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Report on

TDY Jamming Tests

Naval Research Laboratory

Anacostia Station

Washington, D. C.

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1. **ABSTRACT.**

1-1 The primary purpose of the tests conducted at the Chesapeake Bay Annex on 30, 31 May, 1 and 2 June was to determine the minimum jamming range of the TDY transmitter to jam out a destroyer echo against a 700 Mc fire control radar (Mark IV) mounted on another destroyer. From the information gathered during these tests a suitable antenna for use with the TDY which would jam out a destroyer echo in to 6000 yards was to be developed at Radio Research Laboratory.

1-2 Echo measurements were made of the U.S.S. Cooper (695) to determine the effective radar cross section at several radar frequencies.

1-3 Minimum jamming ranges were determined for most aspects of the destroyer with several jammer antennas and two antenna heights.

1-4 Minimum jamming range was also determined against the "Hot Dog", simulated Wurzburg, on 560 Mc at the Chesapeake Bay Annex and against the Mark V radar on 400 Mc at the Chesapeake Bay Annex.

1-5 Screening tests were run to determine the order of magnitude of bearing errors caused by off bearing jamming.

1-6 Interference aboard ship caused by the TDY transmitter was checked.

1-7 A suitable method of setting the TDY jammer on a radar frequency was determined.

2. **INTRODUCTION.**

2-1 This is a report on the jamming and echo measurement tests conducted at the Chesapeake Bay Annex on May 30 through 2 June 1944.

2-2 The tests involved two destroyers, the U.S.S. Cooper and the U.S.S. Trippe, and the following equipment installed on board the Cooper:

- (a) TDY jamming transmitter,
- (b) AN/APT-2 jamming transmitter (Carpet),
- (c) AN/APQ-2 jamming transmitter (Rug),
- (d) AN/APR-1 search receiver,
- (e) AN/RDK-1 panoramic adaptor,
- (f) AN/APA-6 pulse analyzer,
- (g) AS-71/SPT-2 corner reflector,
- (h) CAKZ-66-AHN Dipole,
- (i) NRL "Oil Can" cone,
- (j) Experimental RRL bent dipole,
- (k) AS-37/SPT-4 dipole.

The Mark IV and SG radars aboard the destroyers, the Mark V and "Hot Dog" (simulated Wurzburg) radars at the Chesapeake Bay Annex were used in addition to the listed equipment.

2-3 The tests had the following definite aims:

(1) to make echo measurements of the latest class destroyer to determine its radar cross section as a function of aspect and range.

(2) to determine the minimum jamming range of a TDY jammer to self-screen a destroyer for its various aspects and to determine accurately how much antenna gain would be required to screen a destroyer at all aspects with the TDY in to 6000 yards.

(3) to determine the amount of FD bearing error created by off bearing jamming.

(4) to determine a suitable means of setting the TDY jammer on frequency.

3. <u>CONCLUSIONS AND RECOMMENDATIONS.</u>

3-1 The TDY under service conditions will self-screen a large destroyer for all aspects at ranges beyond 6000 to 7000 yards against a 700 Mc fire control radar such as the Mark IV with antenna height of 55 feet if used with an antenna of 9 db gain and a height of about 40 feet.

3-2 Nuisance jamming with screening of some aspects will carry the jamming range in to about 4000 yards, except for the bow aspect which can be jammed in to 600 yards. Bearing errors to a lobe-switched radar will be caused by off bearing jamming even though the range indication is not jammed.

3-3 An increase in jammer power by at least 10 times would be required to screen a destroyer at the above mentioned ranges with a fixed non-directive antenna.

3-4 Location of a rotatable corner reflector on a stub mast on the after deck of a destroyer shows no significant loss through the ship's superstructure providing the antenna is sufficiently high to clear the stacks by a few feet.

3-5 Some interference to radio communications and meter wave radars was encountered aboard ship. The SC-3 radar showed a 10 db loss in sensitivity when its antenna was directed at the TDY antenna. The TBS high frequency communication channel showed a reduction in sensitivity between 10 and 20 db when the TDY was operating. The normal communication receivers, IFF and the SG radar were unaffected by the jamming. Since all interference from the jamming appeared to come through the antenna circuits, proper antenna siting and wave traps might alleviate the situation.

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3-6 The main difficulty with the TDY was due to the fact that it had numerous gaps in its tuning range. This made it impossible to tune the equipment to some frequencies. On frequencies where the TDY did operate normally the setting on procedure was simple and effective by means of the APR-1 carrier meter and RDK panoramic adaptor.

3-7 It was determined that a "line stretcher" inserted in the TDY transmission line made possible, under most conditions, tuning the TDY to critical frequencies.

3-8 It is recommended that a line stretcher capable of changing the transmission line length by at least 50 centimeters be included with all TDY equipments.

3-9 An AS-71/SPT-2 corner reflector antenna or equivalent with a gain of 9 db is on the borderline for use with the TDY to give complete self-screening of a destroyer in to 6000 yards against a 700 Mc radar equivalent to a Mark IV. For assurance of complete screening in to 6000 yards an antenna gain of about 12 to 15 db is desirable. A directional antenna of any type requires an operator to continuously train it toward the victim ship, but this appears to be a necessary condition for effective jamming with the jammer powers available at present.

3-10 By proper siting of jammer antenna and receiver antenna, making use of antenna patterns and ship structure for attenuating the pick-up between the two antennas it is possible to continuously monitor at moderate ranges the radar signal through the jamming signal and to see immediately on the RDK panoramic adaptor if the jammer deviates from the radar frequency or vice versa.

3-11 A table follows which gives the various minimum jamming ranges achieved with the TDY jammer:

(See next page)

Antenna	Radar	Freq.	Broadside Minimum Jamming Range (Yds.)		Bow-on Minimum Jamming Range (Yds.)	
			Measured	Calculated	Measured	Calculated
Corner Reflector AS-71/SPT-2	Trippe Mk. IV	700 Mc	7400 to 5400	7800	600	
Dipole CAKZ-66-AHN	Trippe Mk. IV	700 Mc	>10,000	16,000	5,000	5,300
NRL Oilcan	Trippe Mk. IV	700 Mc	>10,000	13,000	3,700	4,300
Experimental RRL Bent Dipole	Trippe Mk. IV	700 Mc	5,500	8,000	>8,000	
Corner Reflector at Main Deck	Trippe Mk. IV	700 Mc	10,000	10,500	3,500	3,200
Corner Reflector	CBA Hot Dog	560 Mc	----		2,100	
Rug Dipole AS-37/SPT-4	CBA Mk. V	400 Mc	----		1,500	

4. ECHO MEASUREMENTS.

4-1 Reference to Naval Research Laboratory reports on Echo Measurements concerning methods of measurement, significance of results and methods of calculation is requested. (NRL reports R-2232 and R-2332).

4-2 Plates #40 through #58 of this report show the echo measurement plots of the DD-695 made during the subject tests.

4-3 Of major interest to this report are Plates #40 and #41 which show the echo strength of the DD-695 on the Mark IV radar aboard the DD-405 as a function of range and aspect and Plate #42 which shows effective area as a function of frequency. By means of these curves in comparison with the runs showing the minimum visible signal through jamming as a function of range (Plates 20 through 37) it is possible to approximate the minimum jamming range for each set of conditions by determining the points where the echo amplitude is equal to the minimum visible pulse through the jamming. It should be noted that the signal strength in Plates 20-37 is plotted in minus db so that the lower the numerical value the higher the signal strength.

4-4 By means of the echo measurement plots as a function of frequency of the DD-695 shown in Plate #42 which give the effective area of the destroyer it is relatively easy to calculate the jammer power times antenna gain required to jam out the destroyer echo at any range on a radar whose peak power times antenna gain is known. Two values of radar cross section of the DD-695*were determined. $\sigma_f = 1.2 \times 10^{14}$ was the

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value obtained from the DD-405 at 700 Mc. $\sigma_f = 4.1 \times 10^{14}$ was the value obtained from the Chesapeake Bay Annex at 700 Mc. Due to experimental difficulties in obtaining standard target data from the DD-405 it is felt that the value of σ_f determined from the Chesapeake Bay Annex is the most accurate of the two. The difference in minimum jamming range as calculated for each of the two values of σ_f is about 36%. Using the larger value of σ_f the calculated minimum jamming range is slightly greater than the greatest experimental reading. Using the smaller value of σ_f gives a calculated value of minimum jamming range which falls in the same region as the average experimental value. If the larger value of σ_f is used complete safety is assured that under no conditions will the minimum jamming range be greater than the calculated value. σ_f is the value of the radar cross section for distances beyond about 2500 yards.

4-5 Assuming an eighth power law for the echo power and a fourth power law for the jamming power which holds approximately at ranges beyond the first maximum of the lobes, a simple equation can be derived for determining minimum jamming range:

(1) Received echo power $= \dfrac{P_r \, G_r^2 \, \sigma_f \, h_r^4 \, . \, \lambda^2}{(4\pi)^3 \, r^8}$

(2) Effective masking power $= \dfrac{P_j \, G_j \, G_r \, h_r^2 \, h_j^2}{r^4} \; k$

where P_r = radar peak power, G_r = power gain of radar antenna, σ_f = effective area of target, P_j = jammer average power, G_j = power gain of jammer antenna, r = range between radar and target, h_r = radar antenna height, h_j = jammer antenna height, λ = wavelength, k = $\dfrac{\text{jamming power}}{\text{echo power}}$ for obscuring echo (dependent on type of modulation on jammer and AJ properties of receiver.

(3) For minimum jamming range if it is assumed that jammer power must equal echo power at the radar receiver (which is approximately true when noise modulation is used) (1) and (2) can be equated, making k = 1:

$$\frac{P_r \, G_r \, \sigma_f \, h_r^4 \, \lambda^2}{(4\pi)^3 \, r^8} = P_j \, G_j \, h_j^2 \, h_r^2$$

$$r^4 = \frac{P_r \, G_r \, \sigma_f \, h_r^2 \, \lambda^2}{(4\pi)^3 \, P_j \, G_j \, h_j^2}$$

4-6 Calculating the minimum jamming range for the broadside aspect of the DD-495 for event 8 where $P_r = 50 \times 10^3$ watts, $G_r = 150$, $\sigma = 4 \times 10^{14}$ square meters (from Plate 42), $P_j = 20$ watts (effective), $G_j = 8$, $h_r = 50$, $h_j = 40$.

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$$r^4 = \frac{50 \times 10 \quad \times 150 \times 4 \times 10^{14} \times 2500 \times .206}{2000 \times 20 \times 8 \times 1600} = 2.9 \times 10^{15},$$

$r = 7.3 \times 10^3$ meters

$r = 7.3 \times 10^3$ meters $= 7900$ yards for $\sigma_f = 4 \times 10^{14}$ (as measured from CBA).

$r = 5600$ yards for $\sigma_f = 10^{14}$ (as measured from Trippe).

Experimentally as shown on Plates 1, 2, 3 and 4 the minimum jamming range of the broadside aspect for event 8 was between 5400 and 7400 yards

The calculation of minimum jamming range, therefore, is in excellent agreement with the experimental results.

4-7 Inside the first maximum of the lobe the echo power appears to increase no more rapidly than the jammer power so that if complete jamming is possible in to the first maximum where

$$r = \frac{2\, h_1 h_2}{1/2\ \lambda}$$

it appears likely that the minimum jamming range will be considerably less than would be calculated from the equation of 4-4 and might conceivably be zero range if the jammer antenna height were reduced as range decreased to maintain it at optimum height. Since the first maximum is at 3100 yards at 700 Mc, for antenna height of about 50 feet it is inside of the useful range and so will not be analyzed at this time. What can be mentioned however is that in event 8 the theoretical minimum jamming range from the equation of 4-5 for the bow aspect is about 2200 yards while actually in the tests the bow aspect was jammed in to minimum radar range of 600 yards.

5. <u>MINIMUM JAMMING RANGE.</u>

5-1. The jamming equipment and two APR-1 receivers complete with RDK panoramic adaptors and APA-6 pulse analyzers were temporarily installed on the forward port quarter deck of the Cooper. One APR-1 was installed on the after deckhouse with its antenna well shielded from the jammer antennas by the ship's superstructure. The jammer antennas were mounted in turn, as needed, on a five-foot pedestal situated on the second five inch gun turret just forward of the bridge except as noted for events 12 and 14. During the jamming runs an operator kept the antenna trained on the victim ship except during events 11 and 12. The forward receiving antenna (M-801 cone) was mounted at the bridge level just below the forward navigation light. The after receiving antenna was mounted on the after deckhouse well shielded by the ship's superstructure from the jammer antenna location forward.

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5-2 The U.S.S. Cooper was designated as the jamming or "J" ship and the U.S.S. Trippe the victim or "V" ship. During the jamming runs the "J" ship made slow tight circles with its jamming antenna continuously trained on the "V" ship which was running in and out on a fixed course to determine the minimum jamming range versus "J" aspect. Data was taken at half minute intervals with synchronized watches to permit coordination of information on the final plots of data. The SG radars on the "V" ship and on the "J" ship kept a continuous record of relative ship ranges and bearings and the "J" ship kept a continuous record of its heading while the FD operators on the "V" ship kept a continuous record of jamming strength (measured in reference to minimum visible pip from a standard pulsed signal generator) and whether or not the "J" echo was visible. Since readings were taken at half minute intervals and the "J" ship circled at a rate of about 360 degrees in five minutes an uncertainty factor of about 36° for each point is evident.

5-3 The results of the minimum jamming range tests are plotted in graphical form showing the "J" as stationary with the "V" ship circling in a spiral fashion with continuously decreasing range. This method simplifies plotting and presents the information in an easily interpreted manner. A small circle indicates that a reading was taken but the "J" echo was not visible during a half minute interval. Arrows indicate points where the echo was visible during a half minute interval and a double line is drawn between points where the echo could be seen for three or more consecutive half minute periods. Radial dotted lines show the included area where jamming was ineffective due to shielding of the jammer antenna by the ship's superstructure and therefore should be disregarded.

5-4 Event 8 consisted of a series of four runs using the TDY with the "Carpet" corner reflector antenna (AS-71/SPT-2), which has a gain of about 8.8 db over a dipole at 700 Mc, trained against the Mark IV fire control radar on the "V" ship. The TDY was radiating about 50 watts at this frequency.

Plate 1 is the plot of event 8, run 1. It is evident that broadside echoes could be seen through the jamming out to about 5500 yards but the bow on aspect was jammed in to about 600 yards.

Plate 2 is the plot of event 8, run 2. The first broadside echo was seen at 7400 yards but the bow aspect was jammed in to minimum range of 1200 yards. It appears that a time error entered the picture on the minimum range circle on this plot at 1200 yards since the jammed portion has rotated from bow to starboard aspect.

Plate 3 is the plot of event 8, run 3. The first broadside echo appears at 5800 yards and, except for one reading at 4600 yards the bow on aspect is jammed in to minimum range of 1600 yards.

Plate 4 is the plot of event 8, run 4. The first broadside echo appears at a range of 5200 yards and the bow aspect is jammed in to minimum range of 1500 yards.

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5-5 An analysis of event 8 shows excellent agreement between the four runs. Except for one exception (which may be due to a slight timing error) the bow aspect of the destroyer was jammed in to the minimum range of each run, between 700 and 1500 yards. The broadside aspect, which gives the strongest echo, could only be jammed in to between 5200 and 7400 yards. Since on the four runs only one reading was obtained beyond 5800 yards it appears safe to say that the TDY with the AS-71/SPT-2 corner reflector antenna at a 40 foot antenna height can completely jam a new class destroyer echo for all aspects at 6000 yards against a Mark IV fire control radar on 700 Mc.

5-6 Event 9 was similar to event 8 except that the type CAKZ-6L-AHN broad band dipole was used with the TDY.

Plate 5 is the plot of event 9, run 1. The first broadside echo was obtained at 9700 yards but no bow aspect echoes were visible in to 6300 yards, minimum range of this run.

Plate 6 is the plot of event 9, run 2. The first broadside echo appears at 9700 yards. No bow aspect echoes appear in to the minimum range of 6000 yards.

Plate 7 is the plot of event 9, run 3. The first broadside echo appears at 11000 yards. No bow aspect echoes appear in to minimum range of 5000 yards.

Plate 8 is the plot of event 9, run 4. The first broadside echo appears at 6600 yards and the first bow aspect echo appears at 4500 yards.

5-7 An analysis of event 9 shows that jamming was spotty with the dipole antenna but that some aspects of the destroyer were jammed in to 5000 yards. Complete jamming appears impossible inside of 10000 yards but nuisance jamming of some value takes place in to 5000 yards.

5-8 Event 10 is the same as events 8 and 9 except that the Naval Research Laboratory "Oilcan" (broad band cone) antenna was used with the TDY.

Plate 9 is the plot of event 10, run 1. The first significant echo (which probably corresponds to a broadside aspect) appears at a range of 9200 yards. No bow aspect echoes appear in to minimum range of 3400 yards.

Plate 10 is the plot of event 10, run 2. The first echo appears at 10000 yards and probably corresponds to a broadside aspect. No bow-on echoes are visible in to minimum range of 4900 yards.

5-9. An analysis of event 10 shows that the cone antenna is roughly equivalent to the dipole. Complete jamming is impossible inside of 10000 yards although nuisance jamming of some value occurs in to at least 3400 yards where the bow aspect is still jammed.

5-10 Event 11 is similar to preceding events except that a fixed antenna (bent dipole with reflector) which was furnished by Dr. Alford of Radio Research Laboratory was used with the TDY. This antenna was mounted at the director level directed straight out on the port beam about 55 feet above the water level. It was hoped that an antenna of this type would screen a 180° sector of the destroyer.

Plate 11 is the plot of event 11, run 1. A broadside aspect included angle of 140° at 8000 to 9000 yards is screened by the jamming. A broadside aspect included angle of 60° to 70° at 6000 to 7000 yards is screened and inside of 5000 yards apparently only nuisance jamming takes place with alternate observations showing the pip visible.

Plate 12 is the plot of event 11, run 2. A broadside aspect included angle of about 60° at 7500 yards and of 50° at 5000 to 5500 yards is jammed.

5-11 An analysis of event 11 indicates that insufficient coverage for bow and stern aspects is available. Four fixed antennas of this type might conceivably give complete jamming coverage in to 6000 yards if a selector switch was used to switch in the appropriate antenna for covering the desired aspect. Two antennas of this type, one on each side of a destroyer would not give complete jamming inside of 10000 yards.

5-12 Event 13 is similar to preceding events except that a "Carpet" AN/APT-2 jammer was used with the corner reflector antenna to obtain a relative idea of the effectiveness of the TDY as compared to a piece of equipment widely used by the services.

Plate 13 is a plot of event 13, run 1. There was no self-screening inside of 8000 yards. The bow aspect was jammed in to 8400 yards and the broadside aspect in to 9200 yards.

Plate 14 is a plot of event 13, run 2. Very few observations are noted where the signal is jammed but a few points are jammed in to 7500 yards. This plot is not conclusive but one would assume that a time error of about 1½ minutes is present in the data for this run and that the jammed points at 7500 yards should fall off the bow rather than broadside.

5-13 An analysis of event 13 indicates that the AN-APT-2 jammer is entirely inadequate to self-screen a destroyer inside of 10000 yards and sufficient information is not available from this test to give a minimum jamming range.

5-14 Event 14 is a test of the TDY with the corner reflector at the main deck level forward of number one 5-inch gun turret at about 25 feet antenna height. This test was run to determine the effect of reduced antenna height.

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Plate 15 is the plot of event 14, run 1. The broadside aspect is not jammed inside of 8800 yards and the bow aspect is not jammed inside of 5400 yards.

Plate 16 is the plot of event 15, run 2. The broadside aspect is not jammed inside of 7800 yards except for one point at 4200 yards which may be a "wild" reading. The bow aspect is jammed in to 3400 yards.

5-15 An analysis of event 14 (which should be compared to event 8) shows that a very serious increase in minimum jamming range takes place when the antenna height is reduced by two to one.

5-16 Event 12 consisted of a series of three runs in which the Carpet jammer and corner reflector mounted on a stub mast on the after deckhouse were used to determine the affect of the ship's superstructure on the antenna pattern.

Plate 17 shows the affect on the antenna pattern with the antenna directed straight toward the bow through the ship's superstructure. Since the antenna height was slightly above the top of the stacks, the only major obstruction was the mast.

Plates 18 and 19 show the pattern with the antenna pointed 30° off the bow right and left respectively.

5-17. Analysis of event 12 shows that no signal strength is lost due to the ship's superstructure except that the pattern is cut up to some extent into several fairly sharp lobes with a maximum ratio of 14 db between peaks and valleys. Since the bow aspect of a destroyer is the easiest one to jam no serious loss in jammer performance should be caused by locating the jammer antenna on a stub mast on the after deckhouse if the mast is sufficiently high to clear the stacks by several feet.

6. JAMMING RUNS AGAINST CBA RADARS.

6-1 In these tests, the Cooper started at a range greater than 10000 yards from the Chesapeake Bay Annex and advanced slowly toward the station until the radar operators could detect the Cooper echo through the jamming.

6-2 The TDY jammer, used with the corner reflector antenna AS-71/SPT-2 allowed the bow aspect ship echo to be seen at 2100 yards on the "Hot Dog" (simulated Wurzburg) radar, as shown in Plate 36.

6-3 The TDY jammer, used with the Rug dipole antenna (AS-37/SPT-4), prevented the ship echo from being seen in to 1500 yards on the Mark V radar, as shown in Plate 37.

6-4 Two tests were made to determine the effect on FD radar bearing accuracy by a jammer carried in a ship at a distance from the target ship.

For these tests, the Trippe was stationed at a fixed distance from Chesapeake Bay Annex (about 9000 yards), and the Cooper, carrying the jammer, moved approximately in the paths shown in Plates 38 and 39 at 10000 yards range off shore.

6-5 The graphs show the bearing error (the difference between radar bearing and optical bearing) as a function of the difference between jammer and target bearings. The bearing error for the FD radar without jamming is plus or minus 15 minutes, or about 4.5 mils. This value is shown on the graphs.

6-6 Plate 38 shows that most of the bearings obtained with jamming exceed the allowable tolerance for the Mark IV fire control system. Plate 39 shows that nearly all of the jammed bearings in this run have errors in excess of the unjammed average. The absence of values in the region near zero relative bearing indicates that the radar was jammed sufficiently to prevent the operator from training on the target by pip-matching.

6-7 It was hoped that some definite relation could be found between relative jammer bearing and bearing error. The graphs reveal no such relation. We conclude only that outside of the sector in which the radar is completely jammed (about plus or minus 10 degrees), the bearing error is increased considerably above the normal average.

7. RADIO AND RADAR INTERFERENCE.

7-1 An attempt was made to check for interference aboard the Cooper caused by operation of the TDY. During the time available it was not possible to make a check with the TDY operating at all frequencies in its band but a few point checks were obtained.

