CONFIDENTIAL

NOVEMBER 1947

BUSHIPS Electron

NavShips 900,100

NOVEMBER 1947 • VOLUME 3 • NUMBER 5

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FRONT COVER—The front cover of this issue ties in with the leading article, MOVING TARGET INDICATION. The artist has shown an abstract of the reason for the MTI: to enable moving targets to be detected through the strong return from stationary targets such as land masses. He has picked out the moving targets and shows them clearly against the suppressed background of unimportant echoes, linking them to the MTI Conversion Unit.

BUSHIPS Electron

A MONTHLY MAGAZINE FOR ELECTRONICS TECHNICIANS

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Bureau of Ships (Code 993-b)
Navy Department
Washington 25, D. C.

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BUREAU OF SHIPS — NAVY DEPARTMENT

MOVING TARGET INDICATION

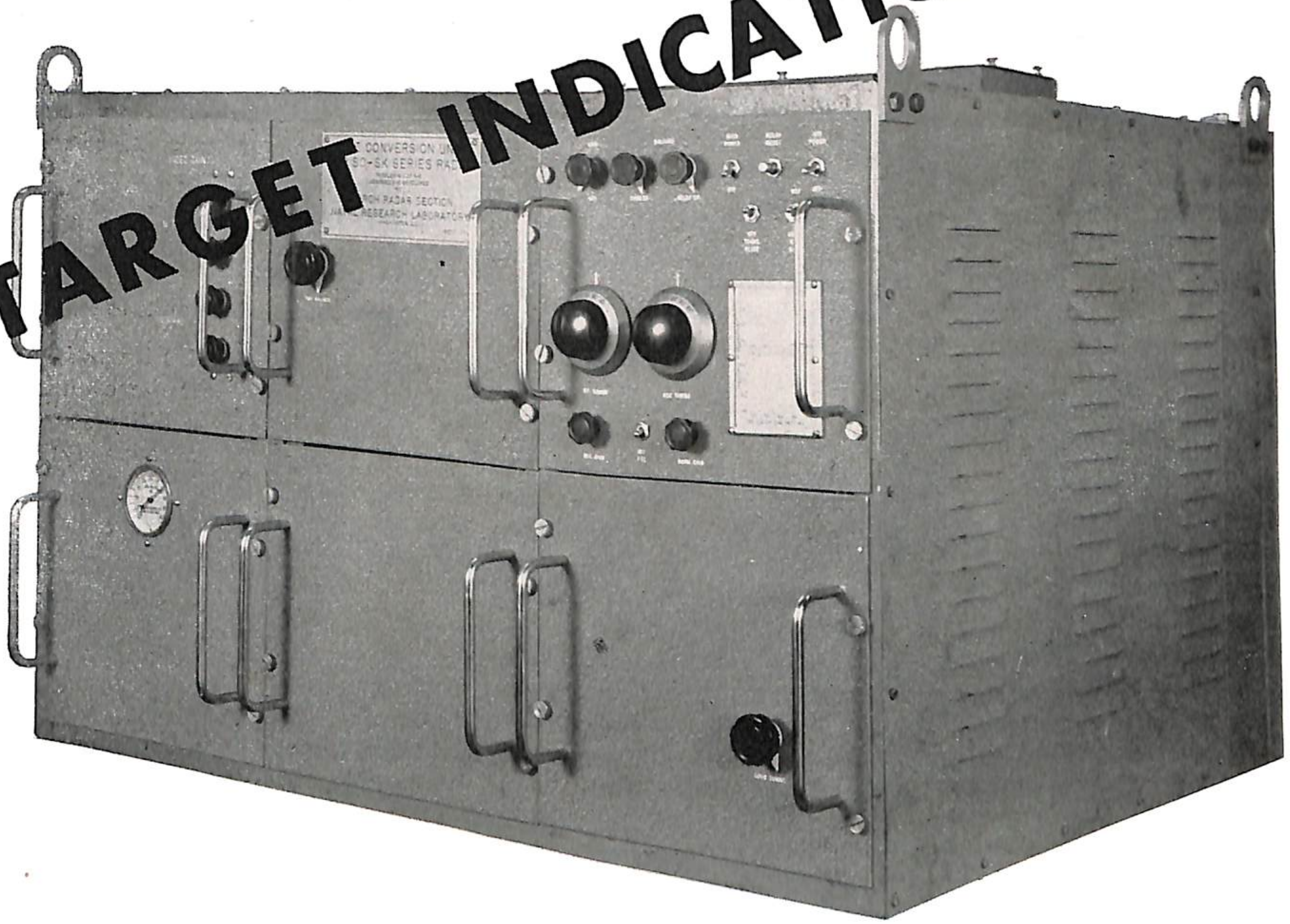


Figure 2—*The MTI Conversion Unit for the SC-SK radars.*

MOVING TARGET INDICATION

I. H. Page and T. H. Chambers

■ Radar engineers have been working intensively for many years to increase the performance of radar systems so that smaller targets can be detected at greater distances. This endeavor has been valuable as it tended to improve the probability of detecting aircraft and surface targets aboard ships operating well out to sea. However, the last phases of the war in the Pacific required naval support of huge landing operations. It was soon discovered that fleet operations in the shadow of relatively large land masses saturated our powerful radars with literally millions of echoes from land objects. As a result the few enemy aircraft echoes intermixed with the multitude of landscape echoes and were virtually undetectable. In addition, echoes from waves, clouds, "window" (tin-foil strips dropped by enemy planes), and echoes from our own planes and ships created such a confused picture on the radar indicators that the enemy was often able to come in very close *without detection*, the first warning sometimes being a roaring Kamikaze coming in at mast height. The fact that over 250 naval vessels were struck by these sneak attacks in the Okinawa campaign alone clearly emphasized the need for a radar which would detect all targets with some degree of certainty.

The British, being faced with the radar clutter problem early in the war, made the earliest attempts at devising methods of improving radar performance in detecting moving targets in the presence of large fixed land echoes. Most of their attempts were doomed to failure; but out of their early work came the supersonic delay line and the proposal for a system which was theoretically capable of eliminating fixed echoes from a radar indicator. It remained for Radiation Laboratory at M.I.T. to develop the basic idea into a demonstrable laboratory system. This device was designated "MTI," meaning "Moving Target Indicator." Since that time the designation "MTI" has been used for any radar system which performs the function of eliminating fixed echoes and presenting moving target echoes on the indicator.

The principle of operation of this basic MTI system is simple. As a radar transmitter transmits a series of recurrent pulses, and the receiver receives the echoes which are returned from objects during the time periods between the transmitted pulses, it should be possible to store the echoes (in a memory device of some kind) following one transmitted pulse and then subtract them (in an electronic circuit) from the echoes which follow the next transmitted pulse. All echoes which have not moved during this period will cancel but moving targets in general will not cancel because they are not in the same position from one pulse to the next. However, in a practical radar system the pulse duration is in the order of one microsecond which is equivalent to 167 yards in range. Even a high-speed airplane will move only a few feet between transmitted pulses, and its echo will cancel just about as well as a fixed echo unless something is done to enhance its movement.

This enhancement of movement is accomplished by means of a "coherent receiver." A coherent receiver may be just like any other radar receiver except for one added element—a continuous wave signal at the transmitter frequency (or at the receiver intermediate frequency) which is very stable and which locks in phase with the transmitter during each transmitted pulse. This coherent c-w in the receiver will always have the same phase at any particular range from pulse to pulse. Now, as we have this c-w signal injected into the receiver as a phase reference, a very small amount of movement of any target will give an echo which is different in phase with respect to the coherent c-w from pulse to pulse, and which when passed through the receiver detector will show a different pulse amplitude from pulse to pulse. Therefore, in general, a moving target will not cancel in the fixed echo cancellation device. For example, suppose one echo pulse from a plane is exactly in phase with the coherent c-w. If the plane should change range by 1/4 wave length (meaning a path length difference of 1/2 wave length for the signal to go out and back) the echo will now be exactly out of phase with the coherent c-w. The first pulse, being in phase, will add to the c-w in the detector and give increased output. The second pulse, being out of phase, will subtract from the c-w giving decreased output. It is seen therefore that if these signals are subtracted, the two being of opposite polarity, their voltages will add and the resultant signal from the aircraft will be present. A fixed signal, on the other hand, will remain in the same relative phase from pulse to pulse and when subtracted will vanish to zero. The means by which all this is accomplished are explained in simple terms in the paragraphs to follow.

Although the basic principle in MTI is relatively simple, the necessary equipment is quite complex and requires circuit precision and stability far exceeding that formerly required of a radar equipment.

In order to cancel fixed echoes to 1/30 of their former amplitude (a practical engineering goal) all instability effects in the radar, such as frequency modulation, amplitude modulation, and pulse-rate jitter, must be reduced so that their combined effect is less than 1/30 of the pulse amplitude.

After this is accomplished there must be injected into the receiver a coherent c-w signal which is highly stable, yet capable of being phase-locked to the transmitter without appreciable indeterminacy. A fixed echo-cancelling device may then be added with some chance of success.

A fixed echo-cancelling device contains a memory or storage unit which accepts signals as a function of time and at some later moment can exactly reproduce these signals in wave shape and time sequence. Additional electronic circuits are required which will subtract the stored signals from the direct signals, giving a signal output only in the event that dissimilar signals indicating the presence of moving targets are present. Depending upon the type of storage device, various pulse-synchronizing, sweep, and trigger circuits are required to assure that the pulse timing and storage comparison timing are exactly right to superimpose the direct and the stored signals.

Although early work was done at the Naval Research Laboratory on sonic delay lines (quartz crystal transducers cemented to metal rods), it remained for the British to develop a liquid supersonic delay line capable of delaying a radar pulse with sufficient fidelity for MTI applications.

The British delay lines used a water medium (contained in a pipe) with plated quartz crystals coupled to each end of the water column. A carrier frequency (about 10 Mc) on which the radar video pulses were modulated allowed a transmission spectrum of about 600 kc band width and a delay time of approximately 1000 microseconds, which is sufficient for many radar applications.

In 1943 Radiation Laboratory assigned a group to MTI work and their research resulted in the mercury delay line which was capable of much better fidelity and lower transmission losses than water delay lines. They developed an MTI system for a microwave radar which successfully demonstrated the principle and, under laboratory conditions, was capable of virtually eliminating fixed echoes while showing moving targets quite well. This system was in operation in the fall of 1944.

At that time NRL was requested by BuShips to survey the MTI field and to develop an MTI system for air-search radars which could be operated aboard naval vessels. The problems incident to MTI operation on a moving ship compared to operation at a fixed ground site are considerable. Motion of the ship makes even fixed targets appear as though they are moving. In addition roll, pitch, and vibration are factors which have to be taken into consideration in the design of many critical elements in which any mechanical instability can cause echo modulations from pulse to pulse, thereby causing fixed echoes to appear as moving targets.

The amplitude of response in a delay line cancellation unit can be expressed by the following equations:

$$E_o = E_I \sin \pi \frac{f_d}{f_r} \qquad (1)$$

where E_o = output voltage after cancellation,
E_I = input voltage,
f_r = repetition frequency of radar, and

$$f_d = \text{doppler frequency} = \frac{2Vf_o}{c} \qquad (2)$$

where V = target radial velocity,
f_o = r-f frequency of radar pulse, and
c = velocity of light.

It is seen from the above equations that the radar repetition frequency, the radar transmitter frequency, and the doppler frequency are all interrelated. Doppler frequency is directly proportional to the r-f frequency with a fixed target velocity. Repetition rate is associated with doppler because of the fact that it is during the time interval between radar pulses that the phase change due to the motion of the target takes place.

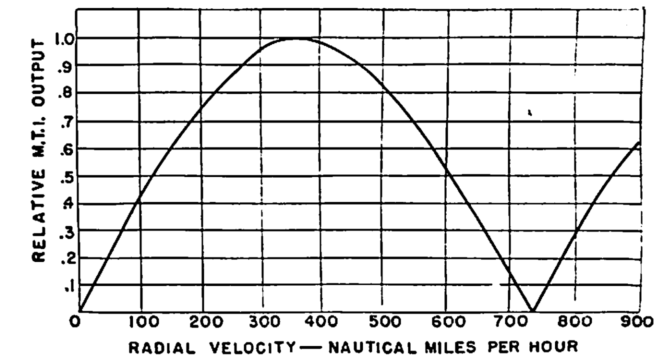


FIGURE 1—*Velocity Response SC-SK MTI.*

Equation (1) gives a clue to a method of reducing the effect of ships' motion to a low value. If we arbitrarily state that a ship speed of 20 knots will not cause a reduction of cancellation ratio below 10 to 1 in voltage, we can determine the ratio of pulse repetition frequency to radio frequency which can be tolerated in the system.

Rewriting equation (1)

$$E_o = E_I \sin \pi \frac{2Vf_o}{cf_r}$$

and rearranging,

$$\frac{E_o}{E_I} = \sin \pi \frac{2Vf_o}{cf_r}$$

$$\frac{2Vf_o}{cf_r}\pi = \sin^{-1}\frac{E_o}{E_I}$$

equation (2) becomes

$$\frac{f_o}{f_r} = \frac{c}{2\pi V}\sin^{-1}\frac{E_o}{E_I}$$

$$\frac{f_o}{f_r} = \frac{186{,}000 \times 3600}{2\pi \times 23}\sin^{-1}\frac{1}{10}$$

$$\frac{f_o}{f_r} = 463{,}000$$

which is the ratio of radio frequency to repetition frequency necessary to allow a cancellation ratio of ten to one with the ship moving at 20 knots. If we consider a 220 Mc radar

$$f_r = \frac{220 \times 10^6}{463{,}000} = 475 \text{ pulses per second}$$

Reconsidering equation (1) to determine at what velocity maximum moving-target output will be obtained, it is evident from observation that E_o will be maximum when the target moves one-quarter wave length during the interval between pulses, or when

$$f_d = \frac{f_r}{2}$$

Since

$$f_d = \frac{2Vf_o}{c}$$

$$V = \frac{f_d c}{2f_o}$$

For maximum output

$$f_d = \frac{f_r}{2} = \frac{475}{2} = 237.5$$

$$\text{So that } V = \frac{237.5 \times 186{,}000 \times 3600}{440 \times 10^6} \text{ mph}$$

$$= 362 \text{ mph or } 315 \text{ nautical mph.}$$

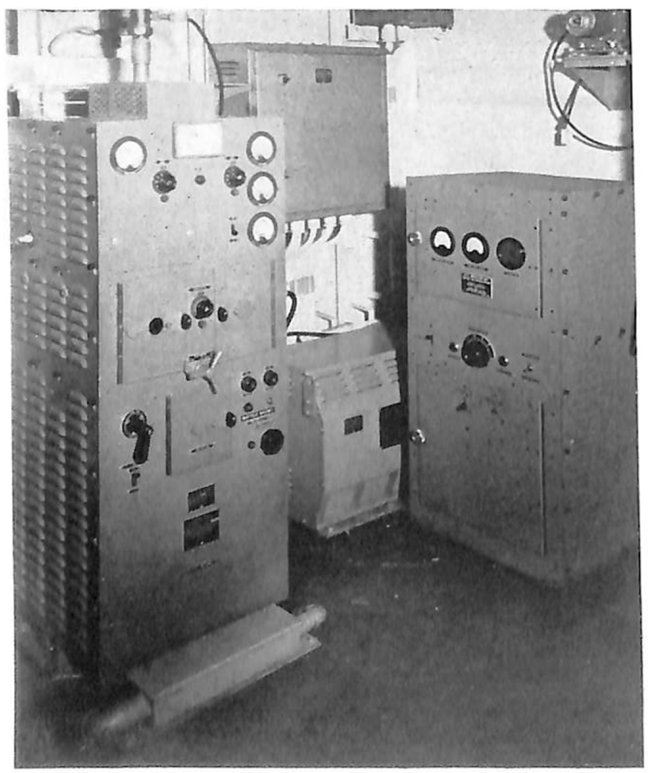


FIGURE 3—*The New MTI Modulator Unit for SC-SK radar mounted beside the transmitter in a typical shipboard installation.*

Output will be 0.7 at 181 and 543 mph, and 0.5 at 121 and 605 mph, which satisfactorily covers the operational speeds of aircraft.

