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PHASESHIFTER STUDY

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An experimental phase-locked phase shifter was designed and tested. This phase shifter is intended for use as the local oscillator for a mixer, shifting the phase of a signal as it passes through. The output frequency was 915 MHz, though results are independent of frequency down to 12.8 MHz and up to at least 2 GHz. This makes phase shifter performance independent of signal bandwidth. This phase shifter is linear and stable over a ± 600 degree range. Maximum error from best straight line was + 2.3 and - 9.4 degrees, limited

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20. phase detector linearity. Settling time to within 10% was 1.6μs. Circuit description, schematic, and performance curves are contained in the report.

A dual element conical monopole antenna was interfaced with the phase shifter and a phase reference oscillator. Antenna patterns for this combination were recorded for frequencies from 7 to 15 GHz. These patterns are contained in Appendixes A through H. Omnidirectional beam steering was demonstrated and octave bandwidth was easily obtained.

microseconds

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1. INTRODUCTION

The "FLAT 360" antenna system proposed by Northrop in August, 1976 (NRTC 76-41P) offers an unconventional method of manufacturing a phased array antenna to obtain high gain, 360° steerability, and an octave bandwidth, together with adaptive nulling of undesired signals. The proposed antenna would provide full 360° azimuth coverage for five receivers simultaneously, with independent adaptive nulling of interfering signals for each receiver. A version of this antenna can be constructed to provide similar beam steering for one transmitter, with independent transistor power amplifiers for each antenna element. Beam steering would be accomplished by using multiple conversion with phase shifted local oscillators. By using identical phase shifted local oscillators in a matrix arrangement, a 144 element antenna can be pointed using only 6 phase shifters for beam forming, and an additional 16 phase shifters for adaptive nulling of interfering signals. For a 5 beam antenna, a total of 110 identical phase shifters and 15 phase reference local oscillators are necessary. This is a substantial reduction in the quantity of phase shifters required to implement the system, considering that the conventional approach for 144 antenna elements requires 720 phase shifters.

A prototype of the phase shifted local oscillators required for the "FLAT 360" antenna system referred to above has been developed during this program, and tests were conducted to determine its suitability for application in large-scale, octave-bandwidth, adaptive phased arrays. This prototype was designed to operate at 915.2 MHz, because this is the frequency required by the "FLAT 360" system, but the frequency choice will be seen to have very little effect upon the implementation technique, performance, or cost.

A pair of conical monopole antennas were designed and constructed for operation from 7 to 15 GHz. These were mounted on a ground plane, first singly and then together, and the antenna patterns were measured between 7 and 15 GHz. The phase shifted local oscillator was interfaced with the pair of antennas, and the ability of this phase shifter to rotate the antenna pattern was demonstrated. The phase between the antennas was varied, but not the amplitude, so it was possible to vary the direction of any pattern notch or peak, but the notch depth could not be maximized with this setup.

2. HARDWARE DESCRIPTION

The hardware assembled on this program consisted of a phase shifted local oscillator, a reference phase local oscillator, and a pair of conical monopole antenna elements which were mounted on a ground plane in order to make antenna pattern measurements for one or two elements, with variable phasing, over the frequency range from 7 to 15 GHz. A phase locked loop was used as the basis for the phase shifted local oscillator, and the reference phase oscillator was constructed identically except that no provision was made for phase shifting. The conical monopole antennas were constructed of copper foil over a plastic foam core, and were soldered to coaxial type N receptacles which were mounted on the ground plane.

2.1 Phase Shifted Oscillator Design

The phase shifted local oscillator can be efficiently implemented by using a phase locked oscillator to translate a change in reference voltage into a change of local oscillator phase. This technique was used to build the phase shifter for this program. Figure 1 is a block diagram of this phase shifter.

The phase shifter must provide 360 degrees phase change with addressability of ± 20 degrees relative to a reference phase. To achieve this kind of accuracy, it is important to evaluate the possible phase errors in the phase locked loop and minimize the error wherever practical.

2.1.1 Phase Detector Design

A very common type of phase detector, generally used in synchronous demodulators for communications systems, is the multiplier, in which a sinusoidal signal is multiplied by the reference signal. The resulting phase detector response is a sinusoid of the nature $V_{out} = K \sin \theta$, with θ equal to the phase angle and K proportional to one or both of the input signal amplitudes. This type of phase detector is only operable over a 180 degree detection

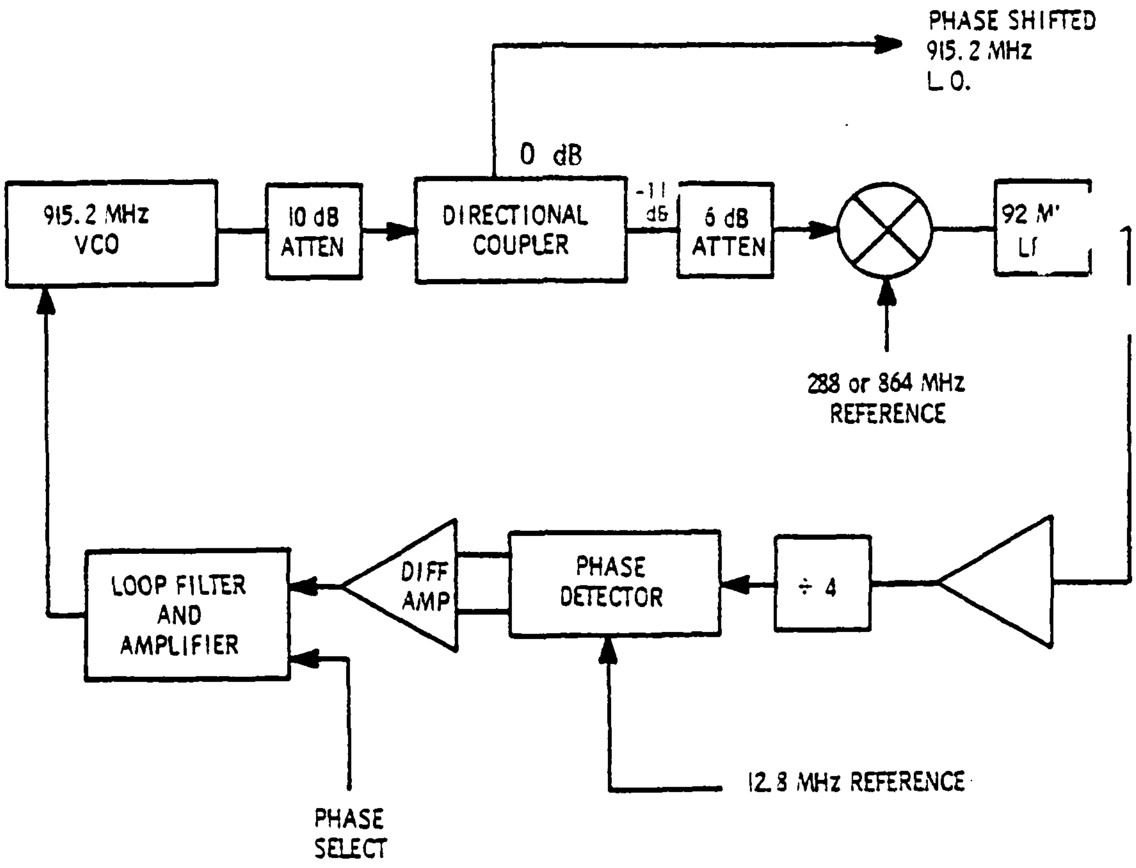


Figure 1. Phase locked phase shifter block diagram.

range, so something would be required to expand this to 360 degrees. This can be done by placing a divider inside the phase locked loop so that the phase change at the phase detector is a submultiple of the phase change at the VCO frequency. If a divide by 4 is used, as in Figure 1, then a ±180 degree phase shift at 915 MHz is represented by ± 45 degree phase shift at 12.8 MHz. For use with an antenna pattern optimizer, it is necessary to have an excess phase adjustment range so that a 360 degree correction (required to get back within phase shifter range after the maximum phase adjustment is reached) is not required when the phase is dithered to test the quality of the antenna pattern null. A reasonable choice here is to require the phase shifter to shift ± 270 degrees while still maintaining the required accuracy. Inside the loop, this is only ± 67.5 degrees, which is well within the tracking range of the loop. Unfortunately, the sinusoidal response of the phase detector causes the gain with this 67.5 degree offset to be only 38% of the gain when the offset is zero. This substantial nonlinearity would not only cause the phase control characteristic to be nonlinear, but would also substantially change the frequency response of the loop, and nonlinearity correction would be required if this phase detector were used.

The most significant advantage of the sinusoidal phase detector is low power consumption. However, in addition to its nonlinearity, it is also amplitude sensitive. An alternative phase detector which is inherently linear and amplitude insensitive should present a better choice.

To obtain a phase detector output which is a sawtooth function of phase, as in Figure 2, a sample and hold circuit or a clocked flip-flop may be used as a phase detector, as shown in Figure 3. The sample and hold phase detector is ideal, since its output remains constant at all times once the loop is locked. The flip-flop detector yields identical performance if the output is low-pass filtered so that only the dc component remains. With either phase detector, the operating range of the detector extends over a full

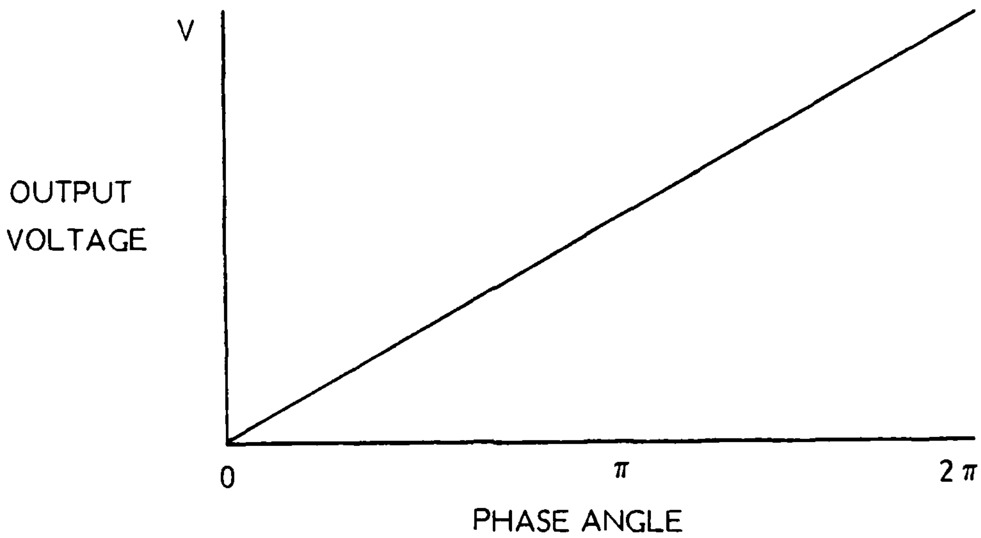
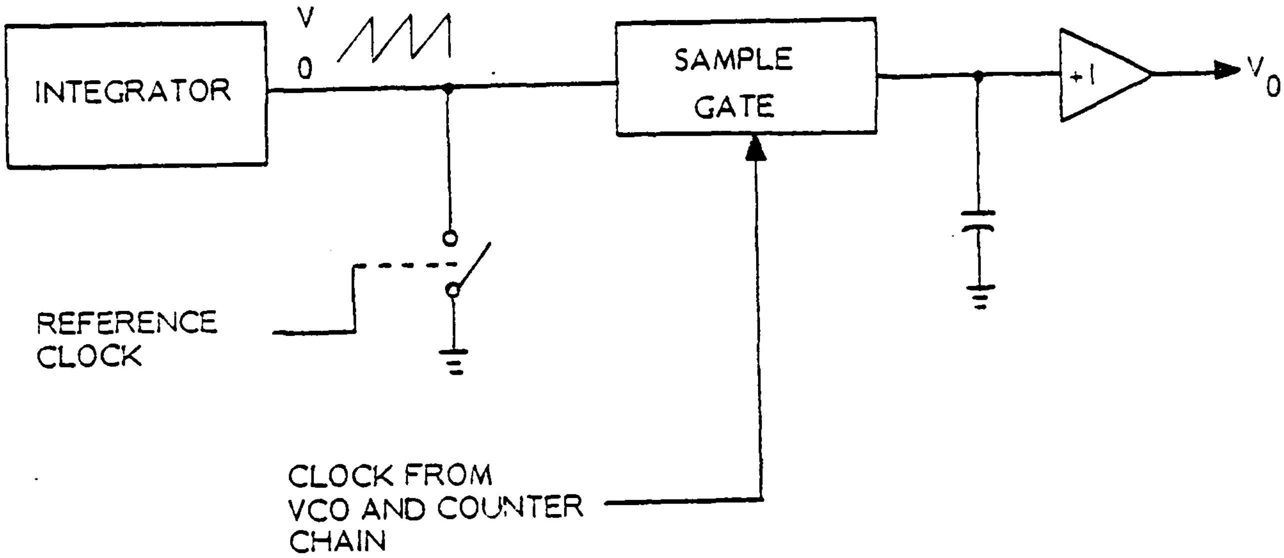
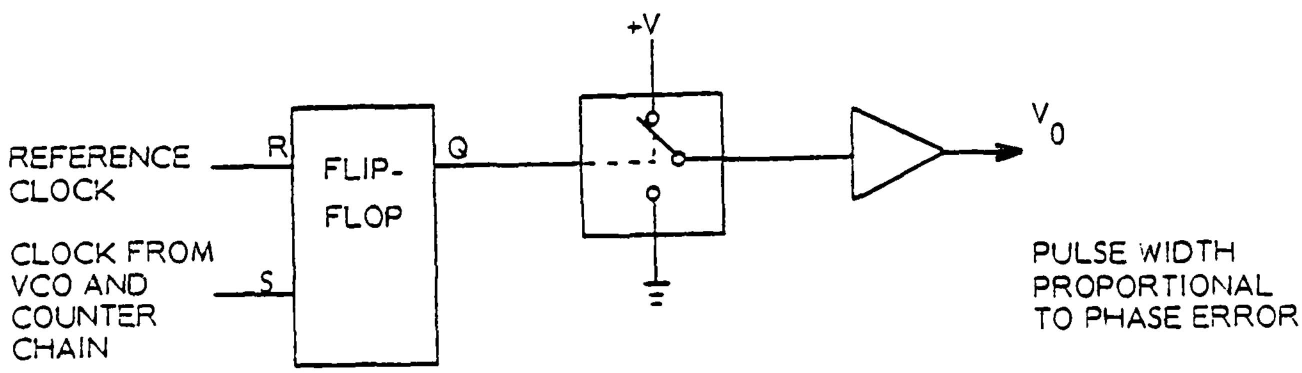


Figure 2. Sawtooth phase detector curve.



a. SAMPLE AND HOLD PHASE DETECTOR



b. FLIP-FLOP PHASE DETECTOR

Figure 3. Sawtooth phase detectors.

360 degrees, less a small allowance for clock widths. It should be possible to obtain the desired ± 270 degree output adjustment with only a divide by 2 counter in the phase locked loop.

Implementation of the phase detector using the flip-flop circuit was given serious consideration. ECL flip-flops of the MECL 10k variety should operate readily in this circuit using clocks of 12.8 or 25.6 MHz. However, it is also desirable to have very high open loop gain in order to minimize the phase error caused by steady-state drift, particularly of the VCO tuning characteristic. Also, the resting frequency of the loop must be accurate enough to allow initial acquisition of the loop when power is turned on, even in the presence of maximum phase-shifting voltage. These are contradictory parameters, since an increase in open loop gain will cause a larger offset in tuning, and the presence of a phase-shifting voltage may well keep the loop out of the lock range. This indicated that it may be necessary to sense loss of lock and switch the loop to an acquisition mode to reacquire.

There are several phase detectors on the market which operate to sense the edges of two pulse trains and maintain lock by generating positive or negative pulse slivers to control the VCO. These detectors generally operate into an integrator, and operate in a manner to maintain zero phase shift between the pulse trains. Such a loop would not be stable in the out of lock condition, so these phase detectors incorporate a second operating mode which senses an out of lock condition when one of the pulse trains triggers the phase detector more often than the other pulse train. When this occurs, a high or low output with duty cycle proportional to frequency offset is generated, depending upon which output is the higher frequency, and this voltage drives the loop in the direction to reduce the frequency error until phase lock is acquired. Thus, these phase detectors can be used in a loop with near infinite dc gain, and will automatically reduce the frequency error so that phase lock is possible.

The Motorola MC12040 ECL phase detector was chosen for use on this program. A block diagram of this integrated circuit is shown in Figure 4. This phase detector is normally operated into an integrating buffer amplifier so as to maintain the output pulses as slivers, thereby reducing the phase offset near zero degrees. However, the phase detector outputs are not just slivers, but will remain high during the entire time of a phase offset in one direction, from 0 to 360 degrees, and will remain low during the entire time of a phase offset in the opposite direction, from 0 to 360 degrees. This phase detector is actually capable of measuring phase errors over a full 720 degree range, without ambiguity, as the flip-flop in the phase detector remembers which pulse train was present first. Though there would appear to be an ambiguity in this determination of the first pulse train, actually there is no ambiguity because only one decision will produce outputs which drive the loop into lock. If the other decision occurs during acquisition, the loop will cycle-slip until the correct decision is made, then it will lock. The duration of the output pulse is a linear measure of the phase error, therefore the phase control will be nominally linear, and the loop gain (and bandwidth) will remain constant as phase is varied. This phase detector appears to operate linearly over the entire required region of ±270 degrees, which is equivalent to ± 1080 degrees at 915.2 MHz because of the divide by 4 counter in the loop. Operation of the completed phase shifter showed nonlinearities which appeared every 360 degrees, but otherwise the transfer function was equally linear for ± 820 degrees or more. Inclusion of the divide by 4 counter in the loop did not make any measurable difference in linearity, but it did allow smaller offset voltages to be programmed to obtain the desired phase shift. This is important because the loop will reliably acquire phase lock only when less than 150 degrees of phase offset is requested (measured at 12.8 MHz).

A schematic of the complete phase shifted local oscillator is shown in Figure 5. The inputs to the phase detector are buffered with an MC10216

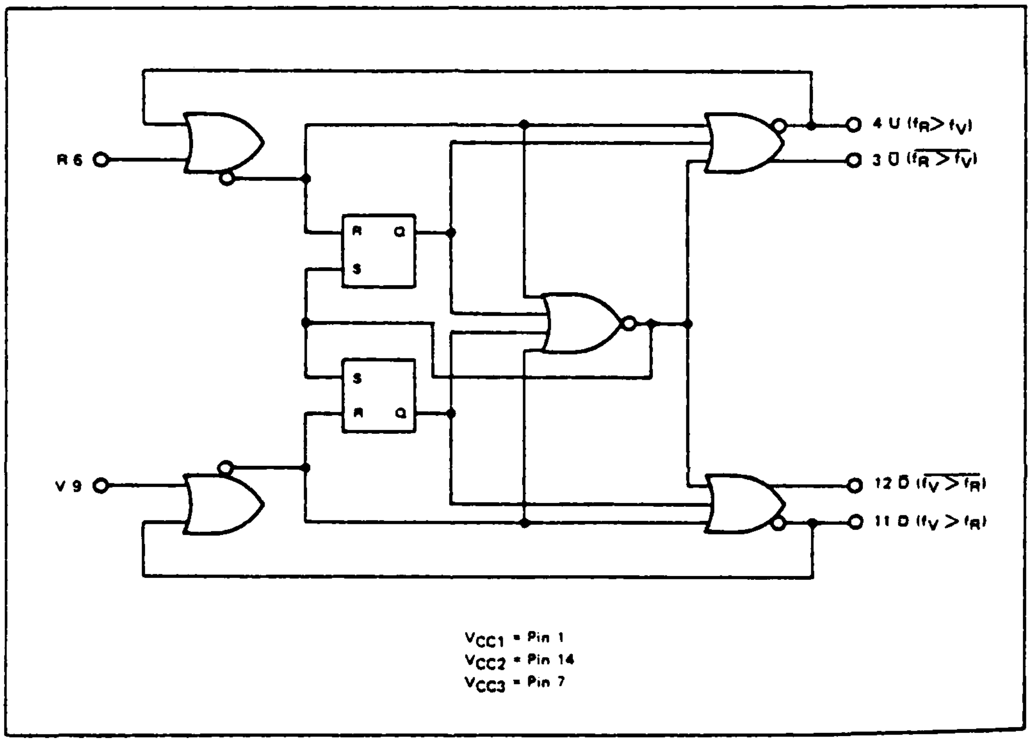
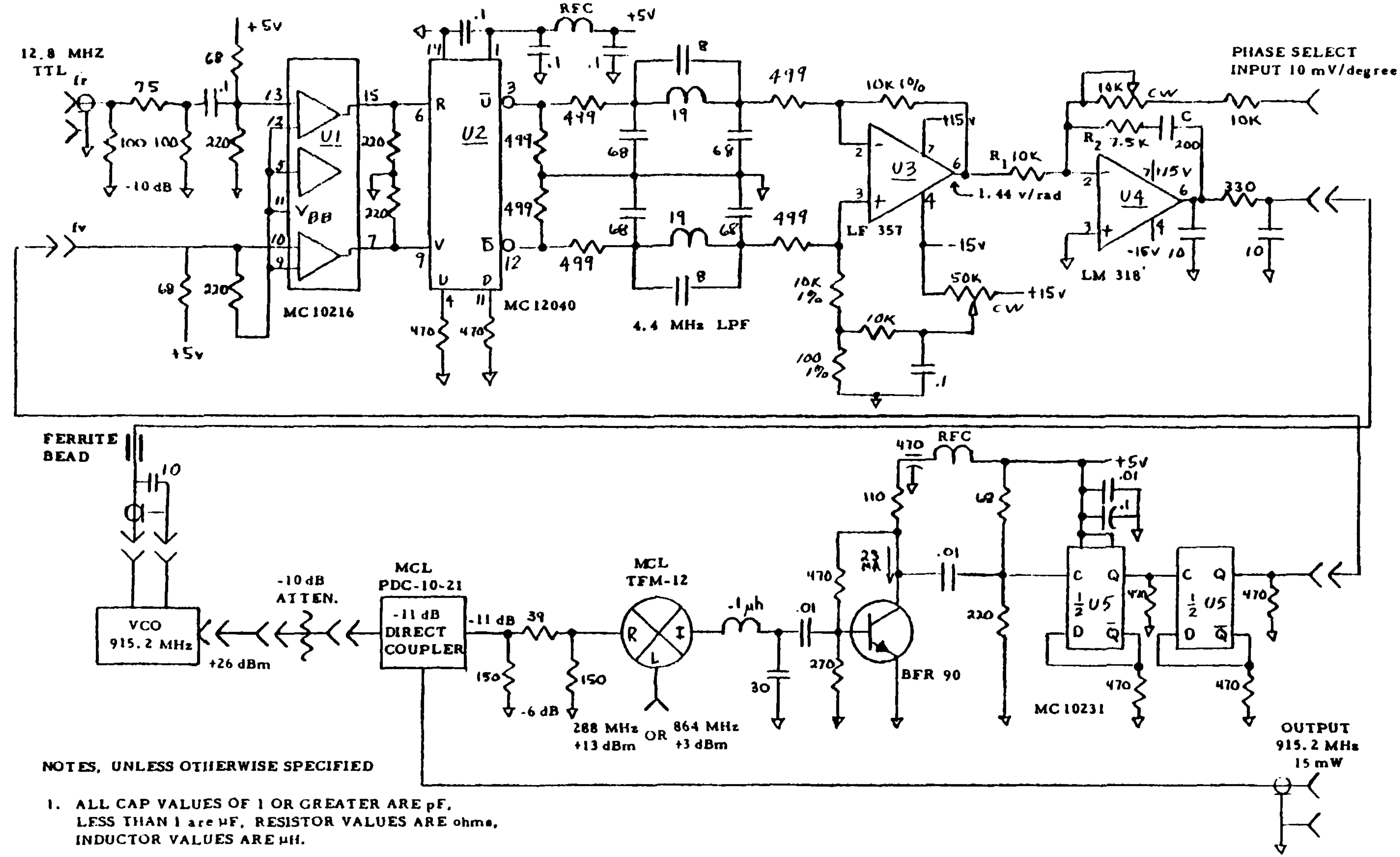


Figure 4. MC 12040 phase-frequency detector block diagram.



NOTES, UNLESS OTHERWISE SPECIFIED

1. ALL CAP VALUES OF 1 OR GREATER ARE pF, LESS THAN 1 are μF, RESISTOR VALUES ARE ohms, INDUCTOR VALUES ARE μH.

2. RF CHOKES ARE 6T AWG 32 ON FAIR-RITE 264300101 BEAD.

Figure 5. Phase shifted local oscillator schematic.

high speed line receiver. This device was included to sharpen the edges of the 12.8 MHz or 25.6 MHz reference clock, which was driven from a laboratory source incorporating a TTL line driver. This phase detector is capable of operation to 80 MHz, and will respond to pulses only 2 nanoseconds long. In order to avoid reflection pulses which may affect the phase detector, the TTL frequency reference usually must be transmitted on a matched transmission line of either 50 or 75 ohm impedance, meaning that the input impedance of the phase detector must be either 50 or 75 ohms. A very convenient and effective TTL to ECL level translator in this instance becomes a 10 dB resistive attenuator pad followed by a coupling capacitor to an ECL gate which is biased at the ECL threshold, as is shown in this schematic. This supplies approximately 1.1 V_{p-p} to the 10216 input buffer. The inputs to the 10216 are both biased using 220 ohms to ground and 68 ohms to +5V, providing a 52 ohm input impedance and 3.82V bias voltage. An input of the unused buffer in the 10216 is connected to the 3.76V V_{BB} on the device in order to properly load the internal bias networks. The buffer and termination on the f_v line are not necessary, since this is driven from an ECL device in this module, but it was included to allow testing using 50 ohm laboratory generators. It is possible that this 10216 device could be eliminated or replaced with a transistor drawing much less power, depending upon the nature of the distribution network for the 12.8 MHz reference.

The two outputs of U1 drive the R and V inputs of the 12040 phase comparator, U2. There are four outputs from U2, only two of which are used. The unused U and D outputs are terminated in 470 ohm resistors to ground, to enable these outputs in case that is necessary for internal operation of the 12040 (the data sheet is unclear about this).

The $\overline{U}$ output is a negative pulse when R is leading V, at which time the $\overline{D}$ output is a constant high level. If V is leading R, then the output conditions are reversed. The duration of the negative pulse from either output is proportional to the phase shift between the signals applied to the V and R inputs. If R and V are separated by an offset frequency, then the output duty cycle becomes proportional to the offset frequency and the device functions as a frequency discriminator, which will cause the loop to decrease the offset frequency until phase lock can be achieved.

The outputs of the phase detector possess a large dc component of approximately 3.72V, which will vary with temperature and is also proportional to the +5 V supply voltage. These signals must be amplified using a differential amplifier in order to minimize the effect of this dc component. In phase locked loops of this type, the differential amplifier and an integrating loop filter are often combined in one operational amplifier. This could have been done here, thereby simplifying the circuit further, but there would have been no point in the circuit where the phase control voltage could have been injected, unless this were done differentially also. The phase detector outputs drive amplifier U3, an LF357 operational amplifier which is connected as a differential amplifier with a voltage gain of 10. This amplifier is a decompensated unit (it will oscillate if gain is set less than 5) which has 2.5 MHz bandwidth at this gain. The gain of this amplifier was set with 1% resistors, allowing a common-mode error of .3% plus .1% caused by the offset adjustment at the + input of the amplifier. These resistors should be .5% tolerance in a production unit, and the offset adjuster should be moved to the loop filter stage so that its injection resistor does not upset the common-mode rejection of the differential amplifier. If this is done, the common-mode gain will be only .15% of normal mode gain, and 100 mV of common-mode voltage shift on the 12040 output will shift the output of U3 by only 1 mV, which is equivalent to .16 degree error in the 915.2 MHz output phase.

When no phase offset is programmed, the outputs of the 12040 phase shifter are thin sliver pulses, and there is very little residual 12.8 MHz component. However, when a phase shift voltage is injected, the detector output pulse width will increase to as much as a square wave, providing substantial frequency components at 12.8 MHz and all its harmonics. This caused 12.8 MHz harmonic sidebands to appear on the 915.2 MHz output until a low-pass filter was installed to reject them. It is desirable to provide this filtering before the signals can enter U3 and generate distortion, so two identical filters were installed on the two lines between the phase detector and the differential amplifier. To minimize phase shift in the loop, the low-pass filter was designed for as high a frequency as practical, while still rejecting 12.8 MHz. For the same reason, and for cost, the filter should have only three poles. The filter was designed as a 3 pole elliptical filter with a 4.375 MHz corner, with .098 dB ripple. The design was chosen to provide its infinite notch at 12.8 MHz while maintaining at least 30 dB attenuation throughout the stopband. The filter response was plotted, using a network analyzer and an X-Y plotter, to verify this amplitude and phase response. This response plot is shown in Figure 6. It can be seen that there is 60 dB loss at 12.8 MHz, and over 30 dB for all the harmonics. There is 22 degrees phase shift at 1 MHz, which will cause a negligible 3 degrees phase shift at the loop corner frequency of 150 kHz.

The phase detector gain was measured at the output of U3 in order to estimate detector linearity and calculate loop filter parameters. The gain was measured at 12.8 MHz for phase shifts of -60 degrees to 60 degrees, and this is plotted in Figure 7. The line drawn on the plot is a least squares curve fit to the data, and this shows that the nonlinearity errors are quite small, with maximum nonlinearity occurring in the region of 0 to 10 degrees. The measured gain is 25.2 mV/degree, or 1.44 V/radian.

2.1.2 Voltage Controlled Oscillator and Mixer-Divider

The voltage controlled oscillator (VCO) generates the 915.2 MHz phase-shifted output signal. A sample of this output is also taken, and this sample is compared with a reference signal to generate an error voltage

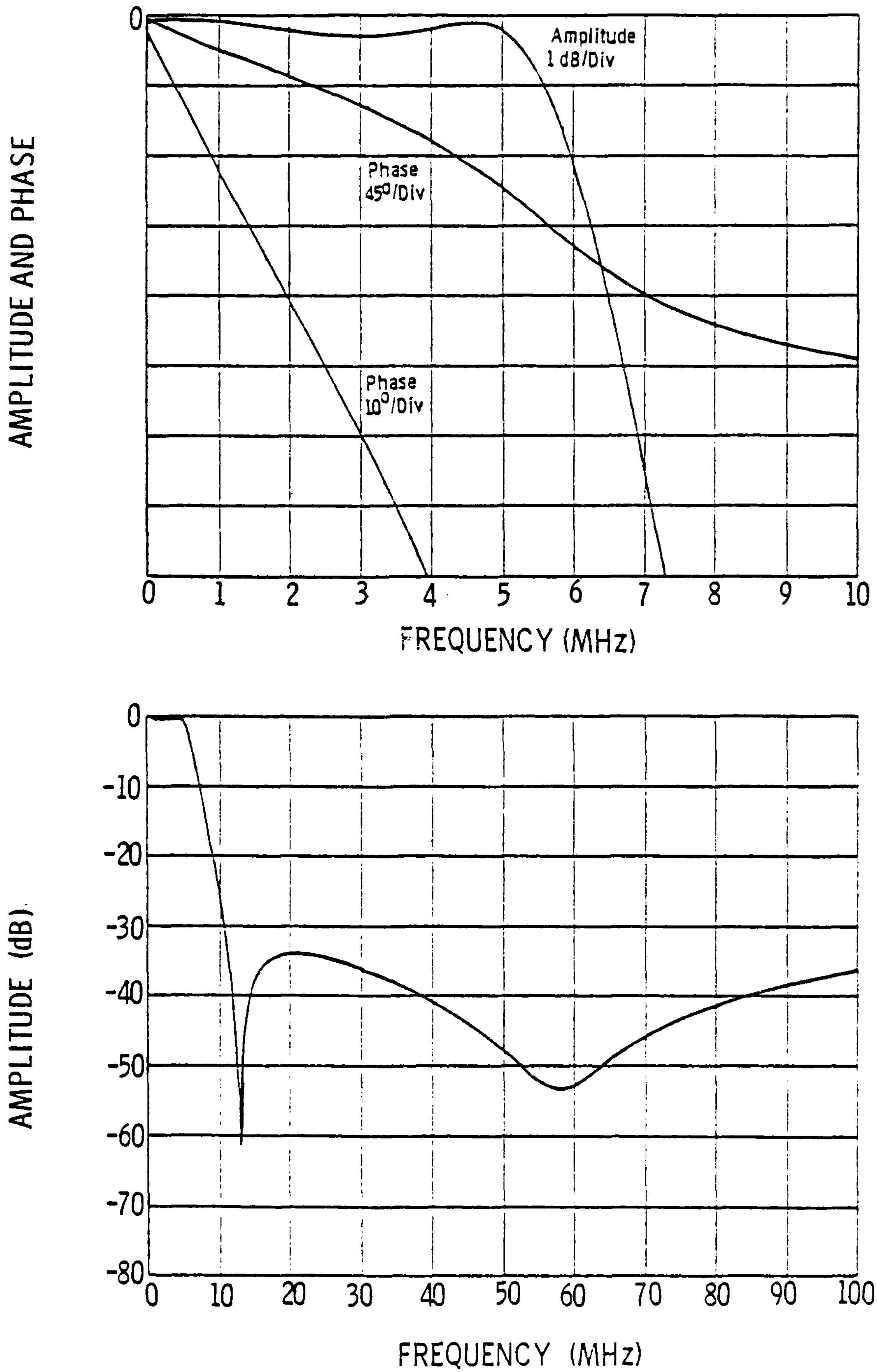


Figure 6. Response of 4.4 MHz 3 pole low pass filter.

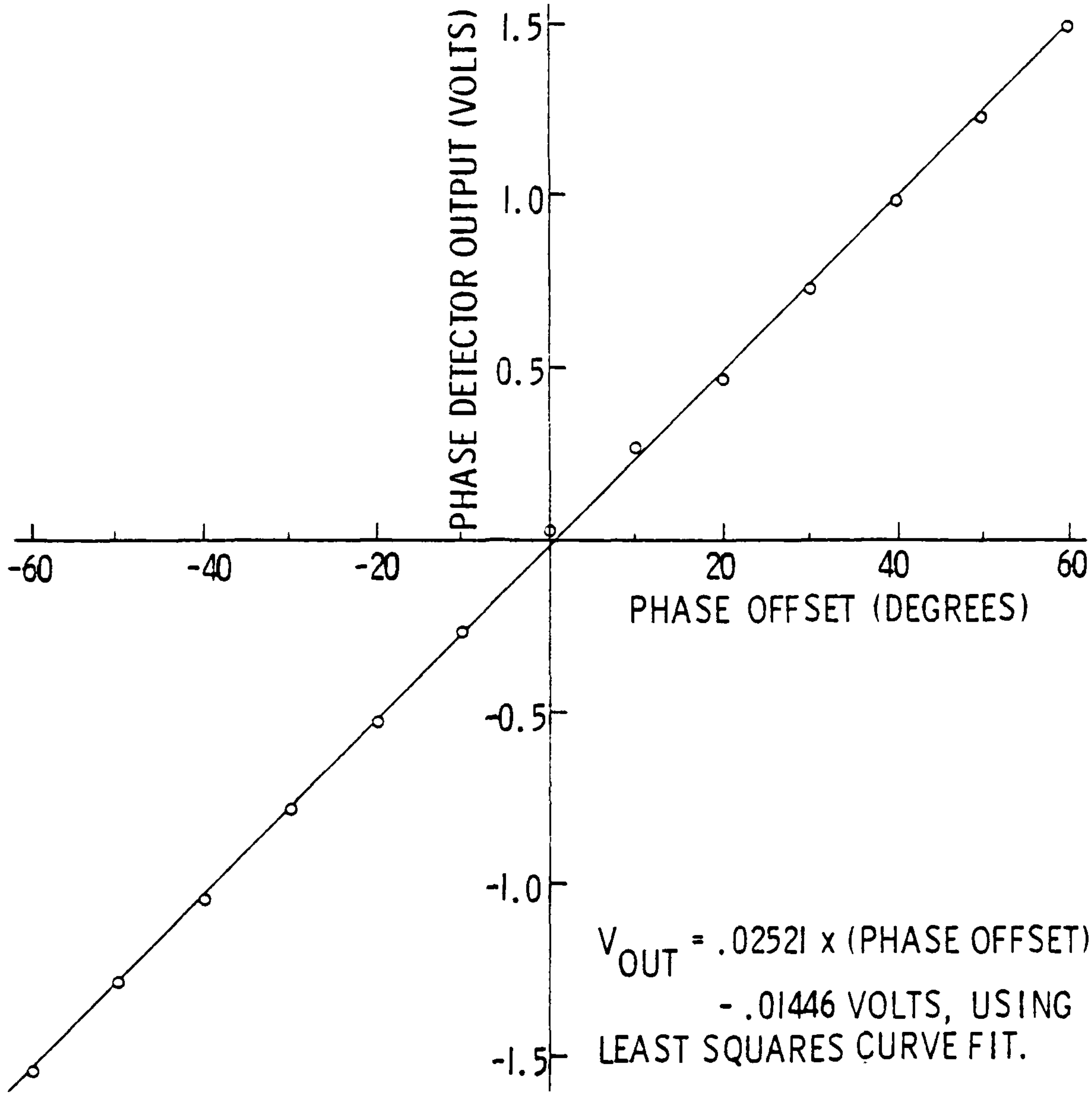


Figure 7. Phase detector voltage response.

proportional to the phase offset between the sample and the local reference. This error voltage is amplified and filtered, and used to control the VCO frequency in order to eliminate any frequency or phase error.

A very critical parameter for the phase shifter is the isolation of the reference signals (nominally 12.8 and 864 MHz) from the output signal. Good design practice calls for spurious signal suppression of at least 70 or 80 dB in order to achieve a similar level of suppression of spurious responses in the receiver. The choice of a VCO and its interfacing circuits control the level of the 864 MHz spurious, which is a signal which will pass from the mixer local oscillator port back to the main output of the VCO with some sort of predictable attenuation. The attenuation required here is approximately 70 to 80 dB, which must be provided by the combination of mixer isolation, attenuation, and power divider isolation. The mixer can be relied upon for 25 dB isolation, but the rest must be provided by other devices. An approach which will usually yield enough isolation is to follow the VCO with an attenuator, power divider, and a buffer amplifier on each output line, followed by a 10 dB attenuator in the line to the mixer. This will typically provide 80 dB isolation from the 864 MHz reference to the 915.2 MHz signal output.

The chosen technique for this study was to purchase a low cost cavity stabilized VCO with 350 milliwatts output, and use attenuators and directional couplers to isolate the VCO from the load and to isolate the 864 MHz from the VCO output. The VCO output first drives a 10 dB attenuator to provide load isolation to the VCO and to establish an accurate 50 ohm output impedance. The rest of the RF components are mounted on a circuit board which includes a ground plane. An 11 dB directional coupler provides a sample of the output, at a power level of approximately 1 mW, while providing a reverse isolation of 30 dB. The phase shifter output is taken directly from the straight through port of this directional coupler, with a level of approximately 15 mW. The reference output from the coupled port goes through

6 dB pad (12 dB isolation) to the R port of a miniature double balanced mixer where it is mixed with either 288 MHz or 864 MHz to provide a 51.2 MHz IF signal for further processing. The mixer provides an additional 25 to 35 dB isolation, for a total isolation of 67 dB back to the 915.2 MHz output. The use of a 288 MHz LO provides slightly higher isolation because the 864 MHz mixing frequency exists only inside the mixer, where it is generated by clipping in the mixer diodes, and therefore no 864 MHz is coupled between components of the circuit board.

Identical VCO's were procured for both the phase shifted loop and the reference phase locked loop. Initially, both VCO's showed tuning characteristics ranging from 400 kHz/V at 20 V tuning bias to 1300 kHz/V at zero volts bias. However, during testing, the varacter diode of one VCO, serial number 389, was accidentally destroyed, and the manufacturer supplied his normal replacement diode instead of the higher gain unit used in these VCO's, which resulted in a 40 to 60 percent reduction in the gain of this VCO. This gain reduction made it impossible to achieve as wide a loop bandwidth as desired for rapid phase control, but there is no bandwidth requirement on the reference phase locked loop so this unit was used in the reference loop, with an appropriate adjustment of loop filter parameters in order to obtain a stable loop. The tuning characteristics of both VCO's were measured so that the operating point could be chosen and to provide gain parameters for calculation of the initial loop filter components. From the tuning curves the differential VCO gain was calculated between adjacent data points. The tuning and gain curves for VCO serial number 388 are plotted in Figure 8, and these curves for serial number 389 are plotted in Figure 9. Evaluation of these curves indicated that the center of the tuning range is approximately 5 volts, so that voltage was chosen as the nominal control voltage for which the loops were designed. In operation, the VCO is initially adjusted to 915.2 MHz with 5V applied to the VCO control line, then the loop is locked and the VCO tuning knob is adjusted to obtain 5V on the control line while the loop is locked.

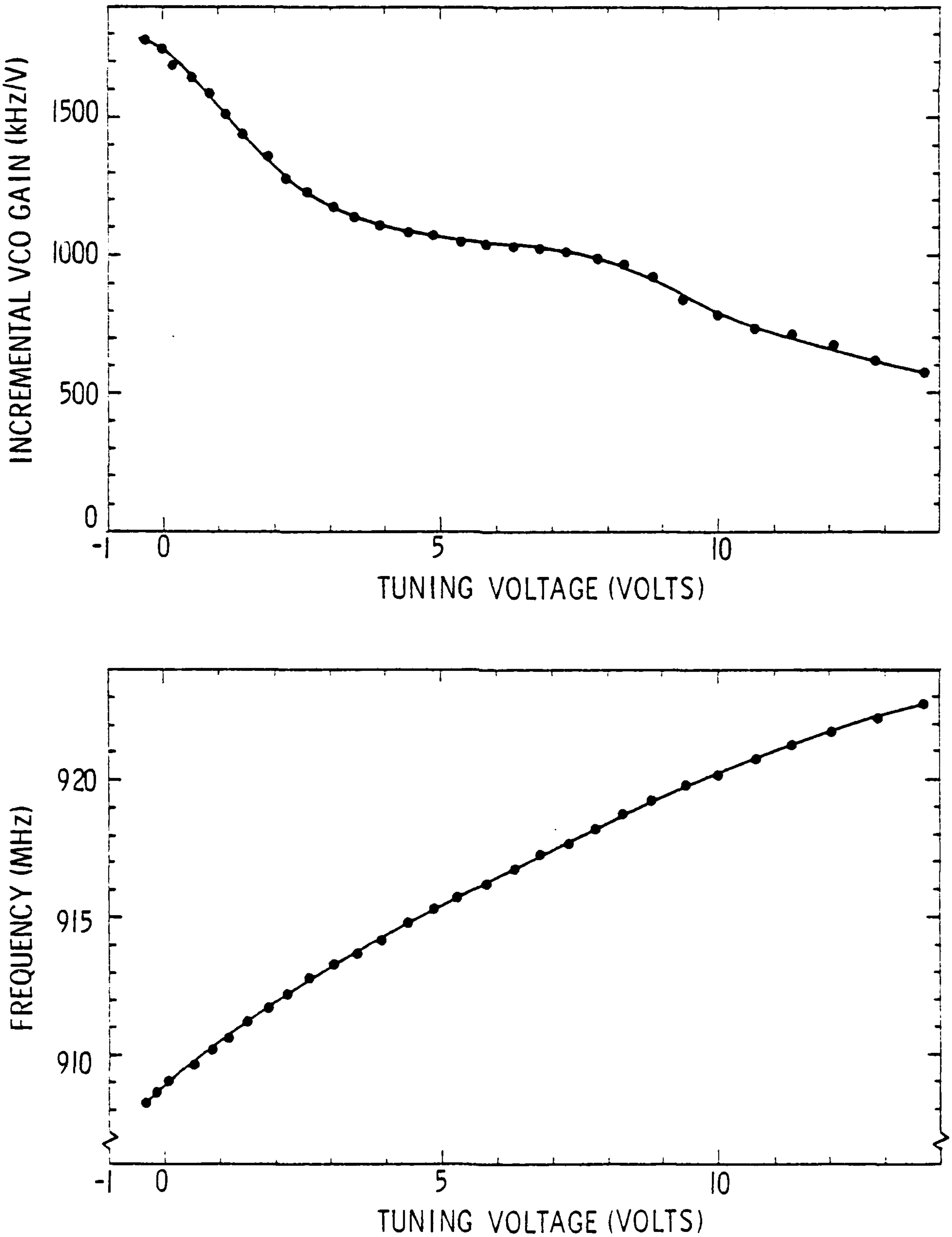


Figure 8. Voltage controlled oscillator tuning characteristics (S/N 388). This oscillator is used in the phase-shifting PLL.

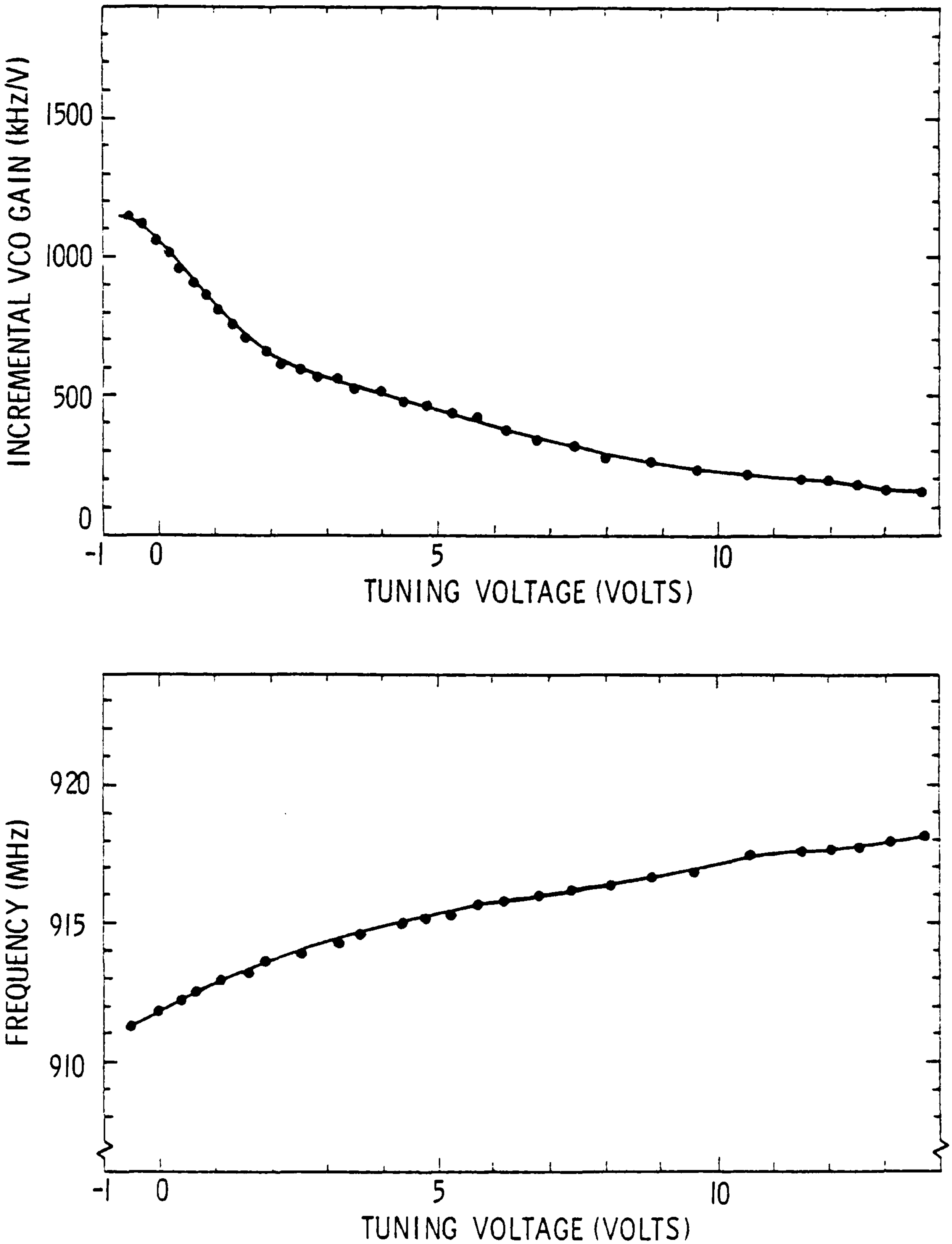


Figure 9. Voltage controlled oscillator tuning characteristics (S/N 389). This oscillator is used in the reference PLL.

The output of the mixer is a 51.2 MHz signal, with a level of approximately -24 dBm. This passes through a 92 MHz 2 pole low-pass filter, to remove the 288 MHz local oscillator signal and any spurious components, then passes through a single stage transistor amplifier with 20 dB gain and 200 MHz bandwidth. The output of this stage is 400mV peak to peak, which is sufficient to drive AC coupled into the clock line of U5, an MC 10231 ECL dual D flip-flop which divides the signal to 12.8 MHz. This 12.8 MHz output is connected to the f_v input of the 12040 phase detector in order to close the phase locked loop.

2.1.3 Active Loop Filter

The final element of these phase locked loops is the active loop filter, composed of operational amplifier U4 and its associated parts. U4 is an LM318 device, chosen because it has a unity gain bandwidth of 15 MHz and is stable with unity gain feedback or any integrator circuit.

The bandwidth (ω_n radians per second or f_n hertz) and the damping factor (ζ) are primarily controlled by the time constants in the active loop filter. The response time to a phase step to reach the 10 percent error band is approximately $1/\omega_n$, so, for 1 microsecond response time, ω_n should be 1 megaradian per second, and f_n is 159 kHz. Optimum performance occurs when ζ is in the vicinity of .707; lower damping factors cause excessive overshoot and approach oscillation, and higher damping factors tend toward excessive noise bandwidth and long response time, and also will cause oscillation in wideband loops because the high damping factor decreases the rolloff rate of the feedback in the loop, allowing high frequency poles in the loop components to reduce the phase margin to zero.

The active loop filter in these phase shifters consists of an LM318 operational amplifier, U4 in Figure 5, together with its feedback components, R_2 and C, and its input resistor, R_1. The component values for the loop filter are determined from the set of equations derived to describe phase-locked loop response[1]. For the active loop filter, these equations are written to define either ω_n and ζ, or to define τ_1, τ_2, R_1, and R_2 as follows:

$$\omega_n = 2\pi f_n = \left(\frac{K_o K_d}{\tau_1}\right)$$

$$\zeta = \frac{\tau_2}{2} \cdot \left(\frac{K_o K_d}{\tau_1}\right) = \frac{\tau_2}{2}\,\omega_n$$

$$\tau_2 = 2\zeta\omega_n^{-1} \quad ; \qquad R_2 = \frac{\tau_2}{C}$$

$$\tau_1 = \frac{K_o K_d}{\omega_n^{\,2}} \quad ; \qquad R_1 = \frac{\tau_1}{C} ,$$

where K_o is the oscillator control gain, in radians per second per volt, and K_d is the phase detector gain, in volts per radian.

The loop filter calculations and empirical modifications are summarized in Table 1. The lowest section of the table shows the results of empirical adjustment of the filter parameters to approximate the desired response. Frequency response curves for the reference phase-locked loop and for the phase-shifted phase-locked loop are shown in Figures 10 and 11, respectively. The frequency response was measured by injecting a signal into the phase-control port of the loop and measuring the frequency response at the output of the phase detector differential amplifier, U3, while monitoring this point to assure that distortion and noise were minimal. The natural frequency and damping factor were derived from each curve by comparing it

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1. Floyd M. Gardner, Phaselock Techniques, Wiley, New York, 1966. (Cf. Chapters 2 and 4).

Table 1. ACTIVE LOOP FILTER DESIGN

	Phase Locked Phase Shifter	Reference Phase Locked Loop
Design Goals:		
	f_n = 280 kHz	f_n = 106 kHz
	$\omega_n = 1.76 \times 10^6$ radian per second	$\omega_n = 666 \times 10^3$ radian per second
	ζ = .707	ζ = .707
Measured Design Parameters:		
	$K_o = 6.66 \times 10^6$ radians/second/volt	$K_o = 2.88 \times 10^6$ radians/second/volt
	K_d = 1.444 V/radian	K_d = 1.444 V/radian
	C = 200 pF	C = 220 pF
Design Calculations:		
	$K_oK_d = 9.62 \times 10^6$ second^{-1}	$K_oK_d = 4.16 \times 10^6$ second^{-1}
	τ_1 = 3.1 μs	τ_1 = 9.4 μs
	τ_2 = 804 ns	τ_2 = 2.1 μs
	R_1 = 15.5 K	R_1 = 43 K
	R_2 = 4.4 K	R_2 = 9.7 K
Results of Empirical Adjustment:		
	f_n = 280 kHz	f_n = 106 kHz
	ζ = .7	ζ = .707
	R_1 = 10 K	R_1 = 12.4 K
	R_2 = 7.5 K	R_2 = 10 K
	τ_1 = 2.0 μs	τ_1 = 2.7 μs
	τ_2 = 1.5 μs	τ_2 = 2.2 μs

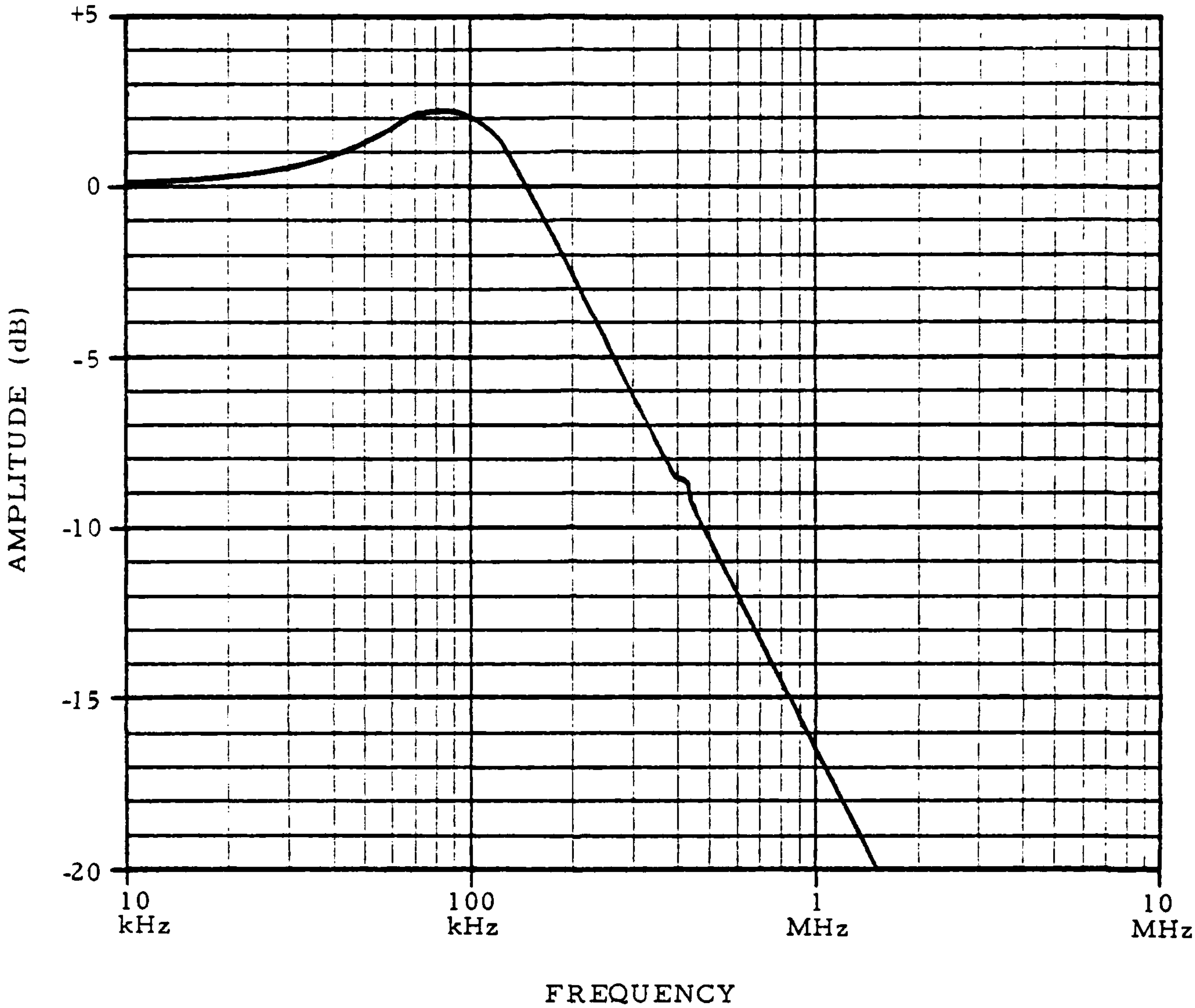

Figure 10. Frequency response of reference phase-locked loop.

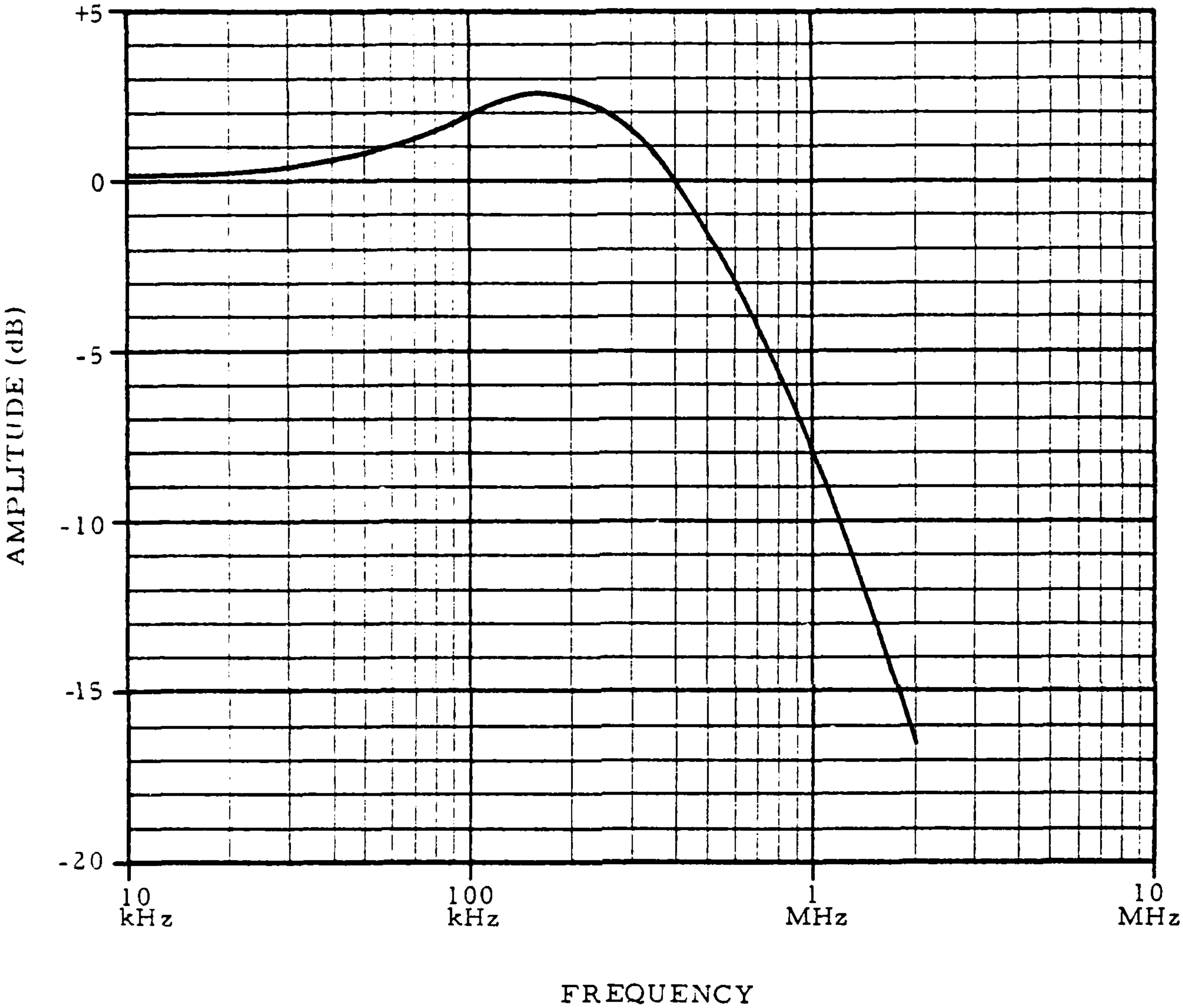

Figure 11. Frequency response of phase-controlled phase-locked loop.

with the theoretical curves of second order loop response [2]. A 2.2 dB response peak indicates that the damping factor is .707. Above the peak frequency, the response again passes through a 0 dB level. The natural frequency, f_n is equal to .707 times this frequency, regardless of damping factor.

The components shown on the schematic between the output of the active loop filter and the 915.2 MHz VCO control line are included in order to prevent 915 MHz energy from reaching the input of U3, where it could rectify and cause an offset voltage which is proportional to oscillator power. The components added here consist of three 10 pF mica capacitors, a 330 ohm resistor, and a ferrite bead. Before this network was added, the output phase could change significantly when the manual tuning screw on the VCO was adjusted. After the network was added, the mechanical tuning could be adjusted over the entire phase-lock range without changing phase more than one half degree.

2.2. Antenna Design

For a horizontally-oriented planar array, an element which radiates isotropically in the azimuthal plane and has an elevation plane pattern that approximates cosecant-squared is desirable. The element should have at least an octave bandwidth and be simple to fabricate. The obvious candidate is a conical element mounted above a ground plane, forming a conical monopole antenna, which meets all the requirements listed above.

The conical monopole antenna design was made to optimize the correspondence of the vertical radiation pattern to a cosecant-squared θ pattern by careful choice of the slant angle of the cone. This element design is shown in Figure 12, with the dimensional parameter λ_h corresponding to

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2. Op. cit., p. 11.

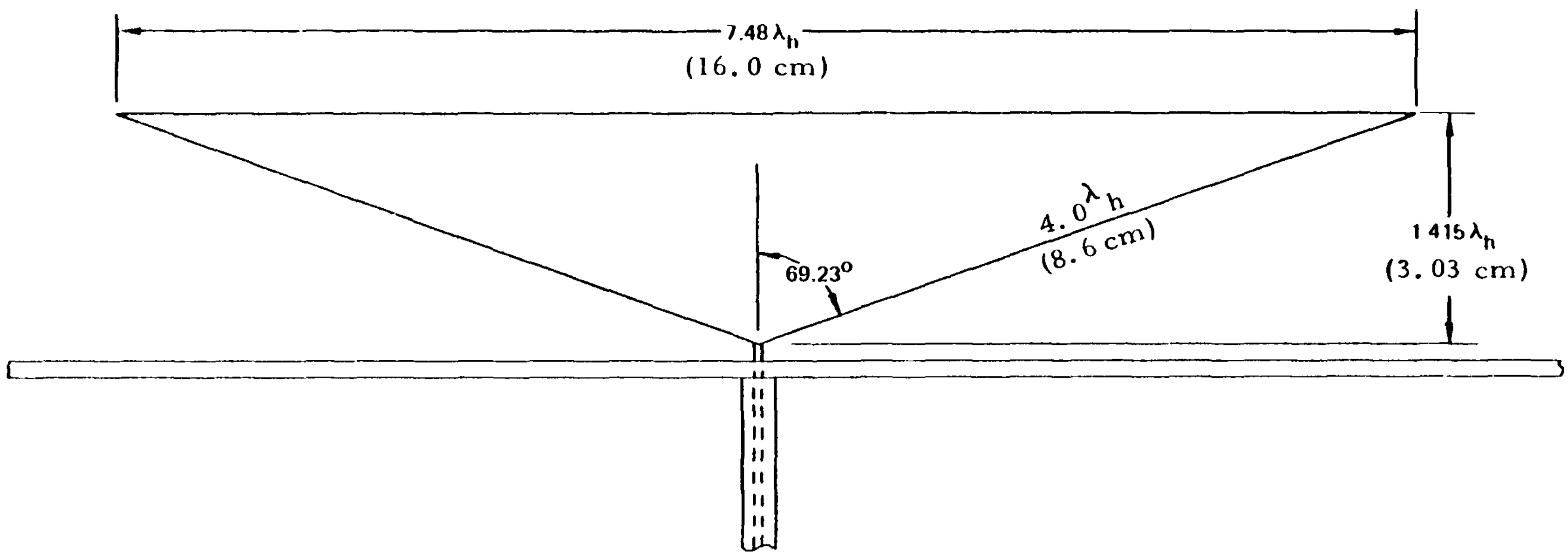


Figure 12. Conical monopole antenna element.

the maximum desired operating frequency of 15 GHz. The antenna element was mounted onto the back of a type N receptacle which in turn was mounted onto a ground plane to form the conical monopole antenna. The theoretical elevation plane field strengths of this antenna are shown in Figure 13. Note that the field strength at the high end of the band approximates a cosecant function which was truncated at a range of 30 km and an altitude of 3 km. The gain of the antenna at the high end of the band is calculated to be 9.57 dBi.

At the low end of the band (an octave away, or 7.5 GHz) the beam broadens as shown in the figure and the calculated gain is 1.5 dB less, or 8.07 dBi. The large flare angle (69.23 degrees) and a greater than 2 slant length throughout the octave bandwidth insures an almost constant impedance across the band.

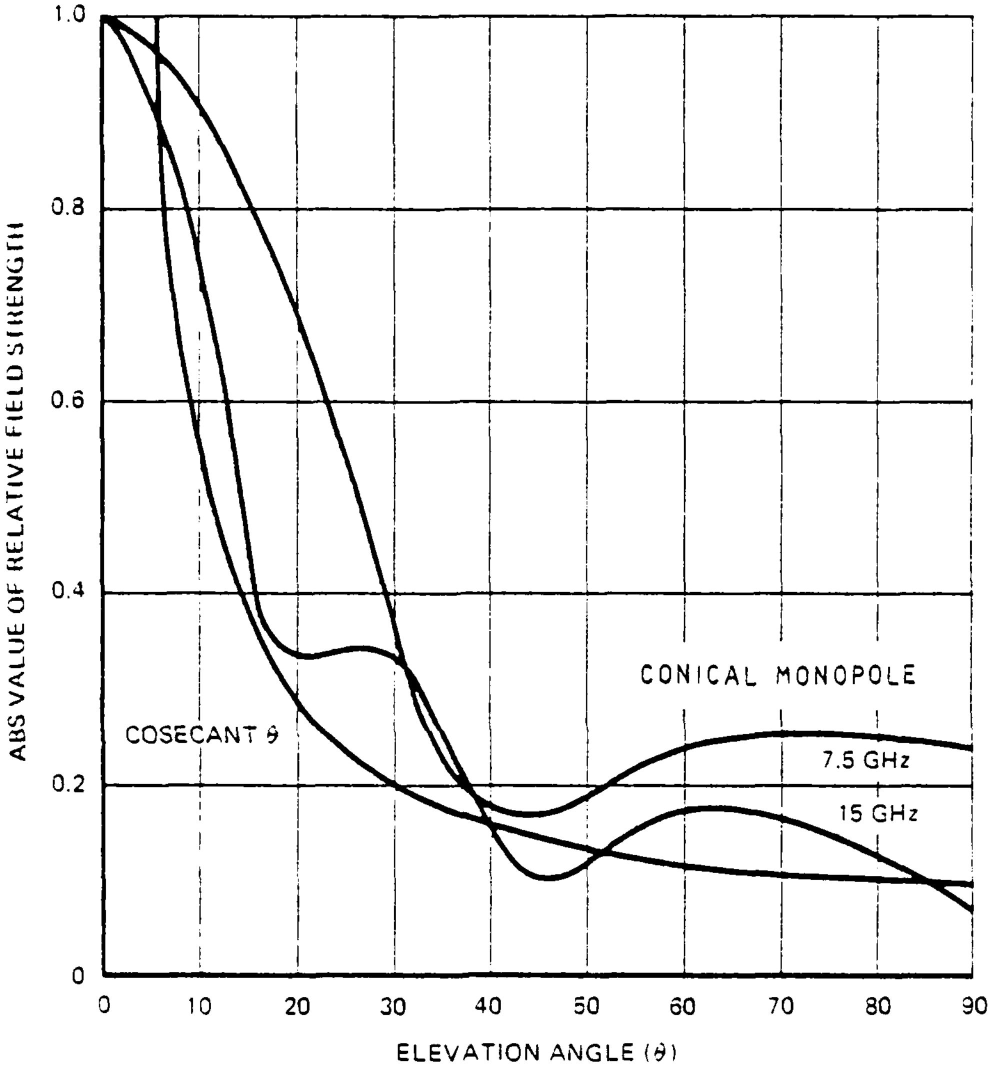


Figure 13. Field strength of conical monopole antenna element.

3. RESULTS

A pair of phase-locked 915.2 MHz sources were designed and fabricated, one of which can be phase-shifted in response to an external control voltage. The phase shifter controls phase over a region in excess of plus and minus 1000 degrees with linearity such that the error from a best straight line never exceeded 16 degrees positive or 9.4 degrees negative. Over a more limited region of plus or minus 660 degrees, the phase error never exceeded plus 2 degrees or minus 9.4 degrees, with the only significant error in the zero degree region.

A pair of conical antenna elements were assembled according to the drawing in Figure 12. An element was assembled onto a four foot diameter ground plane and antenna patterns were recorded for test frequencies between 7 and 15 GHz. Then, a pair of the conical elements were mounted on a six foot diameter ground plane and similar patterns were measured for this two element array.

3.1 Phase Shifter

The testing of the phase-locked phase shifter consisted of testing the frequency response of the phase-locked loops, verification of the phase-shifting pulse response, and measurement of the phase control sensitivity and linearity.

The phase-locked phase shifter and the reference PLL mechanical assemblies are essentially identical, the only difference being that the phase control input connector is not included on the reference PLL. Figure 14 is a photograph of the phase-locked phase shifter. The housing is a cast aluminum box, measuring 2.25 inches high, 4.75 inches wide, and 7.4 inches long. The phase-locked loop, except for the VCO, is mounted inside the box on two copper-clad circuit boards. This circuitry occupies 12 square inches on the circuit boards. The VCO with its protruding tuning screw is too long to fit inside the box, so it was mounted on the outside of the box cover.

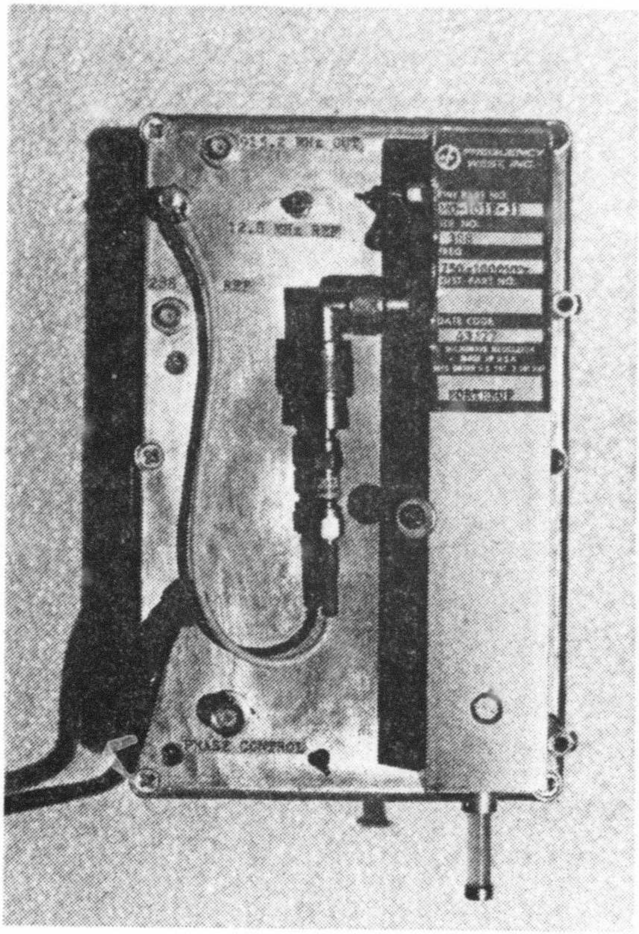


Figure 14. Photograph of phase-locked phase shifter.

The power requirements of both the phase-locked phase shifter and the reference PLL are identical. They each require +5 V at 330 mA, +15 V at 100 mA, and -15 V at 14 mA, for a total power consumption of 3.4 watts apiece. These supplies are used as reference voltages inside the phase-locked loops, but the amount of offset derived from them is limited to approximately ± 50 degrees maximum and ±20 degrees typical. If the +15 V regulation is 1%, and the other two supplies are regulated within 2 or 3 percent this should be adequate to hold better than 2 degree inaccuracy from this cause.

3.1.1 Frequency Response

The frequency response testing was discussed in section 2.1.3, and frequency response curves of the two phase-locked loops are shown there. Those curves were measured with the VCO set at the center of its range, with a control voltage of 5 volts on the tuning line. As can be seen in Figures 8 and 9, the sensitivity of the VCO's changes over a three to one range as the tuning voltage is varied. Frequency response curves were plotted for both loops with VCO tuning voltages of 0.5, 5.0, and 13.1 volts. These response curves are Figures 15 and 16 for the reference phase-locked loop (PLL) and the phase-shifting PLL respectively. The gain variation of the VCO in the reference PLL is much greater than in the phase-shifted PLL, which causes the response to vary more in the reference PLL. In both loops, the highest tuning voltages result in the lowest bandwidth and damping factors, as predicted from the design equations. The bandwidth of the reference PLL is approximately 50 kHz, 106 kHz, and 170 kHz for the tuning voltages of 13.1 V, 5 V, and .5 V, respectively, with corresponding damping factors of .5, .707, and 1.0. The bandwidth of the phase-shifted PLL is 163 kHz, 280 kHz, and 297 kHz for the same three voltages, with corresponding damping factors of .6, .7, and .707. The bandwidths are calculated as .707 times the zero dB crossover frequency, and the damping factors are estimated by comparison with the peaking levels of theoretical

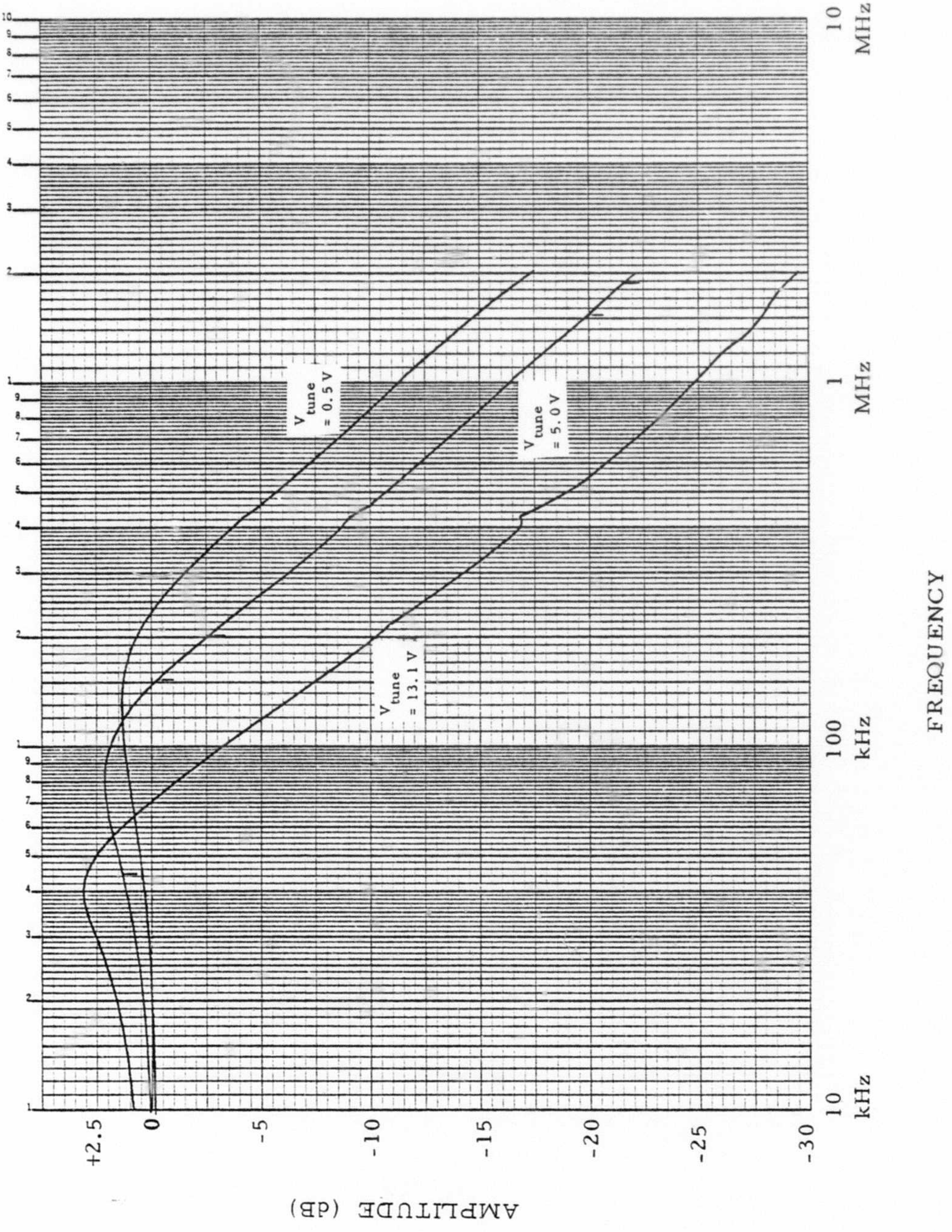


Figure 15. Frequency response variation of reference phase-locked loop as VCO tuning voltage is varied.

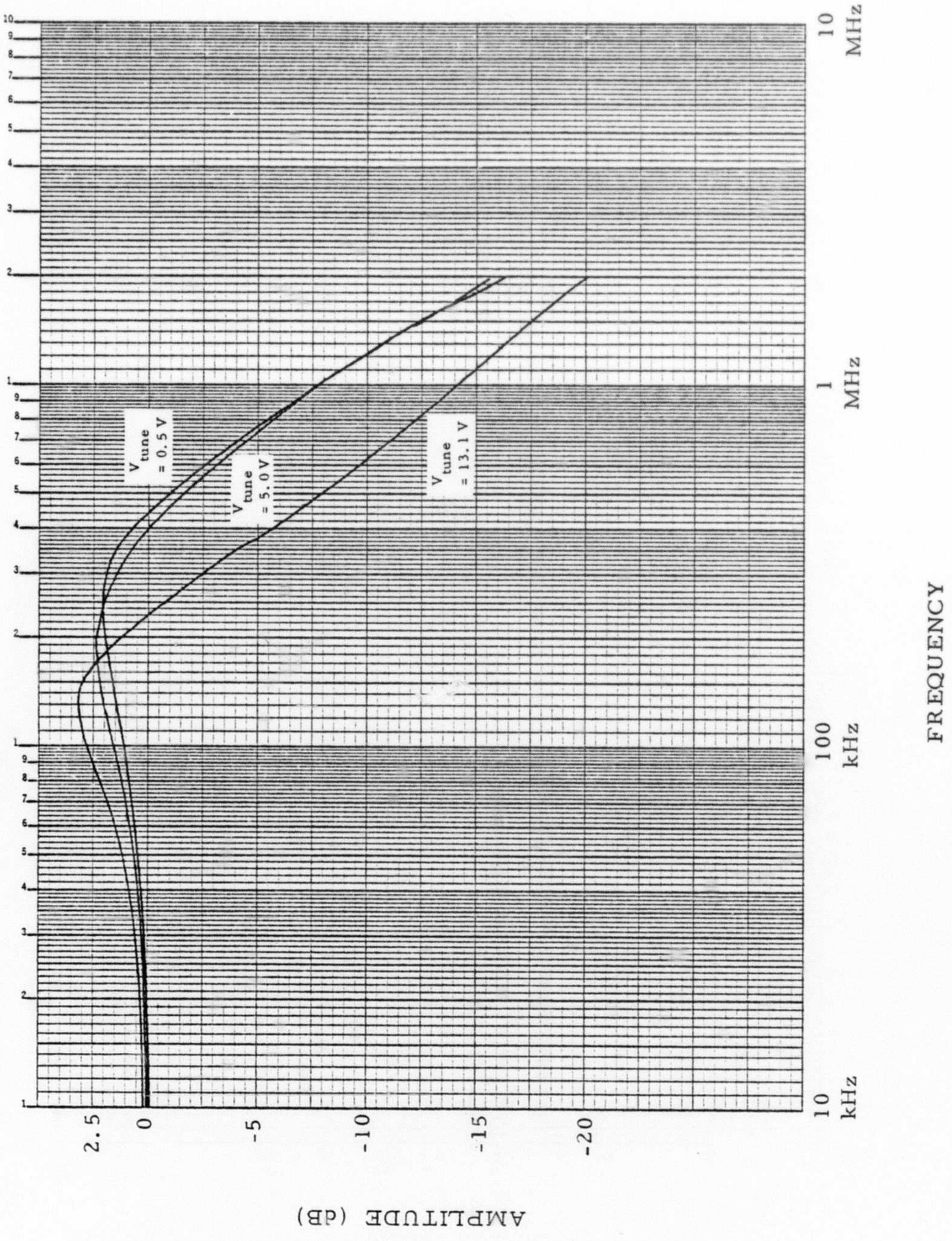


Figure 16. Frequency response variation of phase-shifted phase-locked loop as VCO tuning voltage is varied.

curves. The important factors to note here are that the damping factor never gets extremely low (say, in the vicinity of .3), so there will not be excessive overshoot in the phase-shifter nor will the loops tend to oscillate, and the bandwidth of the phase-shifting PLL stays high enough to allow rise times less than two microseconds at all tuning voltages. Since the stability of these cavity-stabiliized VCO's is better than .1 percent, the tuning voltage should not vary more than plus or minus .5 volt to maintain lock, so the frequency response should remain essentially constant. However, these curves do indicate that operation will be quite tolerant of a wide variation in VCO gain which might occur if a less stable (and lower size and cost) VCO is substituted for the cavity-stabilized VCO. A less stable VCO would normally have much higher tuning gain, which will minimize the nonlinearity, and the resulting stability would probably not be significantly changed if one is incorporated.

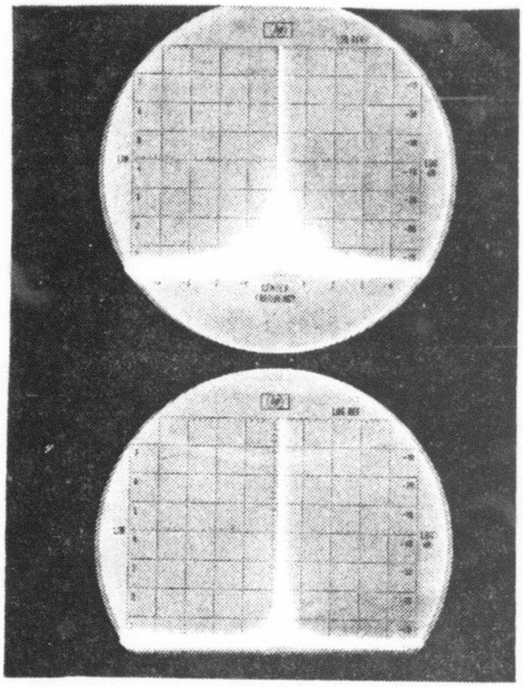
The frequency response of the PLL is also related to the spectral purity of the 915.2 MHz output. If the loop response is at all close to instability, this will show up in the output spectrum as noise sidebands offset from the carrier by the frequency of maximum instability. Also, the loop should be wide enough so that the spectral purity close to the carrier is a direct translation of the purity of the two reference signals (12.8 MHz and 288 or 864 MHz). Generally, the noise sidebands will occur if it is attempted to make the loop so wide that extraneous poles in the circuits are causing significant excess phase shift near the loop corner frequency, or if the damping factor is especially low or high. High damping factor has almost the same effect upon noise sidebands as increased loop bandwidth, f_n, because it causes a much slower rolloff of the loop response.

The output spectrum was observed on a spectrum analyzer. No spurious signals were observed more than 200 kHz from the center frequency, with an 80 dB measurement range. The second harmonic was over 48 dB down for both units. The spectrum photographs shown in Figure 17 were taken with a scan on 200 kHz per division horizontally and 10 dB per division vertically. The photograph in part A of the figure was taken using a laboratory synthesizer as the mixer reference, and the photograph in part B used a cavity-tuned generator as the reference, both at 288 MHz. Both spectra are typical of the spectrum obtained from that type of generator, with no noise contribution from the PLL in evidence.

3.1.2 Phase-Shifting Pulse Response

The phase-shifting pulse response was tested by injecting a square wave test signal into the control voltage port of the phase-shifting PLL. When the input signal was connected directly to the phase-control input, it resulted in 25% overshoot in the phase response (measured at the output of U3, which resulted in a settling time of three microseconds with 10% accuracy. This response is shown in Figure 18, with part A showing a double exposure of both rise time and fall time at 1 microsecond per division, and part B showing the entire output square wave with reduced resolution.

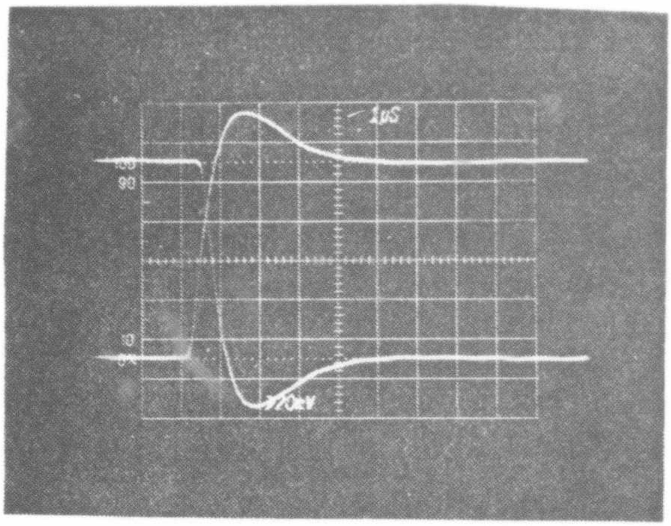
Excessive pulse overshoot was expected for the loop with a .7 damping factor, and this 25% overshoot would actually correspond to a damping factor of .6. An effective method to reduce the overshoot to an acceptable level is to drive the phase-control line through an R-C lag filter with its time constant adjusted for any desired overshoot level. When the lag time constant was adjusted to 800 nanoseconds, the pulse response shown in Figure 19 resulted. Part A shows a double exposure of both rise time and fall time at 1 microsecond per division, and part B shows the entire output square wave with reduced resolution. The overshoot is now under 10%, and the settling time for 10% accuracy is 1.6 microseconds, almost a 100% improvement over the results in Figure 18.



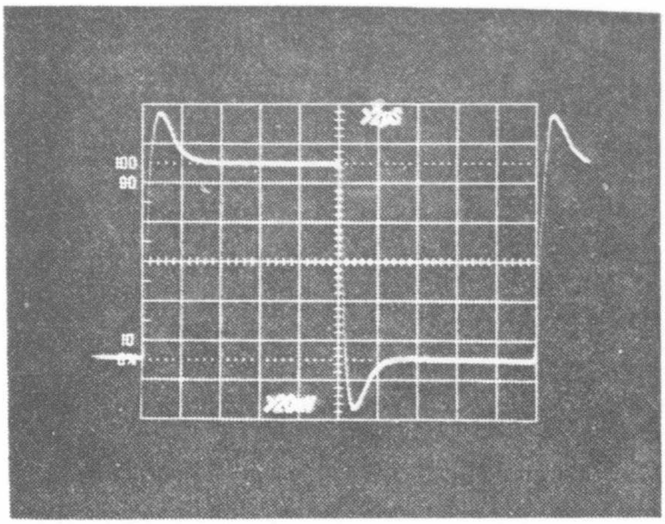
A. Output spectrum at 915 MHz using Wavetek 3000 synthesizer as mixer reference.
200 kHz/div, 10 dB/div.

B. Output spectrum at 915 MHz using HP 8640 signal generator as mixer reference.
200 kHz/div, 10 dB/div.

Figure 17. Output spectrum of phase shifter at 915 MHz.

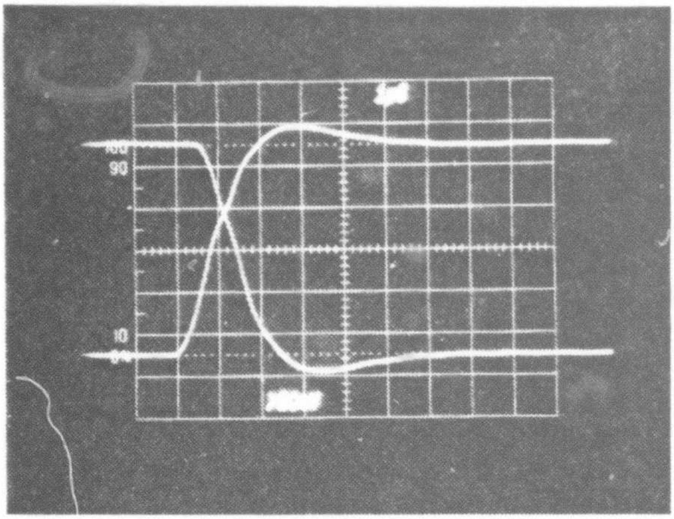


a. Rise and fall settling times, 1 μs per division.

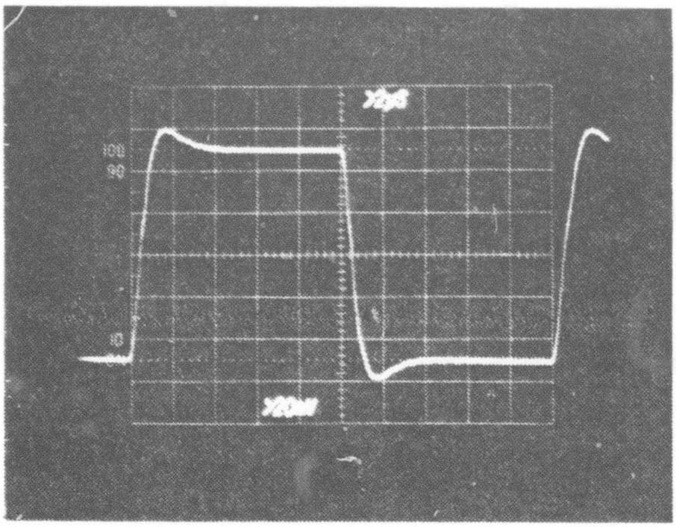


b. Square wave response shape, uncalibrated.

Figure 18. Phase shifter settling time with no filter in phase-control line.



a. Rise and fall settling times, 1 μs per division.



b. Square wave response, uncalibrated.

Figure 19. Phase shifter settling time using 800 ns lag filter in phase-control line.

3.1.3 Phase Control Sensitivity and Linearity

The phase control sensitivity was measured by applying accurate voltages in 10 millivolt steps to the phase control port of the phase-shifted PLL. The output phase was compared between the two phase-locked loops using a Hewlett-Packard 8405A vector voltmeter and its high frequency termination kit. The voltmeter reference channel was connected to the output of the reference PLL. This meter provides 1.5 degree accuracy when used at a single frequency up to 1000 MHz. A least squared curve fit was made from this entire data set, from -7.2 V to +7.2 V, using a linear approximation. The derived equation describing the phase versus voltage is: Phase = 8.24 -102.09 V_{in}, with measurements in volts and degrees. This equation correlated well with the data, with a correlation coefficient of -.99996. The equation was used to predict the phase shift for each input voltage, and the error was calculated for each data point.

Table 2 is a tabulation of the measured phase data, together with the calculated errors from predicted phases. From -7.2 V to 7.2 V the maximum errors encountered were +15.8 degrees and -9.4 degrees. From +6.7 V to -6.7 V, approximately ± 680 degrees, the maximum error was essentially the same as in the required operating range of ±2.7 V, with maximum errors of +2.3 degrees and -9.4 degrees. If the data is reduced over just the desired operating range of ±2.7 V, the least squares curve fit will be identical except that the O V phase is only 6.36 degrees. The curve fi' over the extended range was chosen for Table 2 so that its calculations would be accurate over this entire range. The maximum nonlinearity error occurs in the region around zero degrees.

Since the largest errors are of a tolerable magnitude, and since they only occur in a limited region near zero degrees, there should be little impact upon antenna phase steering accuracy as long as the nonlinearity doesn't move around greatly with temperature. The absolute phase shift, and

Table 2. PHASE SHIFTER SENSITIVITY DATA

Control Voltage V	Phase Angle Degrees	Linearity Deviation Degrees	Control Voltage V	Phase Angle Degrees	Linearity Deviation Degrees
-7.2	+754.6	+11.3	-3.6	+375.0	-0.7
-7.1	746.6	+13.5	-3.5	+364.9	-0.6
-7.0	735.0	+12.2	-3.4	+354.7	-0.6
-6.9	721.6	+9.0	-3.3	+344.6	-0.5
-6.8	707.9	+5.5	-3.2	+334.4	-0.5
-6.7	694.5	+2.3	-3.1	+324.2	-0.5
-6.6	682.8	+0.8	-3.0	+313.9	-0.6
-6.5	672.0	+0.2	-2.9	+303.6	-0.7
-6.4	661.6	0	-2.8	+293.3	-0.8
-6.3	651.4	0	-2.7	+282.8	-1.1
-6.2	641.4	+0.2	-2.6	+272.6	-1.1
-6.1	631.8	+0.8	-2.5	+261.9	-1.6
-6.0	621.7	+0.9	-2.4	+251.5	-1.7
-5.9	611.3	+0.8	-2.3	+241.6	-1.4
-5.8	600.8	+0.5	-2.2	+231.9	-0.9
-5.7	590.4	+0.3	-2.1	+222.1	-0.5
-5.6	579.9	0	-2.0	+212.1	-0.3
-5.5	+569.8	+0.1	-1.9	+201.5	-0.7
-5.4	+559.8	+0.3	-1.8	+190.3	-1.7
-5.3	+549.8	+0.5	-1.7	+179.1	-2.7
-5.2	+539.4	+0.3	-1.6	+169.1	-2.5
-5.1	+529.4	+0.5	-1.5	+159.6	-1.8
-5.0	+519.1	+0.4	-1.4	+150.2	-1.0
-4.9	+508.6	+0.1	-1.3	+140.5	-0.5
-4.8	+498.2	-0.1	-1.2	+130.0	-0.7
-4.7	+487.9	-0.1	-1.1	+118.8	-1.7
-4.6	+477.6	-0.2	-1.0	+107.7	-2.6
-4.5	+467.4	-0.2	-0.9	+97.6	-2.5
-4.4	+457.1	-0.3	-0.8	+88.9	-1.0
-4.3	+447.2	0	-0.7	+80.4	+0.7
-4.2	+437.0	0	-0.6	+71.2	+1.7
-4.1	+426.8	0	-0.5	+60.2	+0.9
-4.0	+416.6	0	-0.4	+46.7	-2.4
-3.9	+406.3	-0.1	-0.3	+32.0	-6.9
-3.8	+395.8	-0.4	-0.2	+19.5	-9.2
-3.7	+385.3	-0.7	-0.1	+9.0	-9.4

Table 2. PHASE SHIFTER SENSITIVITY DATA

Control Voltage V	Phase Angle Degrees	Linearity Deviation Degrees	Control Voltage V	Phase Angle Degrees	Linearity Deviation Degrees
0.0	0.0	-8.2	3.6	-360.0	-0.7
0.1	-8.0	-6.0	3.7	-369.4	+0.1
0.2	-16.1	-3.9	3.8	-379.6	+0.1
0.3	-24.4	-2.0	3.9	-390.0	-0.1
0.4	-33.9	-1.3	4.0	-400.3	-0.2
0.5	-43.8	-1.0	4.1	-410.5	-0.2
0.6	-53.3	-0.3	4.2	-420.6	-0.1
0.7	-63.4	-0.2	4.3	-430.4	+0.3
0.8	-74.1	-0.7	4.4	-439.9	+1.0
0.9	-85.0	-1.4	4.5	-449.2	+2.0
1.0	-95.7	-1.8	4.6	-459.1	+2.3
1.1	-106.3	-2.2	4.7	-469.8	+1.8
1.2	-116.3	-2.0	4.8	-481.6	+0.2
1.3	-126.2	-1.7	4.9	-494.1	-2.1
1.4	-136.0	-1.3	5.0	-506.0	-3.8
1.5	-146.0	-1.1	5.1	-516.3	-3.9
1.6	-156.0	-0.9	5.2	-525.5	-2.9
1.7	-166.4	-1.1	5.3	-534.0	-1.2
1.8	-176.8	-1.3	5.4	-542.2	+0.8
1.9	-187.3	-1.6	5.5	-551.4	+1.8
2.0	-197.7	-1.8	5.6	-561.9	+1.6
2.1	-207.9	-1.8	5.7	-573.6	+0.1
2.2	-217.9	-1.5	5.8	-585.3	-1.4
2.3	-227.8	-1.2	5.9	-596.4	-2.3
2.4	-237.8	-1.0	6.0	-606.0	-1.7
2.5	-248.	-1.0	6.1	-614.8	-0.3
2.6	-258.3	-1.1	6.2	-623.5	+1.2
2.7	-268.4	-1.0	6.3	-632.9	+2.0
2.8	-278.6	-1.0	6.4	-643.9	+1.2
2.9	-289.1	-1.3	6.5	-655.8	-0.5
3.0	-299.4	-1.4	6.6	-666.4	-0.9
3.1	-309.3	-1.1	6.7	-673.2	+2.6
3.2	-319.2	-0.8	6.8	-678.0	+8.0
3.3	-329.2	-0.5	6.9	-683.1	+13.1
3.4	-339.5	-0.6	7.0	-690.6	+15.8
3.5	-349.7	-0.6	7.1	-702.3	+14.3
			7.2	-717.2	+9.6

therefore, the position of the maximum nonlinearity, are dependent upon the matching of the components preceding and including the phase detector, particularly the mixer, RF amplifier, and phase detector. These errors total approximately 10 degrees per component, when the same type numbers are used in each PLL. If the errors remain in this region for larger batches of components, it will not be significant, otherwise these components can be selected in matched batches.

The phase-shifting response was also plotted by recording the input voltage and the vector voltmeter phase analog output on an X-Y recorder, using a very slow sweep. These phase-shift plots are shown in Figures 20 and 21, plotted for control voltage ranges of ± 6 V and ±12 V respectively. These curves show the highly linear response of the phase-shifter, but the nonlinear regions can also be seen quite readily. The tails extending from the top and bottom of each sawtooth excursion are caused by overshoot of the X-Y recorder as the phase switches from -180 degrees to +180 degrees during the upward control voltage sweep and switches the opposite way during the downward sweep. These plots were both made by sweeping the control voltage up and down, without lifting the pen, and the fact that only one trace is visible is proof of excellent retrace accuracy in both the phase shifter and the test equipment.

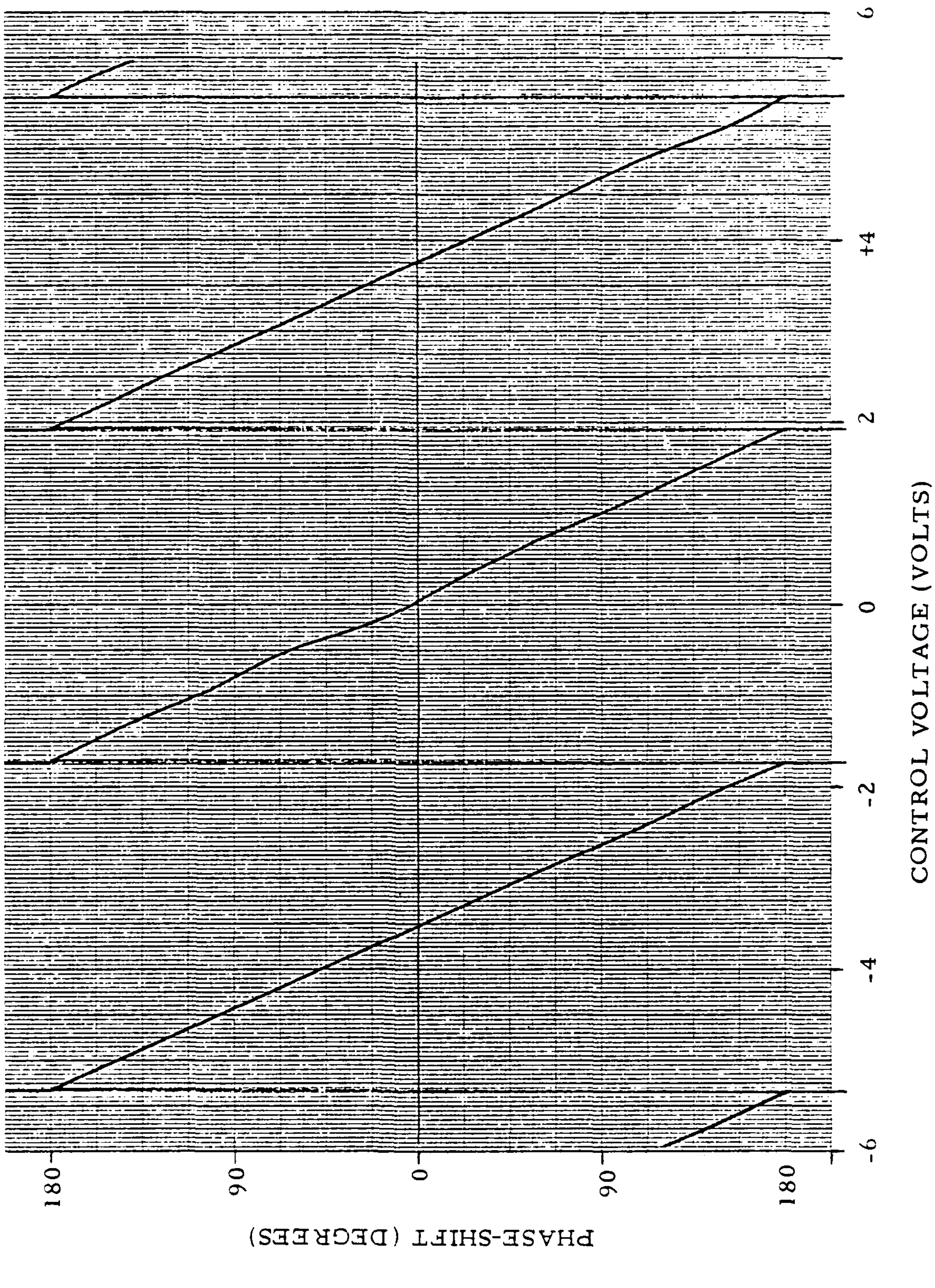


Figure 20. Phase response for ± 6V phase control voltage into phase-shifted PLL.

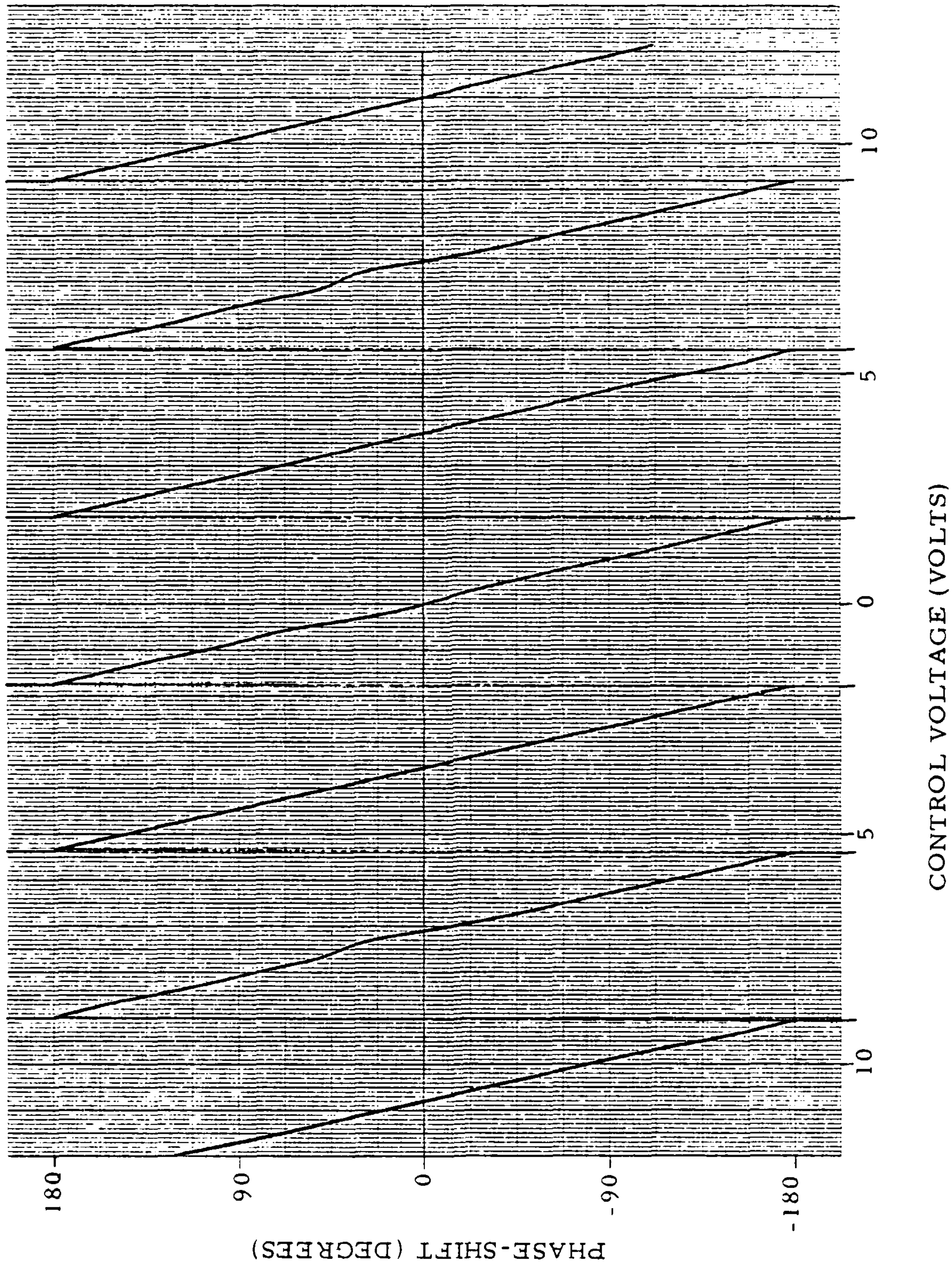


Figure 21. Phase response for ±12V phase control voltage into phase-shifted PLL.

