maintenance Bulletin, or in the Sonar Bulletin, all of which are available aboard most any vessel in the fleet.

There is also a report required on radar equipment only, known as the Performance and Operational Report. Complete information on correct form can be found in the Radar Maintenance Bulletin.

The Bureau has recently instituted a new system for maintaining inventories for all electronic equipment which requires two additional reports from each and every ship. One is the ship's annual inventory report, submitted concurrently with the Ship's Characteristics Card on 1 January, and the other is a report which should be forwarded to the Bureau when any changes are made in the type, quantity, or location of any electronic equipment. This last report should be submitted by the activity which actually makes the change or replacement, (repair ship, naval shipyard, or ship's force). Detailed instructions on these reports have been promulgated in a BuShips letter to the commanding officers of all Active and Reserve ships. A general description of the new system can be found in the June and November 1946 issues of ELECTRON.

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FAULTY RAU-2 TAPPER-BAR ACTION

By J. A. GAUTHIER, ETM2C, USS *Shangri-La* (CV-38)

The Cycloray Amplifier (recorder) of our RAU-2 radio-sonde equipment did not function properly. The tapper-bar would operate only when the light assembly was turned over by hand.

All tubes were tested and found to be in good condition. All voltages in the photocell and preamplifier were tested and appeared to be satisfactory. It was believed, however, that the bias on V-202, a 2051 tube, was too high. Upon investigation the actual trouble was found to be that the sliding contact of R-204 was making poor contact. This caused the bias on V-202 to become very unstable. The sliding contact was cleaned off with crocus cloth, and the tapper-bar then operated properly.

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YOU, TOO, CAN BE A DEAD TECHNICIAN!

By J. D. METCALFE, CETM, USS *Shangri-La*

Is high voltage dangerous? Well, I'm assuming that you are an average technician so well steeped in electrical safety measures that you are oblivious to them all. You've seen a DANGER HIGH VOLTAGE sign in every compartment where you tote a repair kit, but familiarity breeds contempt.

"OK, so I'll get a shock", you say. "This scuttlebutt that it'll kill you is just another page in an instruction book. If the Bureau thought there was actually much danger they'd include artificial respiration in the rate requirements. After all, Wilson took 15 kv last month on the forward Mark 12 and it didn't hurt him at all except where he bumped his elbow flying around inside the director. And last week Bert touched one of the elements on our SR antenna and took half a megawatt. And every technician in the fleet has some interlocks tied down, or 'cheaters' plugged in, but you never hear of any of them getting killed. And what about these…"

Slow down there, Salty, and let's consider you as a circuit component. Personally, you are a quarter-megohm one-watt resistor, and as long as you don't try to dissipate too much power, you won't bake your coating. Say, for example, that you're soldered across a d-c source with a 3-kv potential applied. (Warning: Don't, due to the present critical shortage of ETM's.) You act as a high-resistance conductor and there will be current flow. Its path must be largely through the moist salty fluids of your body (that's you cooking) past nerve ends which are accustomed to stimuli below the micro-amp level. The effect of a sudden flow of current seems to be a rapid contraction of all the muscles in the path of current flow. (Just try and holler now—that's your heart that just stopped pumping!) Assuming that the current flow has not been heavy enough to cause chemical reaction or cooking, the only damage done is that you're not breathing. Maybe when your head hits the deck, the shock will start your heart—otherwise there's an opening for another striker.

The voltage necessary to complete this barbecue depends largely on contact resistance and the state of the nervous system of the individual. Some people get a thrill for 22 volts while others would blow out the 100-ampere fuse in the electric chair. The cases you hear of people taking very high voltages and joking about it afterwards either 1—didn't have current flow past the heart (i.e. hand to elbow), 2—didn't make good contact, or 3—died the next day.

Concerning those cases of taking half a megawatt from an antenna, that is a long story. It must include average power, detuning, skin effect, etc. Based purely on personal experience, however, I don't believe that there is enough r-f energy obtainable from a shipboard radar antenna (including the high-powered SM, SP, SR and SV) to do more than surprise or warm you. The only danger from the antennas is that you may hit the deck or water when you fall.

Incidentally, you can't usually outrun nor hold back a rotating antenna. I find my head fits quite tightly between the mast and the SG reflector. If your Man Aloft sign has been ignored, you failed to throw off the safety switch on the antenna, and the antenna starts up—grab hold and ride for free. When you swing around facing the quarterdeck, you might request permission to get the radar secured.

I'm not bumpkin enough to think that technicians will ever always cut the main power while making adjustments to their gear, no matter how much is written about it. Facing the practical case of the man making adjustments to hot gear with interlocks shorted, here is some practical advice:

(1) Don't, if there is any other way.

(2) Don't, if ship is rolling badly.

(3) Be sure that there is someone around to disconnect you.

(4) Keep a tight grasp on your tools in a strong magnetic field.

(5) Use insulated tools (tape is cheap).

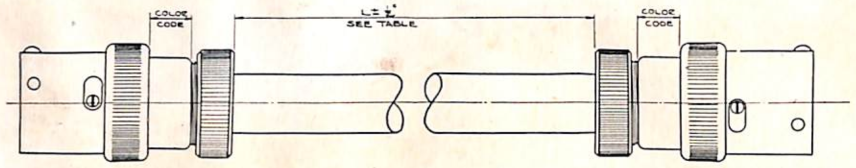
(6) Put a minimum number of hands in the gear (keep the other one ungrounded).

(7) Always use your right hand (this lessens the chance of your heart being in the path of the short circuit).

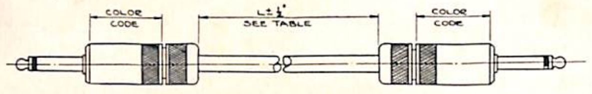
(8) Have plenty of light.

(9) Be stoical. When you bump the 300-volt repeller or 110-volt heaters don't thrash around and bump into really high voltage. Remove your hand from the hot spot slowly while cursing rapidly.

(10) The high-voltage transformer and capacitors mean business and assume that you can read and will heed the DANGER HIGH VOLTAGE sign. You can ignore the sign, but the sentence is stiff—the penalty is death.



PATCHCORDS FOR TRANSMITTER AND RADIOPHONE TRANSFER PANELS



PATCHCORDS FOR RECEIVER TRANSFER PANELS

PATCHCORDS

The following table provides a ready reference from which activities may determine the quantities and lengths of patchcords allocated to each type of radio remote-control transfer panel. In this connection it should be noted that all transfer panels should be shipped, transferred and stocked complete with the proper quantities and lengths of patchcords.

Color coding consists of a band of bright enamel completely surrounding each plug, as indicated on the sketch.

QUANTITIES OF PATCHCORDS PER PANEL

Type No. of Panel	Length in Inches (L) and Color Code										Total Quan. of Patch-cords
	6" Brown	12" Green	18" Red	24" Gray	30" Yellow	36" White	42" Orange	48" Blue	54" Purple	60" Black	
RECEIVER TRANSFER PANELS											
23182	5	5	5	10		10		10			45
23183	5	5	5	10		10		10			45
23184	5	5	5	10		10					35
23185	5	5	5	10		5					30
23186		5	5	5							15
23187	5	5	5								15
23188		5	5								10
23189		5	5								10
23190	5	5									10
23191	5	5	10	5							25
23293	5	5	5	10		10					35
23436	3	2									5
TRANSMITTER TRANSFER PANELS											
23192			5	5	5	5	5	5	5		35
23193			5	5	5	5	5	5	5		35
23194			5	5	5	5	5	5			30
23195		5	5	5	5	5					25
23196		5	5	5	5						20
23197		5	5	5							15
23198			5	5							10
23199			5	5							10
23200		5	5	5							15
23201		5	5								10
23202		5	5	5							15
23203		5	5								10
23204		5	5								10
23294			5	5	5	5	5	5			30
23437		3	2								5
RADIOPHONE TRANSFER PANELS											
23205					5	5	5				15
23206				5	5	5					15
23207				5	5						10
23208				5	5						10
23209				5	5						10
23467			3	2							5

SONAR RANGE RECORDERS

CNO's letter serial 2002P413 of June 1946 authorizes the declassification of certain types of sonar range recorders after the depth charge tactical data plates have been removed. These data scales control the classification of the recorders so their removal will automatically reduce the classification to Unclassified.

Recorders, Type CAN-55069, Type CAN-55070, A, B, C-series, Type CAN-55100, A, and Type CAN-55134, A, are involved in this change as they have removable depth charge data scales.

The recorders, Type CAN-55171 and Type CAN-55181, are not affected as they are an integral part of a Restricted equipment. They shall remain on the Restricted list.

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MAINTENANCE OF NANCY EQUIPMENT

The cognizance of Nancy equipment has been transferred from the Shipbuilding Division to the Electronics Division of the Bureau of Ships. All correspondence relating to this equipment should now be addressed the same as correspondence concerning radio, radar, sonar, etc.; that is, to the Bureau of Ships, Electronics Division.

In naval shipyards the maintenance and installation of this equipment is the responsibility of the Electronics Officer. When the necessary repairs are beyond the capacity of the local electronics officer the equipment should be forwarded to the Mare Island or Norfolk Naval Shipyard, attention Electronics Officer, as these two activities have special equipment and trained personnel capable of making extensive repairs.