This fortunate choice of radio frequency and pulse repetition frequency results in a system with very satisfactory characteristics in shipboard use. As the navy SC-SK series air-search radars operated in the 200-Mc band it was opportune, as a first step, to develop MTI equipment for those systems. A pulse repetition frequency of 500 per second, requiring a mercury delay line of 2000-microseconds delay was chosen to give a workable compromise between reduction of effects caused by ships' movements combined with good sensitivity to targets moving at typical aircraft speeds. The resulting velocity response curve for the SC-SK MTI is shown in figure 1.

The MTI Conversion Unit for the SC-SK is shown in figure 2. It will be seen that this unit was built in approximately the same form factor as the PPI supplied with this series radar so that it might be installed in the space previously occupied by this unit. Figure 3 shows the new modulator unit applied to the transmitter in conjunction with the conversion of this system to MTI. The new unit is shown mounted beside the transmitter in a typical shipboard installation.

A block diagram of the complete radar system after conversion to MTI is shown in figure 4. This diagram was especially drawn to show considerable detail in the Conversion Unit since this unit contains the major MTI circuitry in addition to the normal receiver. It will be noted that the Conversion Unit is shown divided into four major parts: the normal channel, the coherent system, the cancellation system and the trigger system. It will be worthwhile to describe each of these four parts briefly.

The normal channel is just what its name implies. It is a good anti-jam receiver utilizing nonamplified back-bias and switchable fast time constant to give normal radar performance on all targets, both fixed and moving. It is shown receiving i-f from the coherent system, but this should not be interpreted to mean that its operation is in any way tied in with the coherent system. Indeed, as a closer examination of the block diagram will show, the i-f is supplied directly from the signal converter which is normal in every way and is shown as part of the coherent system only to make the discussion of this latter system a little clearer.

The second part of the Conversion Unit, the coherent system, performs the first of the two func-

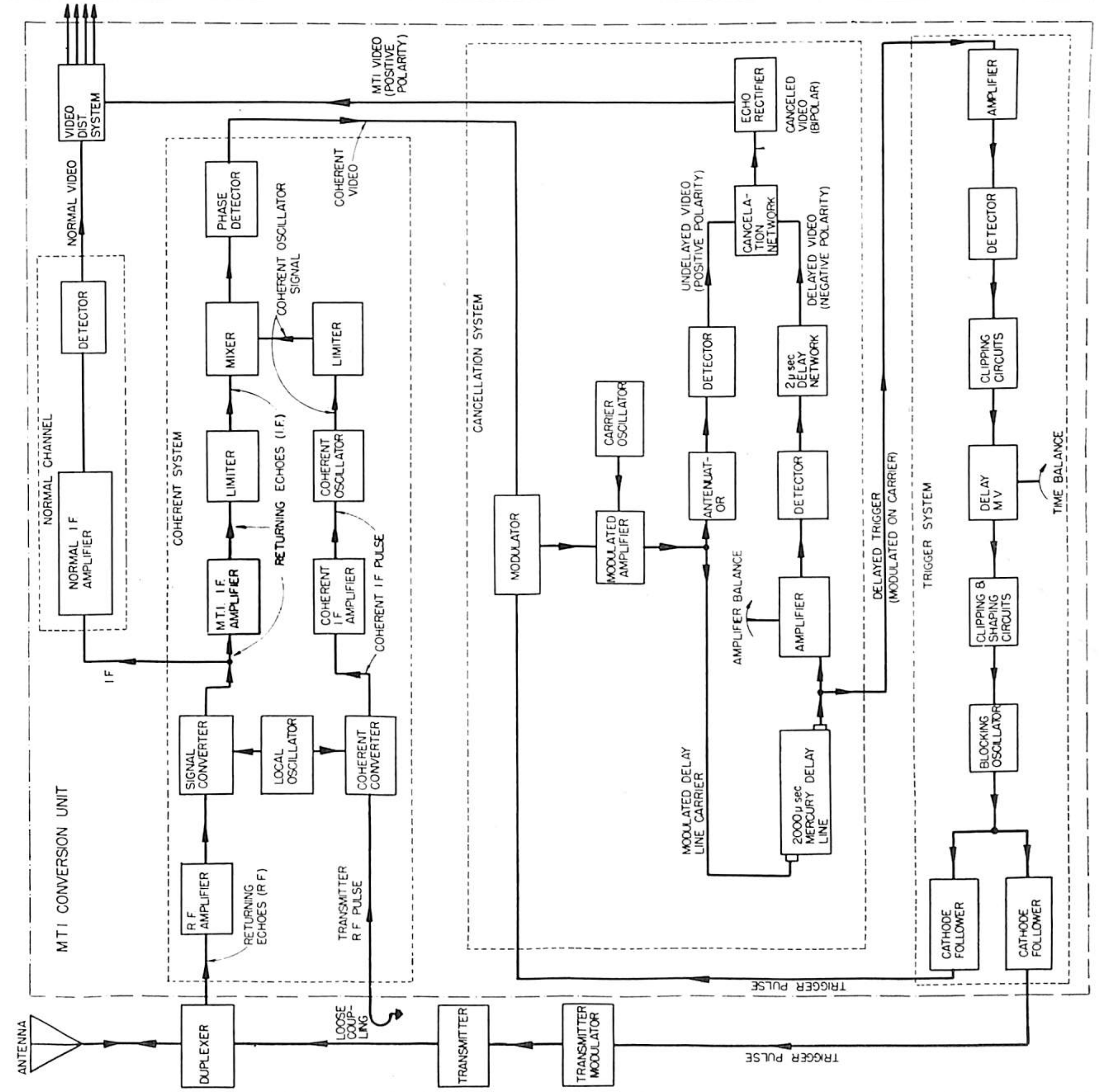


FIGURE 4—*Block diagram of the SC-SK MTI system.*

tions necessary in any MTI system, namely, the detection of doppler shift due to target motion. The method by which this detection is accomplished can perhaps best be described in connection with figure 5. This diagram, showing the r-f signal for two successive transmitter pulses, includes the all important phase relationships. For the sake of clarity two simplifications have been made in this drawing: the transmitted pulse is shown to consist of only three cycles rather than the hundreds of cycles radiated by an actual radar transmitter (400 cycles in the case of the SC-SK converted to MTI), and the phase comparison is shown as taking place at r-f rather than at i-f after conversion. Since phase relations are preserved intact through conversion, this has no effect.

Consider now the wave forms of figure 5. Line (1) shows the transmitted pulse. Line (2) shows the output of the coherent oscillator. This will be seen to be nothing more than an extension of the transmitter pulse for an indefinite period of time. Line (3) shows two returning echoes from the Nth pulse. Although the time at which these echoes return is arbitrary (depending on their range) they are assumed for the sake of simplicity to return at a time such that they are in phase with the coho. The resultant after adding these two echoes to the coho signal is shown in line (4). After detection, the video signal of line (5) is obtained.

Consider now the next, or (N + 1) th pulse. The transmitter pulse and coho output will be the same as shown in lines (1) and (2) for the Nth pulse. Assume now that the first echo is from a fixed target and that the second echo is from a target whose range is increasing. Obviously, then, the echo from the first target will return after the same delay (as for the Nth pulse) and will again be in phase with the coho and will give the same resultant and video signal as shown by lines (6), (7), and (8), respectively. On the other hand, because the moving target has increased its range, its echo will return after a somewhat greater delay as shown in line (6). In this case this target is assumed to have moved an amount such that the echo returns one-half cycle later. Thus the echo r-f is now exactly out of phase with the coho and, when added to the coho, gives a resultant as shown in line (7). The video is then as shown in line (8).

Recapitulating, it will be seen that, in the case of a fixed target, the video remains the same amplitude from pulse to pulse while in the case of a moving target, the signal changes in amplitude from pulse to pulse. It is this characteristic which will later be used to separate the moving and fixed targets in the cancellation system.

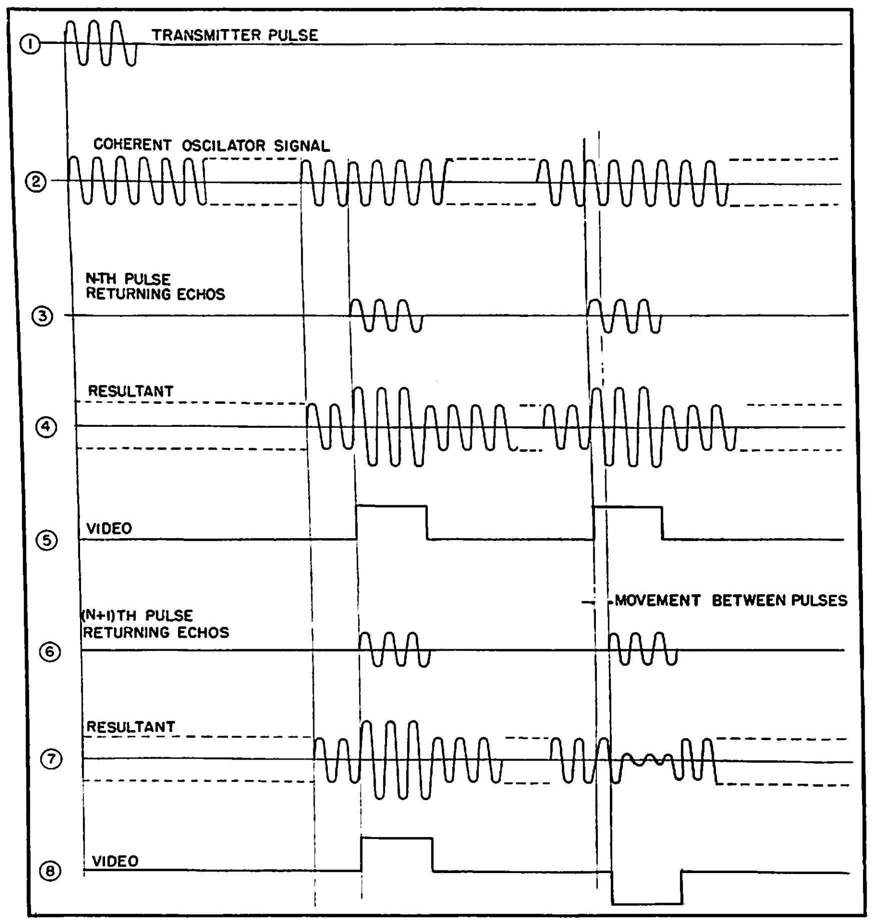


FIGURE 5—*Operation of the Coherent system.*

Returning to figure 4. The circuitry used to obtain this coherent operation is straight-forward. The r-f amplifiers are low-noise, grounded-grid stages and the signal converter is a low-noise triode. The local oscillator differs from standard practice only in that special pains have been taken to secure stability and freedom from microphonics. The MTI i-f amplifiers are standard and the limiter is of usual design and is set to limit peak signal level to about 30 db above noise level.

The coho converter is similar to the signal converter except that the presence of only very strong signals makes it possible to use circuits which are unresonated and need not be retuned when transmitter frequency is changed. The coho i-f amplifier is straight-forward except for the last stage which is operated class C so that it draws no current except during the actual phasing operation. The coherent oscillator is a Hartley oscillator operating at the intermediate frequency (15 Mc) and here again special pains have been taken to insure stability and freedom from microphonics.

The mixer and phase detector are the only two circuits of unusual design, and here the only feature unlike standard radars is the use of a system which is simultaneously push-pull for signal components and single-sided for coho components. Such an arrangement is used to increase the sensitivity of the system to the phase shifts discussed earlier in connection with figure 5.

The cancellation system performs the second function necessary to MTI operation, that of removing the echoes from stationary targets. Its operation is best described in conjunction with figure 6. Line (1) of this figure shows the coherent video signals from first, the Nth pulse, and then the (N + 1) th pulse. These signals are the same as those derived in figure 5 except that the transmitter pulse is included, and for a reason which will become apparent later, a second moving target echo, of polarity opposite to the first, has been added.

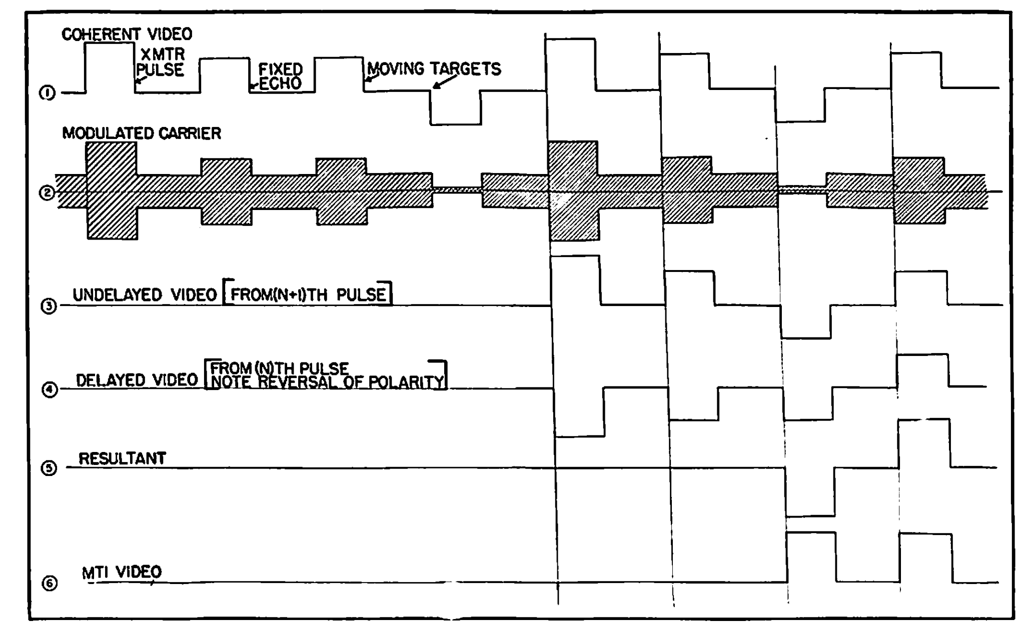


FIGURE 6—*Operation of the Delay and Cancellation system.*

Line (2) shows this video signal modulated on the delay line carrier. Line (3) then shows the undelayed rectified carrier from the (N + 1) th pulse. This, when added to the delayed signal from the Nth pulse shown in line (4) gives the resultant shown in line (5). It will be noted that at this point all the fixed targets have been eliminated, leaving only the moving targets. The video signal is, however, double-sided and must be rectified to throw all echoes up positive for the MTI video. The final waveform is then shown in line (6).

