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NRL REPORT R-3313

FR-3313

INTERIM REPORT ON THE AN/SPS-2(XDQ) RADAR SYSTEM

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INTERIM REPORT ON THE AN/SPS-2(XDQ) RADAR SYSTEM

A. A. Varela

July 14, 1948

UNCLASSIFIED

Approved by:

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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ABSTRACT

For detection of long-range, ballistic-type missiles a triangular-shaped coverage pattern is more desirable than a rectangular pattern. With eight ten-megawatt beams, coverage on a square meter target out to 300 miles and up to about 22 degrees should be possible with a single 20 x 35-ft antenna. Observation time on 500-mile, V-2 type missiles would be about 2 minutes.

Anticipated positioning accuracy is ±200 yards in range, ±18 min. in azimuth, and ±25 min. in elevation. A confusion zone created by surface reflection prevents height-finding below 1.5 degrees. Proposed scan rate is 10 rpm, and pulse repetition rate is 220/sec.

Target elevation is to be determined from the ratio of signal strength in the overlapping beams, given by the difference in output from logarithmic receivers. It is concluded that to obtain a reasonably uniform height-finding characteristic and solid coverage, beam crossover at -2 db is desired. This has been obtained with X-band-models with horizontal side lobes lower than -29 db and vertical side lobes lower than -17 db.

Anticipated weight of the 80-megawatt system is 15 tons above deck and 29 tons below.

Altered requirements now call for reduction of altitude coverage to 90,000 ft, and this permits a 90-percent reduction in total transmitter power. It is proposed to use a single 10-megawatt transmitter, with six to eight separate beam receivers. Mutual instantaneous gain control will be used to alleviate side lobe signal problems. Antenna weight will be reduced to about 9 tons and below deck weight to about 7 tons. Performance adequate for future aircraft interception control is anticipated.

PROBLEM STATUS

This is an interim report on this problem. Work is continuing.

AUTHORIZATION

NRL Problem No. R02-22R (BuShips Problem S-1225X-C).

INTERIM REPORT ON THE AN/SPS-2 (XDQ) RADAR SYSTEM

INTRODUCTION

This is an interim report on the research development work on the AN/SPS-2 (XDQ) very-long-range, height-finding radar system. The work is being done at NRL under Bureau of Ships Problem S-1225X-C. Because the work is far from complete, it is impossible to present a clear picture of the system as a whole. Rather, different aspects are analyzed to show the performance possibilities and limitations.

The basic philosophy behind the development of the SPS-2 radar has undergone considerable change since its inception over two years ago. This is not surprising since it must operate with and against a generation of new weapons. Time was required to establish and evaluate the performance possibilities of these new weapons and the resulting tactical situations under which the radar must function.

The SPS-2 radar was first envisioned primarily as an off-shore, early-warning system against both ballistic and flat trajectory type missiles, and it was toward this end that the planning was directed. The function of detection of long-range, ballistic type missiles was subsequently dropped,[1] and only aircraft and flat trajectory missiles up to 90,000-ft height are now contemplated as targets. This change in requirements has produced changes in the antenna research objectives and has accentuated the study of accurate height-finding possibilities in the hope that the system might prove capable of aircraft interception control.

This report deals primarily with the first phase of the planning, i.e., for high-altitude missile detection, but much of the work and analysis applies to the reduced-coverage system that is now being planned and indicates performance expectations.

A basic discussion of the stacked beam system was given in the original report,[2] and the considerations of that report apply to the systems herein considered.

POSSIBLE TARGET CHARACTERISTICS

The original requirements of the SPS-2 called for ability to detect small targets in a very large volume of space, of which about 90 percent is above the altitude ceiling of the

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[1] Conf. Ltr. CNO to BuShips OP-413-C6/fic (SC) F42-5 Ser. 060P413 Subj: SPS-2 Radar, Altitude Coverage, Military Characteristics, Revision of 4/2/48.

[2] A. A. Varela, "Proposed very long range radar with height finding," NRL Report 2759, (Confidential) 18 February 1946.

most modern aircraft. To meet this requirement would require large and expensive equipment, and a consideration of the character of targets that might possibly be encountered in this space is important to basic design of the radar. This hazards peering into the future, but the immense amount of work done by the Germans in the fifteen years prior to the end of the War may serve as a guide.

Of the missiles produced, or the many proposed, by the Germans, the only ones attaining ionospheric altitudes and supersonic speeds were the A-4 (V-2), A-4b, A-9 and A-9/A-10 combination.[3]

The A-4 or V-2 characteristics are now well known, but what part such missiles might play in a future war is a difficult matter to conjecture. The maximum range that could be achieved by the German missile was about 270 nautical miles, judging from the altitudes obtained at White Sands Proving Ground. The U.S. Naval Technical Mission Report, page 42, gives the maximum range as only 300 km (165 nautical miles) with a peak altitude of 80 km (263,000 feet). The accuracy obtained in the trials was ±1 percent of the range. Certainly the range of such missiles might be greatly increased by the use of detachable boosters such as the A-10, but the pay load could not be much increased and the cost would rise rapidly. By way of comparison the A-10 booster rocket, which perhaps could have been used in conjunction with the V-2 to deliver the same warhead, carried about 146 times as much fuel as the V-2, yet the range of the combination would be somewhat less that 10 times that of the V-2. It appears that, even with accuracy maintained as a constant percentage of range, the economic status of the V-2 type of missile must fall very rapidly as range is increased. But it must be recognized that direct defense against such weapons is very nearly impossible. It must also be recognized that the use of nuclear fission motors and warheads may change the economic picture.

For greater range than that of the V-2, the German thinking led to winged missiles designed to soar and glide. The A-4b was an A-4 (V-2) equipped with small wings to increase the range about 50 percent by gliding. The A-9 was similar but of more advanced design with an expected range of about 330 nautical miles (600 km). It is not clear whether these missiles were intended simply to glide to the target or to soar and then glide, but with soaring the height to be achieved after the first parabolic portion of the path should not exceed 300,000 feet.

For bombardment of the United States the Germans planned to use the A-9 in combination with the A-10, the latter being a very large booster rocket which would be jettisoned. A maximum range of about 2900 nautical miles was expected. Early drawings (Figures 94 and 95, Reference 3) show a rather flat starting trajectory, reaching an altitude of about 360,000 feet, some 1200 nautical miles from the target. The missile was then to dive to about 160,000 feet, at 800 nautical miles from the target, and then soar to 650,000 feet before its final dive. The peak velocity, reached before the end of the first descent, is given as 9200 ft/sec (92 nautical miles/min). It was proposed to use a human pilot in both the A-9 and the A-9/A-10 combination, and he was supposed to have some chance of landing the missile after releasing the warhead.

It is submitted, then, that within the next fifteen years it is very unlikely the SPS-2 radar will be required to detect targets above 90,000 feet other than the following, and that for design purposes only these targets need be considered:

(1) V-2 type rocket missiles with parabolic trajectories not exceeding 500 nautical miles in range - launched from island bases, surface ships or submarines.

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[3] "Survey of German activities in the field of guided missiles," U.S. Naval Technical Mission in Europe, Technical Report No. 237-45, 31 August 1945

Interception and destruction of such missiles is extremely difficult, and immediate destruction of the source may be the best defense. Hence accurate plotting of the missile path may become an important requirement of the radar. Figure 1 shows the height vs time-of-flight characteristic to be expected of this type missile.

(2) A-4b (winged V-2) type missile with a parabolic trajectory at the start and either a long glide or a soar-and-glide finish. Maximum range about 800 miles. The radar should give rapid identification and accurate source location.

(3) Very long range missiles having a double-humped trajectory, the second hump being produced by soaring. Speed around 92 nautical miles/min (9200 ft/sec) but forward velocity at end of first dive probably not more than 60 nautical miles/min. The minimum height at the dip in the trajectory should be between 100- and 200-thousand feet and the height of the second hump might exceed 600-thousand feet. The SPS-2 could be expected to do no more than give "early" warning and missile type identification.

Subsonic missiles like the German V-1 and those attaining somewhat over sonic speeds but flying in the stratosphere appear relatively easy to cope with but might pose a problem in saturation of information-handling facilities.

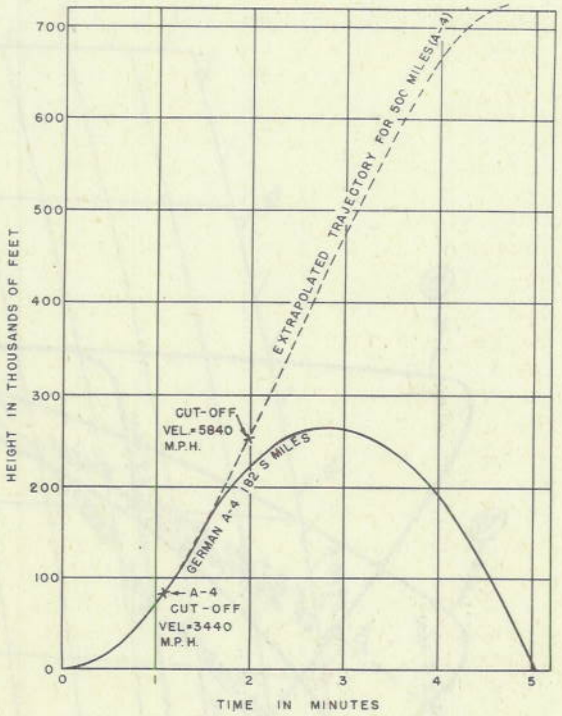

Fig. 1 - V-2 Height vs Time-of-Flight Characteristic, A-4 Data from German Pamphlet

VERTICAL COVERAGE PATTERNS

Figure 2 shows four possible coverage envelopes that might be obtained within the practical limits of Naval service. All four of the envelopes require about the same size and sort of equipment with differences mainly in the antenna. Trajectories of missiles discussed above are shown as they might appear to a ship 200 to 400 miles off the coast under bombardment. Approximate time intervals of radar observation for the different type envelopes are indicated at the intercept points. The missile paths are in a vertical plane passing through the radar and, if off to the side, would appear steeper than shown in Figure 2.

It would seem that the ideal coverage pattern should allow about the same observation time for the variety of trajectories shown but with some increase at the greater ranges. It is also desirable that the trajectories pass through the entire sheaf of beams if possible. From these considerations it is concluded that a pattern somewhere between (3) and (4) of Figure 2 is optimum and definitely preferable to the first proposed pattern (1) giving a constant altitude coverage.

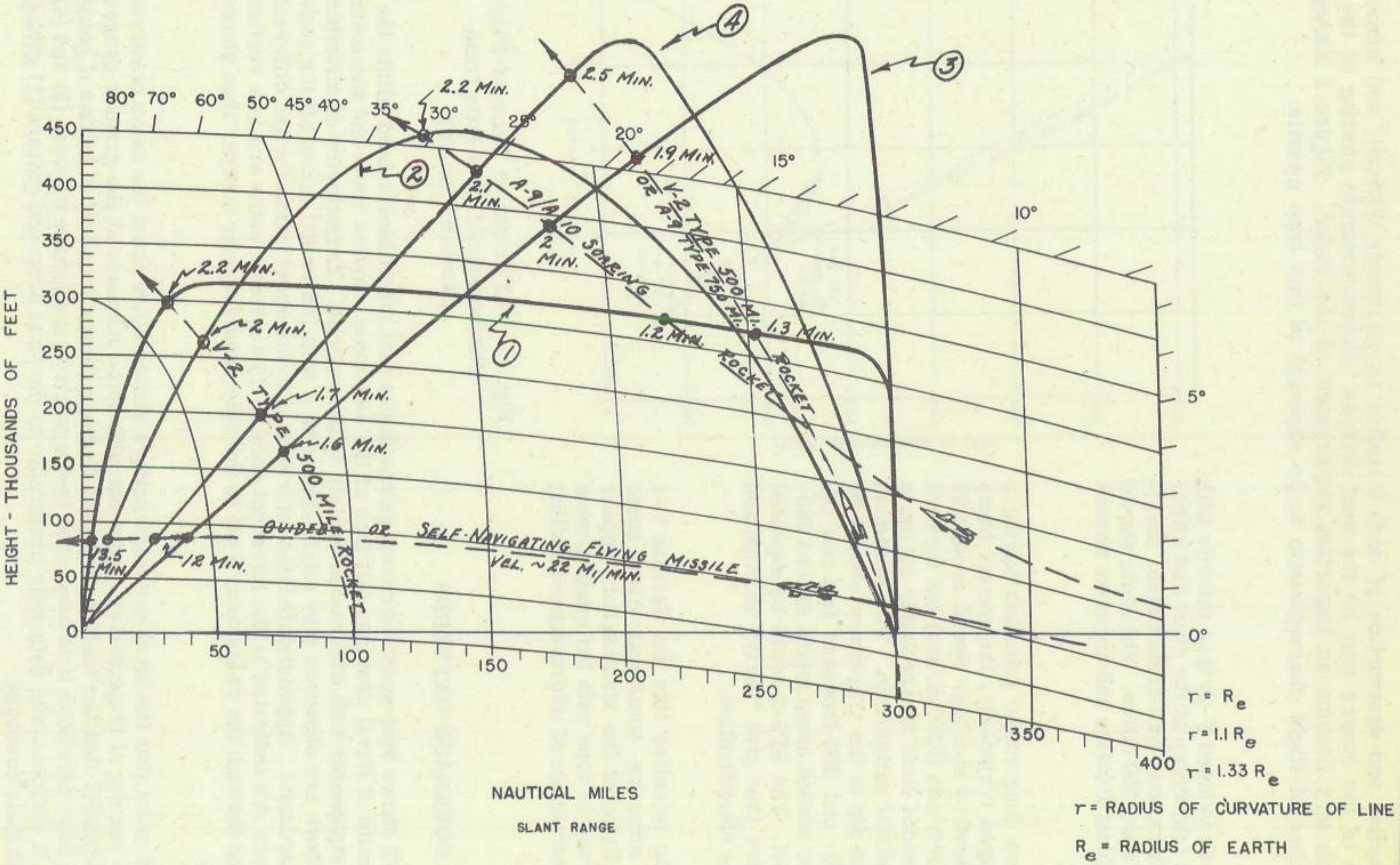

Fig. 2 - Possible SPS-2 Coverage Envelopes, Anticipated Missile Paths, and Corresponding Observation Time

[redacted]

PROPOSED COVERAGE PATTERN

Figure 3 shows the proposed coverage pattern using eight beams with ten megawatts pulse power in each beam. Other principal parameters are indicated on the chart.

