GEN-188

ELECTRONIC COUNTERMEASURES CALCULATOR

4239

LMED

GENERAL ELECTRIC

LIGHT MILITARY ELECTRONICS DEPARTMENT, UTICA, NEW YORK

ADVANCE ENGINEERING IN LIGHT MILITARY ELECTRONICS

This calculator was designed
and developed by
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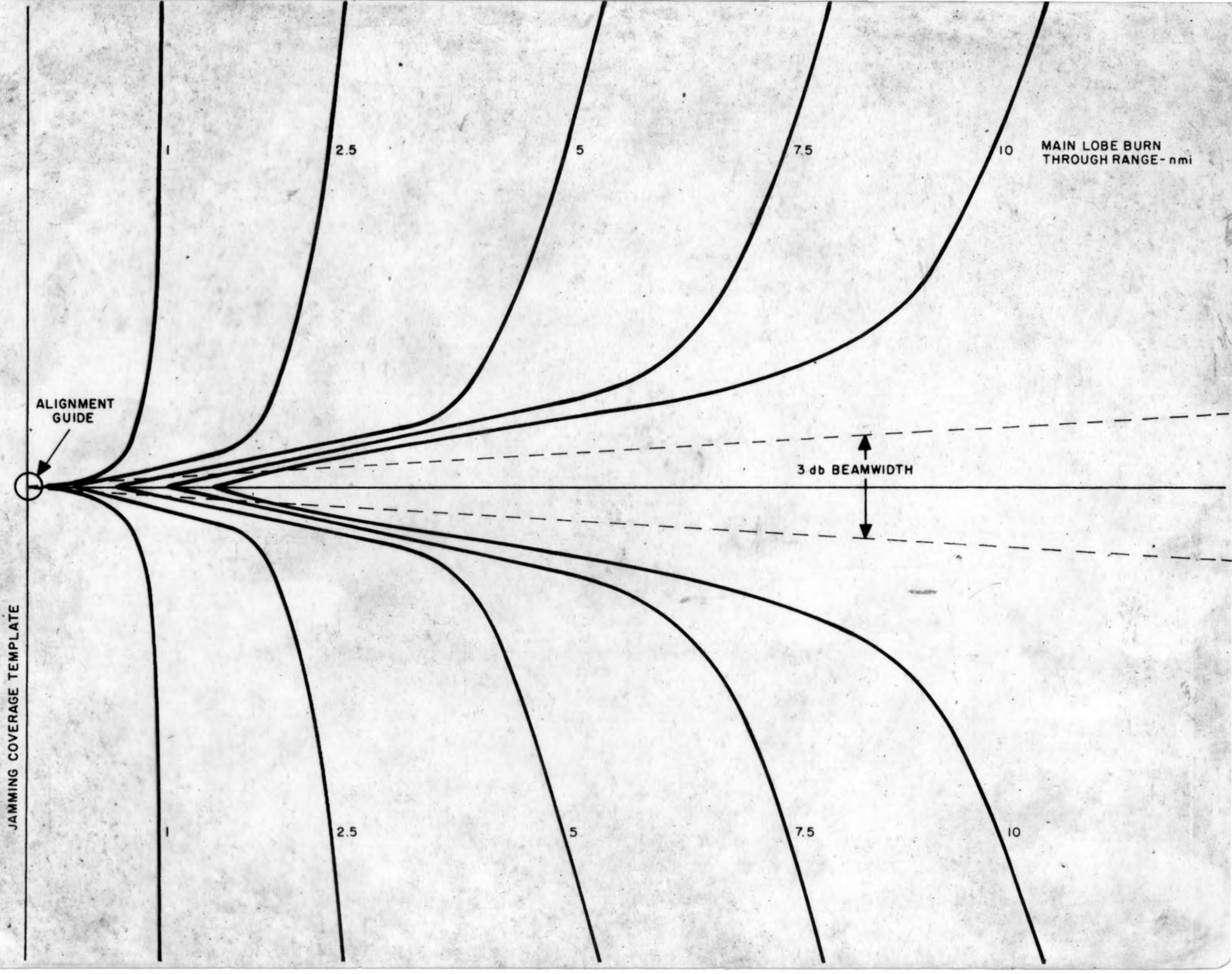
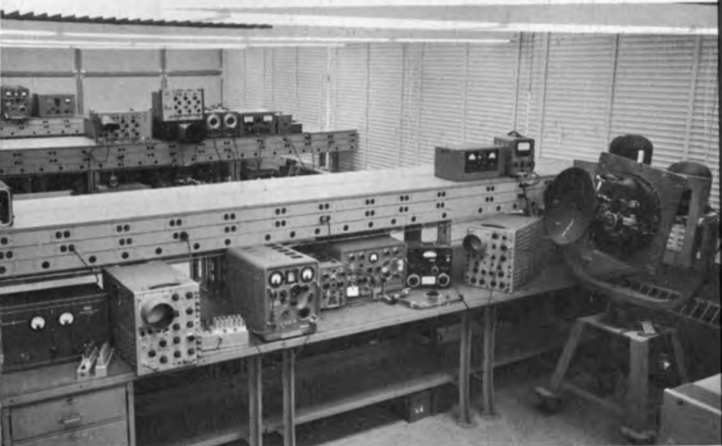