A "Nancy Image-Forming Receiver Maintenance Manual" (NavShips-250-222-19) has been published and is now in the process of distribution. It will be limited to electronic repair facilities and schools, however, as only a limited quantity was printed.

RADAR

Part two of a comprehensive story on radar, by Dr. Edwin G. Schneider, appearing in four consecutive issues of ELECTRON.

RADIO-FREQUENCY TECHNIQUES: TRANSMISSION-LINE TYPES

In the radio-frequency region below a few hundred megacycles, parallel-wire transmission lines may be used. Since the spacing between the two wires must be kept small compared with the wavelength in order to prevent radiation, such lines become mechanically impractical at higher frequencies.

Coaxial transmission lines consist of a wire or rod along the axis of a cylinder. The electric field is applied between the wire and cylinder, the wave being completely enclosed so radiation cannot occur. Such lines may be conveniently used at low as well as high frequencies, but at frequencies above 3000 megacycles the losses become rather high. Another difficulty at microwave frequencies arises from the fact that, when the circumference of the outer conductor becomes comparable with the wavelength, the electric fields need not be radial, much of the energy being carried as a space wave which has different velocity from the simple radial wave. Hence, at wavelengths of around 1 centimeter, coaxial lines are too small to carry appreciable power. Even at 10 centimeters, the maximum allowable size of a coaxial line is too small to carry the now-available pulsed powers without arcing.

For microwave frequencies the most practical transmission line is a wave guide. This consists of a hollow pipe in which the energy is carried as a confined space wave. Because the wave guides were not in common use before the war, a more detailed discussion of their properties will be given after a brief review of the behavior of the more familiar types of transmission lines.

PROPERTIES OF TRANSMISSION LINES

The ratio of the voltage to the current in a transmission line carrying a single wave is a constant which depends on the wire size and spacing. This ratio is called the "characteristic impedance" and is expressed in ohms. When a resistance equal to the characteristic impedance is placed across one end of a transmission line and a transmitter is used to drive the other end, no reflection of the wave will occur at the resistance. If, on the other hand, the line is not terminated by a resistor equal to its characteristic impedance, a part of the power in the wave will be reflected back to the transmitter. The reflected wave will then combine with the original wave to form "standing waves." Where the reflected and original waves are equal in amplitude, the wave pattern will appear to be stationary along the line but will still vary in instantaneous value with time; hence the term "standing waves." A vibrating string is a mechanical example of a standing wave. Whenever standing waves appear on a transmission line, the line is said to be "mismatched," the standing wave being evidence of a reflection due to a discontinuity in impedance along the line. Obviously, the efficiency of the transmission line is decreased under these conditions because part of the power is returned to the source. Therefore, it is desirable to reduce the standing waves to a minimum.

When standing waves exist, points of maximum and minimum voltage may be located by sliding an alternating-current voltage-measuring device along the line. For example, a small probe may be inserted in a slot cut lengthwise in the outer conductor of a coaxial line. If the probe is connected to a vacuum-tube voltmeter or to a calibrated crystal detector, the voltage developed by the wave along the line may be measured by placing the probe at various points along the slot. In order to avoid the introduction of spurious standing waves, the probe should not penetrate an appreciable distance into the coaxial line. The "voltage-standing-wave ratio" is then the ratio of the maximum voltage to the minimum voltage. When no reflected wave is present this ratio will be unity, while with a reflected wave equal in amplitude to the transmitted wave the ratio becomes infinite, because there are points at which the voltage is always zero. The distance between adjacent maximum and minimum voltage points will be a quarter wavelength.

Let us now examine the standing-wave conditions on a transmission line which ends in an open circuit. When the wave reaches the open end of the line the current I must be zero, because there is no conductor to carry it. The impedance Z at this point will then be

$$Z = E/I = \infty \qquad (12)$$

because the voltage E will not be zero at an open circuit. The power must be reflected, since there is nothing to dissipate the power at the open circuit. The reflected wave will then add to the transmitted wave in a proper phase to keep the current zero at the open end. This will result in a current standing wave, as shown in figure 24(a), and the current will be found to vary in

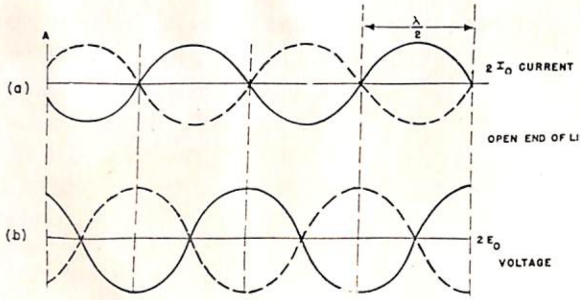


FIGURE 24—*Standing waves.*

time between the limits indicated, the dotted line occurring a half cycle later than the solid line. Figure 24(b) shows the voltage accompanying this current wave, the voltage being a maximum at the open end. Since the instantaneous maximum current or voltage occurs when the incident and reflected waves are adding momentarily in phase, the value will obviously be twice that of the incident wave. The separation between the nodes or points where the wave is zero is a half wavelength ($\lambda/2$). A quarter wavelength from the open end of the line the voltage is zero but the current is finite. Therefore,

$$Z = E/I = 0. \qquad (13)$$

Zero impedance denotes a short circuit; the line will, therefore, appear to be short-circuited here. Placing a short-circuiting bar across the line at this point will not alter conditions in the part of the circuit to the left of this short circuit. Between these two conditions of infinite and zero impedance the voltage-current ratio will be finite and may be either positive or negative. A positive value of the impedance corresponds to an inductance and a negative value to a capacitance. Therefore, if the line were cut and terminated in the proper value of inductance or capacitance, conditions to the left of this point would remain unaltered. From another point of view, at some point *A* the apparent impedance due to the remainder of the line can be altered by changing the position of an open circuit along the line.

In practice it is easier to change the position of a short circuit than to adjust the line length. Therefore, a brief summary of the properties of a short-circuited line is in order. At a short circuit the voltage must be zero and the current a maximum; hence, the impedance is zero. As in the case of the open line, the wave must be reflected without loss in amplitude because there is no dissipation of energy in an ideal short circuit. Thus a standing wave is established. A simple analysis of this standing-wave pattern shows that the voltage is always zero at points an integral number of half wavelengths from the short circuit. Hence, these points appear to be short circuited when seen from the source of the original wave. At points an odd number of quarter wavelengths from the short circuit, the line appears to be

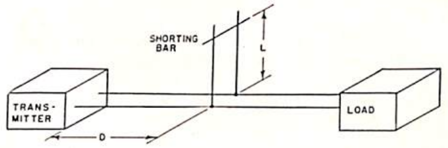


FIGURE 25—*Transmission line with T junction.*

open or infinite in impedance because the current is always zero. At distances between the points just discussed, the impedance appears inductive or capacitive. A comparison with the open-circuit line shows that a short circuit is equivalent to an open circuit placed a quarter wavelength from the position of the short circuit.

PROPERTIES OF STUBS

If we have a T junction in a transmission line, either parallel wire or coaxial cylinder, as shown in figure 25, the side branch will form a parallel circuit because the current divides at the T. When the branch line is short-circuited, there will be a reaction back on the main line and hence on the transmitter. Let us consider several cases. If *L* is a quarter wavelength, the impedance of the side arm at the junction will appear infinite. Then, since this side arm is a parallel circuit with infinite impedance, it will have no effect on the main line. On the other hand, if the short-circuiting bar is placed at $L = 0$ or $L = 1/2$ wavelength or any multiple of a half wavelength, the line will appear to be short-circuited at the T; and the load will be cut off from the transmitter. This short circuit at the T will, in turn, appear as an impedance at the transmitter.

If *D* is some integral number of half wavelengths, the transmitter will see a short circuit on the line; while if it is an odd number of quarter wavelengths, the line will appear to be disconnected from the transmitter. At intermediate values of *D* the line will act as an inductance or capacitance.

This property of a T junction may be used to modulate the transmitter. If the load is the antenna and a tube placed electrically an integral number of half wavelengths from the T is used as a short-circuiting bar, the power reaching the load may be controlled by turning this tube on and off. The length *D* should be adjusted to some number of half wavelengths to prevent overload of the transmitter during the short-circuited condition of the side arm. Further discussion of the use of this arrangement for switching purposes will be given later.

This property may also be used to provide supports for the inner conductor of a coaxial line. Side arms a quarter wavelength long and short-circuited at the end are used, as shown in figure 26. The successful operation of this "stub-supported line" depends on the fact that the short circuit is a quarter wavelength from the line. Therefore, the band of frequencies which may be passed without setting up serious standing waves is limited. A right-angle stub-supported bend is shown at the end of this line.

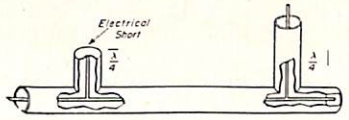


FIGURE 26—*Stub-supported line.*

Still another application of these principles is the "choke joint" for coupling two coaxial lines together, particularly where rotation between the two sections of line is required. In figure 27(a), energy leaking out through the gap *A* goes out past *B* to *C* where it is reflected by the short circuit. If *BC* is a quarter wavelength, the circuit at *B* will appear to be open. This open circuit will in turn appear to be a short circuit across the gap at *A* if *AB* is quarter wavelength. Now, since the crack at *B* is in series with the path *ABC*, and the impedance is infinite at *B* due to the short circuit at *C*, it will be immaterial whether the contact at *B* is good or bad. No energy will leak as long as the gap at *B* is small compared with a quarter wavelength.

