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A STUDY OF WINDSHIELD ANTENNA PERFORMANCE LEVELS FOR AUTOMOBILES

by

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ABSTRACT

The impedance and radiation characteristics of one GM and four Ford windshield antennas have been studied experimentally. The Ford antennas were mounted on Thunderbird and LTD-II model cars and the GM antenna on a Chevrolet Caprice. The performance of the windshield antennas has been compared with that of standard Ford whip antennas currently in use on Ford-built cars. Although the present windshield antennas are found to be of some promise, further work is needed to achieve their full potentialities.

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I. INTRODUCTION

The present report discusses the results of an investigation carried out to evaluate the performance of windshield antennas on automobiles. Specifically, the radiation and impedance characteristics of the following antennas have been studied experimentally: four Ford windshield antennas mounted on Ford-built automobiles; one General Motors (GM) windshield antenna mounted on a Chevrolet Caprice; and two Ford whip antennas mounted on Ford-built cars. The goal of the present investigation was to obtain sufficient data to evaluate the performance of windshield antennas relative to that of the standard whip antennas commonly used in Ford-built cars.

The study involved the following measurements for each test antenna: (a) the horizontal plane radiation patterns at three selected frequencies (88, 98 and 108 MHz) in the FM band, (b) the horizontal plane radiation patterns at three selected frequencies (0.55, 12. and 1.6 MHz) in the AM band, and (c) the input impedance at the three FM band frequencies. The techniques used to measure the radiation pattern and input impedance of each test antenna are similar to those described in a previous report [1] and will not be repeated here.

In addition to the above measurements, tests were conducted to study the effects of (i) windshield wipers on the performance of a whip antenna; (ii) a crash-pad on the performance of a windshield antenna; (iii) grounding various parts of the windshield antenna configuration; (iv) a whip antenna on the performance of a windshield antenna; and (v) of windshield wipers on the radiation patterns of windshield antennas, as well as (vi) the method used by GM to minimize the effects of windshield wiper blades on the windshield antenna performance.

II. FM BAND PATTERNS AND IMPEDANCES

2.1 Whip Antenna

At the outset the horizontal radiation patterns were recorded for the standard whip antenna mounted on a Ford Thunderbird (1977 model). The results are shown in Figure 1 for the three test frequencies. The front of the car was pointed toward 0^o with the whip antenna located as shown in Figure 1A, and the patterns were obtained by rotating the vehicle in the azimuthal plane. For convenience we have chosen to record all FM band patterns with the vehicle antenna functioning as the transmitter, the receiving antenna being a vertically oriented log-periodic antenna designed to operate in the band 50 MHz - 500 MHz. The receiving antenna was located approximately 8 feet above ground and 150 feet away from the test vehicle, oriented such that it received the maximum energy from a direction 3^o above the local horizon. The test antennas being passive, the received radiation patterns would be the same as the transmitting patterns shown here.

It can be seen from Figure 1 that the patterns at 98 and 108 MHz are approximately uniform. The pattern at 88 MHz has two minima in the directions 150^o and 240^o. Although the results shown in Figure 1 apply to the whip antenna mounted on a Thunderbird, later results obtained for a similar antenna mounted on a Ford LTD II exhibit a similar behavior (Figures 3 - 6). In general the FM band patterns were found to be asymmetric; also it has been bound that patterns recorded for the same test antenna on different days exhibit variations in both pattern shape and size in spite of the fact that the transmitted power level and the receiver sensitivity were kept constant during the tests. The asymmetries in the measured patterns may be explained in a manner described in [1]. At the frequencies of interest the skin of the vehicle serves as a conducting ground plane approximately 2 λ long and 0.6 λ wide; the whip antenna is located asymmetrically on the ground plane as noted in Figure 1A. The observed minima and the asymmetry in the patterns are attributable to the finite ground plane and the geometry of the antenna configuration. The entire antenna assembly being located electrically close to the earth (nominally $\lambda/10$ above earth) causes the radiation characteristics to be sensitive to varying earth conditions due to weather changes during the time period (April - June) of the measurement program.

A visual comparison of the radiation patterns for whip antennas mounted on Thunderbird and LTD II cars indicates that they are similar. This observation is reasonable since the two vehicles are electrically similar in size and shape and the whip antenna is mounted in approximately the same location on both cars.

2.2 Windshield Antennas

The radiation patterns for the windshield antennas mounted on Ford and GM automobiles have been obtained under the following three conditions: (i) windshield antennas only, (ii) windshield antenna with the windshield wipers running at low speed and (iii) windshield antenna with simulated back-lite in place.

2.2.1 Windshield Antenna Configurations

Both the Ford and GM windshield antennas are basically in a T-configuration. However, they differ significantly in their physical appearance as noted below. The leg of the GM antenna (Figure 7A) starts at the base of the windshield as a single feed point which is attached to the central conduction of a coaxial line the outer conductor of which is attached to the vehicle frame. From the feed point two fine wires are attached, parallel to each other and nominally 0.5 inches apart, and running vertically up the center of the windshield to within approximately 1 inch of the top edge of the windshield. A horizontal arm is attached to the top of each leg, i.e. the left arm is attached to the left leg and the right arm to the right leg and it is important to note that they are not connected together at the top of the leg. Each arm of the antenna extends across the top of the windshield (and parallel to the top frame) for approximately one quarter of the total width of the windshield. The entire antenna assembly is sandwiched between the two layers of glass plate used to form the windshield safety glass.

The Ford windshield antennas are sketched in Figure 7B. The leg of the antenna consists of a single printed conducting wire attached to the central conductor of the input coaxial line whose outer conductor is attached to the vehicle frame. This single printed conducting wire extends from near the bottom of the windshield to within approximately 0.5 inches of the top. The left and right arms of the antenna are joined at the top of the leg and each extends approximately 45 percent of the total windshield width. Each arm is folded back and forth to form a co-planar quadra-loop. This particular configuration was chosen based on previous data collected by the Ford Glass Plant. Ford windshield configurations 1 - 3, shown in Figure 7B, are etched on the outside of the windshield. The antenna configuration 4 is sandwiched between two layers of glass as in the case of the GM antenna. Further details of the four Ford windshield antennas may be found in Figure 7B.

2.2.2 Windshield Antenna Patterns

The measured horizontal plane radiation patterns of windshield antennas mounted on GM and Ford cars are showin in Figure 2 - 6. Qualitative understanding of the patterns is facilitated by regarding the inside of the car as a rectangular parallel plate region supported along the sides by the vertical A-, B- and C-pillars of the car. The parallel plate region is excited by the vertical element of the windshield antenna. Ideally the pattern of the vertical element would be uniform. However, the radiations from the parasitically excited pillars combine with the direct field, thereby producing non-uniformiies in the patterns. The distance between the B- and C-pillars being small compared to wavelength, their effect may be described as that due to a single equivalent pillar. In a forward region direction the field produced by the B- and C-pillars may combine constructively with the direct field thereby producing a maximum as in Figure 2A at $\pm 60^0$; if the fields combine destructively there will be a minimum in the pattern as in Figure 3F at $\pm 60^0$. Of course, the conditions for constructive and destructive interference will be a function of the spacing between the B- and C-pillars and the windshield antenna, and hence of the car size. The minima in the patterns in the backward half region (for example the minima at angles $\pm 130^0$ in Figure 2D) may be similarly explained by taking into account the shadowing effects of the B- and C-pillars. For a better quantitative explanation the present hypothesis should be investigated further.

Table I shows the approximate FM-band gains of the windshield antennas relative to a standard whip $\lambda/4$ (= 30") long whip antenna mounted on the test car. These results have been obtained by comparing the average area of each windshield antenna pattern with that of the corresponding whip antenna pattern. The results indicate that the gain of a windshield antenna is nominally 5 dB below that of a standard Ford whip antenna. Table II shows the approximate differences between the maximum and minimum FM-band gain of a given windshield antenna mounted on the test car.

The gain of a linear antenna of length ℓ_t relative to a $\lambda/4$-long monopole is given approximately by the following expression [1]:

$$\text{Relative gain in dB} = -20 \log_{10}[1 - \cos(k\ell_t\, \varepsilon_r)],$$

where $k = \frac{2\pi}{\lambda}$ is the propagation constant,

ε_r is the dielectric constant of the medium in which the test antenna is immersed.

Assuming $\ell_t \simeq 15"$, $\lambda = 120"$ and $\varepsilon_r \simeq 6$ the relative gain of the windshield antenna is found to be equal to about -2.6 dB. This assumes that the antennas are matched. If the relative mismatch loss of the windshield antenna is taken into account the above simple expression predicts fairly well the overall gain of the windshield antennas under consideration. Ignoring the mismatch losses, it may be concluded that a windshield antenna having a vertical height $\ell_t \simeq 15"$ would have a FM-band gain nominally 3 dB less than that of a standard 30"-long whip antenna. From the results discussed so far it appears that the Ford windshield antenna configurations 1, 2 and 4 are approximately equivalent in performance. With some modifications to the designs, the theoretical limit of the gain discussed earlier may be achievable. It should be noted that for Ford and GM windshield antennas $\ell_t \simeq$ 13 5/8" and 14 1/2" respectively.

2.2.3 Effects of Windshield Wipers and Back-lite

The radiation patterns of windshield and whip antennas have also been obtained with the windshield wiper operating and with a simulated heated back-lite. These results are also shown in Figures 2 - 6.

The GM windshield antenna patterns exhibit less than 2.0 dB fluctuations of pattern with the windshield wipers operating, whereas under similar condi-

Frequency (MHz)	Windshield Antenna Configuration				
	FORD				GM
	1	2	3	4	
88	-4.6 dB	-5.2 dB	-7.4 dB	-6.3 dB	-5.0 dB
98	-7.0 dB	-5.0 dB	-10.5 dB	-3.5 dB	-5.6 dB
108	-4.1 dB	-5.5 dB	-11.1 dB	-4.6 dB	-8.8 dB

Table I. FM-band gains of windshield antennas relative to a 30" whip antenna mounted on Ford and GM cars.

Frequency (MHz)	Windshield Antenna Configuration				
	FORD				GM
	1	2	3	4	
88	-8.3 dB	-10.8 dB	-10.9 dB	-4.7 dB	-11.0dB
98	-9.5 dB	-4.5 dB	-10.2 dB	-15.0 dB	-19.4dB
108	-6.0 dB	-10.0 dB	-10.7 dB	-13.4 dB	-5.4dB

Table II. Difference between the maximum and minimum gains of windshield antennas mounted on Ford and GM cars.

tions the Ford configurations exhibit 5 - 10 dB pattern flucturations. It has also been observed that under similar conditions the Ford whip antenna patterns exhibit about 2 dB pattern fluctuations (see Figure 8). On close examination it has been found that the GM windshield wiper blades and arms are attached by means of a dielectric assembly. To study the effects of insulating the wiper assembly, the blades and the arms of the GM windshield wiper system were conductively connected. The resulting FM-band patterns for the GM windshield antenna with grounded windshield wiper blades in operation are shown in Figure 9. Observe that the pattern fluctuations in Figure 9 are in the range 5 - 10 dB which is similar to that observed earlier for the Ford windshield antennas with wiper blades running. A comparison between the earlier results for the wiper blade effects and the results shown in Figure 9 clearly indicate the desirability of insulating the wiper blade assembly.

The results shown in Figure 10 were obtained to determine which part of the Ford windshield wiper system contributes most to the pattern fluctuations. The results shown in Figure 10 indicate that the right wiper blade assembly is the chief source of interference. However, it is suggested that some consideration be given to electrically separating the wiper blades and arms so as to minimize their effects on the patterns.

From the results shown in Figures 2 - 6 it can be seen that the heated back-lite has no appreciable effect on the windshield antenna patterns. The reason for the lack of interference by the heated back-lite is that the heating elements (being horizontal) are significantly decoupled from the vertical components of the field.

2.2.4 Effects of Crash Pad and the Guard Ring

A series of patterns for the Ford windshield antennas have been recorded after removing the crash pad and the ground connections of the antenna. In the latter case the antenna remains electrically floating with the grounding of the guard ring also removed. The results are showin in Figure 11. The removal of the crash pad was found to reduce the antenna sensitivity in the forward direction. However, for the particular windshield antenna under test no significant effects have been observed after removal or alteration of grounding of the windshield antenna and the associated guard ring assembly.

2.2.5 Coupling between the Windshield and Whip Antennas

The results of this section were obtained to demonstrate the effects of installing both a whip and a windshield antenna on the same car. The patterns shown in Figure 12 are for the windshield antenna with the whip antenna left open-circuited and it acts like a parasitic element. The results indicate considerable pattern distortion caused by the whip antenna. The length of the whip antenna being near resonance, the windshield and whip antennas together act like a 2-element array thereby producing the deep null in the pattern shown in Figure 12A. The resulting pattern is, in general, a function of frequency and of the magnitude and phase of the currents in each antenna, as well as their separation distance. Comparison of the results of Figure 12 with the corresponding windshield antenna patterns shown in Figure 5 brings out the consequences of coupling to the whip antenna. The effect of the passive windshield antenna on the patterns of the whip antenna were not investigated.

2.3 Impedance Characteristics

The FM band impedance characteristics of the various test antennas were measured using the standard techniques described in [1]. All the impedances were measured at the input terminals of the coaxial cables (i.e. at the radio end) associated with the antennas. The results for the whip antennas are presented in Figures 13A and 13B which show that the nominal impedance of the whip antenna is about 75 Ω (VSWR $\sim$ 1.5).

The input impedances of the Ford windshield antenna configurations 1, 2 and 4 are shown in Figures 13C, 13D and 13E respectively. (It was discovered later that the impedance at 88 MHz shown in Figure 13C was incorrectly obtained and hence should not be trusted). The results indicate that the above three Ford windshield antenna configurations exhibit similar impedance characteristics. Figure 13F shows the impedance behavior of the Ford windshield antenna configuration 3. The results are significantly different from those for the previous Ford windshield antenna configurations. The reason for this is that the antenna configuration 3 uses an impedance transformation section attached to the bottom of the windshield (see Figure 7B).

The impedance characteristics of the GM windshield antenna are shown in Figure 13G. The results suggest that the base impedance is less than that for the Ford windshield antenna and this may be due to the smaller amount of top loading used in the GM antenna (see Figures 7A and 7B).

III. AM BAND PERFORMANCE

Since all the test antennas are electrically short at AM frequencies, their horizontal plane patterns can be expected to be omnidirectional. This was demonstrated conclusively in our previous study of automobile antennas [1]. Instead of measuring the actual AM band patterns of the antennas, we therefore measured the field strengths received by each test antenna using the local AM broadcast transmitters as the source. The field strength received by each antenna may be considered to be a measure of its sensitivity. Table II shows the measured field strengths (in dBM) at the AM band frequencies for the whip and windshield antennas.

The results shown in Table III indicate that Ford and GM windshield antennas have rather similar performances at AM frequencies. They also indicate that the performance of windshield antennas is equal to that of the whip antennas in this frequency band.

Frequency in MHz	Field Strength in dBM						
	T-Bird Whip	LTD II Whip	Windshield Antennas				
			Ford 1	Ford 2	Ford 3	Ford 4	GM
0.55	-88	-94	-92	-94	-94	-96	-95
1.2	-70	-70	-73	*	-74	-74	-70
1.6	-76	-80	-80	-81	-80	-81	-80

*Station not transmitting at the time of test

Table III. Received AM-band field strength (in dBM) at the antenna terminals.

IV. CONCLUSIONS

On the basis of the results obtained, the following general observations can be made regarding the performance of windshield antennas:

(i) in the FM band the theoretical gain of a windshield antenna is typically 3 dB less than that of a whip antenna.

(ii) a windshield antenna pattern in the FM band appears to be more directive having maxima along the longitudinal axis directions of the car, the maximum in the forward direction being larger.

(iii) in the AM band, windshield and whip antennas have equivalent performance.

(iv) GM antennas are less susceptible to windshield wiper effects than are the Ford antennas. The performance of Ford antennas may be improved by better design of the windshield wiper assembly.

(v) heated back-lite does not have any significant effect on the windshield antenna performance.

(vi) the crash pad seems to increase the gain of the windshield antenna in the forward direction.

At the present time the performance of windshield antennas are not well understood. It is therefore recommended that further theoretical and experimental work be initiated to evolve a more efficient design for such antennas.

V. ACKNOWLEDGEMENT

The authors are pleased to acknowledge the benefit of several discussions with Mr. Robert Schuessler of the Ford Motor Company. We also acknowledge the valuable counsel and suggestions by Professor T.B.A. Senior, and we are grateful for the help of Mr. W.F. Parsons during the measurements.

VI. REFERENCES

[1] Sengupta, D.L. and J.E. Ferris, "A Study of CB, FM and AM Antennas for Automobiles", University of Michigan Radiation Laboratory Report, No. 320626-1-T, Ann Arbor, Michigan, September 1976.

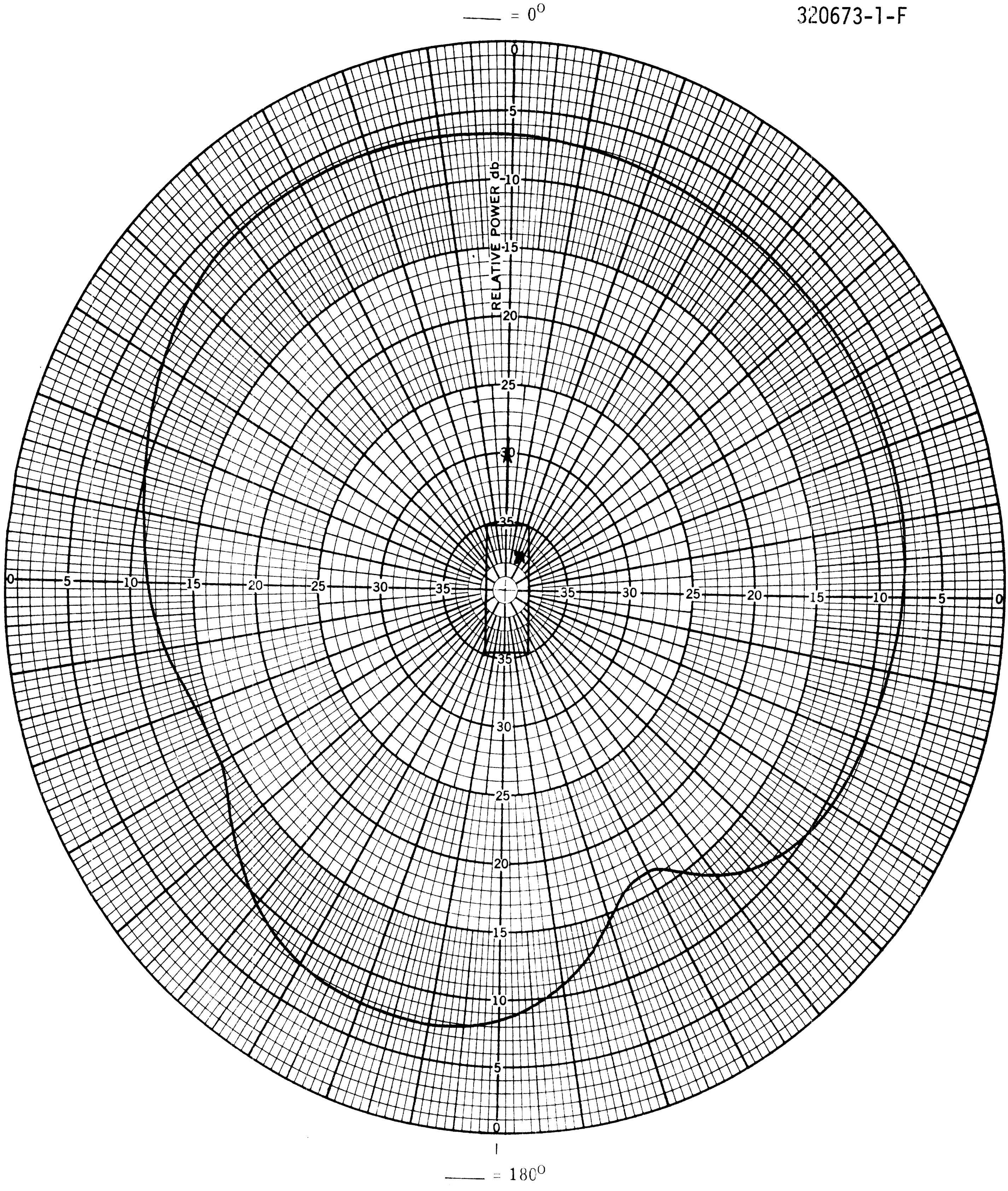


Figure 1A. Radiation pattern of whip antenna on Ford Thunderbird. f = 88 MHz.

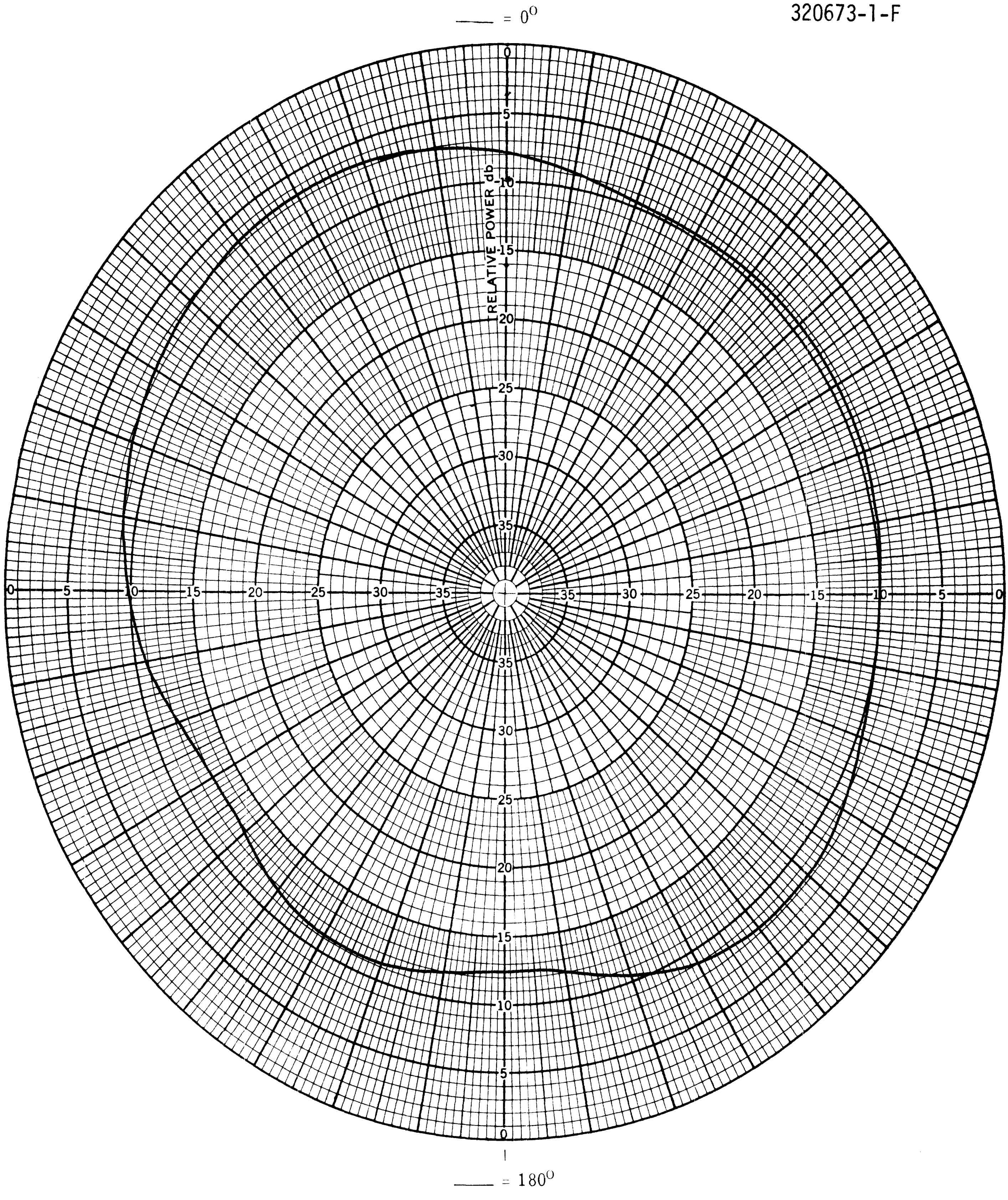


Figure 1B. Radiation pattern of whip antenna on Ford Thunderbird. f = 98 MHz.

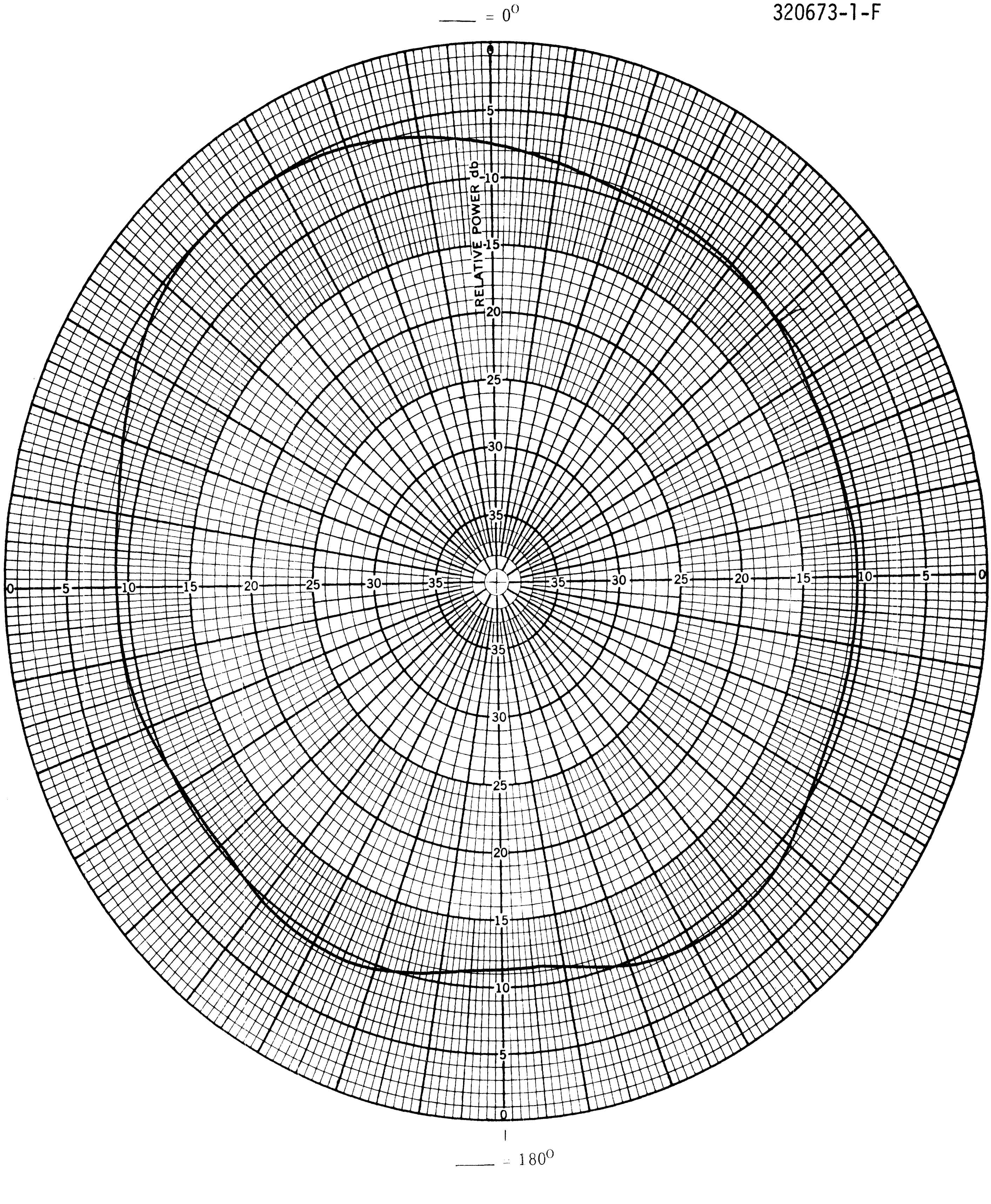


Figure 1C. Radiation pattern of whip antenna on Ford Thunderbird. f = 108 MHz.

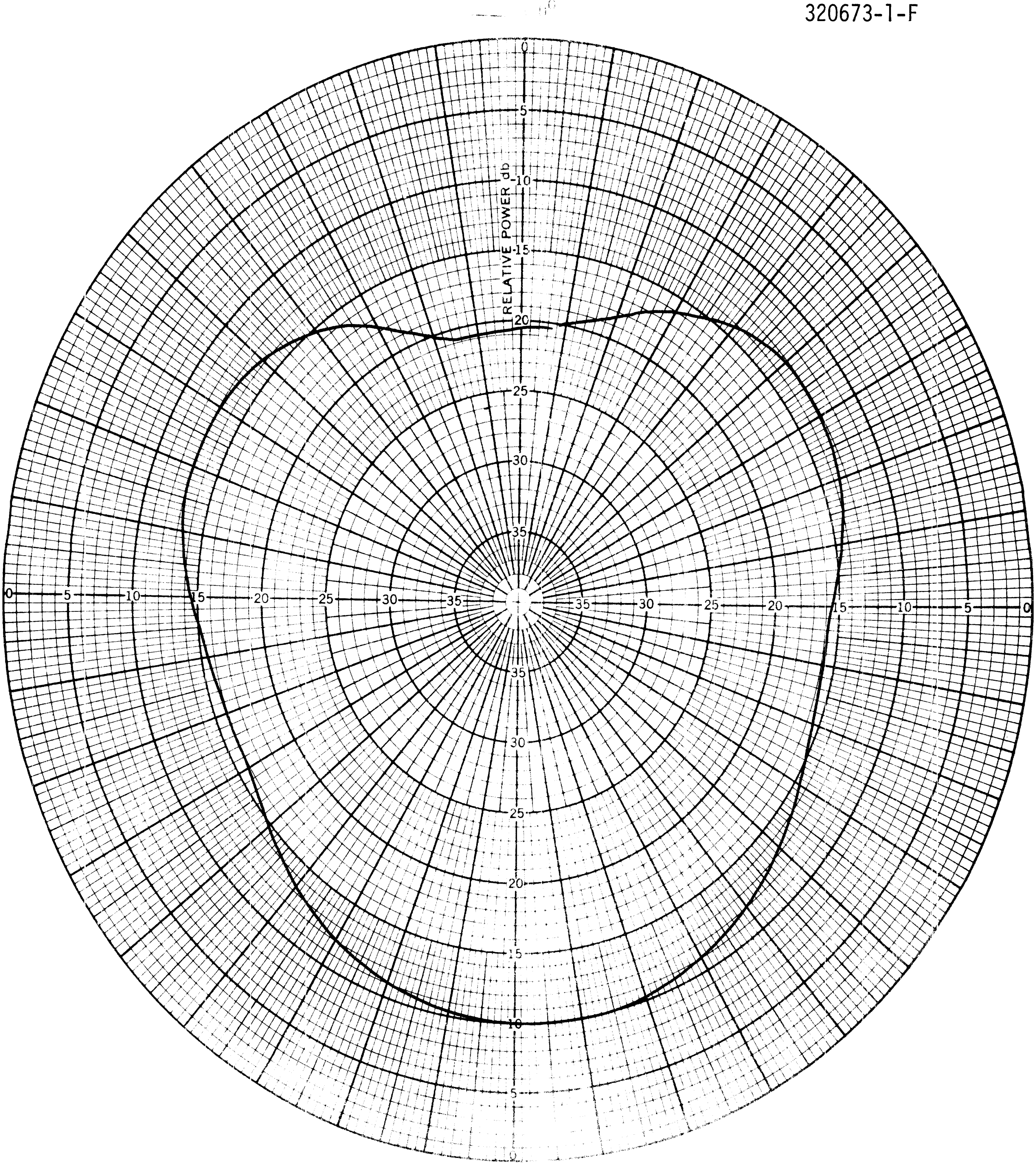


Figure 2A. Radiation pattern of windshield antenna on Chevrolet Caprice.
f = 88 MHz.

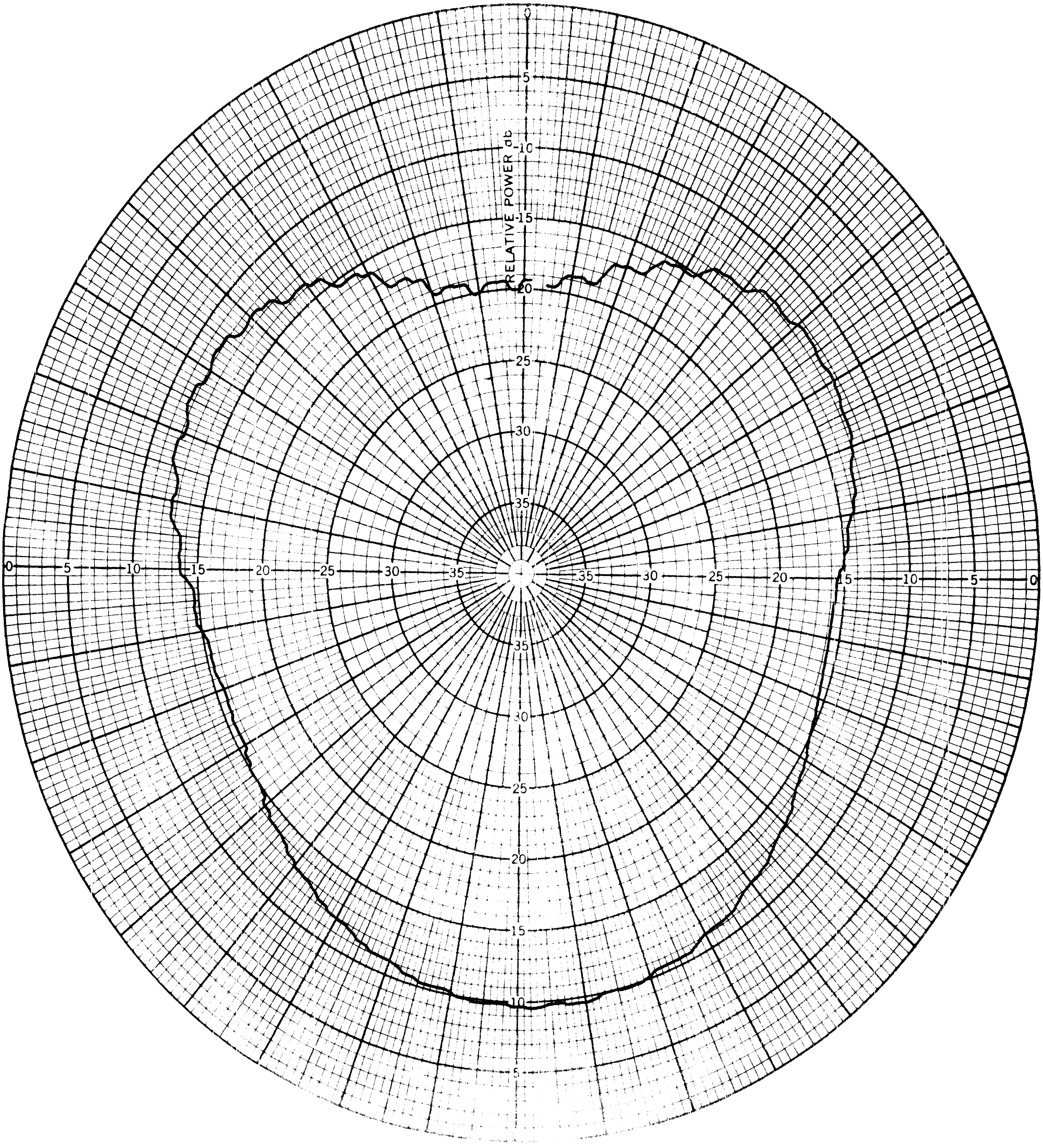


Figure 2B. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow. f = 88 MHz.

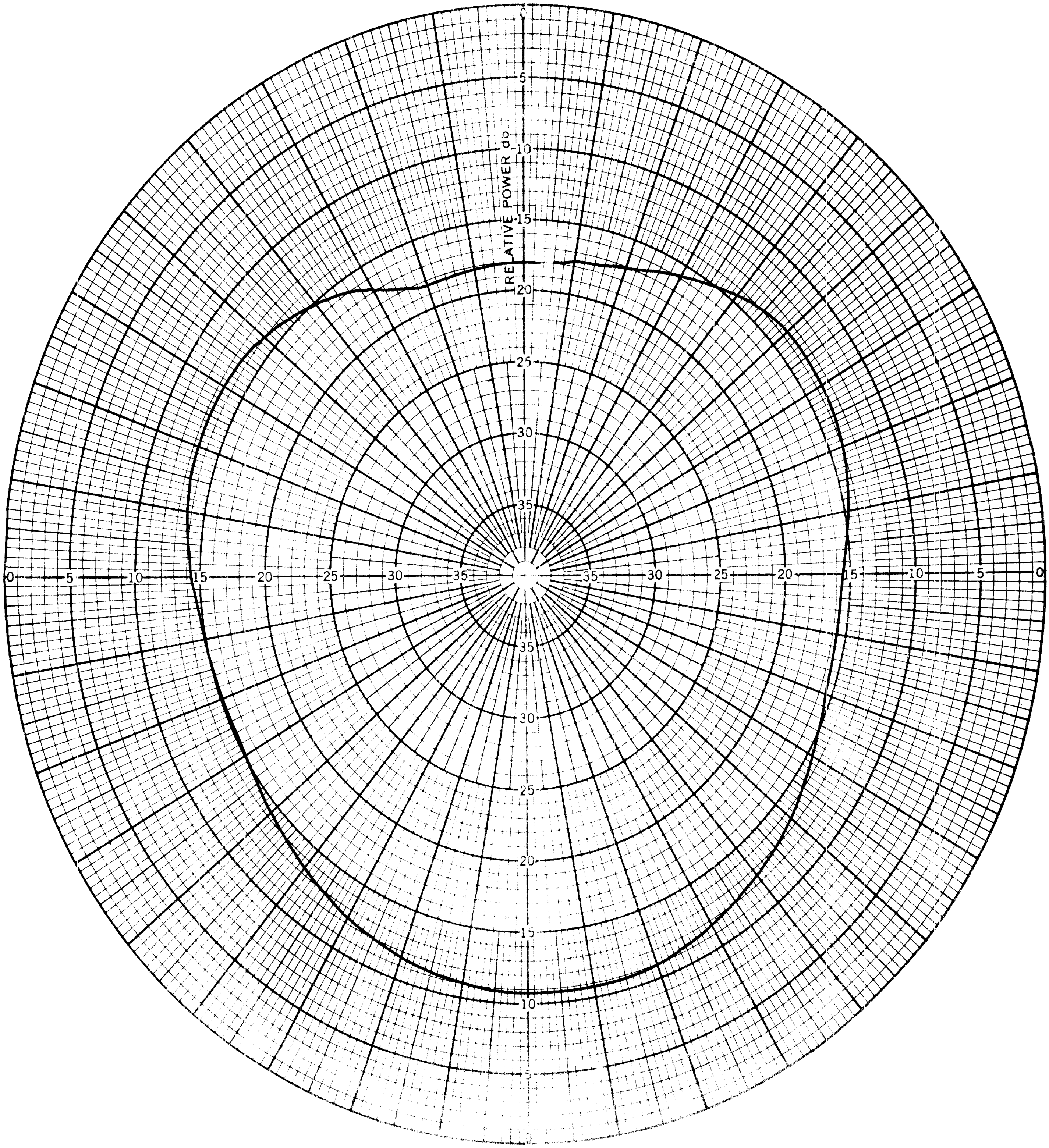


Figure 2C. Radiation pattern of windshield antenna on Chevrolet Caprice with simulated heated back-lite. f = 88 MHz.