MAIN LOBE BURN THROUGH RANGE - nmi
1
2.5
5
7.5
10
ALIGNMENT GUIDE
3 db BEAMWIDTH
1
2.5
5
7.5
10
JAMMING COVERAGE TEMPLATE

INSTRUCTIONS FOR THE COUNTERMEASURES CALCULATOR

The Engineering Development Laboratory produces models and prototypes for engineering evaluation.



New Radar Evaluation Laboratory at the Advanced Electronics Center, Ithaca, New York.

LMED's extensive computer facilities are available to process Quick Reaction Capability schedules and Line of Balance information.

AN/ALT-6 POWER SUPPLY

*"Other AN/ALT-6 equipment photos are classified."

AN/ALR-18 RASE RECEIVER

AN/ALR-18 RASE CONTROL BOX

QRC-139 BARRATRON JAMMER

INTRODUCTION

In the design or evaluation of electronic countermeasures, radar, and line of sight communications systems, the overall system performance is described by two basic transmission equations involving the parameter of the transmitter, receiver, transmission path, and in the case of radar, the target reflectivity.

In these three electromagnetic radiating systems the trade-off of the various system parameters under a designers control can be a tedious mathematical process. For this reason a circular slide rule, the Countermeasures Calculator, has been designed as an engineering tool to assist in the trade-off choice, solving the one-way, the two-way, and the self-screening range transmission equations. In addition, other pertinent information is given on the reverse side of the rule.

BASIC EQUATIONS:

The One-Way Equation

The line of sight communications system is concerned with the amount of power received at a particular location where the transmitter and receiver are separated in range. This received power is expressed by the One-Way Equation.

$$J = C_1 \left(\frac{P_j \, G_r \, G_j \, \lambda^2 \, B_r}{(4\pi)^2 \, R_j^2 \, B_t} \right)$$

expressing

J = Signal power, peak or average (watts) received at the receiving antenna terminals as a function of:

P_j = Power transmitted, peak or average respectively (watts)

G_r = Gain of the receiving antenna (db)

G_j = Gain of the transmitting antenna (db)

λ = Wavelength of the transmission frequency (meters)

R_j = Range from transmitting antenna to receiving antenna (nautical miles)

B_t/B_r = Bandwidth ratio of transmitted spectra to receiver bandwidth

In order that a desired signal-to-noise ratio may be received, the wavelength, the gain of the antenna, and/or the transmitted power, may be traded off to achieve optimum results.

The Two-Way Equation

Of primary importance in a radar system however, is the power returned to the transmitting antenna after reflection from a target: thus requiring the use of the Two-Way Equation:

$$S = C_2 \left(\frac{P_r G_r^2 \lambda^2 \sigma}{(4\pi)^3 R_t^4} \right)$$

expressing

- S = Signal power, peak or average (watts) returned to the terminals of the transmitting antenna upon reflection from a target as a function of:
- P_r = Power transmitted, peak or average respectively (watts)
- G_r = Gain of the antenna (db)
- λ = Wavelength of the transmission frequency (meters)
- σ = Effective target area (meters^2)
- R_t = Range from transmitting antenna to target (nautical miles)

These various parameters may also be traded off for best results.

