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THEORY AND MEASUREMENT OF PULSE RADAR SYSTEM PERFORMANCE

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
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THEORY AND MEASUREMENT OF PULSE RADAR SYSTEM PERFORMANCE

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For explanation of distribution formula see TM 38–405.

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SECTION I

INTRODUCTION

1. Purpose of Manual

a. Many different types of test equipments have been supplied to field units for the purpose of testing and monitoring the performance of pulse radar equipments. However, little or no literature has been available describing the techniques used in making these measurements, or the theory underlying such measurements. This technical manual will assist personnel in measuring the performance of pulse radar equipments and in interpreting the results obtained. Throughout this manual the term *radar set* is used to indicate only pulse radar equipment.

b. Experience has shown that if adequate test equipment is not used, operating and maintenance personnel may not be aware when the performance of a radar set is extremely low. This was demonstrated when the performance of approximately 100 different radar sets was checked with reliable test equipment. In each case, the radar set was thought to be operating normally or better by the radar personnel concerned. The tests showed that *on the average* the maximum effective range of the radar sets was only one-half of the maximum range possible had the equipment been operating at peak efficiency. The proper use of suitable test equipment would have enabled the radar personnel to recognize and correct this inefficient operation. Since this test equipment is relatively new, it involves ideas and techniques which may be unfamiliar to many of the personnel concerned. This technical manual presents this information and, in so doing, places an increased emphasis on the maintenance of the r-f (radio-frequency) components of a radar set as distinguished from other circuit components. Thus, this manual gives interested personnel a theoretical knowledge of r-f system performance testing and of the types of equipment involved in making these tests. It also stresses the value of r-f performance testing as an *operational* check. In addition, this manual shows how proper interpretation of the results of performance checks will reveal the actual condition of the r-f components of the radar set.

2. Factors Affecting Radar Range

The expression *radar range* is used to describe the ability of a radar set to detect distant targets. Thus, this expression is analogous to the term *sensitivity* as applied to a radio communications receiver (the latter term describing the ability of the receiver to detect weak signals). In operational use, the range of a radar set depend on a number of factors: The area of aperture of the radar antenna, the effective scattering area of the target, the operating wavelength of the radar transmitter, the propagation factor (which accounts for variations in range caused by the conditions existing between the radar set and the target), the peak power output of the radar transmitter, and the peak power of the target echo signal returned to the radar antenna.*

a. Area of Antenna Aperture (A_a). Radar range varies directly as the square root of the area of the antenna aperture. However, since the antenna aperture is fixed in the design of a specific radar set, it cannot be controlled by the radar personnel to give increased range.

b. Scattering Area of Target (Σ). The range of a radar set varies directly as the fourth root of the effective scattering area of the target, Σ. This quantity will vary widely with different targets, or even with different aspects of the same target. However, whatever the value of this factor, it obviously cannot be controlled by the radar personnel.

c. Operating Wavelength (λ). Radar range varies *inversely* as the square root of the operating *wavelength* of the transmitter (*or directly* as the square root of the transmitter *frequency*). Theoretically, therefore, if all other factors remain unchanged, it seems possible to increase the range of a radar set by increasing the transmitter frequency. In most radar sets, however, either the transmitter frequency cannot be varied at all or it can be varied only slightly as determined by the design of the radar set. Furthermore, reduced transmitter power output and decreased receiver sensitivity may result from an increase in transmitter frequency, with a resulting decrease of radar range.

d. Propagation Factor (F). Radar range also depends on

---

*The relationship between the range, R, of a radar set and the factors upon which it depends may be expressed by the equation—

$$R = \sqrt[4]{\frac{A_a{}^2\,\Sigma F}{4\pi\,\lambda^2} \times \frac{P_{pk}}{P_r}}\,,$$

in which A_a represents the area of the antenna aperture, Σ the effective scattering area of the target, λ the operating wavelength, P_{pk} the peak power output of the transmitter, P_r the peak power of the echo returned to the radar antenna, and F the propagation factor.

the propagation factor, F. This factor is used to account for all variations in range which result from changing conditions between the radar set and the target, such as the length of the propagation path and weather conditions.

(1) *Propagation path.* It is customary to think of the radiation from the radar antenna as traveling in a straight line from the antenna to the target and back again. However, it is likely that not all the radiated energy will have a propagation path which is a straight line, especially in the case of low-flying aircraft, ground targets, or in propagation over water. In such cases, some of the radiated energy may be reflected from the earth's surface and then strike the target. Similarly, some of the energy reflected from the target may follow this same path. Obviously, the length of the two paths is different, but this difference is too small to introduce any difficulty in determining the range of the target. The importance lies in the fact that the lengths are subject to changes. This can be shown easily in the case of coastal targets where the rise and fall of the tide alter the length of the path of such energy as may be reflected from the water's surface. At any instant, the strength of the signal returning to the radar set depends on the phase relationships between the energy which has followed a straight-line propagation path and that which has been reflected from the earth's surface. Thus, whether they reinforce or cancel at the radar set depends on the difference in path lengths. This results in instability of echo strength. The effect of differences in path length is experienced, in varying degree, in the signal return from all targets. A normal target is never a single point but is composed of a number of variously oriented surfaces and corners, each of which is responsible for a portion of the returned echo. Distances between the radar set and various parts of the target or targets will differ. These differences may be considerable when measured in terms of wavelength. Consequently, the strength of the over-all signal depends upon the phase relationship between the return from the many different portions of a target. Normal swaying motion of a target may alter this phase relationship and result in variations in over-all signal strength. A slight drift in the frequency of the transmitter may manifest itself in like manner, since the different distances previously mentioned, in terms of wavelength, will change.

(2) *Weather conditions.* Weather conditions probably influence radar range to a greater degree than any other single factor considered under propagation. Normally, temperature and humidity conditions are such as to bend radar radiation earthward and allow the radar set to detect targets slightly beyond the optical

horizon. However, these atmospheric conditions are extremely variable. At times, the radar beam is bent strongly upward and thus rapidly dissipated. Signals are then weak and the effective range of the radar set is short. At other times, the beam is bent downward and a "duct" is formed between the earth's surface and the refracting layer of the atmosphere. Radiation is then propagated in what may be thought of as a two-dimensional waveguide. In such instances, dissipation of the radar energy is delayed and echo strength is increased; the range at which targets can be detected increases enormously. However, it is evident from the above discussion that none of the variable elements included in the propagation factor F can be controlled by radar personnel to improve the performance of a radar set.

e. TRANSMITTER PEAK POWER OUTPUT (P_{pk}) AND ECHO SIGNAL PEAK POWER (P_r). Since none of the factors affecting radar range described in the preceding subparagraphs can be controlled by the radar personnel, their combined effect can be expressed in a single variable, V. Therefore, the relationship between the radar range, R, and the factors upon which it depends may be expressed by the equation $R = V \sqrt[4]{P_{pk}/P_r}$, in which P_{pk} represents the transmitter peak power output and P_r the peak power of the echo signal returned to the radar antenna. To keep the range of the radar set at a maximum, the value of the ratio P_{pk}/P_r must be kept close to optimum, within the limitations of the design of the radar set. This ratio is a measure of the performance figure, S, of a pulsed microwave radar system.

3. Concept of Radar Performance Figure

a. Using the analogy of sound echoes, the strength of an echo is determined by the ability of a man to shout and, equally, by his ability to hear. A man somewhat hard of hearing must shout much louder than one whose hearing is unimpaired to discern an echo traveling the same path length. This concept, applied to a radar system, is what is meant by radar performance. In other words, radar performance can be improved equally through an improvement in the ability of the radar set to receive weak signals as through an increase in the transmitter power output.

b. To aid in determining radar performance, and to enable measurements to be repeated, it is necessary to assign a more definite value to P_r. Radar range is maximum when P_r (the denominator of the ratio P_{pk}/P_r) is minimum. This occurs when the signal power input to the receiver is just barely discernible from the receiver noise. The symbol P_m is used to represent this minimum discernible signal power, and controllable radar range then varies as the fourth root of the ratio P_{pk}/P_m. The ratio P_{pk}/P_m replaces the somewhat indefinite ratio P_{pk}/P_r as a measure of performance. The ratio P_{pk}/P_m is denoted by S, the radar performance figure.

c. Note that P_{pk} may be in the order of 100,000 watts and P_m in the order of 0.000,000,000,000,1 watt. The ratio P_{pk}/P_m is a very large number. For the values given above, this ratio is 1,000,000,000,000,000,000. Quantities of this magnitude can be dealt with more conveniently by using a logarithmic scale. For this reason, the decibel (db) is used.

4. The Decibel and Its Use

a. THE BEL. The *bel,* as originally used, represented a *power ratio* of 10 to 1 between the strength of two sounds. Consider three sounds of unequal power intensity. If the power intensity of the second sound is 10 times the power intensity of the first, its power level is said to be 1 bel above that of the first. If the third sound has a power intensity which is 10 times that of the second, its level is 1 bel above that of the second. Now, the power level of the third sound is *100 times* that of the first and is also *2 bels above* it. Thus, a power ratio of 100 to 1 is represented by 2 bels. Similarly, a power ratio of 1,000 to 1 can be represented by 3 bels, 10,000 to 1 by 4 bels, etc. But, the logarithm of 100 to the base 10 equals 2 (since 10^2 equals 100), the logarithm of 1,000 equals 3 (since $10^3 = 1{,}000$), the logarithm of 10,000 equals 4, etc. Thus, the concept of bels represents a logarithmic relationship. Suppose one sound has a power intensity equal to P_2 watts and another a power intensity equal to P_1 watts, and it is desired to find how many bels higher P_2 is than P_1. This can be found from the formula—

$$bels = log_{10}(P_2/P_1),$$

where P_2/P_1 is the ratio of the two powers. Using the formula, if P_2 equals 500 watts and P_1 equals 5 watts, the ratio P_2/P_1 equals 100, and the logarithm of 100 to the base 10 equals 2. Thus, the result obtained from the formula is in accord with the previous discussion that a power ratio of 100 to 1 (which is the same as 500 to 5) can be represented by 2 bels. As in the numerical case given, when P_2 is larger than P_1, the ratio P_2/P_1 is greater than 1, and the logarithm of the ratio, or the number of bels obtained as the final result, is positive. Therefore, in the numerical case, P_2 is said to be *2 bels up with respect to* P_1. If P_2 were equal to 5 watts and P_1 equal to 500 watts, the ratio P_2/P_1 would equal 1/100 or 0.01, the logarithm of which is —2. Thus, the numerical result obtained is the same, but the negative quantity shows that P_2 is *2 bels down with respect to* P_1.

Note. In the formula for bels given above, the subscript 10 indicates that this is the base used. Since the same base is used in all succeeding formulas involving logarithms, the subscript will no longer be used.

b. THE DECIBEL. The bel is a rather large unit and, in practice, its use may prove inconvenient. Usually, therefore, a smaller unit, the *decibel,* is used. Ten decibels equals 1 bel. A 10 to 1 power ratio, which can be represented by 1 bel, can also be represented by 10 decibels (10 db). A 100 to 1 ratio (2 bels) can be represented by 20 db, a 1,000 to 1 ratio (3 bels) by 30 db, etc. The previous formula for bels may be rewritten to give a result in decibels merely by multiplying by 10. Thus, the formula becomes—

$$decibels\ (db) = 10\ log\ (P_2/P_1).$$

c. CONVERSION OF POWER RATIO TO DECIBELS. Table I is included to assist in converting specific power ratios to decibels, without having to use the formula for decibels given above. The correct power ratio is selected from the left-hand column and from the column heads; then the corresponding decibel value is read from the body of the table. For example, the decibel value representing a power ratio of 2.3 (that is, 2.3 to 1) is 3.6 db and that representing a power ratio of 5.8 is 7.6 db. The further use of the table is explained in the illustrative examples given in *d* below.

Table I. Power Ratio to Decibel Conversion

Power ratio	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	0.0	0.4	0.8	1.1	1.5	1.8	2.0	2.3	2.6	2.8
2	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.3	4.5	4.6
3	4.8	4.9	5.0	5.2	5.3	5.4	5.6	5.7	5.8	6.0
4	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9
5	7.0	7.1	7.1	7.2	7.3	7.4	7.5	7.6	7.6	7.7
6	7.8	7.8	7.9	8.0	8.1	8.1	8.2	8.3	8.3	8.4
7	8.4	8.5	8.6	8.6	8.7	8.7	8.8	8.9	8.9	9.0
8	9.0	9.1	9.1	9.2	9.2	9.3	9.3	9.4	9.4	9.5
9	9.5	9.6	9.6	9.7	9.7	9.8	9.8	9.9	9.9	9.9
10	10.0									
100	20.0									
1,000	30.0									
10,000	40.0									
100,000	50.0									
1,000,000	60.0									

d. USE OF DECIBELS. (1) Decibels are particularly useful because they can be added or subtracted when the corresponding power ratios are to be multiplied or divided, respectively.

Example: The output of an amplifier is 20 db above 1 watt. How many db above 1 milliwatt is this output?

Solution: One watt equals 1,000 times 1 milliwatt. From table I, this ratio represents 30 db. The output of the amplifier is given to be 20 db above 1 watt, which in turn is 30 db above 1 milliwatt. Therefore, the amplifier output is 50 db above 1 milliwatt.

(2) The number of decibels corresponding to power ratios intermediate to the power ratios given in table I can be found readily.

Example: Convert a power ratio of 2,800 to 1 into decibels.

Solution: 2,800 may be written 2.8 × 1,000. From table I, a power ratio of 2.8 may be represented by 4.5 db, and a power ratio of 1,000 by 30 db. The number of decibels representing a product may be found by adding the decibels representing each factor; therefore, a power ratio of 2,800 may be represented by 4.5 plus 30 db, or 34.5 db.

(3) The number of decibels corresponding to a power ratio *less* than 1 may be found by inverting the power ratio, finding the db value corresponding to this new ratio, and affixing a negative sign before the db figure.

Example: Convert a power ratio of 1 to 2,800 into decibels.

Solution: Inverting 1/2,800, a ratio of 2,800 to 1 is obtained. In the preceding example, this ratio was found to correspond to 34.5 db. Affixing a negative sign to this value, the power ratio 1 to 2,800 is expressed as —34.5 db.

(4) Table I may also be used to convert a given db value into a power ratio.

Example: Express —26.4 db as a power ratio.

Solution: Consider first the positive value 26.4 db. This may be expressed as 20 db plus 6.4 db. From table I, 20 db corresponds to a power ratio of 100 and 6.4 db to a ratio of 4.4. The sum of the two db values corresponds to a power ratio of 100 times 4.4, or 440. Therefore, the original negative value of —26.4 db represents a power ratio of 1 to 440.

e. **Power Reference Level.** In radar measurements, it is often desired to express the power output of a transmitter in decibels. This cannot be done unless a fixed power level is used as a reference. This reference level has been selected as 1 milliwatt (0.001 watt), and this value will be used throughout this manual. If the transmitter power output is expressed in this manner with reference to 1 milliwatt, it is said to be a certain number of *dbm*. The abbrevation dbm indicates decibels relative to 1 milliwatt.

Example: A pulsed radar transmitter has a peak power output (P_{pk}) of 100,000 watts and an average power output (P_{av}) of 100 watts. Express these values of power output relative to 1 milliwatt.

Solution: P_{pk} equals 100,000 watts or 100,000/0.001 milliwatts. Therefore, P_{pk} equals 100,000,000 milliwatts. Extending table I to include a ratio of 100,000,000, P_{pk} is found to be 80 dbm. Similarly, P_{av} equals 100/0.001 milliwatts, or 100,000 milliwatts. Therefore, P_{av} equals 50 dbm.

Note. Power conversions of this type (from watts or kilowatts to dbm) can be done most readily by means of figure 2.

f. RADAR PERFORMANCE FIGURE EXPRESSED IN Db. In paragraph 3 it was mentioned that the ratio P_{pk}/P_m (where P_{pk} is the peak power output of the transmitter and P_m is the minimum discernible signal power) is a measure of the radar performance figure, S. It was also shown that this ratio could be an extremely large and unwieldy figure. For this reason, the concept of decibels is used and the radar performance figure, S, is defined in db as—

$$S_{(db)} = 10 \log (P_{pk}/P_m).$$

For the ratio given in paragraph 3*c*, the performance figure S would equal 180 db.

SECTION II

THEORY OF RADAR MEASUREMENTS

5. Importance of Radar Measurements

It was shown in paragraph 2 that, of all the factors affecting the ability of a radar set to detect small or distant targets, only the performance of the radar set can be controlled by the radar personnel. The importance of measuring radar performance each time the radar set is placed in operation and periodically thereafter must be emphasized.

a. In paragraph 3*b* it was shown that controllable radar range varies as the fourth root of the ratio P_{pk}/P_m. Assume that, for a particular radar set, the ratio P_{pk}/P_m is reduced to $1/16$ its optimum value (equivalent to a 12-db drop in performance, as found from table I). This decrease in performance might be caused by changes in the transmitter output, or in the minimum discernible signal, or both. The range, R^1, of the radar set under these conditions, in terms of the optimum range, would be:

$$R^1 = V \sqrt[4]{P_{pk}/P_m} \times 1/16 = \tfrac{1}{2} V \sqrt[4]{P_{pk}/_{m}}.$$

This means that a 12-db decrease in performance is equivalent to *halving* the range at which a target can be detected, all other factors being equal. The area covered by the radar set is thus one-quarter what it might be, and the radar set is unaware of three-quarters of the number of targets it might normally detect. To a rough approximation, it might be said that each db loss in performance is equivalent to a 5 percent loss in maximum range. This relationship is shown more exactly in figure 15.

b. It might be said that a 12-db decrease in performance is extremely large and is not likely to occur in practice. That is not the case. It was mentioned in paragraph 1 that approximately 100 different radar sets, each of which was thought to be operating normally or better by the radar personnel concerned, were tested with reliable test equipment. On the average, these sets were down 12 db. As a matter of fact, 69 of these sets, more than half the total number tested, were down from 10 to 35 db. These data are presented only to stress the importance of making periodic performance measurements with suitable test equipment.

c. Concerning the periodic measurement of performance, there is no way of determining how long a radar set will maintain a given performance, nor what period must elapse before repair is necessary. This is analogous to stating that the exact life of a given crystal or T/R tube is indeterminate. However, with adequate equipment radar performance can be checked with little or no loss of time. The operation is similar to tuning the local oscillator of a receiver, or checking the line voltage. Therefore, the measurement of performance should be considered an integral part of the operating procedure of a radar set.