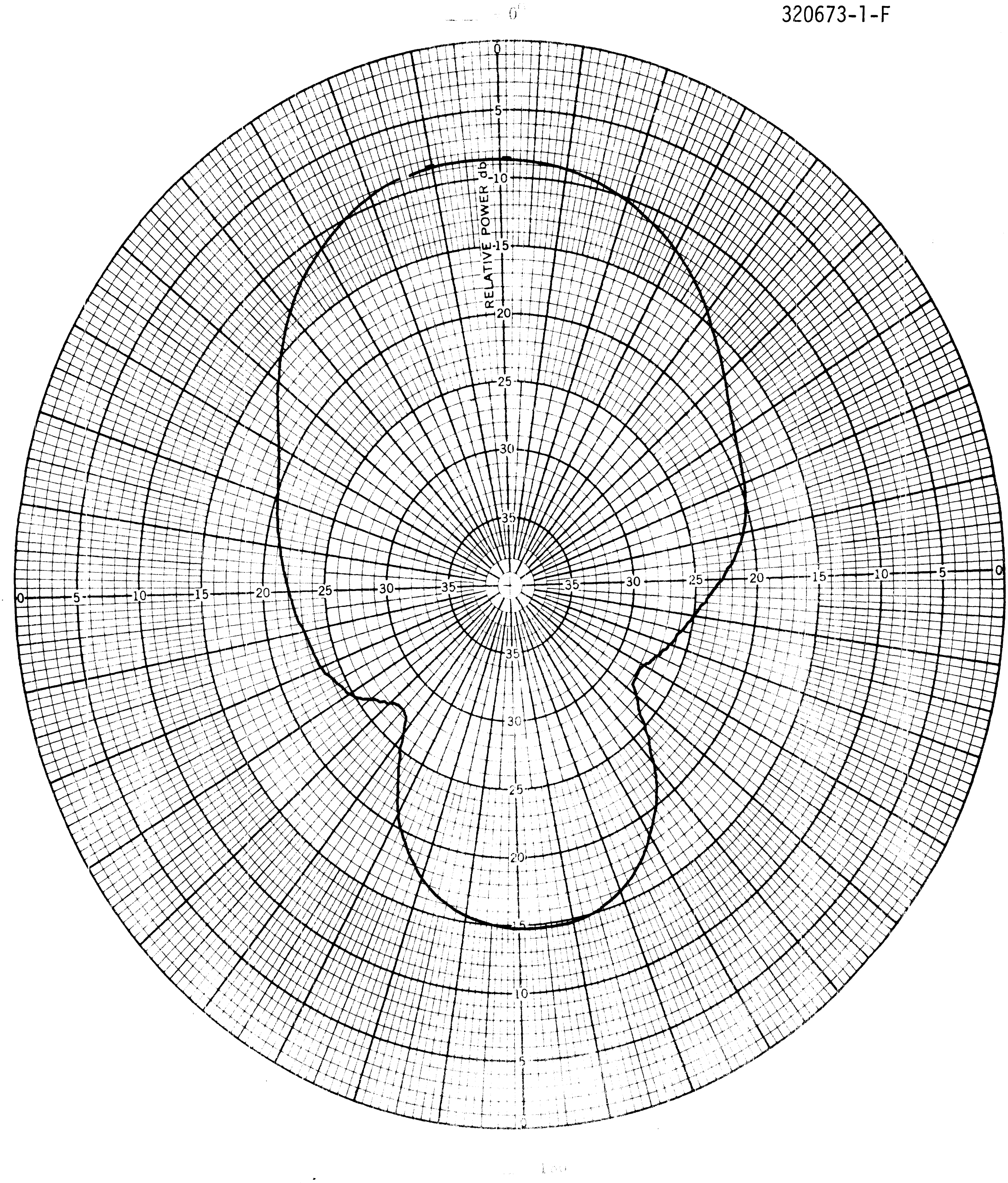


Figure 2D. Radiation pattern of windshield antenna on Chevrolet Caprice. f = 98 MHz.

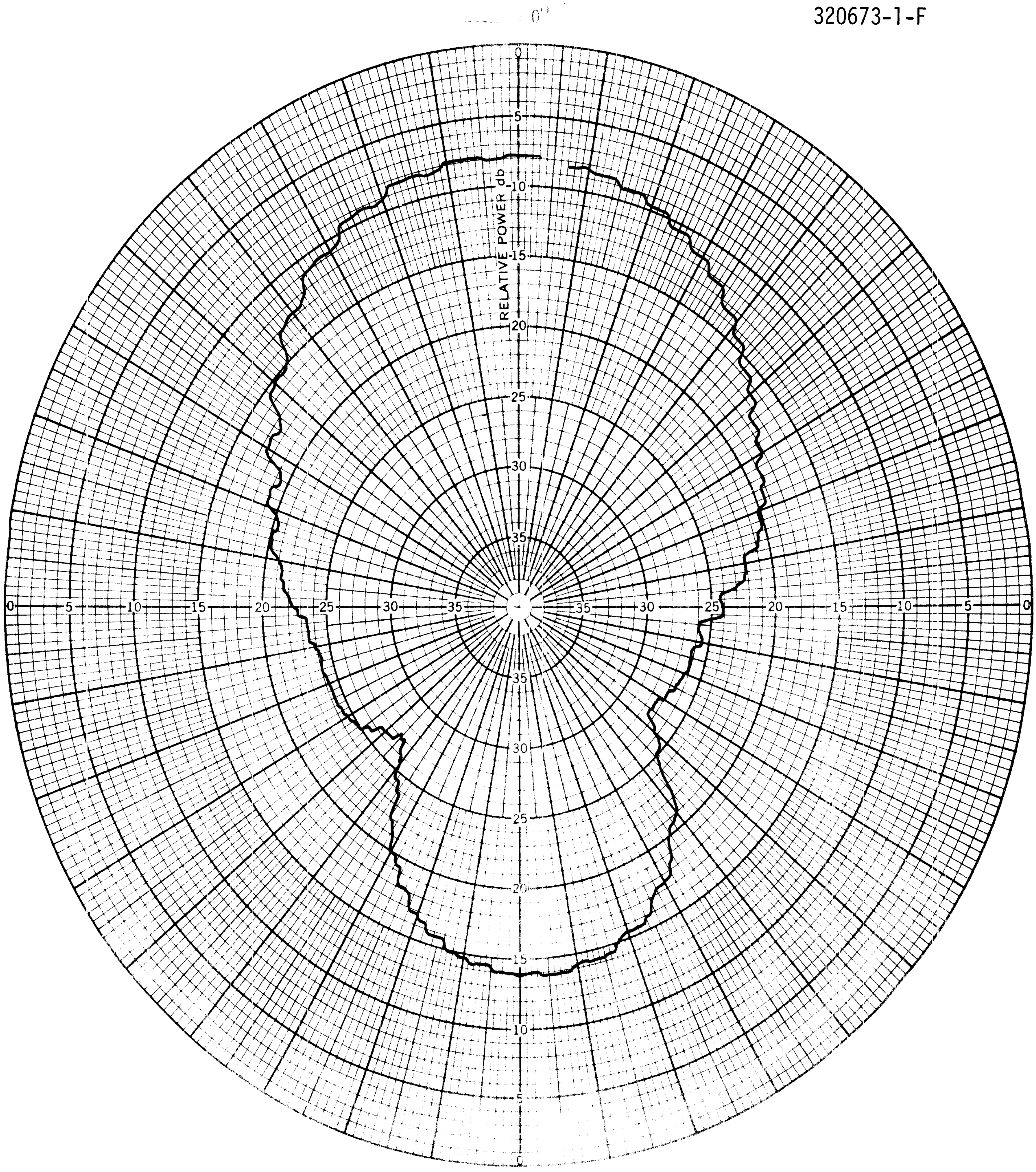


Figure 2E. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow. f = 98 MHz.

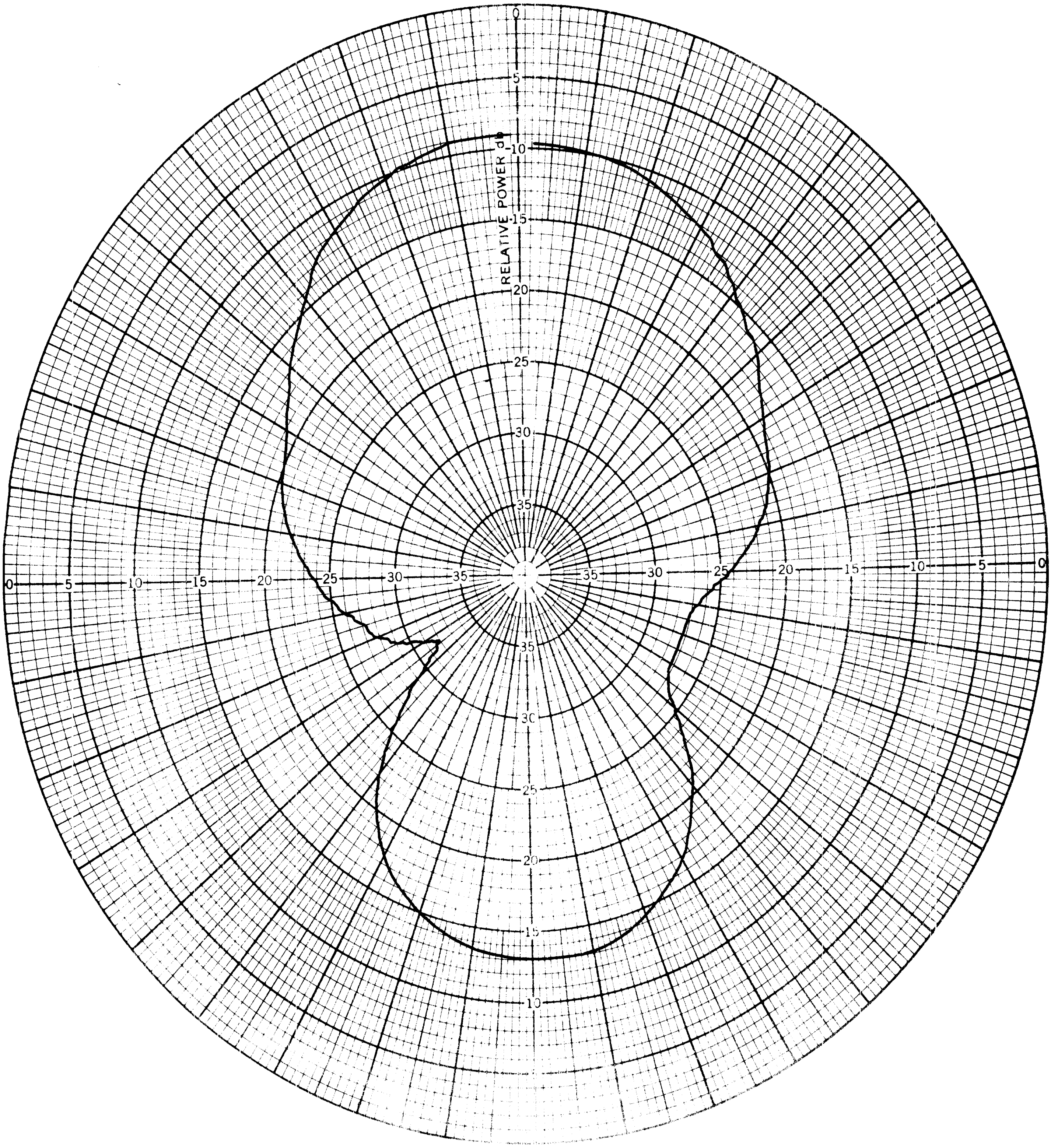


Figure 2F. Radiation pattern of windshield antenna on Chevrolet Caprice with simulated heated back-lite. f = 98 MHz.

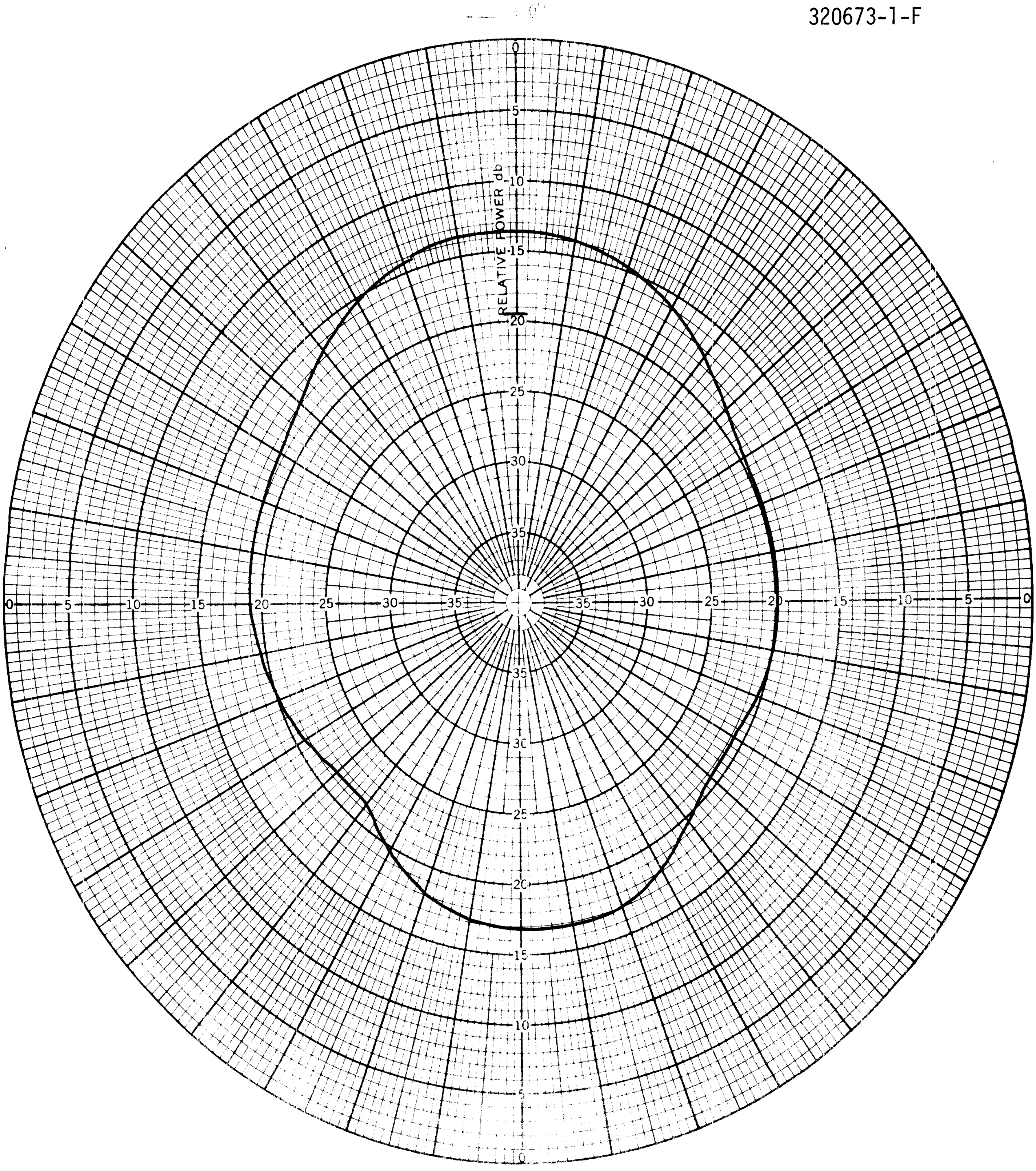


Figure 2G. Radiation pattern of windshield antenna on Chevrolet Caprice.
f = 108 MHz.

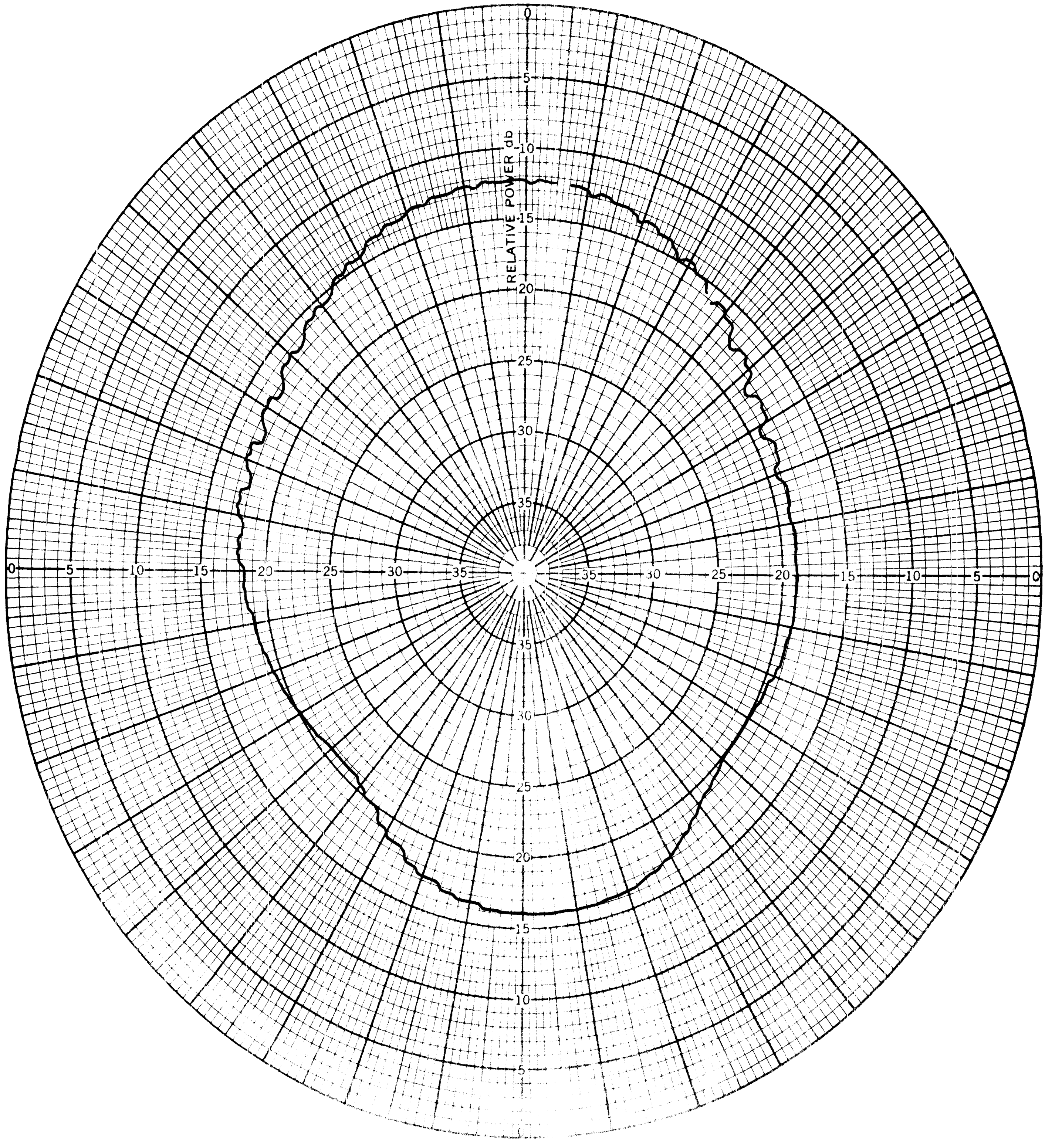


Figure 2H. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow. f = 108 MHz.

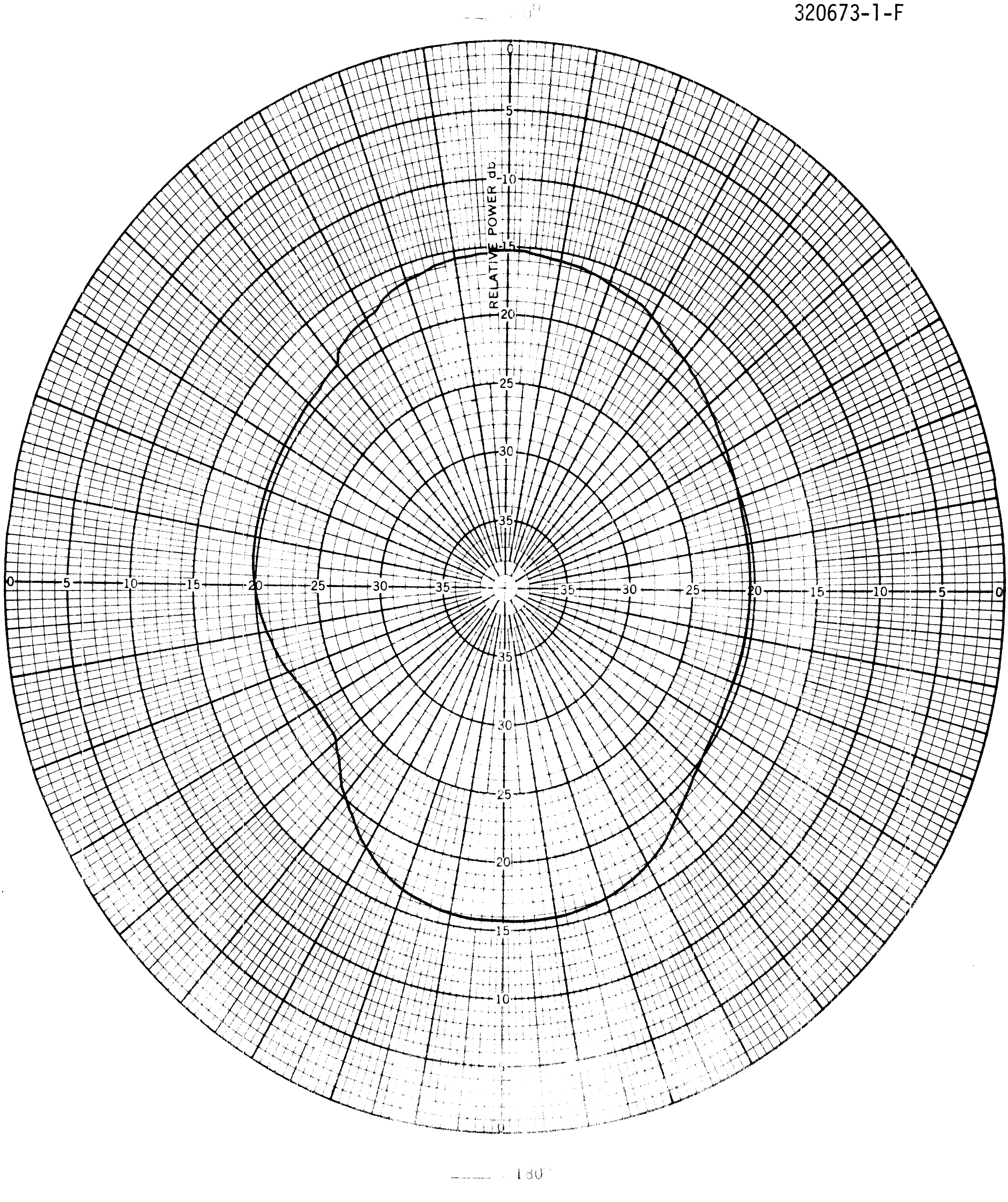


Figure 21. Radiation pattern of windshield antenna on Chevrolet Caprice with simulated heated back-lite. f = 108 MHz.

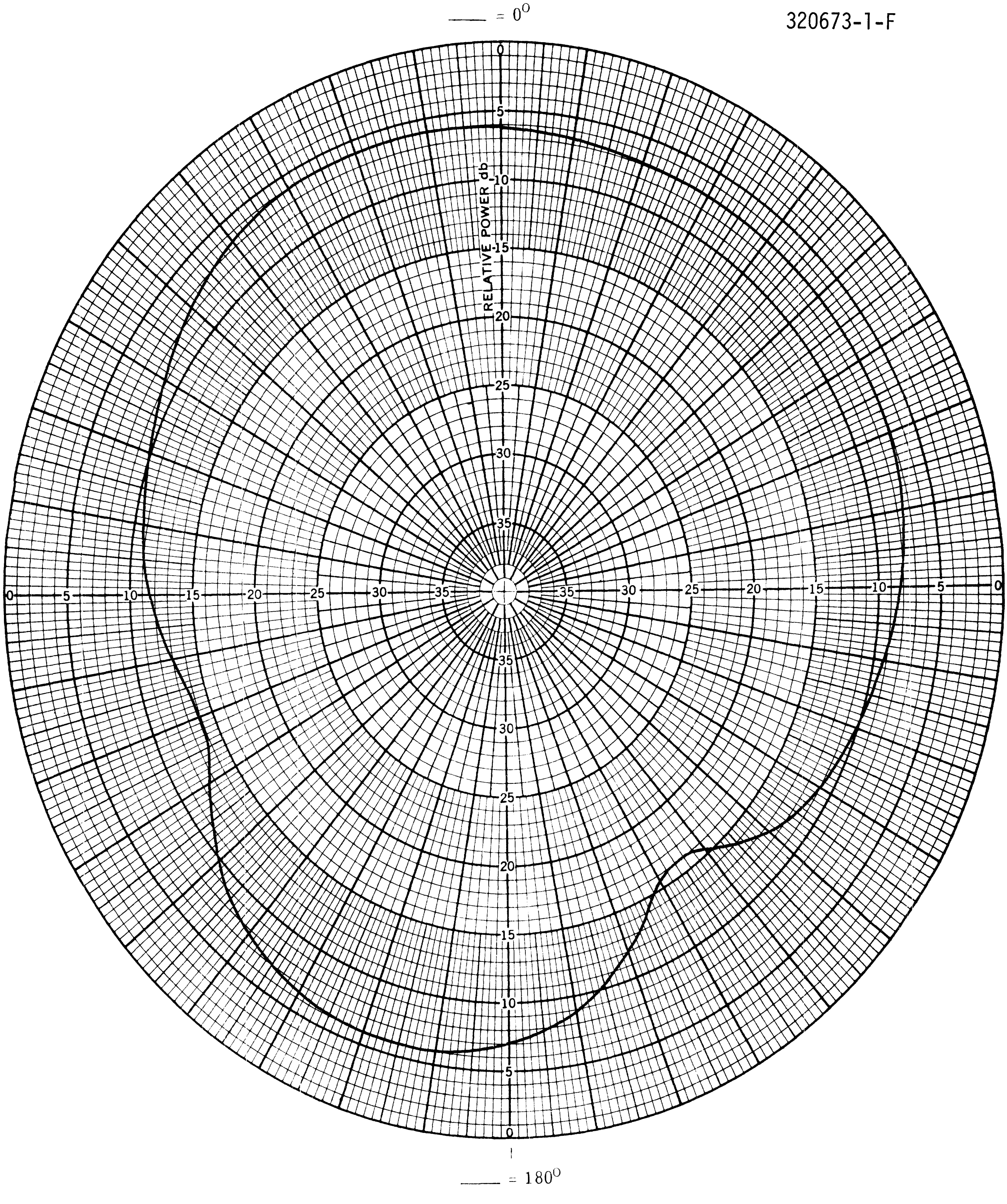


Figure 3A. Radiation pattern of whip antenna on Ford LTD II. f = 88 MHz.

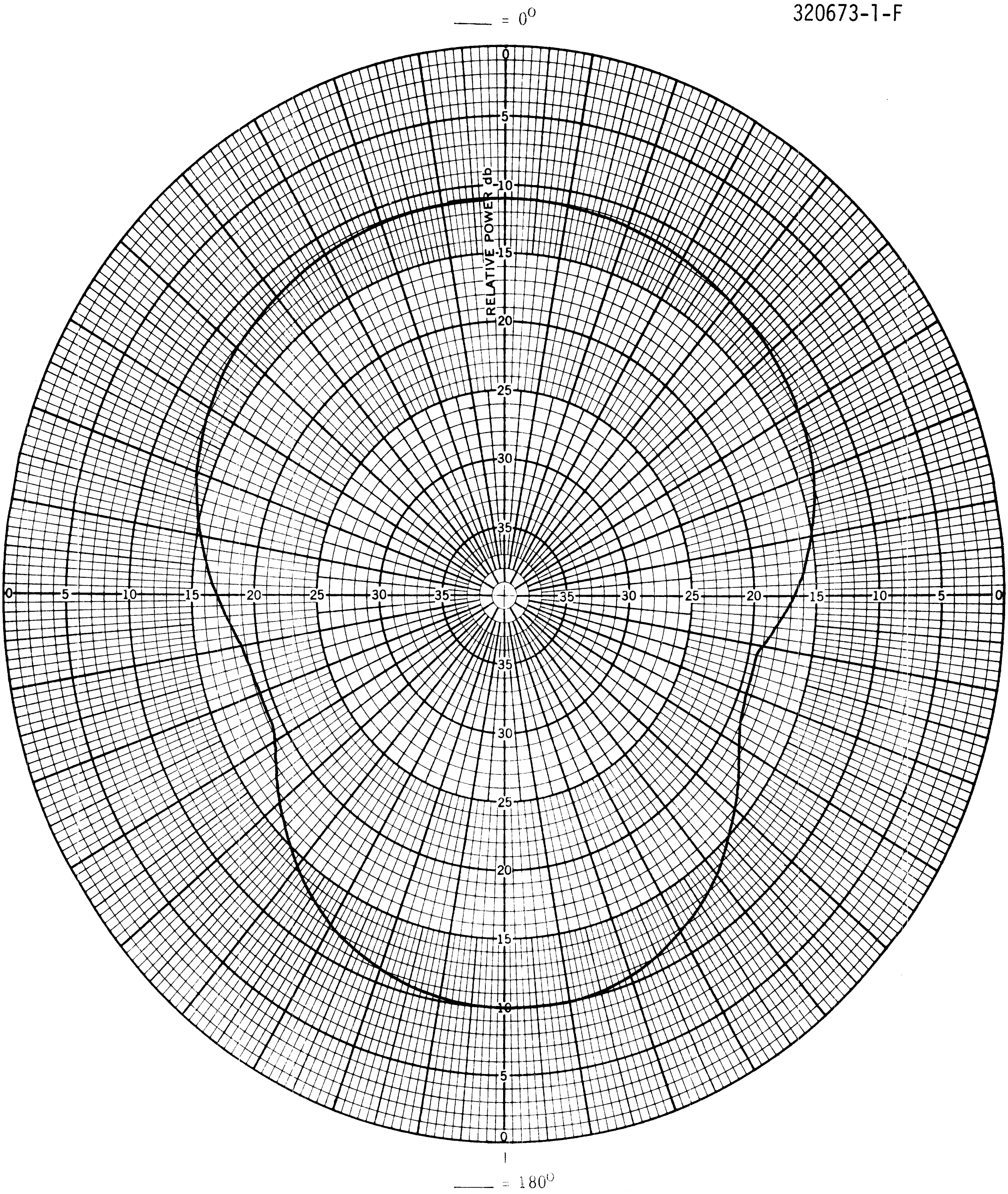


Figure 3B. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II. f = 88 MHz.

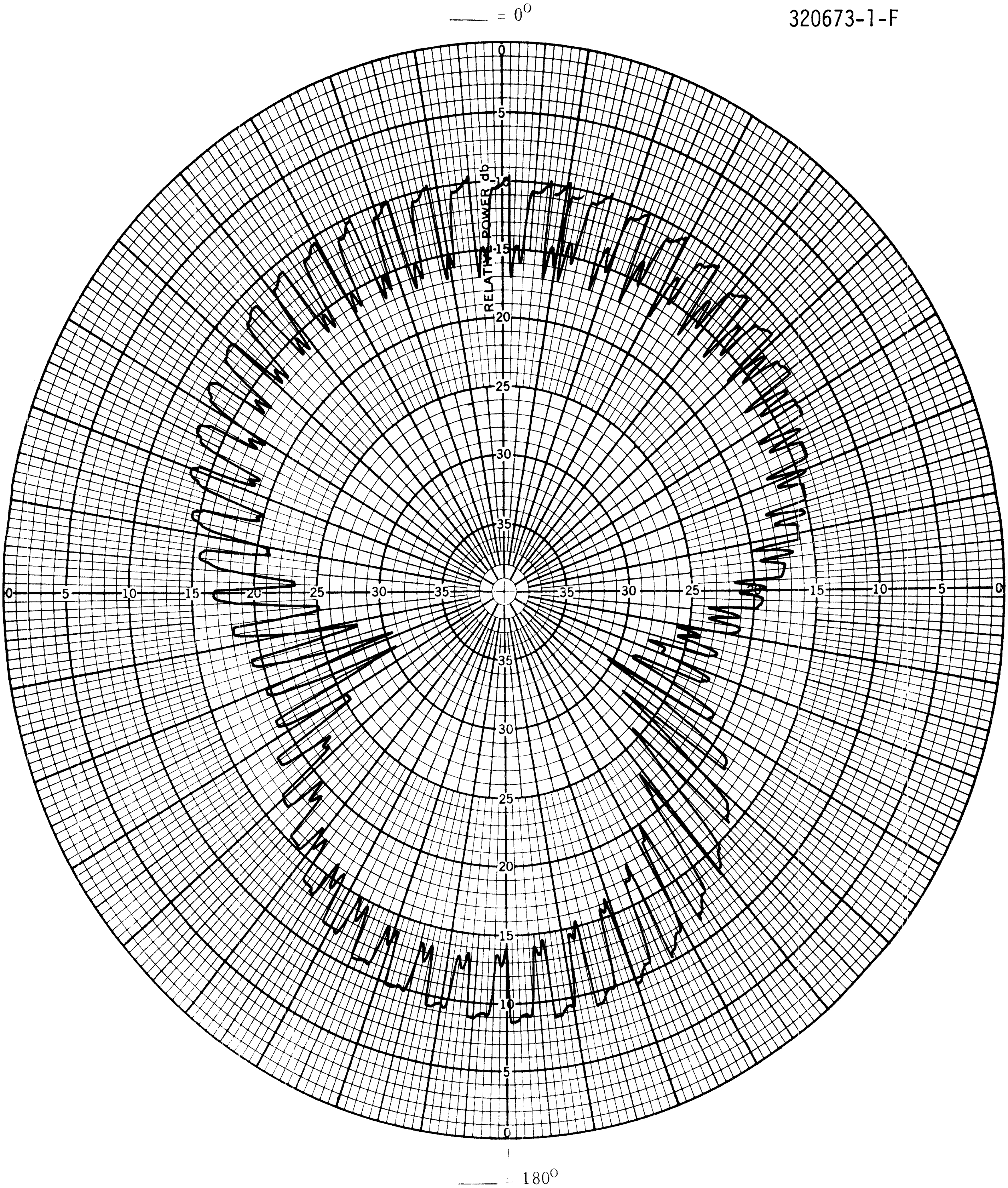


Figure 3C. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with wipers running slow. f = 88 MHz.

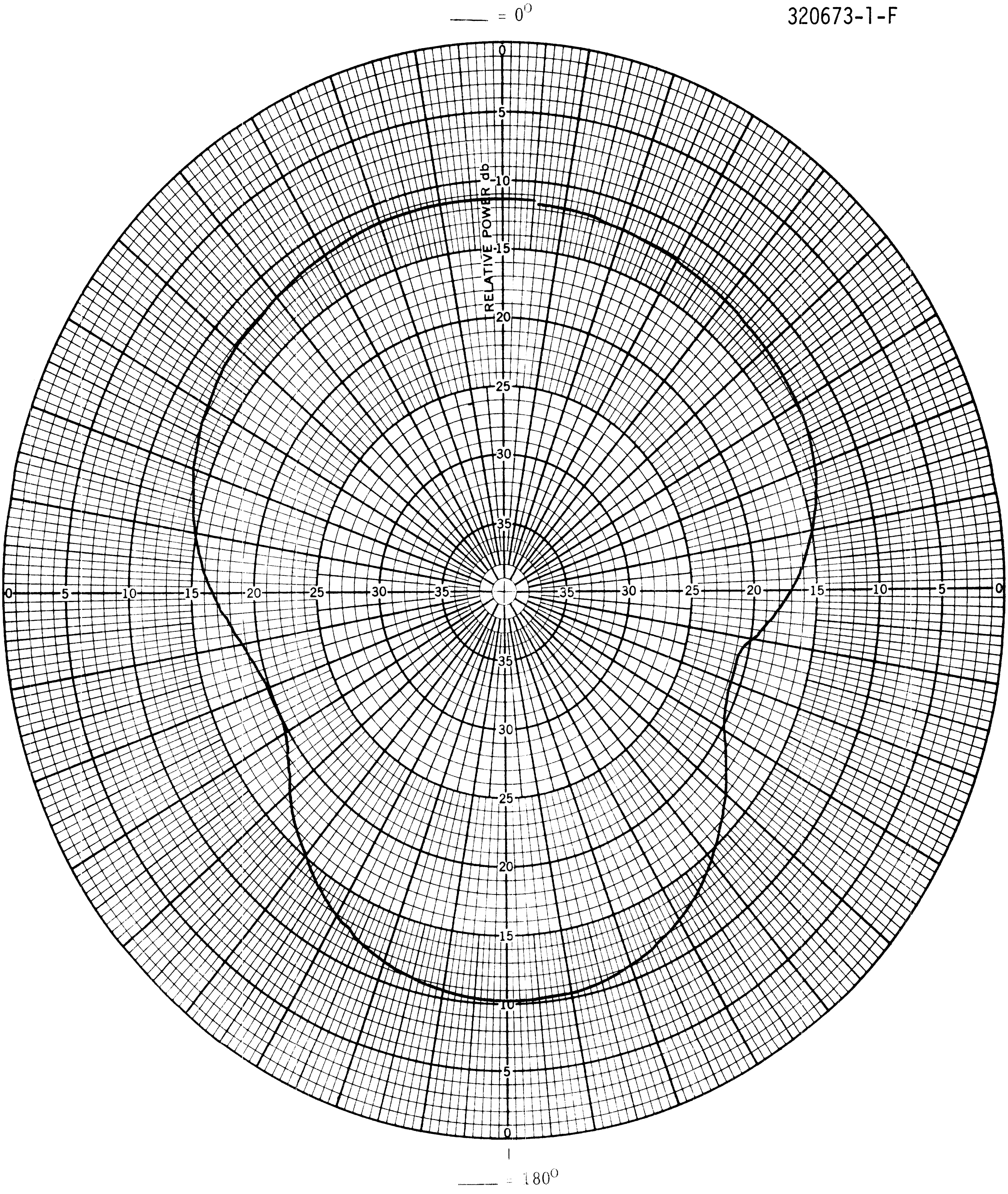


Figure 3D. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with simulated heated back-lite. f = 88 MHz.

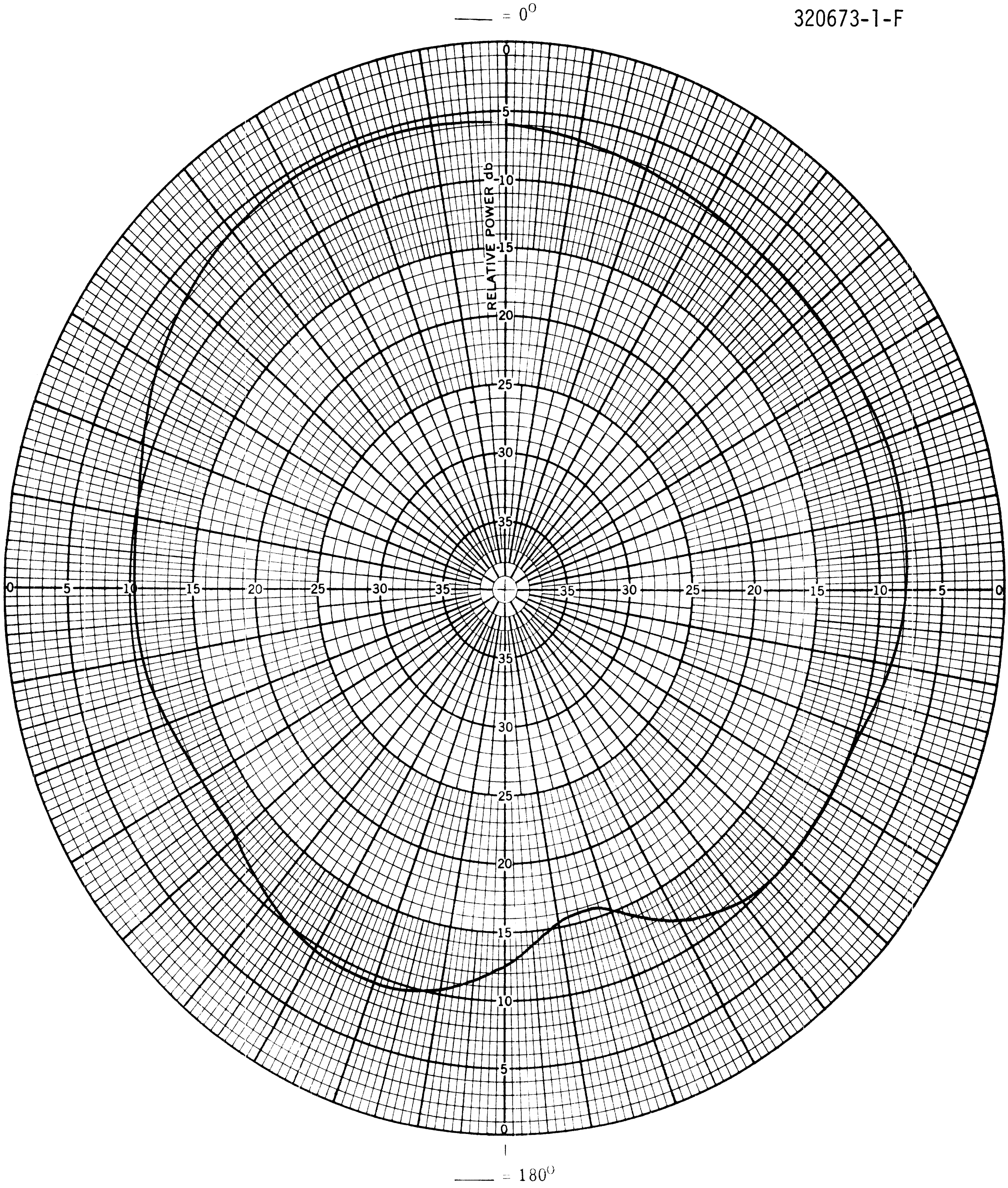


Figure 3E. Radiation pattern of whip antenna on Ford LTD II. f = 98 MHz.