The circuitry used in the cancellation unit, although unusual in arrangement, is all of a type familiar to fleet radar personnel. The carrier oscillator, modulator, and modulated amplifier constitute in reality a small transmitter. This

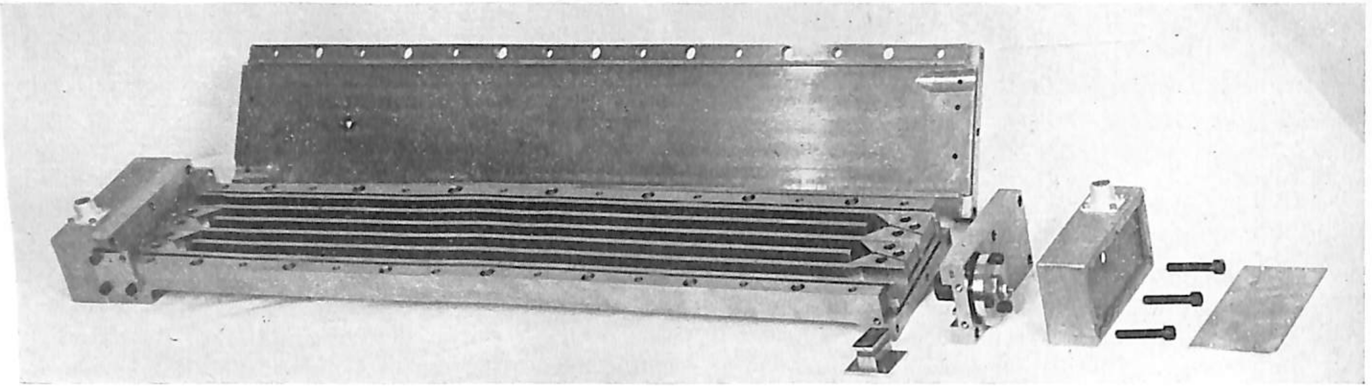


Figure 7—*Test model of the Pressurized Mercury Delay Line.*

transmitter delivers a 15 Mc carrier, modulated by the video signal, and at a carrier level of about 60 volts, to the transmitting crystal of the delay line. This delay line is the only component of the system which will be completely new to the radar technician. It consists essentially of a column of mercury, excited at one end by means of a quartz crystal with a supersonic (15 Mc) signal, carrying (as modulation) the signal which it is desired to delay. This supersonic wave travels down the column of mercury at a speed of about 1 foot in 200 microseconds so that by making the mercury column have the correct length the signal may be delayed by the desired amount. At the receiving end of this mercury column, the wave strikes a second quartz crystal which converts it back to an electrical signal.

In a practical delay line for use in a radar system, the mercury column becomes quite long (in the SC-SK system it is 10 feet long) so that the line is "folded" to make it a more convenient size. This "folding" consists simply of folding the mercury column back on itself and then reflecting the supersonic wave around the turn by means of a corner reflector. Figure 7 shows a view of the delay line for the SC-SK with the cover removed so that the channels and corner reflectors may be seen. This line uses five channels each 2 feet long and has a total length of 28 inches. It operates with the mercury confined under a pressure of 35 lbs. per square inch and has proven quite satisfactory for use on shipboard.

Returning to the actual circuitry, the output of the delay line, which has been reduced to a few millivolts by losses in the line, is first built up to a level of several volts by a 15 Mc amplifier and then is detected to secure a video signal delayed 2000 microseconds and of negative polarity. This signal is then delayed an additional 2 microseconds (the reason for which will be discussed in connection with the trigger circuit) in a lumped constant video delay line and combined with the undelayed video signal. This undelayed video signal is obtained from a monitor on the output of the modulated amplifier driving the delay line. It is of positive polarity, and when added to the delayed signal in the resistance cancellation network, gives the bi-polar cancelled video signal of line (5) figure 6. This signal is then rectified to give the MTI video.

The last important part of the MTI Conversion Unit is the trigger system. This system serves to control the repetition rate of the transmitter extremely accurately (within 0.01 microsecond) so that the delayed Nth pulse and the undelayed (N + 1) th pulse will arrive at the cancellation network simultaneously.

Assume that the blocking oscillator (second block from the left in the trigger system) initiates a pulse. This pulse is simultaneously fed to the radar transmitter modulator where it initiates a radar pulse, and to the delay line carrier modulator where it is modulated at extemely high level (+125%) on the delay line carrier. It then passes through the delay line suffering precisely the same delay as the delayed video signal (2000 microseconds) and then through a separate carrier amplifier and detector. After passing through this detector, the pulse is clipped off the delayed signal (which of course also contains the delayed video signal) by means of high level clippers, and used to initiate a pulse from the delay multivibrator. This delay multivibrator is a one shot multivibrator having a pulse length variable from 1.5 to 2.5 microseconds. The trailing edge of this pulse is recovered by means of clipping and shaping circuits and used to initiate a new pulse in the blocking oscillator so that the cycle is repeated. Thus, a new trigger pulse is initiated after a delay time of 2002 ±0.5 microseconds. Since the video signal is delayed 2002 microseconds the system may be adjusted to a high degree of precision.

The other new unit added in the conversion of the SC-SK series radars to MTI is the transmitter modulator. It uses a pulse forming line and d-c resonant charging and is similar in general design to those used in many of the present shipboard radars.

Before leaving the SC-SK MTI system it might be well to mention briefly a few of its characteristics:

a—Exclusive of controls incidental to distribution of the new MTI video signal, it contains only two controls not found on an ordinary radar system: the amplitude balance control and the time balance control. Both of these controls are extremely stable and noncritical.

b—The entire system is very stable, being capable of operation for extended periods of time without readjustment.

c—Performance against clutter is excellent. The system has proven capable of tracking navy fighter planes through solid clutter in excess of 60 db strength.

d—System sensitivity is within 2 db of the sensitivity of the normal SC-SK series system.

e—System reliability is excellent. The mercury delay line, the element which has caused most trouble in previous systems, has operated for almost a year without servicing. This year's operation included four days of shock and vibration testing and a week and a half of sea trials.

This system also pioneered several important improvements in the MTI art. These are as follows:

a—Judicious choice of radio frequency and pulse repetition frequency to allow shipboard operation without comprising fixed target cancellation performance.

b—Invention and development of a compact, pressurized mercury delay line which will operate under conditions of roll, pitch and vibration encountered aboard ship.

c—Development of a locked-in trigger generator which automatically spaces the transmitted pulses by an interval exactly equal to the delay time of the delayed video, eliminating the need for frequent and critical adjustment of pulse repetition frequency.

In conclusion it may be stated that although the MTI principle has been definitely accepted many equipment problems are far from solved. Higher frequency radar systems need MTI probably even more so than the SC-SK systems which are now obsolescent, and exact methods of velocity compensation for own ship's speed must be developed. Simplified methods of signal storage and cancellation which may aid in reducing the complexity of the present MTI system are under investigation. It is the desire of the navy that all future radar systems contain MTI features to aid in the detection of planes and submarines and all promising leads are being investigated to accomplish an early fulfillment of this operational need.

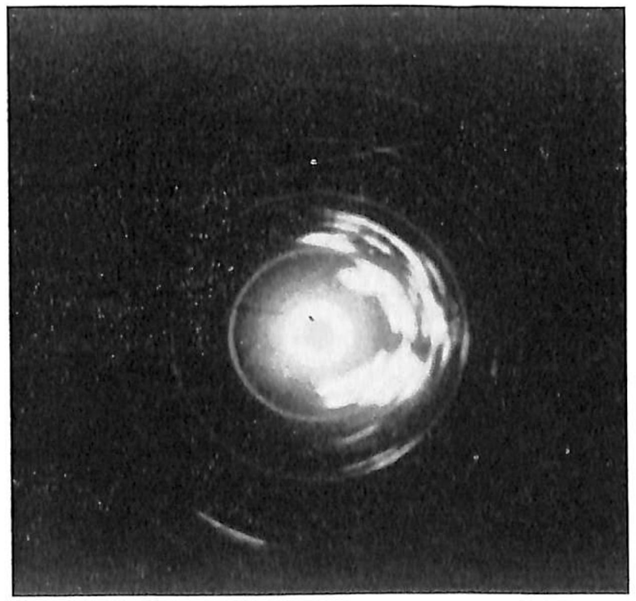


Figure 8—*PPI Indicator without MTI.*

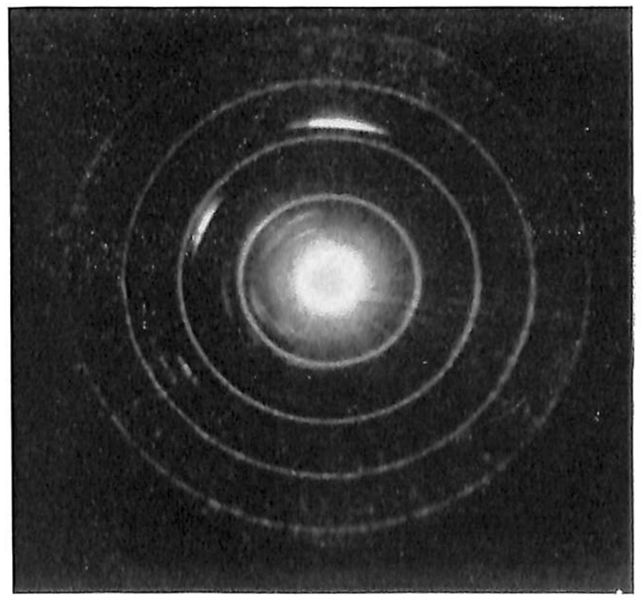
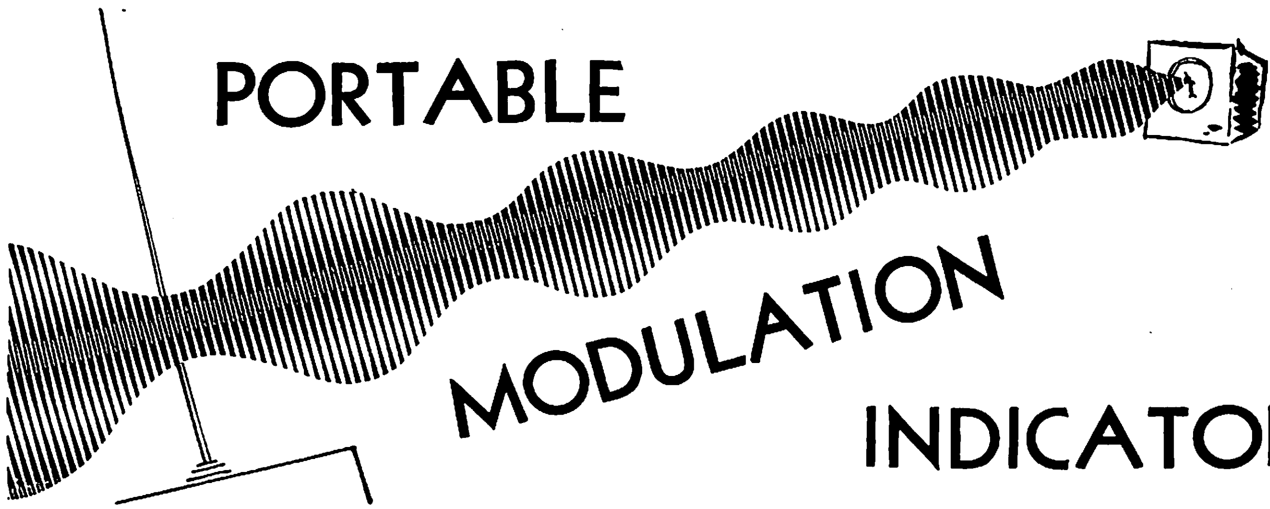


Figure 9—*PPI Indicator with MTI.*

PORTABLE MODULATION INDICATOR



PORTABLE MODULATION INDICATOR

■ An instrument based on a new idea but an old principle was recently designed at the Terminal Island Naval Shipyard to provide a convenient means of testing radio-phone transmitters without requiring the assistance of another station. It eliminates the time-wasting method now in use and will consequently fill a definite need in every naval facility engaged in repair, test, installation or inspection of radio transmitters. Described as a portable, batteryless modulation percentage and dynamic carrier shift indicator it enables a rapid quantitative check of transmitters without utilizing valuable air time or congesting regular communication circuits.

Designed so that operation is obtained only through utilization of the radio frequency signal from the transmitting antenna this unit gives a positive indication of the effectiveness of an entire radiophone system from microphone through antenna. Failure of any unit or component part of the system will show up under test.

For example, if one obtains a normal carrier reading, but when the microphone is spoken into gets no indication of modulation he has a positive indication of an abnormal condition somewhere in the system exclusive of the carrier generating components.

Should the modulation be asymmetrical, the meter will so indicate. It checks the percentage of modulation of both positive and negative half cycles of the modulating wave.

Should dynamic carrier shift exist, a deviation from the average meter reading (with the indicator selector in the CARRIER SET position) will be obtained upon application of modulation to the transmitter. Such a condition would indicate a weak or improperly adjusted or excited r-f amplifier.

The device consists of a short whip antenna coupled electrically to a resonant circuit whose frequency is continuously variable over a range from 2 to 75 Mc. A band switch divides this range into three bands: 2 to 7 Mc, 7 to 26 Mc, and 26 to 75 Mc.

The resonant circuit output is coupled to a type 1N23 silicon crystal which rectifies the r.f. The d-c output is then fed through a voltage dividing network to a microammeter which indicates average r-f carrier voltage. There is no attenuator in this device so it is necessary that the coupling be adjusted until the meter reads to a previously-calibrated carrier set mark. This may be accomplished either by changing the relative distance between transmitter and indicator or by changing the length of the whip antenna.

The same microammeter is also made to indicate the average value of either the positive or negative half of the modulating wave through the use of a selector switch circuit arrangement. This selector switch, when placed in either the positive or negative position, connects the meter to the output of a full wave dry disc rectifier. By switching back and forth from the positive to the negative position and at the same time noting the meter reading it is possible to determine whether or not the modulation is asymmetrical. If both readings are the same the modulation is symmetrical.

An additional feature of this unit is an earphone jack which enables the operator to obtain an aural indication of the operating condition of the equipment under test.

The parts list and schematic diagram for the modulation indicator are included in this article to provide interested activities with all the information necessary for its construction. It is simple

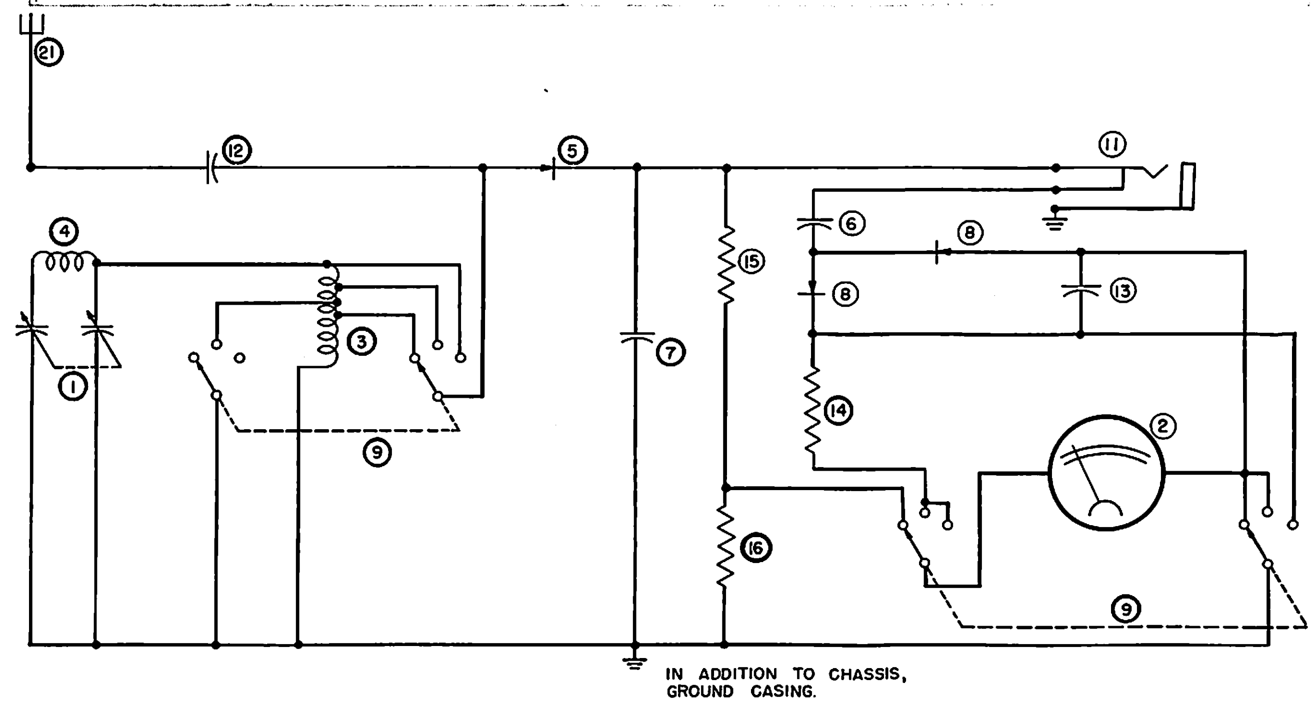


FIGURE 1—*Portable modulation indicator schematic diagram.*

TABLE I—*Parts List*

Item No.	*Description*	*Quantity*
1	Two-gang 100 μμfd per section variable	1
2	0-100 microamp d-c meter—3″ scale	1
3	R-f coil 30 μH, tapped at 3 μH, each section center-tapped	1
4	H-f r-f coil—0.7 μH	1
5	1N23 Sylvania silicon crystal	1
6	0.5 μfd condenser, 400-volt	1
7	0.005 μfd mica, 400-volt	1
8	Half-wave copper oxide rectifier (Conant)	2
9	5-position 2-pole selector switch	2
10	1½-inch feed-through insulators and hardware	2
11	Closed-circuit phone jack	1
12	50 μμfd mica, 400-volt	1
13	50 μfd, 50-volt dry electrolytic	1
14	5000-ohm, ½ watt	1
15	4000-ohm, ½ watt	1
16	250-ohm, ½ watt	1
17	Indicating knob, 1¼-inch	1
18	Indicating knob (frequency)	2
19	Terminal box, 6⅛″ x 6⅛″ (container)	1
20	Miscellaneous hook-up wire, nuts, screws	
21	Whip antenna, in three sections	

to build and costs very little as the majority of the parts are available in salvage. The two frequency determining inductance coils, Items 3 and 4 in the schematic drawing, have to be manufactured. Those in the original unit were designed by the builder and cannot be duplicated.