3.2 Antenna Testing

Testing of the conical monopole antennas was conducted at the antenna range of the Northrop Aircraft Division, located at their Hawthorne, California plant. Testing was divided into two parts; first the single conical element was tested when mounted on a four foot diameter ground plane, then after the phase shifter design was completed, a pair of the conical elements were mounted on a six foot diameter ground plane and were tested as a phased array using the phase-locked phase shifter to vary the phasing of the two elements. Both ground planes were constructed of stainless steel, which has been found to give the best results in use at the antenna range. Both ground planes had been designed for general purpose range use, and accepted an 18 inch square insert at the center of the plane on which various antennas could be mounted. The six foot ground plane was fabricated after the single element tests, and is much sturdier than the four foot plane was. In addition, the support structures at the back of the six foot plane provided a good place to mount the phase shifter and associated hardware for the two element test.

3.2.1 Antenna Pattern Recording Format

All antenna patterns were recorded on polar plotting paper which records antenna direction as the recorded angle, from zero to 360 degrees, and relative amplitude, logarithmically from zero to -40 dB in the radial direction. The plotting paper is oriented to use for plotting patterns relative to the motions of an airplane, thus the three plot axes are labeled roll, pitch, and yaw. Although these antennas are intended for use on a ground platform, it is convenient to make the measurements in relationship to these notations on the patterns.

For the single antenna elements, this translation of coordinate reference is very simple. The roll plot is an elevation plot in one direction, and the pitch plot is an elevation plot at right angles to the roll plot. Since the single antenna element and circular ground plane are symmetrical about the vertical axis, there is no frame of reference for differentiating these two plots, and no attempt was made to label the plots with reference to a mark on the antenna. Both pitch and roll plots were taken for the single element at each frequency, but they were essentially identical so only the more representative of the two was included in the appendix of this report. The pitch and roll plots for the single element were oriented as if the antenna were mounted on the belly of an aircraft, looking downward. Therefore, to refer these plots to a ground based antenna, the area below the 90-270 degree axis should be considered as angles above the horizon, and those above this axis should be considered as below the horizon. The plots for the dual element antenna were made conventionally, related to a vertically-polarized ground-based antenna. The yaw plot for the single element antennas is simply an azimuth response plot about a plane 90 degrees from the zenith, or top of the antenna.

For the dual element antennas the pattern orientation is more difficult to describe because now the plane of the antenna is not symmetrical. The two conical antenna elements were mounted on an 18 inch square adapter plate which was then mounted in the center of the 6 foot ground plane. The mounting plate is shown in Figure 22 with the antenna elements mounted on it. The spacing between elements is 8.4 inches which is 5.0 wavelengths at 7 GHz and 10.7 wavelengths at 15 GHz. The antenna element positions are shown on this drawing and the directions relative to the directions on the antenna patterns are shown at the edges of the drawing. In order to define the front and rear of the antenna (nose and tail on the patterns) a piece of tape was placed in the location shown as the front marker. Then, the right side of the antenna is labeled "right wing" and the left side of the antenna is labeled "left wing."

Figures 23, 24, and 25 show antenna patterns measured for the dual antenna with the phase control set at zero volts, for the azimuth (yaw) and the two elevation cuts of roll and pitch, together with designations at the

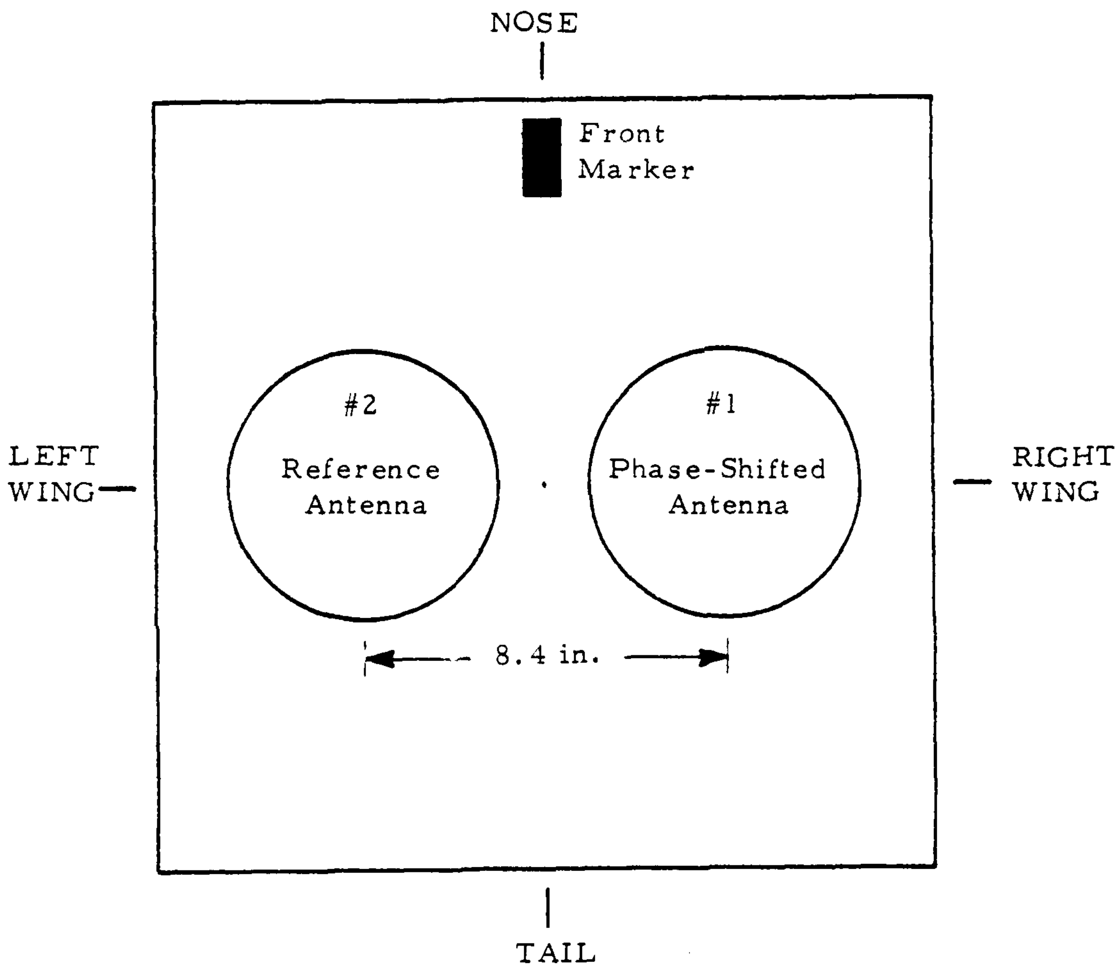
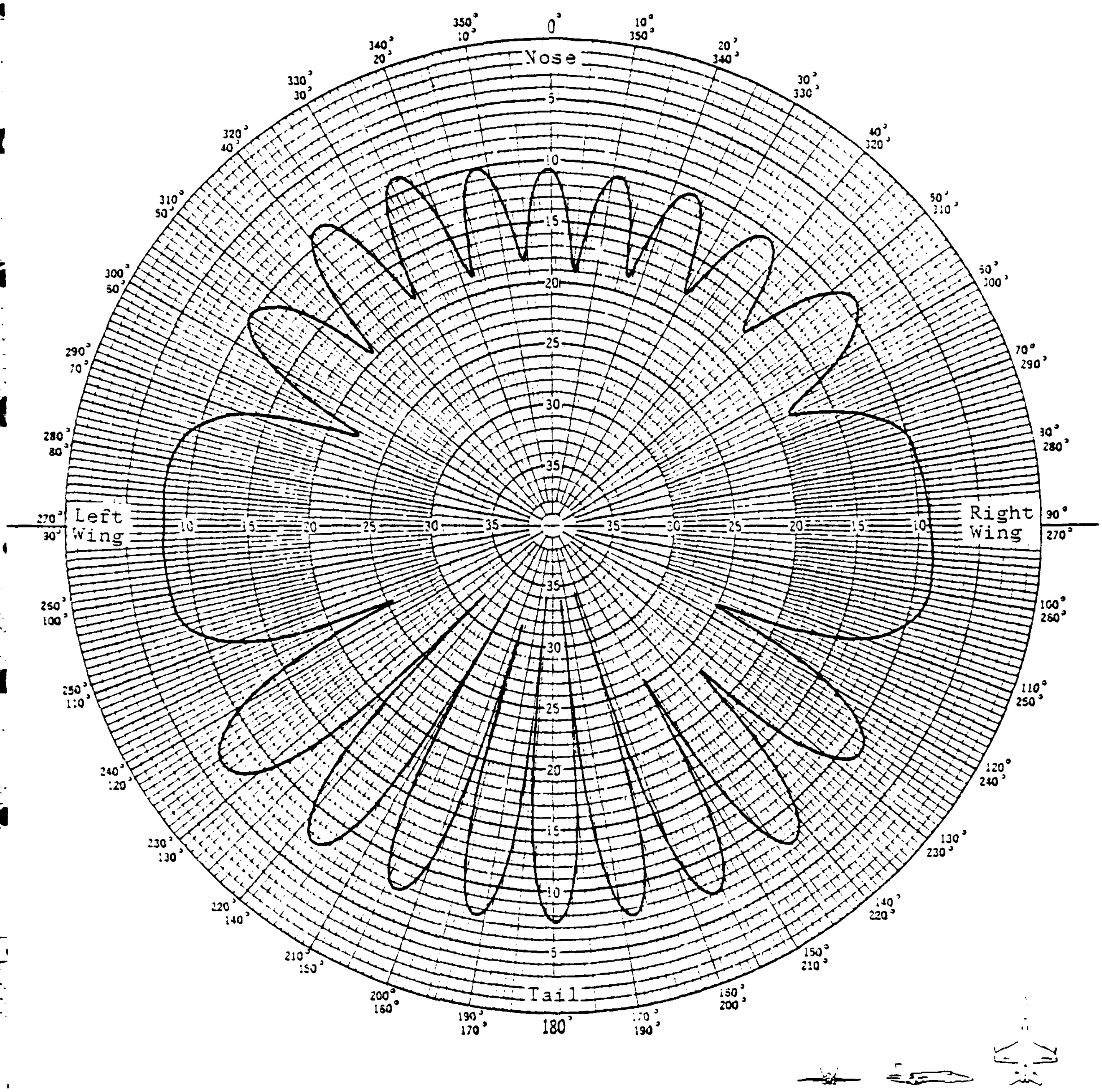


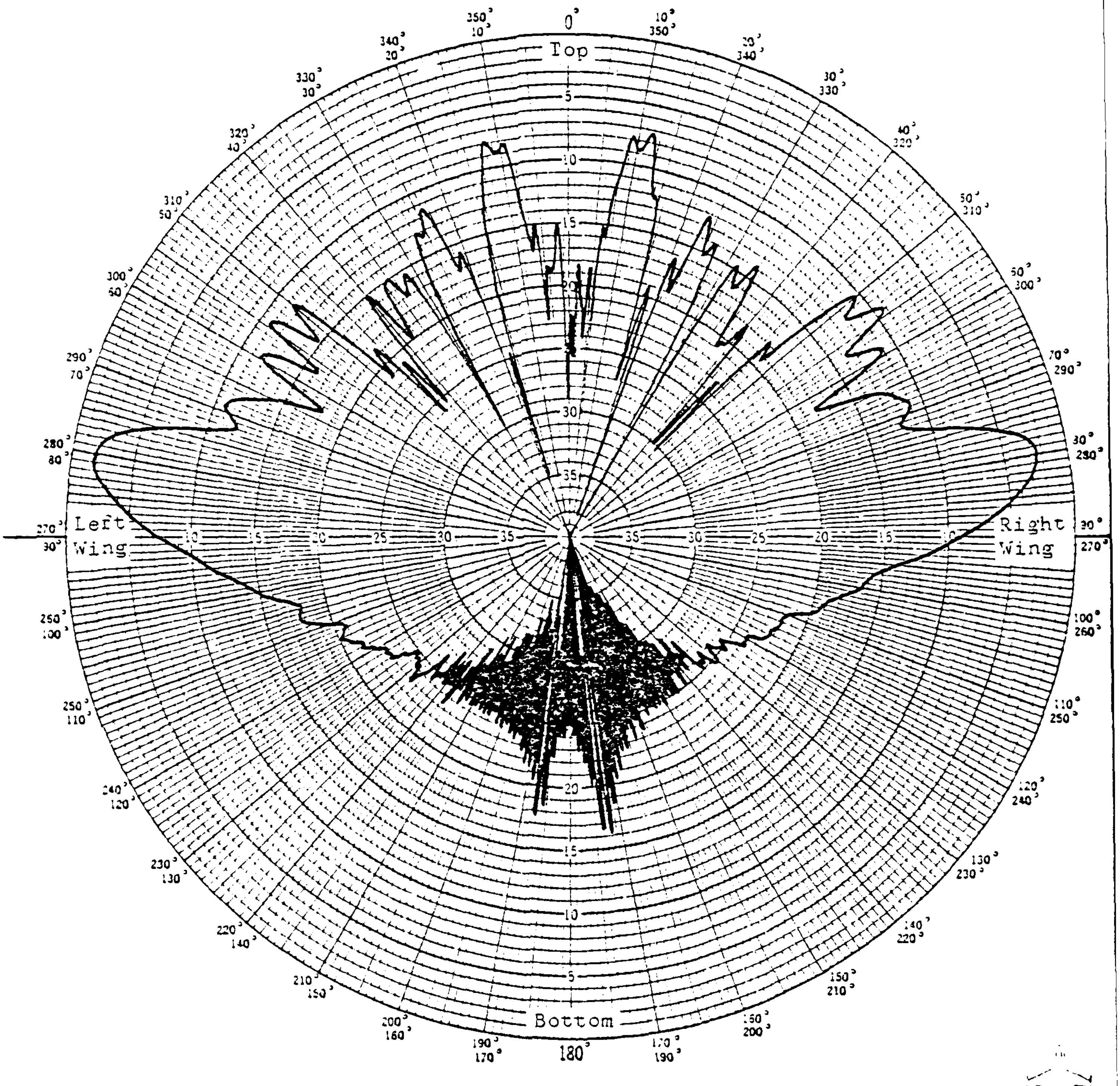
Figure 22. Top view of dual conical antenna mounting plate showing directional references for antenna patterns.



MODEL TYPE 5' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90° Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V = 0°

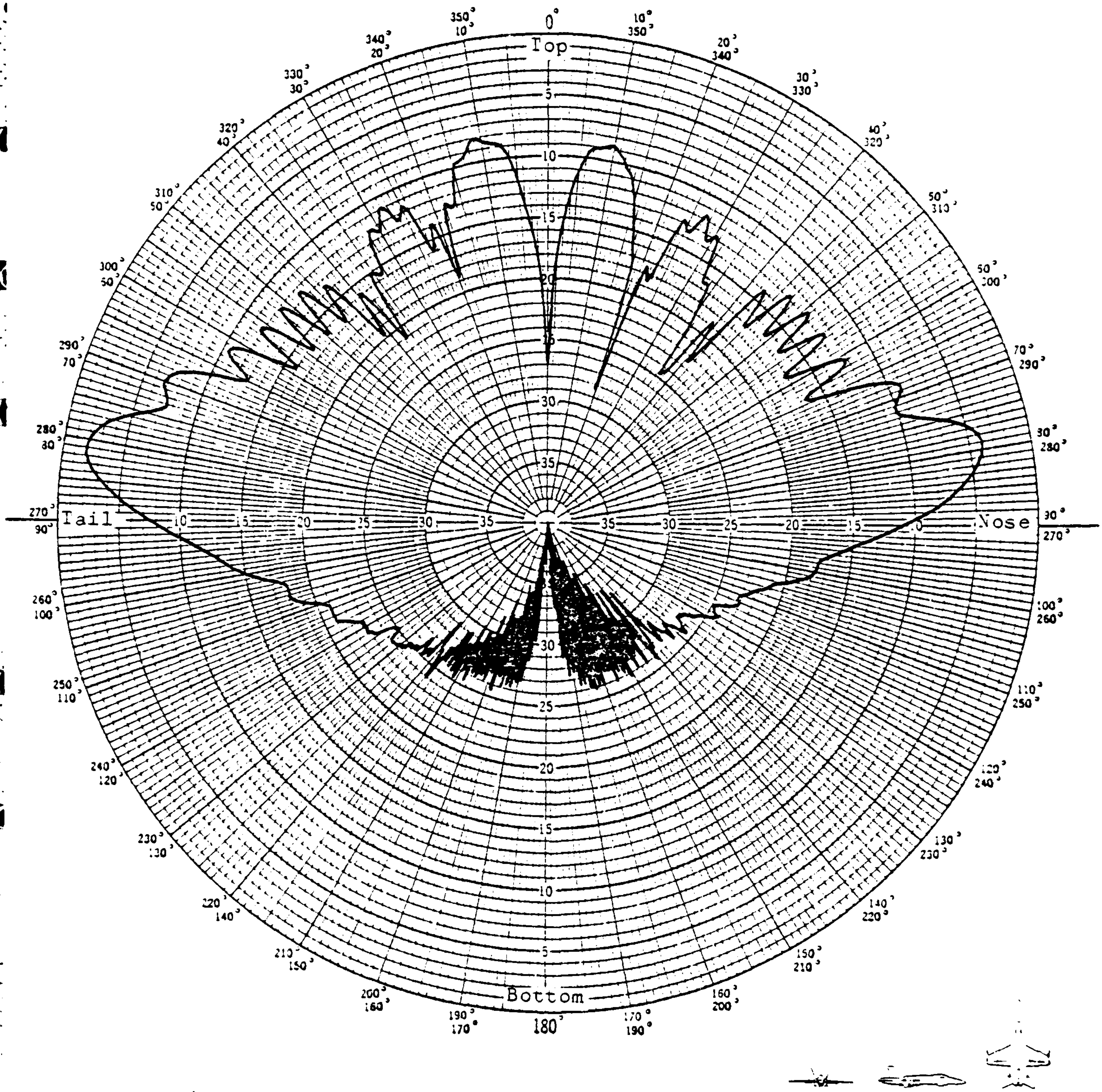
Figure 23. Yaw (azimuth) cut for dual conical monopole at 7 GHz, showing direction designations.



MODEL TYPE 6' DIAM. GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ✓ PITCH YAW
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) ϕ ( ) POLARIZATION VERT
REMARKS ØREF = 0V

Figure 24. Roll (elevation-end-fire) pattern for dual conical monopole at 7 GHz, showing direction designations.



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION ______

REMARKS Ø REF = 0V.

Figure 25. Pitch (elevation--broadside) pattern for dual conical monopole at 7 GHz, showing direction designations.

cardinal points of the patterns to show the pointing directions relative to the directions on Figure 22. The azimuth patterns, or yaw cuts can be taken at any elevation angle, θ, where θ is the elevation angle below the zenith. This angle is indicated on all of the yaw cut patterns after the designation "pattern θ." Thus, in the yaw pattern of Figure 23, the angle is indicated as 90 degrees, which means that the circle of rotation is aimed at the horizon. A pattern θ of 80 degrees describes an azimuth pattern taken at an elevation angle 10 degrees above the horizon, 100 degrees is 10 degrees below the horizon, and so forth.

The cardinal points of all yaw patterns correspond to points on the pitch or roll cut which correspond to the designation at that point of the yaw pattern, offset to an angle equal to the angle of the yaw cut. Thus, the right wing and left wing directions will be recorded on the roll plot. Since this is a 90 degree yaw cut, the corresponding points on the roll pattern for right wing and left wing will be at 90 degrees and 270 degrees, respectively, and the pattern amplitudes of the two plots will be equal at these points. Likewise, the zero and 180 degree points of the yaw cut will correspond to the 90 and 270 degree points of the pitch cut. To compare with an 80 degree yaw cut, the corresponding points on the roll and pitch cuts will be at 80 and 280 degrees, with a similar correspondence for all other yaw cuts. A complete set of patterns for the dual conical antenna operating a 7 GHz is contained in Appendix D, including yaw cuts at many angles above and below the horizon.

A useful key to the pointing directions contained on any type of plot is shown on each plot in the form of small airplanes above the designations roll, pitch, and yaw. If these airplanes are considered to rotate about an axis pointing out from the paper, the pointing directions for the plot are identical to the part of the airplane pointing at each part. Thus, the 90 degree point will be the right wing for roll, the nose for pitch, and the right wing for yaw, and 180 degrees will be the bottom for roll and pitch, and the tail for yaw.

3.2.2 Patterns for a Single Element

One of the conical antenna elements described in section 2.2 was assembled at the center of a four foot diameter ground plane, using a BNC receptacle to interface to a coaxial transmission line. A small hole was drilled into the apex of the cone, and this was slipped onto the stud of the BNC receptacle and soldered as low on the stud as practical. This assembly was mounted on an antenna test tower on an outdoor range and antenna patterns were plotted on 40 dB logarithmic polar paper for test frequencies of 7, 9, 11, 13, and 15 GHz, for azimuth and elevation, and with both vertically and horizontally polarized sources. This set of patterns is Appendix A.

Next, the same antenna was mounted in the compact range, an indoor antenna range measuring approximately 20 feet high and wide, and 40 feet long, which uses a parabolic reflector to obtain a collimated beam within this short range. This range is useful to test antennas up to 4 feet in diameter over the frequency range of 6 to 18 gigahertz. Antenna patterns were measured at the same frequencies as were used on the outdoor range, for vertical polarization only. These patterns comprise Appendix B, and contain a 90 degree yaw (azimuth) plot and a single elevation plot for each frequency.

The patterns in Appendix B were taken in order to get a direct comparison of outdoor measurements and compact range results. Comparing the two pattern sets, it is seen that they correlate well enough to accept either pattern set as the data. On all frequencies, the outdoor patterns contain a small high frequency ripple which is not present on the compact range patterns. This is probably caused by either wind modulation of the antenna, positioner vibration, or reflective surfaces near the outdoor range. This level is not very high, but it does appear to obscure some of the detail of the pattern. From 7 to 11 GHz, the patterns are nearly identical, the outdoor patterns being slightly better, while the compact range patterns are better at 13 and 15 GHz.

The patterns measured on the compact range are all omnidirectional within ±1 dB on the azimuth patterns. The elevation patterns all show a response peak of approximately 6 decibels relative to the azimuth response, occurring at an elevation of 11 degrees at 7 GHz down to an elevation of 7 degrees at 15 GHz.

The response of the conical antenna to horizontally-polarized transmissions was also tested on the outdoor range. The cross-polarization response was more than 20 dB below the vertically-polarized response over all of the azimuth (yaw) plots, and over all the significant portions of the elevation cuts.

Patterns were also taken of a small stub antenna, cut .31 inch long and .125 inch diameter. This was mounted on the four foot ground plane in the compact range, and patterns were taken, which are shown in Appendix C. Comparing these patterns with the patterns for the conical element in Appendix B shows that the yaw patterns are virtually identical, indicating that the aberrations in the yaw response are more an indication of range performance than antenna element performance. The elevation patterns for the stub antenna show beams approximately 50 percent wider than the beams from the conical antenna, so the gain should be approximately 2 dB less than for the conical. Also, the stub antenna is not a broadband design, so its input impedance should show much greater variation with frequency.

3.2.3 Patterns for the Dual Conical Monopole

The dual conical monopole antenna utilizes an active phase shifter to combine the outputs of the two elements. This phase shifter is the 915.2 MHz phase-locked phase shifter described in this report. The interface for this phase shifter requires a mixer in each antenna channel using

915.2 MHz as the local oscillator (LO). This interface is shown in Figure 26. All of the units shown in Figure 26 were mounted in the support structure at the back of the six foot ground plane. Dual conversion was used in order to combine the signals at a low frequency where component matching and filtering are simpler. No filtering or amplification was used in the interface because spurious signals need only be avoided, not rejected, on the antenna range.

Mounting the interface on the back of the antenna simplified the signal handling and reduced the losses in the received signal transmission line, but greatly increased the number of cables going up to the antenna. Normally, only one coaxial cable would go to the antenna, carrying both the LO and the 60 MHz IF return. However, this interface requires three RF cables, a cable for the phase control voltage, 115 VAC power, and three DC voltages. These cables were routed out from the back of the ground plane and allowed to trail on the ground. Movement of these cables did not change the antenna pattern significantly. This cabling interface would not have been practical on any of the outdoor antenna ranges. Figure 27 shows some photographs of the compact antenna range, with the ground plane mounted on the antenna positioner, and the conical antenna elements mounted on the ground plane. The interface cable may be seen trailing from the lower right of the antenna positioner.

Performance of this antenna was measured at frequencies of 7, 9, 11, 13, and 15 GHz. The local oscillator frequencies were chosen to keep them away from the extremes of this band, and they were, in the same order, 8.515, 10.515, 9.485, 11.485, and 13.485 GHz. The receiver was operated in the noncoherent mode, using a bolometer demodulator. In order to overcome the losses in the cabling and the antenna interface, both transmitter and LO power were kept above one watt at all frequencies, and 2.4 watt was required for the 13.485 GHz LO in order to achieve 12 milliwatts into the LO power splitter.

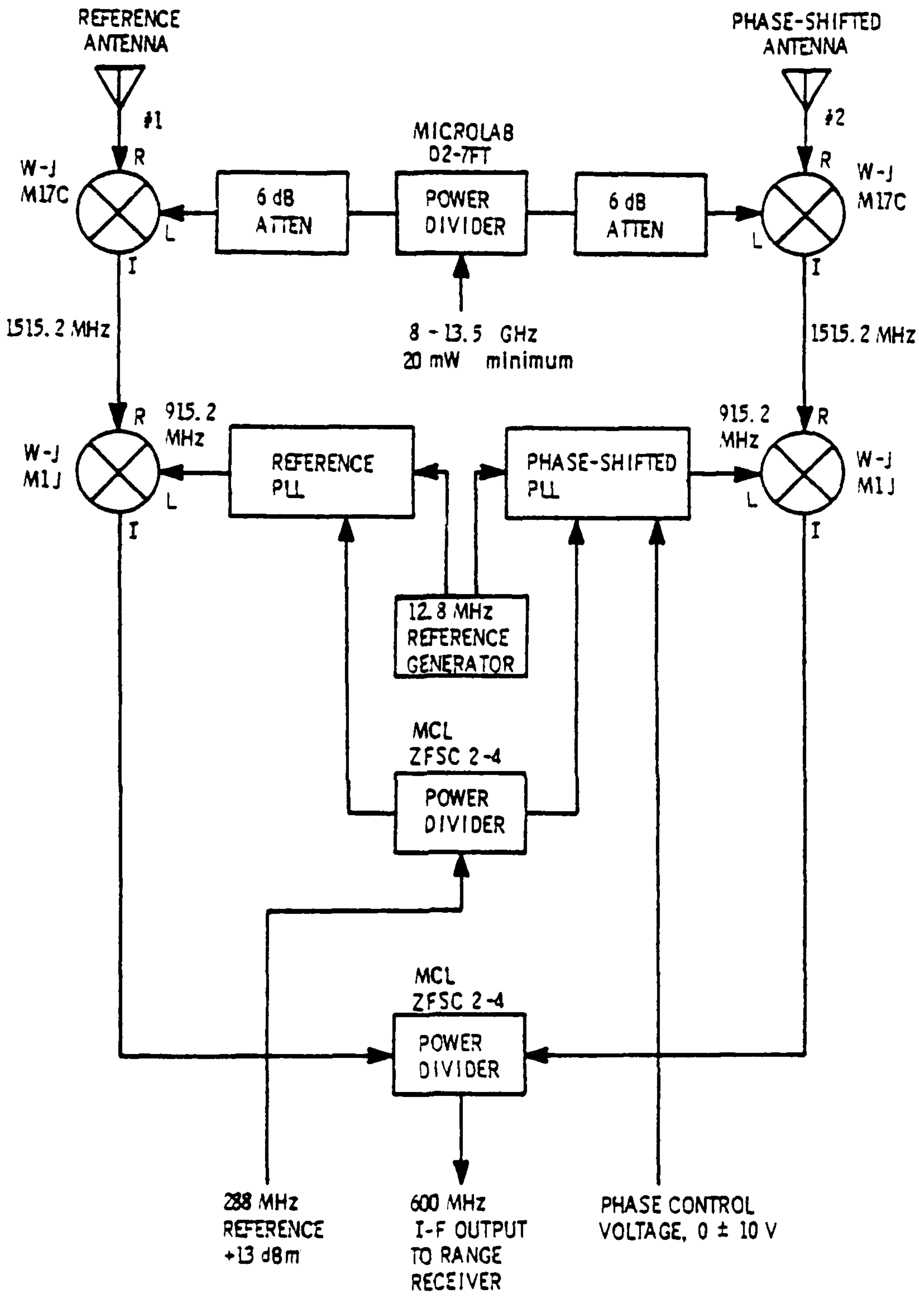
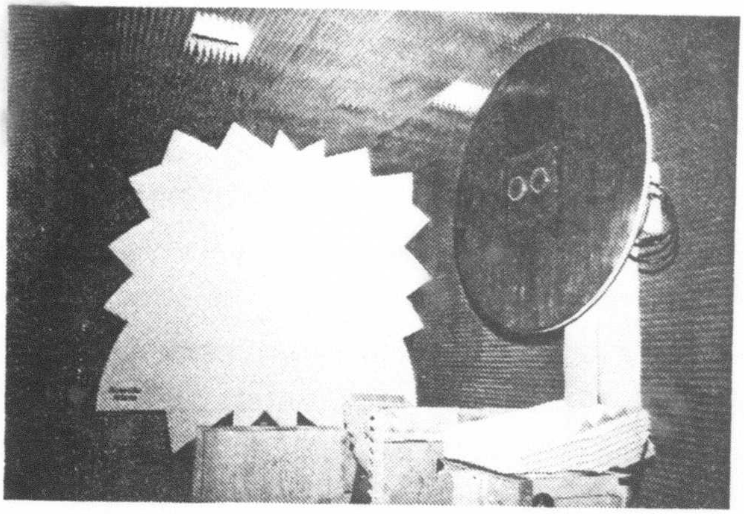


Figure 26. Antenna interface for dual conical monopole tests.



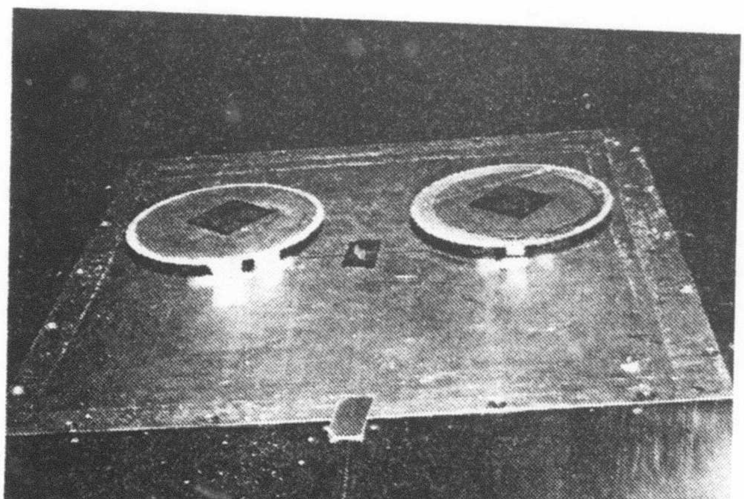


Figure 27. Compact antenna range and dual conical antenna elements mounted on six foot diameter ground plane.

At each frequency, antenna patterns were taken with zero phase control voltage for the 90 degree yaw (azimuth) and the roll and pitch elevation plots. The elevation angle for peak gain was read from the roll and pitch plots, and yaw plots were taken at this elevation for various phase control voltages to record the antenna pointing response. A single curve was plotted using swept phase control at 9 and 11 GHz to show the total range of phase control on one curve. A similar curve was constructed at the other frequencies by overplotting on one plot with stepped phase control in .3 or .6 volt increments. Comparable plots were made for roll and pitch at each frequency using the same technique. Individual roll and pitch plots were also made for phase control voltage steps of .3 and .6 volt so that the pattern changes could be correlated with the phasing. Yaw plots were made for various elevation angles to show the complete response at these angles. These plots are only important within 30 degrees of the horizon, but at 7 GHz the entire range from zero to 180 degrees was included for reference. Finally, plots were made with horizontally-polarized transmission for 90 degree yaw, yaw at the peak elevation angle (80 or 83 degrees), and pitch and roll.

The number of antenna plots generated during this testing was too numerous to include in the body of this report. The plots for each frequency are included in a separate appendix for ease of access, from 7 GHz results in Appendix D up to 15 GHz results in Appendix H. The patterns are in the same order in each appendix, starting with the principal azimuth and elevation plots, then the composite phase plots for azimuth, roll and pitch, then individual phase plots, followed by other yaw cuts, and the horizontally-polarized patterns. At each frequency the recording linearity was verified using a precision attenuator to plot various levels. The calibration plot for 15 GHz is included for reference; results were similar at all other frequencies.

The azimuth and yaw cut plots of the antenna patterns were multi-lobed patterns, as would be expected from a two-element antenna with 5 to 10 wavelength spacing between the elements. There were 22 lobes in the 7 GHz yaw patterns, and 44 lobes in the 15 GHz yaw patterns. The beam-width of each lobe was 6 degrees to 16 degrees at 7 GHz and 2.8 degrees to 11 degrees at 15 GHz. The narrowest lobes were pointing in directions toward zero and 180 degrees, where the radiation was broadside to the line of the antenna elements, and the broadest lobes were at 90 and 270 degrees, where the elements were in an end-fire configuration. These end-fire lobes were probably so wide because the effective element separation changes rapidly in this region, causing signal reinforcement over a much greater angle than in the other direction. For certain phasing conditions, at all frequencies, the lobes adjacent to the 90 and 270 degree lobes would merge together to form one single lobe approximately twice as broad as the maximum size noted above.

There was no evidence of any shading of one element by the other in the end-fire region. The peak response was as high as it was in any other directions. However, the pattern did broaden substantially in this region, which will reduce the closeness with which the notch could approach the peak.

Rejection in the notches ranged from 10 dB to over 40 dB, but this does not represent a performance limit. Rather, it is indicative of a mismatch in the received amplitude through the two antenna channels. This mismatch was mainly caused by the existence of a very high VSWR in the reference antenna element (see section 3.2.4), which was not observed as an anomaly until after the antenna patterns were taken. When the antenna elements are combined into an adaptive array, both amplitude <u>and</u> phase will be adjustable, and it will be possible to create a very deep null at any pointing direction. Also, at that time the antenna VSWR's would be more closely matched with a limit of approximately 2 : 1.

The elevation patterns are also multi-lobed, due primarily to the wide element separation, but also affected by the long slant length of the antenna elements. However, the higher angle lobes, closer to the zenith, are narrower and smaller than the main lobes near the horizon, so they do not cause significant gain reduction in the antenna. The pitch plots show broader peaks than the roll plots, which is related to the changing effective element separation as the antenna is rotated in the end-fire direction.

3.2.4 Antenna VSWR tests

The input impedance of each antenna was measured using a Hewlett-Packard 8410A network analyzer. The impedance was recorded directly on a Smith Chart by using an X-Y plotter connected to the network analyzer output. Measurements were made for each of the two conical antennas and also for the small stub antenna which was included for comparison. All the antennas were tested while mounted on the 18 inch square ground plane adapter separate from the full ground plane. Though both conical antennas were on the same ground plane, the termination status of one had no effect upon the impedance of the second.

The antennas were tested in two frequency ranges, first from 8 to 12.4 GHz, then from 12.4 to 18 GHz. The reflection test set in the network analyzer was only rated up to 12.4 GHz, but the readings from 12.4 GHz to 18 GHz do discriminate impedance trends, as can be seen by comparing the Smith Charts of the three antennas.

Figures 28 through 30 are the impedance plots of the three antennas measured from 8 to 12.4 GHz. Circles have been drawn on each plot to define VSWR's of 2.0 and 5.0. As can be seen, the three antennas display quite different impedance plots. Conical antenna #1 shows a VSWR varying between 3.4 and 4.5, whereas the VSWR is only 1.2 to 1.7 for conical antenna #2. The stub antenna lies in between, with a VSWR of 1.7 to 3.5.

IMPEDANCE OR ADMITTANCE COORDINATES

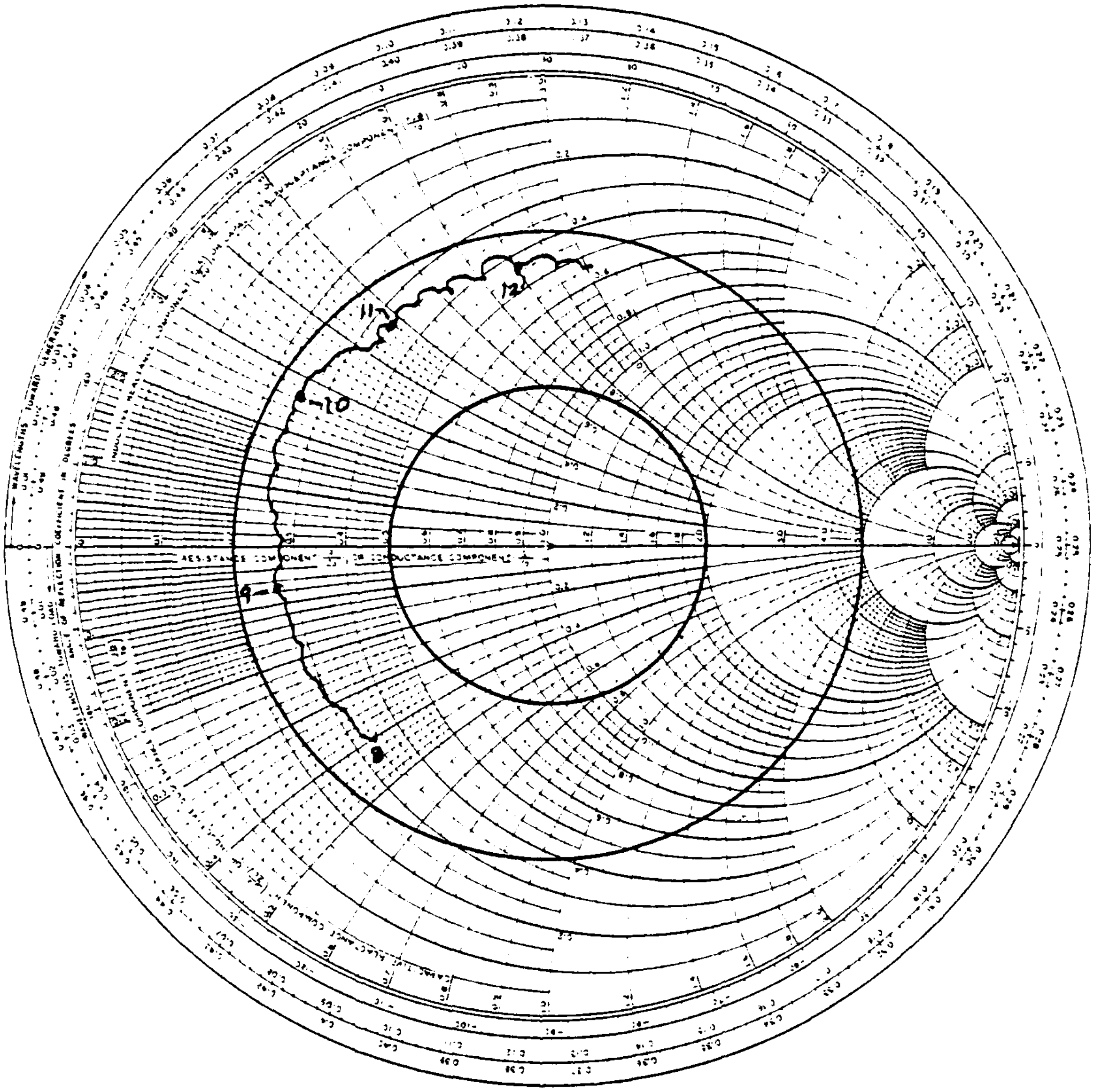


Figure 28. Impedance plot of conical antenna #1, 8 to 12.4 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR =5.

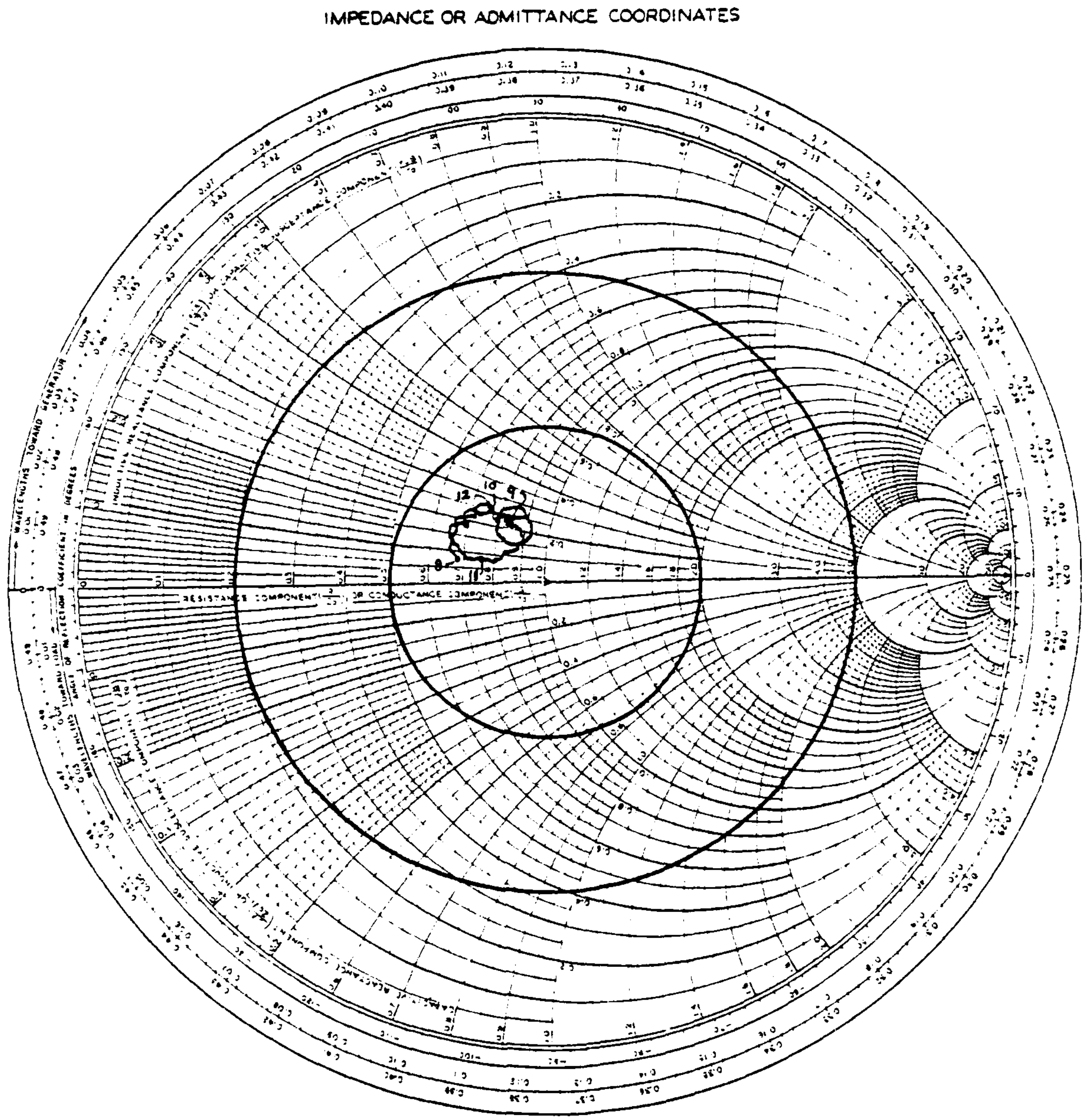


Figure 29. Impedance plot of conical antenna #2, 8 to 12.4 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR = 5.

IMPEDANCE OR ADMITTANCE COORDINATES

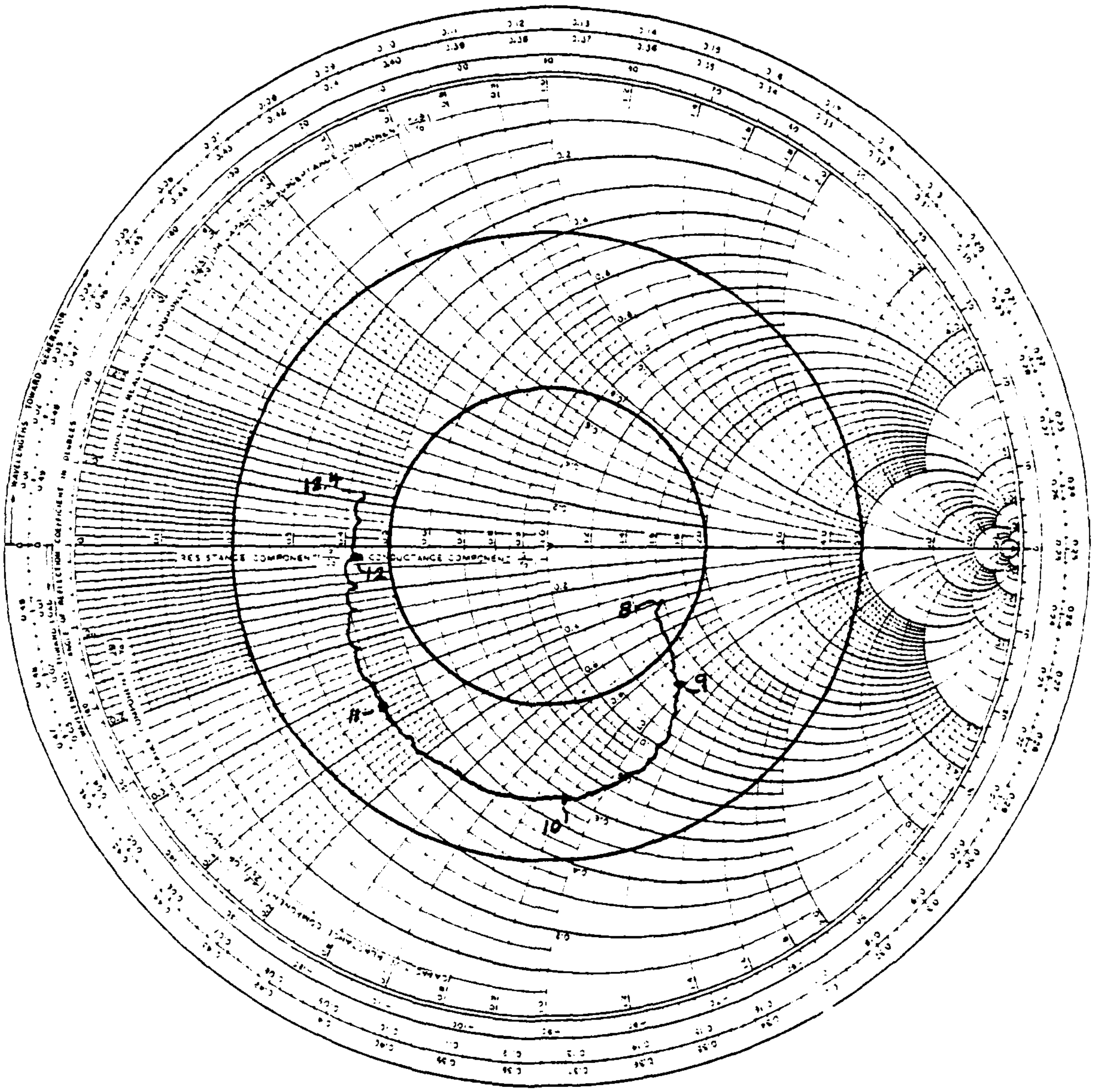


Figure 30. Impedance plot of stub antenna, 8 to 12.4 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR = 5.

The antenna impedance plots for the frequency range of 12.4 GHz to 18 GHz are Figures 31 through 33. Conical antenna #2 shows a VSWR which is approximately 2 : 1 or less over the entire frequency range, whereas the stub antenna and conical antenna #1 are both above 5 : 1 over most of the frequency range.

The performance of this stub antenna is approximately what one would expect of such an antenna over such a wide frequency range. The impedance appears to vary less than what one would expect of a narrowband radiator, because the diameter of the stub is over one third of its length. The cause of the difference between the two conical antennas was not found. The only discernible differences between the two antennas were at the apex of the cone, where it is soldered to the coaxial receptacle. Conical element #1 was soldered flush with the teflon at the end of the receptacle, whereas conical element #2 was soldered about .08 inches above the teflon. Also, the solder was not smooth in the vicinity of this joint on element #1. Cleaning some of the excess solder off the joint did not help the VSWR of conical element #1. It is probable that there is something inherently wrong in the construction of element #1, rather than something readily corrected, because this element showed high VSWR when it was first tested, using a different connector and ground plane.

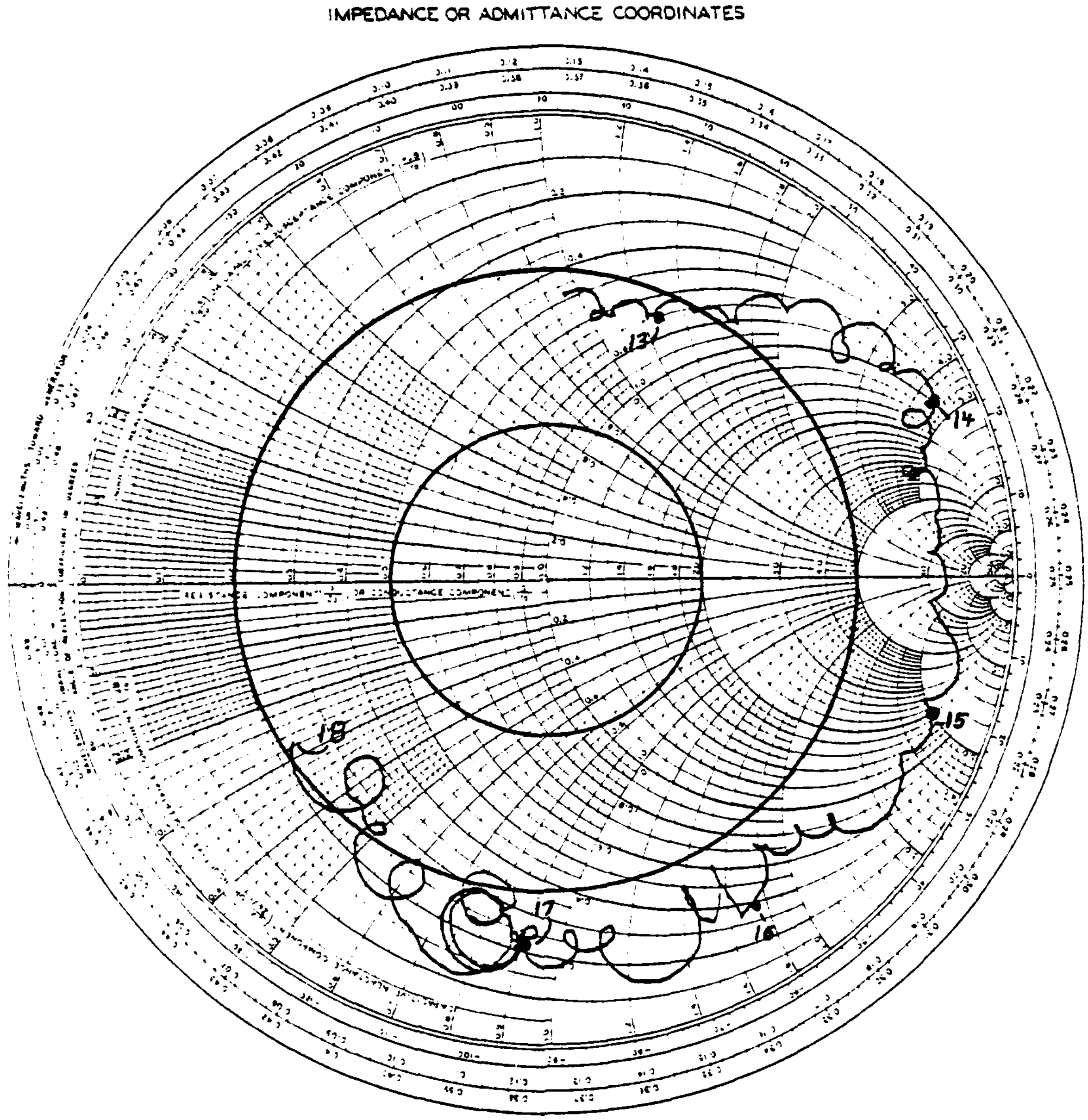


Figure 31. Impedance plot of conical antenna #1, 12.4 to 18 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR = 5.

IMPEDANCE OR ADMITTANCE COORDINATES

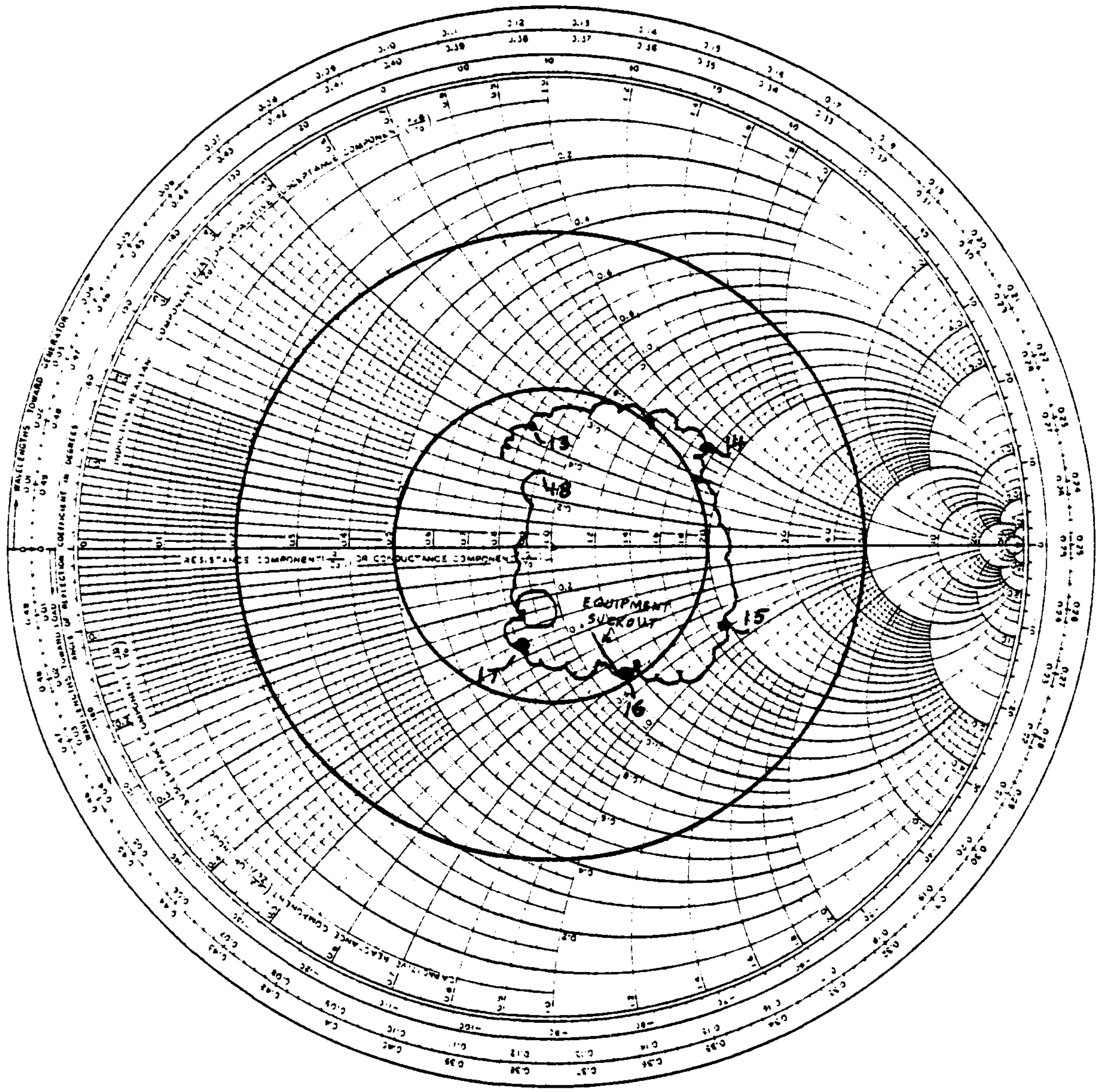


Figure 32. Impedance plot of conical antenna #2, 12.4 to 18 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR = 5.

IMPEDANCE OR ADMITTANCE COORDINATES

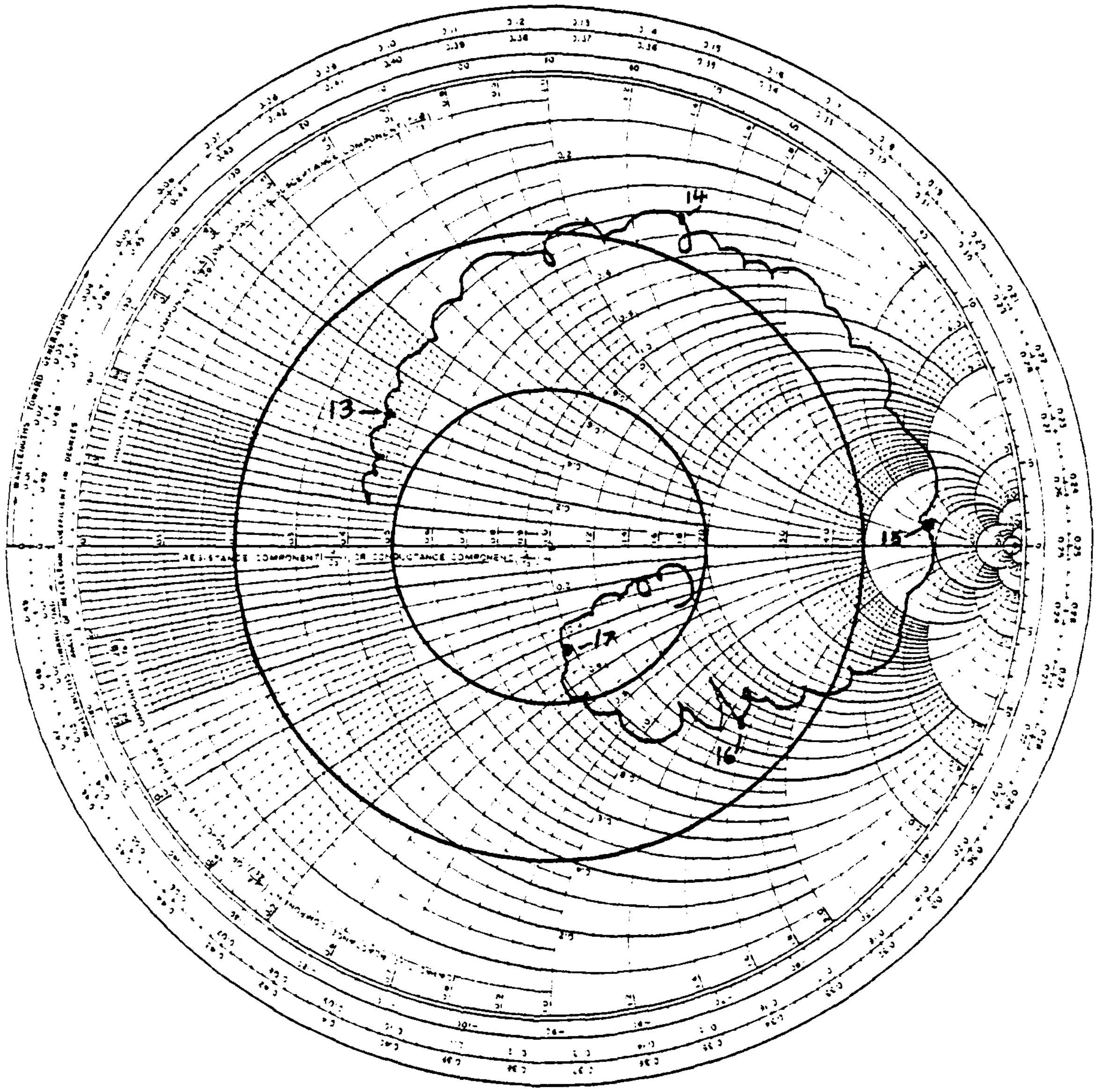


Figure 33. Impedance plot of stub antenna, 12.4 to 18 GHz. Frequencies in GHz are marked on trace. Inner circle is VSWR = 2; outer circle is VSWR = 5.

4. CONCLUSIONS

A phase shifter has been developed based upon control of phase offset in a phase-locked loop. This phase shifter provides linear control of the phase of a local oscillator signal over a region exceeding $\pm$ 270 degrees. The prototype phase shifter provides a phase-shifted output at 915.2 MHz, although the output may be varied from 750 to 1000 MHz by retuning the VCO and selecting appropriate reference and mixing frequencies. The settling time of the phase shifter is 1.6 microseconds to within 10% of the final value.

This phase-shifted local oscillator was designed to provide phase shifting for antenna arrays, such as the Northrop "FLAT 360" antenna described on page 1 of this report. The performance requirements of the phase shifter can be derived from the performance requirements of such an array. The phase-shifting error should be no more than 20 degrees to limit the combining loss to 0.54 dB (combining efficiency = cosine of phase error). To realize a 40 dB adaptive nulling depth implies short term phase stability of 0.5 degree (nulled amplitude = sine of phase error).

For the array to function over a wide frequency band, it is desirable to divide up the band into sub-bands and adaptively null the jamming signals in each of the sub-bands. This means that the phasing of the array must be reestablished each time one returns to a particular sub-band and implies a repeatability requirement for the phase shifters of 0.5 degrees on a short term basis.

During adaptive pattern optimization of the "FLAT 360" antenna system (nulling undesired signals and peaking the desired signal), the pattern will be perturbed every 10 microseconds by varying the local oscillator phase, which requires that the phase settle within 10% in one to three microseconds.

The phase-locked phase shifter must achieve the desired setting accuracy of $\pm$20 degrees when operated in a military temperature environment of -25°C to +85°C.

The phase shifter developed on this program was tested for all of these requirements except temperature drift. The variation of phase-shift from a straight line curve was only 11.7 degrees peak to peak, concentrated in the region where the two inputs to the phase detector pass through zero phase error. Repeatability of phase settings was excellent. Phase could be changed and reset within 0.1 degree over periods of 30 minutes or more. Phase noise is 0.2 degree RMS measured in a 4 MHz bandwidth when a low noise source is used for the 288 MHz reference. Thermal drift was considered in the design, and should be primarily dependent upon the input offset voltage and common mode rejection of operational amplifier U3. The input of this operational amplifier will drift less than 0.5 millivolt over a 100°C temperature range, corresponding to a phase shift of 0.5 degree. Shifts in the common mode output voltage of the phase detector are cancelled by the differential input configuration of amplifier U3.

This phase shifter is suitable for incorporation within a prototype 360 degree steerable antenna array in its present form. If prototype size is important, the phase shifters could be assembled in a smaller box to achieve a 50 to 75% size reduction with little effort. No other changes would be recommended for use in a prototype antenna array based upon the "FLAT 360" concept. The closed-loop response of the phase shifter may require separate adjustment on each prototype, in order to obtain a stable loop. If instability is encountered, it may be diminished by reducing the excess phase shift in the loop, either by reducing the closed-loop bandwidth or by increasing the bandwidth of loop components, particularly operational amplifier U4.

Temperature performance should be verified and properly compensated before a production design is made. Also, the VCO in the present design is too large and too costly for production application. The VCO could be redesigned as an L-C oscillator with reduced size and production cost. An attractive alternative which should be considered at these frequencies is to design the VCO with a surface acoustic wave (SAW) resonator. Such a resonator can be obtained at low cost in production quantities, and they can be produced with such accuracy that no tuning adjustment would be required on the finished oscillator. In considering changes to the VCO, it should be remembered that the phase shifter is insensitive to changes in the VCO tuning; frequency changes of plus and minus 6 MHz caused less than 0.5 degree total phase shift of the output signal.

A prototype conical monopole antenna was assembled and tested over the frequency range from 7 to 15 GHz. A pair of these elements were assembled 8.4 inches apart on a six foot diameter ground plane, and interfaced with the phase shifter. The resulting antenna patterns were multi-lobed, and the lobes could be steered by varying the phase shift between the two antenna channels. The steering effect moves the antenna pointing angle from one lobe to the next adjacent lobe as the phase is changed 360 degrees. In an adaptive-null and peaking antenna system, this multi-lobed antenna pattern will allow the generation of spacial rejection notches closer to the direction of the desired signals than would occur if the antenna elements were closer together.

The peak radiation of the antenna occurs approximately 7 to 10 degrees above the horizon, with the lowest angle occurring at the highest frequency, and the radiation at the horizon is 6 to 7 dB less than that peak. This corresponds with the theoretical values for a 6 foot diameter ground plane. There was no evidence of any shading of signals by the adjacent element. These results indicate that performance will be comparable if a full 144-element flat antenna array is constructed, and the gain will then increase 18.6 dB (voltage gain equal to 72), compared to the two element antenna array.

5. RECOMMENDATIONS

The phase-locked phase shifter is recommended for use in systems which require variable phase shifting of signals, such as phased-array antennas. This phase shifter is used as a local oscillator in a mixing process in order to change the signal phase. This phase shifter is especially applicable for use in systems which use row and column phasing, requiring equal phase shifting for multiple signals.

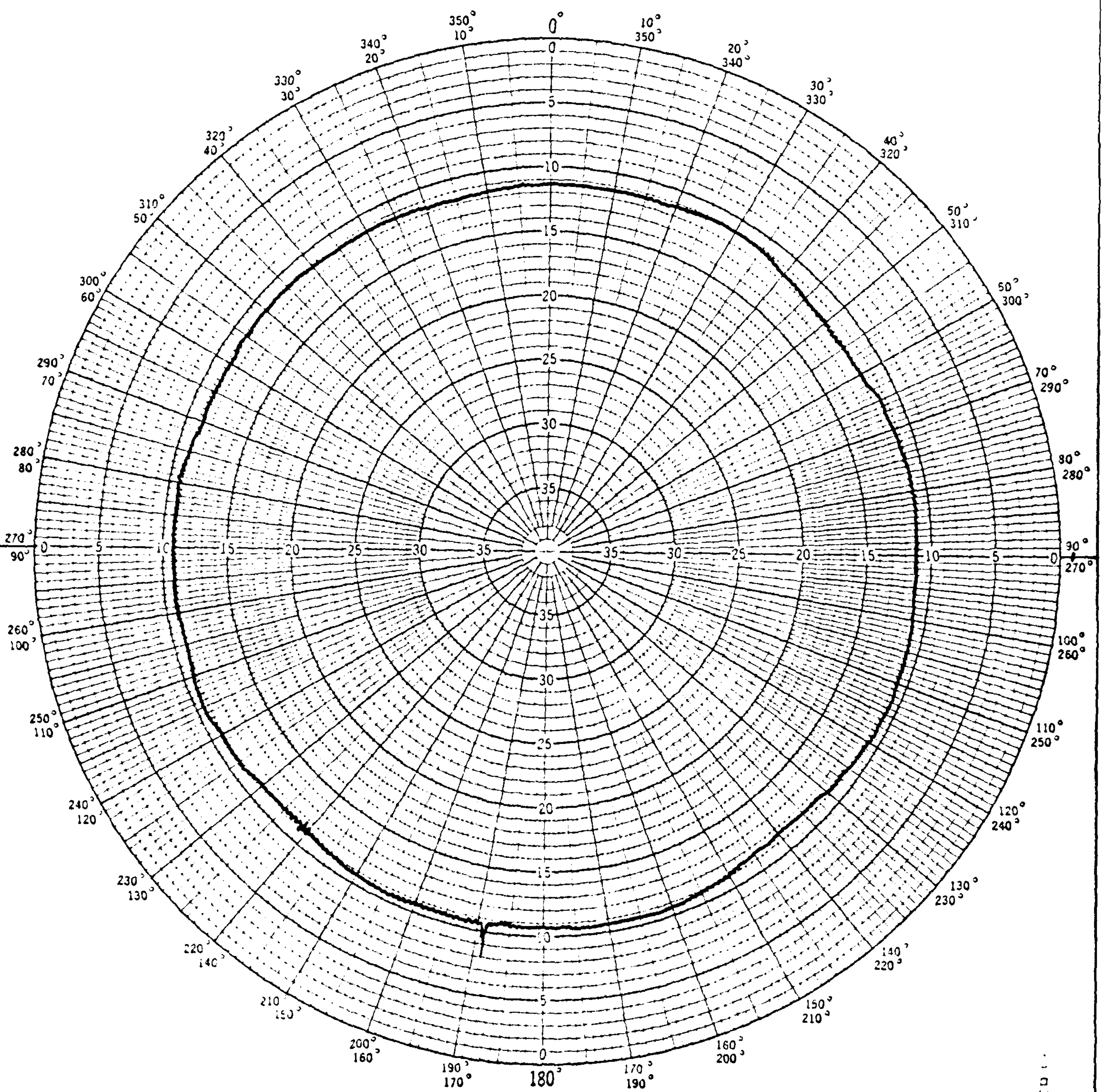
The phase shifter and conical antenna elements can be used to implement the Northrop FLAT 360 antenna concept, a large 2-dimensional horizontal array providing 360 degree coverage in azimuth and an octave bandwidth. This antenna concept provides adaptive peaking of desired signals, and adaptively-controlled nulls for jamming signal rejection. In order to demonstrate the applicability of the phase shifter in large phased arrays, it is recommended that a 16-element 4 x 4 rectangular array based on the FLAT 360 concept be built and tested.

APPENDIX A

Single Conical Monopole Antenna Patterns--Measured on Outdoor Range

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 4 FT DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE CONICAL (SINGLE) MODEL FREQUENCY 7.0

ANTENNA LOCATION ℄ STATION

OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓

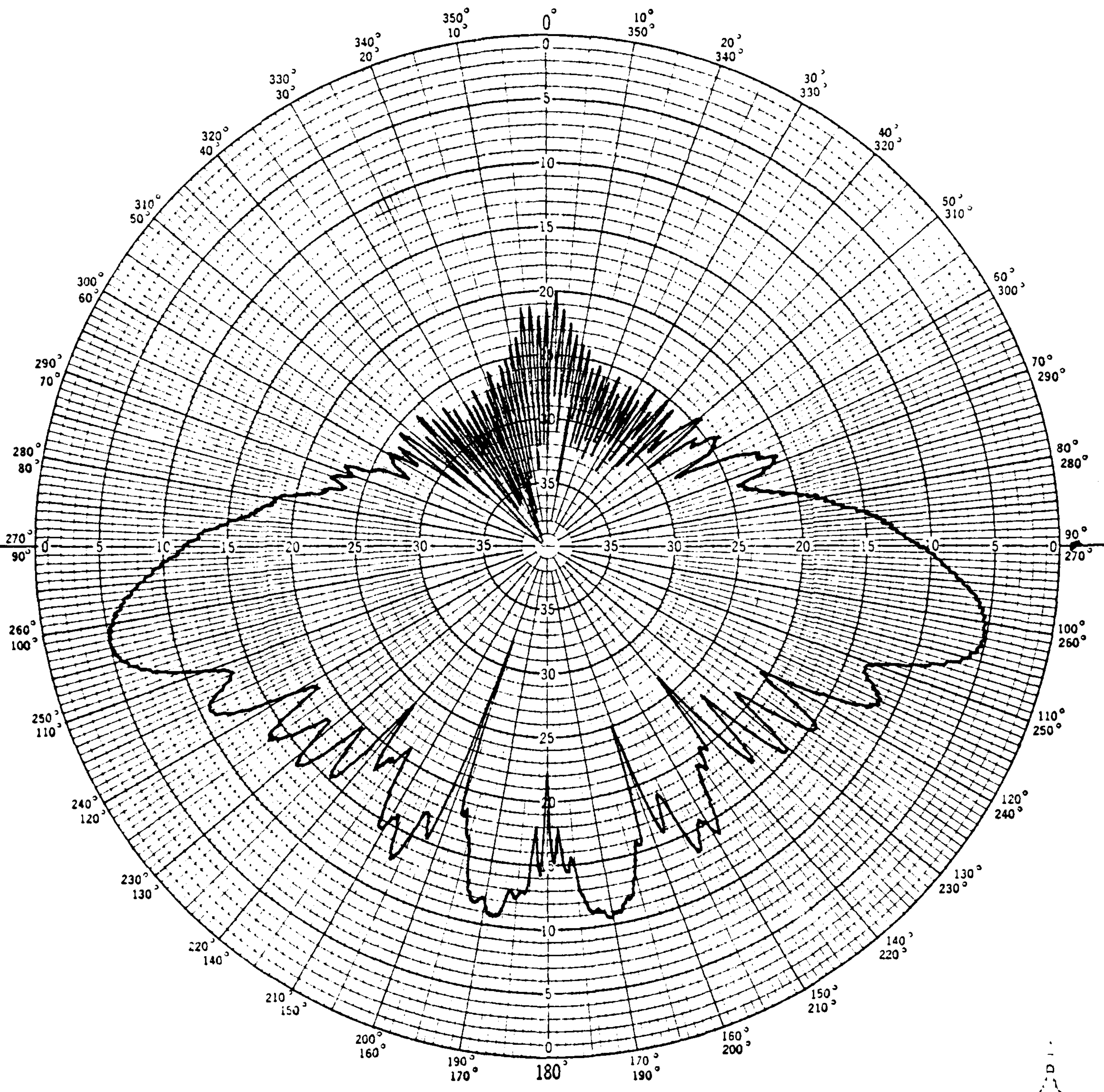
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓

PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT.

REMARKS

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division



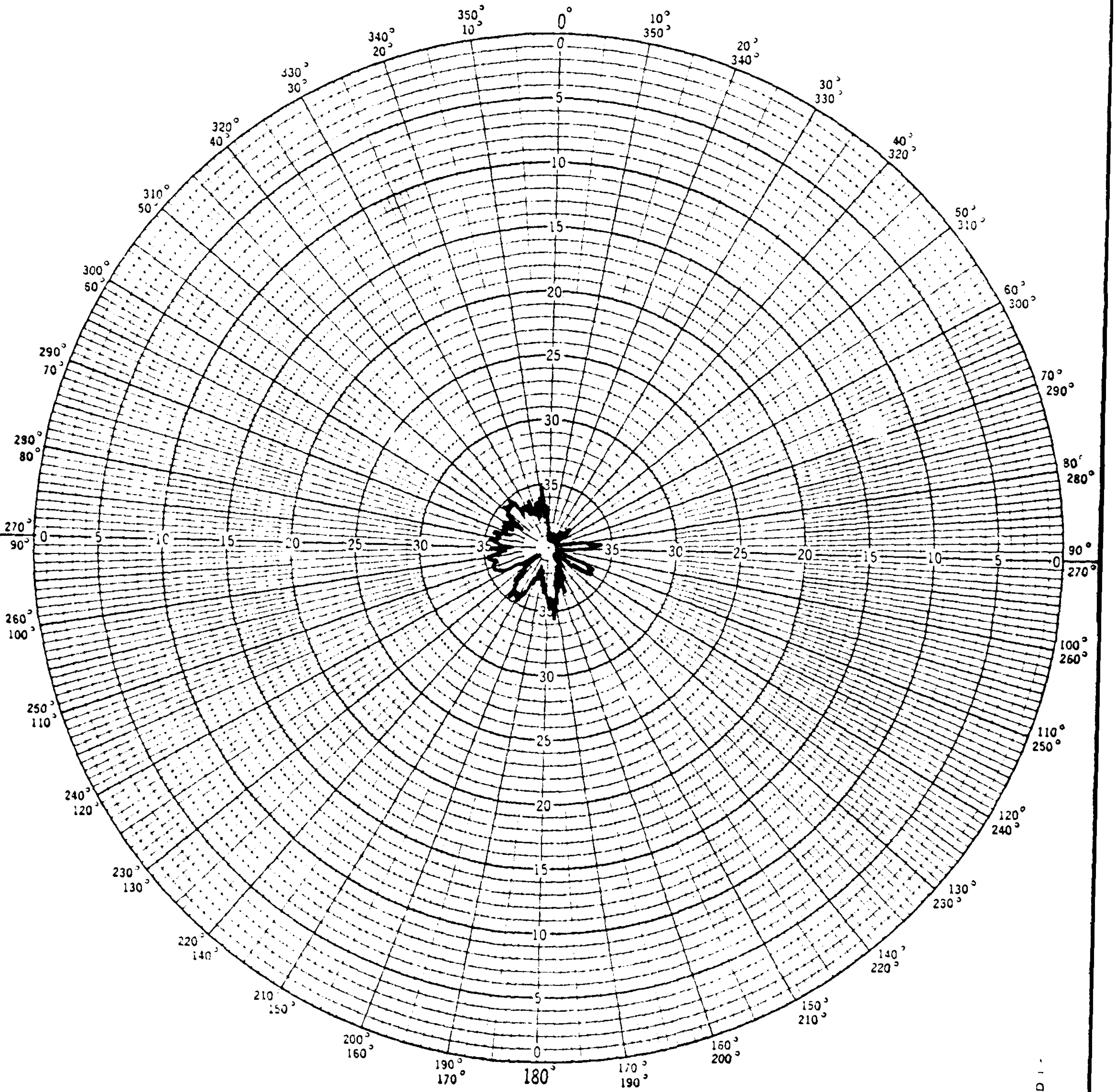
MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 7.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL ✓ PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT.
REMARKS

Form 47-63 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE CONICAL MODEL FREQUENCY 7.0

ANTENNA LOCATION ℄ STATION

OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

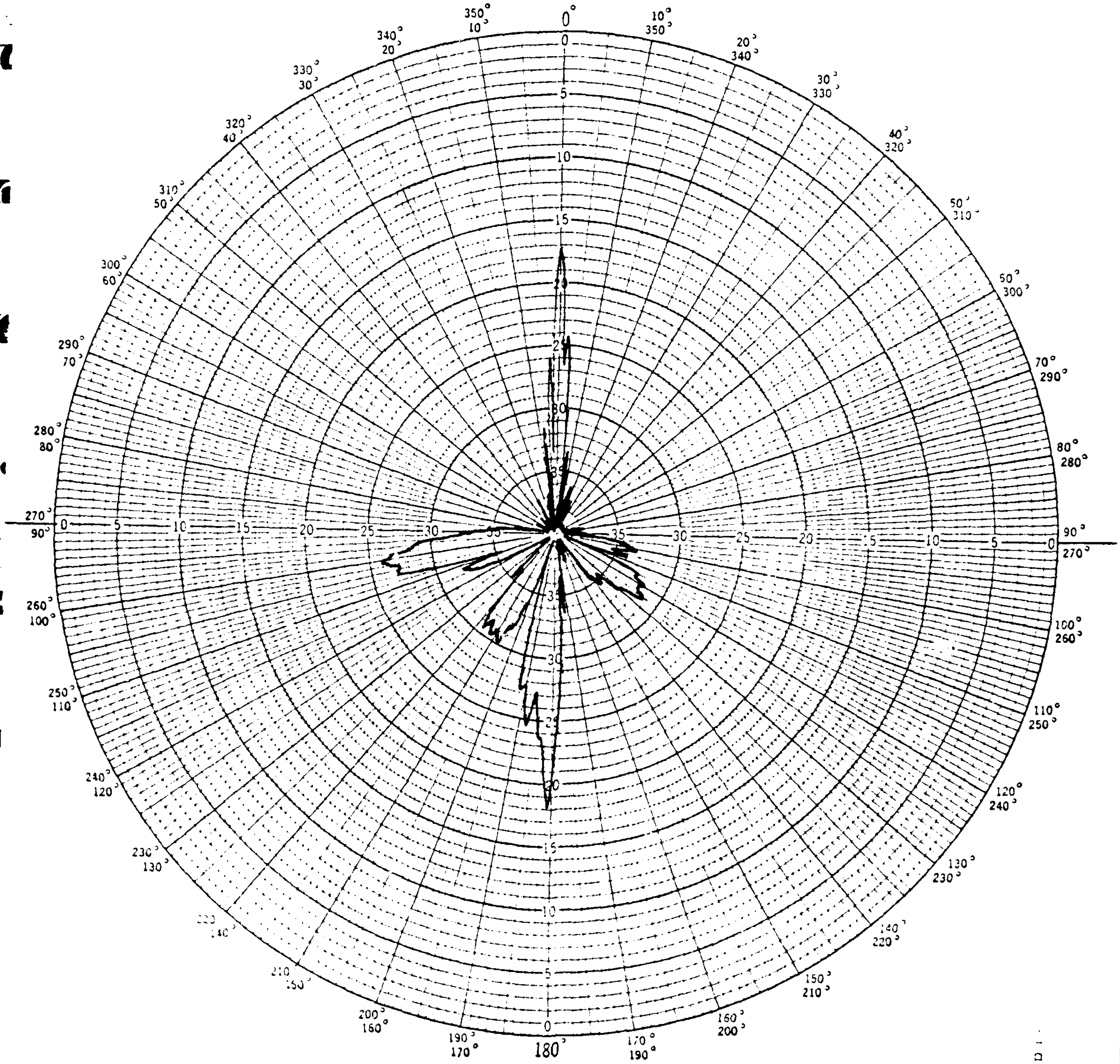
PATTERN θ 90 ϕ ( ) POLARIZATION ϕ, HORIZ.

REMARKS

Form 47-63 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE CONICAL MODEL FREQUENCY 7.0

ANTENNA LOCATION ℄ STATION

OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION Φ, HORIZ

REMARKS

Form 47-63 (R 3-72)

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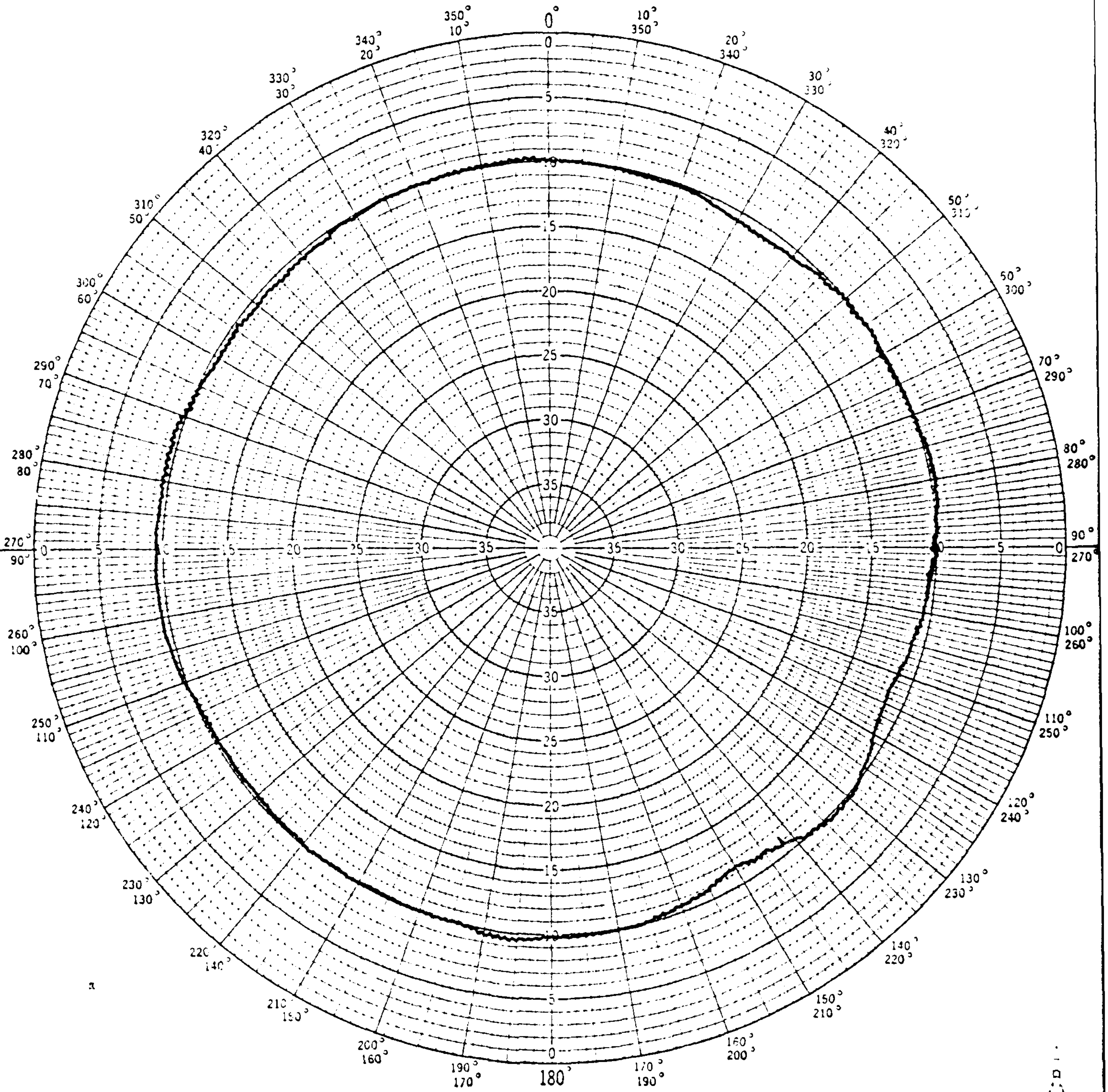
Aircraft Division

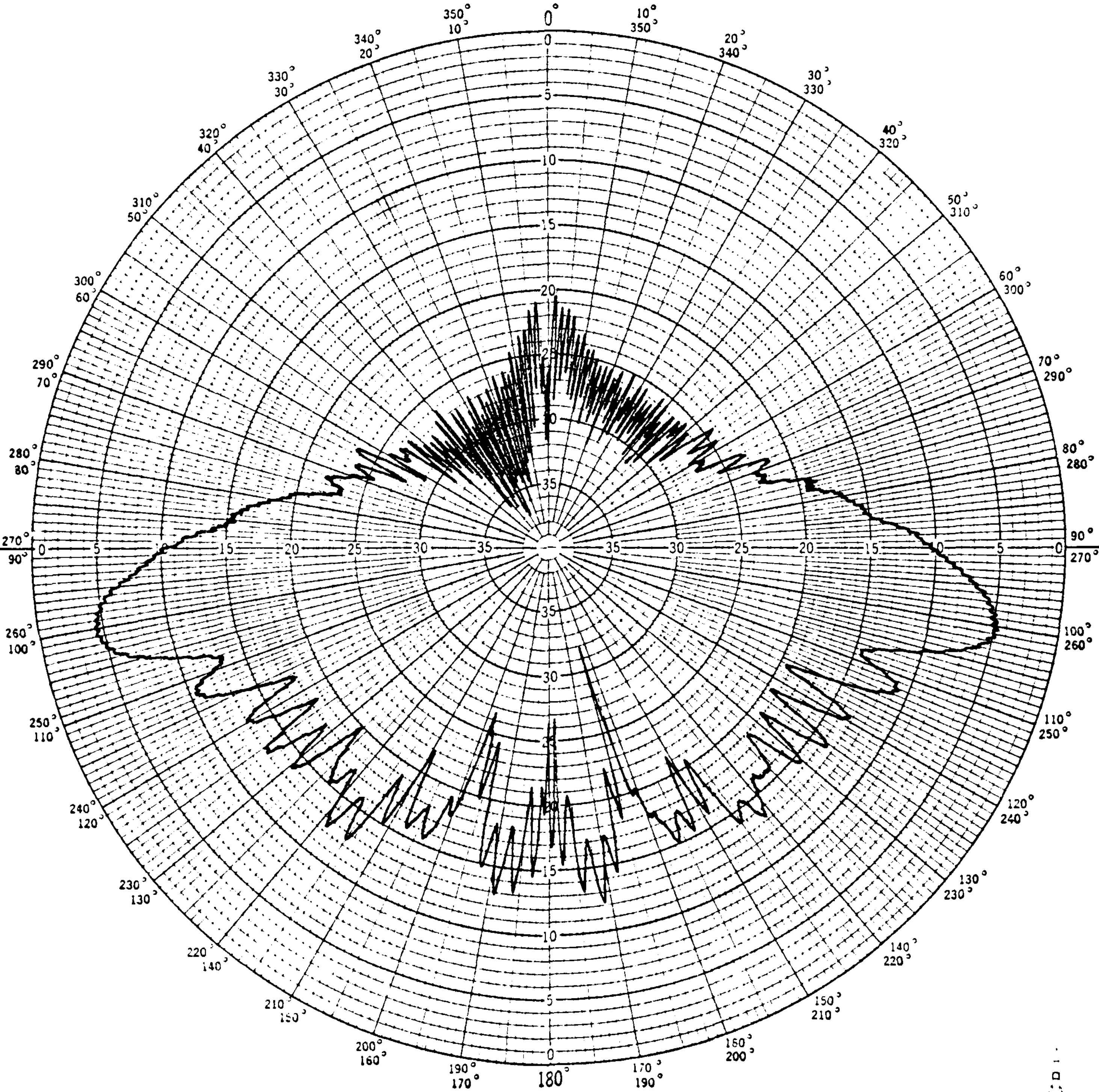


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 9.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT.
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

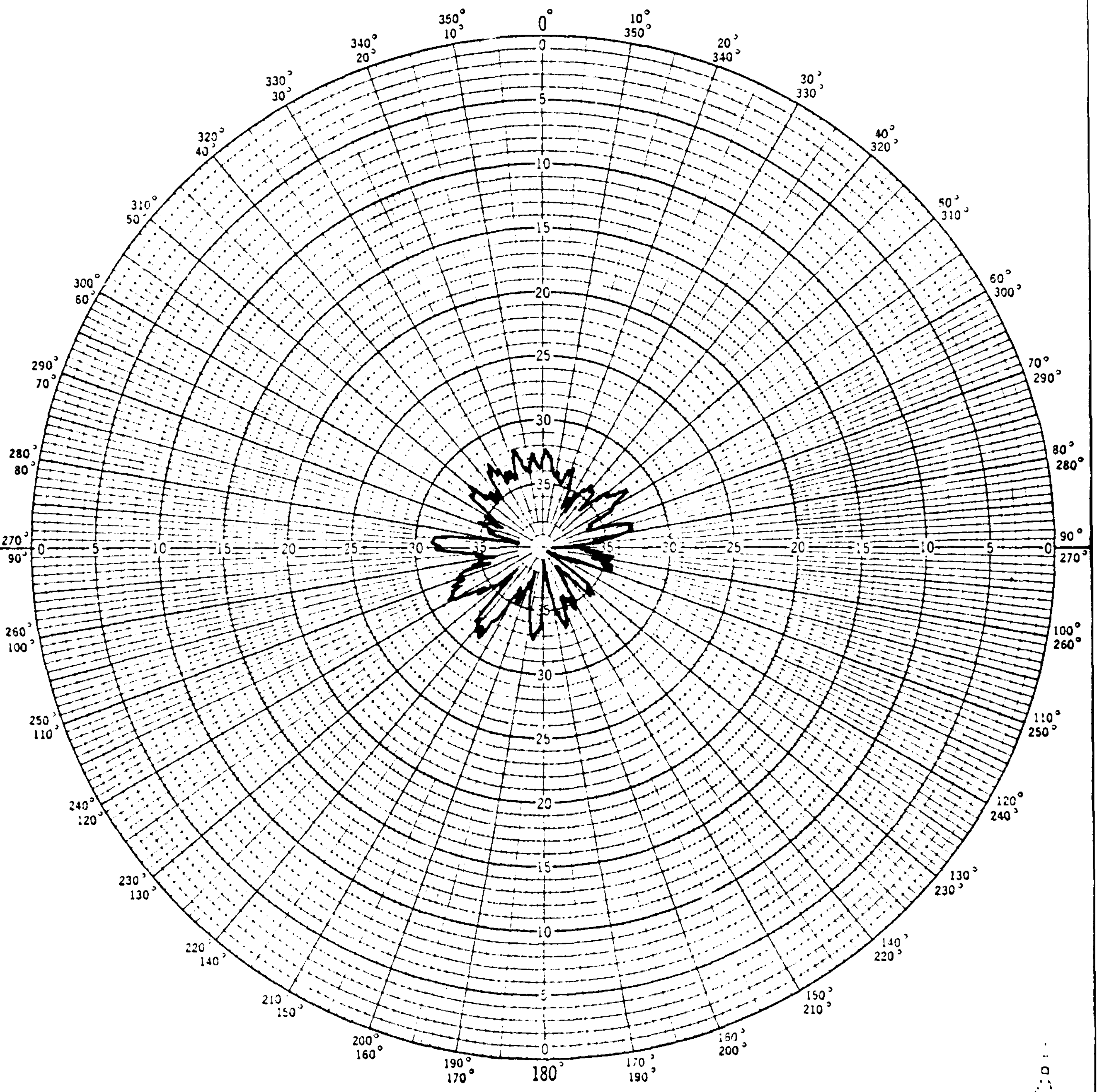


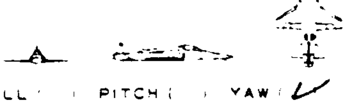
MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 9.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



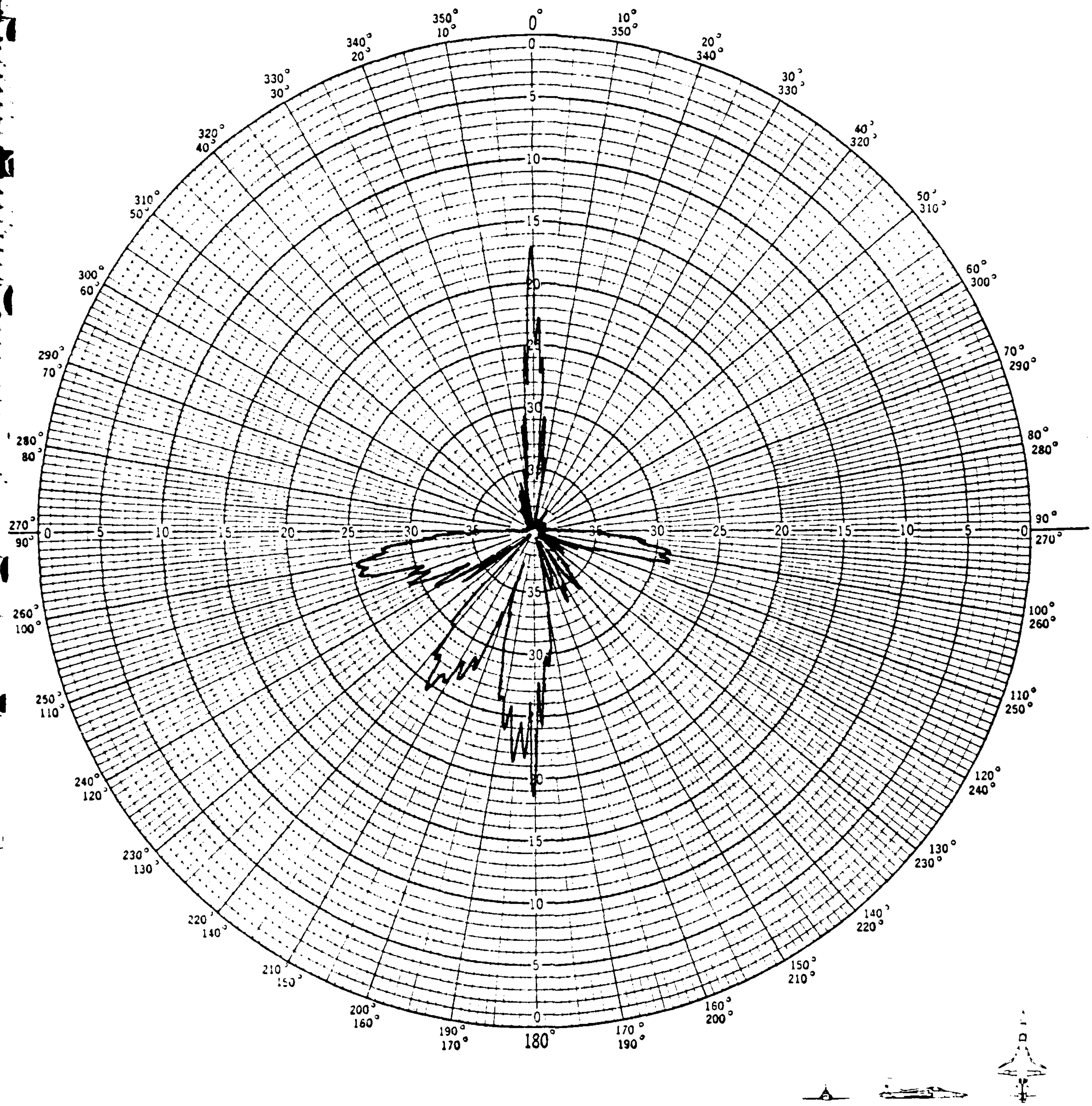


MODEL TYPE *4' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *CONICAL* MODEL FREQUENCY *9.0*
ANTENNA LOCATION *℄* STATION
OPERATOR DATE *10-10-77*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ( )
PATTERN θ *90°* ϕ POLARIZATION *ϕ, HORIZ*
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



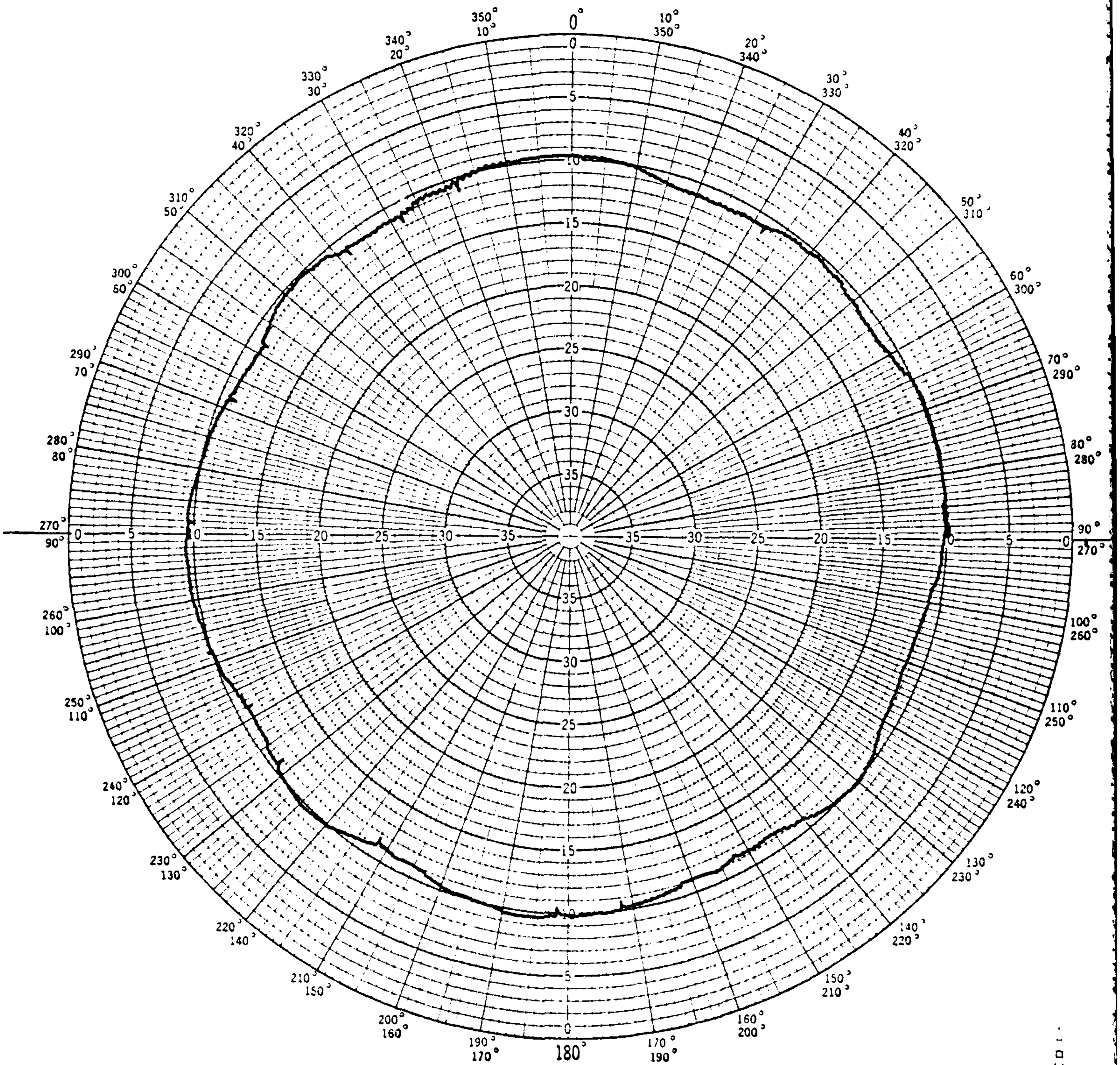
MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 9.0
ANTENNA LOCATION ℄ STATION ______
OPERATOR ______ DATE 10-10-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) Φ ( ) POLARIZATION Φ, HORIZ
REMARKS ______

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



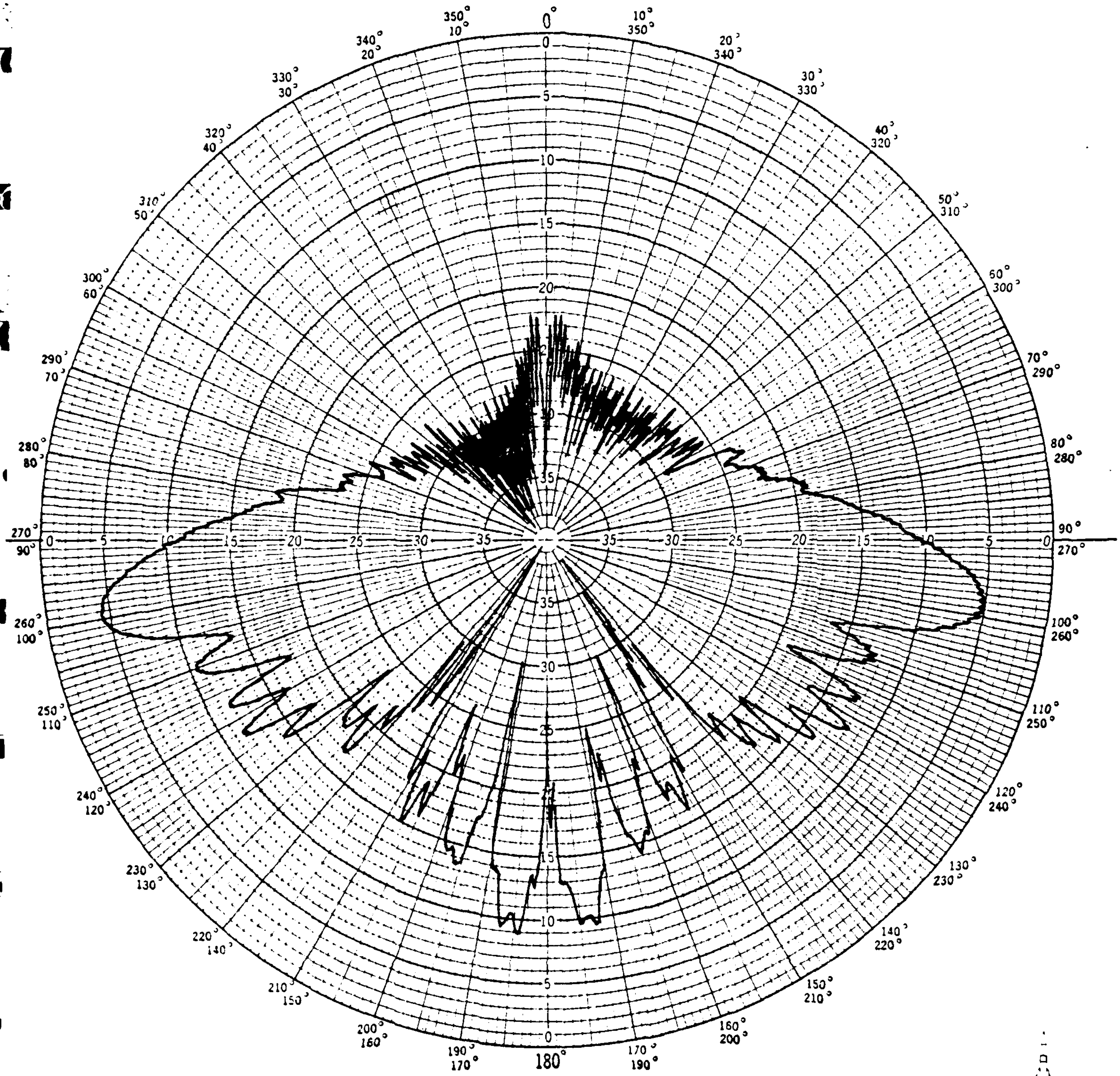
MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 11.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 1/ 19-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ( )
PATTERN θ 90 Φ ( ) POLARIZATION θ
REMARKS