The inner conductor may be coupled by maintaining a good electrical contact or by an arrangement as shown in figure 27(b). If there is no contact or contact only at the center of the hole, this coupling will act in the same manner as the choke in figure 27(a) if the distances *AB* and *BC* are again a quarter wavelength.

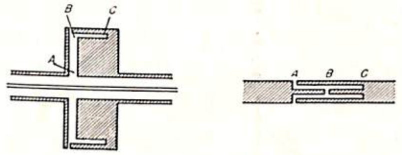


FIGURE 27—*Choke joint.*

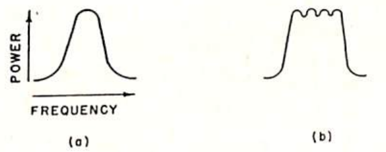


FIGURE 28—*Frequency response.*
(a) Single circuit
(b) Coupled circuits

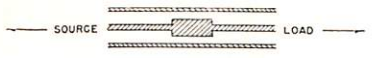


FIGURE 29—*Radio-frequency impedance-matching transformer.*

IMPEDANCE MATCHING

Now let us consider the case of a circuit shown in figure 25, in which the load is not matched to the transmission line. The relative impedances of the load and of the side arm as seen at the T can be adjusted by changing *L*. Since these circuits are in parallel, the division of the transmitted power at the T will be determined by these impedances. Part of the power from the load is reflected, while all of that from the side arm is returned. Therefore, if the length *L* is adjusted to present the proper impedance at T, the reflected wave from the short circuit will be just equal in amplitude to that from the load. These two reflected waves will not be in the proper phase to cancel, however, unless the T is at the proper place on the line. If the T can be moved along the line or the length of line between the T and the load can be varied by using a telescoping section, the two reflected waves can be made to cancel in the line *D*. Changing the length of the line between the load and the T will change the apparent load impedance at the T, thereby necessitating a change in the short-circuiting-bar position. Hence, the final adjustment must be made in a series of steps during which both variables are changed to reduce the standing waves in the line *D*. Thus a variable-length stub may be used to match the load to the transmitter. Where the power to the load is high, a telescoping section in the line is undesirable because arcing corrodes the sliding contacts causing power losses. For matching such a load two tuning stubs placed a quarter wavelength apart along the line will match many loads into the transmitter. Three stubs placed at quarter-wave intervals will match any load to the transmitter but are almost impossible to adjust properly if the shorting bars are moved independently. By ganging the two outer short-circuiting devices so that they move together, only two independent adjustments are needed, thereby making the manipulation reasonably simple. Although tuning stubs and variable-length lines were used in earlier radar systems, there has been a continued and successful attempt to make the radio-frequency system sufficiently broad-band to make such variable matching devices unnecessary. A system perfectly tuned by an expert may perform a few per cent better than a well-designed fixed-tuned set, but it has been thoroughly demonstrated that the average performance over a period of time will be better if the number of necessary adjustments is made as small as possible.

BROAD-BAND SYSTEMS

The problem of making a radio-frequency system with a broad bandpass is, to a large extent, a matter of designing individual components whose impedances are not frequency sensitive, and are nearly equal. It is usually impossible to have all components in the system perfectly matched; hence, it is necessary to make use of stubs and other tuning devices. In many cases, however, these tuning devices may be adjusted on the basis of bench tests and permanently set. One rule where a broad bandpass is desired is to place the matching device as close to the point of origin of unwanted reflections as possible. Consider the case of figure 25, where the load is not matched to the line. If the distance between the T and the load is many wavelengths, it is obvious that a slight change in wavelengths will cause a large shift in phase of the reflected wave at the T. The reflection from the stub will no longer cancel that from the load when this occurs. On the other hand, if the T is only a fraction of a wavelength from the load, a small change in wavelength will not appreciably alter the phase. A second practice in broad banding is to use several matching devices rather than a single one. This practice is based on the principle that the matching devices act as resonant circuits which are coupled together by the transmission line. As in the case of standard tuned circuits, the bandpass of a single circuit will appear as in figure 28(a), while multiple-coupled resonant circuits will give a bandpass as shown in figure 28(b). The flat frequency characteristic over the desired region is obtained at the expense of poor frequency response outside this region. A bandpass, as shown in figure 28(b), may be obtained by using several matching stubs properly adjusted rather than a single one.

Since the impedance of a coaxial transmission line depends on the ratio of the diameter of the inner and outer cylindrical conductors, a change in this ratio may be used in place of a stub as a matching device. Figure 29 shows such a transformer. The change in diameter of the inner conductor, the length of the raised portion, and its position along the line must be properly chosen to accomplish the desired matching. In general, any device which alters the line impedance may be used as a matching device if it can be adjusted to cancel the standing waves.

WAVEGUIDES

Most of the discussion of the properties of parallel-wire and coaxial transmission lines applies to wave guides, but there are some differences which will be pointed out in the following sections. Since a complete discussion of wave-guide properties is beyond the scope of this paper, only those items which have direct application to radar techniques will be considered. Although any hollow pipe of the proper size may be used as a transmission line for a range of frequencies, rectangular pipes are most frequently used. Figure 30 shows the distribution of electric and magnetic fields for two "modes" of propagation in a rectangular pipe. The electric field is perpendicular to the wide dimension and runs straight across the pipe. The electric-field distribution is shown by the curves sketched beside the pipe. The magnetic field surrounds the strong electric-field regions and lies in a plane parallel with the wide pipe dimension. In the TE_{01} mode, which is the most widely used, the currents flow lengthwise at the center of the broad face and on the sides flow parallel to the electric field inside the pipe. This means that a lengthwise slot can be cut in the center of the broad face without disturbing the currents. Such a slot is used for a probe entrance to measure standing waves.

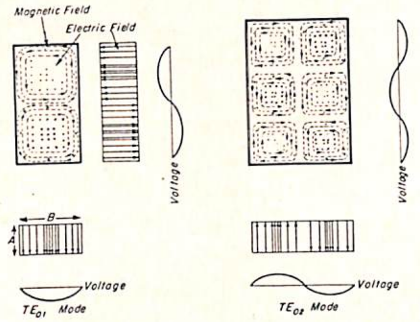


FIGURE 30—*Modes in rectangular wave guide.*

The TE_{02} mode is effectively two TE_{01} modes side by side in the same pipe. Higher modes in this series are designated by increasing the last subscript and correspond to more TE_{01} modes running side by side. The velocity of propagation of waves in these modes is higher than that in free space and is given by

$$V = v_0 \frac{1}{\sqrt{1 - (n\lambda_0/2B)^2}} \qquad (14)$$

where v_0 and λ_0 are the normal wave velocity and wavelength in the medium with which the pipe is filled. B is the width of the pipe perpendicular to the electric field, and n is a whole number designating the mode. When the quantity inside the parenthesis is greater than unity, the velocity becomes imaginary and the wave will be highly attenuated. The condition for propagation of a wave is, therefore, that B must be larger than $n\lambda_0/2$. For pipe of a given size and $n = 1$ there will be a maximum wavelength which can be transmitted. For the $n = 2$ mode this maximum wavelength will be half as large. Hence, there will be a band of wavelengths for which the pipe will transmit only the TE_{01} mode. At longer wavelengths the guide acts as an attenuator, while at shorter wavelengths more than one mode may exist simultaneously. When two or more modes exist in the pipe it is difficult to control the distribution of energy between them, and it is usually impossible to match both modes into the load. Therefore, the pipe size is normally chosen to transmit only the TE_{01} mode.

So far, nothing has been said about the dimension A, as in figure 30. This dimension can be made as small as one pleases without altering the wave-transmission properties, but since a strong electric field exists in this direction, electrical breakdown may occur if this distance is too small. This dimension can theoretically be increased indefinitely, but from a practical point of view it should be kept smaller than the cut-off guide width to prevent formation of a TE_{01} wave at right angles to that shown.

Many more complex modes can be excited in rectangular guides, but they will not be discussed because they are not commonly used.

In round guide, the TE_{11} mode is similar to that in rectangular guide, the only difference in field distribution being that shown in the end view in figure 31(b). Because there is no preferred direction across a circular pipe, the polarization of this wave in a long line is likely to rotate by an amount determined by irregularities in the pipe. Although this can be prevented by stretching a wire across the pipe diameter at intervals, the further difficulty exists that the difference between the cut-off diameter and that which will allow the next higher mode to exist is rather small. On straight runs this causes no trouble, but at bends and T joints higher modes may be excited. In the case of a given-sized rectangular pipe, the two longest wavelengths λ_m which can be transmitted are carried in the TE_{01} and T_{02} modes with values $\lambda_m = 2B$ and $\lambda_m = B$ respectively. For circular pipe, the two longest wavelength modes are the TE_{11} and TM_{10} modes with $\lambda_m = 3.412R$ and $\lambda_m = 2.62R$, respectively, where R is the pipe radius.