ANTICIPATED PERFORMANCE CHARACTERISTICS

For high-altitude missiles of the types discussed, the region of detection is best described by the pattern of Figure 3. Manned aircraft may be expected to have a reflecting area not less than 10 square meters, and hence the maximum detection range (Figures 3, 27, 28) may be multiplied by about 1.8. This gives practical limits set either by the repetition rate or the radar horizon depending upon altitude of the aircraft. Since within the detection region the echo will be very strong, the maximum reliable detection ranges may, except for the vagaries of atmospheric propagation, be anticipated with a high degree of certainty. They are tabulated below:

Normal Propagation

Plane Altitude	Range at 1st Interference Max.*	Signal Strength†
Feet	Nautical Miles	db above P min.
500	19	63
1000	29	55
2000	42	48
4000	75	39
8000	110	32
15000	145	27
20000	170	24
25000	190	22
30000	210	20
50000	245	18
75000	295	15

* Based on the assumption of reflection from a plane earth. For very-low-altitude targets, the curvature of the earth must be considered, but these calculations have not yet been made.

† Based on the assumption that the target will be in the center of the first interference lobe. Since the signals are near or above indicator saturation, the statistical deviation should be quite small.

Anomalous propagation due to moisture gradient inversion may result in progressively increasing diffraction below 0.5° with complete trapping below perhaps 1000 ft.[4] This might permit detection of a plane at 500 or 1000 ft out to 300 miles, while a plane at 1500 ft could

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[4] "Radar pointing errors caused by atmospheric refraction" Ltr. NRL to BuOrd S-567 - 7 (538A) Ser. 5499 S-301-145/45 dated 9 Oct. 1945, Declassified 1/48 to Unrestr; "Measurements of the angle of arrival of microwaves in the X-band" BTL Report, MM-44-160-249, 7 Nov. 1944; "Predicted low levels coverage of S-band shipborne radars as affected by weather" USNRS Lab. Report, WP-14, 1 Nov. 1944.

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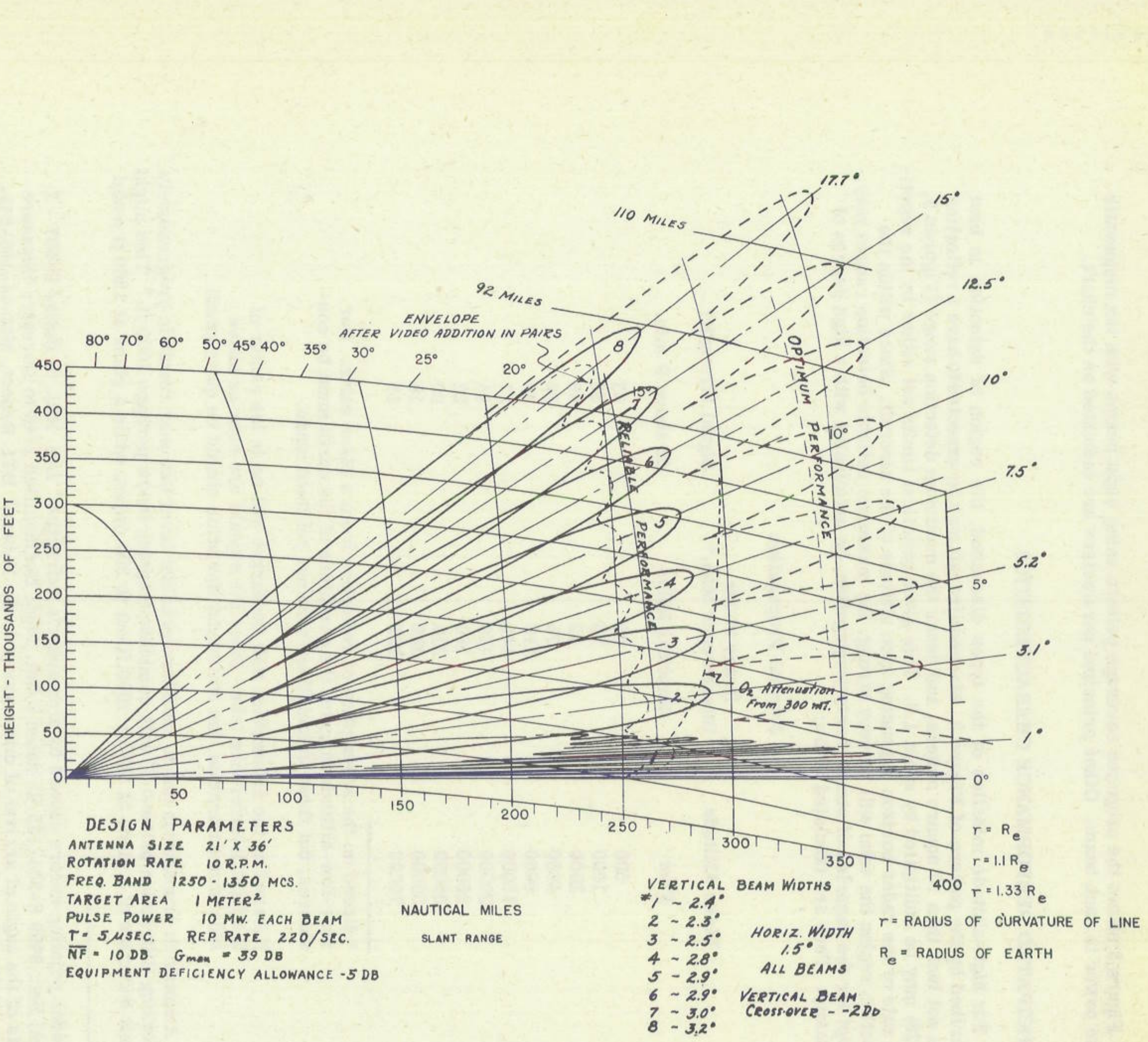

Fig. 3 - AN/SPS-2 Proposed Coverage Pattern, January 1948

be detected only to 35 miles. But it does not appear that the detection ranges on any aircraft will ever be substantially less than under normal conditions, although signal strengths may be lower and substantial null regions must be expected to appear as a result of spreading of the interference pattern.

POSITION DETERMINATION ACCURACY

Since a pulse length of 5 to 7 microseconds is planned, by the use of appropriate expanded sweeps and range circuits a range accuracy of about ±200 yds, and ability to resolve targets about a mile apart, may be expected as minimum limits. The horizontal beam width proposed is 1.5^0, but with only seven pulses on target each scan, it is doubtful that the azimuth determination limit will be better than one fifth of this, or ±18 min. Pulse-to-pulse variation of the echo may, however, increase the error to as much as ±30 min. With fairly strong signals a resolution of about 2° may be expected. Elevation accuracy is difficult to forecast because of unevaluated factors such as variation of target echo area with frequency, stabilization accuracy, equipment performance stability, etc., but from studies to be described later in this report it seems reasonable to expect elevation determination within ±25 min will be possible for targets above 1.5°. For targets at the same range and azimuth, it does not appear that elevation resolution better than the beam separation, i.e., about 3°, can be relied on. The radar positioning accuracy may then be given as about ±10 yds laterally and ±14 yds vertically, per mile of range, with ±200 yds range acc accuracy. Thus, for a target at 100 miles range and above 20,000 ft, a single data point should give position within ±200 yds in range, ±1000 yds laterally and ±1400 yds in altitude. With simple computing and data-smoothing from a series of scans, the position knowledge will of course be much better.

MAXIMUM DETECTION RANGE CALCULATIONS

The minimum detectable signal power with very nearly the SPS-2 parameters has been measured at this Laboratory using a type VE PPI indicator. This work, which also included video mixing studies, is described in a separate report.[5]

Corrections were made by known laws for the small deviations from the following parameters proposed for the SPS-2:

Antenna rotation	10 rpm
Pulse length	5μ sec
Horizontal beam width	1.5^0
Repetition Rate	220/sec
i-f bandwidth	0.4 Mc
Receiver noise factor	10 db

With allowances of +1 db for r-f plumbing loss and +3 db for operator deficiency a minimum signal power of 10.1×10^{-14} watts for 87 percent detection probability was obtained. The i-f signal-to-noise ratio (visibility factor) was then 7.4 db.

The 3-db factor for operator deficiency has been questioned and seems unnecessarily high in view both of the high probability basis of the measurement and the fact that no

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[5] H. W. Lance, G. D. M. Peeler, and C. R. Randall, "Video mixing and minimum detectable signal in the SPS-2 radar," NRL Report R-3123, Sept. 1947.

distracting clutter will be present ordinarily on the SPS-2 indicators. An allowance of 1 db is perhaps sufficient. On the other hand, a heavy allowance must be made for operational deficiency of the equipment. Operational reports and equipment checks during the last war showed Naval radar to be on the average some 12 db down from maximum sensitivity. But there was also shown to be a wide variation between classes of ships with battleships averaging only 4 or 5 db and destroyers running as high as 20. Presuming that the SPS-2 will be relatively well-manned and provided with complete and modern test equipment, an allowance of 5 db for operational deficiency seems adequate.

A minimum detectable signal power at the antenna of 6.25×10^{-14} watts is then anticipated in service with an i-f signal-to-noise ratio of 4.4 db. With the deficiency factor of 0.32 (5 db) the maximum free space detection range for a square meter target is then given by

$$R_0 = \left[\frac{0.32\, G^2 \lambda^2 P_t}{(4\pi)^3 \times 6.25 \times 10^{-14}}\right]^{\frac{1}{4}} \times 0.546 \times 10^{-3} \text{ nautical miles}$$

where G = antenna power gain
λ = wavelength = 0.23 meters
P_t = pulse power = 10^7 watts

The measured gain of the X-band scale model of the 14 x 36 ft XDQ antenna with 2-db beam overlap (for which the vertical patterns obtained are shown in Figure 4) was 35.6 db over an isotrope. Later measurements showed a gain of 35.1 db for this antenna, but a more recent one without slots and with larger horns gave similar patterns and a gain of 36.4 db.

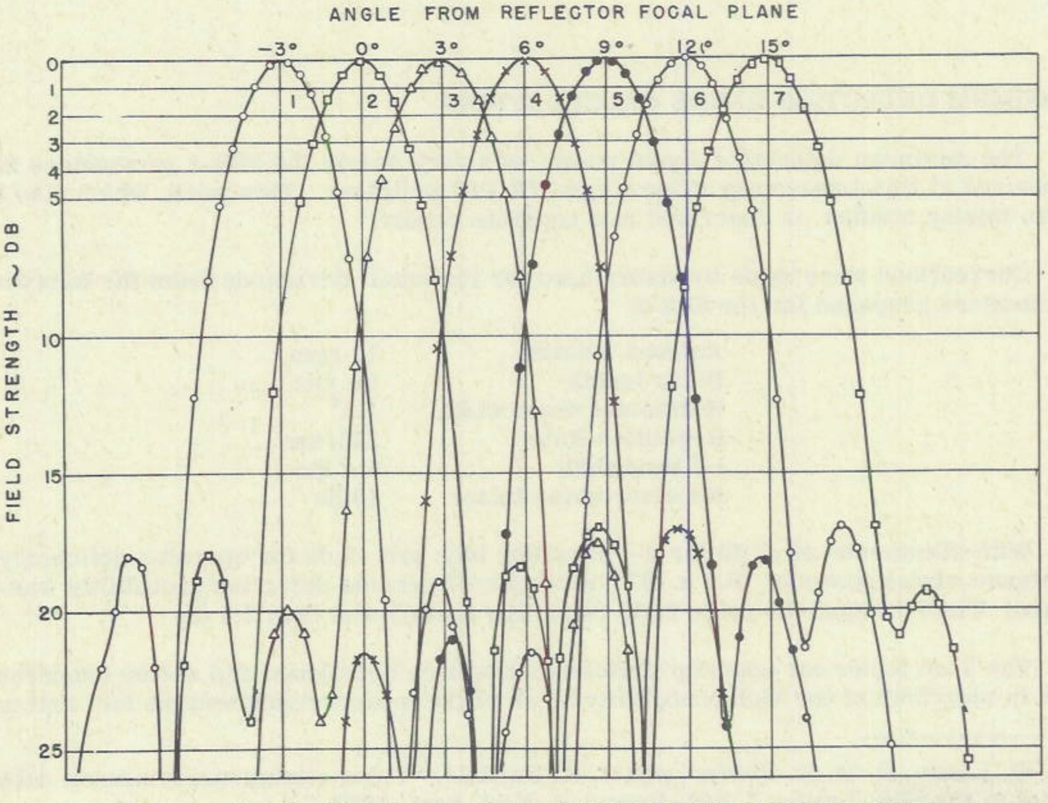

Fig. 4 - Vertical Patterns, X-band Scale Model of XDQ Antenna

Substituting this gain figure of 35.6 db, the calculated maximum range comes to 200 nautical miles, showing a gain shortage for the system of about 8.5 db from the required sensitivity to give 320 mile lobe tips. But for the SPS-2 an antenna with a vertical aperture of 20 ft is planned which should result in a 3.2-db system improvement. This, together with the expected improvement in gain from the new split focus reflector, should give perhaps a 4.4-db system improvement.