6. Factors Determining Over-all Radar Performance

The *over-all* performance of a radar set is determined by several factors. These factors are listed below in the order of their importance and are explained in the paragraphs which follow.

a. The radar performance figure. This may be found either directly or by finding its component parts, which are the transmitter peak power output (P_{pk}) and the receiver minimum discernible signal power (P_m).

b. The correlation between the transmitter frequency (f_t) and the receiver frequency (f_r). This may require determining the absolute value of both.

c. The transmitter spectrum width (Δf_t).

d. The receiver bandwidth (Δf_r).

7. Radar Performance Figure

To find the radar performance figure, both the transmitter peak power output and the receiver sensitivity in terms of minimum discernible signal power must be determined.

a. DETERMINATION OF TRANSMITTER PEAK POWER OUTPUT. The peak power output of a radar transmitter cannot be measured directly. Any test equipment will measure only the *average* power output, which, depending on the specific test equipment, may be given either in watts or dbm. Therefore, the relation between peak power and average power for a rectangular pulse must be determined. It is most convenient to express this relationship in terms of db.

(1) A graph of the power output of an ideal pulsed radar transmitter is shown in figure 1. For the duration of the pulse, which is d seconds, the output of the transmitter is at a peak value of P_{pk} watts. At the end of the pulse, the power output drops to zero where it remains until the start of the next pulse. If the repetition rate of the pulses is r pulses per second, the time between the start of two consecutive pulses is $1/r$ seconds. The *average* power output of the transmitter in watts is shown as equal to P_{av}, where P_{av}

is that value which makes the two shaded areas in figure 1 equal. Mathematically, this equality can be expressed as—

$$P_{pk} \times d = P_{av} \times 1/r.$$

Rewriting:

$$P_{pk} = P_{av} \times 1/rd.$$

Replacing $1/rd$ by D, the duty-cycle figure, the equation becomes—

$$P_{pk} = P_{av} \times D.$$

The peak power output of the transmitter in decibels relative to 1 milliwatt, $P_{pk}(dbm)$, can be found from the relation—

$$P_{pk}(_{dbm}) = 10 \; log \; \frac{P_{av} \times D}{1mw} = 10 \; log \; \frac{P_{av}}{1 \; mw} + 10 \; log \; D.$$

Therefore:

$$P_{pk}(_{dbm}) = P_{av}(_{dbm}) + D(_{db}).$$

(2) The above relationship shows that the peak power output of the transmitter in dbm equals the sum of the average power output in dbm and the duty-cycle figure in db. For a given radar transmitter, the two latter quantities are easily determined. The average power output is measured by means of test equipment. If the value obtained from the test equipment is expressed in watts, it must be converted to dbm. This can be done easily by means of figure 2. Some test equipments are calibrated directly in dbm and no conversion is required. The duty-cycle figure $D(_{db})$, which depends on the duration of the transmitter pulse and on the pulse repetition rate, can be found directly from figure 3.

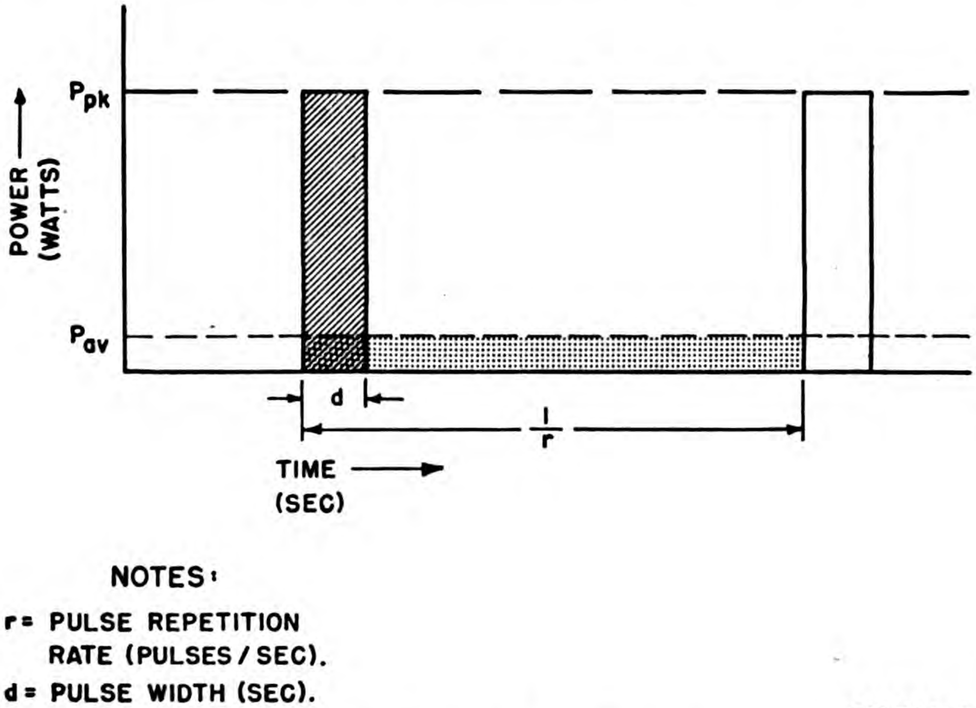


Figure 1. Transmitter power output.

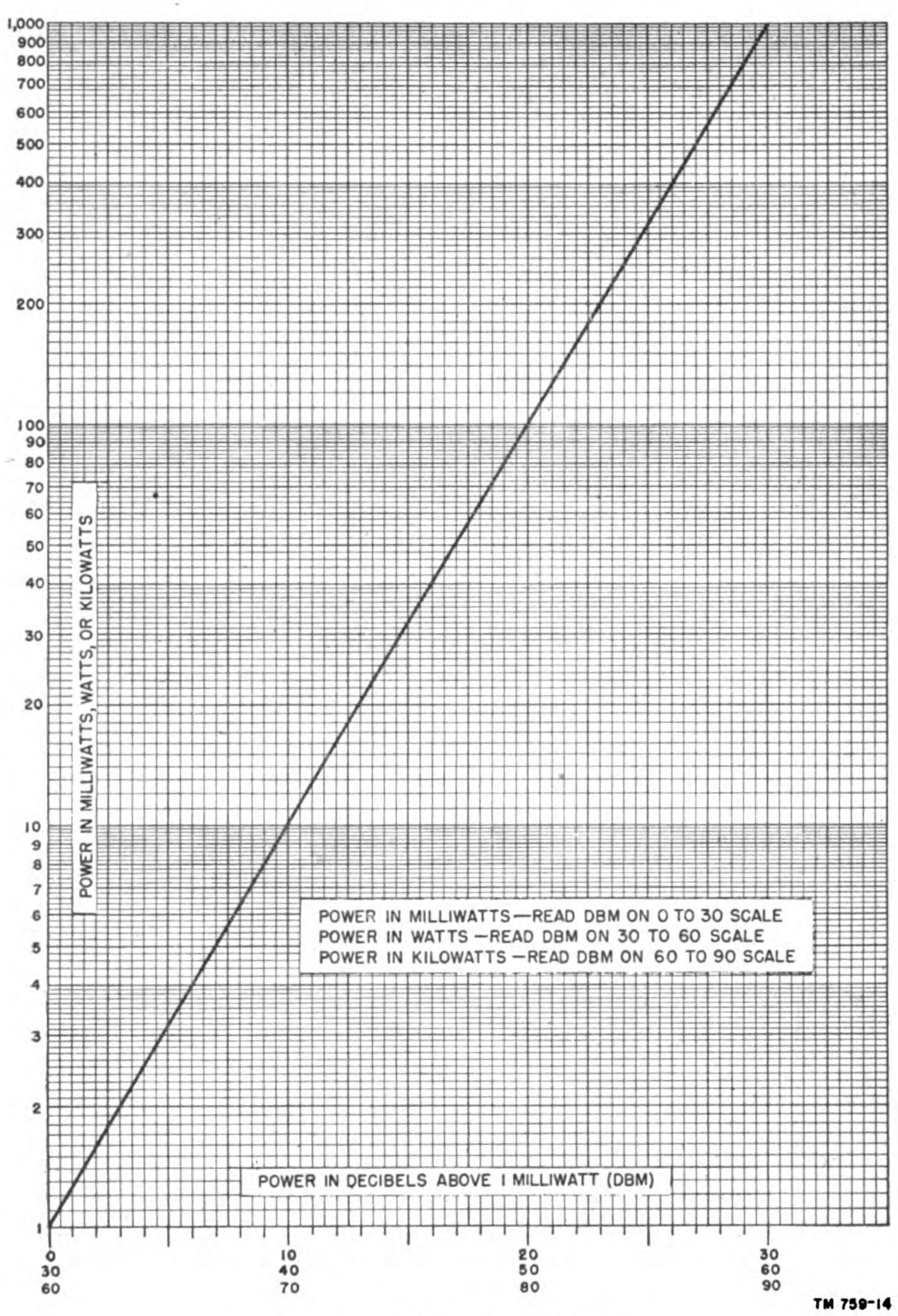
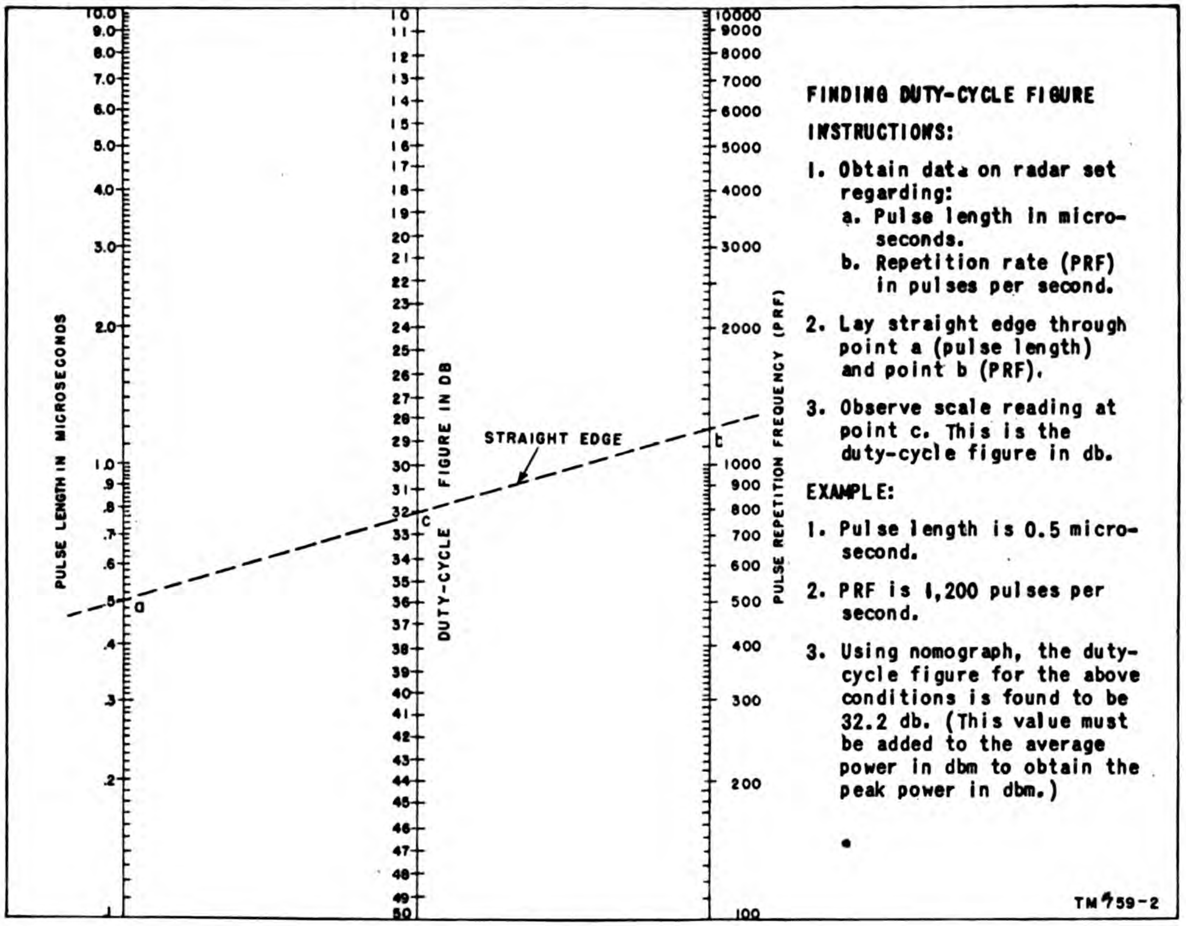


Figure 2. Conversion of power to dbm.

Example: The average power output of a radar transmitter is found to be 30 watts. If the pulse repetition rate is 1,200 pulses per second and the pulse width is 0.5 microsecond, what is the peak power output in dbm?



FINDING DUTY-CYCLE FIGURE

INSTRUCTIONS:

1. Obtain data on radar set regarding:
   a. Pulse length in microseconds.
   b. Repetition rate (PRF) in pulses per second.
2. Lay straight edge through point a (pulse length) and point b (PRF).
3. Observe scale reading at point c. This is the duty-cycle figure in db.

EXAMPLE:

1. Pulse length is 0.5 microsecond.
2. PRF is 1,200 pulses per second.
3. Using nomograph, the duty-cycle figure for the above conditions is found to be 32.2 db. (This value must be added to the average power in dbm to obtain the peak power in dbm.)

Figure 3. Determining duty-cycle figure (in db).

Solution: From figure 3, the duty-cycle figure for the given repetition rate and pulse width is 32.2 db. The average power output P_{av} is given as 30 watts. Converting this to dbm by means of figure 2, $P_{av(dbm)}$ equals 44.8 dbm. Therefore, $P_{pk(dbm)} = 32.2 + 44.8\ dbm = 77\ dbm$.

b. DETERMINATION OF RADAR PERFORMANCE FIGURE. (1) In paragraph 4*f* the radar performance figure was defined, in db, as follows:

$$S_{(db)} = 10\ log\ (P_{pk}/P_m),$$

where P_{pk} is the peak power output of the transmitter and P_m the minimum signal power discernible at the receiver. Dividing both numerator and denominator of the fraction by 1 milliwatt,

$$S_{(db)} = 10\ log\ (P_{pk}/1mw \div P_m/1mw), \text{ or}$$

$$S_{(db)} = 10\ log\ (P_{pk}/1mw) - 10\ log\ (P_m/1mw).$$

Since the first of the two expressions on the right side of the above relation is actually the peak power output of the transmitter in dbm and the second is the minimum discernible signal in dbm, this can be written—

$$S_{(db)} = P_{pk(dbm)} - P_{m(dbm)}.$$

(2) Since the peak power output of the transmitter is greater than 1 milliwatt, $P_{pk(dbm)}$ is a positive quantity. However, $P_{m(dbm)}$ is negative because the minimum signal power discernible at the receiver is considerably less than 1 milliwatt. Therefore, $S_{(db)}$, which is really the algebraic difference between $P_{pk(dbm)}$ and $P_{m(dbm)}$, may be obtained merely by adding their numerical values.

(3) The use of the relation given above is shown in the following example.

Example: The peak power output of a transmitter, as found in the example given in *a* above, is 77 dbm. The minimum signal power discernible at the receiver is 0.000,000,000,1 watt. Find the radar performance figure in dbm.

Solution: Before $S_{(db)}$ can be determined, the value of P_m given must be converted to dbm. $P_m = 0.000,000,000,1$ watt $= 0.000,000,1$ milliwatt $= 1/1,000,000$ milliwatt. From table I, a power ratio of 1,000,000 to 1 corresponds to 60 db. Therefore, $P_{m(dbm)} = -60\ dbm$. $S_{(db)} = 77\ dbm - (-60\ dbm) = 77\ dbm + 60\ dbm = 137\ db$.

8. Transmitter Spectrum

a. Consider an ideal radar transmitter which is triggered with a perfect rectangular pulse (that is, one which has perfectly vertical sides and a completely flat top). It is often said that the output frequency of such a transmitter is some nominal frequency, f_t. Actually, the radiated energy is not at any one single frequency but is distributed over a range of frequencies above and below the nominal frequency f_t. The distribution of energy with frequency is known as the transmitter frequency spectrum. The spectrum for a transmitter pulse of width equal to d seconds is shown in figure 4. The greatest portion of the energy is radiated at frequencies lying between the first minima on either side of the nominal transmitter frequency f_t. This portion of the spectrum (Δf_t) bears a definite relation to the pulse width d, namely Δf_t equals $2/d$, where Δf_t is in cycles and d is in seconds. In the ideal transmitter represented in figure 4 only a very small portion of the generated energy is at the frequencies covered by the smaller side lobes. Therefore, the spectrum width of a radar transmitter (Δf_t) is accepted as being merely the width of the main lobe. For a pulse width of 0.5 microsecond, the transmitter should have a spectrum width equal to 2/0.000,000,5 or 4,000,000 cycles (4 mc (megacycles)).

b. The above discussion applies to an ideal spectrum, produced by perfectly rectangular pulses. In practice, the keying pulses applied to a magnetron are not rectangular. The leading edge does not rise vertically, the top is not flat, and the trailing edge usually drops slowly. Since the shape of the pulse affects the frequency of the magnetron as well as its power output, the shape of the spectrum is affected. The shape of the spectrum for a specific transmitter may prove helpful in indicating improper operation of transmitting or r-f components (par. 28*a*). Certain test equipments kown as spectrum analyzers are designed to show the spectrum of radar transmitters.