Item No. 3 is comprised of two coils wound ⅛″ apart on a 1″ low-loss mica-shellac base coil form. The first coil consists of 8 turns of No. 20 P.E. copper wire tapped at the center of the fourth turn and the second consists of 32 turns of No. 20 tinned copper wire tapped at the sixteenth turn.

Item No. 4 consists of 10 turns of No. 20 tinned copper wire wound on a ½″ form. After winding, the coil is slipped off the form and made self-supporting by soldering each lead to the two stator plate connections of the two-gang variable condenser.

There are many advantages to be derived from the use of this unit and it is recommended that all activities have one available. With the above data it is very simple to build and is considered to be well worth the effort. Its use will not only provide considerable saving in man-days but will also enhance the military effectiveness of our naval vessels by augmenting the communication qualifications of reliability and integrity.

RESERVE OFFICER TRAINING DUTY

Naval Reserve Officers who are graduates of the M.I.T. Radar School (or whose classifications contain the letter "T") are eligible to request annual fourteen days training duty at the Navy Electronics Engineering School, Harbor Building, M.I.T., Boston, Massachusetts.

Not more than ten officers will be ordered to this duty for any single two-week period. This training duty, however, is available at any time of year.

Officers eligible for and desirous of this training duty should submit requests to their commandants (or the Chief of Naval Air Reserve Training, if appropriate) indicating the dates this training duty is desired.

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DCDI AND DCRE TRANSFERRED

Depth Charge Direction Location Equipment, which consists mainly of the DCDI (Depth Charge Direction Indicator) and the DCRE (Depth Charge Range Estimator), has been transferred from the cognizance of the Shipbuilding and Maintenance Division to The Electronics Division. All future correspondence relating to this equipment should therefore be addressed to the Electronics Division of the Bureau of Ships.

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CLARIFICATION OF OCL TEST DATA

There seems to be some confusion in the field as to whether the data presented on the chart furnished in the cover of the OCL tube testing equipment or that given in Table 4-1 (Mutual Conductance Test Data) in the Model OCL Instruction Book, NavShips 900,807 is correct. Actually confusion is unwarranted. Both sets of data are correct although they give different settings of the controls. In paragraph 3(a) of the instruction book, NavShips 900,807 it is stated that the cover chart lists settings for a selected group of tubes on the basis of the red-green scale readings while the test data in the book gives settings for reading mutual conductance directly from the numerical scales.

The above information should clarify the situation, but to further reduce the possibility of future confusion it is recommended that the warning note, "Settings are for reading mutual conductance" be prominently placed on each sheet of the test data in NavShips 900,807.

TRAINING ERROR ON JT SONAR

The Bureau's attention has recently been called to a training error which exists in the JT sonar when Generated Target Train is being used. This report has resulted in steps toward instigating procurement of a field change kit which will provide an exact 36:1 ratio between the 5DG and the hydrophone shaft so that the TDC generated rate of change of bearing will track with the JT received bearing.

Until these kits are procured and installed, it is recommended that the JT operator be instructed to crank in the differential error and that special maintenance precautions be taken to keep the V-belts adjusted at all times. Worn belts should be replaced.

• • •

ELECTRONIC REPAIR KITS

During the late war the Bureau of Ships procured quantities of CZY-10223 Electronic Repair Kits for the primary purpose of supplying field activities with a kit of expendable tools and an electronic test instrument for emergency repairs and other work associated with electronics.

In view of the fact that both tools and improved electronic multitesters are available for ships and shore activities, the Bureau does not plan to procure this kit in the future. Fiscal restrictions dictate the policy of absolute economy in the procurement of such items.

It is intended that the CZY-10223 electronic repair kits remaining in stock be issued to ships only, except in unusual circumstances.

• • •

UHF EQUIPMENT INSTALLATIONS

It is again requested that every u-h-f installation be reported to the Bureau of Ships, Code 980. Each installing activity should take this action immediately upon completion of an installation, giving the type and serial numbers of the equipment.

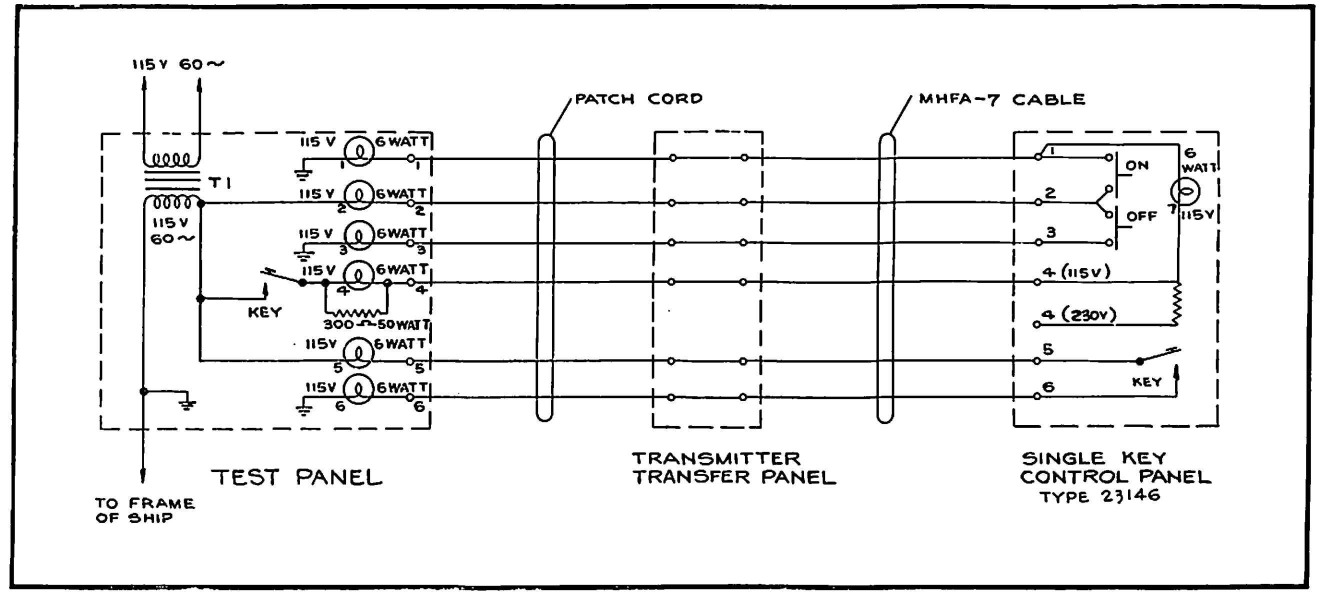
This accurate and up-to-date information must be available to the Bureau at all times if the important u-h-f conversion program is to be completed and coordinated satisfactorily with other military agencies.

The Bureau is now distributing monthly progress reports showing the percentage of completion of the u-h-f conversion program.

KEY CONTROL TESTER PANEL . . . . . .

■ A new device which provides a means of rapidly checking navy transmitter 6-wire control circuits has been submitted to the Bureau as a beneficial suggestion. Its use by field personnel will reduce considerably the time required to check and maintain in operating condition the Type -23146 key-control panels, radiophone units, transmitter transfer panel receptacles and associated patchcords.

This device, known as the Key-Control Tester Panel, consists of a 115-volt 60-cycle isolating transformer, a key contactor, six 6-watt 115-volt lamps and a terminal block. The lamps which are used as indicators on the panel are numbered one to six and have one side connected to terminals one to six on the terminal strip. These terminals then terminate in a receptacle mounted on the side of the tester case to provide a means by which the tester may be conveniently connected to a transmitter transfer panel. As this receptacle in the tester is a duplicate of the type used in practically all types of transmitter transfer panels, the only additional accessory necessary for testing is a patchcord containing a male plug on each end. A completed test layout is shown below.



Above—Schematic circuit diagram of panel. Below—Trouble-shooting chart.

TEST CONDITION	LAMP INDICATION	PROBABLE TROUBLE
Remote ON button released	No. 1 and 2 lighted	Wires No. 1 and 2 shorted
" " " "	No. 2 lighted	Wire No. 2 grounded
" " " "	No. 1 and 2 out	ON circuit normal
" " " pressed	No. 1 and 2 lighted	" " "
" " " "	No. 2 lighted, No. 1 out	ON button or wire No. 2 grounded
" OFF " released	No. 2 and 3 lighted	Wires No. 2 and 3 or button shorted
" " " "	No. 2 lighted	Wire No. 2 grounded
" " " pressed	No. 2 lighted	Wire No. 3 grounded
" " " "	No. 2 and 3 lighted	OFF circuit normal
Tester key closed	No. 7 and 1 out	Wire No. 4 or 1 open Lamp No. 7 burned out
" " "	No. 4 lighted	Wire No. 4 grounded
" " "	No. 1 and 7 lighted	Key circuit normal
Remote key closed	No. 6 out	Wire No. 6 grounded
" " open	No. 5 and 6 lighted	Wires No. 5 and 6 shorted
" " "	No. 5 lighted	Wire No. 5 or key grounded
" " closed	No. 5 and 6 lighted	Remote key circuit normal
" " "	No. 5 and 6 out	Open wire or defective key

To use the tester it is first necessary that two leads be run from the tester to the ship's 115-volt, 60-cycle power supply and one additional lead to ground. The two power leads are tied to the primary of the isolating transformer (T1) and the ground lead to the secondary of the same unit. A patchcord is then plugged into the tester receptacle and run to the transmitter transfer panel where it is plugged into the position requiring test. Under this arrangement it is then possible to check the above mentioned units for shorts, grounds, continuity and crosses.

The table shown on page 13 covers test conditions, lamp indications and probable troubles. It has been compiled in an effort to point out the versatility of this tester and to serve as a guide, and does not list the many combinations of opens, grounds and crosses which may occur and which can be detected by use of this unit. It is recommended that maintenance personnel study the table and the circuit schematic carefully and thereby familiarize themselves with the various uses of the equipment.

CABLE LENGTH IN TDP-1 EQUIPMENT

In the TDP-1 Loran Transmitting Equipment there is a length of RG-8/U coax cable running between the transmission line ammeters, M-402 or M-403 in the transmitter and M-901 or M-903 in the coupling unit. The length of this cable is critical and should not be a multiple of a quarter-wave length at the frequency used as there may be an accidental mismatch of impedance present. Such a mismatch would tend to accentuate standing wave effects and consequently reduce operating efficiency. It must be remembered that this mismatch condition is possible even though an impedance measuring device is used in making initial adjustments.

The safest solution to this problem is to cut the cable to an odd number of one-eighth wave lengths; it is satisfactory, however, to avoid multiples of quarter-wave lengths by a reasonable margin. The following table, compiled to cover practically all types of installations, gives cable lengths which avoid multiples of quarter-wave lengths by plus or minus 10 feet.

Table I

1950 KC	*1850 KC*	*1750 KC*
0-73	0-78	0-83
93-157	98-166	103-176
177-240	186-253	196-268
260-323	273-341	288-361
343-406	361-429	381-454
426-490	449-517	474-547
510-573		

As it is practically impossible in many cases to plan an installation wherein the distance between the transmitter and coupling unit will be equal to any one of the prescribed lengths given in the table, it will be necessary to cut the cable to a longer length as shown in the table, and coil up the excess near the transmitter end of the line.

The primary purpose of this article is clarification of the information contained in the text and in table (2-3) on page 2-4 of the TDP-1 Instruction Manual. All activities concerned with this equipment are requested to make the necessary corrections.

• • •

UNAUTHORIZED ANTENNA CONNECTIONS

The Model TDE radio transmitting equipment aboard an LST was operating very poorly. After tests had been made and time consumed by troubleshooting, the fault was traced to the antenna system. Further investigation then disclosed that the far end of the antenna was grounded by a length of wire being used for the antenna of a personal radio broadcast receiver. After removal of the wire, the Model TDE again performed satisfactorily.

The Bureau of Ships wishes to point out that the practices of affixing personal radio antennas to or erecting them near the communication antennas may prove dangerous to the personnel concerned and harmful to their personal equipment. Moreover, such practices reduce the efficiency of Naval communication equipment and should therefore be discontinued.

Grounded-Grid R-F Power Amplifier

• • • • • • • • •

INTRODUCTION

■ The present trend towards increased exploitation of the very-high and ultra-high ranges of the frequency spectrum at greater powers and in such applications as FM and short-wave AM radio communication, both in commercial and military service, have brought into sharp focus the difficulties of achieving adequate transmitter efficiency under the simultaneous dictates of high powers and high frequencies.

These difficulties are formidable. On one hand, large triodes with large tube elements are required in the transmitter amplifier and modulator stages to supply the heavy currents and to withstand the high voltages found at high powers. Large tube elements are required, also, to dissipate the sizable amount of heat generated by electron impact on the plate and grid structures. On the other hand, small tubes and tube elements are also desirable. Otherwise relatively small lead and electrode inductances and capacitances, at the frequencies called for, will produce reactances comparable to and affecting the performance of those in the amplifier resonant circuits themselves. In particular, these reactances may result in parasitic oscillations, in which the r-f amplifier goes into uncontrollable self-oscillations. Such instability chiefly occurs by virtue of feedback through the plate-grid capacitance. These two demands—large tubes and tube elements for high power, and small tubes and elements to avoid the effect of tube reactances—are mutually conflicting and completely irreconcilable.

Accepting the challenge, however, radio engineers have slowly bettered transmitter performance. New techniques have been invented and judicious compromise and clever mitigation of unavoidable effects have been exercised in tube design. Indeed, many high-power high-frequency transmitter tubes as a consequence have assumed shapes that seem to belong more in a surrealistic painting by Salvador Dali than in a prosaic radio station.

An experimental-type grounded-grid r-f power amplifier tube. Fins are provided to aid in dissipating heat.

AMPLIFIER CIRCUIT

Recently, as one of these new techniques, there has appeared on the scene an unconventional r-f power amplifier circuit which promises to alleviate many of the difficulties of today's high-power and high-frequency operations. This new circuit is the grounded-grid amplifier, or inverted amplifier as it is sometimes called. The new line of transmitting equipment for FM broadcast stations just announced by the Radio Corporation of America, for example, features this circuit in its final r-f power amplifier stages to the complete exclusion of conventional circuits.