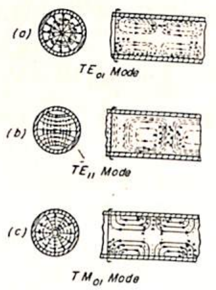


FIGURE 31—*Modes in circular wave guide.*

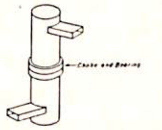


FIGURE 32—*Rotating waveguide joint.*

The TM_{01} mode shown in figure 31 has the property of having axial symmetry and is, therefore, a useful mode for rotating joints. Figure 32 shows a section of circular guide fed by rectangular guides. If the rectangular guides enter about a quarter wavelength from the closed ends of the circular pipe, the TM_{01} mode will be excited. The circular guide is cut in the middle so that one half can rotate with respect to the other, and a choke joint similar to figure 27(a) is used to keep the power from leaking out. Because the TM_{01} mode is symmetrical, the power passing through this system will be independent of the angle between the two rectangular guides.

Since the TE_{01} mode for rectangular pipe is the most important, let us see how this mode can be driven by a transmitter such as a magnetron or klystron. These tubes are the main sources of energy in the frequency region where wave guides are used and are usually built to feed directly into a coaxial line. The problem is, therefore, largely one of transition from coaxial to guide. Because the electric field is transverse in the guide, one method is to terminate the coaxial in a probe as shown in figure 33. This results in an intense field between the tip of the probe and the top of the guide. A suitable matching transformer must be used and may be of the type shown. The closed-end stub is placed a half wavelength from the probe so that the reflected power is in phase with the incoming power. The probe will be broader in its frequency characteristics and less apt to arc if it is large in diameter. This same device can be used to transmit energy from the guide to the coaxial line.

A second and better method is to establish the magnetic field by a current, as shown in figure 34. In this case, large oscillating currents flow from the coaxial to the top of the guide through the metal "doorknob." This establishes a magnetic field in the plane perpendicular to the paper. Since this is the proper direction for the magnetic field in the TE_{01} mode, a wave of this type is generated. The coupling may be just a wire crossing the guide, but the door-knob shape makes the system broad band and helps in matching. Again the position of the closed end is chosen to make the reflected wave add to the input wave.

Two of the transition sections shown in figure 34, with the coaxial lines meeting in a choke, make an excellent rotating joint.

Unlike parallel-wire and coaxial transmission lines, a wave guide does not have a definite characteristic impedance. Although the line can be terminated in a matched load which will give no reflection, the proper resistance value of the load will depend on the method of termination. Nevertheless, the behavior of mismatched lines is similar to that described earlier in the chapter. In a rectangular guide there are two possible ways of attaching a T. When fastened on the narrow side, as shown in figure 35(a), the behavior is as described previously. On the other hand, when the stub or T is fastened on the wide side, as shown in figure 35(b), the currents are interrupted. This effectively puts the side arm in series with the line, thereby reversing the effects of a short circuit and open circuit in cutting off the load. Another important fact in this so-called E plane T is that the phase of the wave is shifted a quarter wave-length in turning the corner. The T and bend shown in figure 35(a) are called H plane because the plumbing lies in the plane of the magnetic field, while those in figure 35(b) are called E plane.

Tuning stubs are made by mounting a rectangular piston in the side arm. Care must be taken to insure good electrical contact of the plunger at the center of the wide sides of the guide because the current is large at these points.

Another method of matching loads in a guide is to insert a screw or diaphragm. A metallic projection into the guide from the wide side adds capacitance, while one from the narrow side adds inductance. Therefore, a load which appears inductive can be matched by inserting capacitive diaphragms, as shown in figure 36(a). Figure 36(b) shows added inductance.

TRANSMIT-RECEIVE BOXES

By proper addition of inductance and capacitance it is possible to keep the impedance of the opening in a diaphragm matched to the guide. Since this diaphragm acts as a lumped resonant circuit, it does not have the cut-off limitation on the width of the hole. The diaphragm must, however, be thin compared with the wavelength. Holes of complicated shape, such as that in figure 36(c), may be matched to the guide so that a low-power wave will pass the diaphragm as though it were not there. On the other hand, a high-power wave will create a high field across the gap in figure 36(c), causing electrical breakdown. When this happens the impedance changes by a large amount, thereby reflecting most of the energy. This principle is used in one type of gas switch used to cut off the receiver during transmission when a common transmitting and receiving antenna is used (see figure 37). Tubes for this purpose are called "TR boxes" (transmit-receive boxes). The most successful of the types built to fit directly into a wave-guide line is a section of wave guide with resonant windows on the two ends and several resonant diaphragms similar to figure 36(c) placed at quarter-wave intervals.

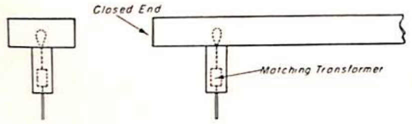


FIGURE 33—*Probe transition section.*

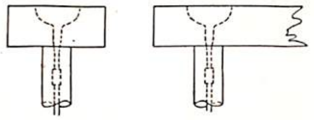


FIGURE 34—*"Doorknob" transition section.*

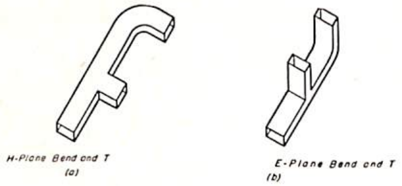


FIGURE 35 — *T's and bends in wave guide.*

The chamber thus formed is filled with low-pressure gas. The high power of the transmitter causes a discharge to flash across the window and some of the resonant diaphragms, thereby preventing the transmitted energy from passing through the TR. The received voltage, however, is too low to cause a gas discharge and, therefore, passes through the TR as though it were a piece of wave guide. By using several resonant diaphragms which act as coupled resonant circuits, broad bandpass is obtained.

Another type of TR box which may be used with either coaxial or wave-guide lines is shown in figure 38. This tube consists of two metal cones which nearly touch and are sealed into a glass envelope containing gas at low pressure. The metal disks holding these cones are clamped in an external cavity to form a resonant chamber. In a coaxial system power is coupled in and out of this cavity by coupling loops, while on a wave-guide system the side of the cavity may be cut away to form a resonant window through which the power may pass. The cavity is tuned for maximum received signal by means of screw plugs. During transmission the high voltage developed between the cones causes an arc which detunes the cavity, thereby preventing power from passing to the receiving system.

DUPLEXERS

Figure 39(a) shows the schematic of a "duplexing system" for a radar which uses a common transmitting and receiving antenna, while figure 39(b) shows a photograph of a 10-centimeter duplexer. The transmitter must be matched to the characteristic line impedance for maximum efficiency. For a long-wave transmitter this may be a transformer of conventional coupled coils, while for microwaves the matching devices described previously may be used. The TR box and anti-TR box are special gas tubes which flash over to form a short circuit when the transmitter operates. During transmission both T's, which act as parallel circuits, should present an infinite impedance at the line so that all of the power goes to the antenna. This means that the gas tubes should be an odd number of electrical quarter wavelengths from the line. Because of the capacitance and inductance of the gas tubes, the actual side-branch transmission lines will, in general, not be of exactly this length. When the TR box flashes it also short-circuits the line going to the receiver, thereby preventing the high power from burning out the input circuits. The gas discharges go out when the transmitter is off. The received signal then finds the TR box matched to the line and, consequently, goes through it to the receiver. In order to prevent loss of energy by reflection at the receiver, the receiver input must be matched to absorb all of the incident power. However, the received energy can also go down the main line to the transmitter. The function of the anti-TR is to prevent this energy loss by cutting off this part of the line. If the side line ends at the anti-TR, the circuit will be open when the gas discharge is out. This open circuit will appear as a short circuit at the T because of the quarter-wave spacing. This short circuit will, in turn, appear on an open circuit at the TR-box T if the spacing between the two T's is chosen as a quarter wavelength. The net result is, therefore, to disconnect the transmitter, thereby forcing all of the received energy through the TR box. If the anti-TR, because of its capacitance, does not sufficiently approximate an open circuit during reception, the line may be extended beyond it by an electrical quarter wavelength and there be permanently short-circuited.

Although the duplexers in a parallel-wire system or a coaxial system look quite different from figure 39(b), the principle of operation is identical.

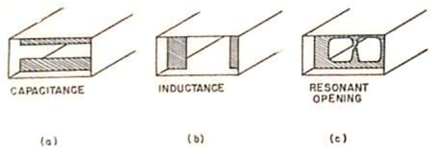


FIGURE 36—*Wave-guide matching diaphragms.*

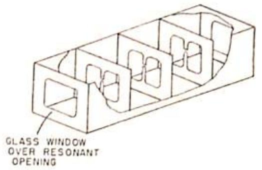


FIGURE 37—*Wave-guide broadband transmit-receive box.*

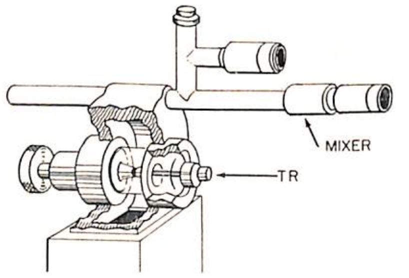
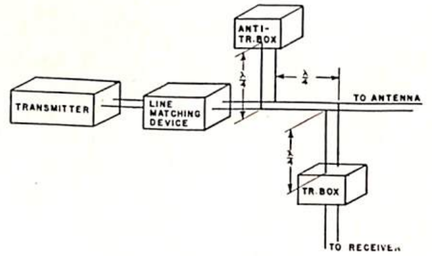


FIGURE 38 — *Tuned transmit-receive box.*



(a) Block diagram.