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE *4' DIAM GND PLANE* MODEL SCALE *FULL*

ANTENNA TYPE *CONICAL* MODEL FREQUENCY *11.0*

ANTENNA LOCATION *℄* STATION ______

OPERATOR ______ DATE *10-10-77*

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )

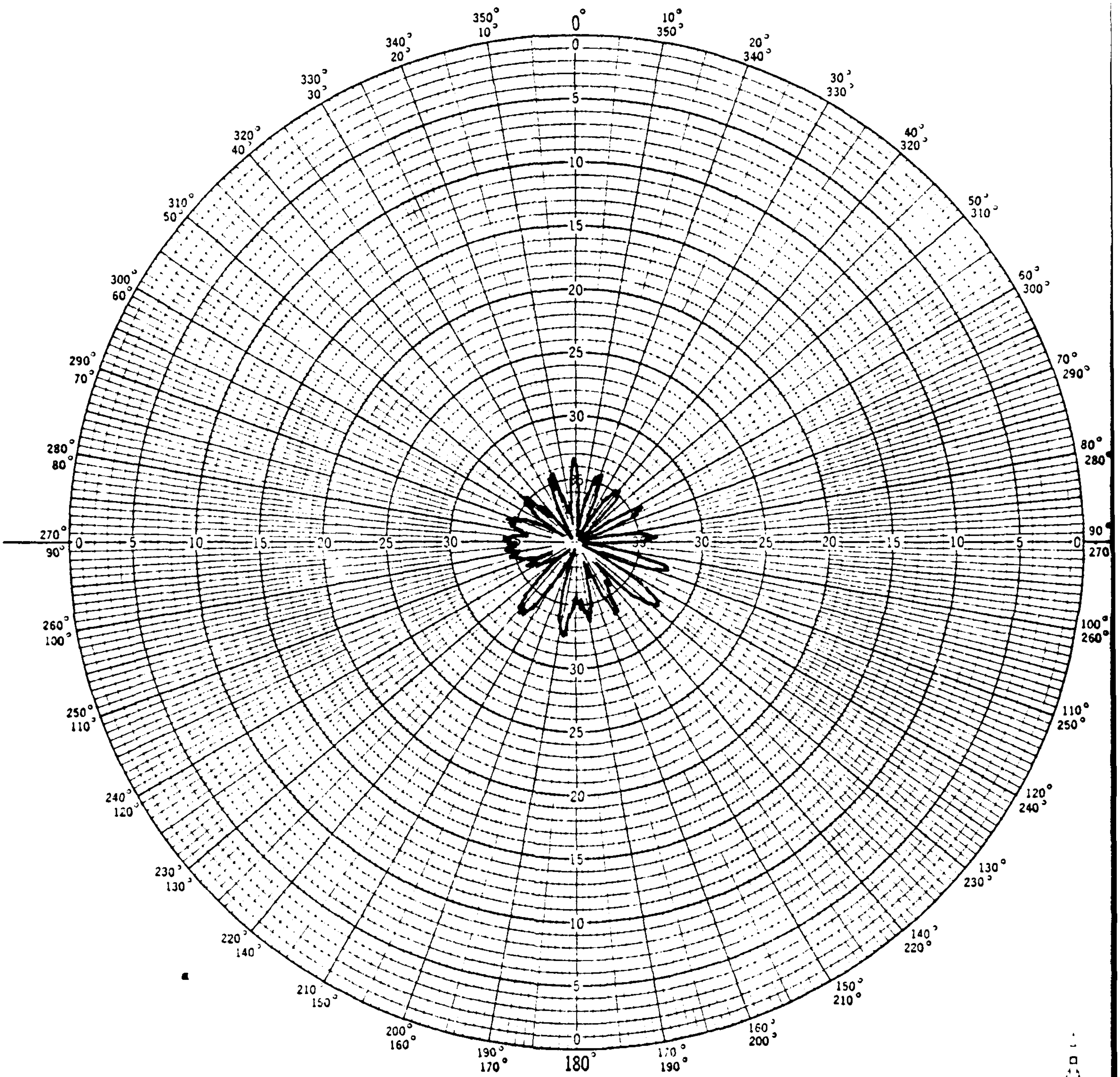
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION *θ*

REMARKS ______

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

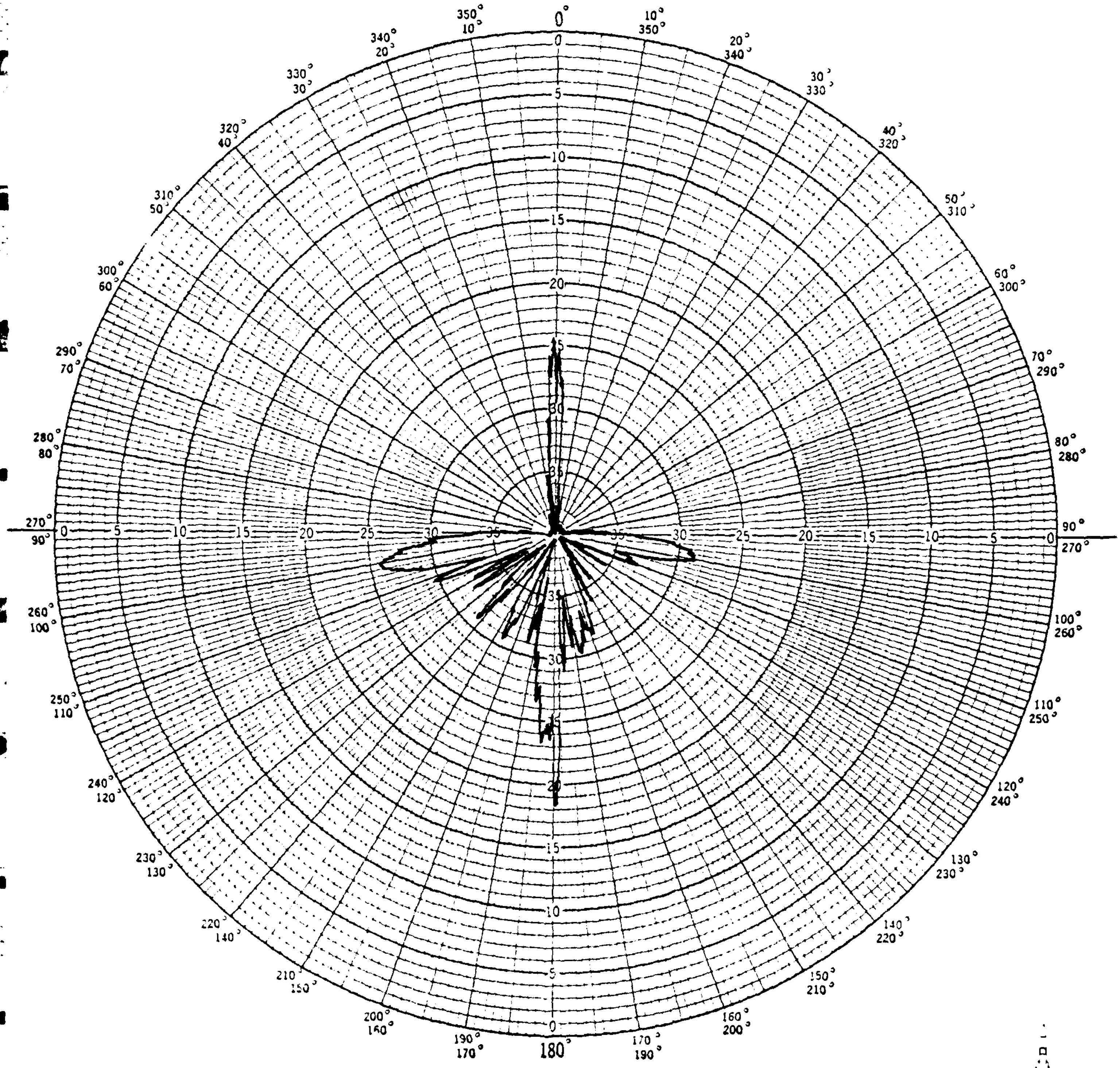


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 11.0
ANTENNA LOCATION ¢ STATION
OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION Φ, HORIZ
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

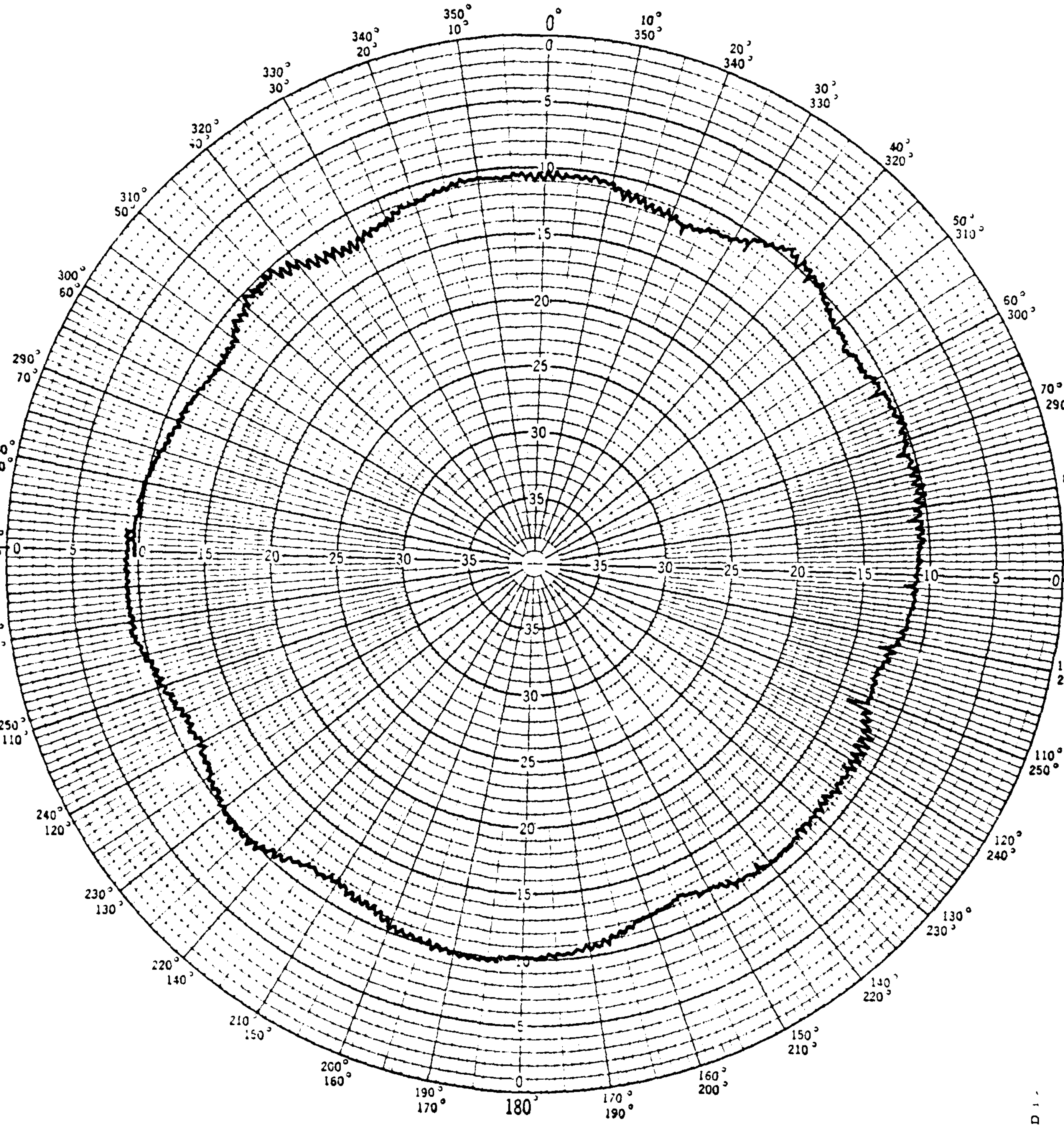


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 11.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-10-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION Φ
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

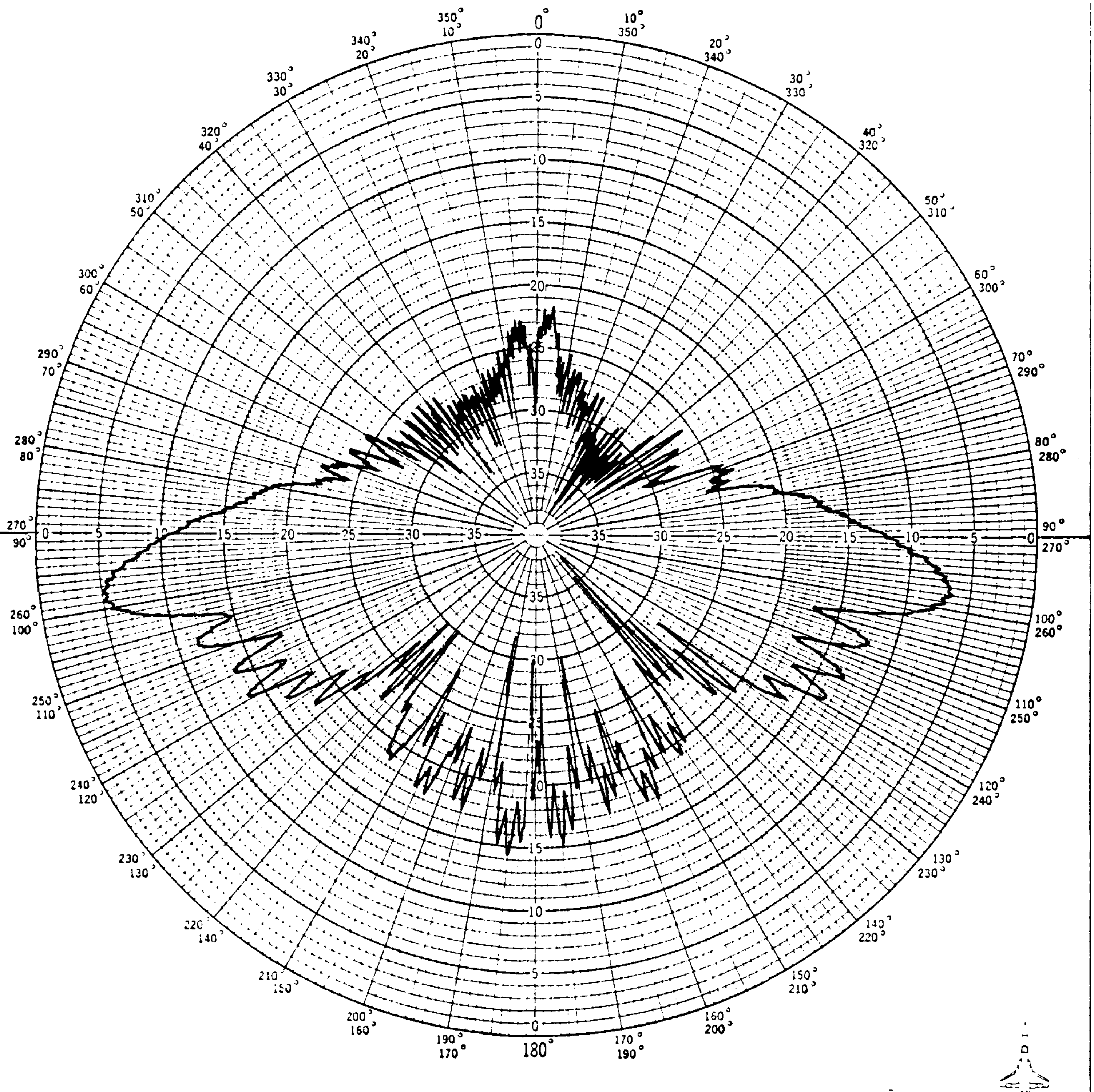


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 130
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-11-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 ɸ ( ) POLARIZATION θ, VERT
REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



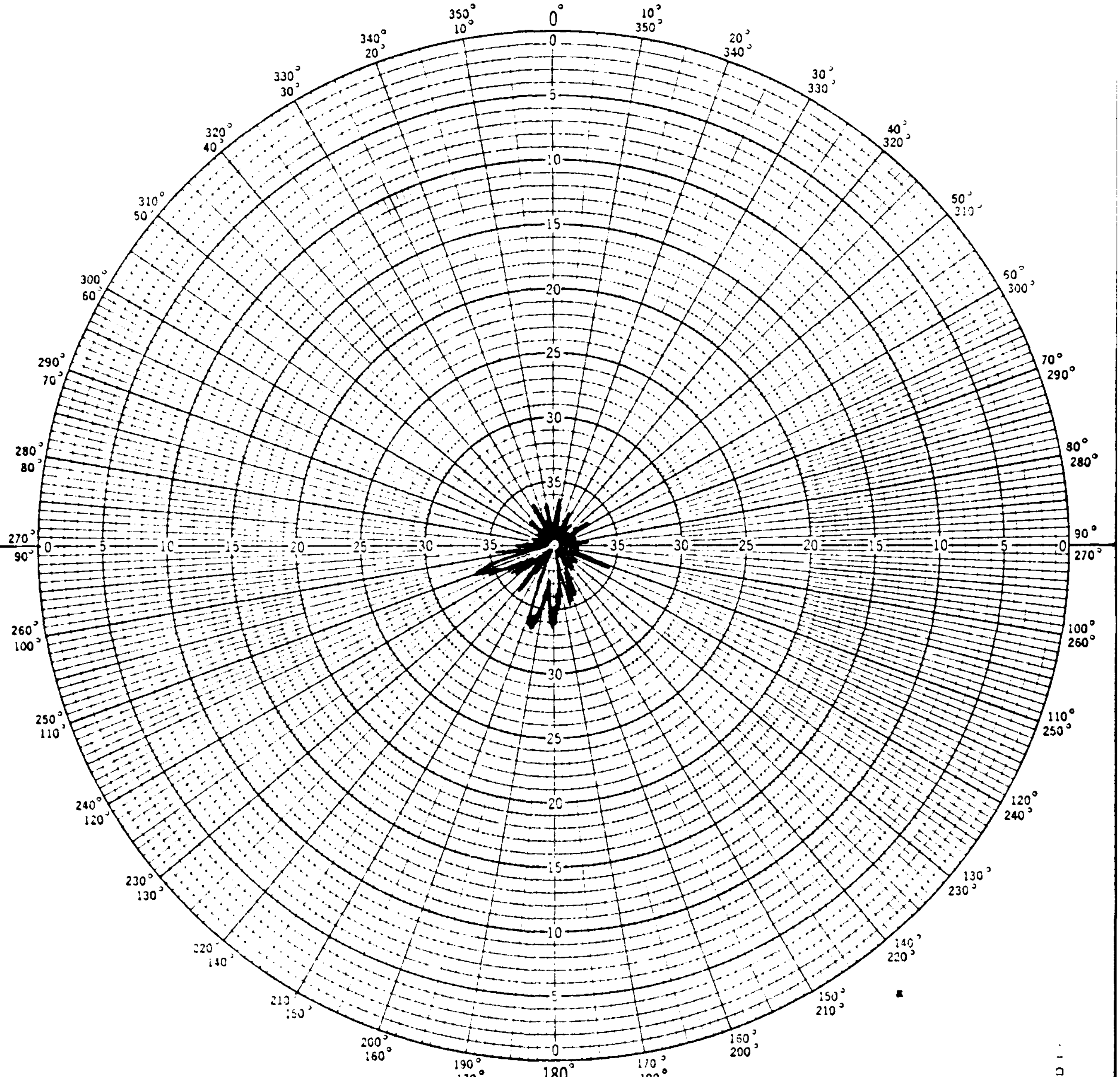
MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 13.0
ANTENNA LOCATION ℄ STATION _____
OPERATOR _____ DATE 12-11-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION θ
REMARKS _____

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE CONICAL MODEL FREQUENCY 13.0

ANTENNA LOCATION ℄ STATION

OPERATOR DATE 10-11-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

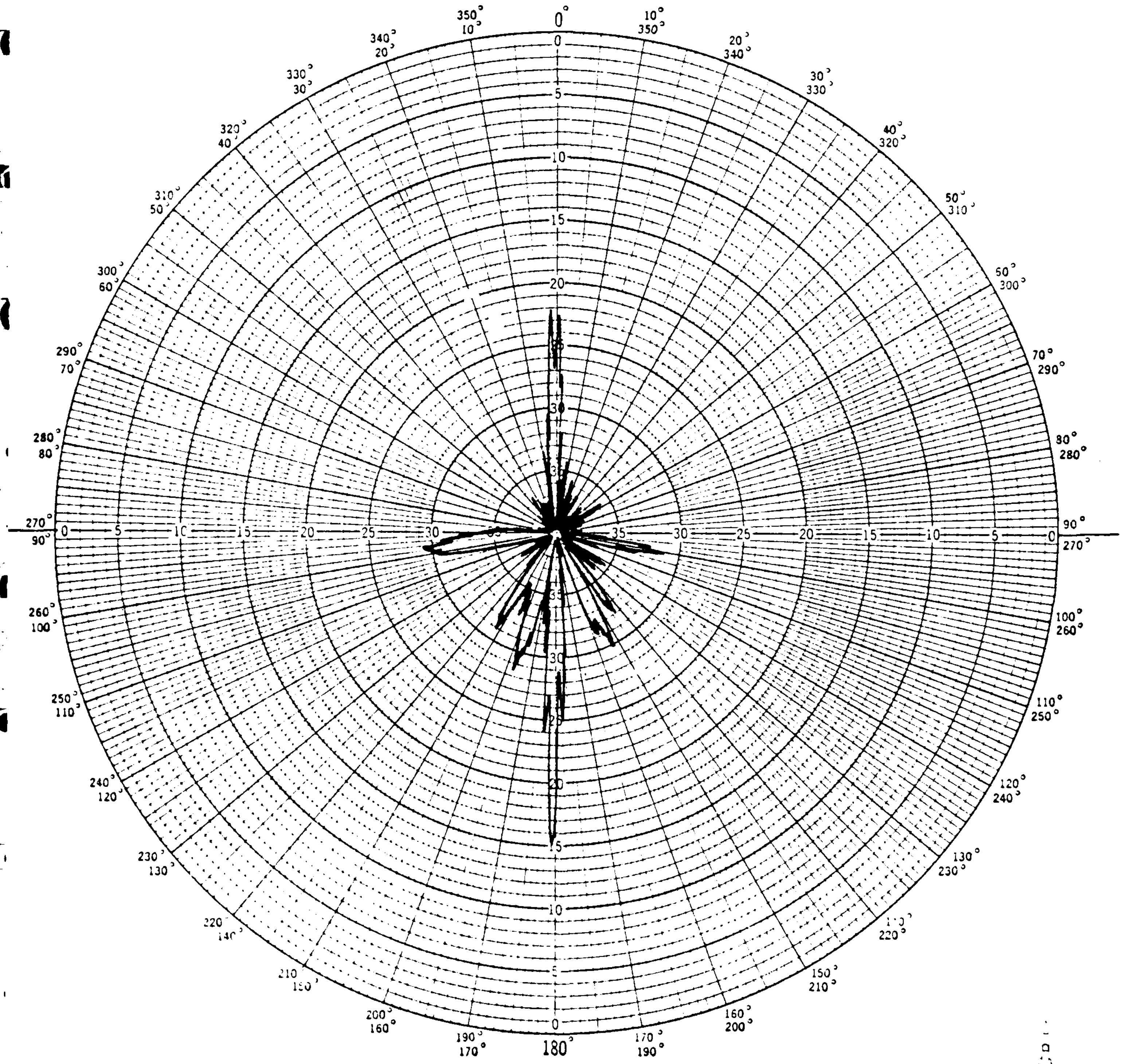
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ( )

PATTERN θ 90 Φ ( ) POLARIZATION Φ, HORIZ

REMARKS

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

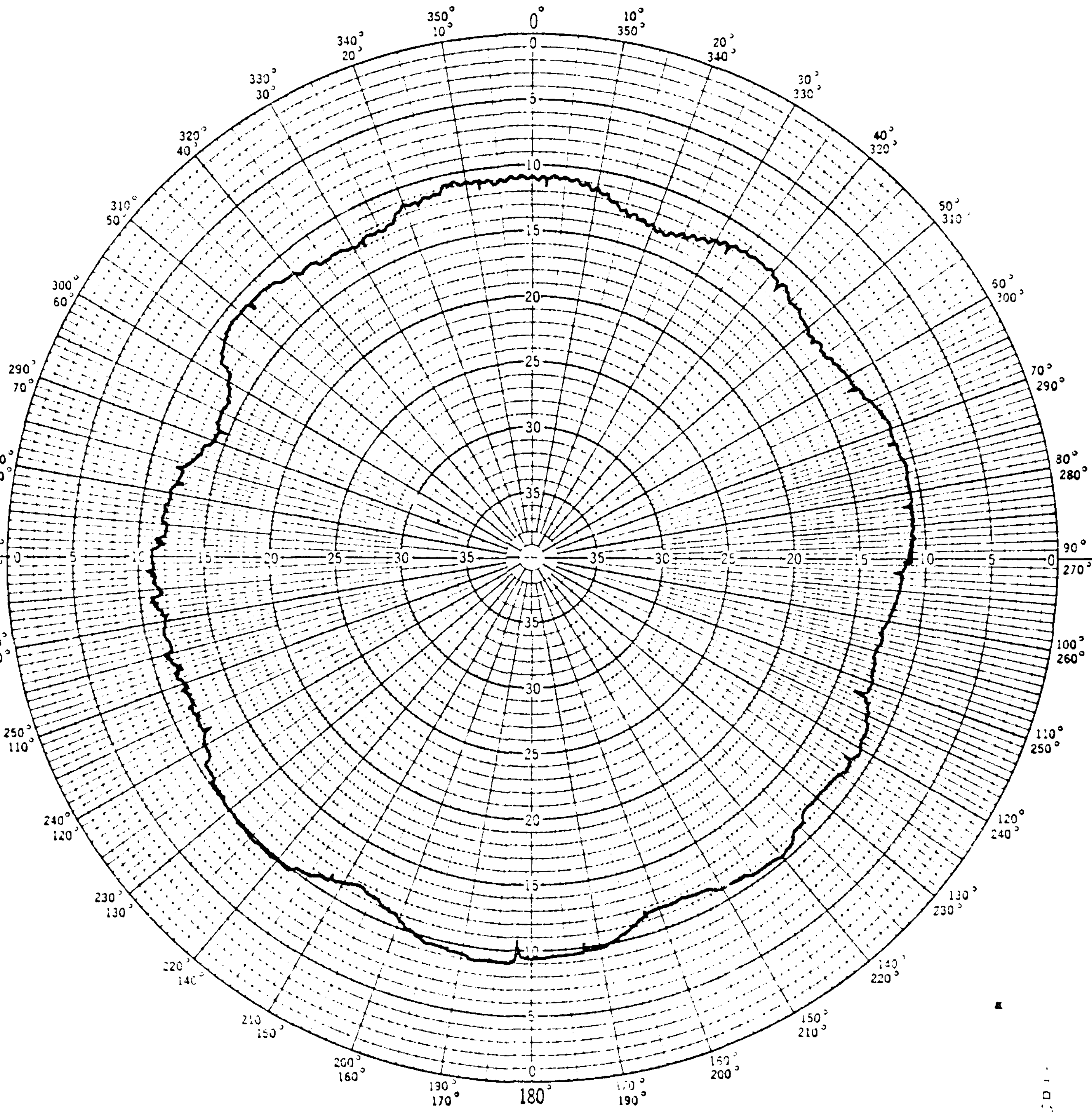


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 13.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-11-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) Φ ( ) POLARIZATION Φ, HORIZ
REMARKS

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division

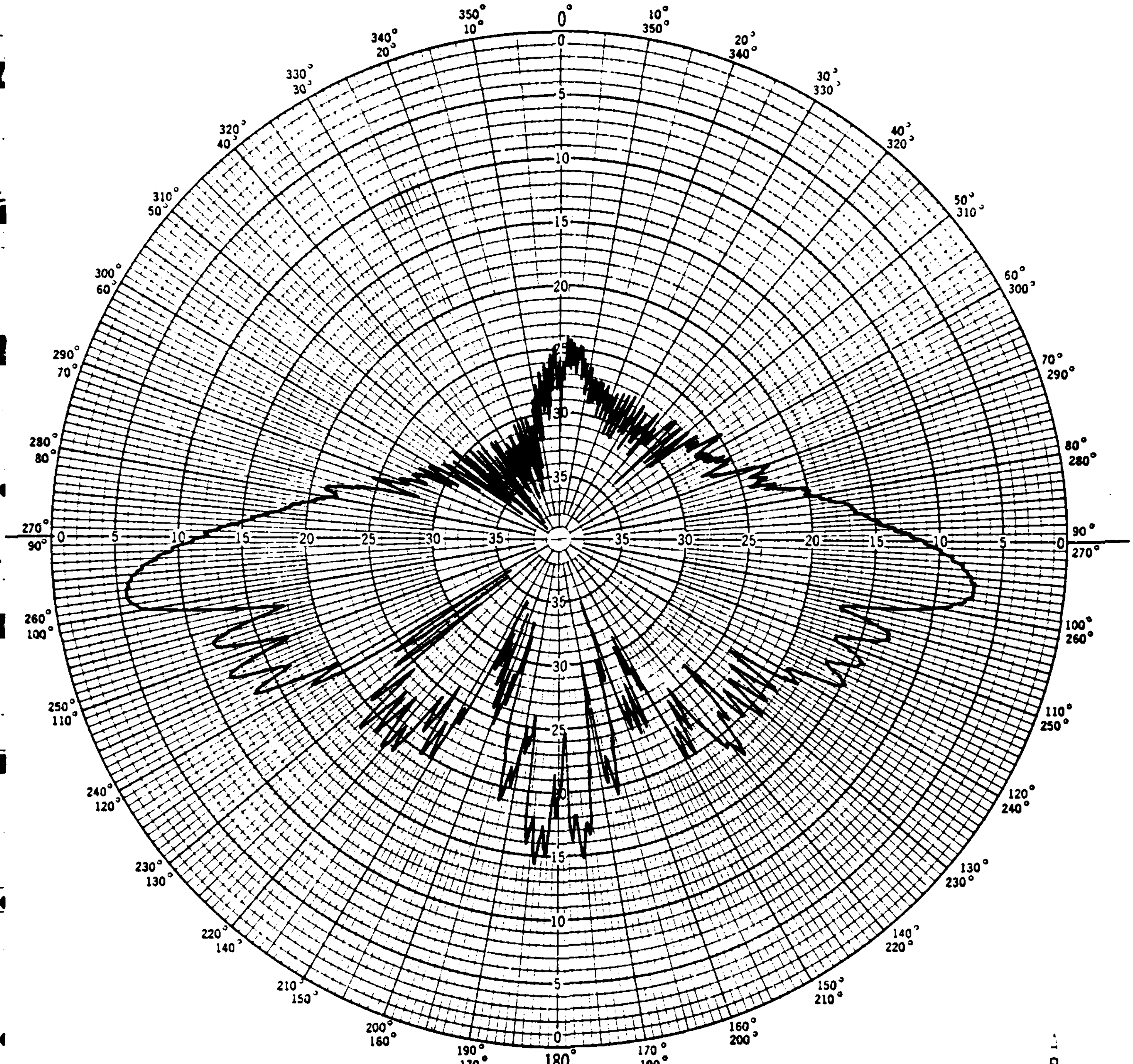


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 15.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-12-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT
REMARKS

Form 47-69 R (72)

NORTHROP
Northrop Corporation
Aircraft Division

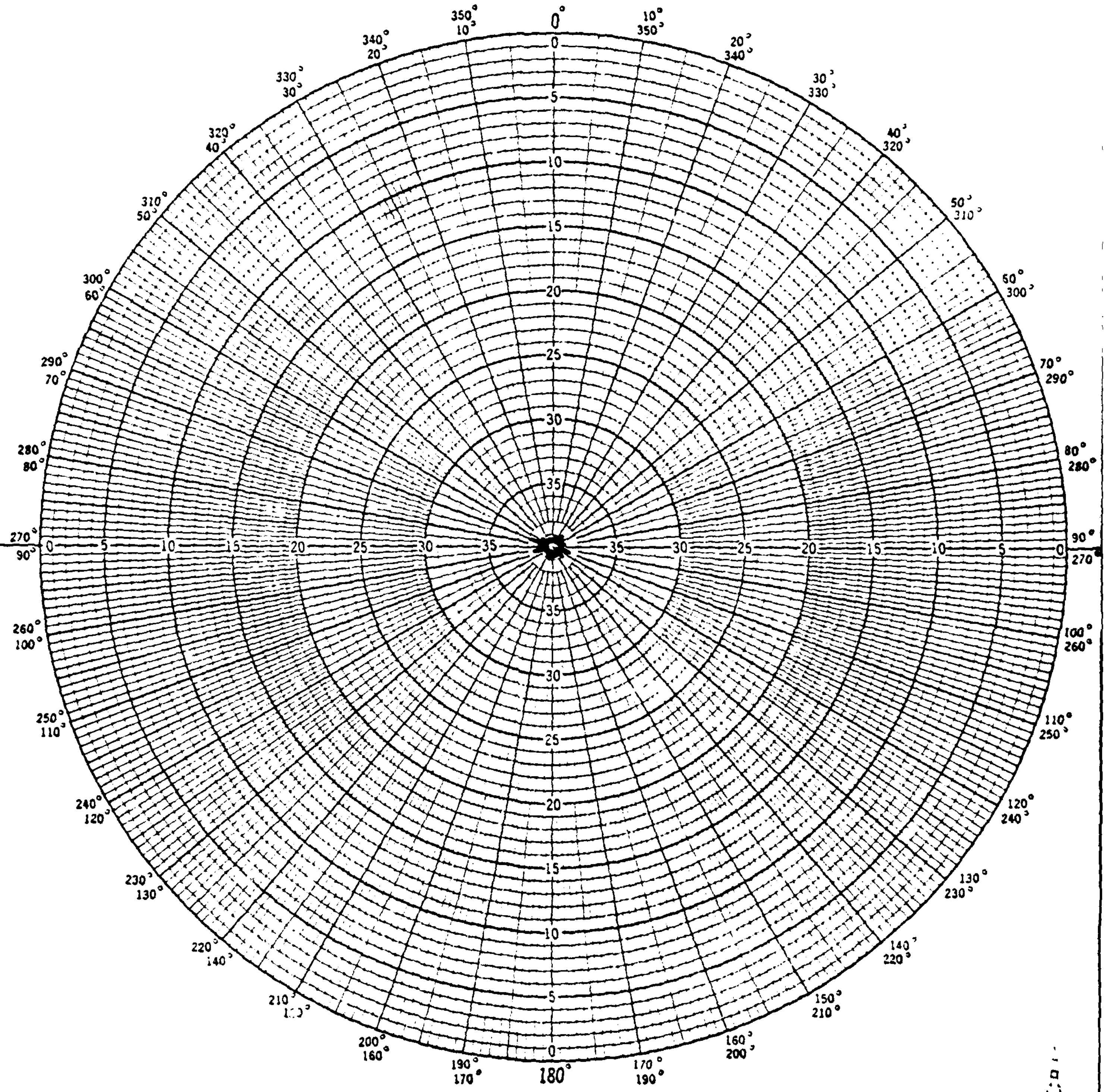


MODEL TYPE *4' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *CONICAL* MODEL FREQUENCY *15.0*
ANTENNA LOCATION *℄* STATION ______
OPERATOR ______ DATE *10-12-77*

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION *θ, VERT*
REMARKS ______

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

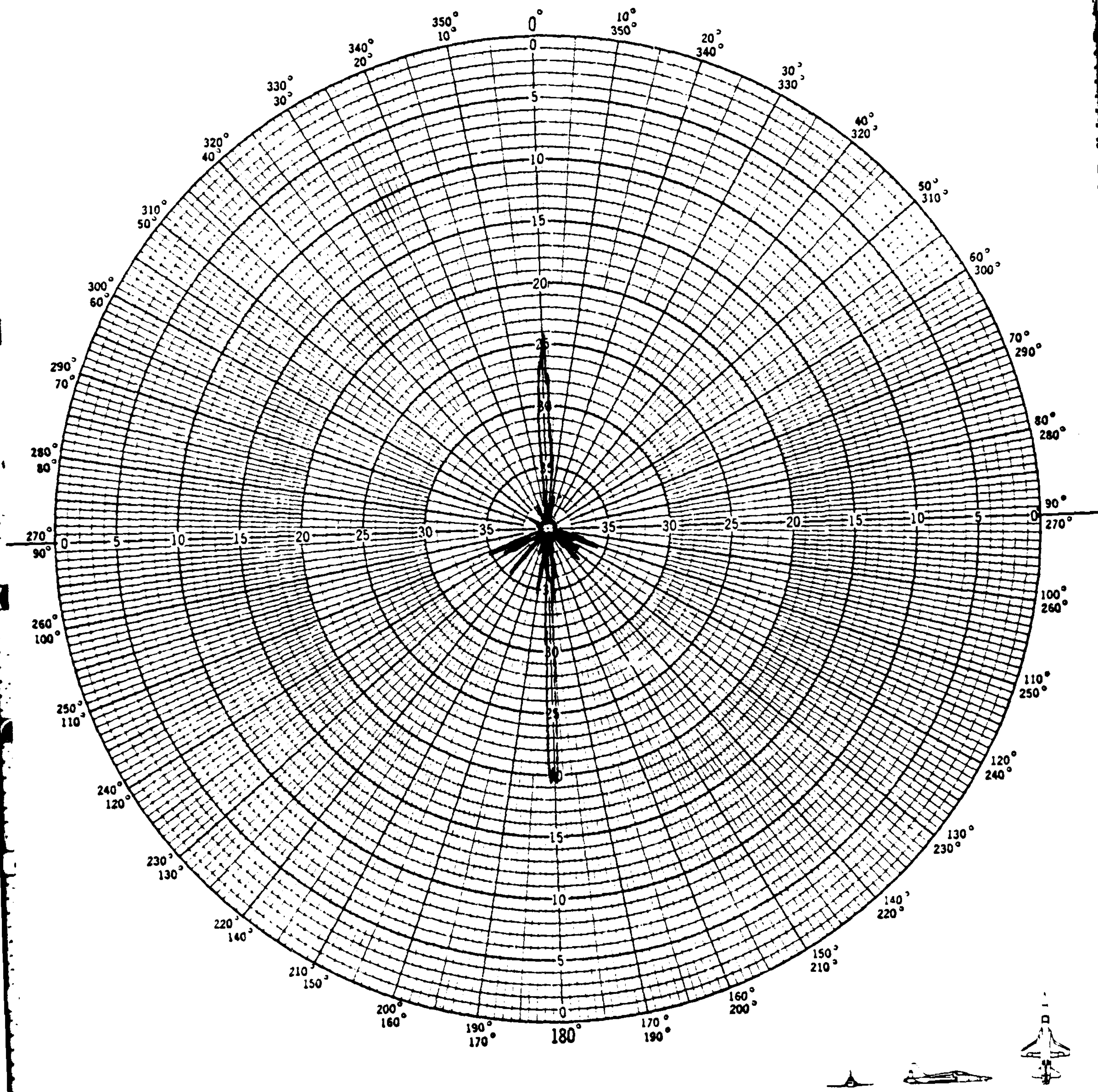


MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 15.0
ANTENNA LOCATION ℄ STATION ______
OPERATOR ______ DATE 10-12-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 90 Φ ( ) POLARIZATION Φ, HORIZ
REMARKS ______

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 4' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE CONICAL MODEL FREQUENCY 15.0
ANTENNA LOCATION ℄ STATION
OPERATOR DATE 10-12-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION Φ, HORIZ
REMARKS

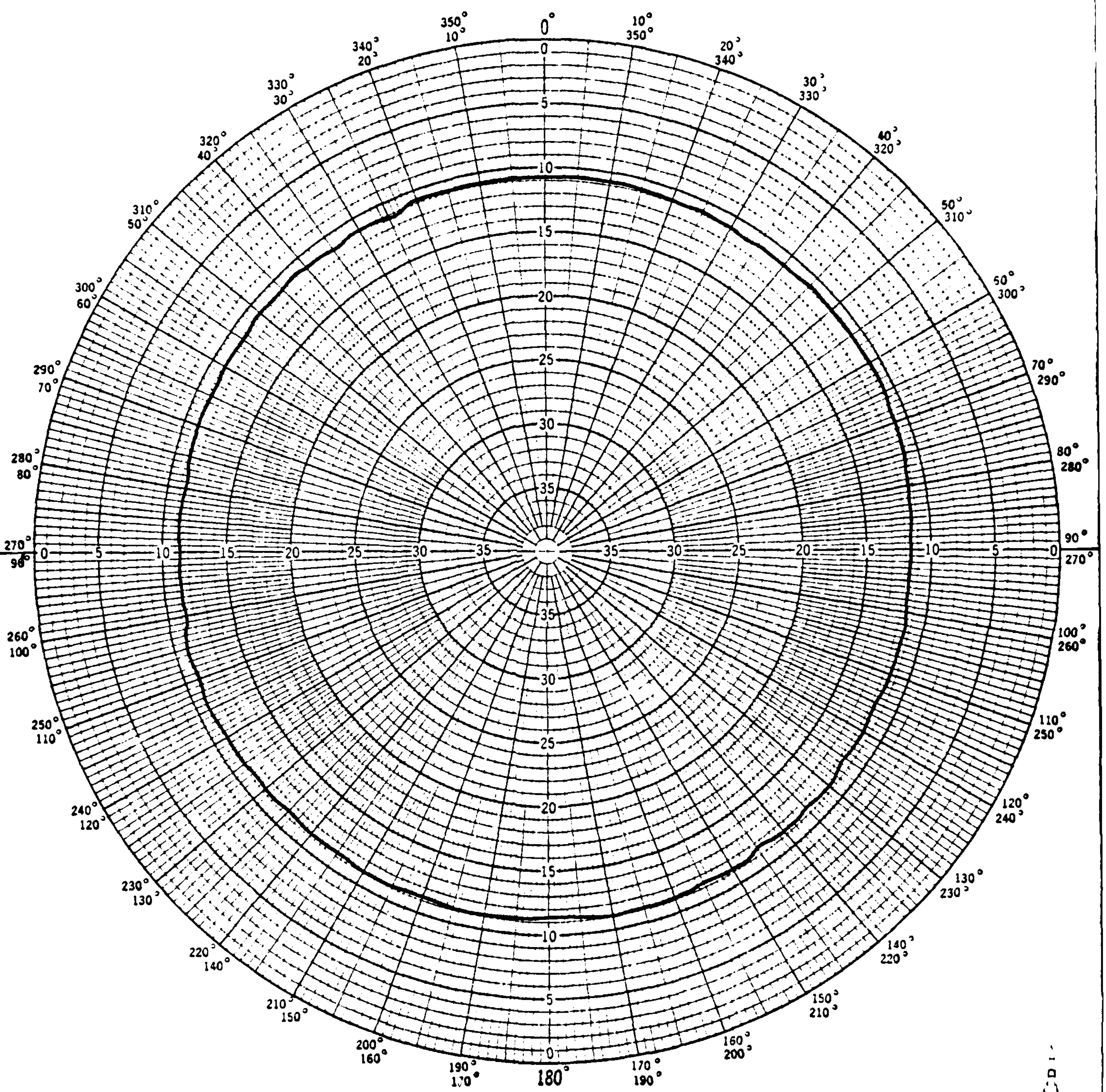
Form 47-69 (R 3-72)

APPENDIX B

Single Conical Monopole Antenna Patterns--Measured on Compact Range

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE ______ MODEL SCALE Full

ANTENNA TYPE Cone MODEL FREQUENCY 7.0

ANTENNA LOCATION ℄ Ø-G Plane STATION ______

OPERATOR 530 DATE 10-20-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

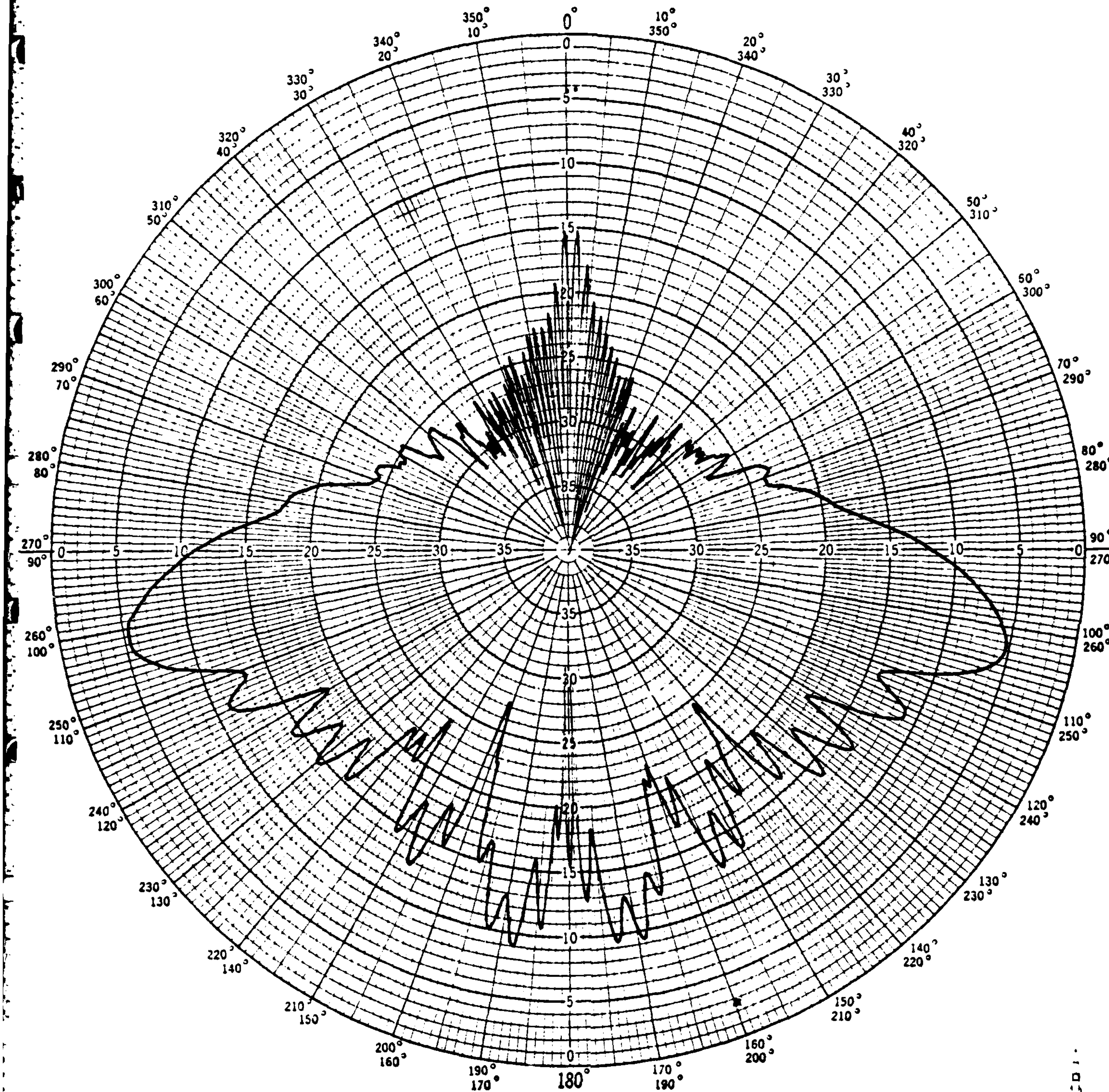
PATTERN θ 90 ϕ ( ) POLARIZATION θ, VERT

REMARKS ______

Compact Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

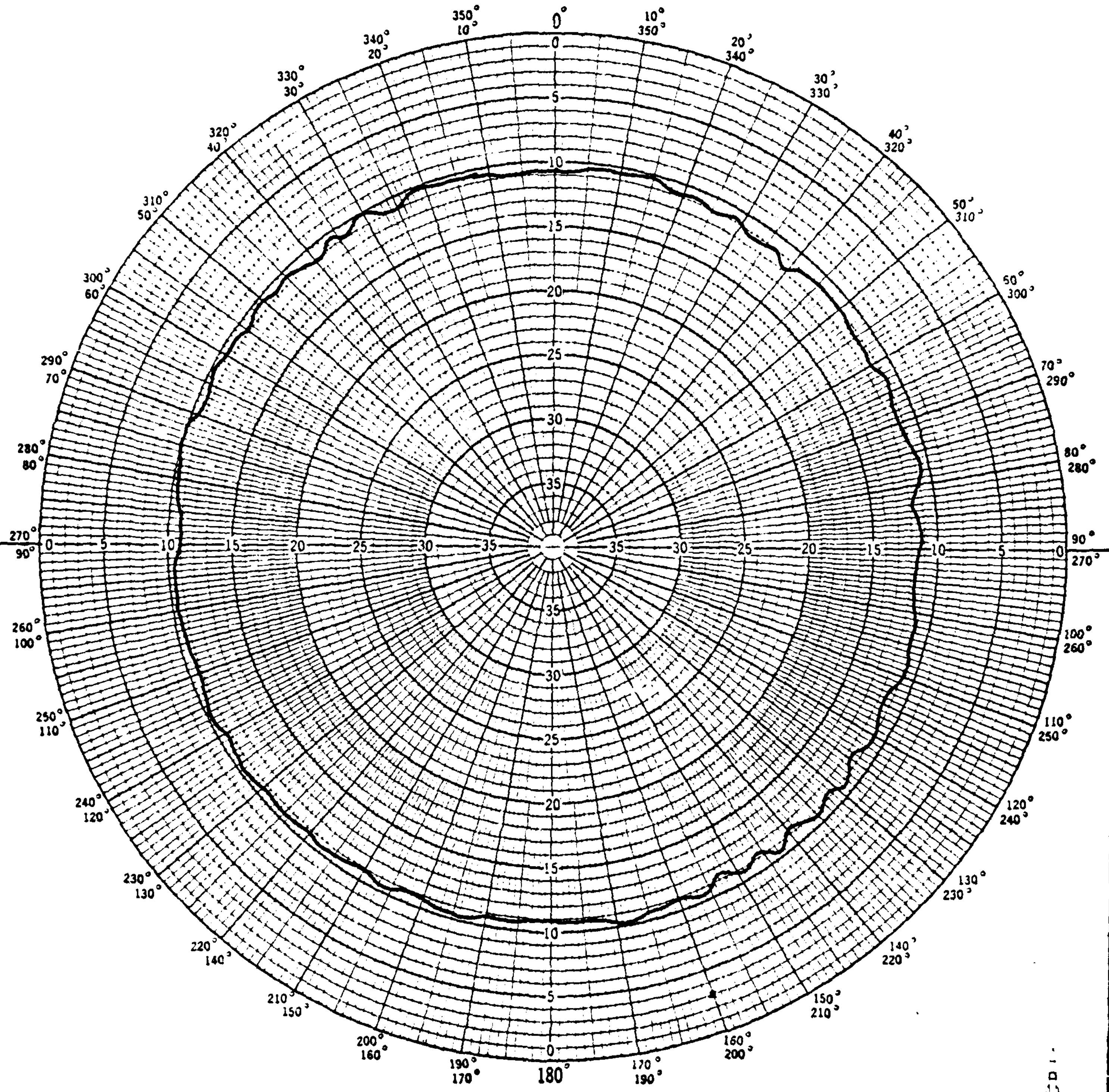


MODEL TYPE ________ MODEL SCALE *Full*
ANTENNA TYPE *Cone* MODEL FREQUENCY *7.0*
ANTENNA LOCATION *¼ 4' G. Plane* STATION ________
OPERATOR *JJO.* DATE *10-20-77*

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION *θ, VERT*
REMARKS ________
Compact Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

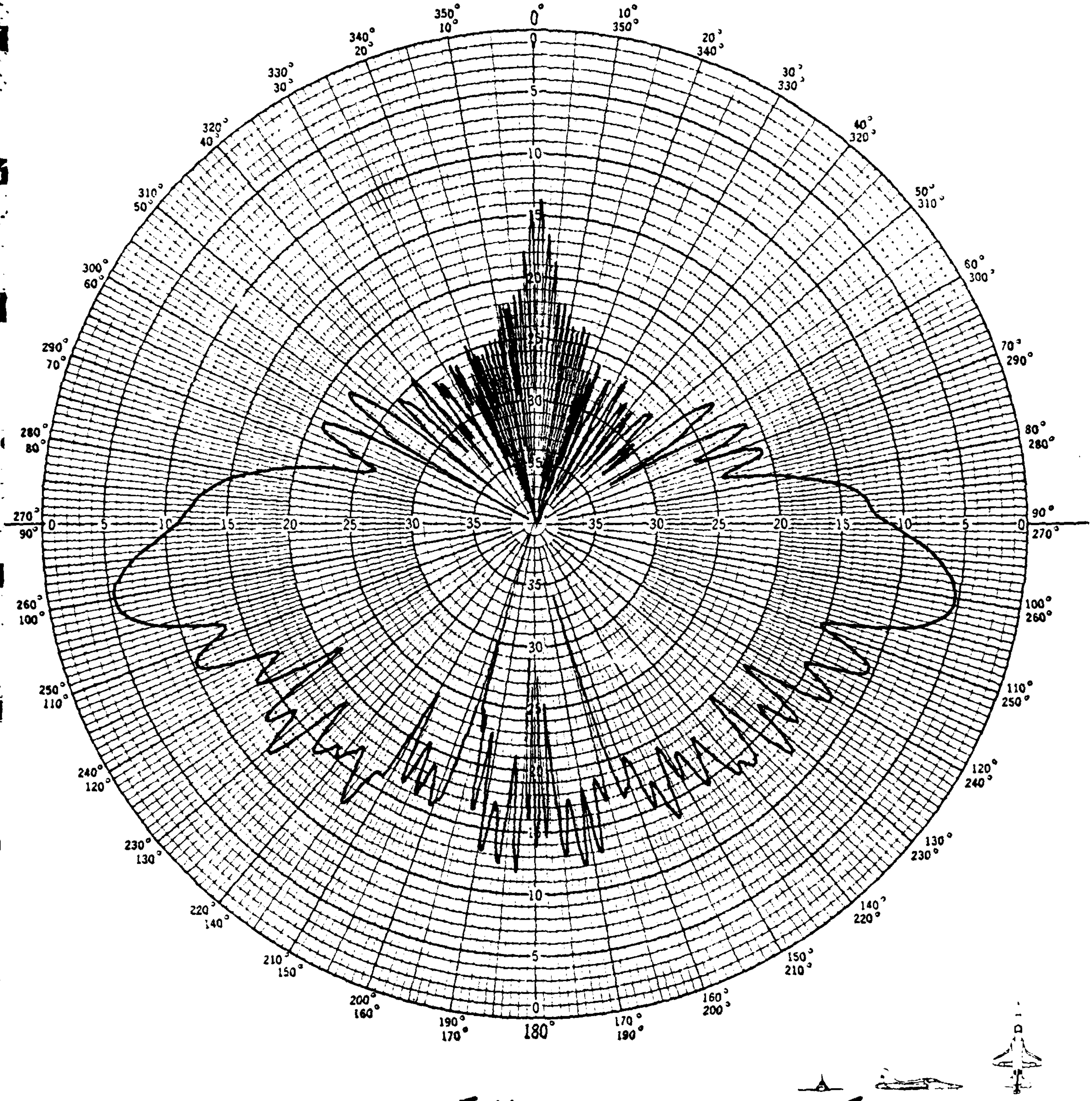


MODEL TYPE ______ MODEL SCALE Full
ANTENNA TYPE Cone MODEL FREQUENCY 9.0
ANTENNA LOCATION ½ 4' Gr Plane STATION ______
OPERATOR SSO DATE 10-20-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT
REMARKS
Compact Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

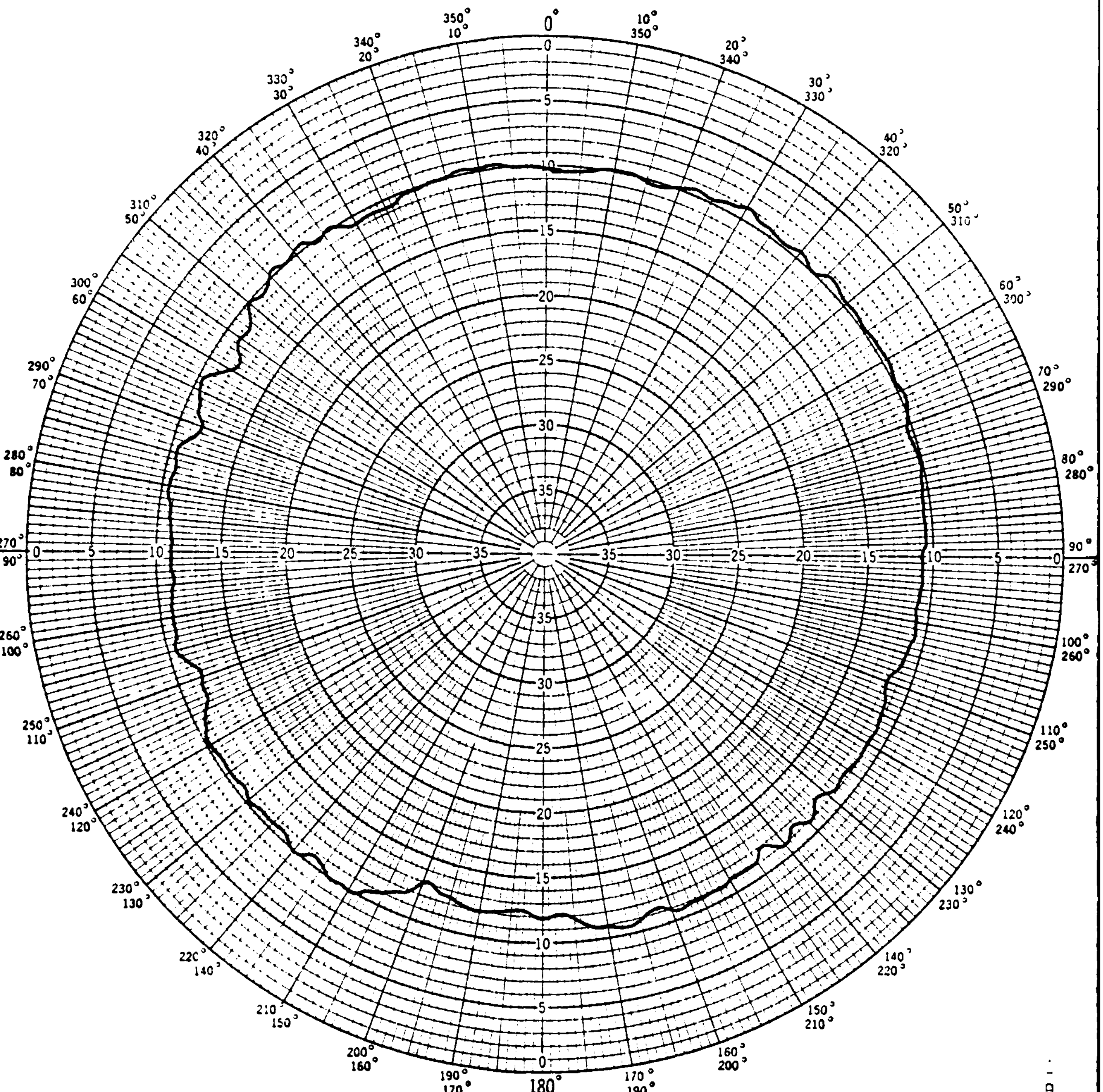


MODEL TYPE ______ MODEL SCALE FULL
ANTENNA TYPE CONE MODEL FREQUENCY 9.0
ANTENNA LOCATION N 4' G RANE STATION ______
OPERATOR 330 DATE 10-21-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT
REMARKS
COMPACT RANGE

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



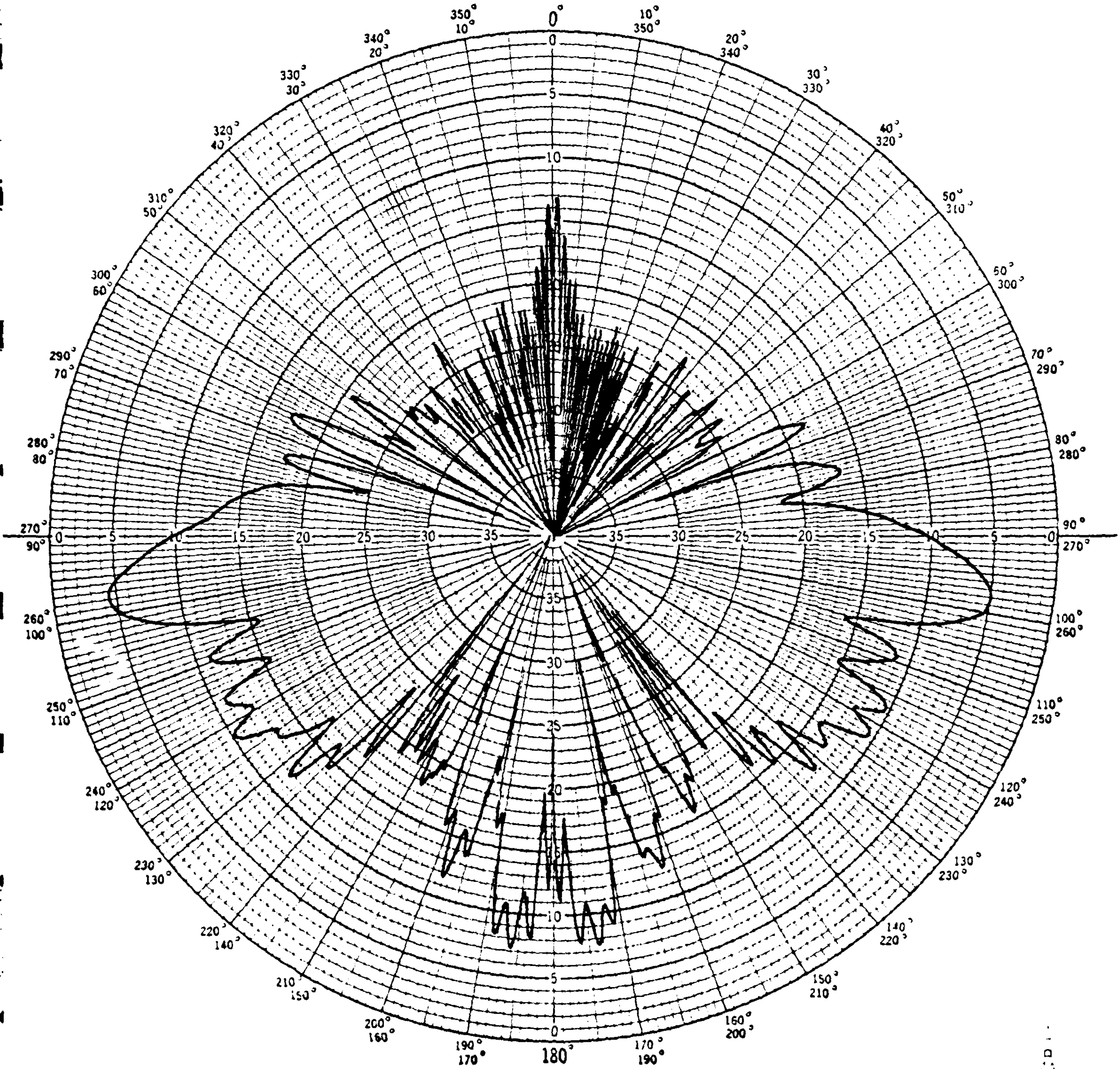
MODEL TYPE ______ MODEL SCALE Full
ANTENNA TYPE Cone MODEL FREQUENCY 11.0
ANTENNA LOCATION ¼ 4' Gr Plane STATION ______
OPERATOR SJD DATE 10-20-77

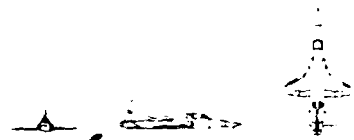
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT
REMARKS ______
Compact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE ____________ MODEL SCALE *Full*
ANTENNA TYPE *Cone* MODEL FREQUENCY *11.0*
ANTENNA LOCATION *X Y G Plane* STATION ________
OPERATOR *JJO* DATE *10-20-77*

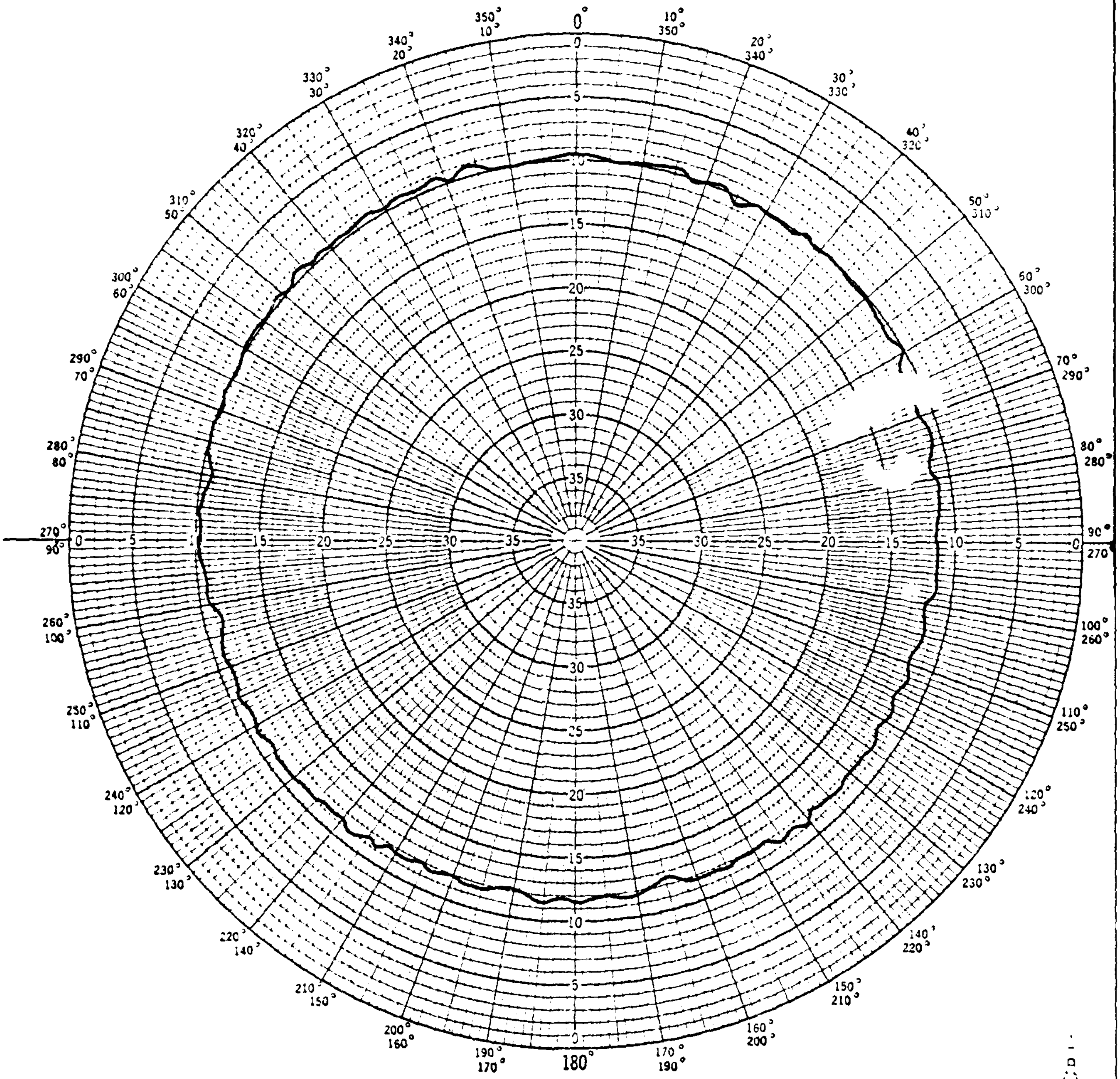
RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) Φ ( ) POLARIZATION *θ, VERT*
REMARKS ____________

Compact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE ________ MODEL SCALE Full

ANTENNA TYPE Cone MODEL FREQUENCY 13.0

ANTENNA LOCATION ¼ 4' Gr Plane STATION ________

OPERATOR JSO DATE 10-20-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

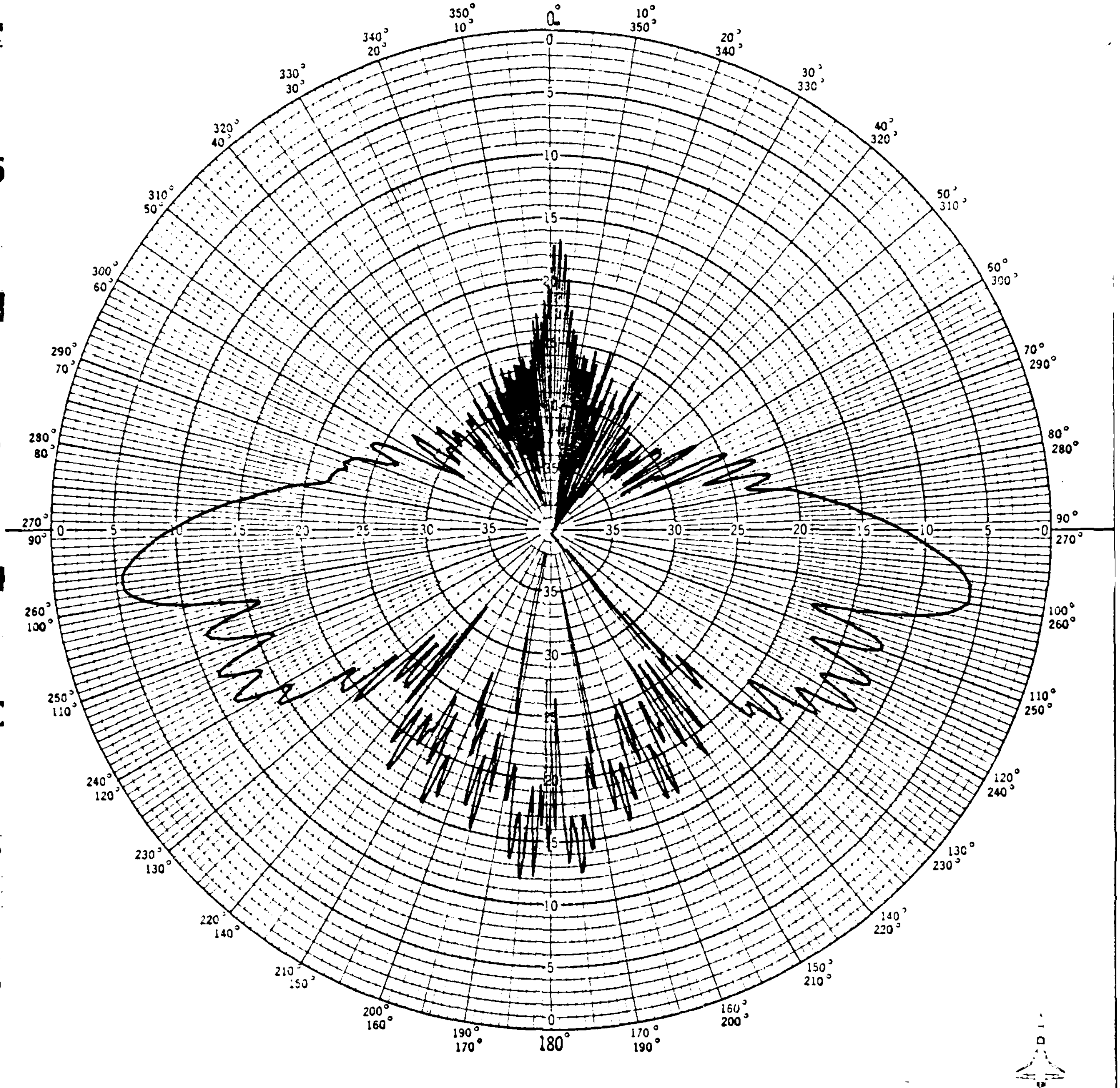
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓

PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT

REMARKS Compact Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

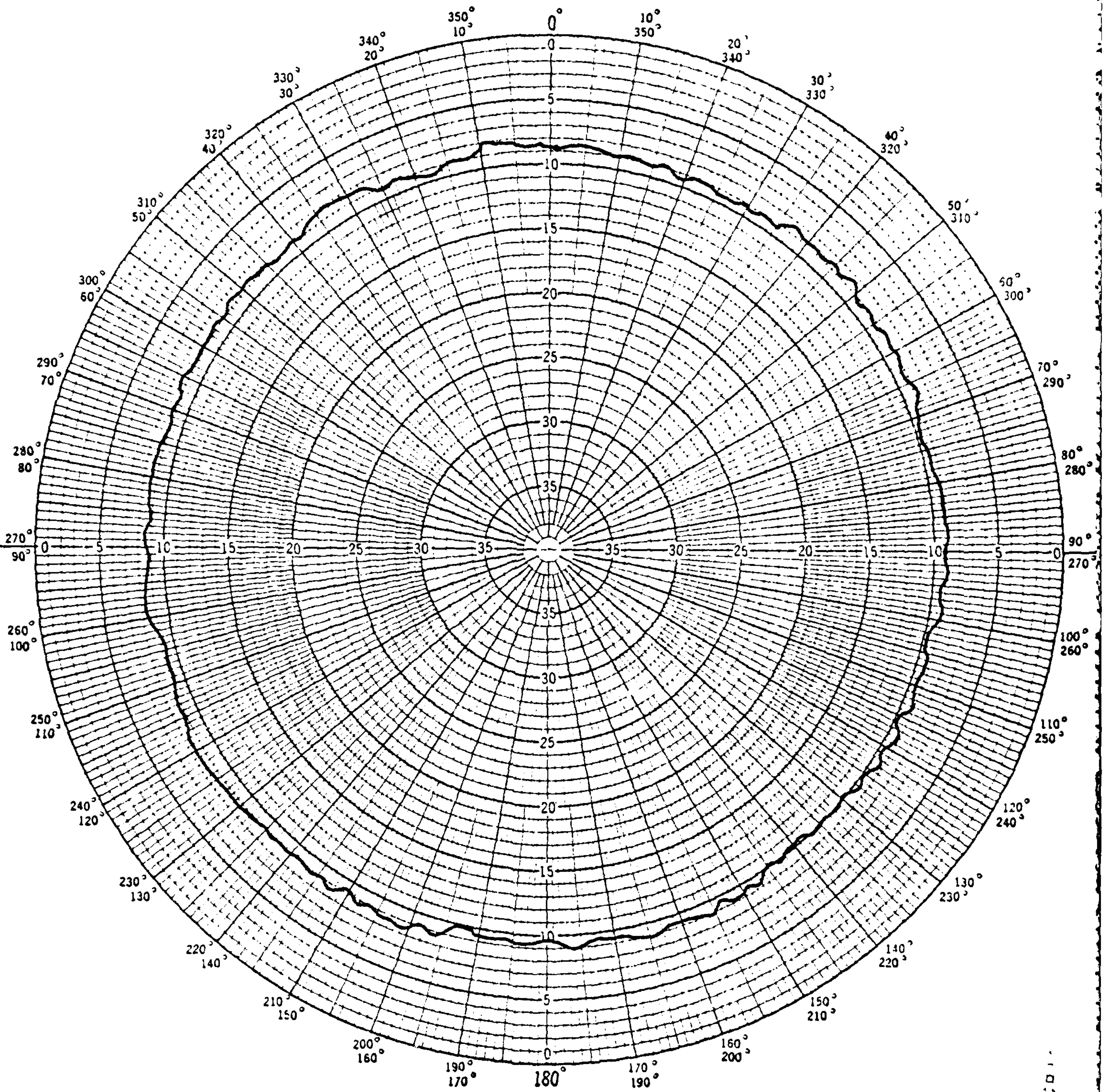


MODEL TYPE ______ MODEL SCALE FULL
ANTENNA TYPE CONE MODEL FREQUENCY 13.0
ANTENNA LOCATION ¼ 4' G. PLANE STATION ______
OPERATOR SJO DATE 10-20-77

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT
REMARKS ______
COMPACT RANGE

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division

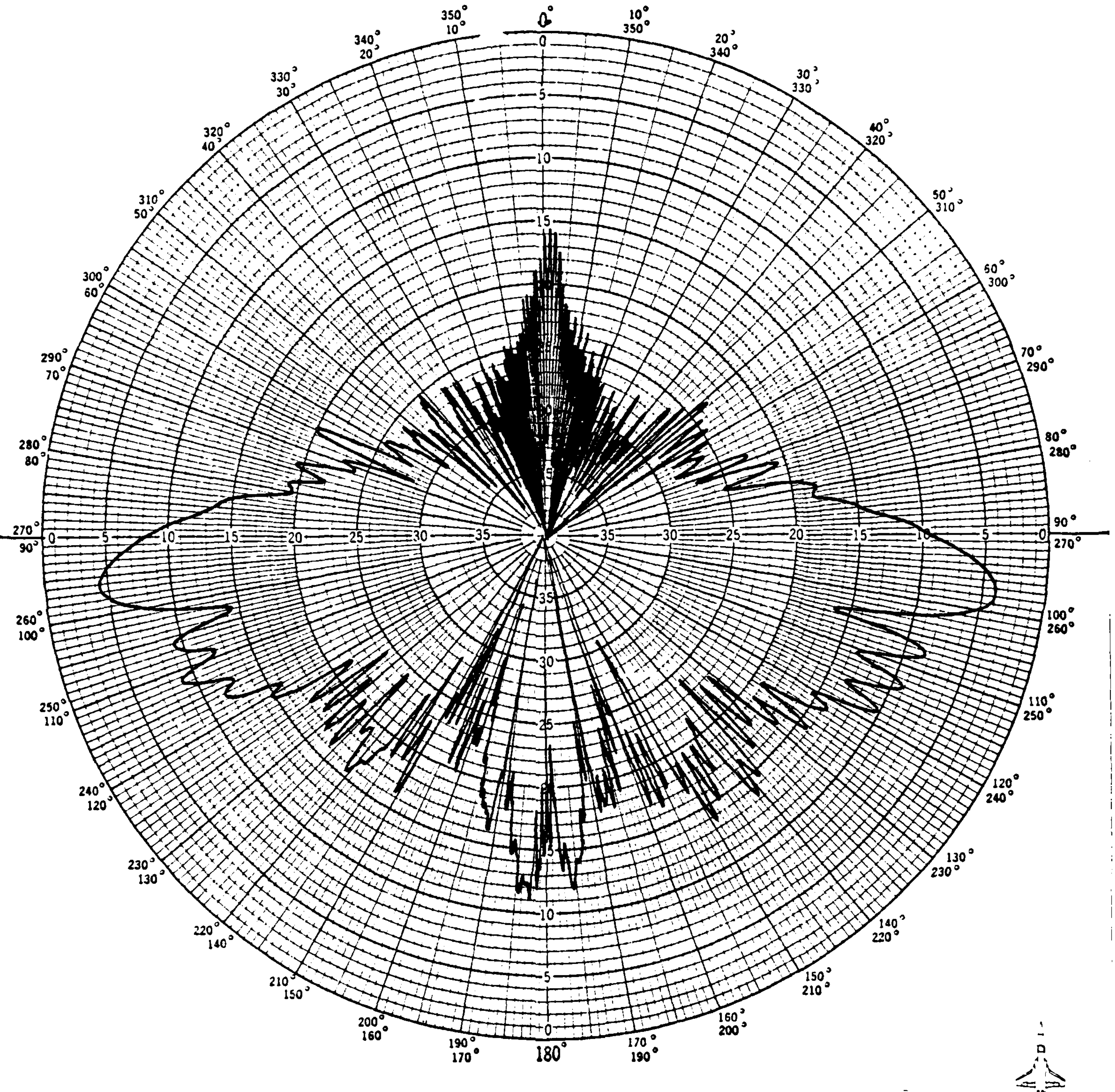


MODEL TYPE ____ MODEL SCALE Full
ANTENNA TYPE Cone MODEL FREQUENCY 15.0
ANTENNA LOCATION ½ Y-G Plane STATION ____
OPERATOR JJo DATE 10-20-79

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT
REMARKS ____
Compact Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE ______ MODEL SCALE FULL
ANTENNA TYPE CONE MODEL FREQUENCY 15.0
ANTENNA LOCATION ℄ 4' G. PLANE STATION ______
OPERATOR 350 DATE 10-20-77

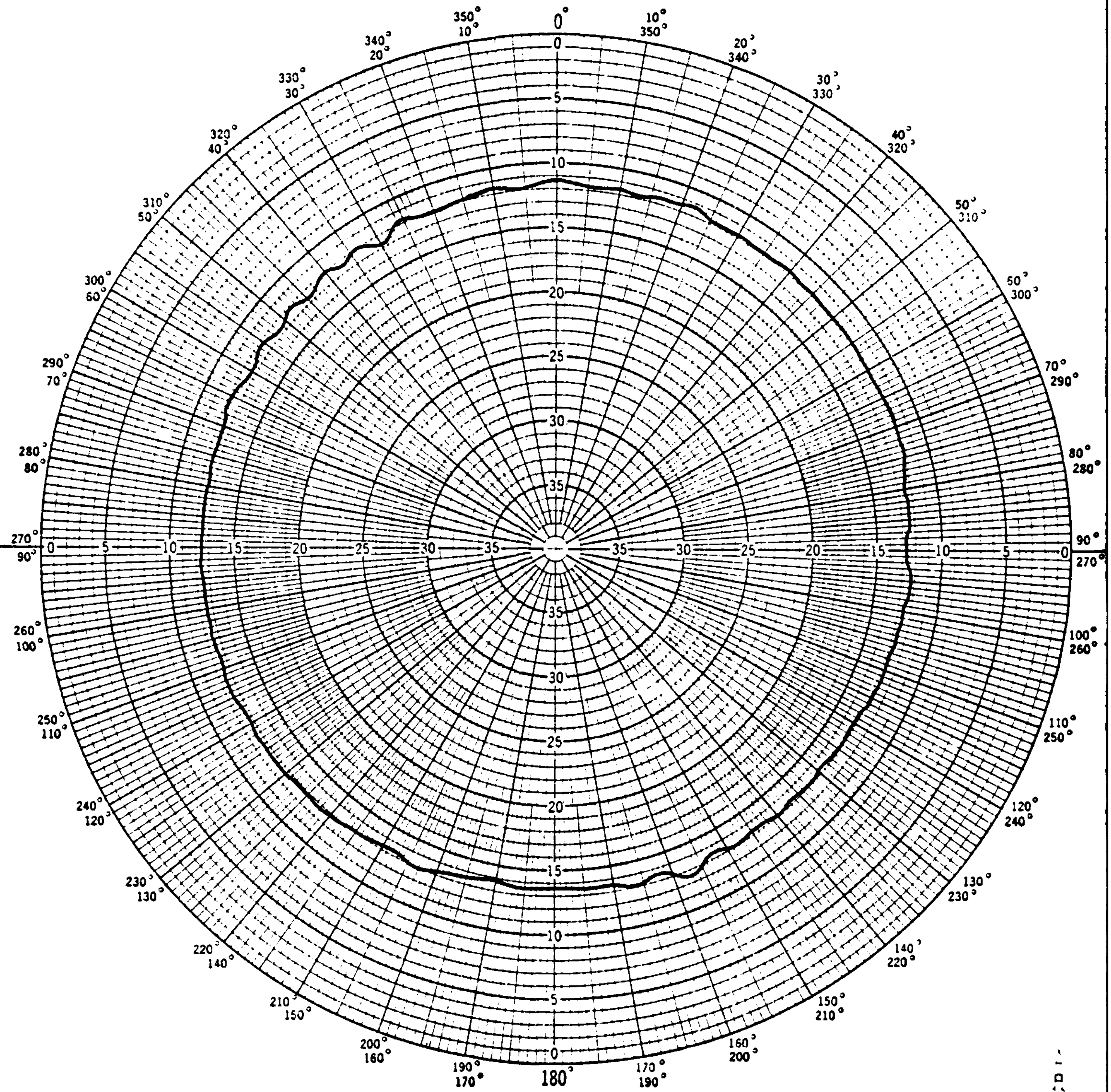
RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT
REMARKS ______
COMPACT RANGE

Form 47-69 (R 9-72)

APPENDIX C

Single .31 inch Stub Monopole Antenna Patterns--
Measured on Compact Range

NORTHROP
Northrop Corporation
Aircraft Division

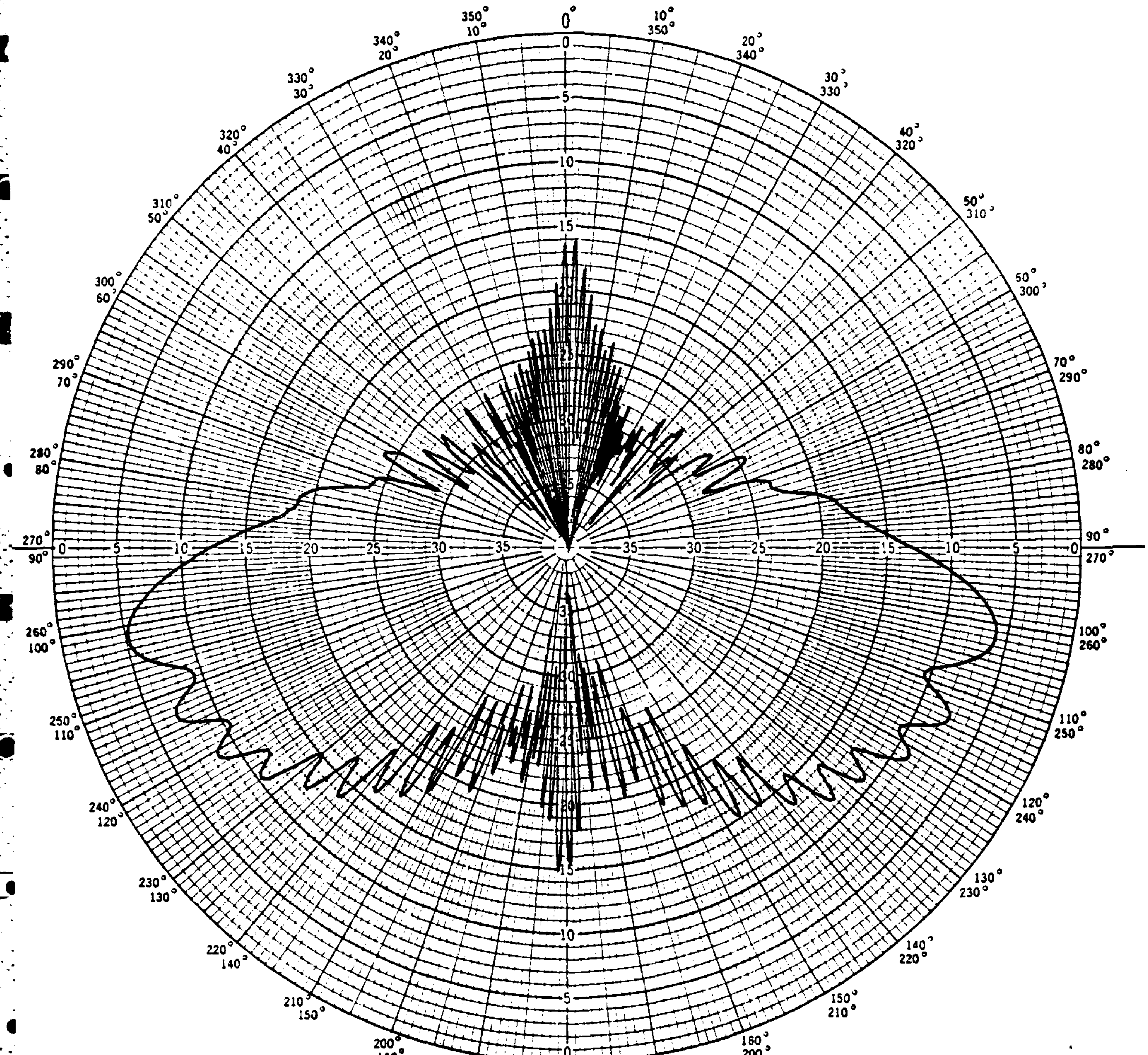


MODEL TYPE ________ MODEL SCALE *FULL*
ANTENNA TYPE *STUB* MODEL FREQUENCY *8.0*
ANTENNA LOCATION *℄ GR PLANE* STATION ________
OPERATOR *JJO* DATE *10-19-77*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *90* Φ ( ) POLARIZATION *θ, VERT*
REMARKS *.31" STUB, λ/4 @ 9.5 GHz*
Compact Range

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division



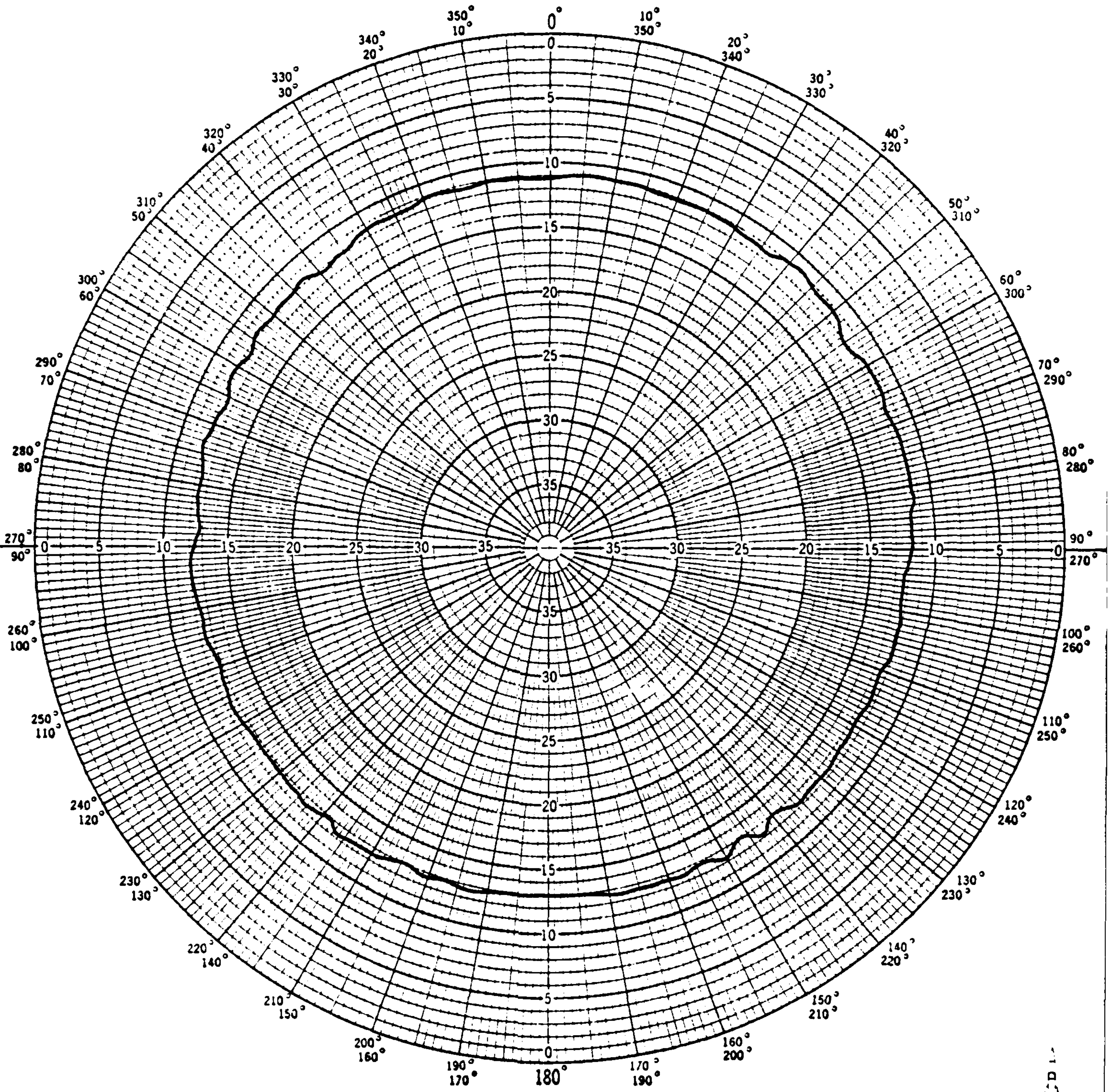
MODEL TYPE ______ MODEL SCALE *Full*
ANTENNA TYPE *STUB* MODEL FREQUENCY *8.0*
ANTENNA LOCATION *4' Gr Plane* STATION ______
OPERATOR *JJO* DATE *10-19-77*

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION *θ, VERT*
REMARKS *.31" STUB. λ/4 @ 9.5 GHz*
Com Pact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE ______ MODEL SCALE *FULL*
ANTENNA TYPE *STUB* MODEL FREQUENCY *9.0*
ANTENNA LOCATION *℄ 4' fr Rave* STATION ______
OPERATOR *JJo* DATE *10-19-77*

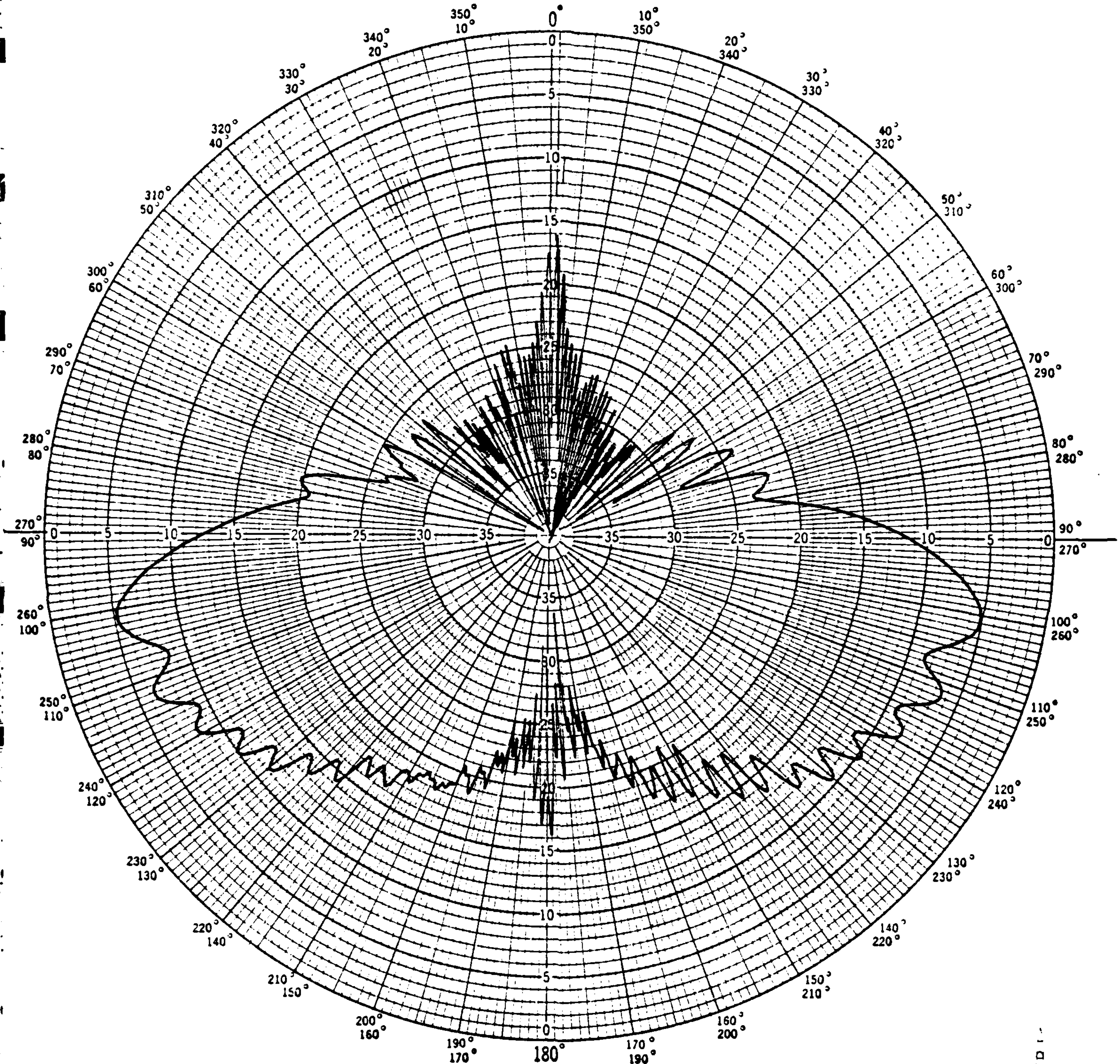
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *90°* Φ ( ) POLARIZATION *θ, VERT*
REMARKS *.31" STUB. λ/4 @ 9.5 GHz.*

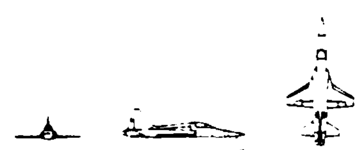
Compact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE ________ MODEL SCALE Full

ANTENNA TYPE Stub MODEL FREQUENCY 9.0

ANTENNA LOCATION ℄ 4' GA PLANE STATION ________

OPERATOR JJO DATE 10-19-77

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT.

REMARKS .31" STUB, λ/4 @ 9.5 GHz

COMPACT RANGE

Form 47-69 (R 9-72)

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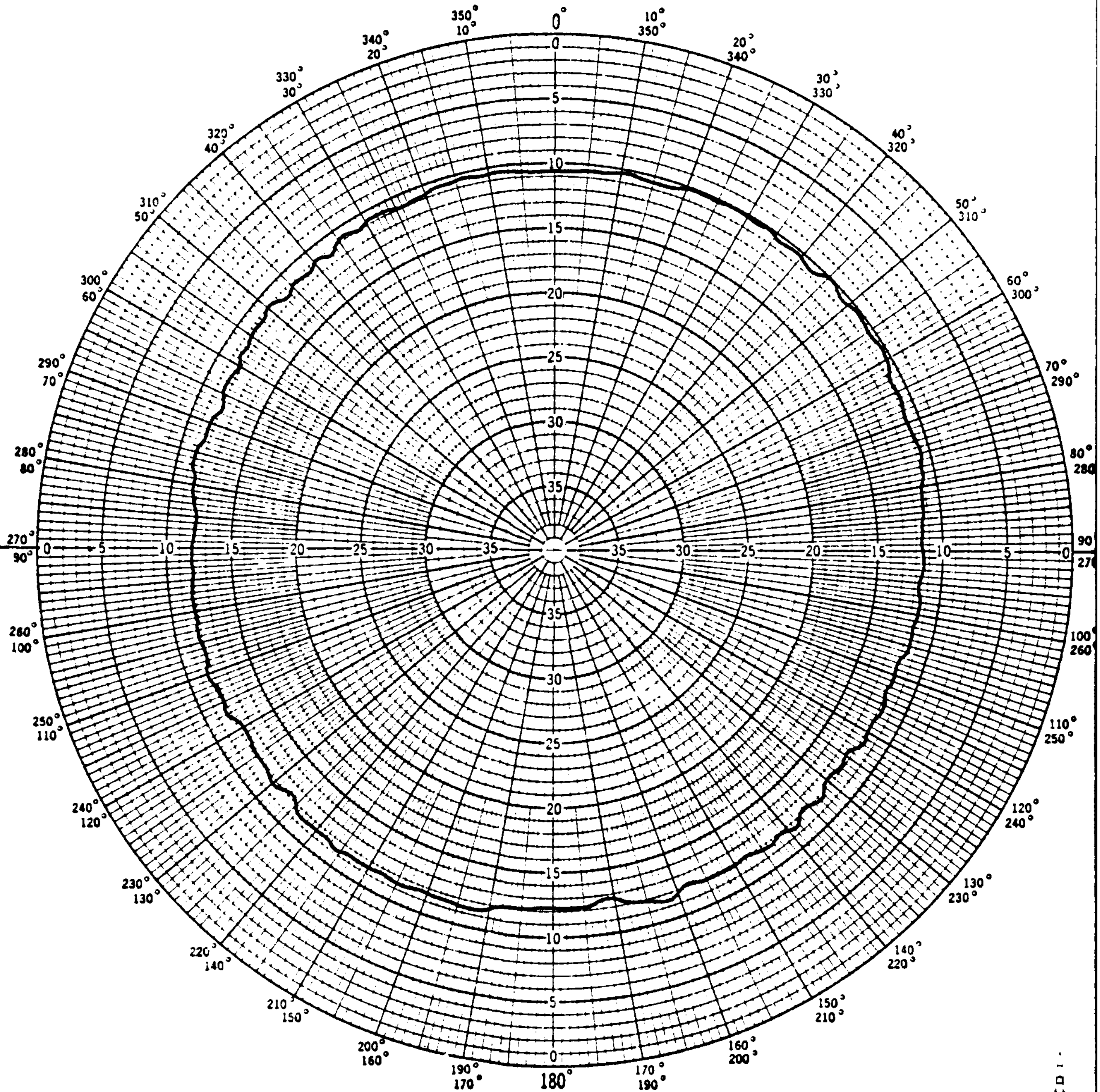
Northrop Corporation
Aircraft Division



MODEL TYPE ______ MODEL SCALE Full
ANTENNA TYPE Stub MODEL FREQUENCY 11.0
ANTENNA LOCATION ℄ 4' Gr Plane STATION ______
OPERATOR JJo DATE 10-19-77

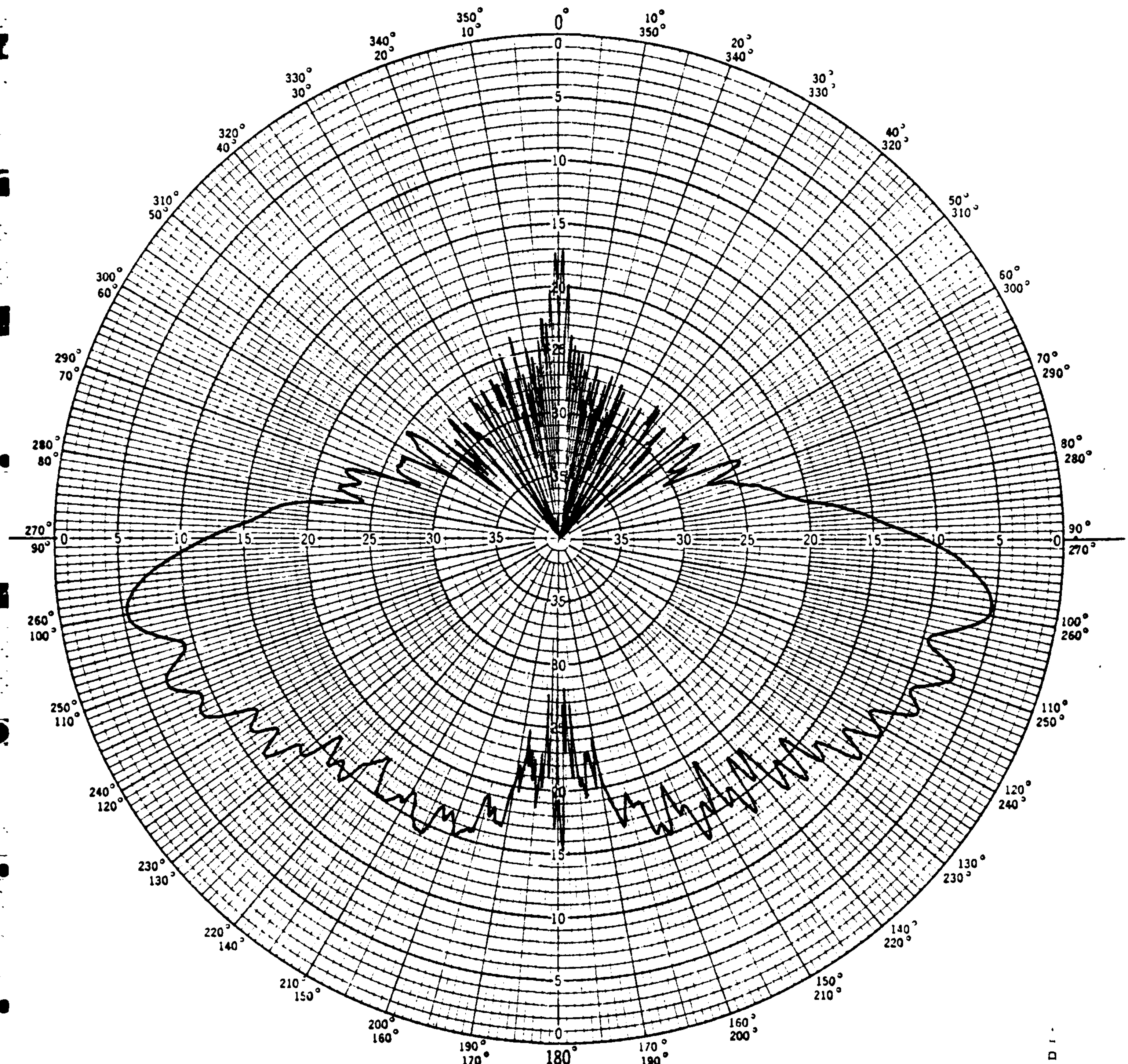
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT.
REMARKS .31" STUB, λ/4 @9.5 GHz

Compact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE ____ MODEL SCALE Full

ANTENNA TYPE Stub MODEL FREQUENCY 11.0

ANTENNA LOCATION ℄ 4' Gr Plane STATION ____

OPERATOR JJ DATE 10-19-77

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

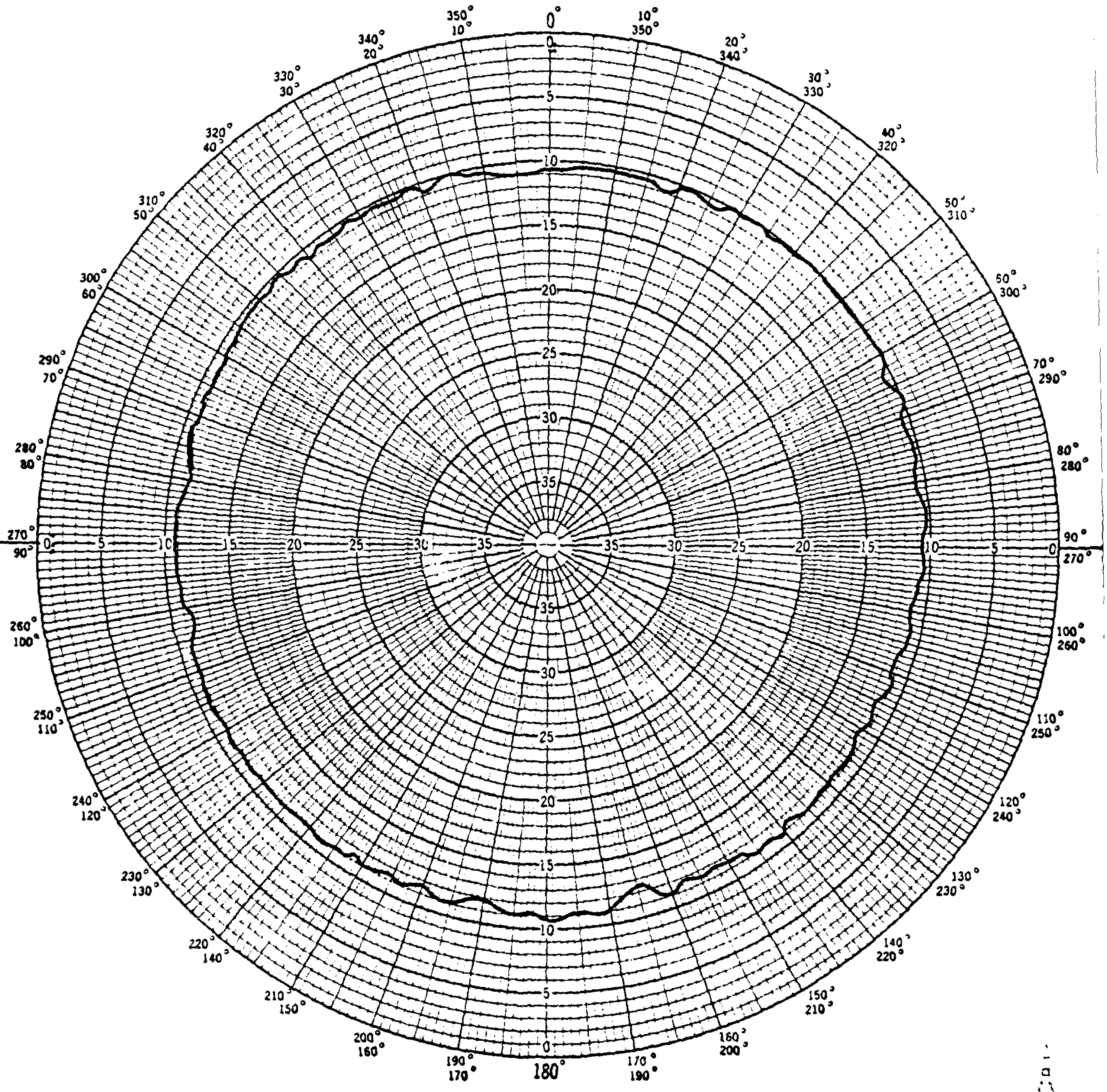
PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT

REMARKS .31" STUB. λ/4 @ 9.5 GHz.