Some small improvement may be expected through video integration by means of storage tubes such as the Haeff Memory Tube and the storage orthicon. Very little data on this is as yet available, but in an RCA report[6] it is stated that "signals that could not be discerned visually from a noise background on a PPI screen could be successfully picked up by the storage orthicon and then viewed on a kinescope screen."

Ruby Payne-Scott, in her brilliant report,[7] shows that the limit of improvement by such integration is reached when the noise background becomes uniform. This will depend on the poorest resolution (τ s/d) in the presentation chain of storage tube, pickup scan and final presentation, and on the amplitude distribution of the noise—the latter determined primarily by the detector law as well as by the pulse repetition rate, the antenna rotation rate, and the horizontal beam width. The criterion for visibility for a non-uniform background is given as $(n/n_c)^{1/2}\ \delta I/I$, where n is the number of noise pulses actually integrated by the system, n_c is the number of pulses required to be integrated for apparent uniform intensity, and $\delta I/I$ is the differential brightness produced by the signal. An accurate forecast of the limit is not possible because parameters such as size of the storage and scan beams are not known, but a rough prediction based on the Payne-Scott experimental results may be made. With the conditions of a 160-mile sweep, a 2-μsec pulse (τ), an aerial rotation of 2 rpm, and a bandwidth of $1.5/\tau$, uniform noise background was obtained with a repetition rate of 200/sec. The cathode ray trace density was then about 16-sweeps/degree. The noise density in the radial dimension is shown to be dependent on the factor $S/2\Delta f$, where S is the sweep rate in mm/μsec and is inversely proportional to the range displayed, and Δf is the receiver bandwidth in Mc. In the SPS-2 a Δf of $2/\tau$ is planned and the proportionality factor between the two systems is then $(\tau^1/4R^1)/(\tau^0/3R_0) = (5/4 \times 300)/(2/3 \times 160)$ which is about 1. The ratio of antenna rotation rates is then the factor required to obtain a uniform noise background which permits a possible gain in sensitivity of $\sqrt{5} = 2.24$ or 3.5 db, and to obtain this will require storing for five rotations of the antenna. This gain may largely be lost however by the loss in super-position of the signal spots from successive scans because of target movement. With 300 miles presentation on a PPI, a spot diameter should be equivalent to about 1.5 miles. Hence, for targets with radial velocities in excess of 900 knots there will be no super-position.

Another opportunity for improvement is in the writing-speed loss of the indicator. With a 300-mile sweep and a 10-in. PPI, the sweep speed (S) is quite slow, 0.033 mm/μsec, and with a 5-μsec pulse, $S\tau$ is only 0.16 mm, whereas the optimum is about 2 mm. NRL Report R-3007,[8] Figure 12, shows the loss in P_{min} to be about 1.8 db. The Payne-Scott Report indicates that the cathode ray spot size (d) enters directly and optimum visibility is obtained with $S\tau/d = 3$. This at least is in agreement with Reference 8 for a normal

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[6] S. V. Forgue, RCA Review, 633-650, Dec. 1947.

[7] R. Payne-Scott, "The ultimate visibility of signals on a PPI display, and the effect of electrical parameters on visibility," Australian Council for Scientific and Industrial Research, Rept. R. P. 252-1, 20 May 1945.

[8] R. M. Ashby, V. Josephson, and S. G. Sydoriak, "Signal threshold studies," NRL Report R-3007, 1 Dec. 1946.

spot diameter of 0.7 mm. But the loss from optimum for the XDQ condition of $S\tau/d = 0.23$ is shown by Figure 6.2 of the Payne-Scott report to be nearly 6 db. Reasoning that this loss is in the nature of a "collapsing loss" and that the area of the spot size observed contains a mixture of one part signal and twelve parts surrounding noise, the loss may be expected to be $\sqrt{3/0.235}$ in power or 5.5 db—a good agreement with the Payne-Scott results. Clearly an experimental check is required and is being undertaken.

This loss, whatever its value, might be alleviated by range sector display, but this complicates the general presentation problem. Any improvement in focus of indicators would help of course. Artificial pulse stretching appears thus far to be a false hope and delusion. All of the schemes studied are, basically, the equivalent of using low pass video filters. A general negative conclusion has not yet been drawn, however, and studies of new ideas will be continued with some skepticism.

With a longer pulse, sensitivity would improve both from reduction of receiver noise-bandwidth and $S\tau$ increase. A 10-μsec pulse length was first proposed for the XDQ but was given up because it did not seem feasible to meet the frequency stability requirement of less than 75 kc carrier shift during the pulse. With anticipated magnetron pulling figures this required the mean voltage change over the pulse to be less than 3 percent and ripples to be very small. However, the adoption of a pulse length of perhaps 7 μ secs rather than 5 is well worth considering. This should produce an improvement in system sensitivity of $(7/5)^{3/2} = 1.66$ or 2.2 db, and the required frequency stability should not be too difficult. Automatic frequency control in the receiver may be required to allow for pulse-to-pulse changes and drifting.

From the foregoing discussion it is apparent that too many factors are still unknown for an accurate forecast of maximum detection coverage, but a reliable lobe-tip range with a square-meter target and free space conditions of about 225 miles seem assured. Even the 290-mile figure, on which Figures 3 and 26 are based, is not unduly optimistic.

ATMOSPHERIC ATTENUATION

Near the horizon the free space range calculations must be corrected for surface reflection and for atmospheric absorption. The latter effect has been derived from data presented in ONR Technical Report No. 4.[9] At 1300 Mc, absorption by oxygen in the air greatly predominates and water vapor attenuation may be neglected. At sea level the attenuation is 0.005 db/km but can be expected to decrease rapidly with increase in altitude. Table XVI of the ONR Report gives the attenuation at various altitudes up to 70,000 ft for a wavelength of 0.5 cm. Since the molecular-spacing to diameter ratio is very large, it is reasonable to assume that a similar characteristic obtains at 23 cm wavelength. On this assumption the curve shown in Figure 5 was obtained. From this data and the curvature of the earth from the radar horizon, Figure 6 was obtained showing attenuation rate as a function of slant range for 0-, 2-, and 5-degree elevation paths. Integration by geometrical averaging gives total losses for 300 miles (out and back) of 3.1, 1.6, and 0.8 db respectively for the three elevations. The resulting curve of attenuation vs elevation is shown in Figure 7. Hence only the first two beams of the SPS-2 will be appreciably affected. Attenuation due to very heavy rain over the entire area would not exceed 0.6 db. Echoes

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[9] A. E. Newton, "Absorption due to water and gas content of the atmosphere," Stromberg-Carlson Co. Technical Report No. 4, 15 April 1947.

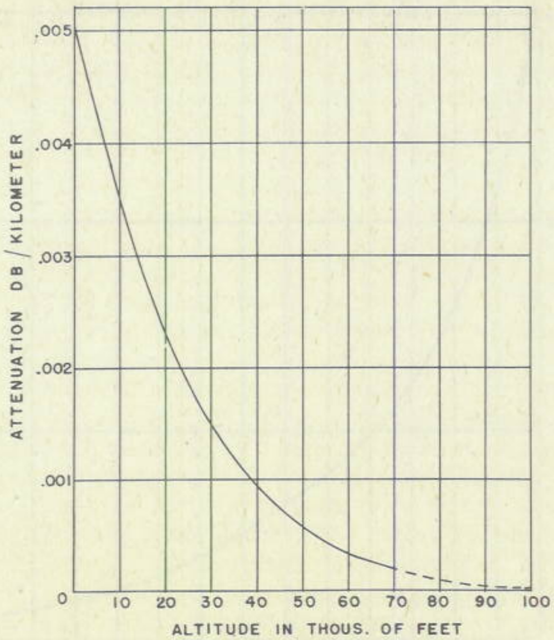

Fig. 5 - Attenuation Due to Oxygen Absorption vs Altitude, λ = 23 cm

from heavy rainstorms should be easily observable but well below those from ordinary aircraft. With delayed sensitivity on the receiver, it appears very unlikely that any cloud echoes will be obtained.[10]

HEIGHT-FINDING

A fair degree of height-finding is inherent in the stacked-beam system since the information received is basically divided into vertical-angle sectors and the target elevation may be called to within perhaps plus or minus the half width of these sectors. From the experimental model patterns given in Figure 4, having 3.4-degree beams intersecting at -2 db, the elevation uncertainty would be ±0.5 degrees, except for the first sector which would be somewhat wider—about

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[10] J. W. Ryde, "Echo intensities and attenuation due to clouds, rain, hail, sand and dust storms at centimeter wavelengths," G. E. Co., Ltd. Report 7831, 13 October 1941.

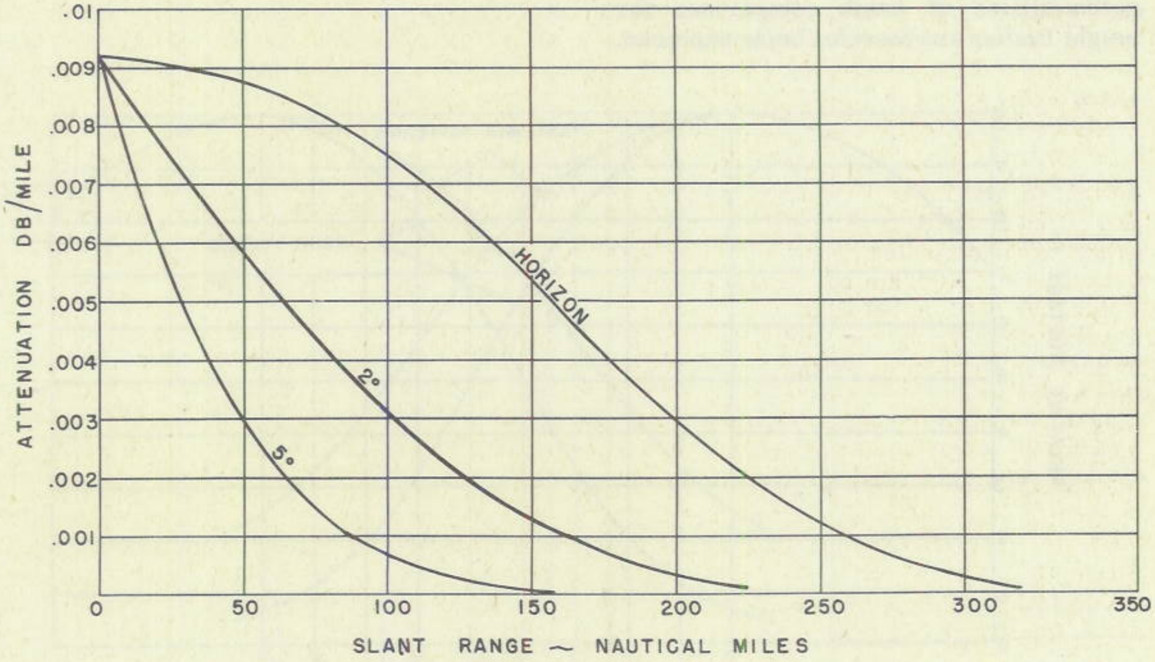

Fig. 6 - Attenuation Due to Atmospheric Absorption vs Range, λ = 23 cm

2 degrees—depending on the first beam elevation. With 2.4-degree beams the accuracies would of course be better by the proportion 2.4/3.4. Because of the high sensitivity of the system, any flying target should give a strong signal immediately upon passing above the radar horizon; and with normal propagation conditions, the height will be accurately determined by the range at first detection. But because of propagation uncertainties, height determination by this means will not be fully reliable until verification is obtained by appearance of the target in the second beam. Ambiguity from the same target appearing on more than one beam at the same time might be largely avoided by use of an instantaneous gain control system common to all channels and with a threshold about 12 db above rms noise.

Whether such rough height-finding is deemed adequate depends of course on the specific tactical functions of the equipment. Certainly, for the possible functions of rocket-source location and aircraft interception control, a much higher degree of accuracy is needed. The maximum potentialities of beam comparison for height finding are therefor being explored.