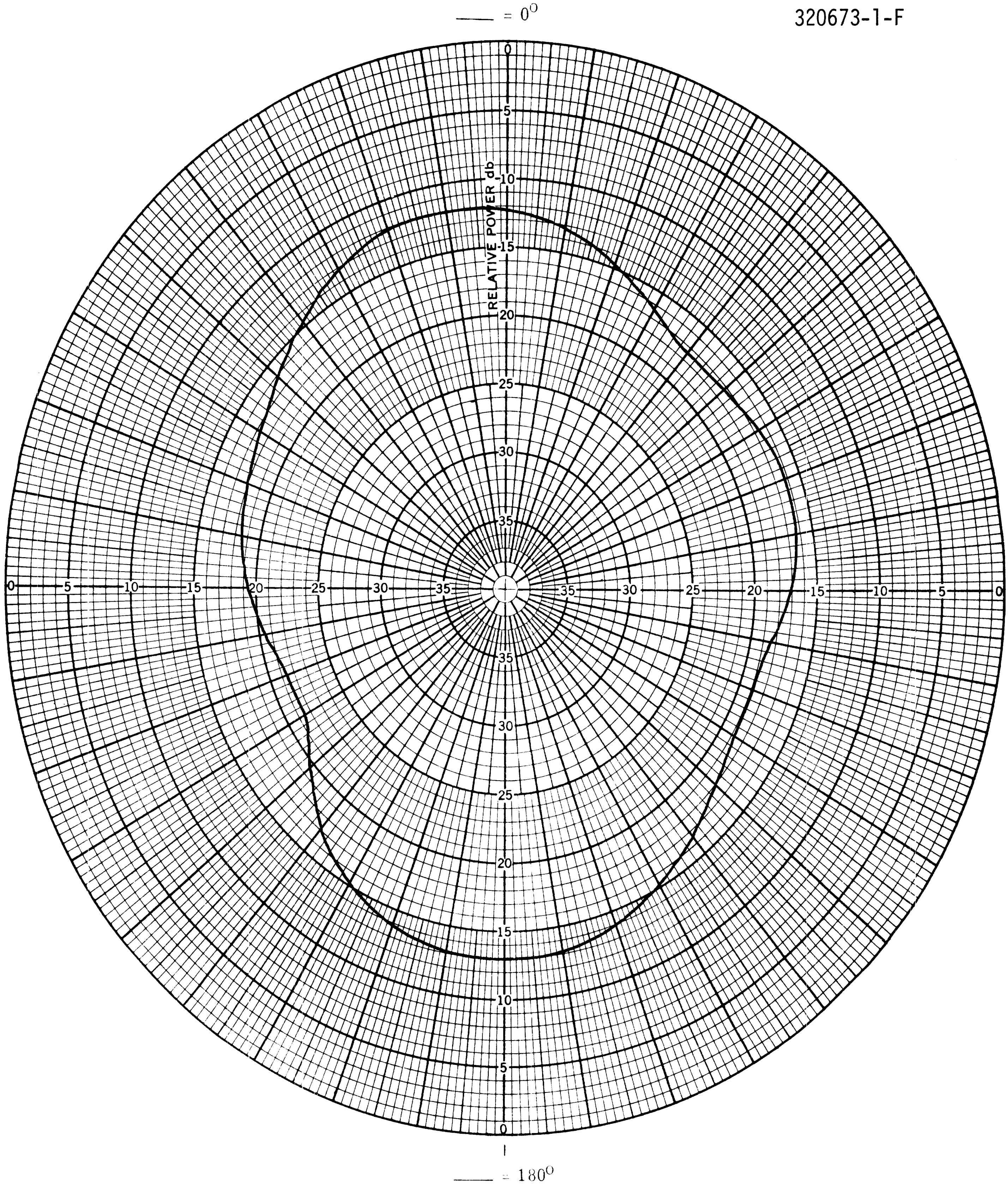


Figure 3F. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II. f = 98 MHz.

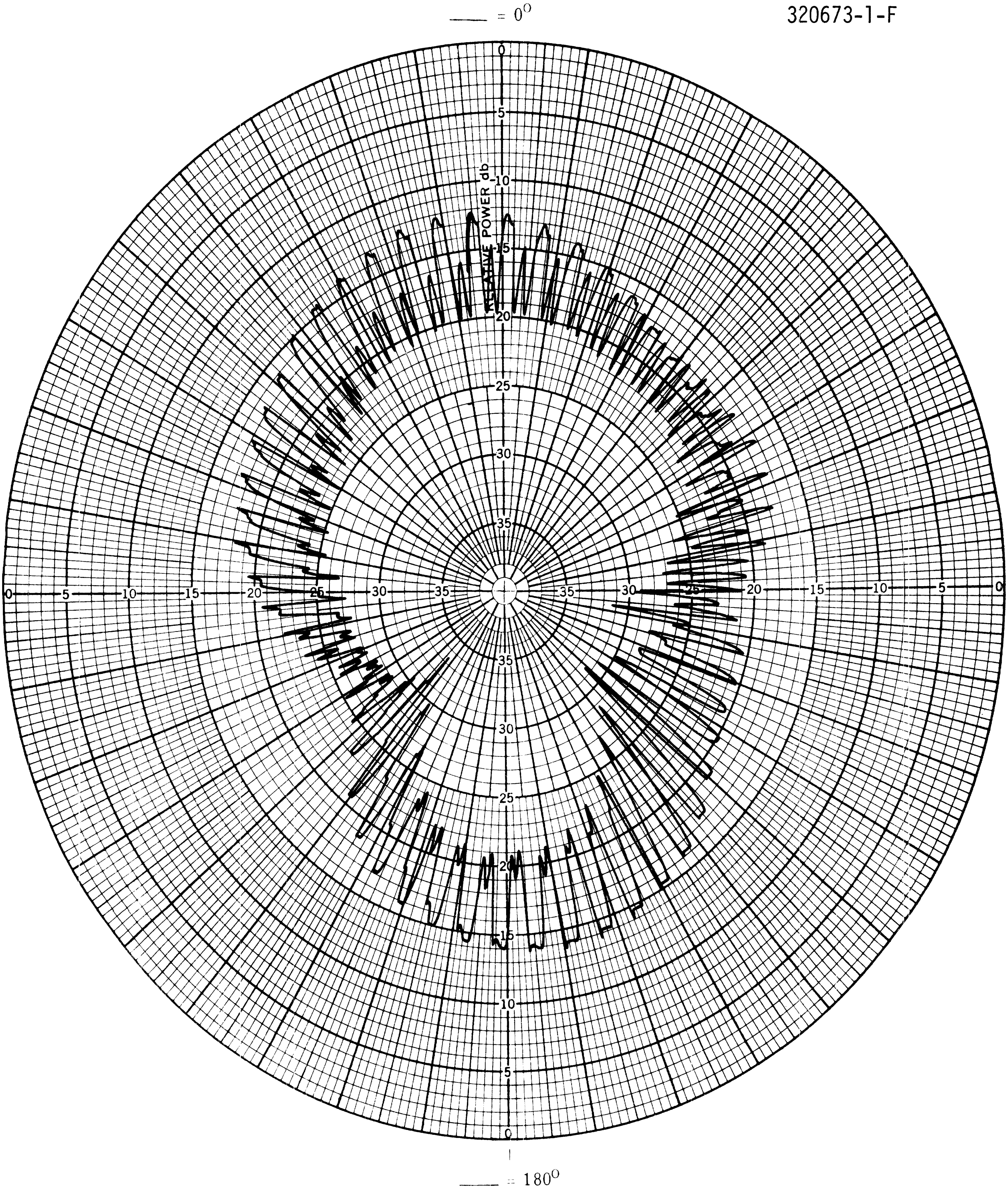


Figure 3G. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with wipers running slow. f = 98 MHz.

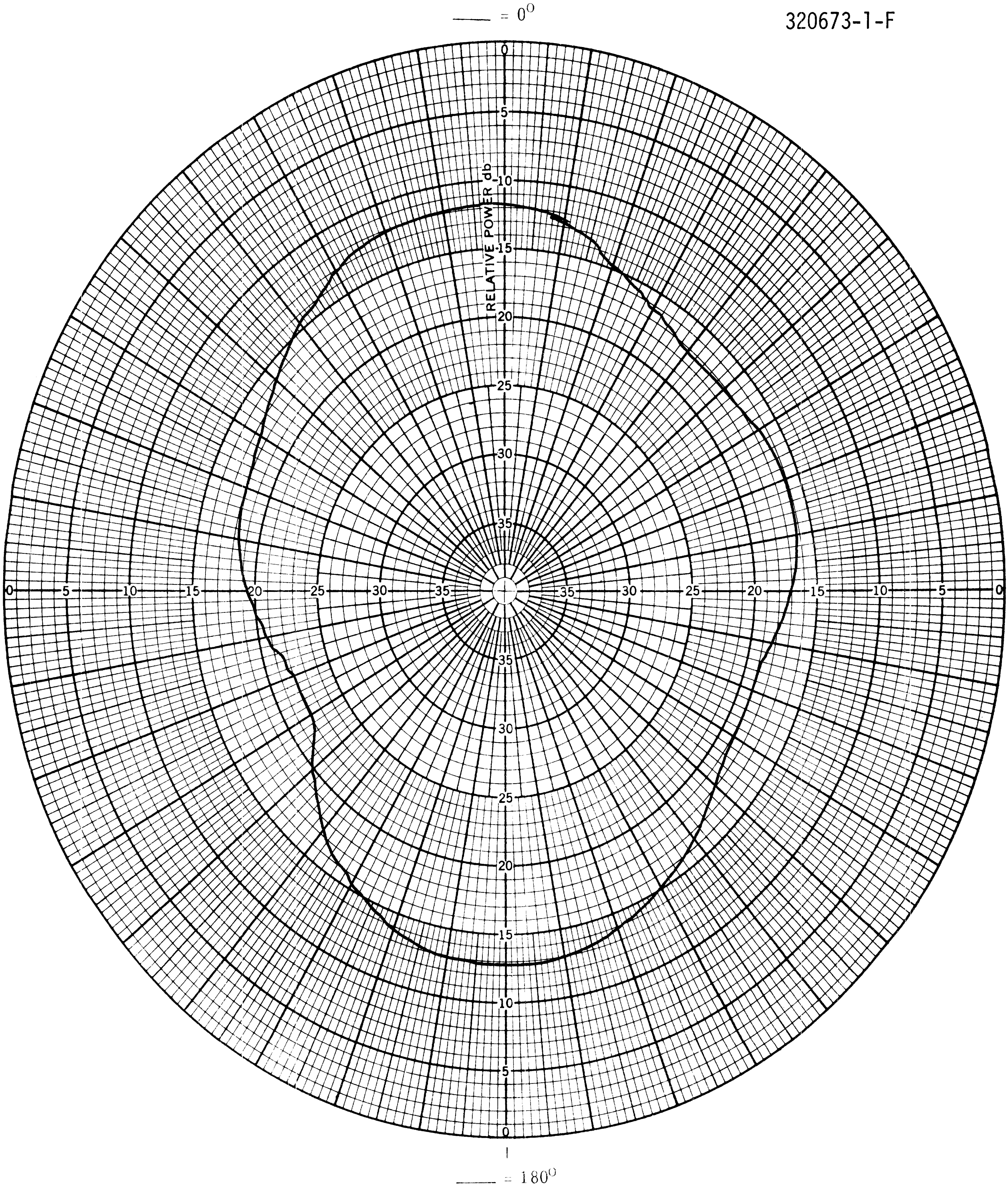


Figure 3H. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with simulated heated back-lite. f = 98 MHz.

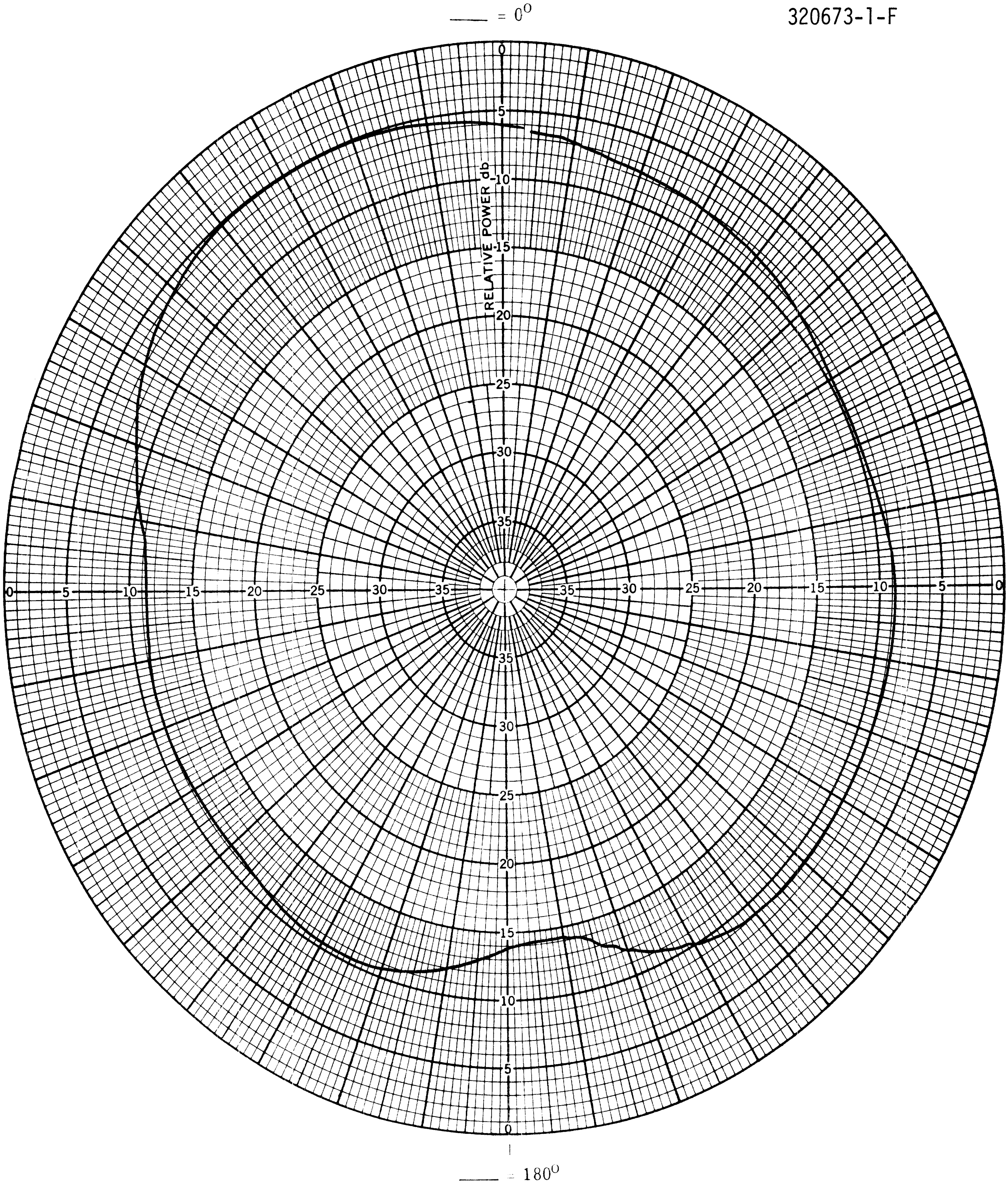


Figure 3I. Radiation pattern of whip antenna on Ford LTD II. f = 108 MHz.

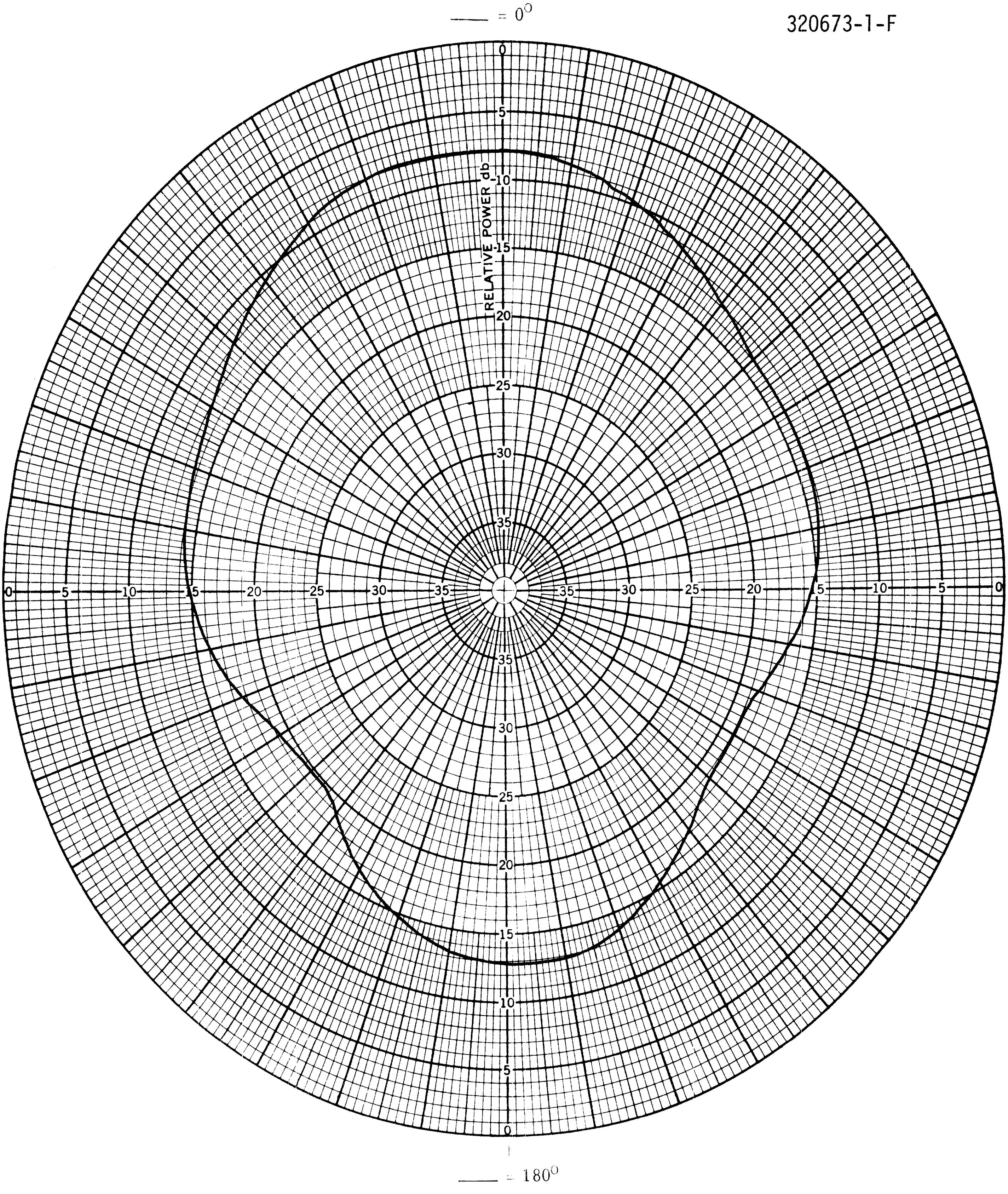


Figure 3J. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II. f = 108 MHz.

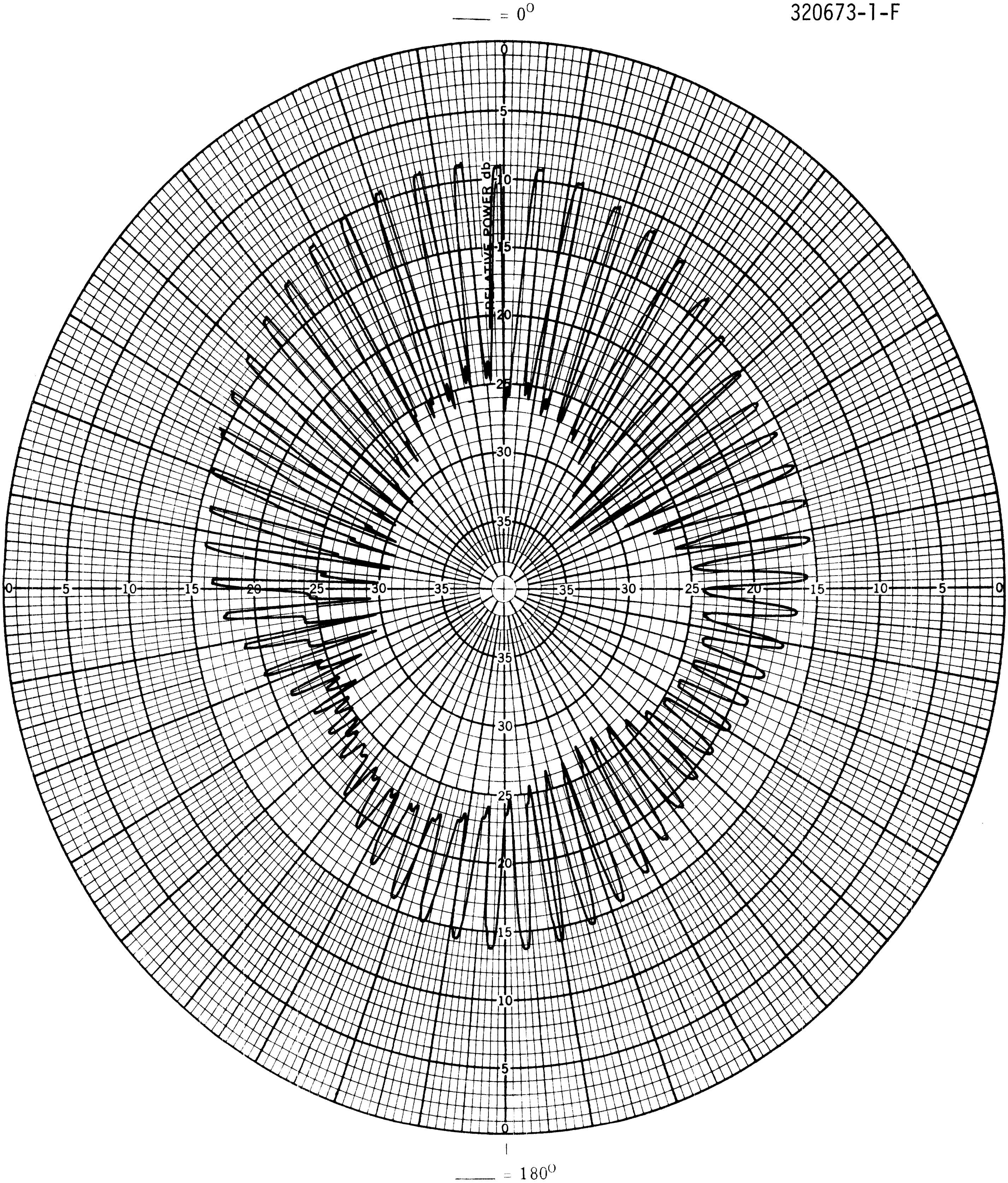


Figure 3K. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with wipers running slow. f = 108 MHz.

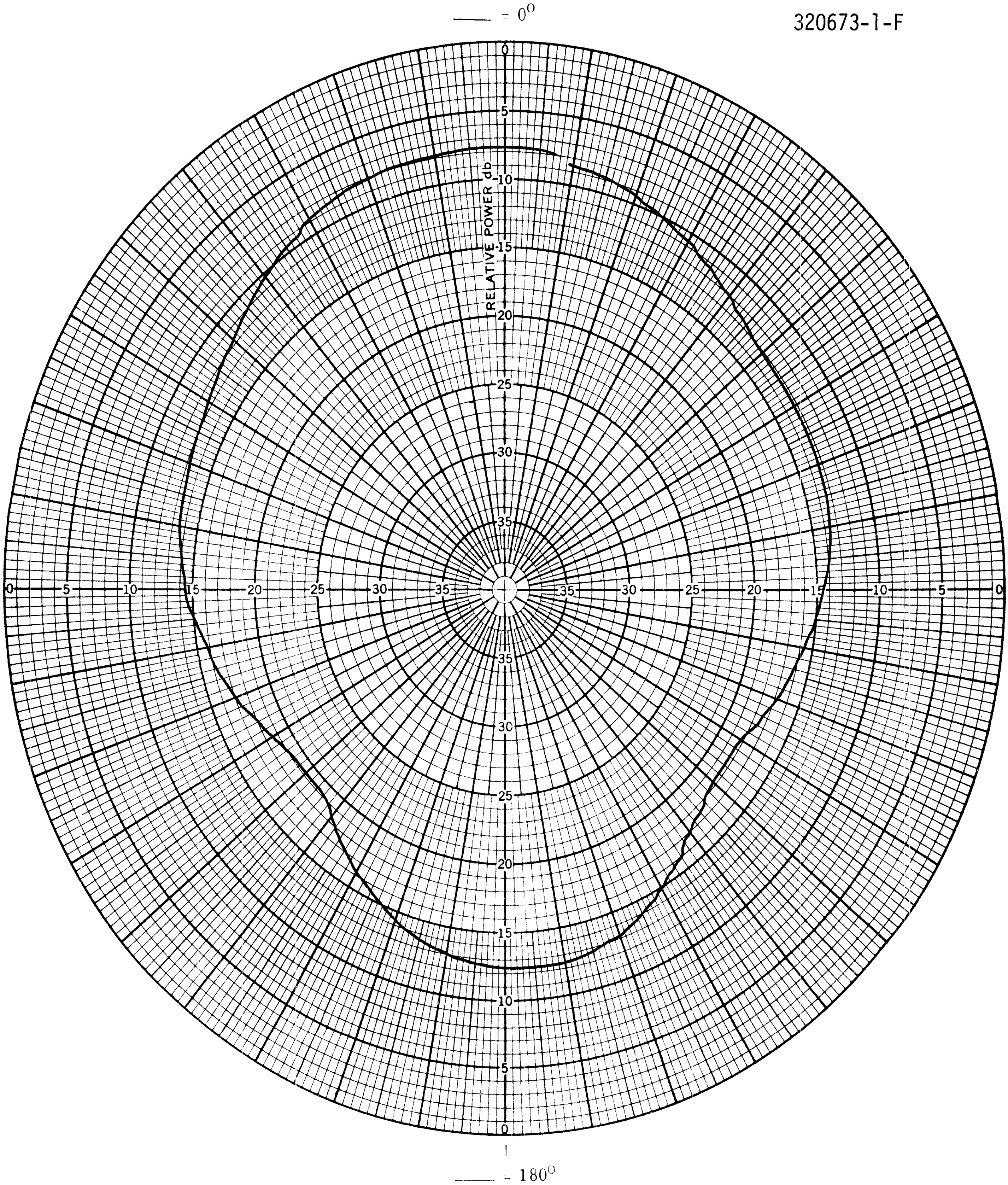


Figure 3L. Radiation pattern of windshield antenna Configuration #1 on Ford LTD II with simulated heated back-lite. f = 108 MHz.

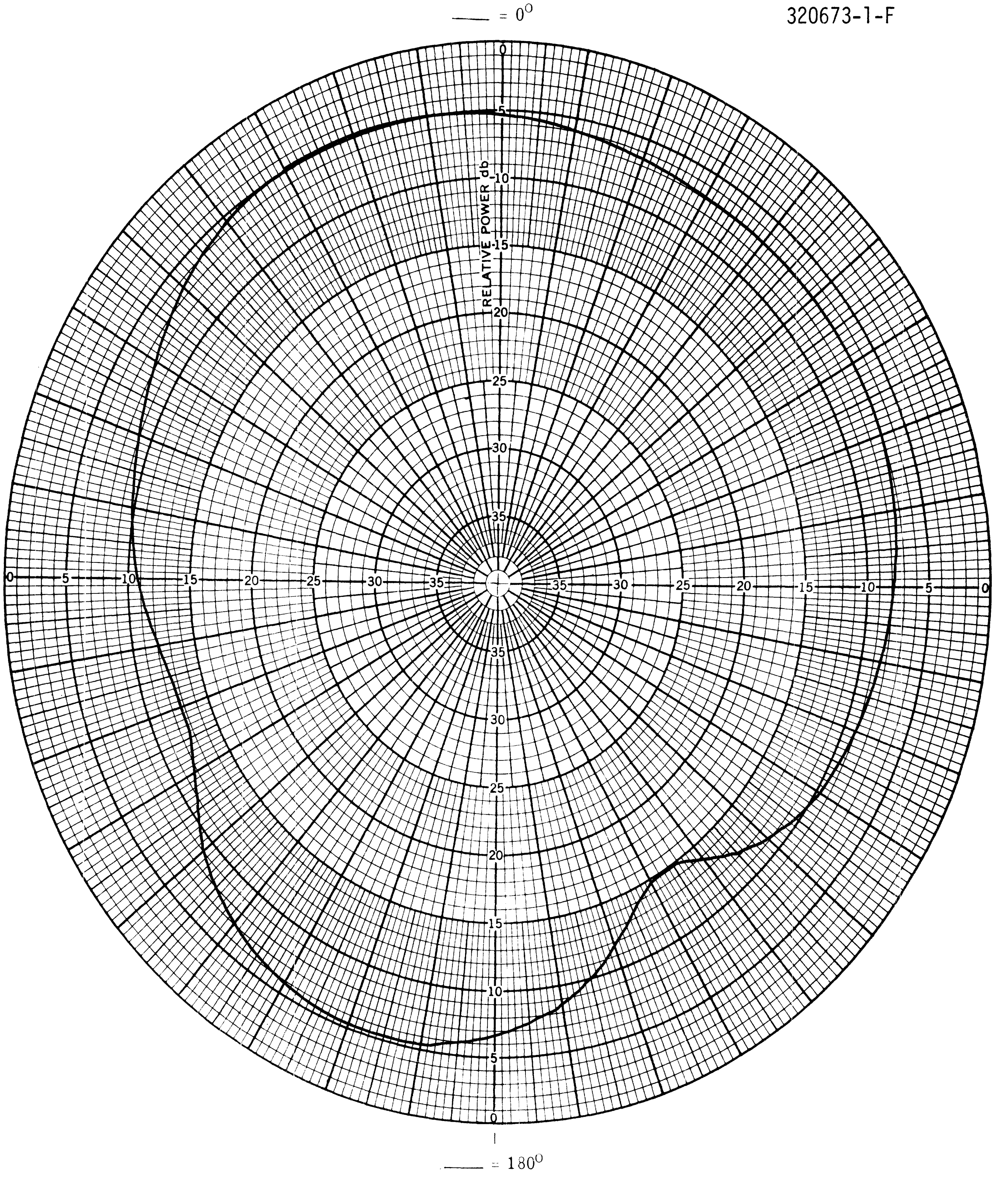


Figure 4A. Radiation pattern of whip antenna on Ford LTD II. f = 88 MHz.

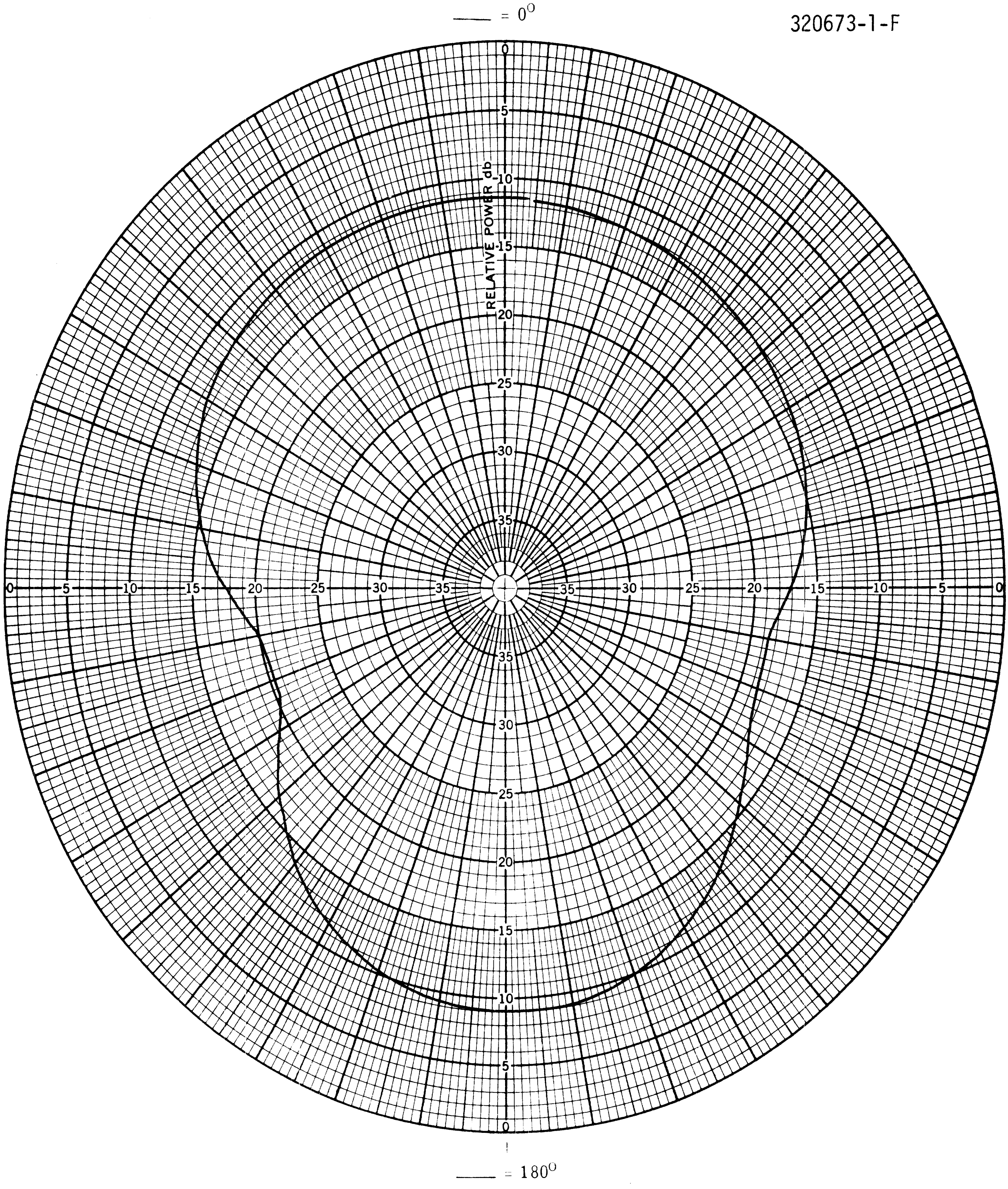


Figure 4B. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II. f = 88 MHz.

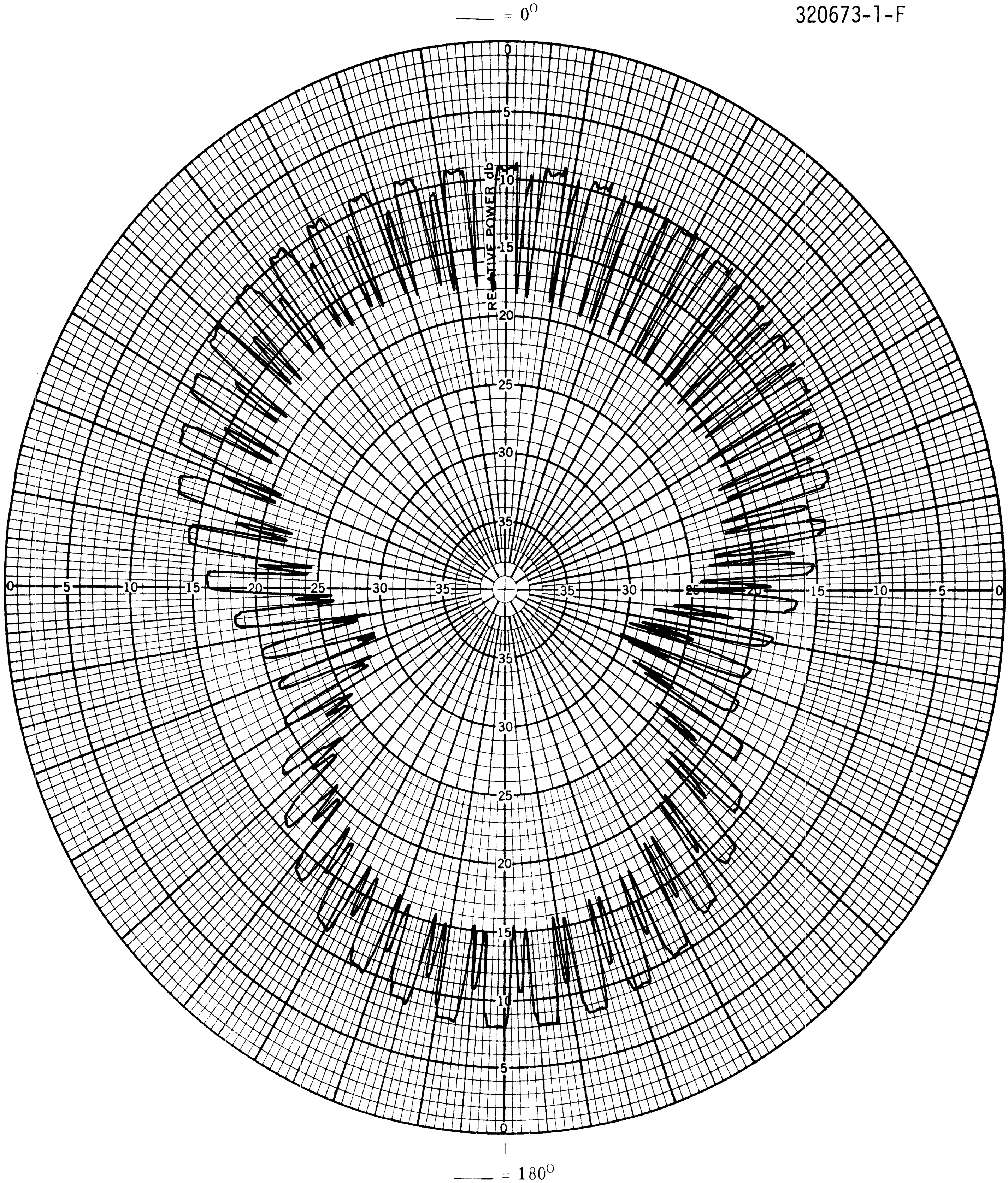


Figure 4C. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with wipers running slow. f = 88 MHz.

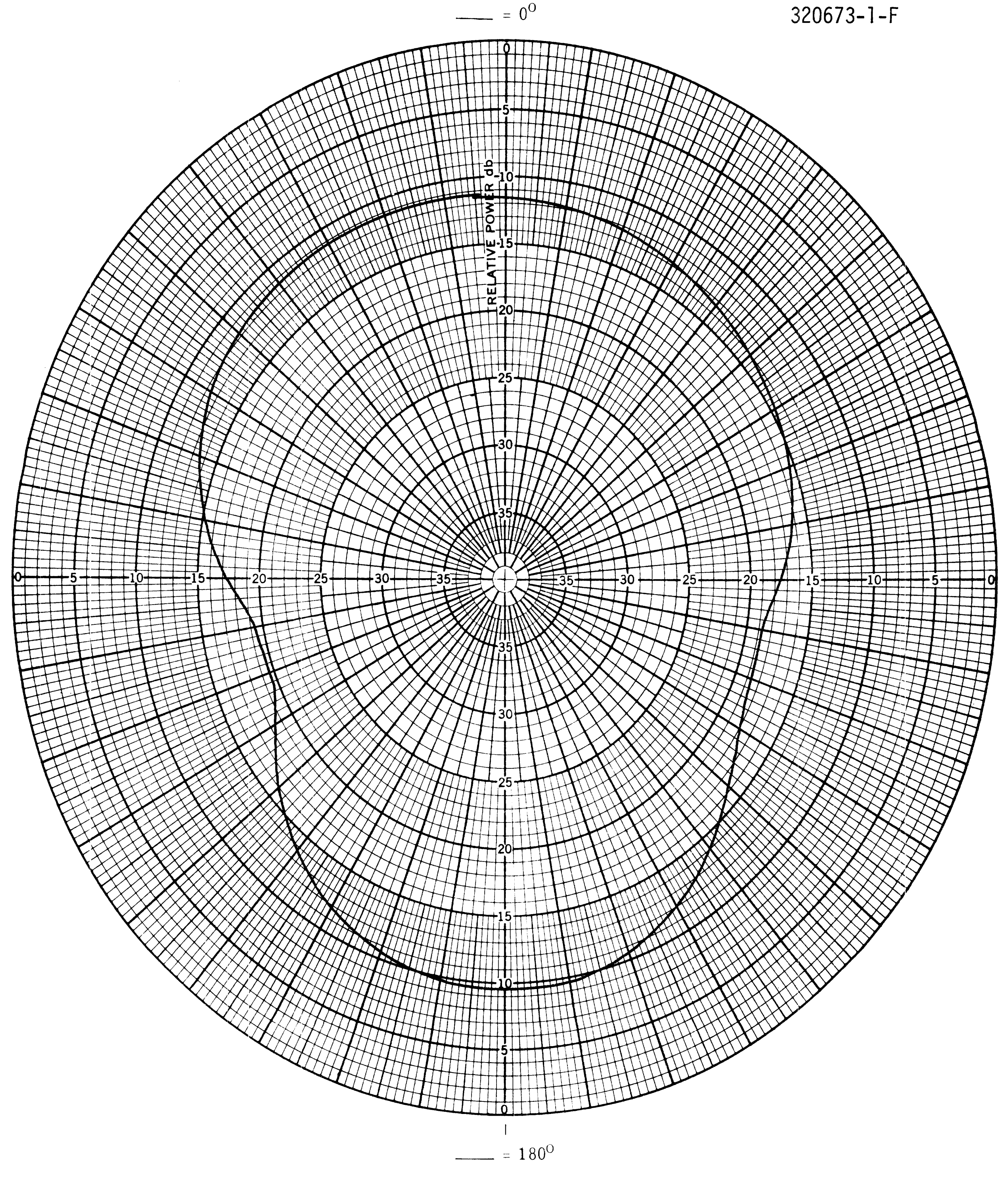


Figure 4D. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with simulated heated back-lite. f = 88 MHz.