7-2 No interference was noted on the standard communication receivers anywhere in their range.

7-3 The noise level in the high frequency communication receiver (TBS-1) was increased ten to twenty db when the TDY was operating.

7-4 The noise level on the SC-3 was increased about 10 db when the radar antenna pointed at the TDY antenna with the TDY tuned to 400 Mc. This might possibly have been due to the second harmonic of the receiver local oscillator beating with the 400 Mc TDY signal and furnishing a 15 Mc i-f beat.

7-5 No noise increase could be noticed on the SG with the TDY operating and no interference could be picked up on the IFF channels.

7-6 The SG radar was causing a very minor amount of interference to communication channels due to transmission of its repetition rate tone on power mains.

7-7 All interference picked up from the TDY was due to antenna pick-up so the obvious method of correction would be to site the antennas for minimum pick-up and to use tuneable wave traps or filters in the antenna lines to eliminate the TDY frequency.

8. EQUIPMENT DIFFICULTIES.

8-1 A major difficulty with the TDY was that many holes in the band were encountered in which the equipment would not tune. This was at least partly due to slight reactance terms in the transmission line termination and the use of a "line stretcher" to reduce the reactance term often made it possible to tune to a difficult frequency. The location of the holes was a function of a particular magnetron but the number of holes was not altered by changing tubes. A standing wave ratio even as low as 1.5 to 1 was still sufficient to cause holes in the tuning range. In the present TDY equipment, however, a "line stretcher" or tuning stubs should be added to make possible tuning the equipment to any frequency within its range. "Line stretchers" should also be furnished for any TDY's or CXFR's which are now in service. The possibility of reducing coupling below the minimum now available would be a further help in cutting down reaction of the antenna on the oscillator.

8-2 It is recommended that the filament voltage control on the magnetron be made available on the front panel since many magnetrons require higher than .9 amperes (1.0 to 1.1 amp) to commence oscillation. After oscillations have started the filament current can be reduced to its recommended value or lower because of filament heating due to electron bombardment.

8-3 The average magnetron life in the laboratory was increased from five hours to 20 hours by running the filament current 10 to 20% high for starting.

8-4 The RDK panoramic adaptor had insufficient bandwidth and insufficient flatness of response for maximum usefulness. It is felt that a panoramic adaptor with 10 Mc total swept band which was flat (in conjunction with an APR-1 receiver) within 3 db over its band would be an extremely valuable tool for setting jammers on frequency and for monitoring the noise spectrum of the jammer.

8-5 Extreme difficulty was encountered in tuning the AN/APT-2 (Carpet) and AN/APQ-2 (Rug) jammers on frequency due to the complexity of tuning (four controls) and due to the serious interaction between controls. Although it was easy to tune the carrier on frequency it took a peculiar and unpredictable combination of the four controls to obtain an effective degree of modulation and on two occasions after an hour's struggle by two carpet "experts" tests were cancelled because satisfactory operation could not be obtained.

8-6 A minor amount of inconvenience was caused by using three APR-1 receivers whose calibrations did not agree closer than ± 10 Mc at 700 Mc.

[redacted]

It would therefore be desirable, in any jamming operation, to align all receivers which must be coordinated so that their calibrations agree within ± 1 Mc over the operating range.

9. SETTING ON PROCEDURE.

9-1 It was determined by experiment that the best setting on procedure for the TDY was as follows:

(a) Tune in radar signal to be jammed on APR-1 and note frequency.
(b) Set coupling and tuning controls of TDY from calibration charts to correct frequency with plate power off.
(c) Turn up plate power on TDY and tune frequency control for maximum response on APR-1 carrier meter.
(d) Check monitor scope on TDY to see if noise character is approximately normal; if self-pulsing is indicated reduce coupling until noise is normal and recheck tuning.
(e) Tune APR-1 back and forth over signal to be sure that only one carrier hump is present. If two humps are present, one each side of the desired frequency, a "line stretcher" is needed and should be adjusted to give a single carrier hump on the correct frequency.
(f) Check on RDK panoramic adaptor. If the TDY has been tuned properly a carrier hump with fairly uniform sidebands out to ± 3 Mc will be apparent. Since the RDK with the APR-1 may not have a flat amplitude response versus frequency it may be necessary to actually tune the receiver through the noise band to determine the uniformity of the side bands.

10. ANTENNA CONSIDERATIONS.

10-1 The characteristics of the Carpet Corner Reflector Antenna (AS-71/SPT-2) were measured at the Naval Research Laboratory and found to be as follows:

Frequency	Horizontal Beam Width	Vertical Beam Width	Power Gain	Gain over Dipole
700 Mc	65.5°	51.5°	8.9	8.8 db
560 Mc	75°	67°	5.96	7.2 db

10-2 Tests aboard the U.S.S. Cooper indicate that a directional antenna is required with the TDY and one with more gain than the Carpet Corner Reflector is desirable. An antenna beamwidth of 30° in both vertical and horizontal at the high frequency end of the TDY range appears to be feasible and would give a gain of about 15 db over a dipole insuring complete jamming of a destroyer echo in to about 5000 yards.

10-3 It was determined that a dipole antenna or other type of fixed non-directional antenna did not have the necessary power gain in conjunction with the TDY to do an effective jamming job.

Appendix 1.

20 June 1944

Interference Due to Pulse Transmission

by John M. Miller, NRL

Summary

Utilizing previously derived Fourier series analyses for rectangular, triangular and cosine-squared pulses, expressions are derived for the amplitude of the side bands at frequencies remote from the carrier with special reference to interference with our own communication equipment by Radars or Jammers. It is pointed out that there is considerable possibility of interference at frequencies widely remote from the carrier when the pulse approaches a rectangular shape.

In considerations of interference, say with communication equipment, due to Radars or Jammers, it is of interest to investigate the amplitude of the side bands of pulse transmission relative to the carrier at frequencies remote from the carrier. This is rather simply derived from Fourier series analyses of pulse transmission of various shaped pulses such as those given by B. Salzberg in a mimeographed laboratory memorandum dated June 23, 1931, and entitled "Pulse Transmission Spectra" He deals with three pulse shapes, rectangular, triangular and cosine-squared and his analyses are given in equations (4a), (4b) and (4c) on page 2. The pulse length τ is defined as the time width at the half-voltage point of the pulse. This makes the carrier component have the same value ED for the three pulse shapes, where E is the peak pulse voltage and D is the duty cycle (product of pulse length τ and repetition rate r). The amplitude of the side bands is seen, from these equations, to be

Rectangular	$ED\left(\frac{\sin \pi nD}{\pi nD}\right)$
Triangular	$ED\left(\frac{\sin \pi nD}{\pi nD}\right)^2$
Cosine-Squared	$ED \cdot \frac{1}{1-4n^2D^2}\left(\frac{\sin 2\pi nD}{2\pi nD}\right)$

where n is the order of the side band. The amplitude of the sidebands is zero when sin πnD is zero and is a maximum approximately when sin πnD is unity. We will define A as the ratio of carrier amplitude to side band amplitude under the latter condition. Thus, if A is one thousand, the side band amplitude will be one thousandth or 0.1 per cent of the carrier amplitude. We have, therefore, the following expressions for A:

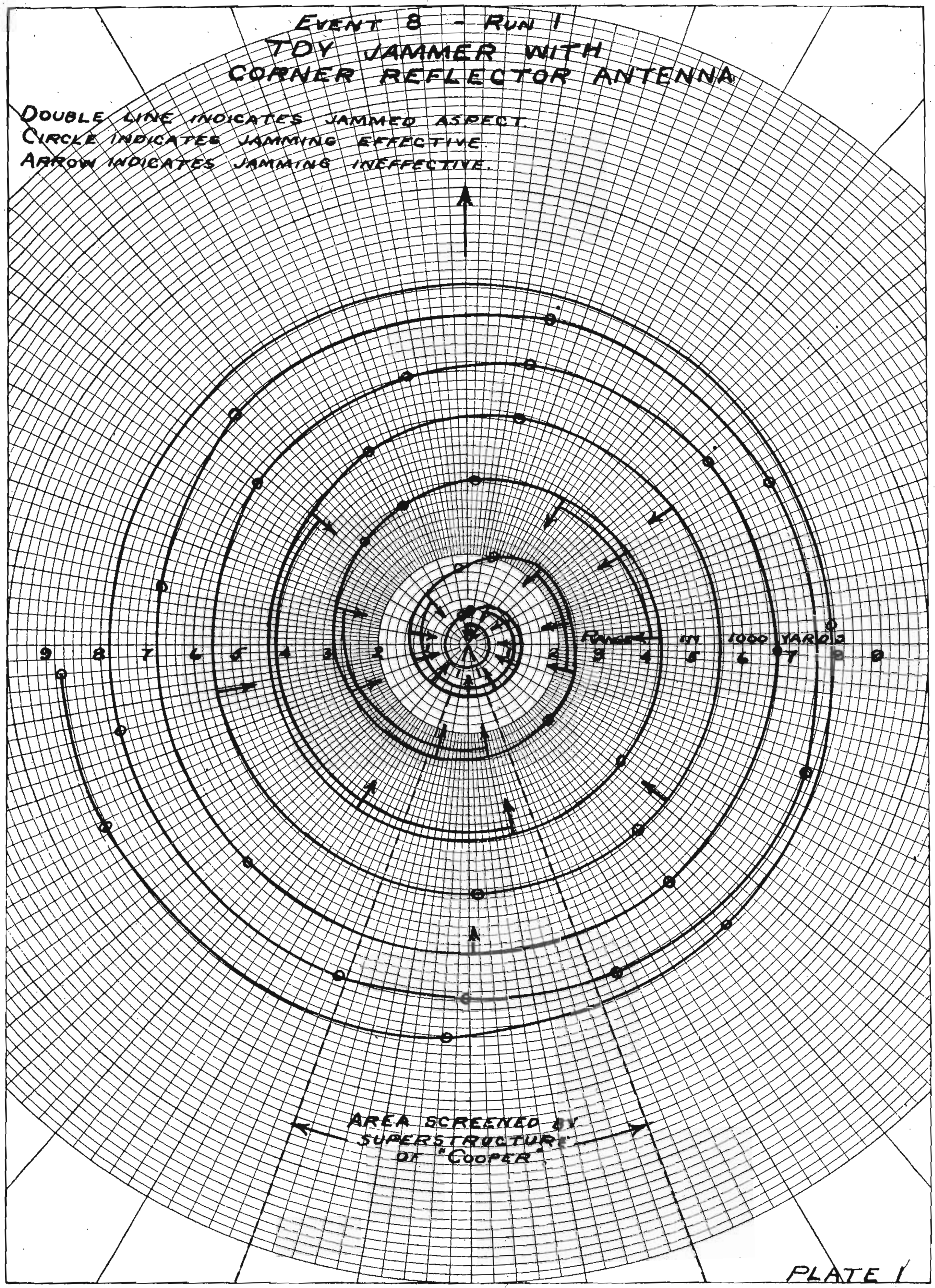

EVENT 8 - RUN 1
TDY JAMMER WITH
CORNER REFLECTOR ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER"

PLATE I

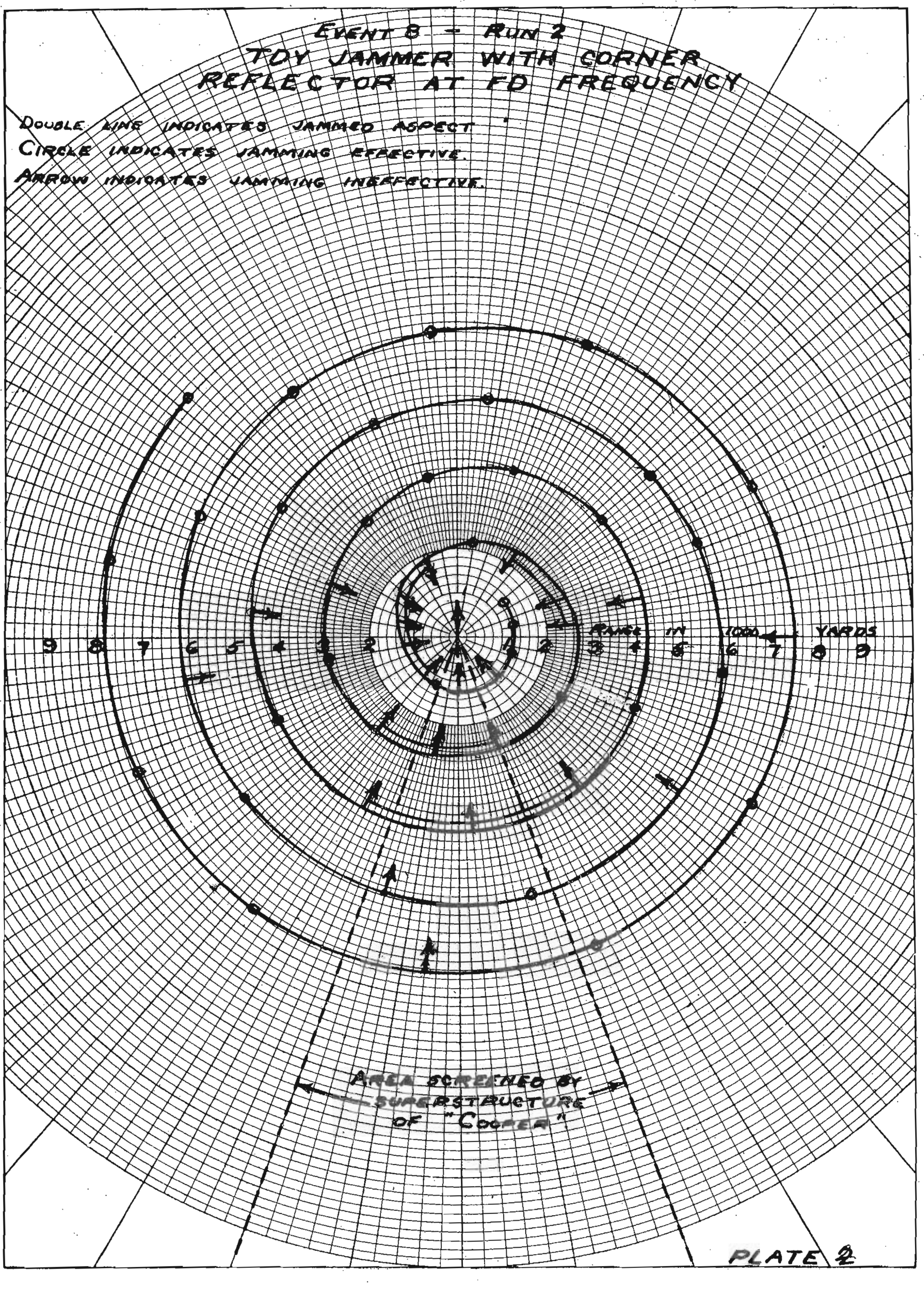
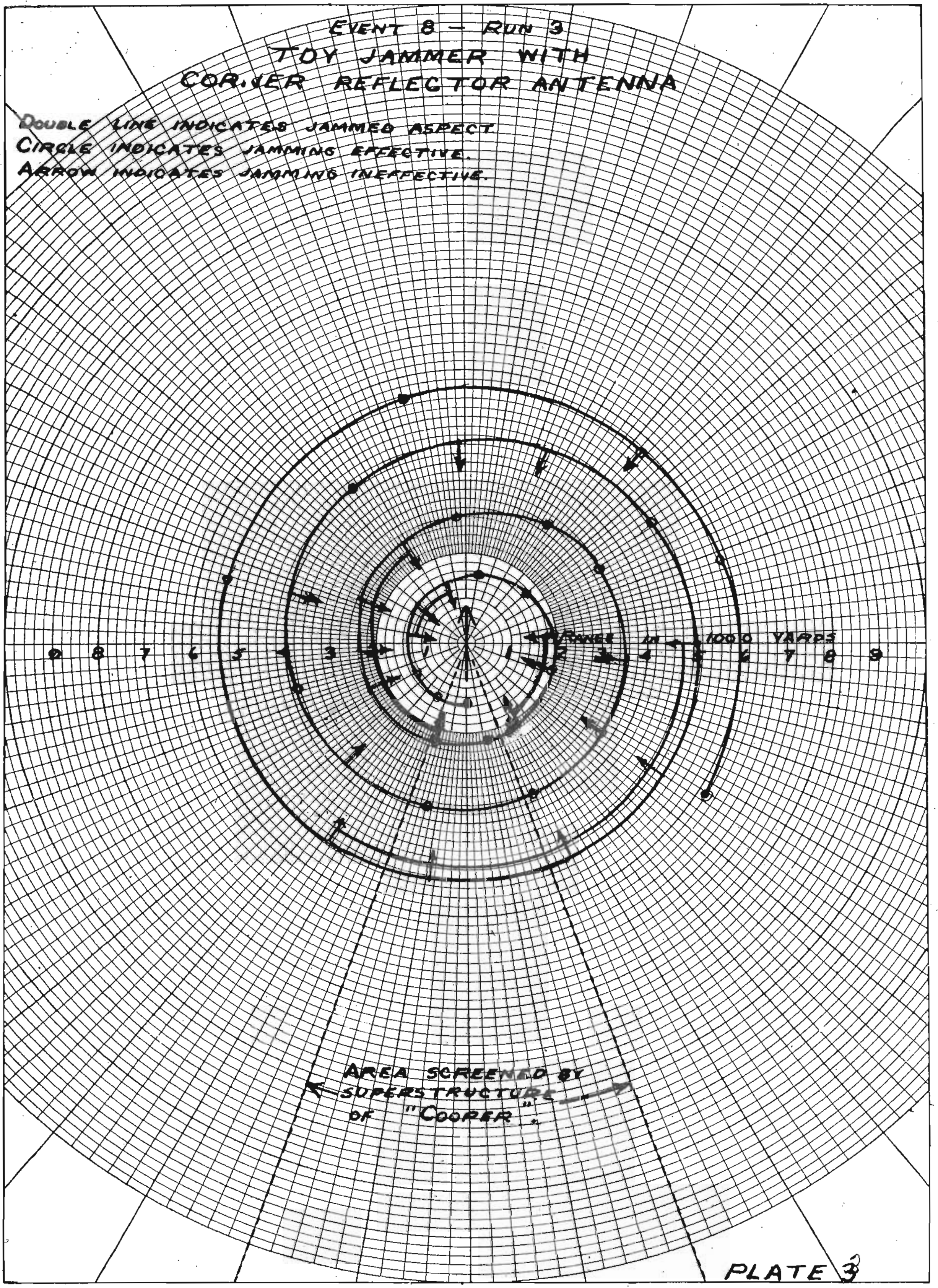

EVENT 8 - RUN 2
TDY JAMMER WITH CORNER
REFLECTOR AT FD FREQUENCY
DOUBLE LINE INDICATES JAMMED ASPECT
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "COOPER"

PLATE 2



EVENT 8 – RUN 3
TOY JAMMER WITH
CORNER REFLECTOR ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER".

PLATE 3

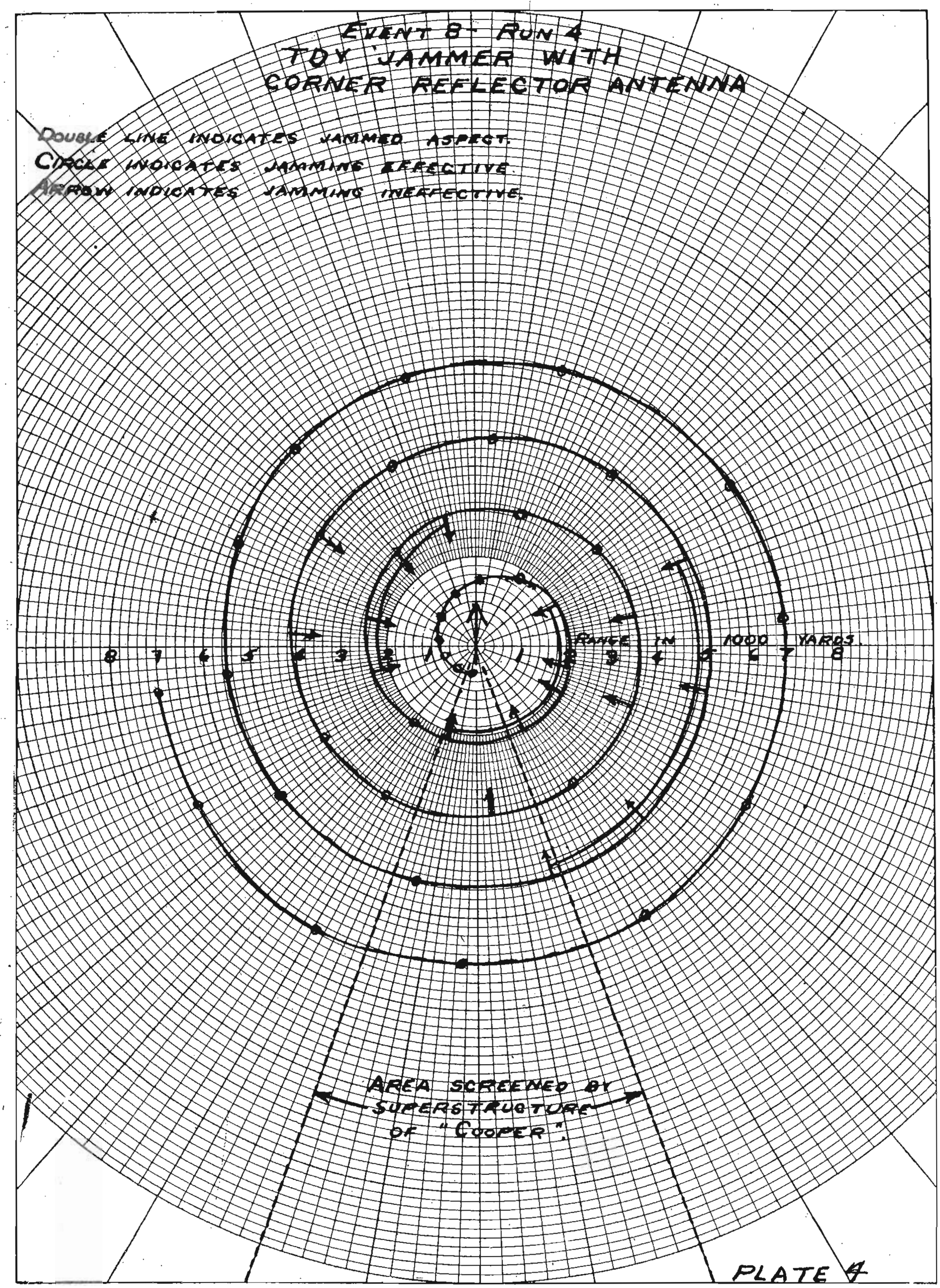

EVENT 8 - RUN 4
TDY JAMMER WITH
CORNER REFLECTOR ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER".