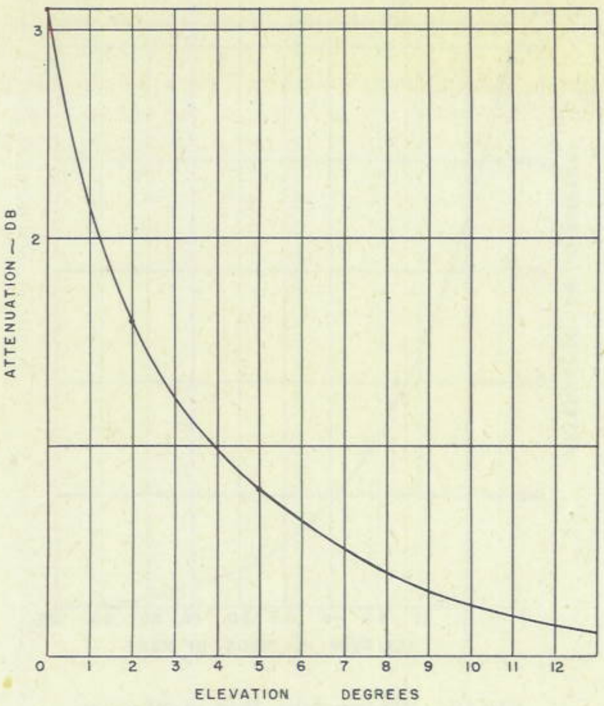

Fig. 7 - Atmospheric Attenuation vs Elevation, λ = 23 cm, Two-way Path of 300 Nautical Miles

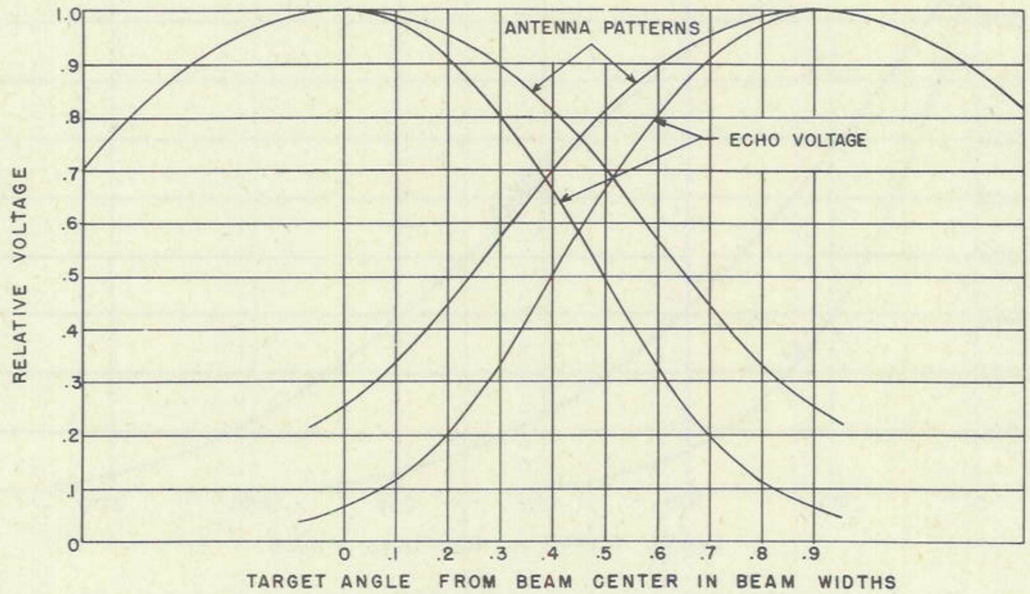

Fig. 8 - Experimental Patterns, -2.3-db Cross-over

BEAM COMPARISON

The proposition is to determine the target elevation relative to adjacent beam centers by comparing the strength of the signals derived from the two beams. Figure 8 shows typical experimental patterns with field strength down 2.3 db at the overlap point and 12 db down at the neighboring beam center. Received echo voltage will vary as the square of the antenna patterns as shown. The frequency differs in the two beams by about 10 Mc, the amount required for receiver discrimination. A comparison signal might be obtained by beating the two i-f signals, but while further study is needed, this method seems to offer complexity without advantage over direct video comparison. In either case the detection process, in which the signal and noise are added vectorially, must be taken into account. Figure 9 shows video output vs i-f signal-to-noise ratio with linear- and square-law detectors.[11] The linear detector gives a more uniform comparison characteristic and will be employed unless it results in appreciable loss in sensitivity. Figure 10 shows the video output vs target position between the two beams after linear detection for various signal levels.

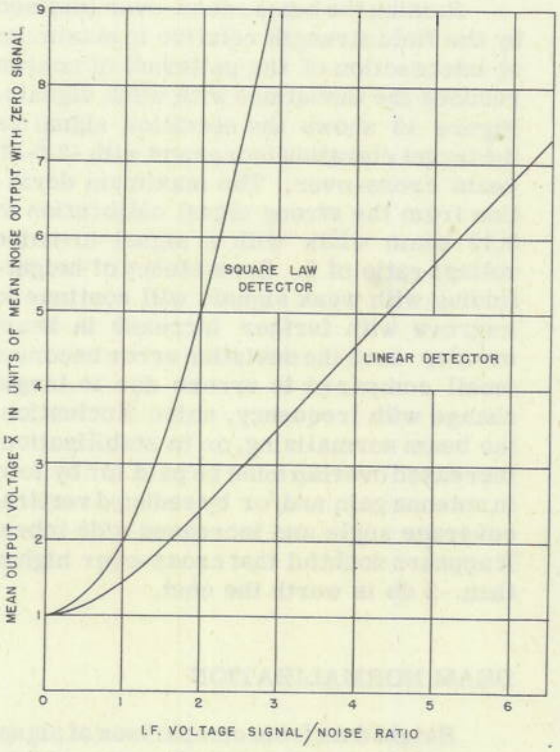

Fig. 9 - Relation of Video Output to I-F Signal/Noise Ratio

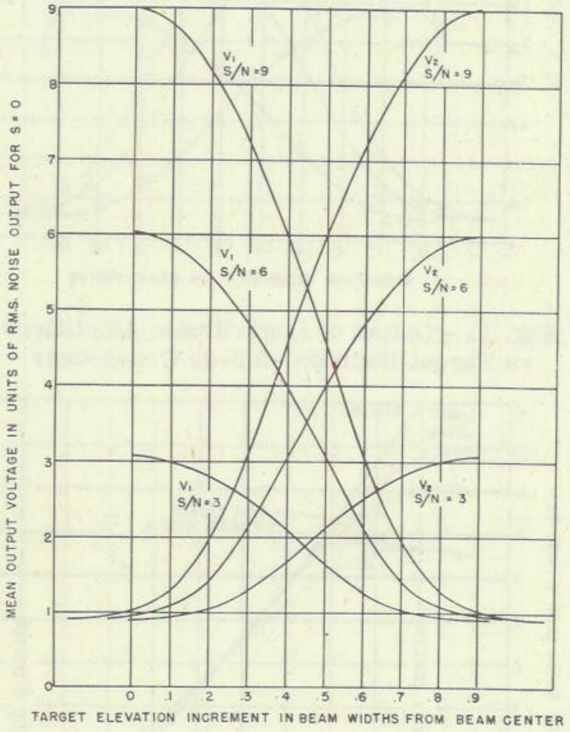

Fig. 10 - Video Output vs Target Position, -2.3-db Cross-over

The signal ratio is probably most easily obtained by passing the signals through logarithmic amplifiers and taking the difference. This was suggested by P. R. Bell in 1945 in a Radiation Laboratory patent application. The outputs to be expected from log amplifiers are

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[11] E. R. Andrew, "An experimental verification of theoretical relations between detector current and receiver signal/noise ratio," Gt. Britain PRDE Report No. 295, 23 August 1945.

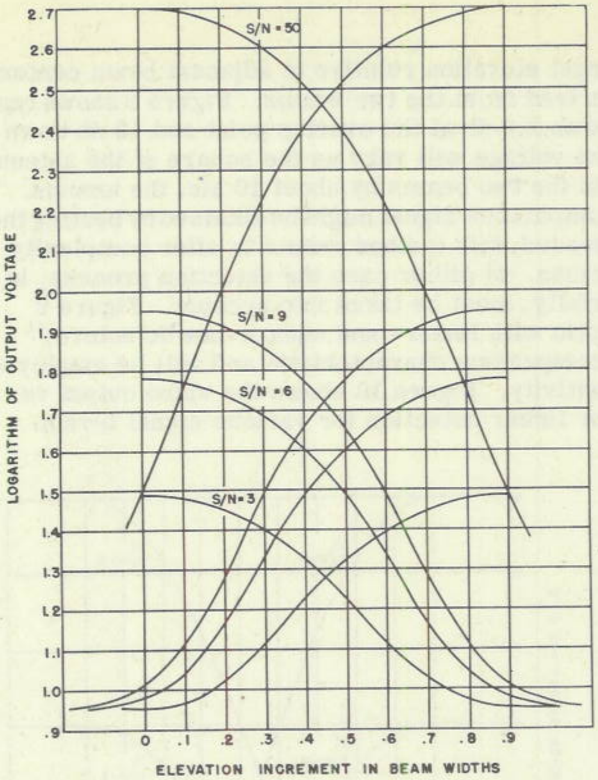


Fig. 11 - Output of Logarithmic Amplifiers vs Target Position -2.3-db Cross-over

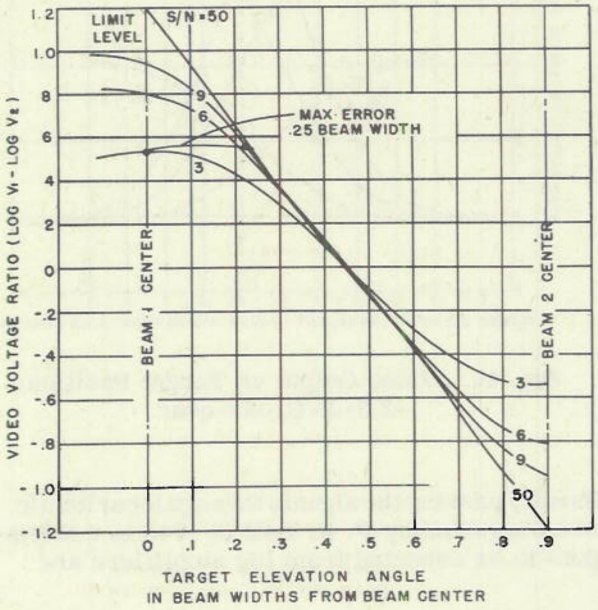


Fig. 12 - Video Voltage Ratio vs Target Position between Two Beams, -2.3-db Cross-over for Various Values of I-F S/N

shown in Figure 11, and the difference curves from which height calibration would be obtained are shown in Figure 12. For very strong signals (say 25 db or more over detection threshold) the curve is quite straight, and without other sources of error elevation determination to within ±0.05 beam width (±7.2 min. with 2.4-degree beams) should be readily possible. But with decreasing signal strength, curvature increases rapidly; and with a signal-to-noise ratio of 3, still some 5 db above detection threshold, the uncertainty at the beam centers has increased to ±0.25 beam width.

Raising the beam cross-over (defined by the field strength relative to maximum at intersection of the patterns) of course reduces the deviations with weak signals. Figure 13 shows the elevation signal vs the target elevation increment with -2.0-db beam cross-over. The maximum deviation from the strong signal calibration is 0.19 beam width with a signal-to-noise voltage ratio of 3. Consistency of height-finding with weak signals will continue to improve with further increase in beam overlap until the deviation error becomes small compared to errors due to target change with frequency, noise fluctuation, the beam normalizing, or to stabilization. Increased overlap must be paid for by loss in antenna gain and/or by reduced vertical coverage angle and increased side lobes. It appears doubtful that cross-over higher than -2 db is worth the cost.

BEAM NORMALIZATION

Height data from comparison of signal strength in overlapping beams must be predicted on a fixed relationship of overall gain in the two radar channels under comparison, and this relationship must be maintained throughout the entire dynamic range of signal strength to be encountered. Aerial target areas are expected to vary from 1 to 200 square meters, and of concern here are ranges from 250 miles in to 50 miles, at which point delayed sensitivity may be used to provide relief. Hence the dynamic range of the receiving channels should be at least $200 \times 5^4 = 125 \times 10^3$

in power, or 51 db, plus the maximum channel ratio of 20 db. The present plan involves the development of i-f amplifiers and final detectors that remain linear over a range of perhaps 75 db, and use of video amplifiers for normalizing and obtaining the signal logarithms. An alternative logarithmic i-f amplifier with 75 db dynamic range is also being engineered. Normalizing, or maintaining constant channel gain relationship, may be accomplished by introduction of a pilot signal during the flyback time, i.e., the time interval between the end of the presentation sweep and the following pulse. Gated output circuits responsive to this pilot signal would then control the video gain. The pilot signal might be derived from a common noise source if sufficient power can be obtained, or perhaps more likely from a sweeping oscillator. The signal would be introduced to the r-f, plumbing preferably through unidirectional couplers, or possibly by a very small radiator mounted above the antenna horns. Since these schemes do not correct for mis-tuning of the receivers, a-f-c may be necessary.

It is not proposed to regulate transmitter power automatically but to show simply the various magnetron outputs on meters for manual correction. It is expected that even a 2-db change here will represent near end-of-life condition for the magnetron, and in any event the height indicators can be recalibrated.

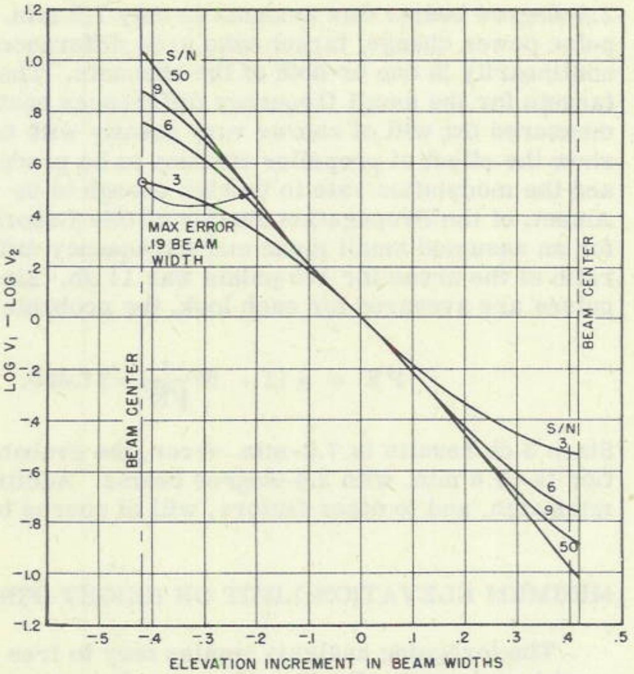


Fig. 13 - Video Voltage Ratio Log V_1 - Log V_2 vs Target Position between Two Beams, -2.3-db Cross-over

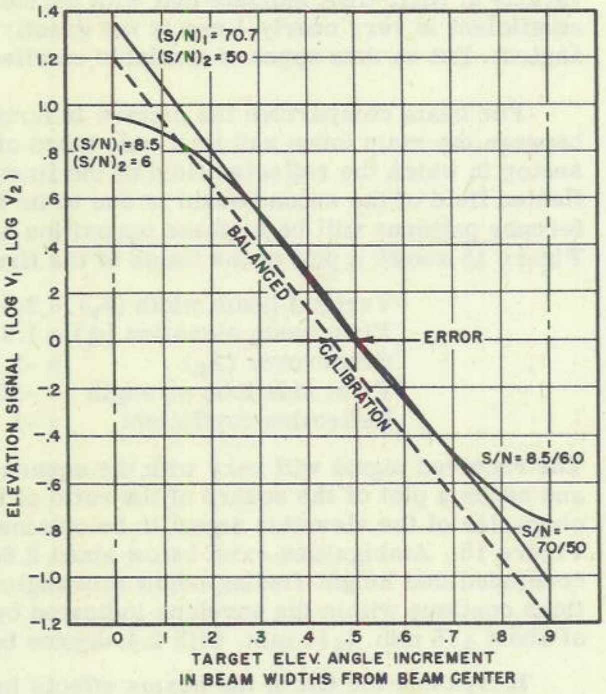


Fig. 14 - Beam Comparison Effect of 3-db Unbalance in the Two Channels on Elevation Accuracy, -2.3-db Cross-over