(b) 10-centimeter duplexer.

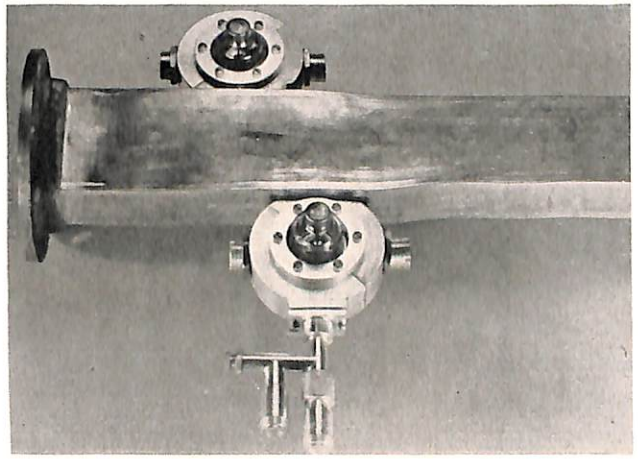


FIGURE 39—*Duplexing system.*

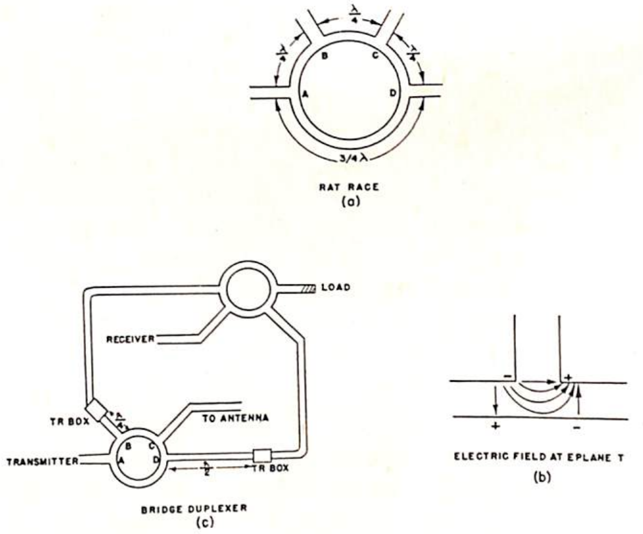


FIGURE 40—*"Rat-race" bridge duplexer.*

RADIO-FREQUENCY BRIDGE DUPLEXERS

Another quite different principle, which may be used to prevent the transmitter power from reaching the receiver, employs a class of devices which are built so that power entering a junction can leave only on certain paths. One example of this tvpe of device is the "rat race" sketched in figure 40. This system is built with waveguides having negligible loss; therefore, the phase balance is the important factor.

In figure 40, all of the T's are in the *E* plane, the narrow side of the guide being parallel to the paper. Power from the transmitter divides at *A* when it enters the guide, which is bent into a circle; but being an *E*-plane T there is a half-wave phase difference between the waves going in opposite directions because of the electric field distribution indicated in figure 40(b). Upon meeting at the entrance of another side pipe these two waves must be a half wave out of phase to send energy into it. If they meet in phase both sides of the branch become positive at the same time, with the result that a TE_0 mode is not excited; and all other modes are beyond cutoff. With this in mind, let us see which paths power can take through the device. For simplicity of argument, let us use the clockwise wave at *A* as the reference. Then the counterclockwise wave is a half wavelength different in phase. At *B* the counterclockwise wave has traveled one wavelength farther than the clockwise wave so the two waves are a half-wave different in phase, the condition for transmission of power into arm *B*. At *D* the two waves have traveled the same distance and, therefore, send power into arm *D,* while at *C* the two waves meet in phase with the result that no power enters arm *C*. Continuing this analysis, we find that power cannot be transferred between line *A* and line *C* nor between line *B* and *D*.

Now let us consider the circuit shown in figure 40(c). If the two TR boxes are identical and the arms between the two circles are of equal length, power from the antenna goes only to the receiver. Also, if the shorting action of the TR's is neglected for the moment, the transmitter power goes only to the load and not to the receiver nor to the antenna. When the TR boxes are allowed to fire, there is a small amount of transmitter power passing through them because the gas discharge is not a perfect short circuit; and this power is still absorbed in the load rather than reaching the receiver, thereby giving better protection than the TR alone. The short-circuiting action of the TR boxes is also used to allow the transmitter power to reach the antenna. The TR box in line *B* is placed a quarter wavelength from the junction. This is an *E*-plane T; therefore, a short circuit in this TR box reflects as an open circuit in the path *ABC* and cuts off the clockwise wave from *A*. In line *D*, which is effectively in series with the path *ADC,* the TR box is a half wavelength from the junction, so that the reflected short circuit completes this path and permits the counterclockwise wave from *A* to pass out through arm *C*.

The "magic T," which is illustrated in figure 41, is another device in which power from one arm cannot transfer to another arm entering the same junction. A wave entering *A* can divide and go out *C* and *D* but, because the polarization is wrong, cannot enter *B*. Likewise, energy entering *B* can go out *C* and *D* but not *A*. On the other hand, a wave entering *C* or *D* can go out all of the other arms.

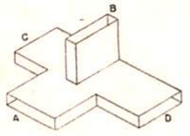


FIGURE 41—*"Magic T."*

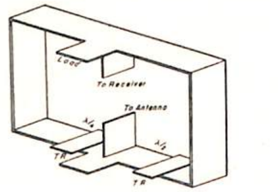


FIGURE 42—*"Magic-T" bridge duplexer.*

Figure 42 shows a method of using the magic T. Remembering that the two waves leaving or entering an *H*-plane T are in phase while those leaving or entering an *E*-plane T are out of phase, it may be seen that the antenna will feed power only to the receiver and the transmitter only to the load when the TR's do not fire. On the other hand, when the TR's place short circuits across the lines, these reflected waves meet at the T with a 180-degree phase shift, thereby allowing the power to transfer from the transmitter to the antenna.

RECEIVERS

Since the receiver input in systems operating at wavelengths shorter than 15 centimeters is very frequently an integral part of the duplexing system, let us begin by discussing the techniques for these wavelengths. So far, radio-frequency amplifiers have not been as sensitive as crystals. Therefore, the usual receiver is of the superheterodyne type, with an intermediate frequency of the order of 30 to 100 megacycles. The local oscillator and the incoming radio-frequency signal without amplification are mixed in a crystal detector to develop the intermediate frequency. The intermediate frequency is then amplified by standard receiving-type tubes such as the 6AC7, or by miniature tubes such as the 6AK5 if space and weight are important.

The local oscillator is normally a klystron of the type which may be voltage tuned, although at the long-wave end of this region triode oscillators such as the lighthouse tube may be used.

CRYSTAL MIXERS

The early crystal mixer was of a tuned-cavity type, one example being illustrated in figure 43. Where the main function of the resonant cavity was to obtain an electrical match between the crystal and the radio-frequency system, careful control of the crystal manufacturing made it possible to build mixers which use a fixed-tuned matching device, thereby simplifying the operation of the receiver. For experimental work on crystals where their radio-frequency impedances may vary over wide ranges, the tuned mixer is still in common use.

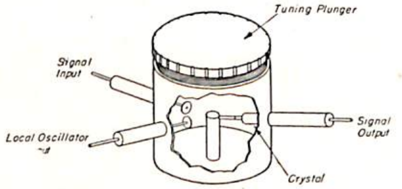


FIGURE 43—*Tuned mixer.*

Figure 44 shows one type of fixed-tuned mixer which is in common use in radar systems operating in the 10-centimeter region. The matching is carried out by adjusting the size of the coupling loop. This mixer is not entirely untuned because the TR tuning for maximum signal results in some improvement in matching of the crystal to the TR box. In this mixer the direct-current path for the crystal current is completed through the coupling loop. The local oscillator power is adjusted by changing the capacitance between the crystal feed line and the local oscillator probe. The cup on the radio-frequency line is a quarter wavelength deep for the third harmonic of the transmitter and, therefore, reflects an open circuit onto the line for this frequency. This third harmonic, which is not stopped by the type of TR shown in figure 38, may be present in amounts up to several watts peak power, while the crystal may be burned out by 0.2 watt.

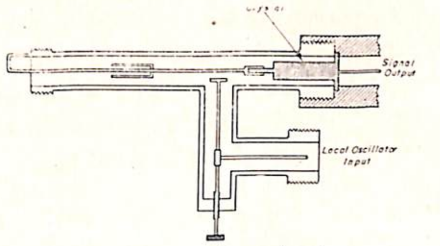


FIGURE 44—*Crystal mixer.*

For broad-band 10-centimeter systems where a wave guide TR is used, the mixer may take the form shown in figure 45. The position of the crossbar, which also acts as a local oscillator input, is adjusted to obtain proper crystal matching.