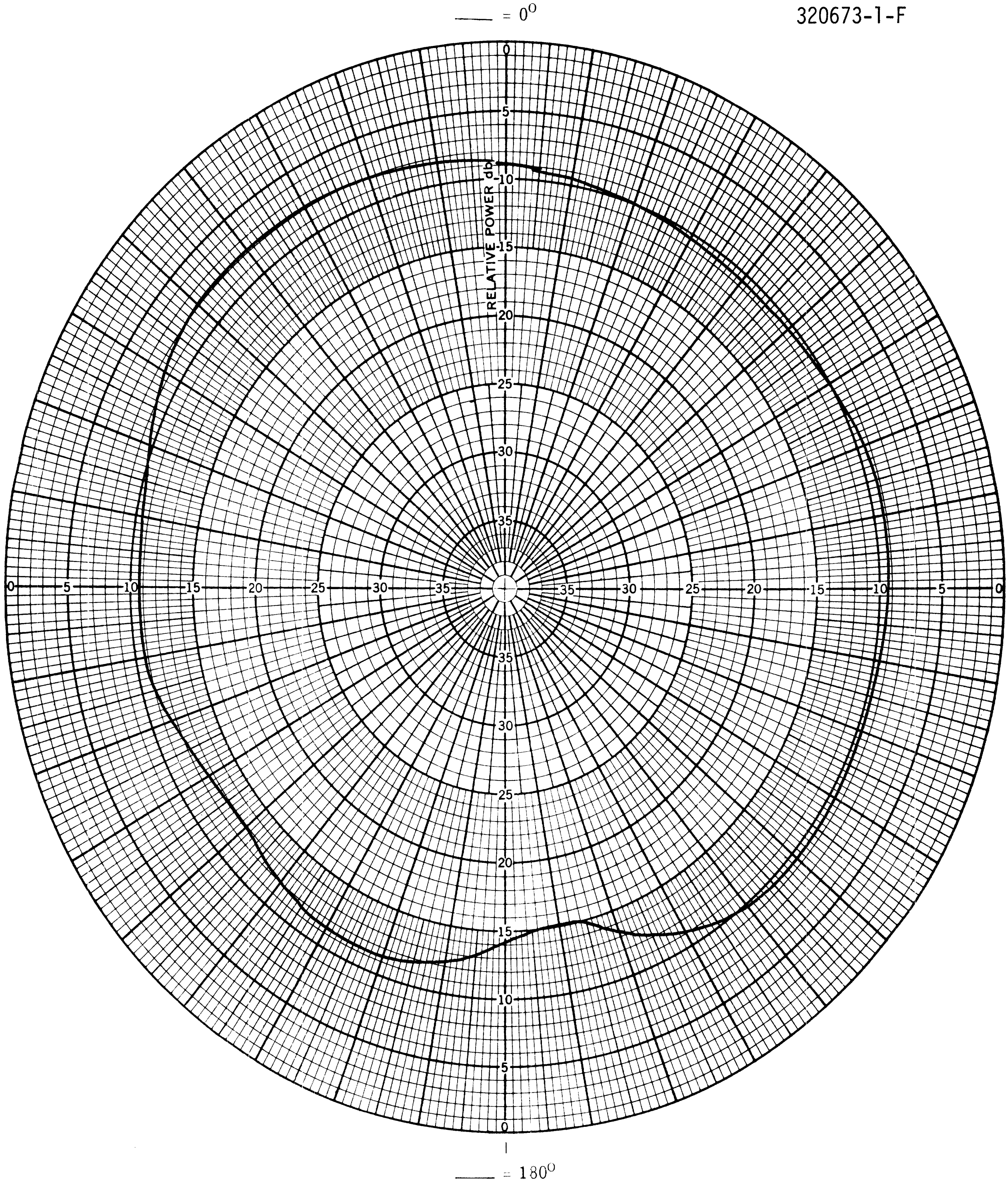


Figure 4E. Radiation pattern of whip antenna on Ford LTD II. f = 98 MHz.

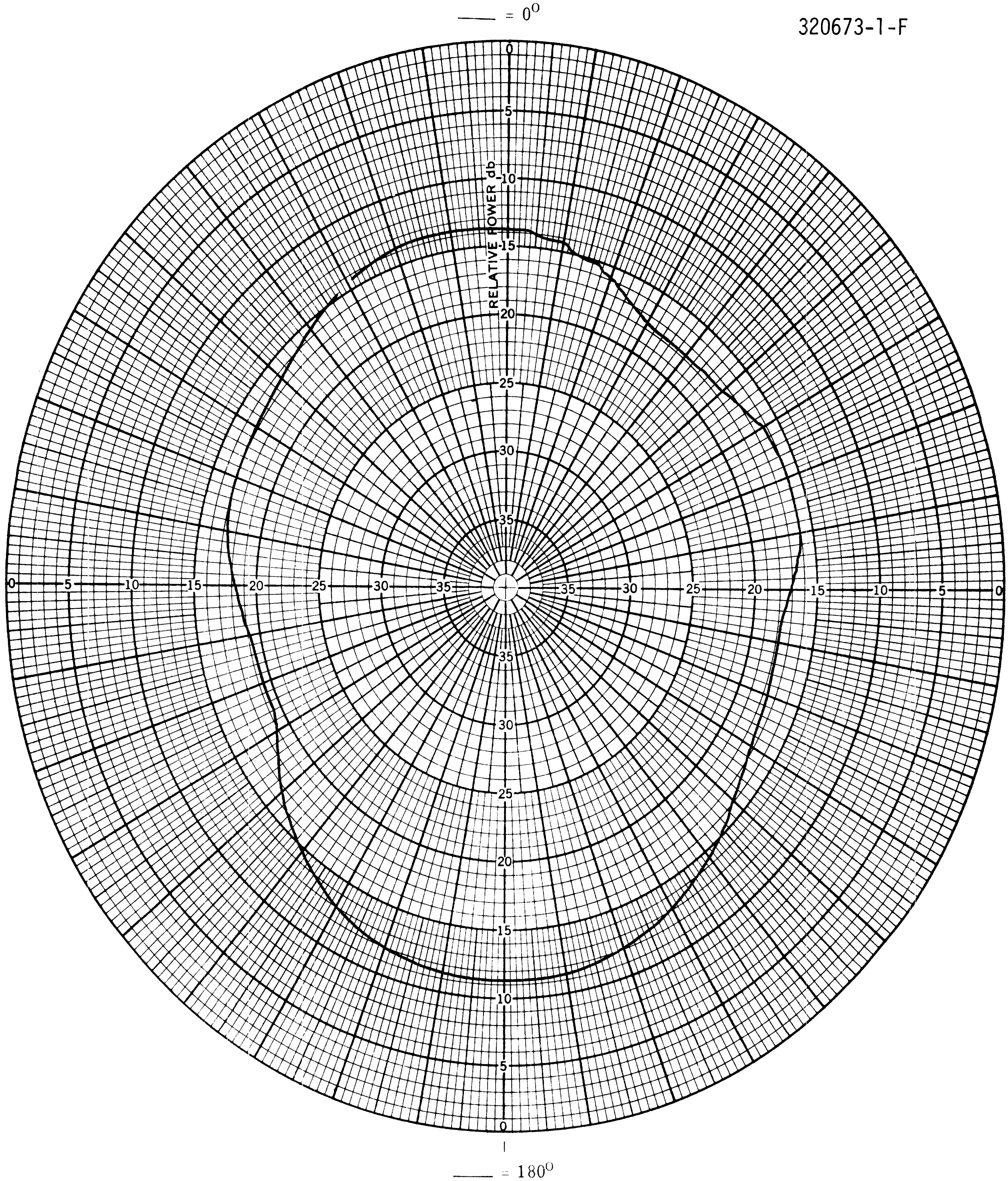


Figure 4F. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II. f = 98 MHz.

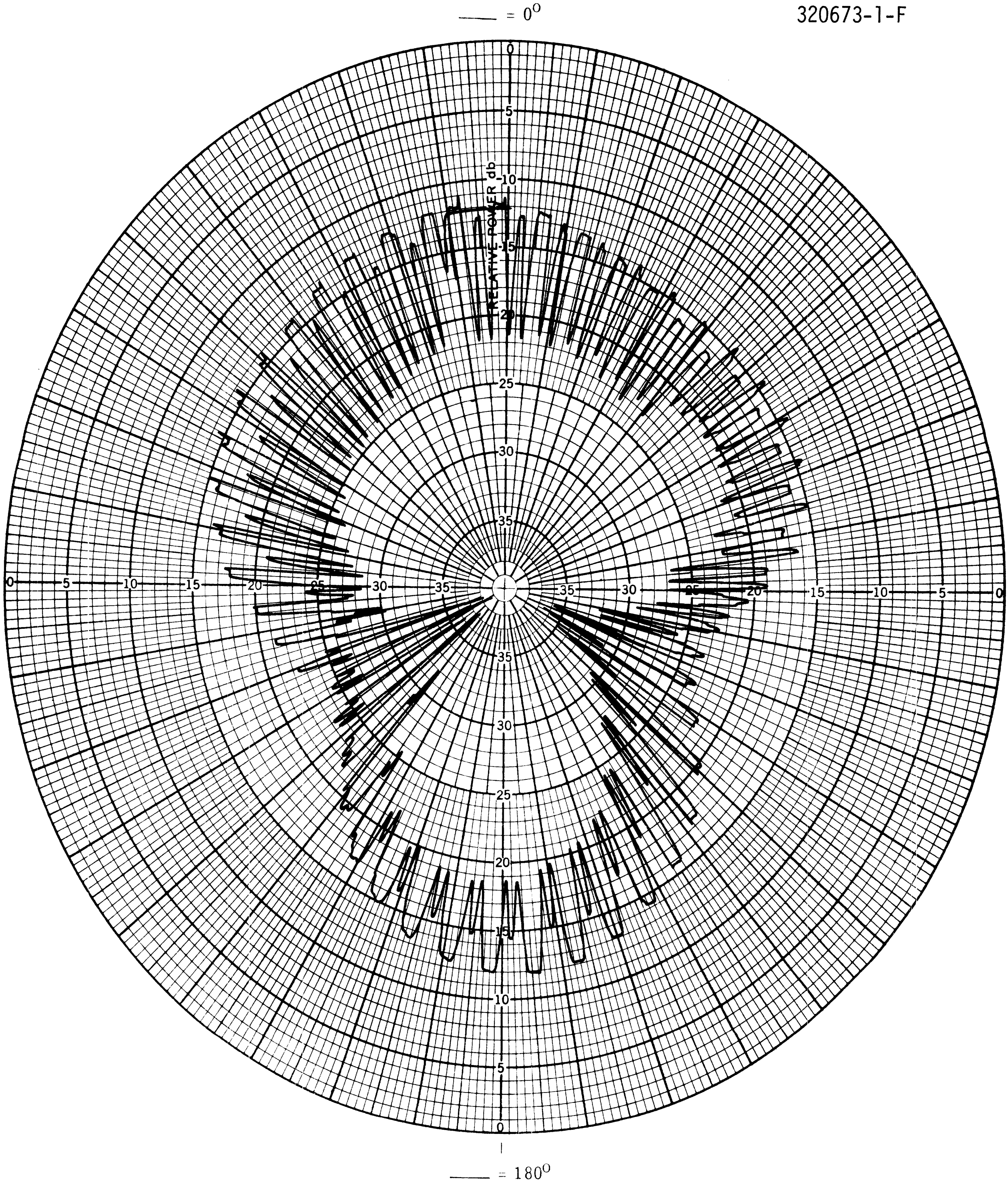


Figure 4G. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with wipers running slow. f = 98 MHz.

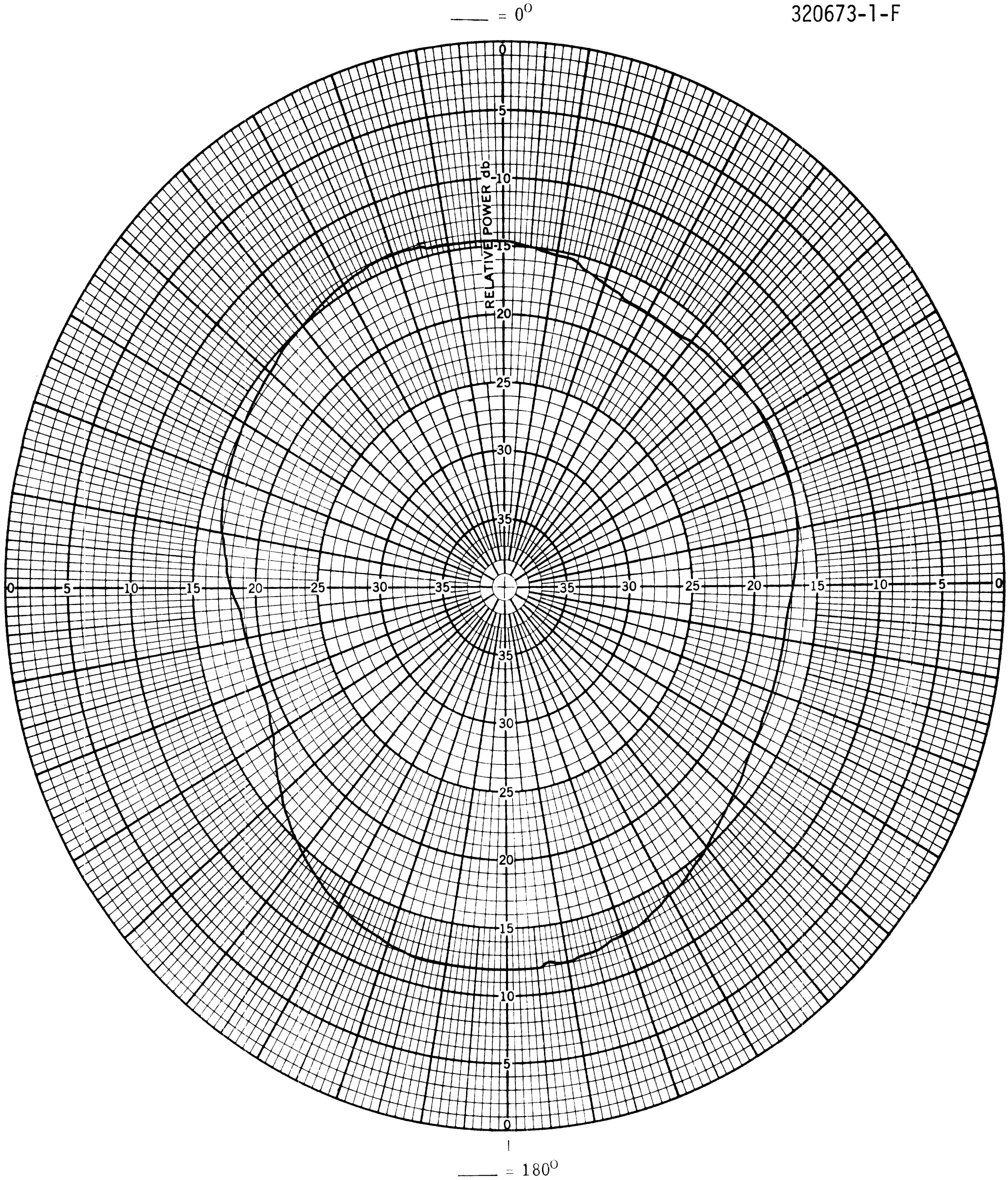


Figure 4H. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with simulated heated back-lite. f = 98 MHz.

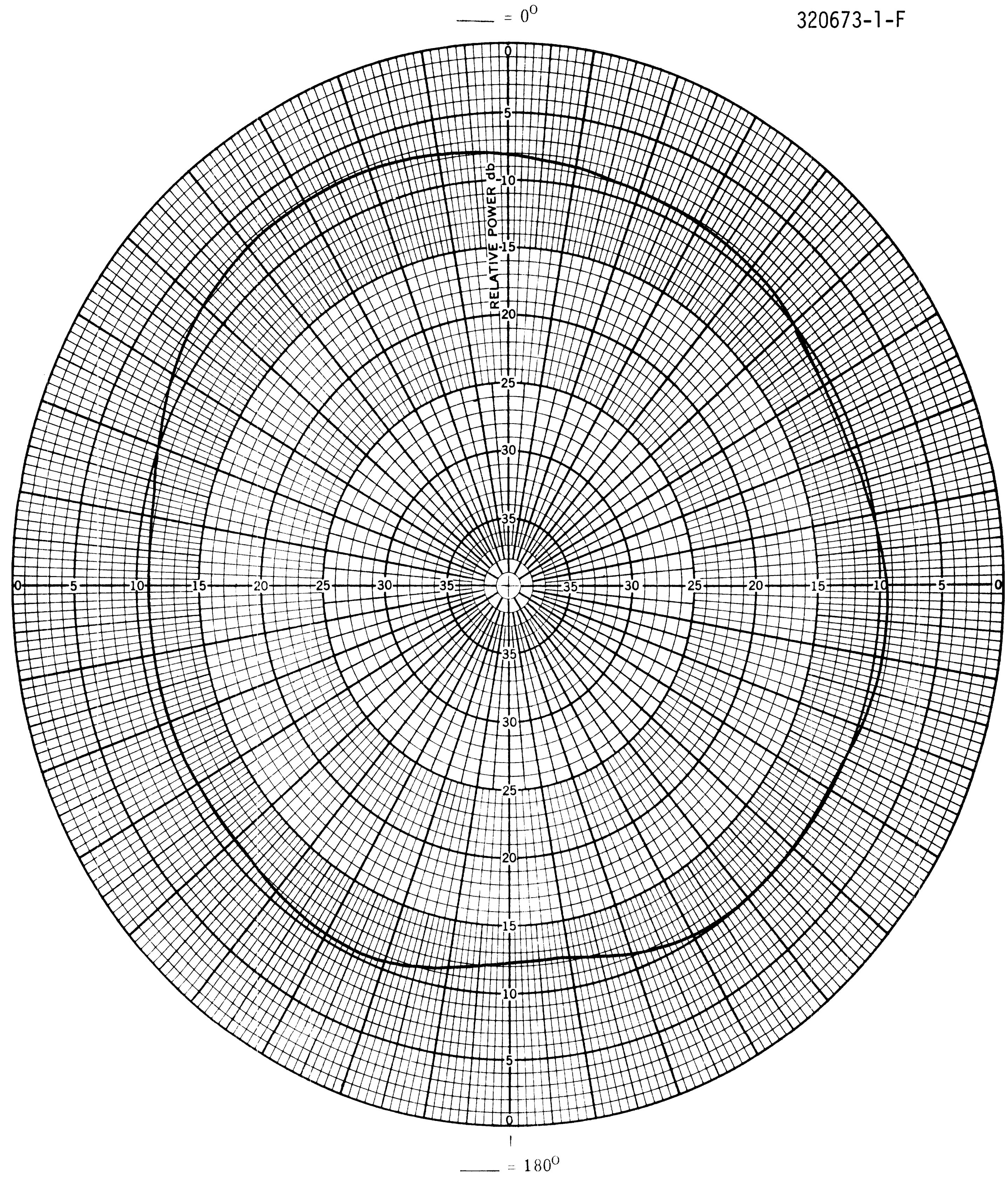


Figure 4I. Radiation pattern of whip antenna on Ford LTD II. f = 108 MHz.

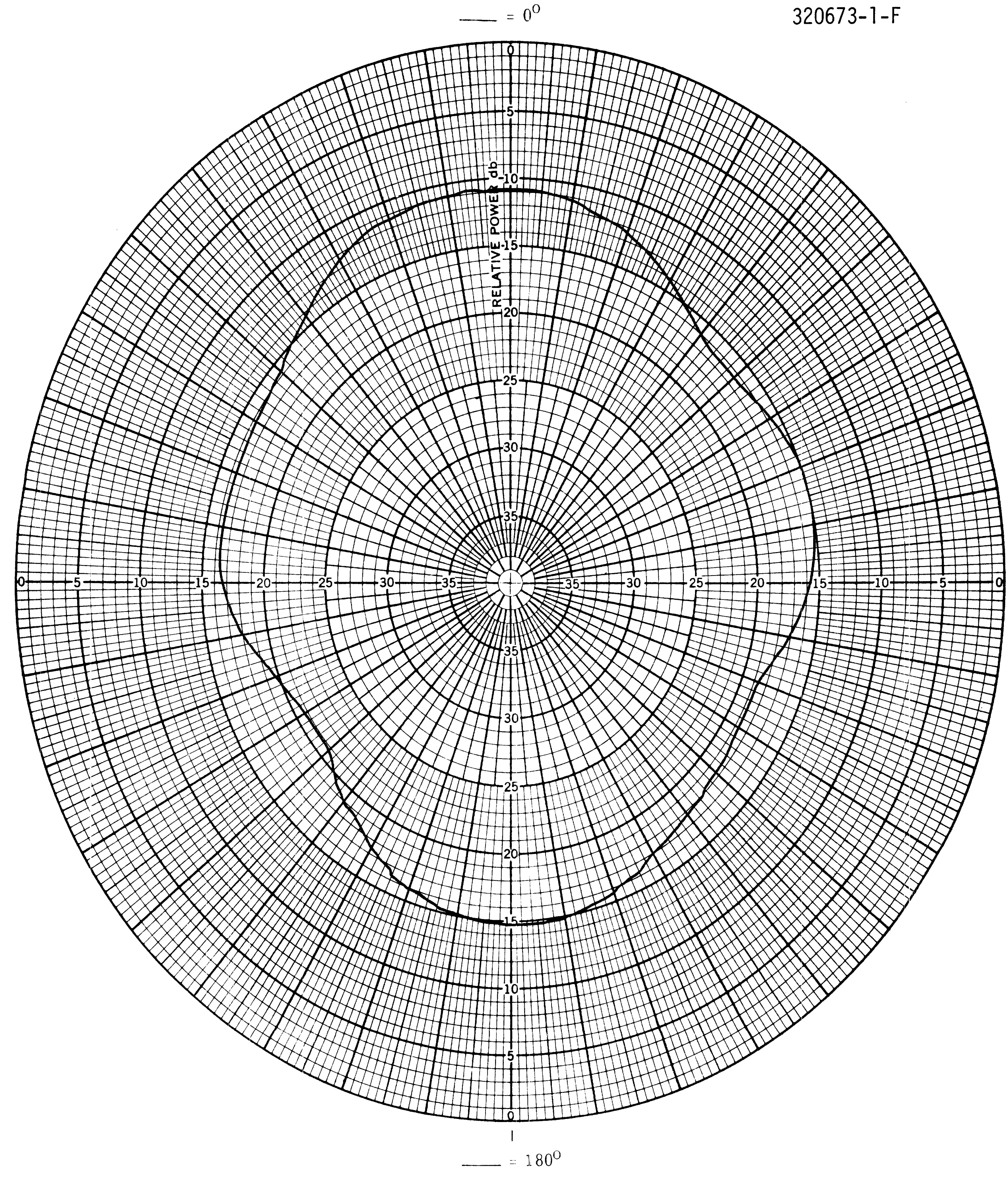


Figure 4J. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II. f = 108 MHz.

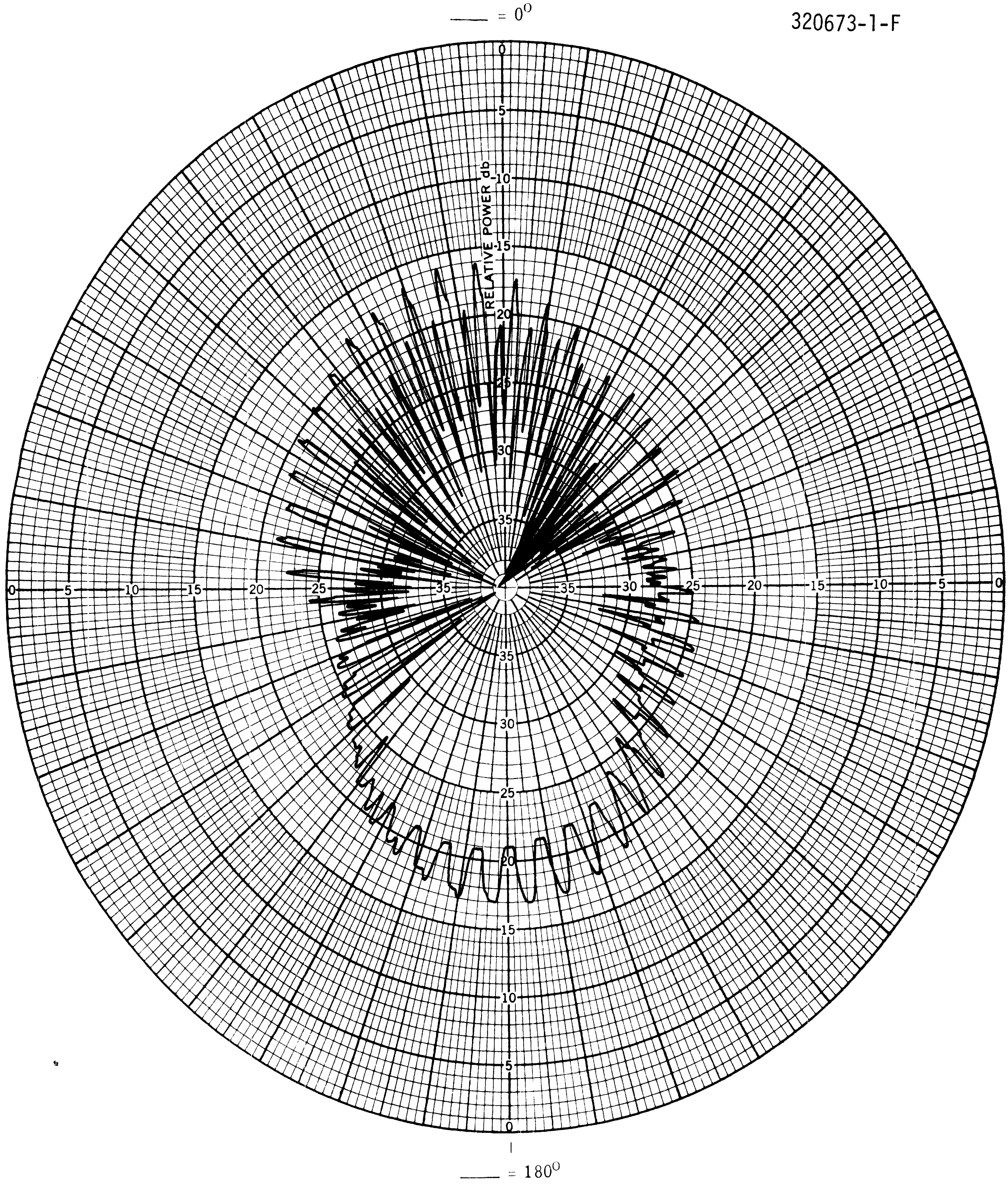


Figure 4K. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with wipers running slow. f = 108 MHz.

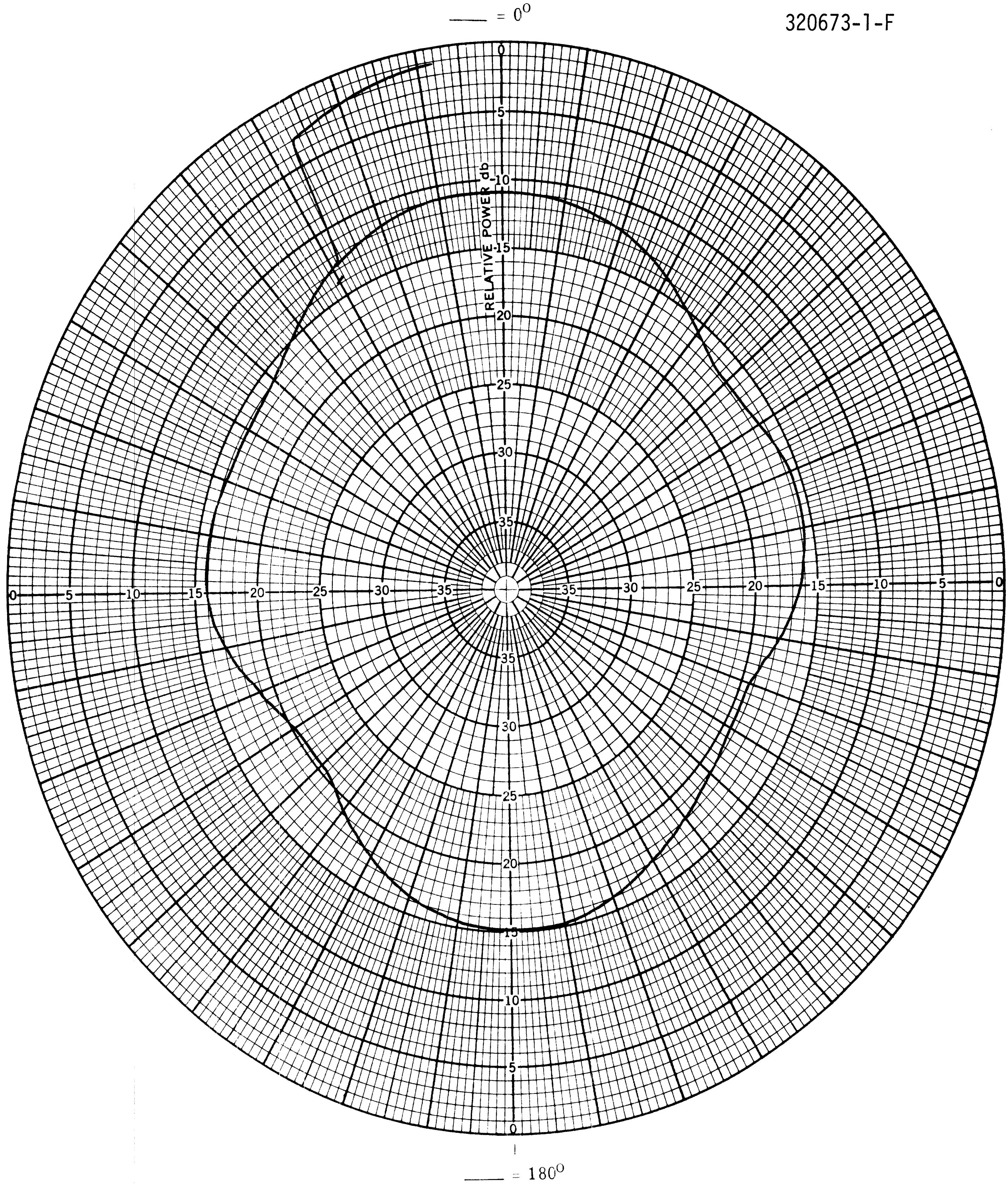


Figure 4L. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II with simulated heated back-lite. f = 108 MHz.

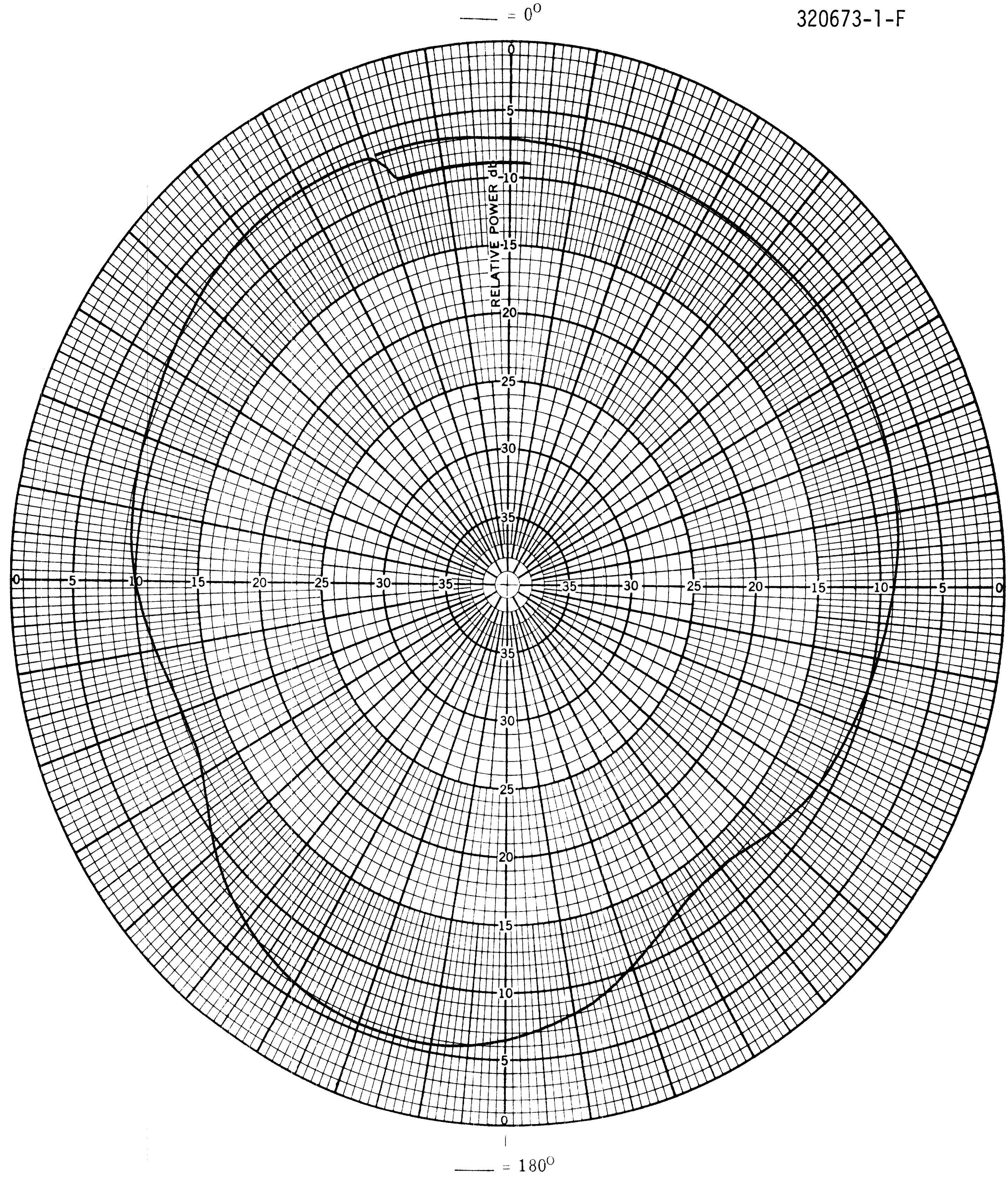


Figure 5A. Radiation pattern of whip antenna on Ford LTD II. f = 88 MHz.

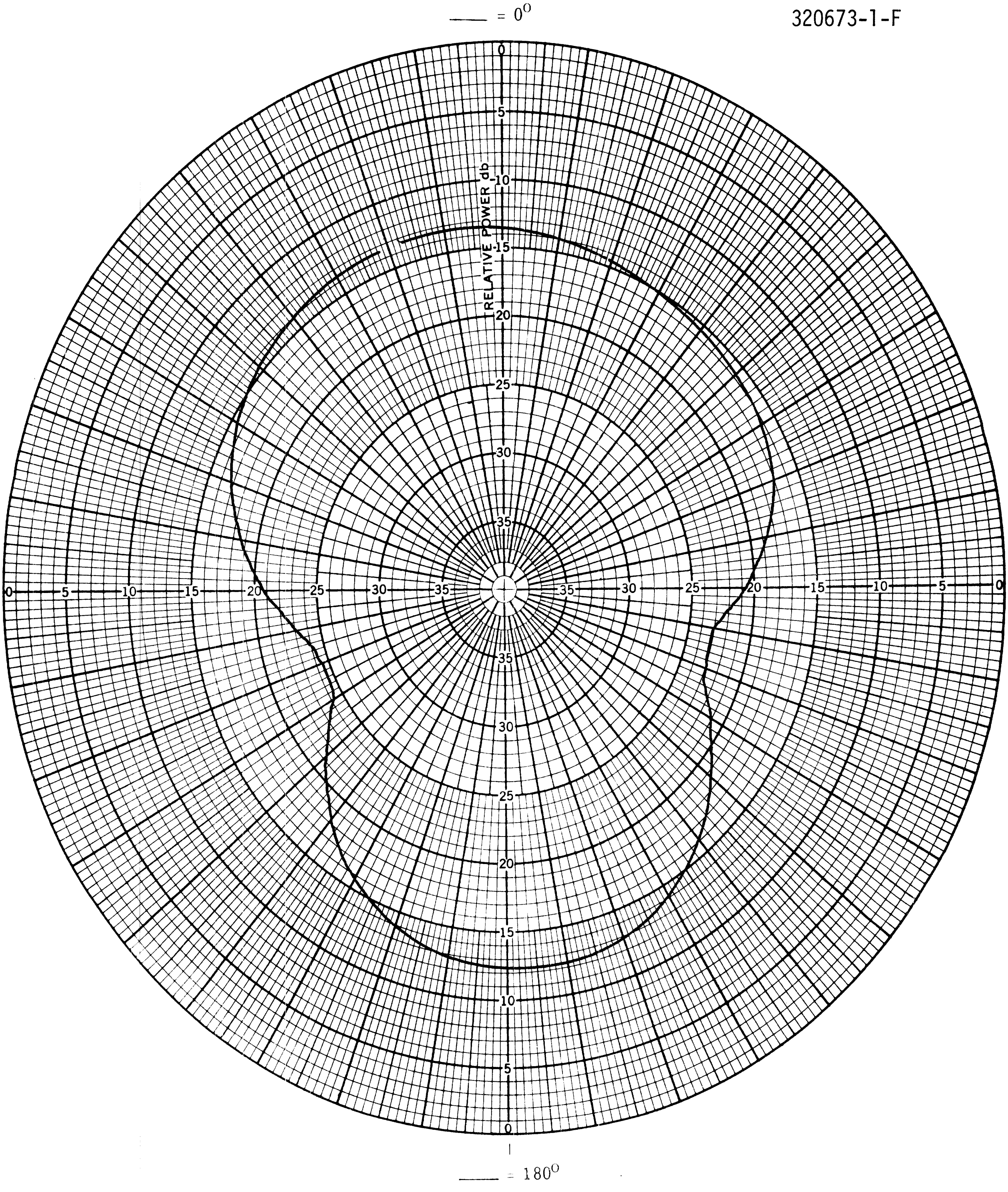


Figure 5B. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II. f = 88 MHz.

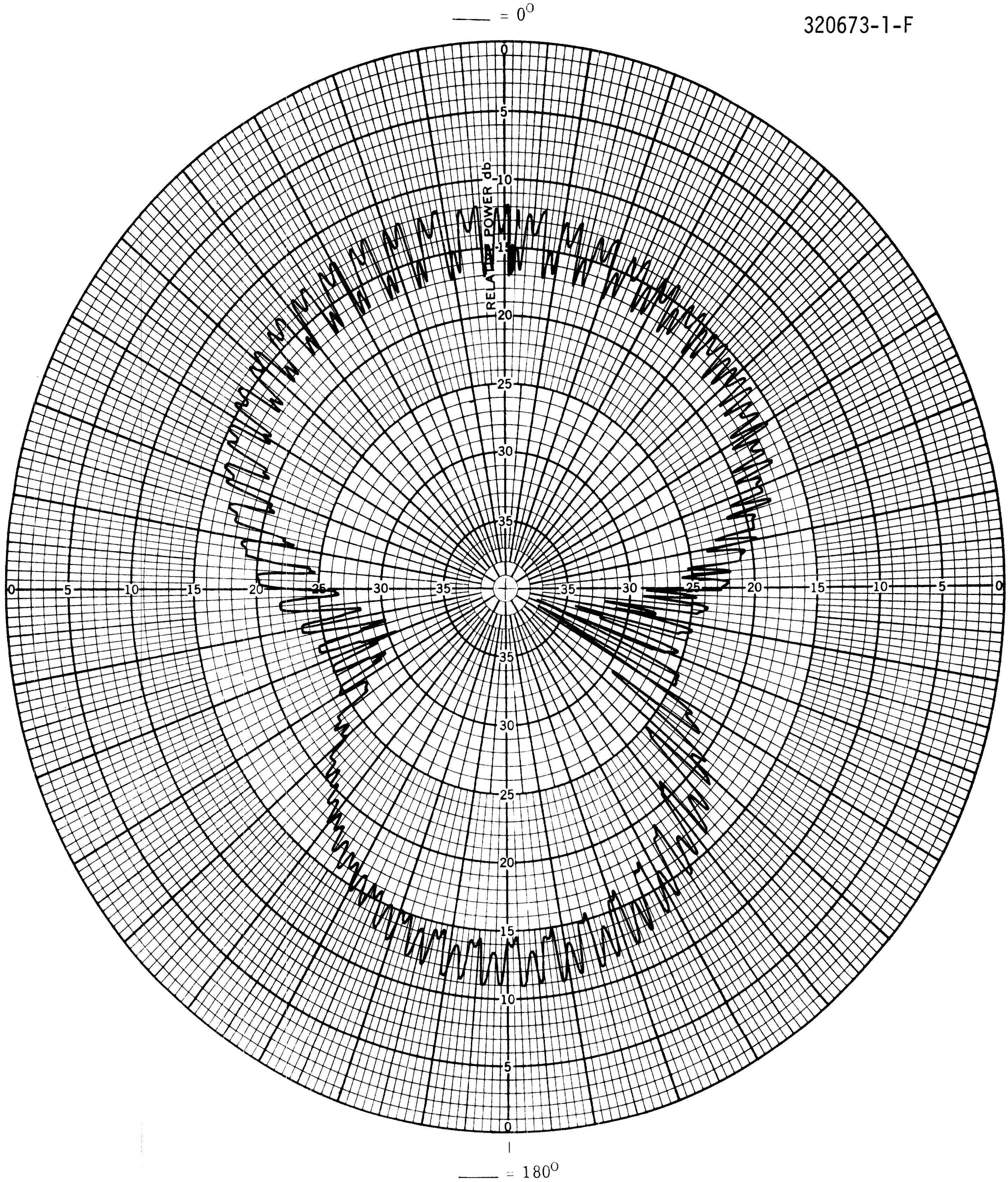


Figure 5C. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with wipers running slow. f = 88 MHz.