EFFECT OF UNBALANCE

Because there is a total change of about 40 db in the ratio of signals from two beams in going from one beam center to the next, there can be considerable unbalance in gain without serious error in height-finding. The effect of deviation in relative gain from the calibrated condition of two channels under comparison is illustrated by Figure 14. Here a difference of 3 db was assumed and curves are plotted for voltage-signal/noise ratios of 8.5 and 6, and 70 and 50. The result is an offset from the calibration giving a fairly constant error of 0.05 beam width. With

2.4-degree beams this amounts to only 7.2 min. Deviation in relative gain might be due to pulse power change, target echo area difference, receiver mistune or mis-normalizing, or nonlinearity in one or both of the channels. The changes in echo area of various expected targets for the small frequency differences contemplated here (0.8 percent) have not been measured but will of course vary greatly with target type and with aspect. Film records show the effect of propeller rotation to be predominant for small interval echo differences and the modulation rate to be high enough to be random with 220 pulses per second. W. S. Ament, of the Propagation Section of this Laboratory, calculated the effect on echo areas for an assumed small plane and a frequency difference of 1 percent. The rms value of the ratio of the areas for 170 points was 11 db. Since the errors are bivariate and about seven pulses are averaged for each look, the probable error in voltage ratio is given by

$$PE = \pm\left(1 + .67\frac{\sigma}{\sqrt{N}}\right) = \pm 1.885.$$

Since 3 db results in 7.2-min. error, the probable elevation error due to propeller modulation is ±9.6 min. with 2.4-degree beams. Additional errors due to receiver and transmitter mismatch, and to other factors, will of course be present.

MINIMUM ELEVATION LIMIT ON HEIGHT-FINDING

The foregoing analysis applies only to free space conditions. Near the horizon, account must be taken of reflection of energy from the ground or sea. The reflected field combines with the direct field to give an interference pattern with lobe periodicity according to the function $\phi = \sin^{-1}(n\lambda/4h)$, where ϕ is the angle above the horizon, n is the lobe number, and h is the antenna height. A lobe separation of about 0.2 degrees can be expected. Observations at NRL-CBA indicate that with horizontal polarization at this frequency the reflection coefficient is very nearly 1 and is not greatly affected by sea state at very low (grazing) angles. But no data appears available on effect of sea state with increasing incidence.

For beam comparison the picture is further complicated by the 180-degree phase shift between the main lobes and first side lobes of the antenna beams. Hence there will be a sector in which the reflected field of the first beam is part of the main lobe while the reflected field of the second beam is due to its first side lobe. In this sector the two interference patterns will be in phase opposition and the signal ratio will oscillate violently. Figure 15 shows a plot of the fields of the first two beams. The conditions assumed were:

Vertical beam width (θ_V) = 3.4 degrees
First beam elevation (ϕ_1) = 1.5 degrees
Cross-over (A_c) = -2 db
First side lobe strength = -18 db
Reflection coefficient = -1 + jo

The received signal will vary with the square of the field strength as plotted in Figure 15, and hence a plot of the square of the ratio of the two field strengths will show the general character of the elevation signal to be obtained by comparison. This has been done in Figure 16. Ambiguities exist below about 2.6 degrees (0.75 beam width) and it must be concluded that height-finding below this angle is not possible. Above this angle, oscillations continue within the envelope indicated by the dashed lines and show an accuracy limit of about ±15 min. (±11 min. with 2.4-degree beams) up to the second beam center, ϕ_2.

Increasing the tilt of the beams effects improvement by causing the second-beam side lobe to combine on itself to give an interference pattern more nearly in phase with that of the first beam. Figures 17 and 18 show the result with first beam elevation increased to 1.75-degrees and 2-degrees tilt respectively. The latter is the best condition and shows freedom from ambiguity down to about 0.65 θ_V.

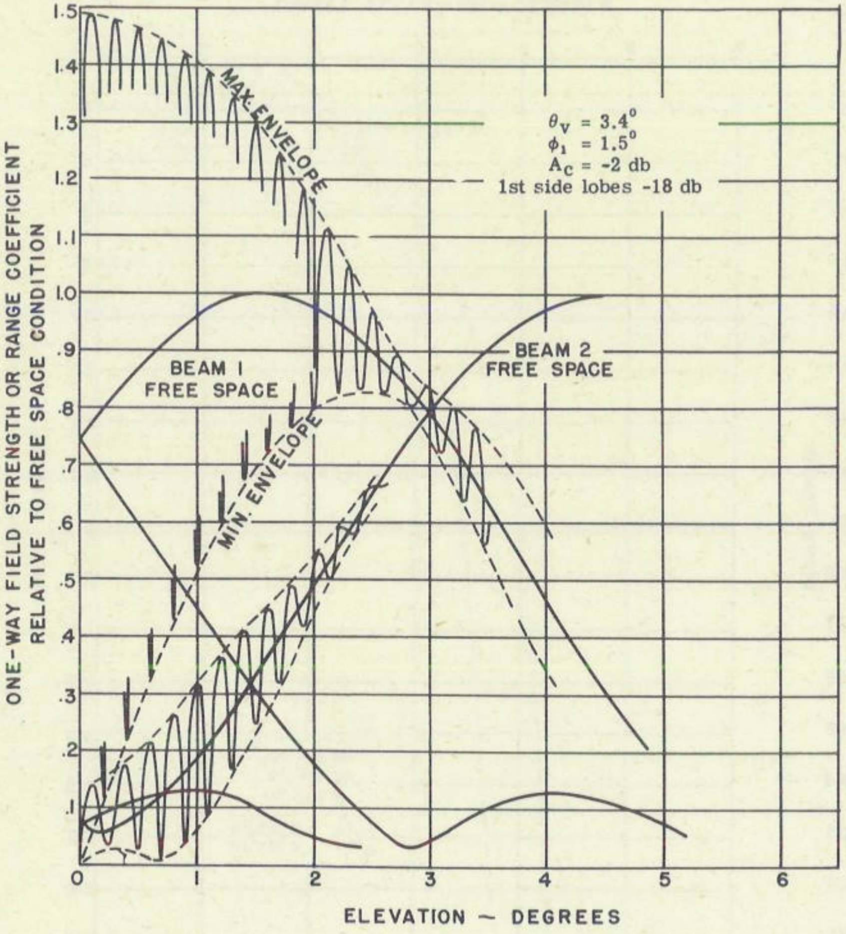


Fig. 15 - Interference Patterns, Beams 1 and 2

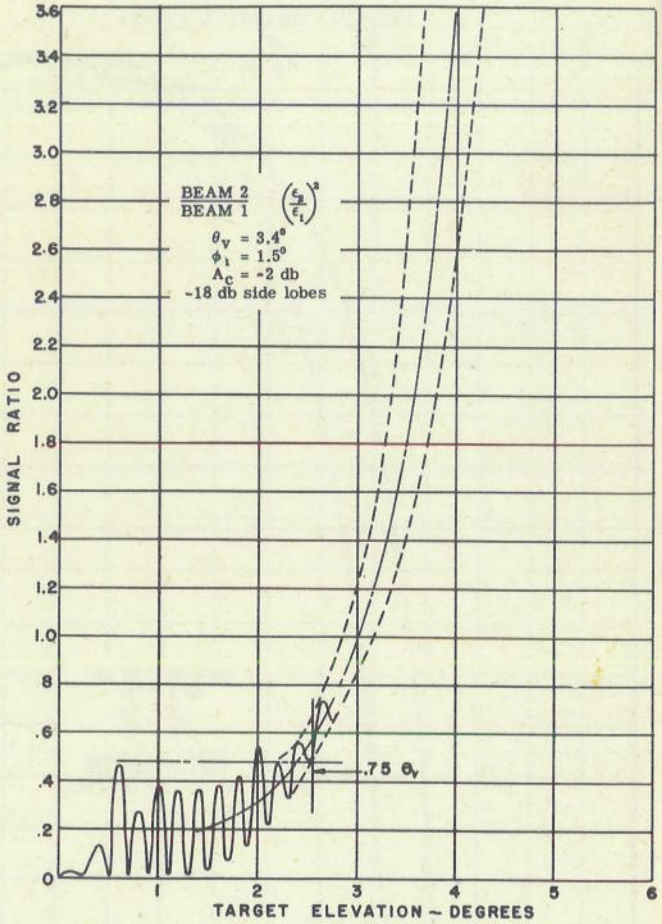


Fig. 16 - Echo Ratio vs Target Elevation

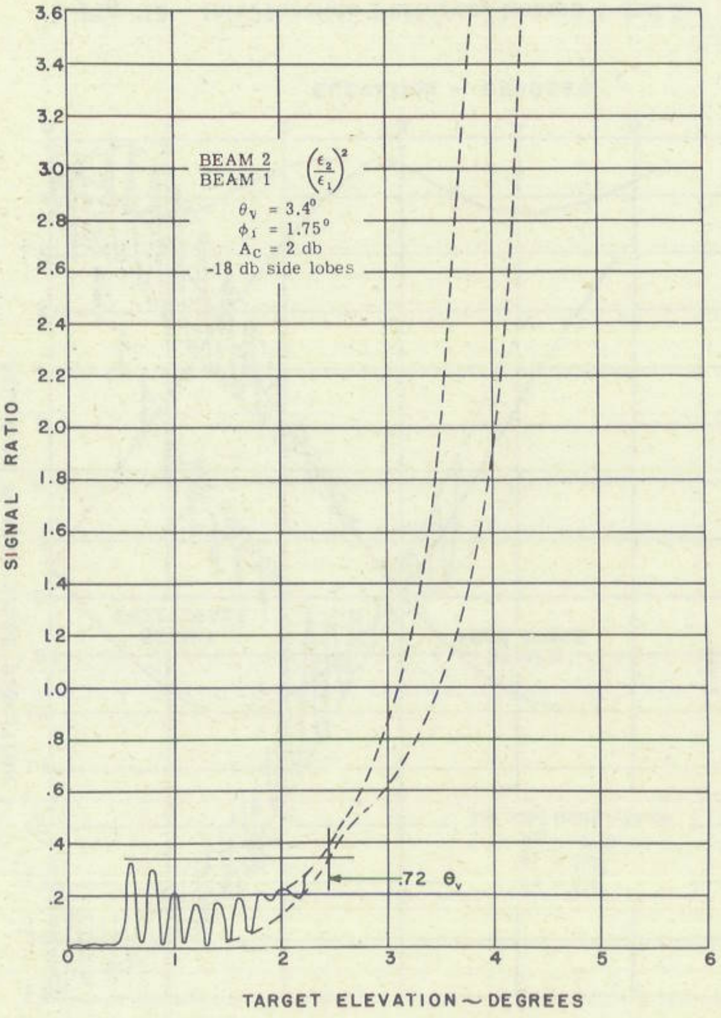


Fig. 17 - Echo Ratio vs Target Elevation

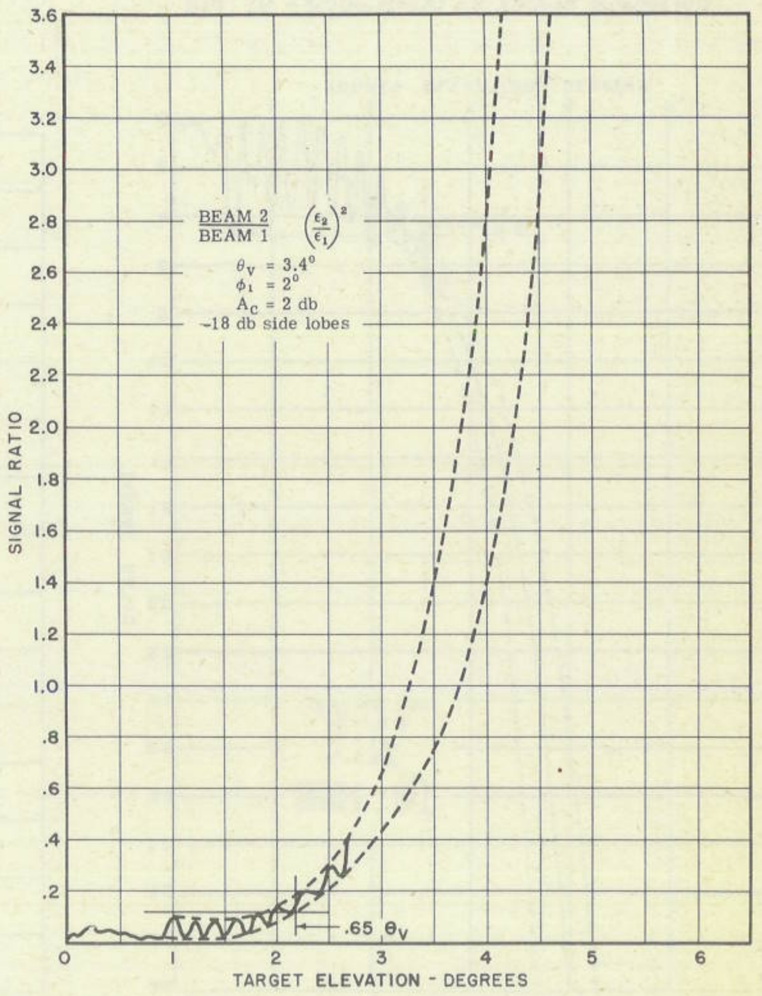


Fig. 18 - Echo Ratio vs Target Elevation

It is apparent that the minimum elevation for height-finding is limited by production, on the part of the lower first side lobe of the second beam, of an interference pattern which is in phase opposition to that of the first beam. The antenna should therefore be designed to favor the second beam and reduce this side lobe to a minimum. From present results given by Figure 4, the first horn should be at the focal point and the critical side lobe is then -20 db.