The grounded-grid amplifier possesses the following advantages:

1—Circuits are simpler and require fewer components. Operating adjustments are made easily.

2—Neutralizing, when necessary, is easy, and is not required at all for low powers.

3—Remarkable stability and lack of critical adjustment are presented.

4—Greater output can be obtained with a tube of a given size, so that smaller, less expensive types may be utilized.

5—The same tube types can be used in both driver and power amplifier, thus reducing the number of tube types required.

Just what is the grounded-grid amplifier that can boast such a list of advantages? As the name implies, it is an amplifier circuit in which the grid is grounded (at least for a-c potentials), and in which the cathode is free to vary in potential under the influence of the driving voltage. This is the direct

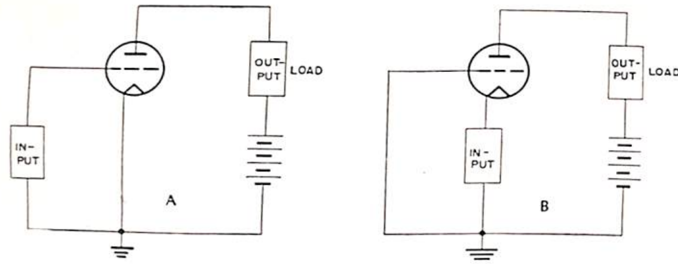


FIGURE 1—*Simplified schematic circuit diagrams of conventional amplifier circuit (A) and the grounded-grid amplifier (B).*

opposite of the conventional amplifier, in which the cathode is grounded for a-c potentials. Figure 1 shows the grounded-grid circuit and compares it with the conventional circuit. As an aid to the understanding of these circuits, there have been included in figure 3 the corresponding simplified a-c equivalent circuit diagrams, in each of which the effect of the vacuum tube is taken into account by replacing it with a fictitious generator in series with a resistance (r_p).

Careful study of these figures will bring out three features of the grounded-grid amplifier:

1—*The output voltage (a-c plate voltage) is in phase with the input voltage.* This is in contrast to the conventional circuit in which it is 180° out of phase. The difference lies in just which tube element is increased positively when the input undergoes a positive increase. In the conventional circuit, a positive-going signal makes the grid less negative with respect to ground and to the cathode, so that the grid-to-cathode potential difference, which controls the plate current, diminishes. Thus, more plate current flows, and the plate voltage drops—a phase change of 180° between input and

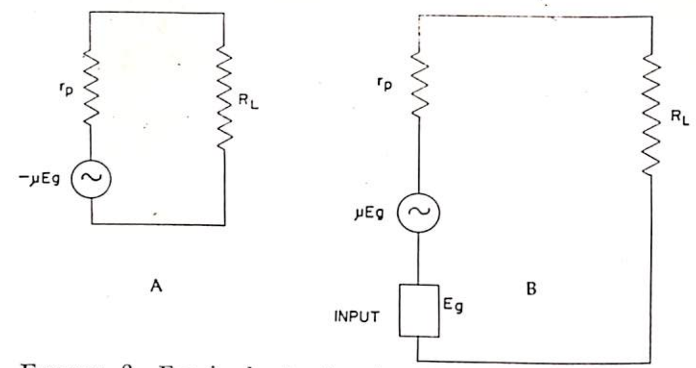


FIGURE 3—*Equivalent circuit diagrams of conventional (A) and grounded-grid (B) amplifiers in Class A service. The input in the latter is shown as a box to indicate that it has internal resistance. For Class B and C operation the input would be shunted by a resistance representing the grid-path losses.*

output voltages. In the grounded-grid circuit, on the other hand, a positive signal increment raises the cathode voltage without affecting the grid. Since the cathode is already positive with respect to the grid, the additional positive boost widens the cathode-to-grid potential difference, and reduces the plate current. The consequent rise in plate voltage is in phase with the initial input rise. This action in the conventional and grounded-grid circuits may be more clearly understood by referring to figure 4.

2—*The driver delivers power directly to the load.* Referring to figure 1, the reader will see that the circuit is so set up that the plate current flows through the driver as well as the load. Polarity connections, moreover, are such that the driver tends to augment, rather than impede, this flow of current. Thus the driver not only furnishes power

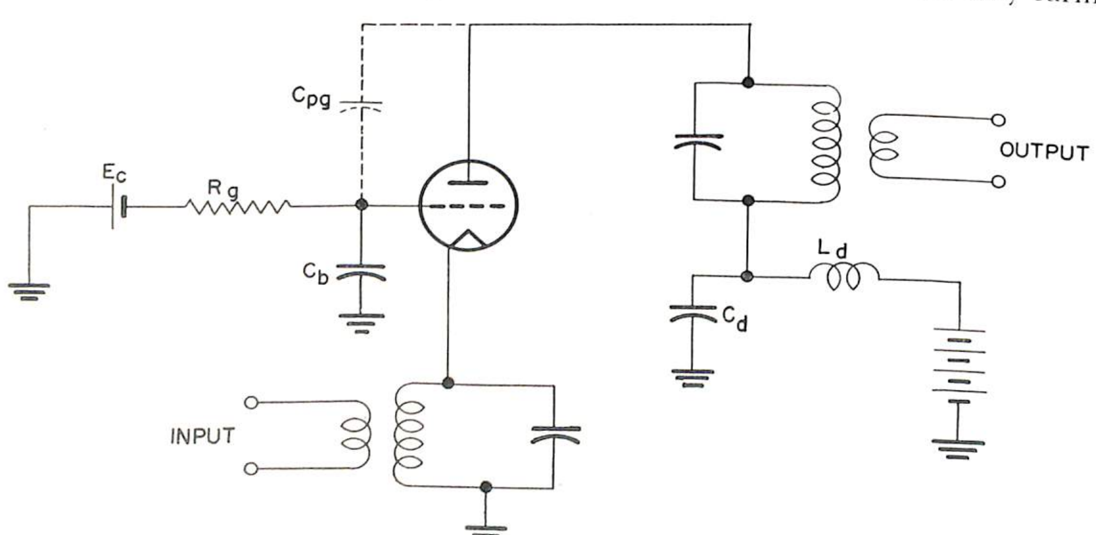


FIGURE 2—*Practical grounded-grid r-f amplifier circuit.*

to the amplifier tube (and loses power in the grid-leak resistor and in the grid-path when grid current flows) but also feeds energy directly to the load itself. For example, an actual inverted amplifier now in use with a power output of 59 kw derives 13 kw of that amount from the driver. Grounded-grid amplifiers act (for Class A operation), as if they were conventional amplifiers containing a tube with an amplification factor of $\mu + 1$.

In r-f power work circuits are often used with Class B or Class C operation, especially in push-pull, where this equivalent amplification is no

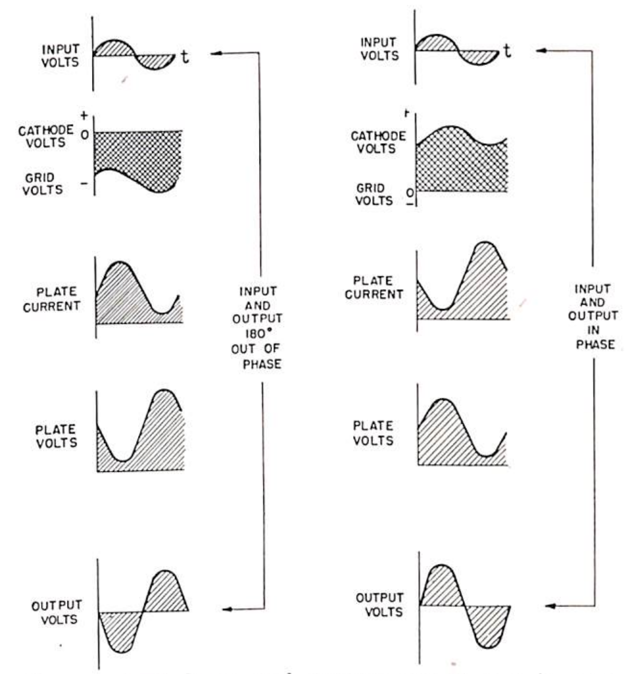


FIGURE 4—*Voltage and current waveforms in conventional (A) and grounded-grid (B) amplifiers, showing the output in phase with the input in the latter.*

longer $\mu + 1$, due to grid path losses. While interesting, the amplification factor is not important; what is important is the power gain. In the grounded-grid circuit, the gain is greater than in the conventional circuit, if tube currents and voltages are made the same. Of course, the added power does not appear from the tube by some sort of electronic magic, but is the power fed directly into the load by the driver. Practical results of this fact are that drivers for grounded-grid use must have higher ratings, and, moreover, that for a given power output, tubes with lesser power ratings may be employed in the grounded-grid circuit, since the amplifier tube supplies only a portion of the load power, rather than carrying the full burden, as in the conventional circuit. Because of this, it is possible to use the same type of tube in both driver and amplifier. For example, in the RCA 100 Mc FM transmitters mentioned above, the final output stage furnishes 3 kw of power, and is driven by a 1 kw driver stage; in both stages the same tube type (7C24) is employed.

3—*The grounded grid acts as a shield between grid and plate.* This third feature is by far the most important, for from it is derived the characteristic stability and freedom from parasitic oscillations that make the grounded-grid circuit worth using and considering in the first place. In conventional circuits, as the frequency of operation is increased, there is reached a point where feedback of energy from the output circuit to the input circuit is great enough to sustain parasitic oscillations, and the amplifier becomes unstable. This feedback occurs through the plate-to-grid interelectrode capacitance, which is relatively large compared to the other interelectrode capacitances. In the grounded-grid circuit, however, the output circuit does not affect the grid potential, since the grid is grounded. Hence, variations in plate potential do not alter the grid-to-cathode potential difference—the plate-current-controlling factor, it will be remembered—and feedback is eliminated. This produces the stability so characteristic of the grounded-grid circuit, permitting amplification to higher frequencies without the neutralization required in conventional circuits to balance out the plate-to-grid interelectrode capacitance feedback. Under high-power and high-frequency operation, some neutralization will be necessitated, but will, in any case, be simpler than with conventional circuits, and will call for smaller and simpler components in the neutralizing circuits.

PRACTICAL CIRCUITS

A practical one-tube circuit of the grounded-grid type is shown in figure 2. This circuit is adequate for certain high-power tubes up to frequencies of 40 Mc or so, and for low-power tubes up to hundreds of megacycles. Under these conditions, no neutralization of the plate-to-grid interelectrode capacitance (shown in dotted lines) is required. Several small points should be observed, in this circuit: First, C_b is a bias blocking condenser, which grounds the grid for a-c potentials, but permits the correct d-c bias voltage from E_c to be applied through the grid-leak resistor R_g. Second, the network L_d and C_d is the plate supply decoupling network. Before leaving this circuit, we should mention that push-pull circuits as well as the one-tube circuit are common.

As higher frequencies and higher powers are reached, the simple self-neutralized circuit above fails to prevent parasitic oscillations. This failure is the result of feedback from three sources of unavoidable reactance:

1—Inductance in the grid-to-ground path, including both the lead inside the tube and the external connection.

2—Inductance in the cathode lead (inside the tube).

3—Plate-to-cathode interelectrode capacitance.

In one case, we have capacitive feedback similar to the plate-to-grid feedback which is eliminated in the grounded-grid circuit. In the other cases, the reactances are common to both input and output circuits, and feedback is possible. The offending reactance elements are shown in figure 5.

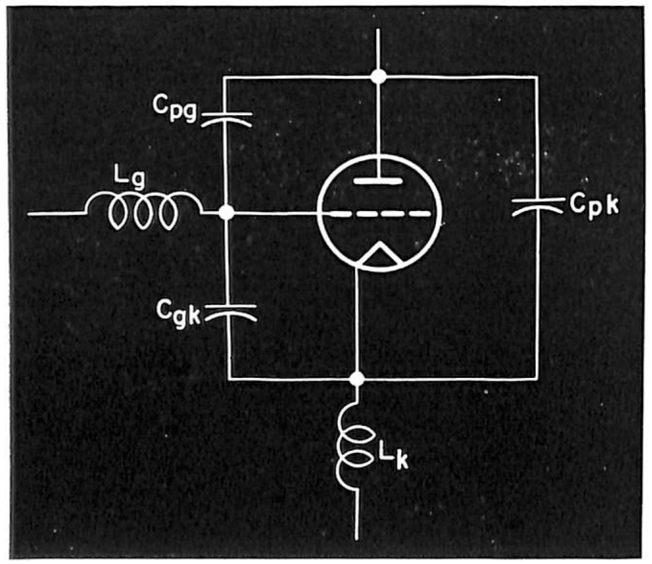


FIGURE 5—*Tube reactances appearing at h-f and u-h-f frequencies and causing the feedback which produces spurious self-oscillations.*

Although there is some tendency for the effect of the plate-to-cathode capacitance to balance out that of the grid lead, the cancellation is not effective beyond a certain frequency. The feedback problem has been appreciably simplified by the appearance of tubes especially designed for grounded-grid service. Such a tube is the RCA Type 7C24. In this tube a special grid structure provides unusually effective shielding between plate and filament, thus lowering the plate-cathode interelectrode capacitance. The grid is a large disc to which the glass of the tube is sealed; with the proper shield attached, this arrangement furnishes very effective isolation of the input from the output circuit. With tubes of this type, the only neutralizing expedient may be the insertion of a small inductance L_n in the grid lead, and the proper choice of the grid bias blocking condenser. This is illustrated in figure 6; neutralization is effective over a wide range of frequencies. At still higher frequencies the blocking condenser may need to be tuned, or L_n may need to be omitted and a tunable condenser substituted in order to achieve neutralization.

With higher powers (100 kw, for example) at these high frequencies, push-pull Class B operation may be utilized. Moreover, at these high powers, tubes especially designed for grounded-grid circuits may not be available. Under these circumstances, neutralization becomes somewhat more complex. All three of the feedback reactances mentioned above must be compensated for, since cathode leads are heavy and their inductance no longer negligible. Moreover, the large size of the tubes and the

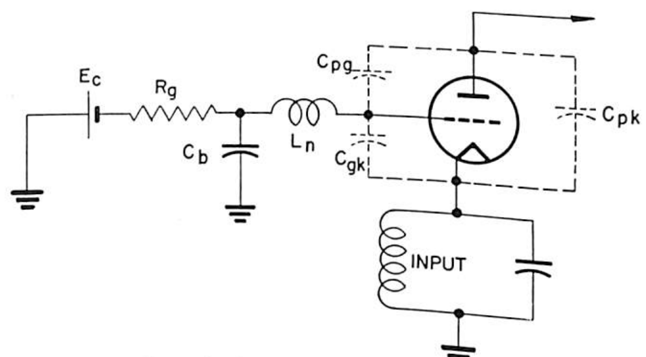


FIGURE 6—*Practical one-tube grounded-grid amplifier using tubes specifically designed for grounded-grid service, and including neutralizing grid inductance L_n. Can handle higher powers and frequencies than that of figure 2.*

necessity in push-pull service that they be set apart a certain distance from each other and from ground to prevent high-voltage arc-over both result in a large amount of inductive reactance in the grid-to-ground path. Moreover, the massiveness of the tubes leads to comparatively large values of plate-to-cathode interelectrode capacitance.