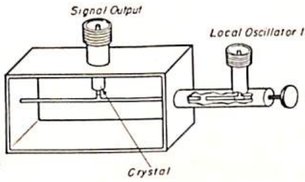


FIGURE 45 — *Wave-guide mixer.*

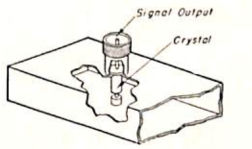


FIGURE 46—*X-band mixer.*

Three-centimeter wave-guide mixers may take the form shown in figure 46. However, at these frequencies a considerable amount of noise is introduced into the receiver input circuit from the local oscillator. In order to eliminate this noise, a balanced mixer, as shown in figure 47, has been developed. The output from the two crystals, which have the added advantage of giving full-wave rectification, is combined so that the received signals add but the local oscillator noise is canceled. This circuit also has the advantage that the received signal does not enter the local oscillator and the local-oscillator output cannot go out to the antenna. The latter is particularly important where a receiver used to monitor enemy installations should not radiate.

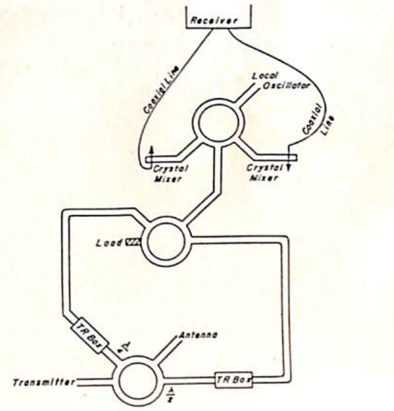


FIGURE 47—*Full-wave balanced mixer.*

RADIO-FREQUENCY AMPLIFIERS

At wavelengths longer than 15 centimeters, good radio-frequency amplifiers exist and are commonly used. In addition to providing more sensitivity to receivers at these frequencies, they are not so easily burned out by the transmitter power as crystals. Since radio-frequency amplifiers are harder to build than intermediate-frequency amplifiers, it is customary to use only enough radio-frequency stages to amplify the signal voltage well above the noise level of the first detector. Beyond this point the amplification is at intermediate and video frequencies. Lighthouse tubes are used for frequencies between 2000 and 600 megacycles, while "high-frequency" tubes which have been on the market for a number of years may be used at frequencies below 800 megacycles.

RECEIVER SENSITIVITY

The ultimate sensitivity of a receiver, regardless of its construction and number of stages of amplification, is limited by the random voltages produced by thermal agitation of the electrons in the conductors and resistors of the circuit. It can be shown that the average noise power *P* introduced into the input circuit of a receiver by these fluctuations is

$$P = cKT\Delta f \text{ watts} \qquad (15)$$

where c is a small number which depends on the exact form of the input circuit, K is Boltzmann's constant having the value 1.371×10^{-23} joules per degree absolute, and Δf is the band width of the receiver. Since a signal of the same magnitude as this noise will be indistinguishable from a random noise pulse, P may be considered the theoretical limit of sensitivity for the receiver. It is customary to express the actual receiver sensitivity as being so many decibels worse than a theoretically perfect receiver for which $c=1$. This quantity, called the noise figure, is

$$\text{noise figure} = 10 \log_{10} \frac{\text{average noise power in receiver}}{KT\Delta f} \text{ decibels.} \quad (16)$$

At frequencies below 100 megacycles, receiver-noise figures of 2 to 6 decibels are possible with present techniques; between 100 and 1500 megacycles noise figures of 4 to 8 decibels may be expected, while at frequencies between 1500 and 30,000 megacycles the values should be around 8 to 12 decibels including losses in the TR system. Substitution in (16) shows that signals of the order of 10^{-13} watts should be detected by a good receiver.

The difference between an actual receiver and a theoretically perfect one arises from the fact that the amplifier tubes and first detector introduce noise into the circuit which is greater than that caused by the resistances. Furthermore, these devices may not be perfectly efficient amplifiers or detectors. If part of the signal is wasted, the noise figure is increased.

At any point in the circuit there will be a certain amount of noise due to the adjacent circuit elements and also due to the noise coming to this point from the input. These two noise powers will add to give the noise level passed on. Now suppose the noise power at the receiver input is P_i and that this is amplified by a factor of 5 by the first stage. This noise will then be $5P_i$ at the input of the second stage. Also, suppose that the first stage itself adds a noise power of P_1. Then the noise power in the grid circuit of the second stage will be $5P_i+P_1$. We see that the first stage has added an amount of noise power to the circuit which is equivalent to increasing the initial input noise by $P_1/5$. Hence the noise figure is

$$\text{noise figure} = 10 \log \frac{P_i + P_1/5}{KT\Delta f} \quad (17)$$

instead of

$$10 \log \frac{P_i}{KT\Delta f}.$$

This argument can be extended to a multistage amplifier where P_i is the input-circuit noise including the detector noise if no radio-frequency amplifier is used, P_1 is the noise of the first amplifier and G_1 is its gain, P_2 and G_2 are the corresponding quantities for the second amplifier, and so on. Then

$$\text{noise figure} = 10 \log_{10} \frac{P_i+P_1/G_1+P_2/G_1G_2+\ldots}{KT\Delta f} \quad (18)$$

From this formula it may be seen that, if the amplifier gain is high, only the first one or two stages add appreciable noise to the circuit. The reason radio-frequency amplifiers are only moderately successful at 10 centimeters is that P_1 is large and G_1 small for the tubes which have been built. Where radio-frequency amplifiers are used, the first detector is inserted at the stage where its noise power divided by the gain is negligible in the above formula. If the noise figures with and without a term in (18) differ by less than one-quarter decibel, that term is considered negligible.

The arguments advanced to derive (18) essentially assumed perfect efficiency in utilizing the incoming signal. Since this is very rarely the case, let us see what effect a partial loss of the signal will have on the noise figure. As was stated previously, the signal should be at least equal to the average noise power to be detected. Therefore, if only, say, a quarter of the incoming signal power is utilized by the receiver, the signal must be four times stronger than if all of the power were used. The same effect would be achieved if we had a receiver which utilized all of the signal power but was four times as noisy. Therefore, if the reciprocal of the fraction of the power actually used by the receiver is denoted by F, the noise of the receiver will be

$$\text{noise} = 10 \log_{10} F\left(\frac{P_i+P_1/G_1+P_2/G_1G_2\ldots}{KT\Delta f}\right). \quad (19)$$

For radio-frequency amplifiers, F is likely to be near unity, which means most of the incoming signal is utilized, but P_1 is apt to be several times $KT\Delta f$. On the other hand, the present silicon or germanium crystals together with their mounts have values of F averaging in the neighborhood of 4 to 6, while P_1 is very near the theoretical value of $KT\Delta f$.

As may be seen from (19), the receiver sensitivity may be increased by decreasing the Δf. However, a certain band of frequencies is required to obtain a reasonably undistorted signal output from a modulated signal. It is obvious that if the signal is so distorted that it is unrecognizable, the receiver cannot be considered sensitive to that signal. This means that Δf cannot be given an arbitrary value, but the receiver bandwidth should be no wider than is necessary to pass the required signal. In a radar system where a pulse length of t seconds is used, the optimum receiver sensitivity occurs when $\Delta f=1.5(1/t)$, approximately. The sensitivity drops off very rapidly when Δf is much less than $1/t$ but is still good when Δf is $5(1/t)$. For applications in which extremely accurate range measurements are required the importance of an undistorted signal may make it desirable to sacrifice some receiver sensitivity by using a wide bandwidth.

INTERMEDIATE-FREQUENCY AND VIDEO AMPLIFIERS

Figure 48 shows one of the best input circuits for use with a crystal detector and also shows a typical stage of an intermediate-frequency amplifier. The coupling coils between the intermediate-frequency stages may be tunable or, by holding the components to close specifications, receivers may be built which require no intermediate-frequency alignment. Once the intermediate-frequency amplifier is properly aligned, the only receiver tuning required is in the radio-frequency stages (if a radio-frequency amplifier is used) and in the adjustment of the local oscillator frequency.

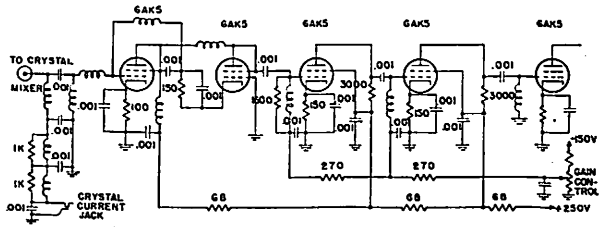


FIGURE 48—*Receiver input.*

Pulsating direct current required for the operation of cathode-ray tubes and other devices used to display the signal is obtained by passing the intermediate-frequency output through a second detector. The signal level entering the detector, as shown in figure 49, is of the order of 1 volt. The detector is followed by one or more stages of video amplification, and a cathode follower may be used to drive a transmission line leading to the indicators. If, as in the case of some applications, it is desired to limit the level of strong signals, the video amplifier may be driven to cutoff.