The resulting interference fields with tilts of 1.5, 2, and 2.5 degrees are plotted in Figures 19, 20, and 21, and the corresponding echo ratio curves are given in Figures 22, 23, and 24. With 2.4-degree beams, height-finding should be possible down to 1.5 degrees elevation.

HEIGHT DATA PRESENTATION

Rough height data can be included in an over-all PPI presentation by use of color, by stereoscopic vision, or other means, but for accurate height indication it is assumed that a range-elevation scope is required with the presentation preferably gated to a small azimuth sector. Several means are considered for accomplishing such presentation with a stacked-beam system, notably:

(1) A multigun cathode ray tube with each gun taking data from a pair of beams. The cathode rays would normally sweep along calibration lines corresponding to the radar beam cross-over elevations. The beam comparison signal would produce up or down deflection simultaneously with intensity modulation by the combined radar video signal.

(2) A trigger or step-function amplifier interposed in each video channel to give an abruptly limited output with any signal exceeding an established threshold. The outputs of these non-linear amplifiers would be mixed, to provide the cathode ray intensity signal, and further amplified separately to different levels to provide deflection voltages corresponding to the respective radar beam elevations. The beam comparison signal would be applied as a correction voltage in the deflection amplifier. In event of simultaneous signals at different elevations only the higher elevation signal would be presented, and an aircraft target would not be blocked out by ground clutter. But to keep false indications from high noise pulses down to the same probability as with a single channel indicator, it will be necessary to raise the threshold of the step-function amplifiers to a level resulting in a sensitivity loss of (5 log N) db, where N is the number of channels being mixed. With 8 channels the loss would be 4.5 db.

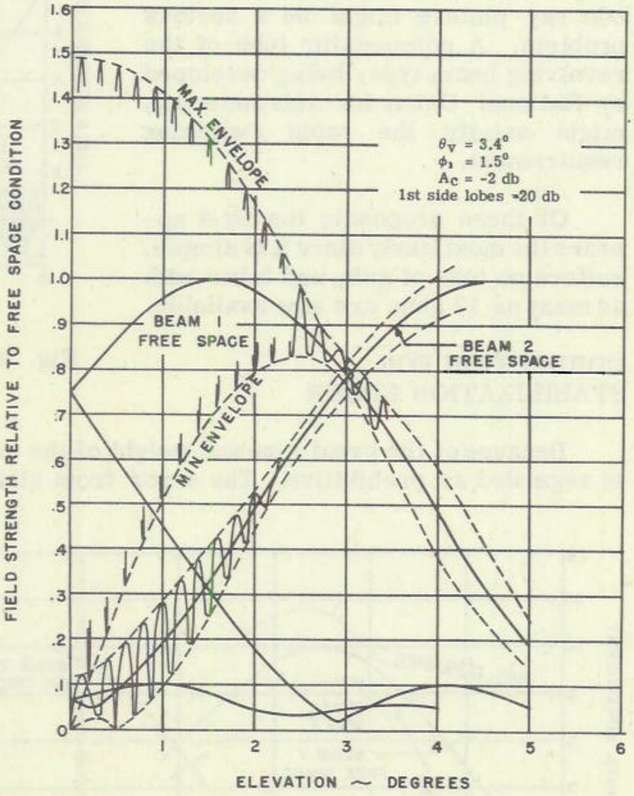


Fig. 19 - Interference Patterns, Beams 1 and 2

(3) A consecutive sampling system. With this an electronic commutator is required to switch the oscilloscope to the different radar channels in succession to give at least one

sample from each channel for every pulse interval. Thus the switch intervals would have to be less than τ/N. A step-sweep, synchronous with the commutation and corrected by the comparison voltages, would provide the elevation deflection corresponding to the sample signal presented. It appears that, with this rather elaborate system, the loss in sensitivity might be less than with the second system proposed, but low intensity of the cathode ray picture might be a serious problem. A commutator tube of the revolving beam type, being developed by National Union for telemetering, might satisfy the rapid switching requirement.

Of these proposals the first appears the most likely since it is simple, suffers no loss of gain, and tubes with as many as 12 guns are now available.

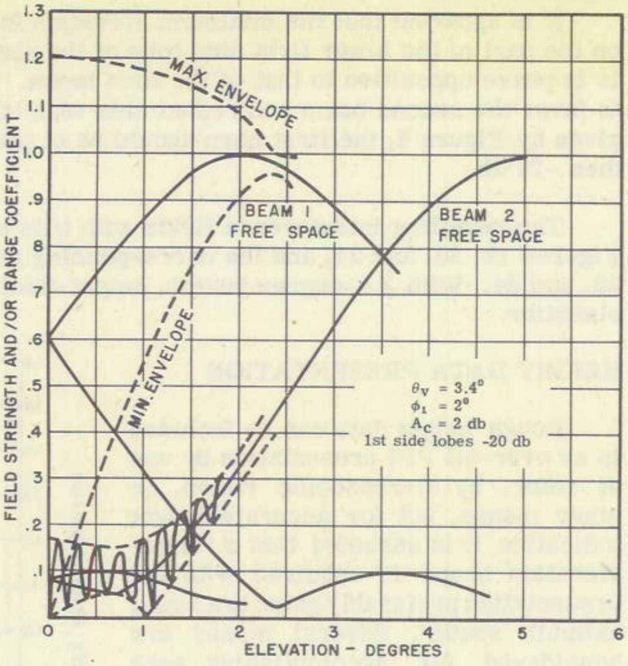


Fig. 20 - Interference Patterns, Beams 1 and 2

CORRECTION FOR STABILIZATION ERROR

Because of the great size and weight of the antenna, stabilization to better than ±20 min. is regarded as prohibitive. The error from stabilization can be removed from the target-height indication simply by using the error voltage from the stabilizer to produce a compensating deflection on the elevation axis of the range-elevation scope. With a linear scale the entire picture could be deflected directly by the error signal, and with a refinement, it could control gain of the first comparison amplifier so as to keep the horizon indication constant.

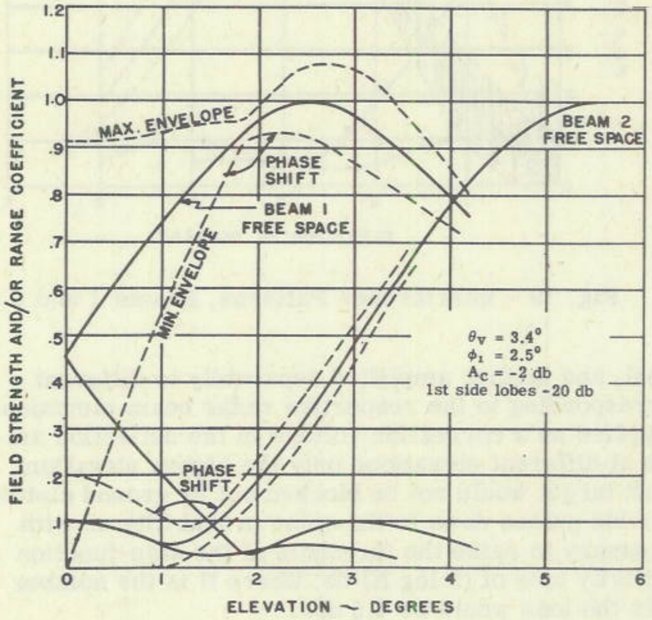


Fig. 21 - Interference Patterns, Beams 1 and 2

STABILIZATION REQUIREMENT

Since it appears that stabilization error can be compensated in the indicators, the permissible tolerance in stabilization becomes governed by loss in reliable coverage and effective increase in the minimum elevation for height-finding. Figures 19, 20, and 21 illustrate the interference fields for the conditions 1.5, 2, and 2.5 degrees tilt of the first beam with 3.4-degree beams. The first lobe tip range relative

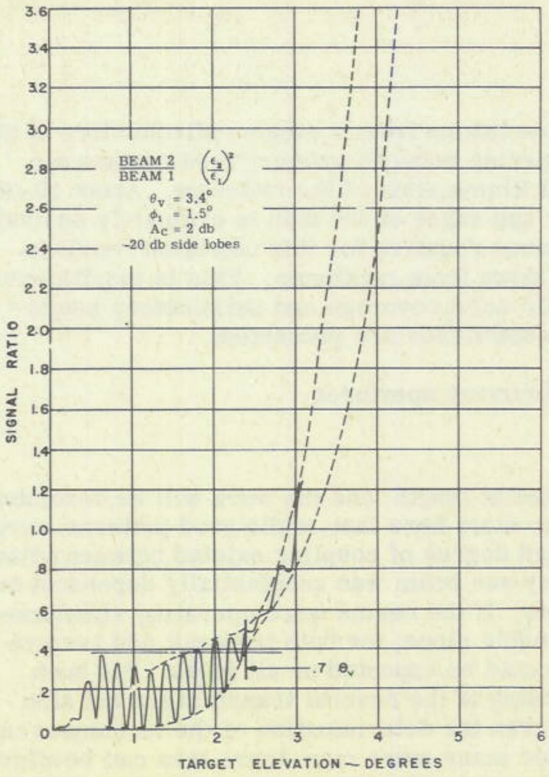


Fig. 22 - Echo Ratio vs Target Elevation

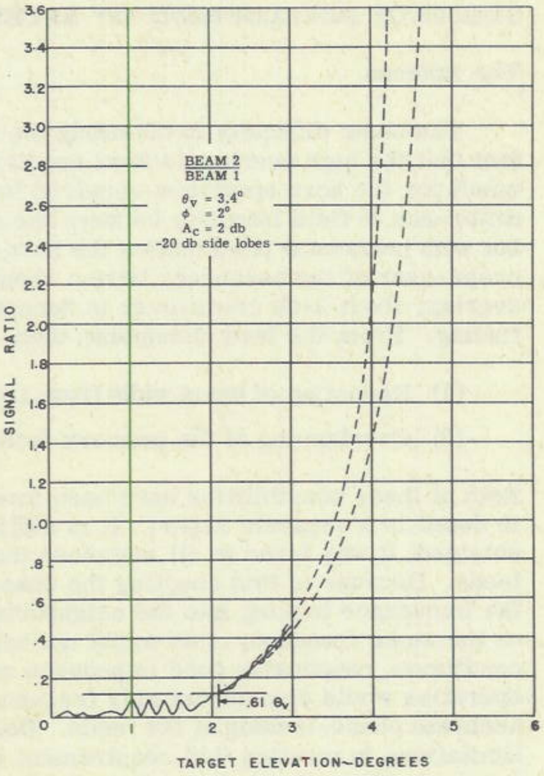


Fig. 23 - Echo Ratio vs Target Elevation

to the free space lobe range is respectively 1.5, 1.2, and 0.91, or about ±25 percent, taking 2 degrees as the normal tilt. This would give a variation in signal strength of about ±4 db, which is not excessive. The corresponding ratio curves (Figures 22, 23, 24) show confusion zones up to $0.7\theta_V$, $0.61\theta_V$ and $0.6\theta_V$ respectively. Other than the displacement which can be compensated by the stabilization error signal, there is no significant change in the mean character of the curves, and hence the only deleterious effect is the rise of the confusion zone with downward tilt.

It may be concluded, then, that with 3.4-degree beams a fixed upward tilt of 2 degrees or slightly more is desirable, and a stabilization error of ±30 min is permissible. But these angles should be expressed as fractions of the vertical beam width, giving 0.59 θ_V tilt and ±0.147 θ_V stabilization error. The corresponding allowable error with 2.4-degree beams is thus only ±21 min. This might be taken as the stabilization objective, but with ±30 min regarded as the acceptable maximum.

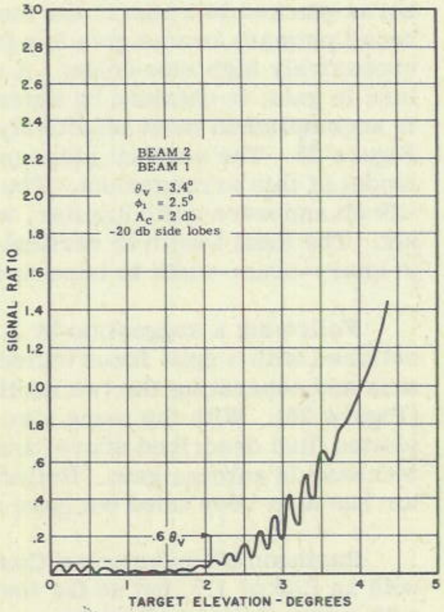


Fig. 24 - Echo Ratio vs Target Elevation

STATUS OF DEVELOPMENT OF ANTENNA

The Antenna

The basic difficulty in obtaining the multiple beams from a single reflector lies in the fact that the high overlap desired requires a spacing between primary feed centers too small for the horn apertures required for good illumination of the reflector. About 10-db difference in field intensity between the center and edges of the dish is ordinarily desirable, but with horizontal polarization the horn apertures required for this condition result in cross-over of the secondary beams about 6 db down from maximum. This is insufficient overlap; about 2-db cross-over is necessary for solid coverage and satisfactory height-finding. From the feed standpoint, then, two possibilities are presented:

(1) Reduction of beam width from limited primary apertures.

(2) Overlapping of the primary feeds.