It is found possible to tune out the inductive reactances by inserting a tunable condenser in series with each inductance. The adjustment is sharp but is an easy one. To eliminate the plate-to-cathode capacitive feedback, the cross-neutralization circuit is indicated. This circuit is similar to the one commonly used in conventional push-pull circuits to neutralize the plate-to-grid feedback by taking advantage of the fact that currents and voltages in

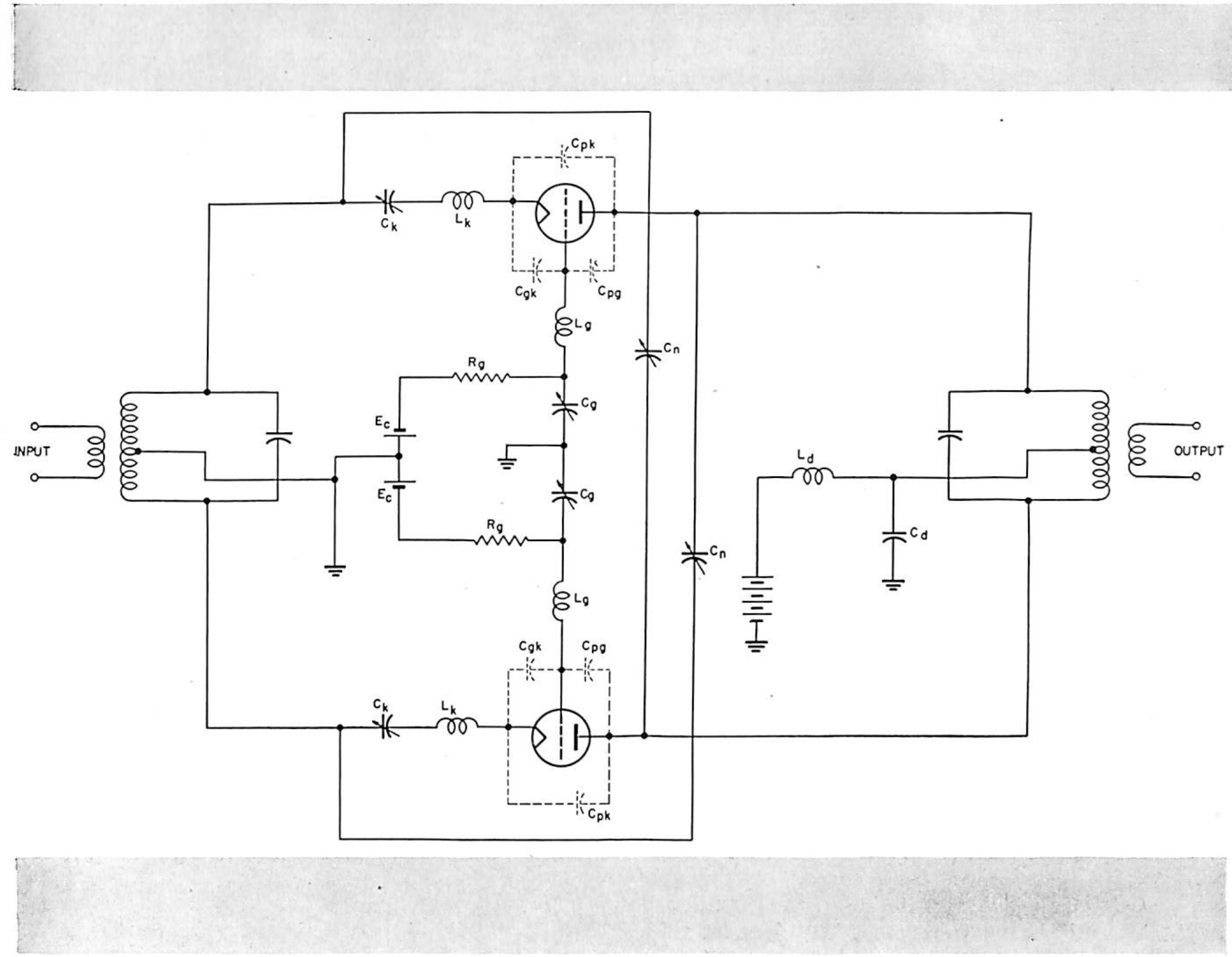


FIGURE 7—*High-power h-f and u-h-f Class B push-pull grounded-grid power amplifier. Shows full complement of neutralization techniques: 1—Resonant condensers C_g to tune out reactance of grid-path inductances L_g. 2—Resonant condensers C_k to tune out reactance of cathode-lead inductances C_k. 3—Cross-neutralizing condensers C_n to balance out feedback through plate-to-cathode interelectrode capacitances C_{pk}. Has greater power-handling capabilities than circuit of figure 6.*

the two tubes are 180° out of phase, so that cancellation can occur. In figure 7 is shown the complete set of push-pull neutralizing circuits, including cross-neutralization condensers from plate to cathode of the opposite tube, and the tunable resonant condensers in grid and cathode circuits.

Although this circuit seems just as complicated as the corresponding conventional push-pull circuit, which would also have series resonant neutralizing and cross-neutralizing condensers, there are several important advantages which this circuit exhibits. First, the grounded-grid circuit has only the relatively small plate-to-cathode capacitance to balance out, unlike the conventional circuit with its relatively large plate-to-grid capacitance. This simplifies equipment layout problems, and removes the need for designing special high-voltage condensers. Second, the capacitance (stray capacitance to ground, neutralizing condensers, etc.) which bleeds off energy from the plate tank circuit is much less because the neutralizing condensers are smaller. Hence, less energy is lost, and greater efficiency results.

It will be seen, then, that just what neutralization expedient will have to be resorted to depends on the conditions of operation, such as the frequency and power, and upon the tube used. In any case, it is found that the grounded-grid circuit is simpler, easier to adjust, and more stable than the conventional circuit.

Modulation of the plate in radiotelephony introduces new problems. It is found that the driver must be modulated simultaneously with the power amplifier, or phase modulation will be introduced. The reason for this is that plate modulation causes the load on the driver to vary because of the varying resistance of the amplifier tube under these conditions. Economically practical drivers do not possess good enough voltage regulation characteristics to handle such load changes (indeed, the ratio of driver loads occurring during modulation is about 2:1 in resistance), without varying in output voltage themselves. As can be shown by detailed study, phase modulation will occur if the driver voltage varies. By properly modulating the driver, we may cancel out the driver variations and eliminate phase modulation.

It should be mentioned that, in the practical adjustment of these circuits for the proper neutralization null, a somewhat different procedure from the usual one must be followed. It is not possible to neutralize a grounded-grid amplifier by feeding in r-f with the plate supply off. Conduction of r-f current through the tube can occur as a result of the manner in which the cathode and grid are connected, and an r-f ammeter in the plate circuit can indicate the flow of current, even when the circuit is neutralized. Consequently, the filaments must be cold when the grounded-grid circuit is neutralized. In this connection it should be pointed out that changes in tube interelectrode capacitance between hot and cold filament conditions may occur, resulting in deneutralization when filaments are turned on after cold-filament neutralization. Checking under actual operating conditions will be the final test, and will indicate any slight adjustments needed. The criterion of neutralization—minimum feedback of r-f energy—still holds, of course.

CONCLUSION

The grounded-grid circuit, especially adapted to high-power high-frequency transmission, is exhibiting in an ever-increasing number of installations its advantages of simpler components, fewer adjustments, and more stable operation. We in the naval service may well expect to see this circuit appear in service equipment, along with other new techniques which are continually extending the benefits achieved from electronics.

2C39 TUBES AGAIN

Failure reports on the type 2C39 electron tube used in the TDZ and MAR equipments are not yet being received by the Bureau in desired or expected number. Correspondence and verbal reports continue to indicate, however, that these tubes are failing abnormally and too frequently.

Approval for the type 2C39 tube was granted by the Bureau after extensive factory tests, but operational tests in the TDZ and MAR equipments were limited. This fact left some doubt in the Bureau about the tubes' performance under operating condition and prolonged storage.

In view of the importance of the ultra high frequency program and the desires of the Bureau to gain as much information as possible on these tubes, all activities with MAR and TDZ equipments are requested to fill out and forward to the Bureau a NAVSHIPS (NBS) –383 Failure Report Form immediately after a failure of a 2C39 electron tube. The form should be sent by air mail from all activities except those based on the east coast of continental United States. The card should be completely filled out and particular attention should be paid to the following items which should appear on the card:

A—Model and serial number of equipment involved.

B—Socket position in which failure occurred.

C—Tube markings, such as manufacturer, serial number, and other markings.

D—Operating conditions, such as voltage and frequency at the time of failure.

E—A description of the nature of the tube failure, or why its performance was unsatisfactory.

F—Total hours of operation to time of failure.

In addition to the failure reports, it is desired that the first five tubes that fail at each activity (except those accidentally broken or mishandled) should be forwarded immediately to the following address:

Commander, New York Naval Shipyard
Material Laboratory
Naval Base
Brooklyn 1, New York
Attention: Mr. J. T. Fetsch—problem No. 1102-ET-6.

Type of Approach	Last Month	To Date
Practice Landings	5,999	57,726
Instrument Landings	245	3,205

GROUND-CONTROLLED APPROACH

The Bureau of Ships desires to pass along to its electronics personnel some of the more interesting details encountered by the thirty-four active Ground-Controlled Approach units now in operation at various Naval Air Stations. To accomplish this, it has been decided to set aside space monthly in BuShips Electron for pertinent facts relative to this equipment. This space will contain a "Box Score" of all approach data for the previous month; in addition, helpful operational and maintenance hints and other items of special interest will be included whenever they become available.

The Box Score will give four figures: the number of practice landings made during the previous month, the total number of practice landings made to the date that Electron goes to press, the number of real instrument landings made during the previous month, and the total number of instrument landings. "Practice landings" will be taken as meaning all operational landings which were aided by GCA but which could have been made without it; "instrument landings" will be interpreted as meaning the operational landings aided by GCA during weather conditions which might otherwise have rendered the landing impossible without serious danger to planes and occupants.

GCA BRINGS IN COMMERCIAL DC-3

GCA Unit No. 23, stationed at the U. S. Naval Air Station, Columbus, Ohio, was alerted by the tower on the morning of 14 September, 1947, to assist a commercial DC-3 which was low on gas and could not reach any field reporting other than "closed conditions." At the time of the alert, the measured ceiling was 200 feet, visibility $\frac{1}{16}$ mile. The pilot reported that he had fifty minutes of gas remaining, provided he kept his power-settings at a minimum.

The conditions for a GCA landing were far from ideal for Unit 23. The pilot had never flown a GCA practice approach and had no v-h-f radio receiving facilities. The unit, having no workable tower low-frequency transmitter had to communicate with the plane by relaying the information through the tower. GCA transmitted static-free v.h.f. to the control tower, where the personnel placed their low-frequency transmitter microphone against their v-h-f receiver loudspeaker.

The pilot reported that he heard the GCA unit loud and clear. In a short time he was directed to a landing with little difficulty other than a reluctance to stay down on the glide path during the last half mile of the approach.

This landing was another "save" for GCA as the plane had only 23 gallons of gas remaining after taxiing to the line.

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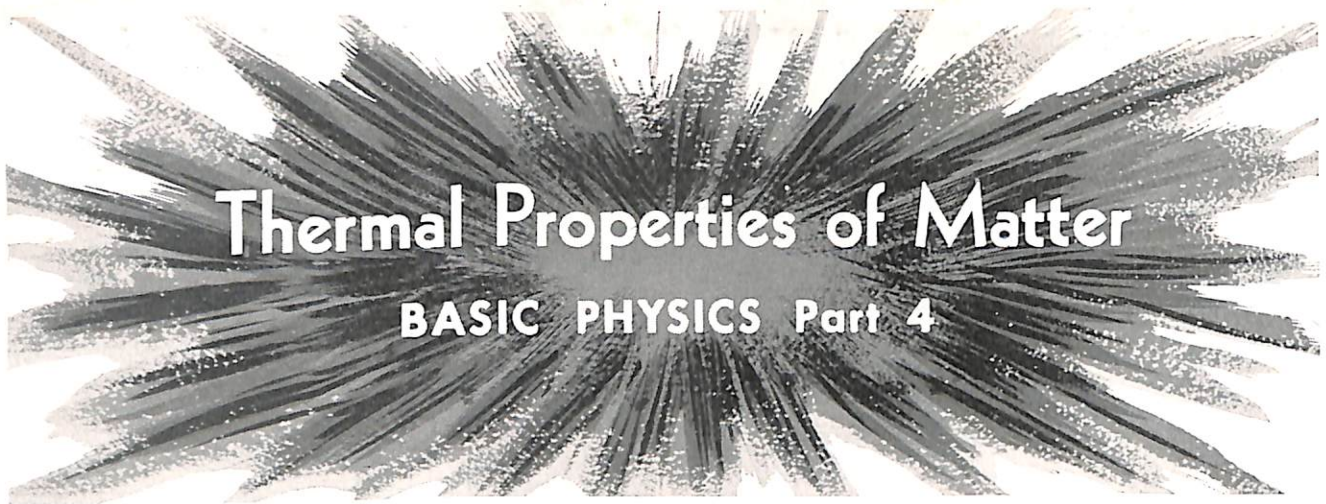
MODEL MBF HANDSETS

One navy type -51064 hand-telephone assembly (handset) is furnished with each Model MBF transmitting-receiving equipment at the time of original issue. These handsets use the Navy standard 5-wire (green) circuit and have a 20-foot cord. They are not stocked nor intended to be stocked as separate items and therefore are not and will not become available for replacement purposes.

The navy standard shipboard handset type -51081, with a 4-foot cord attached is stocked and supplied for replacement purposes. In exceptional cases where the 4-foot cord of the type -51081 handset is insufficient, the short cord can be replaced with the proper length of type MMOP-5 standard headset cable. This cable is stocked at all electronics supply activities.



Thermal Properties of Matter

BASIC PHYSICS Part 4

■ Properties of matter which are primarily a function of temperature are called thermal properties. In this chapter, many of these properties will be discussed, such as thermal expansion, thermal conductivity, melting and boiling phenomena, vaporization, specific heat, thermal capacity, vapor pressure, and humidity.

THERMAL EXPANSION

Most substances expand when heated and contract when cooled. This variation in volume does not change the quantity of matter, but does vary the density (weight per unit volume) of a given mass of matter. In general, the variation in volume with temperature is greatest in those substances in which a comparatively small quantity of heat causes a large change in temperature. This is the condition found in most metallic substances. On this basis, it would seem that the degree of expansion or contraction in a given material is primarily a function of the translational velocity of the molecules. Other indications, however, such as greater expansion in one direction than in another and variation in the degree of expansion with the initial temperature of the substance, offer evidence that the arrangement of the molecules and the cohesive forces between molecules have some effect on the change in volume with temperature.

Experimental evidence indicates that the variation in volume with temperature is not uniform over a wide range of temperatures. However, in the case of most pure substances, particularly with the metals, it has been found that the expansion is reasonably uniform over a range of temperatures in which the molecular arrangement within the substance does not change. Under these conditions, the volume or cubical coefficient of expansion becomes of importance in many practical applications in engineering.

The volume or cubical coefficient of expansion is the change in volume of a unit volume of a substance for a 1° C increase in temperature. For example, the volume coefficient of silver is 0.000058, which means that one cubic inch of silver at 5° C would have a volume of 1.000058 cubic inches at 6° C. For most practical work, within the range of temperatures where the substance does not change state, the following equation may be used to evaluate the change in volume with temperature:

$$V_h = V_l\ [1 + a(T_h - T_l)]$$

where V_h is the volume at the highest temperature T_h, V_l the volume at the lowest temperature T_l, and a the volume coefficient of expansion.

In some materials the molecular arrangement is such that, for a given change in temperature, a substance will expand more in one direction than in another. A quartz crystal, for example, may have a coefficient of expansion of 0.000008 in one direction, and at right angles to this direction a coefficient of 0.000013. In order to determine the change in volume with temperature in such substances, the change in dimensions must be calculated and the volume determined from the new dimensions.

The electronics engineer has greatest interest in the linear expansion of matter, that is, the degree of expansion in one direction. The *coefficient of linear expansion* is the change in length of a unit length of a substance for a 1° C increase in temperature. In those cases just referred to, where the expansion is different in the three dimensions of length, width, and depth, two or three linear coefficients may be required, but usually the expansion is the same in all three directions, fortunately, and we speak of *the* linear coefficient. In a great majority of substances this coefficient is found to be nearly equal to one-third the volume coefficient. The change in length over the range of temperatures where the body does not change its state may be calculated from:

$$L_h = L_l\ [1 + r\ (T_h - T_l)]$$

where the subscripts have the same meaning as in the volume expansion equation and r is the linear coefficient of expansion.