PLATE 4

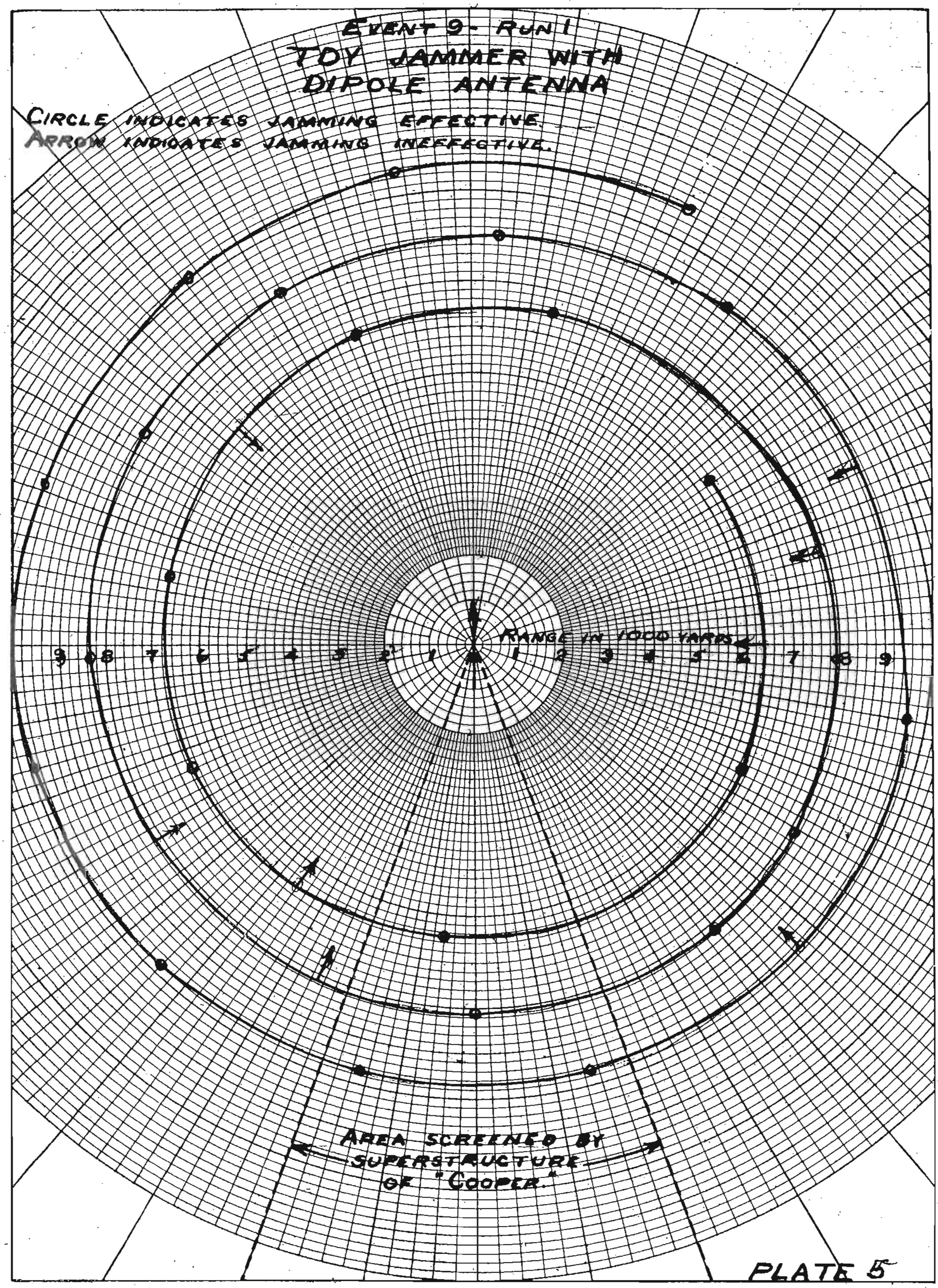

EVENT 9 - RUN 1
TOY JAMMER WITH
DIPOLE ANTENNA
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER."

PLATE 5

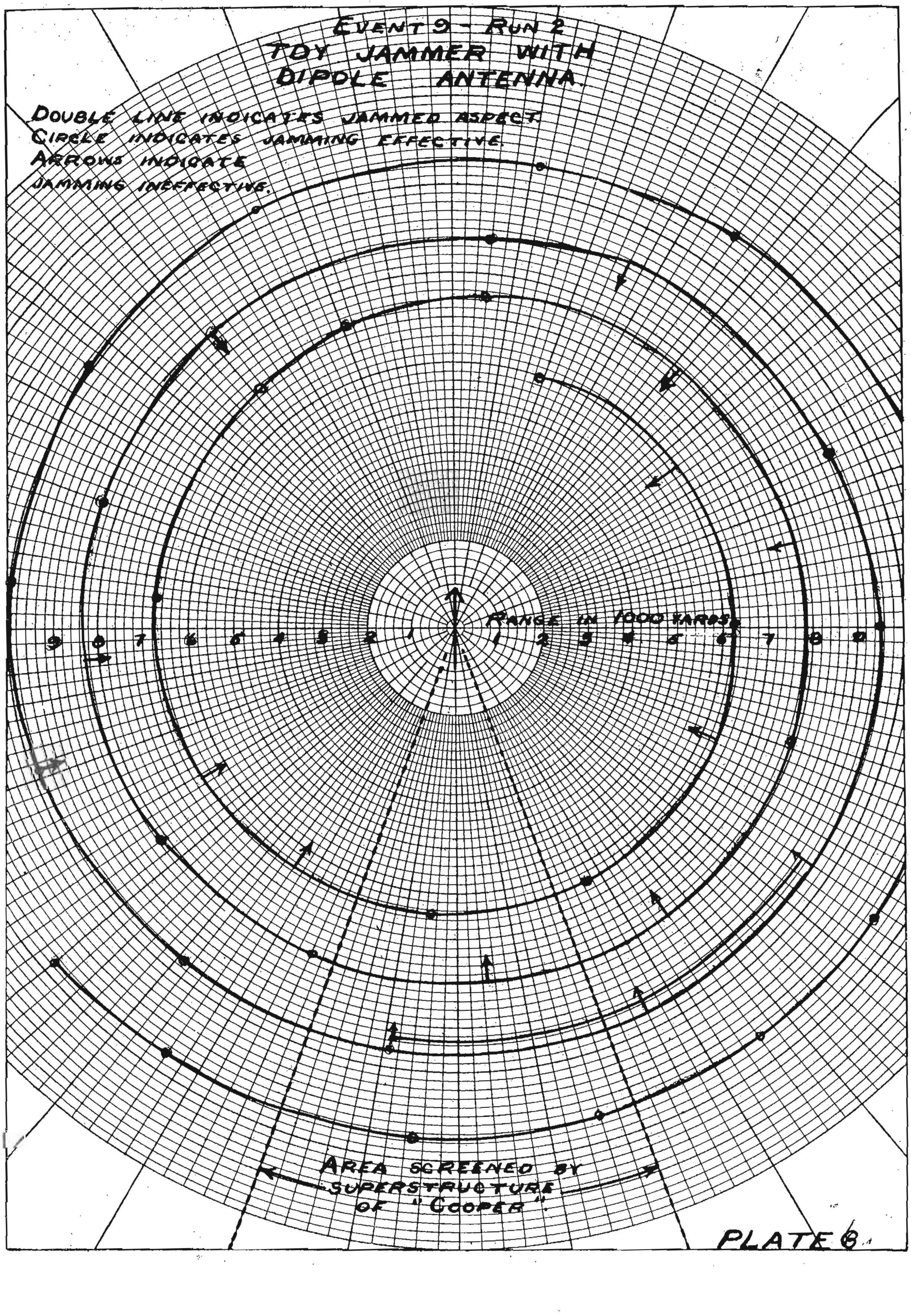

EVENT 9 - RUN 2
TOY JAMMER WITH
DIPOLE ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROWS INDICATE
JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER"

PLATE 8

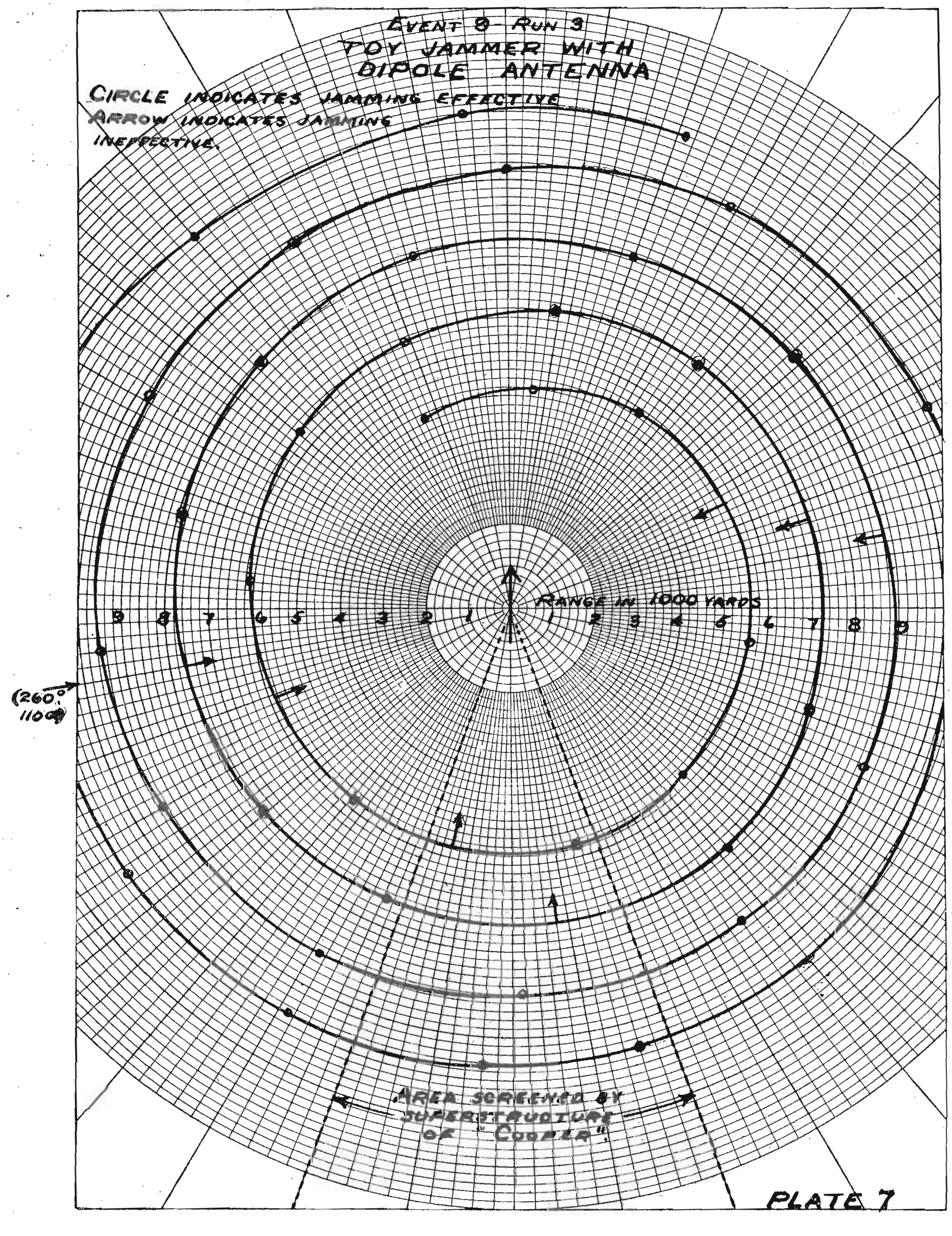

EVENT 9 - RUN 3
TOY JAMMER WITH
DIPOLE ANTENNA
CIRCLE INDICATES JAMMING EFFECTIVE
ARROW INDICATES JAMMING
INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9
(260°
1100)
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER".

PLATE 7

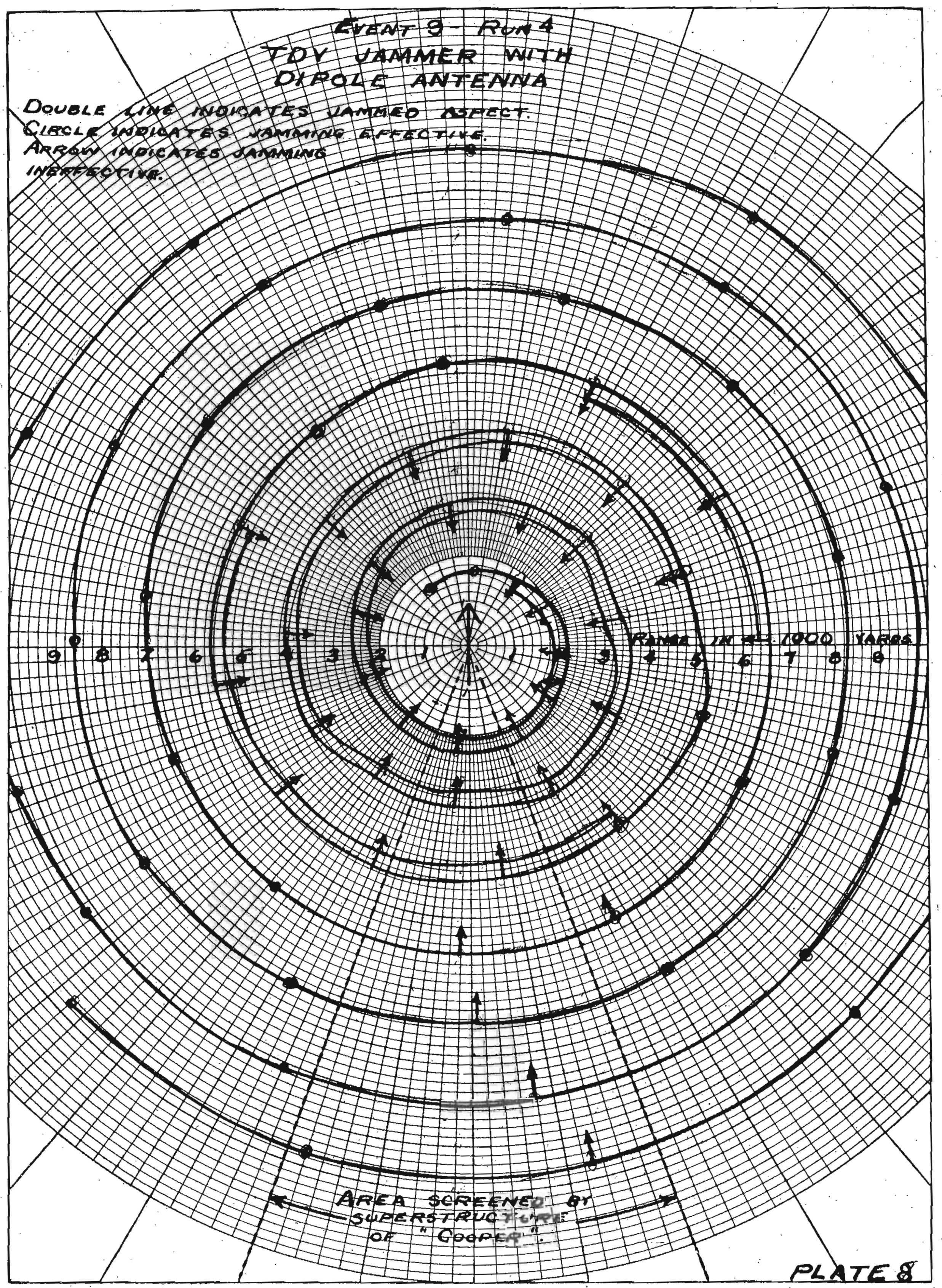

EVENT 9 - RUN 4
TDY JAMMER WITH
DIPOLE ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING
INEFFECTIVE.
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
RANGE IN 1000 YARDS
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER".

PLATE 8

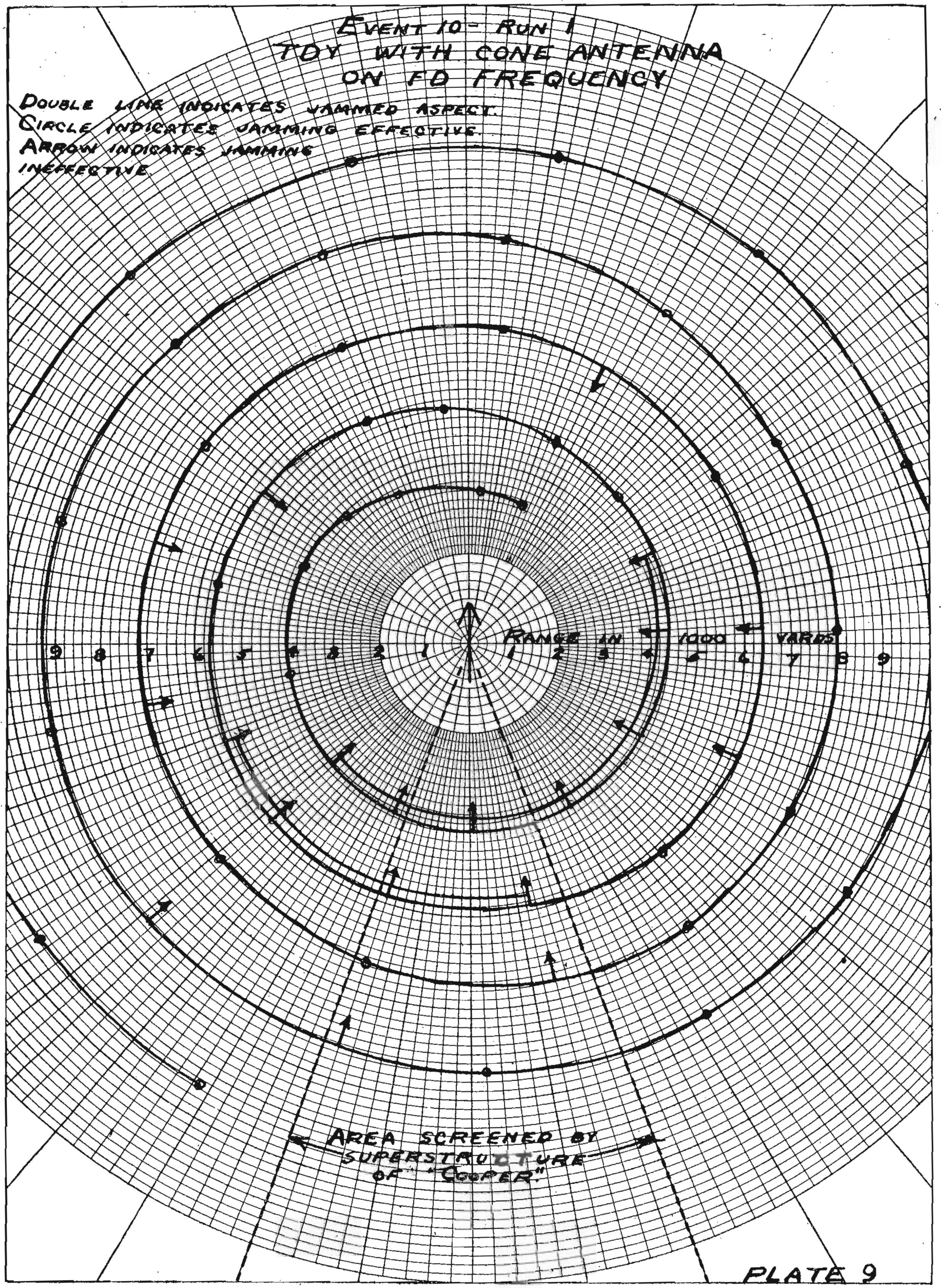

EVENT 10 - RUN 1
TDY WITH CONE ANTENNA
ON FD FREQUENCY
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING
INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER"

PLATE 9

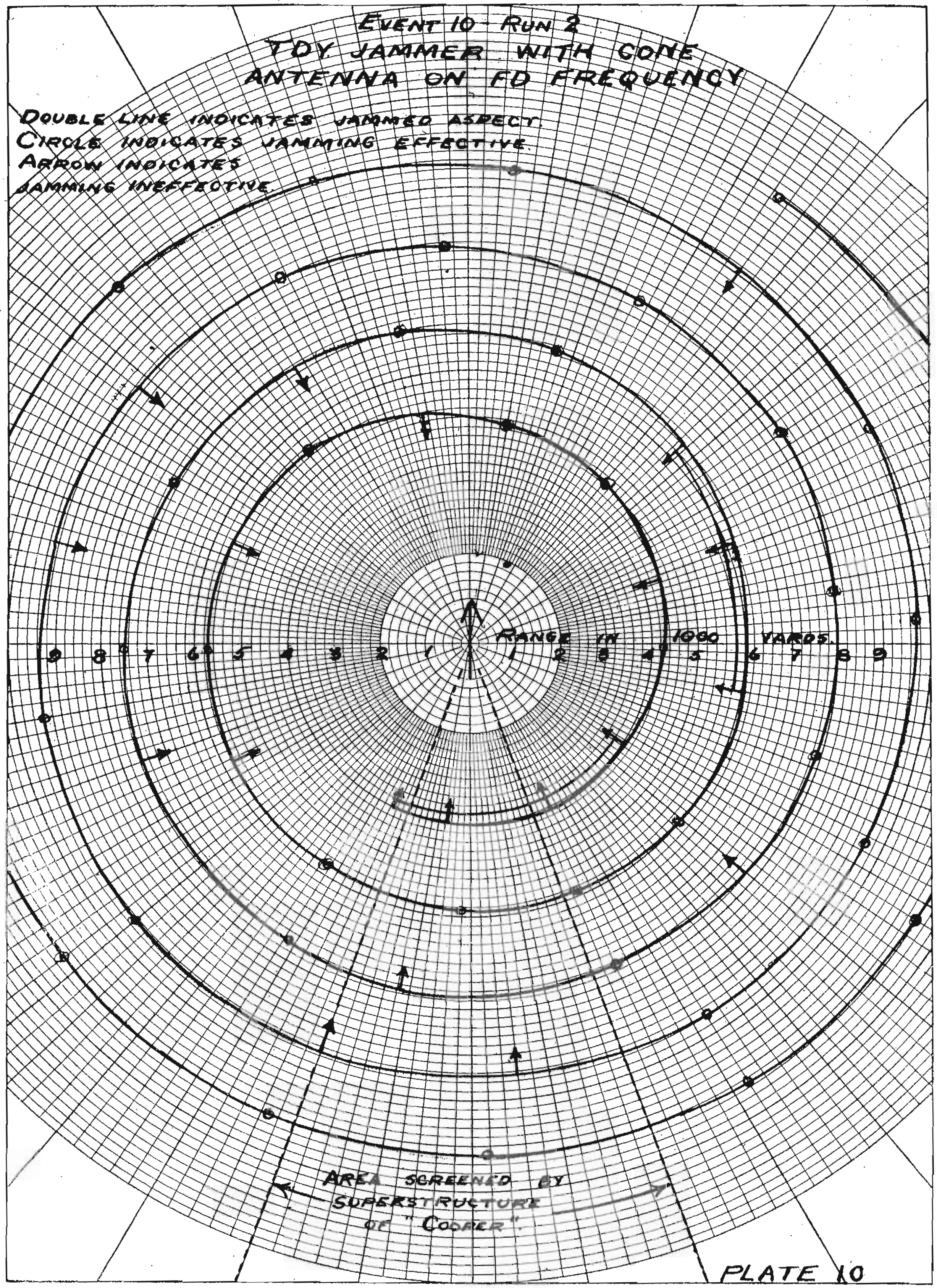

EVENT 10 - RUN 2
TDY JAMMER WITH CONE ANTENNA ON FD FREQUENCY
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS.
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "COOPER".