9. Receiver Bandwidth

a. A radar set is a closed system; that is, it receives a portion of the energy radiated by itself. Since the radiated energy is distributed over a band of frequencies, the radar receiver must be capable of accepting a wide range of frequencies. That is equivalent to saying that the receiver bandwidth must be comparable to the transmitter spectrum width. A receiver bandwidth curve is shown in figure 5, superimposed on a typical transmitter spectrum. The receiver bandwidth (Δf_r) is usually taken as the width of the response curve at the half-power points.

b. In figure 5, the receiver bandwidth, Δf_r, is shown equal to the transmitter spectrum width, Δf_t. It is true that the wider the receiver response, the more signal power is amplified. However, in that case, more noise frequencies also are amplified. For this reason, the receiver bandwidth is usually limited to some value

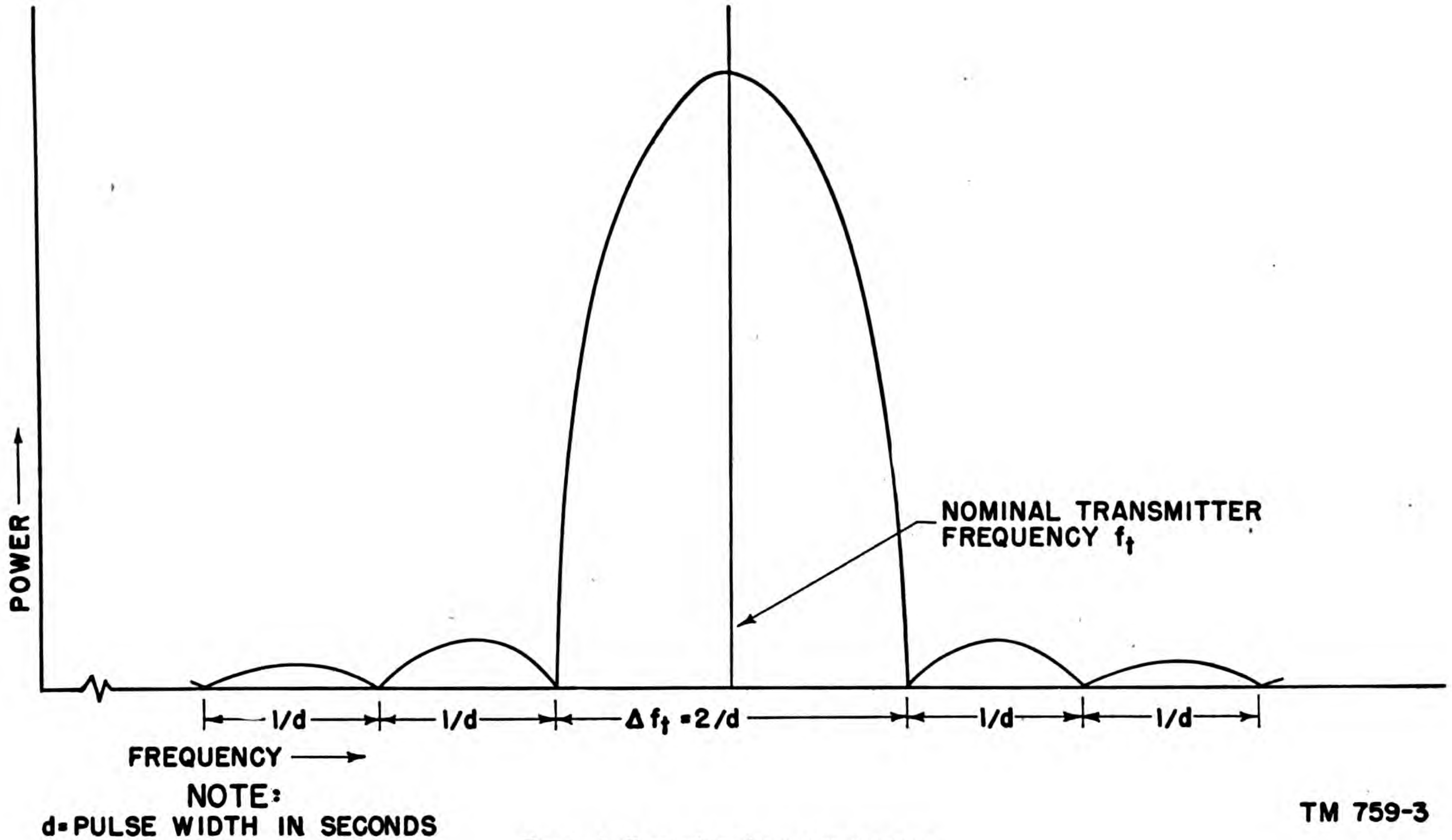


Figure 4. Transmitter frequency spectrum.

slightly below the spectrum width.. The spectrum width was shown in paragraph 8 to be equal to $2/d$, where d is the pulse width in seconds. Radar receivers are usually designed to have a response between $1.5/d$ and $2/d$. Thus, for a pulse width of 0.5 microsecond, the spectrum width is 4 mc and the receiver bandwidth is usually between 3 and 4 mc.

c. The receiver response is usually determined in the basic design of the radar set, and its subsequent effect on performance is not very great. However, if it does vary considerably from the design value, perhaps as a result of very bad misalinement of the receiver amplifier stages, an appreciable effect on radar performance may result.

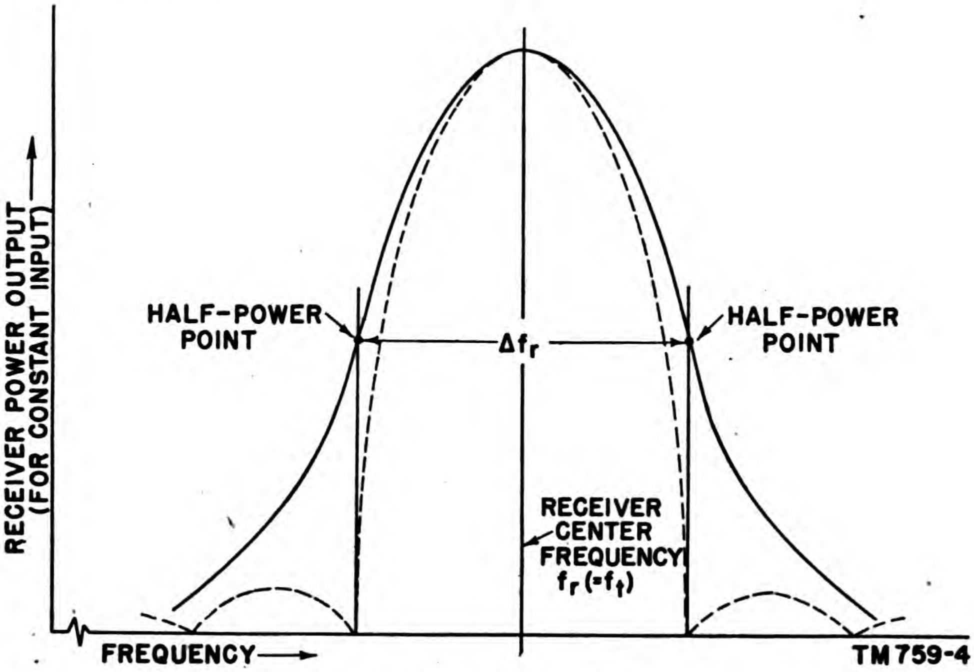


Figure 5. Receiver bandpass curve.

10. Transmitter and Receiver Frequencies

As shown in figure 5, maximum receiver response occurs at a nominal center frequency f_r. Usually this center frequency must coincide with the nominal transmitter frequency f_t for best performance of the radar set. This requires the measurement of f_r and f_t either directly or in comparison with each other.

SECTION III

METHODS USED IN PERFORMANCE MEASUREMENTS

11. General Methods

Several methods have been used to determine radar performance. The value of each of these methods will be considered briefly.

a. GUESSWORK METHOD. The first method is that of rational guesswork, rational because it is presupposed that the guesser is thoroughly familiar with a specific radar set. Thus, the guesser surmises that his specific set is operating in a manner approximately equal to the best performance ever obtained previously. Inherently, guesswork cannot be accurate. Certainly some are better guessers than others, but, on the average, this method can result in performance being down 20 to 30 db.

b. MAXIMUM RANGE METHOD. A second method uses range as a criterion of performance. Radar performance is adjudged good if a target can be tracked consistently to some specific maximum range. In view of the discussion in section I, the fallacy of this method is apparent. When this method is used, radar performance is not separated from those other uncontrollable and variable factors influencing range, such as variations in propagation and in the effective scattering of the target. Performance can be as much as 100 db down if determined by this method.

c. FIXED ECHO METHOD. A third method, which has disadvantages similar to those in the maximum range method, is the use of a standard or fixed target. Normally, the target chosen will not be a simple one; rather it will be a composite, frequency-sensitive one. The strength of the returned echo is, of course, dependent on the relative position of the radar set and target, the frequency of operation, and radar weather, if the target and radar set are greatly separated. Experiments have shown that the return from a standard target, with radar performance maintained at a constant level, can vary from day to day and even hour to hour by as much as 50 to 60 db. Obviously, this method does not offer a reliable criterion of radar performance. However, vast improvement can be realized if targets are so chosen that their echoes are reasonably constant from time to time and from one radar set to another. By selecting a target which fulfills the requisites given below, the variations in echo strength may be kept relatively small, within 1 or 2 db. The fact that it is difficult to find a target which fulfills all these requirements leads to the conclusion that the use of a standard target as a method of determining performance is not satisfactory. The requisites for a fairly acceptable standard target are as follows:

(1) It must be a single, stationary object of a simple geometric shape and of such size that its echo does not saturate the receiver.

(2) It must be shielded from other targets at approximately the same range, even at considerably different azimuth directions.

(3) It must be relatively close (within 5 miles) to minimize atmospheric effects.

(4) It must not be over water, as tidal effects then are present and atmospheric conditions are more variable.

d. CALIBRATED TEST EQUIPMENT METHOD. The last method of measuring radar performance is by means of calibrated test equipment. This method is, of course, superior to all other methods. The accuracy of measurement is from 1 to 5 db, depending on the test equipment used. At very best, all methods previously mentioned offer only a relative measure of performance, showing broad changes in radar performance without measuring the absolute level. Thus there is no real assurance that the radar set is actually operating at a high level consistent with the design of the equipment. The use of test equipment places the problem of measuring performance on much firmer ground. First, measurements made in this manner are free of all disturbances external to the radar set. Considerations of propagation and target characteristics, therefore, are of no concern. Secondly, calibrated test equipment permits the use of several items of the same type of test equipment on different radar sets of the same type with reliable accuracy, within 2 db. Reliable test equipment, then, permits the monitoring of performance of the radar set itself, reflects small and measurable changes in radar performance, and establishes a numerical performance level which may be compared with a practical ideal level.

12. R–f Test Point

Any discussion of the use of test equipment to measure performance must include a description of the methods that are used to couple r-f energy from the radar set to the test equipment. The three most commonly used methods are described below.

a. SLOTTED SECTION. Energy can be removed from or coupled into a radar system by inserting a probe in a slotted section of r-f line. In general, the energy coupled out of or into the line depends on the position of the probe along the line, the depth of the probe within the line, and the orientation of the probe with respect to the axis of the line. In this type of coupling the probe is as receptive to reflected energy within the line as to the energy coming directly from the transmitting oscillator. Obviously, this fact will complicate measurements and may result in incorrect data. Further, since it is difficult to reestablish the exact position of the probe, it cannot be determined exactly whether variations in measurements are caused by changes in the r-f system itself or in the positioning of the probe.

b. TEST ANTENNA. A second method of coupling r-f energy involves the use of a pick-up antenna, placed in front of the radar antenna, usually at a distance greater than the diameter of the parabolic reflector. This distance is chosen to avoid the complex radiation pattern which may be present close to the radar antenna. The position and orientation of the pick-up antenna with respect to the radar antenna must be fixed in such a way that it can be reestablished at will. Further, the initial positioning of the pick-up antenna is influenced by the site of the radar set, since the signal return from fixed targets cannot be allowed to interfere with measurements involving the use of a scope. Also, the surrounding terrain must not influence measurements through the reflection of energy. In this latter regard, note that some pick-up antennas, by their very design, are less responsive to the reflected energy than are others. Fixing the position and orientation of the pick-up antenna is a tedious task, and, once established, it is best not to disturb the pick-up antenna. Then the same coupling conditions can be readily obtained by controlling the radar antenna in azimuth, elevation, and in the angular position of the dipole.

c. DIRECTIONAL COUPLER. A third coupling method or r-f test point is the directional coupler. This method is much preferred to those previously mentioned, chiefly for its greater convenience of use and calibration.

(1) *Unidirectional coupler.* Although there are many different types of unidirectional couplers, based on somewhat different principles, their application and the manner in which they are used are very similar. One type commonly used with waveguide r-f lines is described below. Similar couplers have been designed for use with coaxial, stub-supported, r-f lines. In manufacture, the directional coupler is made an integral part of the r-f line. Once installed, the directional coupler need not be removed from the system since it does not interfere with the normal operation of the radar set.

(*a*) *Physical characteristics.* One type of unidirectional coupler is shown in figure 6. The coupler consists of a section of main waveguide on the narrow dimension of which is mounted an auxiliary piece of waveguide having the same cross-sectional dimensions. The auxiliary guide is closed at both ends. In the common faces of the two guides are two coupling holes, spaced one-fourth wavelength apart. A coaxial, type N connector is attached at the center of the wide dimension of the auxiliary line, between the coupling holes and the shorted end of the line. The center conductor of this coaxial line extends into the guide. The other end of the auxiliary guide is terminated by a thin strip of absorbing material.

(*b*) *Electrical characteristics.* Energy traveling in the main guide from the transmitter toward the antenna enters the auxiliary line both at section B–D and, a quarter wavelength further down the line, at section C–E. Energy following the path A–B–D–E–F is in phase with energy following the path of equal length, A–B–C–E–F. Therefore, there is an additive effect of energy directed toward the r-f connector. Energy following a path A–B–C–E–D travels a half wavelength farther than energy following the path A–B–D. Thus, there is an effective cancellation of energy in the direction of the absorbing material. Reflected energy following the path G–C–E–F effectively cancels the energy whose path is G–C–B–D–E–F because of the half wavelength difference between the two paths. Therefore, reflected energy does not contribute to the energy measured by the test set connected to the r-f connector. Reflected energy also travels the equal paths G–C–E–D and G–C–B–D. In this case, an additive effect occurs in the direction of the absorbing material where the energy is dissipated. In a similar manner, it can be shown that if energy is introduced at the r-f connector, as is done in receiver tests, it is directed toward the T/R box and thence to the receiver and not toward the antenna. Summarizing, then, because of its directional property, such a directional coupler permits power to be coupled out from the power traveling from the transmitter toward the antenna, and not from the reflected wave; and a signal introduced at the directional coupler travels toward the receiver and not toward the antenna system. Power measurements made with the aid of a directional coupler are substantially free from coupling errors associated with standing waves in the r-f line.

(2) *Bidirectional coupler.* A bidirectional coupler is, in effect, nothing but two unidirectional couplers on the same r-f line. They are oppositely arranged so that one may be used to measure the transmitter energy in the main waveguide while the other will

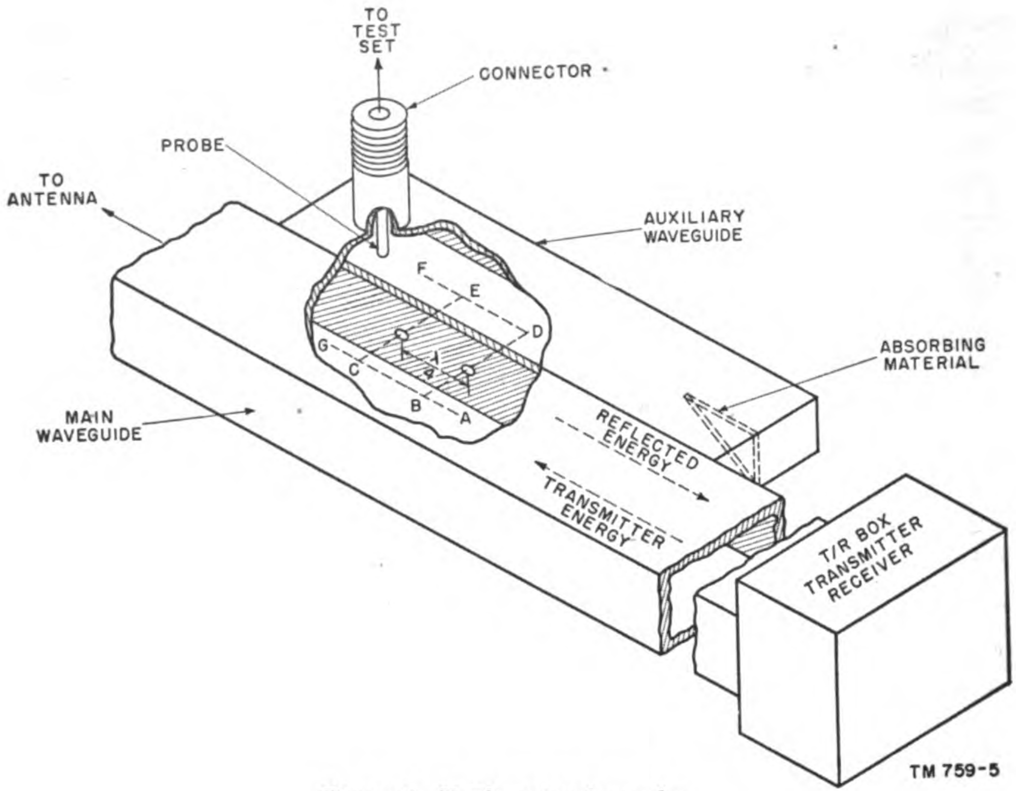


Figure 6. Unidirectional coupler.

measure the reflected energy. From these two measurements, the standing-wave ratio in the main guide can be computed. Very little application in the field has been found as yet for bidirectional couplers. They have been used chiefly in laboratories and for design purposes.

13. Comparative Advantages of Test Points

Of the three test points described in paragraph 12, the directional coupler is by far the preferred method of removing r-f energy from a radar set for application to a test set.

a. The least satisfactory method is the slotted section of r-f line because of the inaccuracy of the results obtained. Power measurements obtained in this manner are subject to errors introduced by variations in positioning and orientation of the probe as well as by the presence of standing waves in the line.

b. Although the test or pick-up antenna is capable of good results, it also has distinct disadvantages. As mentioned in paragraph 12*b*, this method requires painstaking care in the initial positioning and orientation of the antenna, and in reestablishing these conditions. Also, the magnitude of effective coupling between the test antenna and the radar set, that is, the amount of space attenuation, must be calibrated accurately to obtain an absolute determination of transmitter power output. This is also true for the slotted section test point. In general, the calibration of the coupling given by the slotted section or the test antenna is done by comparing the magnitudes of minimum discernible signal powers determined by feeding a signal first through the test point and then directly into the line or through a coupling device giving a known amount of coupling. The difference between these two readings is the magnitude of coupling given by the test point. How often recalibration of the test point is required is not known. However, if measurements at any time are noticeably different from previous values, it is advisable to recalibrate to determine whether the difference is caused by incorrect calibration of the r-f test point or to trouble in the radar set itself. Note that power measurements made by means of a pick-up antenna are proportional to the radiated power and not the total power developed by the transmitter. This is so because of standing waves in the r-f line.

c. The directional coupler is the most convenient to use because it is permanently attached to the r-f line. It does not require calibration by the radar personnel because its calibration, in db, is normally indicated on the coupler itself and is independent of the position of the radar antenna. The calibration is determined by the manufacturer through the use of laboratory equipment and techniques and therefore does not warrant checking unless gross discrepancies are noted. The coupler may then be calibrated as was explained for the test antenna in *b* above. The calibration of a directional coupler implies that the power removed from the coupler is down by that calibrated amount from the transmitter power in the main r-f line. It also means that a signal introduced at the directional coupler is greater at the point of introduction than in the main line by the same calibrated amount. For example, assume that a directional coupler similar to that in figure 6 is calibrated as giving an attenuation of 20 db and a test set is connected to the coaxial connector to measure the average transmitter power output. From table I, the power in the main r-f line must be 100 times as great (20 db) as that measured at the coaxial connector. If the power measured by the test set is 0.3 watt, the power in the main line must be 30 watts. Note that when actually making such quantitative measurements, the additional attenuation introduced by the cable or waveguide connecting the test set must also be taken into account. It must be mentioned that measurements made at a directional coupler do not reveal the condition of the r-f components associated with the antenna system because conditions between the directional coupler and the antenna do not directly influence measurements made at the coupler. However, in most radar sets, trouble occurs in these components less often than in other receiver and transmitter r-f components. When faults do exist in the antenna system, they are sometimes of a mechanical nature and are evident upon inspection. Often such faults cause a high standing-wave ratio, resulting in observable symptoms of frequency pulling, improper operation of AFC (automatic frequency control) circuits, or even arcing at some point in the r-f line.