The Self-Screening Range Equation

The countermeasures system is concerned with both equations. A signal which is present at the radar antenna must be masked by a transmitted signal from a remote location. By combining the One-Way and Two-Way equations the Self-Screening Range equation can be obtained. This equation is valuable in evaluating electronic countermeasures equipment against a particular radar system.

$$R = C_3 \sqrt{\frac{\sigma}{4\pi} \frac{P_r}{P_j} \frac{G_r}{G_j} \frac{B_t}{B_r} \frac{J}{S}}$$

expressing

- R = The maximum detection range (Self-Screening Range) of the radar under noise conditions as a function of:
- P_r = Peak power transmitted by the radar (watts)
- P_j = Average power transmitted by the jammer (watts)
- G_r = Gain of the radar antenna (db)
- G_j = Gain of jammer antenna (db)
- B_t/B_r = Bandwidth ratio of the jammer transmitted signal to the radar receivers bandwidth.
- J/S = The ratio of the jamming power to signal power at the radar antenna terminals to cause required jamming.
- σ = Effective target area (meters^2)

Through the use of these equations and the scales on the reverse side of the rule, the Countermeasures Calculator can be used to find solutions to the following typical problems:

1. What power is received at the terminal of a radar antenna for a given power transmitted by a noise jammer?
2. What sensitivity must a countermeasures receiver have in order to detect a radar signal at a given range?
3. What power is received at the terminals of a radar antenna upon reflection of a transmitted signal from a target?
4. What J/S ratio is required to cause jamming of a given radar set?
5. What is the maximum detection range of a radar under jamming conditions?
6. What power is required by the jammer to screen a radar target when the jammer is not located at the target?
7. What power must a false target jammer transmit to produce a pulse equal to the target return pulse?
8. What is the minimum detectable signal of a given radar set?
9. What is the maximum detection range of a radar?
10. What is the gain of a specific parobolic antenna?

These problems are not the only uses of the countermeasures calculator but are listed as prime solutions that can be obtained. They are used below to provide a basis for the detailed instructions.

USE OF THE COUNTERMEASURES CALCULATOR

The slide rule as discussed above, solves two equations, the One-Way equation (J) and the Two-Way equation (S). These equations are solved independently of each other on the front of the rule and, therefore, each equation has a separate set of scales which are color coded. For the solution of the J equation the scales are printed with blue numbers or have a blue overlay over black numbers. The S scales are printed in red numbers or have a red overlay over black numbers.

The Self-Screening Range equation (R) is a combination of the J and S equations. The rule is constructed to perform this combination. To solve the R equation the appropriate J and S scales are combined by intermixing the scales, thereby, arranging a set of scales to solve the R equation. For identification, all of the scales which are used for the solution of the R equation are printed in black numbers.

For ease of scale alignment an Alignment Guide is provided. If either a J or an S equation solution is to be obtained, starting on the outer disc, align the red and blue alignment guide bars on each disc to form two continuous lines, one red and one blue, extending from the center of the rule to the outer disc. Upon turning the rule such that the printing on the inner disc is upright, it will be found that all scales to the left of the center are either in blue numbers or have a blue overlay (J scales), and that all scales to the right of the center are in red numbers or have a red overlay (S scales). Therefore, the rule is aligned for solution of either the J or S equation respectively.

To align the rule for the solution of the R equation, starting at the alignment guide, align the black strips on each disc such that a continuous straight line extends from the inner to outer disc. Upon turning the rule such that the printing on the inner disc of the rule is upright, it will be found that the black numbered scales are aligned somewhat left of center down to the inner disc and at the bottom of the rule. The slide rule is now ready to solve the R equation.

The units of the scale are noted on each individual scale and listed for each equation as discussed above.

Detailed Example of Use

PROBLEM 1—*What power is received at the terminal of a radar antenna for a given power transmitted by a noise jammer?*

This solution requires the use of the J equation. To begin—align the blue scales, through the use of the Alignment Guide. Assume a typical situation:

Jammer antenna gain (G_j) = 10 db

Radar antenna gain (G_r) = 30 db

$\frac{\text{Bandwidth of transmitter}}{\text{Bandwidth of receiver}}$ (B_t/B_r) = 1*

Wavelength receiver (λ) = 10 cm

Range to Jammer (R) = 50 N. Miles

Power of Jammer (P_j) = 100 watts

*When $B_r > B_t$, use $B_t/B_r = 1.0$

Starting at the center of the rule; align the gain of the jamming antenna and the gain of the radar antenna, then setting the B_j/B_r ratio opposite the blue arrow and aligning the wavelength versus the range, the answer J in dbm can be found opposite the power of the jammer after alignment of the index arrows. These arrows are found on the black P_j and R scales located at the bottom of the rule, the P_j scale is on the center disc and the R scale on the outer disc. These scales are not used for the solution of this equation, but the red and blue index arrows must be aligned to obtain the correct answer of J.