PLATE 10

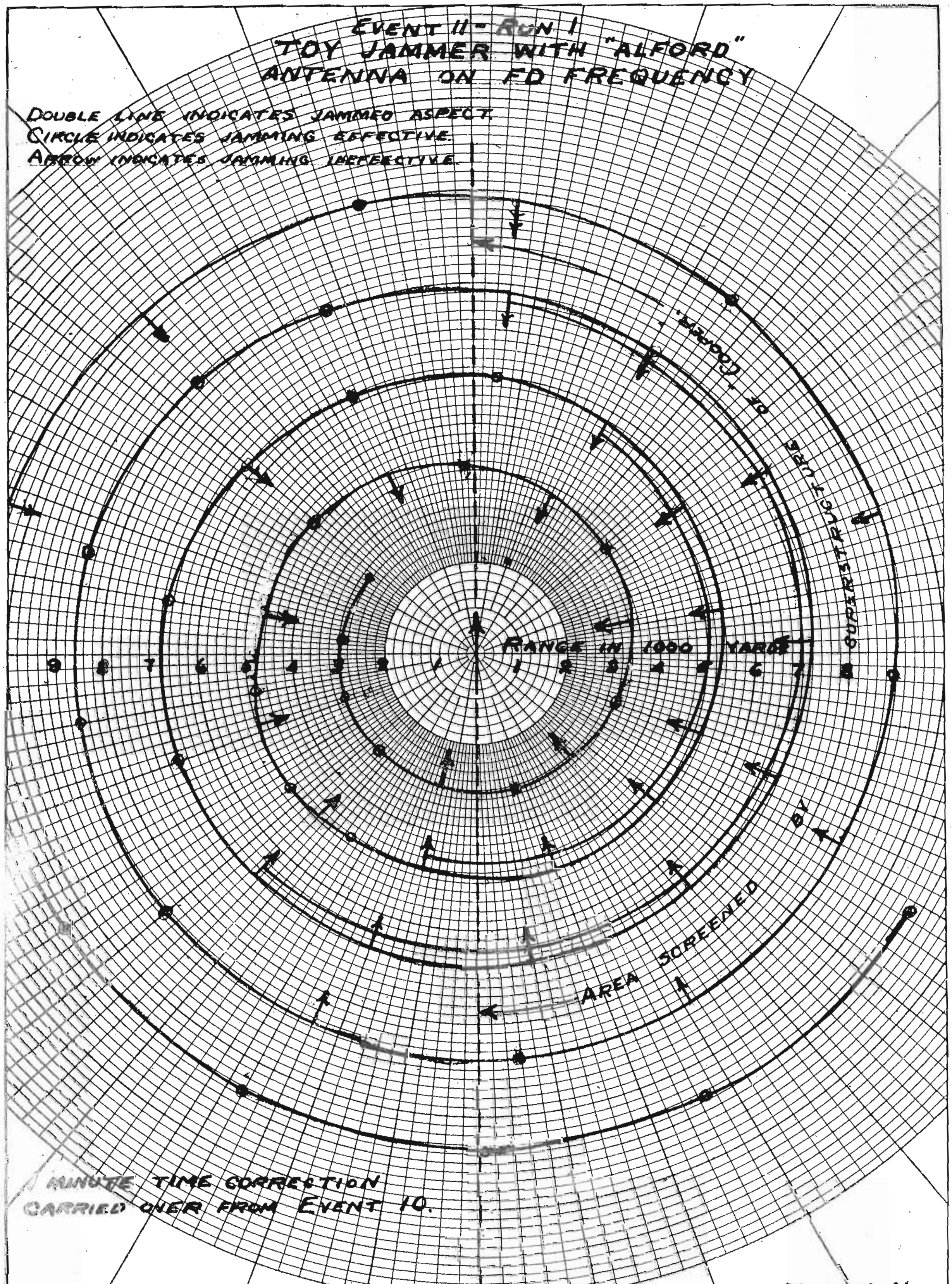

EVENT 11 - RUN 1
TOY JAMMER WITH "ALFORD"
ANTENNA ON FD FREQUENCY
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "COOPER"
1 MINUTE TIME CORRECTION
CARRIED OVER FROM EVENT 10.

PLATE 11

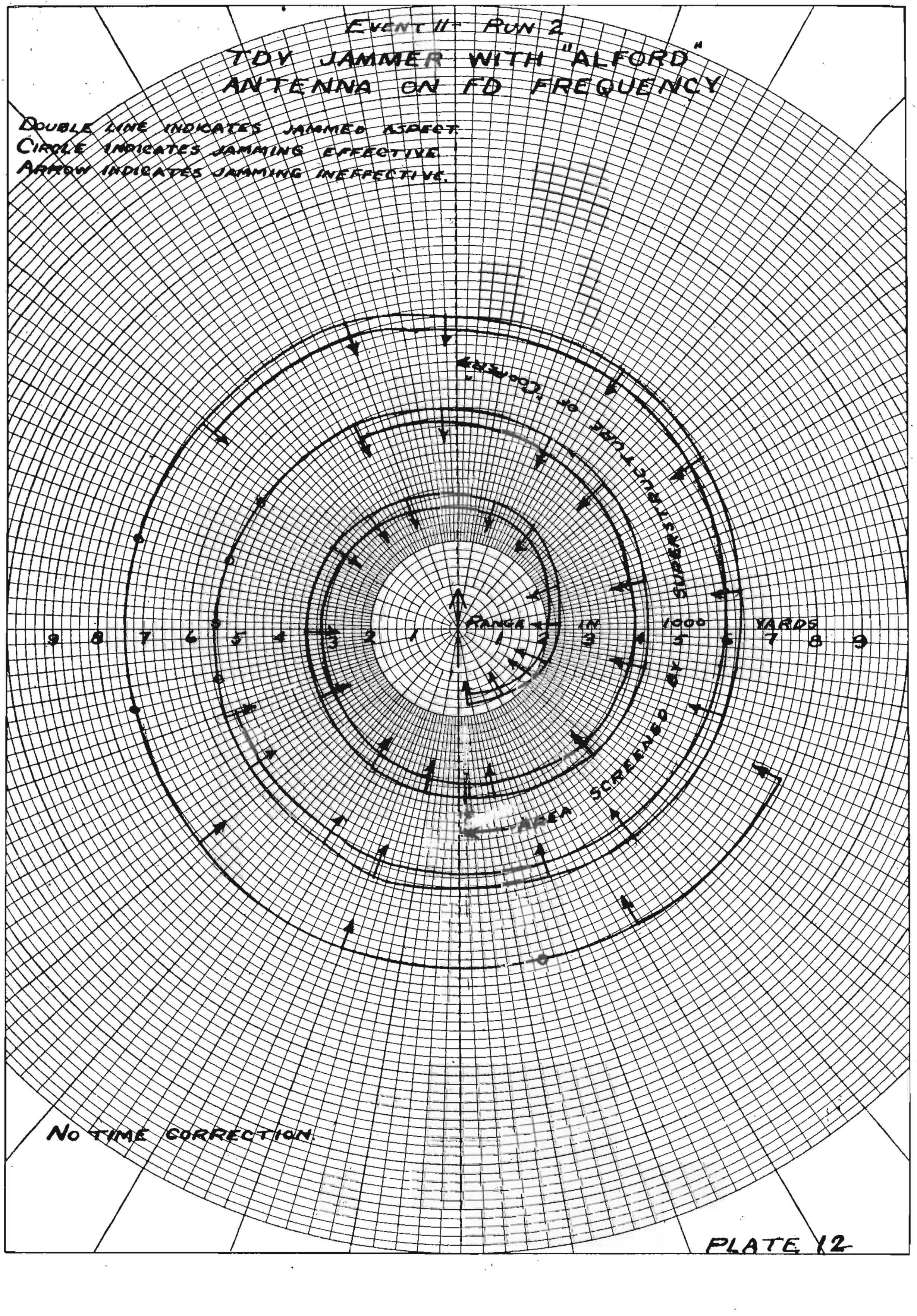

EVENT II - RUN 2
TDY JAMMER WITH "ALFORD" ANTENNA ON FD FREQUENCY
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "CORSAIR"
NO TIME CORRECTION.

PLATE 12

LIBRARY
NAVAL RESEARCH LABORATORY

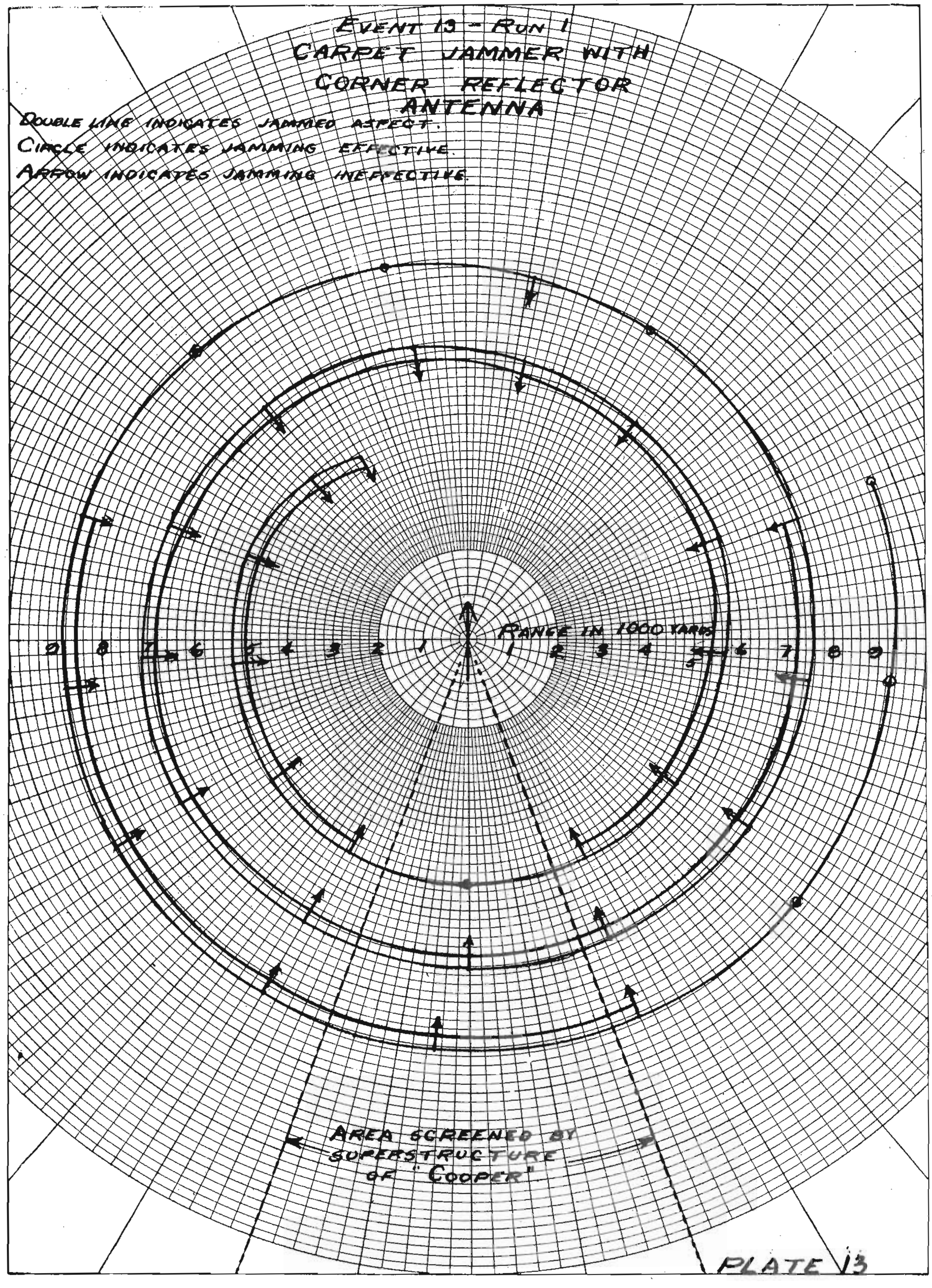
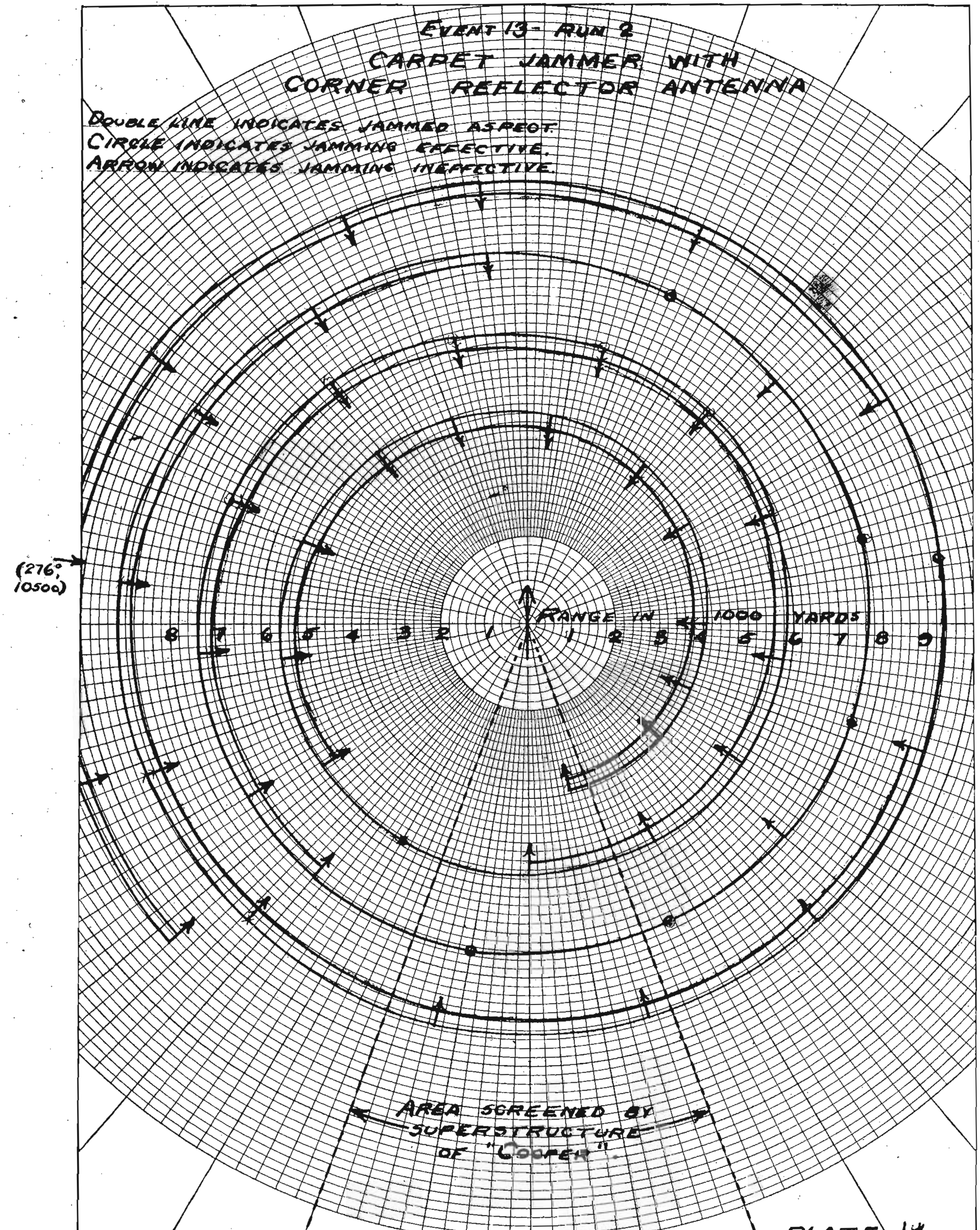


PLATE 13



EVENT 13 - RUN 2
CARPET JAMMER WITH
CORNER REFLECTOR ANTENNA
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
(276°, 10500)
RANGE IN 1000 YARDS
8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "COOPER".

PLATE 14

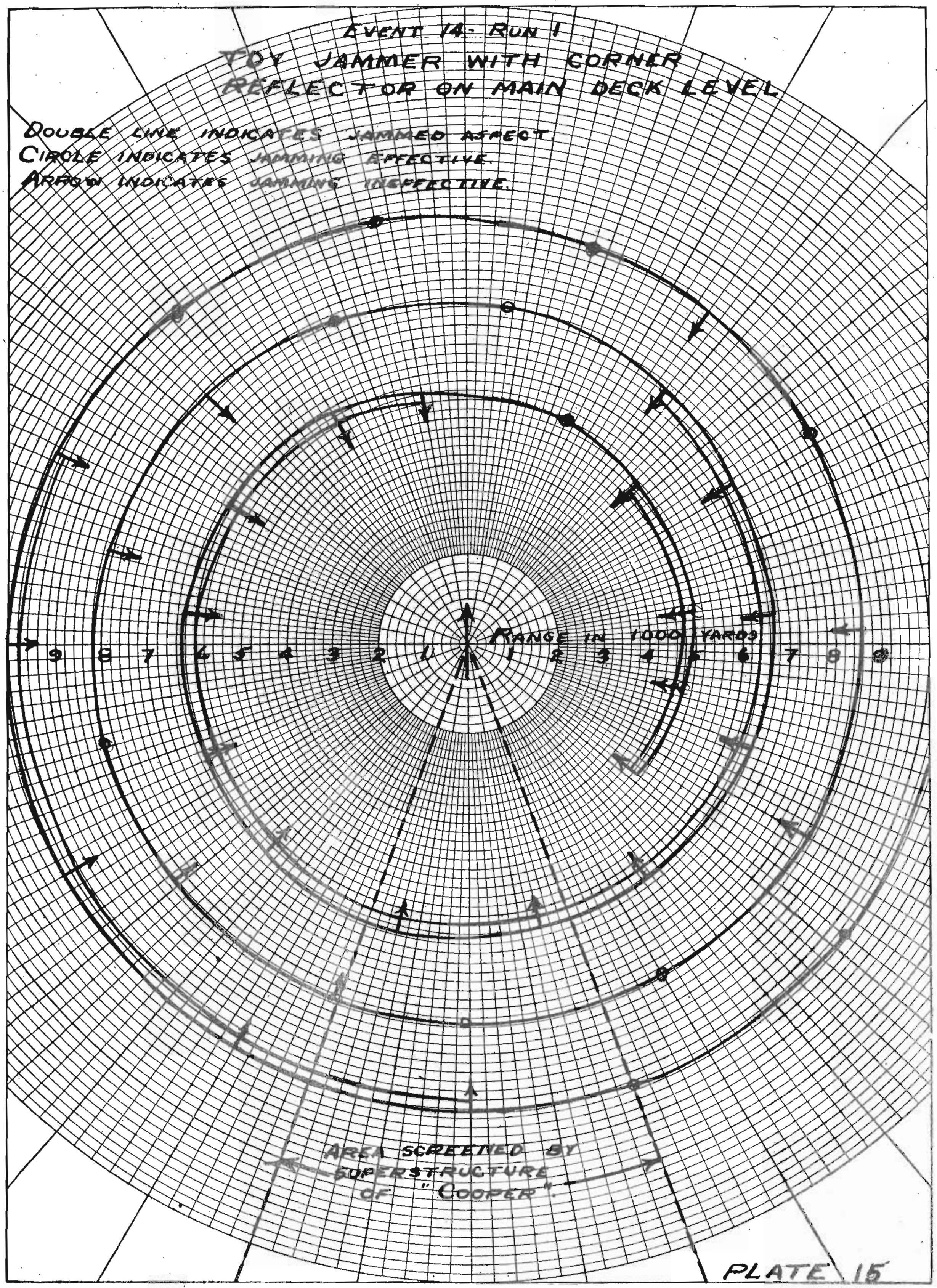
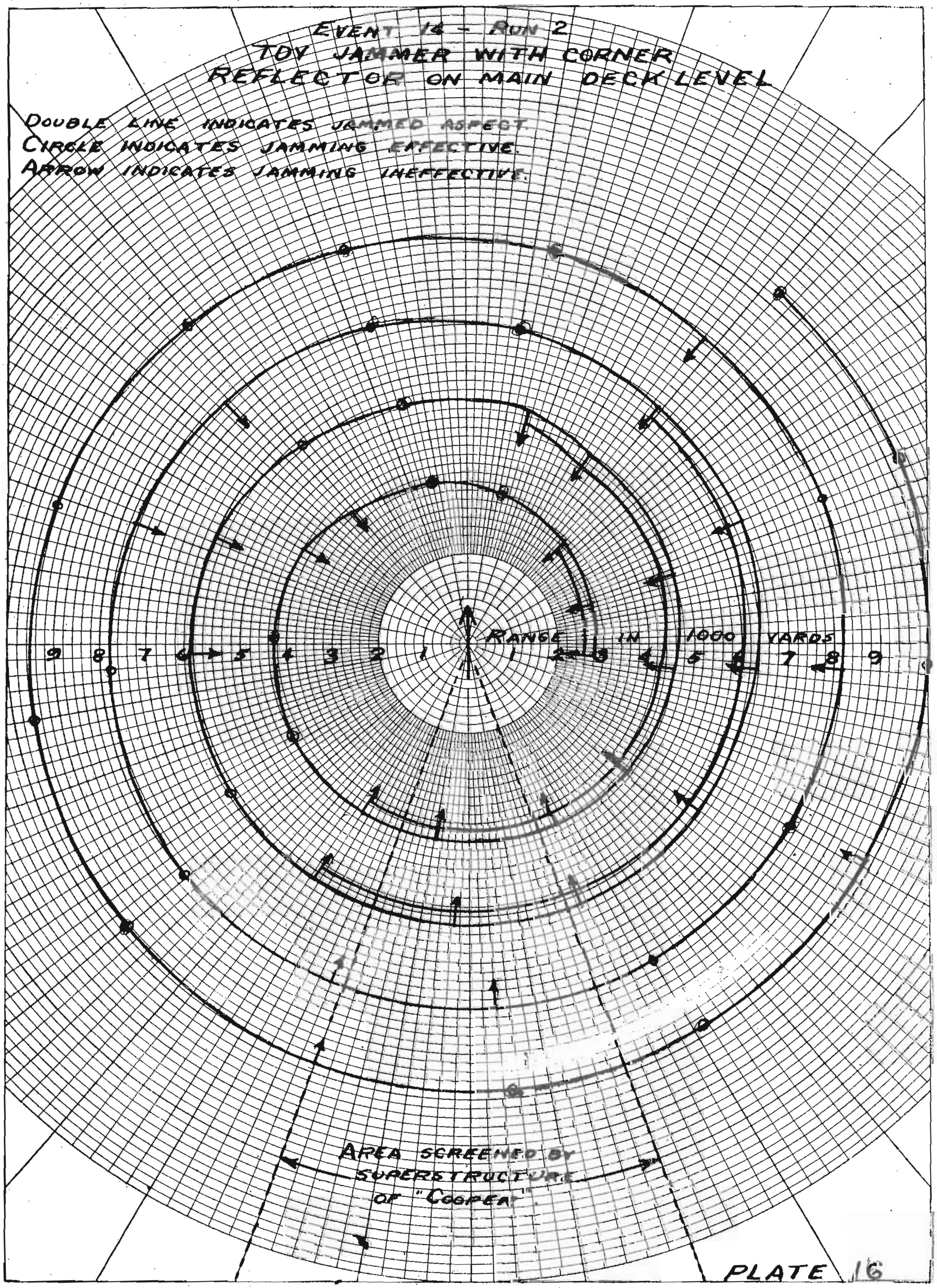