14. Echo Boxes

An indication of radar performance can be obtained by means of an echo box. The echo box is a cavity whose resonant frequency is dependent on its dimensions. When the cavity is excited by an r-f pulse, oscillations are set up in the cavity, the amplitude and duration of the oscillations being dependent on the energy in the r-f pulse. In normal use, the echo box is excited with a portion of the power from the radar transmitted pulse and then the energy stored in the echo box is fed back to the receiver. The oscillation of the echo box is observed on the radar indicator. The length of time between the start of the transmitter pulse and the point at which the oscillation fades into the receiver noise is called the ringtime. Note that the echo box receives power which is proportional to the peak power transmitted, P_{pk}. Since the echo box oscillations are fed to the radar receiver and then observed on the radar indicator, the ringtime observed on the radar scope will be proportional to the peak power transmitted, P_{pk}, and the receiver sensitivity, P_m. This is the same as saying that the observed ringtime is proportional to the performance of the radar set.

a. THEORY. The functioning of an echo box is described with reference to figure 7. Assume the echo box is excited by a transmitter pulse with a peak power of 80 dbm. The peak power supplied to the echo box is attenuated because of the losses resulting from three distinct causes. These are the loss due to the r-f test point, the loss in the cable or waveguide connecting to the echo box, and the coupling loss at the echo box itself. Assuming, as shown in figure 7, that these combined losses cause a total loss in signal power of 35 db, the net power available at the echo box is approximately 45 dbm. This amount of energy is capable of being stored in the echo box, which oscillates. Because of what is termed the flywheel effect, a definite length of time is required for the energy within the box to build up to its maximum value. Thus, as shown in figure 7, the radar pulse may come to an end before the echo box charging curve has reached the maximum value of 45 dbm. After the radar pulse ends, the echo box continues to oscillate and this energy is fed back to the radar receiver. Now the flywheel effect operates to make the echo box discharge its energy slowly, about 2 db drop during each microsecond. The same losses are present during the discharge process as during the charge. In figure 7, it is assumed that the saturation level of the receiver is —80 dbm. As long as the energy fed back to the receiver is greater than this value, the receiver is saturated. If the radar set has an A-type scope, a flat-topped signal appears on the scope. The sloped, lagging edge of the scope pattern represents the gradual signal decay below —80 dbm. The point at which this edge disappears into the receiver noise (—95 dbm in figure 7) is the minimum discernible signal level $P_{m}(_{dbm})$. The ringtime is shown as the length of time between the start of the transmitter pulse and the point at which the signal fades into the receiver noise. In terms of range on an A-scope, this point may be more exactly defined as that point in range at which the echo box signal, when varied slightly on either side of resonance by slowly tuning the box, just fails to cause a change in the amplitude of noise signal. The radar performance figure $S(_{db})$ is shown equal to the algebraic difference or numerical sum of $P_{pk}(_{dbm})$ and $P_{m}(_{dbm})$. If either of these two values is increased, the length of time required for the echo box signal to disappear into the receiver noise level (that is, the ringtime) also increases. Thus, the ringtime is a measure of radar performance.

b. USES. In addition to indicating radar performance, the echo box serves several other functions which make it useful in alining and maintaining a radar set.

(1) The echo box may be used to isolate the source of trouble in r-f components of a radar set. Most echo boxes are equipped with an auxiliary microammeter. Energy is coupled from the echo box to a crystal rectifier and the meter is connected to measure the rectified crystal current. Since meter deflection is a measure of transmitter power output, abnormally low or erratic meter readings suggest trouble in the transmitting system. A low ringtime, with normal meter reading, indicates trouble in the receiving system or T/R box. The T/R box recovery time may be measured by detuning the receiver or the echo box until a definite change in the slope of the echo box decay is observed. The ringtime at this point should be under 12 microseconds (2,000 yards) for a properly functioning T/R box.

(2) Because of its high Q, the echo box makes an excellent wavemeter if its tuning dial is calibrated. Tuning of the echo box

to the nominal transmitter frequency (f_t) is indicated by maximum meter indication. During this process, the transmitter spectrum (Δf_t) may also be determined. Because of its very narrow bandpass, the echo box responds to only a narrow portion of the transmitter spectrum at a time. If the echo box is tuned slowly through the region of resonance, the echo box meter deflection will follow the transmitter spectrum.

(3) The echo box may also be used to determine the extent of transmitter frequency pulling. This may be done by connecting the echo box to a directional coupler. In this manner, the radar antenna may be rotated and the echo box operates continuously for all azimuth directions of the radar antenna. The echo box ringtime should appear as a large circle at the center of the radar PPI scope. With no transmitter frequency pulling, the circle should be fairly regular, indicating constant ringtime for all azimuth directions of the antenna. If transmitter pulling occurs for any direction of the antenna, the length of the ringtime at the corresponding azimuth direction of the PPI scope is reduced. The PPI scope thus displays the direction and severity of transmitter pulling.

(4) The echo box can also be connected to the local oscillator of the receiver to measure the frequency of the oscillator. When the echo box is used in this manner, precautions should be taken that it does not "pull" the frequency of the oscillator. To prevent this from occurring, a long length of test cable, or several joined lengths, should be used so that there is considerable attenuation between the local oscillator and the echo box.

c. LIMITATIONS. Figure 7 shows the general charge and discharge characteristics of the echo box, as well as the various losses that are encountered when using the echo box with a radar set. There are, however, three other factors which will affect the ringtime. These are temperature, frequency, and humidity. Technical manuals for echo boxes suitable for accurate performance measurements sometimes include data for correcting ringtime for frequency, temperature, and humidity. In most cases the effect of humidity on ringtime is small. Therefore, the accuracy of this method of performance measurement is only as good as the accuracy to which the effect of the other factors is known, and the accuracy to which the ringtime is measured. Only a few of the existing echo boxes are provided with the necessary data, and not all radar sets are designed to make accurate range measurements. Therefore the use of the echo box for performance measurements which are accurate within ±2 db is limited.

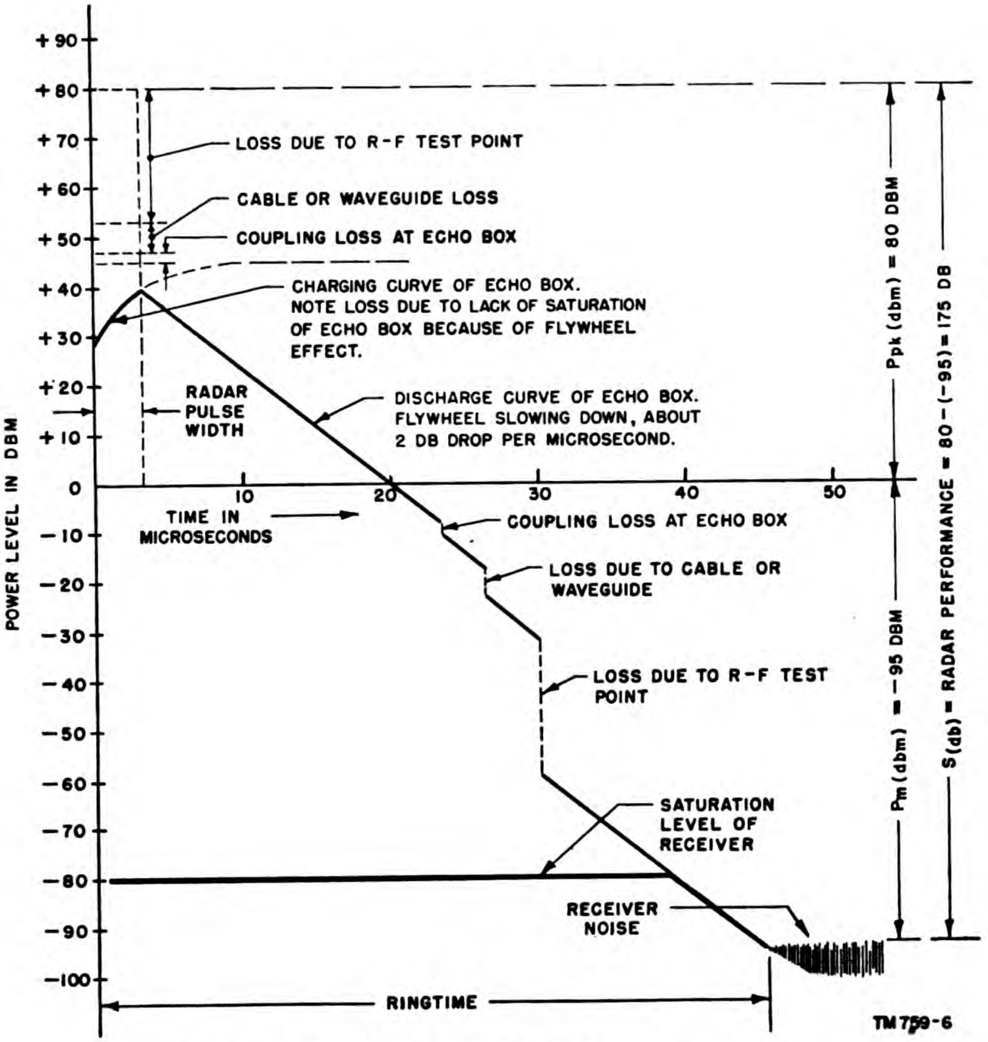


Figure 7. Echo box charge and discharge characteristics.

15. Power Meters

The average power output of a microwave radar transmitter is usually measured with a wattmeter. As shown in figure 8, this wattmeter may be arranged as a simple, battery-operated, bridge circuit, three legs of which are resistors and the fourth leg a bead thermistor. The bead thermistor is a resistive element, the resistance of which varies inversely with the temperature of the thermal bead.

a. In operation, and with no r-f voltage applied, a d-c (direct-current) voltage is placed across the bridge. This voltage is adjusted, by means of a series variable resistor, until the bridge is balanced. This follows from the fact that current through the bead thermistor raises the temperature of the bead and thus changes its resistance. Proper adjustment of the d-c voltage, and therefore the current, results in a balanced bridge. Then, if r-f energy is applied to the thermal bead, its resistance is again changed and the bridge is unbalanced. The amount of unbalance is directly proportional to the r-f energy applied and is indicated by the bridge meter. The meter may be calibrated to read the average r-f power either in milliwatts or dbm.

b. Since the bridge is sensitive to temperature, it must be protected from changes in ambient temperature. This is accomplished by disk thermistor circuits which compensate for ambient temperature effects. The disk thermistors have relatively large mass so that their resistance is comparatively unaffected by the current flowing through them but is dependent primarily on the ambient temperature. They are usually mounted on the outside of the assembly containing the bead thermistor, so that they are affected by the same ambient temperature changes acting on the bead. However, the action of the disk thermistor circuits is such that their effect on the bridge circuit for any ambient temperature change is equal and opposite to the effect produced by the bead. In this manner, after the bridge is balanced, the meter indication is made to depend solely on the r-f power applied to the bead thermistor.

c. The range of the thermistor bridge can be extended by attenuating the r-f power through an attenuator before applying it to the bead thermistor. The attenuator may be either variable or fixed. If a fixed attenuator is used, the amount of attenuation introduced is usually taken into account in the calibration of the meter itself. If the amount of attenuation is not included in the meter calibration, or if a variable attenuator is used, the amount of attenuation introduced (in db) must be added to the meter indication (converted to dbm if not already in that form) to find the average r-f power input in dbm. In some cases, when a calibrated variable attenuator is used, an alternate method of measuring power is available. By adjusting the attenuator with r-f energy applied, the meter is set at a predetermined reference deflection level, and the power is read directly, in dbm, from the attenuator calibration.

d. The use of a specific instrument of this type is usually limited to a definite frequency range. This is due to the fact that r-f energy is coupled to the bead thermistor by mounting the bead within a waveguide, resonant cavity, or other mechanical arrangement which is sensitive to a definite range of frequencies.

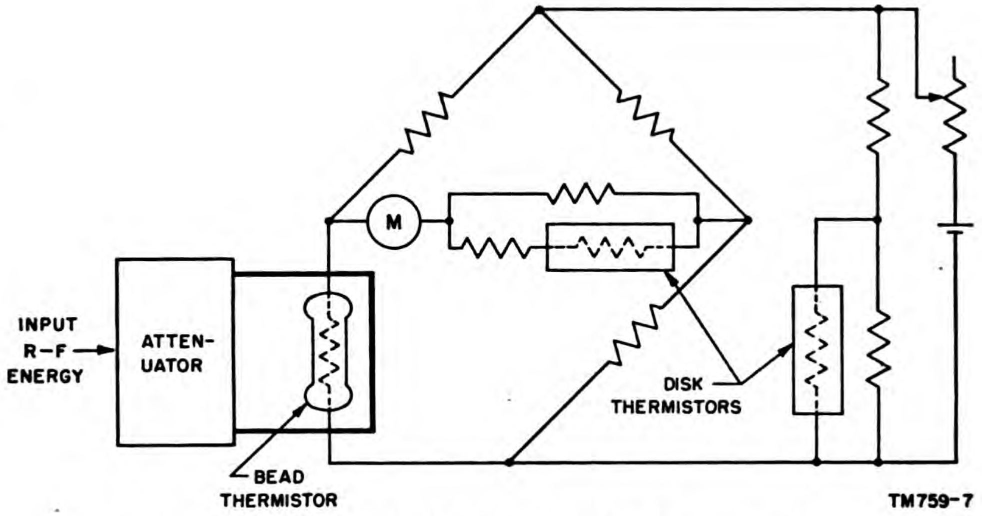


Figure 8. Thermistor bridge circuit for power measurements.

16. Wavemeters

The transmitter frequency f_t and receiver frequency f_r of a radar set are often measured by means of a wavemeter. The wavemeter consists of a cavity containing a movable piston. The piston is used to vary the size and therefore the resonant frequency of the cavity. The position of the piston is usually controlled by a micrometer head, the reading of which indicates the frequency of the cavity. In general, either of two methods of feeding a wavemeter may be used. R-f energy may be coupled into the cavity directly and then removed from the cavity and detected by a crystal to supply current to a d-c meter. With this arrangement, when the cavity is tuned to resonance, the meter reading is maximum. Another method is to feed the r-f energy directly to both the crystal and the cavity, the crystal supplying current to the meter. In this case, the cavity offers a branch path to the r-f energy. When tuned to resonance, the cavity absorbs a maximum amount of r-f energy, causing a dip in the meter reading.

17. Crystal Checkers

The crystal checker is not really an item of r-f test equipment. However, it is of definite value in r-f maintenance because the sensitivity of a radar receiver is affected to a considerable extent by the operation of the crystal. The crystal checker enables an evaluation of the crystal in terms of experimental data collected from tests on a great number of crystals. These data have established that a correlation exists between the results obtained from simple d-c checks performed on a crystal and the r-f properties of the crystal. The crystal checker measures the front-to-back and back-to-front resistances of the crystal and the back current through the crystal under constant voltage. In this manner, the r-f performance of the crystal is determined to be either good or bad, as determined from the appropriate scale of the crystal checker meter.

18. Flux Meters

The flux meter measures the strength of the magnetic field applied to the transmitter magnetron and as such is a useful instrument for r-f maintenance. Essentially, this instrument consists of a d-c voltage source and two milliammeters, all connected in series with a variable amount of resistance. One of the milliammeters, which is calibrated directly in gauss, derives its field power from a self-contained permanent magnet. The other, called the probe meter, is placed between the pole faces of the magnet under test so that it derives its field power from that magnet. The series resistance is varied to give a reference deflection on the probe meter, and the gauss meter measures the current in the circuit. This current is a measure of this field strength of the magnet under test.

19. Spectrum Analyzers

The spectrum analyzer determines the distribution of radar transmitter power with frequency. It consists of a narrow bandpass receiver and an oscilloscope combined in a single unit. The receiver local oscillator is frequency-modulated by a sawtooth voltage. Because of its narrow bandpass, the receiver instantaneously accepts only a small part of the transmitter energy fed to it. Since the scope sweep is obtained from the same sawtooth used to modulate the receiver local oscillator, the spectrum of transmitted energy is displayed on the scope. The receiver is a superheterodyne, so that two spectra can be displayed on the scope for a single r-f input to the analyzer, one when the frequency of the local oscillator is above that of the r-f input and a second when it is below. Usually a tunable cavity is placed so as to absorb a portion of the local oscillator energy when tuned to resonance, thus producing a dip or notch in the scope picture. The frequency of r-f input may be determined with this equipment. Also, the spectrum analyzer may be used to determine the radar transmitter pulse width and the tuning of the radar receiver, as well as to check the operation of automatic frequency control circuits.