Upon alignment of these arrows, the answer is found to be equal to −52 dbm opposite the 100 watt jamming power scale marking.

PROBLEM 2—*What sensitivity must the countermeasures receiver have in order to detect a radar signal at a given range.*

This solution is essentially the same as the above. First align the J scale by the use of the alignment guide. Then starting at the center of the rule align the appropriate values.

For example:

Jammer Antenna Gain (G_j) = 10 db

Radar main lobe antenna gain (for main lobe detection) (G_r) = 30 db

$$\frac{\text{Bandwidth of Radar Spectrum}}{\text{Bandwidth of Countermeasure Receiver}}\left(\frac{B_t}{B_r}\right) = 1.0^*$$

Wavelength of Radar (λ) = 10 cm

Range Radar (R_r) = 50 N. Miles

Power of Radar (P_r) = 1 Meg. Watt

*When $B_r > B_t$, use B_t/B_r = 1.0

Align G_j opposite G_r, B_t/B_r opposite the blue arrow, and λ vs R_r, align index arrows opposite P_r, find J of −12 dbm.

PROBLEM 3—*What power is received at the terminal of a radar antenna upon reflection of a transmitted signal from a target?*

This solution requires the use of the S scales. To begin align the red scales as above using the red alignment guide.

As an example of operation of these scales, assume a radar with:

Antenna Gain (G_r)	= 30 db
Wavelength (λ)	= 10 cm
Range to Target (R_t)	= 50 N. Miles
Power Transmitted (P_r)	= 100 K watts
Target Area (σ)	= 100 m²

To find the signal returned at the radar antenna terminals, start at the center of the slide rule and align G_r and λ, then set R_t opposite the arrow, and align P_r versus σ, adjust the index arrows on the center and outer disc as in the previous problem, and find the answer S opposite the red arrow (marked S) at the top of the rule. For this example, the answer is −91 dbm.

PROBLEM 4—*What J/S ratio is required to cause jamming of a given radar set?*

In order to make an accurate calculation of the Self-Screening Range, the J/S ratio for a specific radar is required. However, if it is not known, it can be estimated by the use of the "Approximate Radar J/S Ratio" scales on the back of the rule for the case of probability of detection of 50 percent and a false alarm probability of 10^{-10} [1].

Assuming a radar-jammer situation such that:

10 radar returns are integrated, and jamming noise is used and equivalent to gaussian noise.

Referring to the "Approximate Radar J/S Ratio" scales, the number of pulses integrated are aligned opposite the arrow. Then opposite the jamming efficiency of 1 (the arrow) the J/S ratio for this radar is found to be −5.5 db. The efficiency of 1 was used as the noise was equivalent to thermal noise. If the jammer noise is not equal to gaussian noise, then the appropriate jamming efficiency must be used.

PROBLEM 5—*What is the maximum detection range of a radar under the jamming condition?*

The Self-Screening Range equations (R) must be used. Aligning the R scales (black numerals) by the use of the black alignment guide and assuming a typical radar-jammer situation:

Radar Integrates 10 pulses
Noise modulation of jammer equivalent to gaussian noise } J/S = −5.5 db

$\sigma = 100\ m^2$

$P_r = 100$ KW

$B_t/B_r = 1$

$G_r = 30$ db

$G_j = 10$ db

$P_j = 10$ watts

set the −5.5 db J/S ratio (as found above on the outer J scale) opposite the J/S arrow, aligning the σ versus P_r, the arrow versus the B_t/B_r ratio and G_r and G_j scales, opposite the 10 watt mark on the P_j scale on the inner disc at the bottom of the rule opposite the answer, the self-screening range, on the R scale. R is equal to 0.8 N Miles.

If the jamming power is given in watts per megacycle then insert the bandwidth of the radar receiver on the B_r scale instead of the B_t/B_r ratio. This scale is directly below B_t/B_r scale.