EVENT 14 - RUN 1
TDY JAMMER WITH CORNER
REFLECTOR ON MAIN DECK LEVEL
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY
SUPERSTRUCTURE
OF "COOPER"

PLATE 15


EVENT 14 - RUN 2
TDY JAMMER WITH CORNER
REFLECTOR ON MAIN DECK LEVEL
DOUBLE LINE INDICATES JAMMED ASPECT.
CIRCLE INDICATES JAMMING EFFECTIVE.
ARROW INDICATES JAMMING INEFFECTIVE.
RANGE IN 1000 YARDS
9 8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
AREA SCREENED BY SUPERSTRUCTURE OF "COOPER"
PLATE 16

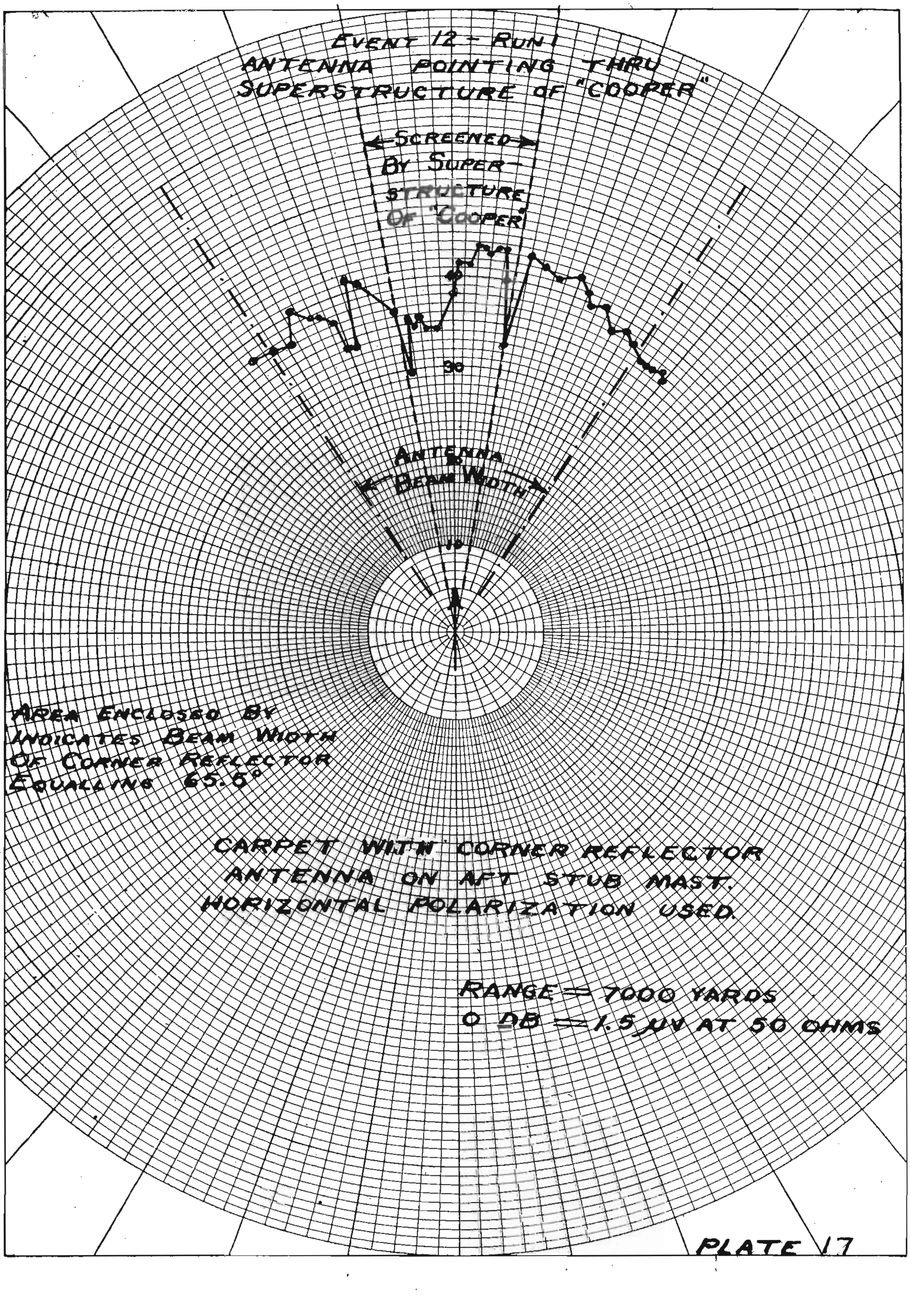

EVENT 12 – RUN I
ANTENNA POINTING THRU SUPERSTRUCTURE OF "COOPER"
SCREENED BY SUPER-STRUCTURE OF "COOPER"
40
30
ANTENNA BEAM WIDTH
10
AREA ENCLOSED BY INDICATES BEAM WIDTH OF CORNER REFLECTOR EQUALLING 65.5°
CARPET WITH CORNER REFLECTOR ANTENNA ON AFT STUB MAST. HORIZONTAL POLARIZATION USED.
RANGE = 7000 YARDS
0 DB = 1.5 μV AT 50 OHMS

PLATE 17

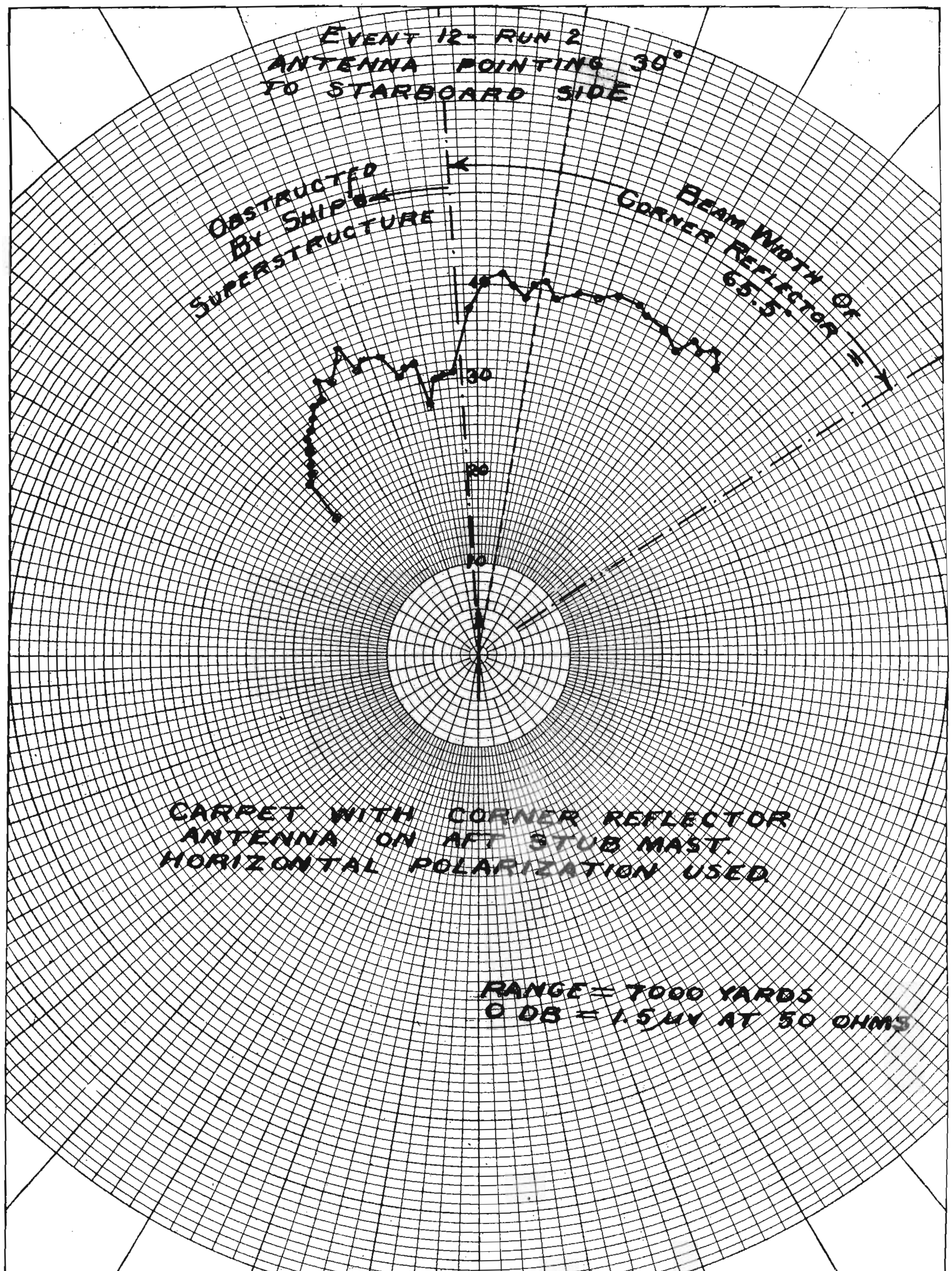

EVENT 12 - RUN 2
ANTENNA POINTING 30°
TO STARBOARD SIDE
OBSTRUCTED BY SHIP'S SUPERSTRUCTURE
BEAM WIDTH OF CORNER REFLECTOR 65.5°
40
30
20
10
CARPET WITH CORNER REFLECTOR
ANTENNA ON AFT STUB MAST.
HORIZONTAL POLARIZATION USED.
RANGE = 7000 YARDS
0 DB = 1.5 μV AT 50 OHMS

PLATE 18

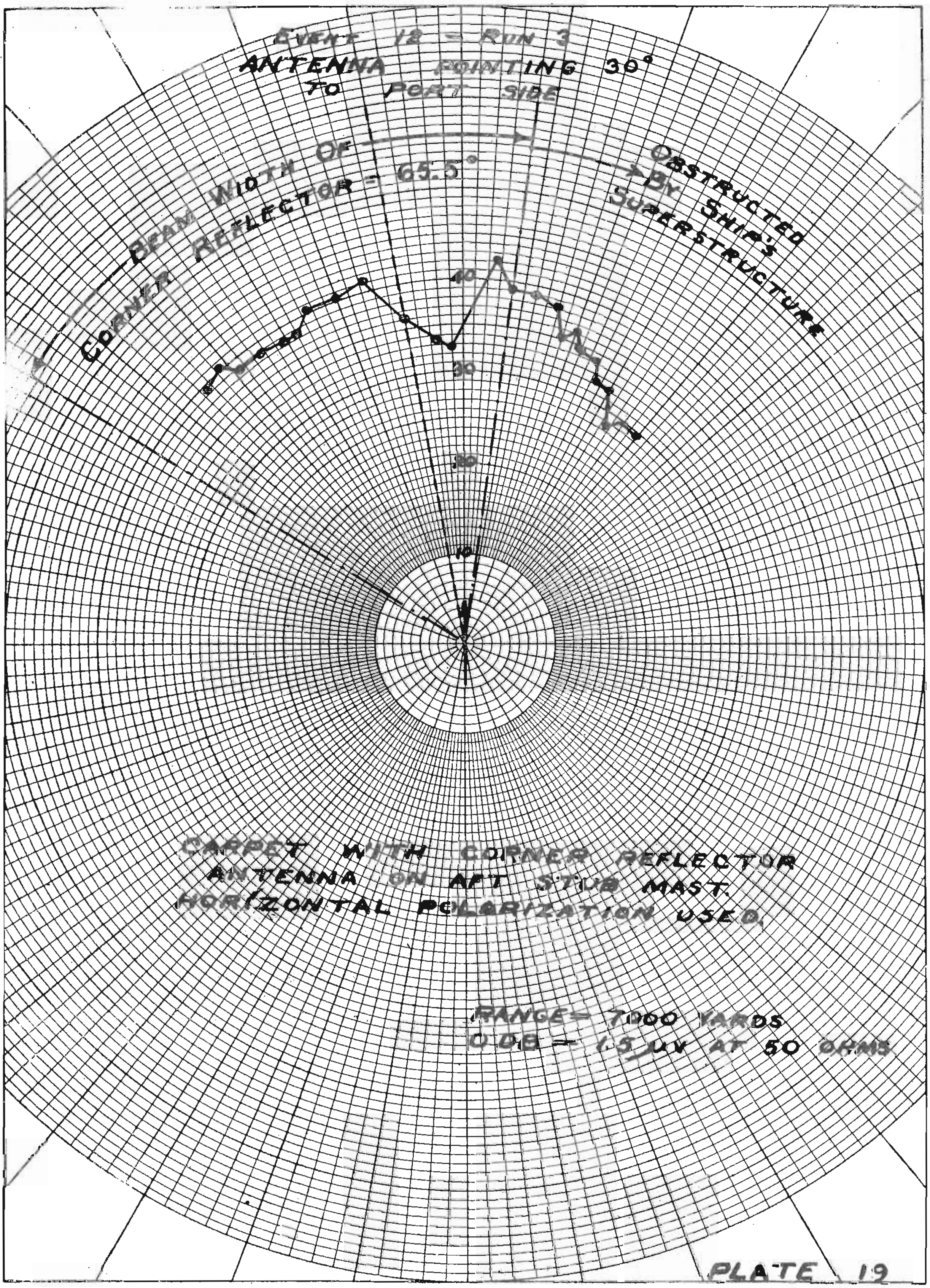

EVENT 12 – RUN 3
ANTENNA POINTING 30°
TO PORT SIDE
BEAM WIDTH OF
CORNER REFLECTOR = 65.5°
OBSTRUCTED
BY SHIP'S
SUPERSTRUCTURE
40
30
20
10
CARPET WITH CORNER REFLECTOR
ANTENNA ON AFT STUB MAST.
HORIZONTAL POLARIZATION USED.
RANGE = 7000 YARDS
0 DB = 1.5 μV AT 50 OHMS

PLATE 19

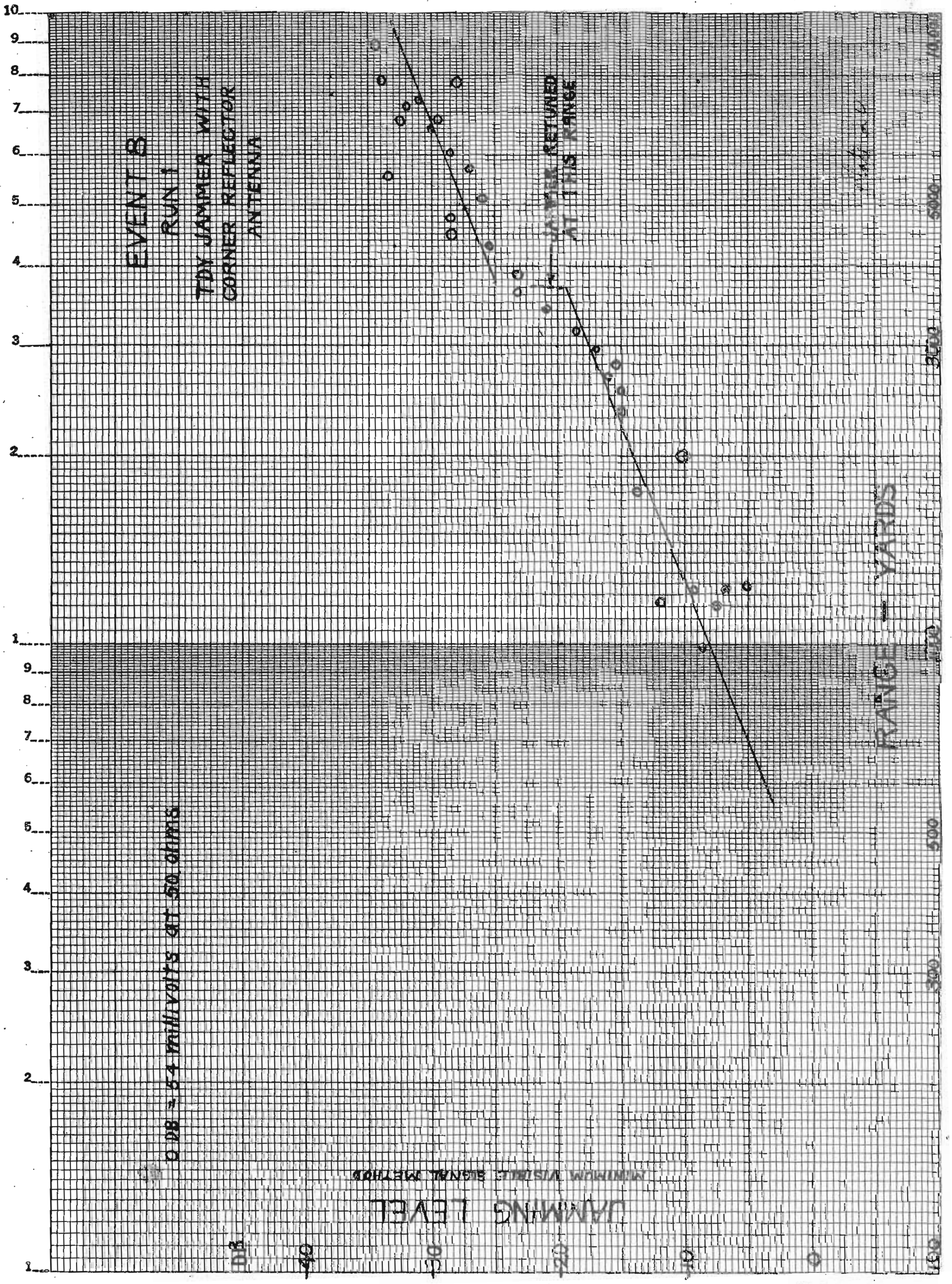

EVENT 8
RUN 1
TDY JAMMER WITH CORNER REFLECTOR ANTENNA
JAMMER RETUNED AT THIS RANGE
RANGE — YARDS
0 DB = 54 millivolts at 50 ohms
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
DB
-40
-30
-20
-10
0
10,000
5000
3000
1000
500
300
100

PLATE 20

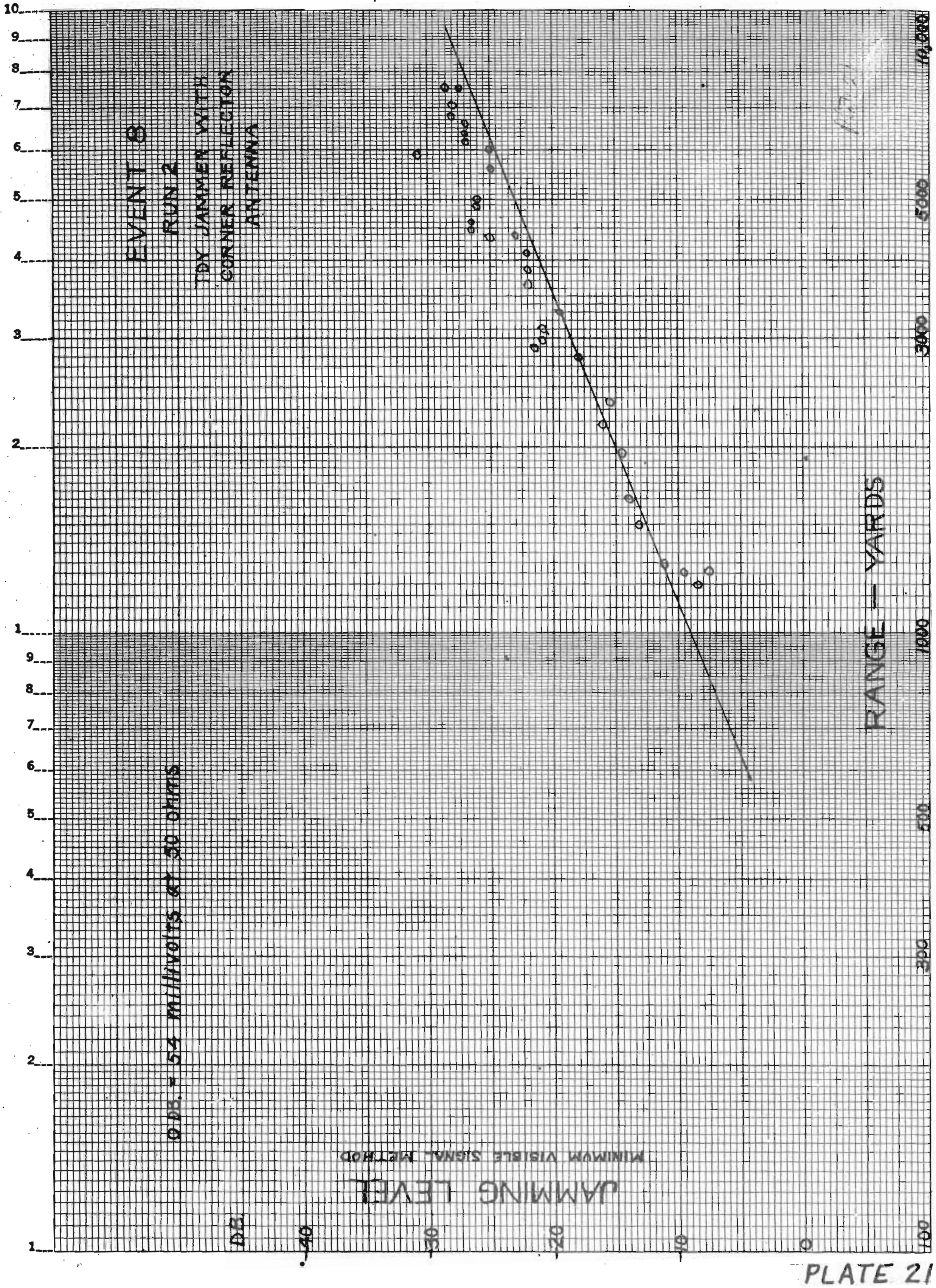

EVENT 8
RUN 2
TDY JAMMER WITH
CORNER REFLECTOR
ANTENNA
0 DB = 54 millivolts at 50 ohms
RANGE — YARDS
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
DB
-40
-30
-20
-10
0
10,000
5000
3000
1000
500
300
100