Both of these possibilities have been investigated at length, and the work will be described in detail in a separate report. It is sufficient to state here that, while good patterns were obtained, it was found in all instances that a high degree of coupling existed between adjacent feeds. Because of this coupling the shape of any one beam was substantially dependent on the impedance looking into the neighboring feeds. If the beams were operating simultaneously on the same frequency, this might not cause trouble since, for both transmit and receive conditions, reasonably good impedance match could be expected on all feeds. But such operation would demand not only frequency-locking of the several transmitters but also accurate phase-locking at the feeds. Because even the determination of the techniques and limitations in meeting this requirement calls for many more man-hours than can be afforded, the proposition of simultaneous operation of several transmitters on a single frequency has been classed as impractical.

An immediate and reasonably satisfactory solution is presented by simple small-aperture horns stacked in a line in the focal plane as shown in Figure 25. The resulting, excessively broad primary beams give low transfer efficiency because of "spill-over" and they also give excessively high side-lobes. A significant improvement in the patterns, without appreciable loss in gain, is obtained by tapering the reflection from the upper and lower dish edges. This is accomplished most effectively by making long open slots in the reflector as shown in Figure 25. The vertical plane patterns shown in Figure 4 were obtained with an X-band model of this arrangement. The horizontal patterns of the beams had side-lobes below -29 db and were quite similar, with no marked tendency toward degeneration with feed off-set. The focal length to vertical aperture ratio of the dish was 0.89, which permitted optimum primary-beam-width to horn-aperture ratio.

Following a suggestion by L. C. Van Atta, some promising patterns are now being obtained with a split focus reflector constructed by splitting a paraboloid on the horizontal axis and separating the two sections by a flat "phasing strip" about 0.8 wavelength wide (Figure 26). With the same size horns, a shorter focal length may be used than with the slotted dish described above, and the improved illumination efficiency may result in 0.6 db increase in antenna gain. Reflector slots may still be a desirable addition. A bifocal reflector has also been tried but gave somewhat less desirable results.

Raytheon Manufacturing Company has been experimenting with asymmetrical reflectors with an f/D of 1.5, but so far the results do not appear as good as those obtained at NRL with symmetrical reflectors.

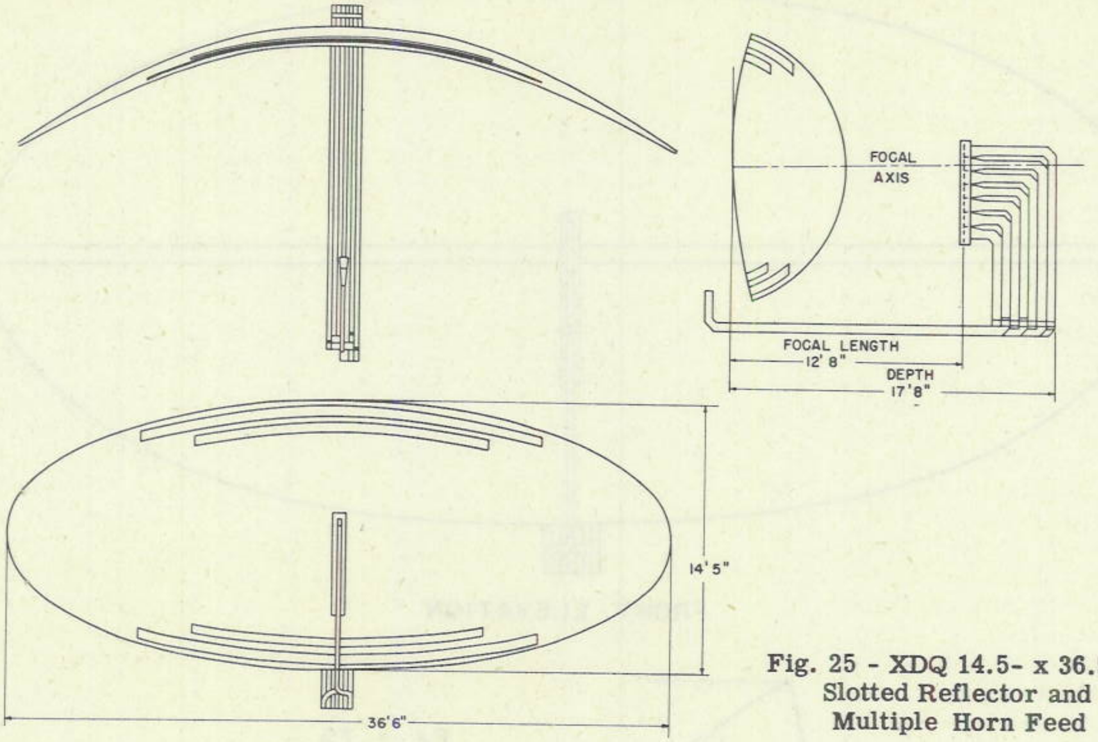


Fig. 25 - XDQ 14.5- x 36.5-Ft Slotted Reflector and Multiple Horn Feed

Ten-Megawatt Magnetrons

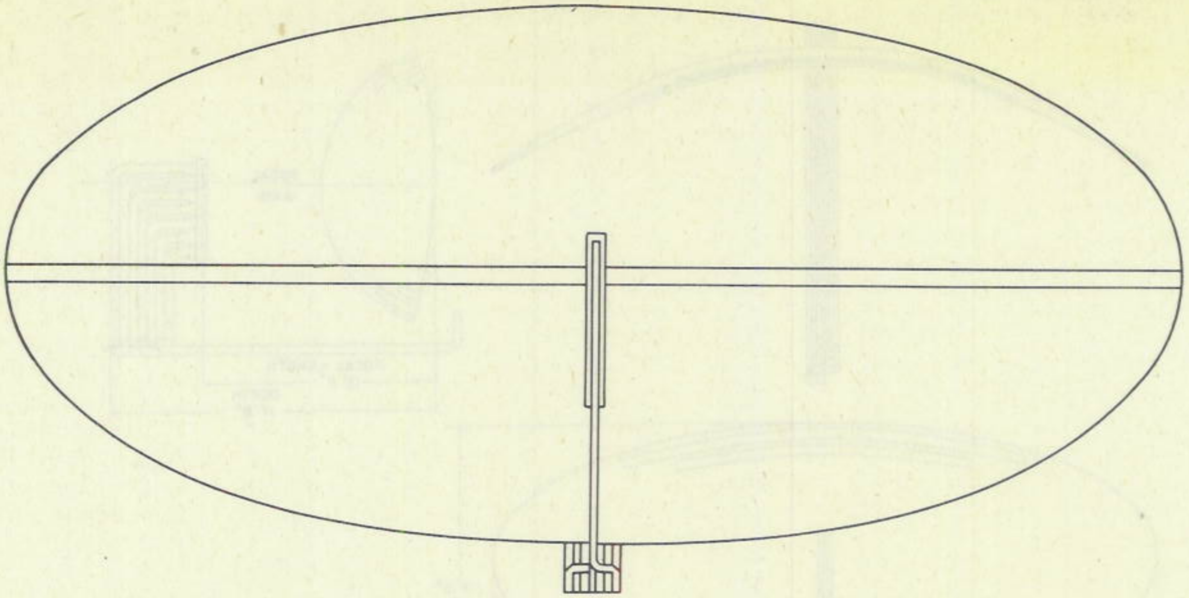
Westinghouse Electric and Manufacturing Company, Bloomfield, New Jersey, is approaching completion of development work on the 10-megawatt fixed-frequency magnetron. Cold tests are complete and hot tests are being started.

Modulators

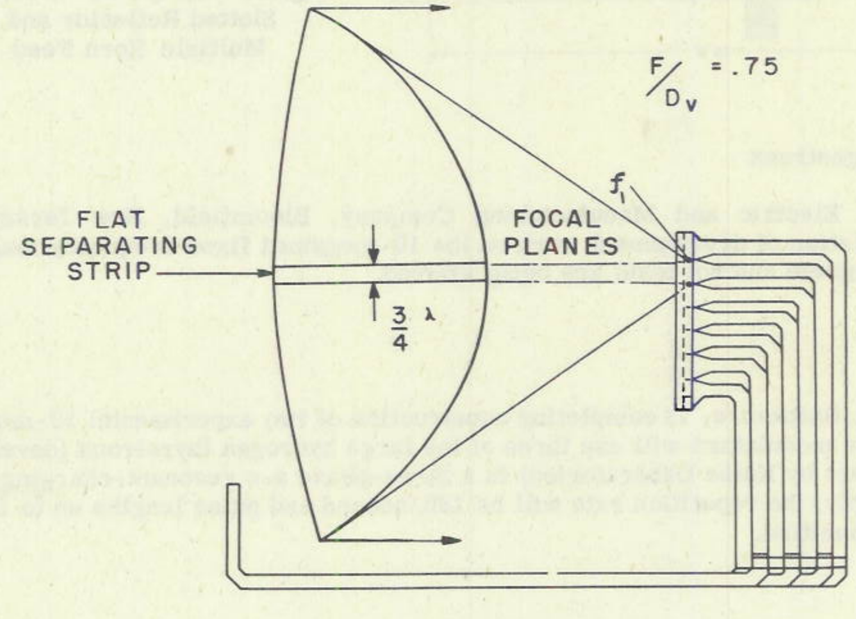
Westinghouse, Baltimore, is completing construction of two experimental 30-megawatt modulators. These modulators will use three of the large hydrogen thyratrons (developed under Army contract by Kuthe Laboratories) in a three-phase a-c resonant-charging circuit. With 60-cycle supply, the repetition rate will be 180/second and pulse lengths up to 10 microseconds will be permitted.

Rotary Joints

Because of the several independent high power channels, transmission of power to the antenna is a difficult problem. It was at first proposed to provide the mechanical break in a section of cylindrical wave-guide, which would serve as the transmission medium for all channels with TM_{01} propagation. Channel separation was to be accomplished at either end by cavity filters. However, it was found that with filters of sufficient Q for 10-Mc-band proximity, magnetron moding invariably resulted. Perhaps multiple iris filters giving flat



FRONT ELEVATION



SIDE ELEVATION

Fig. 26 - Split-Focus Antenna

pass characteristics could be used, but the proposition lacks appeal from the reliability standpoint. Hopes are still placed on a wave-guide joint suitable for multiple stacking that is being developed at this Laboratory. It will consist of a resonant H-plane ring of wave guide, split in the middle for rotation, and provided with window input and output couplers.

Proper performance of the coupling windows has been demonstrated, but a complete model of the joint has yet to be tested for the presence of a bad sector.

Failing success with such r-f joints, there appears no alternative other than to put the magnetrons and receiver front ends up with the antenna. Toward this unattractive end, slip rings for transmission of 100-kv, 20-Mw pulses have been designed and a model constructed.

TR Switching

It can be shown that in the usual impedance-inverting TR switch using a spark gag, the power dissipated in the gap varies approximately as the square root of the transmitter power. Small tungsten points in air were employed in the SC, SA, SK, and SRa radar systems and operated indefinitely without need of replacement, and it is to be expected that satisfactory operation can be obtained with the SPS-2 conditions. The transmitted energy will be up to 300 times that of the equipments cited, but the gap dissipation should not be over 17 times. With larger points and sputtering baffles, life in excess of 1000 hours does not seem unreasonable. A TR cavity with an air gap has been constructed and is being bench tested.

Since the ignition and operating voltages of a spark gap are very nearly independent of the power dissipated, the receiver protection problem is unchanged. If the input is to a vacuum tube, the "spike" energy should give no trouble. But if a crystal mixer is used spike protection must be provided, and for this it is planned either to use a glow-discharge secondary TR or to pre-fire the TR gap with a d-c pulse just ahead of the "main bang".

The Receiver

Construction has begun at NRL on a logarithmic i-f amplifier with a dynamic range of 60 or more decibels. Logarithmic fidelity within 2 db is expected. Raytheon Manufacturing Company is also being awarded a contract to study and develop components for height-finding with stacked radar beams.

Composite Presentation

No work has been done on combining the separate PPI elevation-sector pictures provided by the several beams, because it is believed techniques presently available or being developed elsewhere can readily be applied. For example, IFF marking or other tagging by video insertion with subsequent mixing and common presentation is attractive and requires no equipment development.

WEIGHT ESTIMATES

Size and weight estimates can be made with a fair degree of detail at any time in the research and development stage of new equipment, but it must be understood that such estimates cannot be binding since component weights are bound to change as planning advances. Early estimates may be quite remote from the final production figures. However, since knowledge of size and weight is essential to installation planning, it is recognized that premature estimates must be submitted and corrected whenever any major changes become established. An SPS-2 weight estimate was submitted in memorandum to the Bureau of Ships dated 12 June 1947. The following revised estimate is for a seven-beam system with ten megawatts in each beam.

I. Antenna Structure

1. Antenna Reflector: Symmetrical paraboloid 20 ft x 36 ft (a) scaling from SX dish 5 ft x 15 ft, wt 240 lbs, by 3/2 power gives $(20 \times 36/5 \times 15)^{3/2} \times 240 = 7130$ lbs (b) scaling from AN/CPS-5, 14 ft x 25 ft, wt 1000 lbs gives $(20 \times 36/14 \times 25)^{3/2} \times 1000 = 2960$ lbs. A slat type S-band reflector, such as the SX dish, may be expected to be heavier than the frame-supported mesh type of structure used at L-band. However, the CPS-5 antenna is undoubtedly too frail for naval service. Hence it seems reasonable to allow 5000 lbs for the SPS-2 dish.

2. Antenna Feed: Seven wave guides of mean length about 35 ft guide wt (steel) is 2.5 lbs/ft. Total wave guide weight = 7 x 35 x 2.5 = 615 lbs. To provide for supports, horn covers, fittings, etc., allow 750 lbs.