PROBLEM 6—*What power is required by the jammer to screen a radar target when the jammer is not located at the target?*

In order to solve the problem of the jammer screening range while the jammer is not located at the target, the J and S equations must be used independently instead of combining them to form the R equations as above.

This problem can be attacked from many different aspects, depending upon the answer required. For this solution what is required is the power that the jammer must transmit in order to screen a specific target while the jammer is located at a point in space other than at the radar target.

First, align the S scales, (red numbers) in order to solve for a specific value of S at the radar antenna terminals. Assuming that:

$$G_r = 45 \text{ db}$$
$$\lambda = 3 \text{ cm}$$
$$R_r = 100 \text{ miles}$$
$$P_r = 1 \text{ Mw}$$
$$\sigma = 10 \text{ m}^2$$

and upon aligning these values and the index arrow on the rule the signal S at the antenna terminals is found to be -84 dbm.

Then turning the rule to the J equations (blue numbered scales), align the assumed jammer parameters on the scales. Since the jammer is not located at the target, the effective Radar Antenna Gain (G_R) in the direction of the jammer is less than the gain in the direction of the target.

Therefore, for this particular case:

$$G_R = 10 \text{ db and}$$
$$G_J = 10 \text{ db}$$
$$\frac{B_t}{B_r} = 1$$
$$\lambda = 3 \text{ cm}$$
$$R_j = 50 \text{ miles}$$

and then align the index mark as in the previous calculations opposite the appropriate figure on the J scale will be the number of watts necessary to screen this target. The number to be inserted on the J scales equals the S figure which was obtained from the previous calculations plus the J/S ratio in db necessary to jam the specific radar. From the previous calculation, it was found that a J/S of -5.5 db was needed. Set -84 (S found above) -5.5 db $= -89.5$ dbm. Thus, the power necessary to screen this target is 20 watts.

To find other answers such as range of jammer required instead of watts required, align the known figures on the appropriate scales and observe the answer on the unknown scale, in this case R.

PROBLEM 7—*What power must a false target jammer transmit to produce a pulse equal to the radar target return pulse? (The same type of solution applies to beacon problems.)*

As for the previous equation, the answer is obtained in the same manner the radar return power is first obtained by the use of the S scales. Then this value of S is used on the J scale of the J equation to determine the jammer power after using the appropriate values in the J equation.

PROBLEM 8—*What is the minimum detectable signal of a given radar set?*

This answer is found on the reverse side of the rule. On the scales entitled "Minimum Detectable Radar Target Return Power —S_{min}/dbm." The appropriate numbers are aligned. For example:

Bandwidth of Radar Receiver (B) = 1 mc
Hits per scan of the antenna (H/S) = 10
Noise figure of the receiver (NF) = 10 db

The minimum detectable radar target return power S_{min} (dbm) is found to be −98.5 dbm. These scales are based on the work of Dr. A. V. Haeff at the Naval Research Laboratory[2].

The calculator provides two possible approaches to the determination of minimum discernable signal powers through use of the approximate J/S calculator. For example, J/S for a one hit radar is read as −13.5 db from the approximate J/S scale. This is equivalent to stating that a +13.5 db S/N ratio is required for detection. Signal sensitivity then can be determined from KTB $\overline{NF}$ $\frac{S}{N} = S_{min}$.

The value obtained in this manner will be slightly different than that obtained from the scales provided for this calculation directly. The minimum discernable signal calculated directly on the rule is 3 db more sensitive for a 1 hit system, and is the same for a 10 hit system, and is 2.5 db less sensitive for a 10,000 hit system. The reason of course is that the scales for calculation of S_{min} directly are based upon empirical results and do not define the detection probability and false alarm number.

If the hits per scan of a given radar is not known this value may be calculated by the use of the equation

$\left(\frac{F\,\theta_{HP}}{6\omega}\right)$ printed next to this scale, where F is the pulse repetition frequency of the radar in cycles per second, θ_{HP} is the half power beamwidth in degrees and ω is antenna rotation rate in revolutions per min.

PROBLEM 9—*What is the maximum detection range of a given radar set?*

This answer can be found by using the S scale after having determined the value of S_{min} as above. After aligning the S scales by use of the aligning guide enter on the outer scale the value S_{min} (dbm), as found above, -98.5 dbm.