Example:

Given: 1000 ft of copper cable at 10° C.

Find: Length of cable at 60°.

Linear coefficient of expansion of copper = 0.000017.

$$L_h = 1000\ [1 + 0.000017\ (60 - 10)\ ]$$
$$L_f = 1000\ (1 + 0.00085)$$
$$= 1000\ (1.00085)$$
$$= 1000.85 \text{ ft.}$$

Table I gives the linear coefficient of expansion of some common materials.

Table I

Material	*Linear Coefficient of Expansion*	*Material*	*Linear Coefficient of Expansion*
Aluminum	0.000024	Nickel	0.000013
Antimony	0.000012	Silver	0.000019
Brass	0.000019	Solder	0.000025
Copper	0.000017	(2Pb:1Sn)	
Glass (soft)	0.0000085	Steel	0.000011
Glass (hard)	0.0000095	Tin	0.000027
Glass (Pyrex)	0.0000036	Tungsten	0.0000043
Gold	0.000014	(100° C)	
Invar	0.0000006	Tungsten	0.000006
Iron	0.000011	(1500° C)	
Lead	0.000029	Zinc	0.000026
Magnesium	0.000026		

Several alloys with very low expansion coefficients have been developed. Invar, an alloy of 64% nickel and 36% iron, has a linear coefficient only a fraction of that of its component elements. This is indicative of the fact that molecular arrangement may have considerable effect upon the coefficient of expansion.

Transfer of Heat.—Heat may be transferred from one point to another by three processes: convection, radiation, and conduction. The convection process explains how gases and liquids are heated. When a container of water is placed over a source of heat, the water at the bottom of the container heats more rapidly than that near the top. Water, at any temperature above 4° C, expands with increasing temperature. The cooler water, having greater density, sinks and forces the warmer water to rise toward the surface. The current established in a liquid or gas by a difference of temperature between two points in the medium is called a convection current. It is by means of such currents that heat energy is distributed throughout the medium.

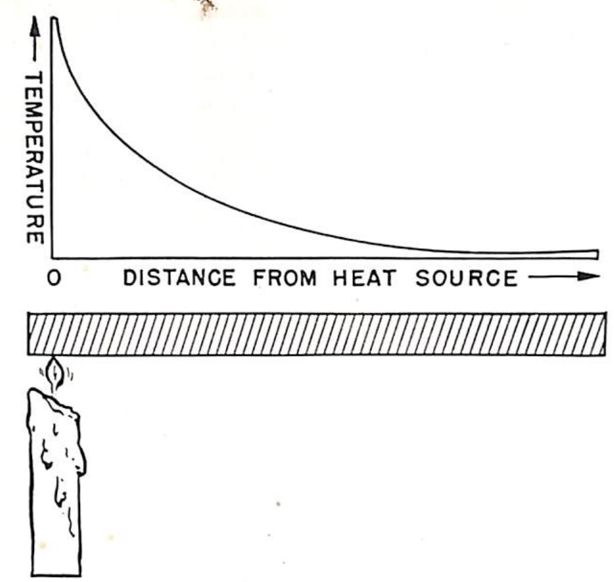


FIGURE 1—*Heat transfer by conduction (temperature distribution in a rod heated at one end).*

In connection with heat transfer by radiation, it may be mentioned that radiant energy is energy in the form of electromagnetic waves. The earth itself receives heat energy from the sun in radiant form. As is well-known, electromagnetic waves have the ability to travel through empty space at the velocity of 186,000 miles per second. The full theory of radiant energy will be discussed in a subsequent chapter.

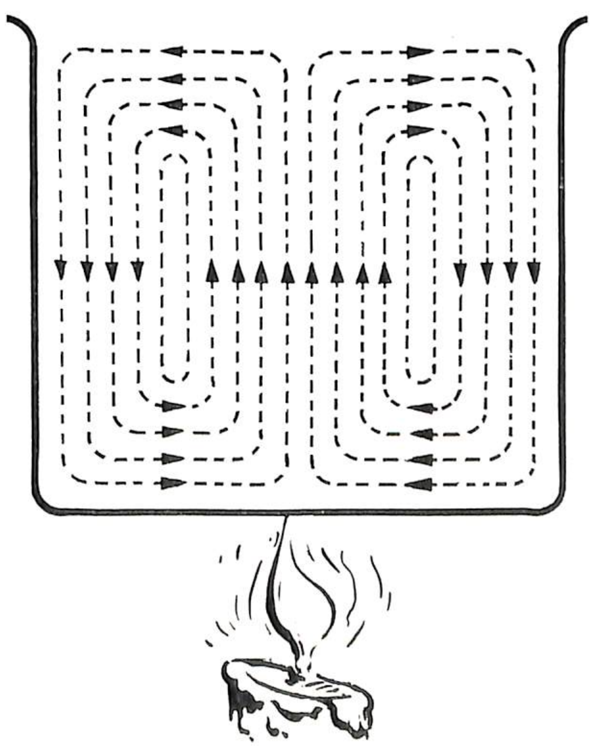


FIGURE 2—*Convection currents in a liquid (or a gas).*

Heat energy is distributed through solids by the process known as thermal conduction. If one end of a metal rod is placed in a flame, as shown in figure 2, heat will travel along the rod by conduction. The high-velocity molecules at the heated end of the rod collide with slower-moving adjacent molecules, forcing the latter to move at a greater velocity. The process continues along the length of the rod until the entire rod is heated. The slope at any point on a plot of the temperature of the rod against the distance from the heated end yields the temperature gradient, which is the change of temperature per unit distance at that point. The temperature does not decrease directly as the distance from the source of heat, because energy is being lost from the rod at the same time by convection and radiation. The greatest loss of heat energy occurs at the points of highest temperature, therefore the curve falls off most rapidly near the heated end.

In general, metals are good thermal conductors, whereas liquids and gases are poor conductors. Taking the thermal conductivity of silver as standard, we find that copper has a conductivity of 0.9, iron of 0.2, water of 0.0014, and air of 0.00006. Thus, the conductivity of silver is more than 700 times greater than that of water and 16,000 times greater than that of air.

The *coefficient of thermal conductivity* is defined as the quantity of heat in calories transmitted in one second through a centimeter cube of a substance when the temperature difference between opposite faces of the cube is 1° C. Thermal conductivity varies somewhat with the temperature at which it is measured. Copper at –160° C, for example, has a thermal conductivity greater than silver—a situation which is the reverse of that occurring at room temperature.

Thermal insulators are materials with very low coefficients of thermal conductivity. Most of such materials are porous, the low conductivity being attributed to the many minute dead air spaces within the material. Thermal insulation is usually rated in terms of density and the number of Btu per hour transmitted through an area of one square foot when the temperature gradient is 1° F per inch of thickness. Rock wool, a non-inflammable material often used to insulate buildings, is rated at 0.26 Btu/hr at a density of 6 lb/ft^3, while celotex, a wall board material made from sugar cane fibre, is rated at 0.34 Btu/hr at a density of 13 lb/ft^3. Rock wool is the better insulator at the density specified, because it conducts a smaller quantity of heat per unit time.

The interest of the electronics engineer in thermal conductivity is mostly qualitative. The power-handling capability of most electronic devices is limited by the ability of the device to dissipate or radiate heat energy. Heat must be conducted from high temperature areas and radiated into the surrounding space if the temperature of the device is to be held within safe limits. Good design necessitates the use of materials of high thermal conductivity with adequate surface area to provide the necessary radiating surface. For many years air-cooled vacuum tubes were limited to a maximum power dissipation of the order of a thousand watts because of the inability to obtain the necessary heat dissipation in tubes of reasonable size. By means of heat-radiating fins plus forced air circulation, the power-handling capacity has been stepped up to more than five kilowatts. For vacuum-tube power ratings greater than five kilowatts it is customary to use water cooling methods.

The student should remember these basic principles of thermal conductivity:

1–The quantity of heat passing through a conductor is proportional to the cross-sectional area of the path, the time of flow, and the difference of temperature across the conducting path.

2–The quantity of heat transferred in a given time decreases as the length of the path increases.

3–For small differences of temperature the quantity of heat radiated from a heated body into the surrounding atmosphere is approximately proportional to the difference in temperature between the body and the surrounding air.

4–For large differences of temperature between a heated body and the surrounding medium, the heat radiated varies approximately as the fourth power of the absolute temperature. Theoretically, an ideal radiator will dissipate 2^4 or 16 times more heat if its absolute temperature is doubled.

MELTING AND BOILING

The change of state that occurs when matter is transformed from the solid to the liquid state is known as *fusion*. The reverse process is called *solidification*. Crystalline solids have well-defined melting and freezing temperatures. Amorphous materials, on the other hand, pass from one state to another gradually, so that no fixed melting or freezing temperature can be specified. Some solids break down sharply from the solid to the liquid state at the melting temperature, whereas in others a certain amount of plastic deformation occurs as the temperature approaches the melting point. Cast iron cannot be welded because it maintains its crystalline structure up to practically the melting temperature. Steel is easily welded, however, because it becomes plastic at a temperature below that at which melting actually occurs.

When a solid melts, it absorbs heat; when a liquid solidifies, it gives up heat. If a thermometer is packed in cracked ice, it will stabilize at a reading of 0° C. If heat is applied and the mixture is kept well stirred, the temperature will remain at 0° until all the ice has melted. While the ice is melting, the heat energy is being used to overcome the cohesive forces between the molecules, rather than to increase the average molecular velocity. Experiment reveals that one kilogram of ice at 0° C will absorb 80 kcal of heat during the transformation from the solid to the liquid state. The figure 80 kcal is called the *latent heat of fusion* of water. In accordance with the law of the conservation of energy, converting one kilogram of water to ice will release 80 kcal of heat. The latent heat of fusion is the quantity of heat required to overcome or establish (depending on whether the change in state is from solid to liquid or liquid to solid) the cohesive forces between molecules, and has been measured for practically all crystalline solids. It is of importance in some fields of engineering. The quantity of heat required to convert a given mass of material from the solid to a liquid state is given by:

Quantity of heat = mass × latent heat of fusion

$$Q_f = mh_f$$

The presence of impurities in a substance can affect the melting and freezing temperatures radically. Glycerine, a substance often used as the base of anti-freeze solutions, freezes at 63° F, but a 1:1 solution of glycerine and water freezes at –9° C. The presence of salt and other impurities in sea water lowers the freezing point to –8.7° C.

VAPORIZATION

The process by which a solid or liquid is converted to the gaseous state is known as *vaporization*. There are three general processes of vaporization:

1–Evaporation, in which vaporization takes place at the surface of a substance,

2–Boiling, in which vaporization takes place in all portions of the substance, and

3–Sublimation, in which a solid passes directly to the gaseous state without passing through the usual intermediate liquid state.

A light fall of snow gradually disappears even though the temperature remains below freezing. Camphor will pass directly from the solid to the liquid state at normal atmospheric temperatures and pressures. At temperatures and pressures which are higher than normal, however, camphor will melt before evaporating.

The kinetic theory explains evaporation as taking place through the action of those molecules in a substance that are moving at velocities in excess of the average velocity. There are always a few such molecules in any substance, and if they are located near the surface of the material, they may have sufficient kinetic energy to escape into the surrounding space. As the temperature increases, the number of such high-velocity molecules increases, and more and more escape. The temperature at which the average velocity of the molecules represents sufficient kinetic energy for practically any molecule to escape from the liquid is called the boiling point. Gas bubbles are formed in the liquid by high-velocity molecules which beat against those of lower velocity. The low density of these bubbles forces them to rise to the surface, where the high-velocity molecules can escape into the atmosphere.

Evaporation and boiling are both processes which cool the remaining matter, because the escape of the molecules of highest velocity from the substance lowers the average velocity of the remaining molecules. A familiar example is the evaporation of perspiration from the human body, Nature's method of cooling. Since remote times it has been known that water will be cooled if placed in a porous earthenware vessel where evaporation will take place through the walls of the container.

It was previously explained that a kilogram of ice at 0° C absorbs 80 kcal of heat in melting, and that the temperature of a water-ice mixture, if it is kept well stirred, will remain constant until all the ice is melted. A similar condition exists in the conversion of water to water vapor. If a kilogram of water at 0° C and normal pressure is placed over a source of heat, the temperature will gradually rise until it reaches the boiling point of water, 100° C. It will require 100 kcal of heat to effect this change in temperature because one kcal of heat is absorbed for each 1° C-increase in temperature. After the water reaches the boiling point —no matter how much heat is applied—the temperature will remain constant until all the water is converted to vapor. It requires about 540 kcal of heat to change one kilogram of water at 100° C to vapor at 100° C. The temperature will remain constant until this heat is absorbed. The figure, 540 kcal, is called the *latent heat of vaporization* of water, and represents the energy required to overcome the forces of cohesion between molecules in the liquid state. Each substance capable of being vaporized has a particular latent heat of vaporization. If the assumption is made that no chemical reaction occurs, the quantity of heat required to effect vaporization of a given substance can be calculated from

Total heat = mass × latent heat of vaporization

$$Q_v = mh_v$$

Vapor pressure.—If a small quantity of water is placed in a closed container, the evaporation process will gradually increase the number of vapor molecules in the enclosure, and the inner pressure will rise above the pressure outside the container. If the temperature remains constant, the space inside the container will eventually become saturated with vapor molecules, and the internal pressure will cease to rise. At the saturation level, the number of molecules escaping from the liquid per unit time is just equal to the number of vapor molecules condensing into liquid form. The difference between the internal and external pressure at the saturation point is called the saturated vapor pressure of water at that temperature. If the experiment is repeated with containers of different sizes, it will be found that the saturated vapor pressure is independent of the volume of the container; it will be found, however, that the larger the container, the greater will be the time required for evaporation to bring the pressure to the saturation level. If the experiment be repeated at different temperatures, it will be found that, as the temperature increases, the saturated vapor pressure also increases. Table II shows the increase in water vapor pressure for each 10° C-increase in temperature from –10° C to 100° C.

Table II

Temperature °C	*Saturated Vapor Pressure in cm Hg*
–10	0.215
0	0.458
10	0.921
20	1.75
30	3.18
40	5.53
50	9.25
60	14.9
70	23.4
80	35.5
90	52.6
100	76.0

Normal atmospheric pressure is equivalent to the pressure exerted by a column of mercury 76.0 cm high. Note that at 100° C, the boiling point of water, the vapor pressure just equals the normal atmospheric pressure. The boiling point of any substance is the temperature at which its vapor pressure equals the external pressure. Alcohol, a more volatile liquid than water, has a higher vapor pressure than water at any given temperature; in fact, alcohol boils at 78° C, and at that temperature it must develop a vapor pressure equal to normal atmospheric pressure.

It should be evident that a liquid can be made to boil in two ways: by increasing the temperature, or by lowering the external pressure. Similarly, increasing the pressure raises the boiling point.

Humidity.—Moisture condensation in electrical and electronic equipment often presents serious maintenance problems. The problem is aggravated in poorly-ventilated spaces and in tropical climates where the growth of fungi is accelerated by comparatively high temperatures and humidities.

The atmosphere always contains some water vapor because the process of evaporation occurs at all temperatures, even those below freezing. The *absolute humidity* of the atmosphere is defined as the weight of the water vapor contained in a unit volume of air. It is usually expressed in grains per cubic feet. One grain is equivalent to 0.0648 gram.