20. Test Sets and Signal Generators

All of the test equipments described in preceding paragraphs have definite shortcomings in that they do not enable an absolute determination of radar performance. For example, the ringtime as determined with an echo box is proportional to radar performance. However, an absolute value of radar performance is not obtained; the ringtime measured at a given time must be compared to a predetermined value which is deemed to be satisfactory. Although r-f power meters do give an absolute measurement of transmitter power output, that is only one of the component parts of radar performance. Test sets and r-f signal generators combined in a single unit allow both the transmitter power and the receiver sensitivity to be measured. From these, the radar performance figure can be calculated. For brevity, such combined test sets and r-f signal generators are referred to in this manual as *test sets.*

a. TYPICAL TEST SET. A simplified block diagram of a typical test set is shown in figure 9. In general, such a test set consists of a power monitoring circuit, a frequency meter, and a variable r-f oscillator together with its associated modulating circuits. The r-f oscillator may be either of two types, depending on the modulation signal applied to it. It may be pulse-modulated, or modulated with a sawtooth voltage to give a frequency-modulated output. Both types are discussed below. In either case, the test set requires, at most, only three connections for proper functioning: 115 volts a-c (alternating-current) power, coupling to the r-f system of the radar set through the r-f test point, and, sometimes, a trigger from the radar set. Complete performance tests can be made quickly, requiring 5 minutes or less once experience has been gained in the use of the equipment.

b. TRANSMITTER MEASUREMENTS. The action of the test set in performing transmitter measurements is independent of whether the test set is pulse-modulated or frequency-modulated because the r-f oscillator and modulating circuits are not used. As shown by the dashed arrows in figure 9, only the calibrated attenuator, the power monitoring circuit, and the frequency meter are used for such measurements.

(1) The power monitoring circuit used in test sets is the thermistor bridge previously discussed in paragraph 15. Power introduced into the test set passes through a calibrated attenuator before reaching the bridge. Power measurements may be made in either of two ways. The calibrated attenuator may be adjusted until the bridge meter-needle reaches a reference deflection, and then the power fed into the test set is read from the attenuator,

usually calibrated in dbm. Or, the attenuator can be set to a reference mark and the power fed into the test set read on the meter in the unbalanced bridge. The meter may be calibrated to read in milliwatts or dbm. Although the bridge circuit is temperature compensated, it is advisable to check the balance of the bridge before making each major measurement.

(2) A tunable cavity is used to determine the frequency of the radar transmitter. When tuned to resonance, the cavity absorbs a portion of the energy directed toward the thermistor bridge. This condition is shown by a dip in the bridge meter reading. The tuning control on the cavity is usually calibrated to read frequency directly, although in some units only arbitrary dial readings are given and must be converted to frequency. Sometimes the cavity of the r-f oscillator in the test set is used as a frequency meter. This gives the added advantage of setting the frequency of the test set oscillator at approximately the transmitter frequency with only a single control, in preparation for performing receiver tests. In this case, the absolute value of transmitter frequency need not be recorded.

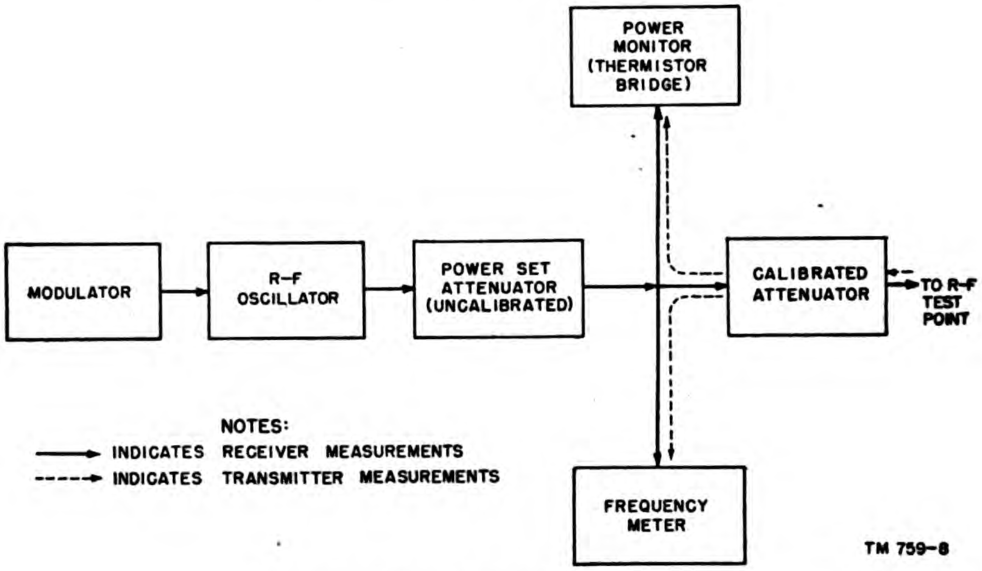


Figure 9. Typical test set, block diagram.

c. RECEIVER MEASUREMENTS WITH PULSE-MODULATED TEST SET. To determine the minimum discernible signal power of a radar receiver, the r-f oscillator of the test set is used to generate a signal at the transmitter frequency. In a pulse-modulated test set this signal is in the form of pulses.

(1) *Pulse modulator.* A simplified block diagram of a typical pulse modulator as used in a test set is shown in figure 10.

(*a*) A positive trigger pulse is supplied to the phase multivibrator from the radar set. If the pulse from the radar set is negative, it is first inverted and then applied to the phase multivibrator. This multivibrator introduces a delay between the trigger pulse and the pulse supplied to the r-f oscillator. Since the width, *W*, of the output of the phase multivibrator is variable, the amount of delay introduced is also variable. This permits the output of the test set to be positioned along the sweep trace of a synchronized oscilloscope. The output of the phase multivibrator is differentiated and the trailing edge is used to trigger a pulse multivibrator. The output of this second multivibrator is also variable in width and, in operation, is set so that it produces a signal which is comparable to a normal radar echo. The pulse is fed to a cathode follower and then amplified before it is applied to the r-f oscillator as a negative pulse.

(*b*) Sometimes pulse-modulated test sets are internally triggered, instead of with a trigger pulse from the radar set. In that case, the radar set is synchronized with a trigger pulse supplied from the test set. The repetition rate of the trigger generated in the test is made variable and is adjusted to be approximately equal to the normal repetition rate of the radar set under test.

(2) *Operation.* The solid arrows in figure 9 show the action of a test set during receiver measurements. For a pulse-modulated test set, the output of the r-f oscillator consists of pulses of r-f power. Before the minimum discernible signal power can be measured, the output of the test set must be calibrated. To do this, first the oscillator is tuned to the same frequency as the radar transmitter. Proper tuning is indicated by setting the frequency meter dial at the transmitter frequency previously determined, checking the balance of the bridge, and varying the oscillator tuning until a dip in the thermistor bridge meter indication is obtained. After the r-f oscillator has been tuned, it is set to operate at a fixed, high duty-cycle (wide pulse width and low repetition rate) and the uncalibrated power set attenuator varied to give a reference deflection on the thermistor bridge meter. With this setting of the power set attenuator, when the r-f oscillator is restored to normal operating conditions of pulse width and repetition rate, the calibrated attenuator will measure the *peak* power output of the test set in dbm. This attenuator is adjusted until the signal displayed on the radar A-scope, or its equivalent, is just barely discernible from noise. Slowly moving the test set signal along the base line of the scope, by adjustment of the phase multivibrator, aids in determining the attenuator setting. The dbm setting of the calibrated attenuator is a measure of the minimum

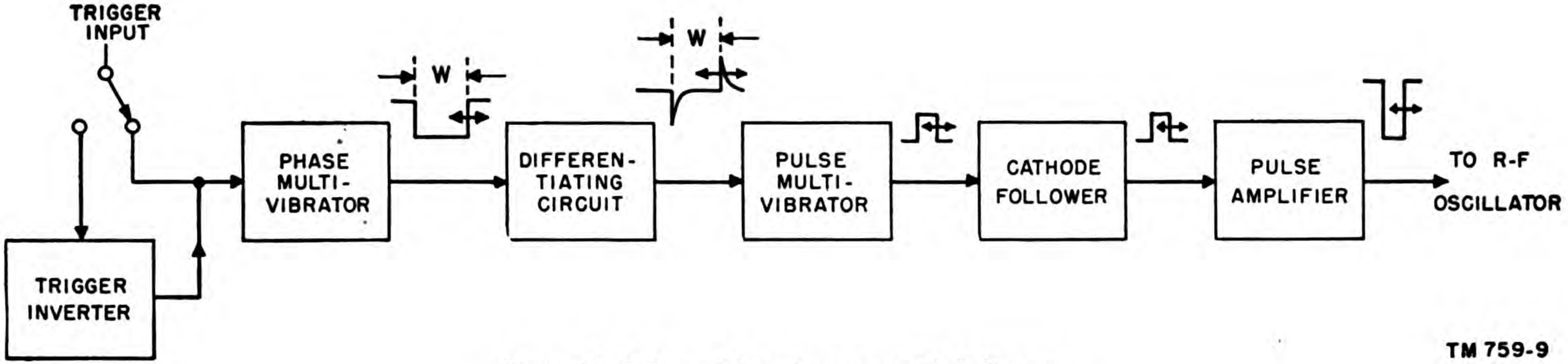


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Figure 10. Pulse modulator for test set, block diagram.

discernible signal power of the radar receiver. To determine the minimum discernible signal exactly, the attenuation introduced by the test point and the connecting cables must be considered.

d. RECEIVER MEASUREMENTS WITH FREQUENCY-MODULATED TEST SET. (1) *Frequency Modulator.* In general, an f-m (frequency-modulated) test set is less bulky than an equivalent pulse-modulated test set, chiefly because of its simpler modulating circuit. A block diagram of a typical modulating circuit for an f-m test set is shown in figure 11. The sweep generator may be triggered in either of two ways. A trigger pulse may be fed directly to it, or a portion of the radar r-f pulse may be detected and amplified and then used to trigger the sweep generator. In the latter case, the radar transmitter must be operating or the sweep generator will not function. The output of the sweep generator is a sawtooth wave which modulates the r-f oscillator. Although the modulating sawtooth usually is generated internally, in some cases it is possible to introduce a sawtooth from an external source. When obtained from an external source, the sawtooth should be checked to see that it is fairly linear.

(2) *R-f oscillator.* Before the effect of the sawtooth wave can be discussed, an understanding of the operation of the r-f oscillator is necessary. The oscillator is a reflex, velocity-modulated tube, such as a klystron, with a resonant cavity the frequency of which can be varied.

(*a*) A generalized characteristic of such an oscillator is shown in figure 12. For a single setting of the tunable oscillator cavity, different modes of operation may be obtained by varying the repeller voltage. Oscillations at different frequencies and different outputs are possible in each mode, the frequency and power output being dependent on the repeller voltage. The range of frequencies possible in different modes differs, although the frequency of oscillation at the point of maximum output in each mode is the same, being the resonant frequency of the cavity. The maximum power output differs from mode to mode.

(*b*) Suppose the repeller voltage is set at a definite d-c value, called the bias level in figure 13. Then suppose that the repeller voltage is caused to vary linearly with time by superimposing a sawtooth voltage. Oscillations at different frequencies and different power levels will be obtained as the repeller voltage passes through each voltage mode of operation. In figure 13, only the output from one mode is shown since the action in the other modes is the same. The output of the test set is at the different frequencies possible in this mode. Since the radar receiver is designed to pass a specific band of frequencies, only that portion of the test

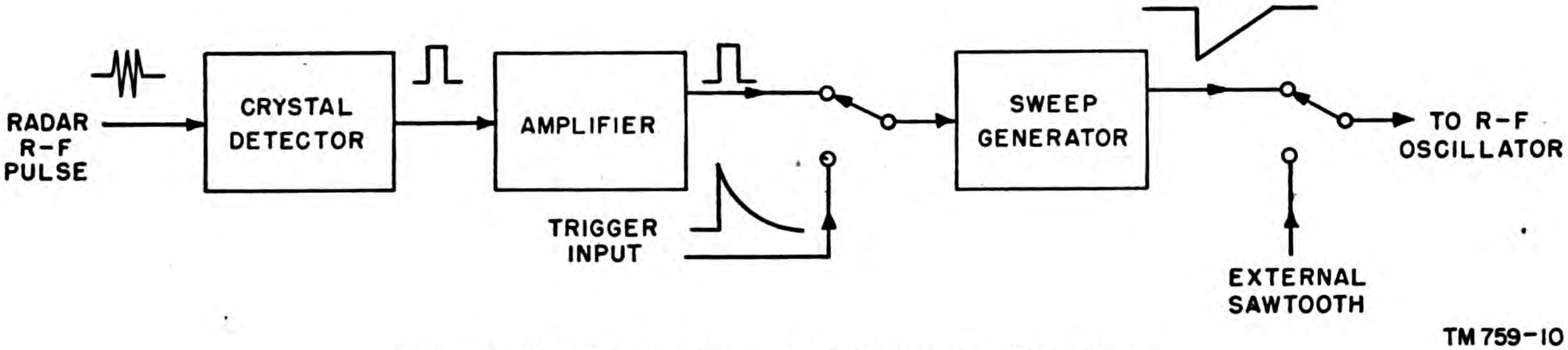

Figure 11. Modulator for frequency-modulated test set, block diagram.

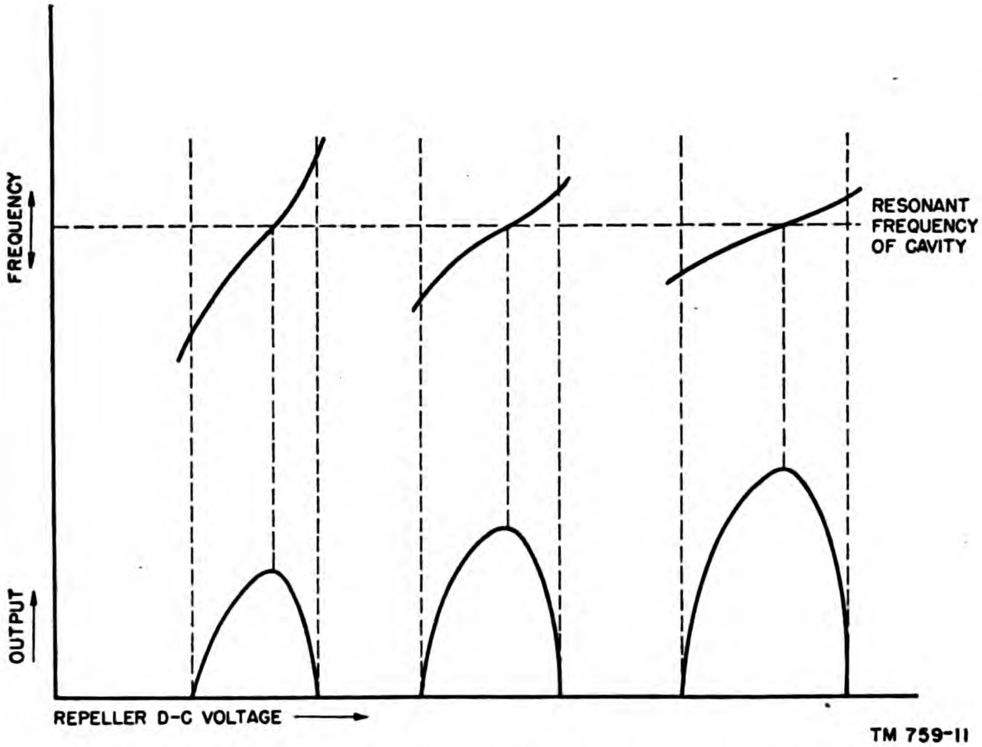

Figure 12. Generalized characteristic of reflex, velocity-modulated tube.

set output passed by the receiver is viewed on the radar scope. Thus, the scope displays the response characteristic of the radar receiver.

(*c*) As shown in figure 13, the test set signal viewed on the radar scope may be moved along the timebase of the scope. The bias level of the r-f oscillator repeller can be varied by means of a phase control. This changes the time during which the repeller voltage passes through that range of voltages representing one mode of operation, and the test set signal appears at a different point on the radar timebase.

(*d*) To adjust the width of the signal on the radar scope, it is necessary to change the slope of the sawtooth but to keep its duration constant. This is shown in figure 14. If the slope or amplitude of the sawtooth is reduced, a longer time is required for the repeller voltage to sweep through one of the modes of operation. But the total frequency range of the output for that mode, and the receiver bandwidth, are constant. Therefore, the frequency of the test set output remains within the limits of the receiver bandwidth for a greater length of time, and the width of the signal on the radar scope is increased.

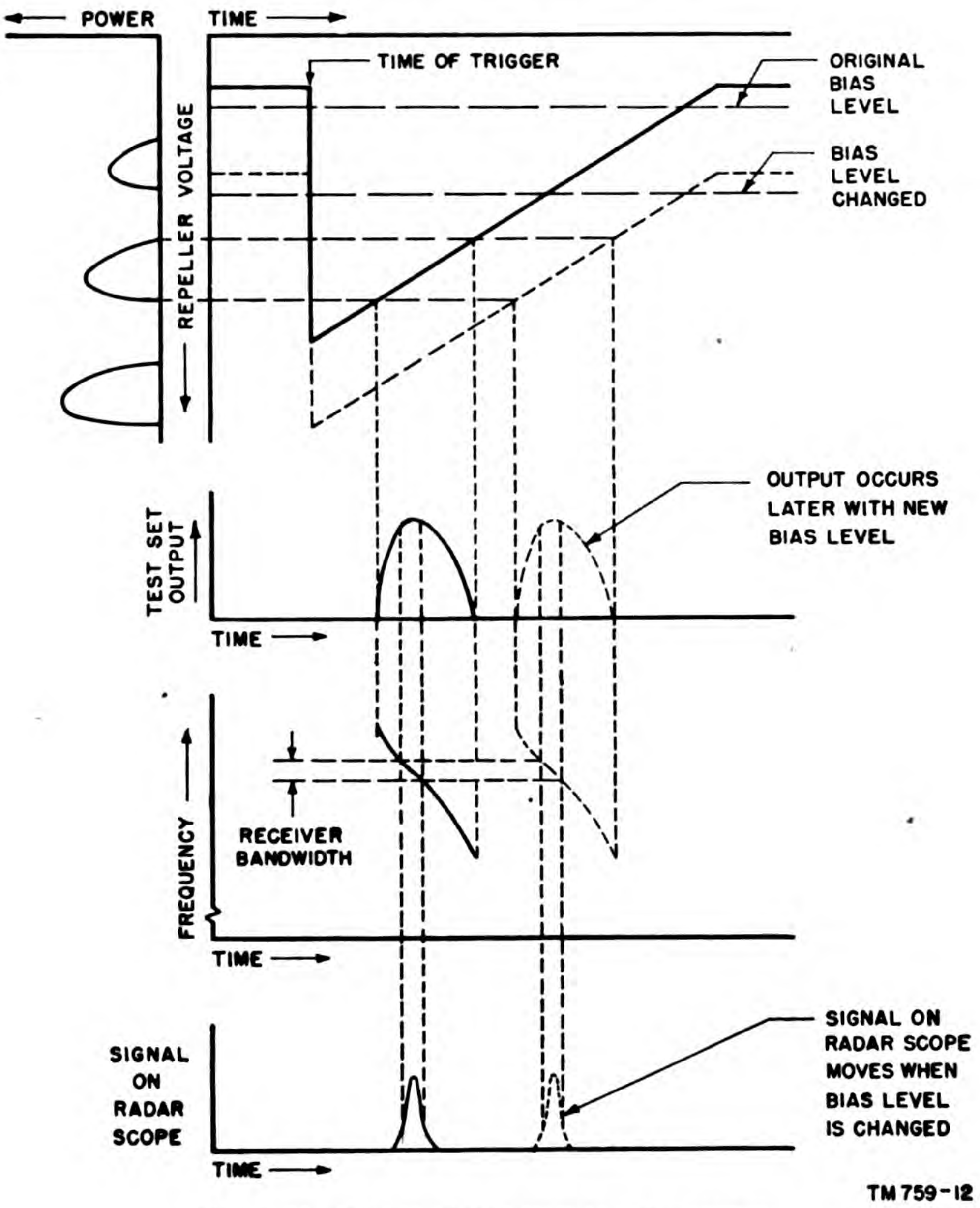

Figure 13. Relation of bias level to pulse position.