Assuming the additional parameters are:

$$\sigma = 10\ \text{m}^2$$
$$P_r = 1\ \text{megawatt}$$
$$G_r = 30\ \text{db}$$
$$\lambda = 10\ \text{cm}$$

align the target area (σ) opposite the power (P_r), then skipping the R_t setting for the moment, go to the center of the rule and align the G_r versus λ. Upon aligning the index marks, the radar detection range, opposite the arrow in the center of the rule is found to be 75 nautical miles.

PROBLEM 10—*What is the gain of a Specific Parabolic Antenna?*

On the reverse side of the rule, the scale marked "Antenna Gain for Parabolic Reflectors" is for this purpose. Assuming a 2 ft. dish at 3 cm the gain is found to be 33 db and has an H plane half power beamwidth of 3.2 degrees.

EFFECT OF LOSSES

The countermeasures calculator does not attempt to take into account all losses which normally occur in the radiation of electromagnetic energy. For example, in radar systems there are losses associated with the propagation of signals through the atmosphere, antenna scanning losses, equipment inefficiencies, and the losses associated with the performance of a human being when used for detection purposes. These losses can however be factored into the calculations for radar performance by adjustment of the system sensitivity for one way losses such as operator degradation, scanning losses, and equipment inefficiencies.

Two way losses effecting both transmission and reception such as antenna and transmission line inefficiencies can be accounted for by adjusting the antenna gain factor accordingly.

Additional losses in the microwave transmission system are produced by atmospheric absorption. This effectively reduces radar range performances. Its effect is frequency sensitive and are not very significant until operation at the higher frequencies under normal atmospheric conditions. At frequencies of X-band and below it can be neglected for most situations. For further discussion of these losses the reader is referred to reference (1).

The calculator can readily be used for computation on non-pulsed radars by using average radar power in situations where either the average power J/S ratio or the minimum discernable average signal power is known. An alternate method is to convert the average signal power to an equivalent single pulse peak signal by multiplying the average power by the effective integration factor, and using the J/S associated with a single hit situation. This factor is approximately the product of the received signal bandwidth (in cycles) and the integration time(in seconds), assuming that an efficient integration technique is used. The integration time is normally determined by the reciprocal of the smoothing filter bandwidth.

RANGE SCALES

In order to solve problems for greater ranges than can be achieved with the markings on the range scales, two additional index marks are provided.

To multiply the range scales for the J equation by a factor of 100, use the blue index mark at the 0.1 NM mark on the range scale at the bottom of the rule. This is located to the right of the normal index arrow.

To multiply the range scale for the S equation by a factor of 100, use the red index mark which is located to the left of the normal index somewhat past the alignment guide.

REFERENCES

1. W. M. Hall, "Prediction of Pulse Radar Performance," Proc. IRE, February 1956.
2. A. V. Haeff, "The Minimum Detectable Radar Signal and its Dependence Upon Parameters of Radar Systems," Proc. IRE, Vol. 34 pp. 857-861, November 1946.
3. G. E. M-12, Radar Range Computer Instruction Manual.

LIGHT MILITARY ELECTRONICS DEPARTMENT

The Light Military Electronics Department of General Electric designs, develops, manufactures, and services electronic equipments and subsystems for operation in missiles, space vehicles, and aircraft used by the armed forces of the free world. Since its establishment in 1952, the Department has grown to include today more than 7,000 employees with facilities occupying over one and a half million square feet of floor space in seven plants located throughout New York State — at French Road, 831 Broad Street, and 901 Broad Street, Utica; Ithaca; Johnson City; Schenectady; and Coxsackie.

Among the most significant products of LMED are the AN/ALT-6B Electronic Countermeasures Transmitter; the AN/ALR-18 Receiver; the Multi-signal Jammer; and different Radar Repeaters. LMED produces the fire control computer for the Polaris submarine and the guidance computer for the Polaris missile; the Skybolt missile guidance computer; the W2F-1 computer; launch computers for the Sidewinder missile; and the toss-bomb computer for the F-105 aircraft. Other products include the MA-7, AN/ASG-14, and AN/ASG-19 fighter armament equipments; the MD-1A, MD-4, and A3A fire control radars; AN/SSQ-23 Sonobuoys; hot gas servos for missiles; liquid metals for space controls; electrostatic and cryogenic gyroscopes; and associated test and ground support equipment.

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