PLATE 21

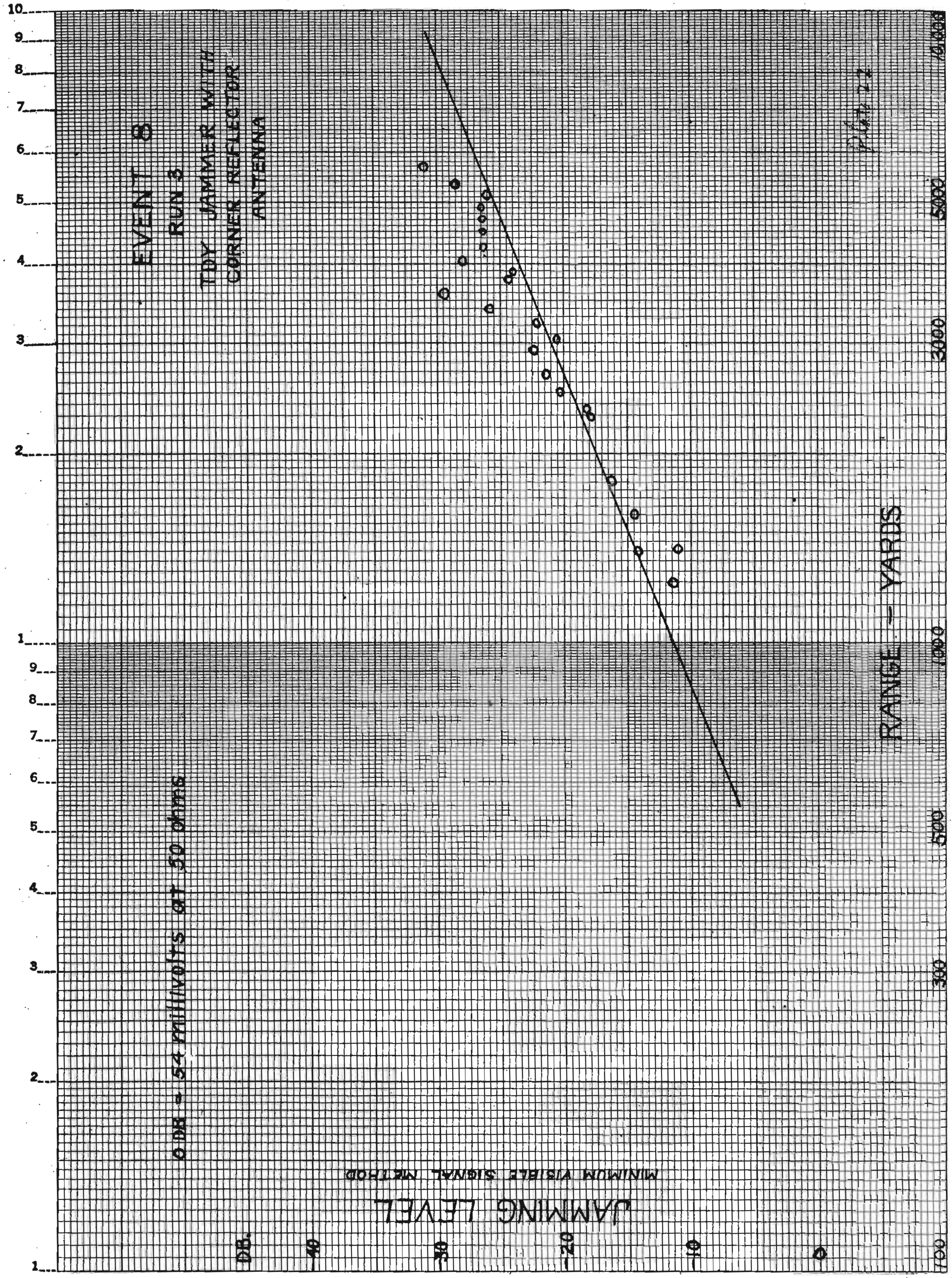

EVENT 8
RUN 3
TDY JAMMER WITH
CORNER REFLECTOR
ANTENNA
RANGE - YARDS
0 DB = 54 millivolts at 50 ohms
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
DB.
40
30
20
10
0
100
300
500
1000
3000
5000
10,000

PLATE 22

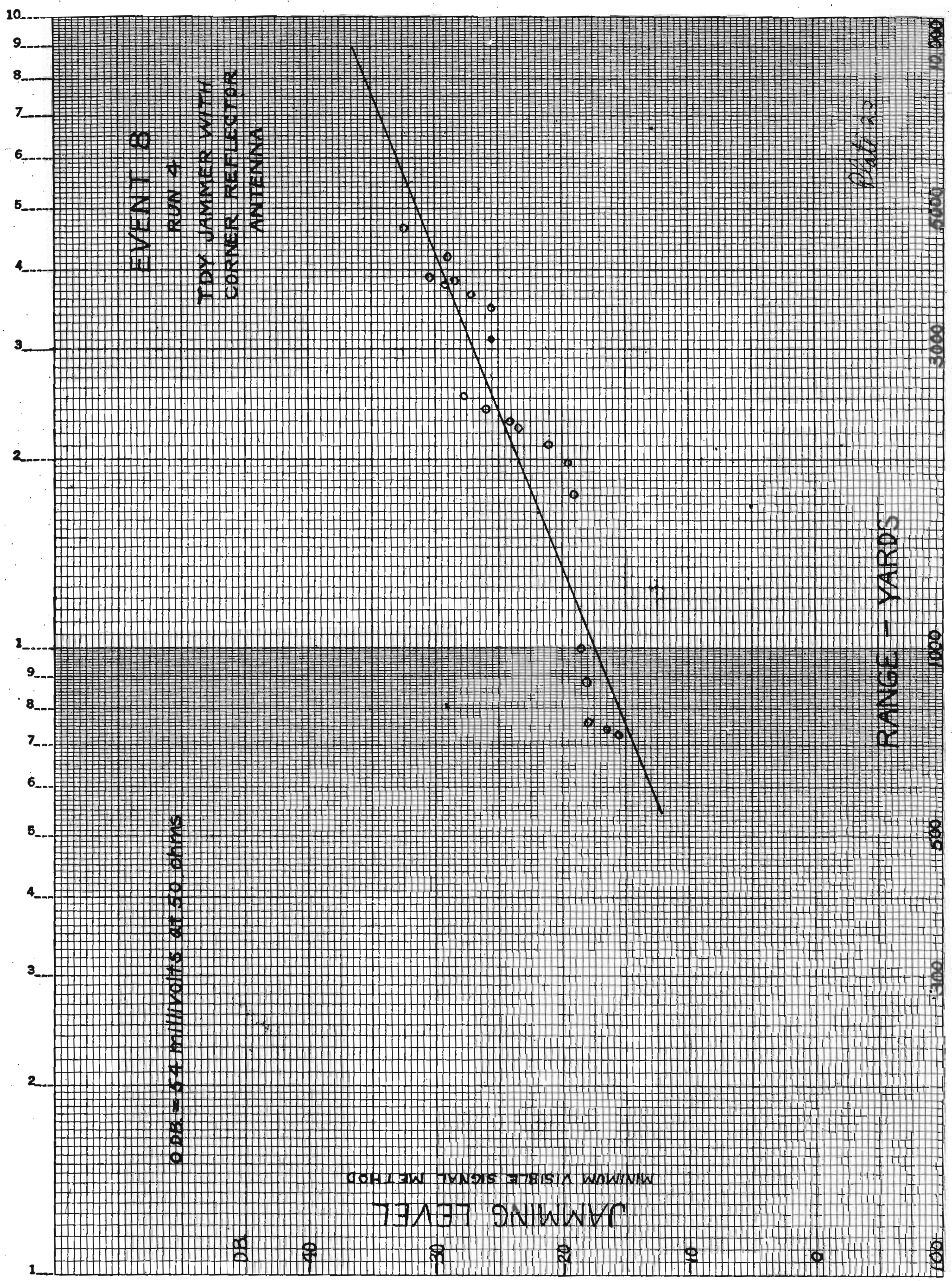

EVENT 8
RUN 4
TOY JAMMER WITH
CORNER REFLECTOR
ANTENNA
0 DB = 54 millivolts at 50 ohms
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
RANGE - YARDS
DB
40
30
20
10
0
100
300
500
1000
3000
5000
10,000

PLATE 23

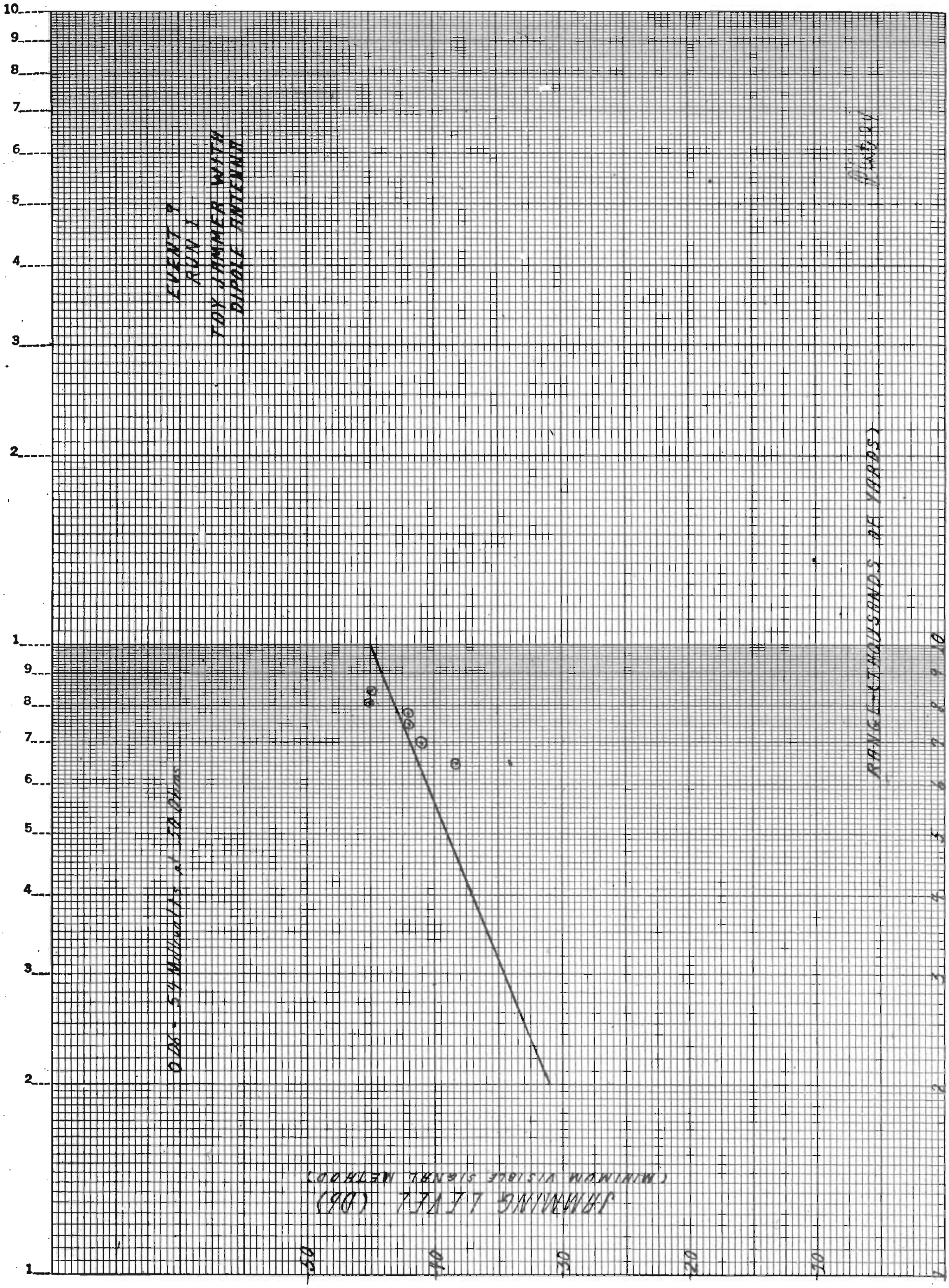

EVENT 7
RUN 1
TOY JAMMER WITH
DIPOLE ANTENNA
0 DB - 54 Millivolts at 50 Ohms
RANGE (THOUSANDS OF YARDS)
JAMMING LEVEL (DB)
(MINIMUM VISIBLE SIGNAL METHOD)
50
40
30
20
10

PLATE 24

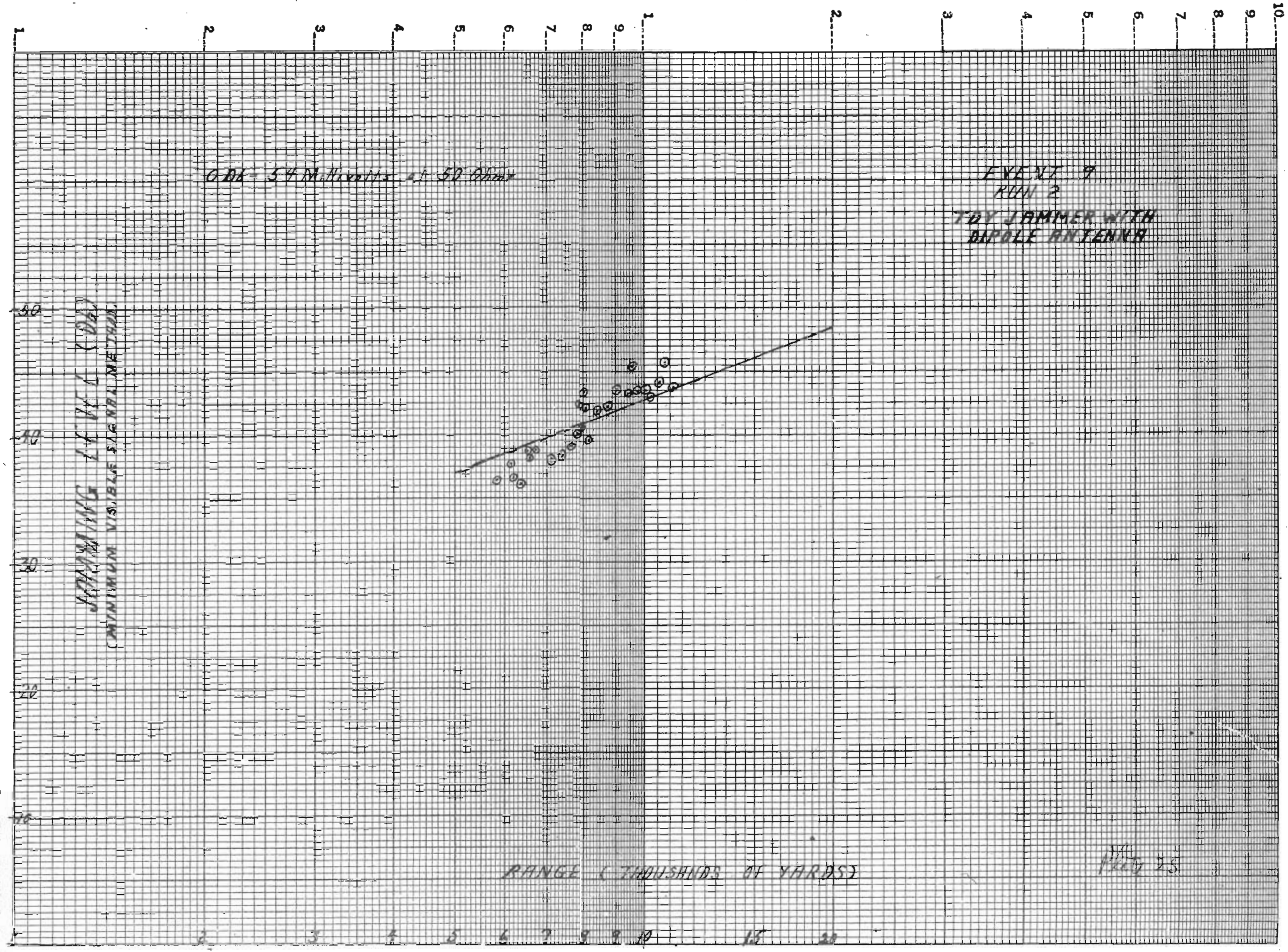

0 Db = 54 Microvolts at 50 Ohms
EVENT 9
RUN 2
TDY JAMMER WITH
DIPOLE ANTENNA
JAMMING LEVEL (DB)
(MINIMUM VISIBLE SIGNAL METHOD)
RANGE (THOUSANDS OF YARDS)

PLATE 25

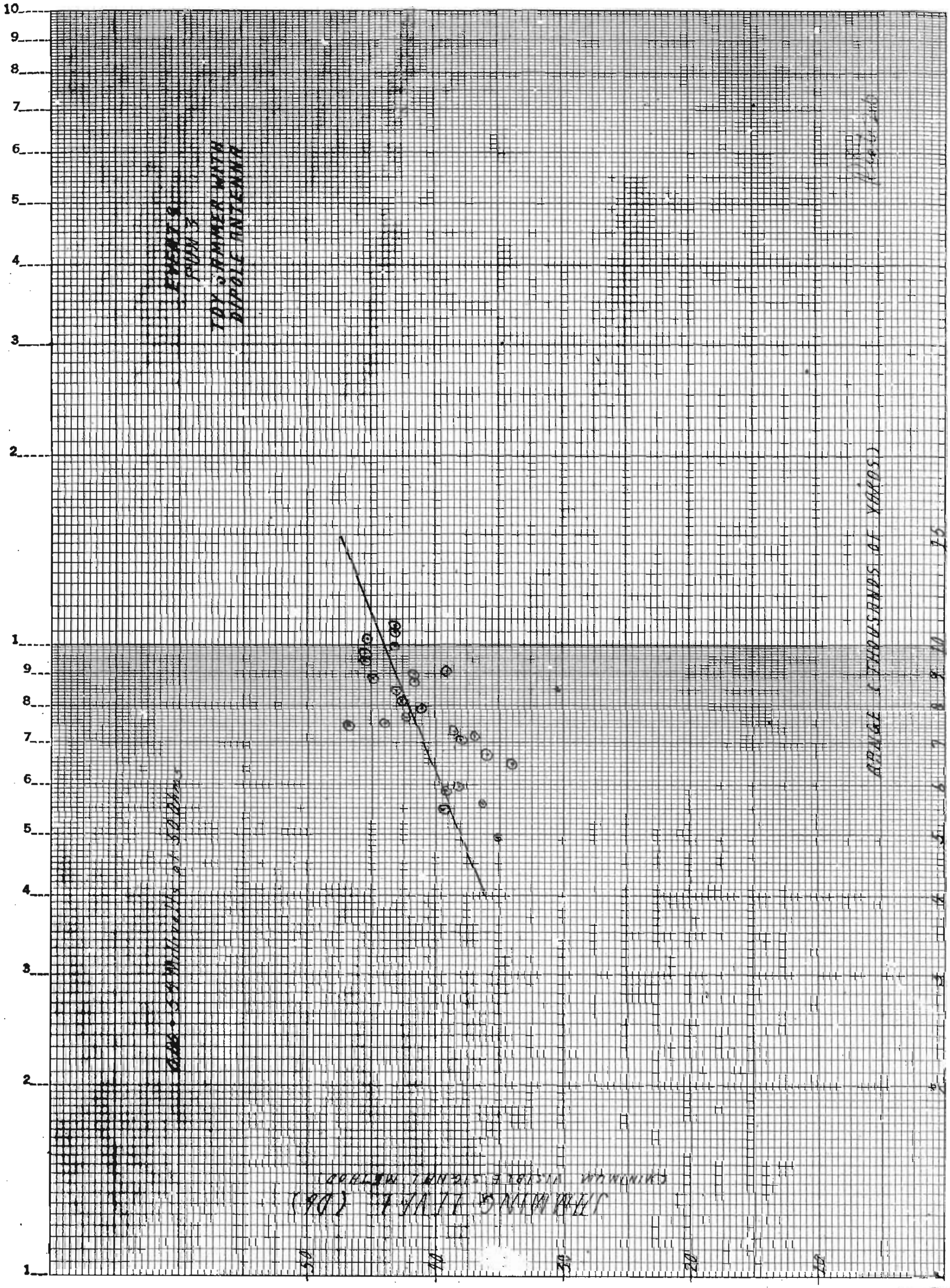
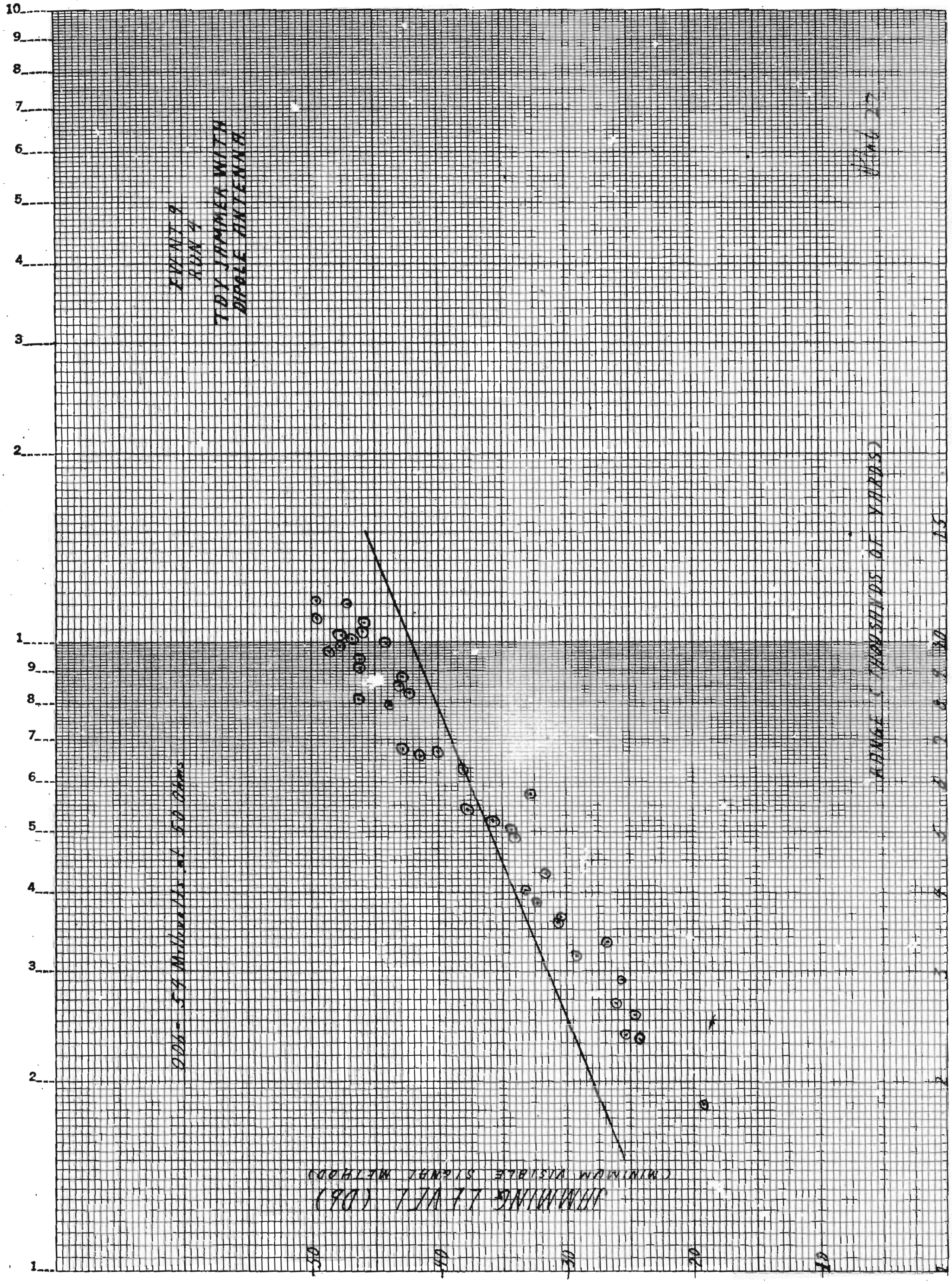