Because the atmosphere is a mixture of dry air and water vapor, atmospheric pressure has two components: 1—the pressure resulting from the dry air, and 2—that resulting from the water vapor. A barometer reads the sum of these two pressures. For any given temperature, evaporation continues until the pressure rises to the saturation level. The quantity of water vapor required to produce saturation in a given volume of air will depend upon the temperature, warm air being capable of containing a greater quantity of water vapor than cooler air. The degree of saturation or the so-called *relative humidity* is of greater importance than the absolute humidity because it may be used in combination with a reference temperature to predicate the likelihood of rain, frost, snow, sleet, or fog. Bodily comfort is also a function of relative humidity. A comparatively high temperature may be comfortable if the air is dry, whereas saturated air at lower temperatures may produce considerable discomfort. *The degree of saturation or relative humidity is the ratio of the mass of moisture actually present in a given volume of air at a given temperature to the mass of moisture required to produce saturation at that temperature.*

$$\text{Relative Humidity} = \frac{\text{moisture in unit volume of air at a given temperature}}{\text{moisture required for saturation at the given temperature}}$$

The vapor pressure is approximately proportional to the amount of water vapor present, so relative humidity may also be defined approximately by:

$$\text{Relative humidity at reference temperature} = \frac{\text{vapor pressure}}{\text{saturated vapor pressure}}$$

Consider the case in which the relative humidity is 50% at 75° F (24° C). The saturated vapor pressure at this temperature is equivalent to the pressure exerted by a column of mercury 2.24 cm high. The pressure of the water vapor at 50% relative humidity will be 0.50 ×2.24 = 1.12 cm of mercury. If the temperature is now decreased to 55° F (13° C), the air will become saturated, because at this temperature the saturated vapor pressure is 1.12 cm of mercury. At 55° F the relative humidity is 100%, and any further decrease in temperature will cause some of the water vapor to condense. The temperature at which the air becomes saturated and condensation begins is called the *dew-point*. The relative humidity may be calculated from the dew-point temperature and a curve of temperature versus saturated vapor pressure. The dew-point may be measured by a condensing hygrometer, which consists of a thin glass plate arranged so that it may be cooled on one side by a stream of cold water or by the evaporation of ether. The opposite side of the plate is exposed to the atmosphere. As the temperature of the plate is gradually reduced, at some temperature a mist or film of water forms on the exposed side of the plate. The temperature of the plate at this point is taken as the temperature of the contacting air, and represents the dew-point temperature.

In poorly-ventilated ship spaces, warm air is cooled by contact with the walls and equipment. If the relative humidity is high, a comparatively small drop in temperature may cause moisture to condense or to "sweat" in a thin film on the equipment. Such condensation causes corrosion, and, under conditions of high humidity and temperature, encourages the growth of fungi on both metal and insulating surfaces. The high voltages often used with electronic apparatus make this a serious problem, because even a small amount of fungus growth or condensation can cause flashovers, reduction in power output, or complete failure of the equipment. Preventive maintenance requires adequate ventilation of spaces in which equipment is operated, daily operation of equipment to keep it dry, and, where fungus growth may be a serious problem, special tropicalization treatment to retard such growth. Under severe conditions, it may even be necessary to air-condition spaces in which important electronic equipment is located. Emergency measures often necessitate heating idle equipment in some way to keep the temperature above the dew-point.

Specific heat.—The specific heat of a substance is defined as that heat (in calories) required to raise the temperature of one gram of the same substance 1°C. In the case of water, the specific heat is approximately unity over the range of from 0° to 100°, because the calorie is defined as the heat required to raise one gram of water 1° C. Copper has a specific heat of 0.093, which statement means that one calorie will raise the temperature of one gram of copper $\frac{1}{0.093}$ or 10.75° C. The specific heat of a substance varies somewhat with temperature. Ice, for example, in the range of from 0 to –20°, has a specific heat of 0.5, just half that of water. If the range of temperature is not too great and the substance does not change state, the specific heat may be considered a constant.

THERMAL CAPACITY

The thermal capacity of a machine is the quantity of heat required to raise the temperature of the machine 1° C. The heat required to raise a mass of *m* grams through a temperature of 1° C is given by:

Heat in calories = mass in grams × specific heat capacity of the material.

$$H = mc_h$$

The quantity of heat required to change the temperature from T_i to T_f degrees is

$$Q = mc_h\,(T_f - T_i)$$

where Q represents the quantity of heat necessary to produce a change in the temperature of the body from T_i to T_f. The change in temperature is assumed to be small enough so that the specific heat may be considered a constant.

Electrical motors and generators are often rated in terms of the maximum permissible temperature rise above normal room temperature (20° C or 68° F). A machine rated at a maximum 40° C temperature rise should not be loaded to a point where the temperature rises above 60° C or 142° F.

It should be noted that the thermal capacity of a machine varies directly as the mass. The larger a machine, the more heat is required to produce a given temperature rise. Experience teaches the engineer to judge thermal capacity in terms of size.

DISSIPATION OF ENERGY

Man has learned to accomplish most energy transformations with a fair degree of efficiency, the one exception being the transformation of heat energy to some other form. The kinetic theory offers a logical explanation for the low efficiency obtained in transformation of heat energy. The only practical method ever suggested for obtaining mechanical energy from heat energy is to supply heat to a compressed gas and use the force of expansion of the gas to operate a mechanical device. This is the fundamental principle of the gas, steam, and Diesel engines. The explosion of a mixture of gasoline vapor and air in the cylinder of a gas engine generates a large quantity of heat which gives the molecules of the mixture a high velocity. The kinetic energy of these molecules may be used to exert a force against a piston. As long as the kinetic energy of the molecules permits them to exert a force greater than the force opposing the movement of the piston, the piston will move, and heat energy will be converted to mechanical energy. The real cause of low efficiency can be traced to the fact that only those molecules moving in a direction parallel to the motion of the piston do useful work. Molecules beating against the walls of the cylinder do not exert a force against the piston. The laws of probability indicate that an average of only one-third of the molecules in any expanding gas will be moving along a line parallel to the direction of movement of the piston; hence, only one-third of the molecules in the cylinder exert a pressure on the piston. The remaining two-thirds simply beat futilely against the walls of the cylinder causing the temperature of the engine to rise.

In any heat engine, heat energy flows from the hot gas to the atmosphere or cooling medium. In flowing through the engine, some of the heat energy is converted to mechanical energy. Since all heat engines function on a basis of the flow of heat energy from a higher to a lower level, it follows that a difference of temperature is necessary before heat energy can be converted to mechanical energy.

Heat energy is sometimes called "decadent" energy because it is so difficult to transform to other forms, and because in all machines some energy is more or less wasted in the form of heat. Perpetual motion machines are impossible to achieve because they would necessarily have to be 100%-efficient. In every machine some of the input energy is converted to heat, usually by some form of friction. Undesired heat energy in a machine is considered a loss although no real loss of energy occurs. Design engineers are vitally concerned with methods that will minimize the undesired transformation of energy to heat.

EXERCISES—PART 5

1. In a certain suspension bridge the supporting steel cables are 6000 feet long. The bridge was designed for a winter-summer temperature range of −15° to 105° F. What expansion in feet can be expected in the supporting cables over this range of temperatures?

2. How many Btu of heat are required to convert 1 lb of water at 100° C to vapor at the same temperature?

3. A tank containing 1000 kg of water is placed in an unheated storage shed. The outside temperature is such that the shed loses heat at an average rate of 8000 calories per minute. How many days will be required to freeze the water under these conditions?

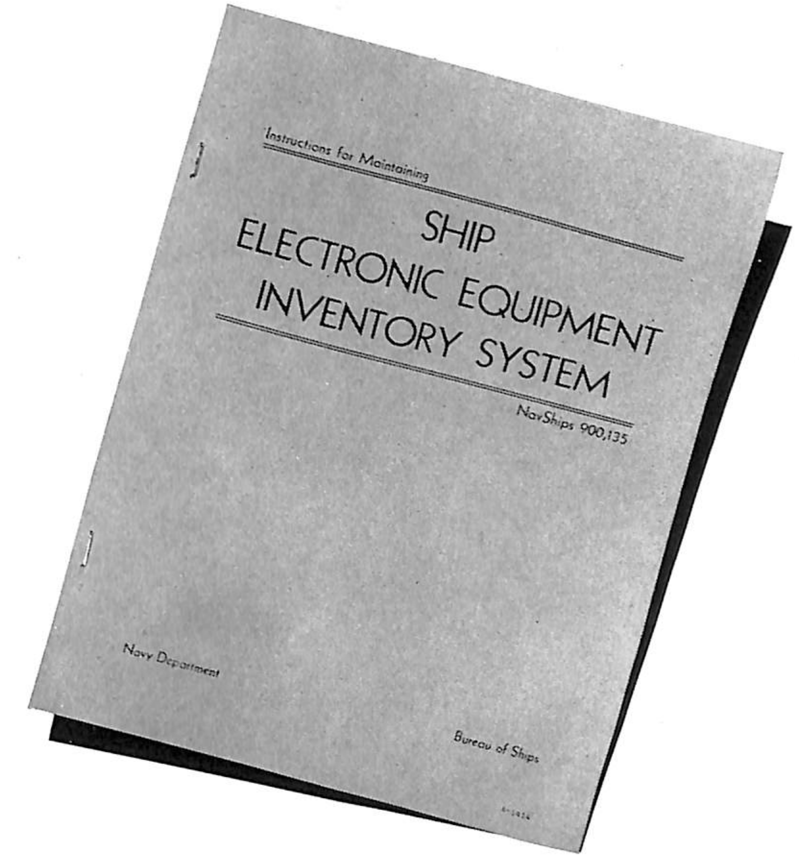
4. If the temperature is 70° F and the dew-point 50° F, what is the relative humidity?

5. At 70° F and 60% relative humidity the atmospheric pressure is 77 cm of Hg. What proportion of the atmospheric pressure is due to water vapor?

ANSWERS TO EXERCISE PROBLEMS, PART 4

1. 33 feet.
2. 0.0000193 lb/in^2.
3. −38 to 675° F.
4. 122° F.
5. −40°.
6. 8 ft.
7. 313° C.
8. 778 ft-lb = 1 Btu.
9. 9050 kcal.

Inventory Instructions



INVENTORY INSTRUCTIONS

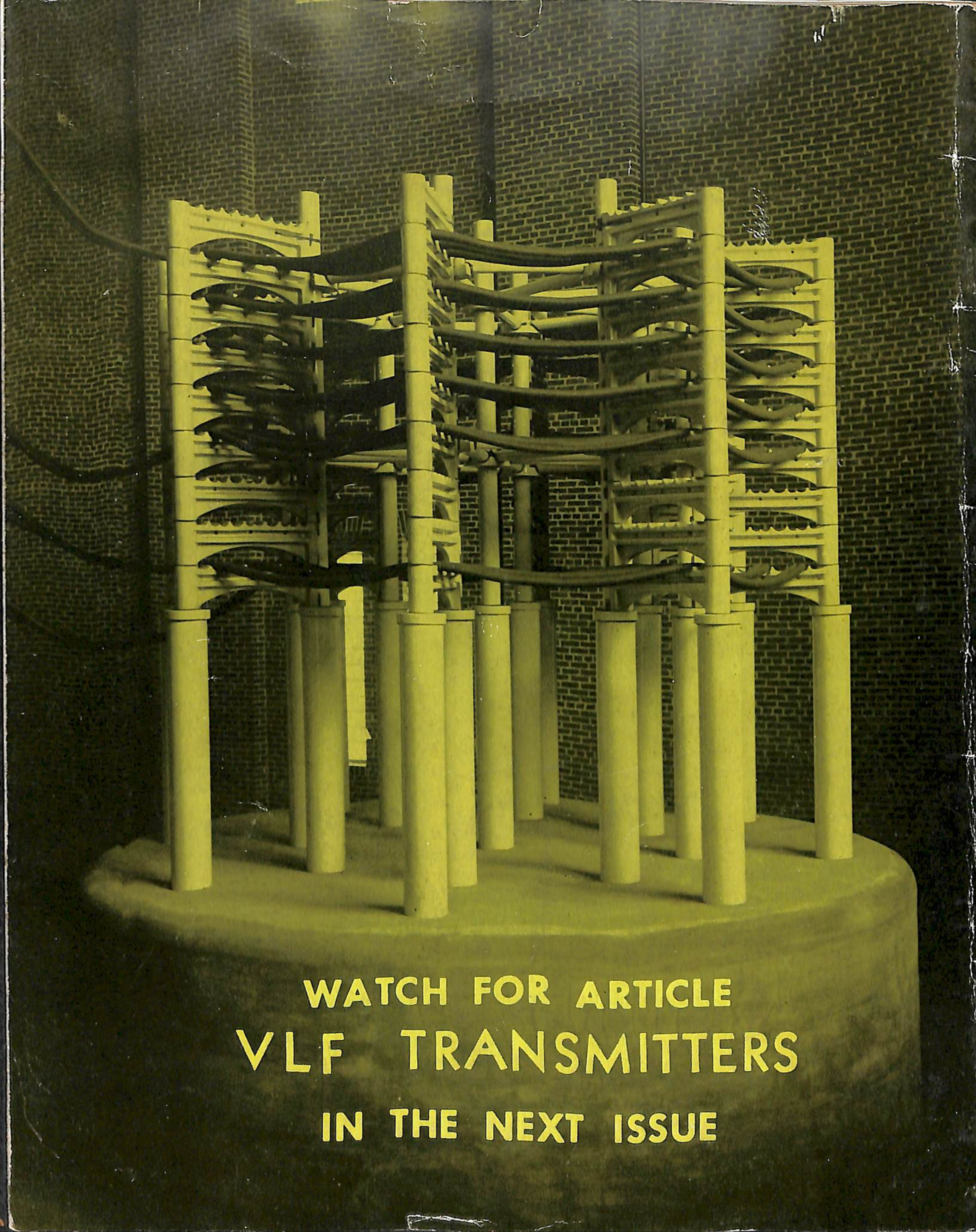
A new pamphlet entitled, "Instructions for Maintaining Ship Electronic Equipment Inventory System," has been published by the Bureau after a compilation of a year's experience in operating and handling the Navy's new equipment inventory system. The pamphlet, identified as NavShips 900,135, contains all the information and data necessary for the proper processing of the inventory forms by both fleet and field activities. It has been distributed to all active ships, and type commanders; to commanders of all reserve fleet groups; to commandants of all naval districts, naval bases, and naval shipyards; and to all industrial managers and assistant industrial managers.

All previous data and instructions concerning this system are now superseded and should be destroyed so as to prevent any confusion or erroneous action at some future date. In the future the information and instructions in this pamphlet are to be followed by all activities concerned with the maintenance of this system both afloat and ashore.

Particular attention is invited to Section IV of the pamphlet, wherein it is stated that the only time a naval shipyard is required to submit a corrected inventory to the Bureau is when that activity has completed yard overhaul or has made some change in the electronic installation on a ship. This inventory report is made by simply correcting the previously printed inventory form (NavShips 4110) with red pencil or red ink and returning this same form to the Bureau of Ships. Ship electronic inventory reports by shipyards are not required at any other time or in any other form.

In naval shipyards the inventory is handled in the following manner. The Bureau furnishes a copy of the ship's printed inventory to the home yard where it is put on file. If the overhaul or change is accomplished at that activity the form is removed from the files, corrected as necessary and returned to the Bureau. In case the overhaul or change is to be accomplished by a yard other than the home yard, the form is removed from the files and forwarded to the Electronics Officer at that yard. It is then available for use in planning the overhaul and for correction and return to the Bureau at the completion of the change or changes.

It is desired to emphasize particularly the fact that the inventories shall not be retyped or rewritten for submission to the Bureau. Although it is not necessary, the inventory may be copied for local files; nevertheless the machine printed copy, NavShips 4110, supplied by the Bureau must be corrected and returned. The submission of a retyped copy entails an unbelievable amount of unnecessary labor in the Bureau which cannot be accomplished without unjustifiable delay.


WATCH FOR ARTICLE
VLF TRANSMITTERS
IN THE NEXT ISSUE