3. Antenna House for magnetrons and receiver pre-amplifiers:

a. Magnetrons 100 lbs each	700 lbs
b. Magnets 100 lbs each	700 lbs
c. Wave guide plumbing	200 lbs
d. Receivers & power supplies	200 lbs
e. House structure	2000 lbs
Total	3800 lbs

4. Pedestal:

a. High voltage rotary joint. This might be $2\frac{1}{2}$ ft in diameter x 4 ft long. Part brass, steel, plastic, and oil. Allow 60 lbs/cu ft: wt = 3 x 2.5 x 4 x 60 =	1800 lbs.
b. Turning motor 10 - 15 H.P.	600 lbs
c. Gears, housing, etc.	1000 lbs
Total	3400 lbs

5. Stable Base: Weight to be stabilized is total of foregoing = 5000 + 750 + 3800 + 3400 = 13000 lbs (approx.). For stable base allow same: 13000 lbs.

6. Pulse Transformers: 7 x 500 = 3500 lbs. Total wt at top of antenna tower = 13000 + 13000 + 3500 = 29500 lbs.[12]

II. Cables

Seven H.V. Cables, 4-inch diameter x 60 ft long, allow 2 lbs/ft. 7 x 60 x 2 =	840 lbs
Additional cable	160 lbs
Total	1000 lbs

III. Modulators (Ship's 2nd Deck)

Induction regulators	7000 lbs
Power transformers	14000 lbs
Pulse networks	14000 lbs
Charging chokes	7000 lbs
Auxiliary equipment	7000 lbs
Total	49000 lbs

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[12] If a multiple wave guide rotary joint can be developed, it will permit putting the magnetrons, etc., at the foot of the tower or below deck, thus eliminating the antenna house. The rotary joint weight should also be reduced by 1000 lbs. With the resultant saving in stable base weight, the total top of tower weight should then be about 17,000 lbs.

[redacted]

IV. C.I.C.

7 12-inch PPI	2100 lbs
7 B-scopes	700 lbs
7 Storage tubes	1400 lbs
6 RH scopes	600 lbs
1 Master indicator	1000 lbs
Additional gear	1000 lbs
Total	6800 lbs

SPS-2 Estimated total weight = 90,000 lbs (approx.)

REDUCTION OF COVERAGE

A recent memorandum from CNO to BuShips[13] concludes that, for use against long range ballistic flight type missiles, the radar coverage should include a major portion of the expected trajectories and that the proposed coverage (Figure 3) is not adequate. It is further stated that the increase in size and weight necessary to give the required coverage is impractical from the ship installation viewpoint. Accordingly, it is concluded in the memorandum that tracking of ballistic flight type missiles should not be attempted with the SPS-2 radar at this time and that its coverage specification should be changed to extend to only 15 miles up throughout the range to 300 miles on the horizon. Very little additional basic engineering should be required to obtain the high coverage if the need is presented.

This change in the performance specification was welcomed as being realistic. It has been felt that a much greater need is indicated for very long range warning and interception control radars to work against present or readily anticipated airborne targets than for a radar to give scant early warning of the largely visionary VLR V-2 type missile against which defense is even more visionary.

As a first step toward obtaining this reduced coverage, it was proposed to adapt the large coverage system simply by grading the power on the beams. A plot such as shown in Figure 27 might thus be obtained. The pulse powers required in the successive beams are related to that of the first beam by the fourth power of the range ratios, with correction for atmospheric absorption. Because of the large ratio in range from the first to the uppermost beam, the grading in power is extreme; and although the coverage plot shown is rather generous for the specifications, the total pulse power is only 16 megawatts with 10 megawatts going into the first beam.

This small ratio between total and first-beam powers leads to consideration of supplying all the beams from one transmitter. The advantages of such a single-frequency system over the multi-frequency system are:

(a) Transmitter simplicity;
(b) Single rotary joint for transmission;
(c) More efficient use of transmitted power, since the fields add in the overlapping regions;
(d) More efficient antenna operation, since the cross-over points may be reduced somewhat;

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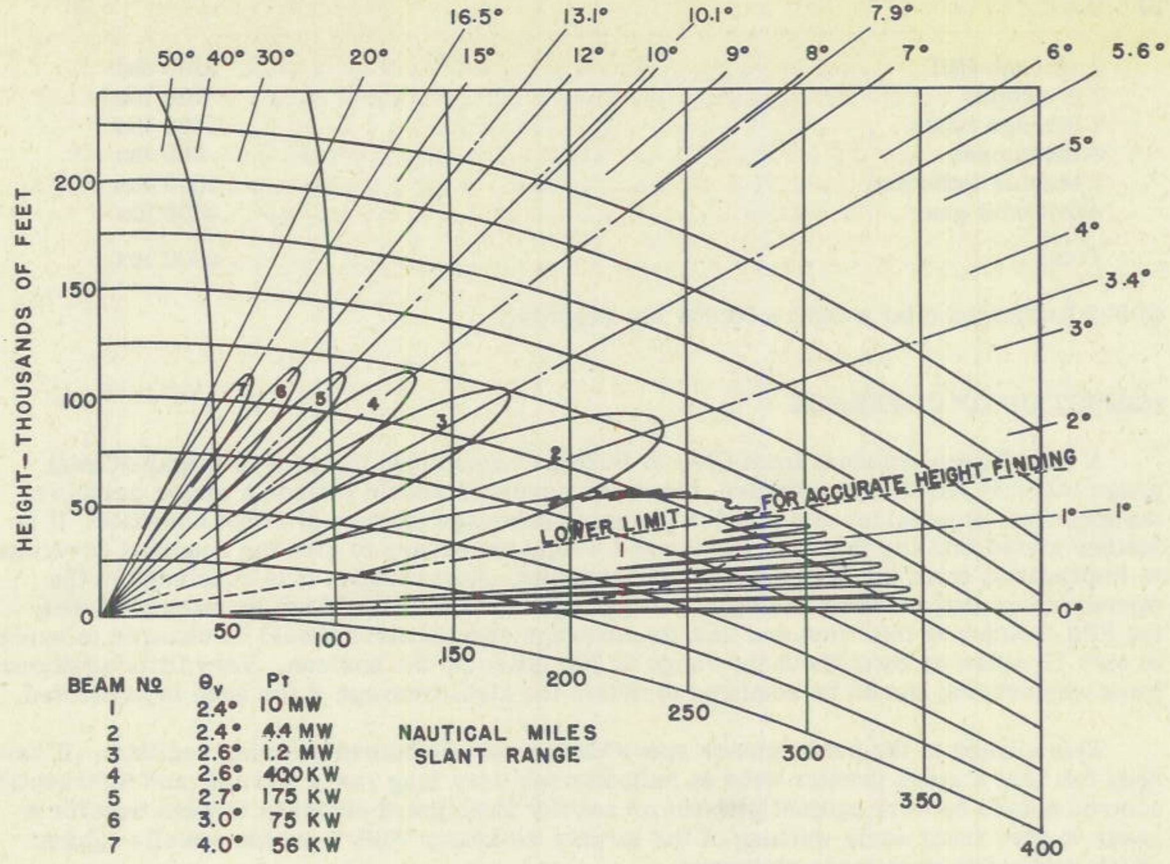
[13] Conf. Lt. OP-413-C6/fic (SC) F42-5 Ser. 060P413 Subj: SPS-2 Radar, "Altitude Coverage Military Characteristics, Revision of," Rc'd NRL 2 April 1948.

[redacted]



BEAM No	θ_V	P_T
1	2.4°	10 MW
2	2.4°	4.4 MW
3	2.6°	1.2 MW
4	2.6°	400 KW
5	2.7°	175 KW
6	3.0°	75 KW
7	4.0°	56 KW

Fig. 27 - Reduced Power Version of SPS-2

(e) Height-finding independent of target characteristics;
(f) Uniform height-finding to lower signal levels;
(g) Height-finding to a lower starting angle, since the anti-phase interference zone is eliminated.

The disadvantages are:

(a) More elaborate antenna feed system with critical phasing adjustments;
(b) TR system must be on the antenna in any case;
(c) Jamming of first beam will more likely jam additional beams;
(d) Side-lobe signals are much more of a problem.

It has been concluded that the advantages very definitely out-weigh the disadvantages and the work is now being directed toward a single transmitter system. Figure 28 shows the anticipated vertical coverage with a square meter target. However, several new and difficult problems arise, and it is being recommended that Raytheon Manufacturing Company start construction on a first experimental system using different frequency transmitters.

Production of the desired transmitting pattern with a single transmitter will be peculiarly difficult because of the extreme power difference required at the minimum and maximum elevations. Thus the power required at 20-degree elevations is down about 30 db from the

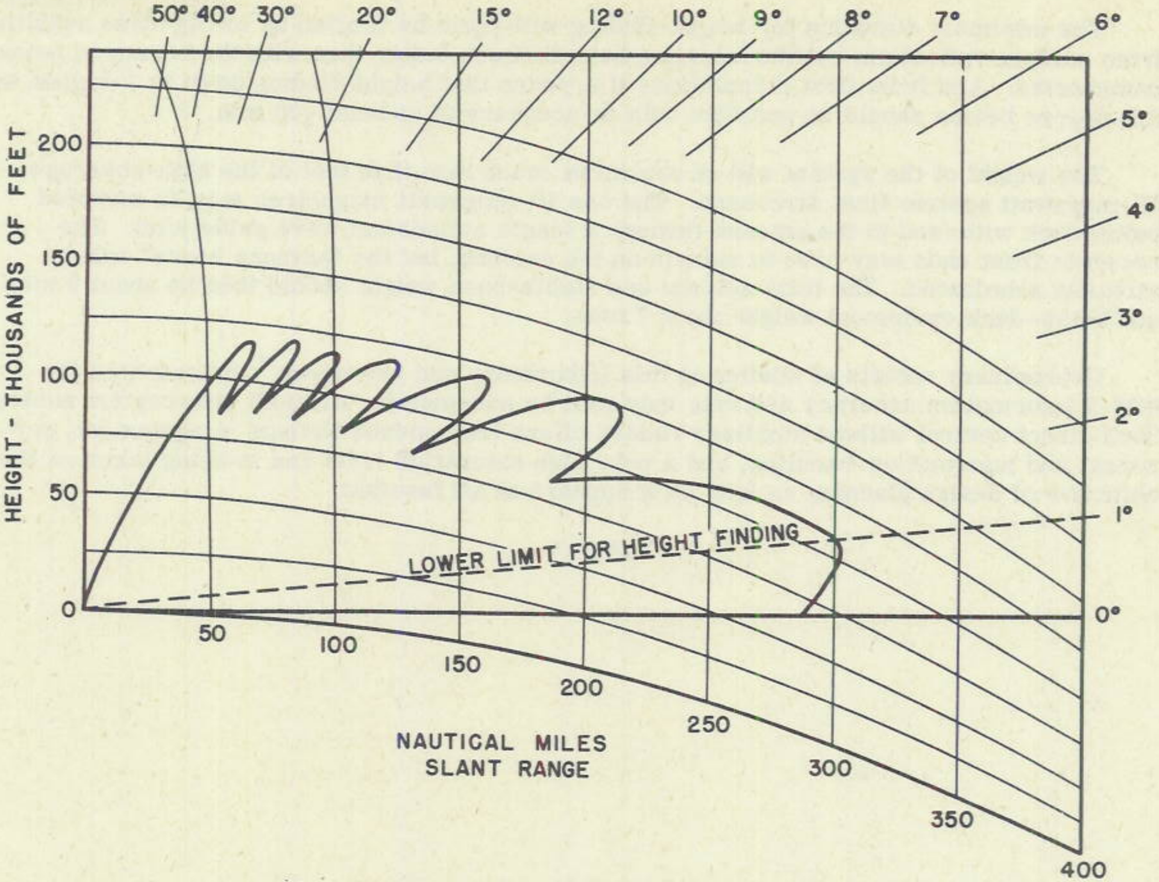


Fig. 28 - Anticipated Coverage, Reduced Power Version
One 10 Mw Transmitter, Seven-Beam Reception

power required at 1-degree elevation. But the side lobes from the first two beams may reach the -30 db level at 20 degrees. It is apparent that side lobe magnitude and phasing is important and that the power required by the upper beams feeds must be determined experimentally. But since the power will be relatively quite small, an excess might be used to advantage. Power dividing junctions and phasing sections must be constructed before transmitting pattern checks can be obtained.

Since the received signal variation with elevation will follow more nearly the beam patterns directly than their squares, the rate of change of signal ratios with target elevation will be approximately half that obtained with the beams on separate frequencies. This, of course, tends to reduce the accuracy of height-finding, but the loss should be more than offset by the elimination of errors from target echoing difference and transmitter power variations. Also, the effect of noise on height-finding with weak signals will be greatly reduced. With the beams on separate frequencies, pattern overlap was planned to give a center-to-center field strength ratio of 10 db. As was brought out in the discussion in this report, this would put the weaker signal down 20 db from the stronger, with consequent liklihood of suppression by noise. With single frequency operation, the same degree of suppression would occur at a 20-db center-to-center field strength ratio. Happily, then, from this standpoint beam overlap can be relaxed to give a much needed reduction in side-lobes.

The minimum elevation for height-finding will again be limited by ambiguities resulting from surface reflection, but the situation here is much better than with the beams on separate frequencies. And from first calculations it appears that height-finding down to 1 degree with 2.5-degree beams should be possible with an accuracy of at least ±30 min.

The weight of the system will of course be much less than that of the high-coverage, 70-megawatt system first discussed. The one 10-megawatt magnetron may be mounted below deck with feed to the antenna through a single cylindrical wave guide joint. The receiver front ends may have to remain on the antenna, but the "antenna house" will be virtually eliminated. The total antenna and stable-base weight should then be about 9 tons and below-deck equipment weight about 7 tons.

Preliminary results of studies at this Laboratory and elsewhere[14] indicate that the SPS-2 information accuracy and rate may well be adequate for aircraft interception control. Such direct control without auxiliary radars offers tremendous savings in equipment, personnel and information-handling, and a very high saturation level and is being taken as the objective of design planning as long as it appears at all feasible.

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[14] James F. Digby, "Some planning factors for GCI System Design," Watson Laboratories Secret Report WLEPL-10, dtd. 1 April 1948, also unpublished results of OEG studies.