(3) *Operation.* The measurement of minimum discernible signal power is accomplished in the same manner as with pulse-modulated test sets. The calibrating technique differs somewhat. After the test set oscillator has been set to the same frequency as that of the radar transmitter, by adjusting the tunable cavity and the repeller voltage, the amplitude of the sawtooth wave is decreased. The signal is kept in view on the radar scope, possibly requiring continuous phasing. When the sawtooth has been completely removed, c-w (continuous-wave) oscillation is apparent on the scope. Then alternate adjustment of the oscillator cavity and

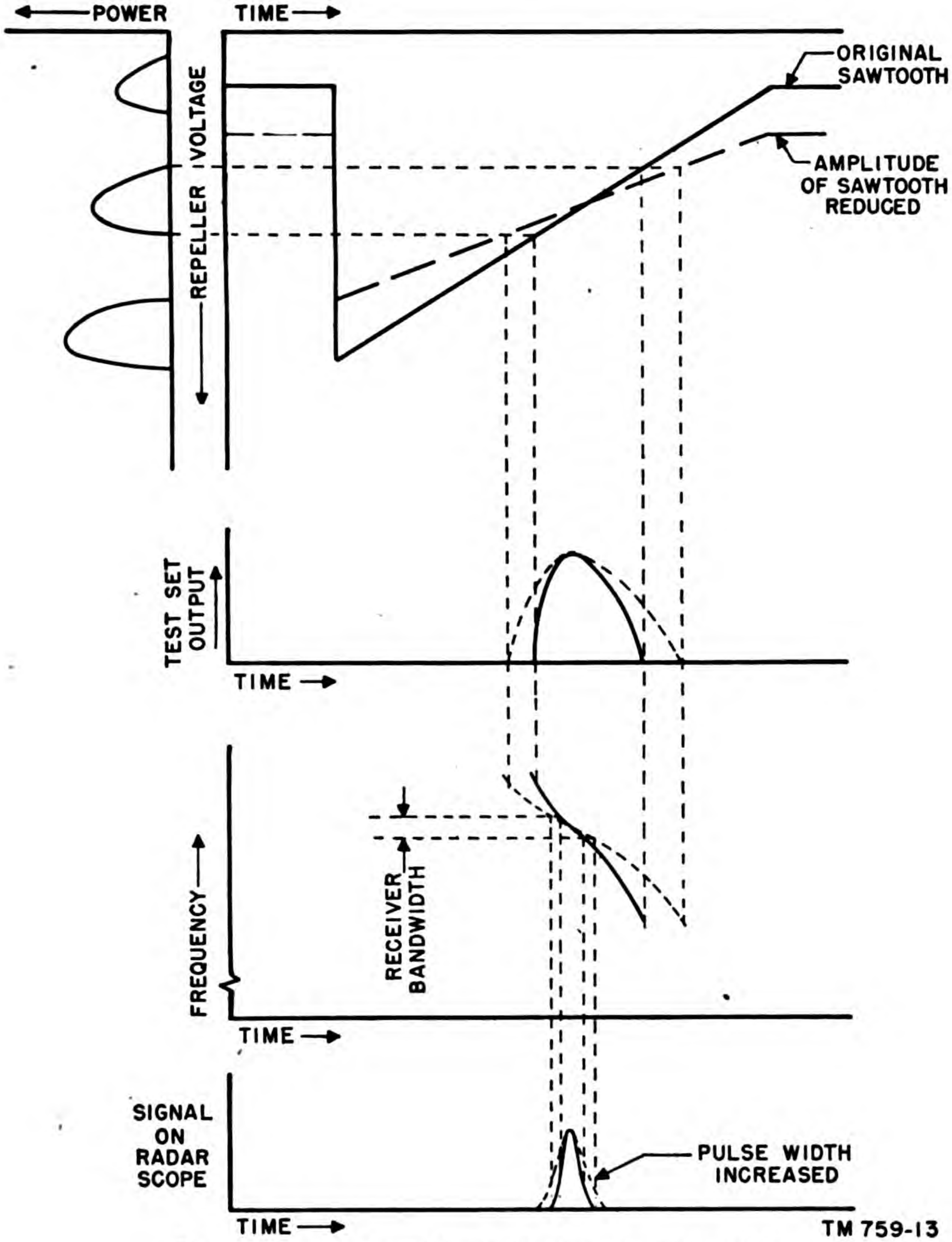

Figure 14. Relation of sawtooth slope to pulse width.

the repeller voltage is necessary to insure that the scope signal and test set power meter peak simultaneously. This provides maximum power output at the radar transmitter frequency and also provides that the frequency range which is of primary interest is at approximately a constant power level. The final step in calibrating this type of test set is to attenuate the r-f oscillator output by means of an uncalibrated attenuator until the power meter attains a reference level. The calibrated attenuator then reads the peak test set output in dbm.

e. ADDITIONAL USES OF TEST SETS. In addition to those uses already described, test sets may be used to determine receiver recovery time by phasing a nonsaturated signal toward the start of the scope sweep and observing the range at which the signal amplitude starts to decrease. F-m test sets may be used to determine the bandwidth of radar receivers and to check transmitter pulling and the performance of AFC circuits.

SECTION IV

INTERPRETATION OF MEASUREMENTS

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21. Radar Performance Data Sheet

In order that the measurements and calculations required to find the performance figure of a radar set can be made quickly and accurately, an orderly and systematic procedure should be followed. For this purpose, a radar performance data sheet, similar to that shown in figure 19, will be helpful. Also, data sheets of this type may be preserved for future reference to give a complete record of past performance of the specific radar set. In spite of its apparent length, the data sheet can be completed quickly because only four items are measurements which must be made with test equipment each time it is desired to find the radar performance figure. The typical data sheet in figure 19 has three main sections, as follows:

a. The upper section, consisting of those items with Roman numerals, gives factual information regarding the type and serial numbers of the radar set and test equipments used, the observer, and the date the observations were made. The only test equipments which should be listed are those which are used in performing the actual measurements listed on that particular data sheet.

b. The main body of the radar performance data sheet consists of items 1 through 24, all of which should be completed in determining the performance of the set. Only four of these items require measurement, and these are indicated by the circled item numbers (items 4, 13, 14, and 15). All other items of this group are either constants for the specific type of radar set and associated equipment, or are calculated from the measured and constant items. For example, items 1 and 2 are constant for the specific type of radar set. From these, and by using figure 3, the duty-cycle figure (item 3) is determined. The other items in the main body of the data sheet are discussed in the paragraphs which follow.

c. The items below the double line can be completed less frequently or whenever the results obtained in determining the radar performance figure indicate a necessity for performing these additional measurements. Items 25 through 29 are discussed in paragraph 28.

22. Computing Transmitter Average Power Output

In measuring the transmitter output power, the test equipment indication establishes the average power level at the test equipment itself. Obviously, of primary interest is the power level in the r-f line of the radar set. The signal power reaching the test equipment is attenuated in coupling through the r-f test point and in the cabling. Therefore, these losses must be added to the instrument meter reading of average power in dbm to determine the average transmitter power in the r-f line. The relation between these quantities can be expressed by the equation—

$$P_{av}(_{dbm}) = P^{1}{}_{av}(_{dbm}) + A + C,$$

where $P_{av}(_{dbm})$ is the average power in the r-f line relative to 1 milliwatt, $P^{1}{}_{av}(_{dbm})$ is the test equipment indication, A is the r-f cable or waveguide attenuation in *db*, and C is the coupling loss in *db* of the r-f test point.

a. The right-hand terms of the above equation are items 4, 5, and 6, respectively, of the data sheet in figure 19, and their sum, $P_{av}(_{dbm})$, is given by item 7. If the test equipment reading is in watts, it can be converted to dbm by means of figure 2. The attenuation of the r-f cable or waveguide connecting to the test equipment may be given on the cable or waveguide itself. If not, it may be easily determined as explained in paragraph 29. The test point coupling loss, *C*, is indicated on the directional coupler, if a coupler is used; if the r-f energy is coupled through a slotted section or a test antenna, the test point coupling loss is more difficult to determine accurately. Approximate values of attenuation for these two types of coupling may be given in the technical manual on the specific test equipment used. If not, the coupling loss must be calibrated by comparing the magnitudes of minimum discernible signal powers determined by feeding a signal first through the test point and then directly into the line or through a coupling device giving a known amount of coupling. The difference between these two readings is the magnitude of coupling given by the test point. Once the amount of coupling has been determined, it is important that the identical coupling conditions are reestablished during succeeding measurements.

b. The data sheet in figure 19 shows the rated or optimum value of $P_{av}(_{dbm})$ as item 8. If this is subtracted from item 7, item 9 is obtained. This difference is the number of db the transmitter performance is below its optimum value.

23. Computing Transmitter Peak Power Output

As explained in paragraph 7*a*, the transmitter peak power output in *dbm*, $P_{pk(dbm)}$, may be found by adding the duty-cycle figure in *db* to $P_{av(dbm)}$. Thus, item 10 of the data sheet is obtained by adding items 3 and 7. The transmitter peak power output, as given by item 10, is sometimes called the transmitter performance figure. If the rated or optimum value of $P_{pk(dbm)}$, item 11, is subtracted from item 10, the difference given in item 12 is the number of db the transmitter performance is below its optimum value. This difference must be the same as that found in item 9 because items 10 and 11 are both obtained by adding the duty-cycle figure to the two values used to obtain item 9.

24. Frequency Measurements and Temperature and Humidity Corrections

a. In the performance data sheet of figure 19, transmitter and receiver frequency measurements (items 13 and 14) are shown with circled item numbers. This indicates that these items must be measured each time radar performance is checked. Strictly speaking, to determine radar performance, direct measurement of these frequencies is not necessary. It is necessary that the receiver frequency, f_r, be the same as the transmitter frequency, f_t. Then, to find the receiver minimum discernible signal, the output from the signal generator or test set must also be set to that frequency. Therefore, the simplest way to insure that the receiver and test set are both adjusted to the transmitter frequency is to measure the transmitter and receiver frequencies directly. In addition, the record of operating frequency obtained in this manner may be useful for future reference.

b. The resonant cavity in most test equipments used for frequency measurements is calibrated accurately for certain conditions of temperature and humidity. With changes of temperature and humidity, the resonant frequency of the cavity changes for two reasons. First, the frequency is affected by the change in the dielectric; and second, temperature changes affect the size of the cavity and thus the frequency. Therefore, to obtain a corresponding degree of accuracy for different conditions, the frequency dial reading must be corrected for changes in both dielectric and cavity size. For the applicable correction charts, refer to the technical manual on the specific test equipment.

25. Computing Minimum Discernible Signal Power

In finding the minimum discernible signal power of a radar receiver, sometimes called the receiver performance figure, a pulse-modulated or frequency-modulated r-f signal is supplied to the receiver from a signal generator or test set, with both the receiver and the generator preset to the same frequency as the radar transmitter. The output of the receiver is observed on the radar A-scope or on a separate test scope, and the input signal is attenuated until the signal on the scope just disappears in the receiver noise or grass. At this point, the power level in dbm of the signal generated by the test equipment is observed and recorded as item 15 in the performance data sheet (fig. 19). Since the signal power level discernible by the receiver is less than 1 milliwatt, this quantity will always be negative. However, the actual power level of the signal arriving at the r-f line of the radar set is not that indicated on the test equipment because of the attenuation introduced by the r-f cable or waveguide from the test equipment and by the loss at the r-f test point. Hence, the receiver sensitivity is greater than is indicated by item 15, or, in other words, the minimum discernible signal power is more negative than the quantity recorded for item 15 by the amount of attenuation introduced by the r-f cable and by the test point. This relationship can be expressed by the equation—

$$P_{m\,(dbm)} = P^1_{m\,(dbm)} + (-A) + (-C),$$

where $P_{m\,(dbm)}$ is the receiver minimum discernible signal power in dbm, $P^1_{m\,(dbm)}$ is the test equipment power output in *dbm*, A is the r-f cable attenuation in *db*, and C is the r-f test point coupling loss in *db*. The three terms on the right side of the above equation (items 15, 16, and 17 in fig. 19) are all negative quantities and their sum, the minimum discernible signal $P_{m\,(dbm)}$, is given in item 18. Item 19 shows the rated or optimum value of minimum discernible signal, and the difference between items 18 and 19 (item 20) represents the number of *db* the receiver performance is below the rated value. Note that, since the receiver can do no better than equal the optimum performance, item 19 will be more negative than item 18. If the same r-f cable and r-f test point are used for receiver and transmitter measurements, items 16 and 17 will have the same absolute values as items 5 and 6, respectively, but will be negative. To determine the r-f cable attenuation, refer to paragraph 29. The problem of determining the test point coupling loss is discussed in paragraph 22*a*.

26. Computing Radar Performance Figure

As explained in paragraph 7*b*, the radar performance figure in *db*, $S_{(db)}$, equals the algebraic difference between $P_{pk\,(dbm)}$ and $P_{m\,(dbm)}$, or, more simply, it may be found merely by adding the numerical values of these two quantities. Thus, on the performance data sheet of figure 19, the radar performance figure (item 21) is obtained by subtracting the negative value obtained for item 18 from the value obtained for item 10, or merely by adding their numerical values. Item 22, the rated or optimum value of radar performance figure, is subtracted from item 21 to obtain item 23. Item 23 represents the total number of db the radar performance is below the rated value. Therefore, item 23 must equal items 12 plus 20 because these items show how far the two component parts of the radar performance figure, the receiver and transmitter performance, are below their optimum values.

27. Radar Performance Versus Radar Range

In paragraph 3*b* it was shown that radar range varied if the ratio of P_{pk} to P_m varied. Radar range also varies with changes of the radar performance figure $S_{(db)}$, because $S_{(db)}$ also depends on P_{pk} and P_m (par. 4*f*). The manner in which radar range decreases (in terms of percentage of maximum range) for each db the radar performance figure drops below its optimum value is shown in figure 15. If item 23 of the performance data sheet shows the radar performance figure to be down 4 db, from figure 15 it is found that only 80 percent of the maximum radar range is available. The percentage of maximum radar range available is entered as item 24 on the data sheet.

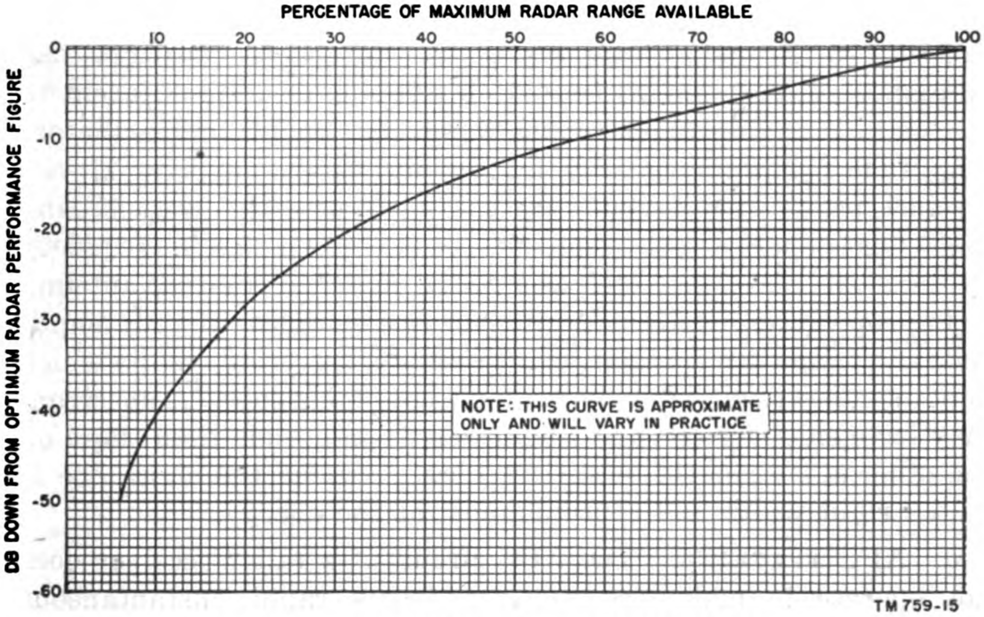


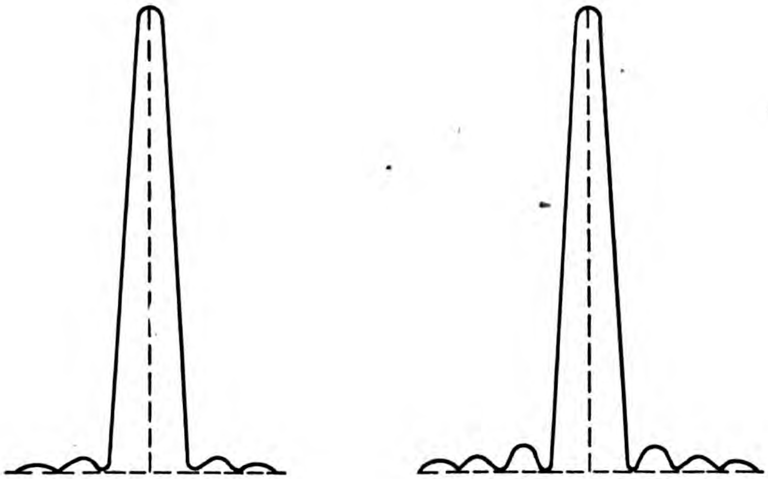
Figure 15. Radar performance versus radar range.