Compact Range

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division



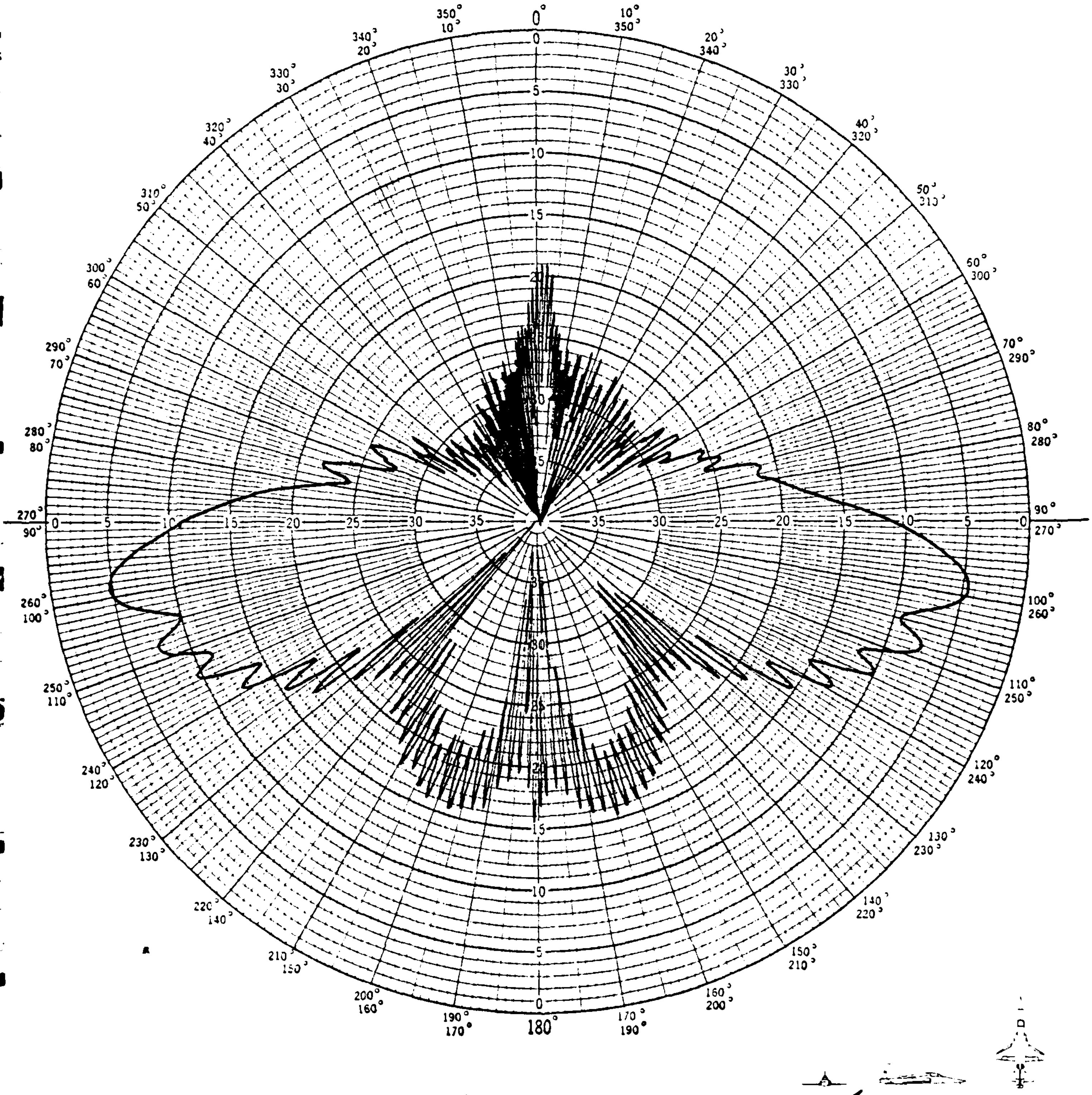
MODEL TYPE ______ MODEL SCALE Full
ANTENNA TYPE Stub MODEL FREQUENCY 13.0 GHz
ANTENNA LOCATION ℄ 4' Gr Plane STATION ______
OPERATOR JJO DATE 10-19-77

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 90 Φ ( ) POLARIZATION θ, VERT
REMARKS 0.31" STUB. λ/4 @ 9.5 GHz
Compact Range

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE ______ MODEL SCALE FULL

ANTENNA TYPE STUB MODEL FREQUENCY 13.0

ANTENNA LOCATION ¼ 4·G PLANE STATION ______

OPERATOR 330 DATE 10-19-77

RADIATION PLOT OF THE ROLL ✓ PITCH ( ) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓

PATTERN θ ( ) Φ ( ) POLARIZATION θ, VERT

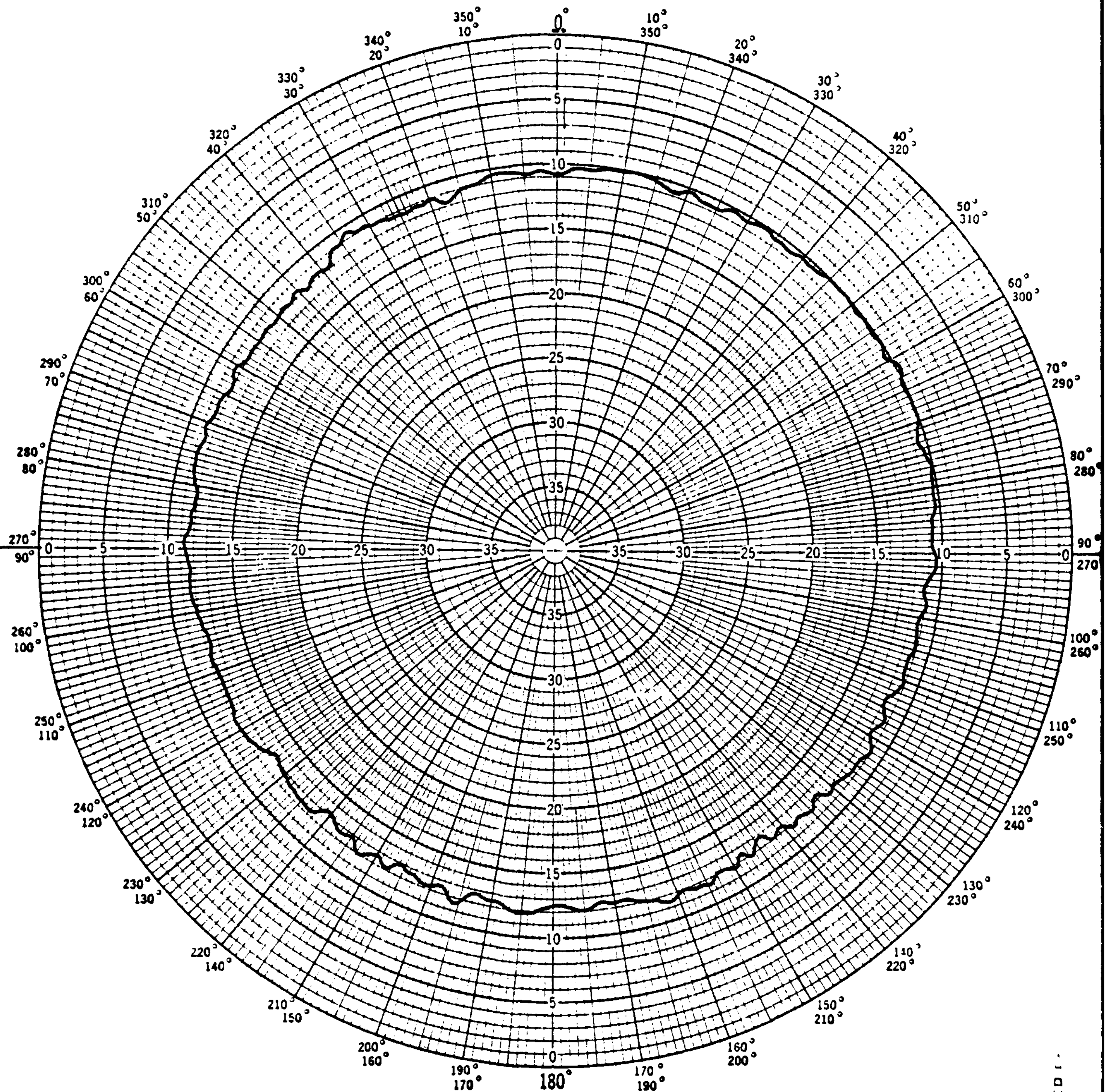
REMARKS 0.31" STUB, λ/4 @ 9.5 GHz.

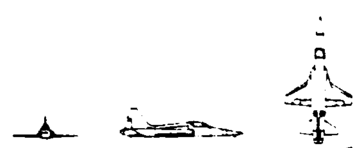
Compact Range

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



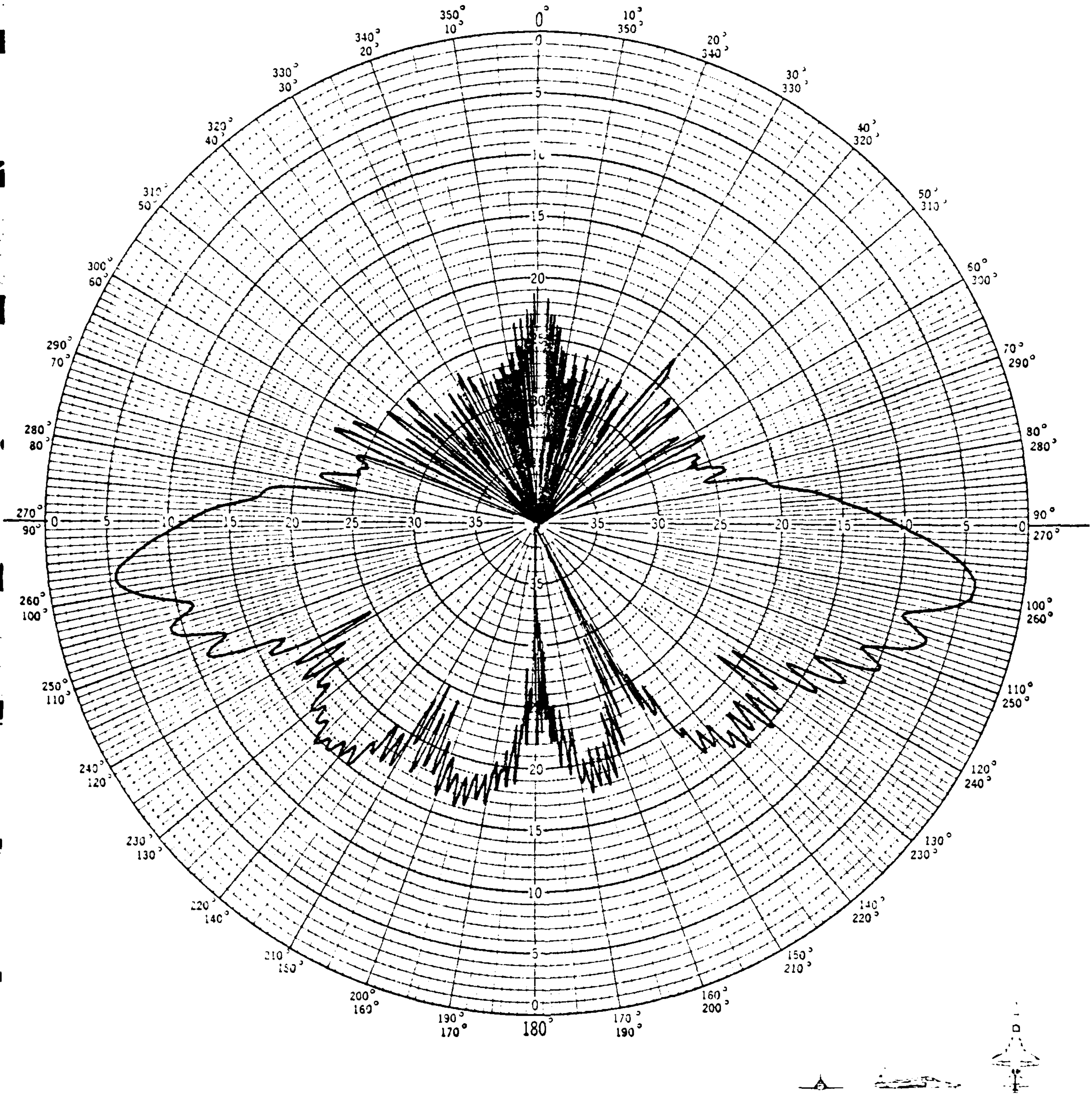


MODEL TYPE ______ MODEL SCALE *FULL*
ANTENNA TYPE *STUB* MODEL FREQUENCY *15.0*
ANTENNA LOCATION *9/6 4' Gr Plane* STATION ______
OPERATOR *SJO* DATE *10-20-77*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *90°* Φ ( ) POLARIZATION *θ, VERT*
REMARKS *0.31" STUB, λ/4 @9.5 GHz*
Cc Pa : Range

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE ________ MODEL SCALE FULL
ANTENNA TYPE STUB MODEL FREQUENCY 15.0
ANTENNA LOCATION 4' Gr PLANE STATION
OPERATOR JSO DATE 10-20-77

RADIATION PLOT OF THE ROLL ✓ PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) ϕ ( ) POLARIZATION θ, VERT
REMARKS 0.31" STUB, λ/4 @ 9.5 GHz.
COMPACT RANGE

Form 37-63 (4-3-72)

APPENDIX D

Dual Conical Monopole Antenna Patterns --7GHz

NORTHROP
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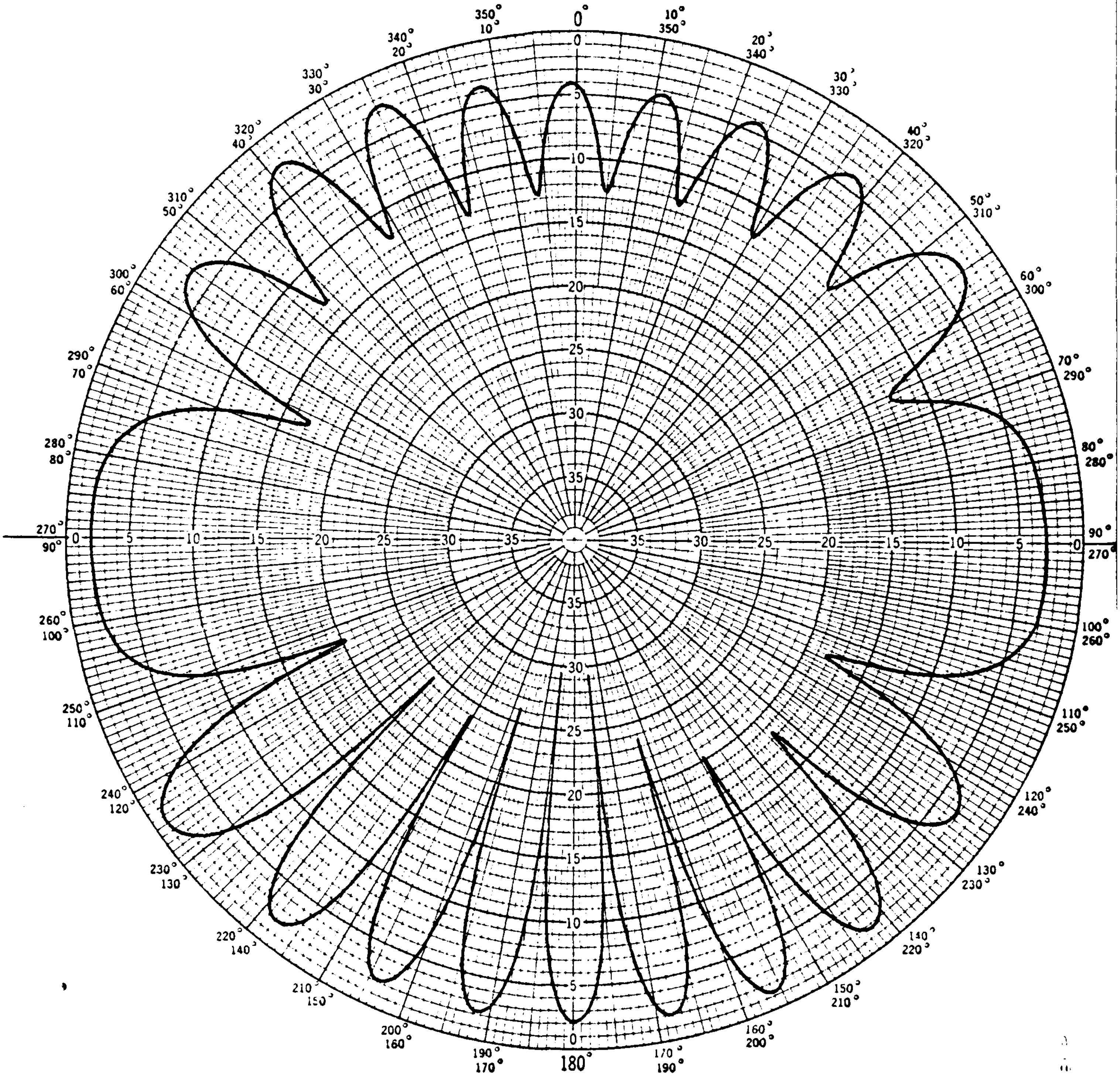
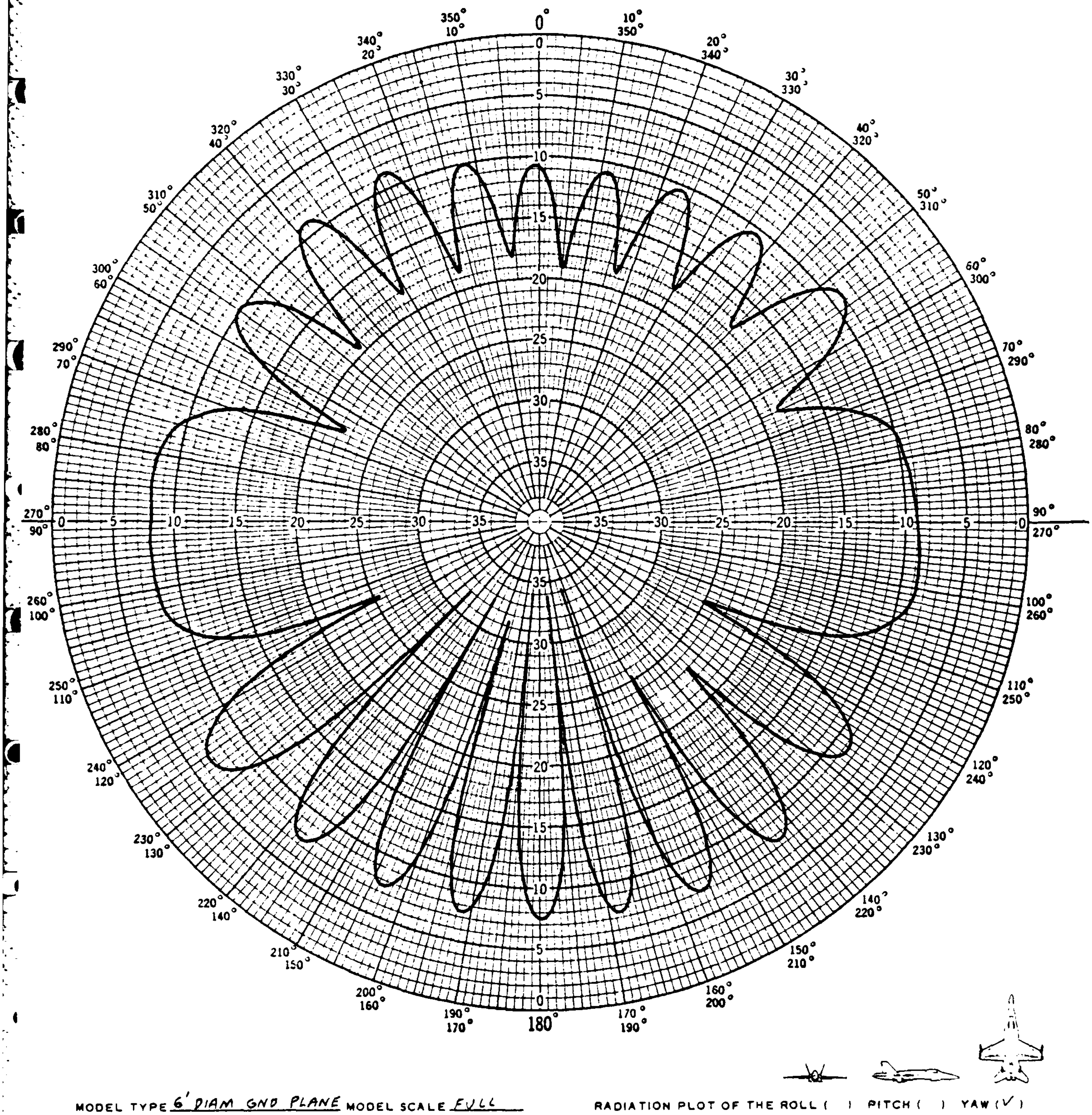
Aircraft Group



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

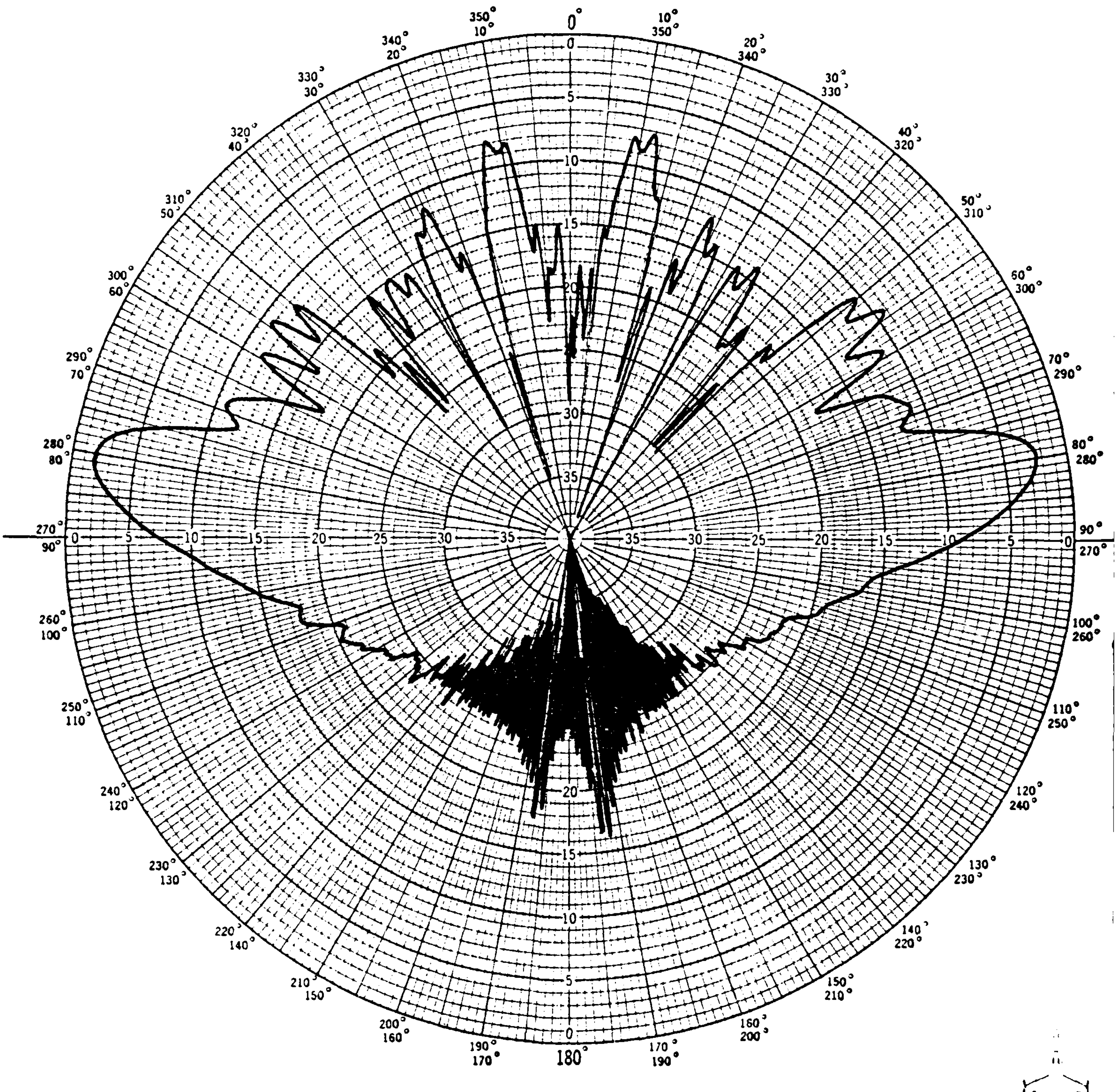
Form 47-69A (5-73)

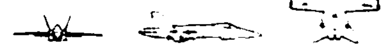


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0V = 0°

NORTHROP
Northrop Corporation
Aircraft Group

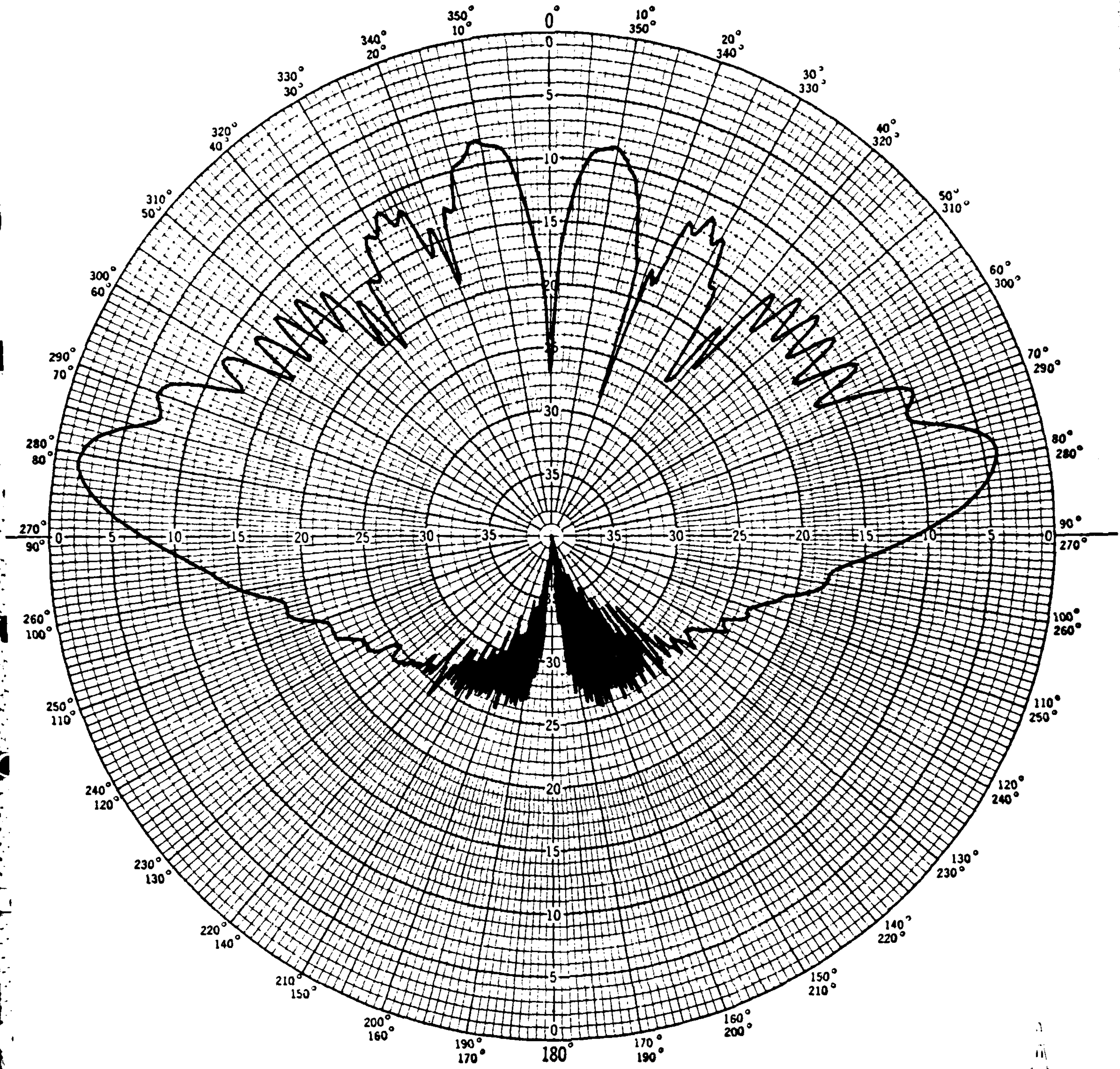


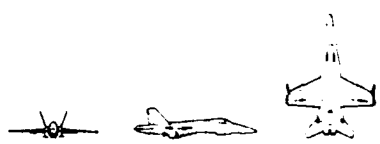


MODEL TYPE 6' DIAM. GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 3-16-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V

NORTHROP
Northrop Corporation
Aircraft Group





MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V.

NORTHROP

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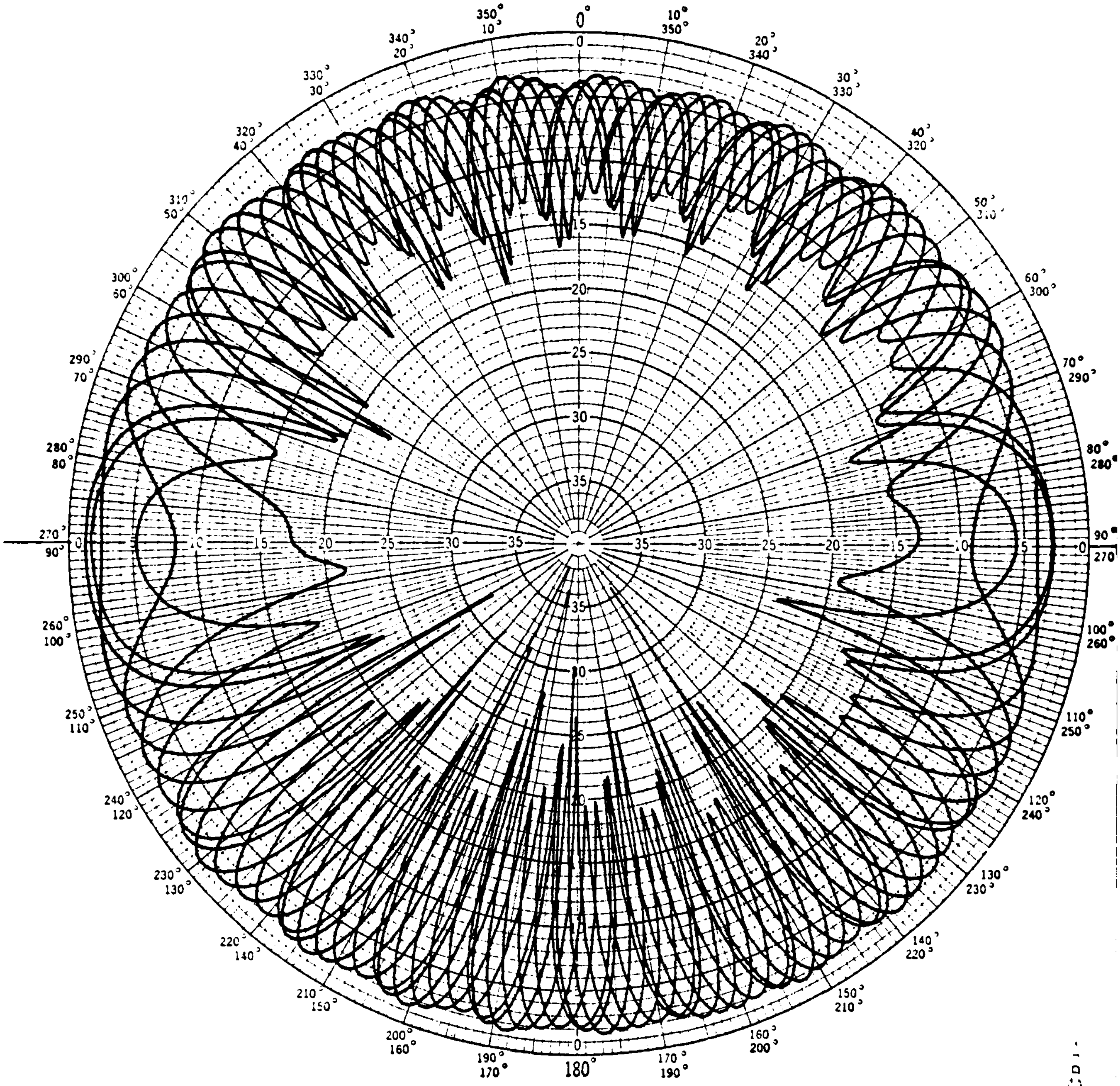
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

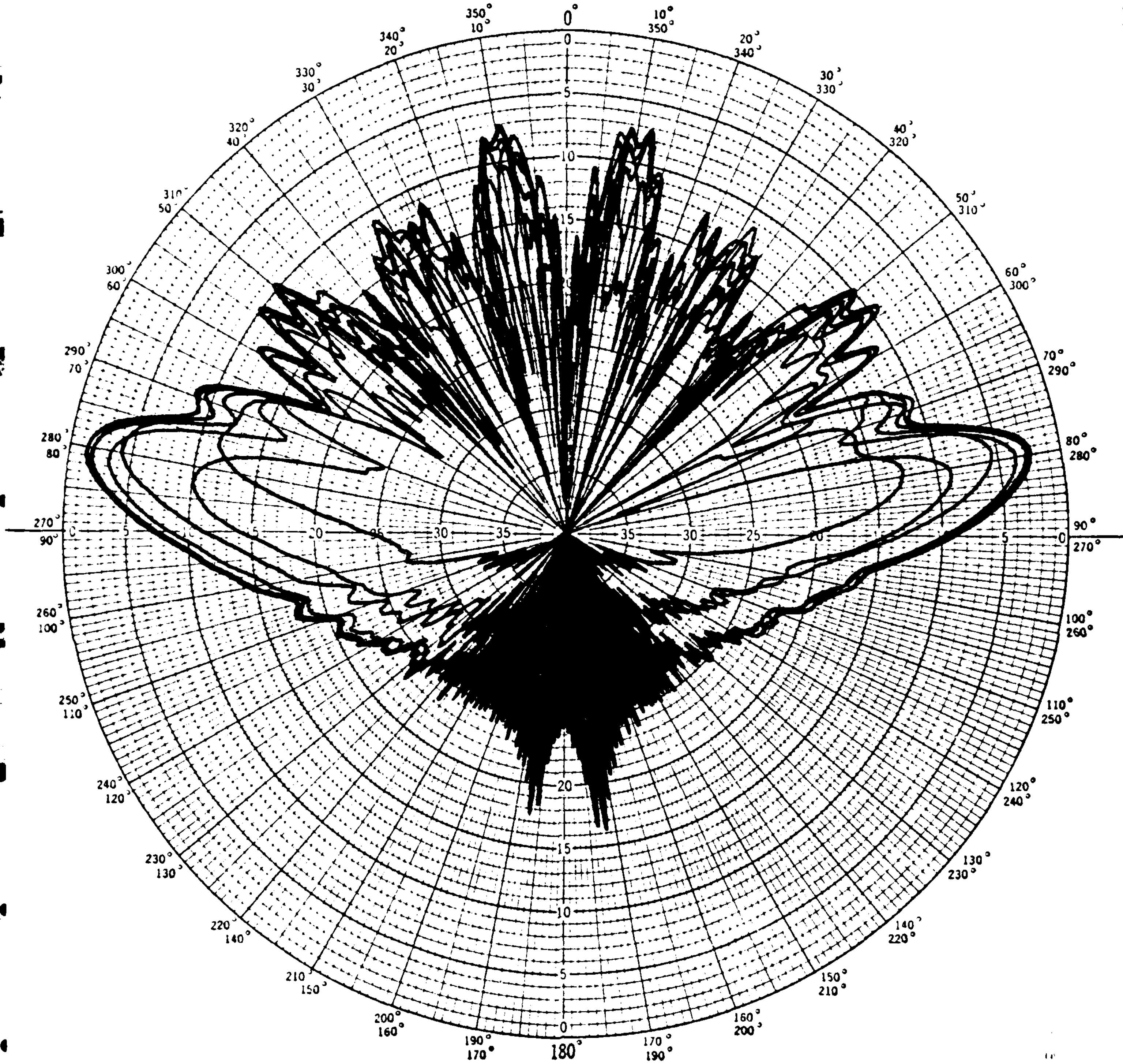
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

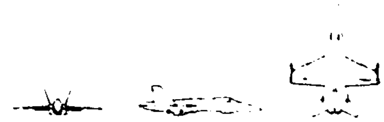
PATTERN θ (80°) Φ ( ) POLARIZATION VERT.

REMARKS ØREF = 0, -.6, -1.2, -1.8, -2.4, -3.0V

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Group



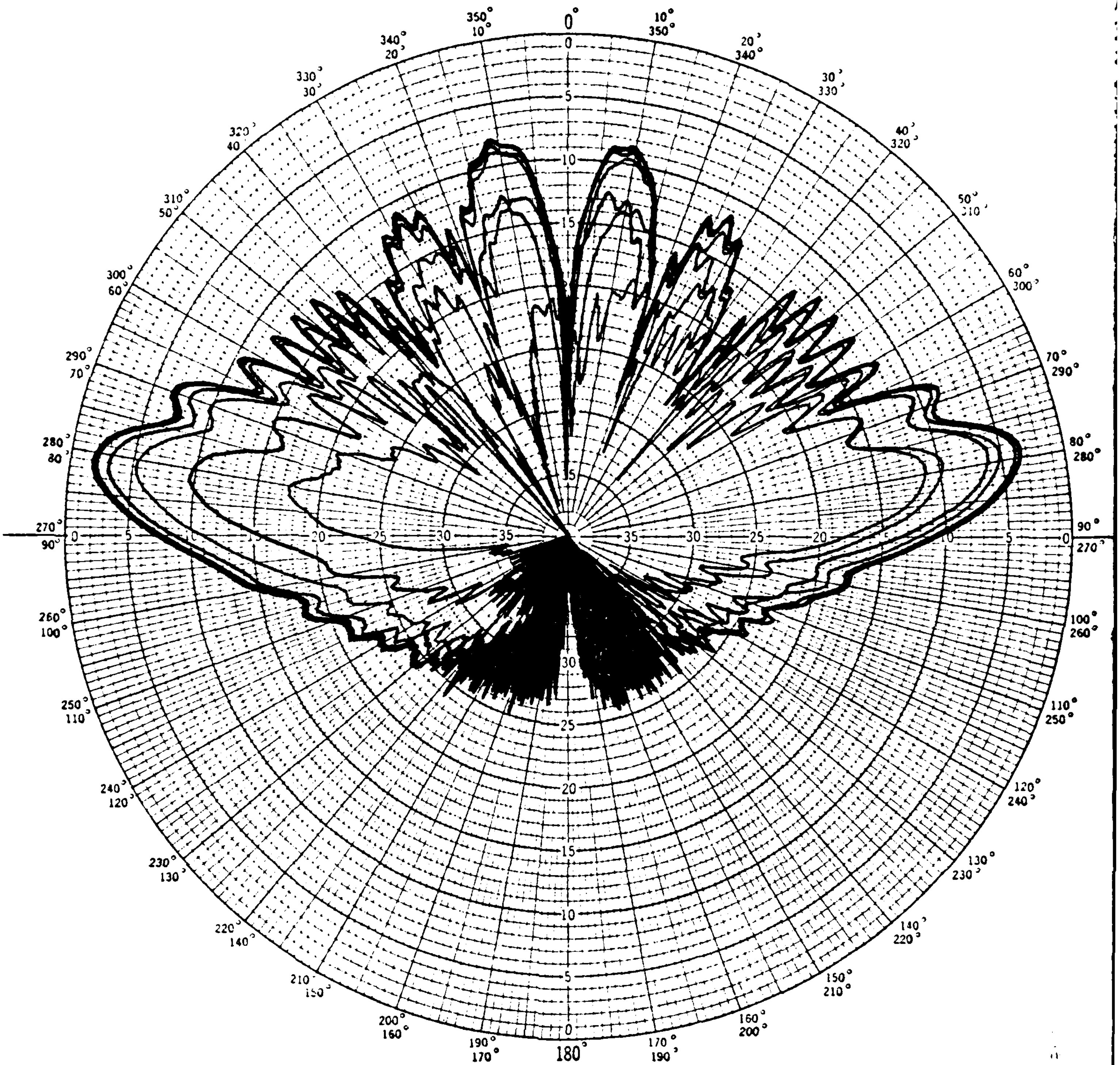


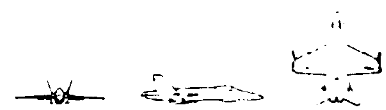
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 3-16-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ZREF = 0.2V, 0.6V, 1.2V, 1.8V, 2.4V, 3.0V, 3.6V, 0.3V.

Form 47-69A (5-73)

NORTHROP
Northrop Corporation
Aircraft Group



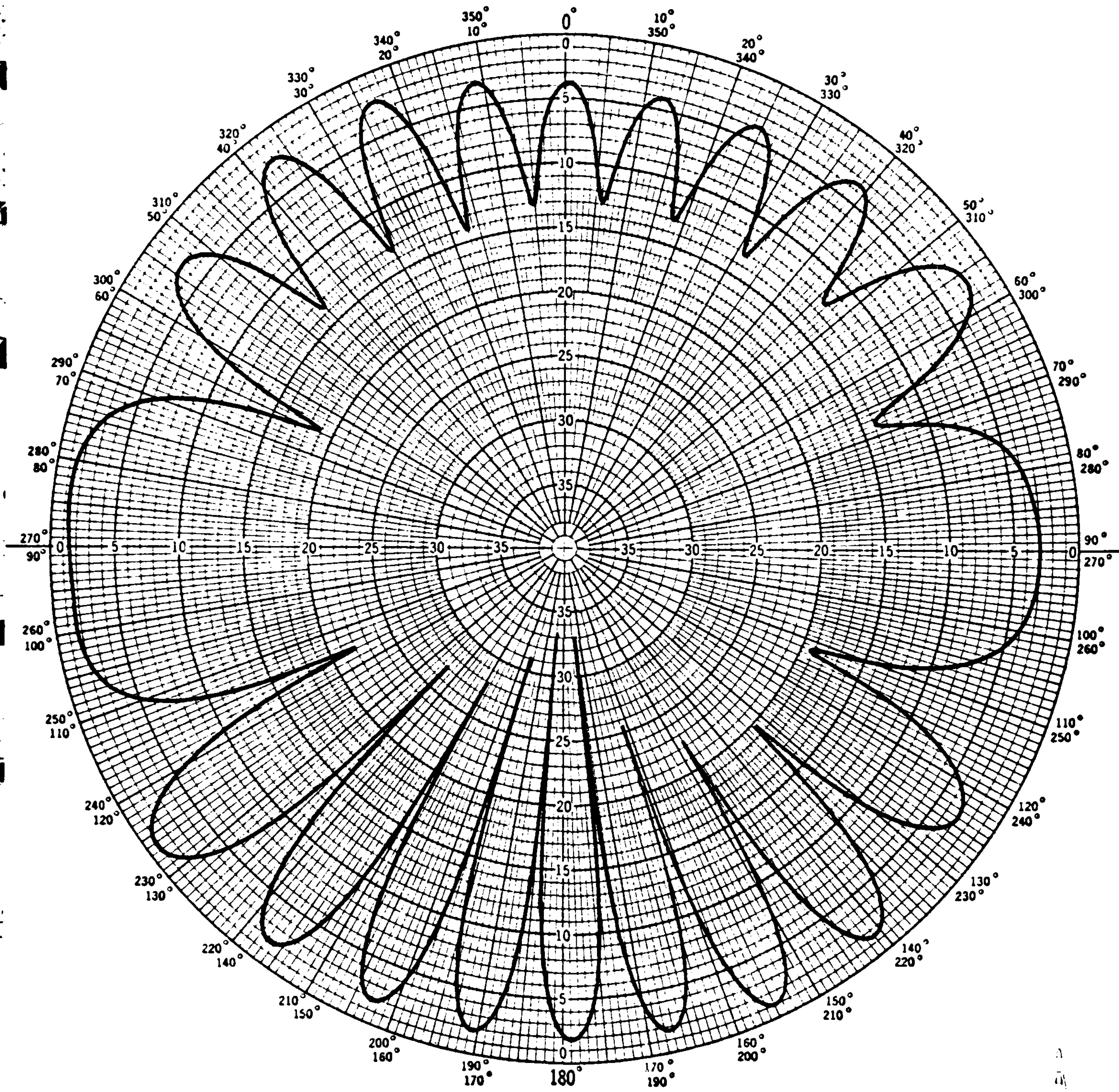


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-73

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ( )
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0.0 V, 0.6 V, 1.2 V, 1.8 V, 2.4 V, 3.0 V, 0.3 V.

Form 47-60A 5-73

NORTHROP
Northrop Corporation
Aircraft Group

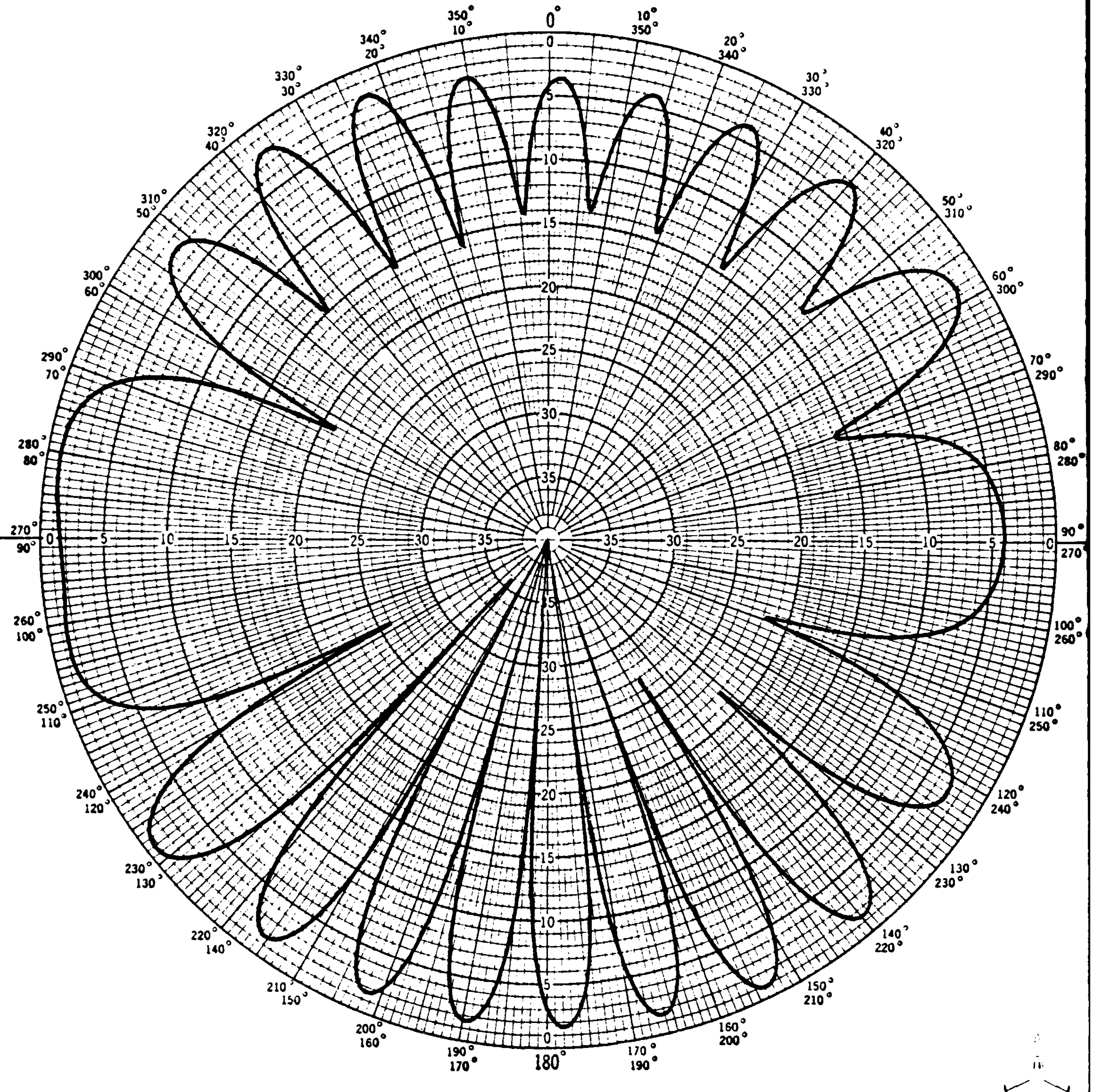


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = +0.3V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group

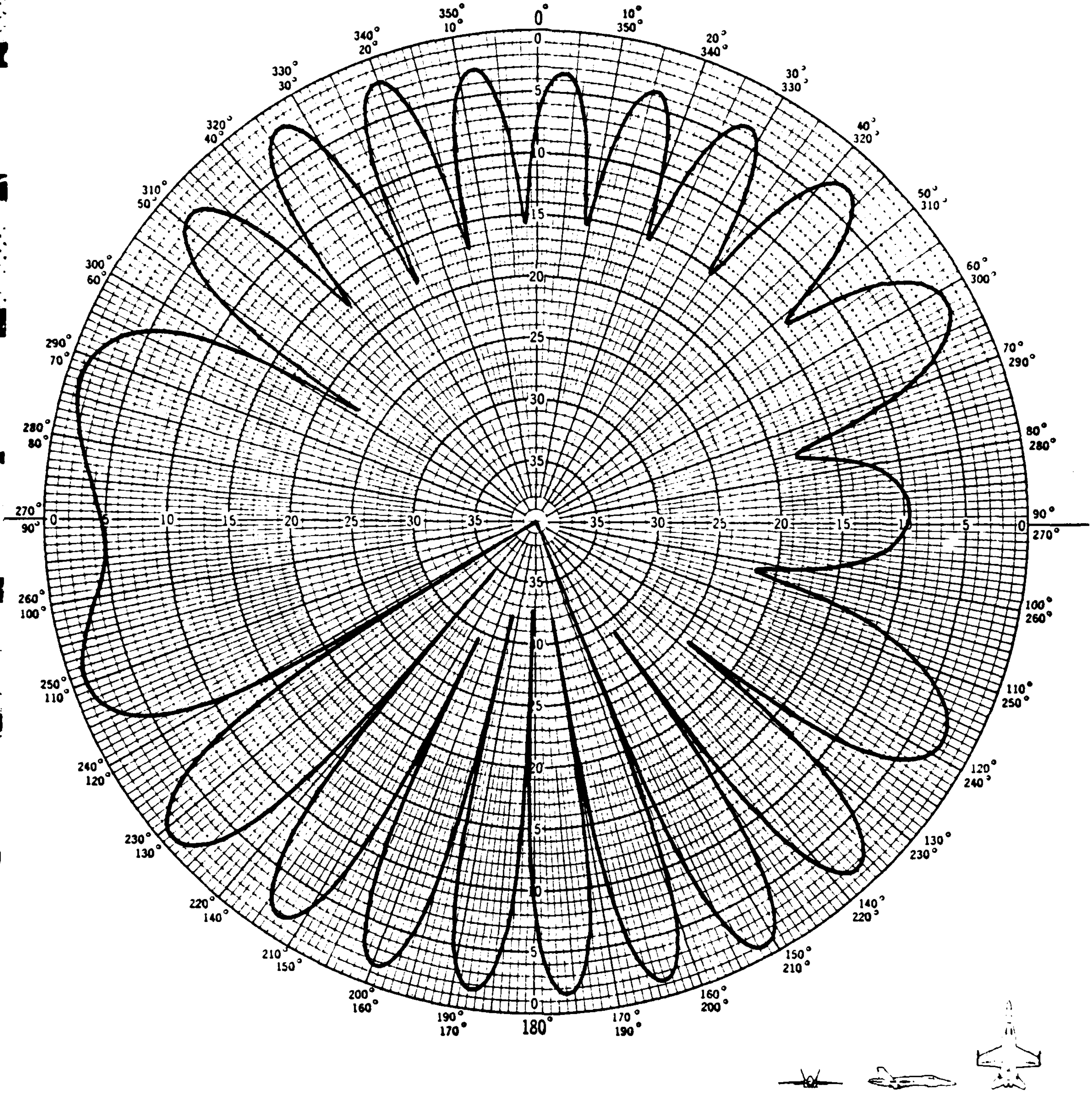


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = + 0.6 V.

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group

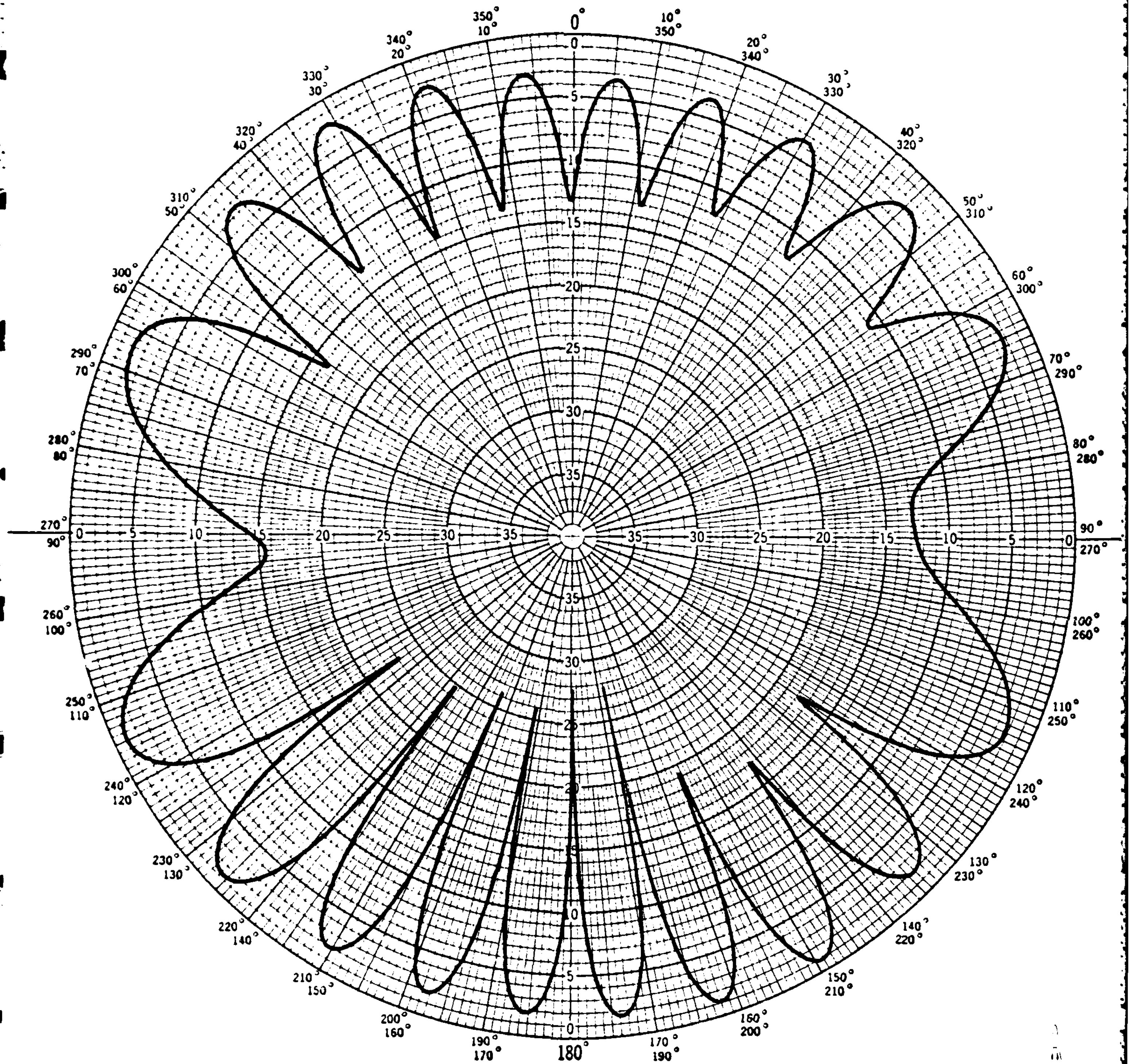


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = +1.2V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group

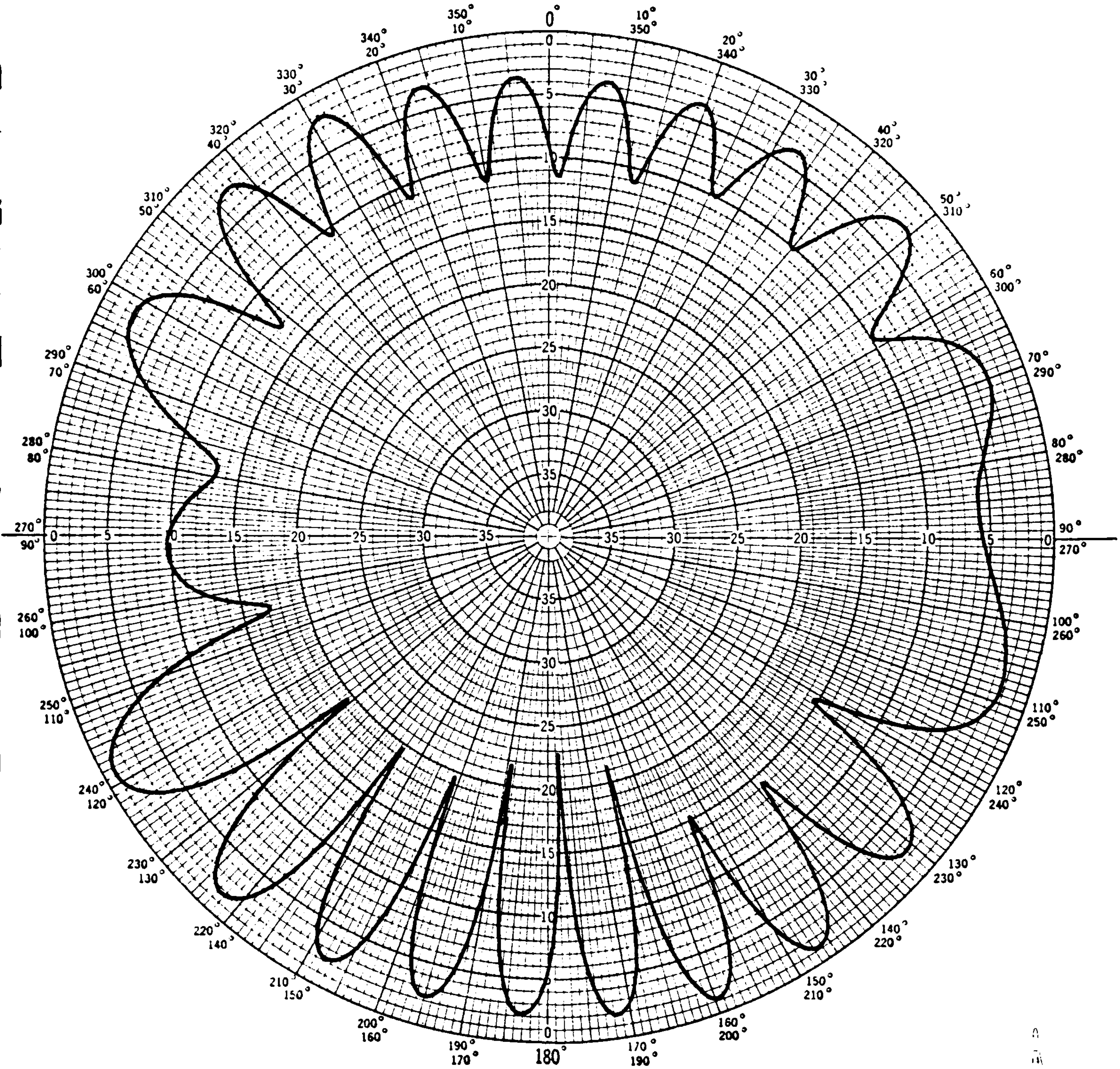


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = +1.8 V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group

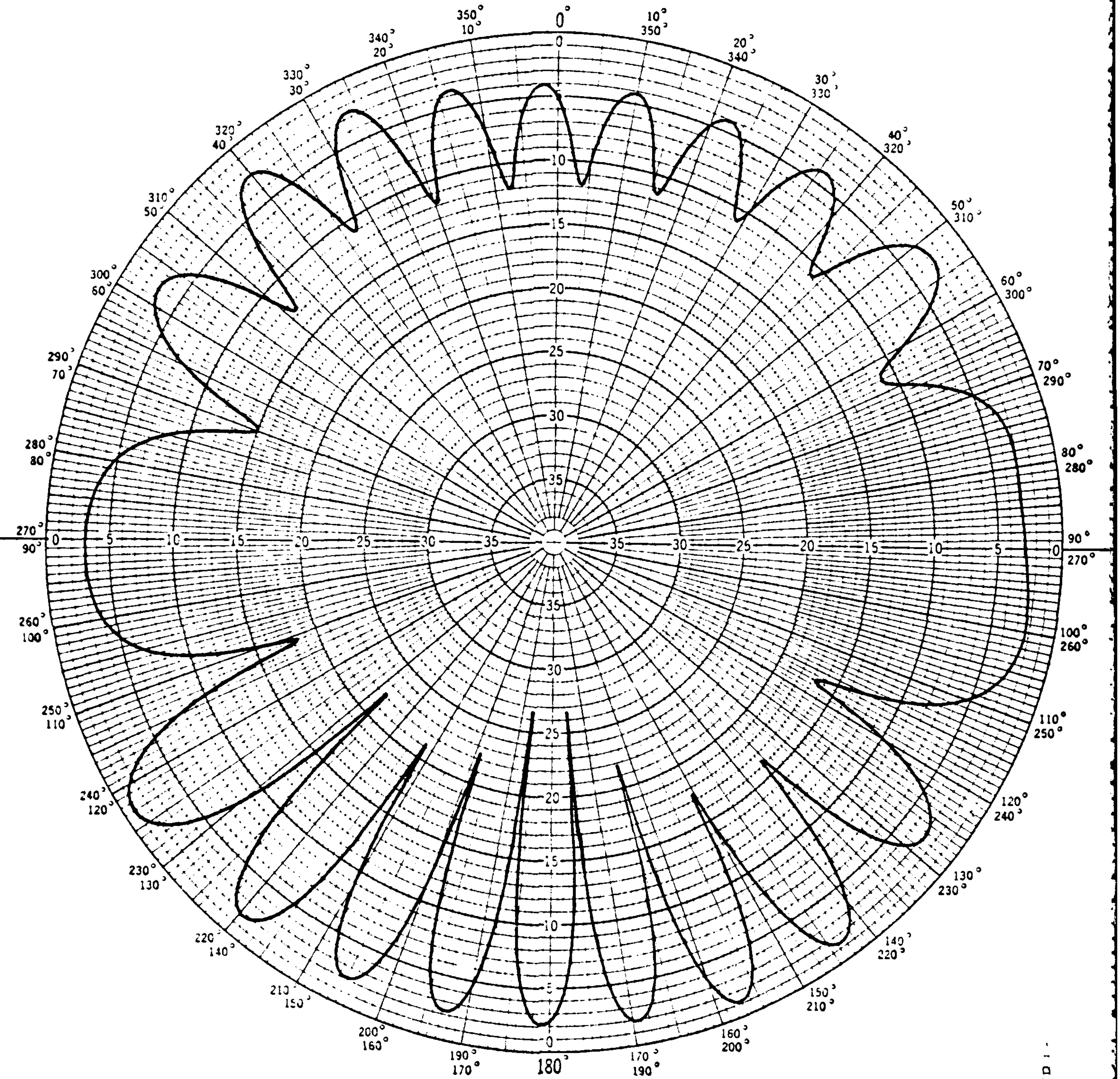


MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *7 GHz*
ANTENNA LOCATION ________ STATION ________
OPERATOR *L. SIMPSON* DATE *8-16-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *180°* Φ ( ) POLARIZATION *Y*
REMARKS *ØREF = 2.4 V*

Form 47-69A (5-73)

NORTHROP
Northrop Corporation
Aircraft Division



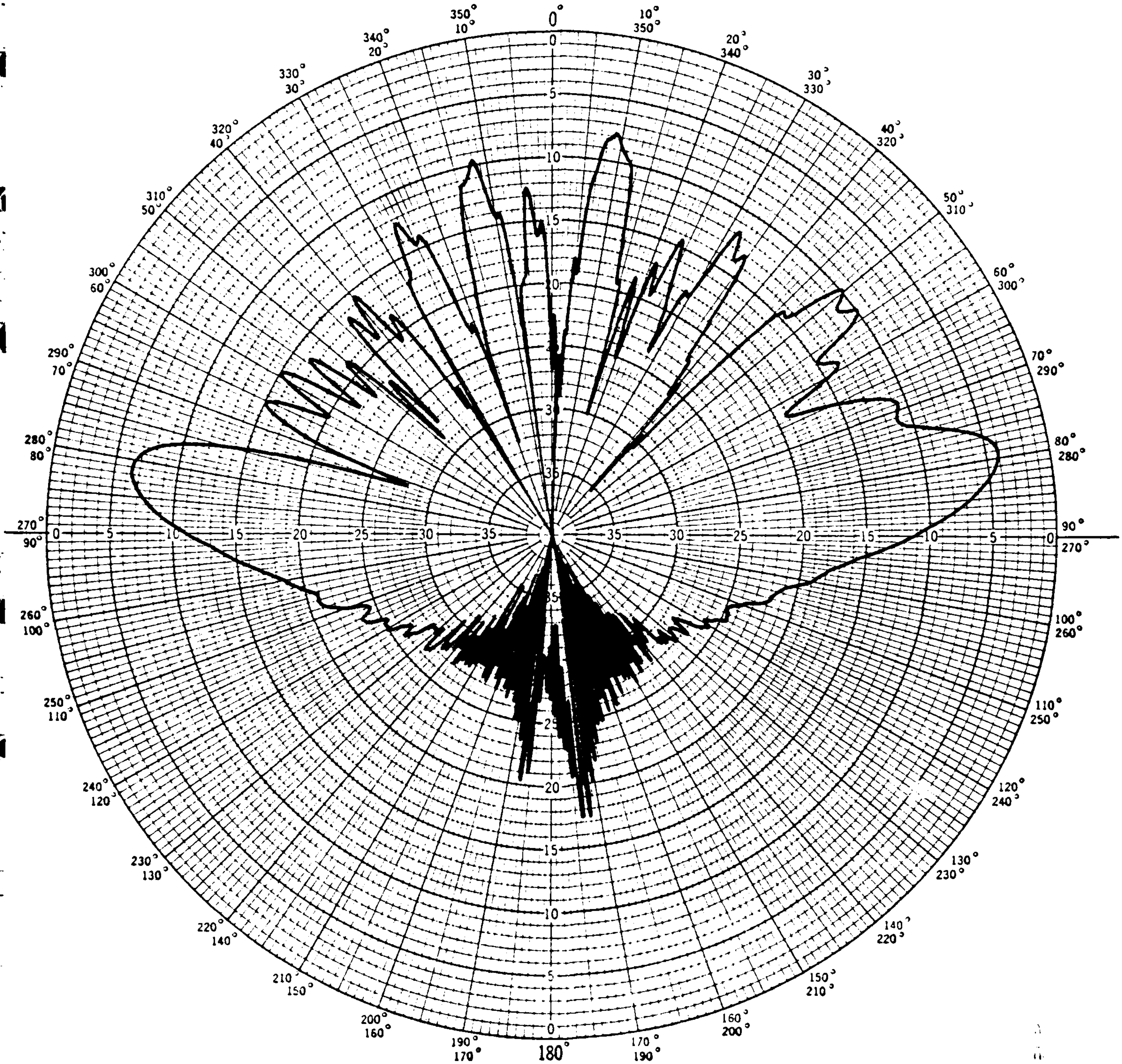
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 80° Φ ( ) POLARIZATION VERT
REMARKS Ø REF =+3.0V

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Group

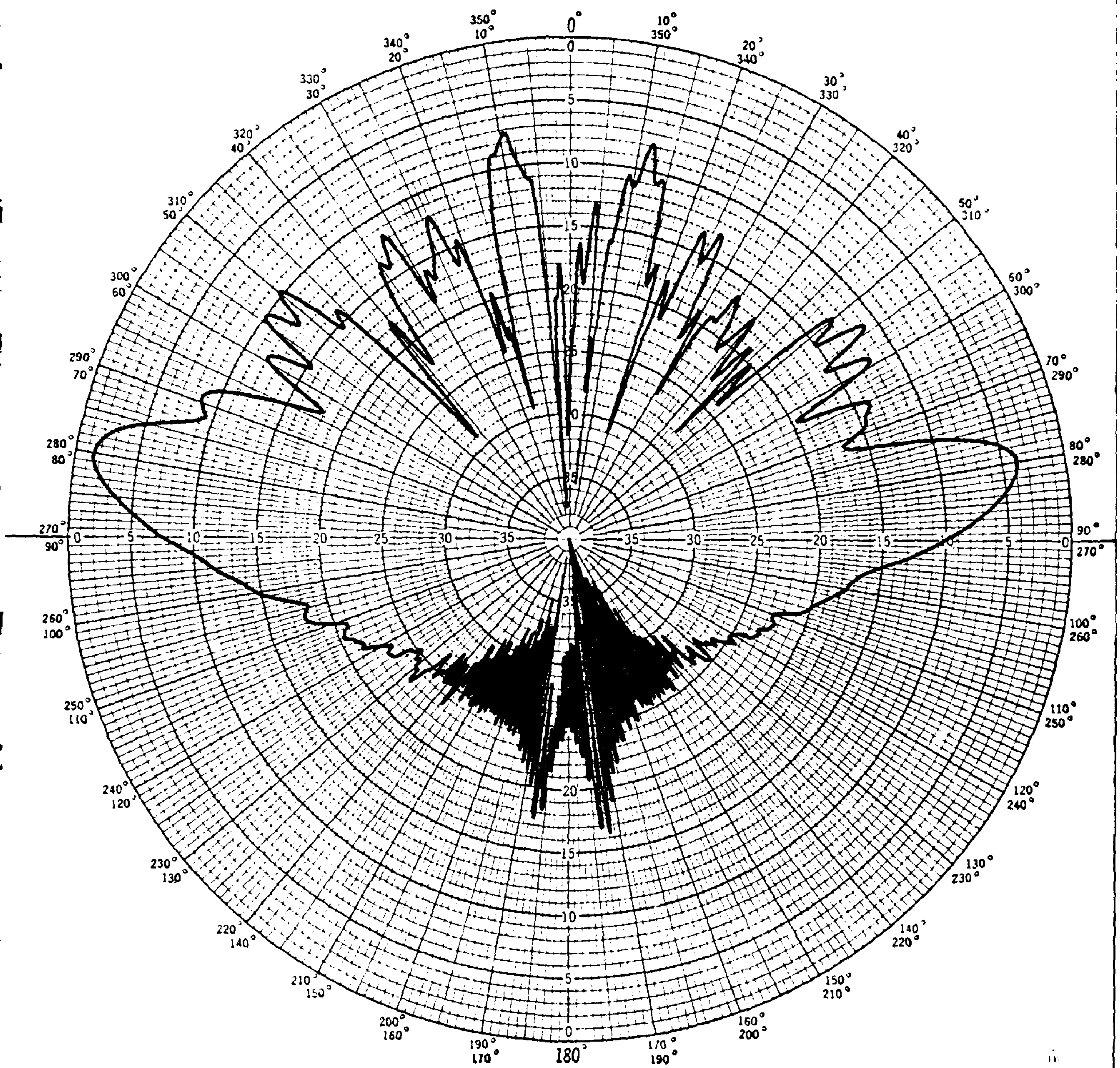


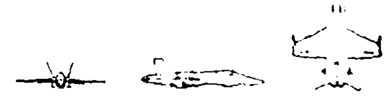
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ________ STATION ________
OPERATOR L SIMPSON DATE 8-16-79

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = -0.6V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group



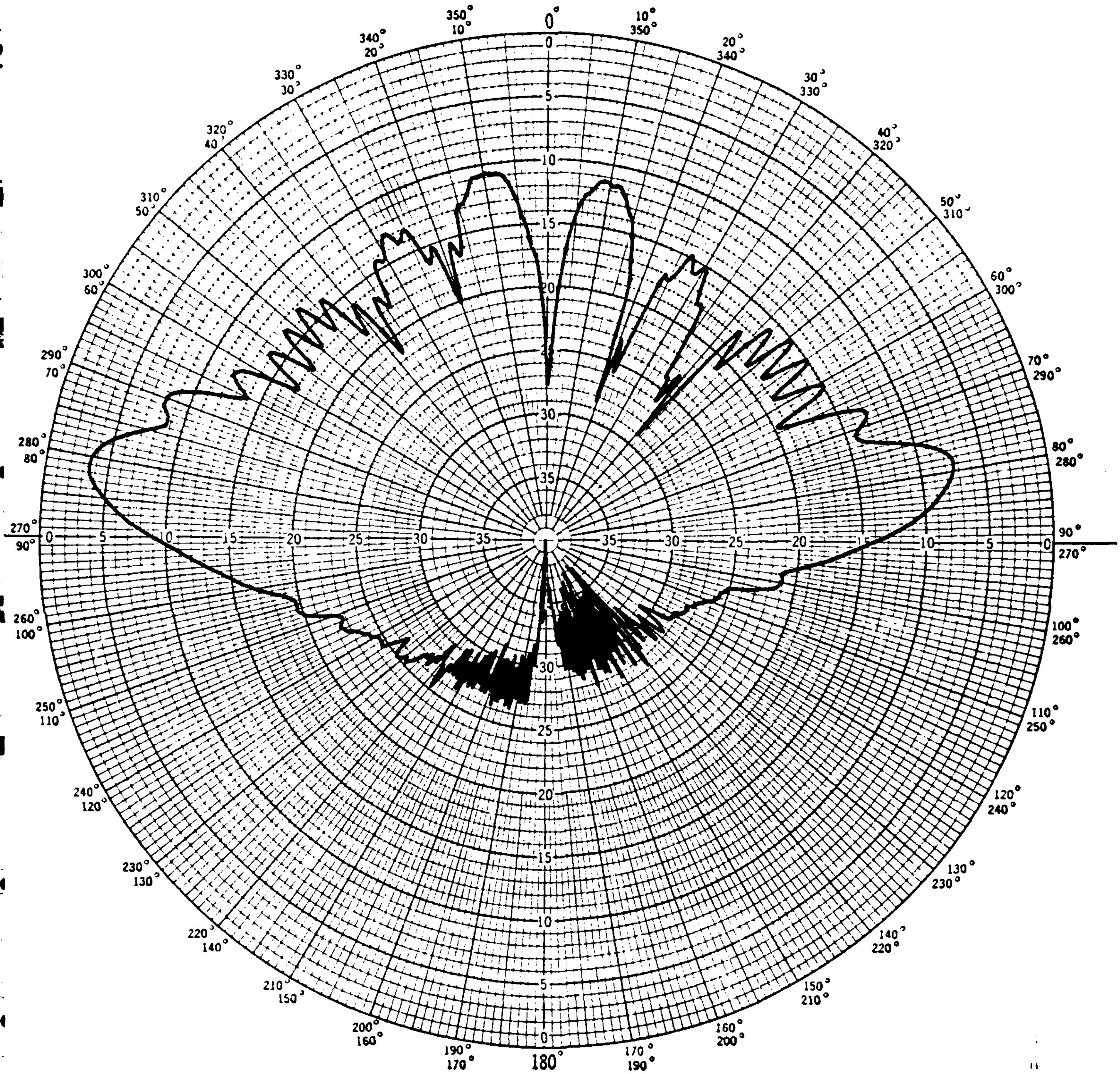


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____________ STATION ______
OPERATOR L SIMPSON DATE 3-16-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = +0.6V

Form 47-69A (5-73)

NORTHROP
Northrop Corporation
Aircraft Group

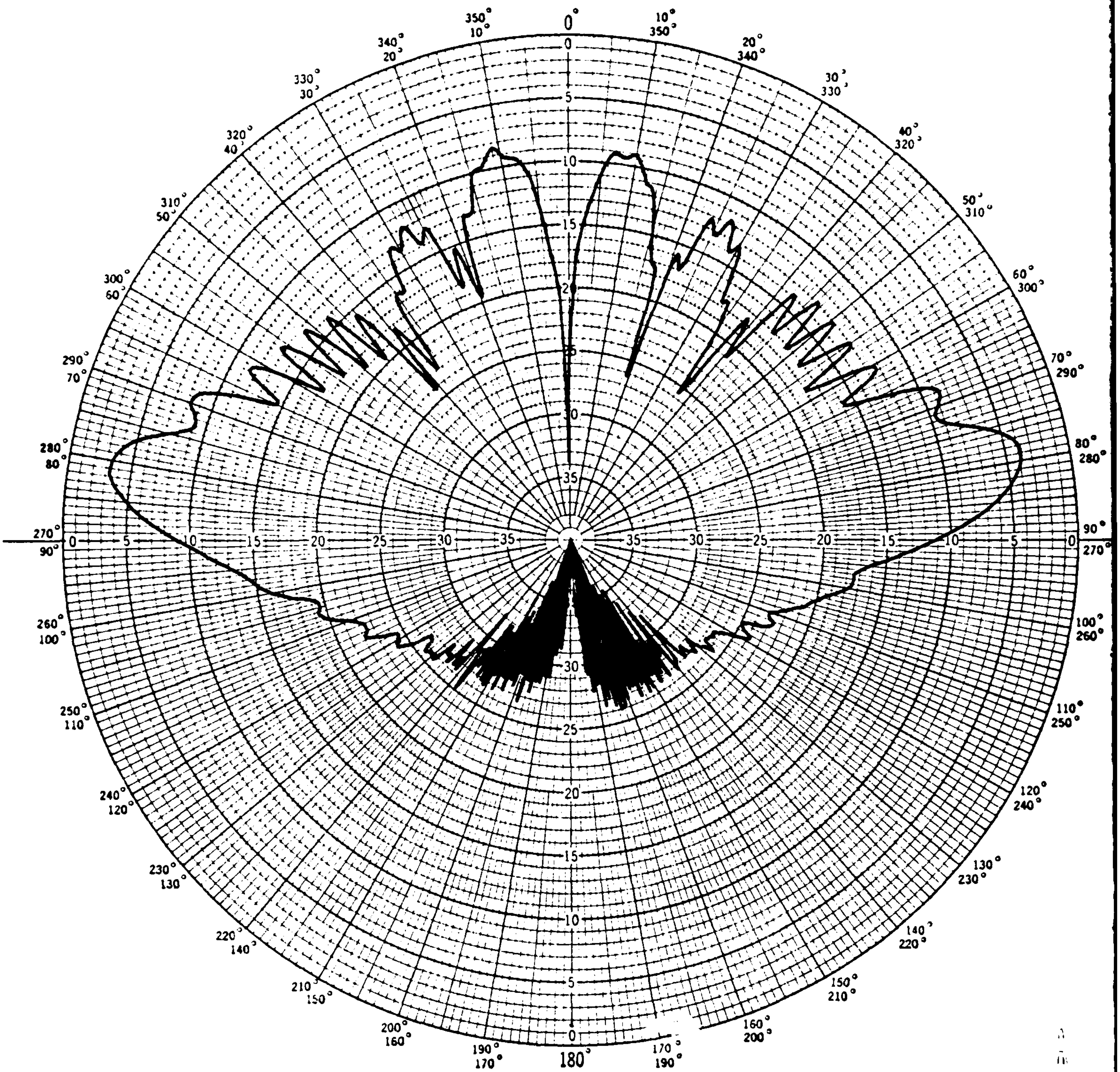


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = -0.6V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group



MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*

ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *7 GHZ*

ANTENNA LOCATION ______ STATION ______

OPERATOR *L. SIMPSON* DATE *8-16-78*

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

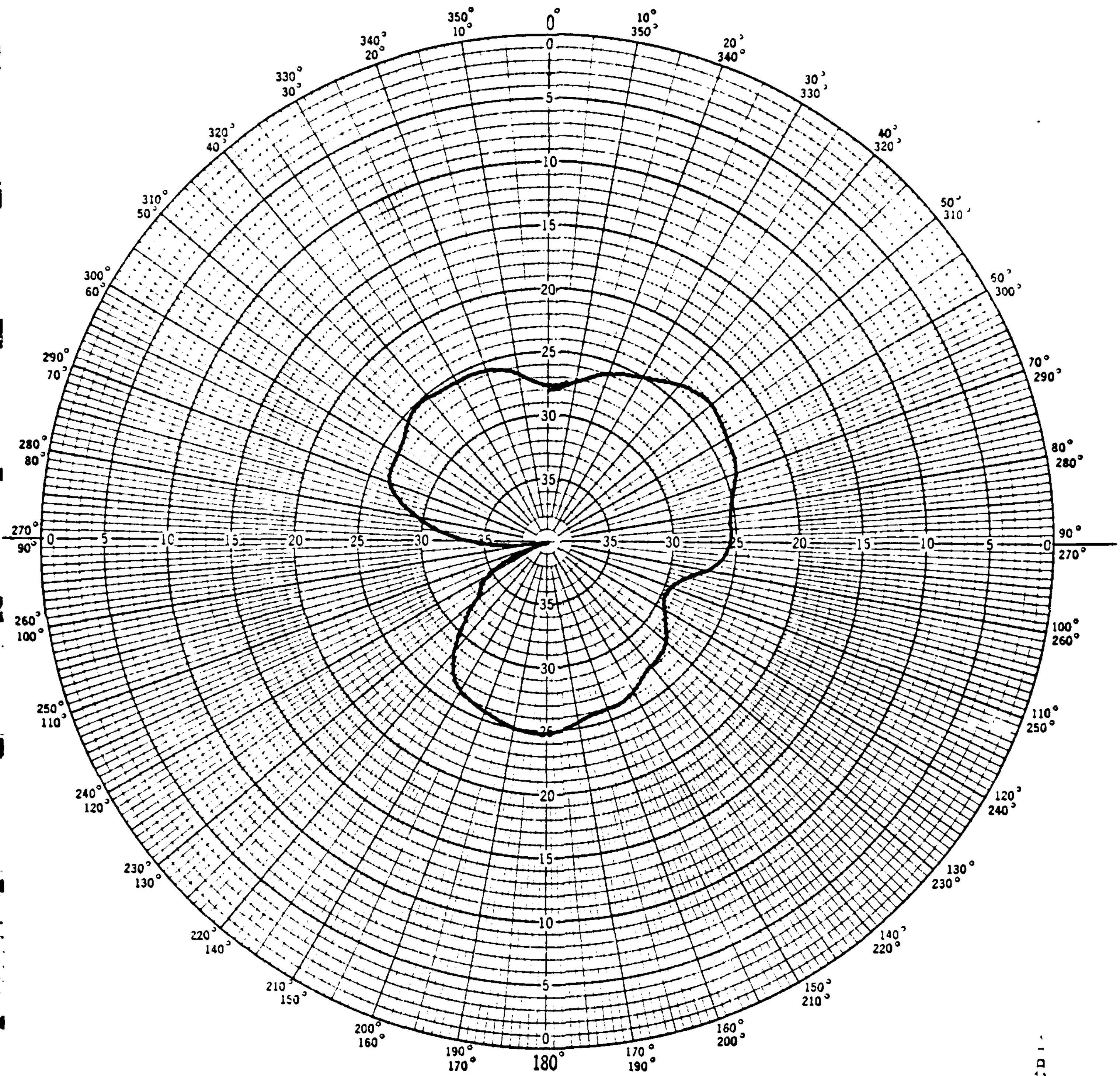
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

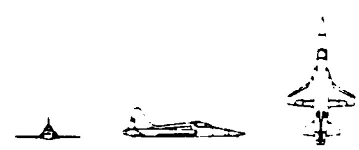
PATTERN θ ( ) Φ ( ) POLARIZATION *VERT*

REMARKS *ØREF = +0.0V*

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Division

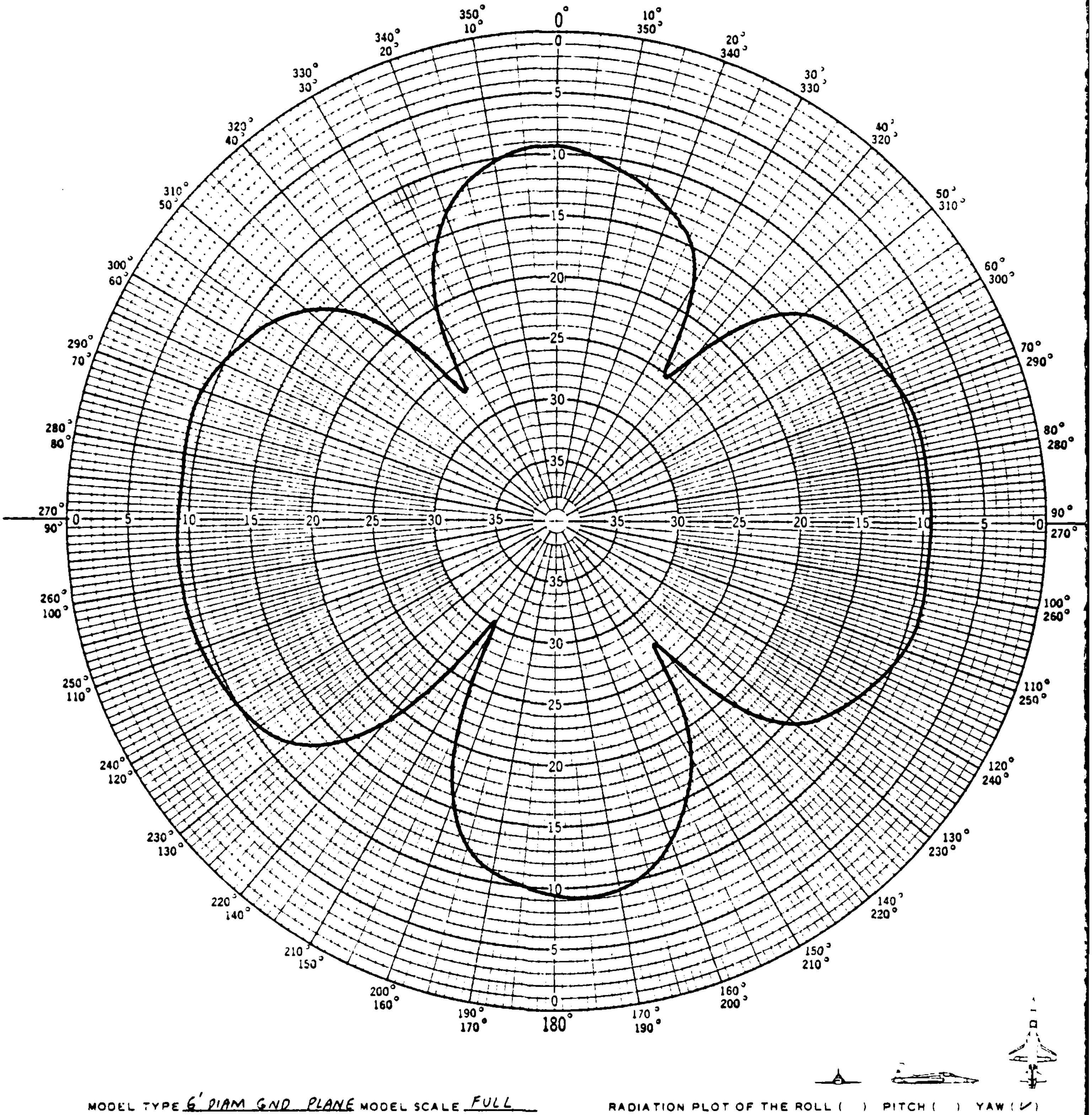




MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-3-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (0°) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V

Form 47-63 (R 9-72)

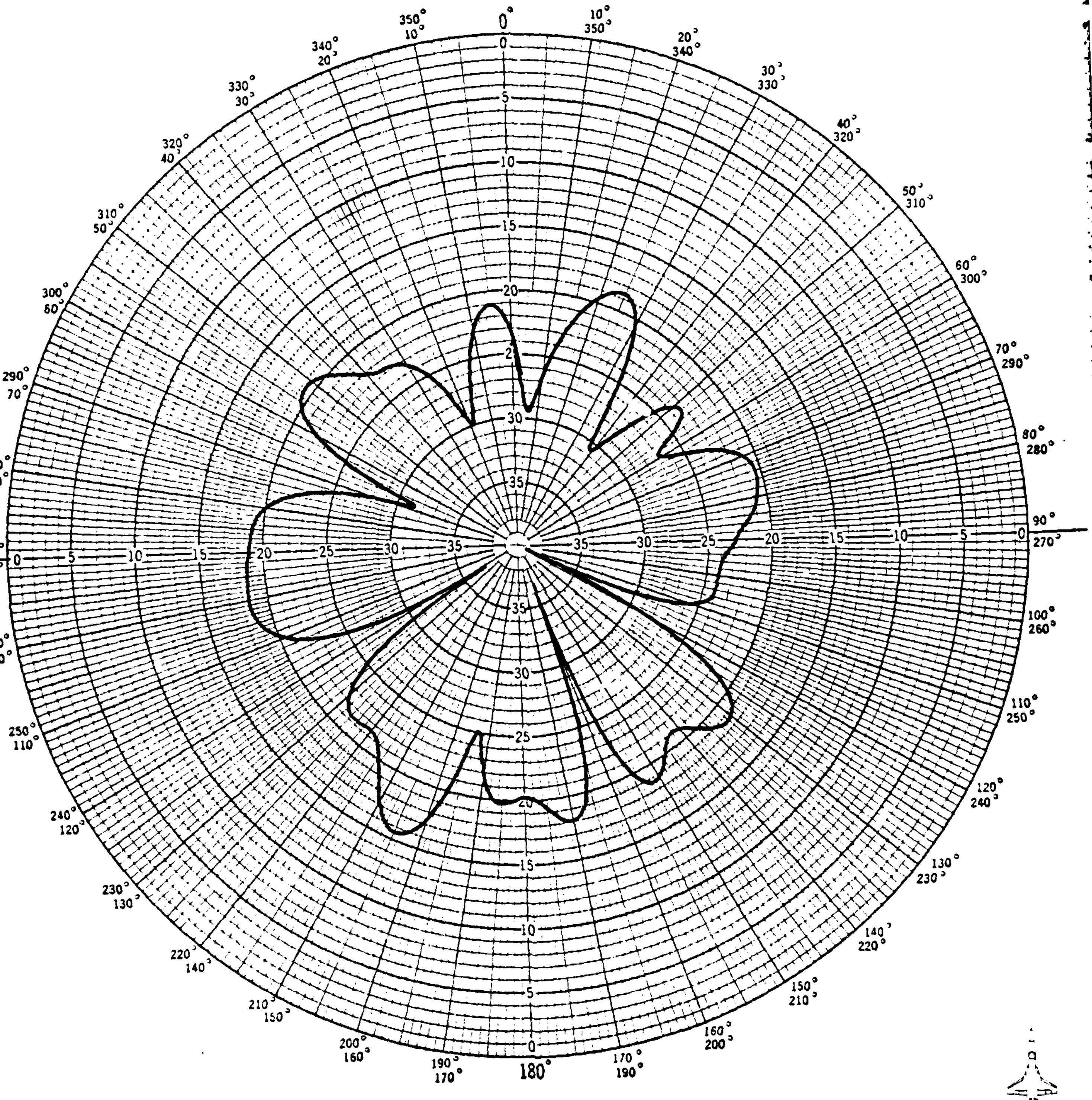


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-3-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 110° Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

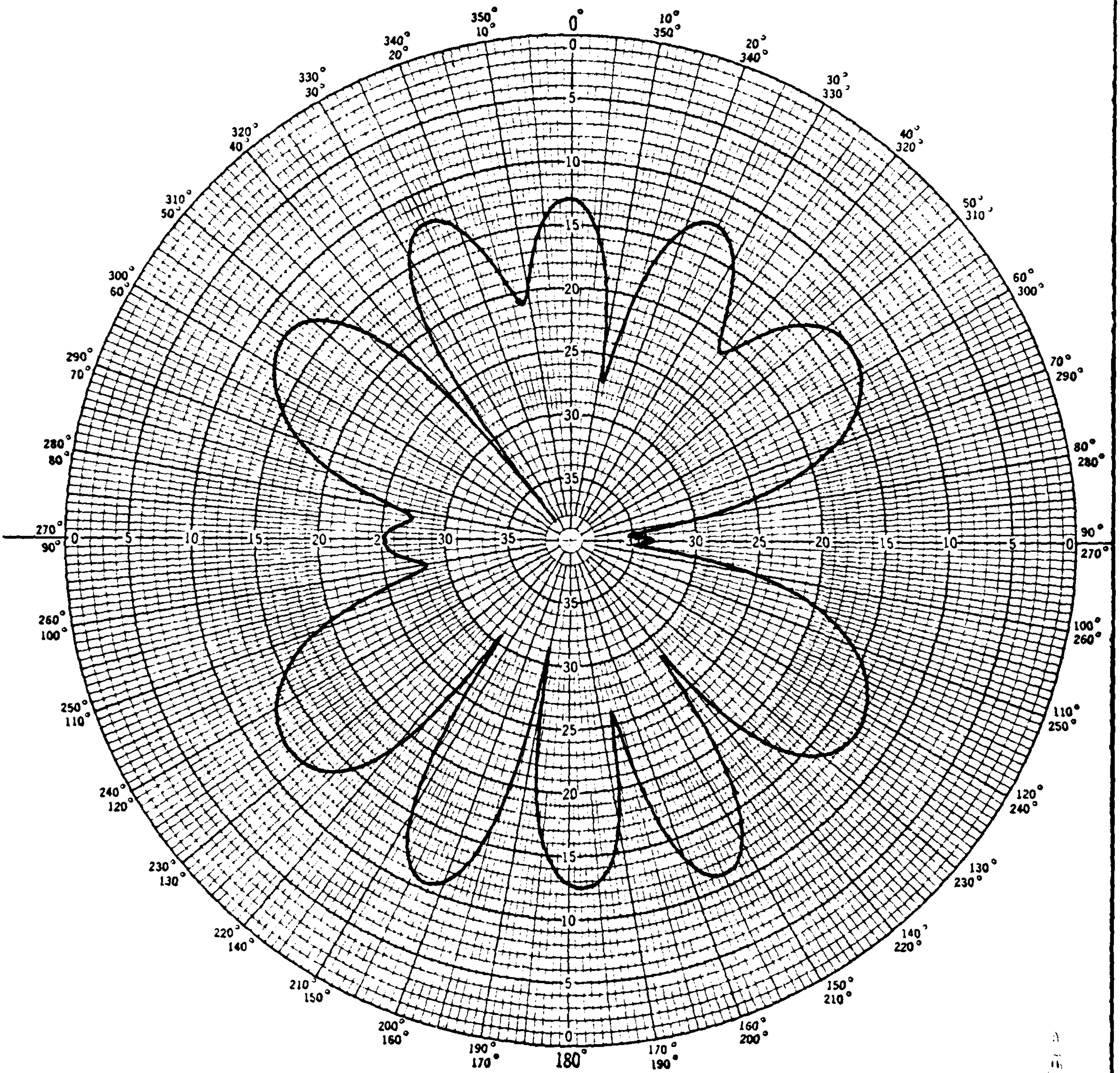


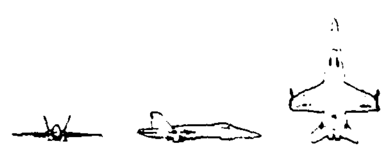
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-3-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 120° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0V

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Group





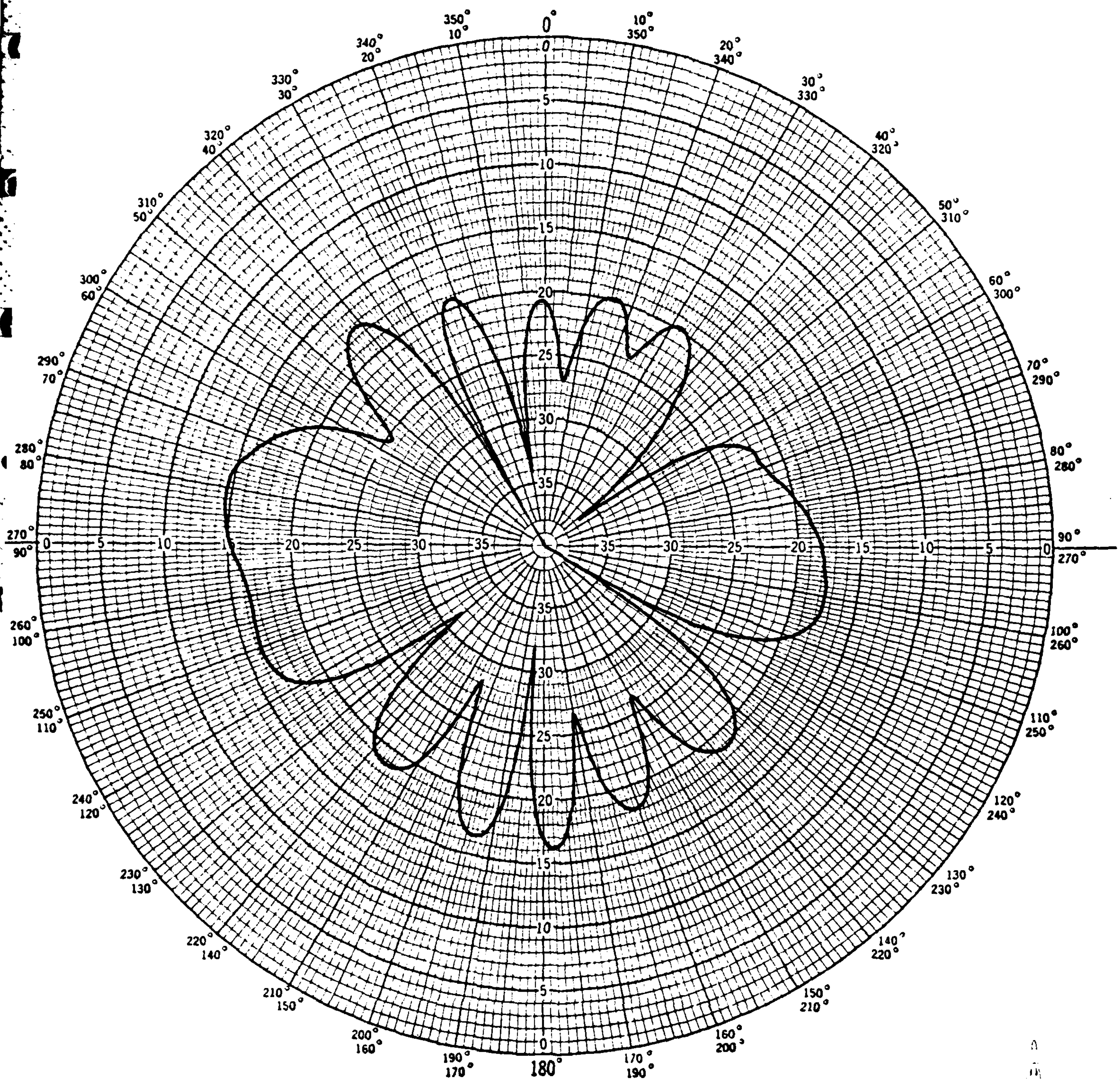
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 130° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0V

Form 47-69A (5-78)