AUTOMATIC GAIN CONTROLS

The strength of radar signals from distant and nearby objects may vary by a factor of more than 1,000,000; hence, a receiver which is adjusted to the proper output voltage for a weak signal may be greatly overloaded by strong signals. Although this overload, (which occurs in the last few intermediate-frequency stages) may be prevented by decreasing the gain of the intermediate-frequency amplifiers, it is usually undesirable to use the manual gain control for this purpose. For example, in a search-radar set it may be necessary to observe weak and strong signals at essentially the same time. Under these conditions the receiver gain should be set to a different value for each signal, an impossible manipulation for the operator. On the other hand, the receiver gain can be electronically adjusted with great rapidity. Figure 50 shows a "back-bias" circuit which uses the signal strength to control the gain at an intermediate-frequency-amplifier stage. For simplicity the intermediate-frequency-amplifier circuit is only partially shown. The detector is cut off when there is no signal output from the intermediate-frequency amplifier, because the cathode voltage in a cathode follower is always more positive than the grid by an amount dependent on the value of the load resistor. When a signal appears on the output of the intermediate-frequency amplifier, it causes the detector to draw current provided the signal amplitude is greater than the cutoff voltage on the detector. Hence, the signal level at which the back bias circuit begins to act may be adjusted by varying R_1. When the signal is strong enough to operate the detector the capacitor C_1 becomes negatively charged, thereby making the follower grid and thence the intermediate-frequency amplifier grid more negative. Since this results in a decrease in the amplifier gain the tendency to overload is reduced; but there may be some signal distortion because the operation is moved to a more curved part of the tube characteristics. The recovery time after a strong signal is adjusted by the values of C_1, R_1, and R_4. R_3 is a small resistor which prevents the intermediate frequency from appearing on the grid of the follower. This type of circuit is most useful where the desired signal is obscured by overloading from certain types of jamming or from the signal return from a storm or waves on the sea. For such applications, the recovery time should not be much longer than the pulse length. Where control of one intermediate-frequency stage does

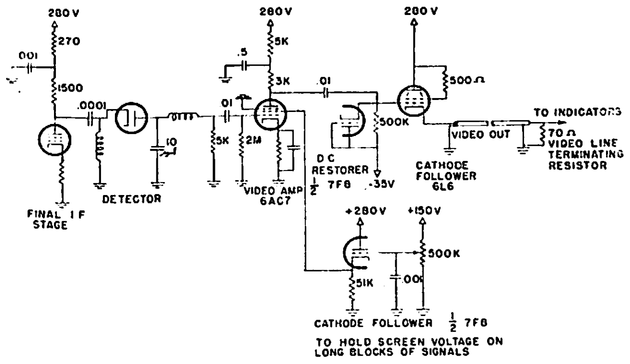


FIGURE 49—*Detector and video amplifier.*

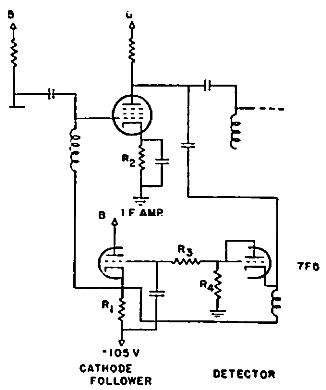


FIGURE 50—*Back-bias circuit.*

not cover an adequate range, similar circuits may be applied to, say, the last three stages. In this case, medium signals cause the back bias to operate only on the last stage, strong signals on the last two stages, while very strong signals cause the back bias to operate on all three stages.

Another method of controlling overloading is to amplify the output of the second detector of the receiver and use this voltage to control the bias on one or more of the early stages in the receiver. This type of circuit has been used as an automatic volume control on broadcast receivers. Because this type of circuit operates on all signals above a certain level, tending to make the output constant, the contrast between strong and weak signals is not as great as with the back-bias circuits when the recovery time is short. On the other hand, where the average amplitude is to be controlled without observing short-time fluctuations in the signal, automatic volume control with a long recovery time is useful. This is particularly true where a single signal is selected to operate an automatic-tracking circuit.

GATED RECEIVERS

A single signal may be selected by "gating," or turning on the receiver only at the time the desired signal is being received. This may be accomplished by applying a square positive pulse to the grids of two or three intermediate-frequency-amplifier stages which are biased beyond cutoff. Figure 51(a) shows a block diagram of a "short-gate" circuit for selecting a single signal. *P* in figure 51(b) is the transmitted pulse and *S* the desired signal. The trigger from the transmitter may be used to trip a multivibrator as a delay mechanism, the duration of its output square wave being adjusted to be just less than the time between *P* and *S*. The back edge of this square wave may in turn trip a second multivibrator which puts out a square pulse just a little wider than the signal. *S* is the only signal reaching the output, since the receiver is turned on only during this time. Several other types of circuits suitable for delaying the triggering of the short gate will be discussed in the section on indicators.

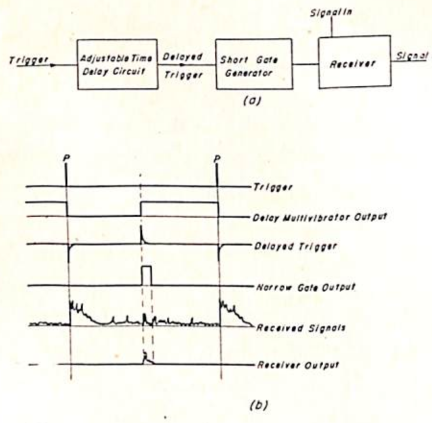


FIGURE 51—*"Short-gated" receiver.*

AUTOMATIC FREQUENCY CONTROL

The local oscillator is the only item which needs tuning in a broad-band system; therefore, completely automatic operation of the transmitting and receiving system can be achieved by using automatic frequency control (AFC). For this purpose a voltage-tuned klystron may be used as a local oscillator, the voltage being controlled by the transmitted signal. Since the receiver input is cut off during transmission, the power to operate the automatic frequency control must be tapped from the transmission line through a suitable attenuator and fed into a separate mixer from the normal receiver mixer. The same local oscillator must, however, feed the two mixers. Figure 52 shows the circuit (above), and the intermediate-frequency and discriminator-output voltages as a function of frequency (below). The intermediate frequency is chosen as 30 megacycles for the sake of discussion.

The 884 works as a relaxation oscillator and provides voltage to sweep the local oscillator over its complete tuning range of 20 megacycles. It is so biased that when its plate reaches —50 volts from ground the tube fires or becomes conducting, and capacitor C_1 is charged to about —230 volts which is close to the potential of the 884 cathode. The characteristics of the 884 are such that, once conduction starts, the grid loses control; and conduction continues until the plate potential drops to or near the cathode voltage. Conduction then ceases, and the grid resumes control.

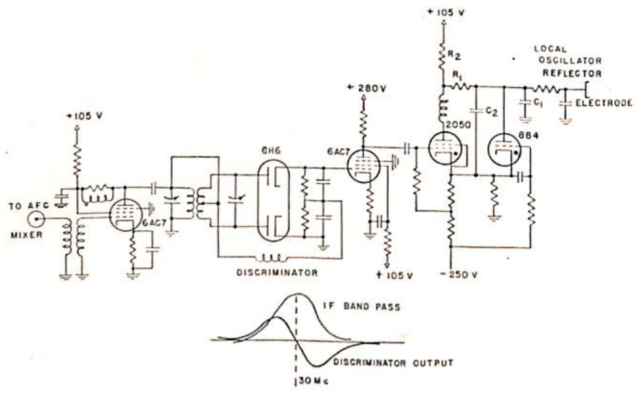


FIGURE 52—*Automatic frequency control.*

The capacitor C_1 and the local-oscillator reflector are connected by R_1 and R_2 to +105 volts, thus sweeping the reflector voltage in the positive direction and tuning the local oscillator from a higher to a lower frequency. When C_1 reaches —50 volts the 884 again fires and starts the cycle over again. Thus a saw-tooth sweep is put on the reflector of the klystron tube.

The 2050 operates the control or holding circuit. Its function is to stop the sweep and hold it when the sweep voltage reaches the point which corresponds to a difference of 30 megacycles between the local oscillator and the transmitter frequencies. It is so biased that it does not conduct at any time unless a positive pulse is applied to the grid. The sweep circuit causes the local oscillator to go from higher to lower frequency; and if the local oscillator is properly tuned to the high-frequency side of the transmitter, the intermediate frequency, which is the difference between the local oscillator and transmitter frequencies, will go from a higher to a lower value.

From figure 52 it may be seen that at first the intermediate frequency, which is much too high, produces a positive pulse output from the discriminator and hence a negative pulse on the grid of the 2050. This negative pulse on the 2050 produces no effect, even though the intermediate frequency continues to become lower. When the intermediate frequency reaches 30 megacycles it is at the crossover in the discriminator pattern; just a little later, it is lower than 30 megacycles. It then produces a negative pulse from the discriminator which becomes a positive pulse on the 2050 grid, thereby firing the tube and charging C_2 to —230 volts.

The grid of the 2050, as in the case of the 884, loses control when the tube fires. Thus the tube conducts until the plate is near cathode potential. When the 2050 ceases to conduct, C_2 swiftly recharges to its former voltage. During the interval that C_2 is more negative than C_1, C_1 which has been charging in the positive direction through R_1, changes its direction of charge and starts to go in the negative direction.

This change of direction of charge also reverses the direction of change in the intermediate frequency, making it higher than 30 megacycles, a condition in which no positive pulse reaches the 2050 grid. After C_2 returns to its former voltage, C_1 resumes its charging in the positive direction, making the intermediate frequency again become lower than 30 megacycles by a small amount; the 2050 again receives a positive voltage on the grid, fires, and the process is repeated.