EVENT 8
RUN 3
TDY JAMMER WITH
DIPOLE ANTENNA
RANGE (THOUSANDS OF YARDS)
JAMMING LEVEL (DB)

PLATE 26



EVENT 9
RUN 4
TDY JAMMER WITH
DIPOLE ANTENNA
0Db - .54 Milliwatts at 50 Ohms
JAMMING LEVEL (DB)
(MINIMUM VISIBLE SIGNAL METHOD)
RANGE (THOUSANDS OF YARDS)

PLATE 27

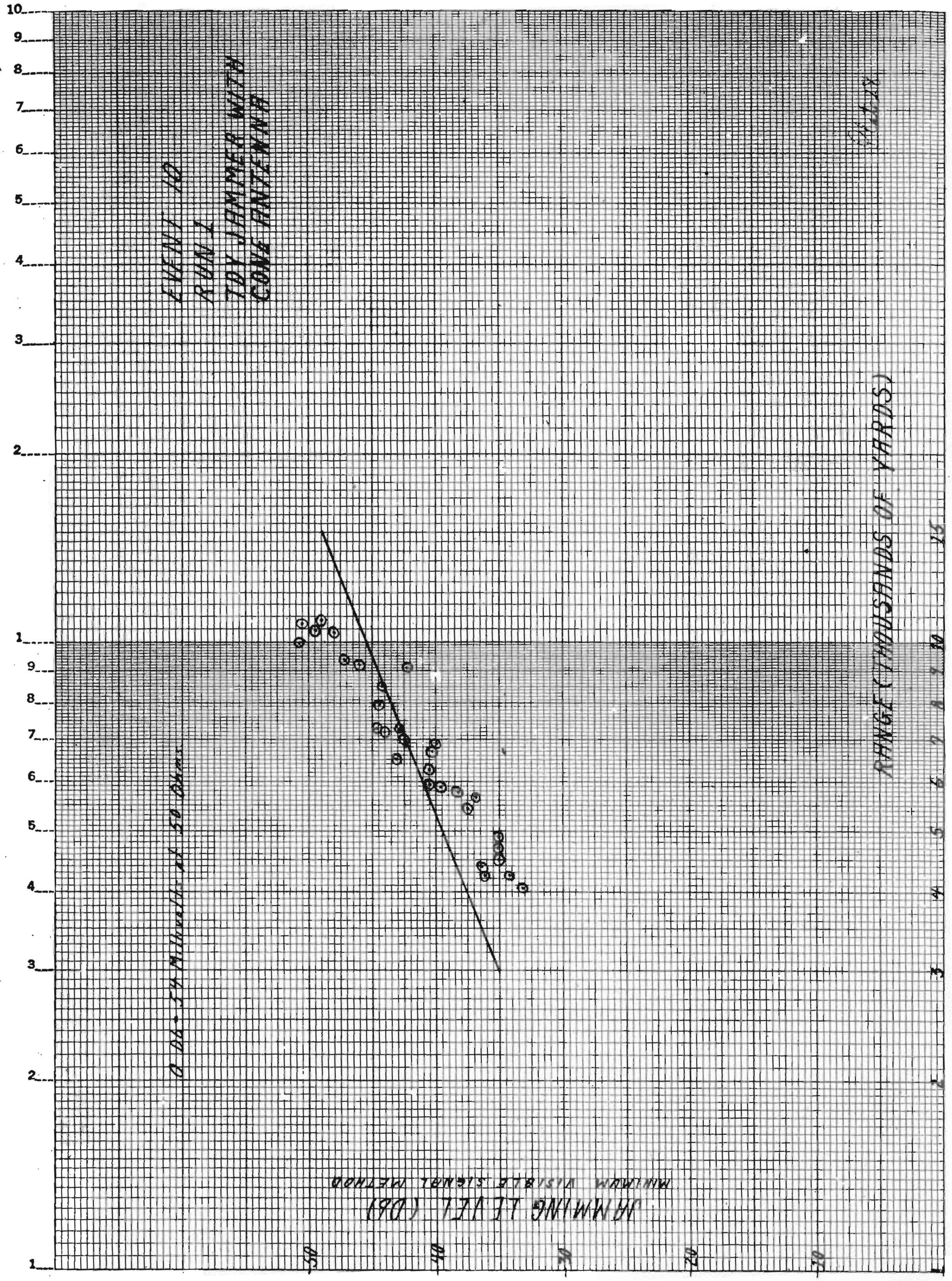

EVENT 10
RUN 1
TDY JAMMER WITH
CONE ANTENNA
RANGE (THOUSANDS OF YARDS)
0 DB = 54 Milliwatts at 50 Ohms
JAMMING LEVEL (DB)
MINIMUM VISIBLE SIGNAL METHOD

PLATE 28

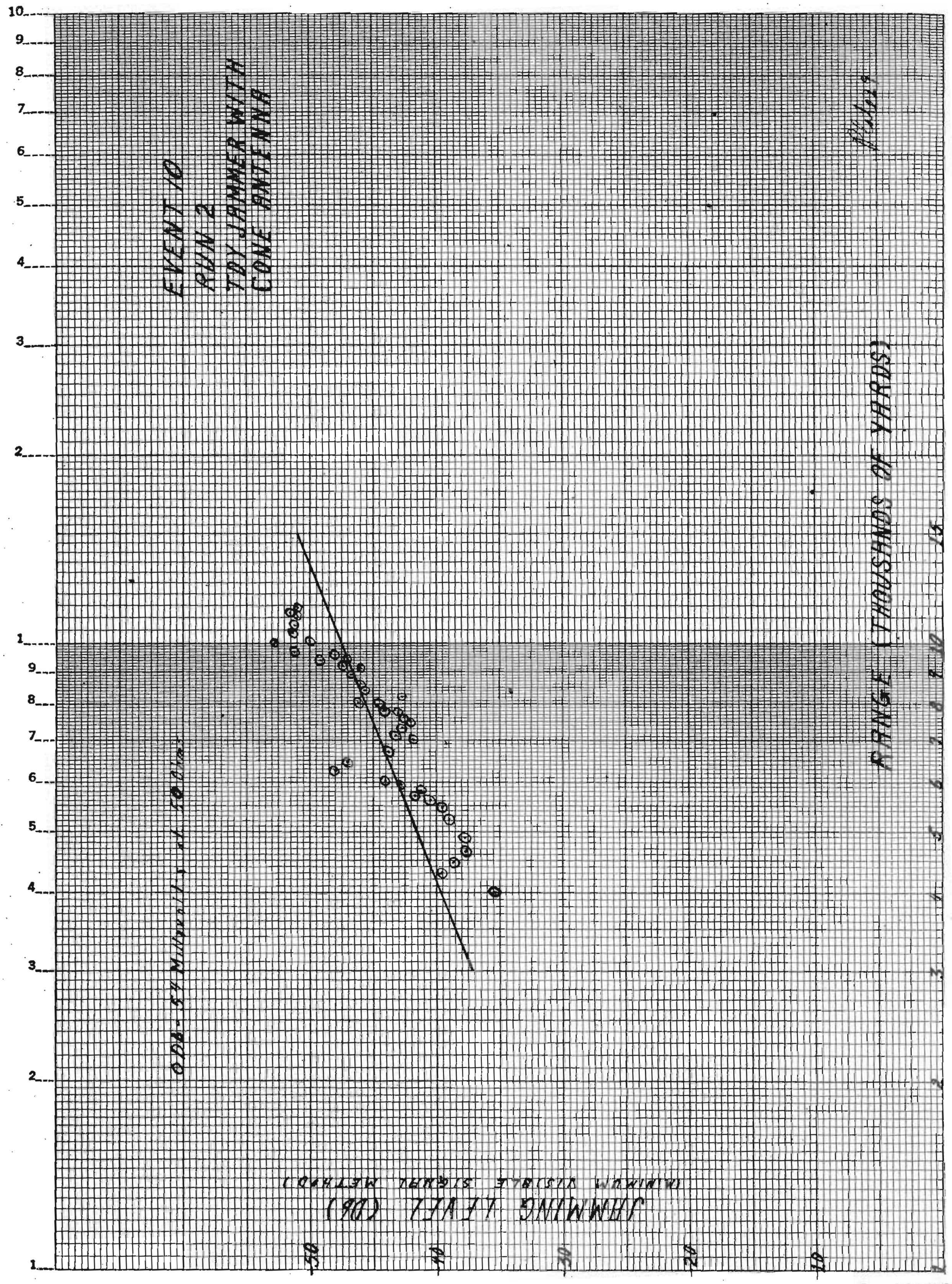

EVENT 10
RUN 2
TDY JAMMER WITH
CONE ANTENNA
RANGE (THOUSANDS OF YARDS)
JAMMING LEVEL (DB)
(MINIMUM VISIBLE SIGNAL METHOD)

PLATE 29

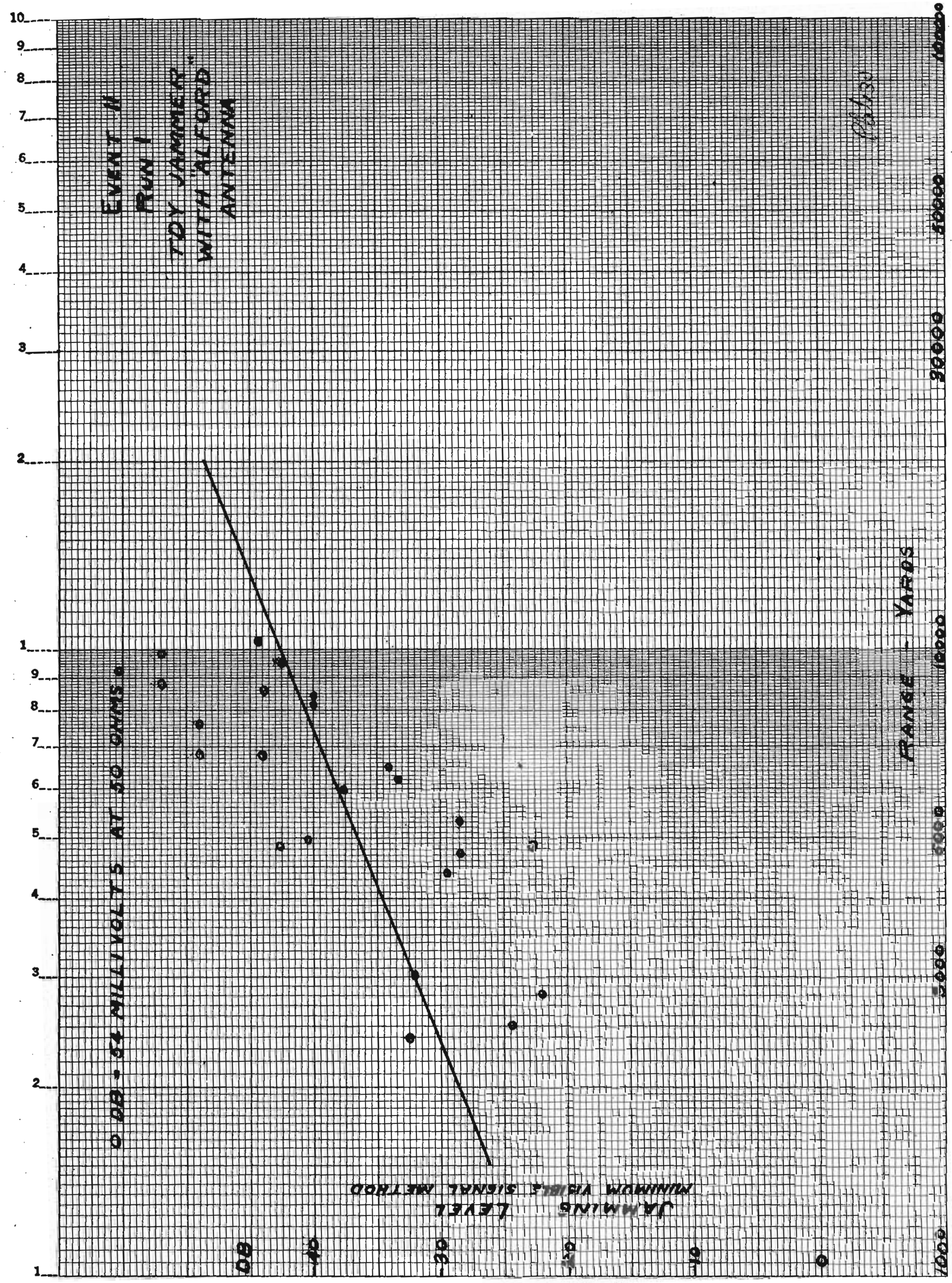

EVENT II
RUN I
TDY JAMMER
WITH 'ALFORD'
ANTENNA
0 DB = .54 MILLIVOLTS AT 50 OHMS
RANGE - YARDS
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
DB
-40
-30
-20
-10
0

PLATE 30

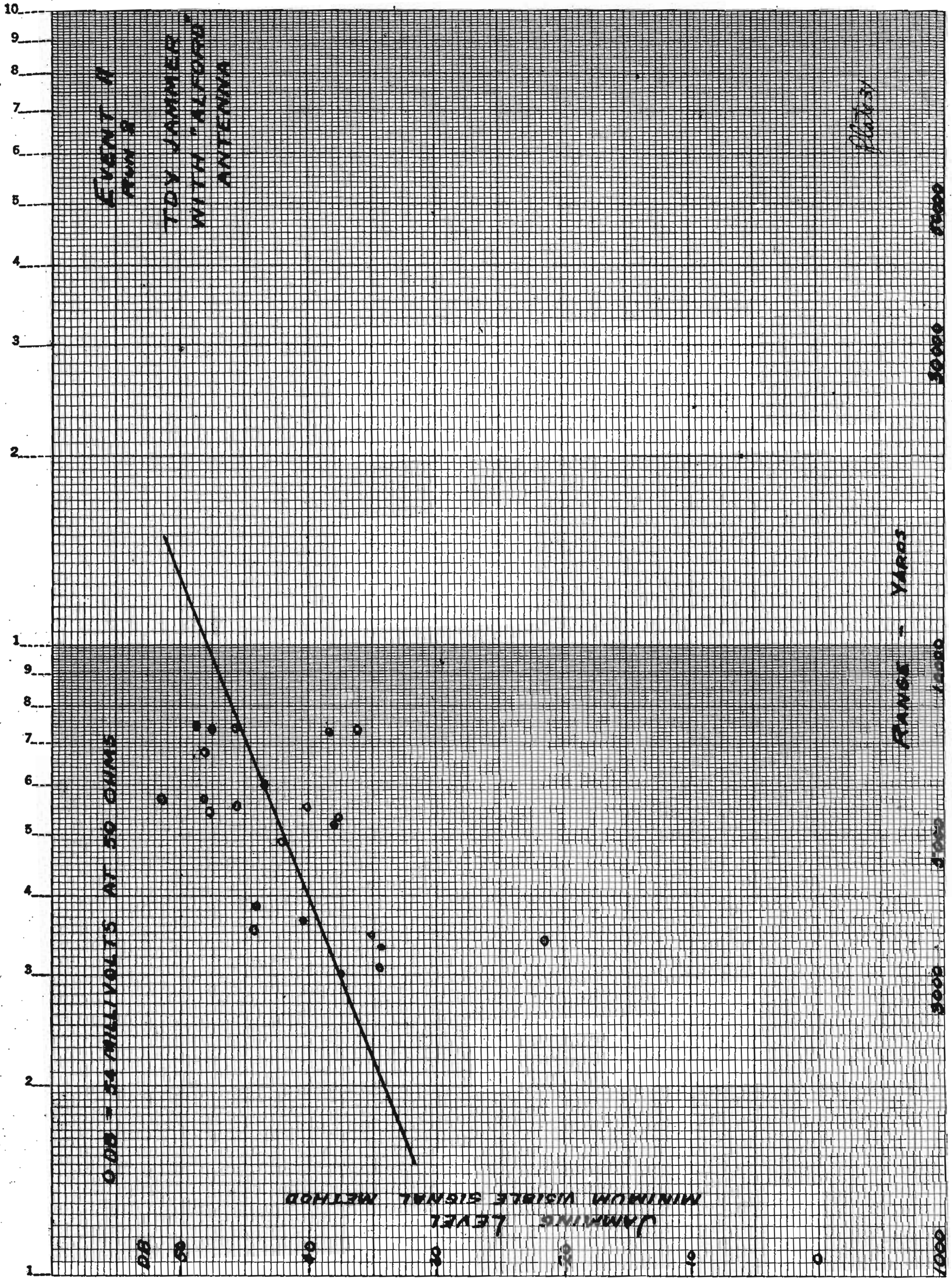

EVENT II
RUN 2
TOY JAMMER
WITH "ALFORD"
ANTENNA
0 DB = 54 MILLIVOLTS AT 50 OHMS
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
RANGE - YARDS

PLATE 31

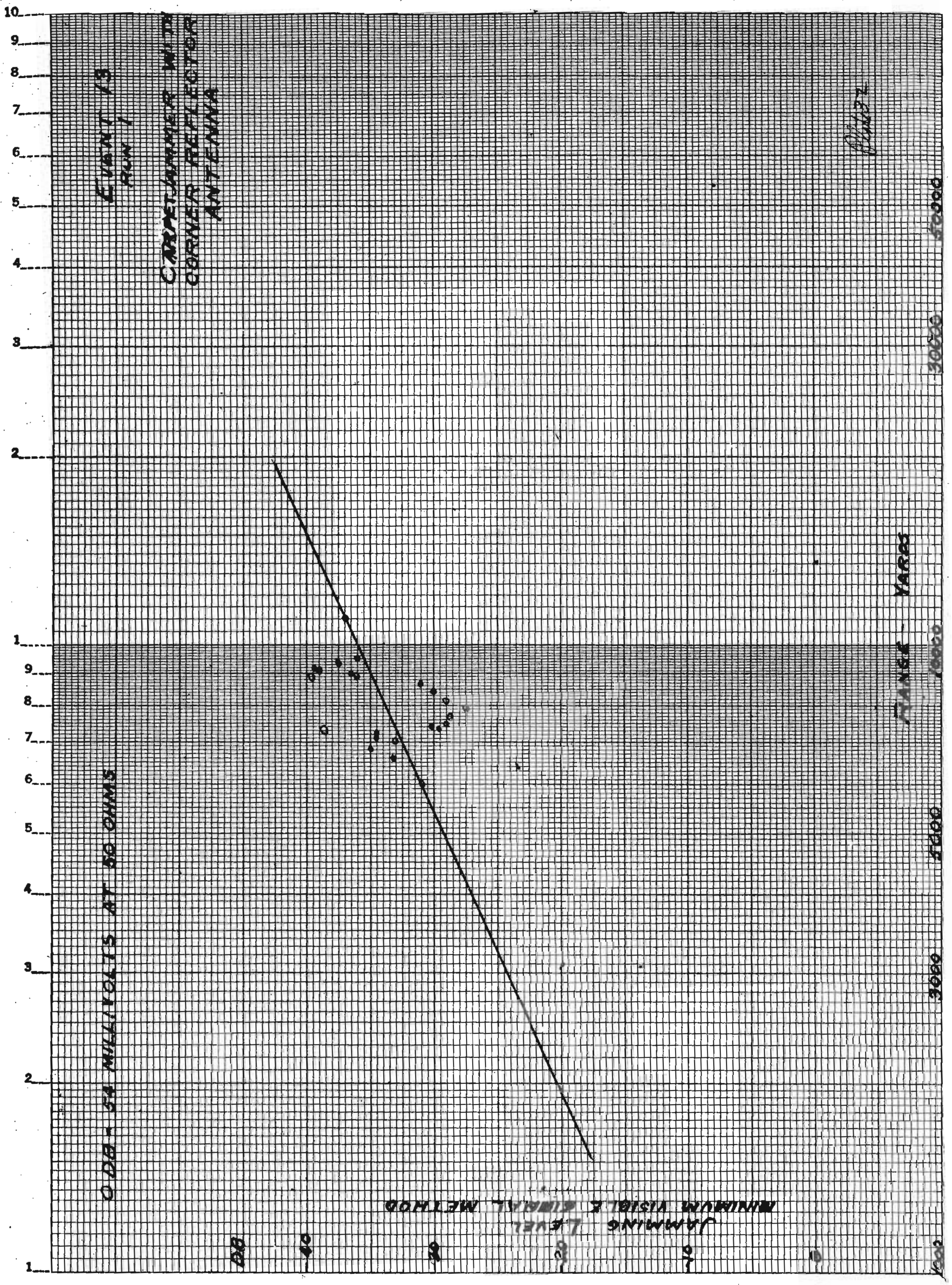

EVENT 13
RUN 1
CARPET JAMMER WITH
CORNER REFLECTOR
ANTENNA
0 DB - 54 MILLIVOLTS AT 50 OHMS
RANGE - YARDS
JAMMING LEVEL
MINIMUM VISIBLE SIGNAL METHOD
DB
50000
30000
5000
3000
40
30
20
10