NORTHROP

Northrop Corporation
Aircraft Group

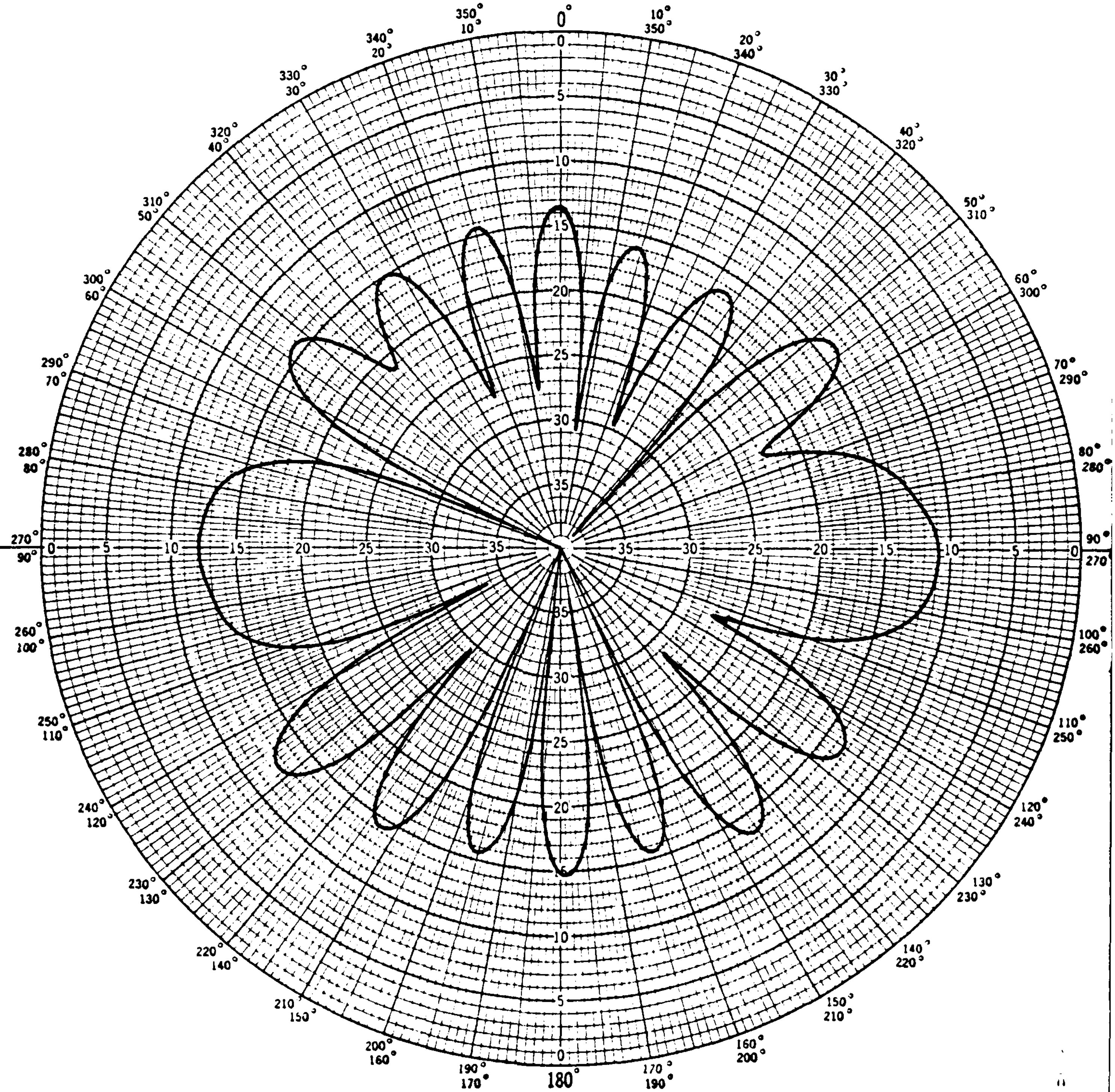


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 1409 Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 2V

Form 47-69A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group

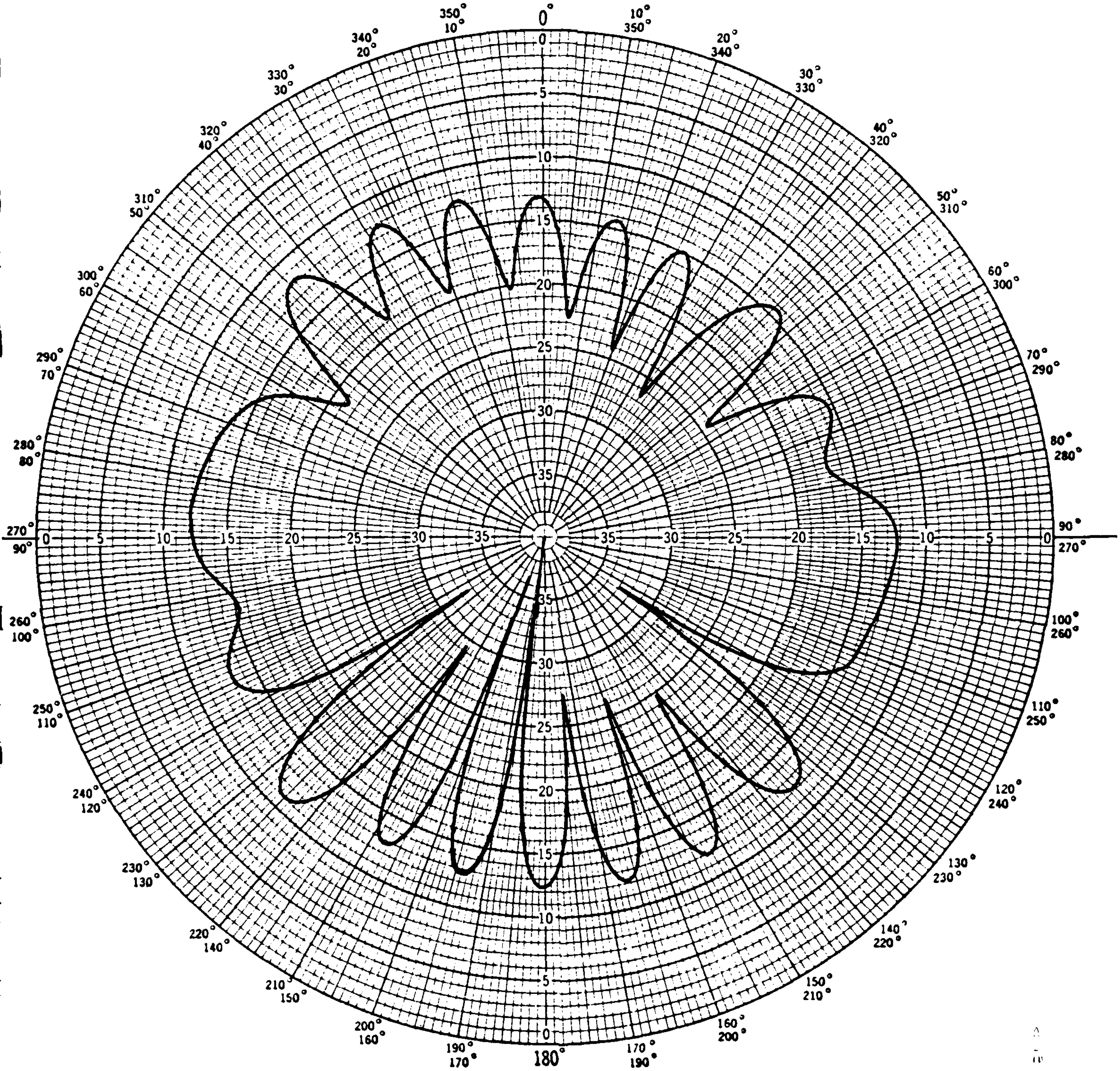


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (50° Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 2V

Form 47-69A 5-78)

NORTHROP
Northrop Corporation
Aircraft Group

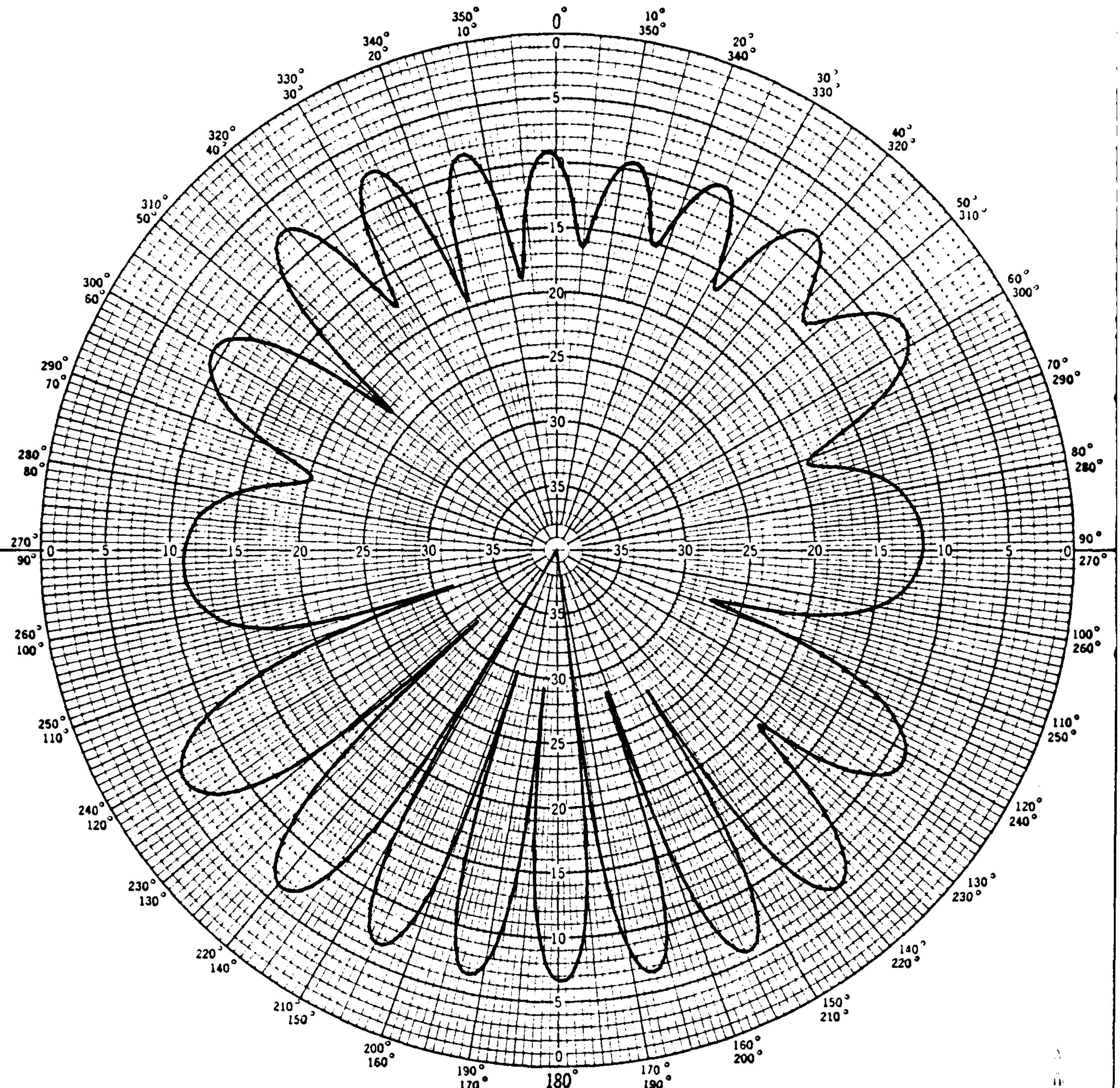


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (60°) Φ ( ) POLARIZATION VERT
REMARKS ________

Form 47-69A 5-78)

NORTHROP
Northrop Corporation
Aircraft Group

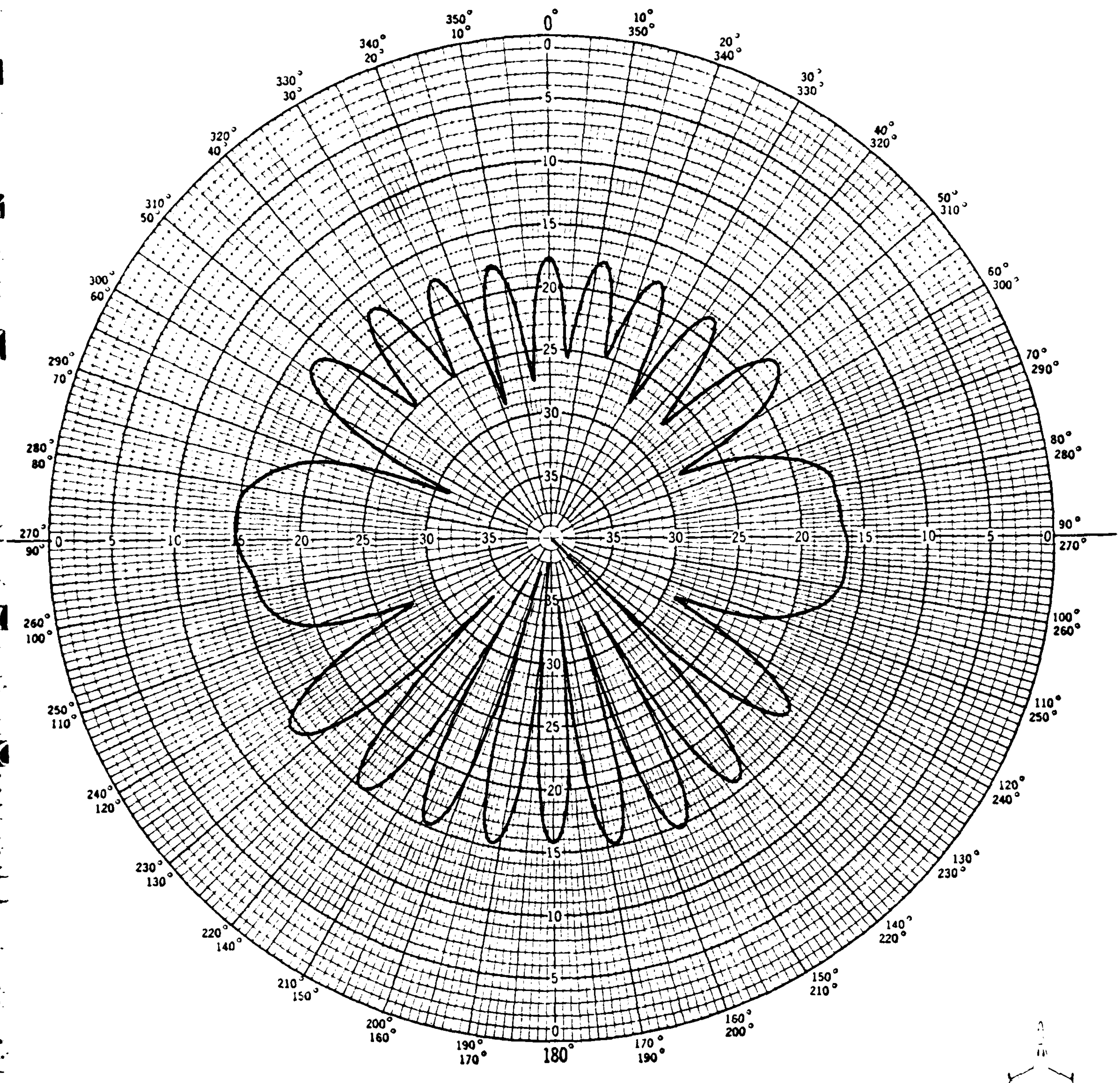


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (70°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

Form 47-63A (5-78)

NORTHROP
Northrop Corporation
Aircraft Group



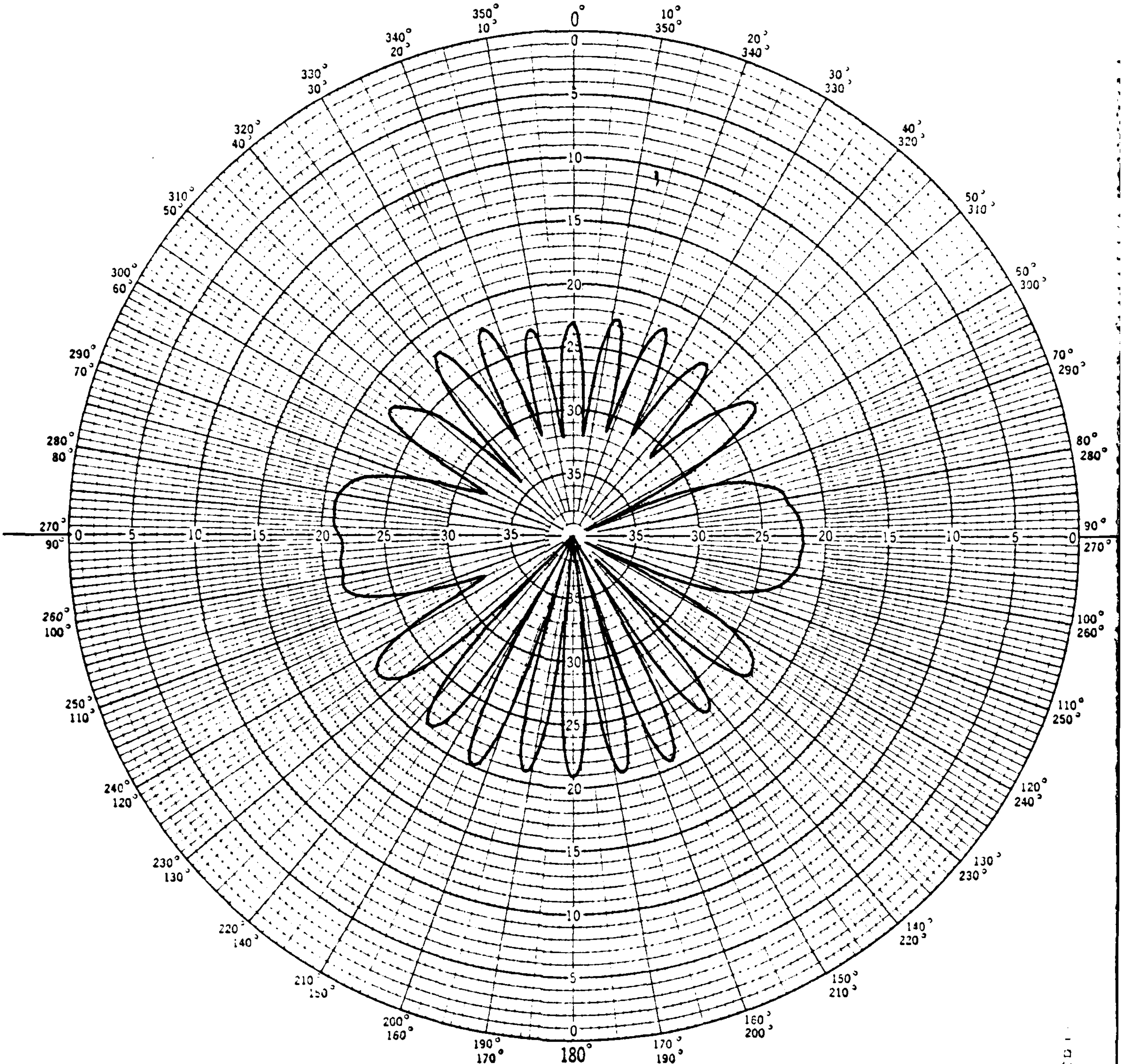
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-16-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (100°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0 V = 0°

Form 47-69A (5-78)

NORTHROP

Northrop Corporation
Aircraft Division



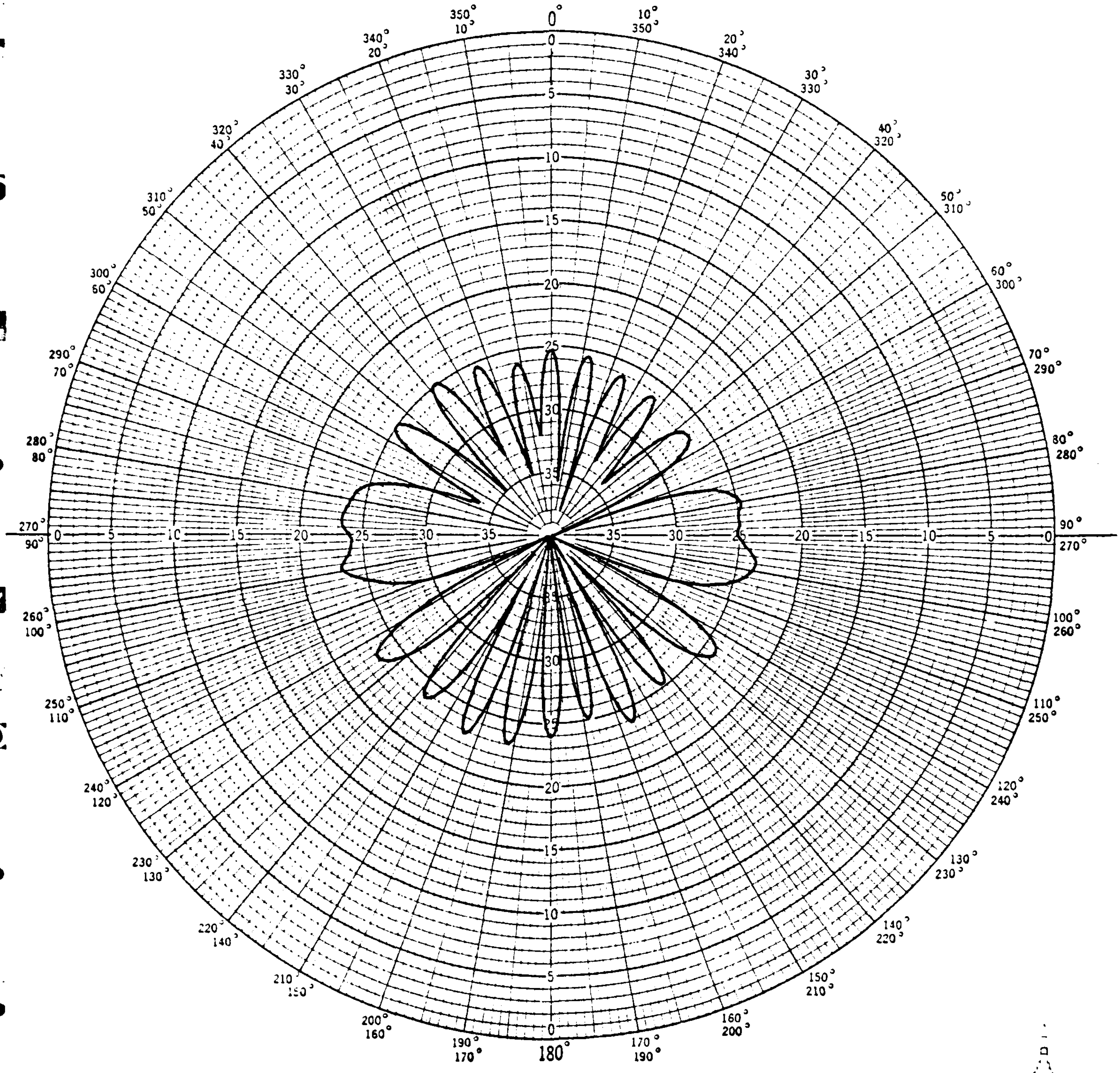
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-4-78

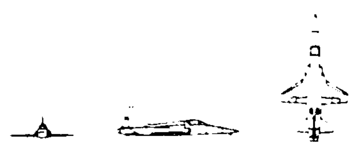
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 110° Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

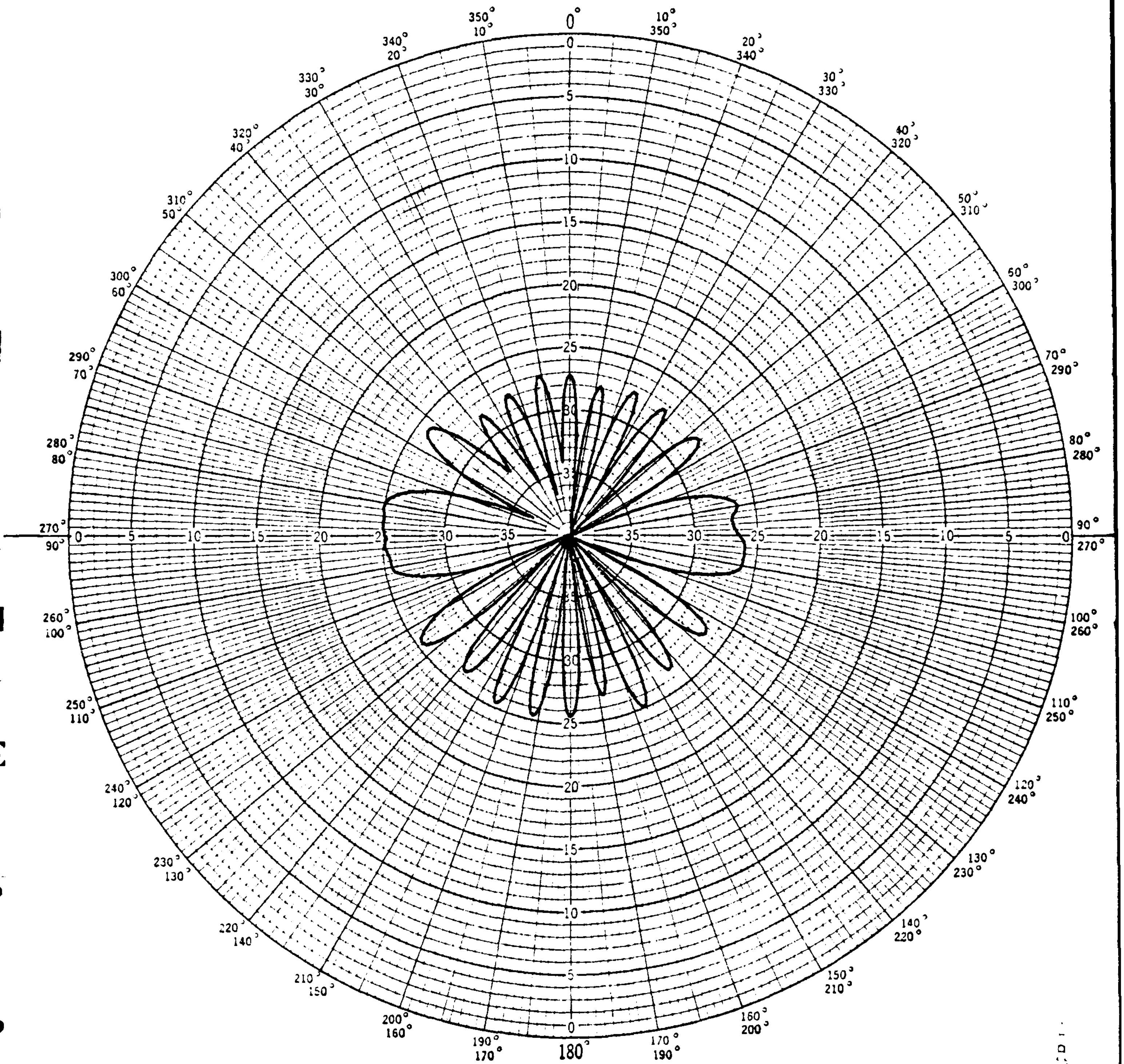
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ 120° Φ ( ) POLARIZATION VERT

REMARKS Ø REF = 0V = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

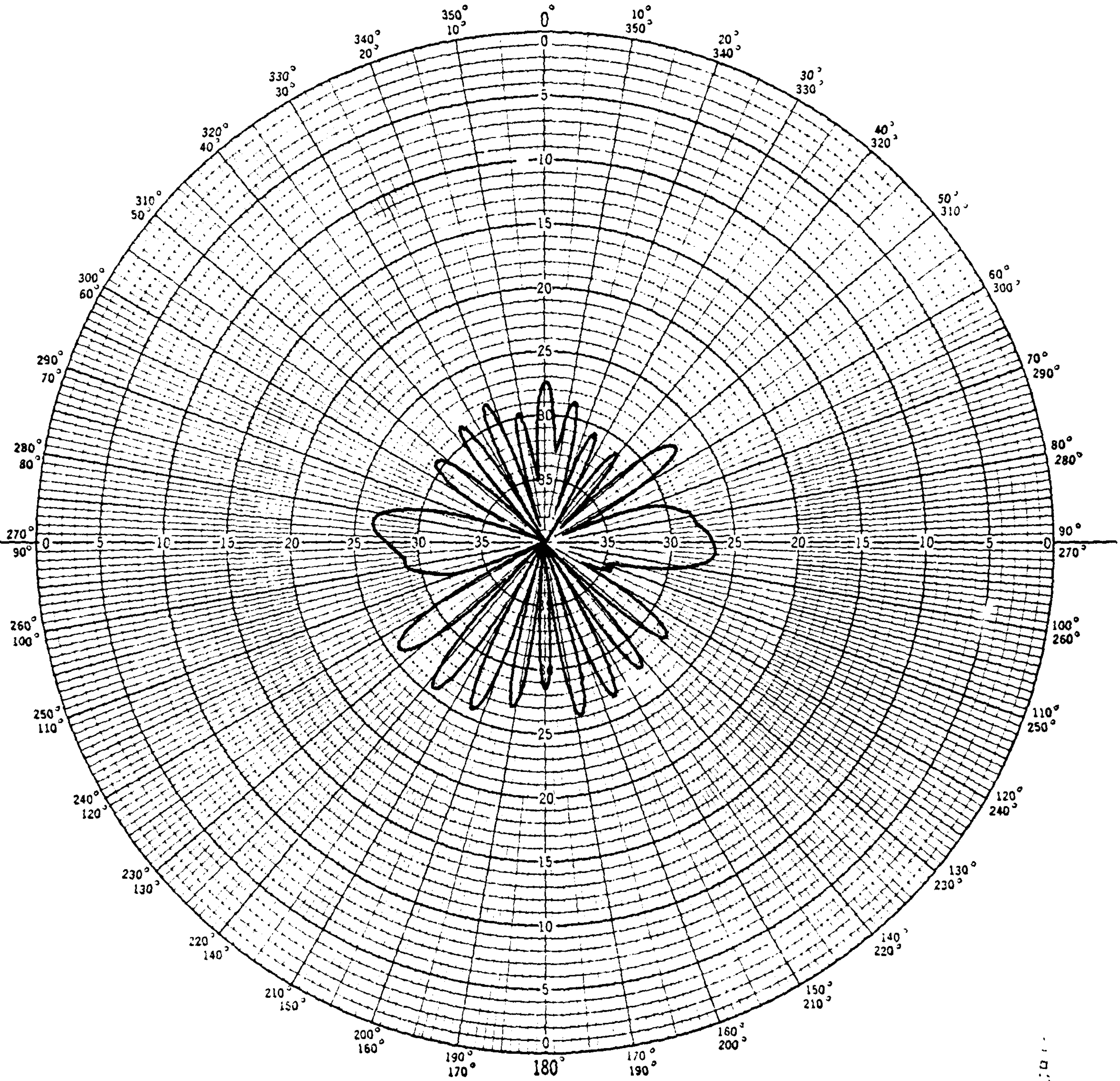


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-4-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (130° Φ ( ) POLARIZATION VERT.
REMARKS Φ REF = CY = 0°

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division

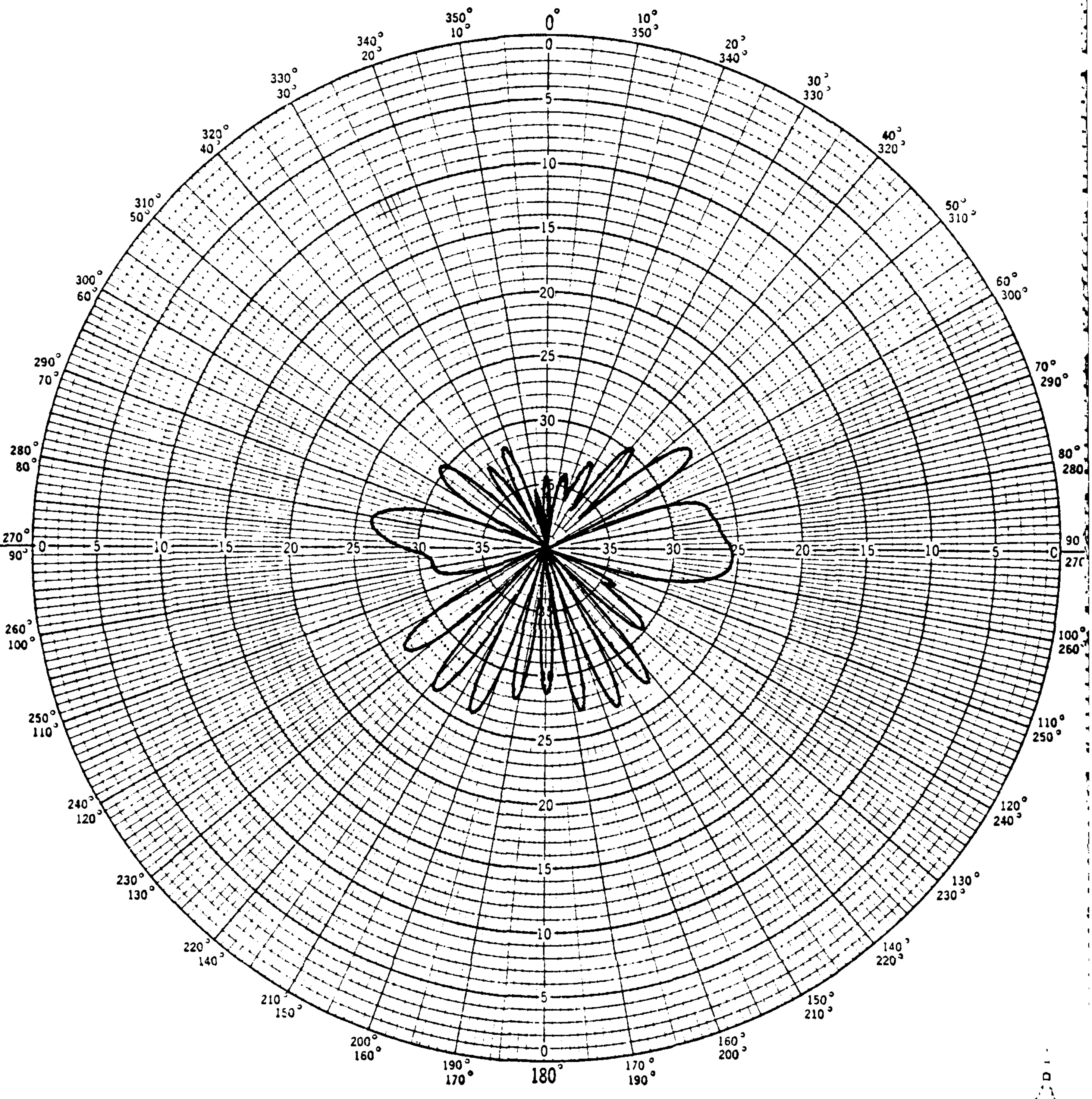


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ____________ STATION ______
OPERATOR L. SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN 9 140 $ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



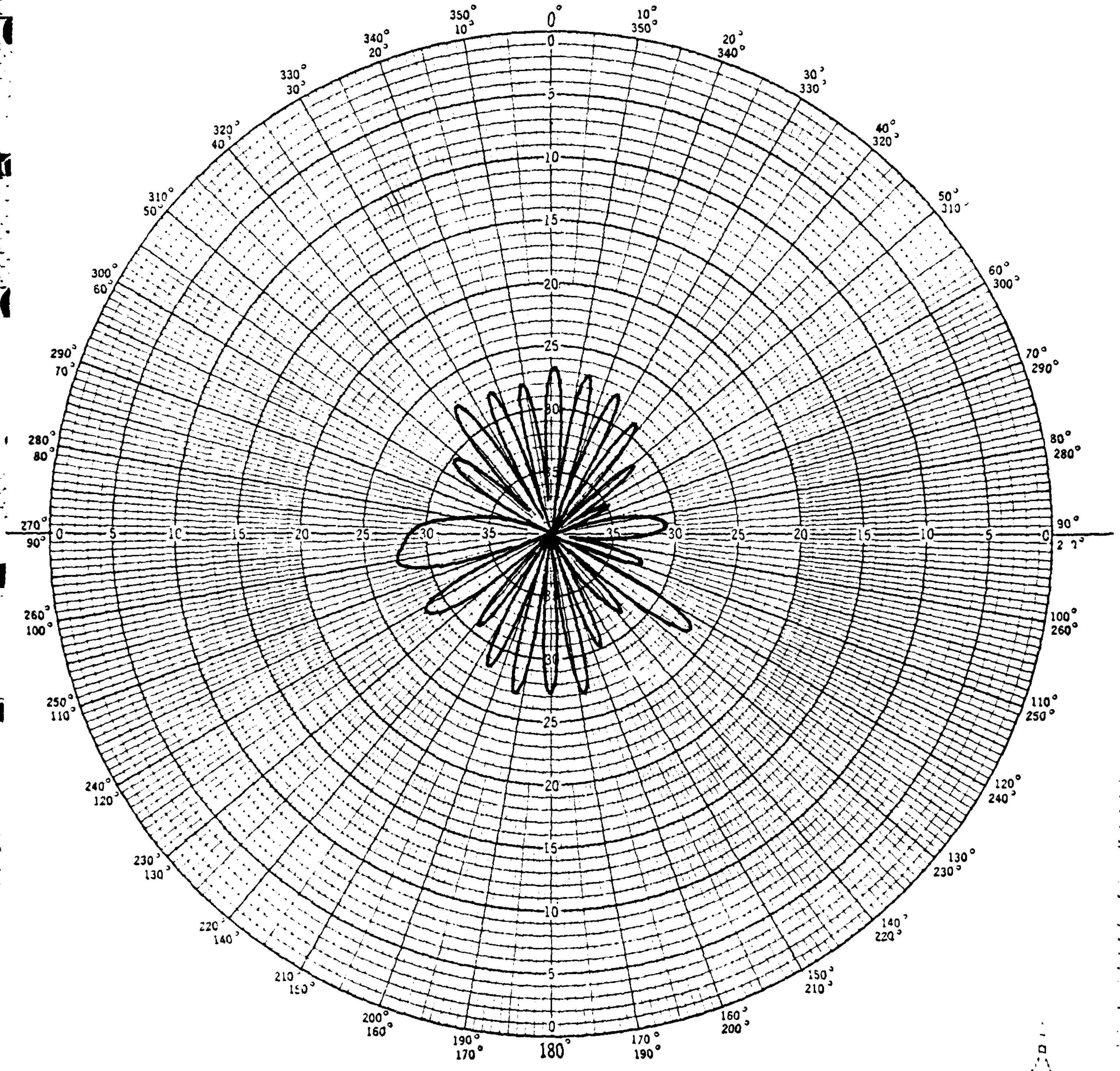
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (158) Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 8-4-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

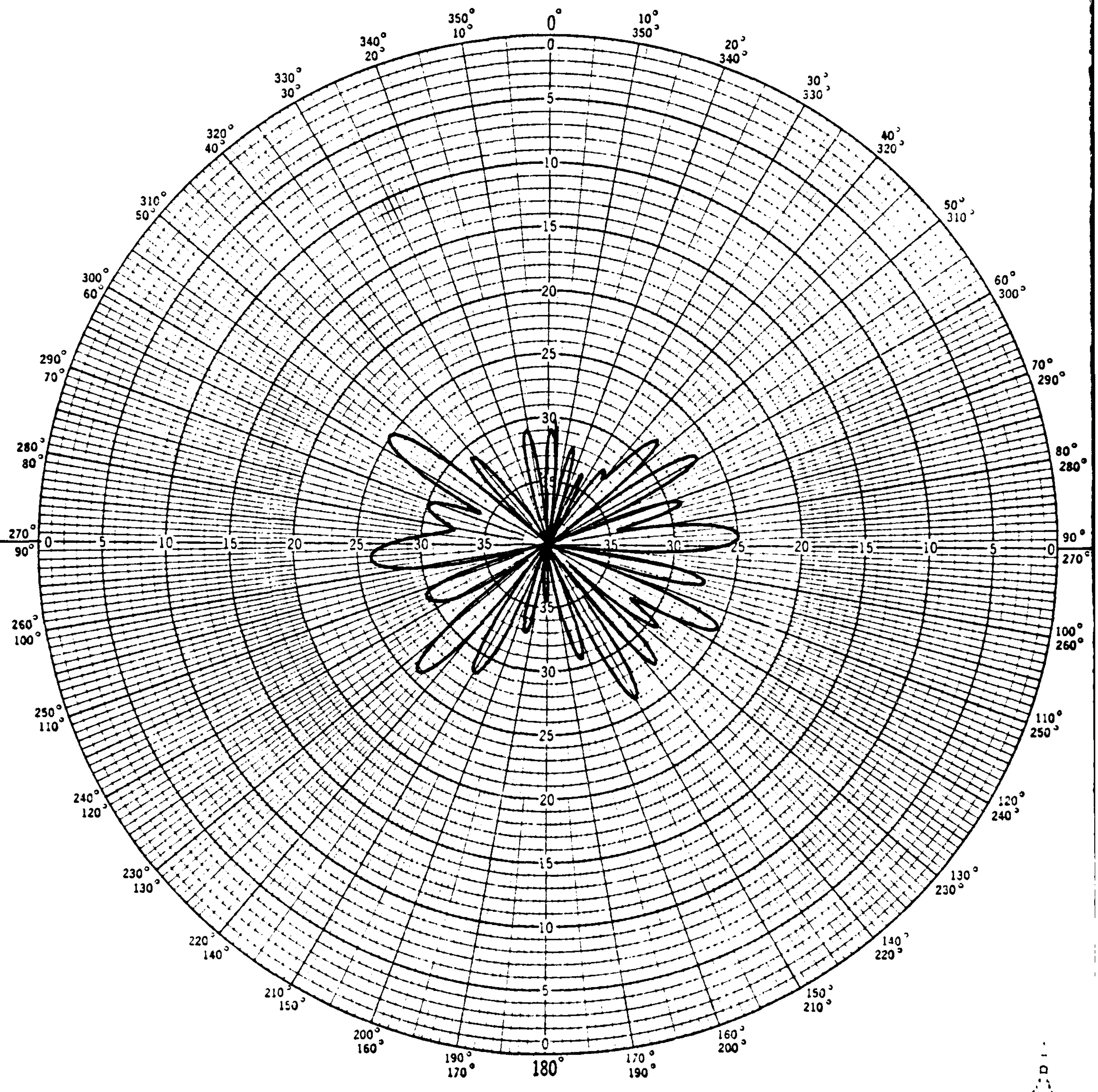
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ 160° Φ ( ) POLARIZATION VERT.

REMARKS ØREF = ØV = 0°

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division

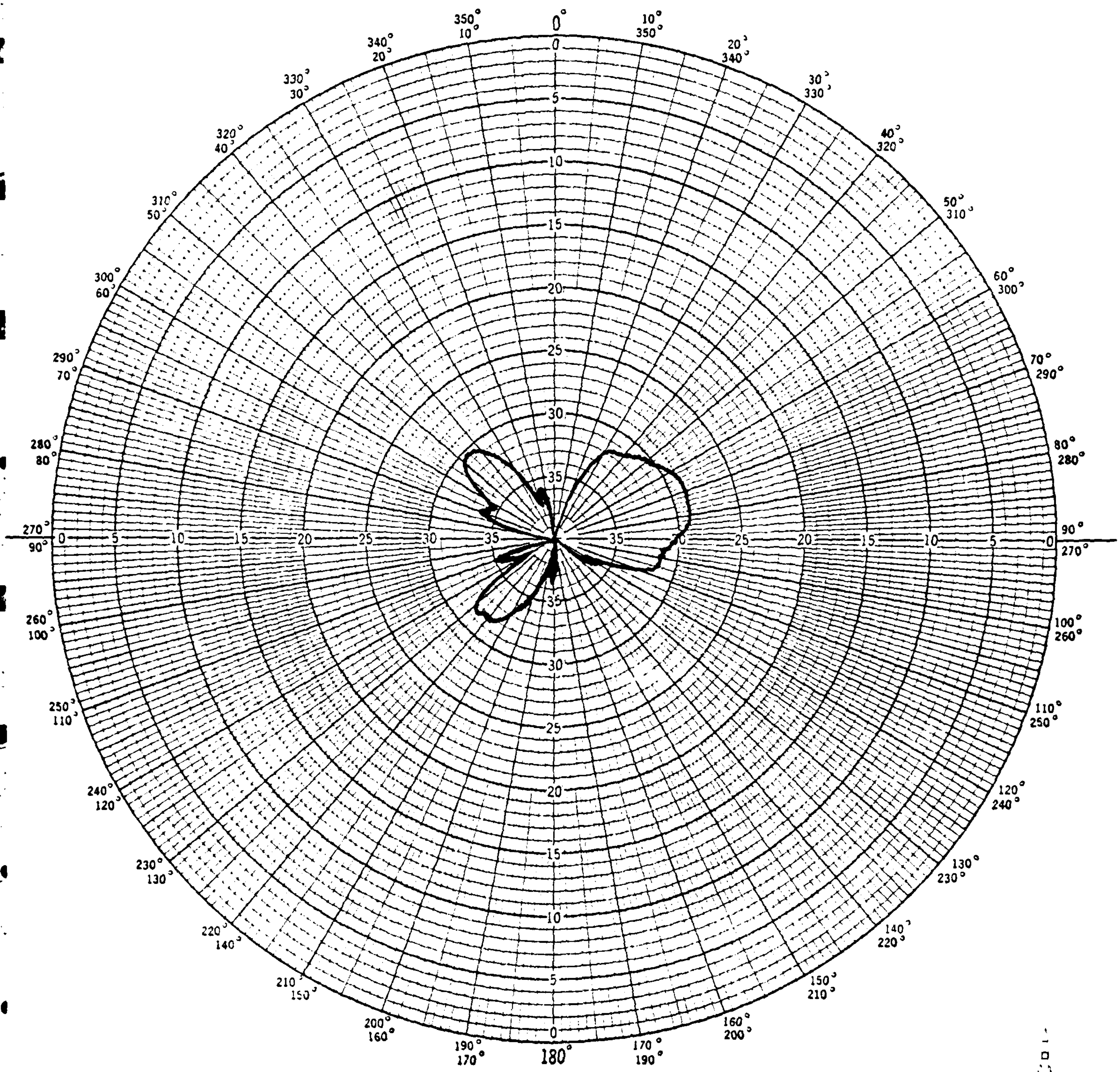


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (170) Φ ( ) POLARIZATION VERT
REMARKS ØREF = CY = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

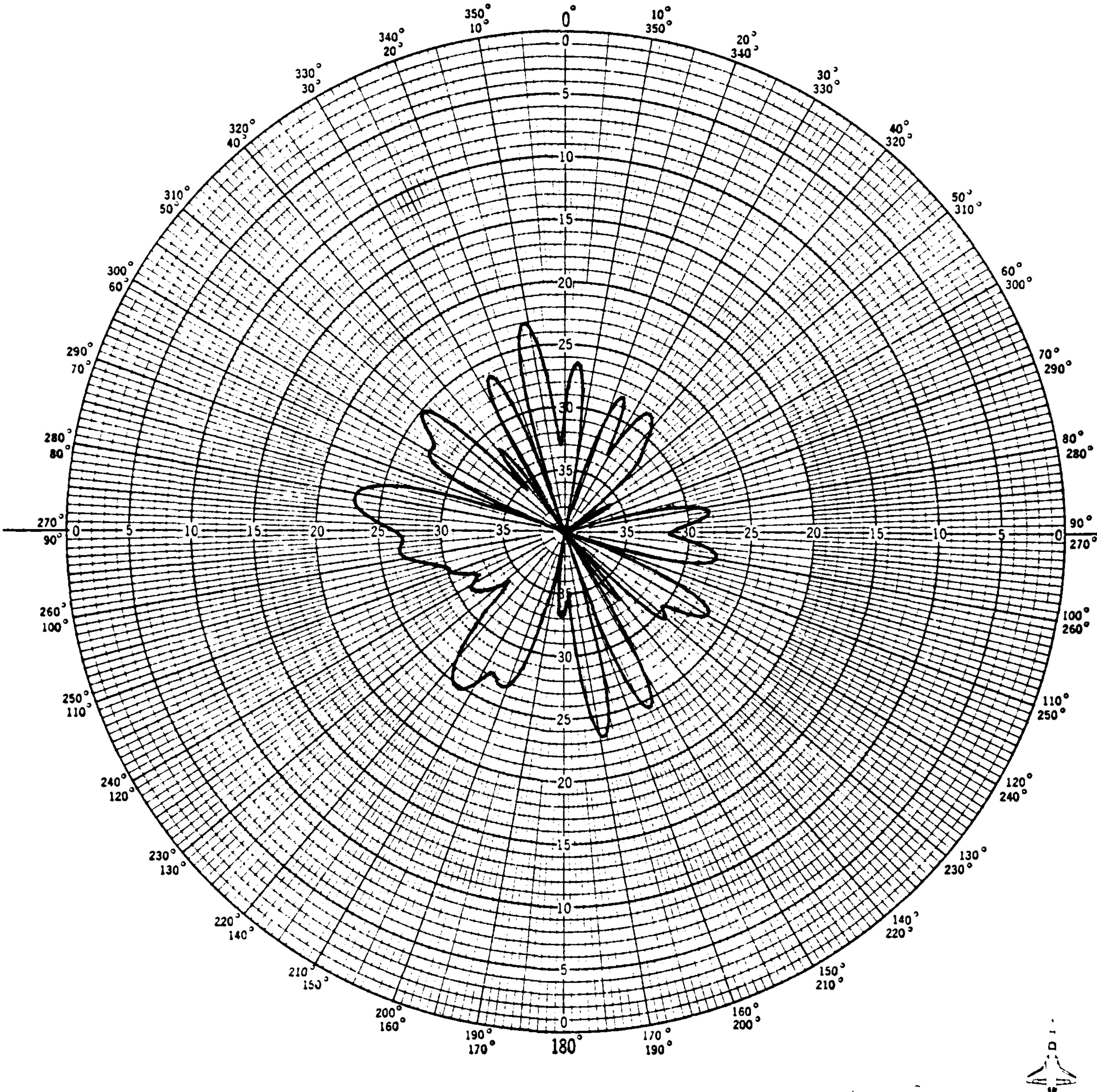


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 180° Φ ( ) POLARIZATION VERT
REMARKS Ø REF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

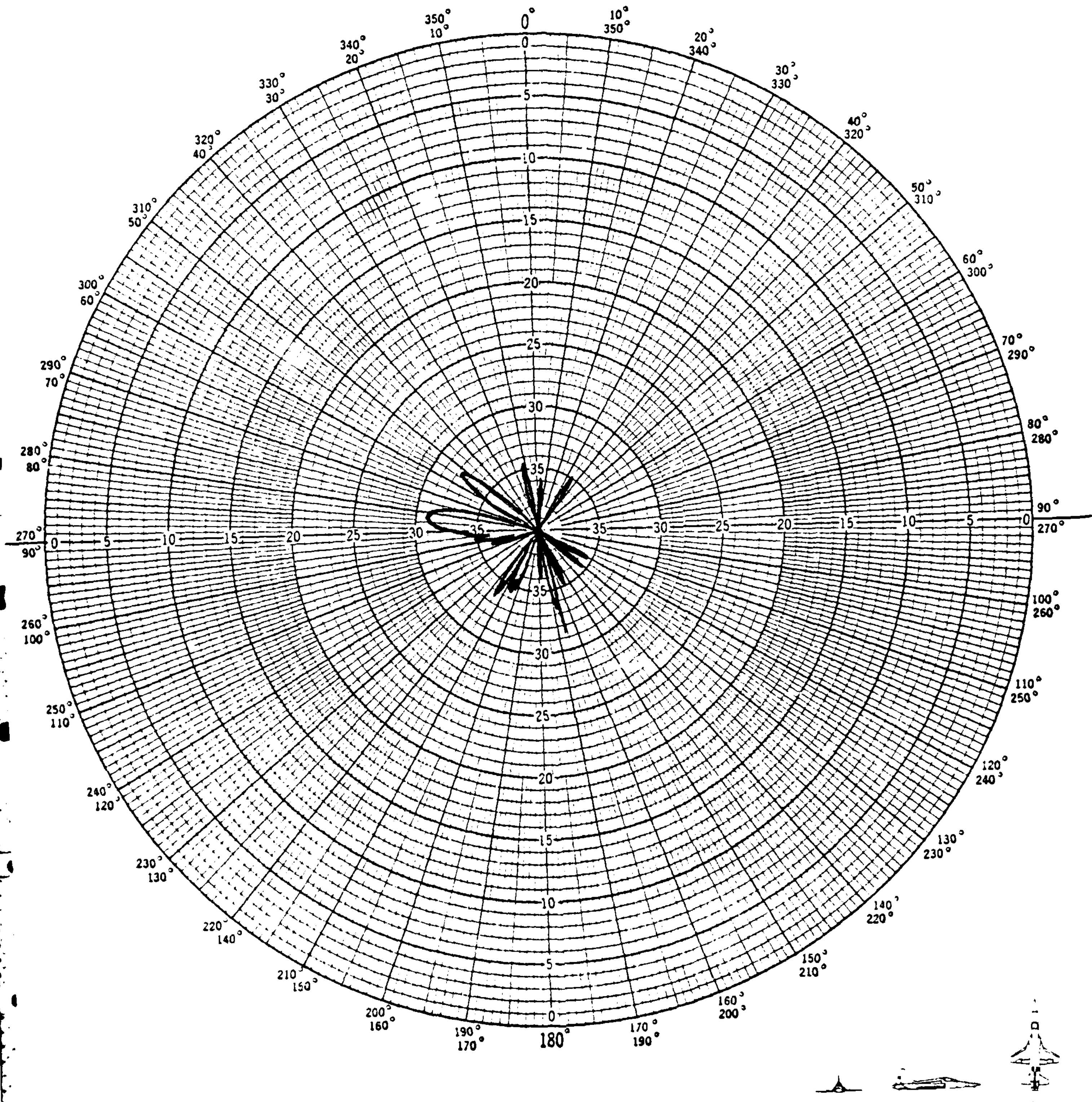


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L SIMPSON DATE 8-4-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80° Φ ( ) POLARIZATION HORIZ
REMARKS ØREF = 3.0V = -299.4°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



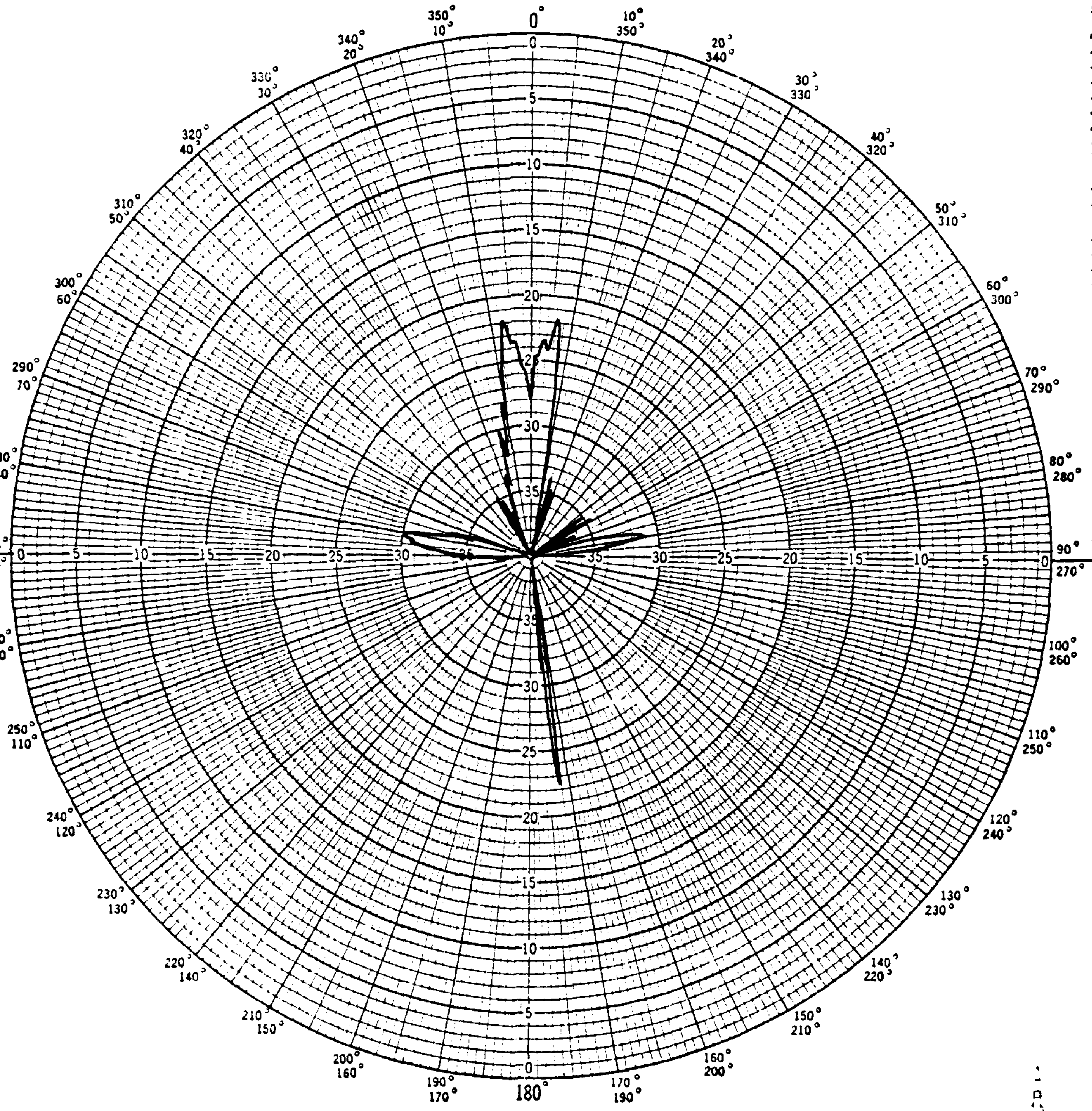
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-4-78

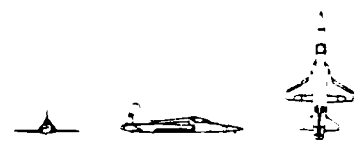
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION HORIZ
REMARKS ØREF = 3.0 V = -299.4°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 8-4-73

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )

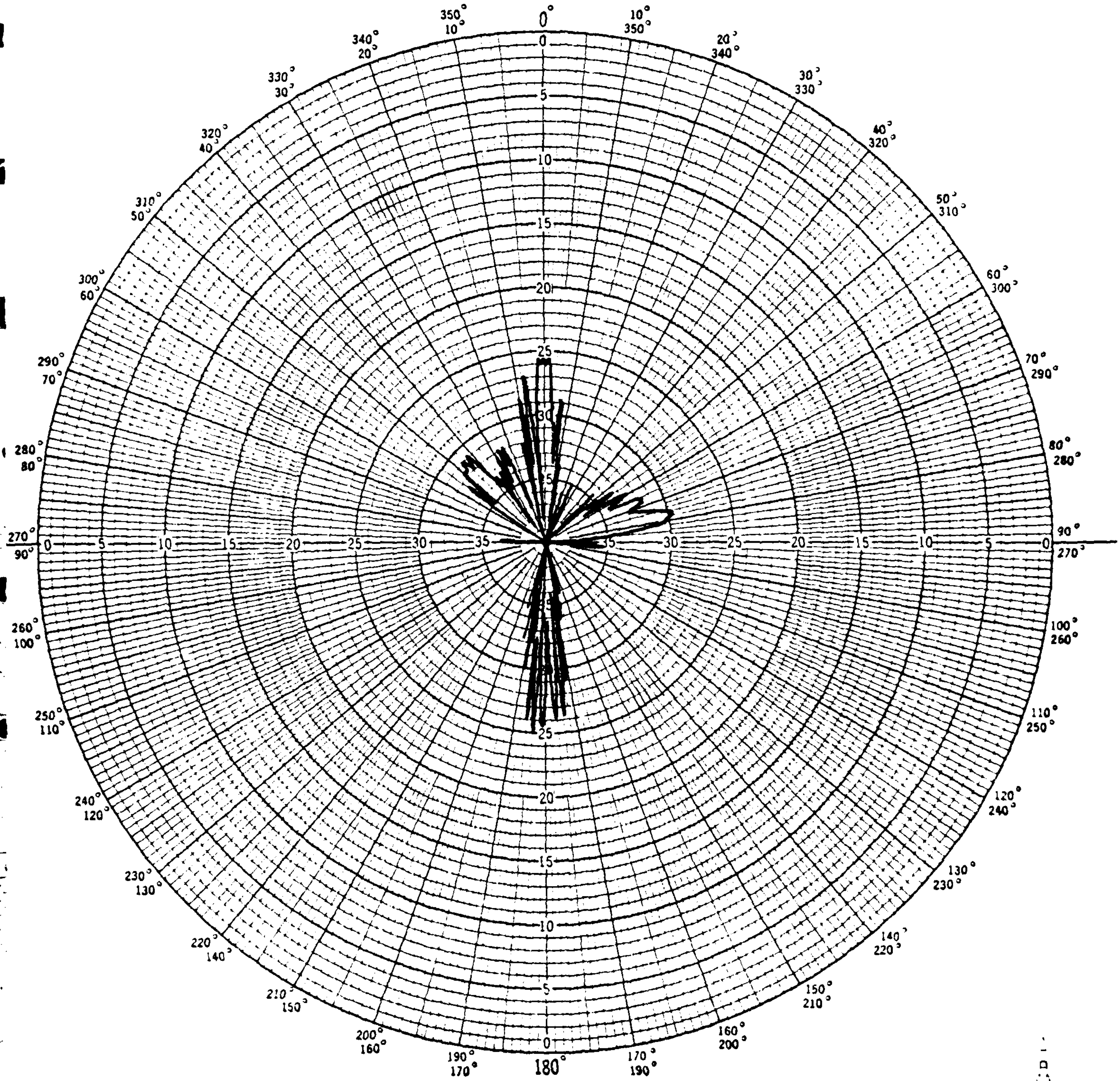
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ

REMARKS ØREF =3.0V

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 5' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 7 GHZ
ANTENNA LOCATION ____________ STATION ______
OPERATOR L. SIMPSON DATE 8-4-78

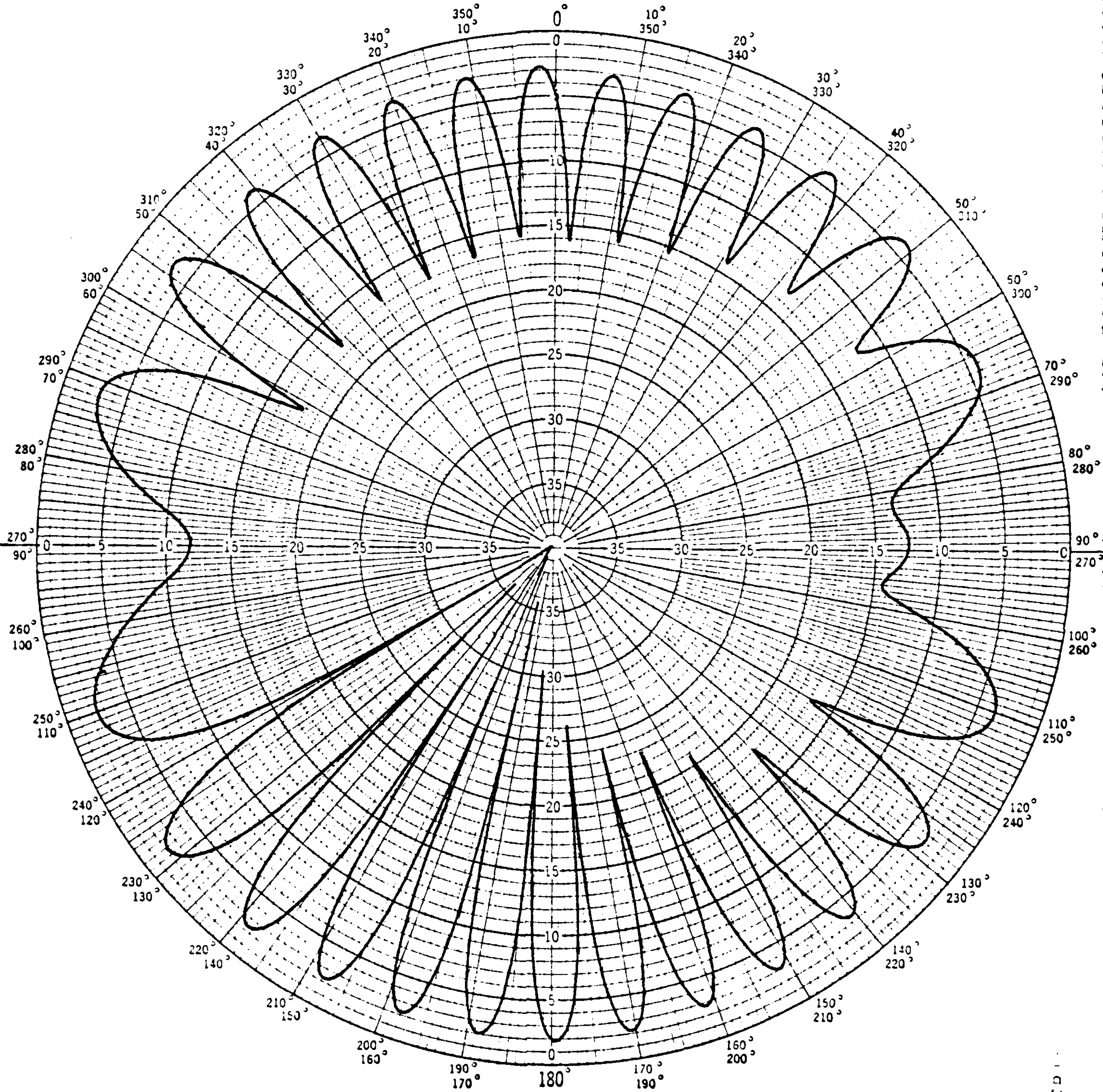
RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ
REMARKS ØREF = 3.0

Form 47-69 (R 9-72)

APPENDIX E

Dual Conical Monopole Antenna Patterns--9 GHz

NORTHROP
Northrop Corporation
Aircraft Division



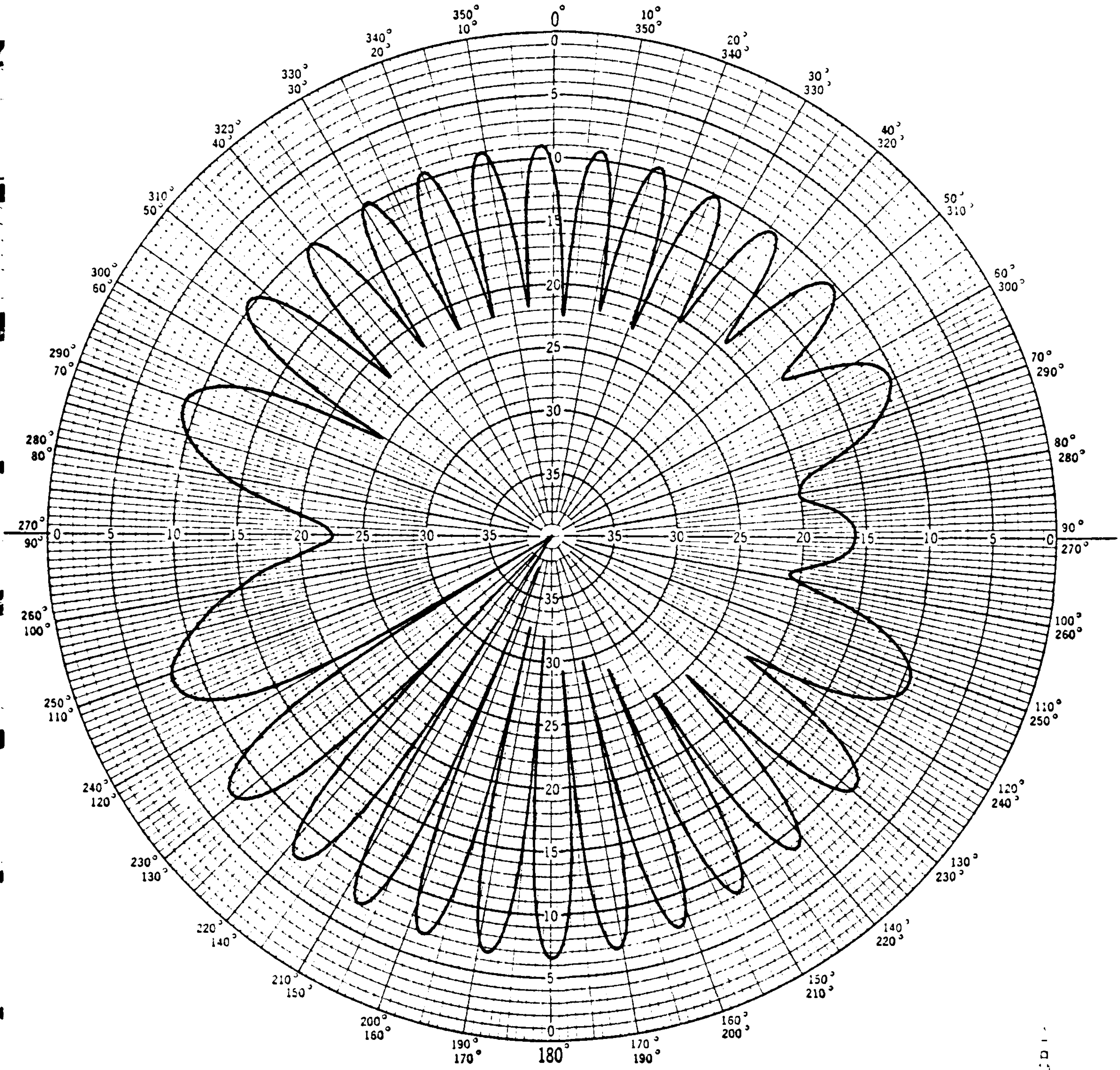
MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 80° φ ( ) POLARIZATION VERT
REMARKS ØREF = 0V = 0°

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM. GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L. SIMPSON DATE 7-25-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

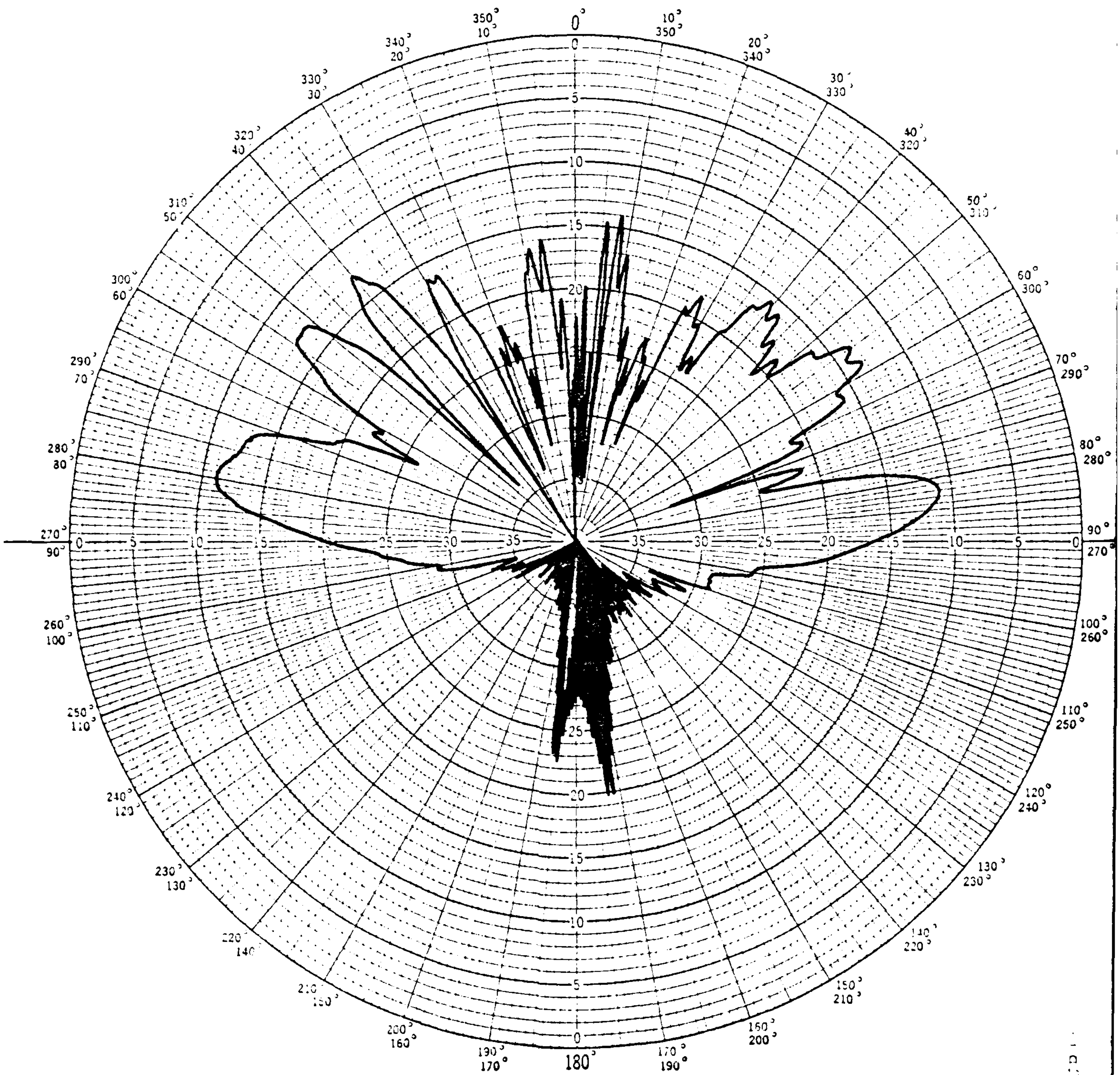
PATTERN θ (90°) Φ ( ) POLARIZATION VERT

REMARKS ØREF = 0 V = 0°.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

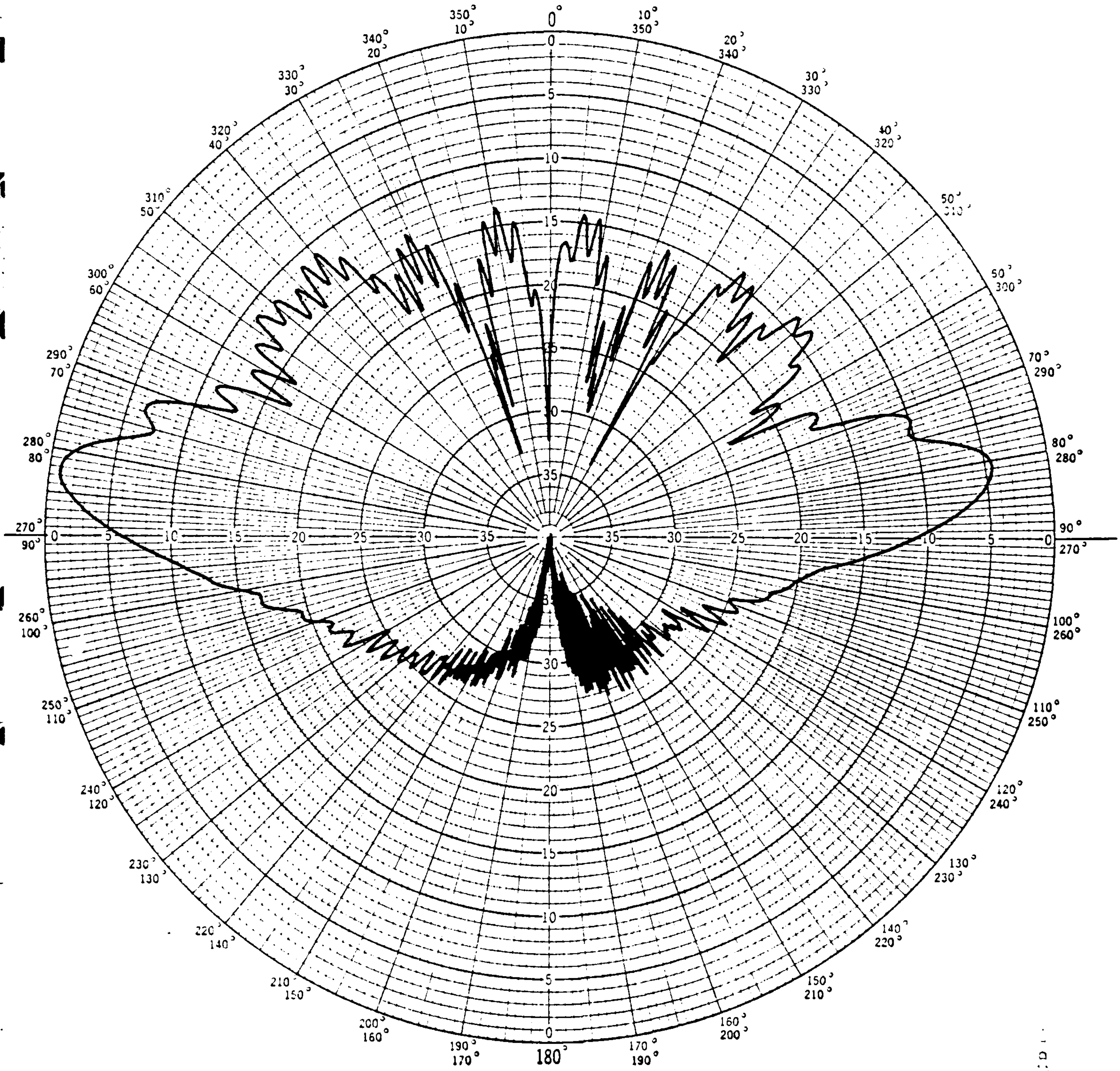


MODEL TYPE 6' GROUND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CON-CAL MODEL FREQUENCY 9GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) ϕ ( ) POLARIZATION VERT
REMARKS ØREC = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

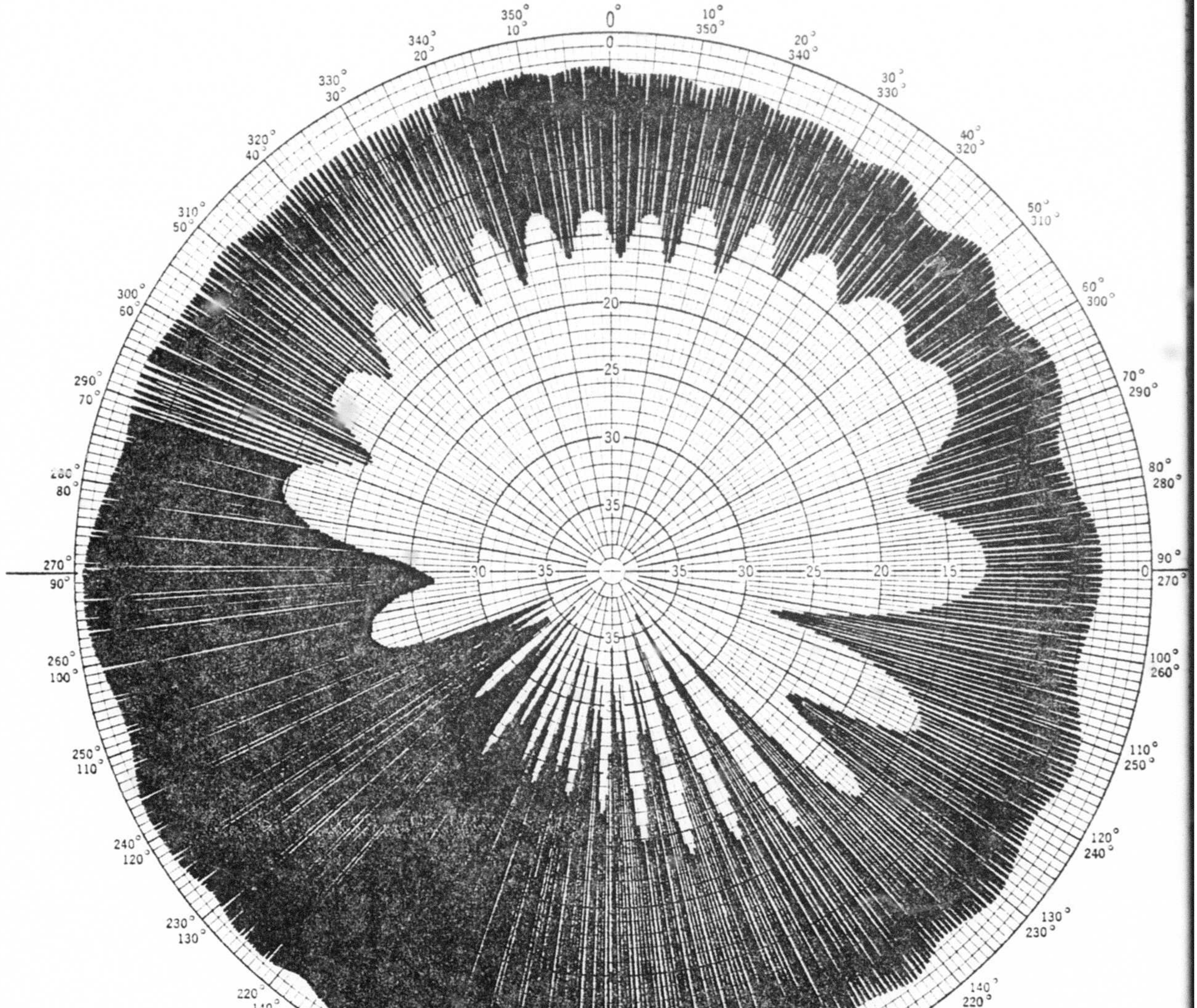


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-29-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = 0 V = 0.0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

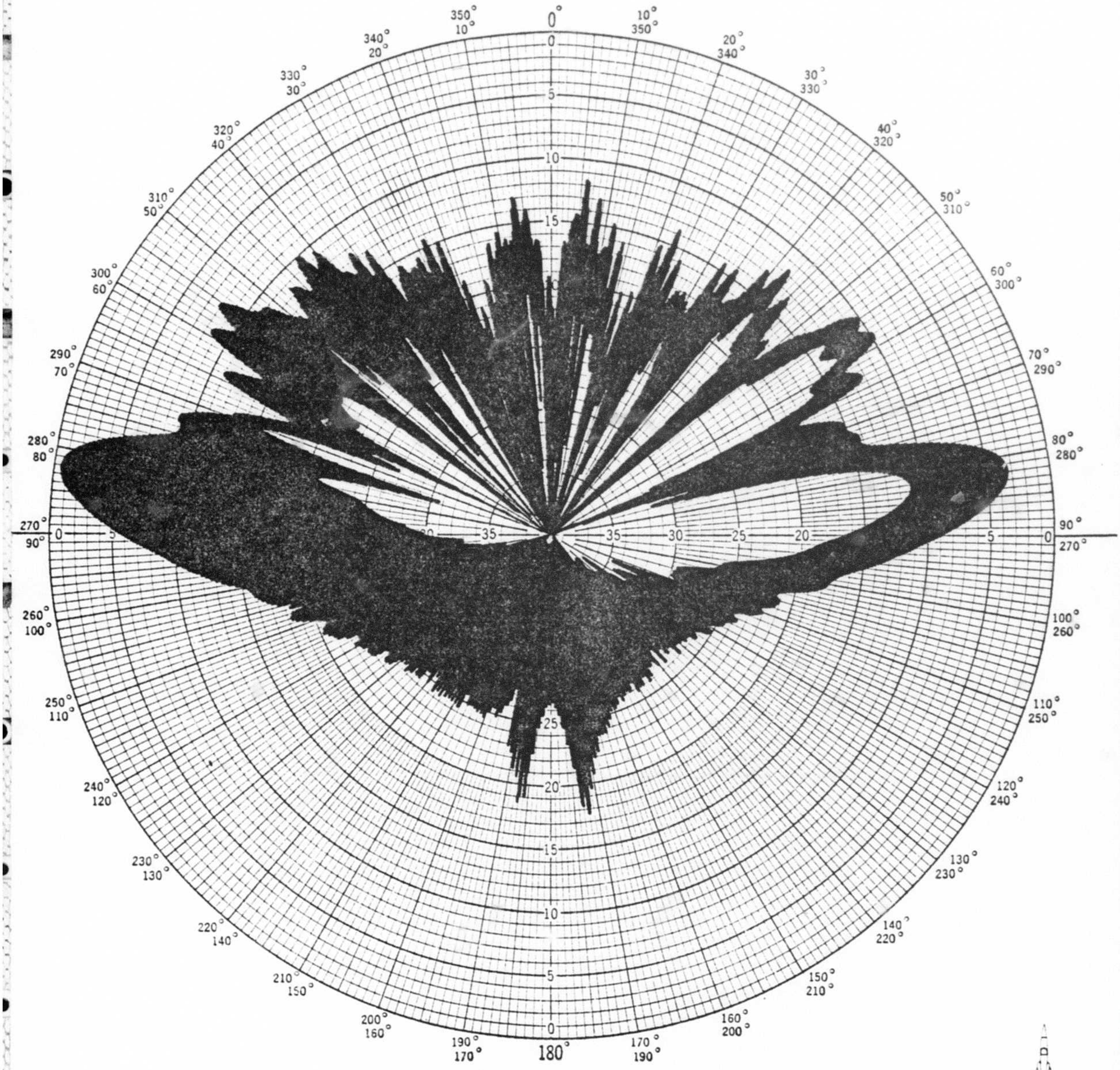


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9GHz
ANTENNA LOCATION ____________ STATION ______
OPERATOR L. SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 180° Φ ( ) POLARIZATION VERT
REMARKS ØREF = -1.65 → +1.65 V. FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

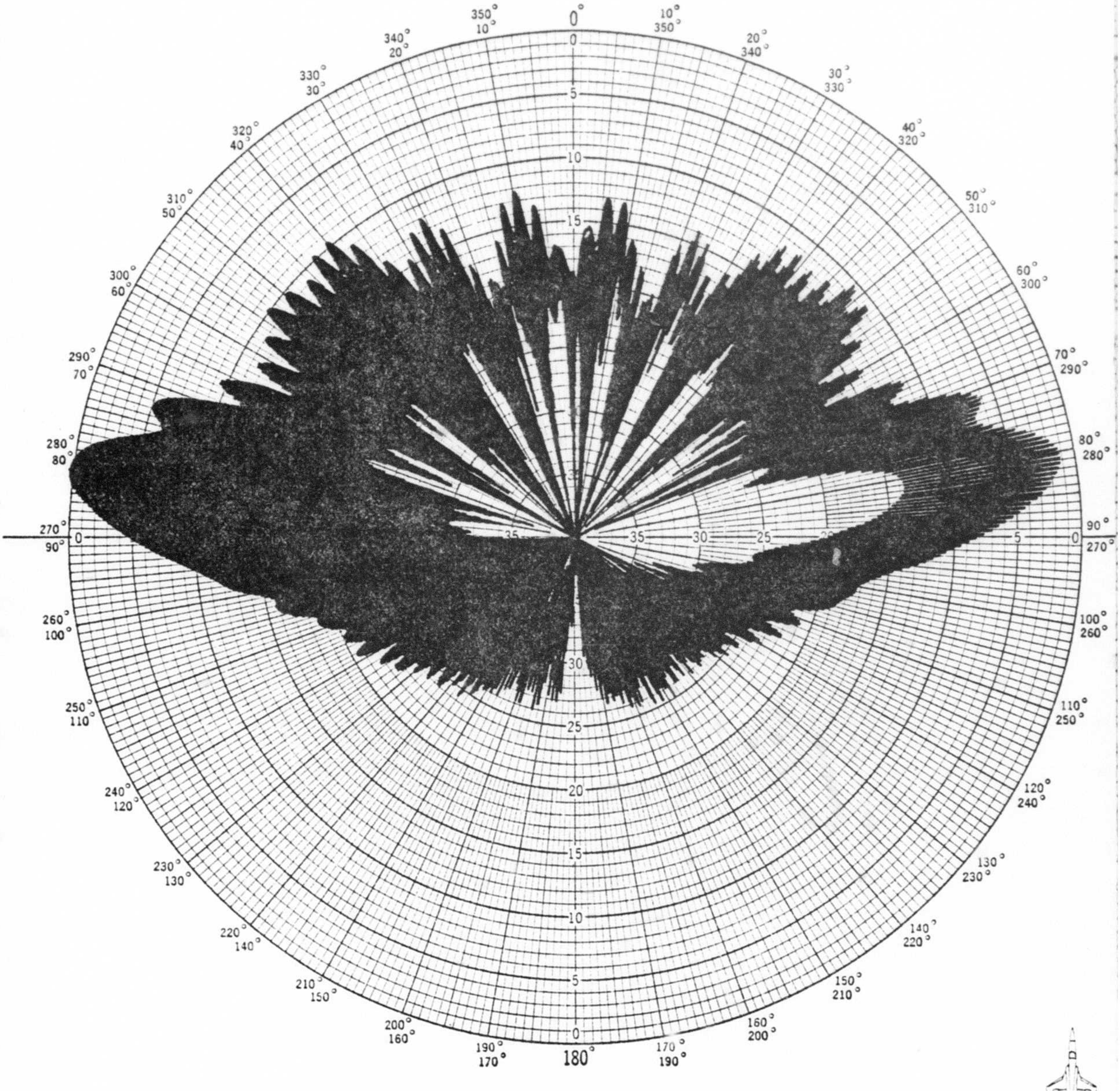


MODEL TYPE 6' GROUND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = −1.65 V → +1.65 V. FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

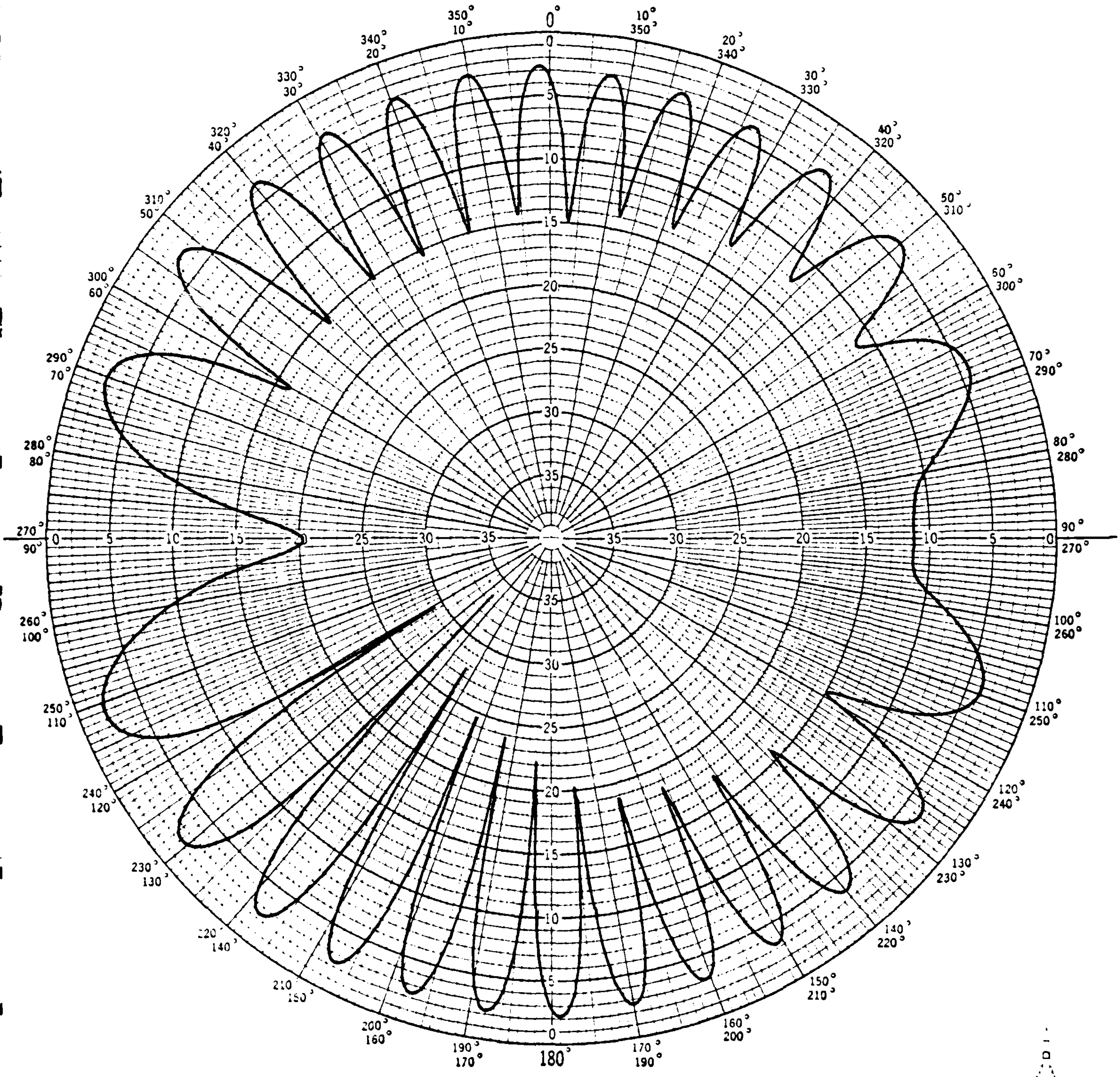


MODEL TYPE 6' GROUND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = -1.65V → +1.65 V. FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



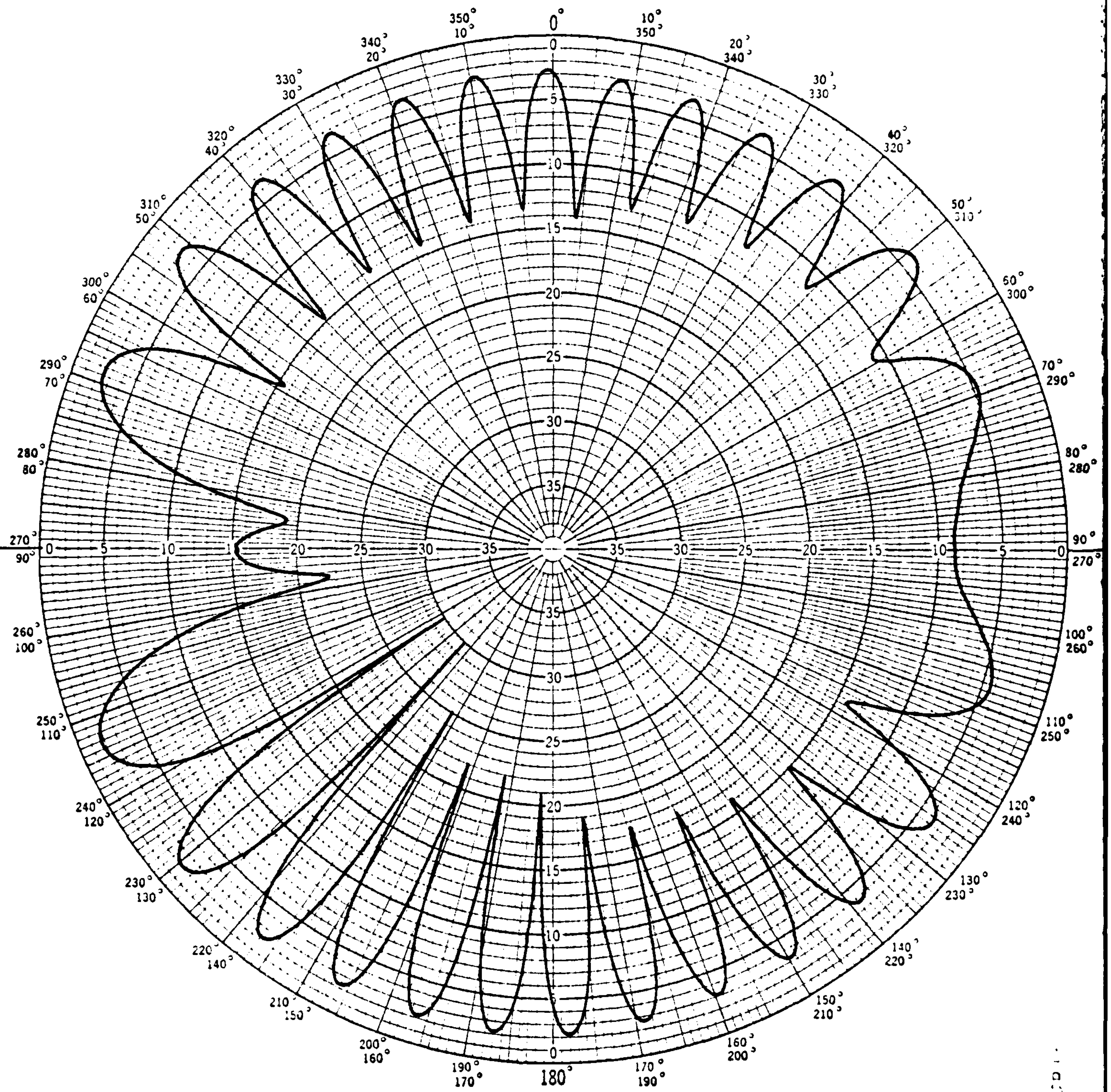
MODEL TYPE 5' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-26-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 180° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0.3V = -24.4°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

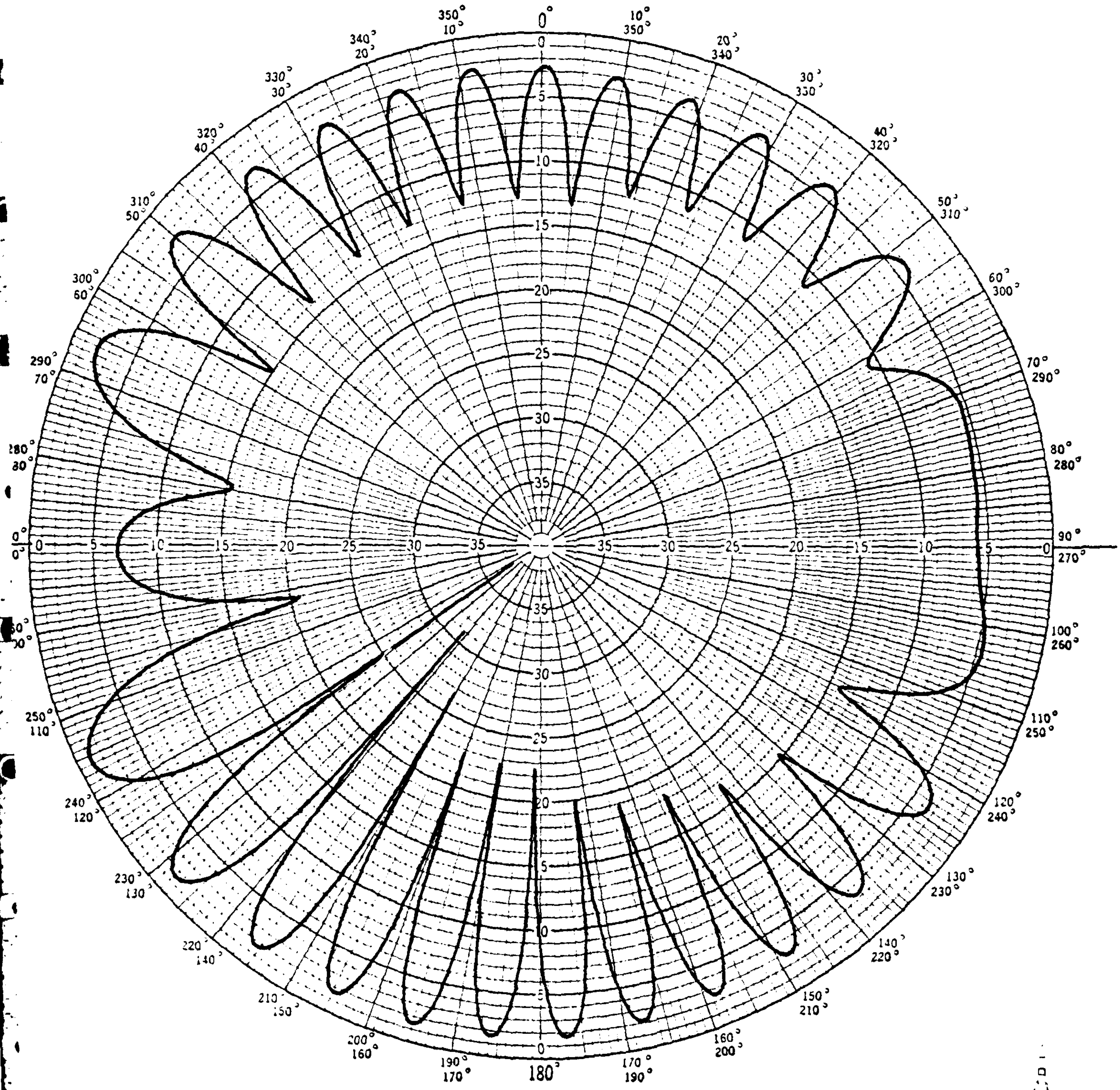
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ 180° Φ ( ) POLARIZATION VERT.