Thus it can be seen that the intermediate frequency shifts slightly from above to below 30 megacycles, the 2050 firing often enough to keep the average voltage at C_1 and hence on the reflector at the value required for an intermediate frequency very close to 30 megacycles.

The 884 cannot operate at this time, or at any other time, unless the voltage at the reflector reaches —50 volts. As long as the transmitter is tuned in and operating the 2050, the reflector voltage is more negative than —50 volts and is held closely at or near the voltage necessary to maintain the proper intermediate frequency of 30 megacycles.

CRYSTAL VIDEO RECEIVERS

The receivers discussed so far have been of fairly narrow bandwidth and are the type used for radar sets where it is undesirable to receive signal frequencies different from the transmitter frequency. There are, however, applications for a very broad-band receiver—for example, radar beacons—which must be tripped by a wide range of transmitter frequencies.

Receivers having very wide bandwidths of the order of 20 per cent of the carrier frequency can be made by converting the radio-frequency signals directly into video pulses and obtaining the desired output voltage by video amplification. The main factor which limits the bandpass in these receivers is the radio-frequency and antenna system. Because of large conversion loss in the detector, the noise figure of these receivers is poor.

(*Continued next month*)

● ● ●

Don't permit yourself to get caught out on a limb for want of spare parts. After taking an item out of a spare parts box, the best system is to stop right then and order yourself a replacement for it. Then you will have it on hand when you need it in a hurry.

● ● ●

Answer to last month's cross-word puzzle

C	A	T	H	O	D	E	■	S	W	I	T	C	H	■	P	E	N	T	O	D	E
U	S	E	■	■	O	C	T	■	I	D	E	A	■	I	N	A	■	■	M	I	L
P	B	■	T	A	L	C	■	S	T	I	N	T	S	■	E	R	O	S	■	M	E
R	■	S	■	S	L	E	P	T	■	O	S	■	T	R	U	N	K	■	H	■	C
O	A	T	S	■	■	N	O	R	■	M	E	■	R	A	M	■	■	S	O	F	T
U	N	I	F	Y	■	T	E	A	L	■	■	S	E	T	A	■	R	O	W	E	R
S	O	L	■	E	A	R	■	N	O	R	D	E	N	■	T	O	E	■	L	A	O
■	D	E	L	A	Y	I	N	G	■	A	U	■	G	L	I	B	N	E	S	S	■
P	E	■	A	R	■	C	C	L	■	Y	E	■	T	I	C	■	O	N	■	T	W
R	■	I	M	■	G	■	■	E	N	■	■	B	H	■	■	N	■	E	R	■	I
E	S	T	I	M	A	T	E	■	A	S	M	E	■	N	E	U	T	R	A	L	S
S	T	E	N	T	O	R	S	■	P	O	U	R	■	M	A	L	I	G	N	E	D
T	■	M	A	■	L	■	■	M	E	■	■	G	M	■	■	L	■	I	T	■	O
O	S	■	T	L	■	S	E	A	■	F	M	■	A	N	A	■	G	N	■	S	M
■	P	L	E	A	D	I	N	G	■	I	A	■	R	E	D	O	L	E	N	T	■
A	R	E	■	I	O	N	■	N	U	T	R	I	A	■	V	E	E	■	A	R	E
F	U	M	A	R	■	G	A	E	L	■	■	E	T	N	A	■	N	O	D	A	L
R	E	O	S	■	■	L	I	T	■	C	A	■	H	U	N	■	■	R	I	P	E
I	■	N	■	C	H	E	R	I	■	O	R	■	O	T	T	E	R	■	R	■	G
C	L	■	F	E	E	T	■	C	O	M	M	O	N	■	A	B	L	E	■	T	A
A	E	R	■	■	R	O	T	■	A	M	O	R	■	A	G	O	■	■	S	E	N
N	E	U	T	R	O	N	■	S	P	A	R	E	S	■	E	N	T	R	A	N	T

Radio-Sonde Maintenance

■ With more and more emphasis being placed on operations at high altitudes and in regions of extreme temperatures, the study of atmospheric pressure, temperature, and humidity becomes very important. This study, known as Air-Mass Analysis (AMA), is very extensive and involves the use of special electronic equipment.

In connection with this program a quantity of model AN-FMQ-1A Radio Sonde equipments is being distributed to the field. These equipments are very similar to their forerunners, the model RAU-2 equipments, except that they use hermetically sealed and tropicalized units. Although most of the components can be used in either model, some of the treated units are not interchangeable due to a difference in size and mounting arrangements. The equipments using the tropicalized units will perform more satisfactorily in hot and humid areas.

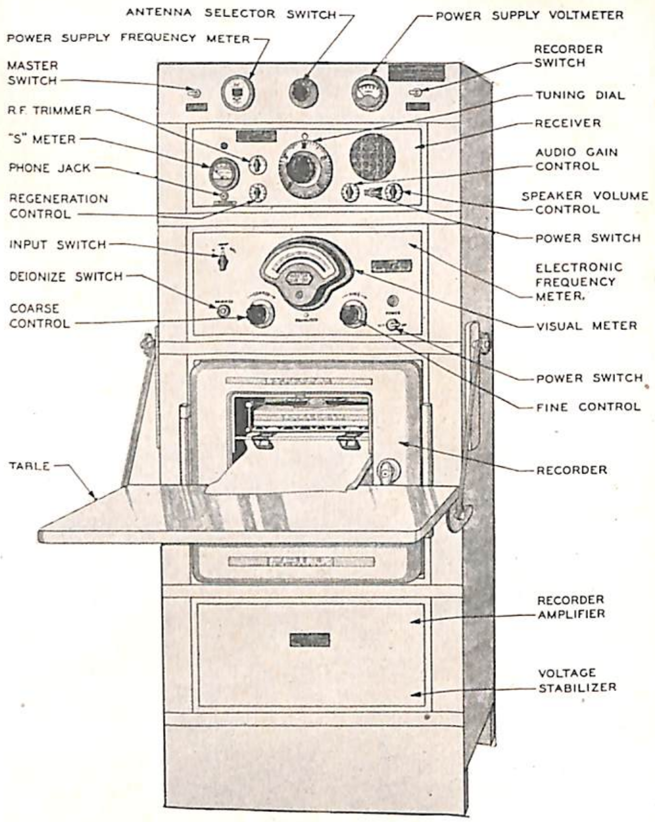
Note from the artist's drawing that the power supply, frequency meter, antenna selector switch, and power supply voltmeter are incorporated in the top panel of the model AN/FMQ-1A equipment. Because of the similarity of these two models the operating and maintenance techniques are essentially the same. One instruction book has been prepared for the model RAU-2 while the following manuals apply to the model AN/FMQ-1A equipments.

Technical Manual	*Date*	*Title*
TM 11-2403	April 1945	Installation and Maintenance of Radio Sonde Receptor, AN/FMQ-1.
TM 11-2403	24 May 1945	Supplement (AN/FMQ-1A)
TM 11-2404	December 1944	Operating Instructions for Radio Sonde AN/FMQ-1A
TM 11-2404	20 April 1945	Supplement (AN/FMQ-1A)

All stations and vessels equipped with radio sonde equipments should ascertain what instruction books are necessary and obtain them, if necessary, from the Bureau of Ships (Code 253).

The appendix of TM-11-2403 includes instructions for moisture-proofing and fungi-proofing components, which will provide a reasonable degree of protection against fungus, insects, corrosion, salt spray, and moisture. The treatment involves the use of a moisture- and fungi-resistant varnish applied with a spray gun or brush. Equipments operating in areas of high temperature and humidity should be kept clean and regularly inspected to see if such a treatment is necessary.

Reference to the instruction books and manuals should always be made when servicing or repairing the equipment. Tinkering with any equipment is a bad policy and should not be practiced. This is especially true of the recorder and tapper mechanism of the radio sonde equipment. By keeping this unit clean and lubricated properly it will give trouble-free operation over a long period of time. The recorder and tapper mechanism should be inspected weekly for cleanliness and for the need of lubrication.



Of all the items called for in the monthly inspection, the following points are stressed and must be thoroughly checked: a—the exciter lamp and optical assembly must be properly adjusted, b—the dog-leg joints must be free of friction but not excessively loose, and c—the arms and tapper bar must be straight.

From time to time the Bureau has been requested to supply tapper-bar coils and dog-leg springs to various activities. The quantities requested indicate that these items are failing rather rapidly in the field. However, very few failure reports have been received whereby data can be secured for the development of improved parts for the existing equipments. All derangements and failures should be reported on NBS-383 failure report cards. In a like manner this card should be used to submit information on maintenance hints. These hints are valuable to technicians not familiar with the equipment.

As a result of a spare parts survey, a quantity of parts necessary to the maintenance of the equipment is under procurement and will be supplied to strategic maintenance bases when available. Each activity should obtain the necessary parts to complete this allowance.

If you think this beautiful dancing girl merits additional or prolonged contemplation . . .

. . . you can retrieve the magazine later for a more detailed study of this or any other items of particular interest to you. In the meantime, however, pass this copy along so that all the technicians may have a chance to give it a quick "once over."

A Stitch in time...

Instead of waiting for a breakdown, sew up your worries by employing regular preventive maintenance procedures. Intimate knowledge of the operating principles and peculiarities of your equipment can be gained by periodic checks and adjustments. Trouble shooting then becomes relatively simple, and many would-be shutdowns will never occur.