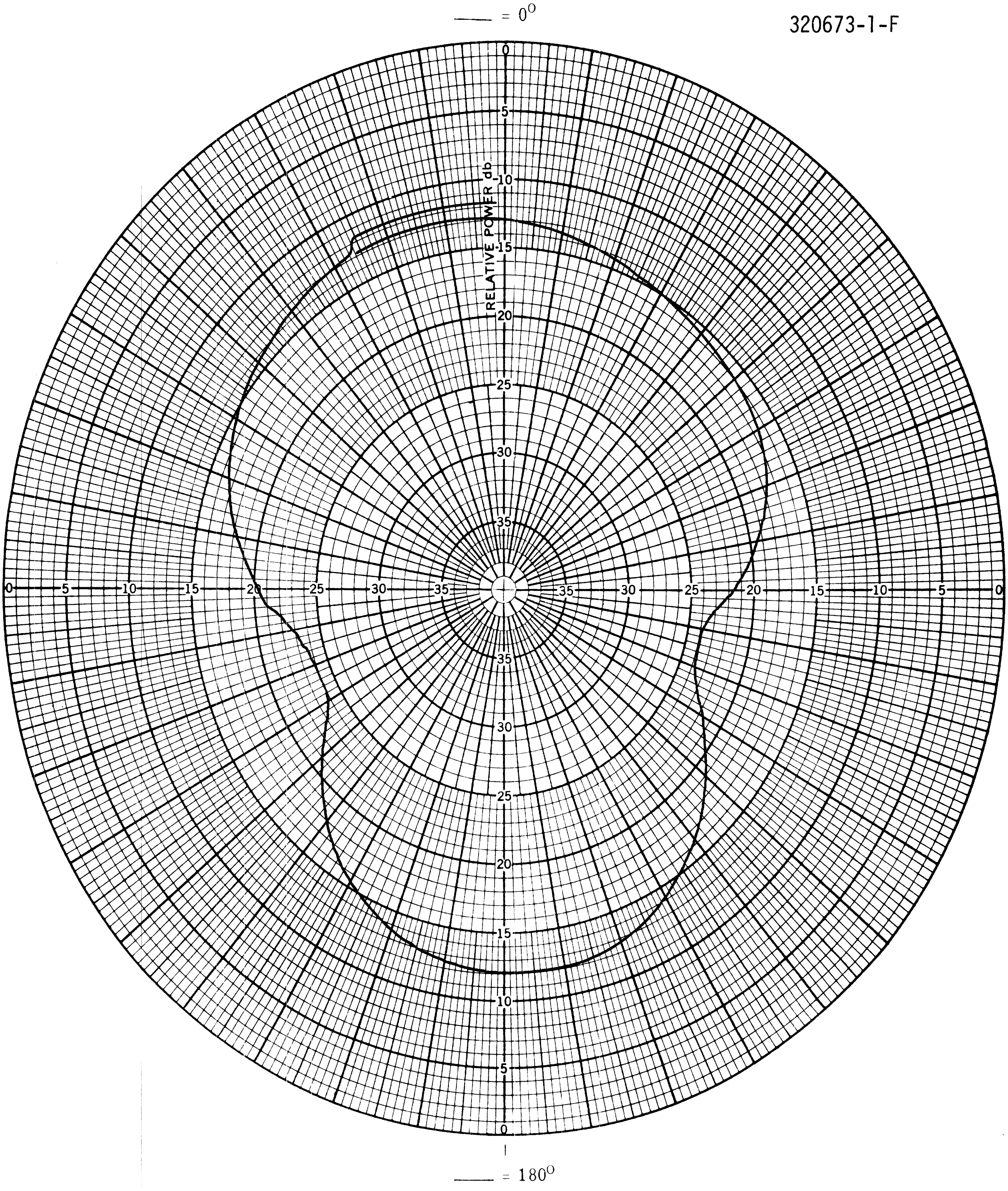


Figure 5D. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with simulated heated back-lite. f = 88 MHz.

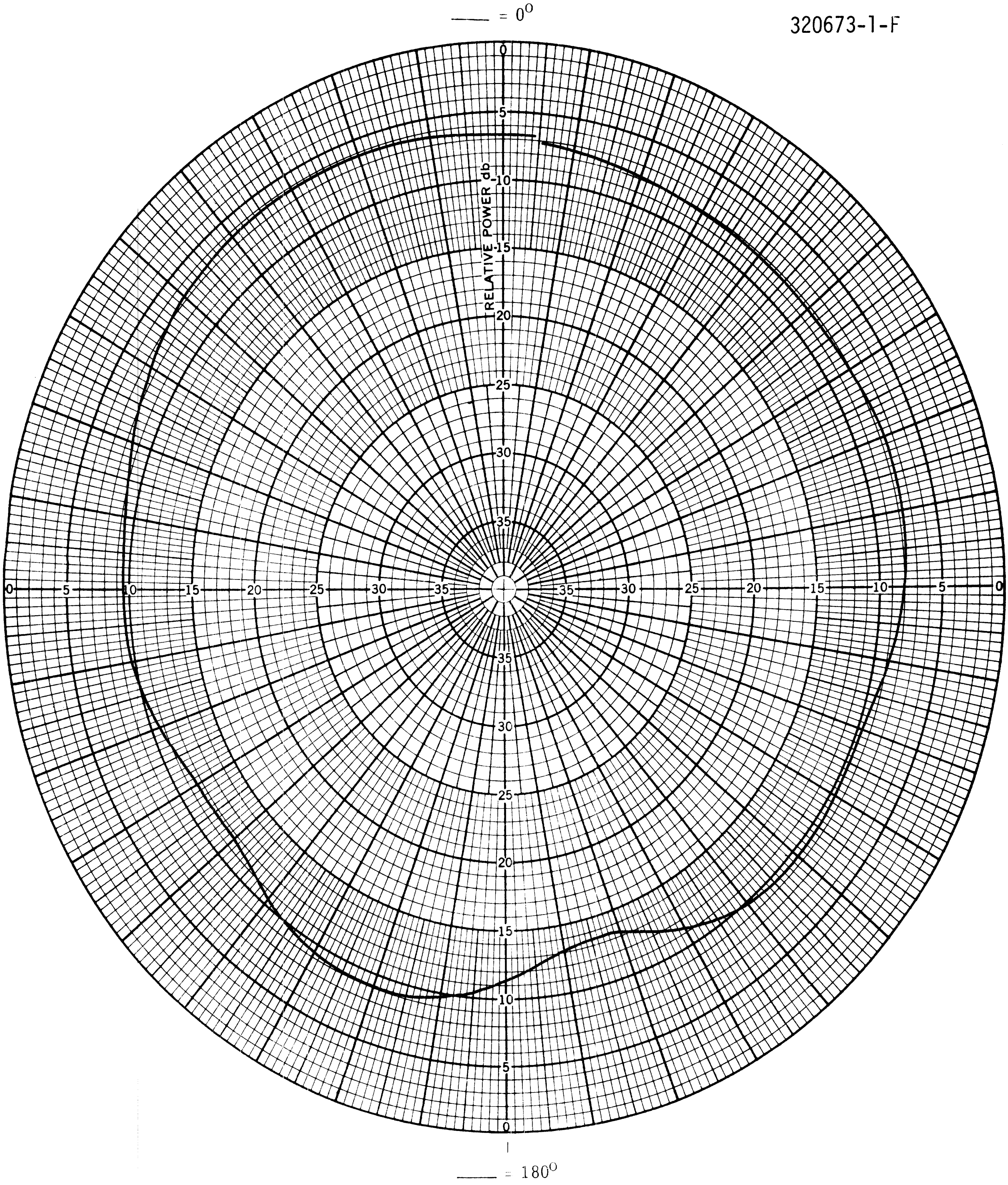


Figure 5E. Radiation pattern of whip antenna on Ford LTD II. f = 98 MHz.

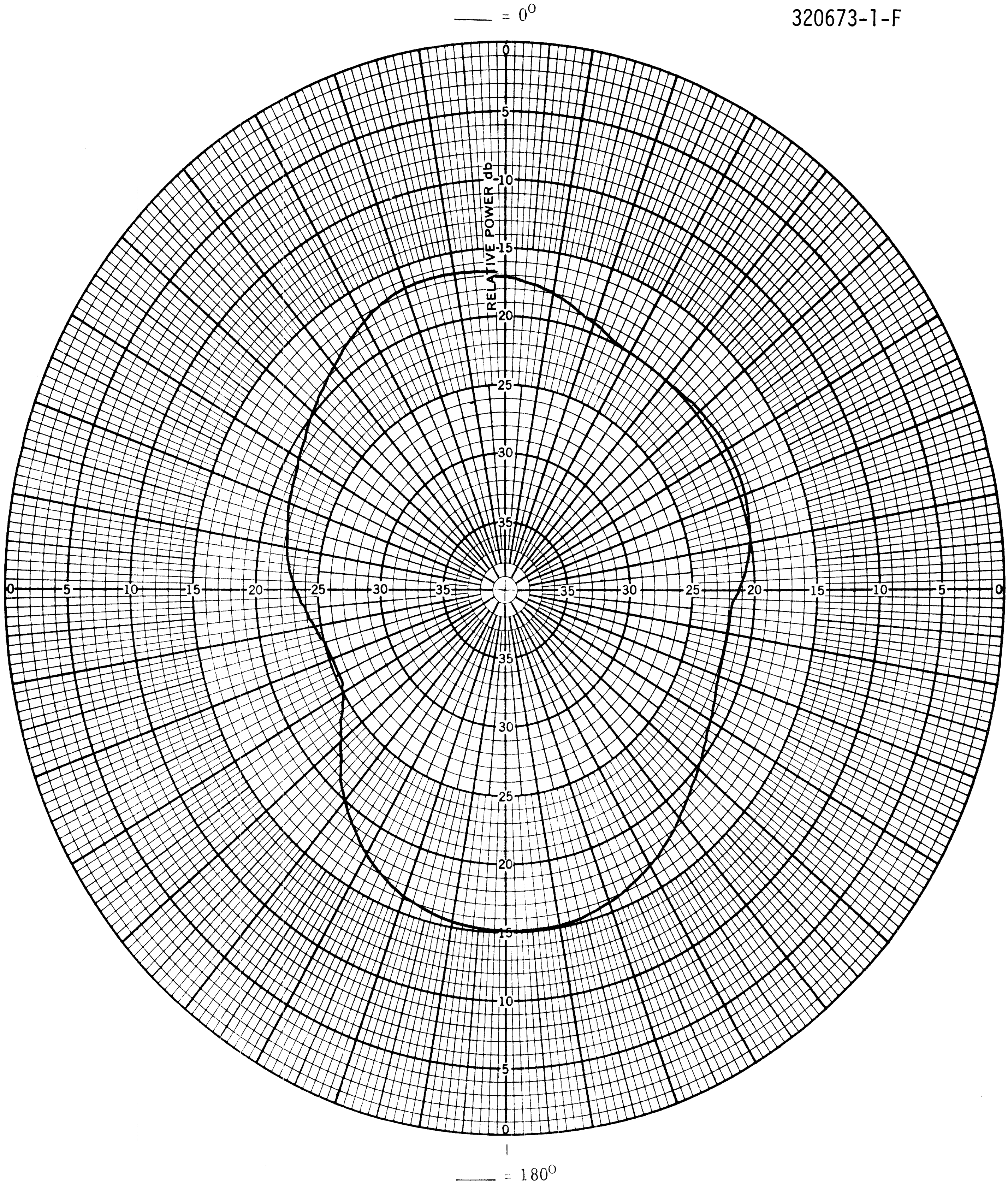


Figure 5F. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II. f = 98 MHz.

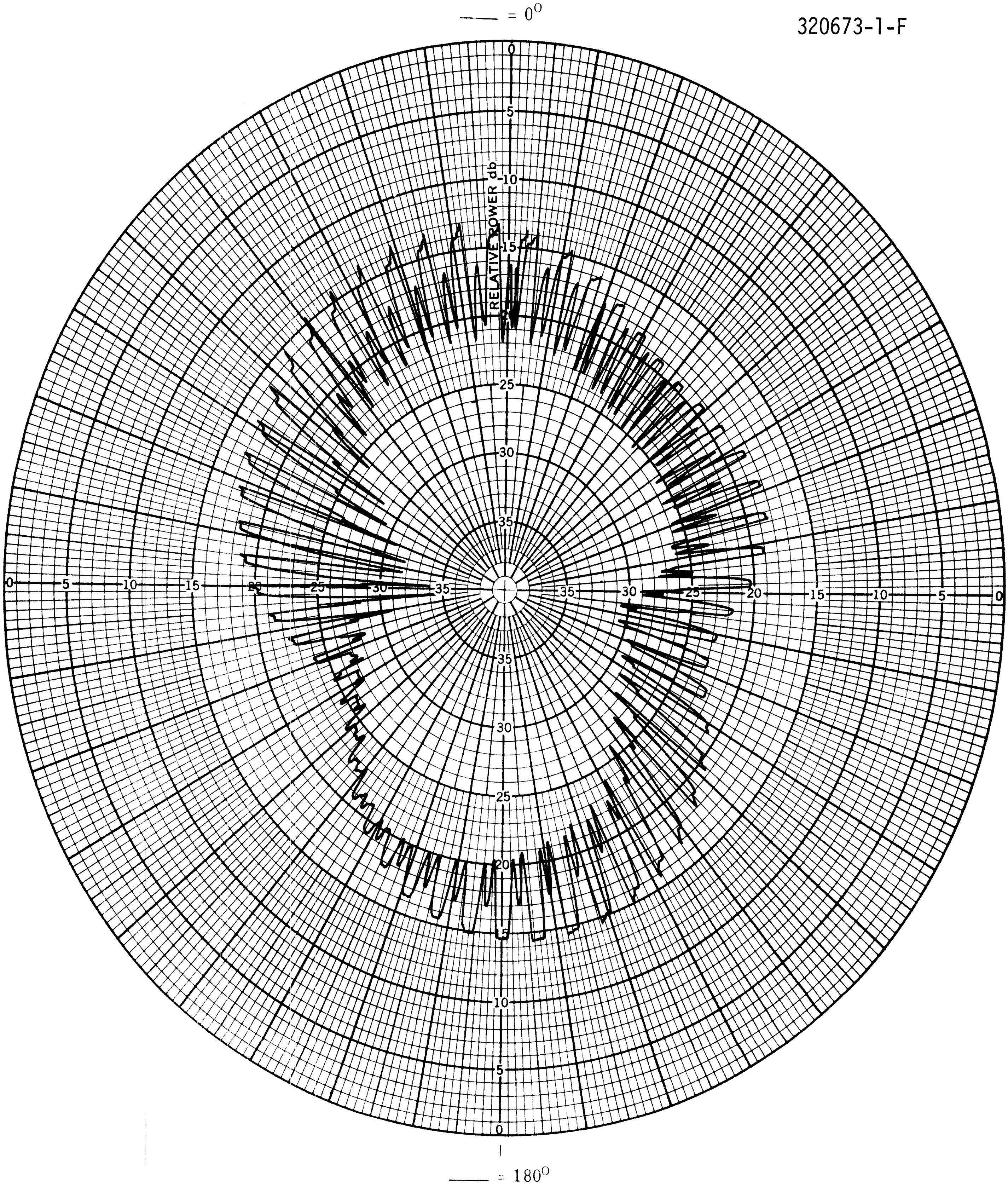


Figure 5G. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with wipers running slow. f = 98 MHz.

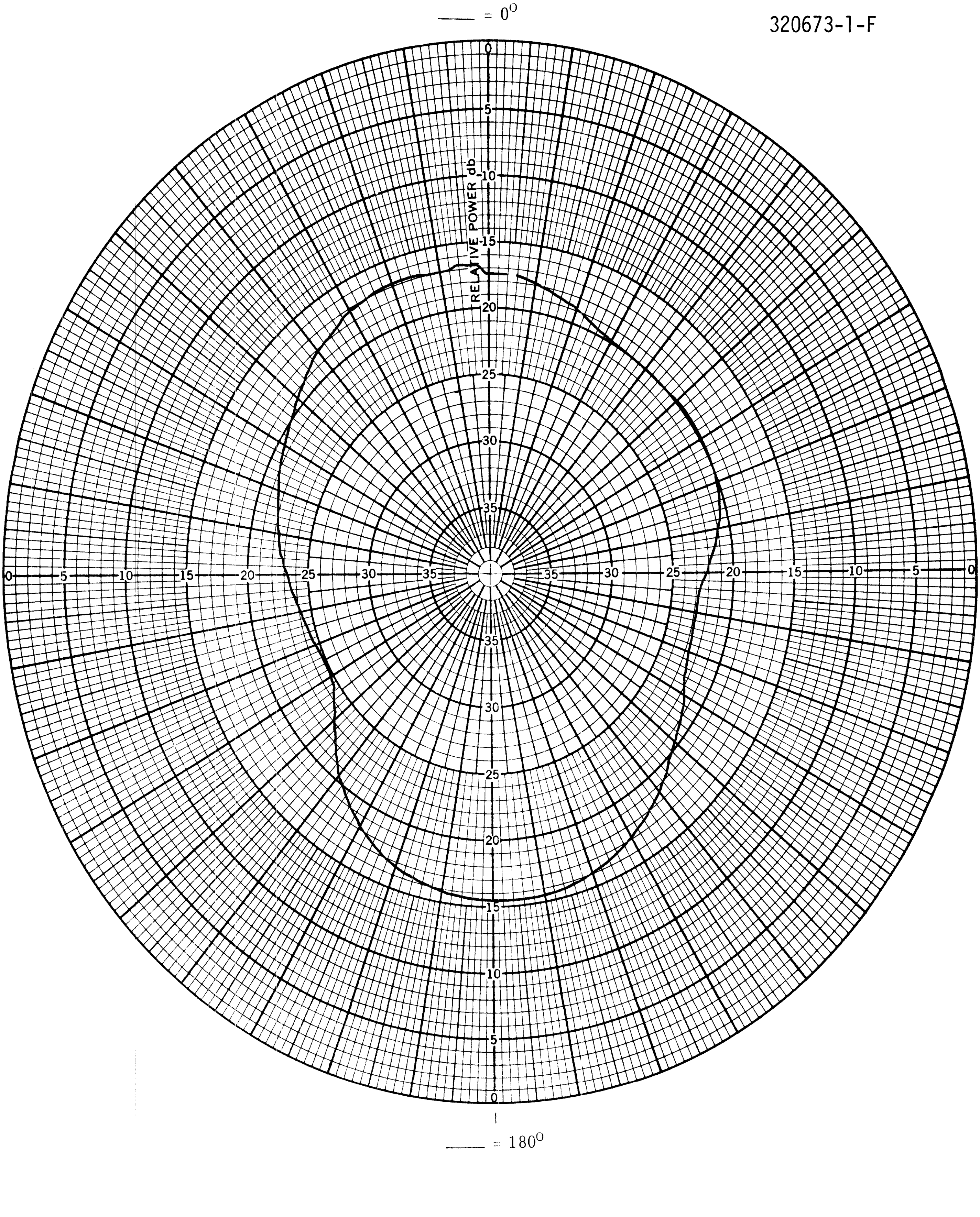


Figure 5H. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with simulated heated back-lite. f = 98 MHz.

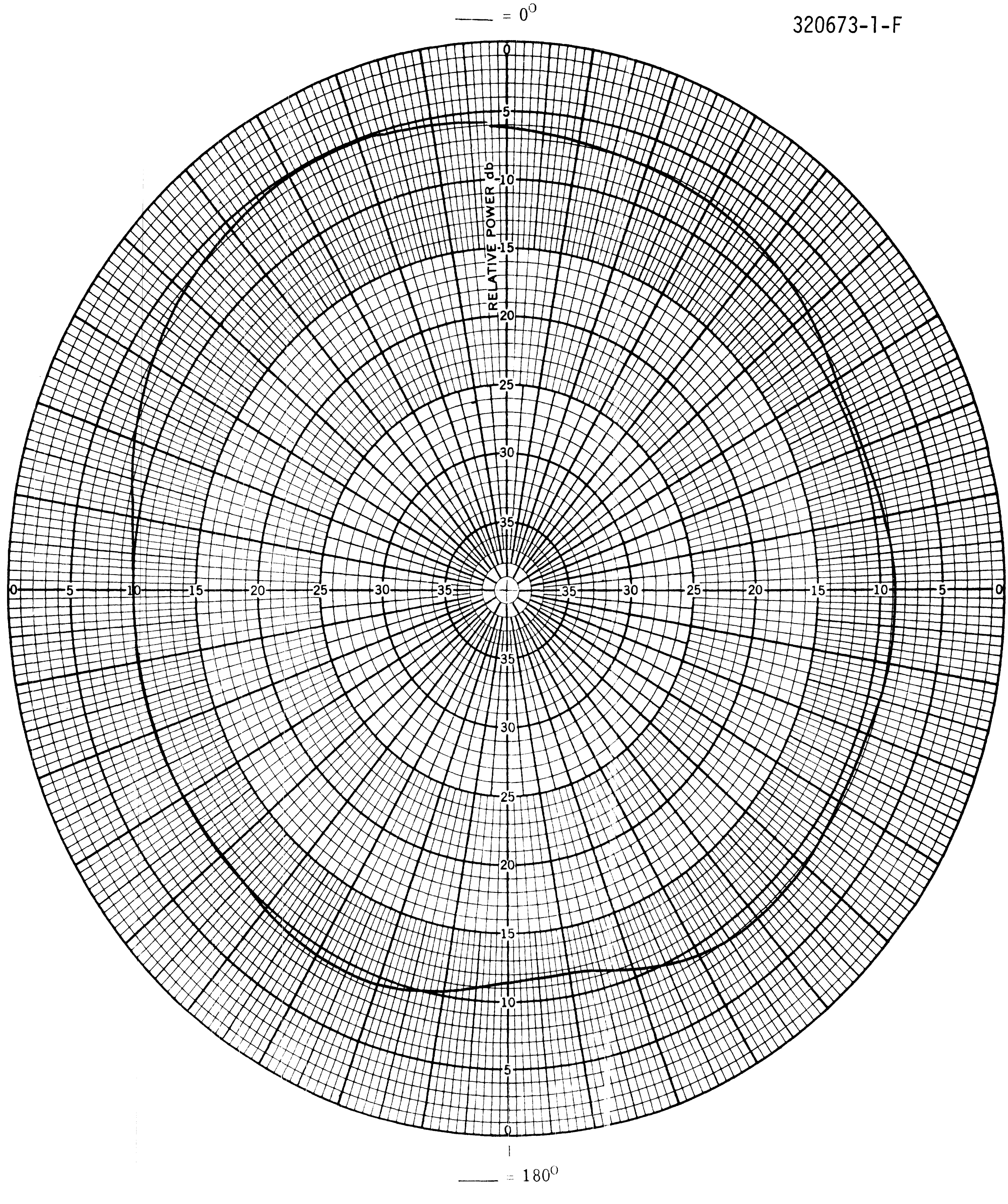


Figure 5I. Radiation pattern of whip antenna on Ford LTD II. f = 108 MHz.

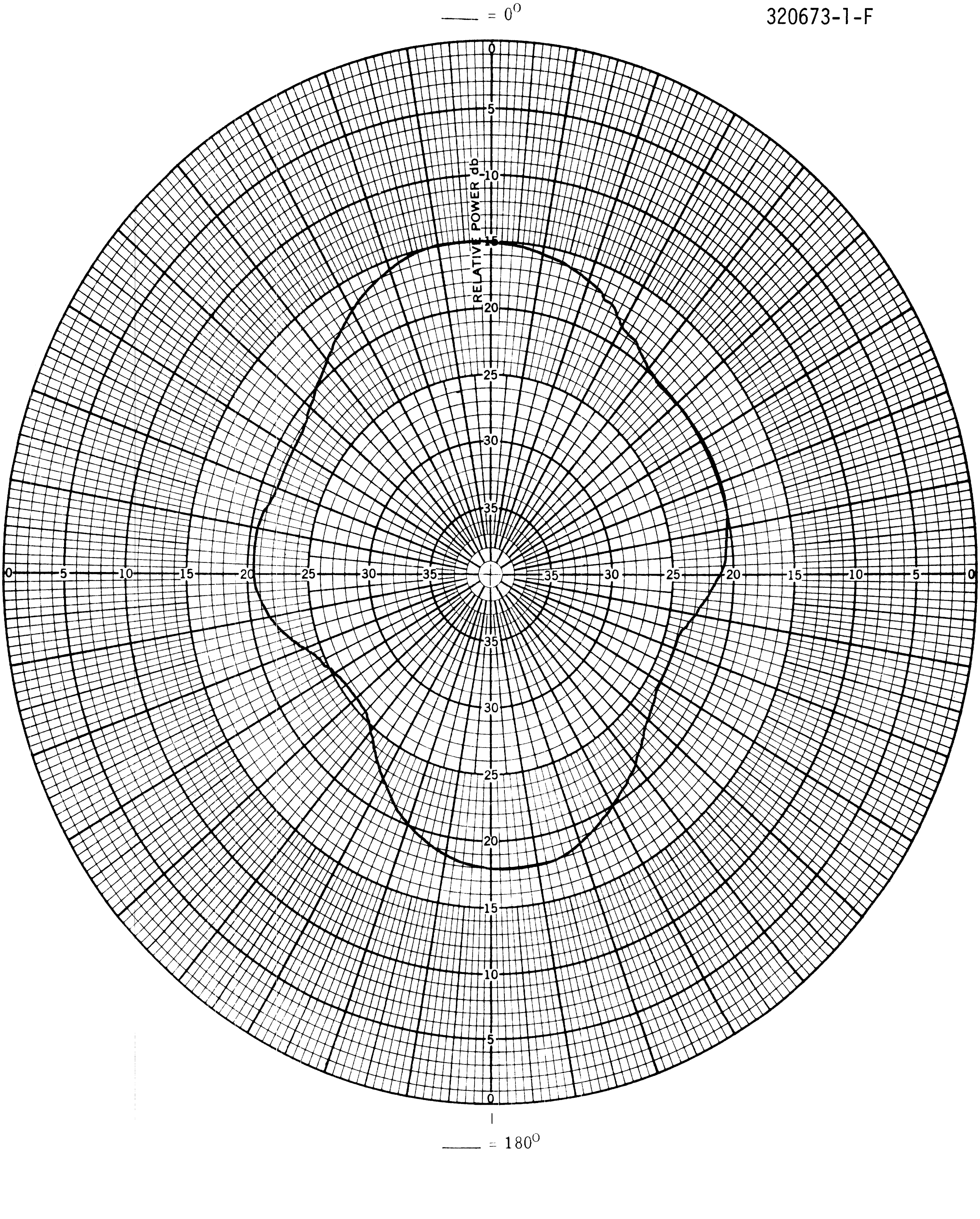


Figure 5J. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II. f = 108 MHz.

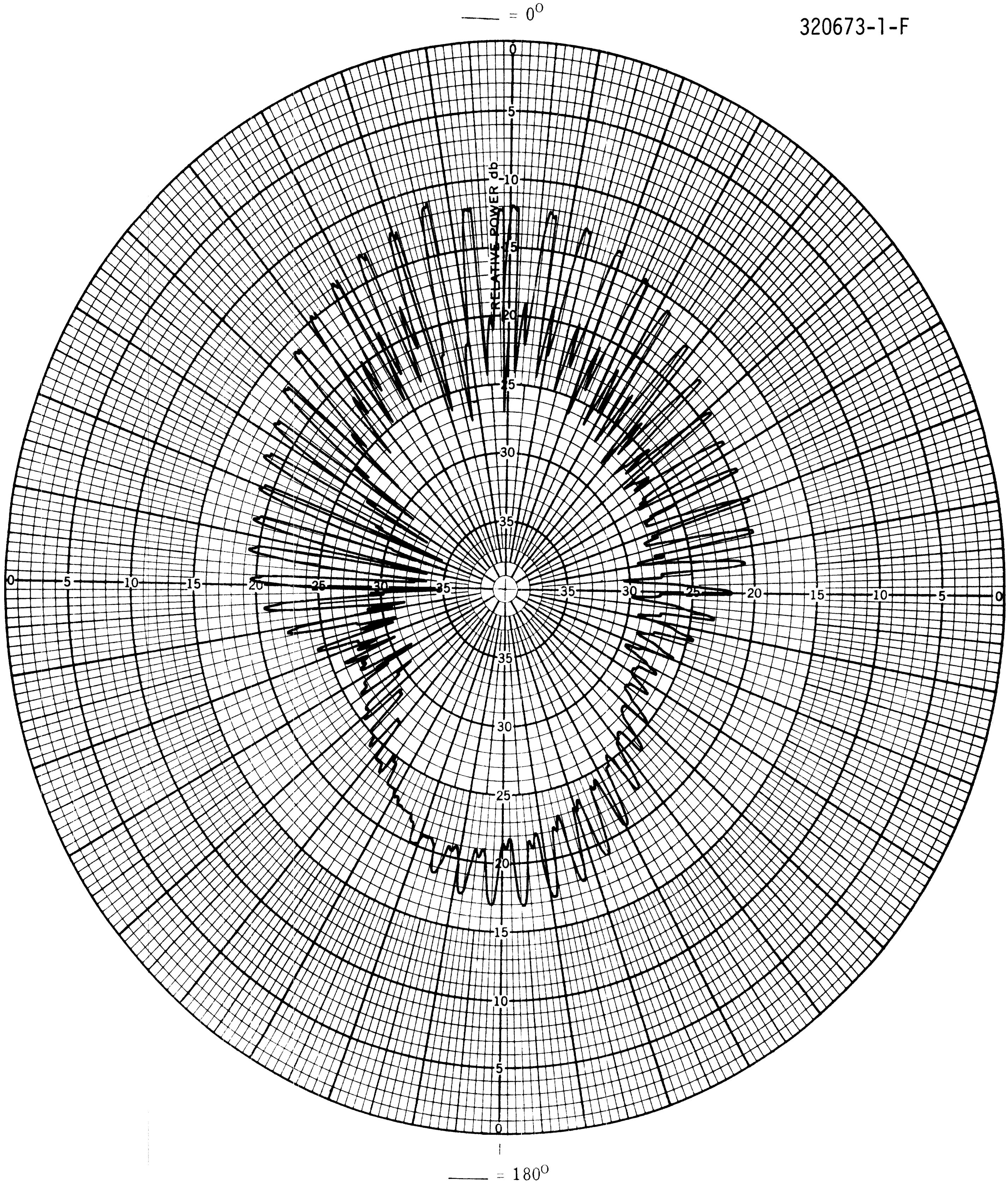


Figure 5K. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with wipers running slow. f = 108 MHz.

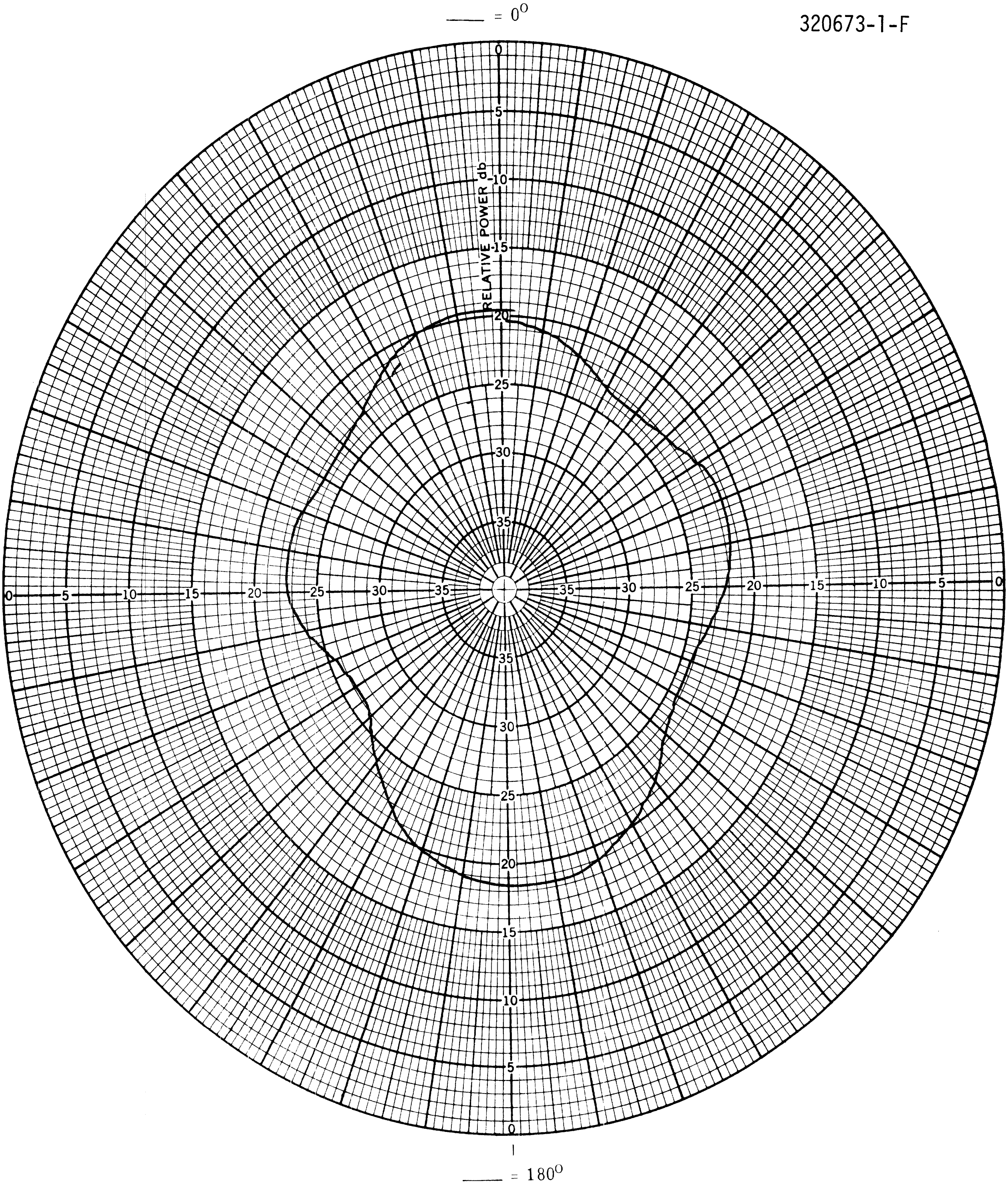


Figure 5L. Radiation pattern of windshield antenna Configuration #3 on Ford LTD II with simulated heated back-lite. f = 108 MHz.

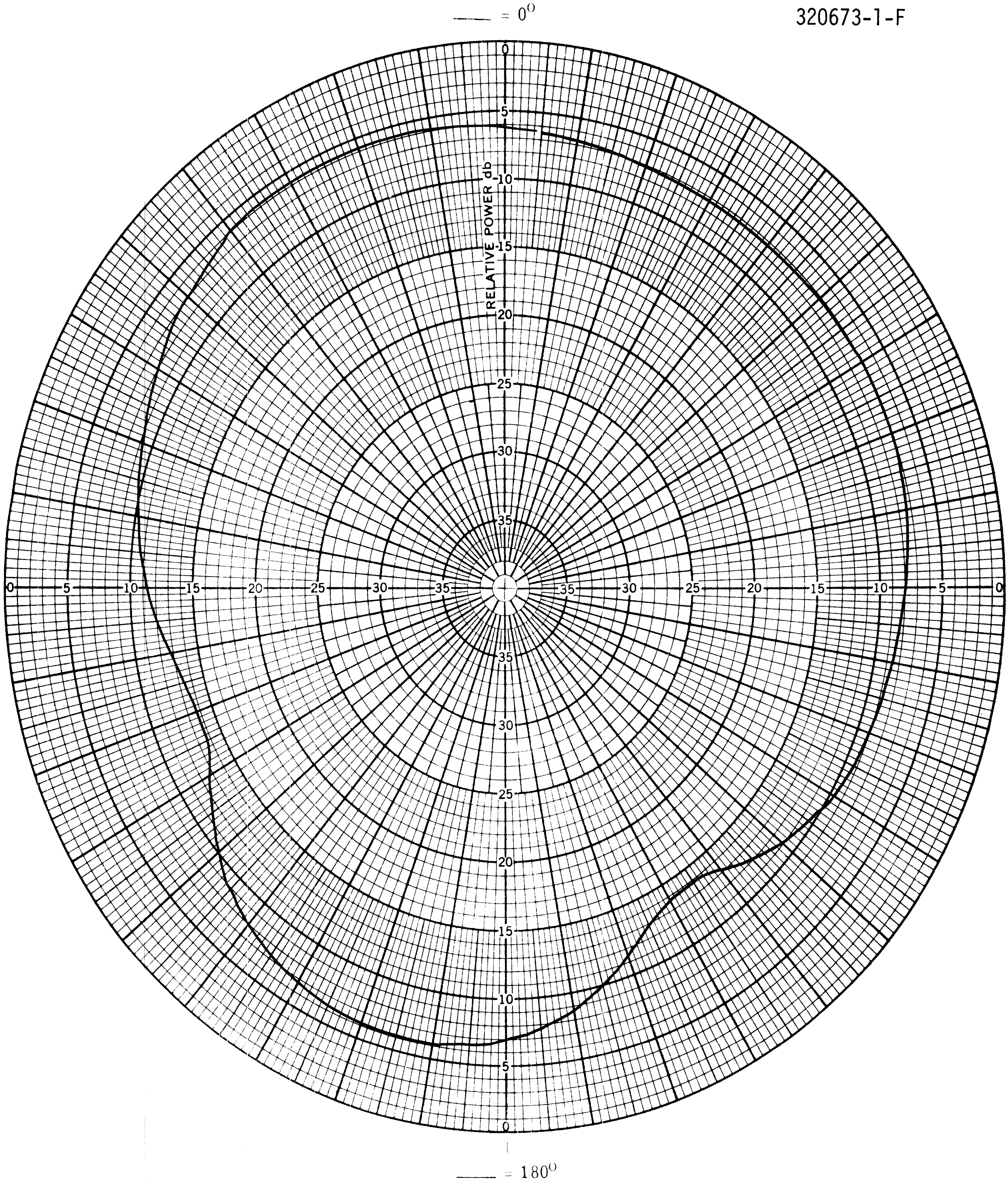


Figure 6A. Radiation pattern of whip antenna on Ford LTD II. f = 88 MHz.