REMARKS ØREF = 0.6V = -53.3°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

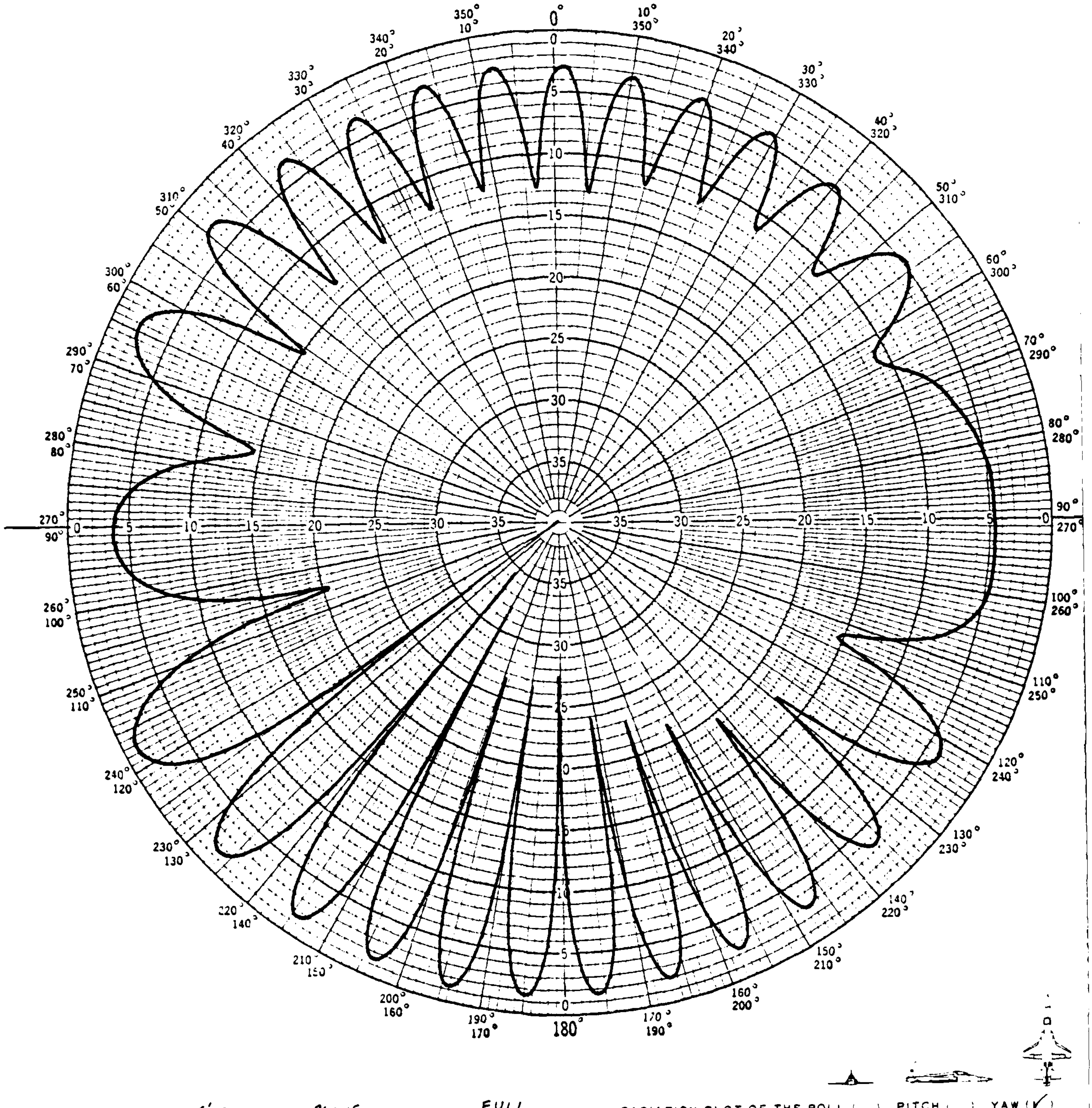


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 180° Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0.9 V = -35.0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 80° ϕ ( ) POLARIZATION VERT.
REMARKS ∅ REF = 1.2V = -116.3°

Form 47-59 (R 9-72)

NORTHROP
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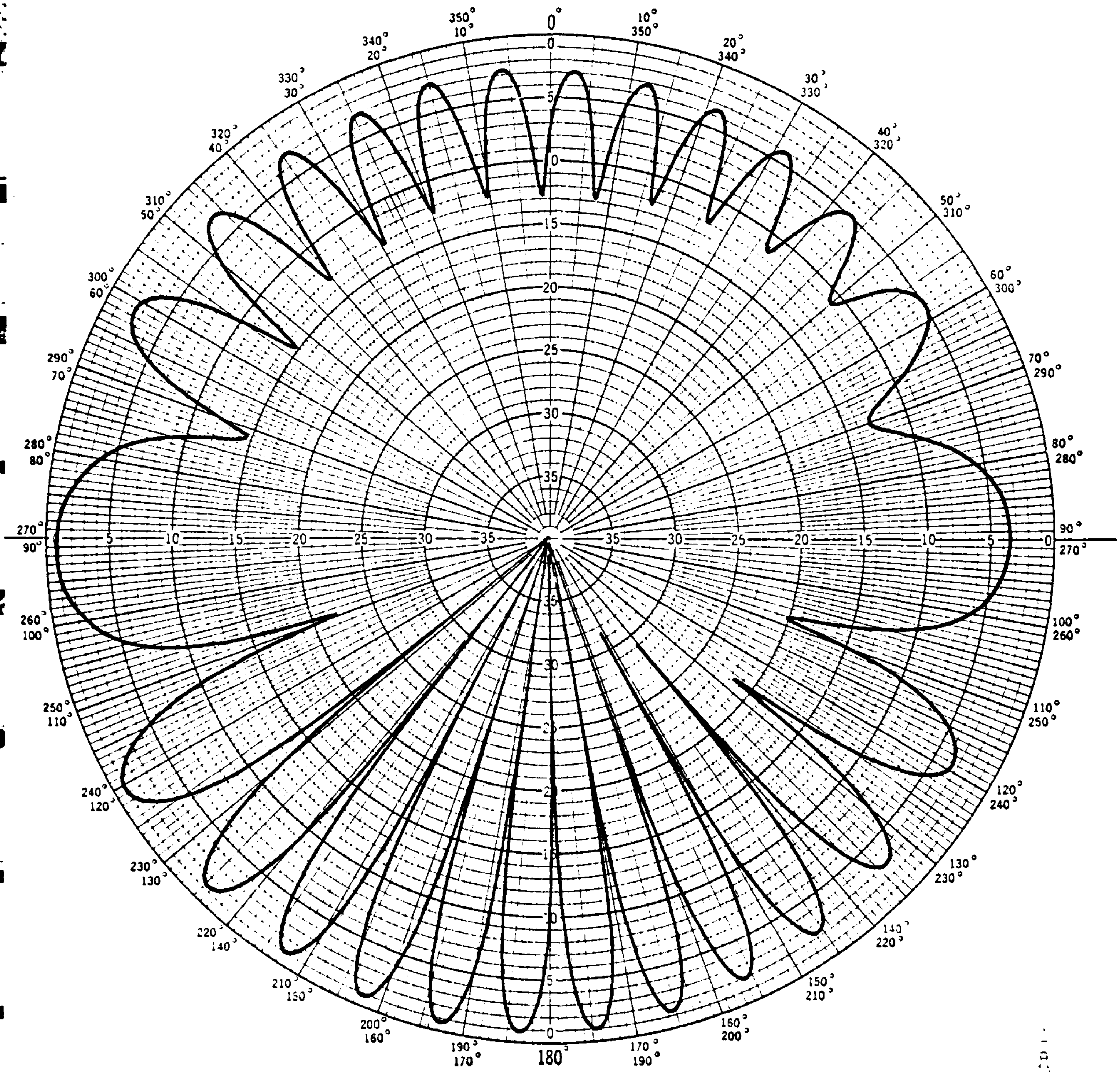
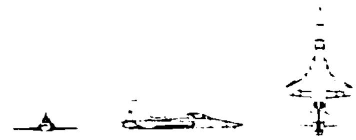
Aircraft Division





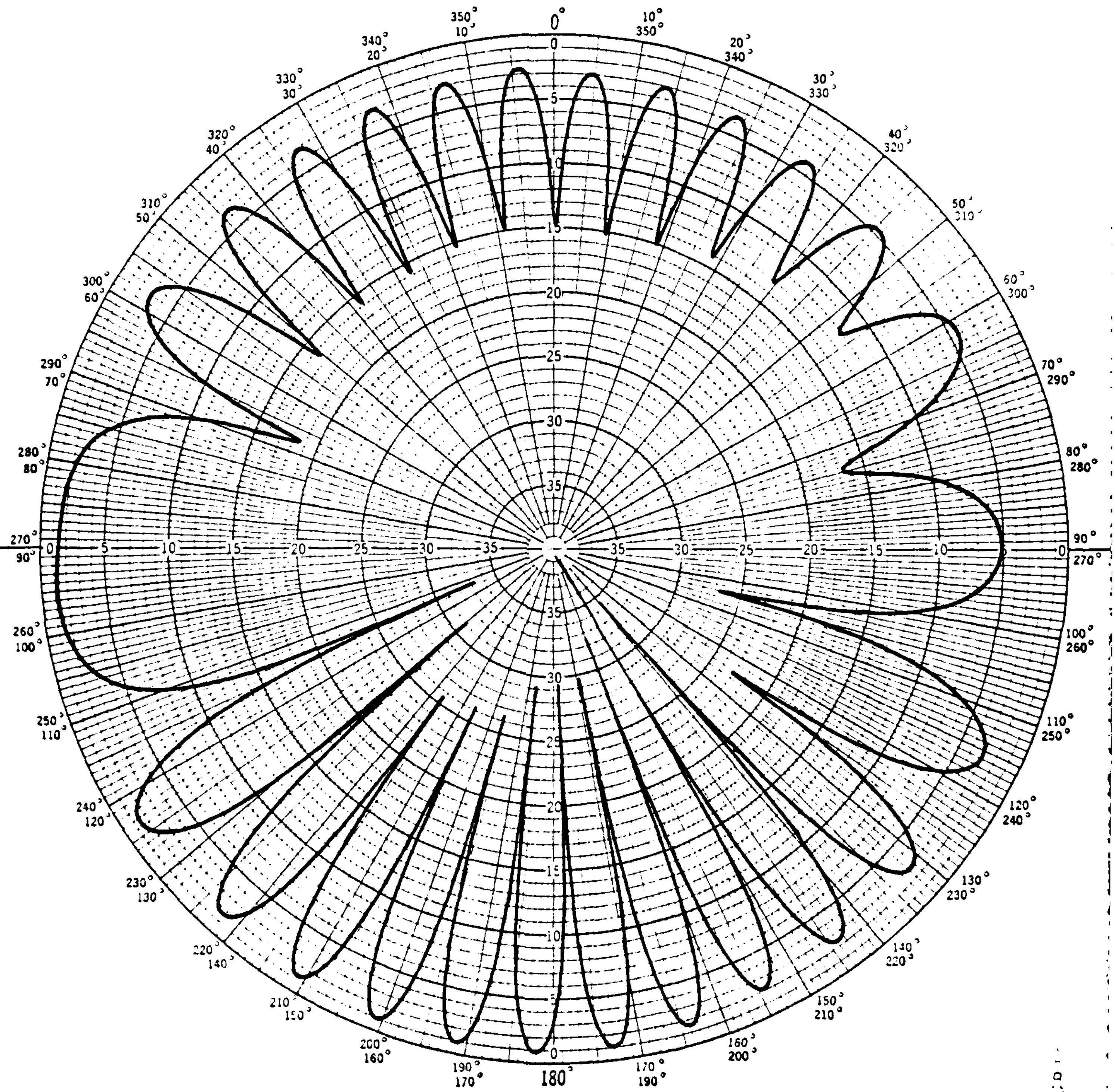
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 7-26-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 1.8V = -176.8°.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L SIMPSON DATE 7-26-78

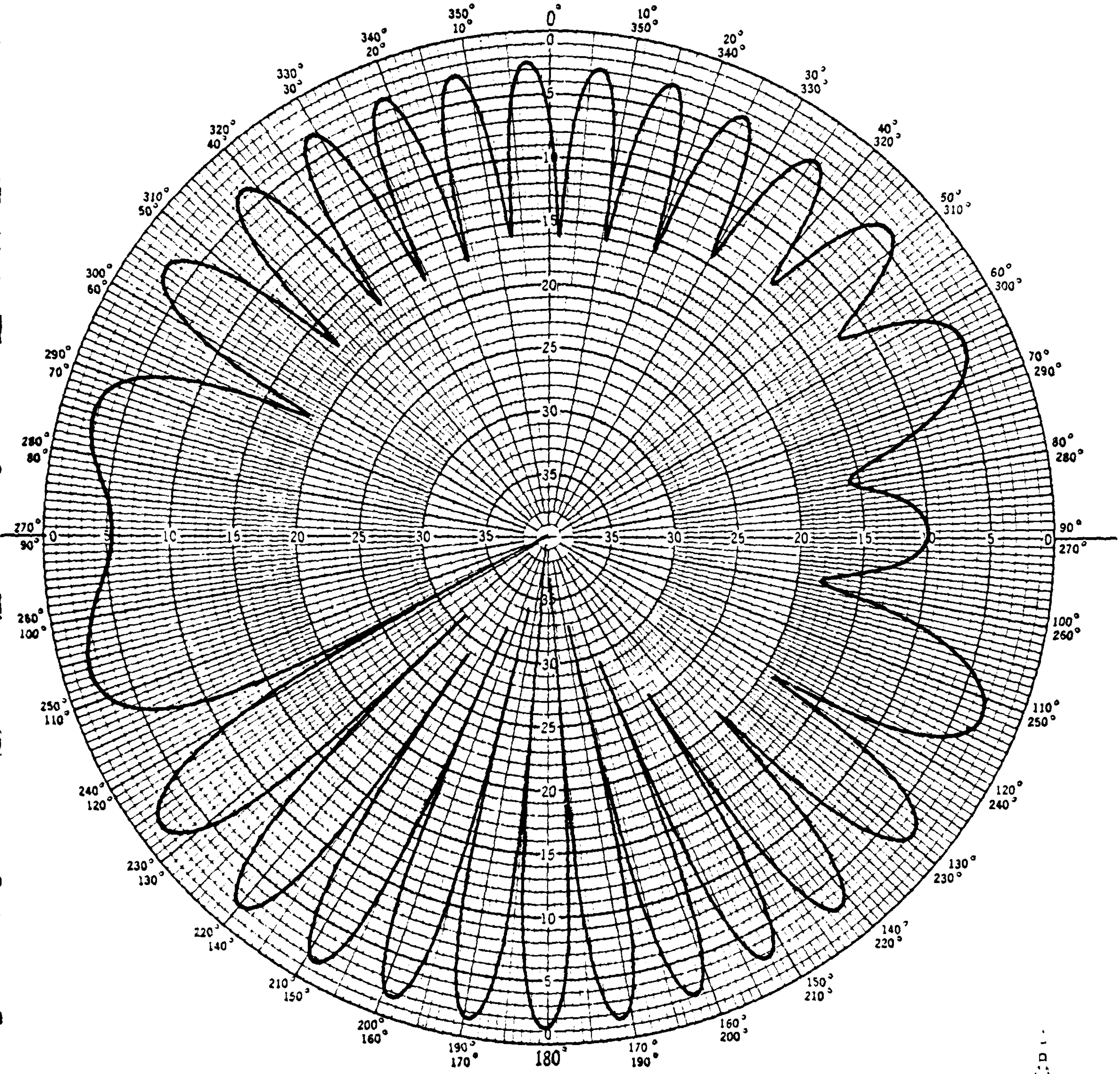
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓

PATTERN θ 80° φ ( ) POLARIZATION VERT.

REMARKS Ø REF = 2.4 V = -237.8°

NORTHROP
Northrop Corporation
Aircraft Division



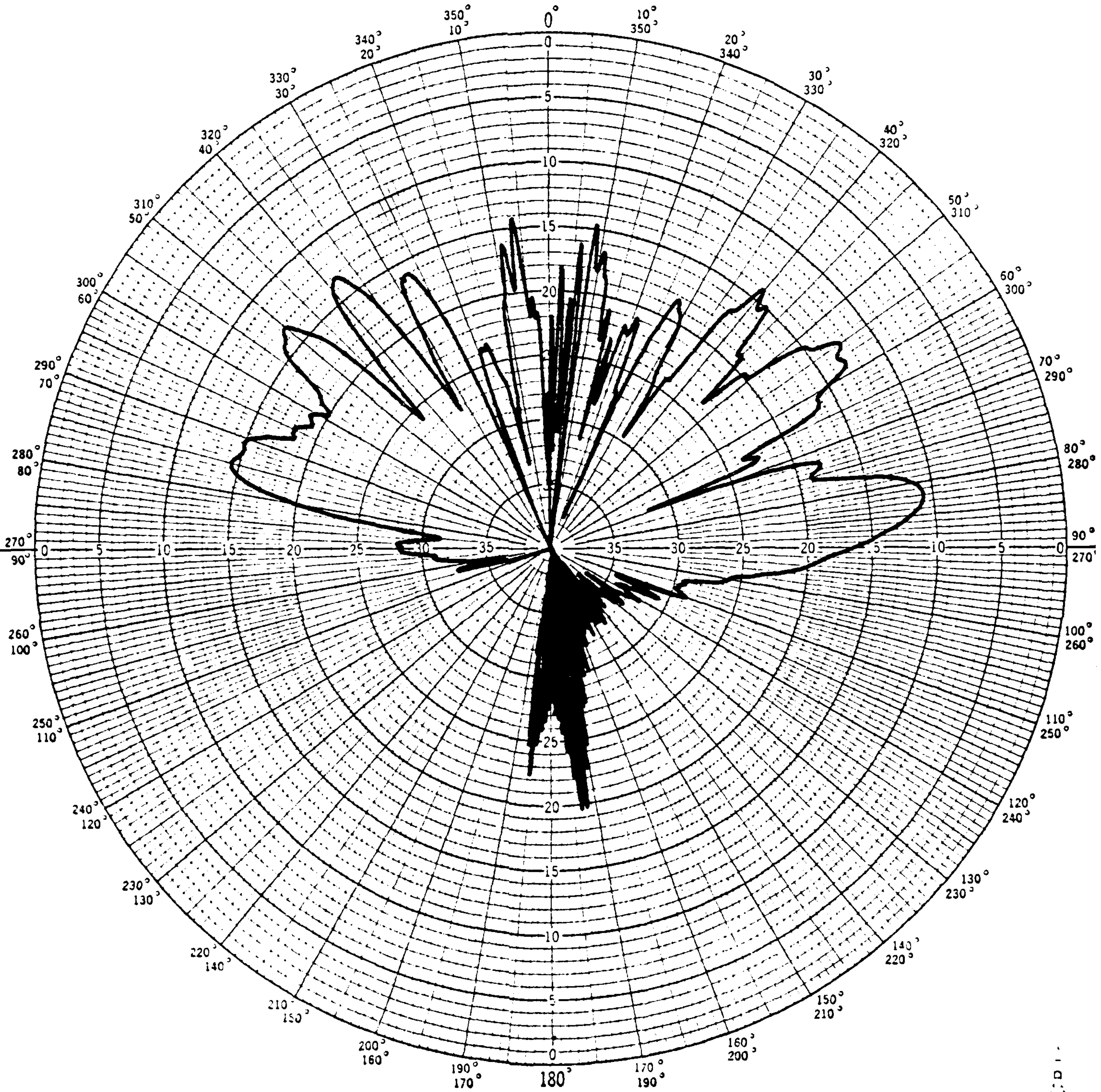
MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *9 GHz*
ANTENNA LOCATION ________ STATION ________
OPERATOR *L. SIMPSON* DATE *7-26-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *180°* Φ ( ) POLARIZATION *VERT.*
REMA[RKS] *ØREF = 3.0 V = -299.4°.*

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

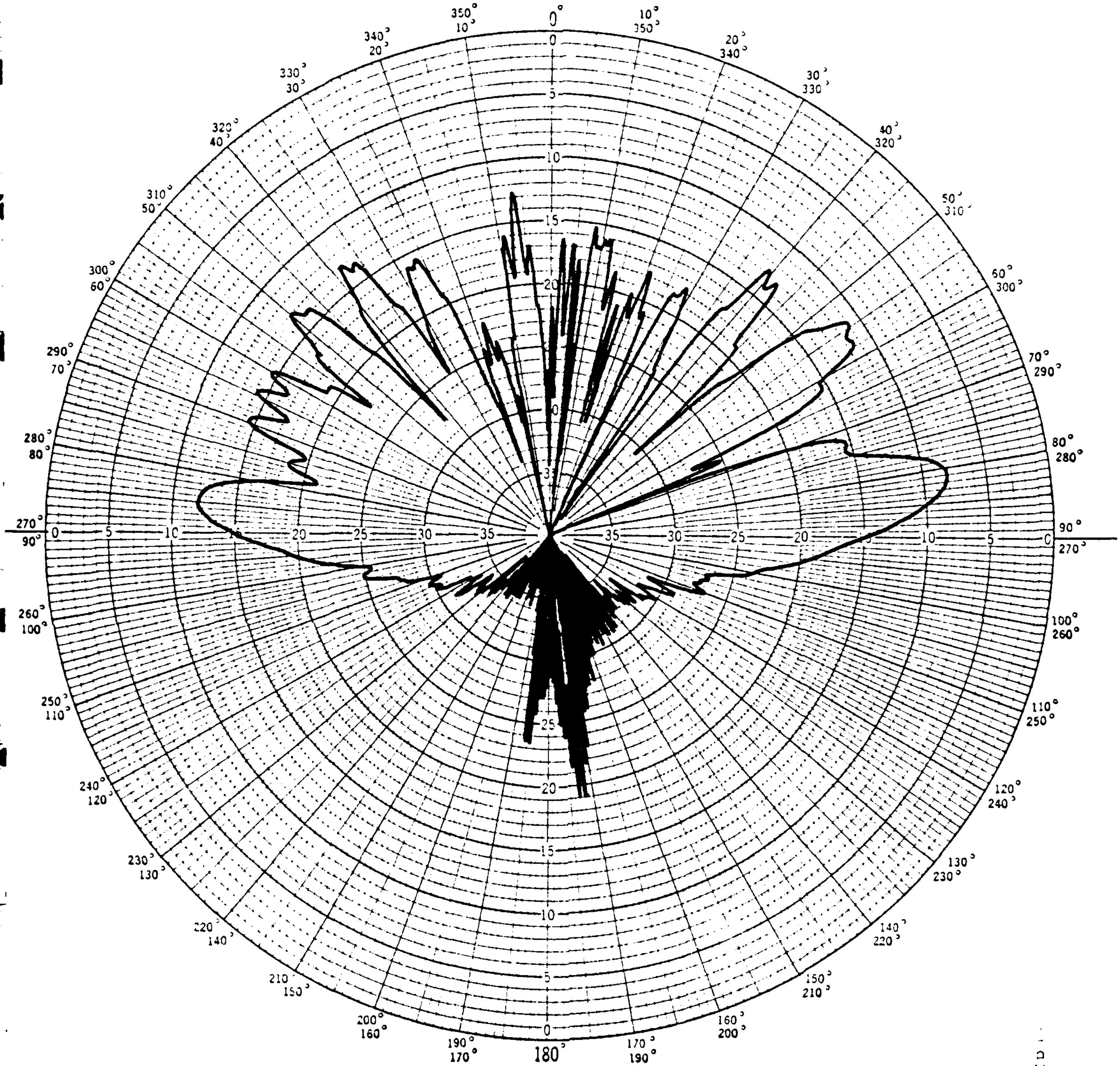


MODEL TYPE 6' GROUND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION ______
REMARKS Ø REF = 0.3V = -24.4°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

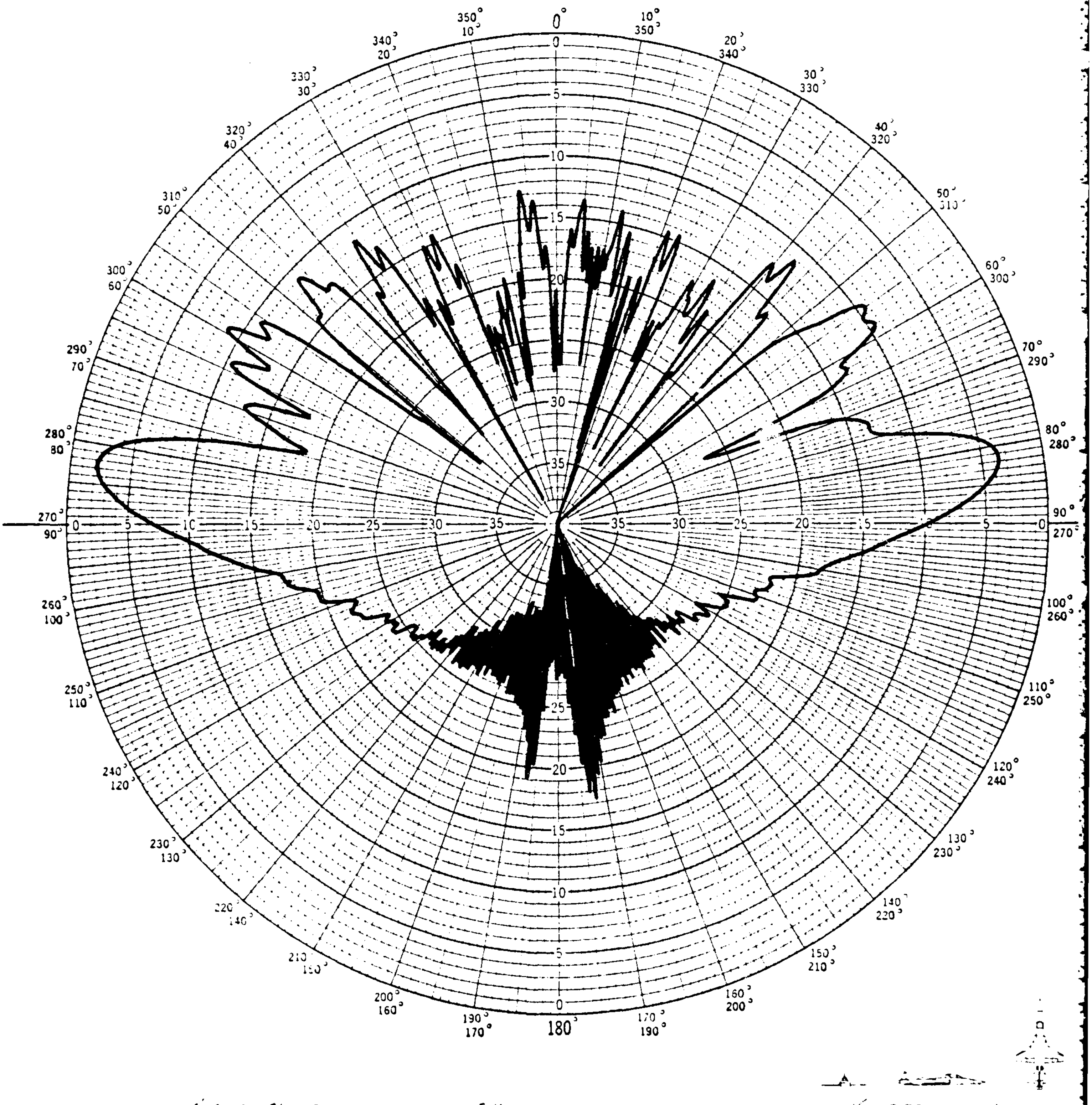


MODEL TYPE 6' GROUND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION ______
REMARKS ØREF = 0.6 V =

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



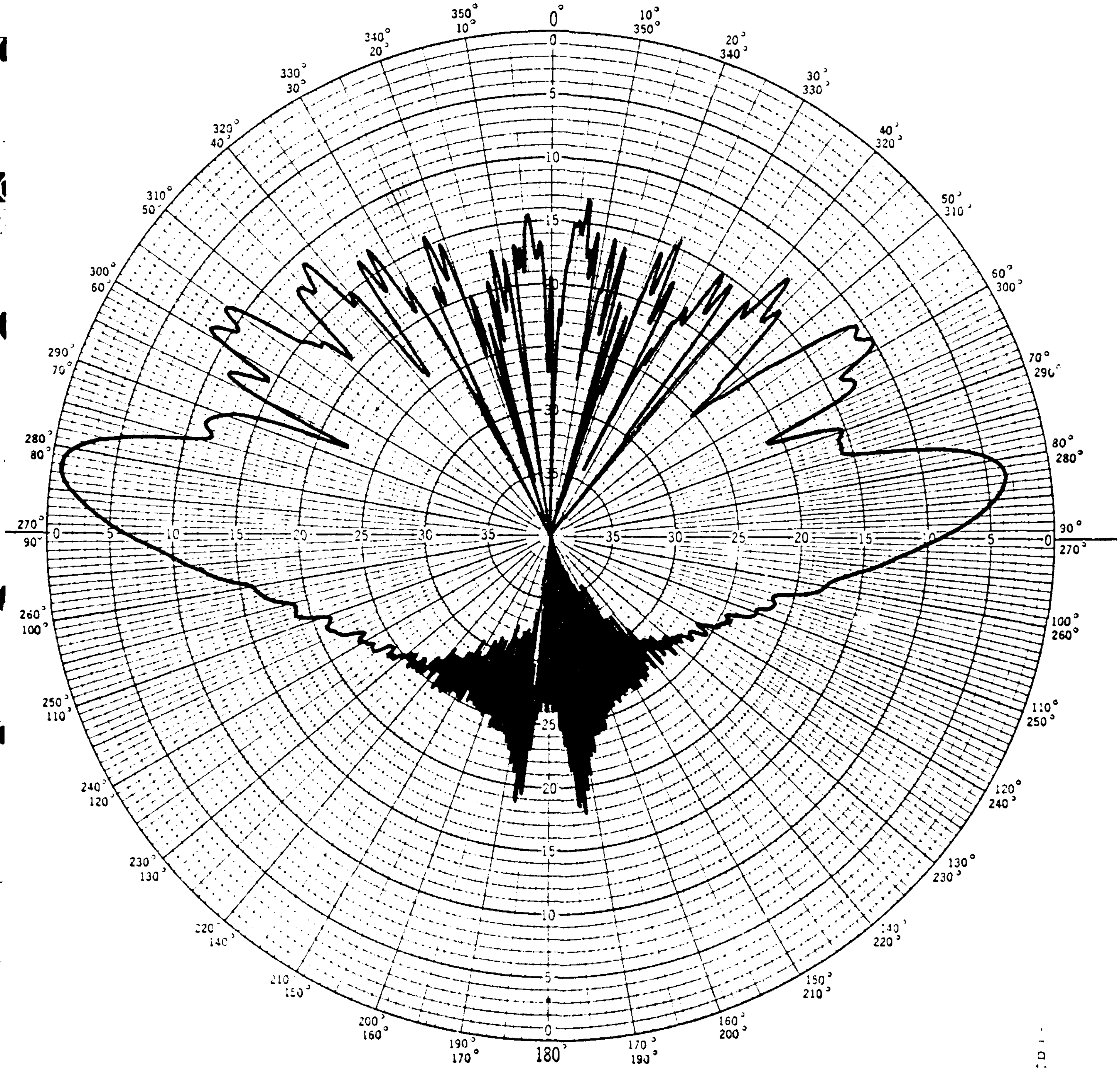
MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-31-78

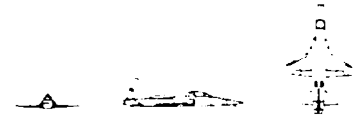
RADIATION PLOT OF THE ROLL ✓ PITCH YAW
CURVE PLOTTED IN: VOLTAGE POWER DBS ✓
PATTERN θ ϕ POLARIZATION VERT
REMARKS Ø REF = 1.2 V = -116.3°

Form 47-63 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE 6' GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L. SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )

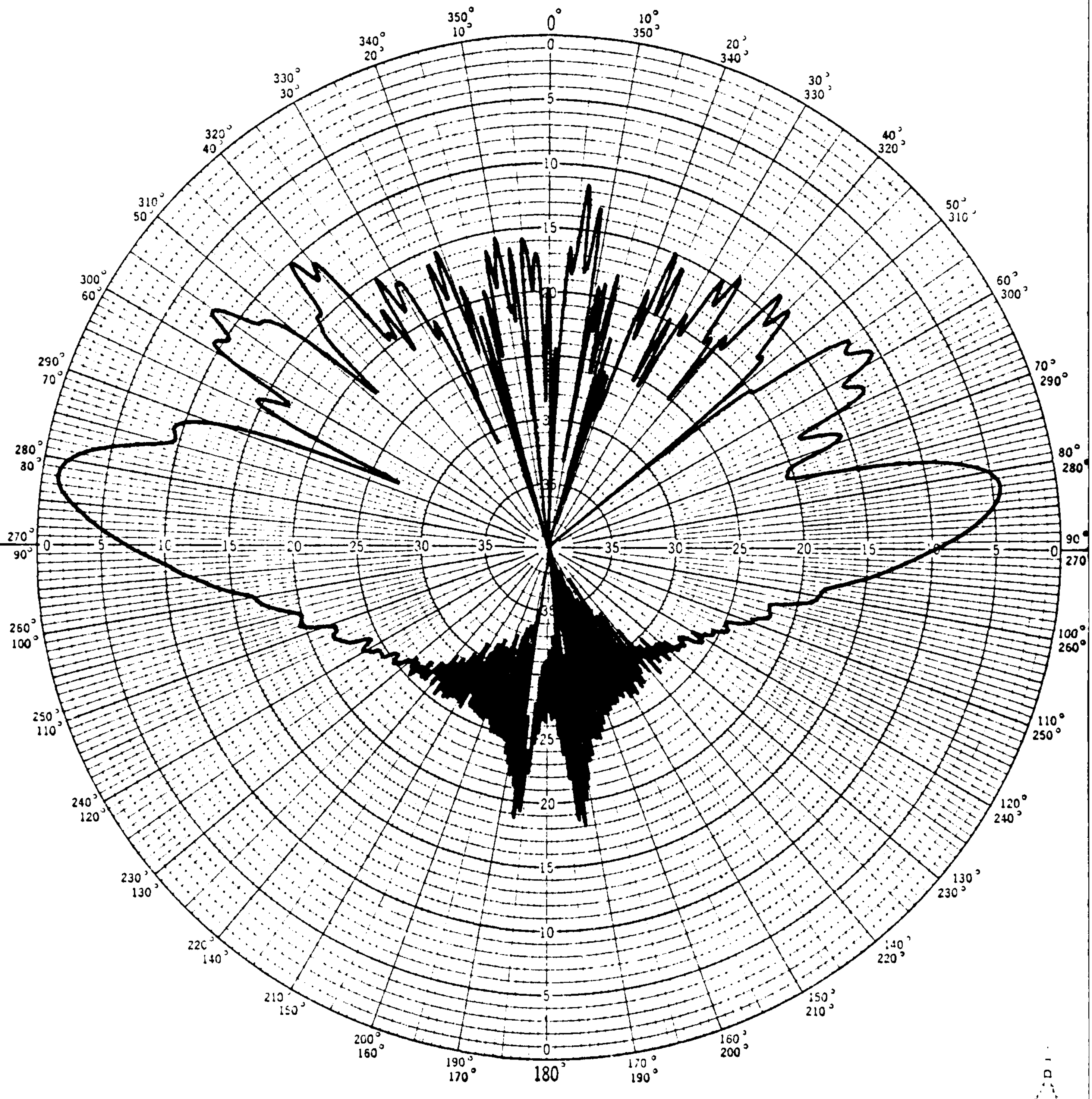
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION VERT

REMARKS Ø REF = 1.8 V = -176.8°.

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division

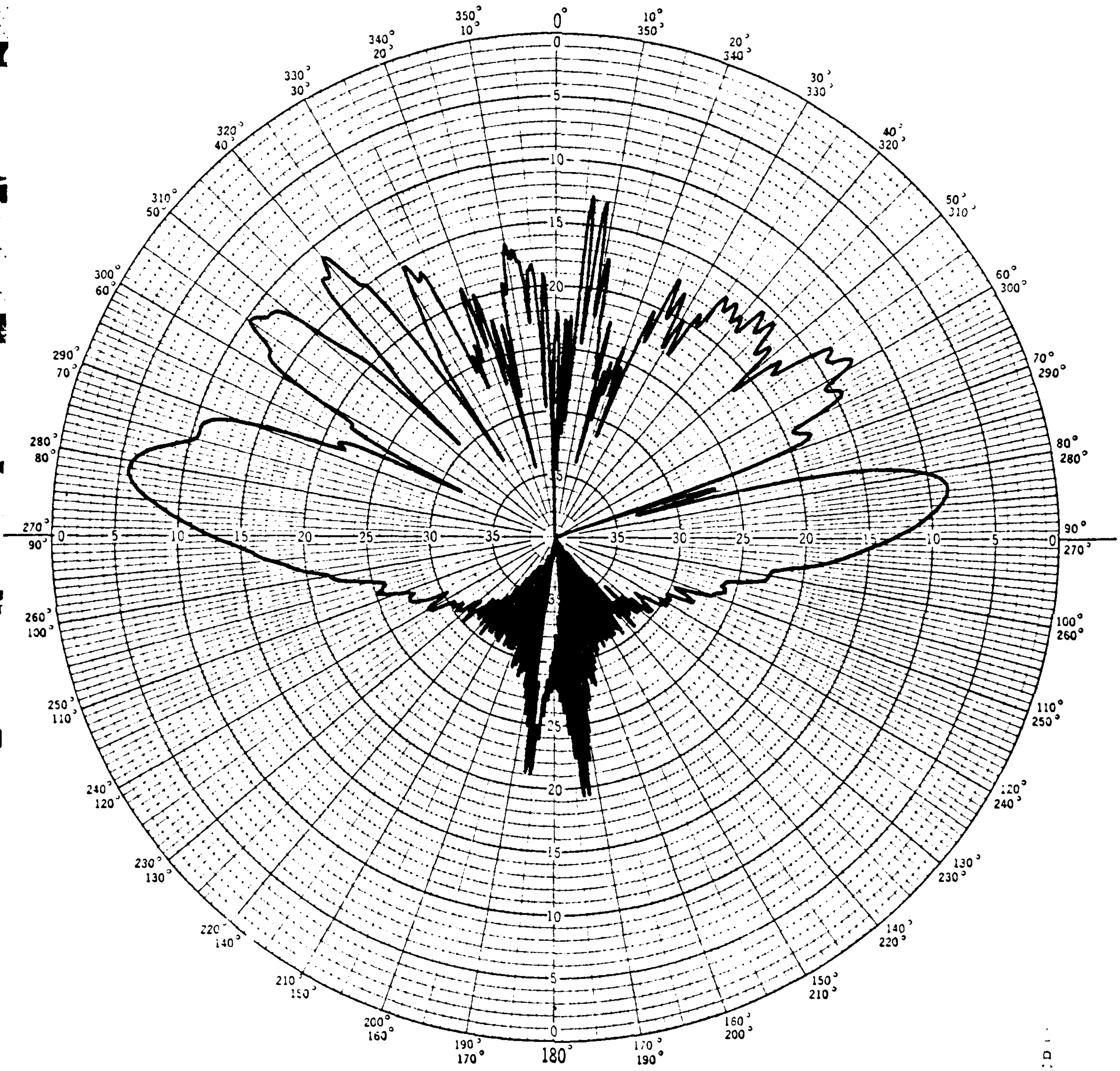


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L SIMPSON DATE 7-31-79

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 2.4 V = -237.8°

Form 47-63 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

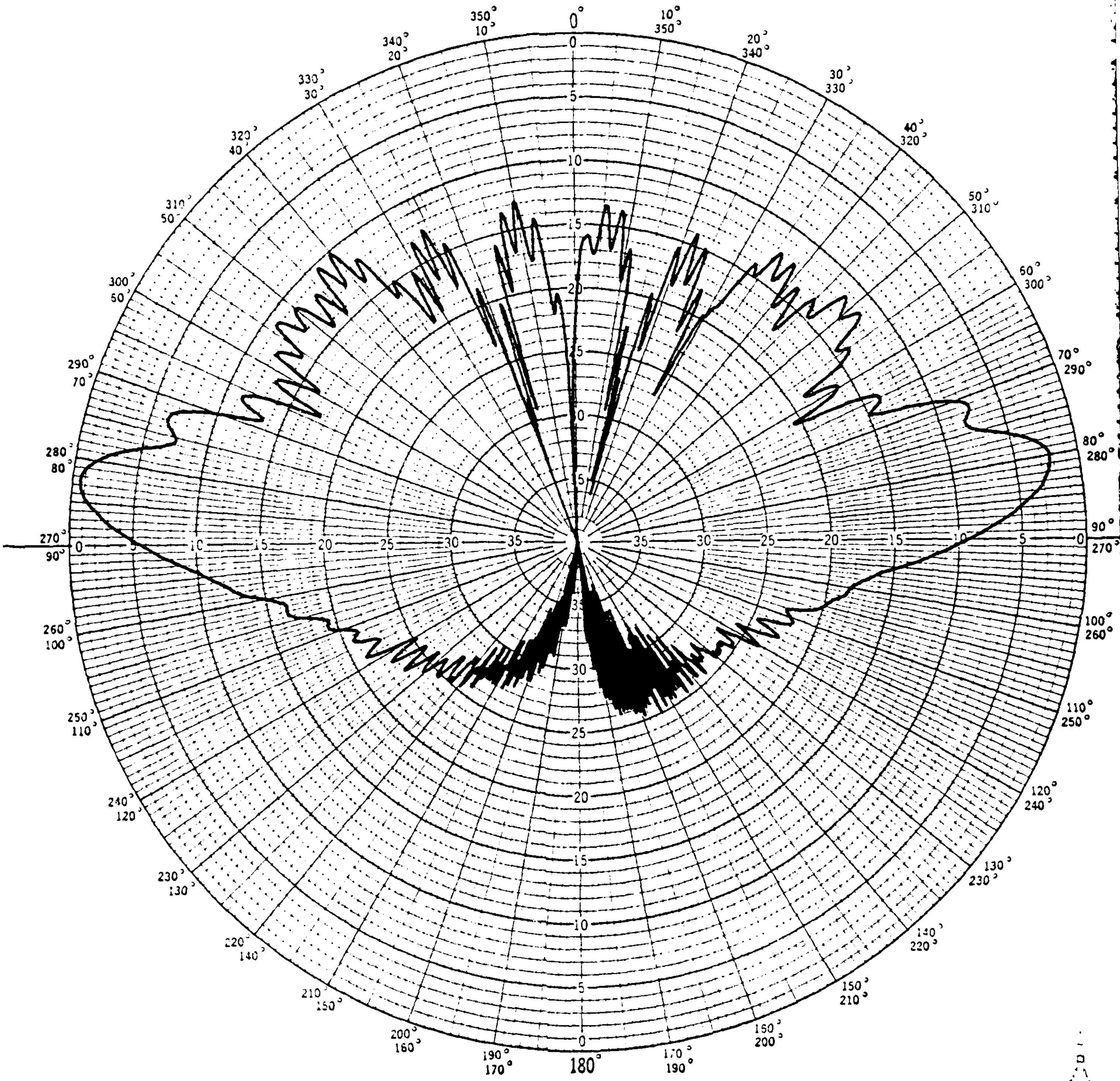


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-31-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 3.0V = -299.4°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

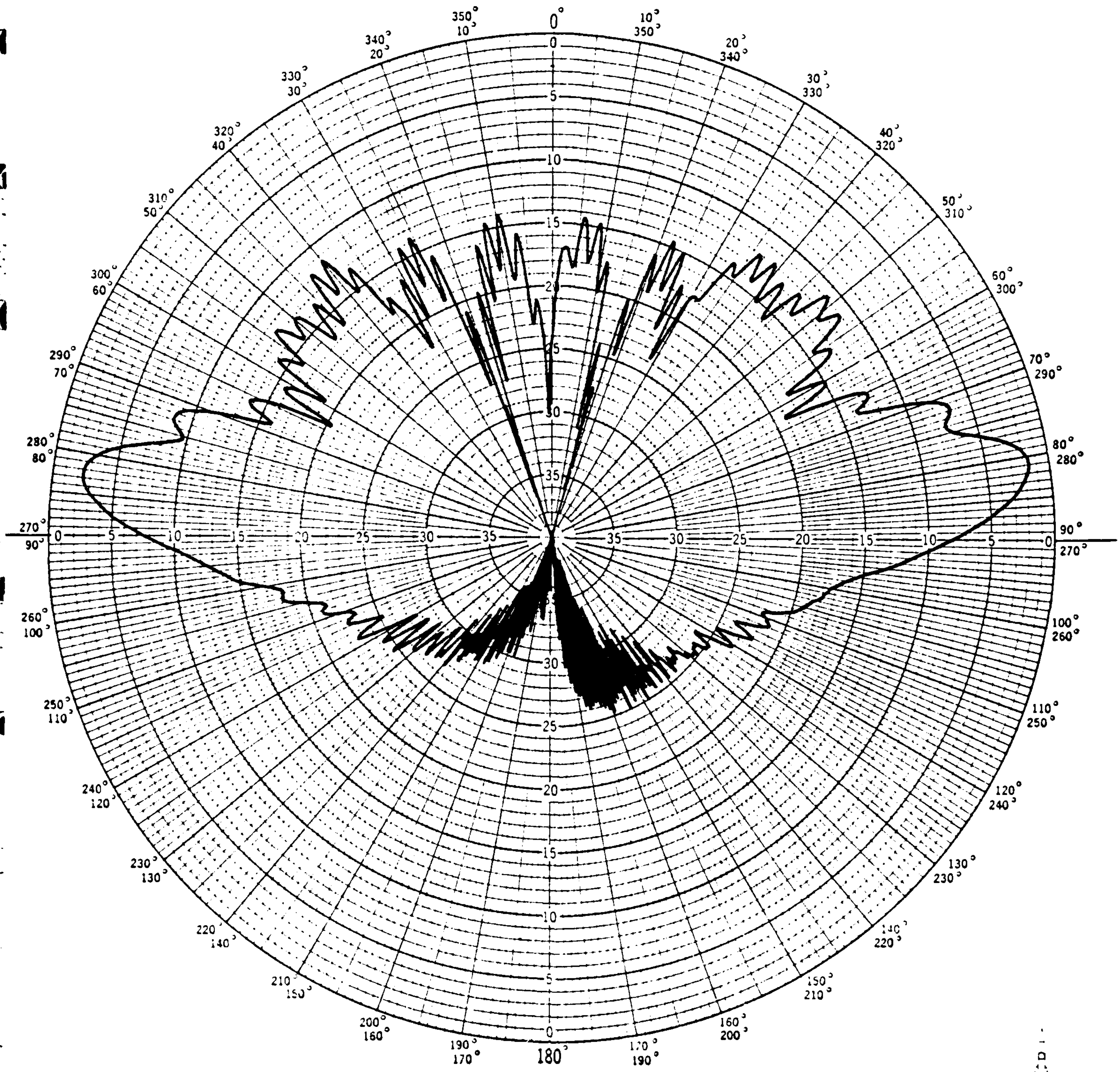


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION ______
REMARKS ØREF = 0.3V = -24.4°

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division



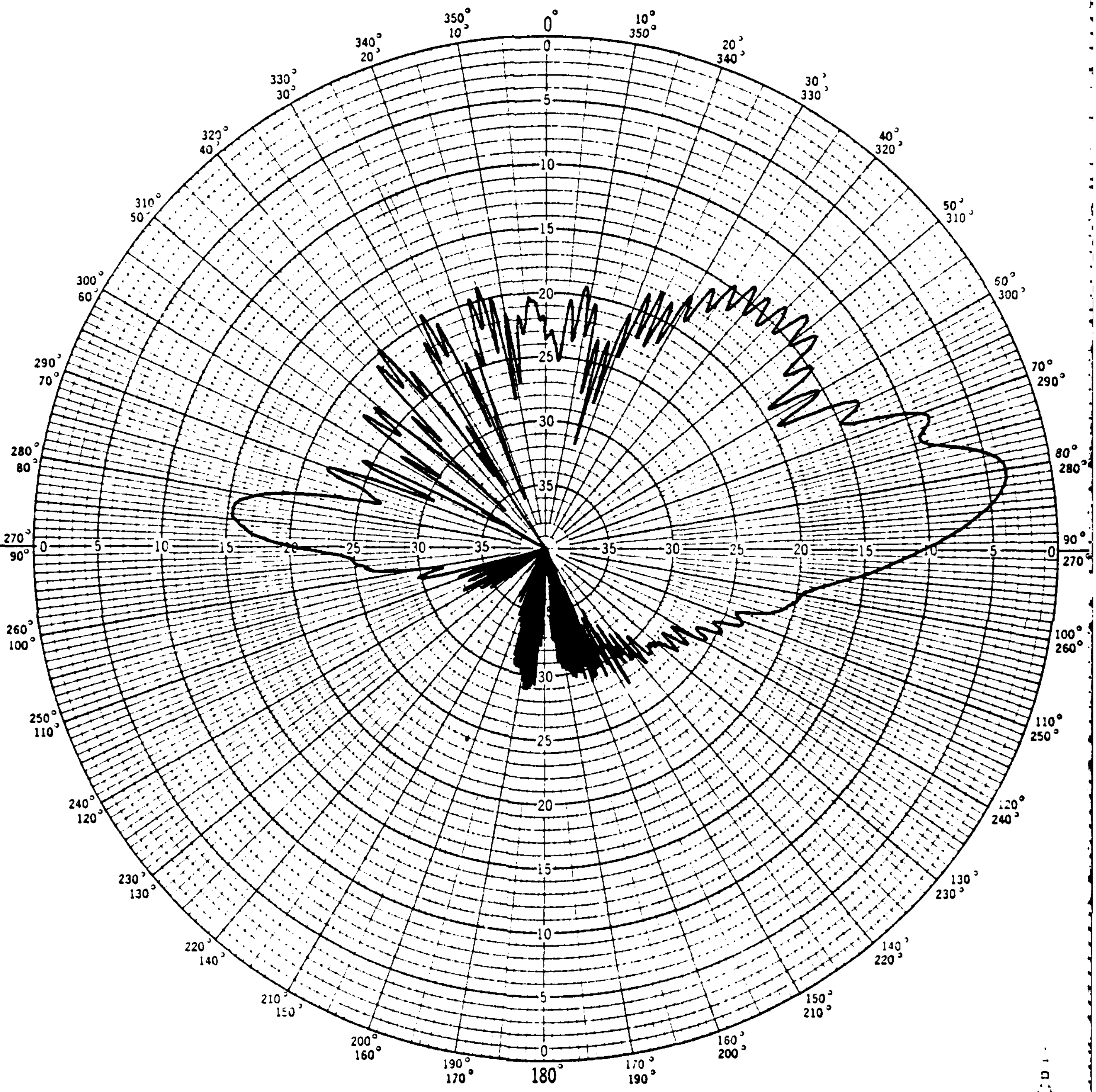
MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0.6V = -53.3°

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L. SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION ________

REMARKS Ø REF = 1.2V = -116.3°

Form 47-69 (R 9-72)

NORTHROP
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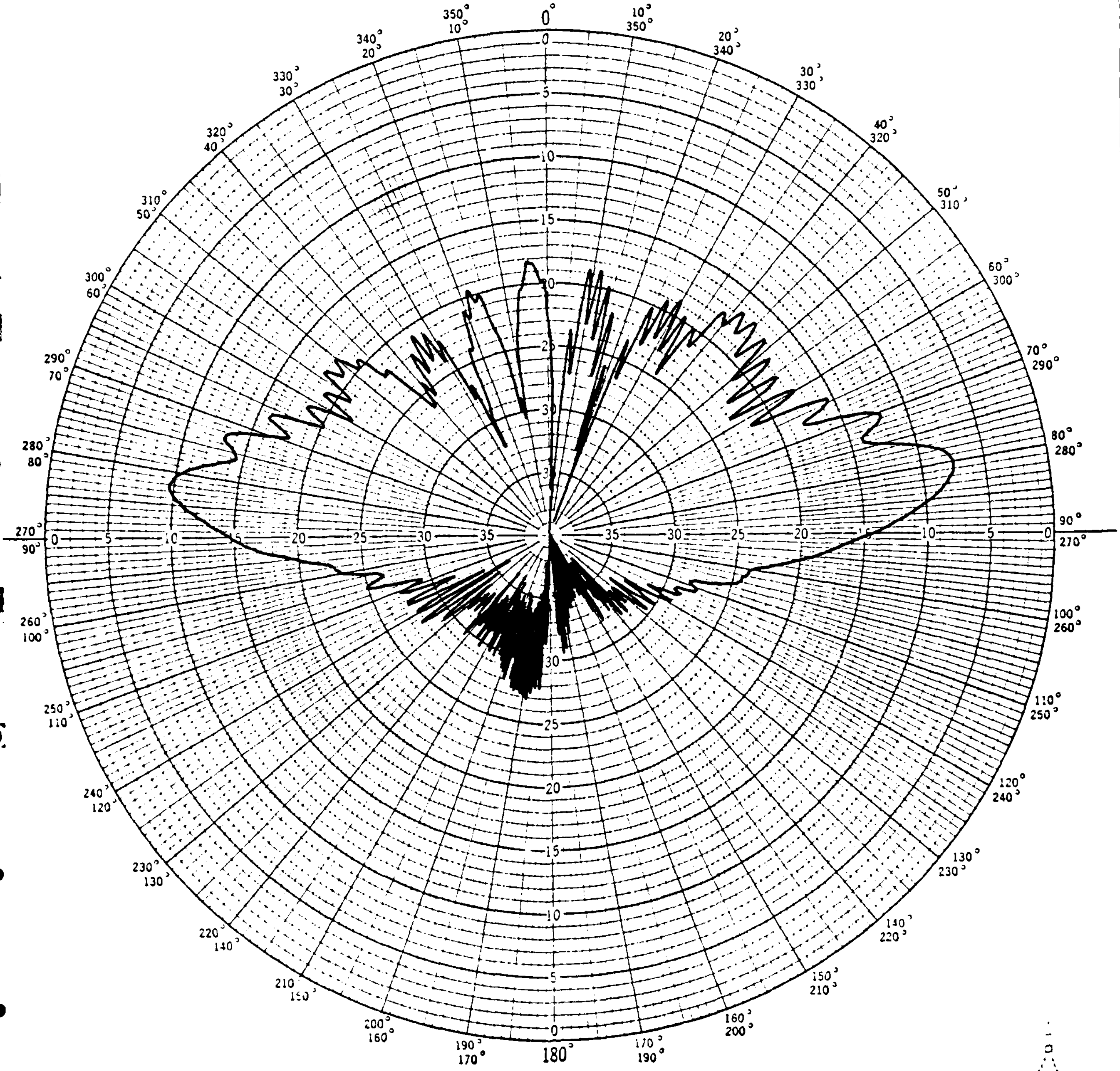
Aircraft Division

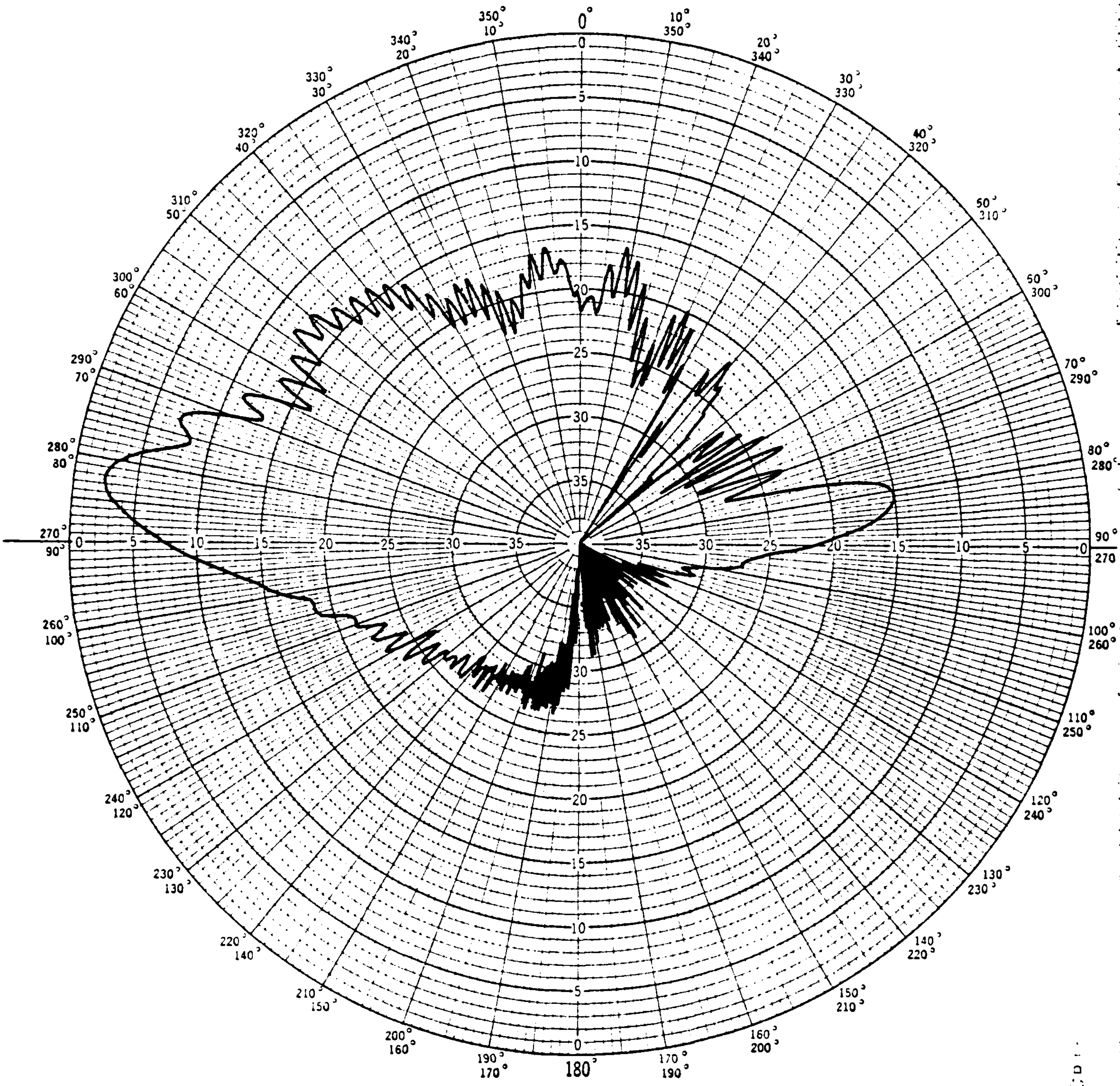


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-28-79

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 1.8V

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 6' GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )

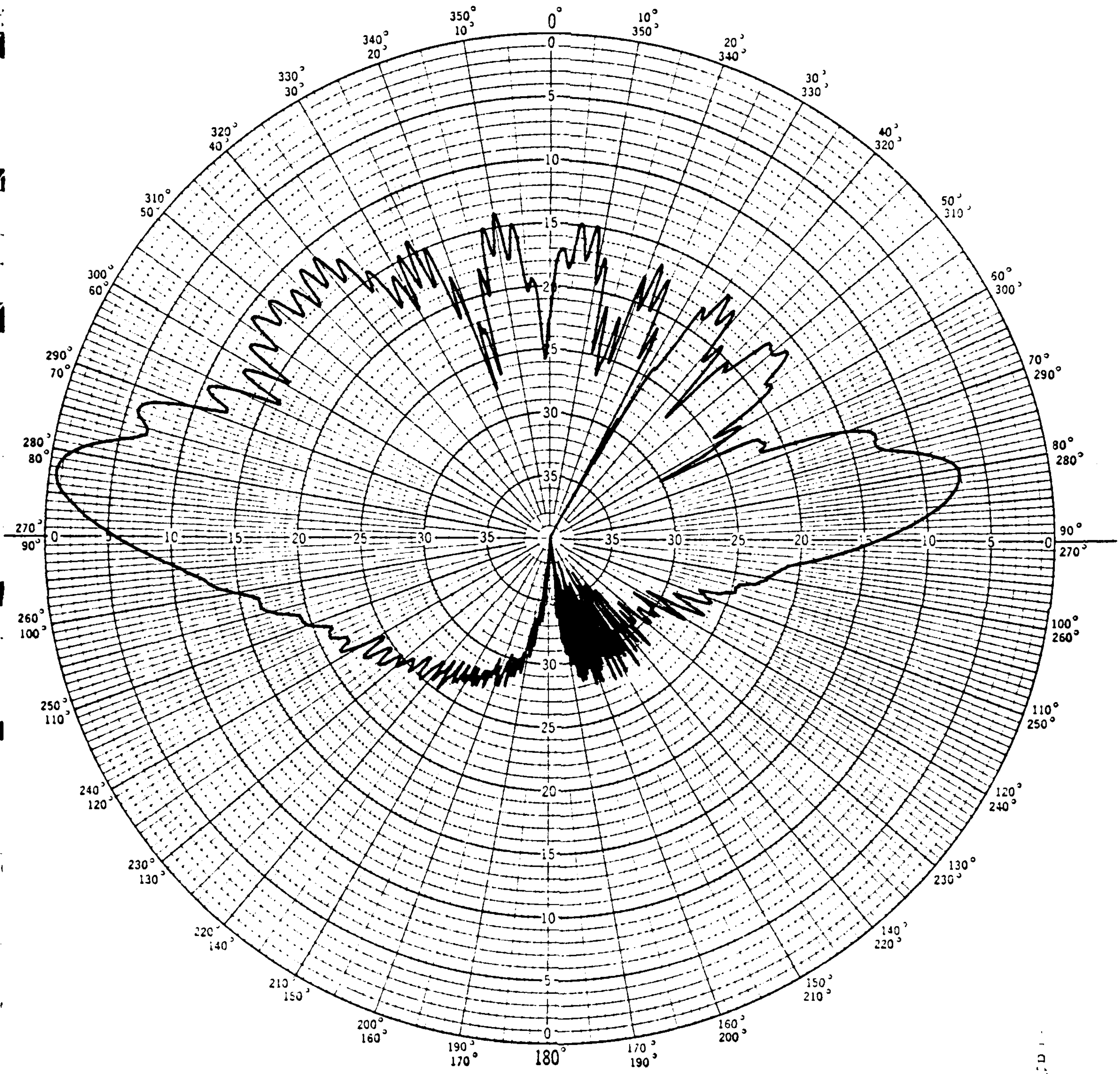
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ ( ) Φ ( ) POLARIZATION ______

REMARKS Ø REF = 2.4V =

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

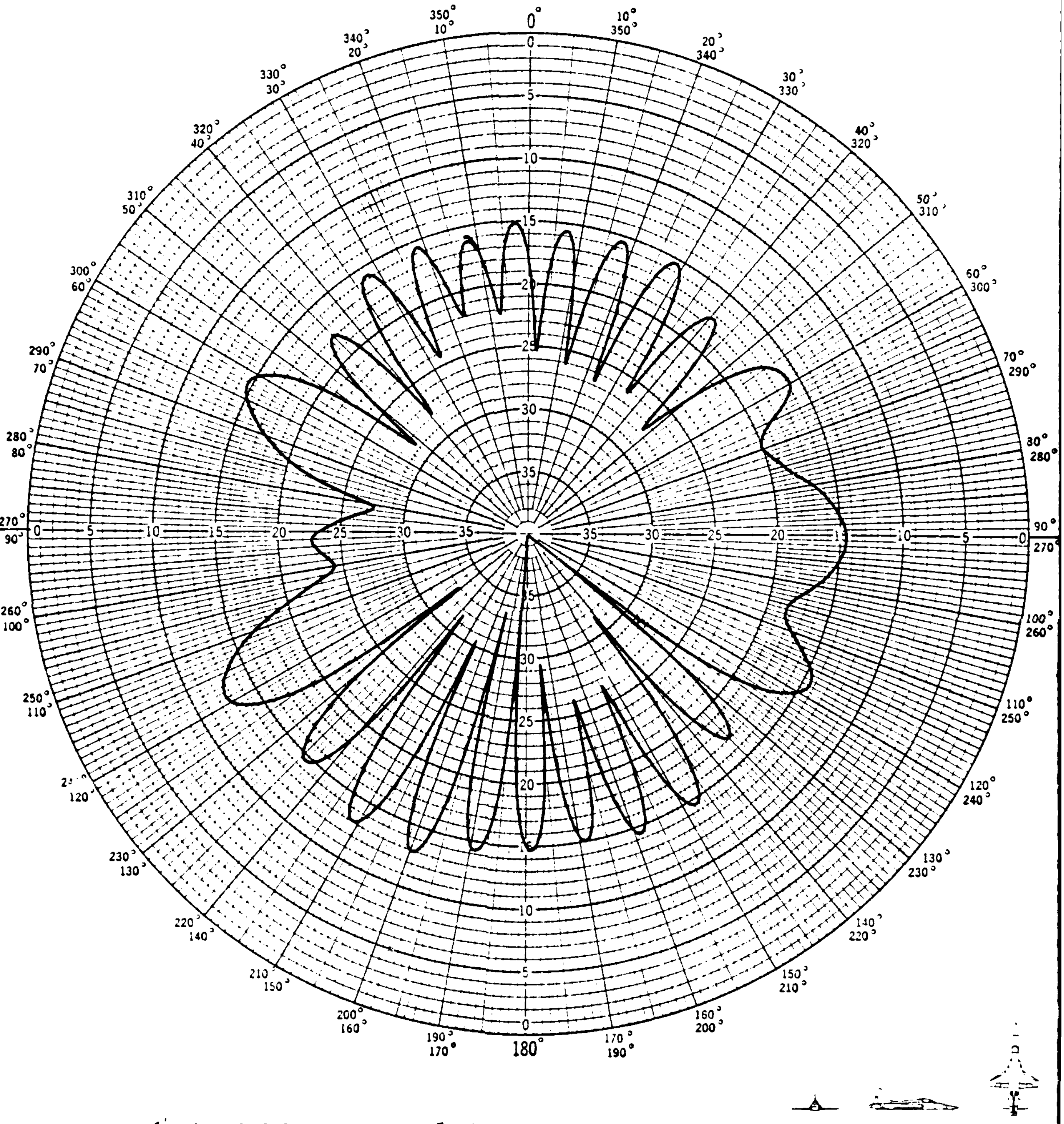


MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-28-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REC = 3.0V =

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



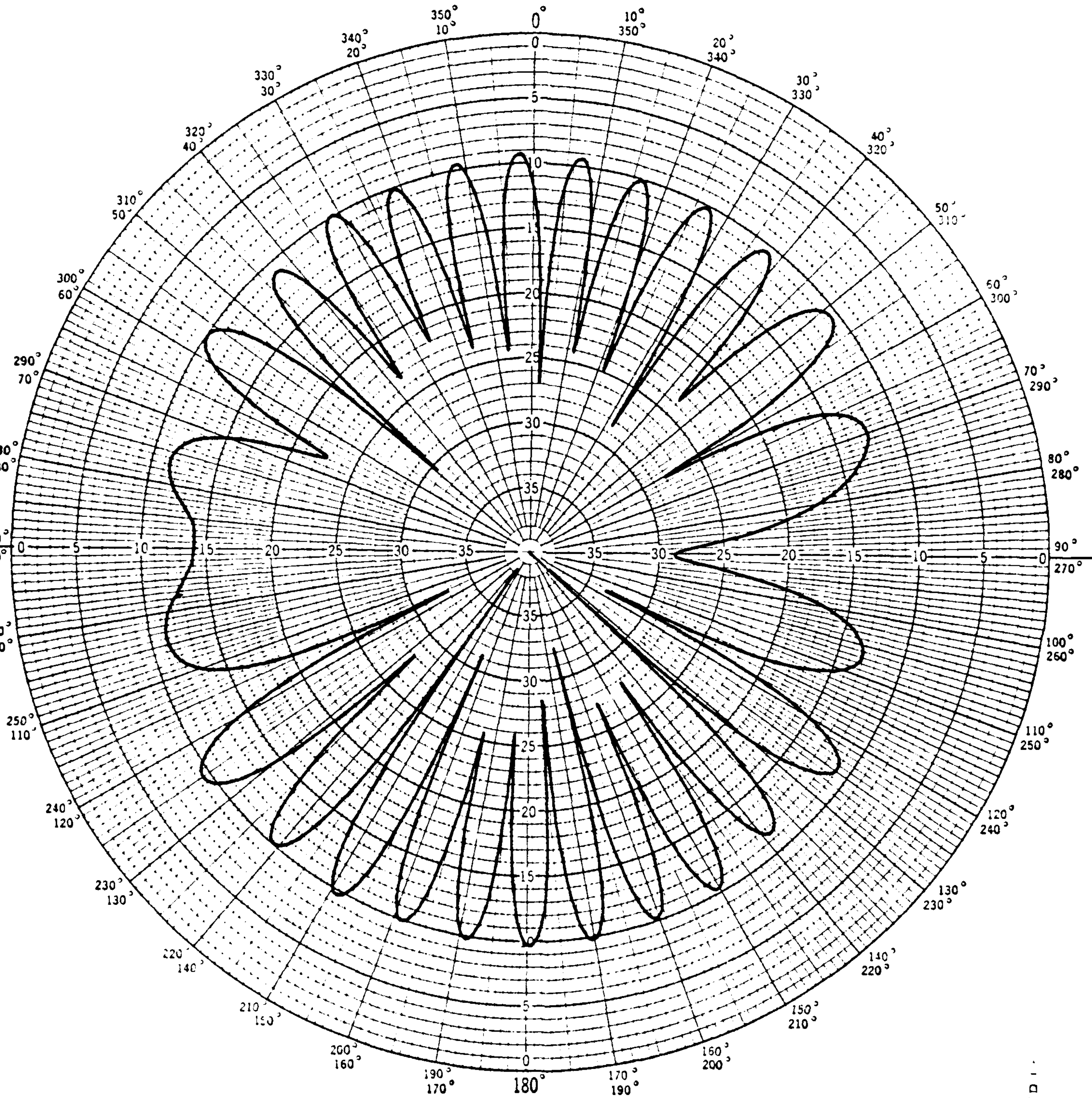
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-25-79

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (60°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 7-29-79

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

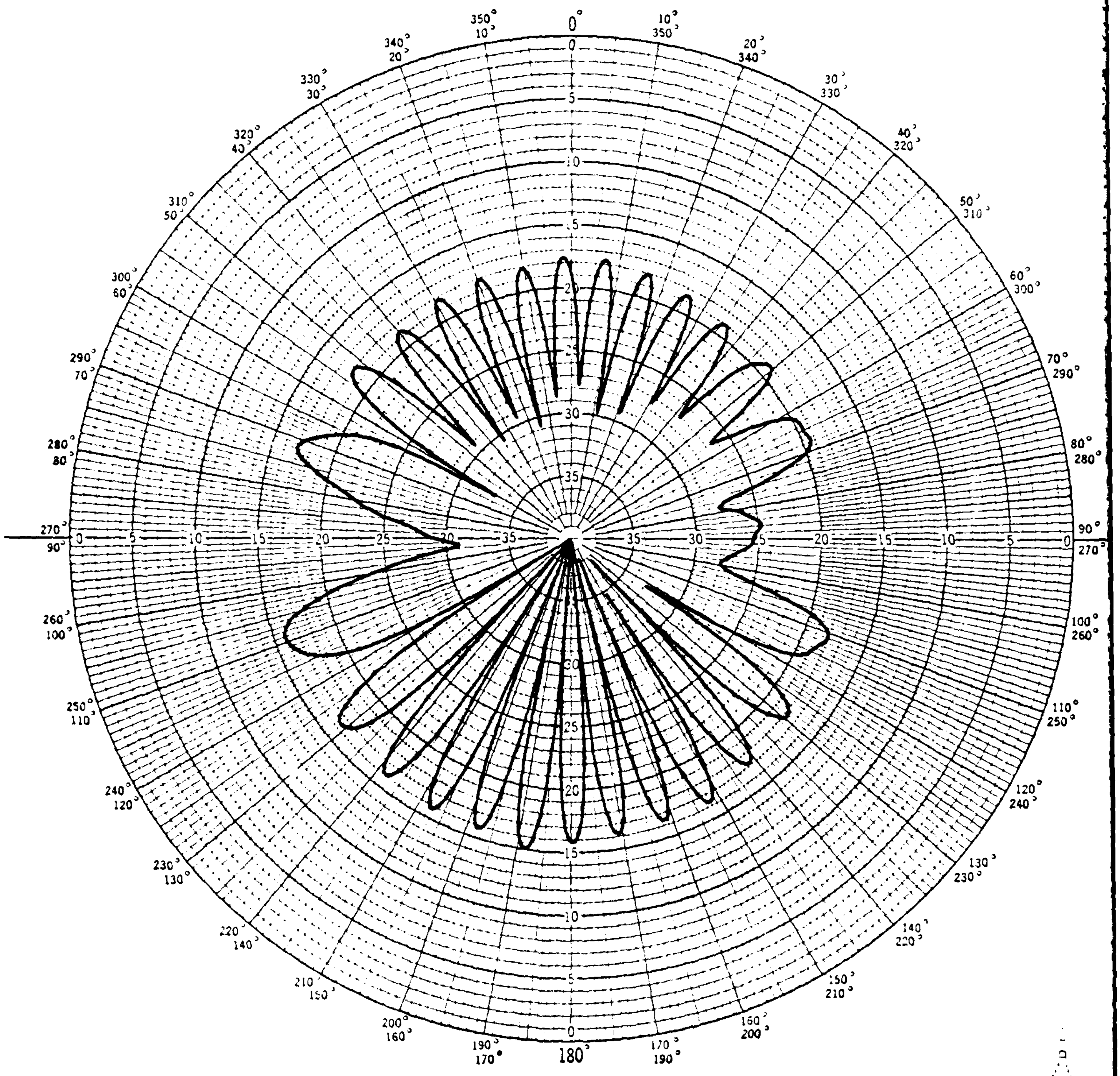
PATTERN θ (70°) Φ ( ) POLARIZATION VERT

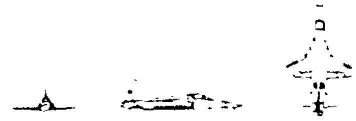
REMARKS ØREF = ØY = 0°.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE 6' GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 9 GHZ
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 7-25-79

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 100° Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = ØV = 0°.

Form 47-69 (R 9-72)

APPENDIX F

Dual Conical Monopole Antenna Patterns--11 GHz

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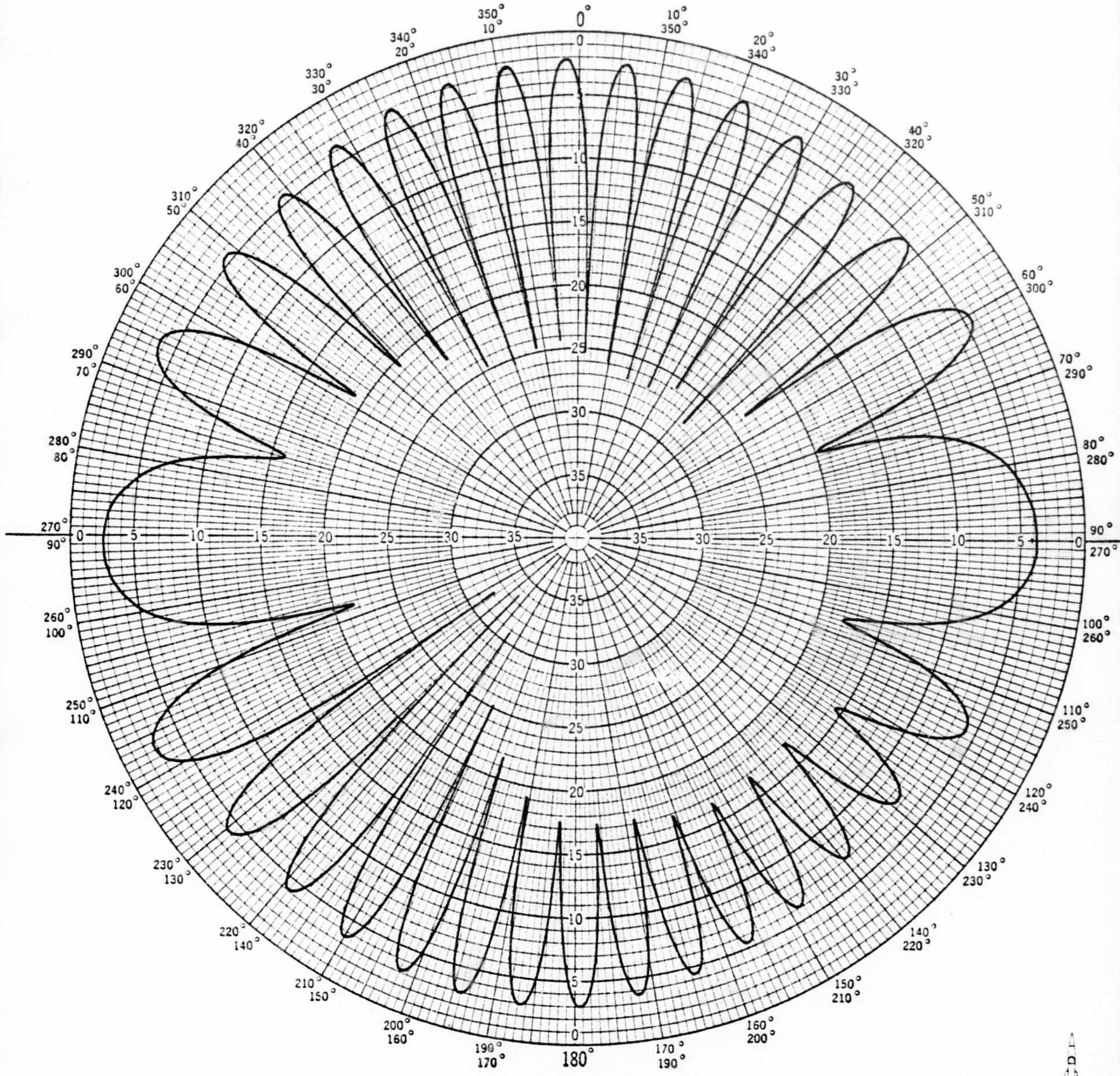
Aircraft Division



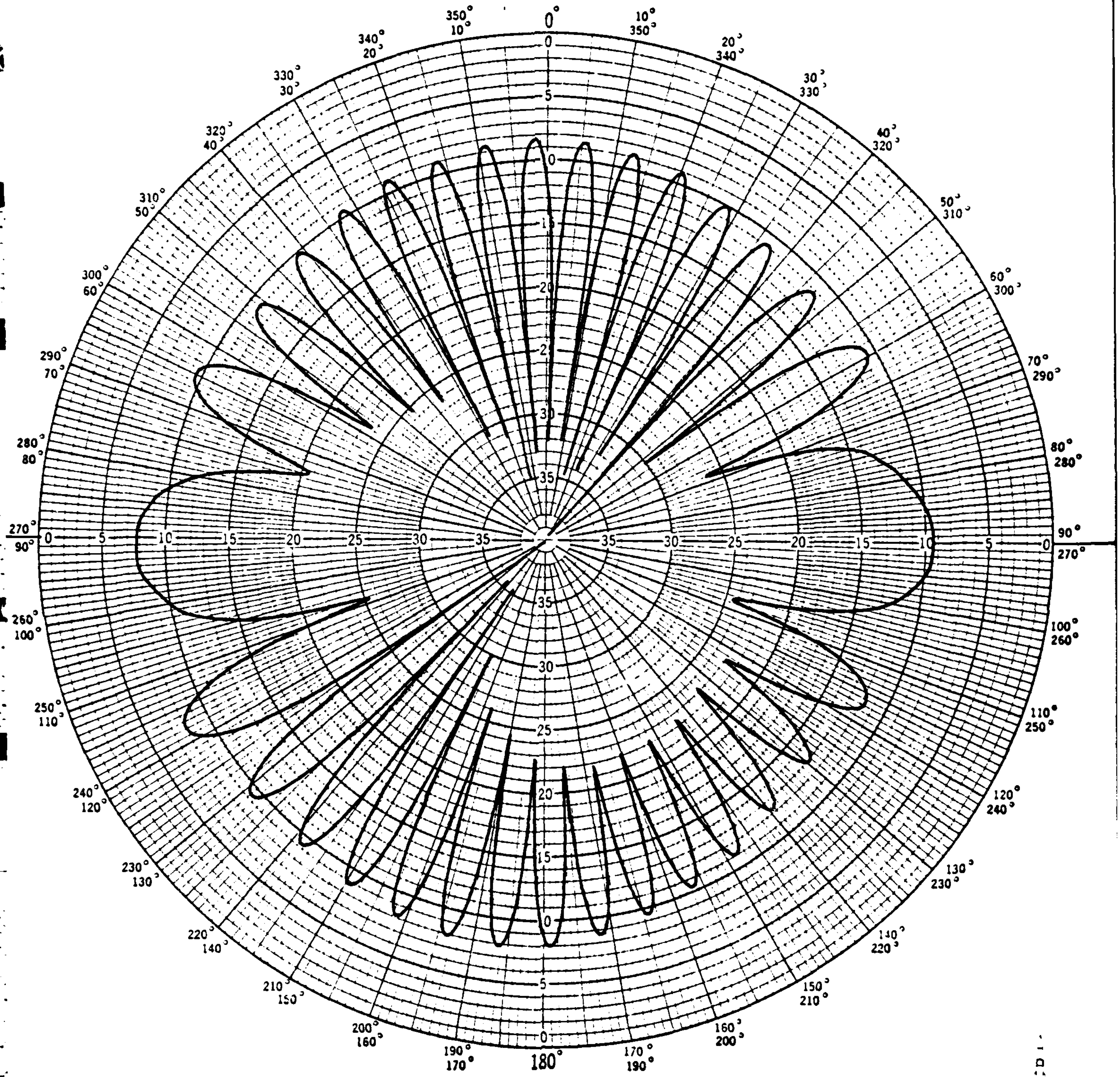
MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *11 GHz*
ANTENNA LOCATION ______ STATION ______
OPERATOR *L. SIMPSON* DATE *8-2-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (*83°*) Φ ( ) POLARIZATION *VERT.*
REMARKS *Ø REF = 0 V = 0°*

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

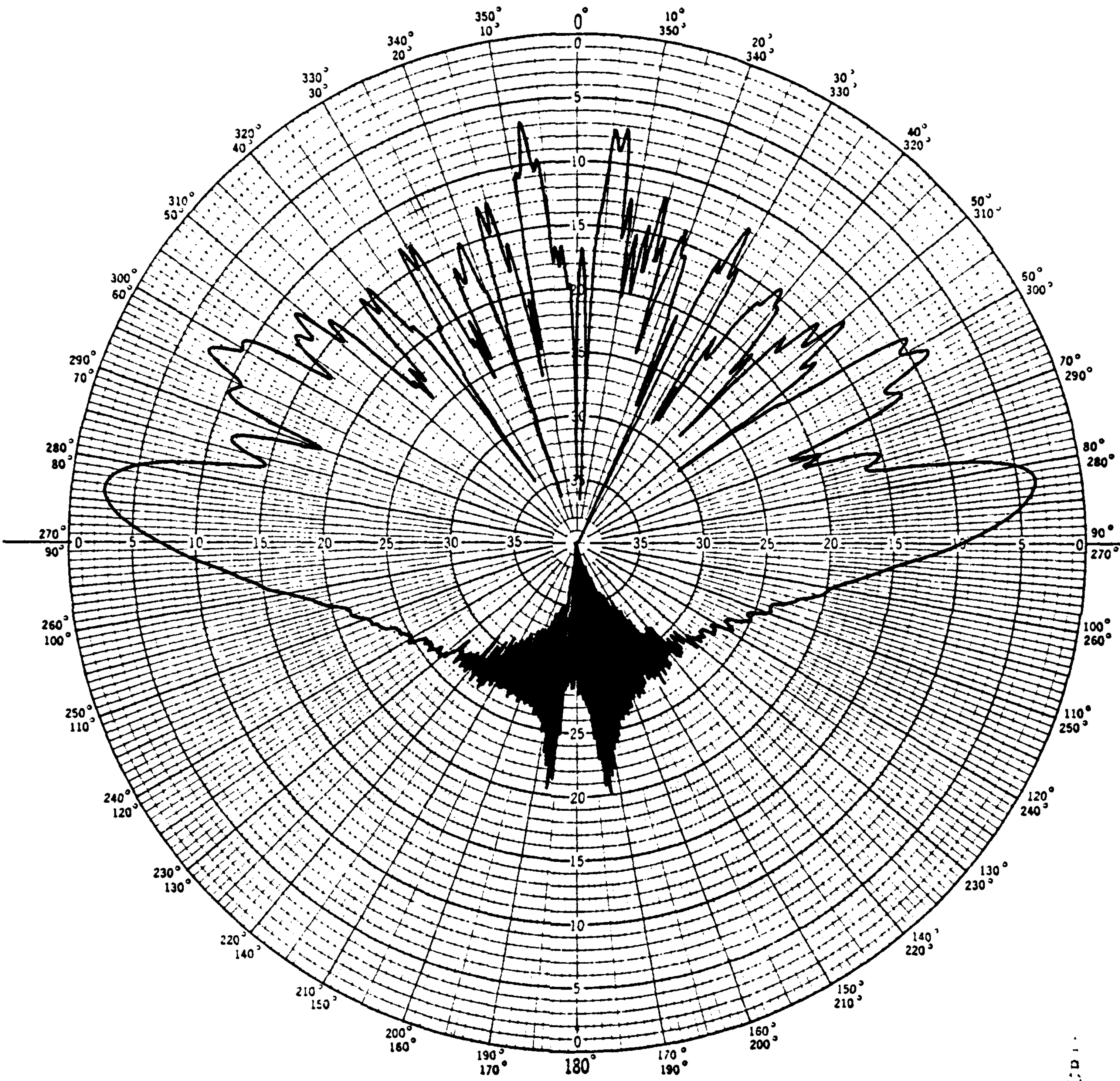


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = OV = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

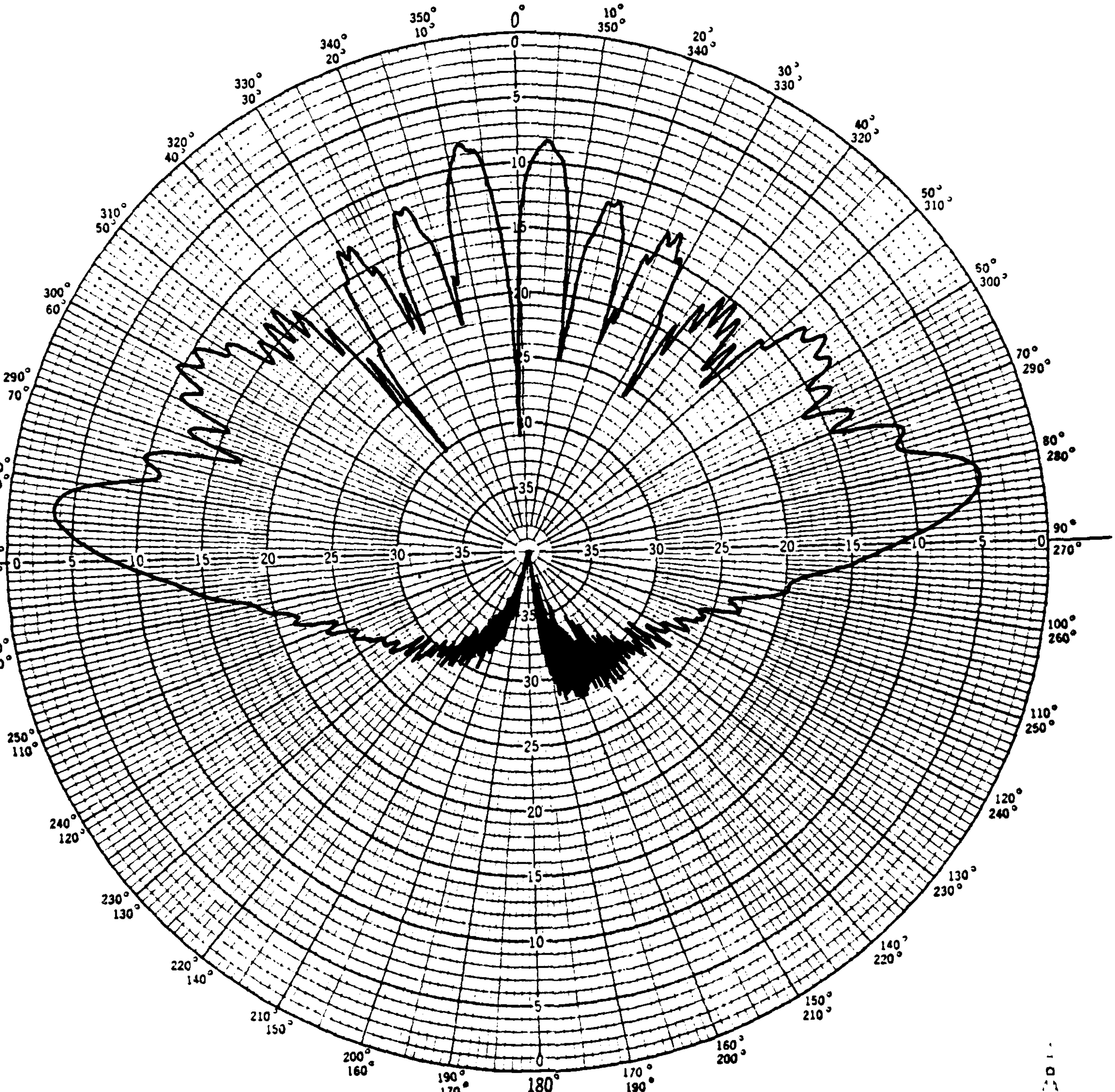


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0Y = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

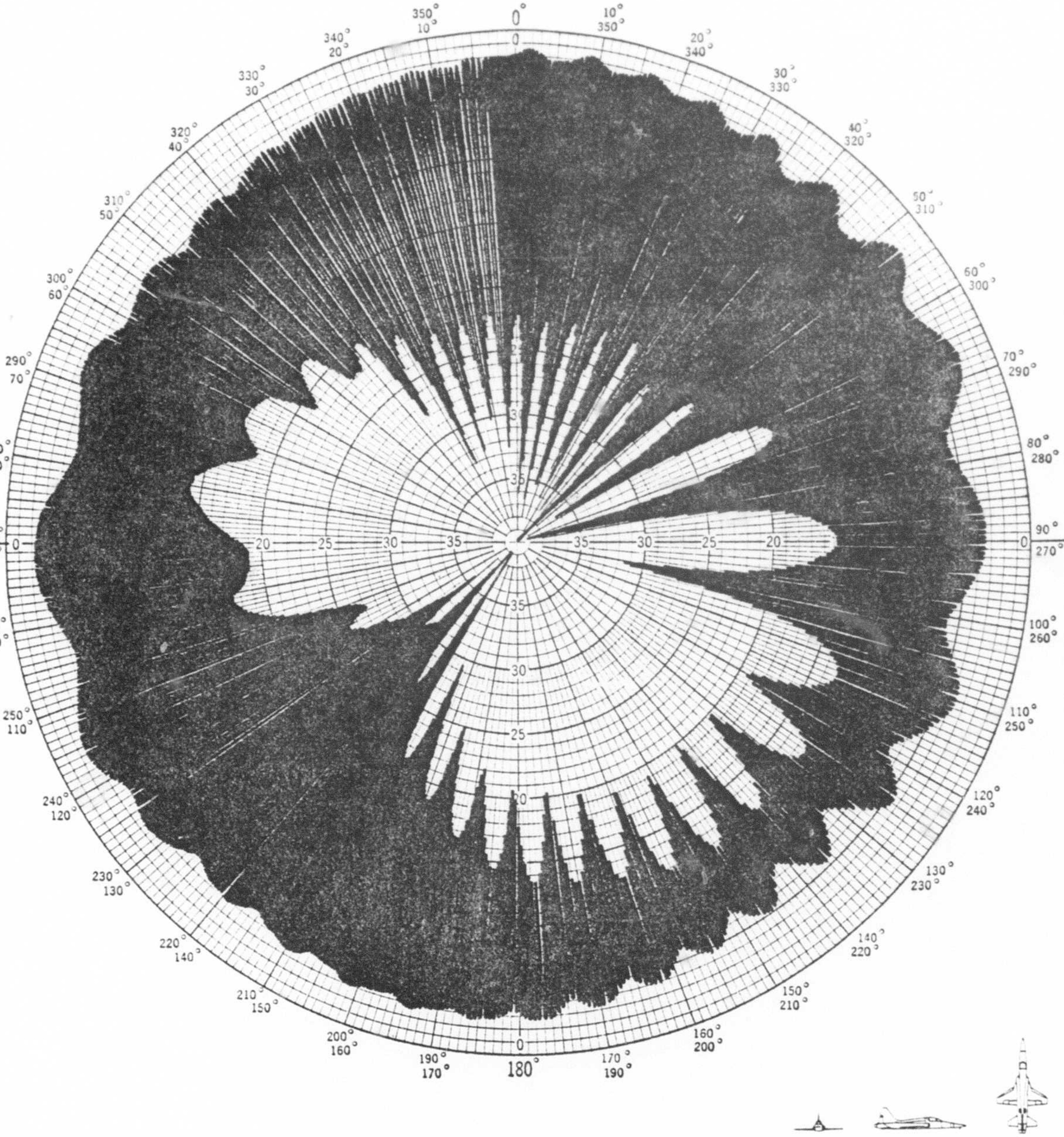


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0 V.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

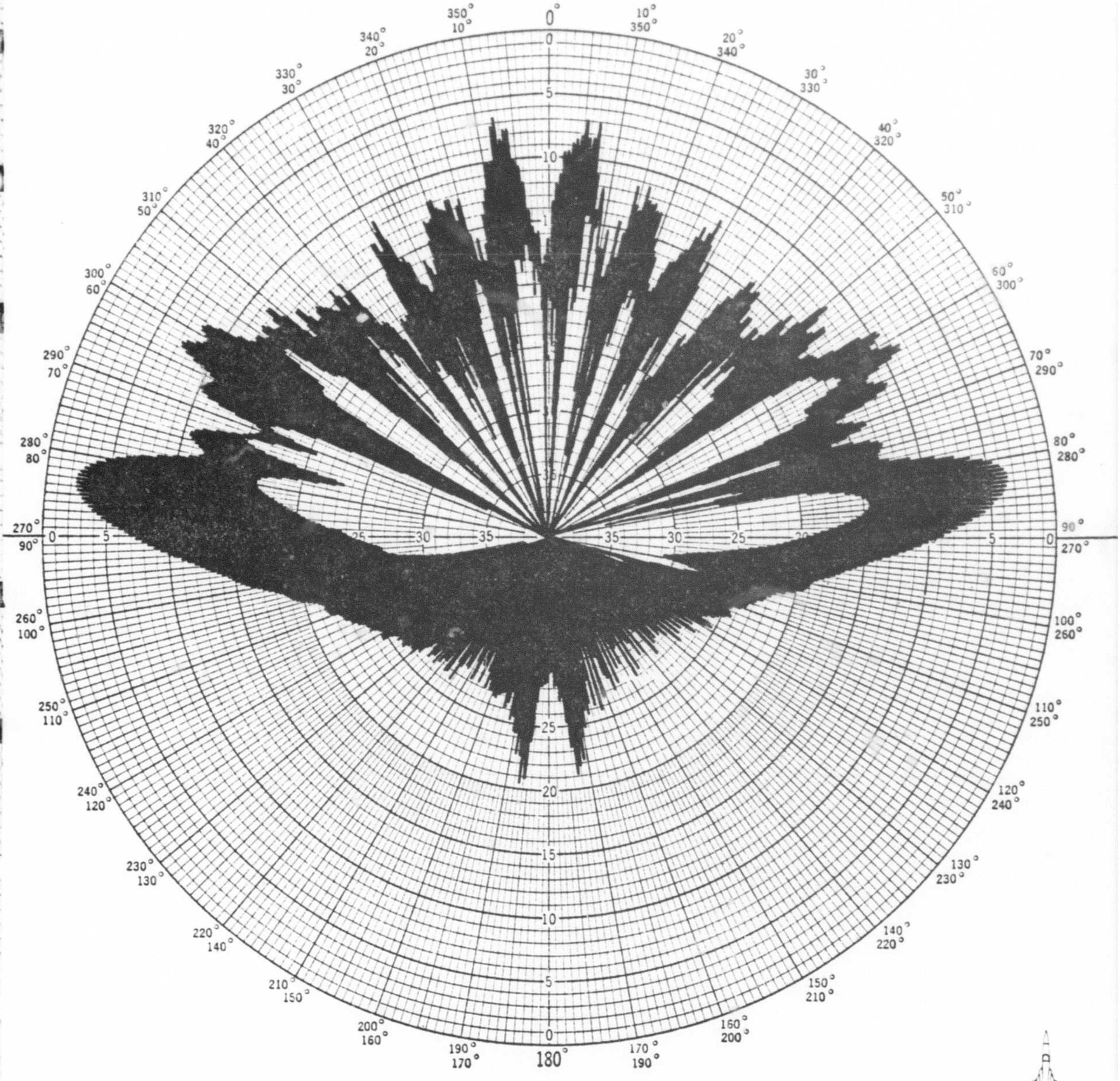


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = -1.65V → +1.65V. FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



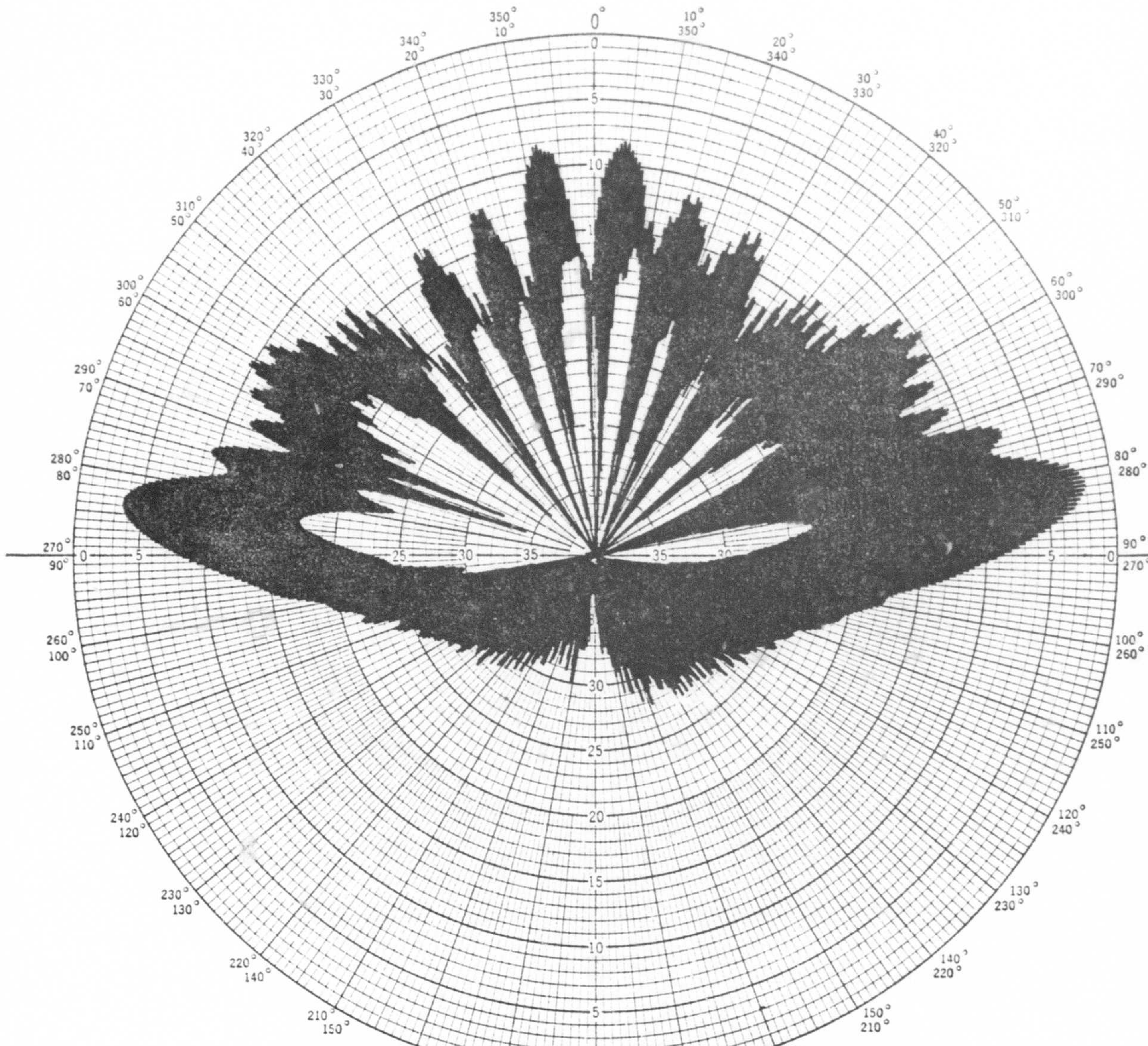
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = -1.65V → +1.65V. FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

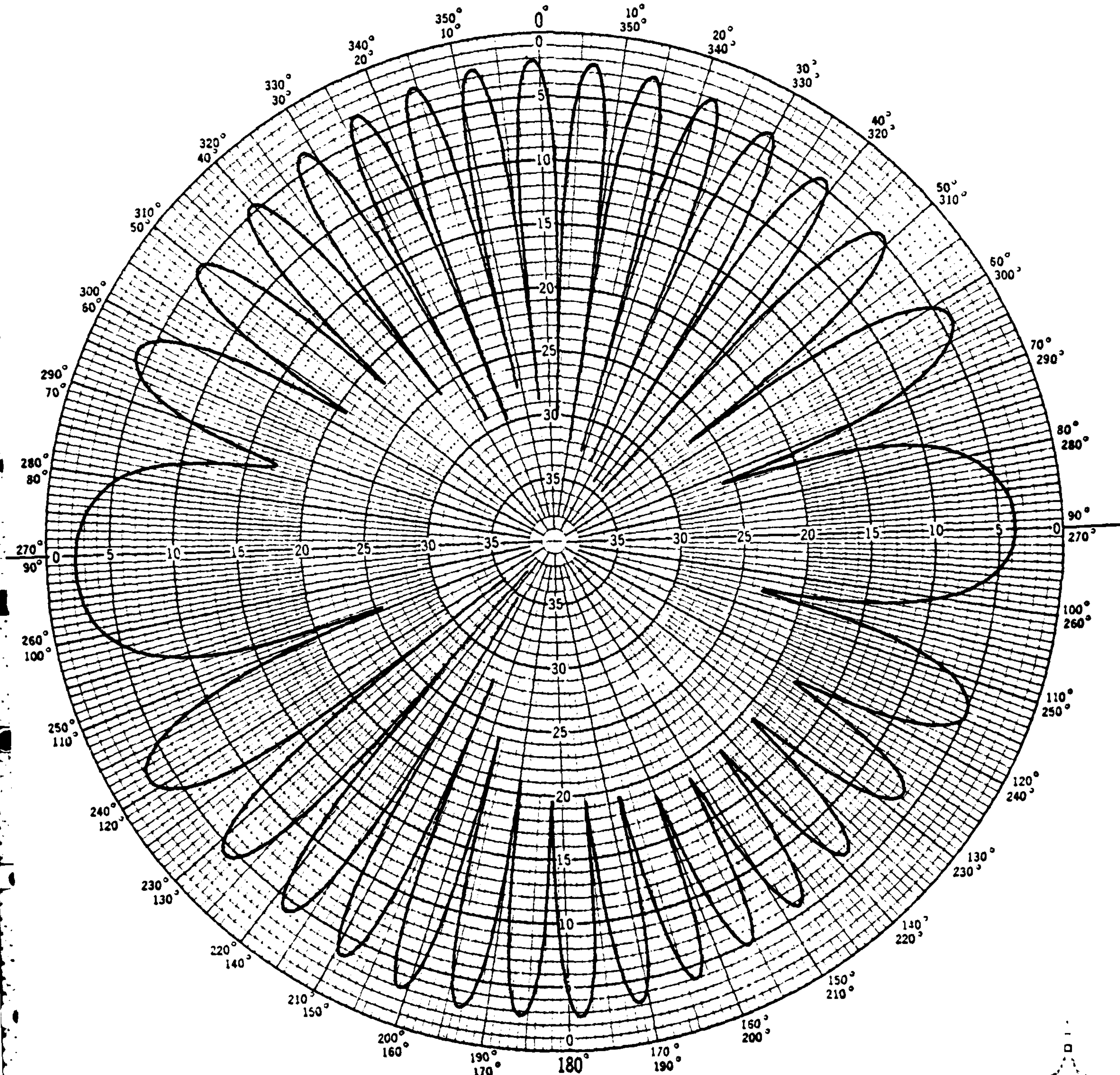


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 8-1-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = -1.65V → +1.65V, FULL SWEEP OF ALL PHASES.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



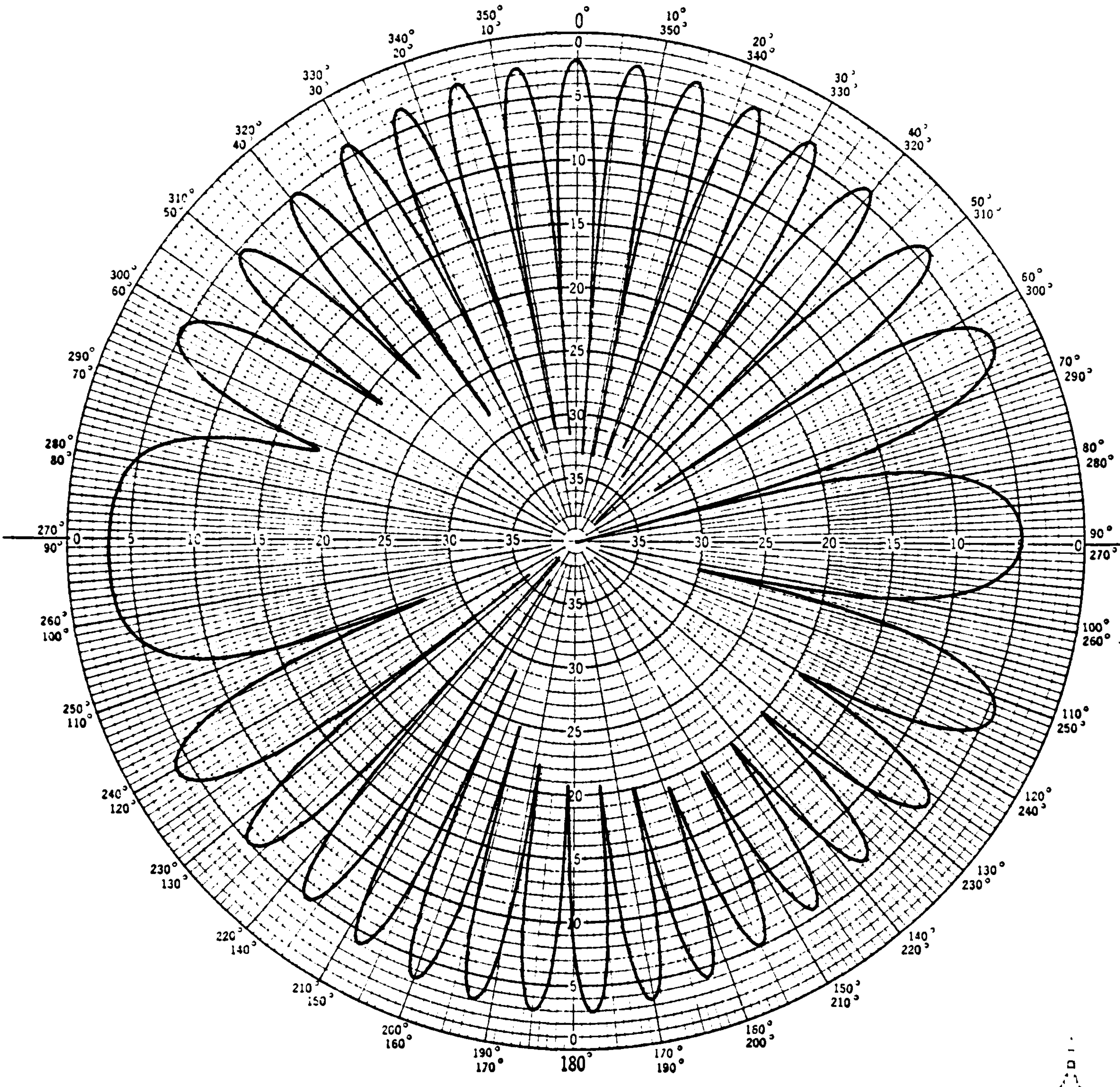
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 83° Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0.3V =

MODEL TYPE 6' DIAM. GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓

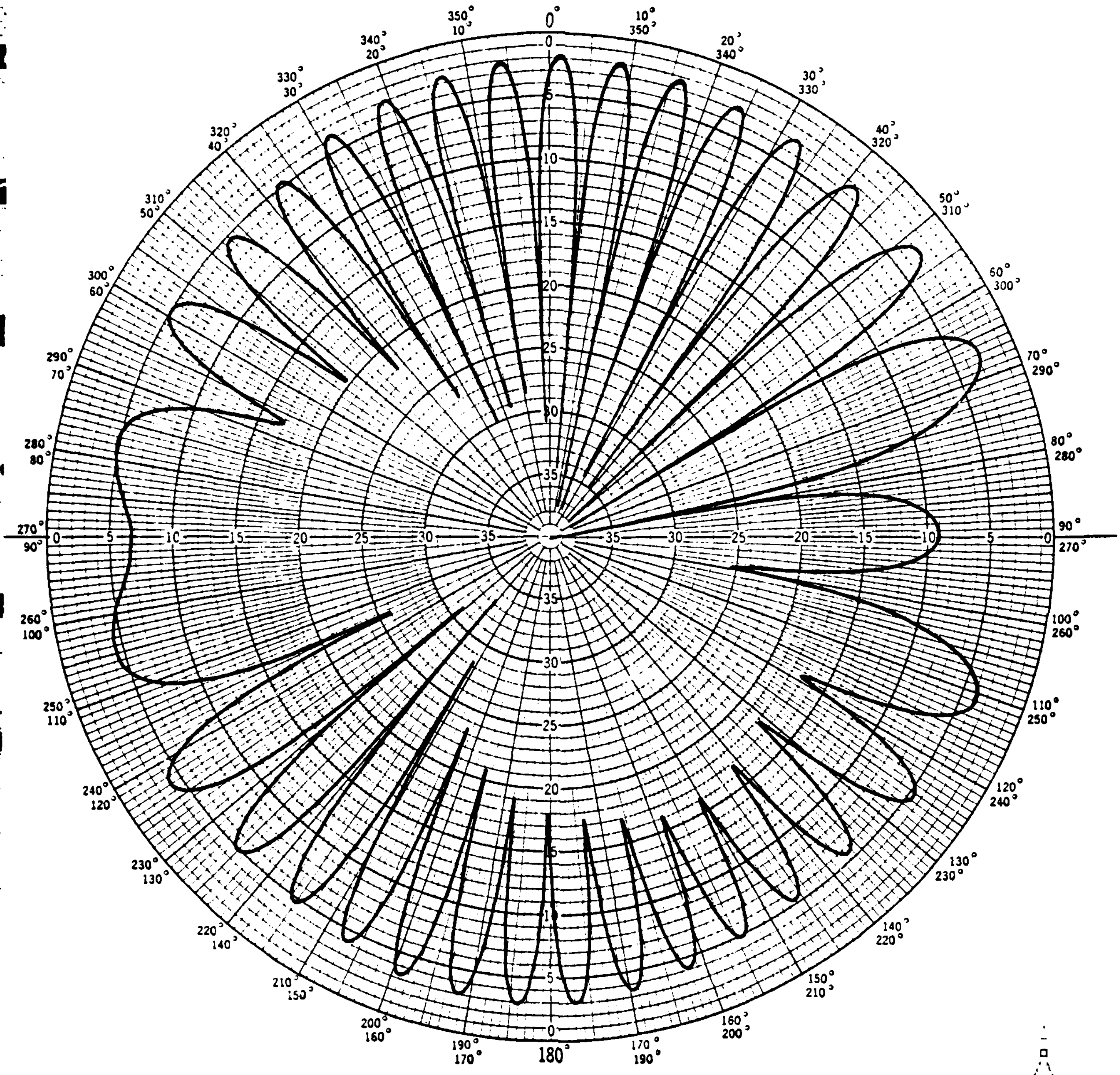
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓

PATTERN θ 83° Φ ( ) POLARIZATION VERT

REMARKS Ø REF = 0.6V =

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83° Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 1.2V =

Form 47-69 (R 9-72)

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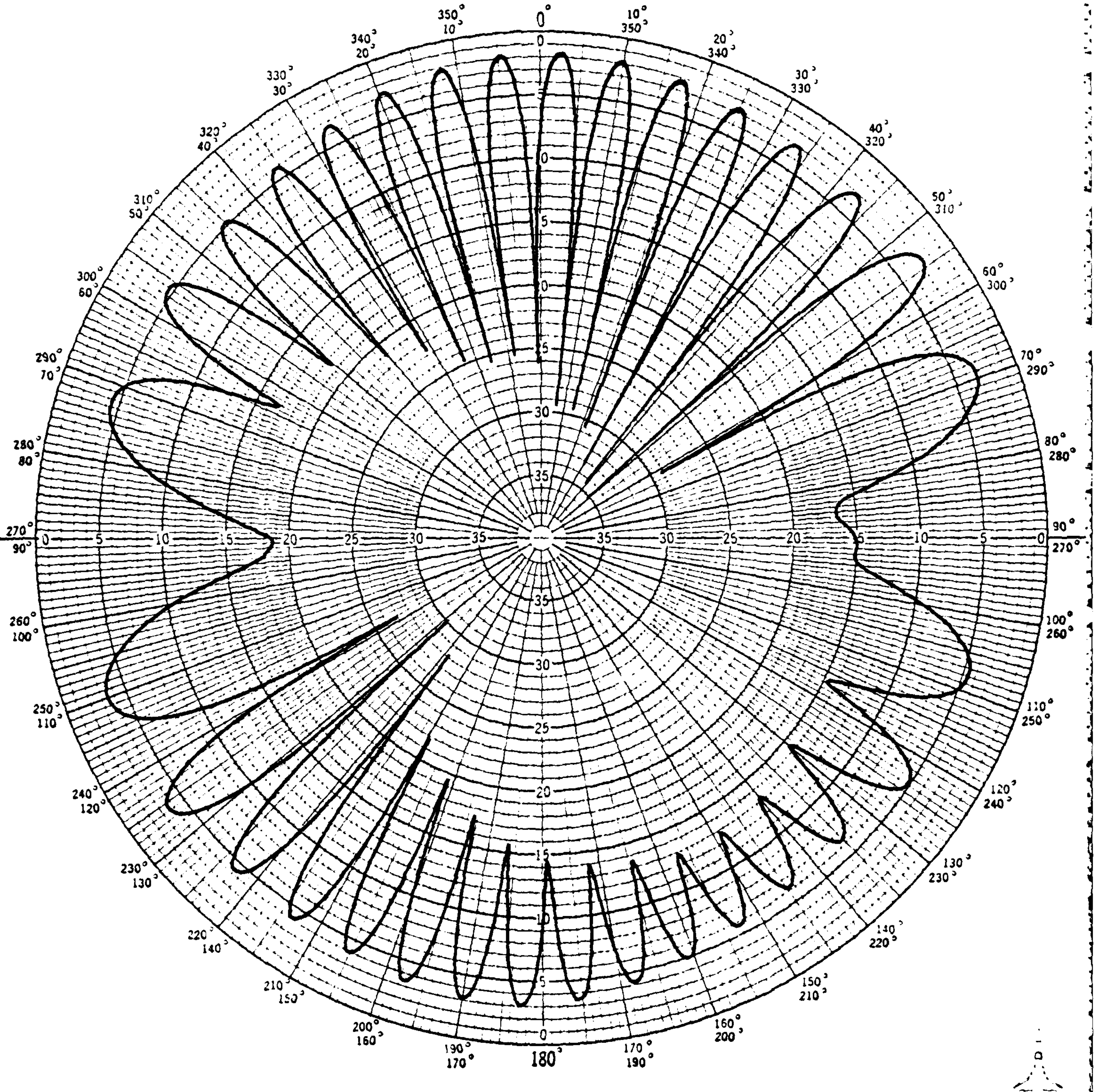

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 183° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 1.9V=

Form 47-69 (R 9-72)

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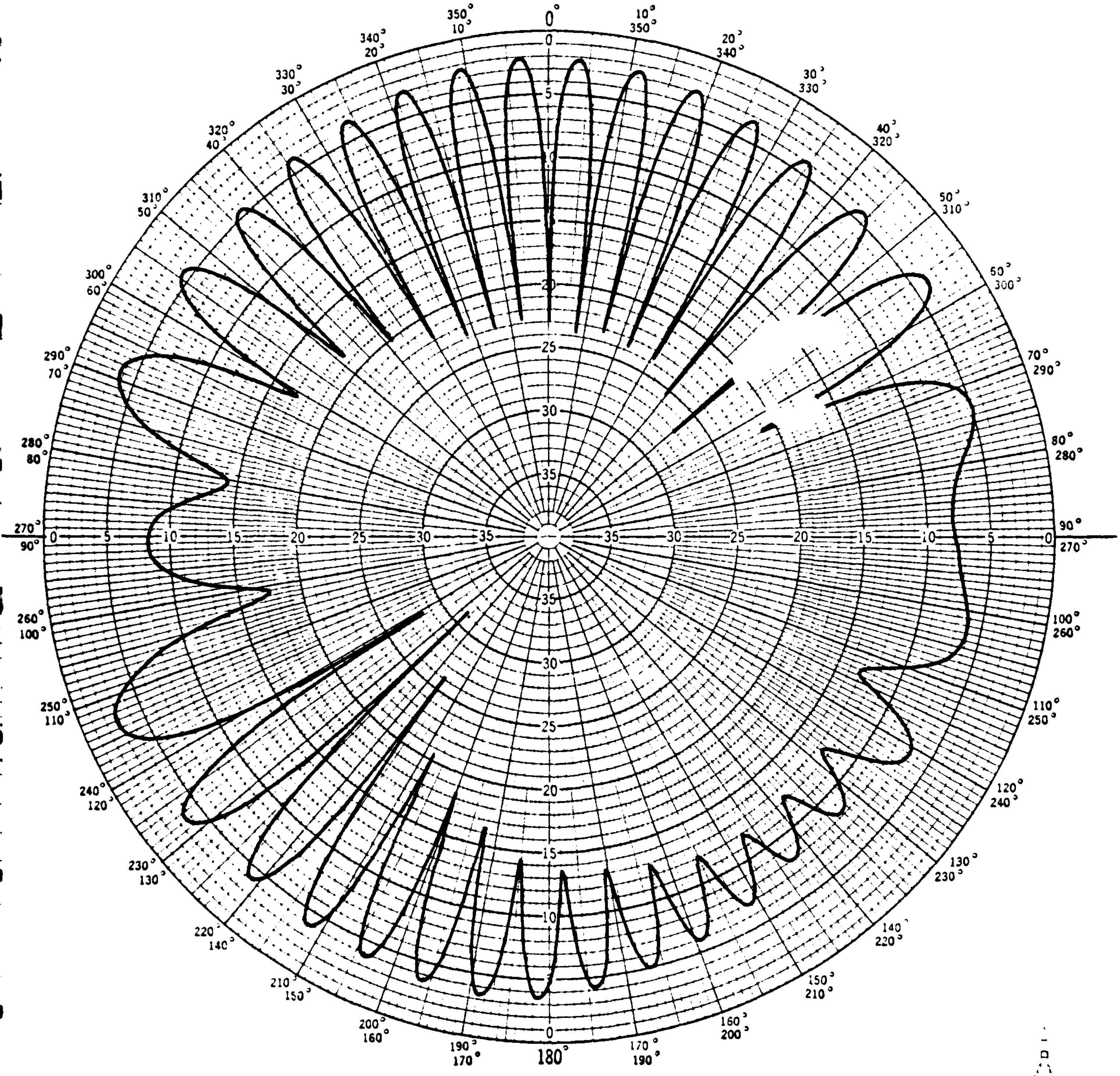

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 2.4V

Form 47-69 (R 9-72)

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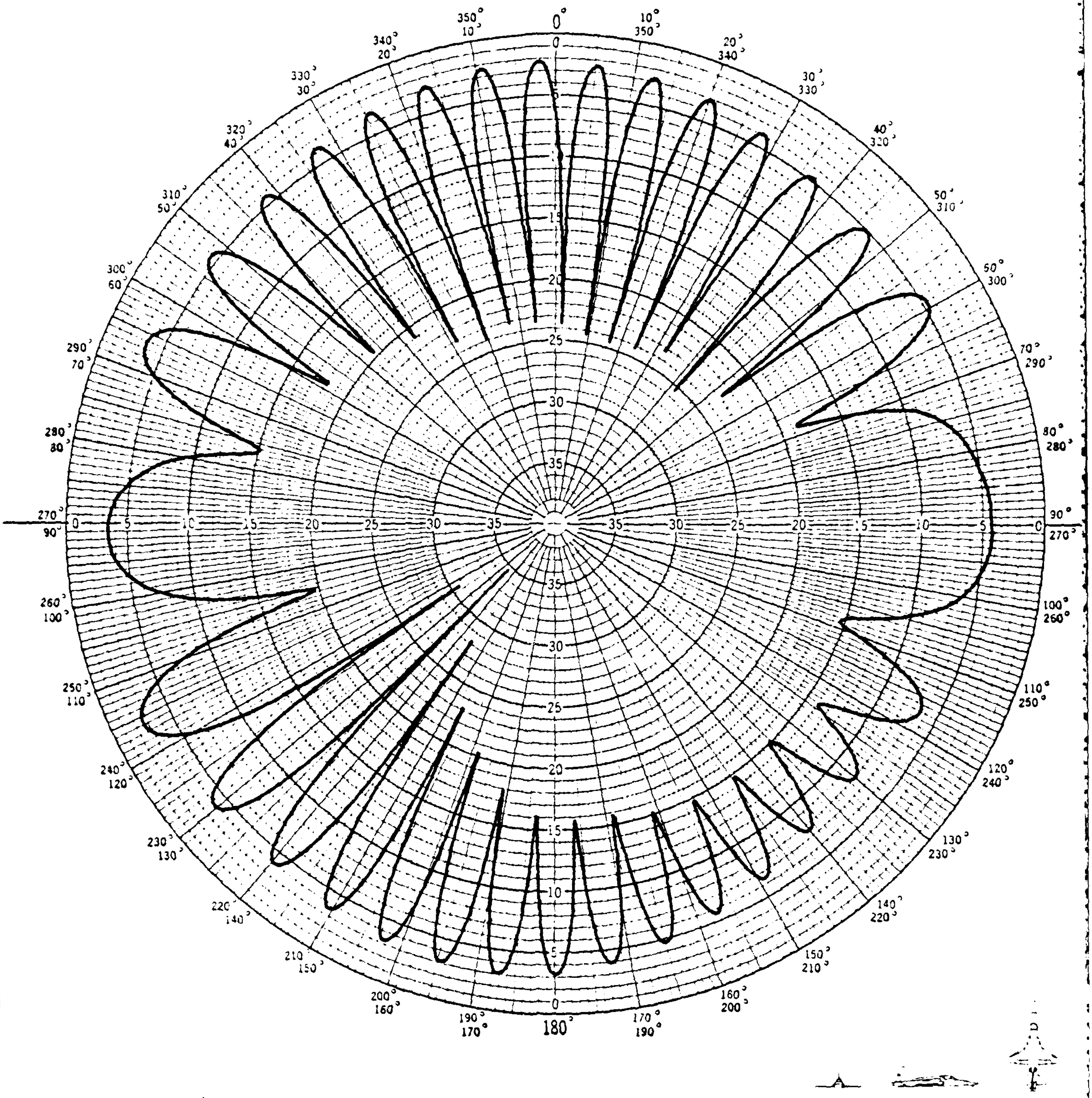

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW ✓
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 3.0V =

Form 47-69 (R 9-72)

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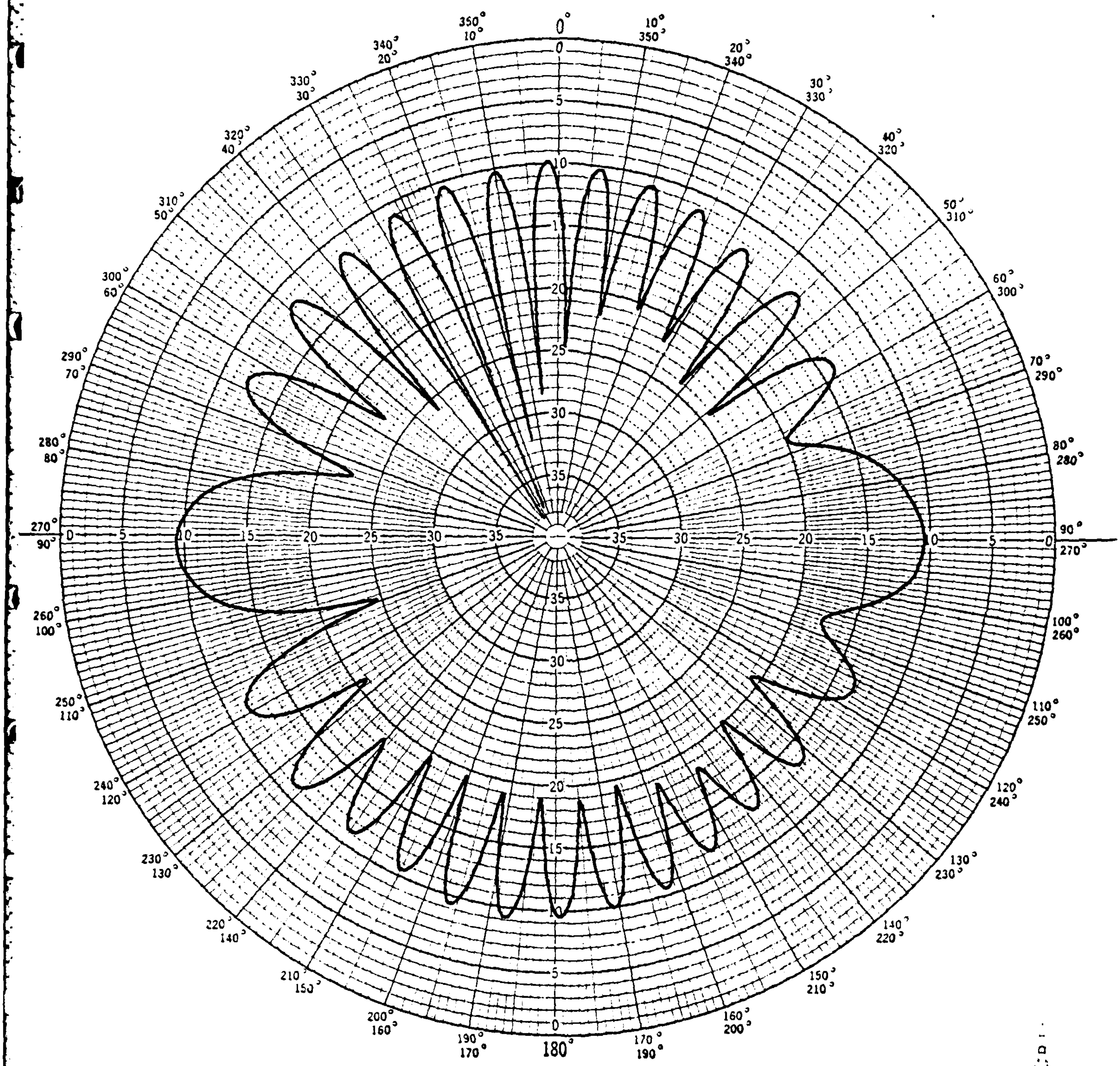

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ (60°) Φ ( ) POLARIZATION VERT

REMARKS ØREF = ØV = 0°

Form 47-69 (R 9-72)

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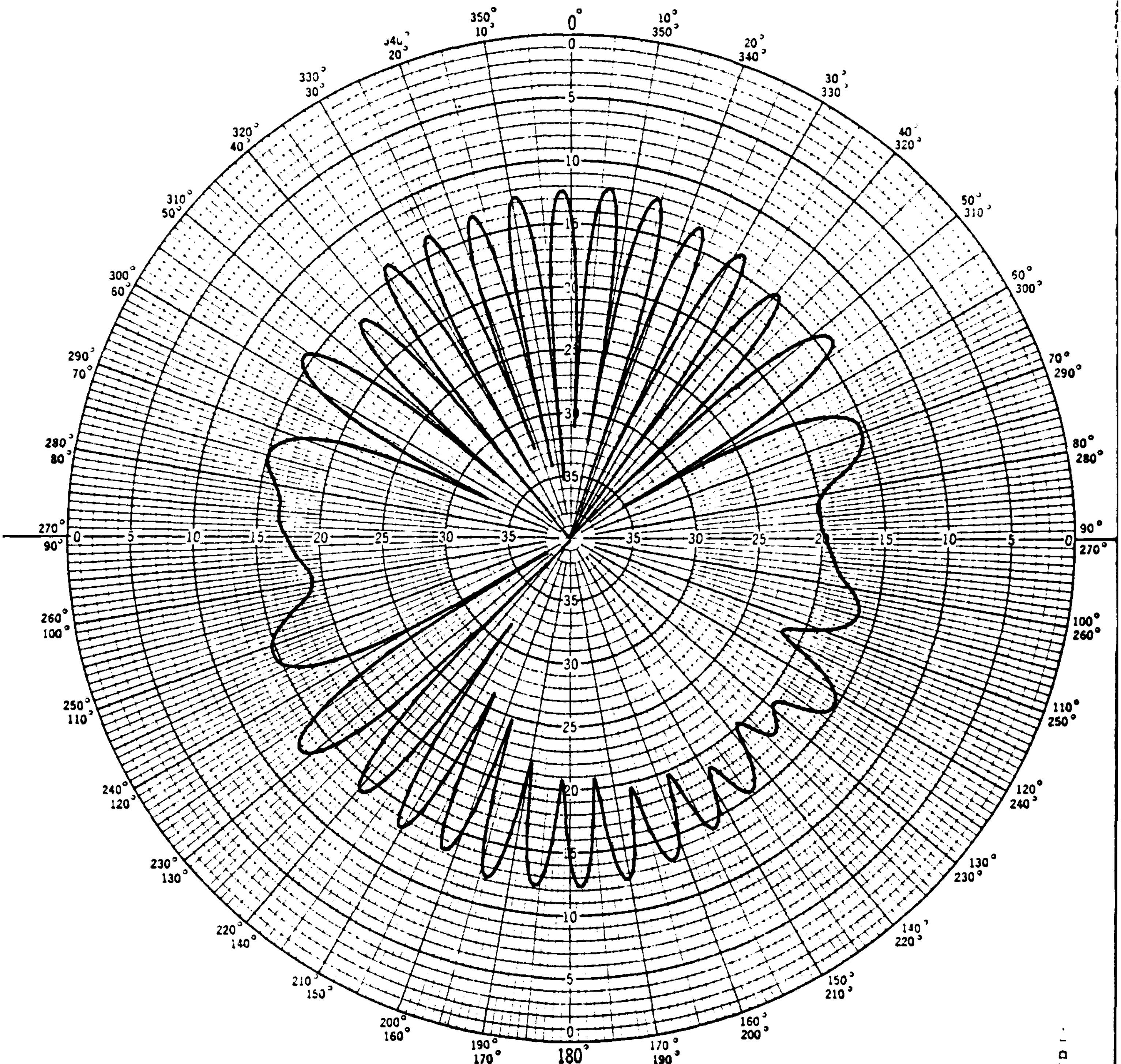

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (70°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0V = 0°

Form 47-69 (R 9-72)

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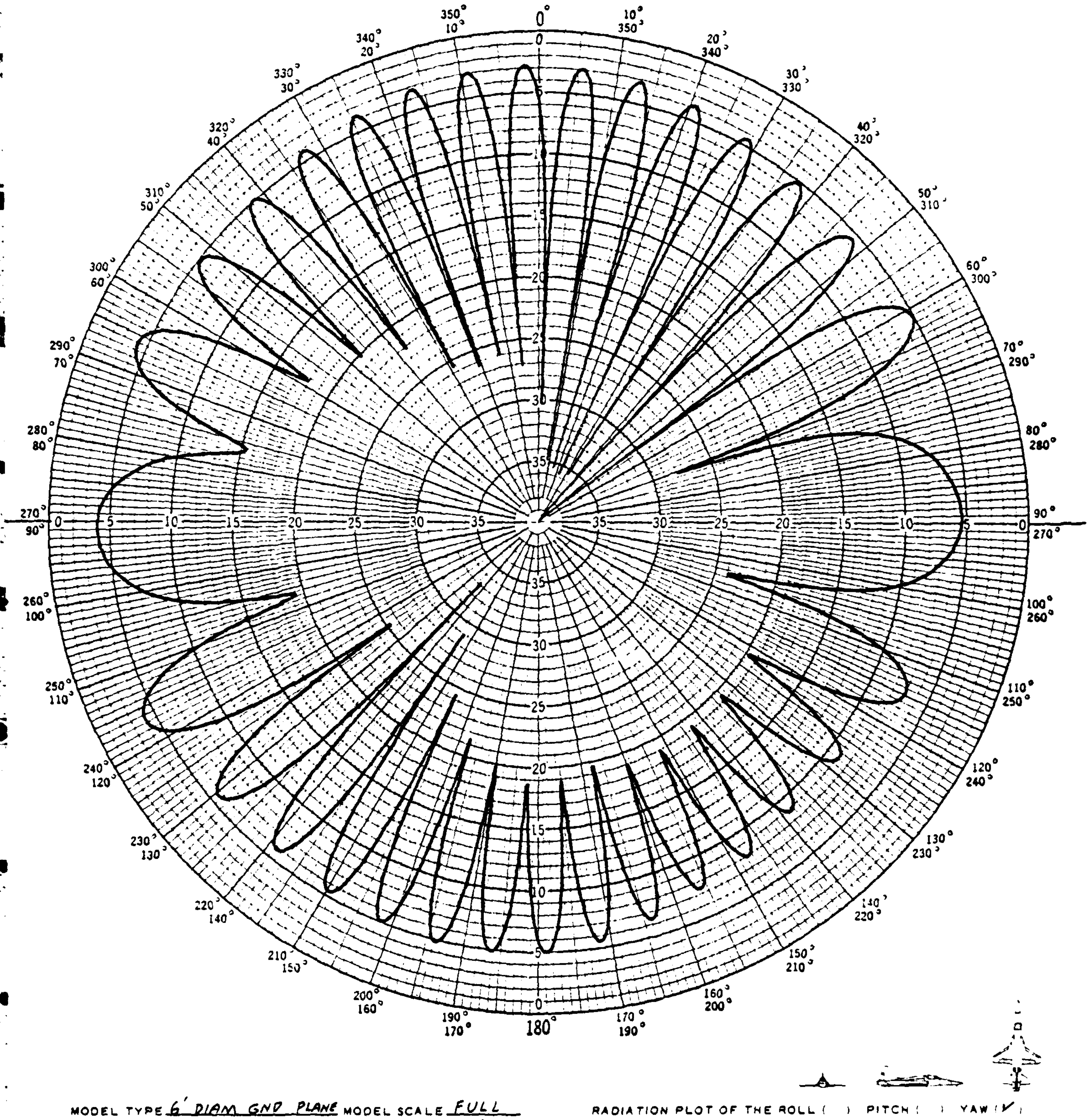

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz

ANTENNA LOCATION __________ STATION __________

OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ (80°) Φ ( ) POLARIZATION VERT.

REMARKS Ø REF = ØV = 0°

Form 47-69 (R 9-72)

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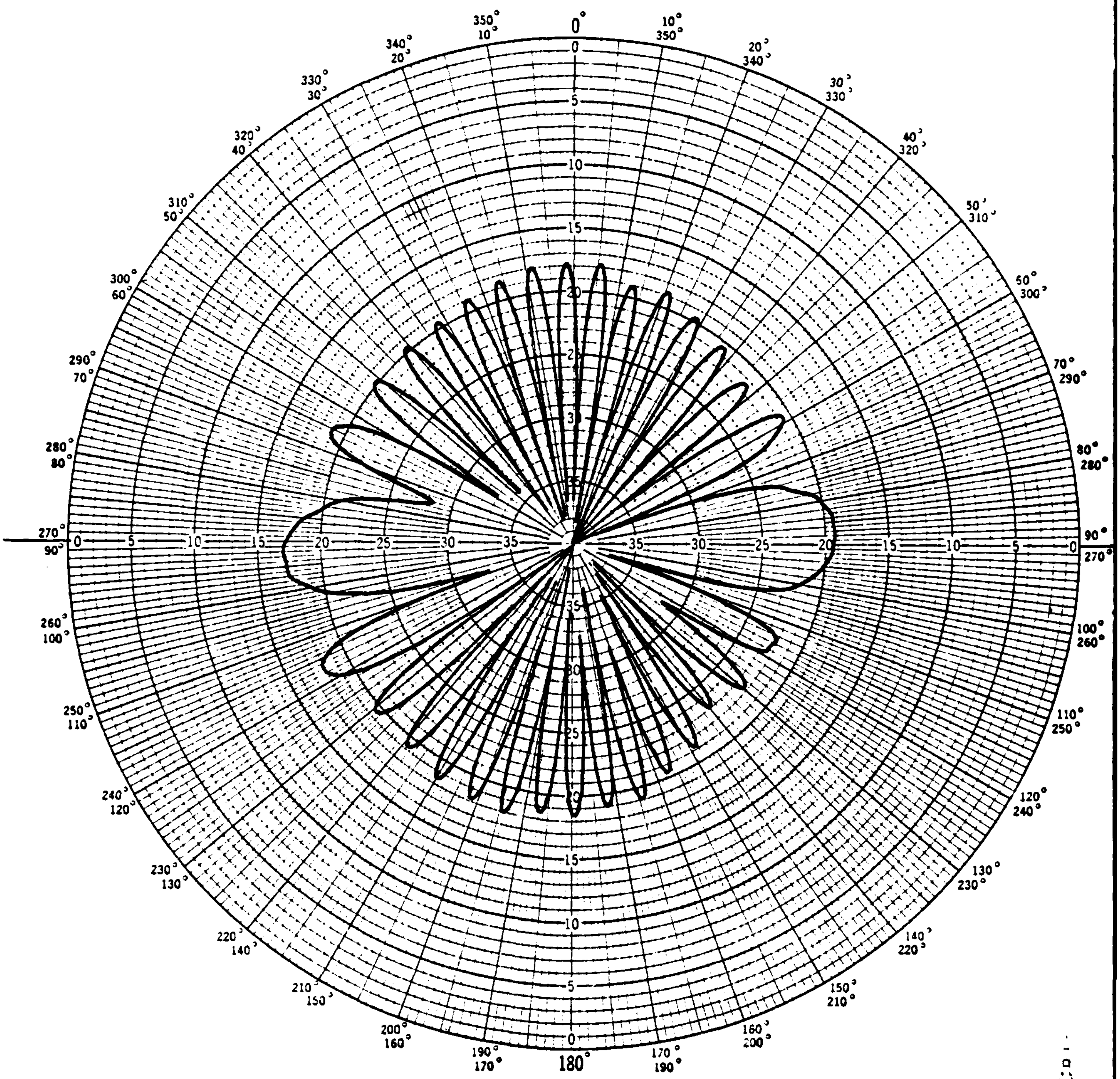

MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *11 GHz*
ANTENNA LOCATION ________ STATION ________
OPERATOR *L. SIMPSON* DATE *8-2-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *100°* Φ ( ) POLARIZATION *VERT.*
REMARKS *Ø REF = OY = 0°.*

Form 47-69 (R 9-72)

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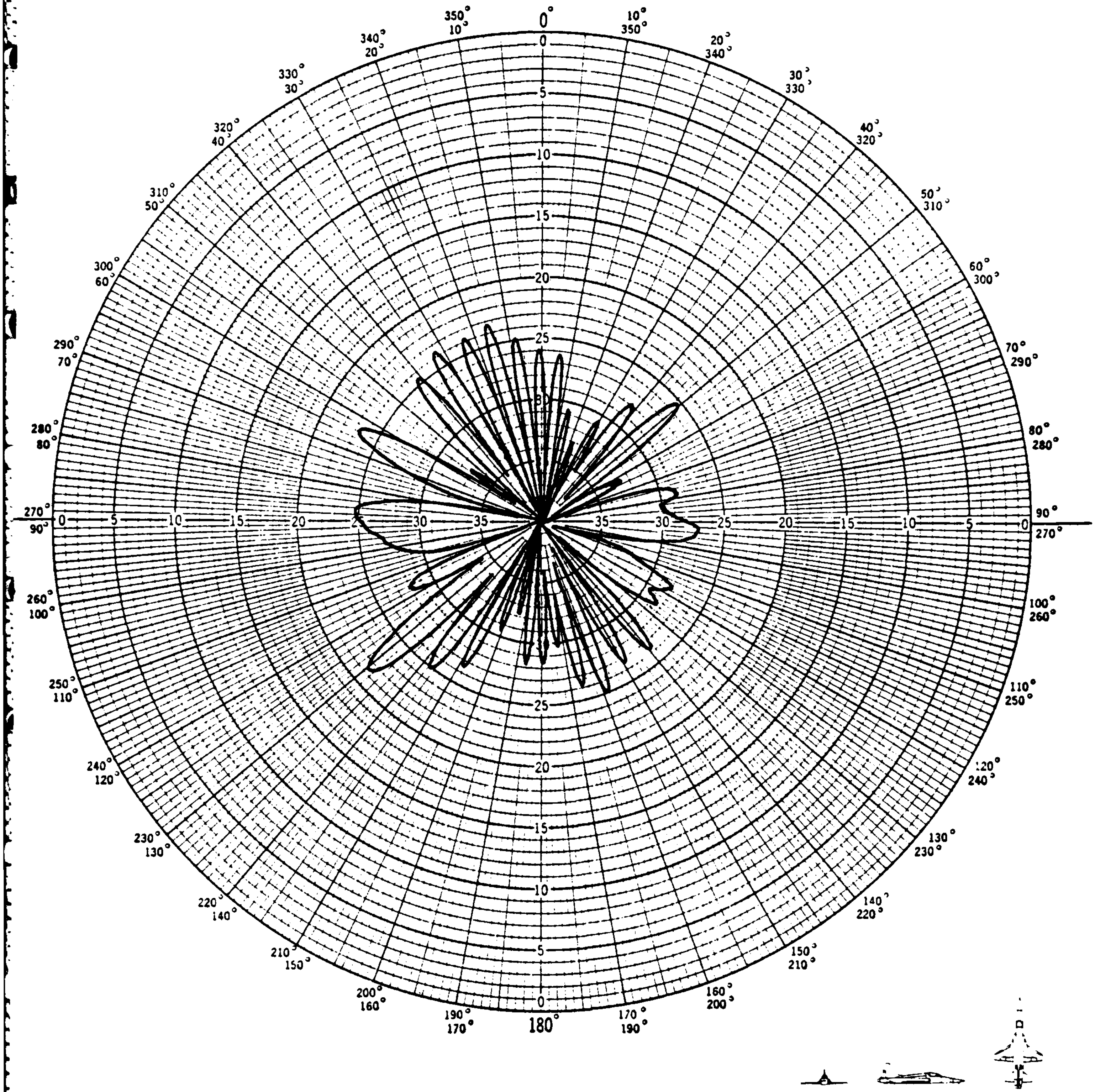

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83° Φ ( ) POLARIZATION HORIZ
REMARKS Ø REF = OY = 0°

Form 47-69 (R 9-72)

NORTHROP

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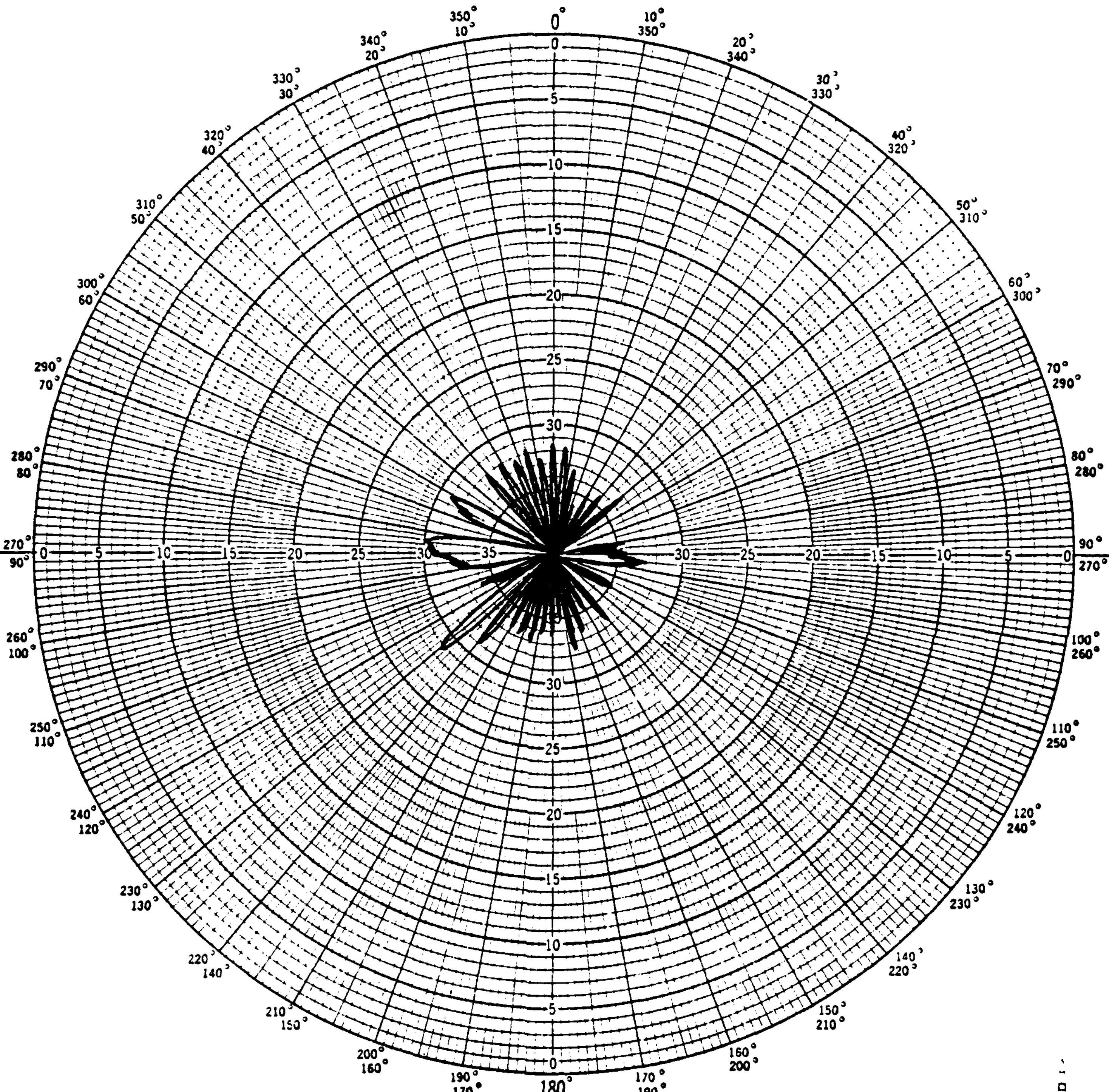

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION HORIZ
REMARKS ØREF = ØV = 0°

Form 47-69 (R 3-72)

NORTHROP
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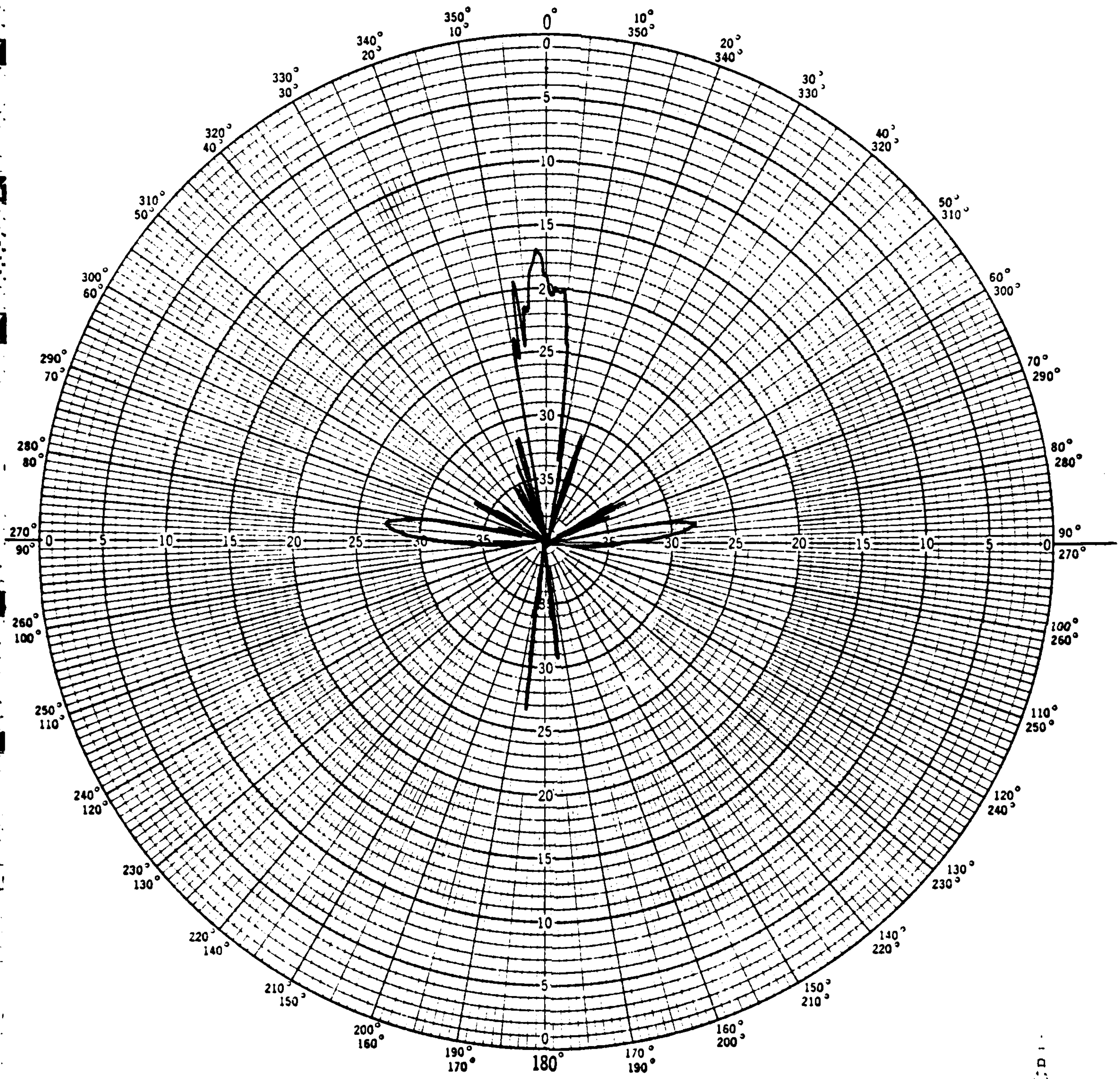
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-2-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ
REMARKS Ø REF = 0V = 0°

Form 47-69 (R 9-72)

NORTHROP
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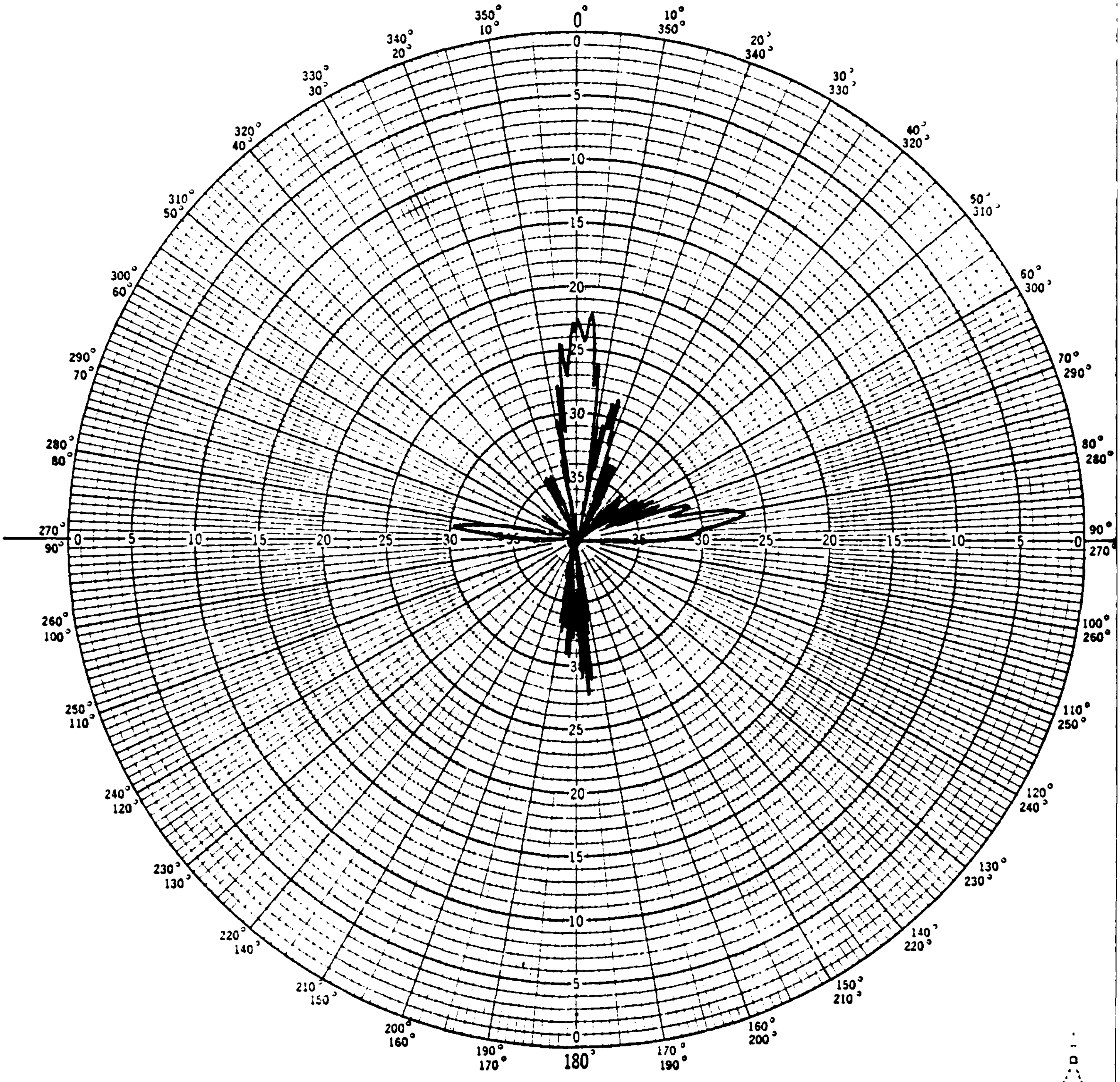
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 11 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 3-2-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ.
REMARKS Ø REF = 0V

Form 47-69 (R 9-72)

APPENDIX G

Dual Conical Monopole Antenna Patterns--13 GHz

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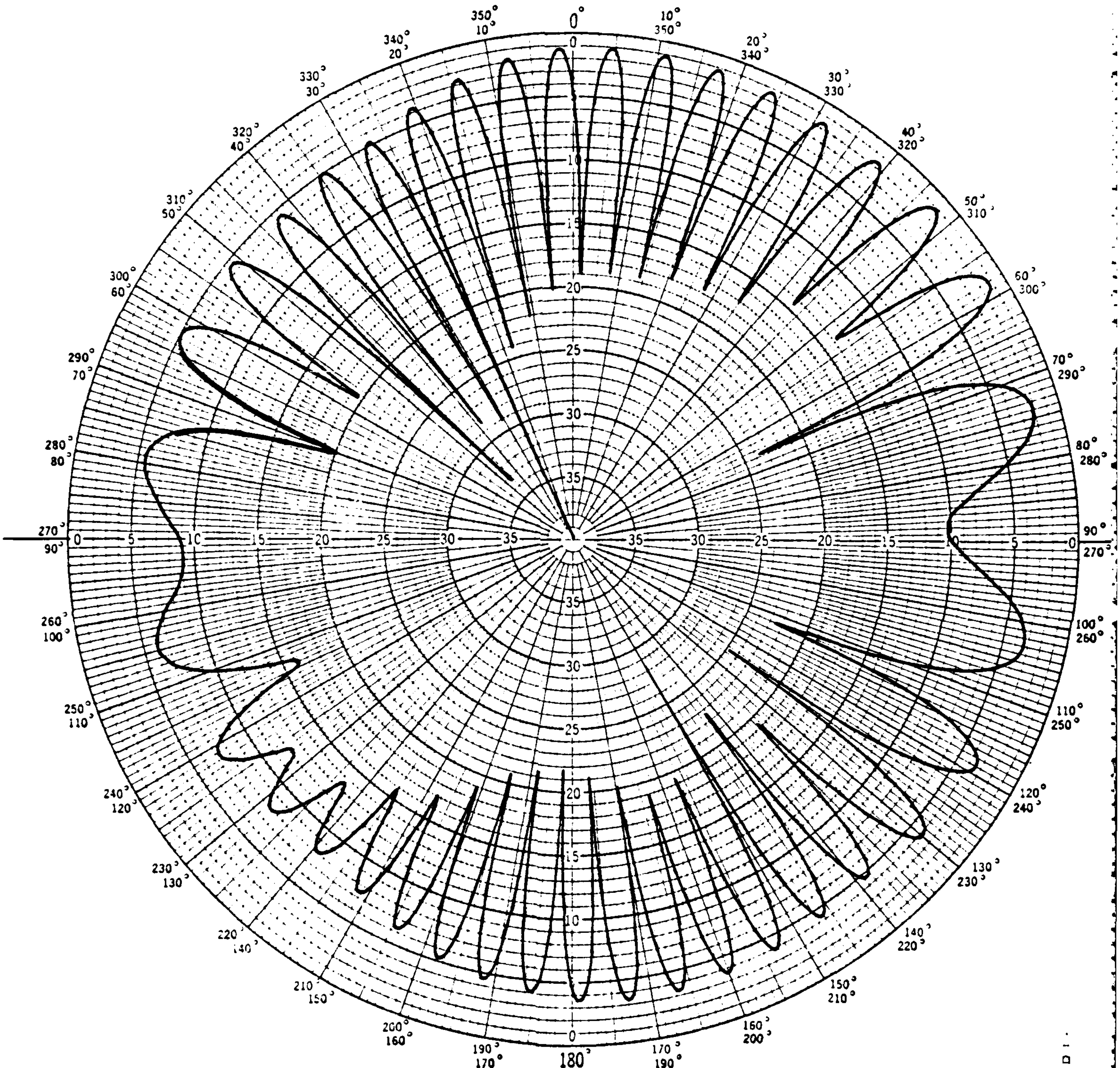
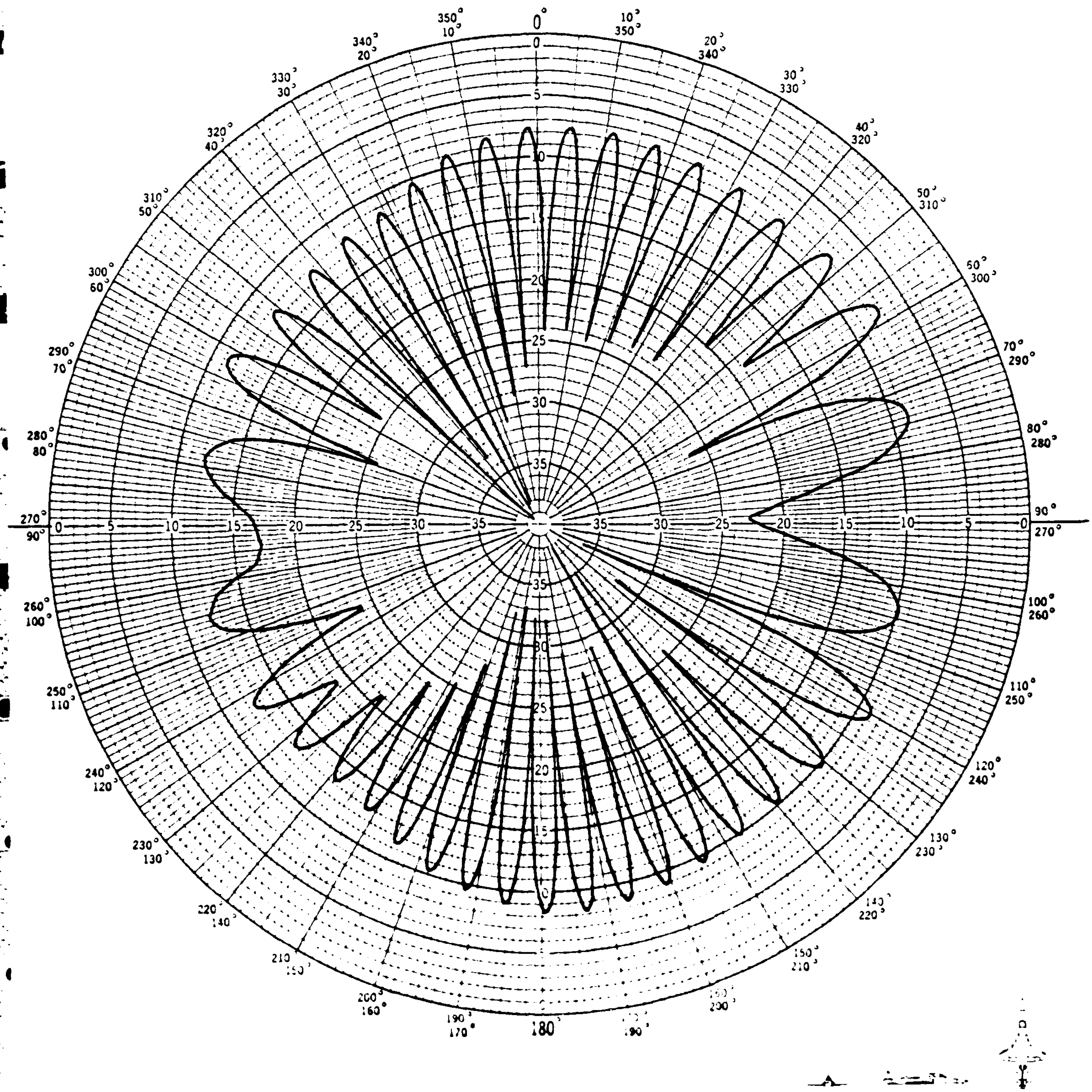


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz*
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-6-78
* 12.9948 GHz @ 2.41W/+33.8 dBm

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 83° ϕ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

Form 47-69 R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



MODEL TYPE 6 DIAM GND PLANE MODEL SCALE [illegible]
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY [illegible]
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE [illegible]
#12.9948 GHz ② 2 - N [illegible] +33.8 dBm

RADIATION PLOT OF THE ROLL PITCH YAW ✓
ARE PLOTTED IN VOLTAGE POWER DBS ✓
PATTERN 90° POLARIZATION VERT
REMARKS [illegible]

Form 47-69 (R 3-72)

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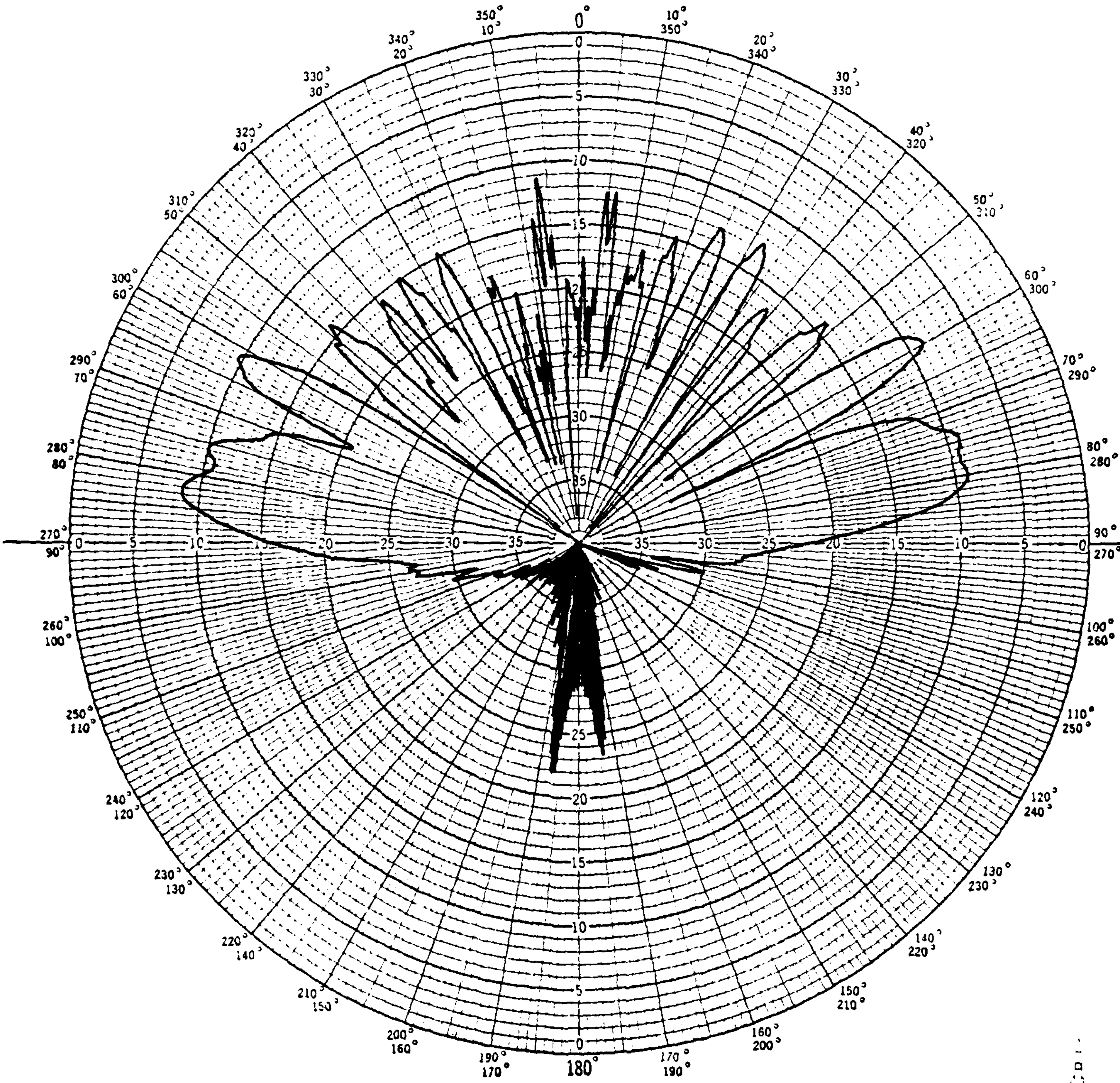
Aircraft Division



MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *13 GHz**
ANTENNA LOCATION ____ STATION ____
OPERATOR *L. SIMPSON* DATE *3-6-78*
** 12.9949 GHz*

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION *VERT*
REMARKS *[illegible] = 0 γ = 0°*

Form 47-69 (R 9-72)

NORTHROP
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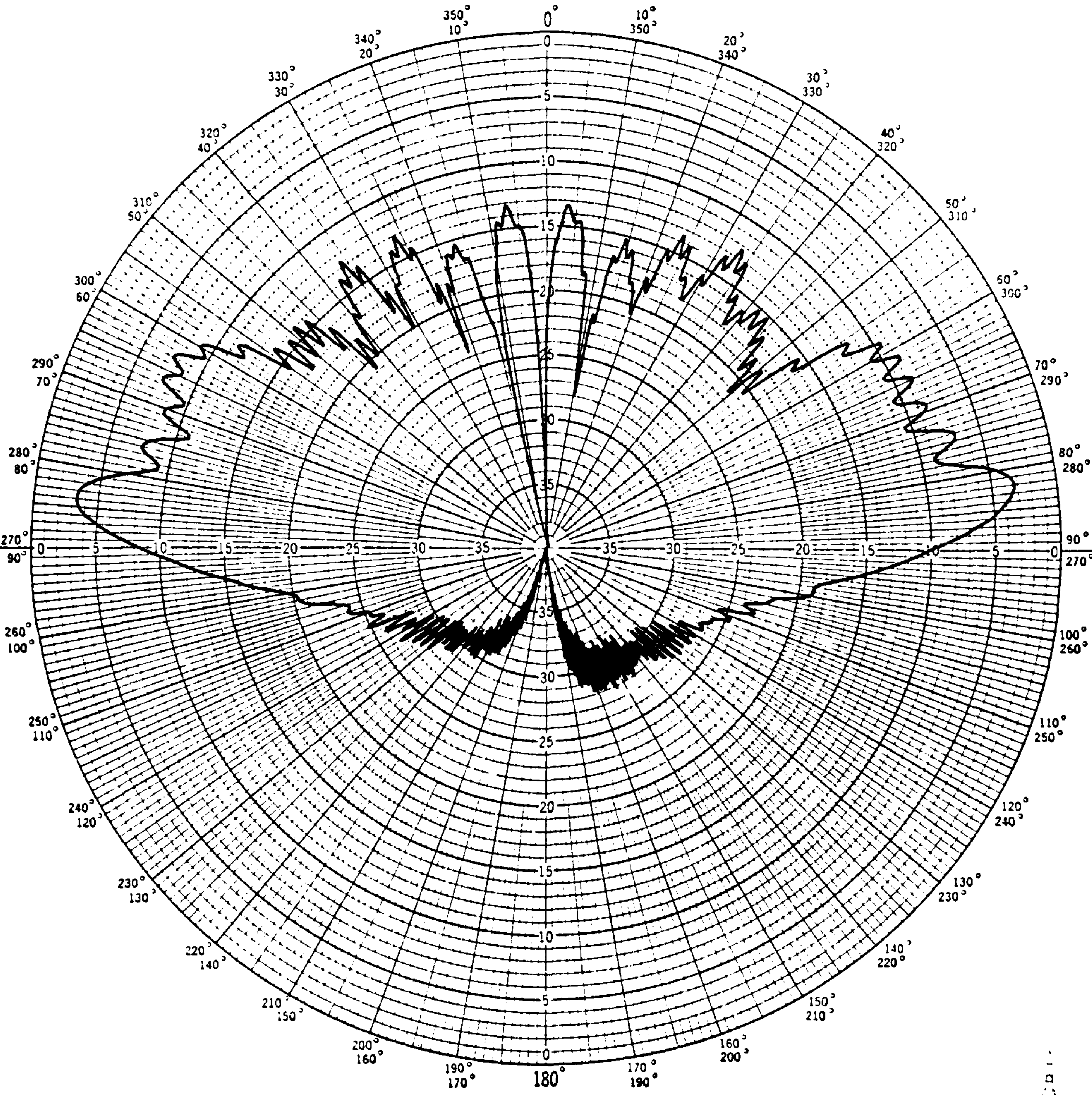
Aircraft Division



MODEL TYPE 5' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = ØY = 0°

Form 37-69 (R 9-72)

NORTHROP
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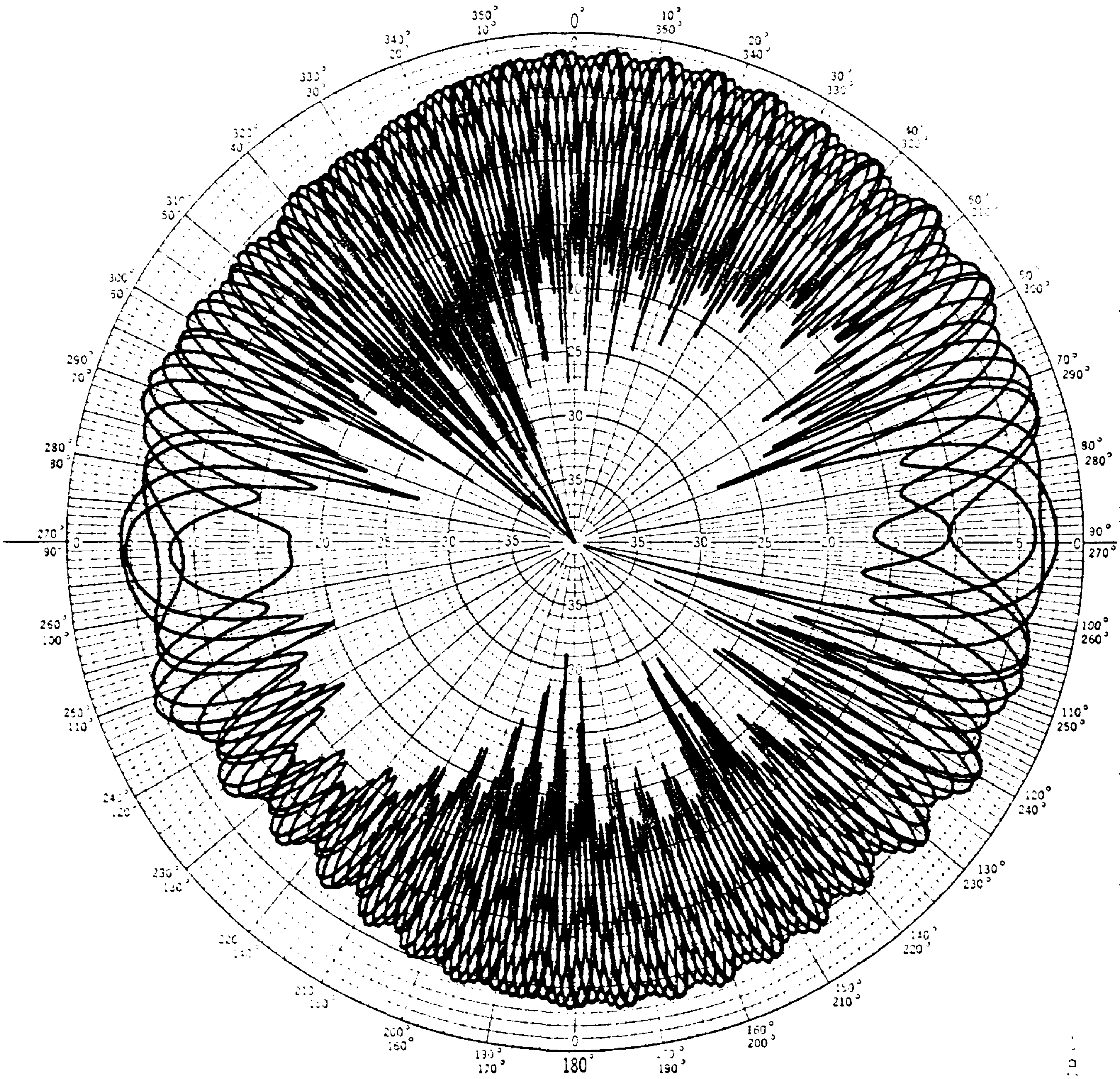
Aircraft Division



MODEL TYPE 6 DAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-6-73

RADIATION PLOT OF THE ROLL PITCH YAW ✓
CURVE PLOTTED IN VOLTAGE POWER DBS ✓
PATTERN A 33° POLARIZATION VERT
REMARKS ØREF = 0, .6V, 1.2V, 1.8V, 2.4V, 3.2V

FORM 47-63 R 3-72

NORTHROP
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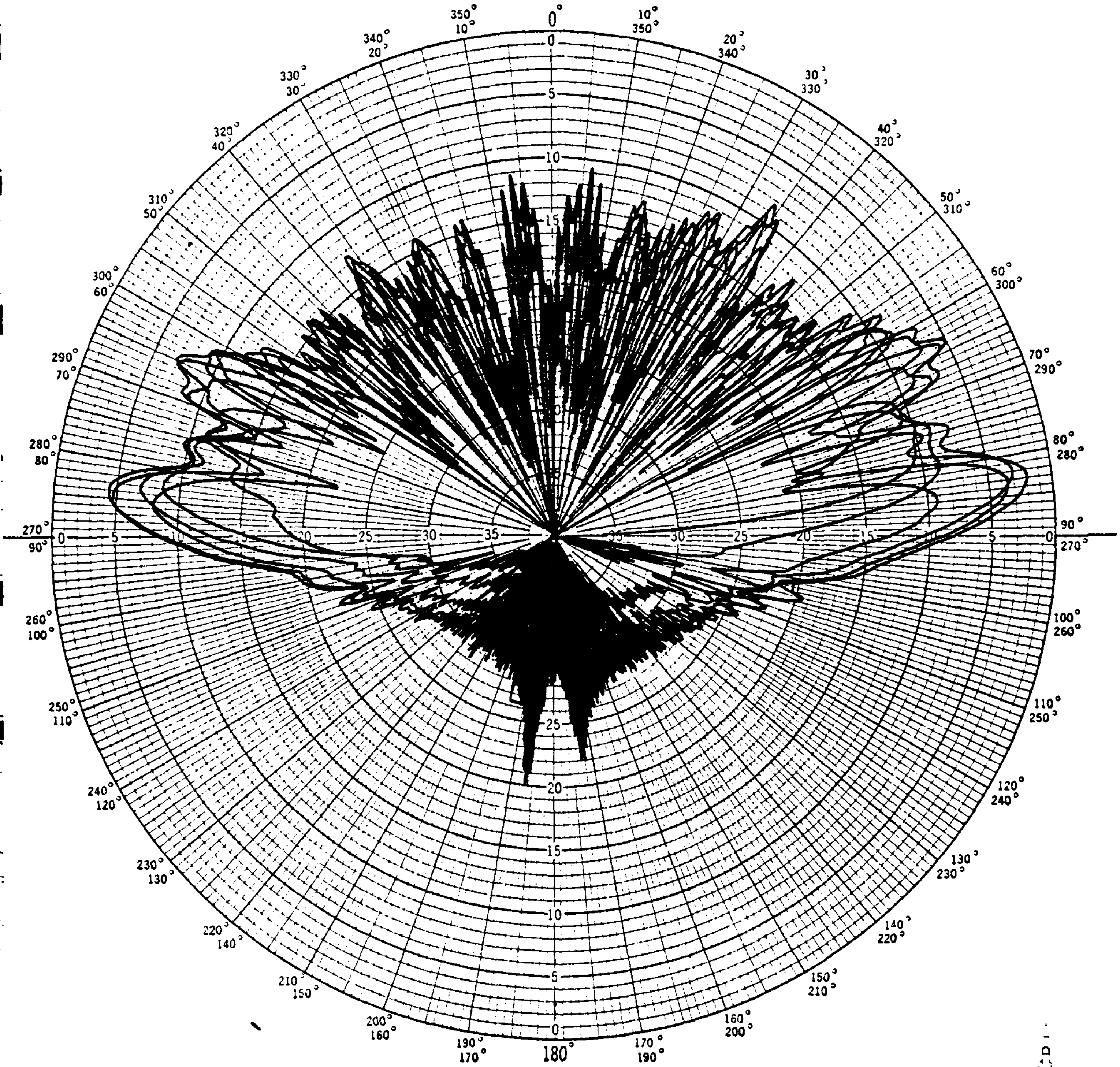

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V, .6V, 1.2V, 1.8V, 2.4V, 3.0V.

Form 47-69 (R 9-72)

NORTHROP
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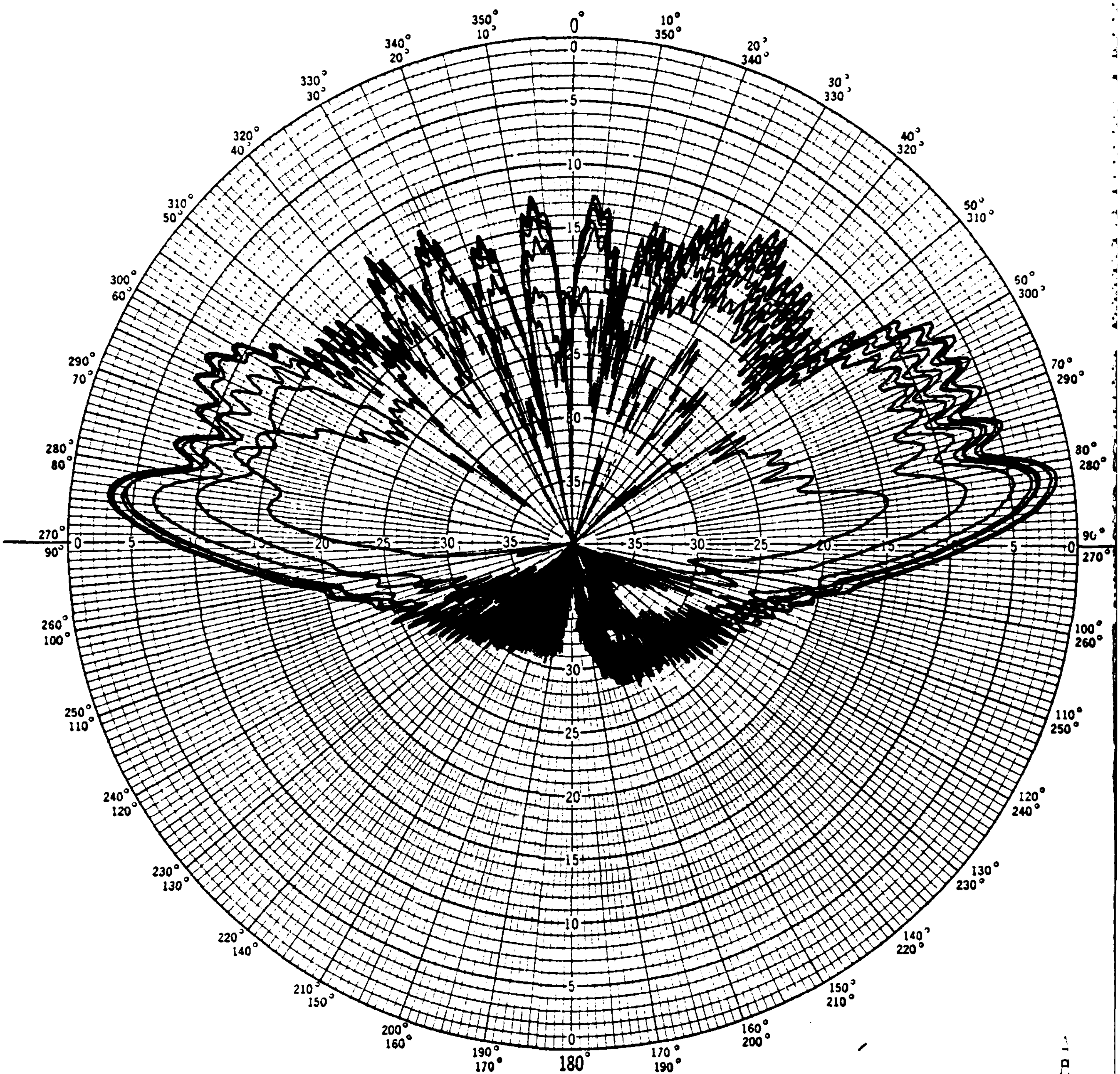

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz *
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-6-78
* 12.9945 GHz

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT.
REMARKS Ø REF = 0V, .6V, 1.2V, 1.8V, 2.4V, 3.0V, 3.3V, .9V,

Form 47-69 (R 9-72)

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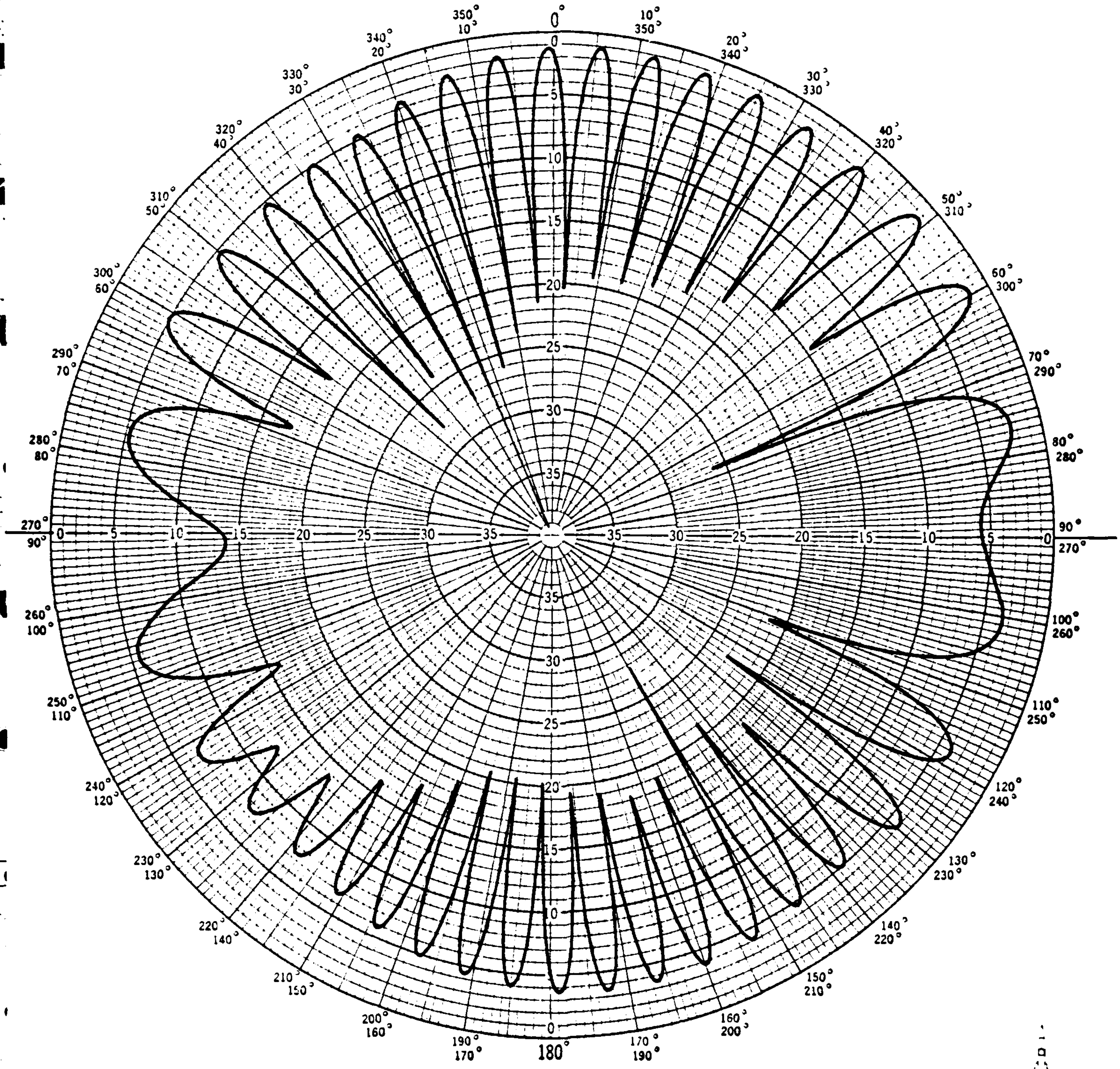

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 83° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0.3V = -24.4°

Form 47-69 (R 3-72)

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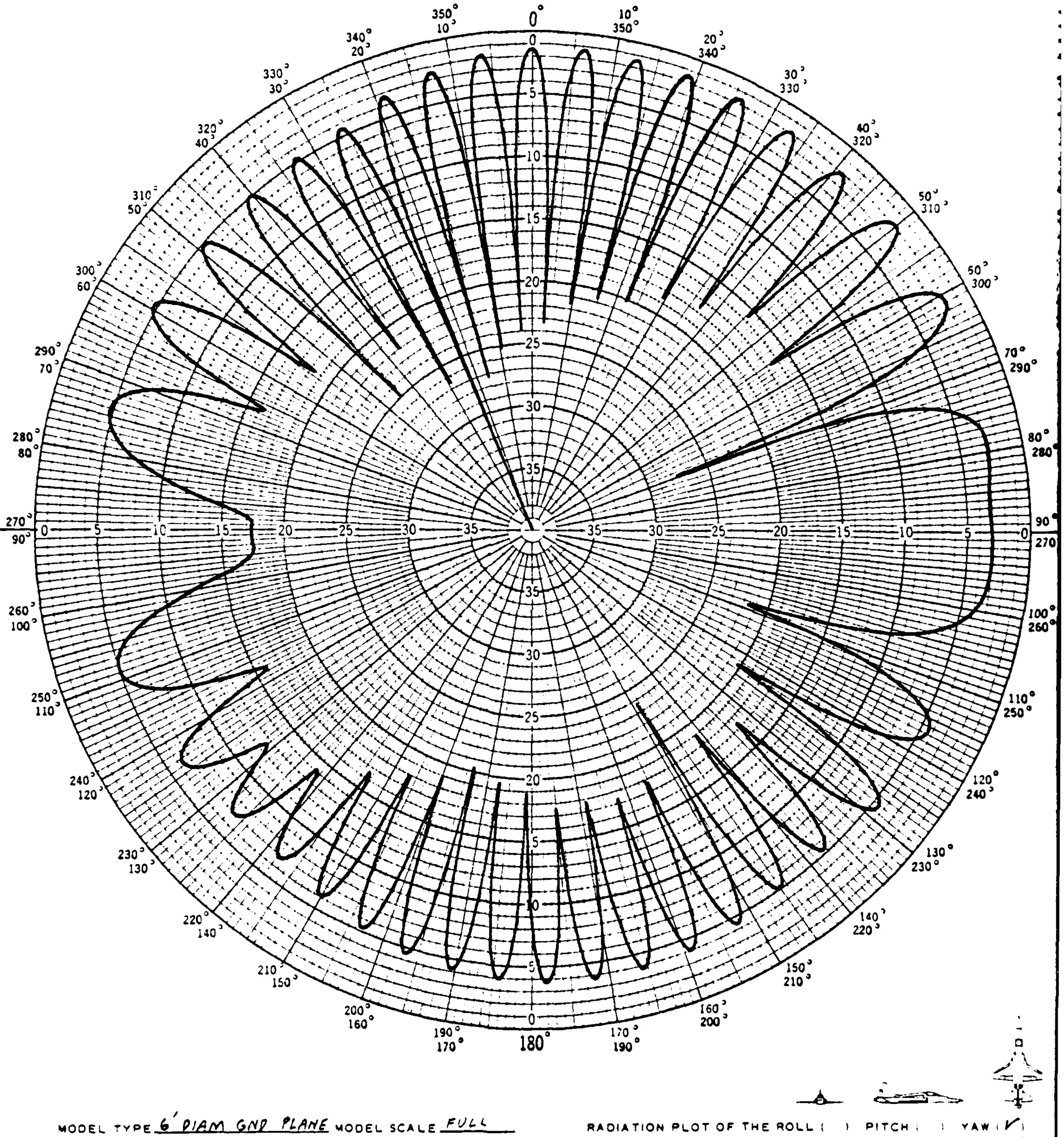

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz

ANTENNA LOCATION ____________ STATION ________

OPERATOR L. SIMPSON DATE 9-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ 83° Φ ( ) POLARIZATION VERT

REMARKS ØREF = 0.6V = -53.3°

Form 47-69 (R 9-72)

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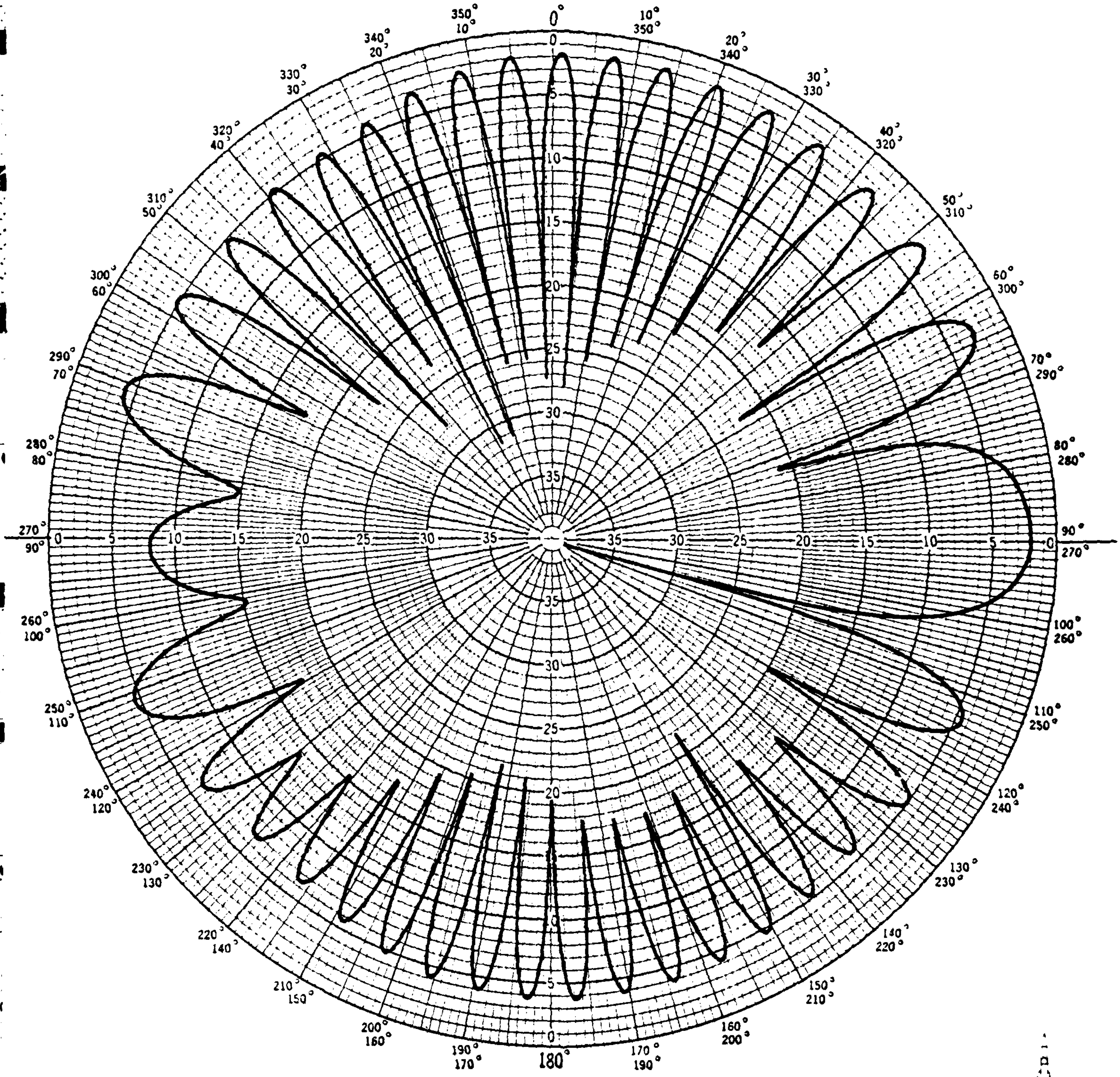
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 1839 Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 1.2 V = -116.3°

Form 47-69 (R 9-72)

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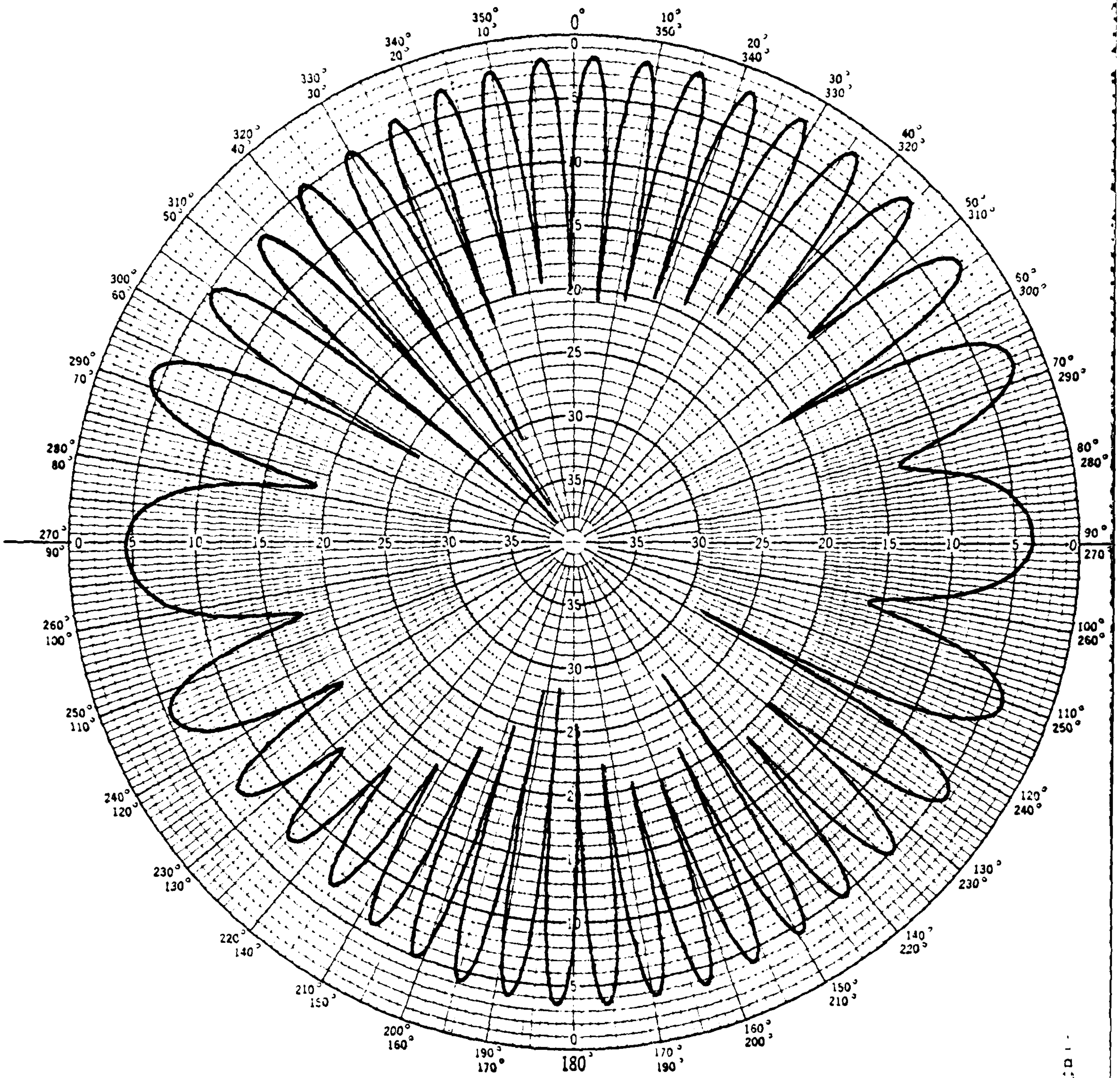

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 9-6-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ✓
PATTERN θ 183° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 1.8 V = -176.8°

Form 47-63 (R 3-72)

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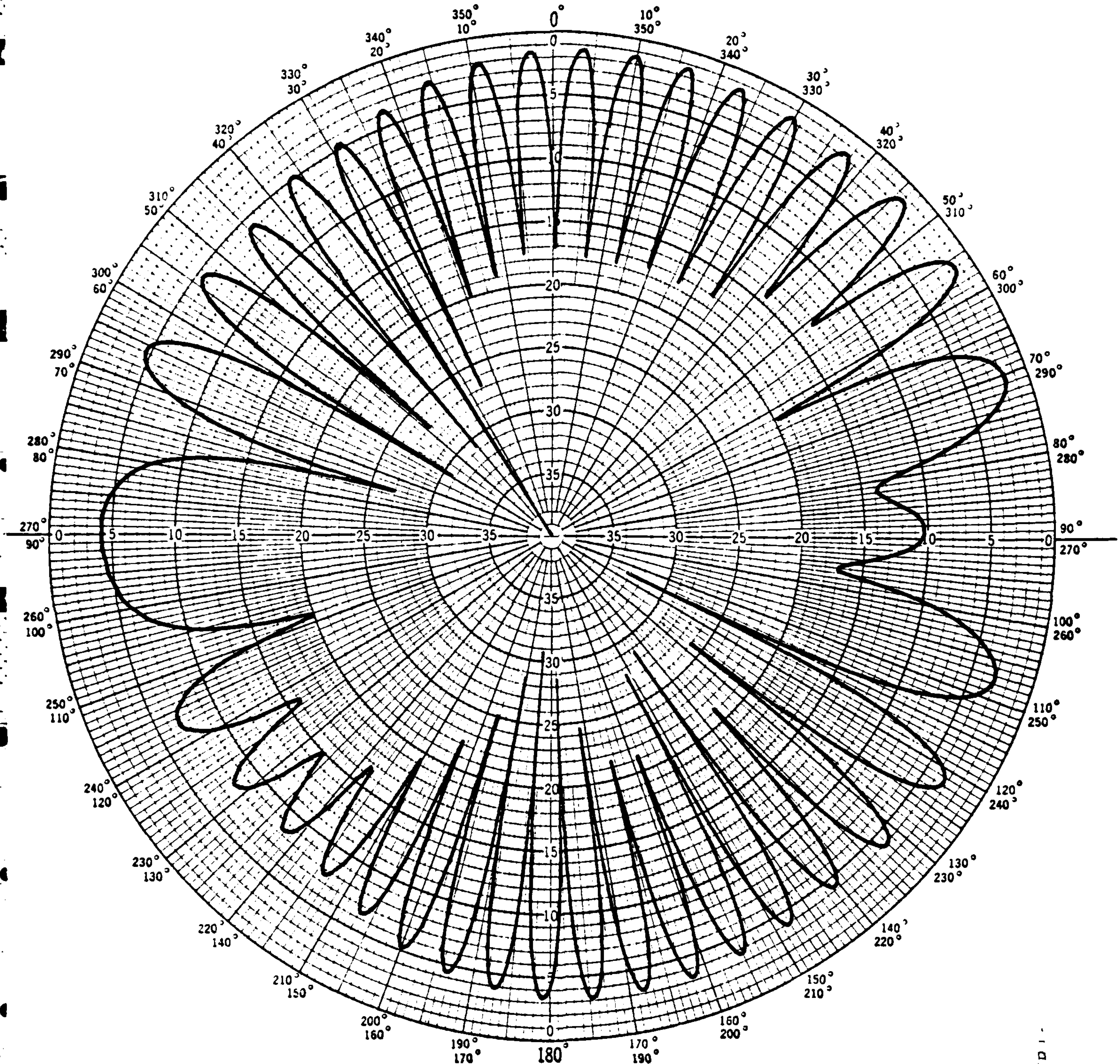
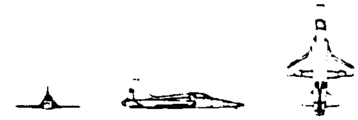
Aircraft Division





MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *13 GHz*
ANTENNA LOCATION ________ STATION ________
OPERATOR *L. SIMPSON* DATE *8-6-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *83°* Φ ( ) POLARIZATION *VERT*
REMARKS *ØREF = 2.4V = -237.8°*

Form 47-69 (R 9-72)

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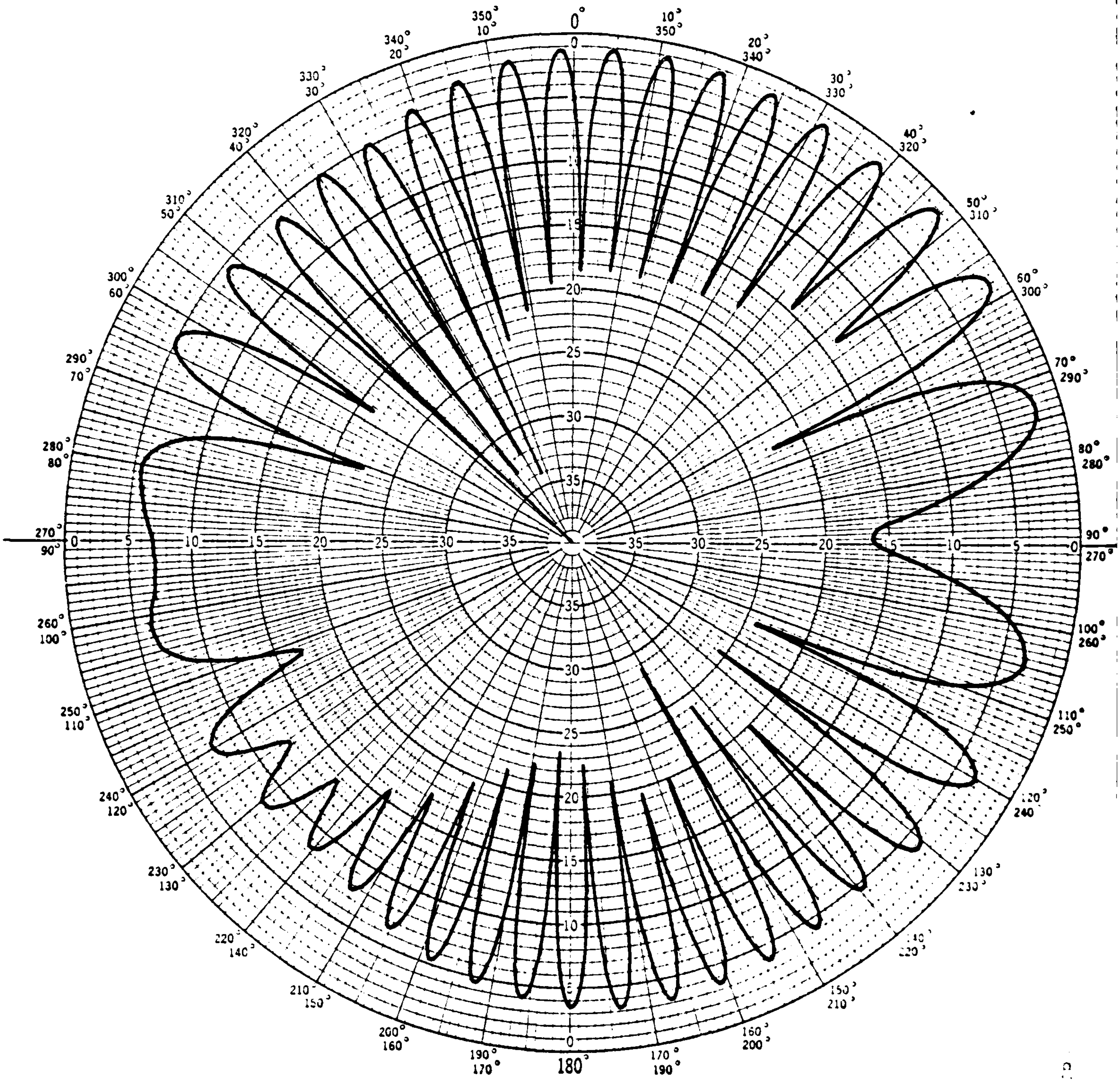

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL PITCH YAW ✓
CURVE PLOTTED IN: VOLTAGE POWER DBS ✓
PATTERN θ 83° φ POLARIZATION VERT
REMARKS ØREF = 3.0V = -299.4°.