28. Additional Radar Measurements

The additional radar measurements discussed in this paragraph are included in items 25 through 29 of the performance data sheet (fig. 19). As previously explained, it is not necessary to perform these measurements to find the radar performance figure. However, valuable information regarding the proper functioning of the r-f components of the radar set may be obtained from the results of these measurements.

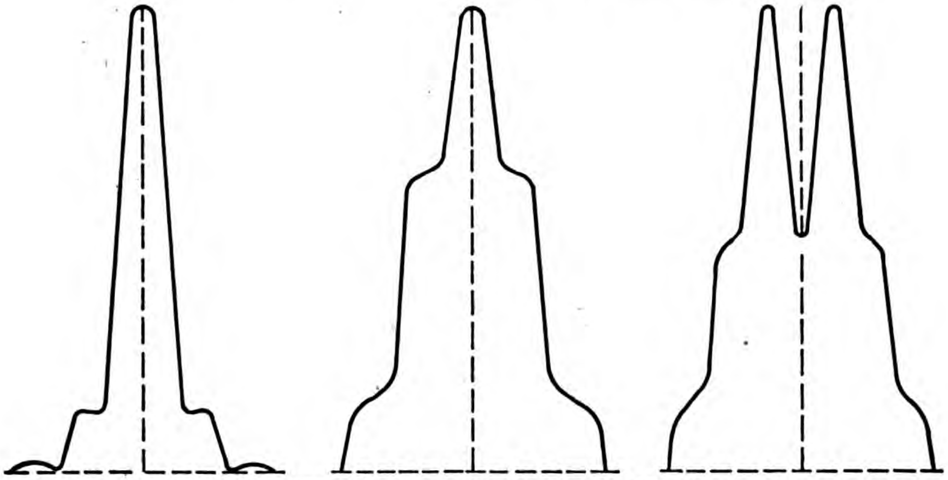
a. TRANSMITTER SPECTRUM. The transmitter spectrum is listed as item 25 of the performance data sheet. This includes both the spectrum width, Δf_t (which is the frequency difference between the first minima on either side of the nominal transmitter frequency) and the shape of the spectrum or spectrum distribution. As explained in paragraph 8*a*, the spectrum width in megacycles equals $2/d$, where d is the pulse width expressed in microseconds. Thus, an incorrect spectrum width may indicate improper transmitter pulse width. In judging the merits of the spectrum distribution, several factors must be considered. First, most of the transmitter energy must be included within the main lobe; that is, the ratio between the amplitude of the main lobe and first side lobes should be approximately 20 to 1. Second, the shape of the spectrum must approximate that of the ideal curve shown in figure 4. Distortion of the spectrum curve may be caused by incorrect waveform of the modulating pulse applied to the magnetron of the radar set, causing amplitude and frequency modulation of the magnetron output. Typical magnetron spectra, showing the effects of amplitude and frequency modulation, are shown in figure 16. From these spectra, certain general observations may be made. A spectrum without deep minimum points adjacent to the main lobe indicates frequency modulation of the oscillator; amplitude modulation causes more side lobes to appear. If two distinct peaks are observed on the spectrum, the transmitting oscillator is operating in two modes, or is being pulled in frequency by some external force, such as a poorly matched rotating antenna or improperly adjusted transmitter or line voltages. If both amplitude and frequency modulation is present, a spectrum results which is not symmetrical about the center of the main lobe. A spectrum may have side lobes on one side lower in amplitude than those on the other side and still be satisfactory, provided the main lobe is of the right width and contains most of the energy.

b. AFC TRACKING. The AFC circuit of a radar receiver does not operate to make the receiver follow rapid, instantaneous changes in transmitter frequency, such as occur when the trans-

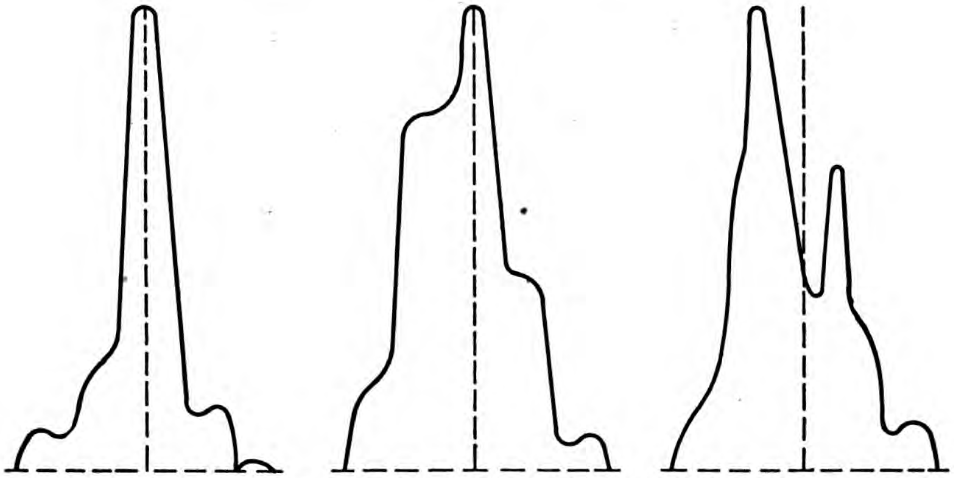


NORMAL SPECTRUM

SPECTRUM WITH
AMPLITUDE MODULATION



SPECTRA WITH FREQUENCY MODULATION



SPECTRA WITH FREQUENCY AND AMPLITUDE MODULATION

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Figure 16. Typical magnetron spectra.

mitter output is frequency-modulated. It does enable the receiver to follow gradual fluctuations, or drift, of transmitter frequency, provided such fluctuations are not too great. An improperly functioning AFC circuit may cause the targets on the radar scope to vary in strength, or perhaps disappear completely, as the transmitter frequency drifts. The most convenient method of checking AFC tracking is with an f-m test set. With the AFC turned off, the radar antenna stationary, and the radar transmitter operating, the radar receiver is tuned manually to the transmitter frequency. The f-m signal from the test set is supplied to the radar set, and the receiver output is observed on the radar A-scope. The test set output is adjusted so that the scope shows the typical receiver bandpass curve. Then the AFC is turned on, and, if the AFC system is operating normally, the bandpass curve will move slightly about the position to which it was adjusted before the receiver was switched to AFC. This is due to the fact that, with the AFC in operation, the receiver frequency follows the gradual changes in transmitter frequency, while the f-m signal sweeps through a band of frequencies which includes the receiver frequency. Therefore, the relative time during which the f-m signal passes through the receiver frequency varies, and the receiver bandpass curve is seen to move back and forth slightly on the scope timebase. If, when the AFC is turned on, the bandpass pattern sweeps across the screen erratically, or moves off the screen entirely, the AFC system is not operating properly. The condition of the AFC system is entered as item 26 in the radar performance data sheet (fig. 19).

c. TRANSMITTER PULLING. Transmitter or frequency pulling (item 27) describes the shift in magnetron frequency caused by improper loading or line voltages. Whether or not this condition exists can be checked readily in conjunction with the AFC test described in *b* above. After the AFC circuit is found to be operating normally, the radar antenna is rotated slowly while observing the bandpass curve on the A-scope. The AFC is left on during this test. If the bandpass pattern moves on the scope in synchronism with the rotation of the radar antenna, it is certain that frequency pulling is taking place. This test is valid only if the AFC circuit is operating properly, because if it is not, the receiver will not be able to follow the changes in transmitter frequency and the pattern will remain stationary on the screen even though transmitter pulling may be present. An alternative method of checking transmitter pulling is with an echo box. In this case the AFC is turned off. With the radar antenna stationary and the transmitter operating, the echo box and the receiver are both tuned to the transmitter frequency. Then, as the antenna is rotated, the echo box ringtime is observed on the radar PPI scope. If no transmitter pulling is present, the echo box ringtime should appear as a large, fairly regular circular target at the center of the PPI screen. A deep indentation in the circular pattern shows that transmitter pulling is occurring for that azimuth position of the antenna which corresponds to the position of the indentation.

d. RECEIVER BANDWIDTH. In most radar sets the receiver bandwidth, Δf_r, is established in the basic design of the receiver and cannot be varied to any great extent by the radar maintenance personnel. However, should several stages of the receiver become badly misalined, the bandwidth of the receiver may be changed considerably. As a result, the receiver may be unable to accept those frequencies which include most of the transmitter energy, and receiver sensitivity is reduced. As discussed in paragraph 9, the receiver bandwidth is taken as the width of the receiver response curve at the half-power points. The bandwidth usually is approximately equal to, or slightly less than, the transmitter spectrum width. The method to be used to determine the receiver bandwidth depends on whether an f-m or pulse-modulated type of test set is available.

(1) The chief difficulty in finding the receiver bandwidth is in determining the half-power points on the response curve. With an f-m test set, these half-power points can be determined readily. With the receiver AGC (automatic gain control), STC (sensitivity time control), and AFC circuits turned off and the receiver tuned to the transmitter frequency, the manual gain control of the receiver and the calibrated attenuator of the test set are adjusted to give a convenient amplitude of the typical receiver response curve on the radar A-scope or separate test scope. The level of the test set signal should be low enough so that the receiver does not saturate. The initial setting of the variable, calibrated attenuator is noted and then changed to *increase* the attenuation by exactly 3 db. Both the input signal power to the receiver and the output power are now reduced to half their original values. A horizontal line is marked on the scope screen, showing the peak amplitude of the reduced signal. This line represents the half-power point for the original setting of the calibrated attenuator. The calibrated attenuator is then returned to its initial setting, and the frequency meter pip from the test set is moved along the bandpass curve. The test set frequency dial readings at the two points where the pip passes through the half-power point are observed and recorded under item 28 of the radar performance data sheet. The band-

width in megacycles is the difference between the two frequency readings.

(2) The bandwidth of a receiver can also be found with a pulse-modulated test set. Although a pulse-modulated test set is inherently less accurate for bandwidth measurements than an f-m test set, fairly satisfactory results are obtained. The receiver AGC, STC, and AFC circuits are turned off, and the receiver is tuned to the transmitter frequency. Without changing the receiver tuning, the frequency of the test set is carefully adjusted to the receiver frequency by checking for maximum receiver output signal amplitude on the radar A-scope or separate test scope. During this operation, the manual gain control of the receiver and the variable, calibrated attenuator of the test set should be adjusted to give a convenient signal amplitude on the scope screen. To check that this initial reference setting of the attenuator does not produce too large a signal for the remainder of the test, the setting is noted and then changed to *decrease* the attenuation by 3 db. The resulting increased signal level must not saturate the receiver. If the receiver is driven to saturation, a different reference setting of attenuator must be selected and the same check performed to make certain that the receiver does not saturate with a decreased attenuation of 3 db. With the attenuator set at the reference point selected, the peak amplitude of the signal is carefully marked on the scope screen for use as a reference signal amplitude. The attenuator setting is then changed to decrease the attenuation by exactly 3 db. If the reference attenuator setting has been properly chosen, the resulting increased signal level will not saturate the receiver. Now the frequency of the test set signal is increased gradually and the amplitude of the scope signal is observed. When this amplitude just equals the reference signal amplitude previously marked on the scope screen, the corresponding frequency reading of the test set output is noted and recorded in item 28 of the radar performance data sheet. This is the approximate frequency of the upper half-power point of the receiver response curve. The frequency of the lower half-power point is similarly determined by decreasing the frequency of the test set until the scope signal just equals the reference signal amplitude and observing the frequency of the test set output at that point. The difference between the two readings so obtained is approximately equal to the receiver bandwidth.

e. RADAR RECOVERY TIME. Radar recovery time is the time required for the receiver and r-f components to return to full sensitivity after saturation by the transmitted pulse. In measuring recovery time, place the radar transmitter in operation and direct the radar antenna away from near-by targets or ground return which may interfere with the measurement. The AFC circuit of the receiver is left on but the STC and AGC circuits are turned off. Either an f-m or pulse-modulated test set may be used to supply a test signal to the radar set. The output of the receiver is observed on the radar A-scope or separate test scope. In either case, the scope must be adjusted to have a very fast sweep (5 to 50 microseconds). If the radar scope is used, the radar set must be adjusted for short range operation. The receiver manual gain control and the calibrated attenuator of the test set are adjusted to give a normal indication on the scope, with the height of the test set signal approximately half that of the transmitter pulse. By means of the phasing control of the test set, the signal is shifted, on the scope, toward the transmitter pulse to a point where the signal amplitude just *starts* to diminish. The distance in microseconds along the scope base line, from the end of the radar pulse to the test set signal, is the full recovery time. If the radar range scope is used, the recovery time is obtained directly in range units (miles or yards) and may be so entered as item 29 of the radar performance data sheet. Yards may be converted to microseconds by multiplying by 0.0061. In general, radar recovery time should be considerably less than 2,000 yards (approximately 1 mile or 12 microseconds). An unusually high recovery time may indicate a faulty T/R tube or a dirty or corroded T/R cavity.

29. R–f Cable Attenuation

For quantitative measurements of transmitter power and receiver minimum discernible signal, the attenuation introduced by the r-f cable connecting the test equipment to the radar set must be known. Usually, the test cable has been precalibrated and the attenuation is marked on the cable. However, if the cable becomes damaged or is repaired, the calibration will probably change. Also, the attenuation may be considerably affected by normal cold temperatures, especially at X-band frequencies. Therefore, the cable attenuation should be checked occasionally to see that it has not changed. In order to measure the r-f attenuation of the cable, an additional r-f cable having the same fittings as the cable to be tested is required. It is not necessary to know the attenuation value of the additional cable. The radar set is placed in operation and, *with the two r-f cables connected in series*, the test equipment is connected to measure the power output of the radar transmitter. The dbm indication so obtained is recorded. (If the indication is in watts, it must be converted to dbm by means of figure 2). Then the cable to be tested is removed, and the power output is again measured. The difference between the two dbm indications so obtained is the attenuation, in db, of the cable removed to obtain the second indication.

30. R–f Trouble-shooting Guide

If the radar data observed and recorded in the performance data sheet reveal that the radar set is operating inefficiently, r-f maintenance may be required. The source of trouble will usually be indicated by careful analysis and interpretation of the data. Figure 18 is intended to serve as a guide to radar personnel in localizing the source of trouble to some specific r-f component.

a. TRANSMITTER POWER. The quantity and the quality (spectrum distributon) of transmitter power depends upon both the input and output conditions under which the radar r-f oscillator operates. For this reason, the trouble-shooting guide in figure 18 lists such items as bad modulator pulse, damaged r-f line, and improperly functioning anti-T/R box as probable sources of trouble for low output power and poor transmitter spectrum.

(1) In most radar sets a magnetron is used as an r-f oscillator. This type of generator is caused to oscillate by the combined effect of the separate electrostatic and magnetic fields applied to it. The power developed depends upon the magnitudes of these two separate fields. For a specific power output, the best quality can be obtained by selecting certain values of magnitude of these separate fields. Figure 17, the performance plot of a typical 2J32 magnetron, illustrates this point. An average power output of 100 watts can be obtained through any number of combinations of magnetic field strength in gauss and electrostatic field strength expressed in peak kilovolts. However, for the best frequency spectrum (that is, the best quality of power output), these variables must be chosen from within the shaded area. In many radar sets these variables have been fixed in the initial design so that they cannot be readjusted.

(2) Normally, the radar r-f oscillator is not modulated by a perfectly rectangular pulse. The pulse is distorted to some degree, and this distortion causes a shift in the carrier frequency of the radar transmitter. As shown in figure 16, the result of this frequency modulation is a poor spectrum. The degree to which frequency modulation affects the quality of the output depends on the region in which the magnetron operates. The shaded area of figure 17 is an operating region in which small changes in voltage result in little change in frequency. Outside this area,

small voltage changes produce a much more pronounced change in frequency. The practical remedy for a bad spectrum caused by frequency modulation is to adjust slightly the pulse voltage applied to the magnetron. This usually moves the operating point of the tube to a more stable region and corrects the trouble. Other remedies consist in reversing the magnetic field or replacing the magnet. In some cases, the transmitter tube itself must be replaced because a poor tube results either in a reduction of power output or in a poor spectrum.

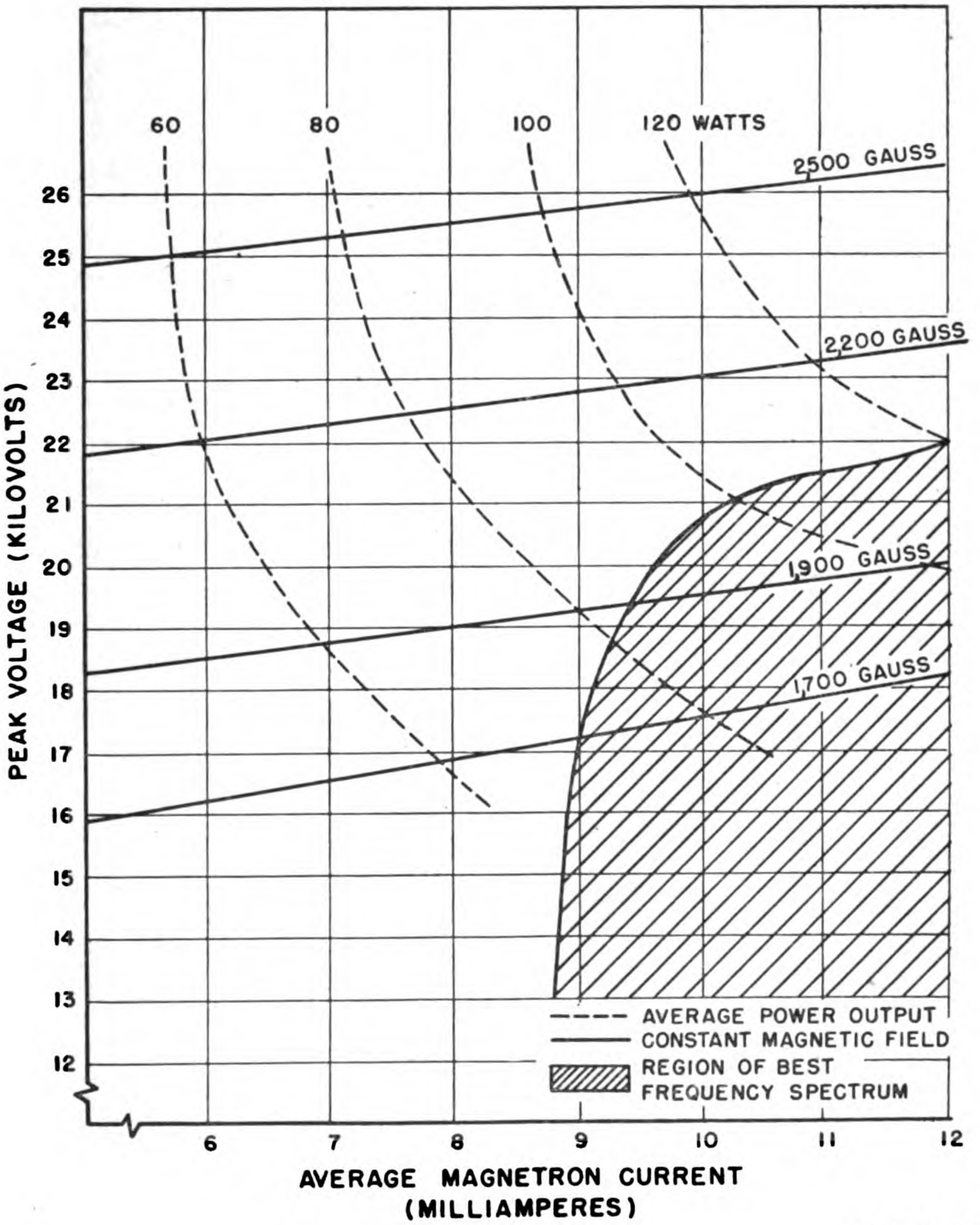

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Figure 17. Performance plot of typical 2J32-type magnetron.