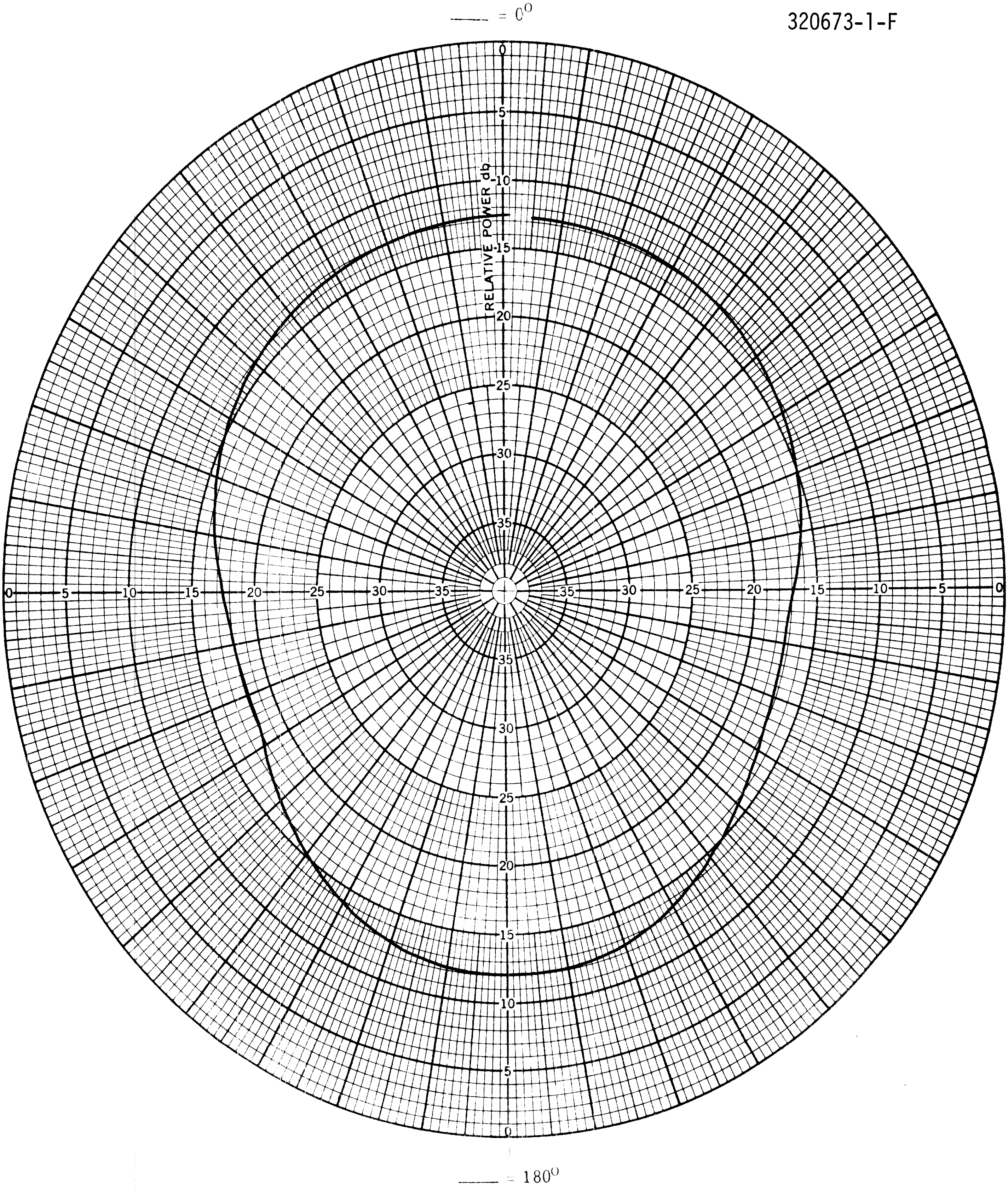


Figure 6B. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II. f = 88 MHz.

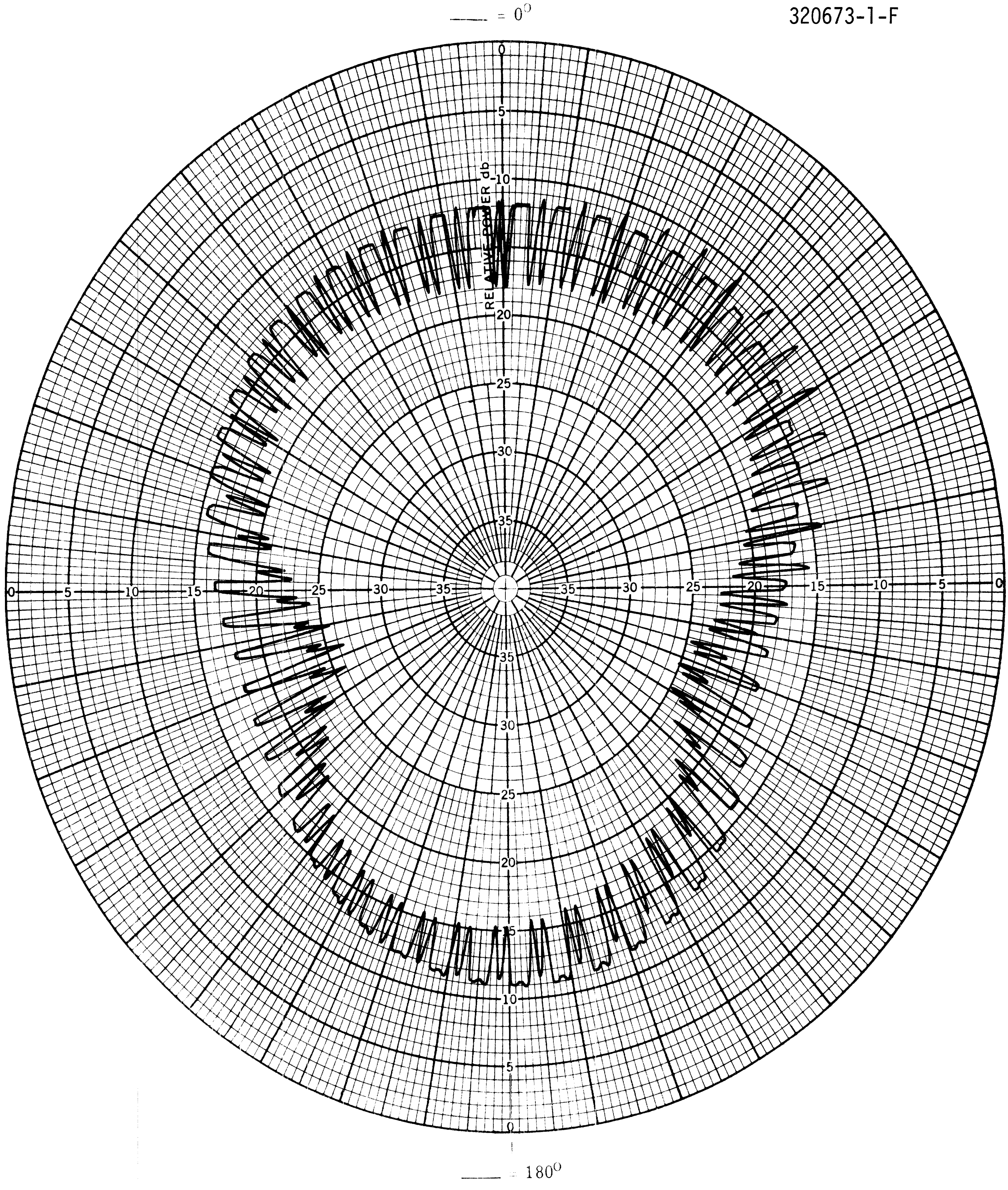


Figure 6C. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with wipers running slow. f = 88 MHz.

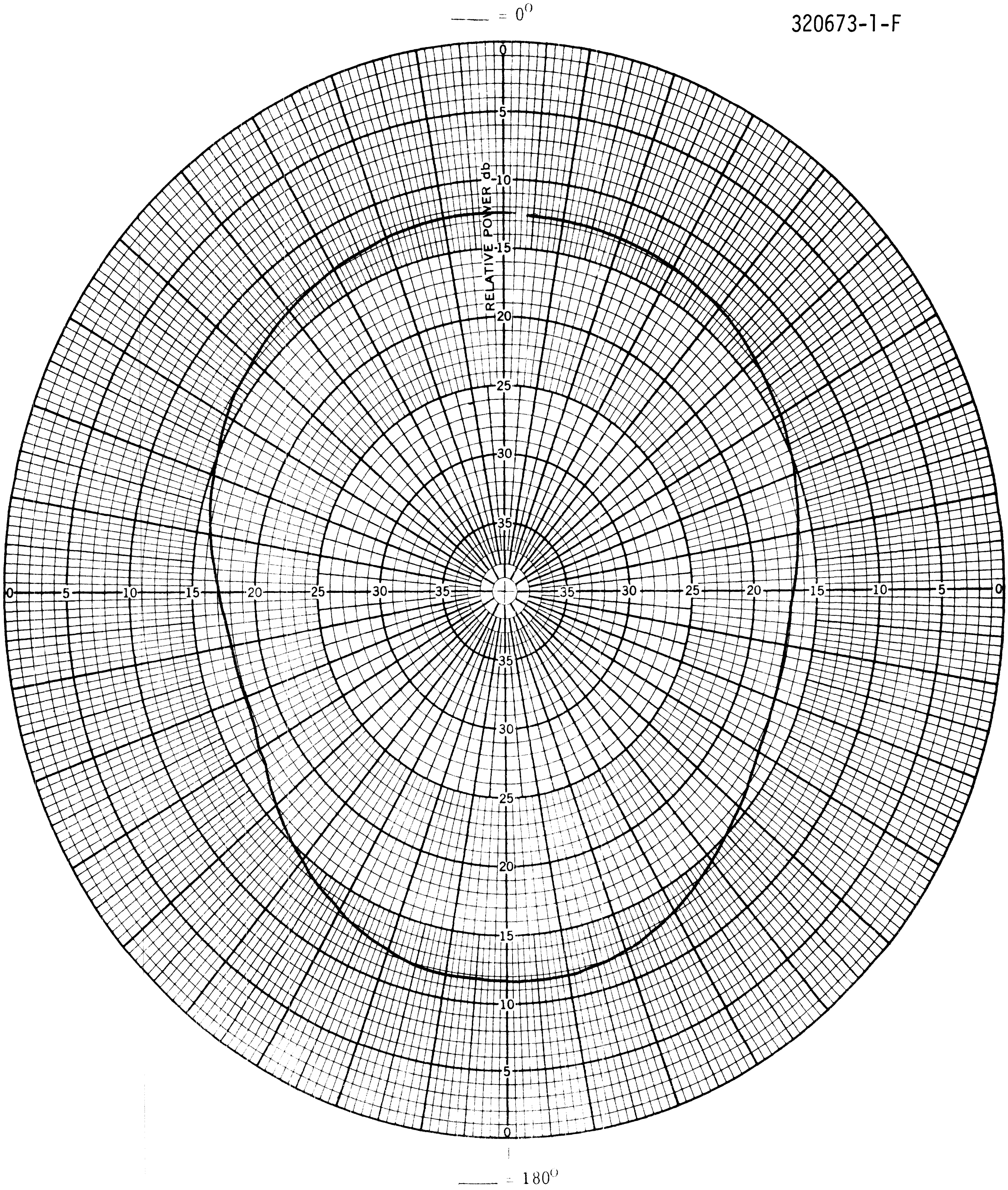


Figure 6D. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with simulated heated back-lite. f = 88 MHz.

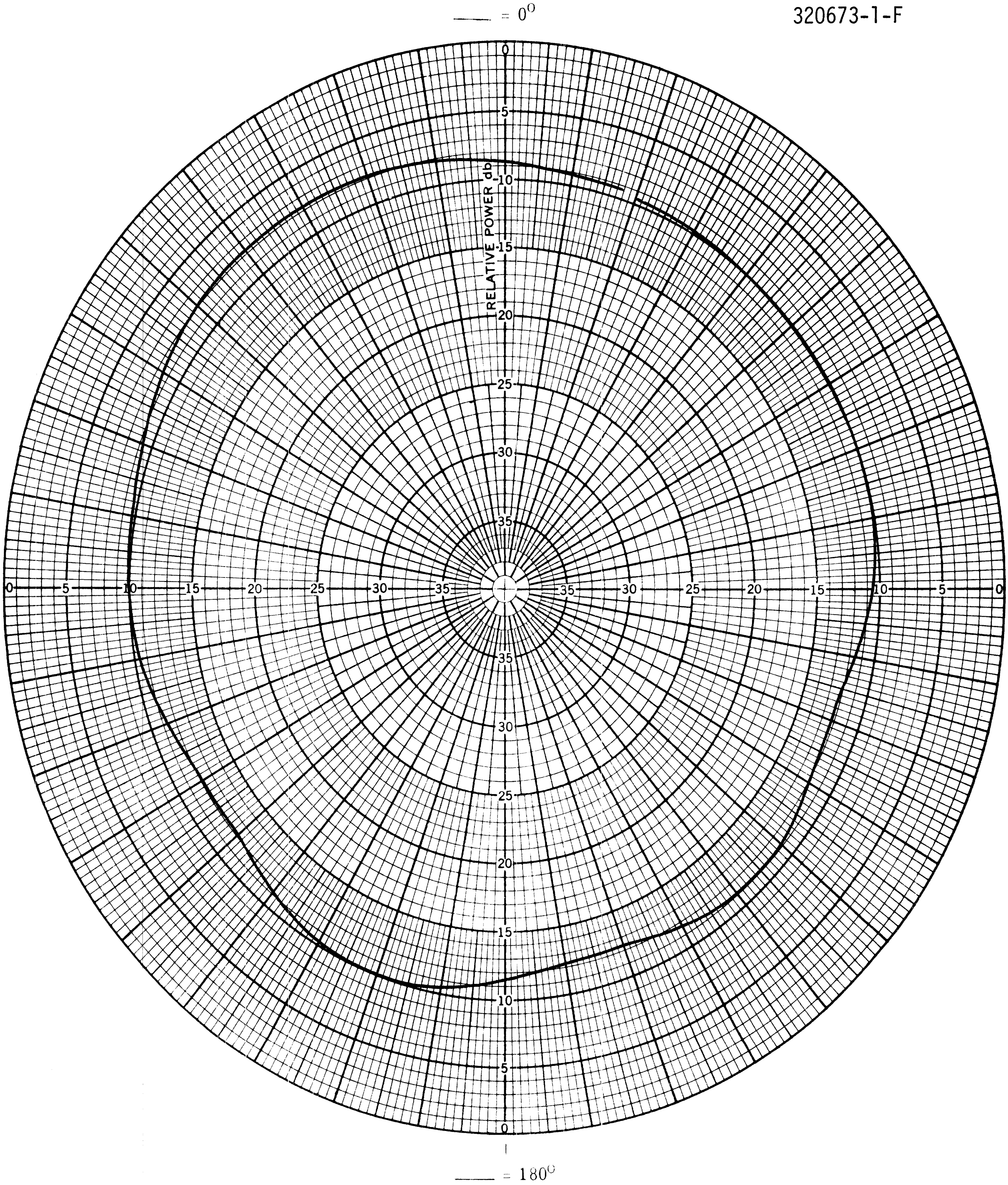


Figure 6E. Radiation pattern of whip antenna on Ford LTD II. f = 98 MHz.

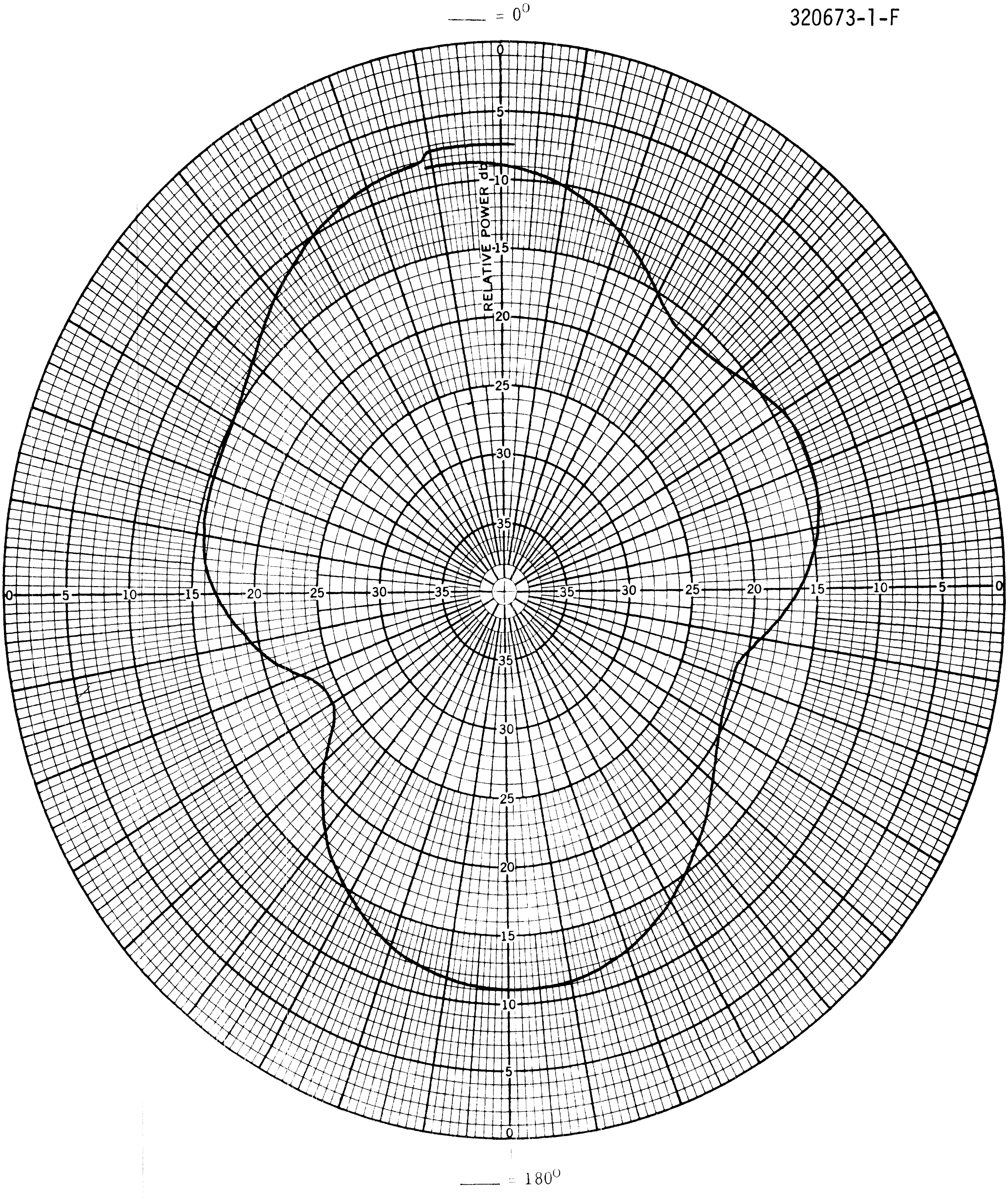


Figure 6F. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II. f = 98 MHz.

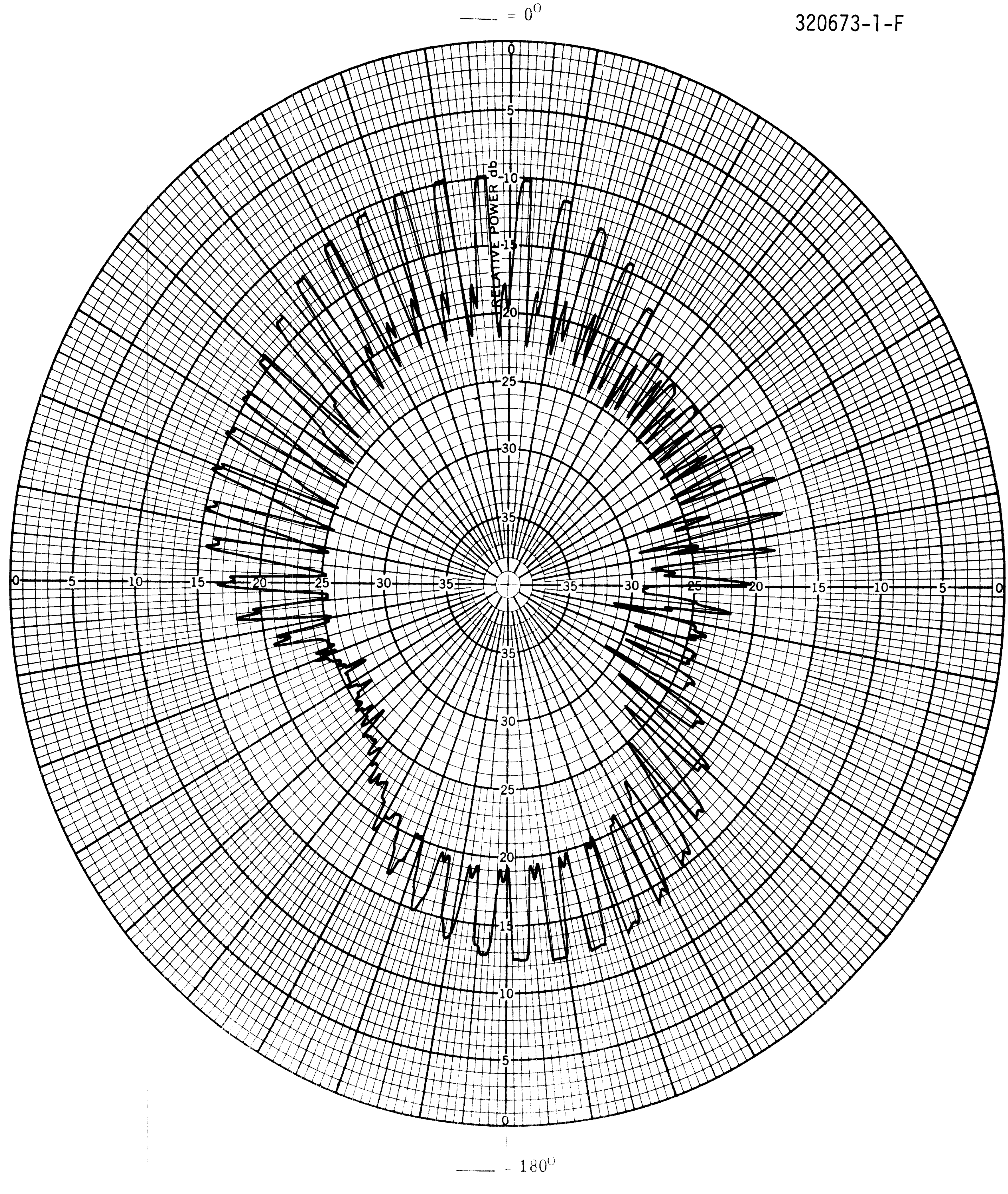


Figure 6G. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with wipers running slow. f = 98 MHz.

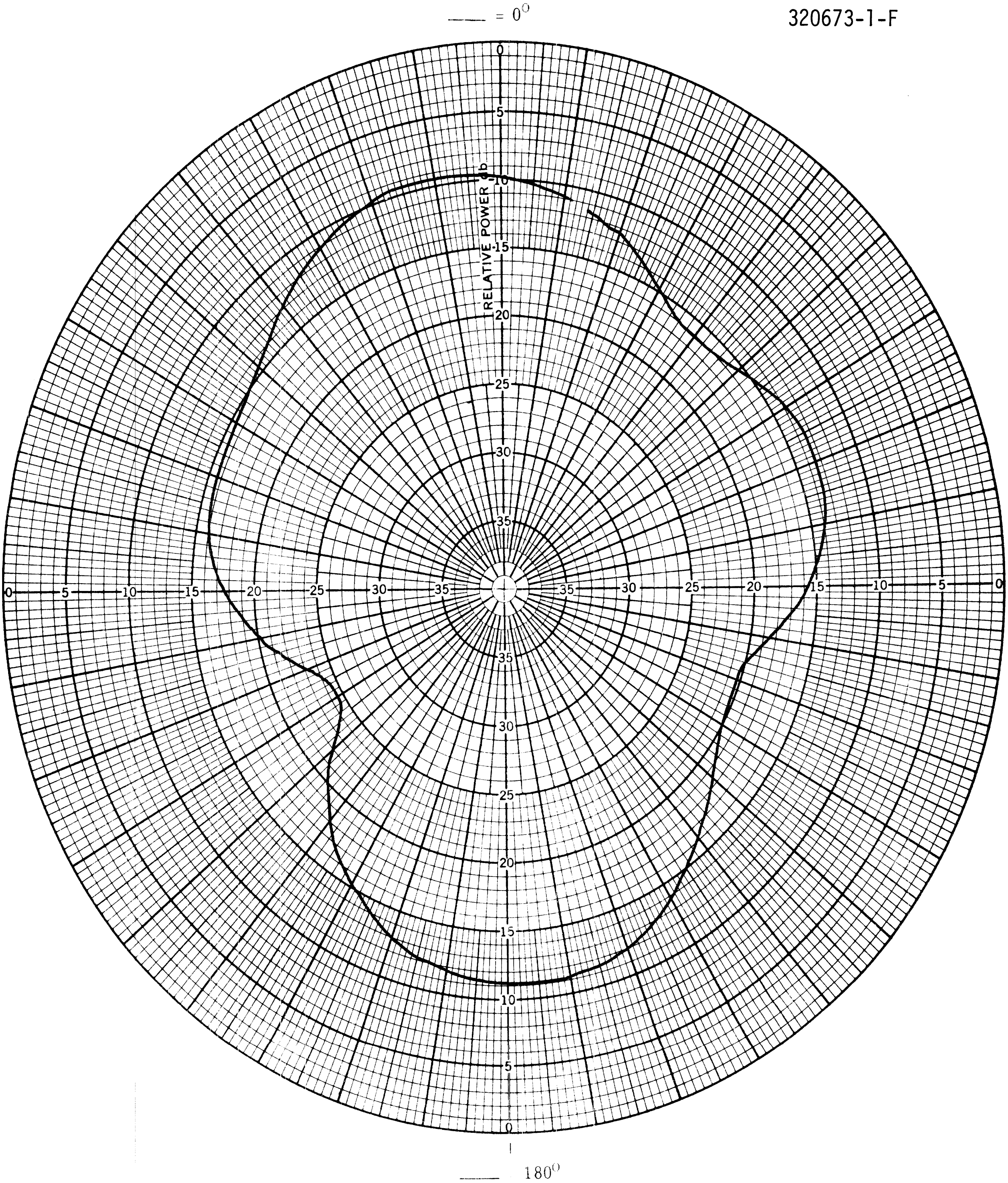


Figure 6H. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with simulated heated back-lite. f = 98 MHz.

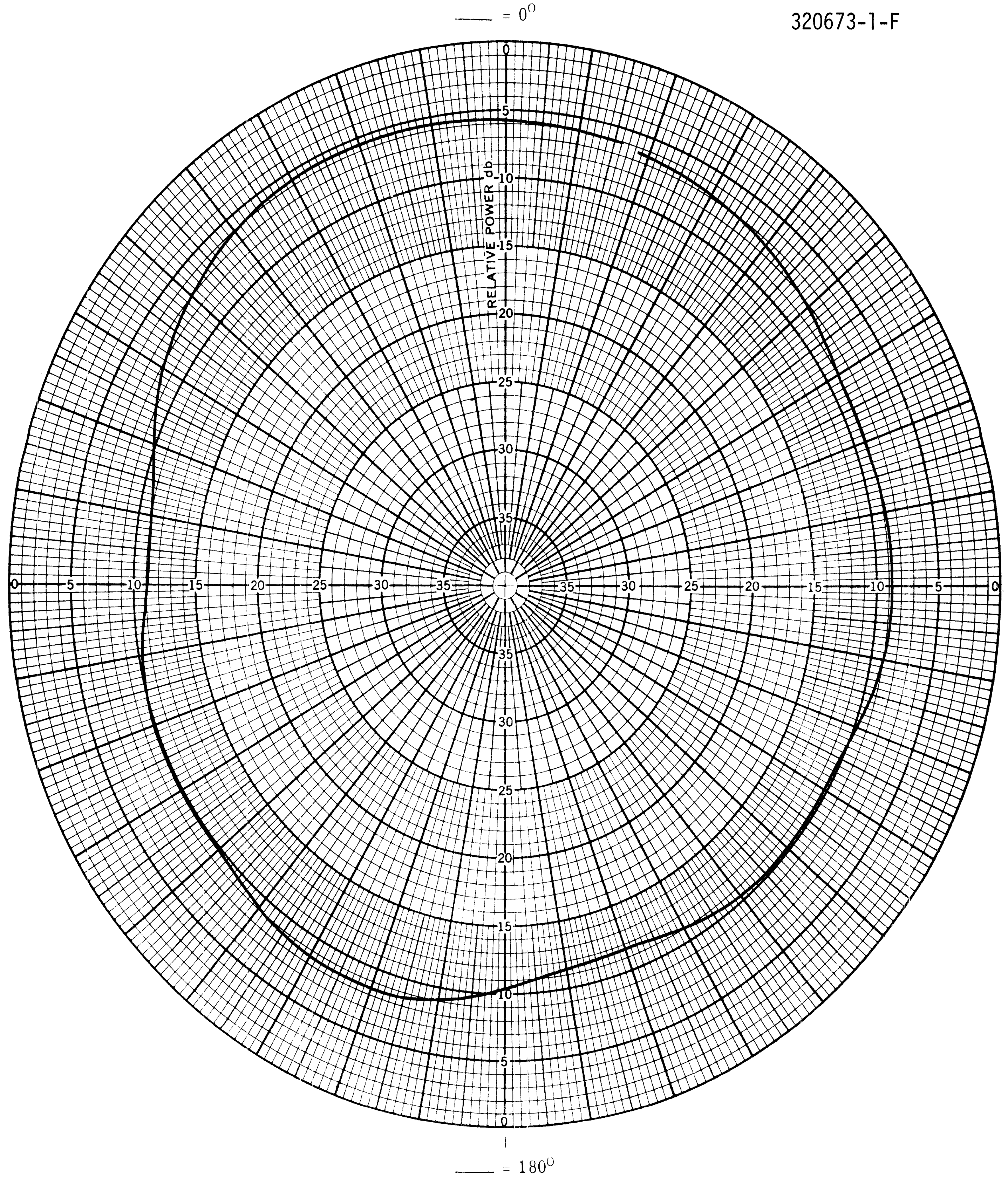


Figure 6I. Radiation pattern of whip antenna on Ford LTD II. f = 108 MHz.

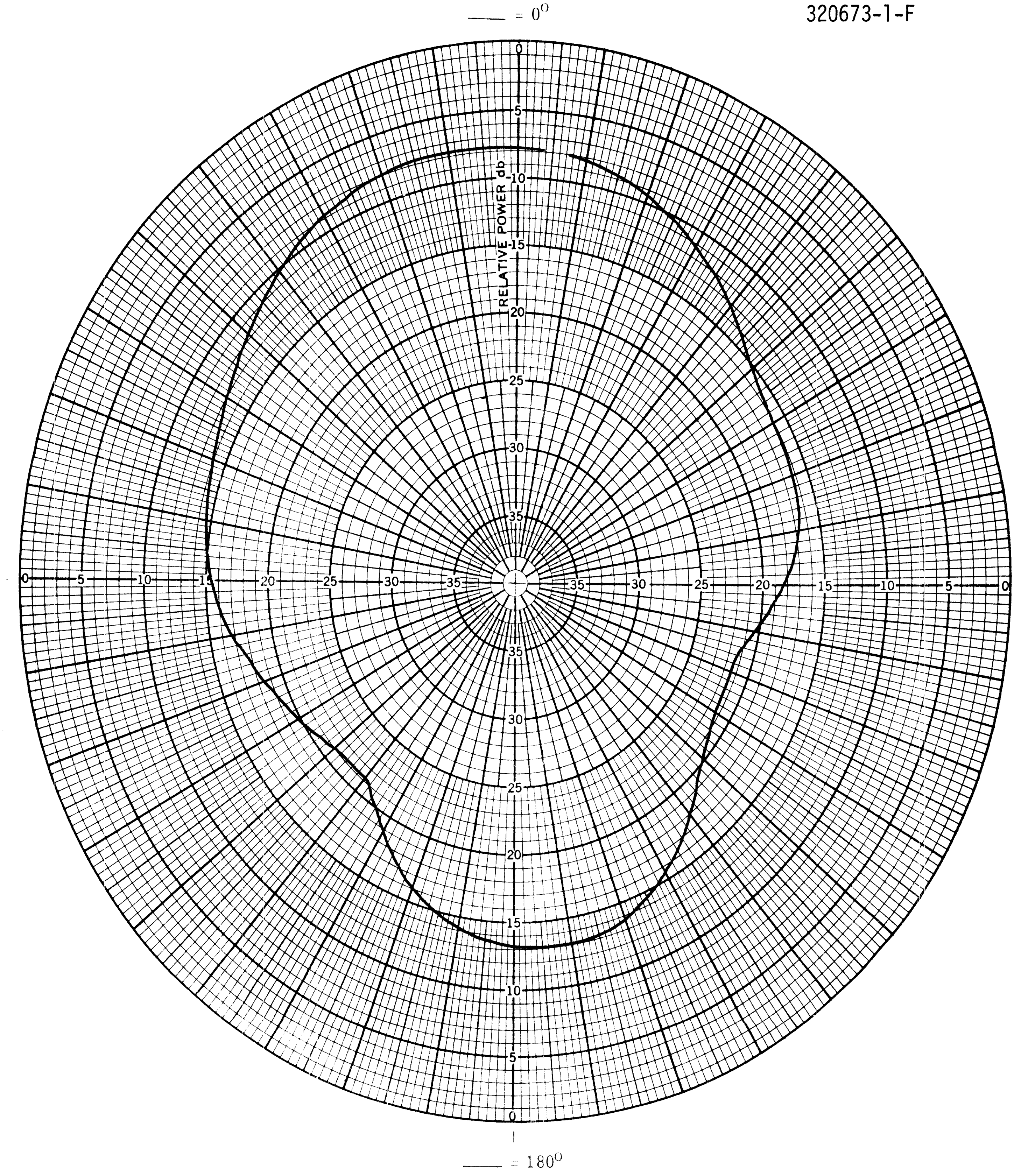


Figure 6J. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II. f = 108 MHz.

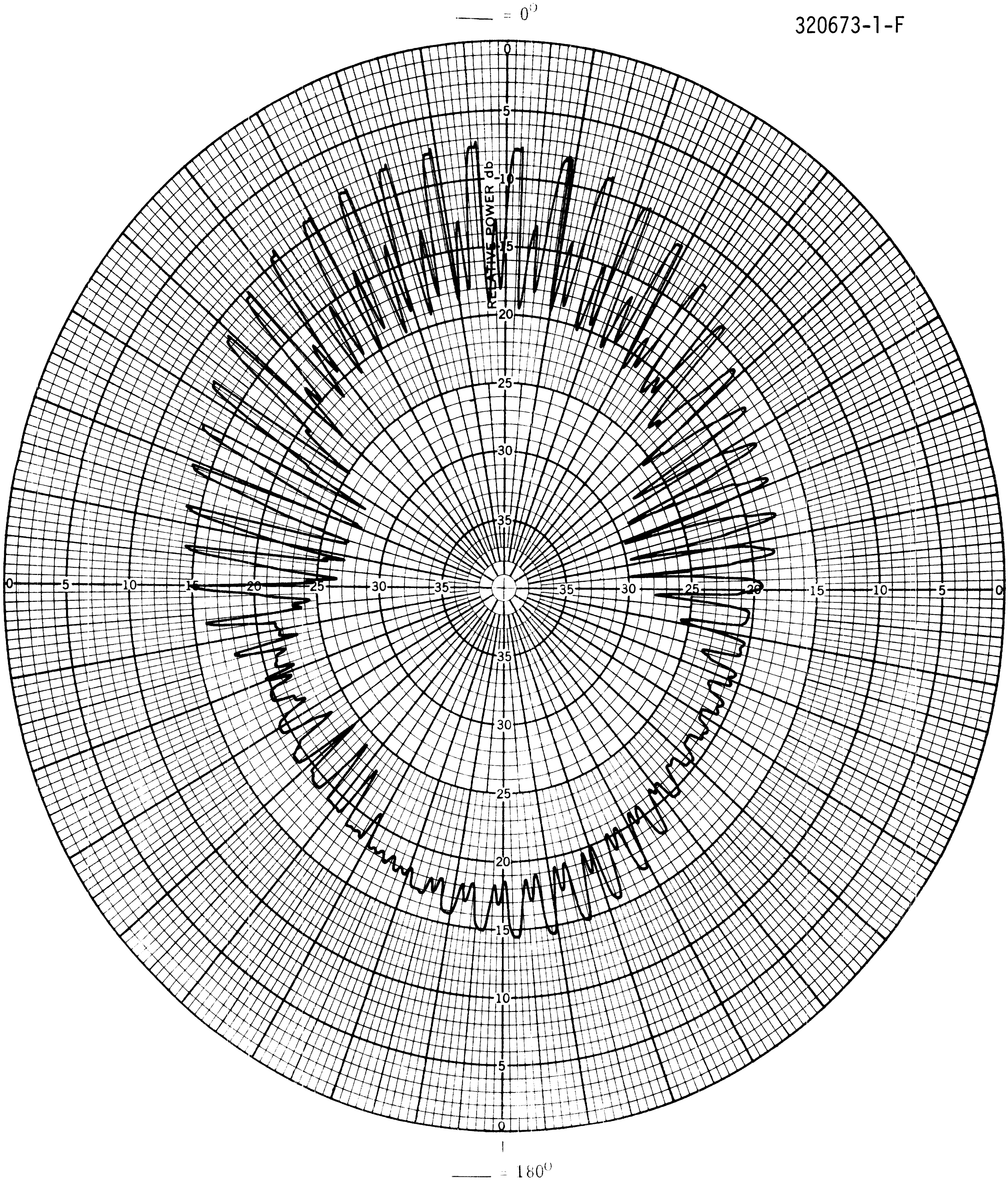


Figure 6K. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with wipers running slow. f = 108 MHz.

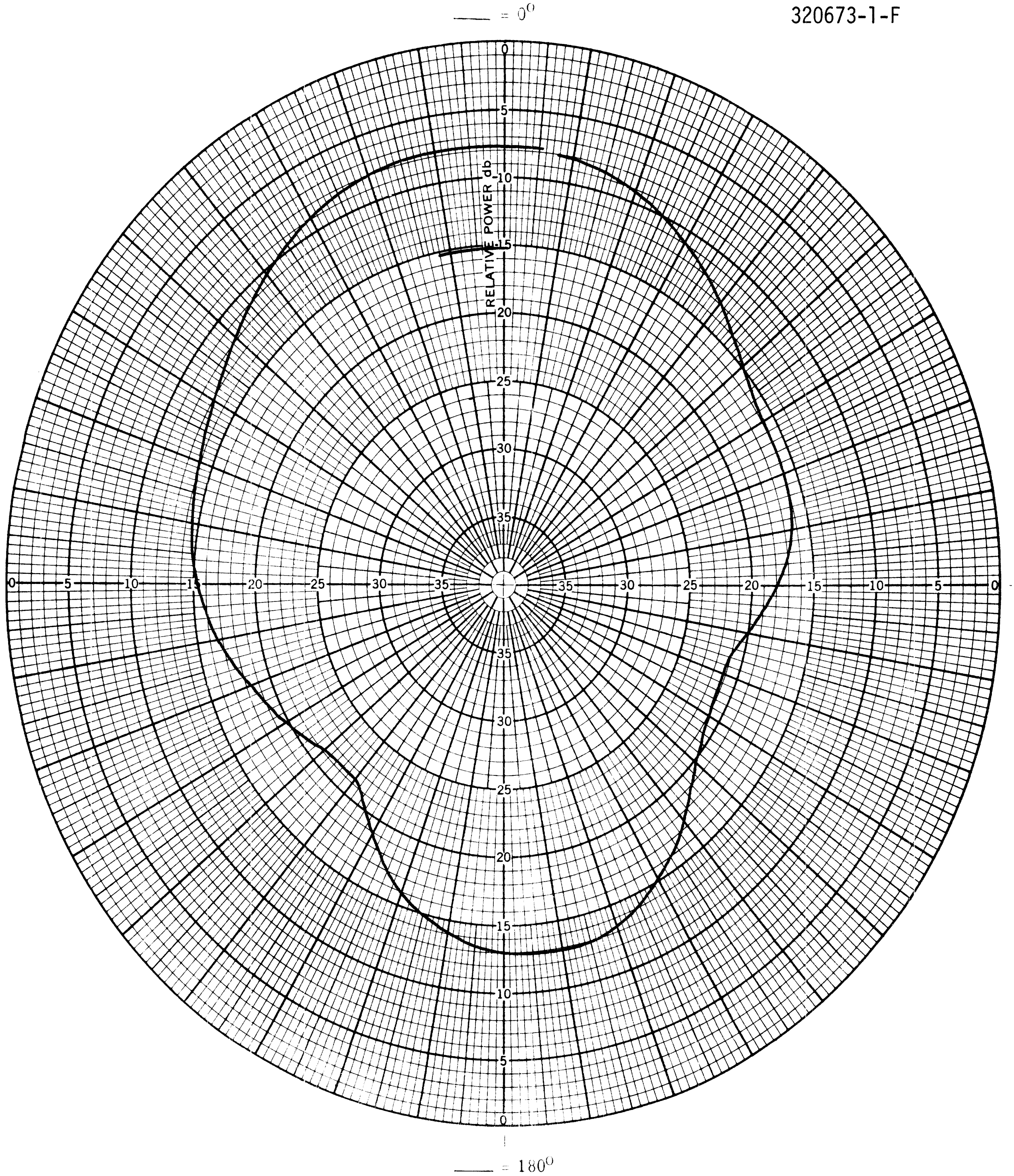


Figure 6L. Radiation pattern of windshield antenna Configuration #4 on Ford LTD II with simulated heated back-lite. f = 108 MHz.