Form 47-69 (R 9-72)

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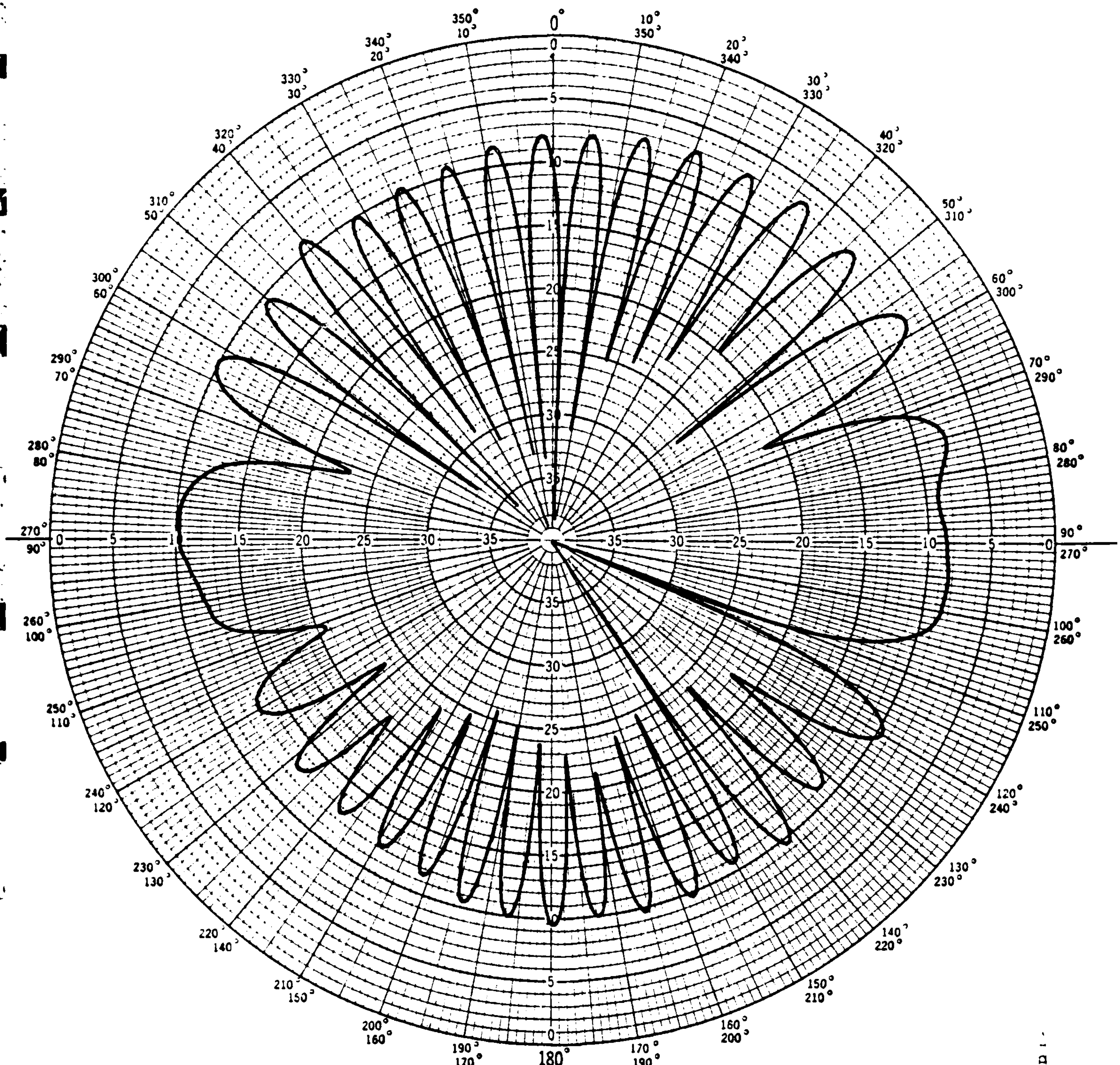

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (60°) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0 Y = 0°

Form 47-69 (R 9-72)

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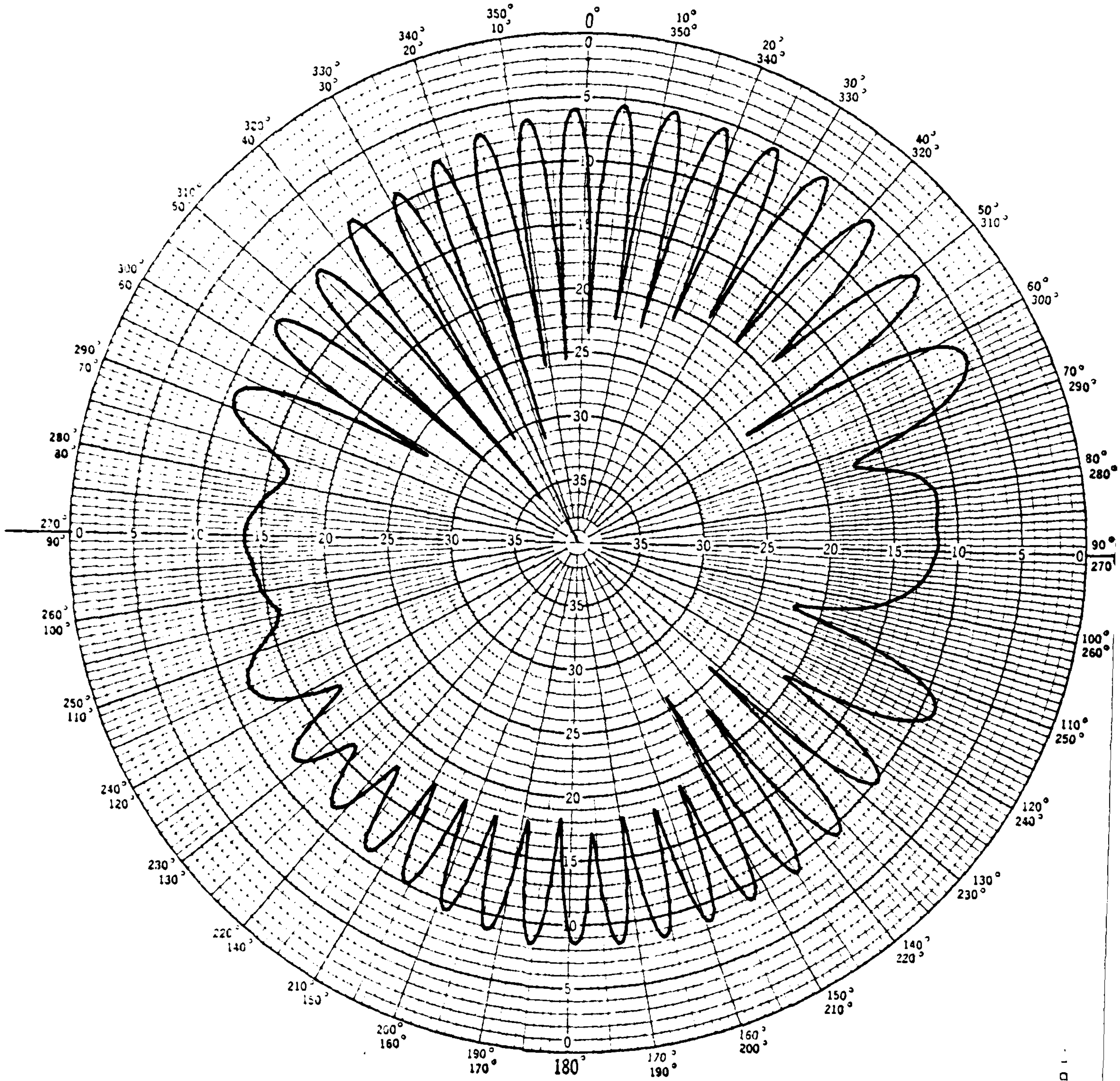
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 3-6-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (70° Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0V = 0°

Form 47-69 (R 9-72)

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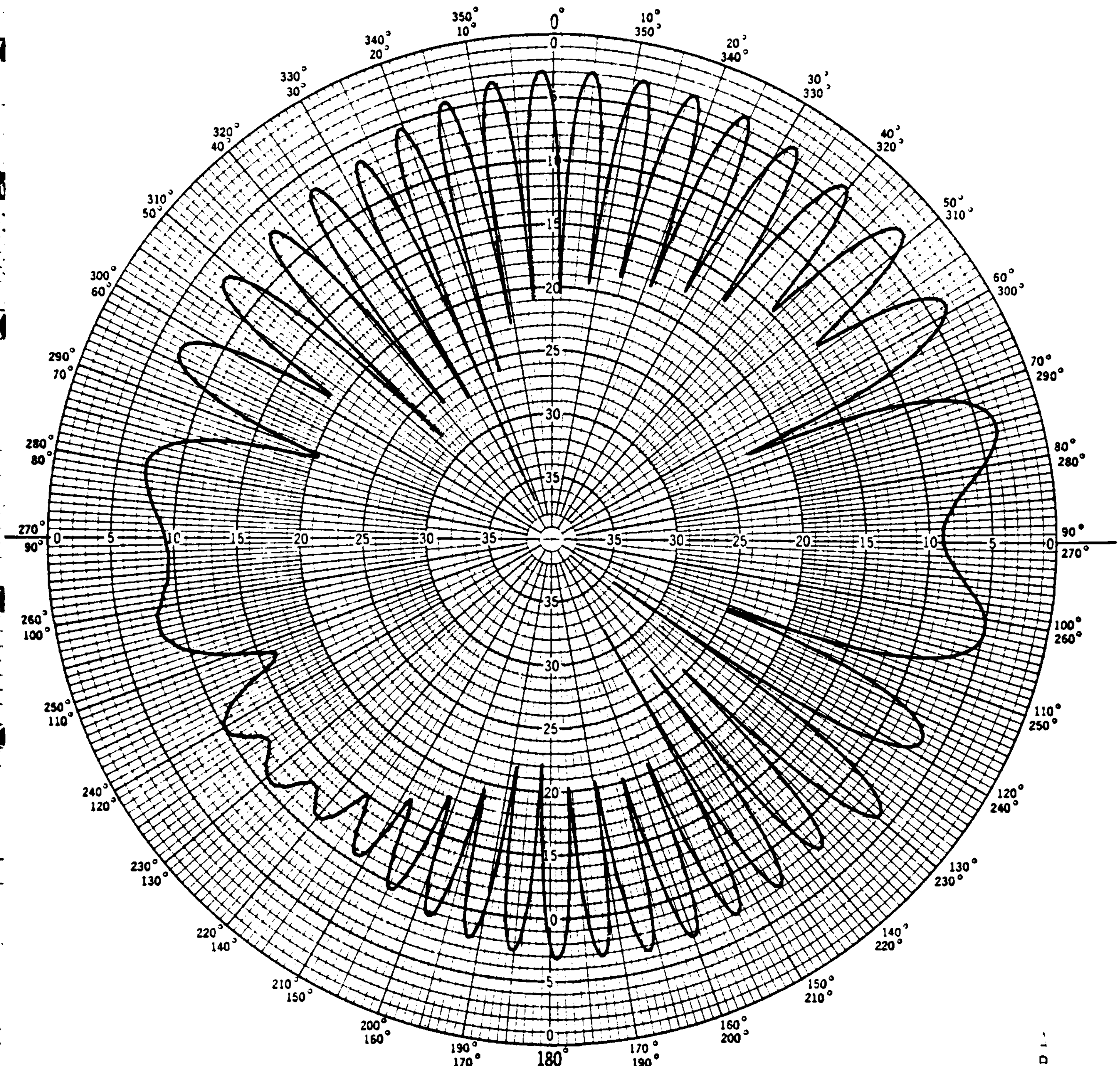
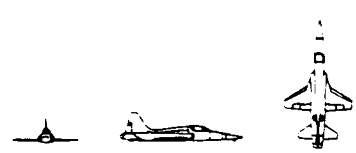
Aircraft Division





MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz *
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-6-78
* 12.9948 GHz
Form 47-69 (R 9-72)

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 180° Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV = 0°

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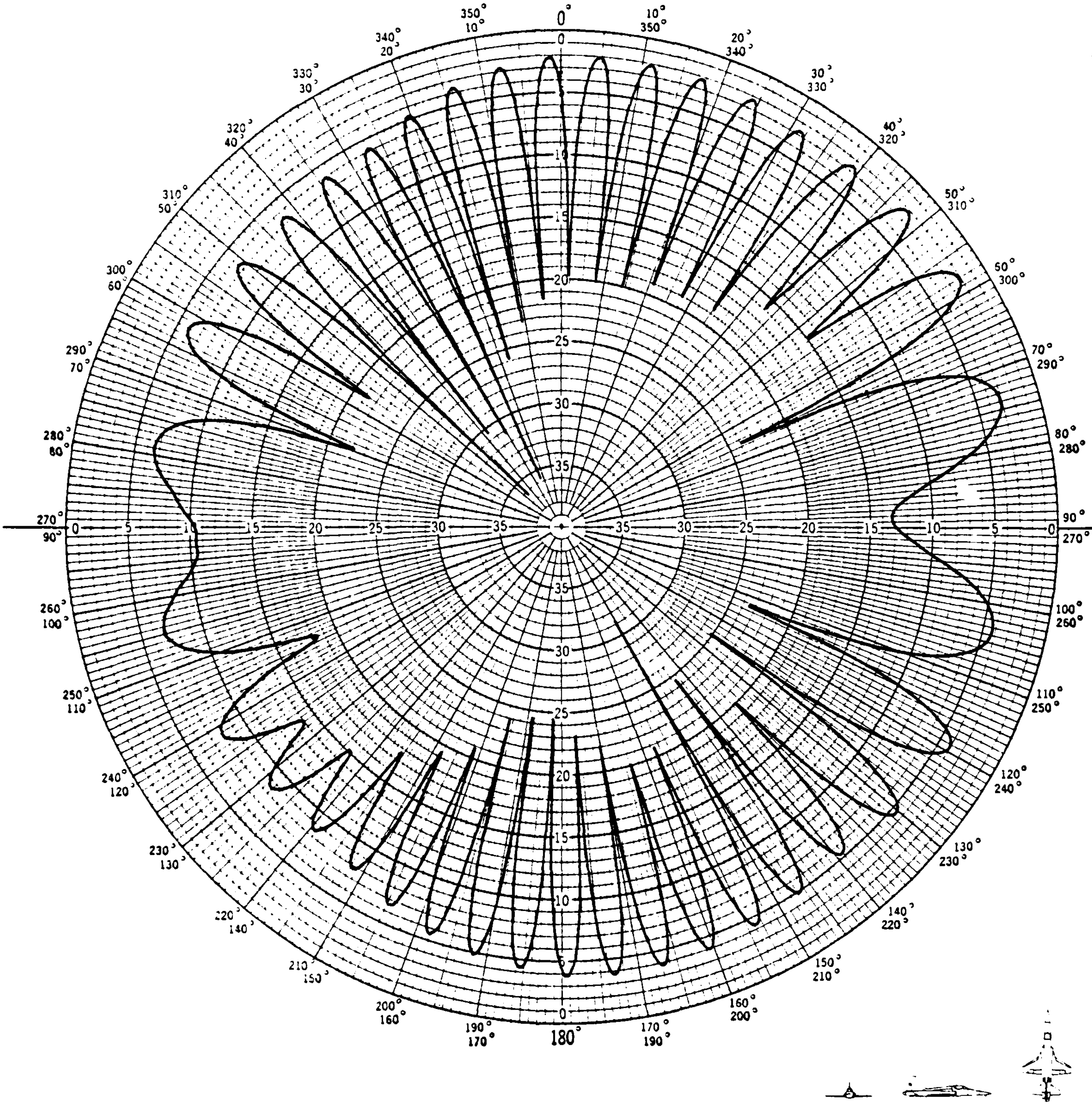

MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13GHz *
ANTENNA LOCATION ______ STATION ______
OPERATOR - SIMPSON DATE 8-6-78
* 2.9945 GHz

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (85° Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV=0°

Form 47-59 (R 9-72)

NORTHROP

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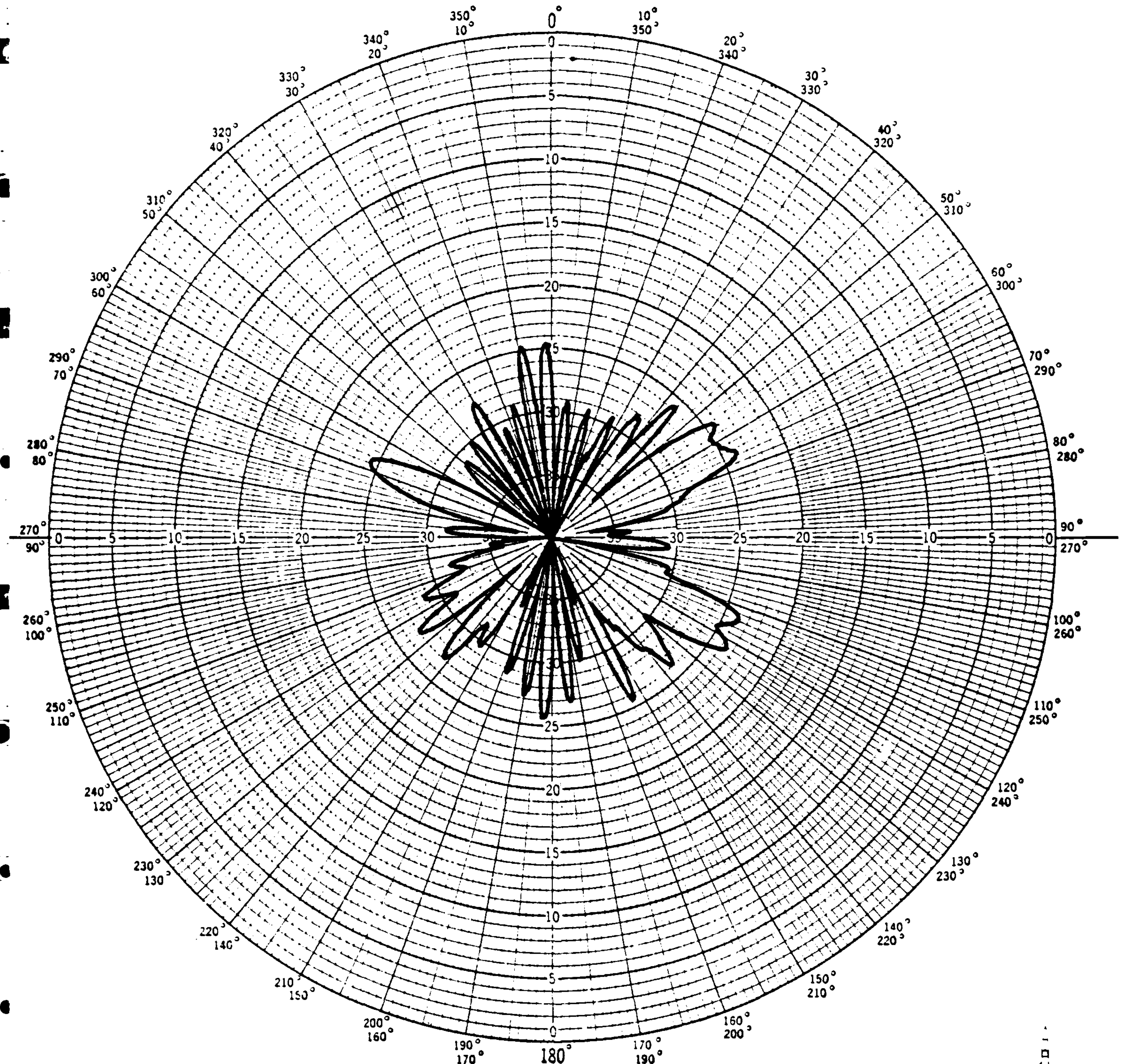
Aircraft Division



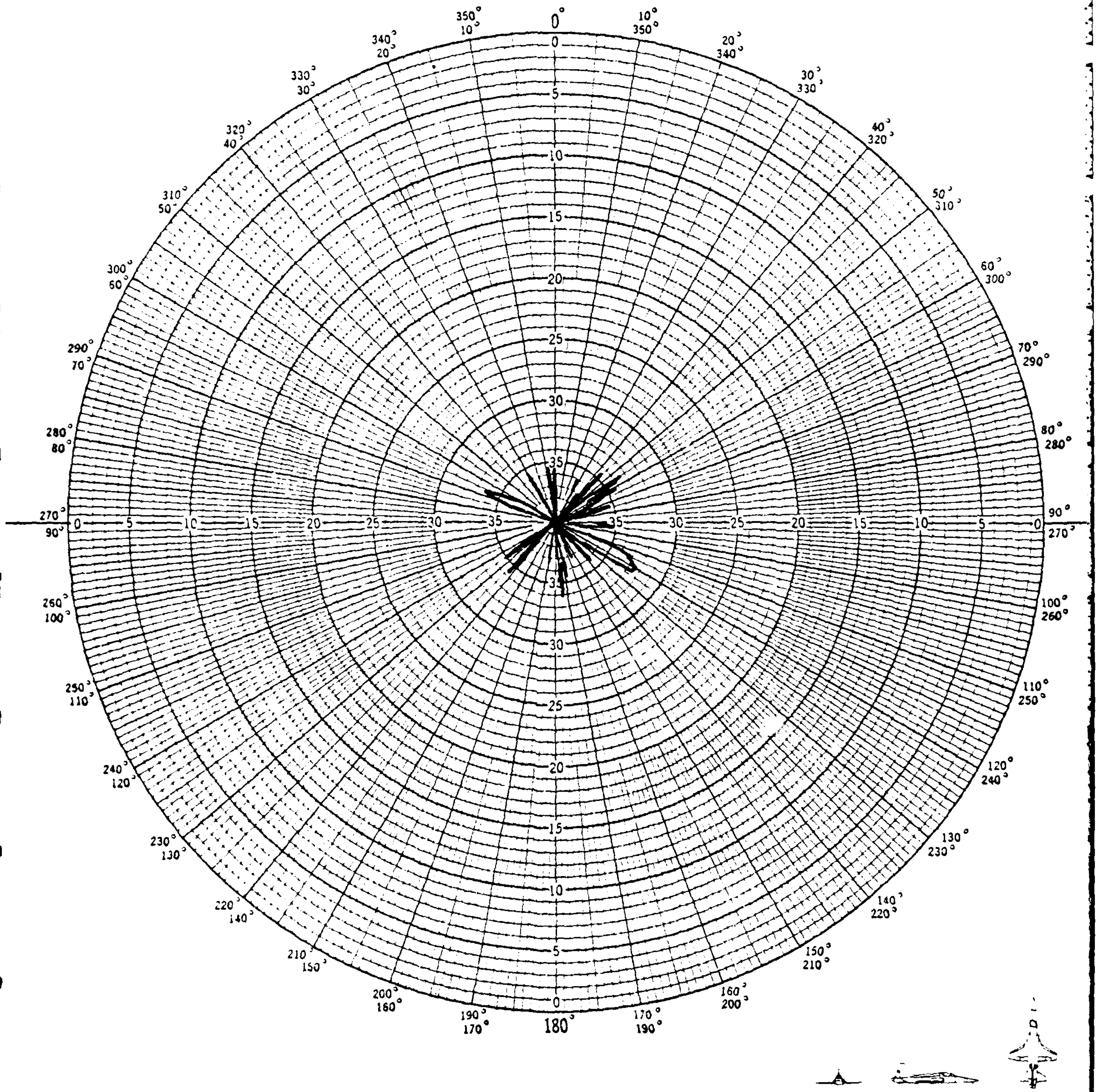
MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *13 GHz*
ANTENNA LOCATION ______ STATION ______
OPERATOR *L. SIMPSON* DATE *8-6-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ *1839* Φ ( ) POLARIZATION *HORIZ*
REMARKS *ØREF = ØV = 0°*

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE 2UA. CONICAL MODEL FREQUENCY 13 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L. SIMPSON DATE 8-6-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

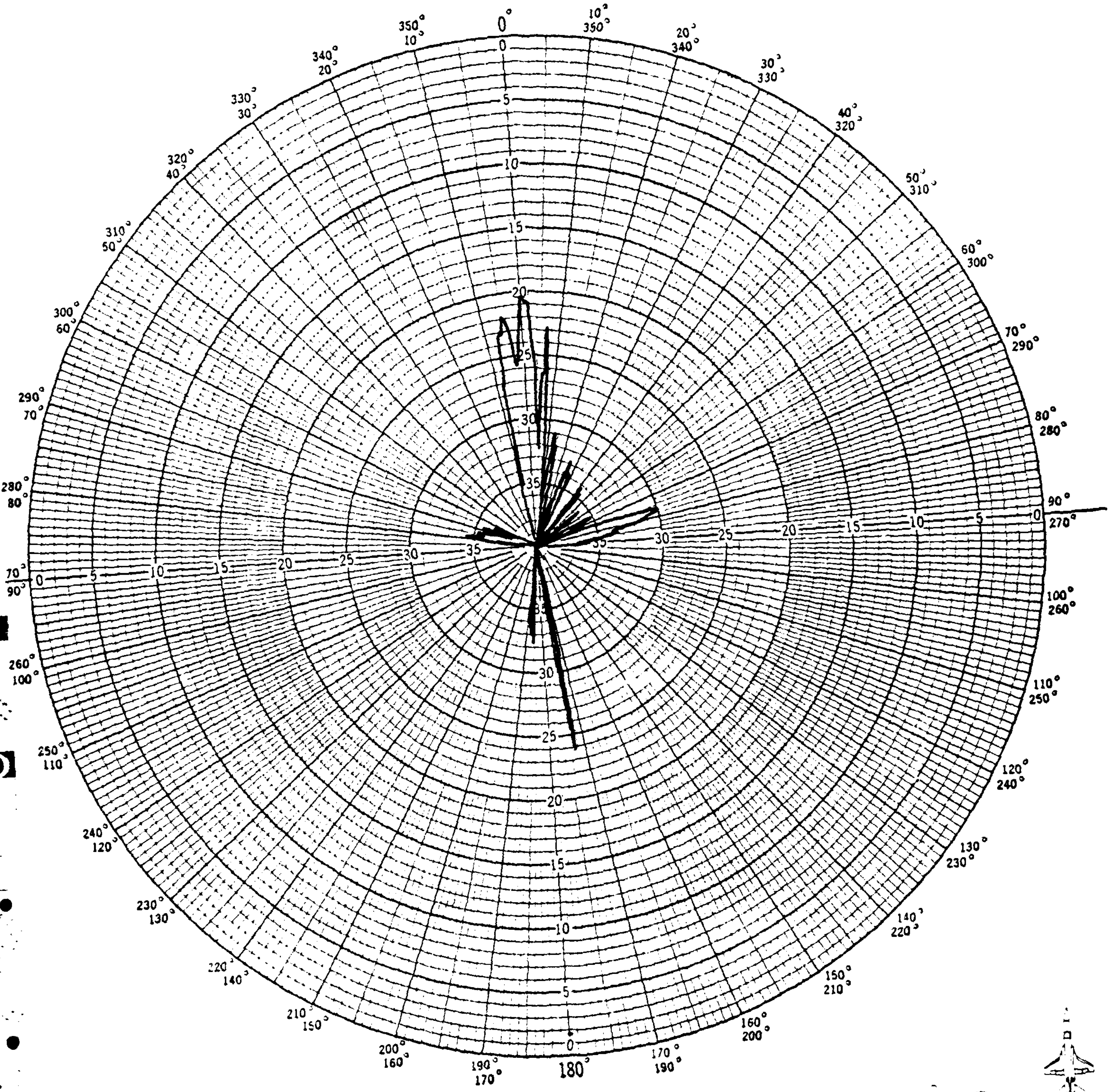
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ (90° Φ ( ) POLARIZATION HORIZ

REMARKS ØREF = 0 V=2°.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



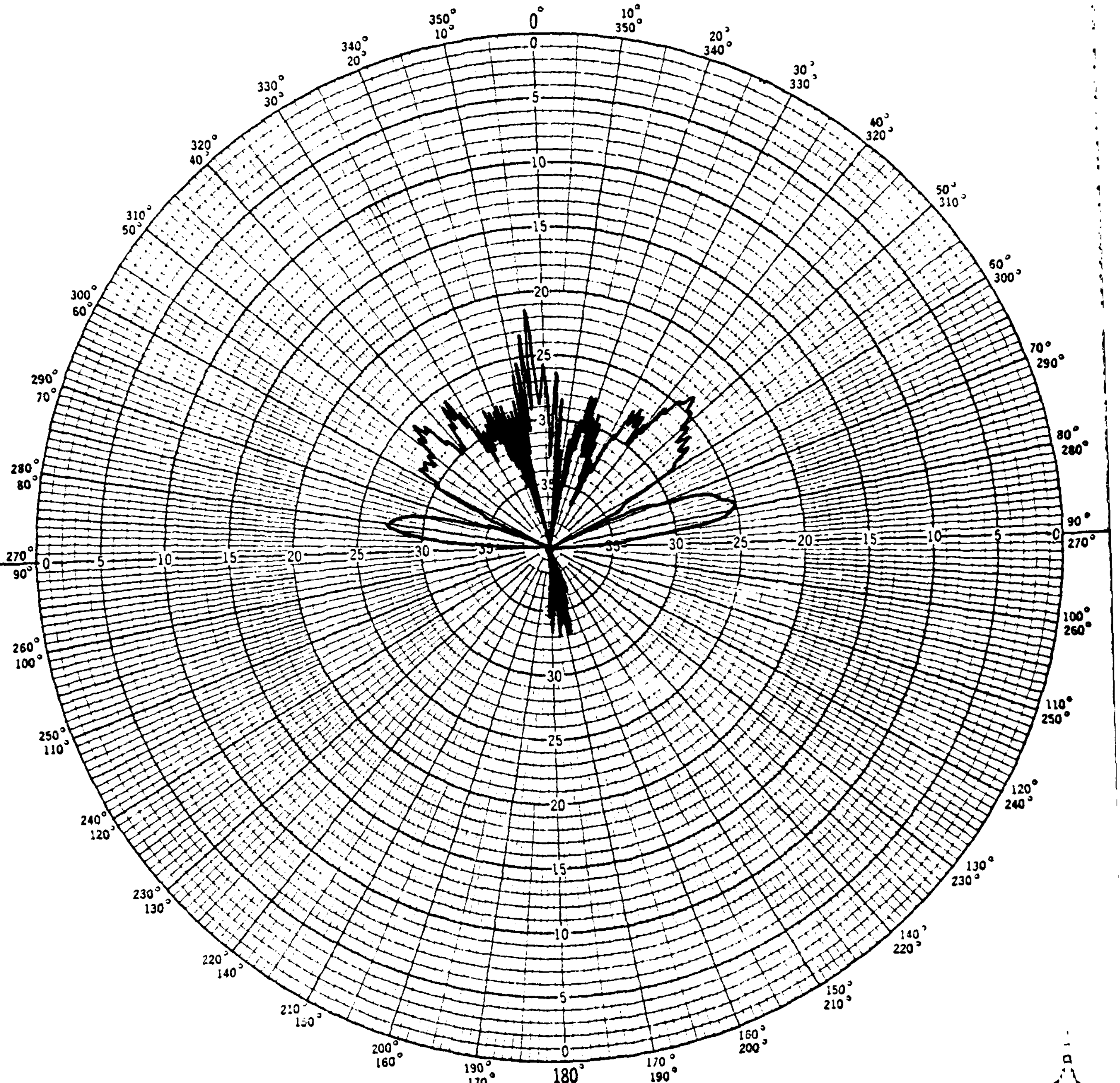
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ
REMARKS Ø REF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 13 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-6-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS ( )
PATTERN θ ( ) ϕ ( ) POLARIZATION HORIZ
REMARKS Ø REF = ΘV = 0°

Form 47-69 (R 9-72)

APPENDIX H

Dual Conical Monopole Antenna Patterns--15 GHz

NORTHROP
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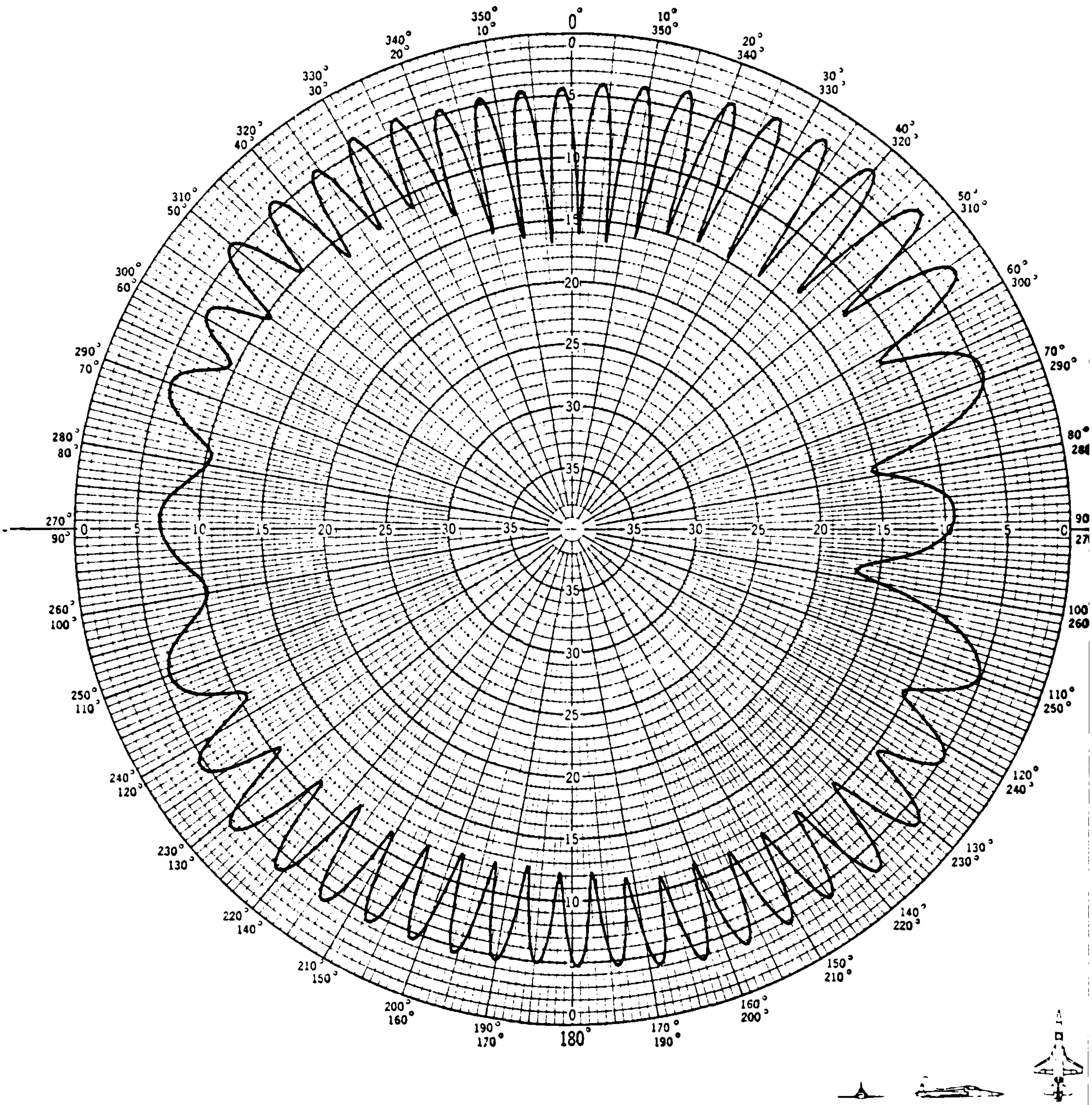
Aircraft Division



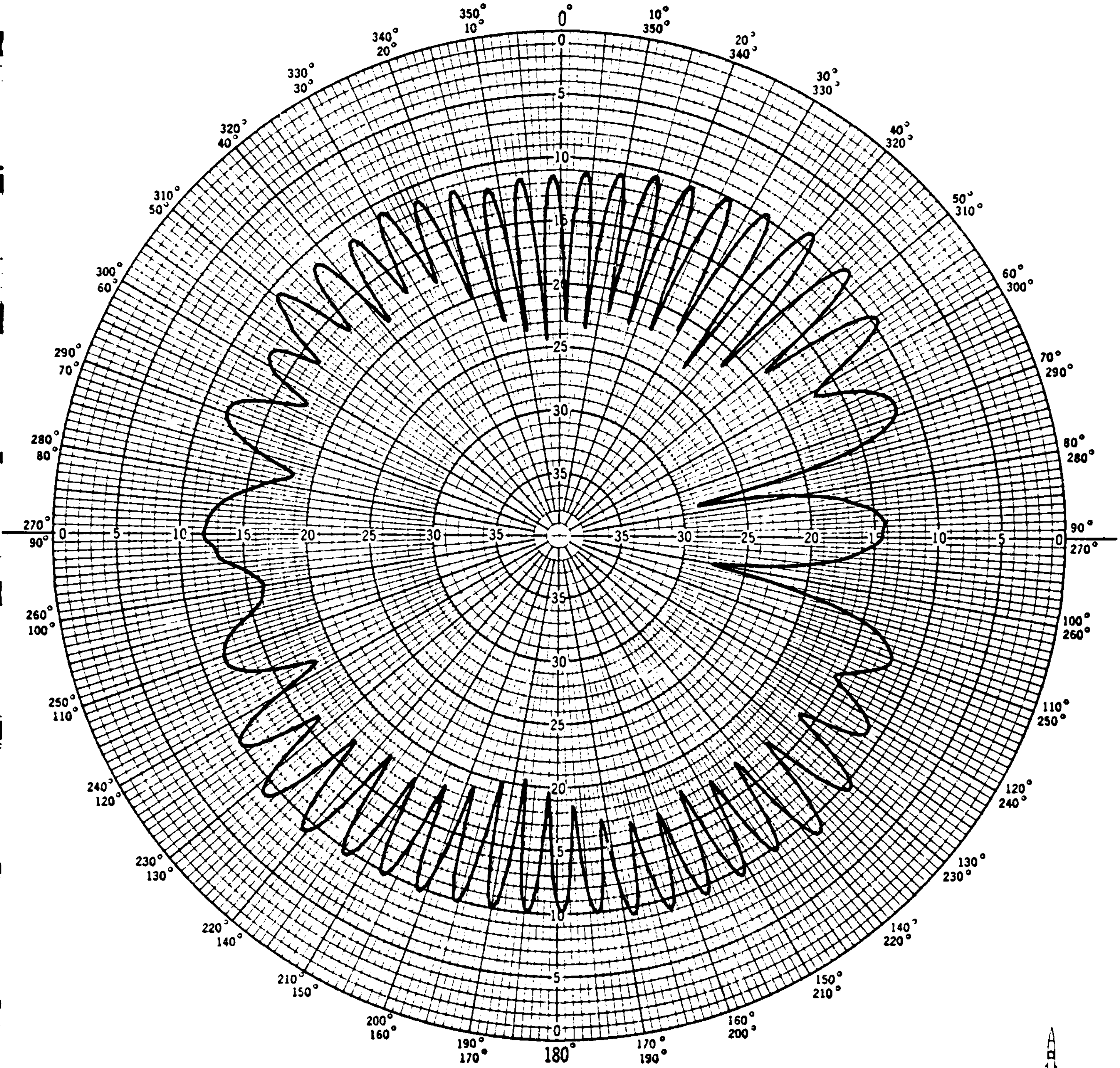
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz *
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78
* 15,000 GHz.

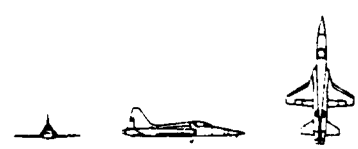
RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0, = 0°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



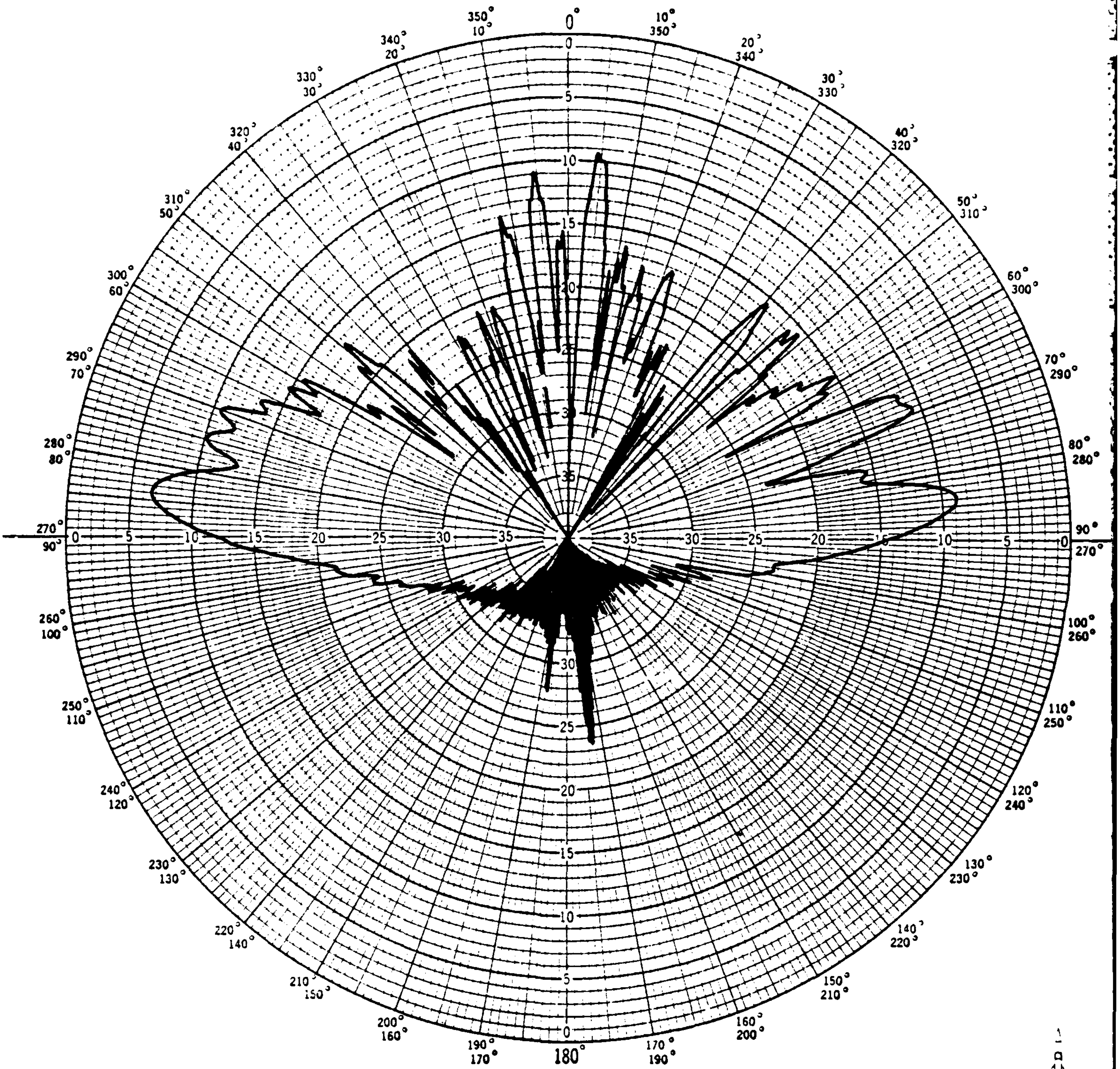


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 3-3-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = ØV = 0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

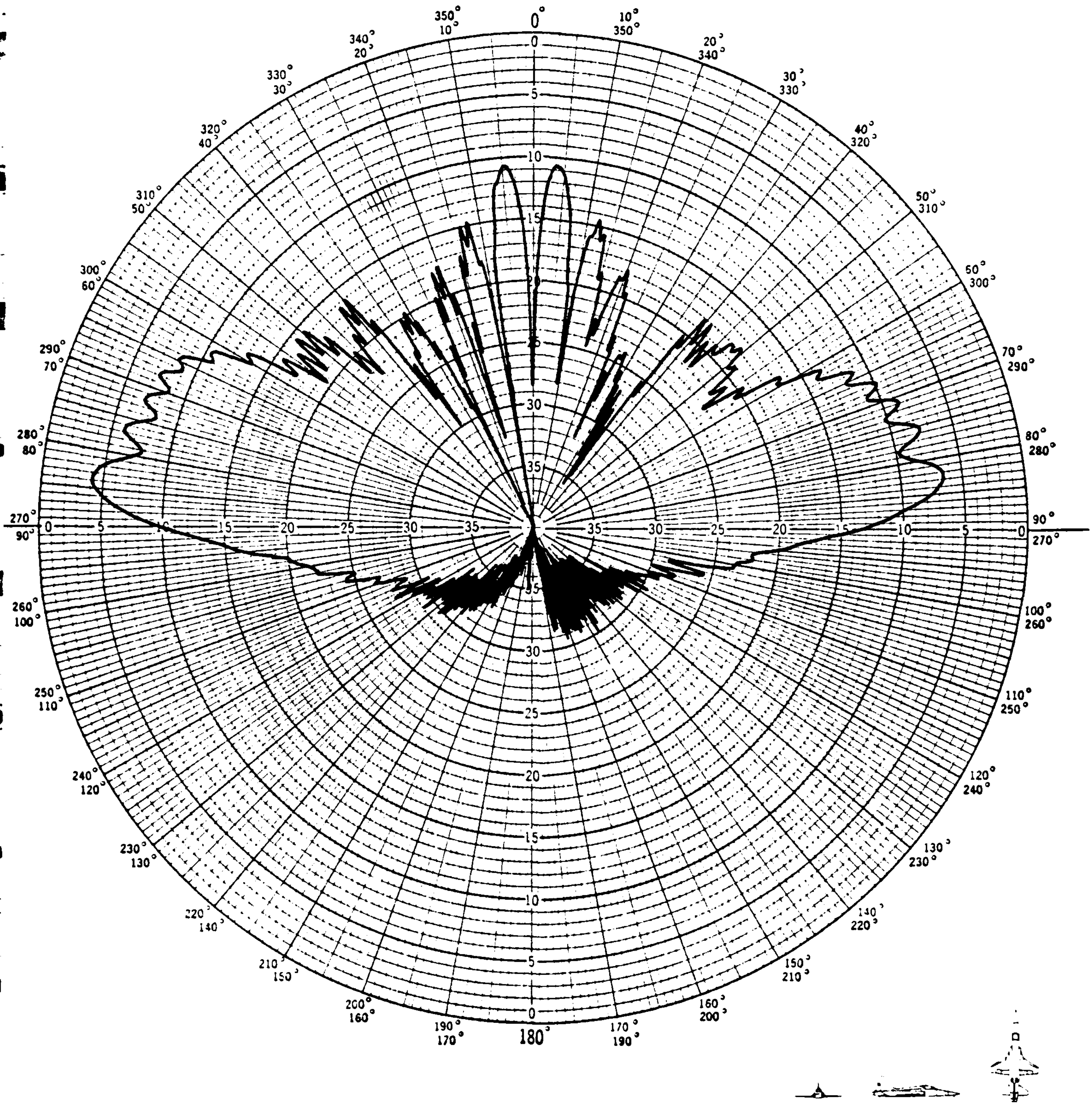


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = ØY=0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



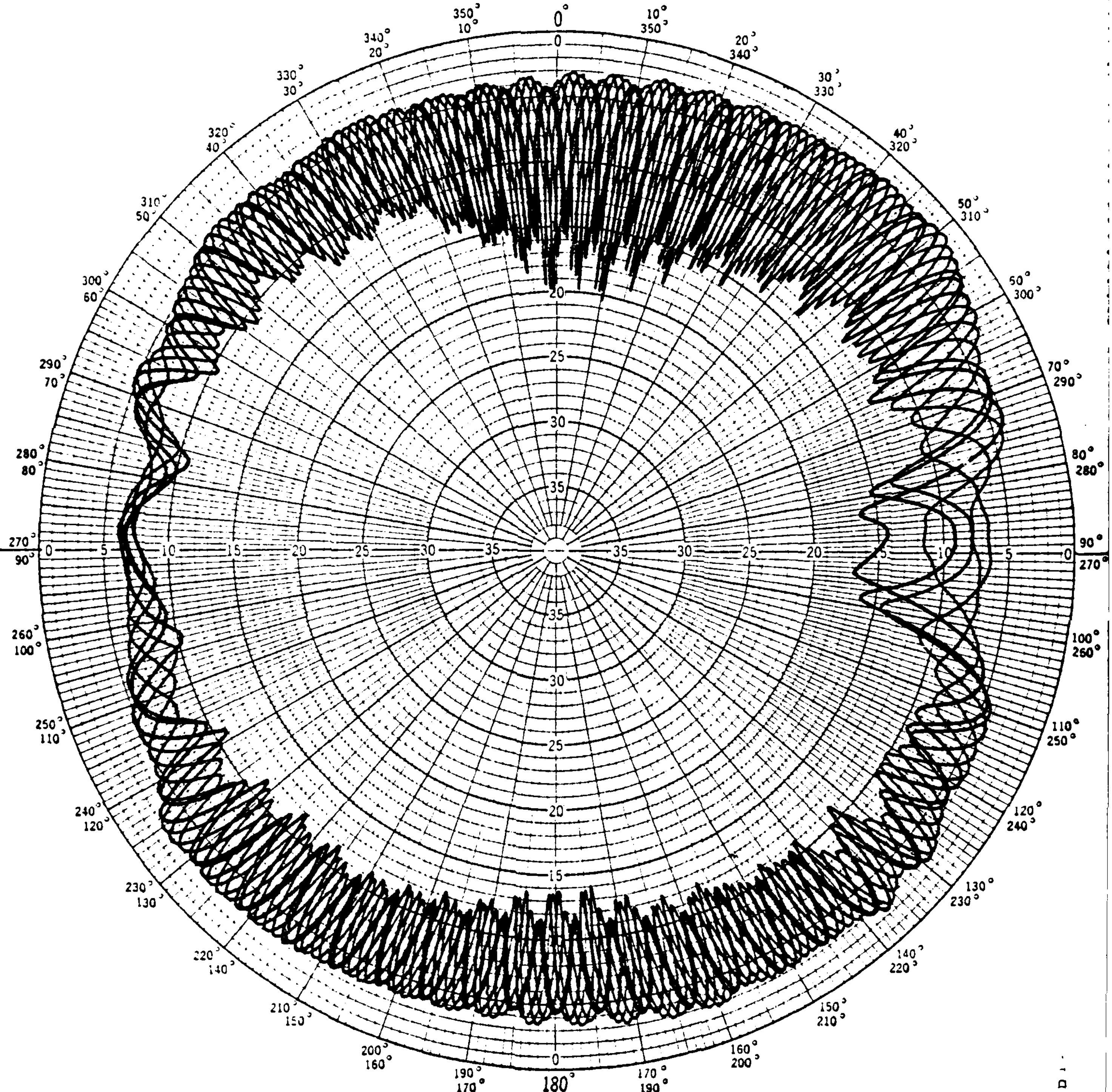
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = OV=0°

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

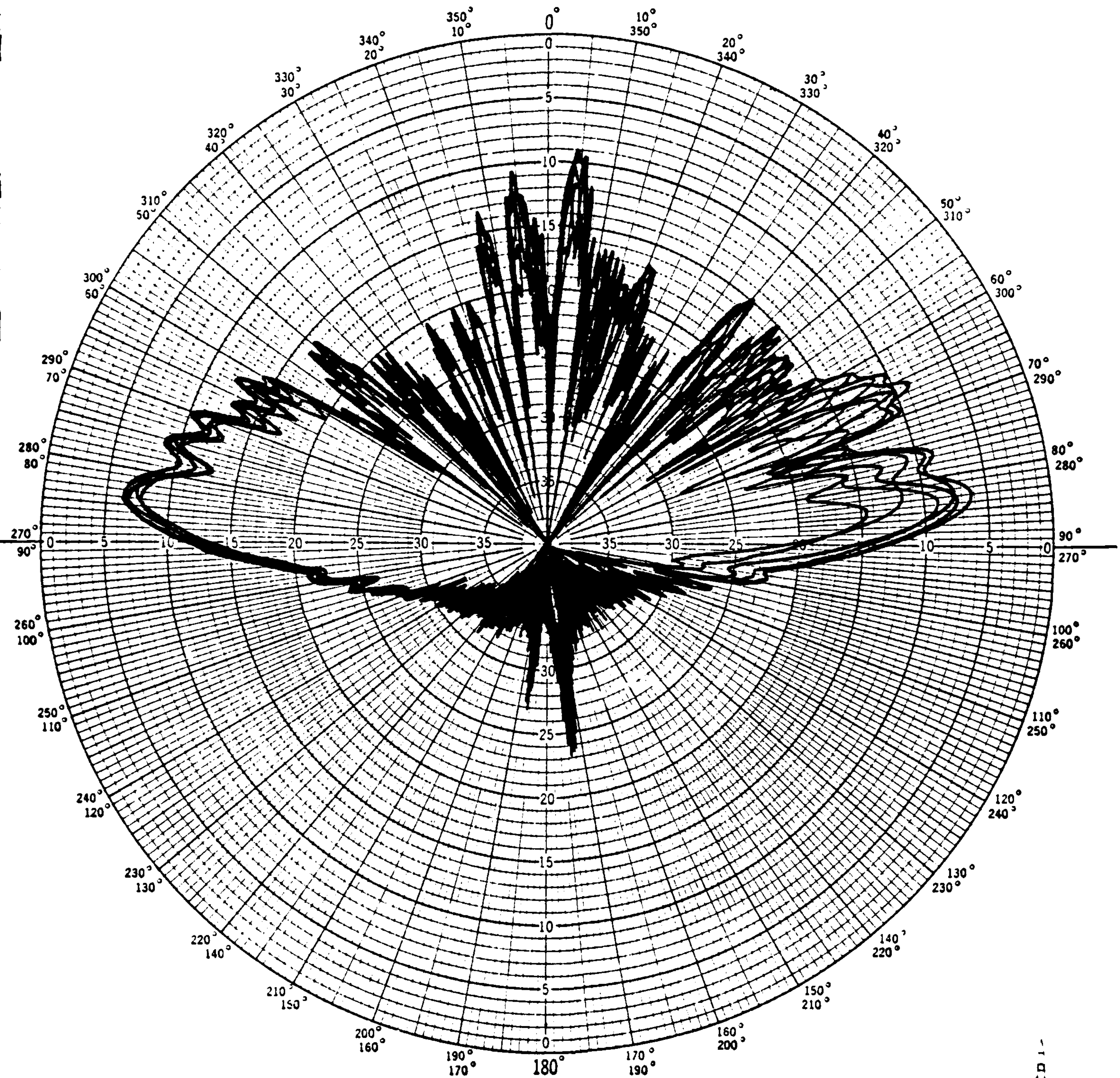


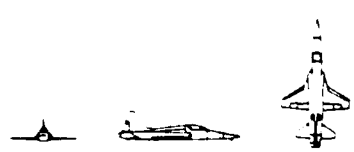
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHZ
ANTENNA LOCATION ____ STATION ____
OPERATOR SIMPSON DATE 3-3-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0, 0.6, 1.2, 1.8, 2.4, 3.0 V.

Form 47-69 (R 3-72)

NORTHROP
Northrop Corporation
Aircraft Division





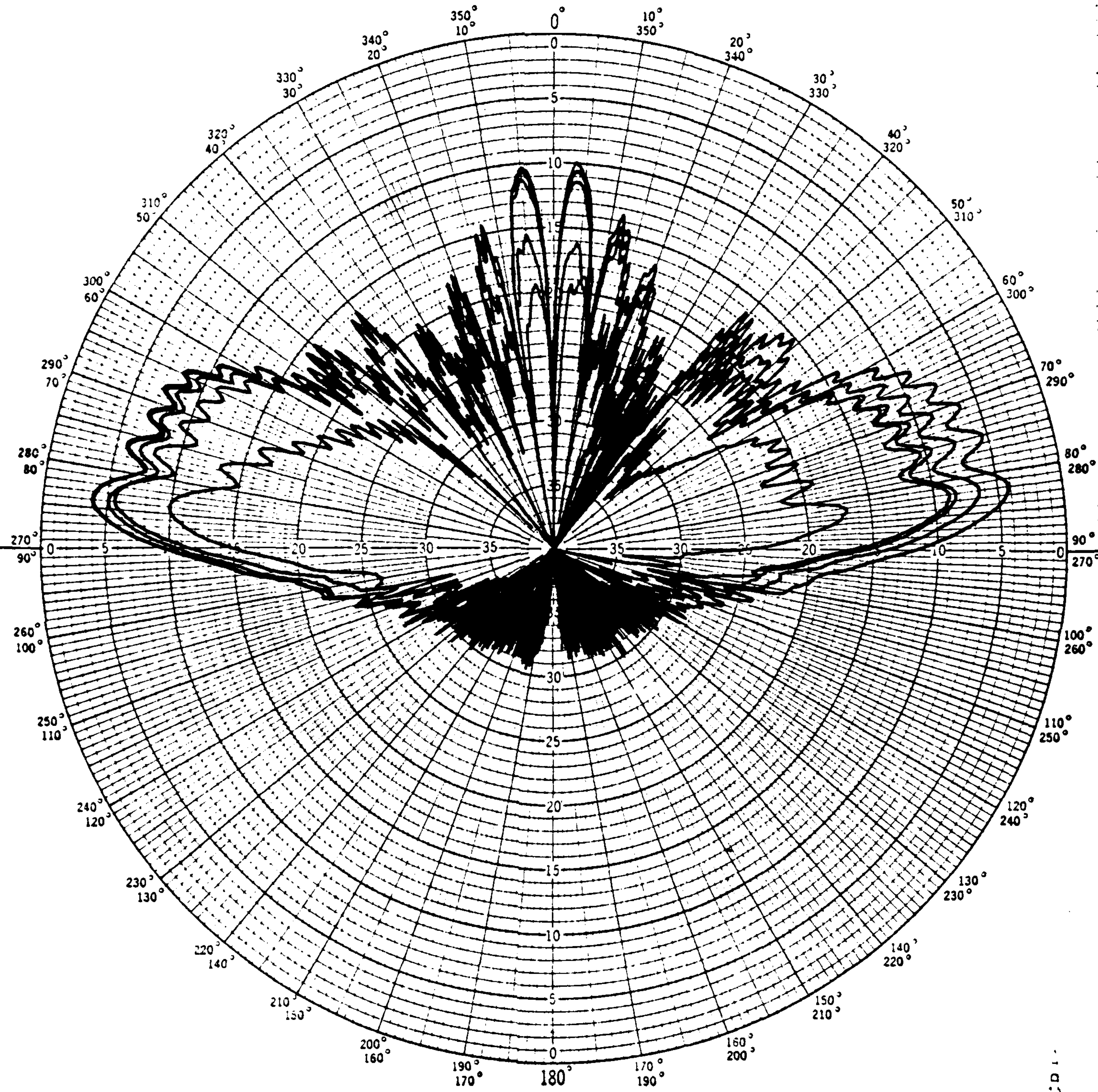
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS Ø REF = 0, .6, 1.2, 1.8, 2.4, 3.0 V.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division

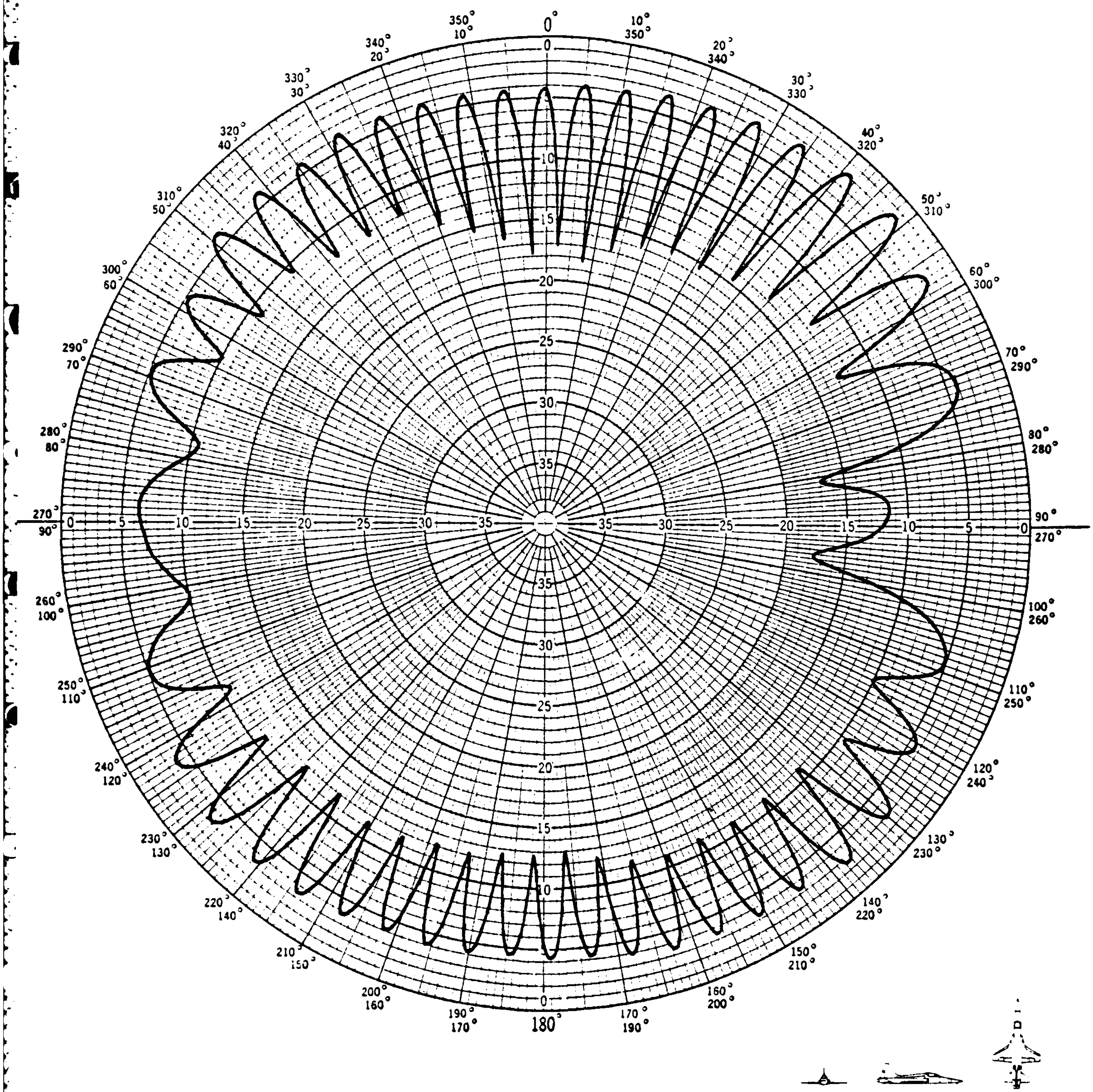


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0, 0.6, 1.2, 1.5, 2.4, 3.0V =

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



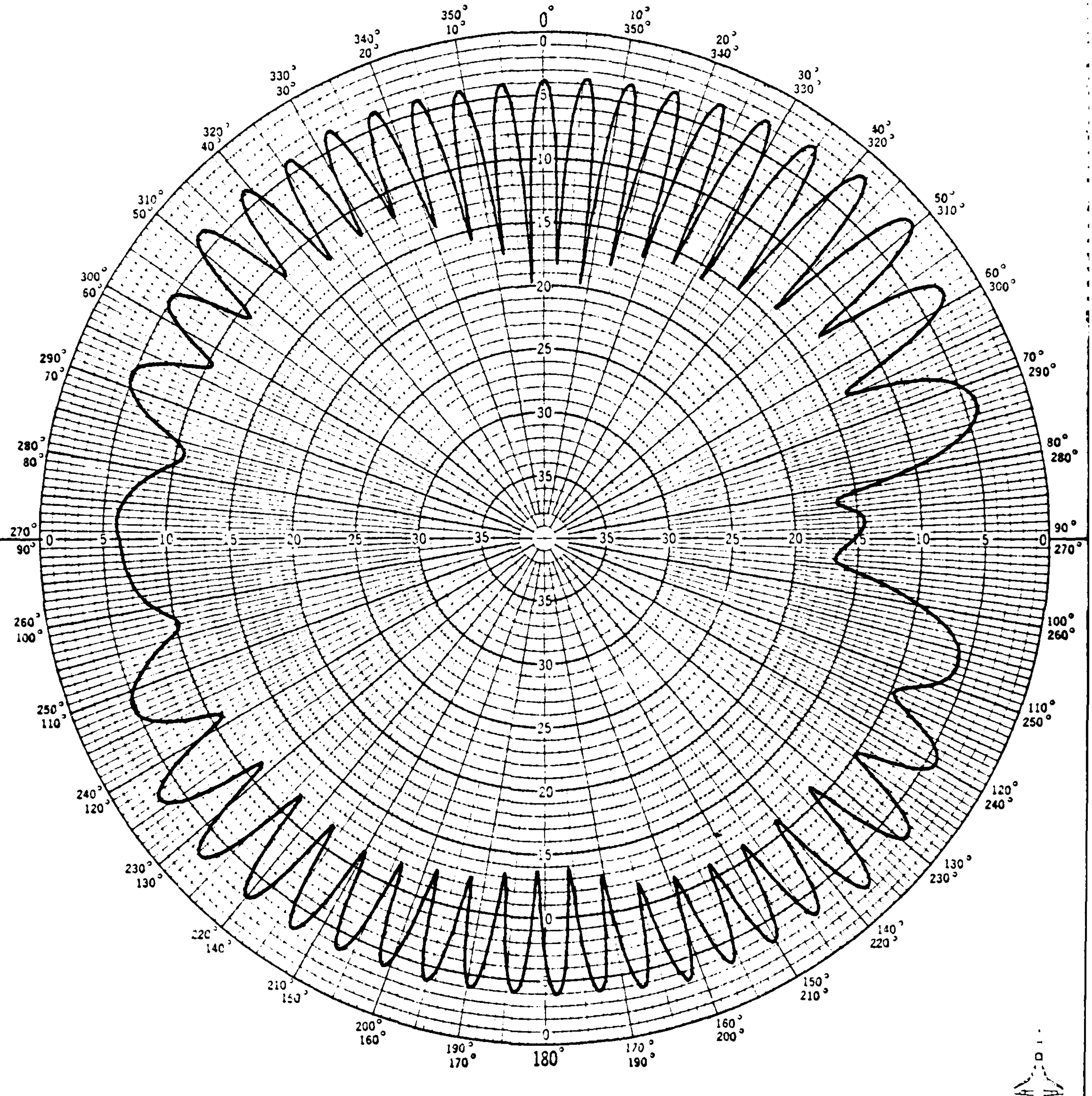
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 0.3V = -24.4°

Form 47-53 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



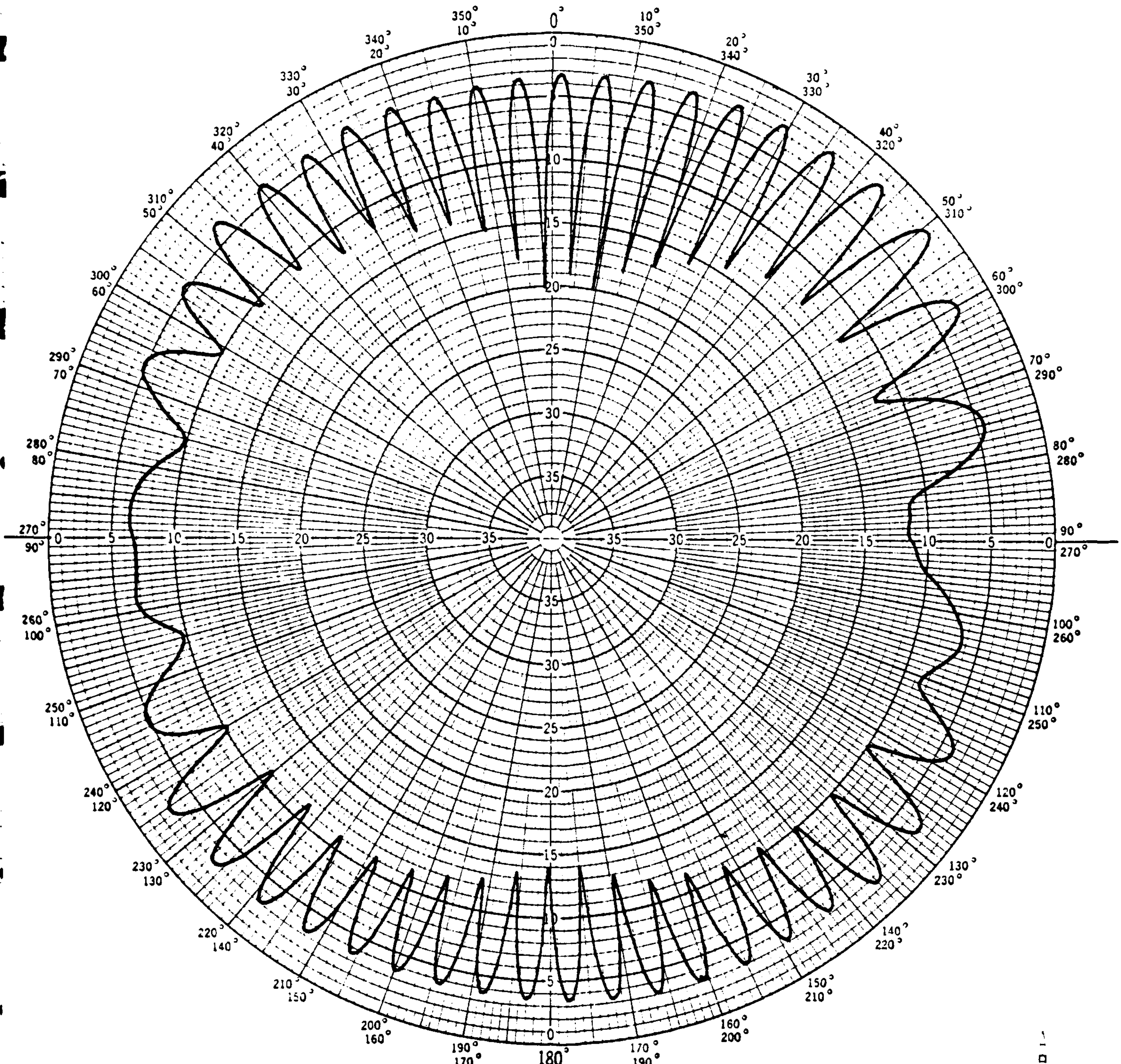
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 183P Φ ( ) POLARIZATION VERT
REMARKS ØREF = 0.6V = -53.3°

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division

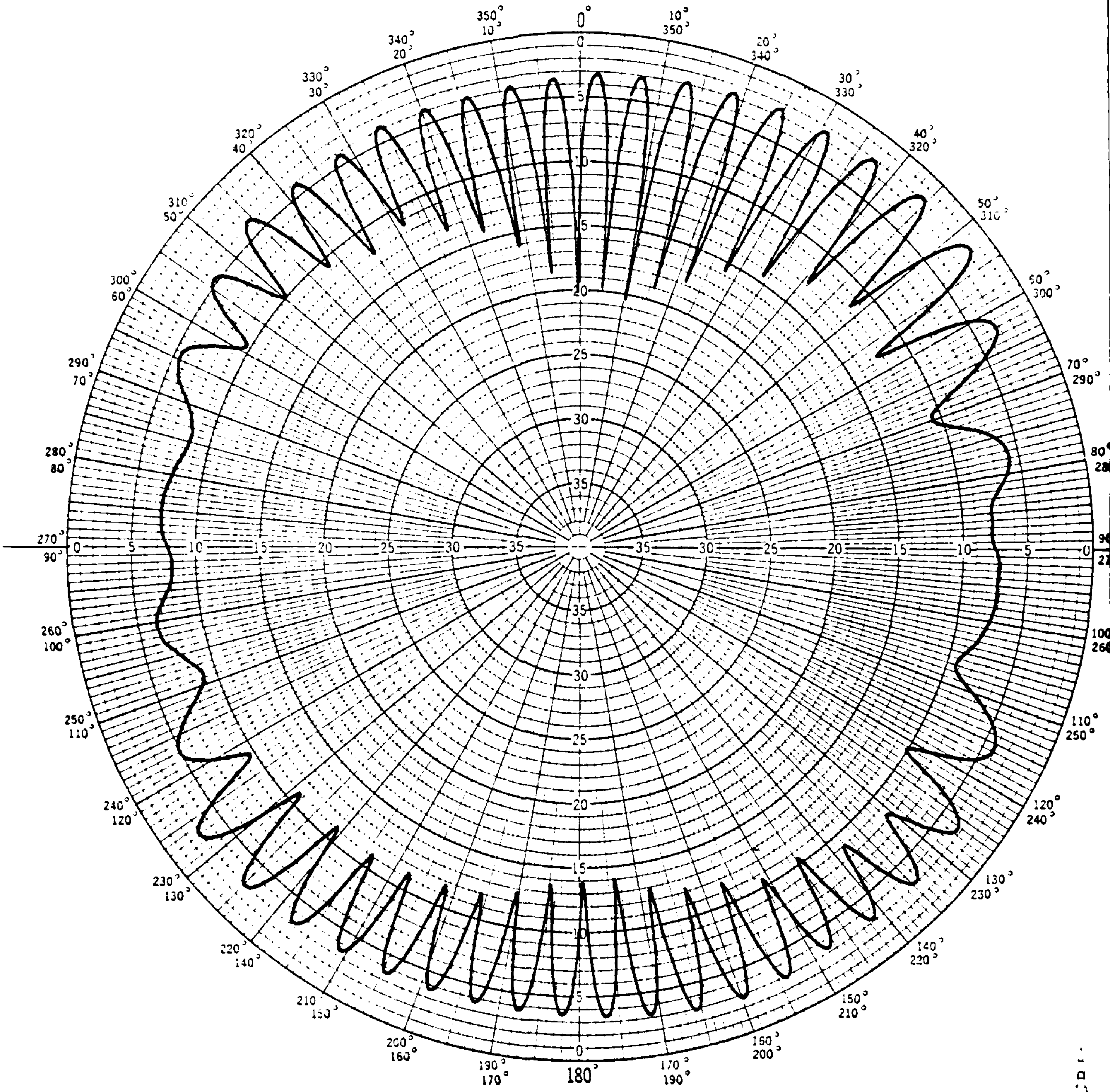


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = 1.2V = -116.3°.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

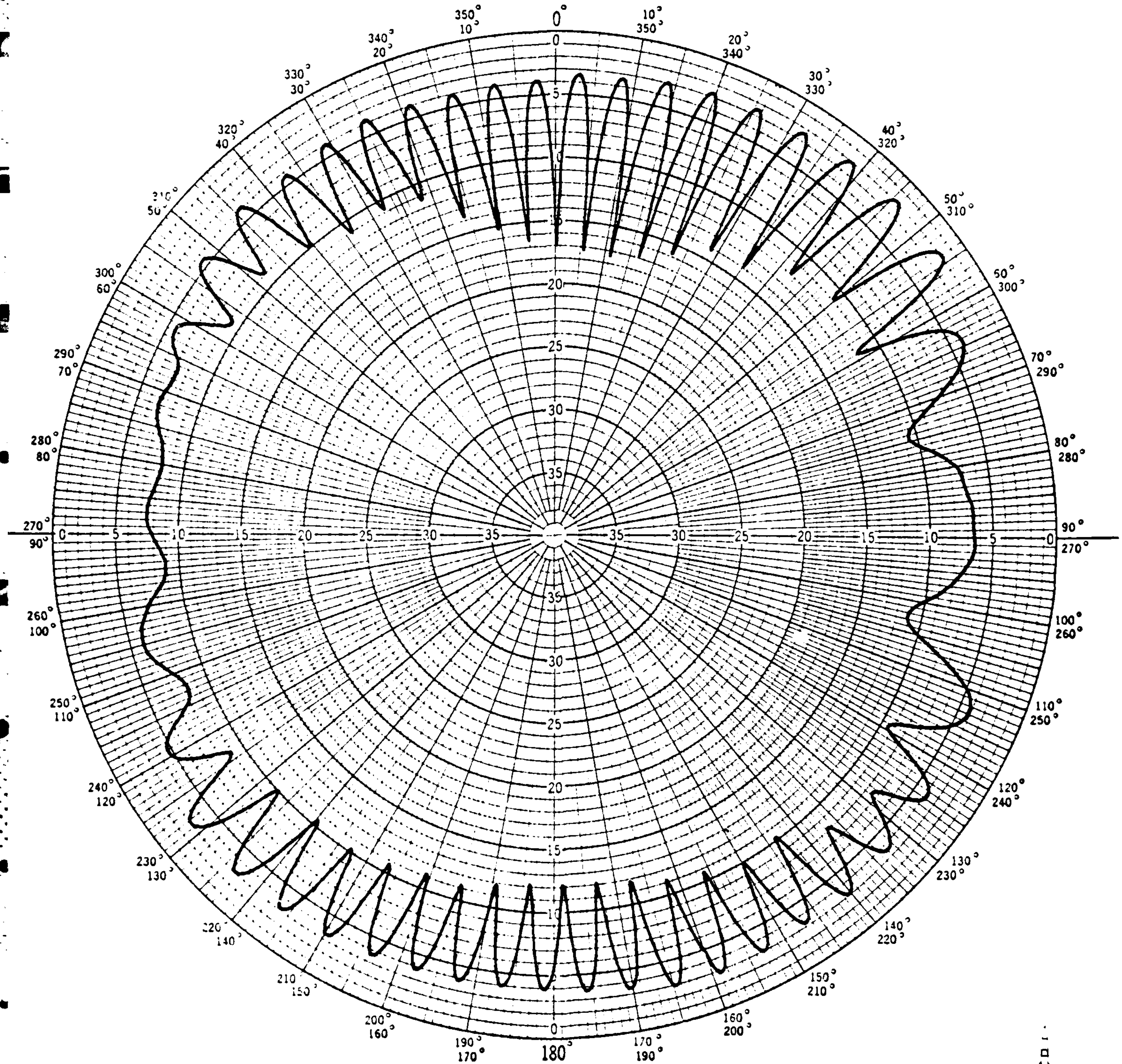


MODEL TYPE *6' 21AM GNP PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *15 GHz*
ANTENNA LOCATION ______ STATION ______
OPERATOR *L. SIMPSON* DATE *8-9-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (93°) Φ ( ) POLARIZATION *VERT*
REMARKS *Ø REF = 1.8V = -176.8°.*

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

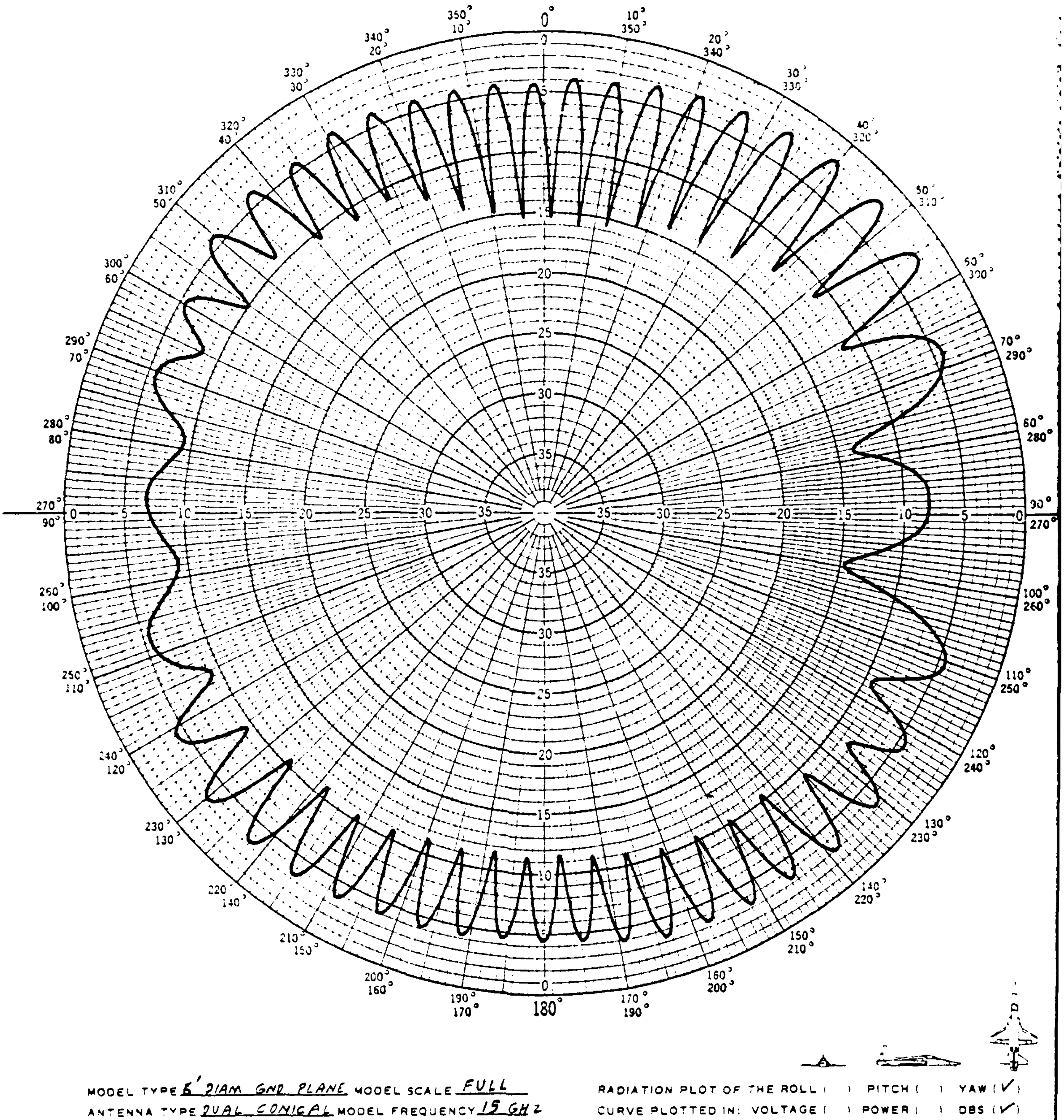


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ________ STATION ________
OPERATOR L. SIMPSON DATE 8-8-73

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83)° Φ ( ) POLARIZATION VERT.
REMARKS ØREF = 2.4V = -237.8°.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

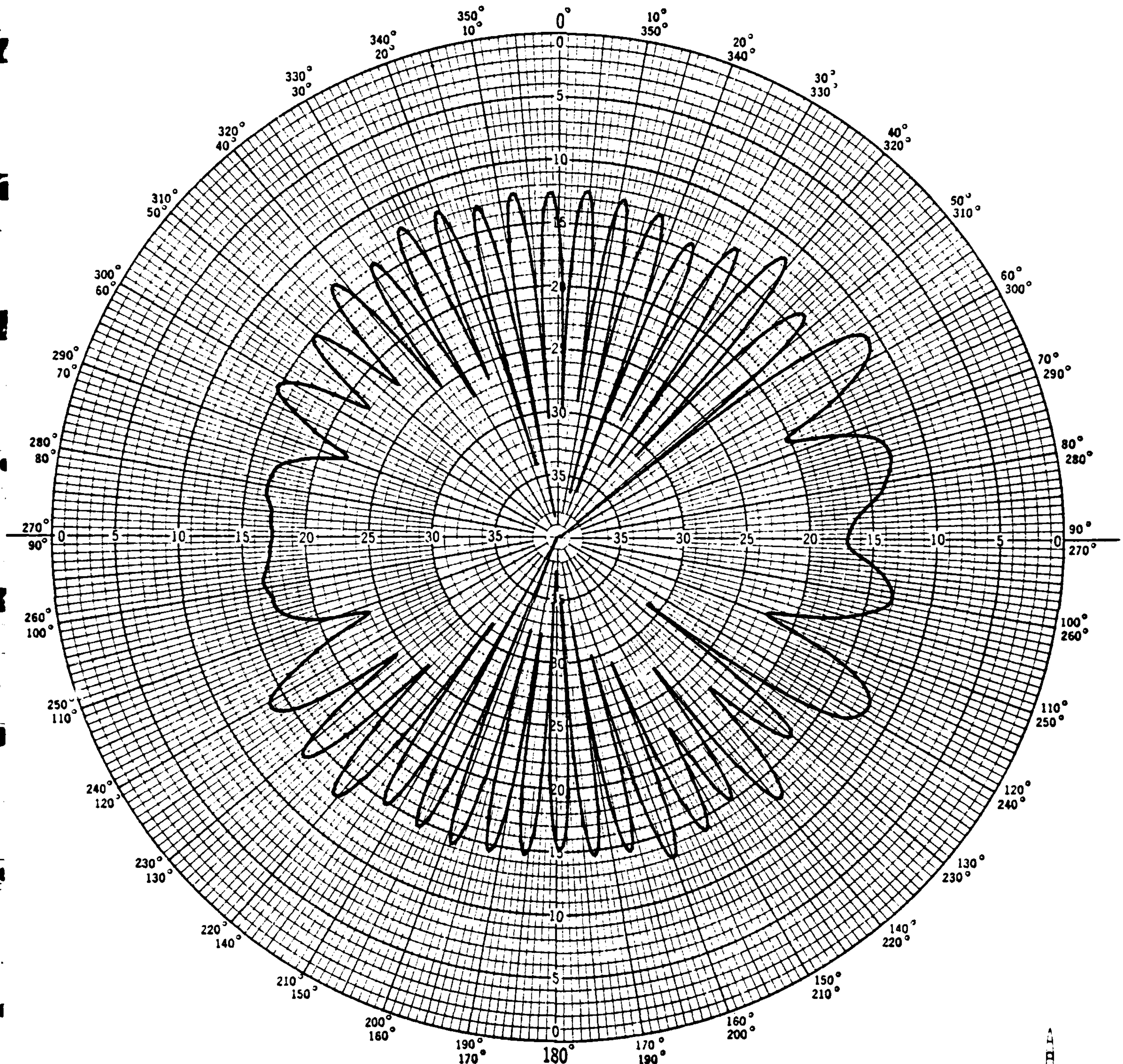


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ 63° Φ ( ) POLARIZATION VERT
REMARKS ØREF = 3.0V = -299.4°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

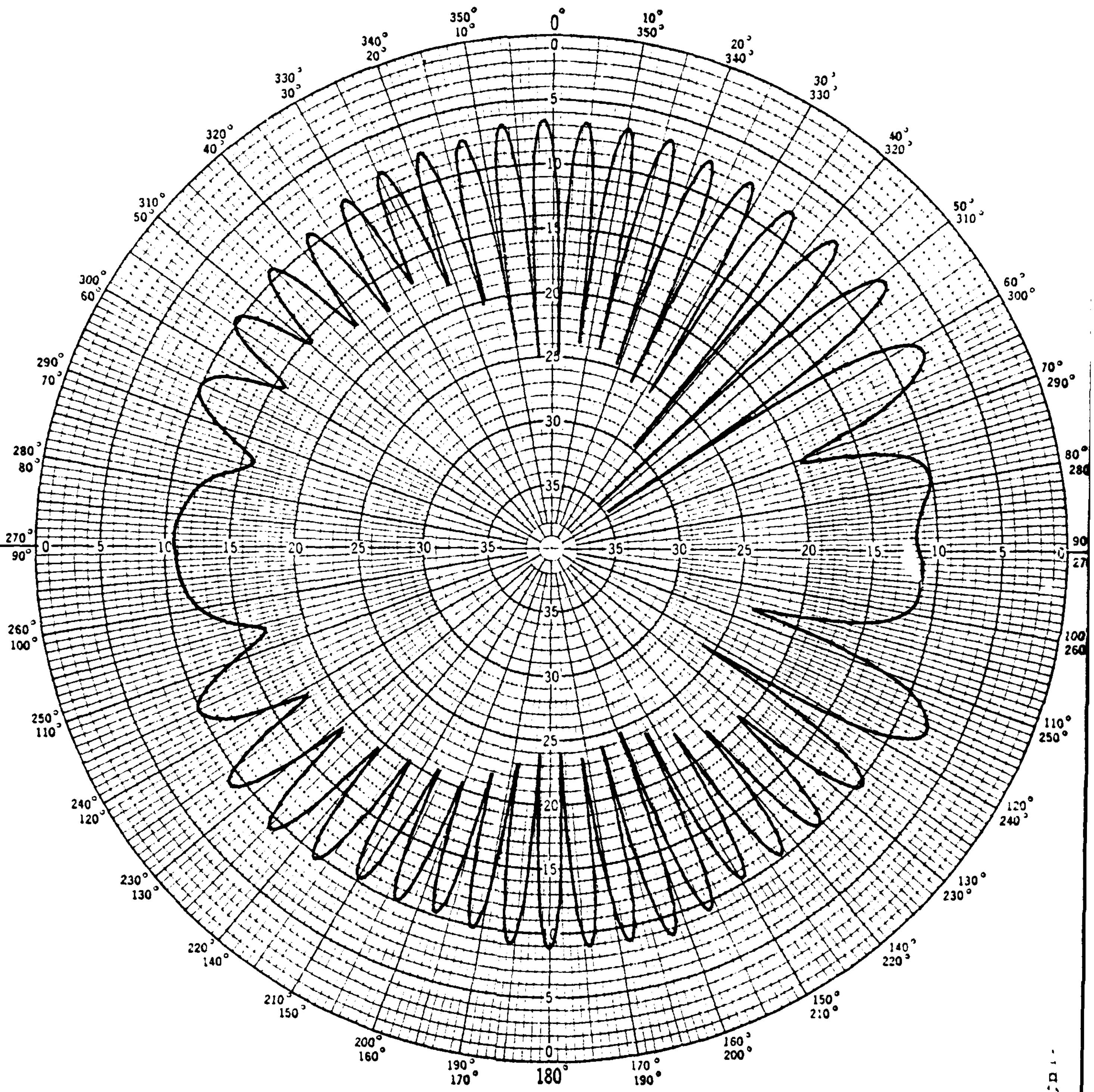


MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *15 GHz*
ANTENNA LOCATION ______ STATION ______
OPERATOR *L. SIMPSON* DATE *8-8-78*

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (60° Φ ( ) POLARIZATION *VERT.*
REMARKS *ØREF = ØV = 0°*

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

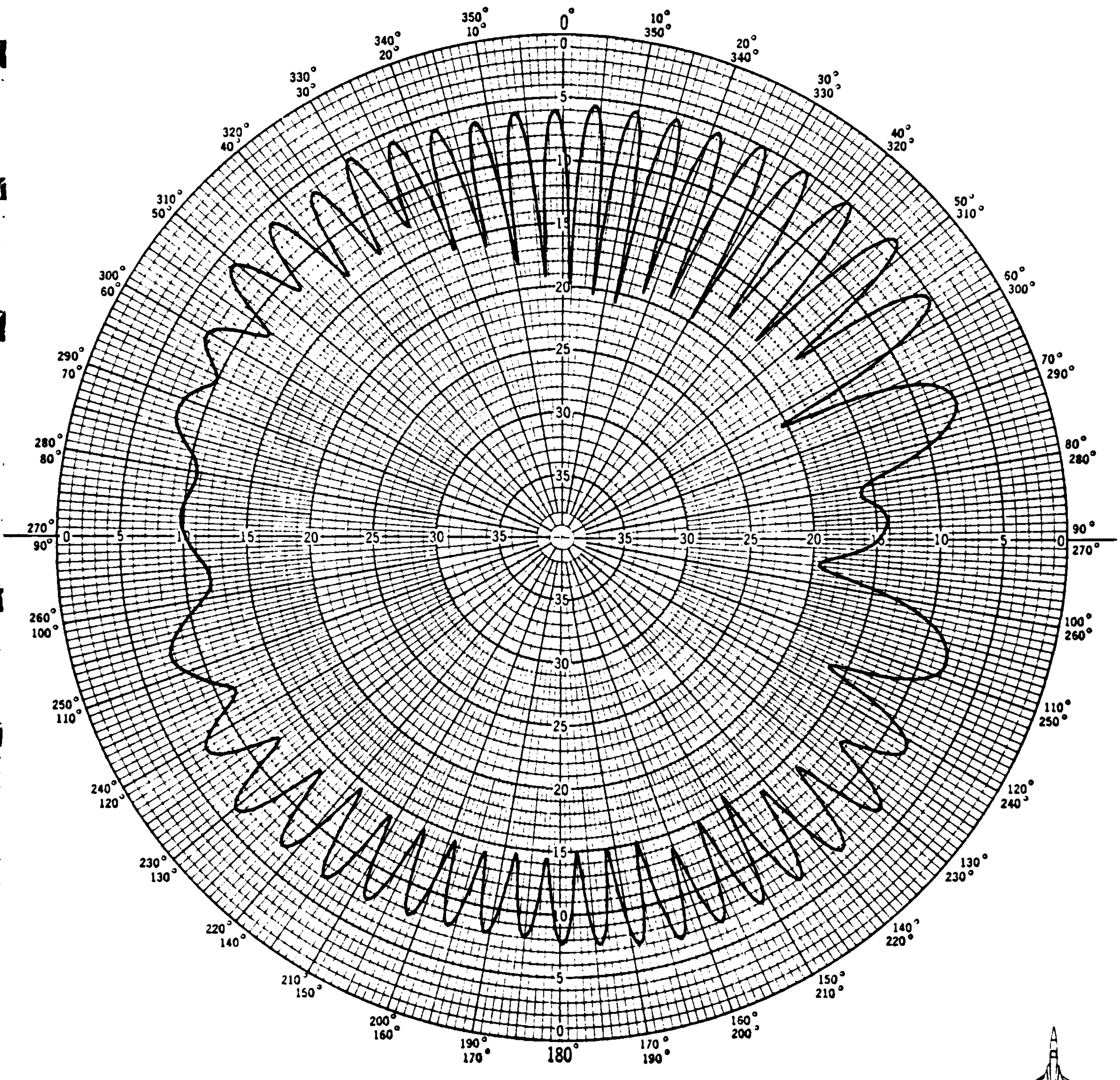


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (70°) Φ ( ) POLARIZATION VERT
REMARKS θREF = CY=0°

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division

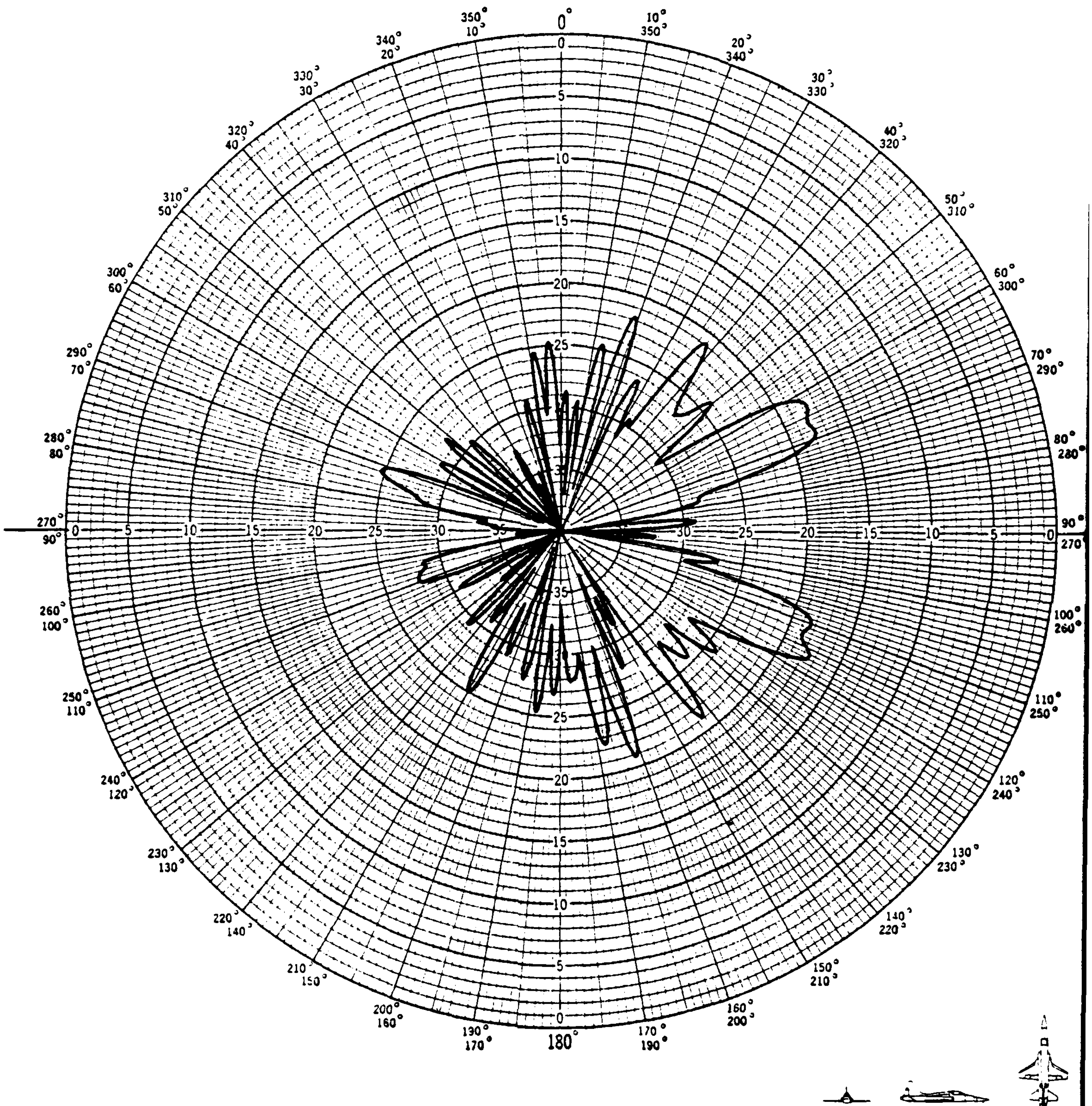


MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ____________ STATION ________
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (80°) Φ ( ) POLARIZATION VERT
REMARKS ØREF = ØV=0°.

Form 47-69 (R 9-72)

NORTHROP
Northrop Corporation
Aircraft Division



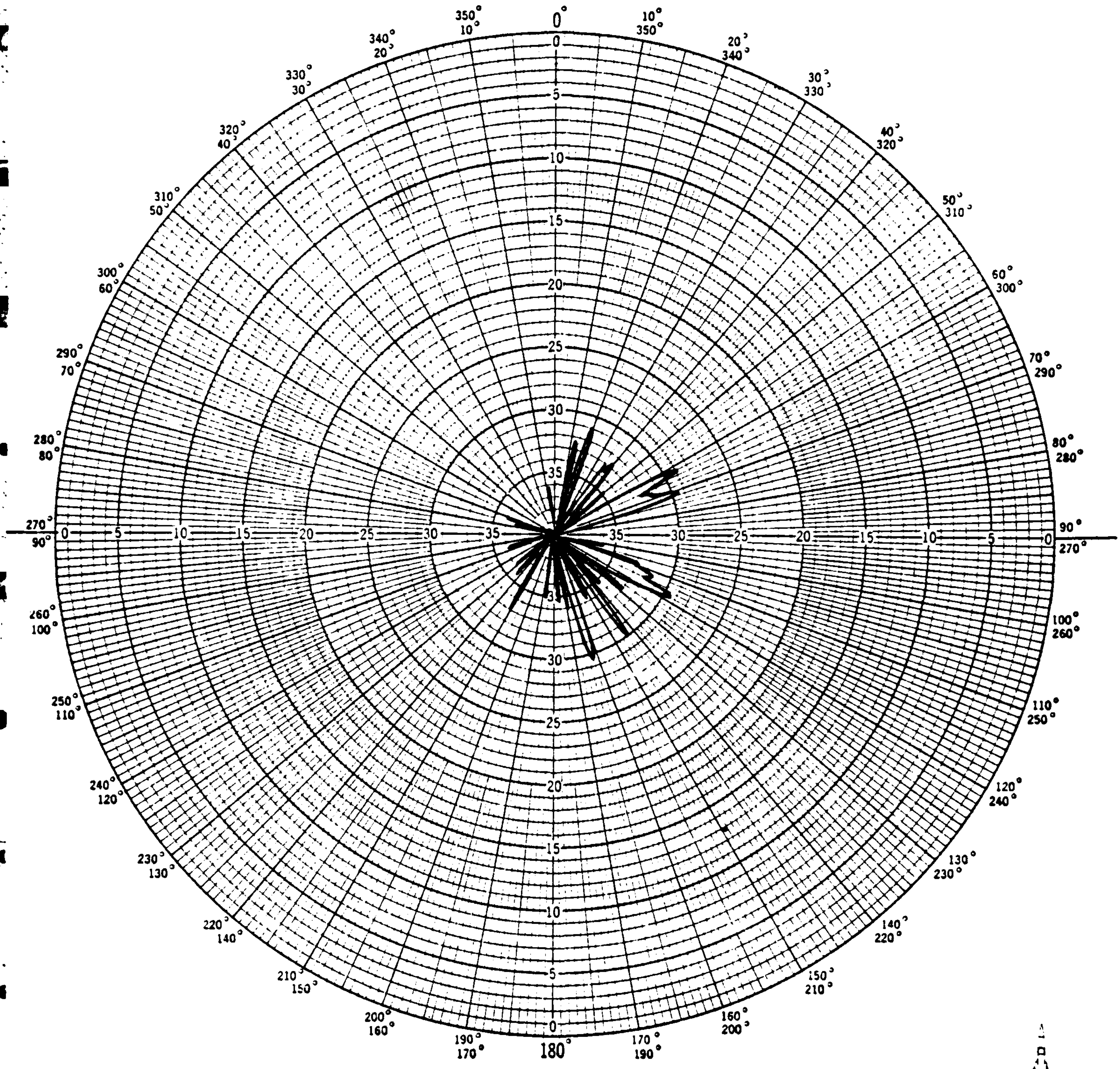
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ____ STATION ____
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (83)° Φ ( ) POLARIZATION HORIZ
REMARKS φ REF = 0V = 0°.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



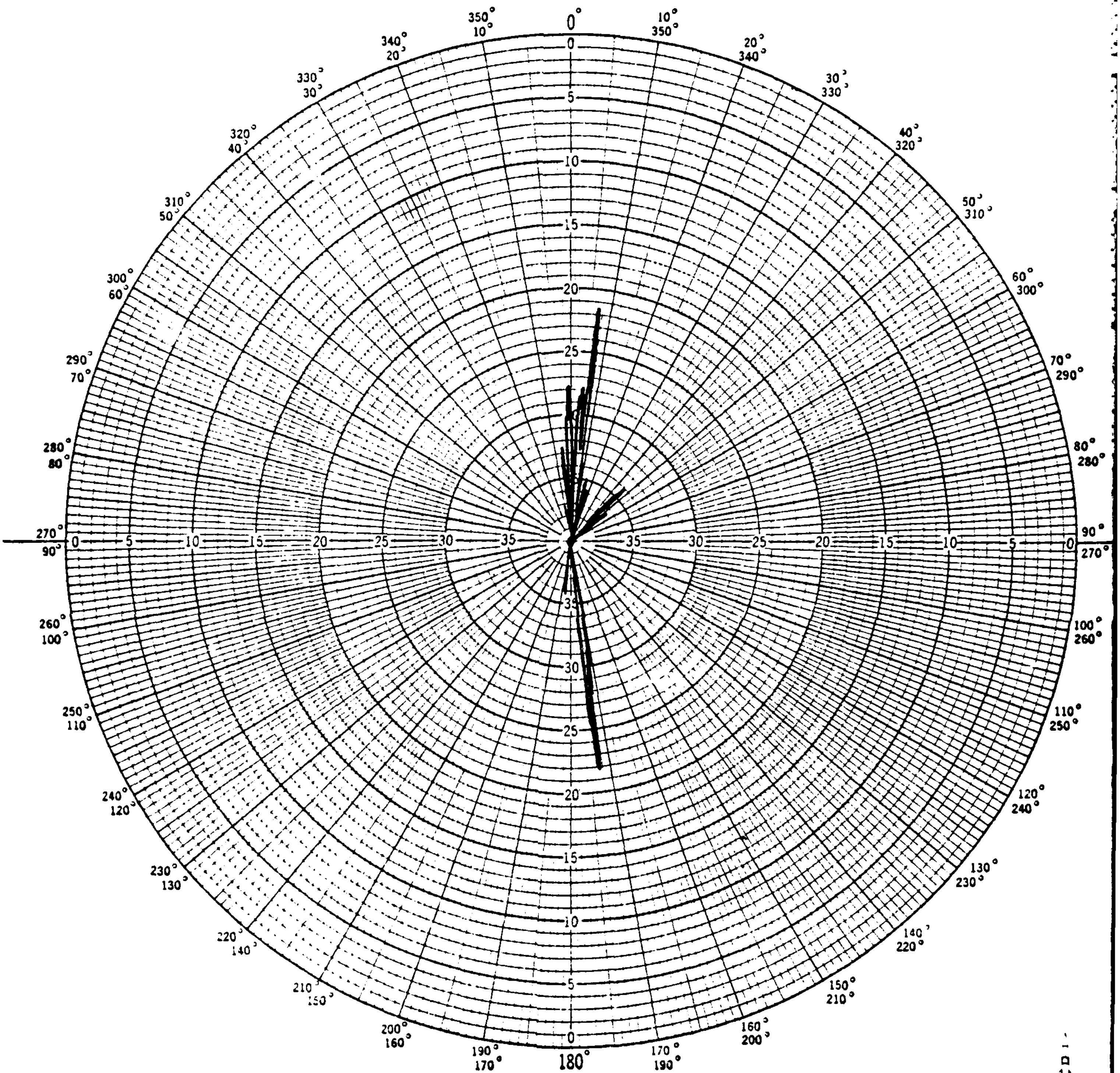
MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL
ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz
ANTENNA LOCATION ______ STATION ______
OPERATOR L. SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ (90°) Φ ( ) POLARIZATION HORIZ.
REMARKS Ø REF = ØV = 0°

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division



MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz

ANTENNA LOCATION ______ STATION ______

OPERATOR L. SIMPSON DATE 3-8-78

RADIATION PLOT OF THE ROLL (✓) PITCH ( ) YAW ( )

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

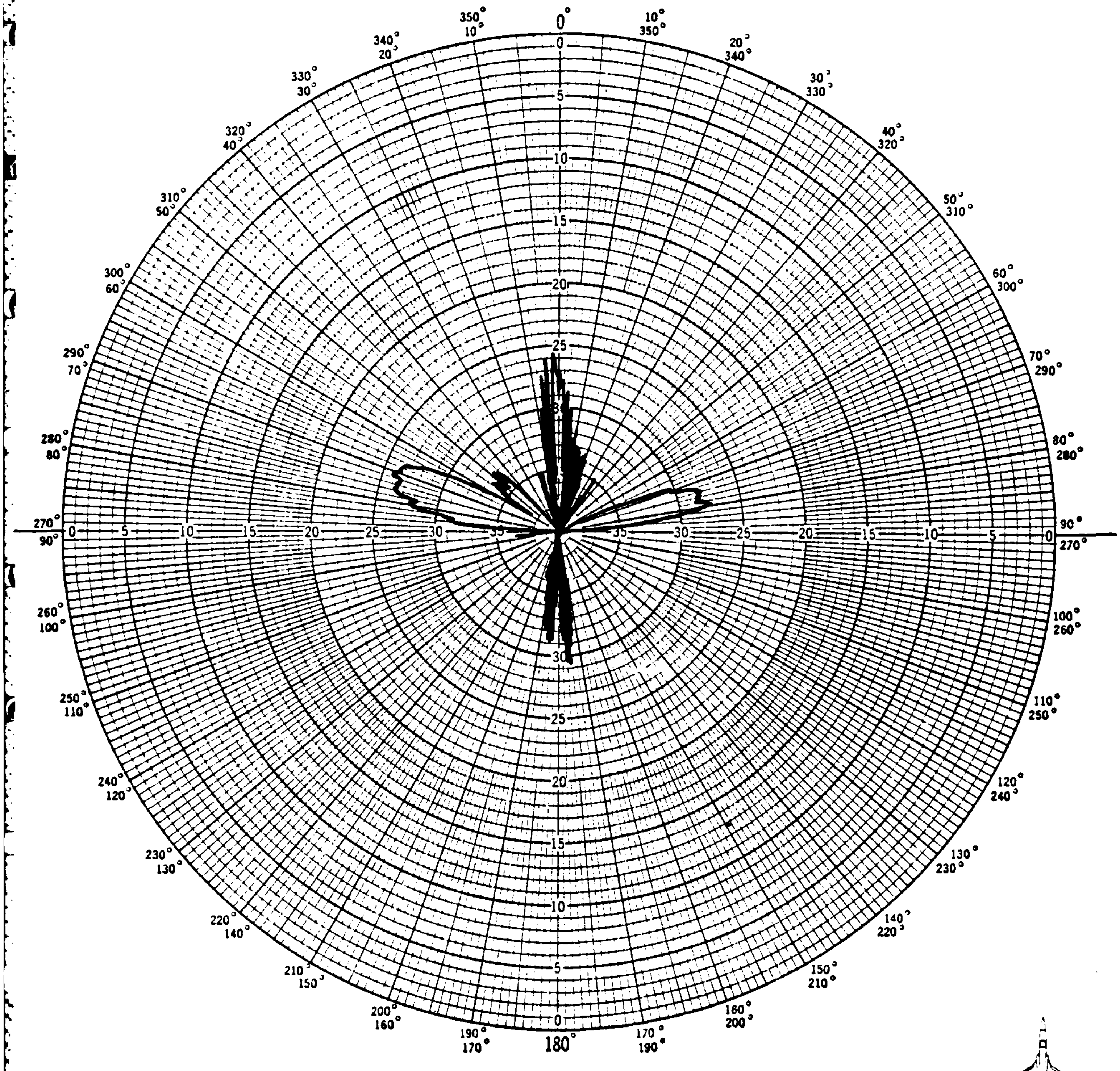
PATTERN θ ( ) Φ ( ) POLARIZATION HORIZ

REMARKS Ø REF = 0° = 0Y.

Form 47-69 (R 9-72)

NORTHROP

Northrop Corporation
Aircraft Division



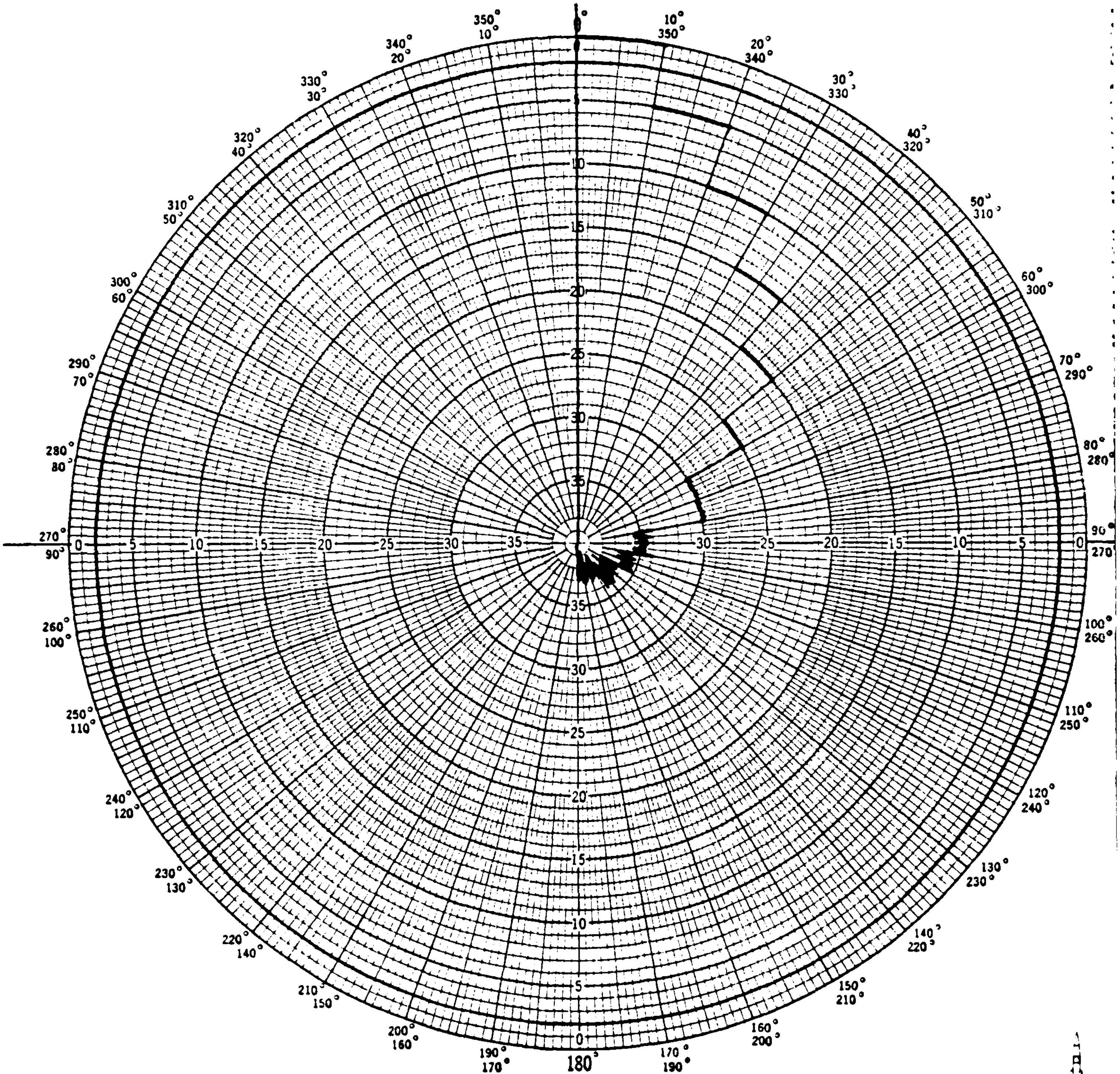
MODEL TYPE *6' DIAM GND PLANE* MODEL SCALE *FULL*
ANTENNA TYPE *DUAL CONICAL* MODEL FREQUENCY *15 GHz*
ANTENNA LOCATION ______ STATION ______
OPERATOR *L. SIMPSON* DATE *8-8-78*

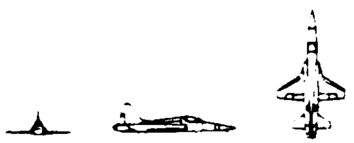
RADIATION PLOT OF THE ROLL ( ) PITCH (✓) YAW ( )
CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)
PATTERN θ ( ) Φ ( ) POLARIZATION *HORIZ*
REMARKS *Ø REF = 0° = 0V*

Form 47-69 (R 3-72)

NORTHROP

Northrop Corporation
Aircraft Division





MODEL TYPE 6' DIAM GND PLANE MODEL SCALE FULL

ANTENNA TYPE DUAL CONICAL MODEL FREQUENCY 15 GHz

ANTENNA LOCATION ________ STATION ________

OPERATOR L SIMPSON DATE 8-8-78

RADIATION PLOT OF THE ROLL ( ) PITCH ( ) YAW (✓)

CURVE PLOTTED IN: VOLTAGE ( ) POWER ( ) DBS (✓)

PATTERN θ 180° Φ ( ) POLARIZATION VERT

REMARKS LINEARITY AMPLITUDE CALIBRATION. 5 dB/STEP DOWN TO -35 dB, THEN 1dB/ STEP

Form 47-69 (R 9-72)