(3) The operation of the r-f oscillator depends as much on the load placed upon it as upon the input. This load consists of the transmission line and antenna and presents a complex impedance to the generator. For maximum transfer of power from the source to the load, the load must be matched to the source. A change in the impedance of the load will pull, or change, the frequency of operation of the oscillator tube. The result is either a decrease of power or a bad spectrum. Changes in impedance may be caused by a damaged or mismatched antenna, the presence of water or dirt in the r-f line, arcing beads, mechanical damage to the r-f line, or mistuned anti-T/R box.

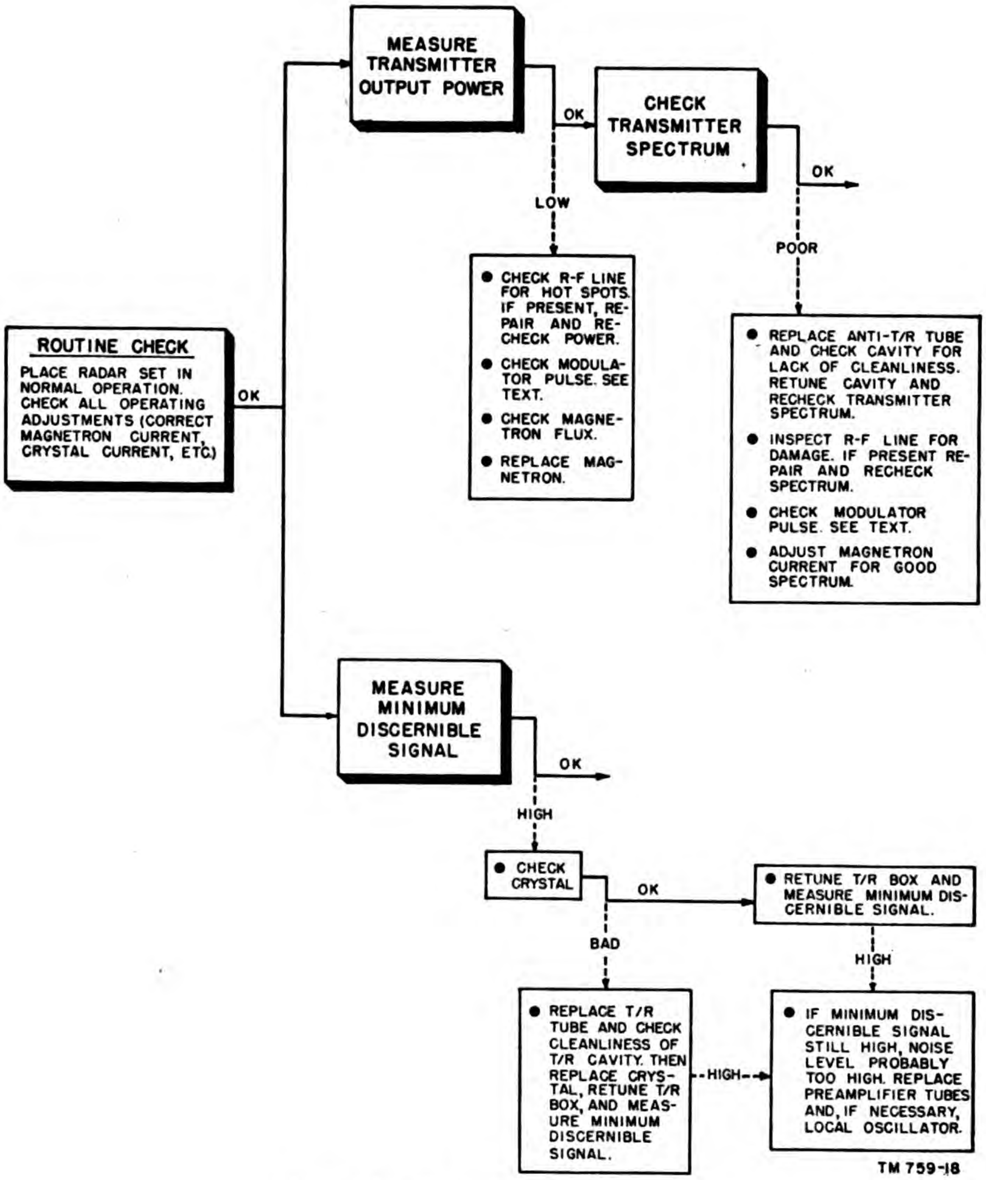

Figure 18. R-f trouble-shooting guide.

b. **MINIMUM DISCERNIBLE SIGNAL.** In measuring the minimum discernible signal, P_m, of a radar receiver, a test signal is attenuated until it can no longer be seen on the radar scope. Certainly the signal is still present, but it is obscured in the random noise on the scope. If there is gain enough in the receiver to present noise on the scope prominently, no further increase of gain will help to see the signal. Both signal and noise will be amplified an equal amount.

(1) Noise can never be eliminated entirely from a receiver. Even in a perfect receiver, in the absence of an input signal, noise is present which is caused by thermal agitation (the random motion of electrons in resistors and other circuit components, and variations in the current through the receiver tubes). This theoretical minimum noise power may be found from the equation—

$$P_{n(dbm)} = -138 + 10 \log (T) + 10 \log (\Delta f_r),$$

where $P_{n(dbm)}$ is the minimum noise power *in dbm*, T is the absolute temperature in degrees Kelvin*, and Δf_r is the receiver bandwidth in *megacycles*. For a receiver operating in a normal or temperate climate, T may be assumed to be approximately 300° Kelvin, and the above equation reduces to—

$$P_{n(dbm)} = -114 + 10 \log (\Delta f_r).$$

Suppose the receiver under discussion has a 3-mc bandwidth. Then the right-hand term becomes 10 *log* (3) which is similar to the expression given in paragraph 4*b* for converting a power ratio into db. Therefore, table I may be used to determine the value of this term, which is found to equal 4.8 *db*. For such a receiver, the minimum noise power $P_{n(dbm)} = -114 + 4.8\ dbm = -109\ dbm$ approximately.

(2) In practice, it is found that the signal power that must be applied to a radar receiver in determining the minimum discernible signal is greater than the minimum noise power obtained by calculation from the equation in (1) above. There are two principal reasons for this fact. First, the input signal power is reduced by losses caused by faults in the transmission line, by the attenuation in the T/R box, by the loss in power suffered in converting from r-f to i-f (intermediate frequency) in the crystal, and by any mismatch from the crystal to the i-f strip. Secondly, the noise generated within the receiver is greater than that calculated from the equation because of the crystal temperature noise (considering the crystal as an equivalent resistor in which noise is generated principally by local oscillator current) and because of noise gen-

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*The absolute temperature in degrees Kelvin may be obtained by adding 273 to the temperature in degrees centigrade.

erated at the i-f input and first i-f stage. The net effect of all these factors is that the minimum discernible signal power must be greater than the minimum noise power by some amount which is denoted by the term *noise factor.* This may be stated in the form of an equation as follows:

$$P_m({}_{dbm}) = P_n({}_{dbm}) + NF({}_{db}),$$

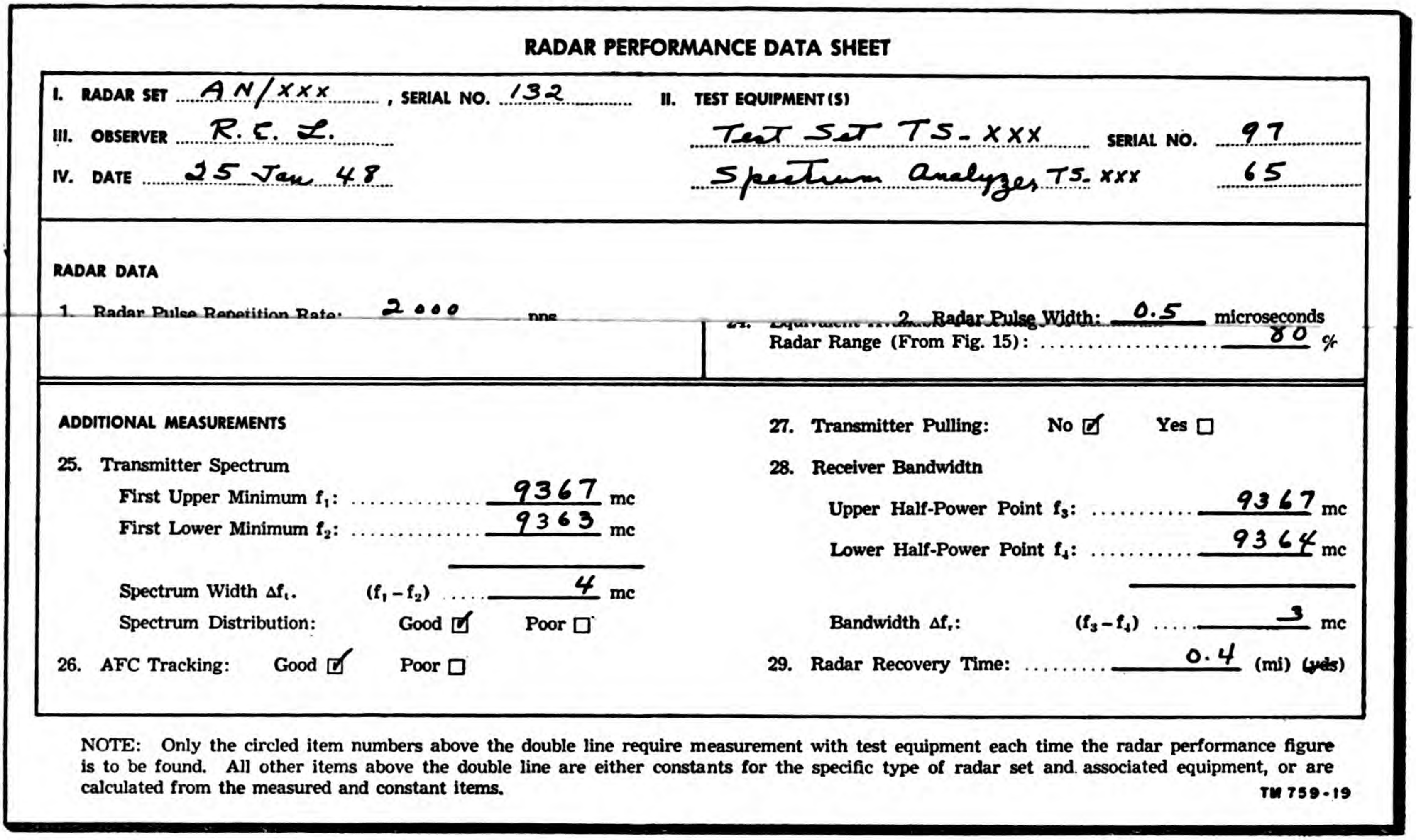
in which $P_m({}_{dbm})$ is the minimum discernible signal power, $P_n({}_{dbm})$ is the minimum theroetical noise power, and $NF({}_{db})$ is the noise factor of the receiver in db. In other words, the noise factor tells how much worse the specific receiver is than the best possible receiver of the same bandwidth and is, therefore, a measure of the quality of the receiver. For example, suppose that for the 3-mc bandwidth receiver mentioned in (1) above ($P_n({}_{dbm})$ equal to —109 *dbm*), the minimum discernible signal is determined to be —97 *dbm.* The noise factor of the receiver equals —97 —(—109) db, or 12 db. This value is consistent with typical values of noise factor determined experimentally. In a well-designed, properly functioning S-band receiver, the noise factor may be as low as 11 db; in receivers operating at higher frequencies, somewhat larger values (perhaps as high as 15 db) may be obtained.

(3) The quality of the receiver will be impaired by any condition which causes an increase in the noise factor and a corresponding increase in the minimum signal power discernible by the receiver. Obviously, the receiver may not have sufficient gain. This condition is usually recognized by observing that the amount of noise of the receiver is either low or lacking entirely. This is a fault of the i-f amplifier and may be found in any of its stages. It is usually caused by a faulty tube, faulty cables, or failure of the power supply. Occasionally, it may be caused by faulty alinement, but this is not often the case. Consequently, if the gain is insufficient, the most probable source of trouble is in the i-f amplifier.

(4) Presupposing the amplifier has sufficient gain, the probable cause of poor receiver sensitivity is in the components preceding the second stage of the i-f amplifier because the signal-to-noise ratio is almost completely determined by the time the signal has reached the grid of the second i-f stage. It may be that the first i-f amplifier tube is noisy or lacks sufficient gain but this condition is relatively rare. The alinement of the transformer connecting the crystal to the first i-f stage can also account for poor signal-to-noise ratio, but realinement is difficult and requires adequate test equipment. A poor crystal would certainly be a big factor in receiver sensitivity and, as shown in figure 18, should be the first thing to be checked. If the crystal is found to be bad, the T/R tube and T/R box should be checked before the crystal is replaced

because defective T/R components will cause crystals to be burned out. Faulty anti-T/R will cause a reduction in over-all receiver sensitivity. The faults that may be present in the T/R and anti-T/R components are poor coupling, mistuning, bad tubes, bad cavities, dirt, corrosion, or poor connections. If the mixer is tunable, it will also cause a reduction of receiver sensitivity when mistuned. The local oscillator coupling to the mixer should be adjusted for best operation. De-tuning of the local oscillator will naturally cause pronounced reduction of sensitivity and, of course, must be kept properly tuned. It is also true that the local oscillator can contribute noise to the receiver and is particularly likely to do so if it is not mechanically tuned so as to operate on the peak of the mode. Also, reduced receiver sensitivity may result from mistuned AFC circuits or from the transmission line troubles of the type mentioned in *a* above.

(5) Many possible causes of poor receiver sensitivity have been given. Mention should be made of those items which are not likely to affect receiver sensitivity. Slight mistuning of the i-f stages, provided the gain is sufficient, should not be a factor. A small amount of regeneration, although not desirable, will probably affect sensitivity very little. A weak or noisy tube after the first i-f stage has very little to do with receiver sensitivity, provided the gain is sufficient. The video amplifier bandwidth almost never has any effect on receiver sensitivity.



RADAR PERFORMANCE DATA SHEET

I. RADAR SET AN/XXX, SERIAL NO. 132

III. OBSERVER R. C. L.

IV. DATE 25 Jan 48

II. TEST EQUIPMENT(S)

Test Set TS-XXX SERIAL NO. 97

Spectrum Analyzer, TS-XXX 65

RADAR DATA

1. Radar Pulse Repetition Rate: 2000 pps

2. Radar Pulse Width: 0.5 microseconds

Radar Range (From Fig. 15): 80 %

ADDITIONAL MEASUREMENTS

25. Transmitter Spectrum

First Upper Minimum f_1: 9367 mc

First Lower Minimum f_2: 9363 mc

Spectrum Width Δf_t. $(f_1 - f_2)$ 4 mc

Spectrum Distribution: Good ☑ Poor ☐

26. AFC Tracking: Good ☑ Poor ☐

27. Transmitter Pulling: No ☑ Yes ☐

28. Receiver Bandwidth

Upper Half-Power Point f_3: 9367 mc

Lower Half-Power Point f_4: 9364 mc

Bandwidth Δf_r: $(f_3 - f_4)$ 3 mc

29. Radar Recovery Time: 0.4 (mi) (~~yds~~)

NOTE: Only the circled item numbers above the double line require measurement with test equipment each time the radar performance figure is to be found. All other items above the double line are either constants for the specific type of radar set and associated equipment, or are calculated from the measured and constant items.

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Figure 19. Typical radar performance data sheet.

APPENDIX

ABBREVIATIONS AND SYMBOLS

The following abbreviations and symbols are used in this technical manual:

Symbol	*Definition*
A	attenuation of r-f test cable or waveguide in db
A_a	area of antenna aperture
a-c	alternating-current
AFC	automatic frequency control
AGC	automatic gain control
anti-T/R	antitransmit-receive
C	attenuation of r-f test point in db
c-w	continuous-wave
d	duration of r-f pulse
D	duty-cycle figure
$D_{(db)}$	duty-cycle figure in db
db	decibel
dbm	decibels referred to 1 milliwatt
d-c	direct-current
F	propagation factor
f-m	frequency-modulated
f_r	nominal receiver frequency
Δf_r	receiver bandwidth
f_t	nominal transmitter frequency
Δf_t	transmitter spectrum width
i-f	intermediate-frequency
mc	megacycle (s)
$NF_{(db)}$	receiver noise factor in db
P_{av}	transmitter average power output
$P_{av(dbm)}$	transmitter average power output in dbm
$P^1_{av(dbm)}$	test instrument reading of transmitter average power output in dbm
P_m	receiver minimum discernible signal power
$P_{m(dbm)}$	receiver minimum discernible signal power in dbm
$P^2_{m(dbm)}$	test instrument reading of receiver minimum discernible signal power in dbm
$P_{n(dbm)}$	receiver theoretical minimum noise power in dbm
P_{pk}	transmitter peak power output

Symbol	*Definition*
$P_{pk(dbm)}$	transmitter peak power output in dbm
P_r	peak power of echo signal returned to radar antenna
r	pulse repetition rate
R	radar range
r-f	radio-frequency
S	radar performance figure
$S_{(db)}$	radar performance figure in db
STC	sensitivity time control
T	absolute temperature in degrees Kelvin
T/R	transmit-receive
V	variable quantity
λ	wavelength
Σ	scattering area of target

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