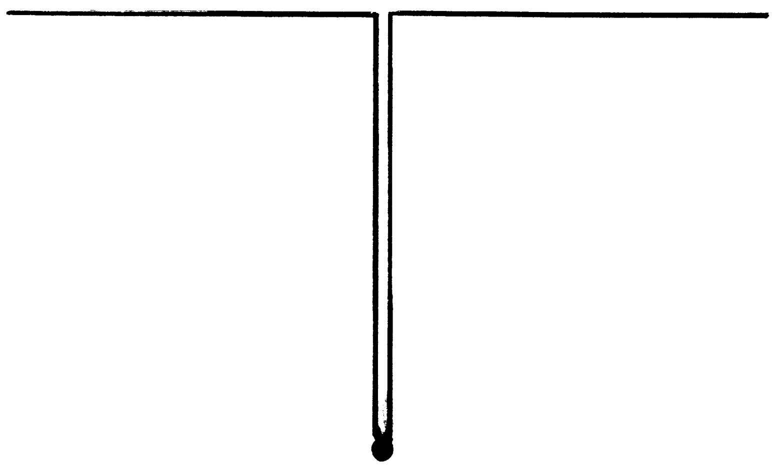
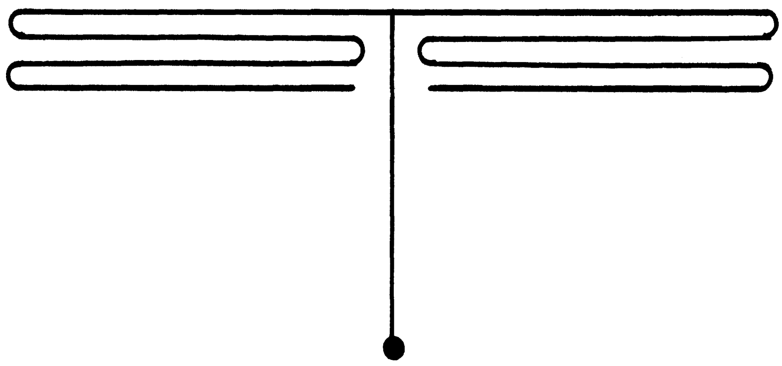
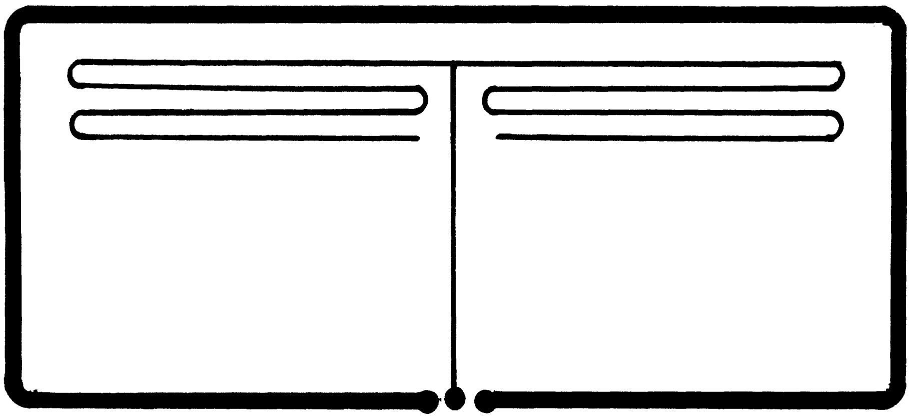


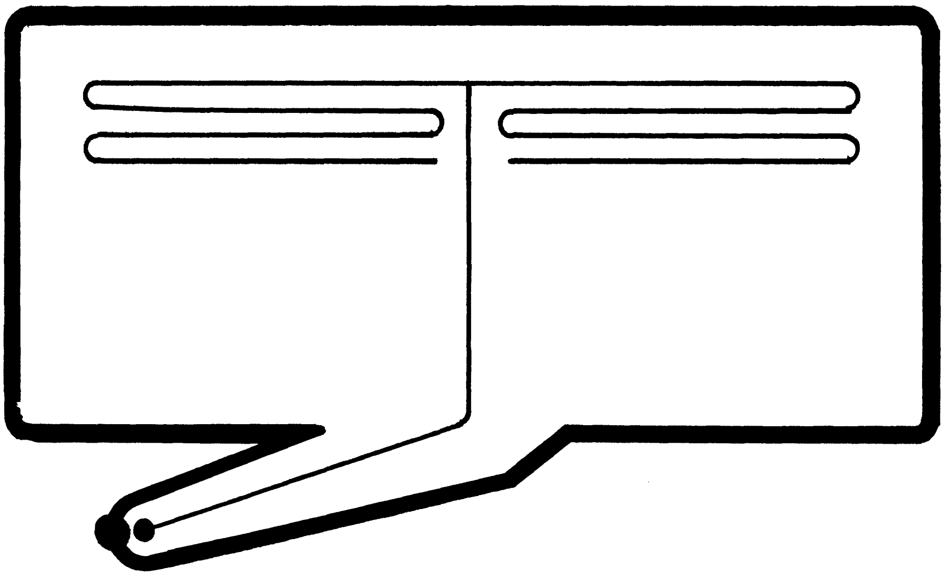
Figure 7A. GM windshield antenna.



Configuration #1



Configuration #2 and #4



Configuration #3

Figure 7B. Ford windshield Configurations 1 - 4.

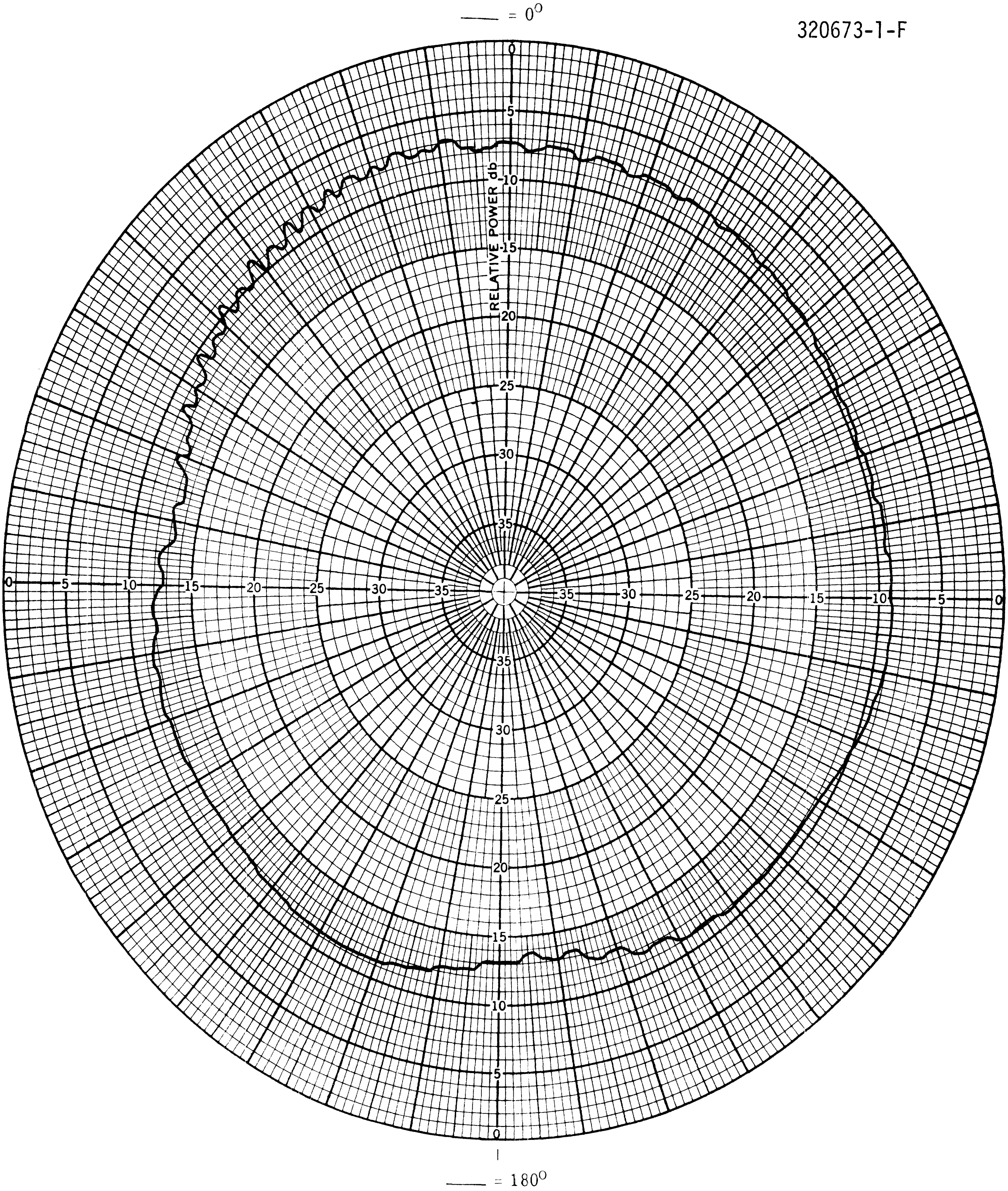


Figure 8. Radiation pattern of whip antenna on Ford LTD II with wipers running slow. f = 108 MHz.

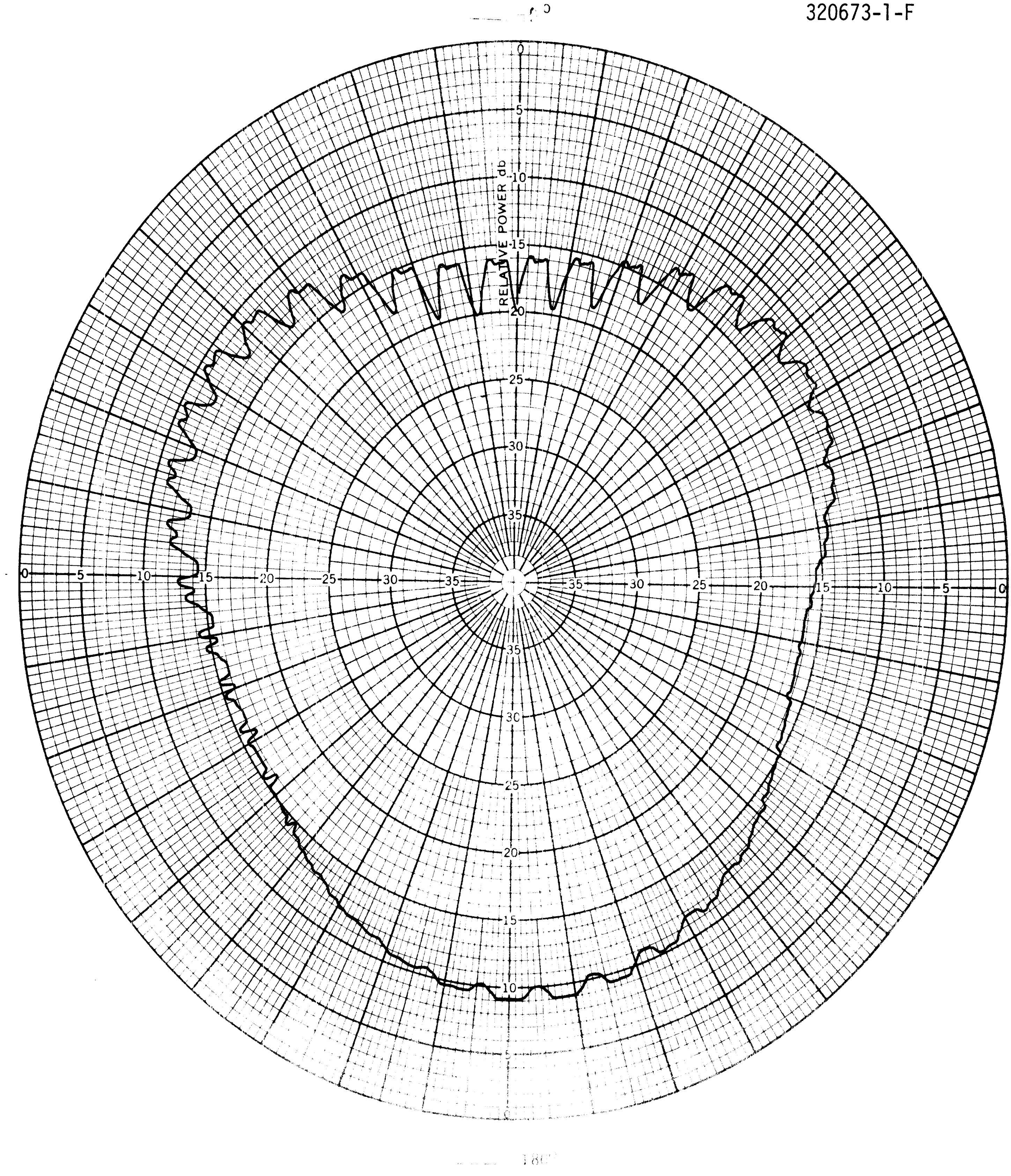


Figure 9A. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow and blades conductively attached to antenna. f = 88 MHz.

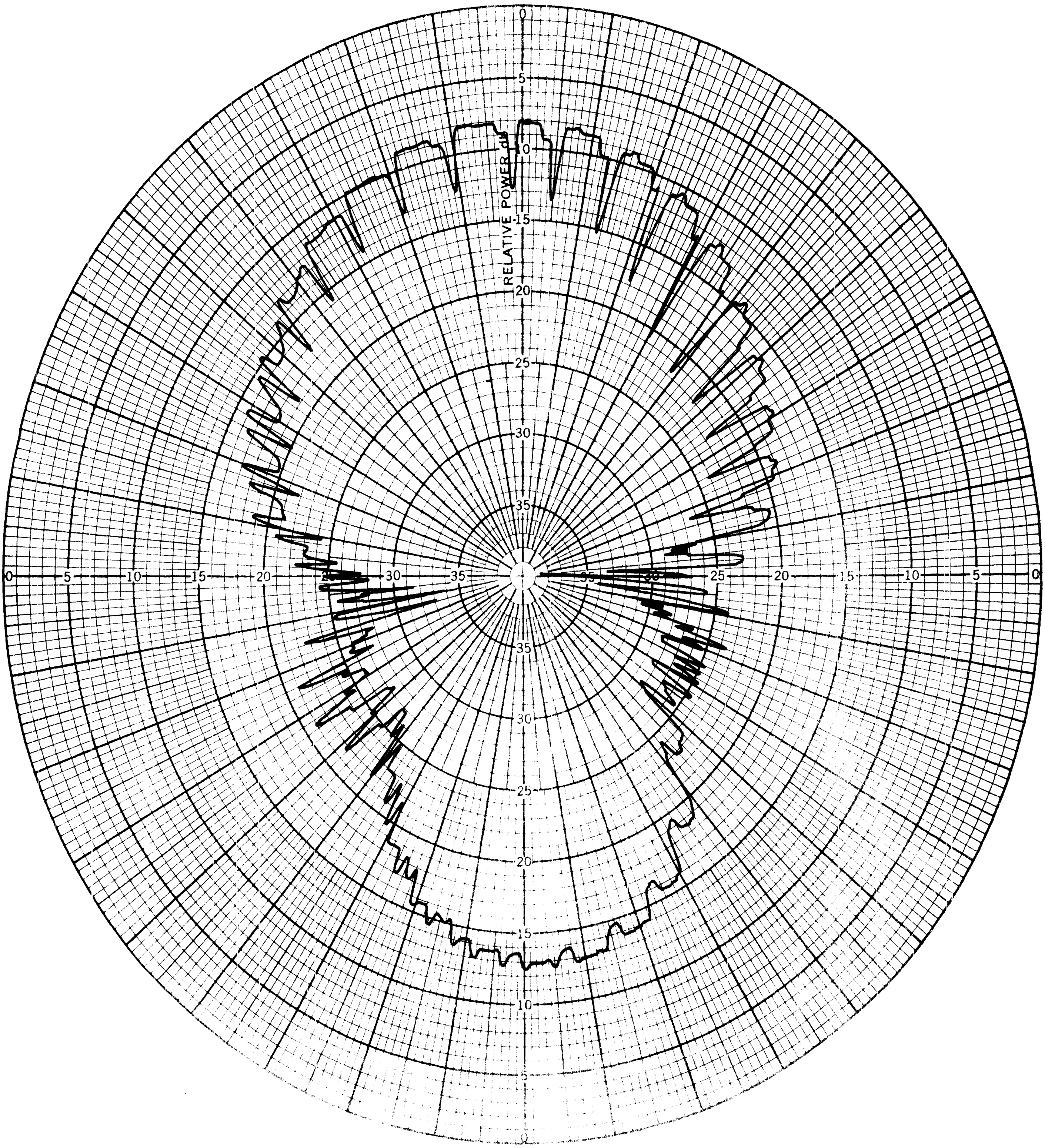


Figure 9B. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow and blades conductively attached to antenna. f = 98 MHz.

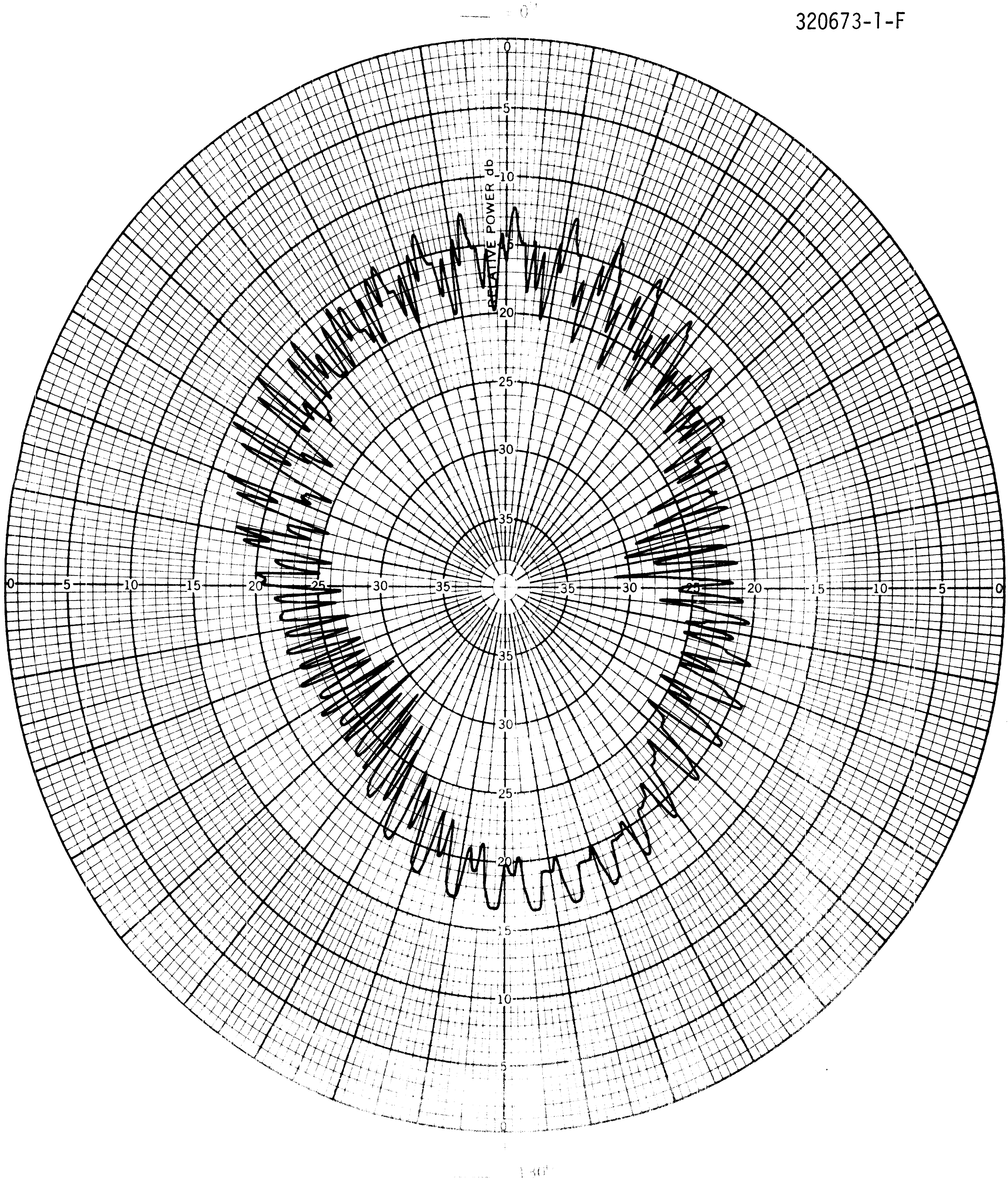


Figure 9C. Radiation pattern of windshield antenna on Chevrolet Caprice with wipers running slow and blades conductively attached to antenna. f = 108 MHz.

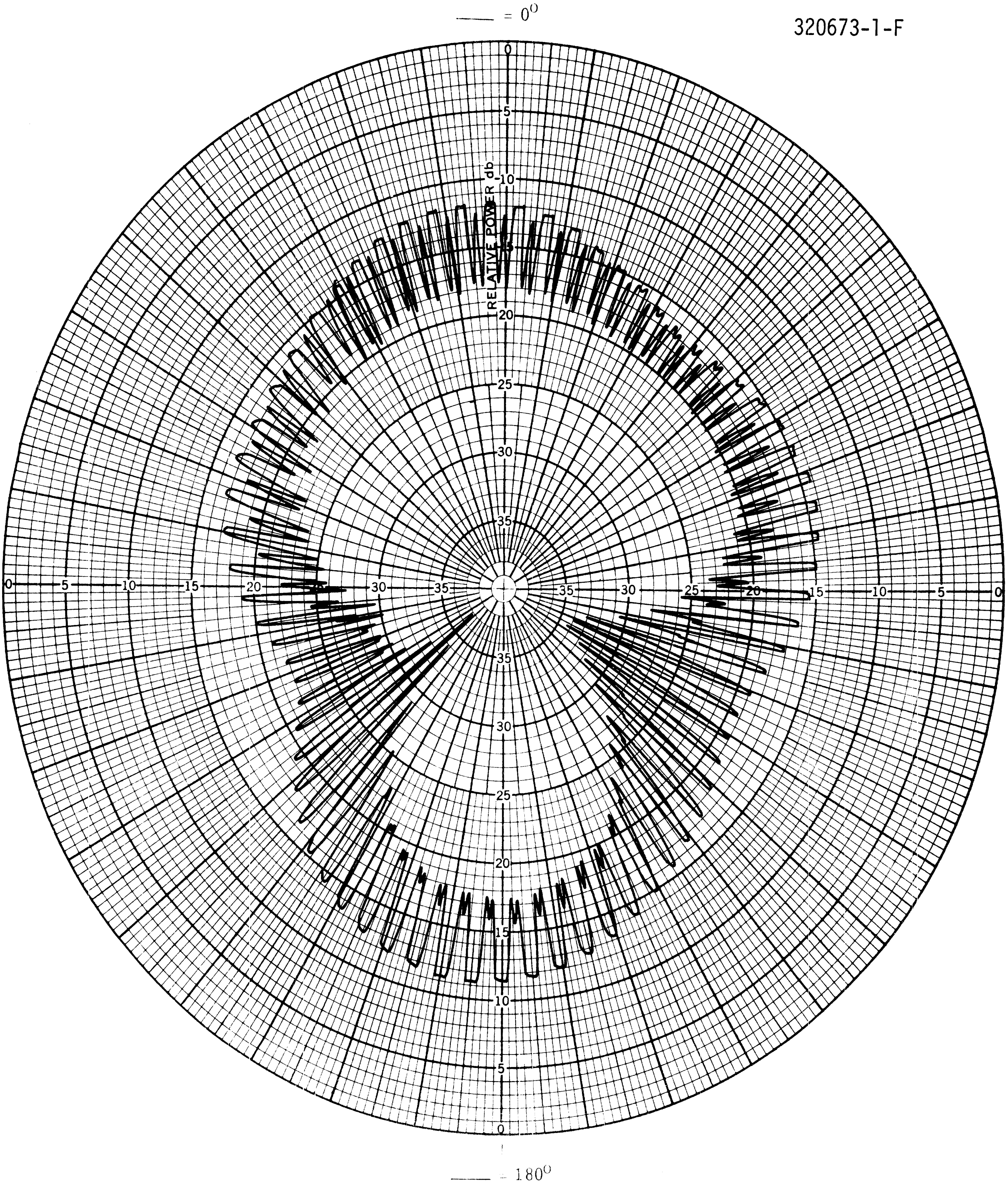


Figure 10A. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (driver's wiper removed). f = 98 MHz.

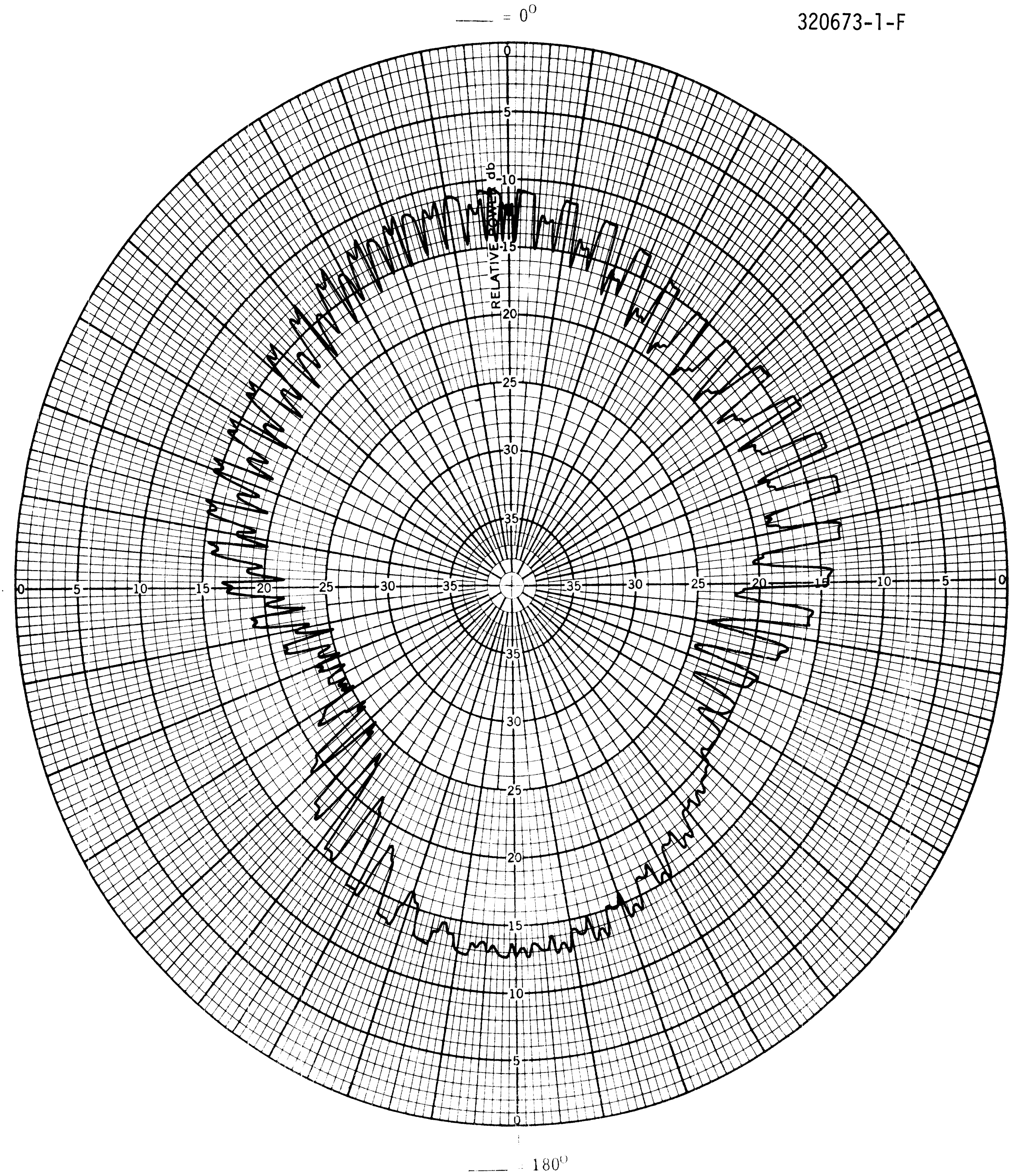


Figure 10B. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (passenger's wiper removed). f = 98 MHz.

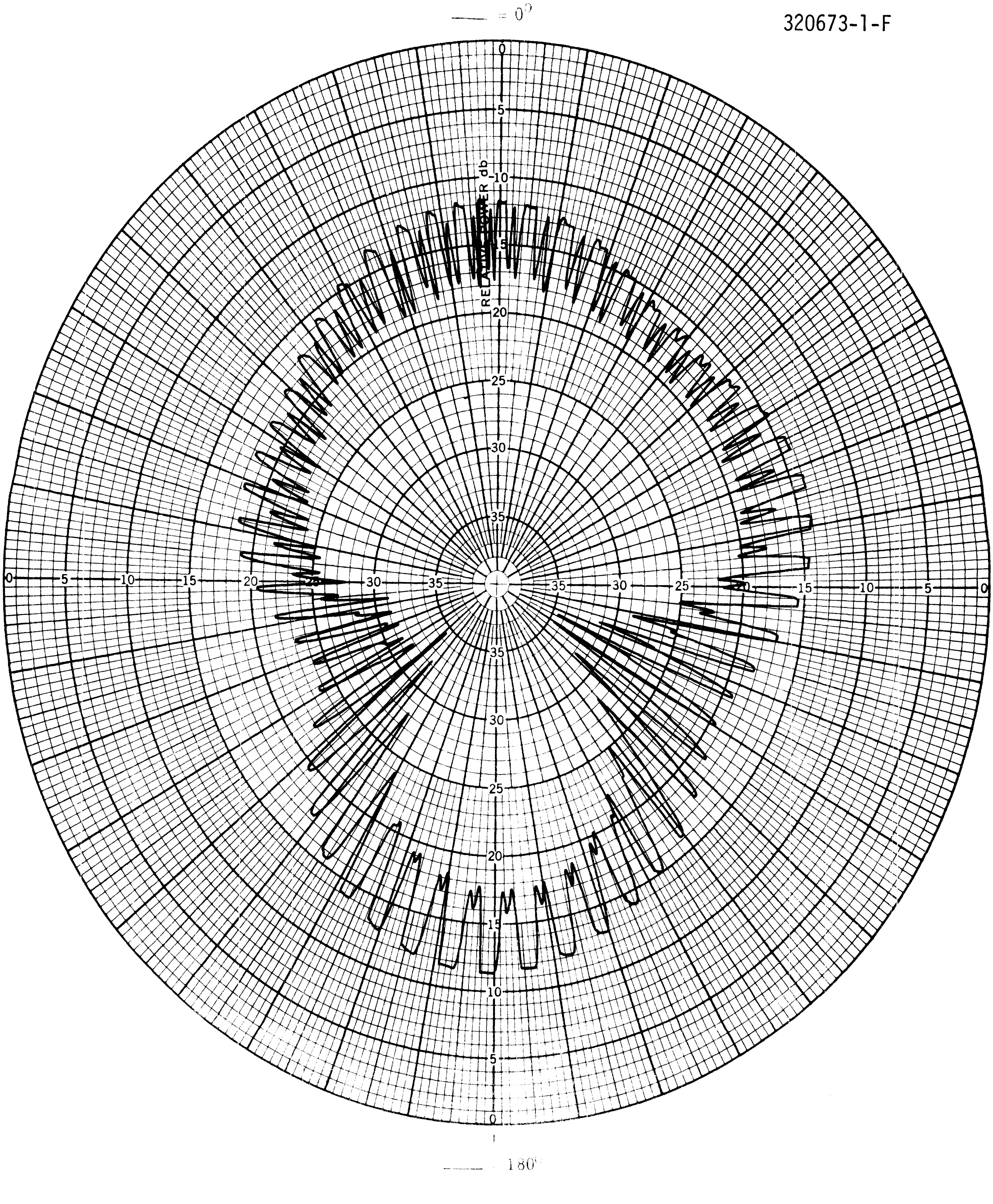


Figure 10C. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (driver's wiper and arm removed). f = 98 MHz.

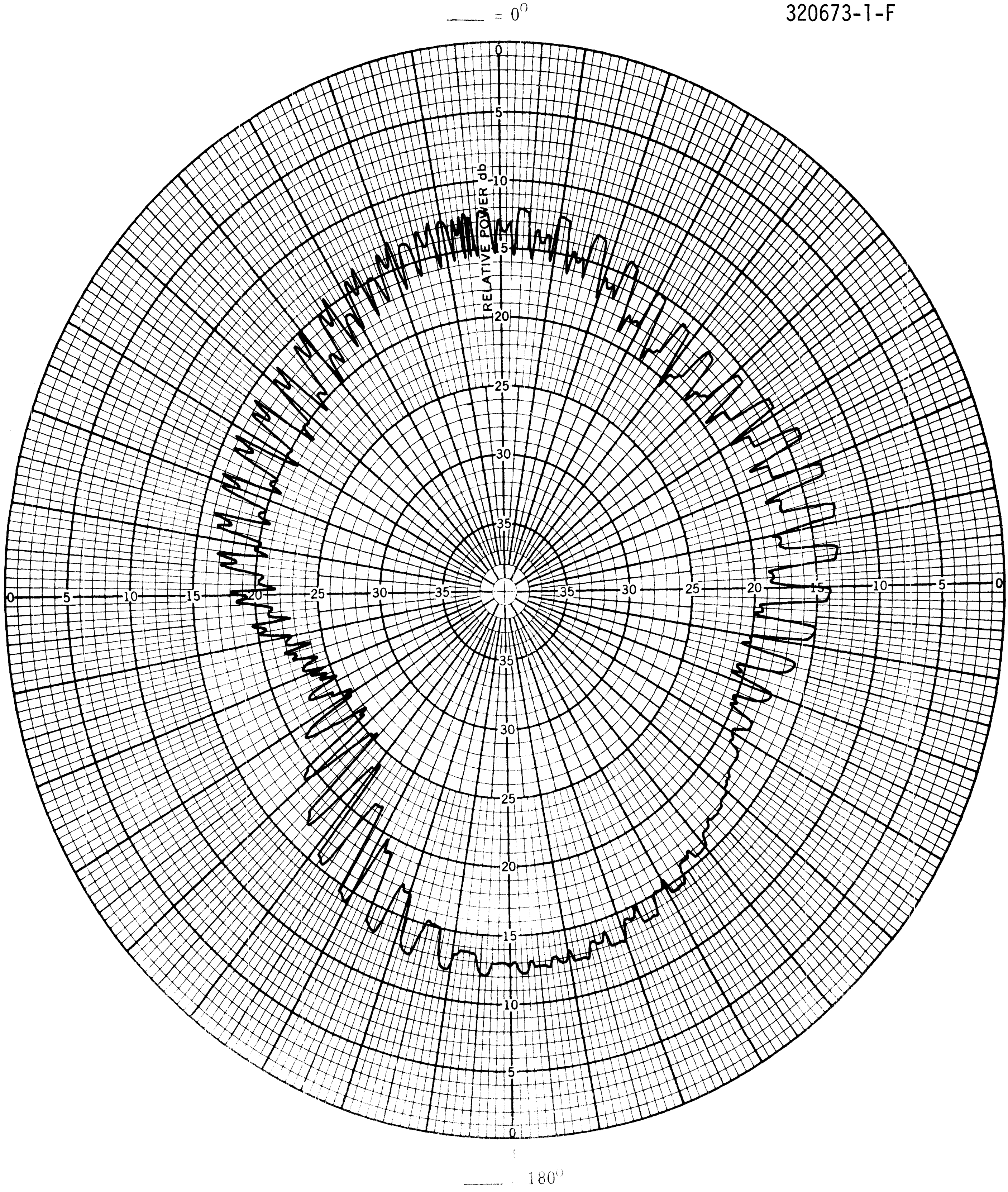


Figure 10D. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (passenger's wiper and arm removed). f = 98 MHz.

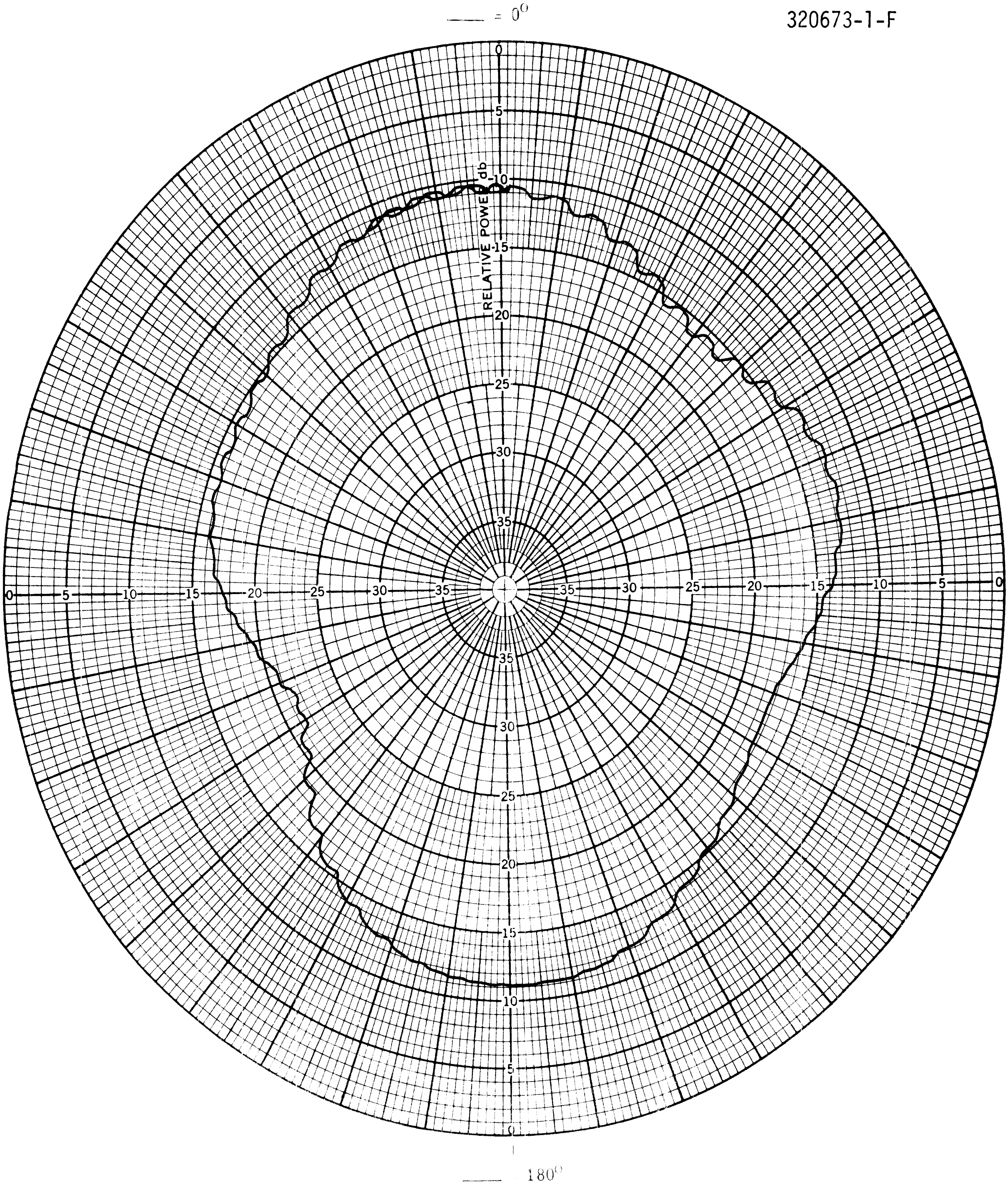


Figure 10E. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (driver's wiper and arm removed and passenger's wiper removed). f = 98 MHz.