PLATE 32

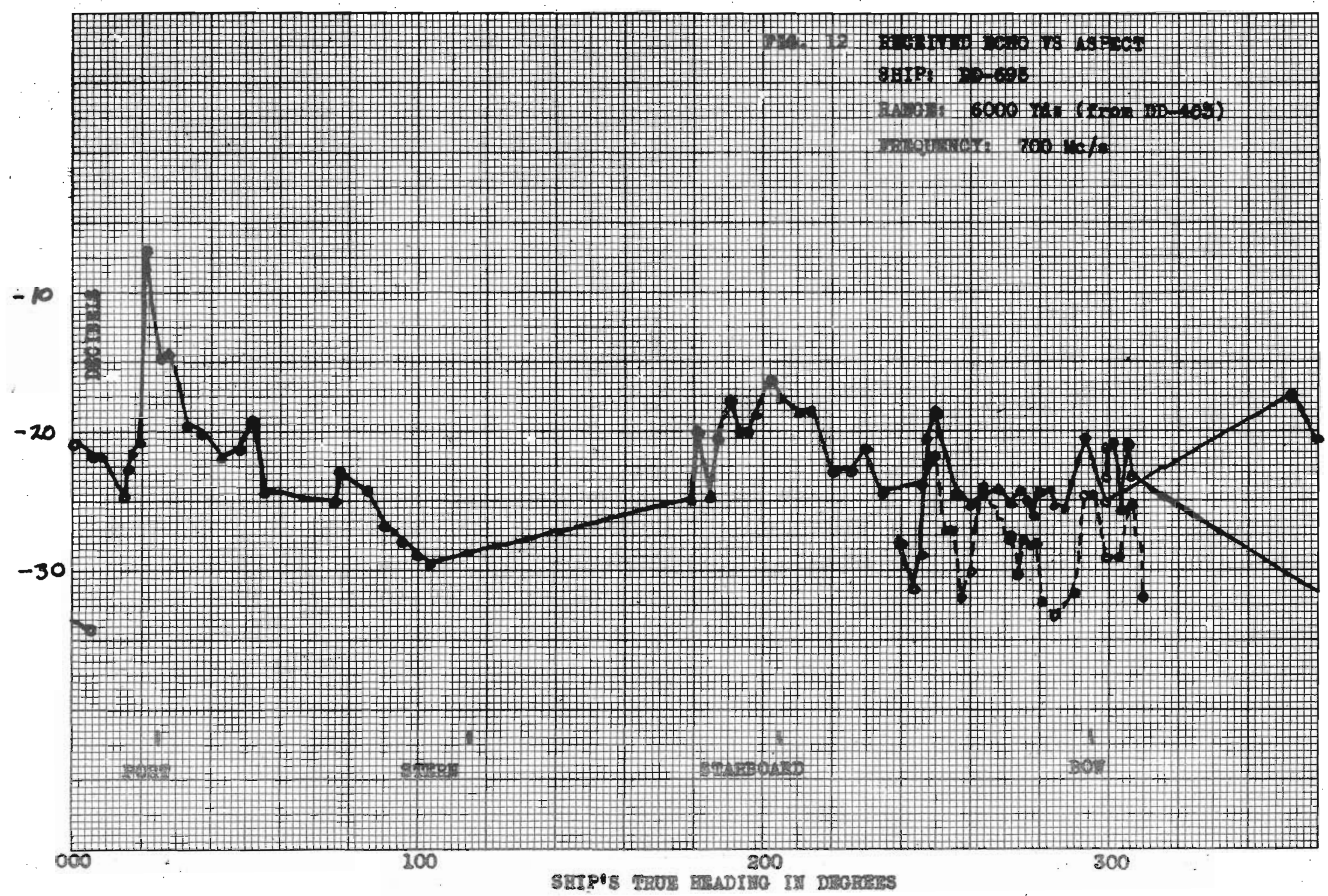


FIG. 12 RECEIVED ECHO VS ASPECT
SHIP: DD-695
RANGE: 6000 Yds (from DD-463)
FREQUENCY: 700 Mc/s
DECIBELS
-10
-20
-30
PORT
STERN
STARBOARD
BOW
000
100
200
300
SHIP'S TRUE HEADING IN DEGREES

PLATE 41

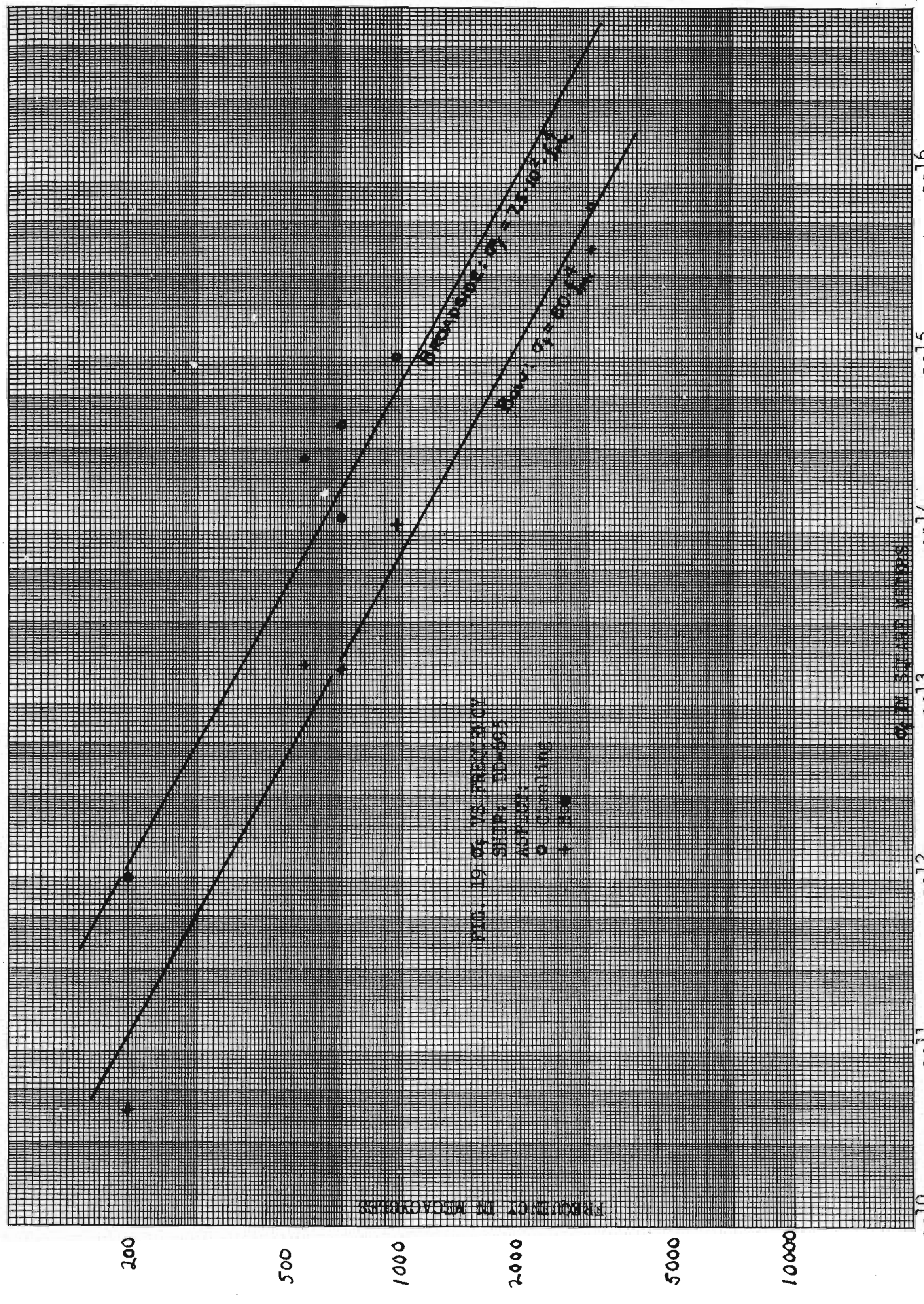


FIG. 19 VS FREQUENCY
SHIP, DD-693
200
500
1000
2000
5000
10000
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}

PLATE 42

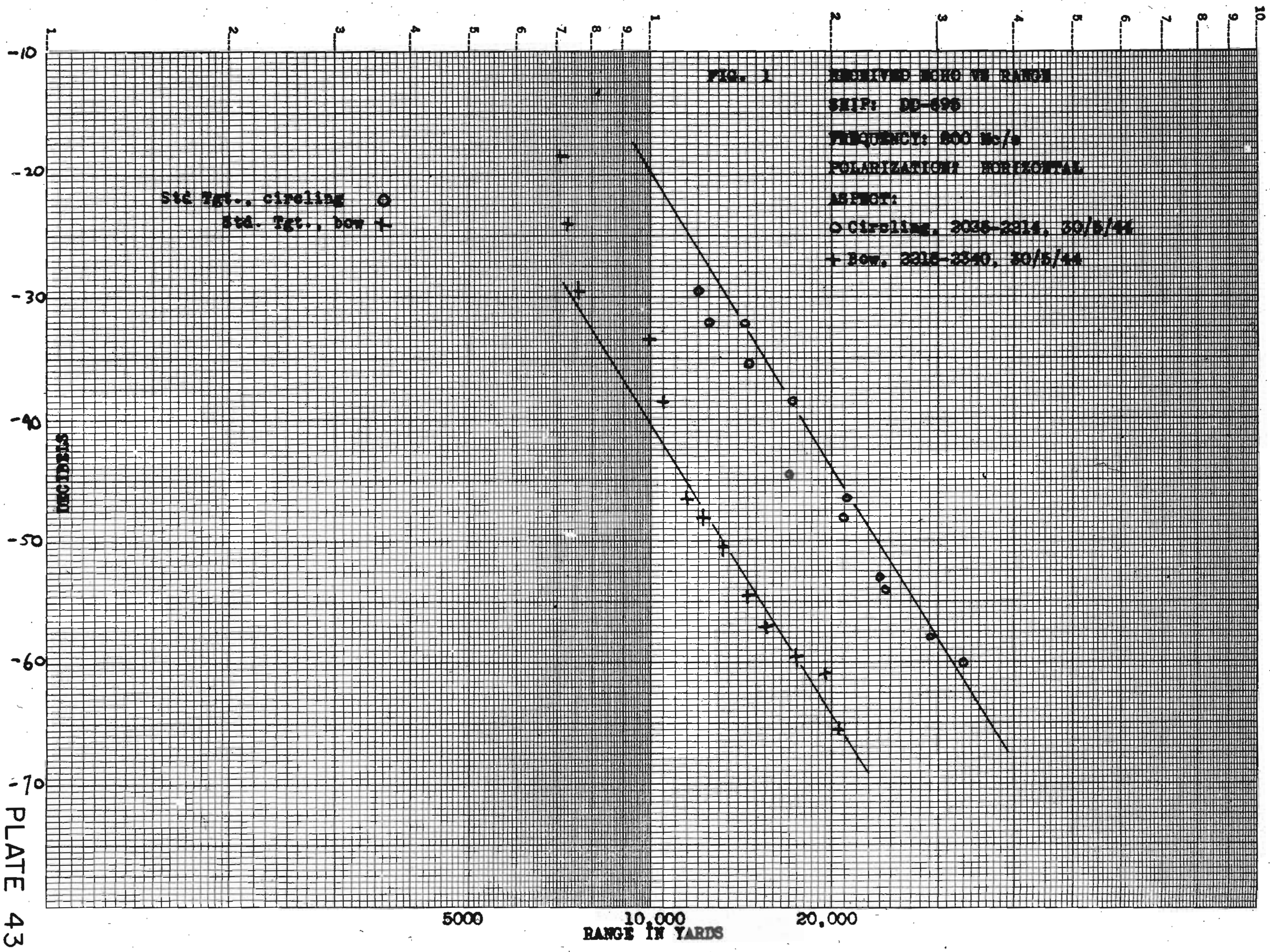


FIG. 1
RECEIVED ECHO VS RANGE
SHIP: DD-696
FREQUENCY: 800 Mc/s
POLARIZATION: HORIZONTAL
ASPECT:
○ Circling, 2036-2214, 30/5/44
+ Bow, 2215-2340, 30/5/44
Std Tgt., circling ○
Std. Tgt., bow +
DECIBELS
-10
-20
-30
-40
-50
-60
-70
1
2
3
4
5
6
7
8
9
10
5000
10,000
20,000
RANGE IN YARDS

PLATE 43

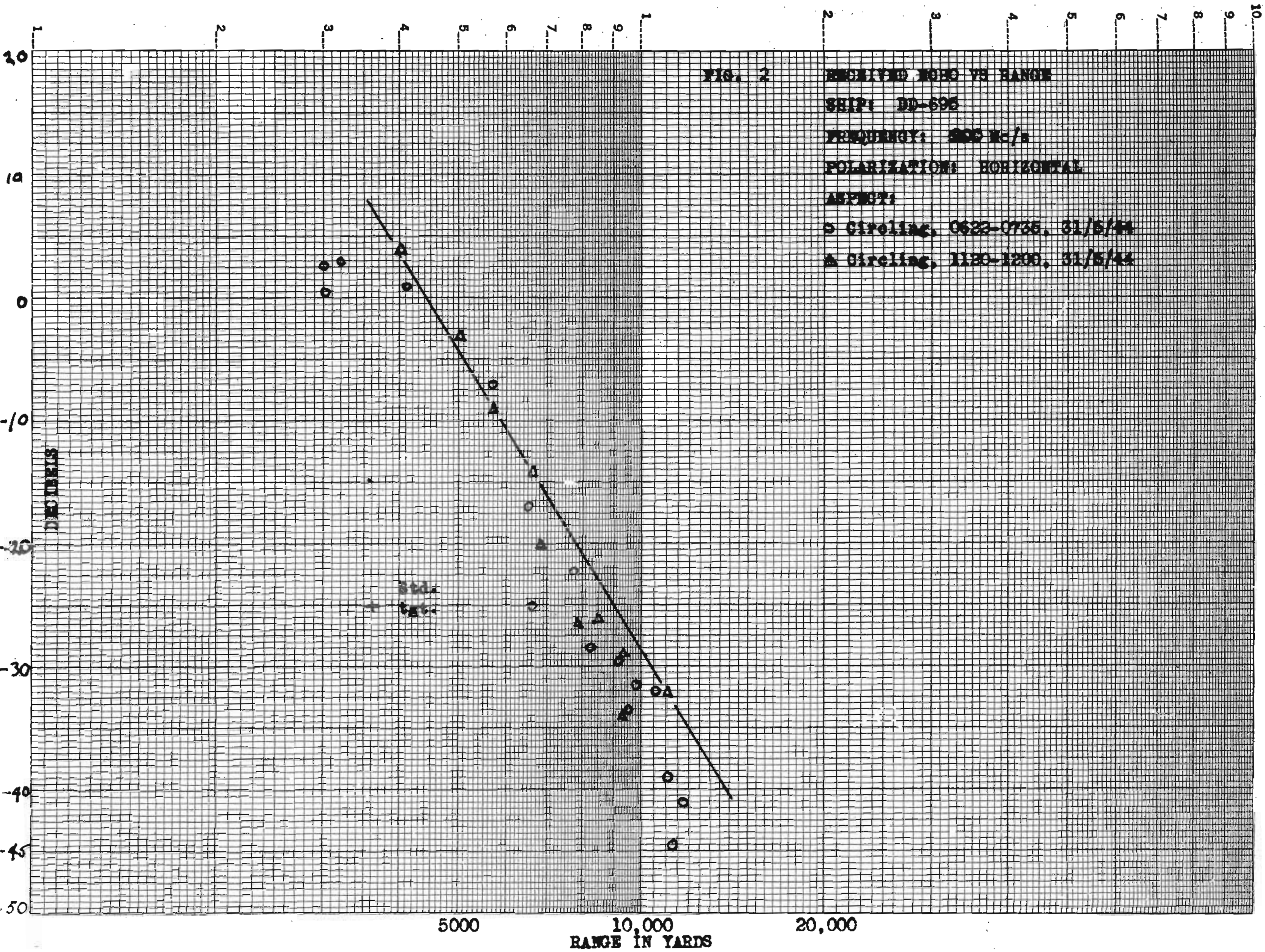


FIG. 2
RECEIVED ECHO VS RANGE
SHIP: DD-696
FREQUENCY: Mc/s
POLARIZATION: HORIZONTAL
ASPECT:
o Circling, 0623-0735, 31/5/44
Δ Circling, 1120-1200, 31/5/44
Std. tgt.
DECIBELS
10
0
-10
-20
-30
-40
-45
-50
5000
10,000
20,000
RANGE IN YARDS

PLATE 44

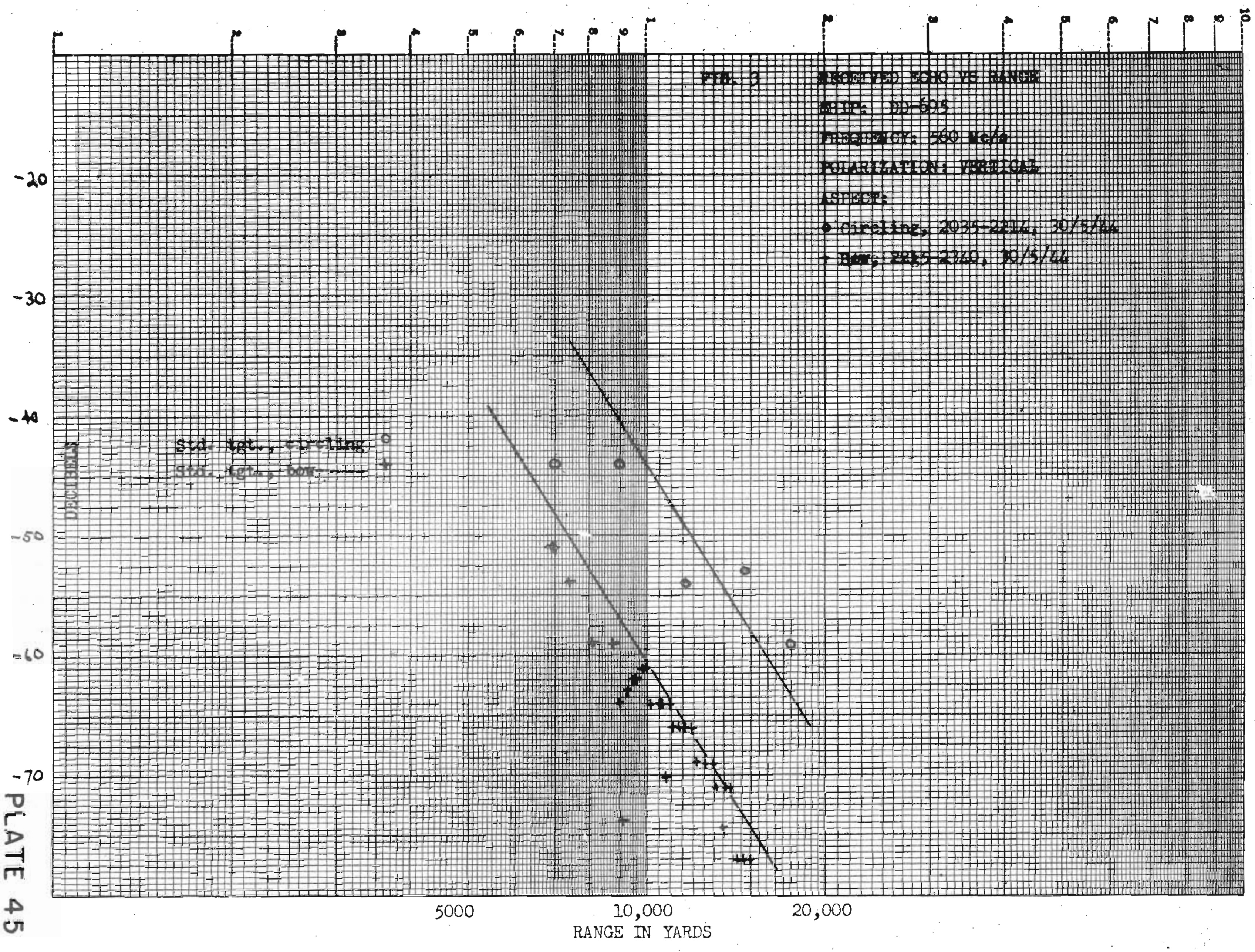


FIG. 3
RECEIVED ECHO VS RANGE
SHIP: DD-595
FREQUENCY: 560 Mc/s
POLARIZATION: VERTICAL
ASPECT:
o Circling, 2035-2214, 30/5/44
+ Bow, 2215-2340, 30/5/44
Std. tgt., circling
Std. tgt., bow
DECIBELS
-20
-30
-40
-50
-60
-70
5000
10,000
20,000
RANGE IN YARDS

PLATE 45

Supplement to TDY Destroyer Jamming Tests

1. Photograph #1 shows the main receiving and analyzing equipment including an APR-1 receiver, APA-6 pulse analyzer, RDK panoramic adaptor, LAE pulse signal generator, P-522 receiver, CXFE spectrum analyzer, "Carpet" jammer, "Rug" jammer, and slotted line.

2. Photograph #2 shows the monitor station set up on the aft deck house using an APR-1, RDK and APA-6.

3. Photograph #3 shows the forward receiving antenna located on the forward part of the bridge.

4. Photograph #4 shows the two TDY's with a monitor oscilloscope.

5. Photograph #5 shows the "Carpet" corner reflector mounted on the #2 forward five inch gun turret on a rotatable pedestal.

6. Photograph #6 shows the "Carpet" corner reflector on the main deck forward.

7. Photograph #7 shows the NRL "Oilcan" antenna on the #2 gun turret.

8. Photograph #8 shows the experimental RRL bent dipole mounted on the port side of the gun director.

9. Photograph #9 shows the "Carpet" corner reflector on the stub mast aft.

SECRET

Rectangular	$A = \pi nD$
Triangular	$A = (\pi nD)^2$
Cosine-Squared	$A = 2\pi nD\,(1-4n^2D^2)$
	$= 8\pi n^3D^3 \quad (nD >> \frac{1}{2})$

The frequency difference Δf between the n'th sideband and the carrier is nr since the sidebands are spaced r cycles apart. Hence, remembering that $\frac{D}{r} = t$, we have:

Rectangular	$\Delta f = \frac{A}{\pi t}$
Triangular	$\Delta f = \frac{\sqrt{A}}{\pi t}$
Cosine-Squared	$\Delta f = \frac{\sqrt[3]{A}}{2.9\,t}$

Example. - With a pulse length of 1 microsecond, the side bands are reduced to 0.01 per cent (A = 10,000) of the carrier at a frequency removed from the carrier by 3200, 32 and 7.4 megacycles, respectively.

The above results for a rectangular wave should not be taken too seriously for in practice such a wave form is never encountered. However, they do indicate the very large spread in the side bands which will accompany an approach to the rectangular shape. Hence, in the case of the D.C. pulse cable (carrier frequency = 0) supplying a magnetron where particular effort is made to obtain a pulse with steep sides there is the possibility of interference with communication receivers at fairly high frequencies. Also in the case of vacuum tube or magnetron jammers modulated with noise, there is the possibility of interference at frequencies remote from the carrier due to overmodulation, clipping or quenching during the modulation cycle.