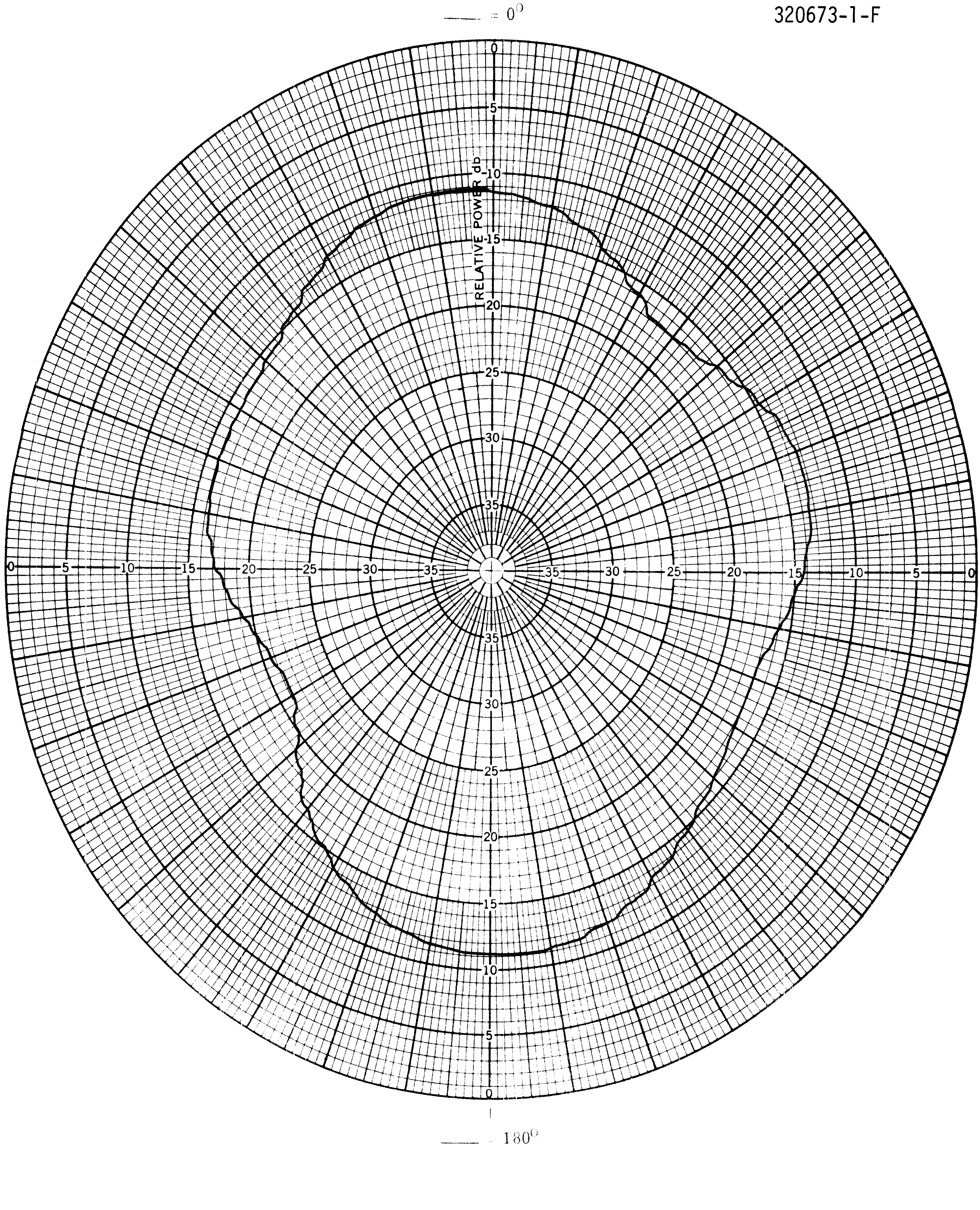


Figure 10F. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (driver's wiper removed and passenger's wiper and arm removed). f = 98 MHz.

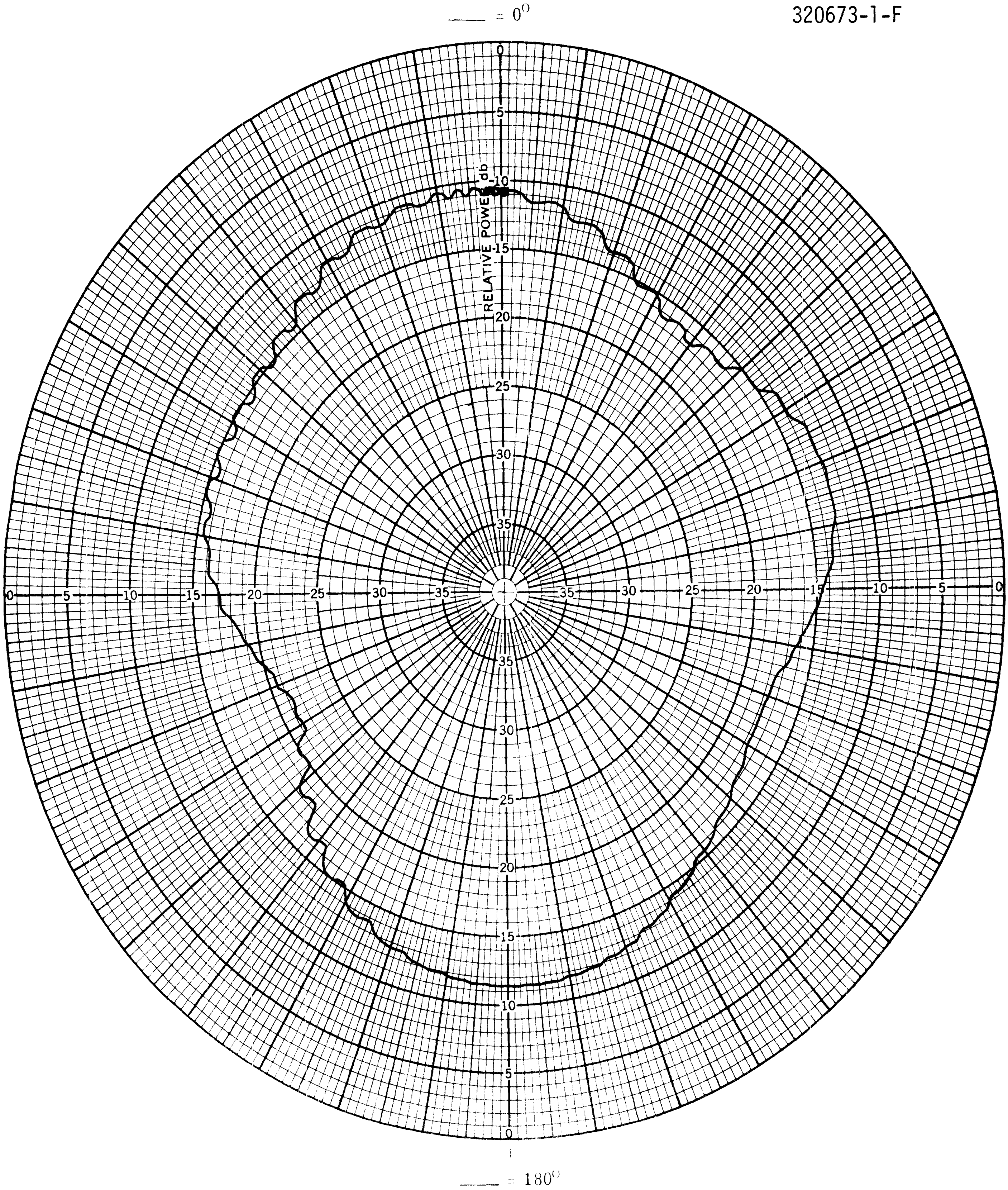


Figure 10G. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (driver's and passanger's wiper removed). f = 98 MHz.

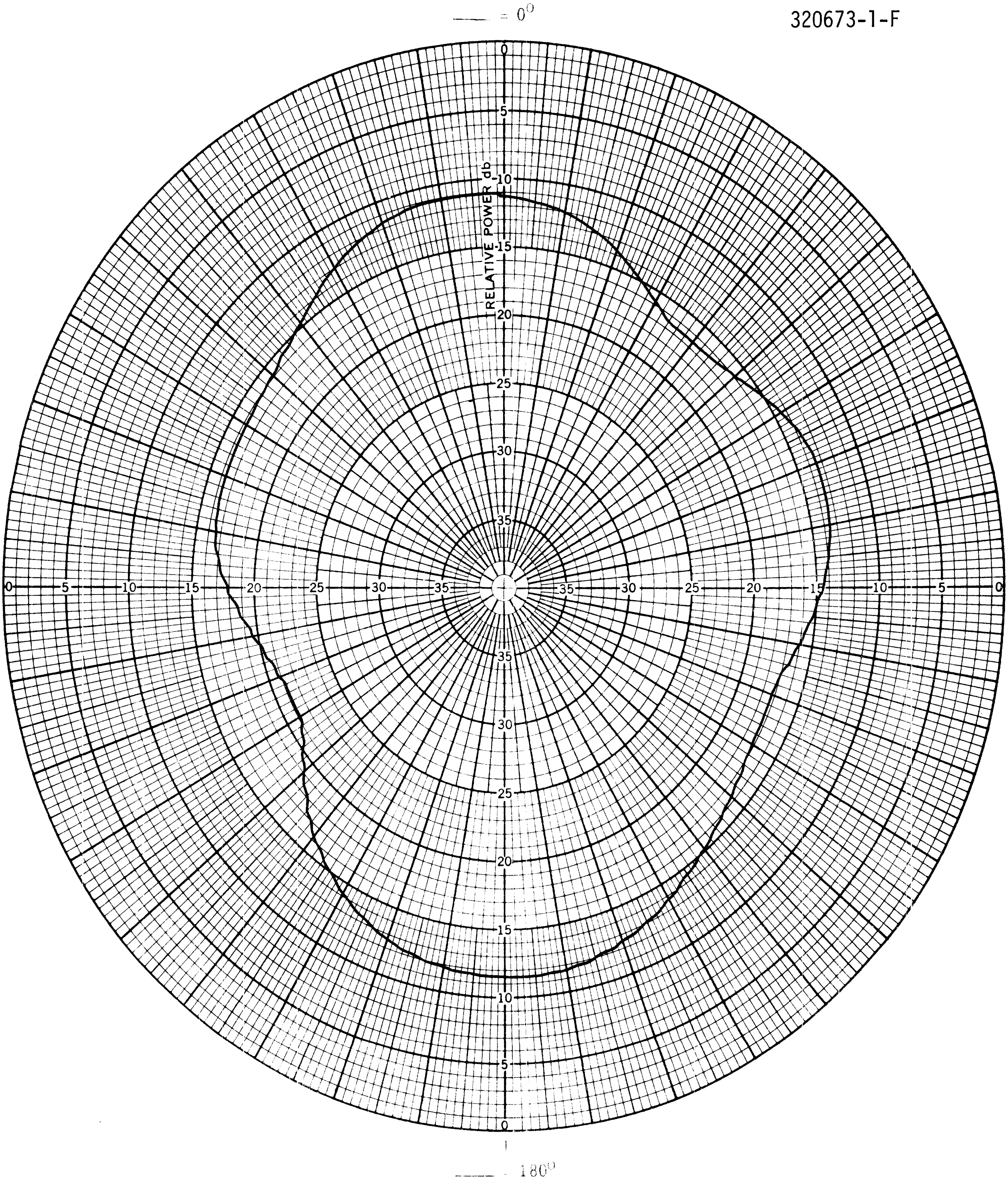


Figure 10H. Radiation pattern of windshield antenna Configuration #4 with wipers running slow (dirver's and passenger's wiper assembly removed and wiper motor running). f = 98 MHz.

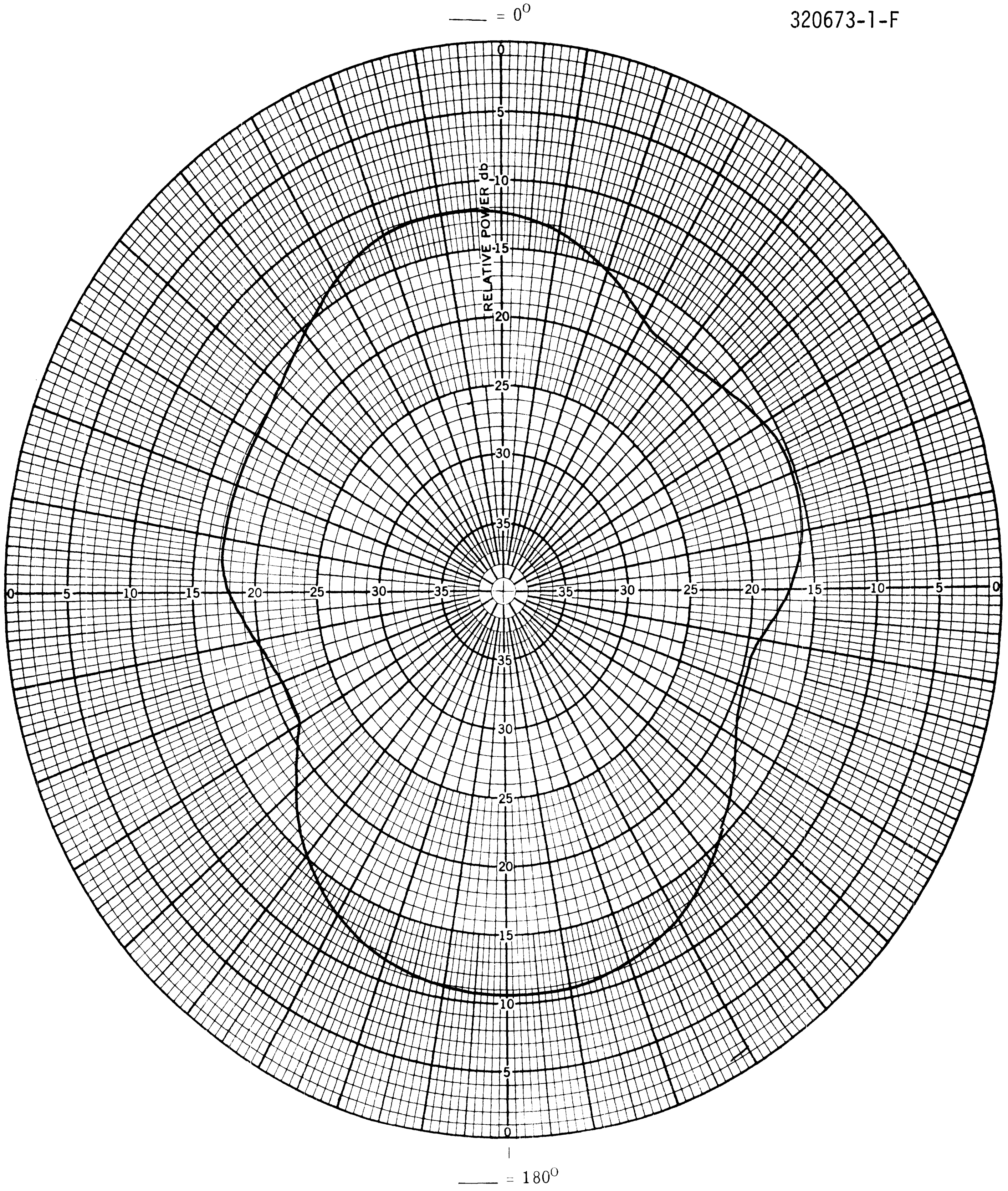


Figure 11A. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II. f = 98 MHz.

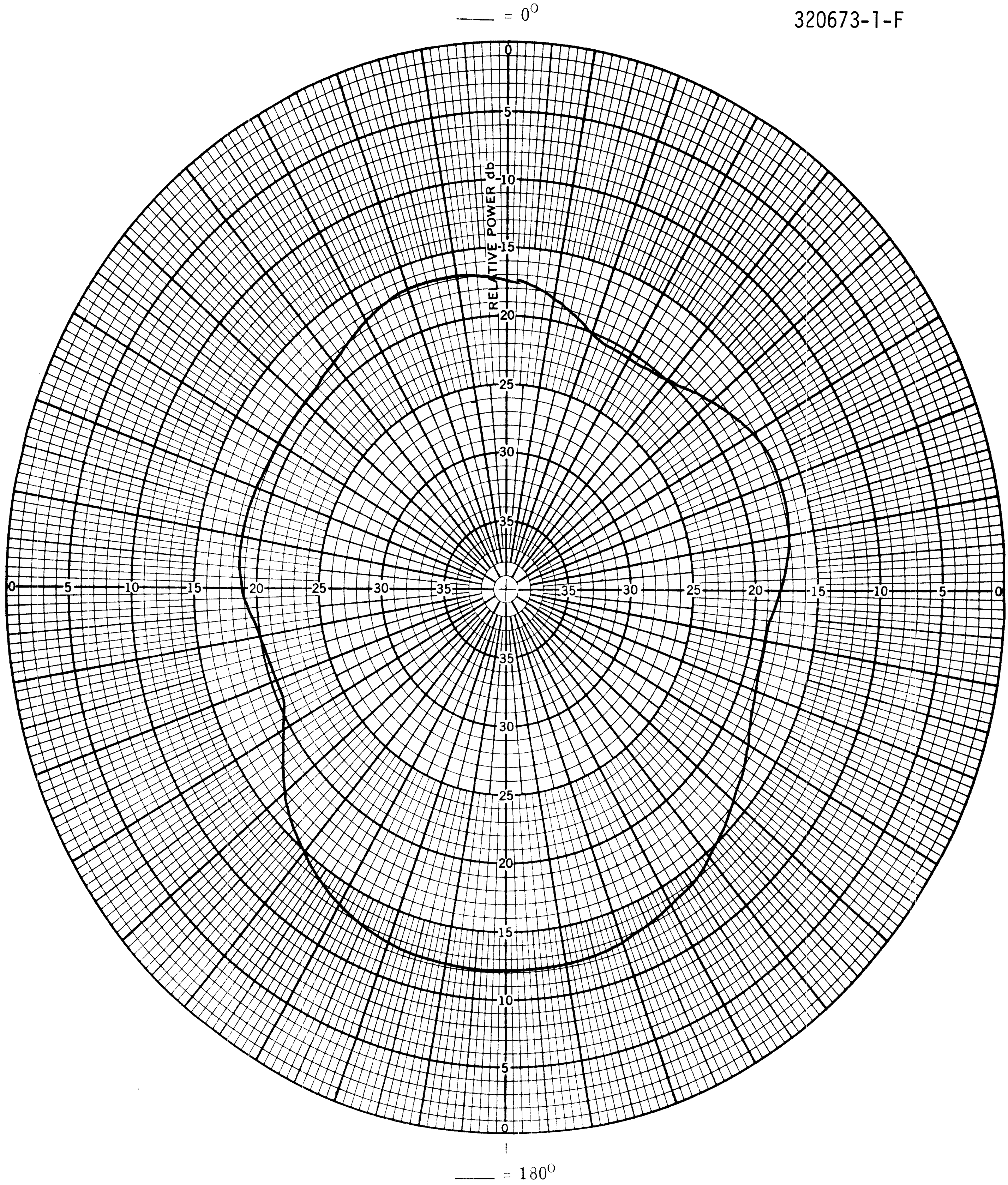


Figure 11B. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II (crash-pad removed). f = 98 MHz.

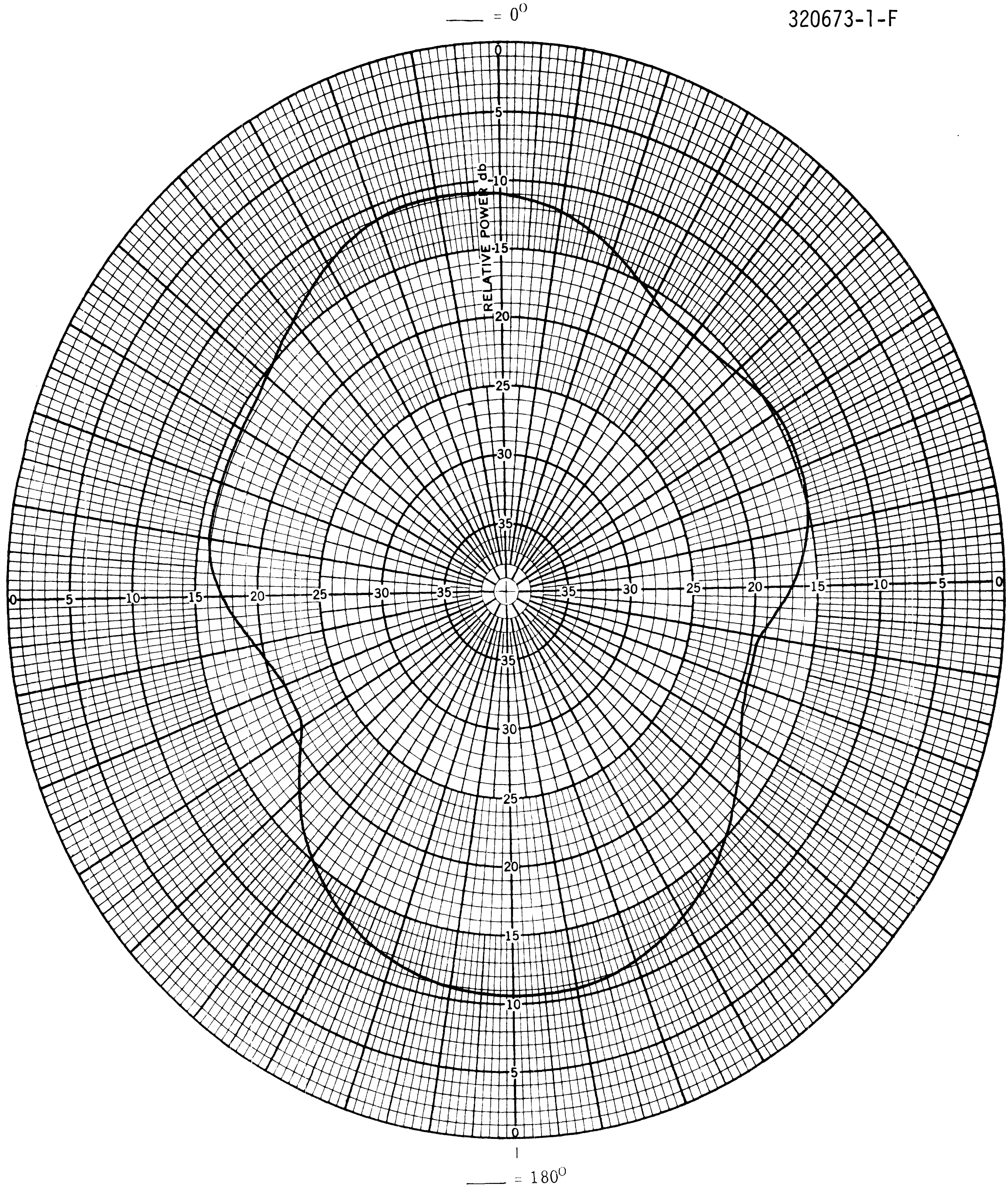


Figure 11C. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II (guard-band ground removed). f = 98 MHz.

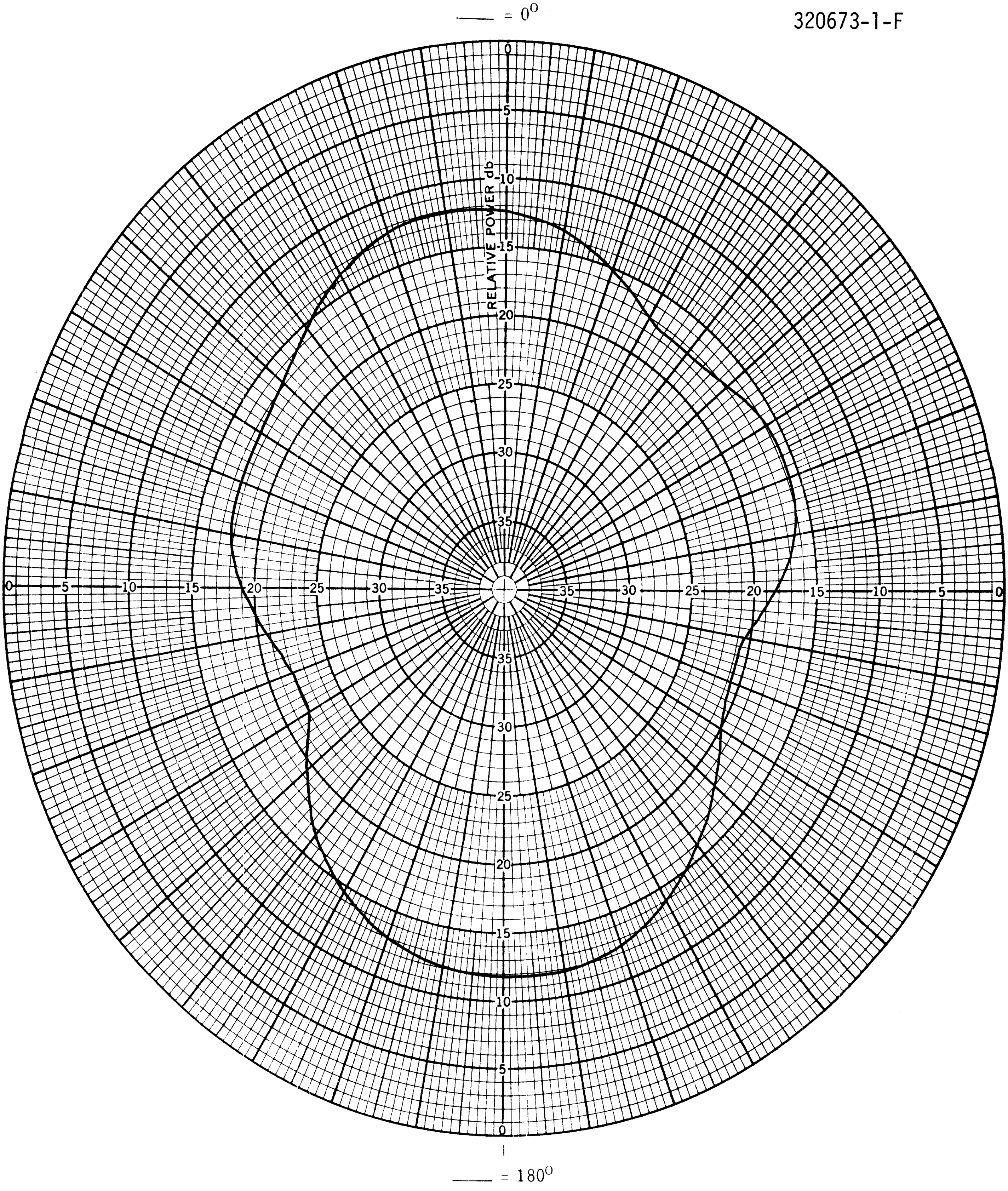


Figure 11D. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II (guard-band and antenna coaxial lead grounds removed). f = 98 MHz.

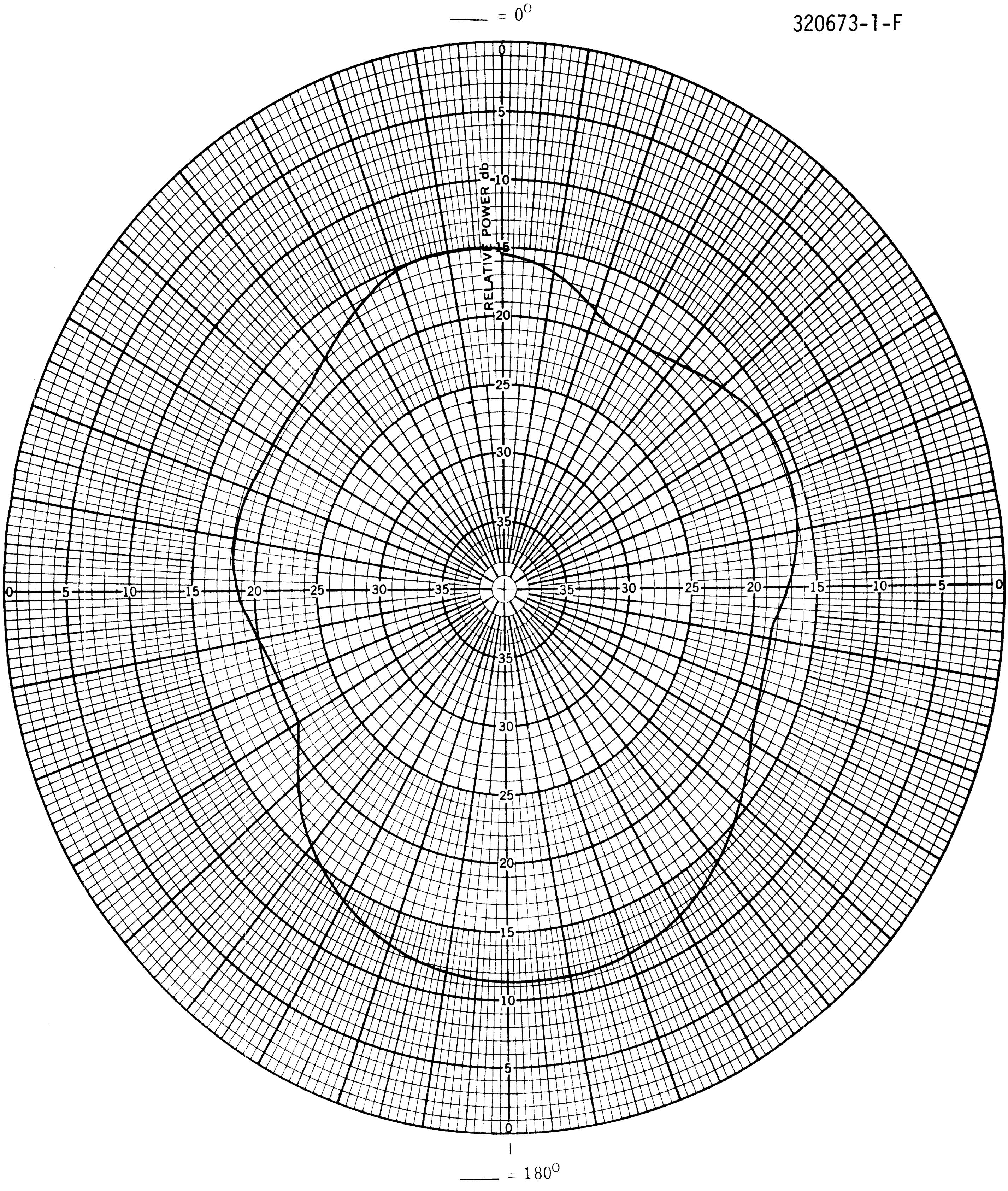


Figure 11E. Radiation pattern of windshield antenna Configuration #2 on Ford LTD II (guard-band and antenna coaxial lead grounds removed and crash pad grounded). f = 98 MHz.

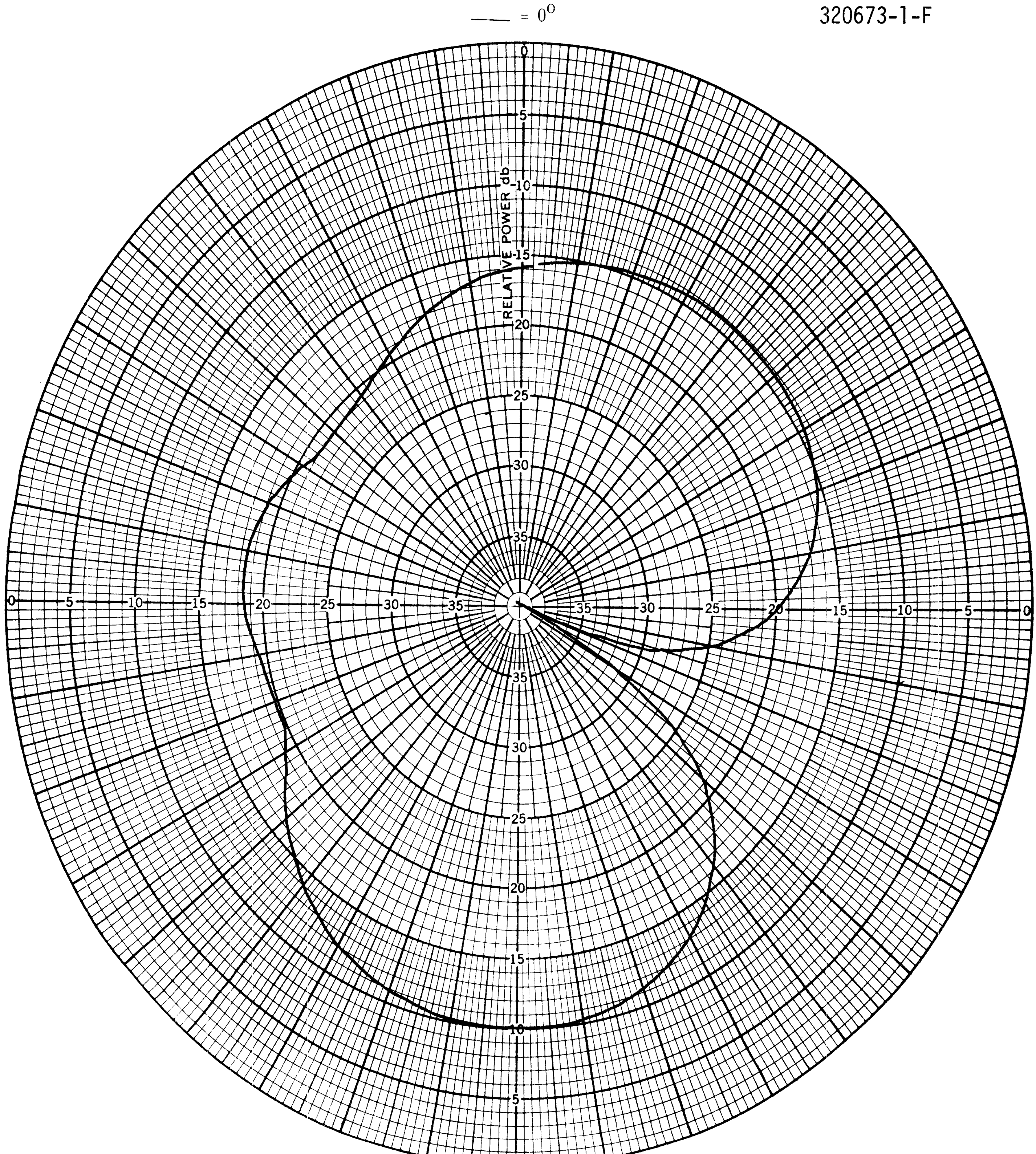


Figure 12A. Radiation pattern of windshield antenna Configuration #3 with inactive whip on Ford LTD II. f = 88 MHz.

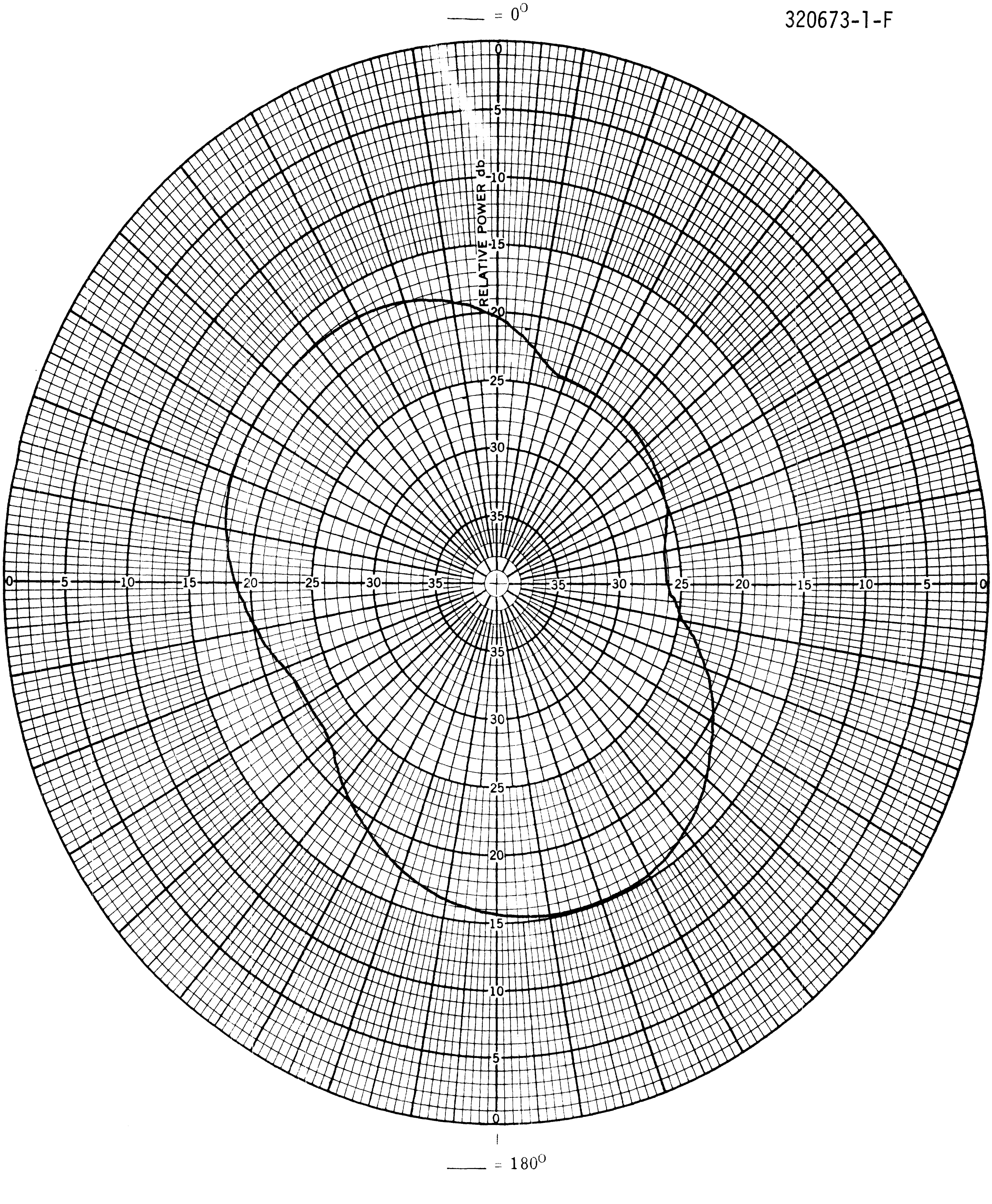


Figure 12B. Radiation pattern of windshield antenna Configuration #3 with inactive whip on Ford LTD II. f = 98 MHz.

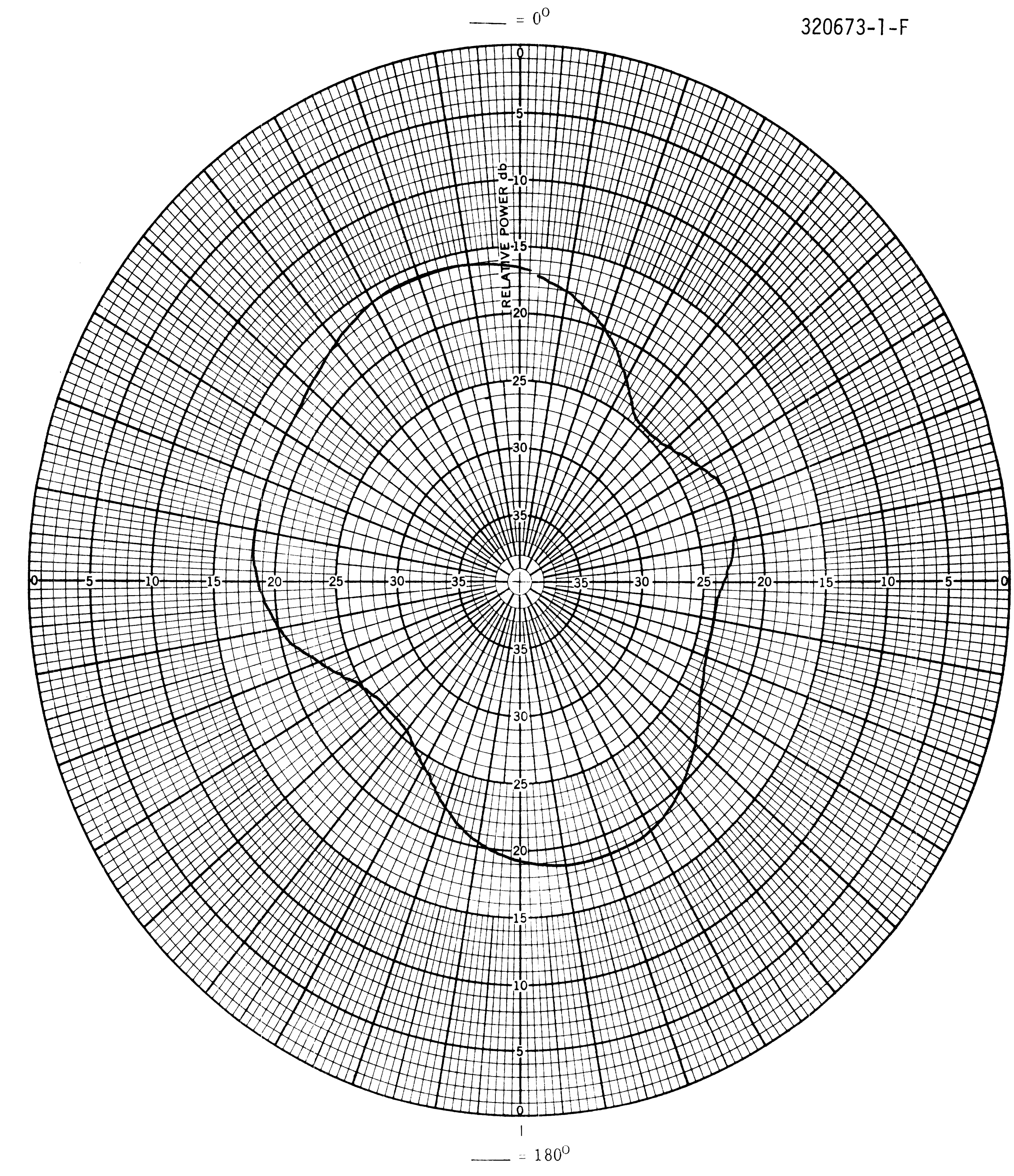


Figure 12C. Radiation pattern of windshield antenna Configuration #3 with inactive whip on Ford LTD II. f = 108 MHz.

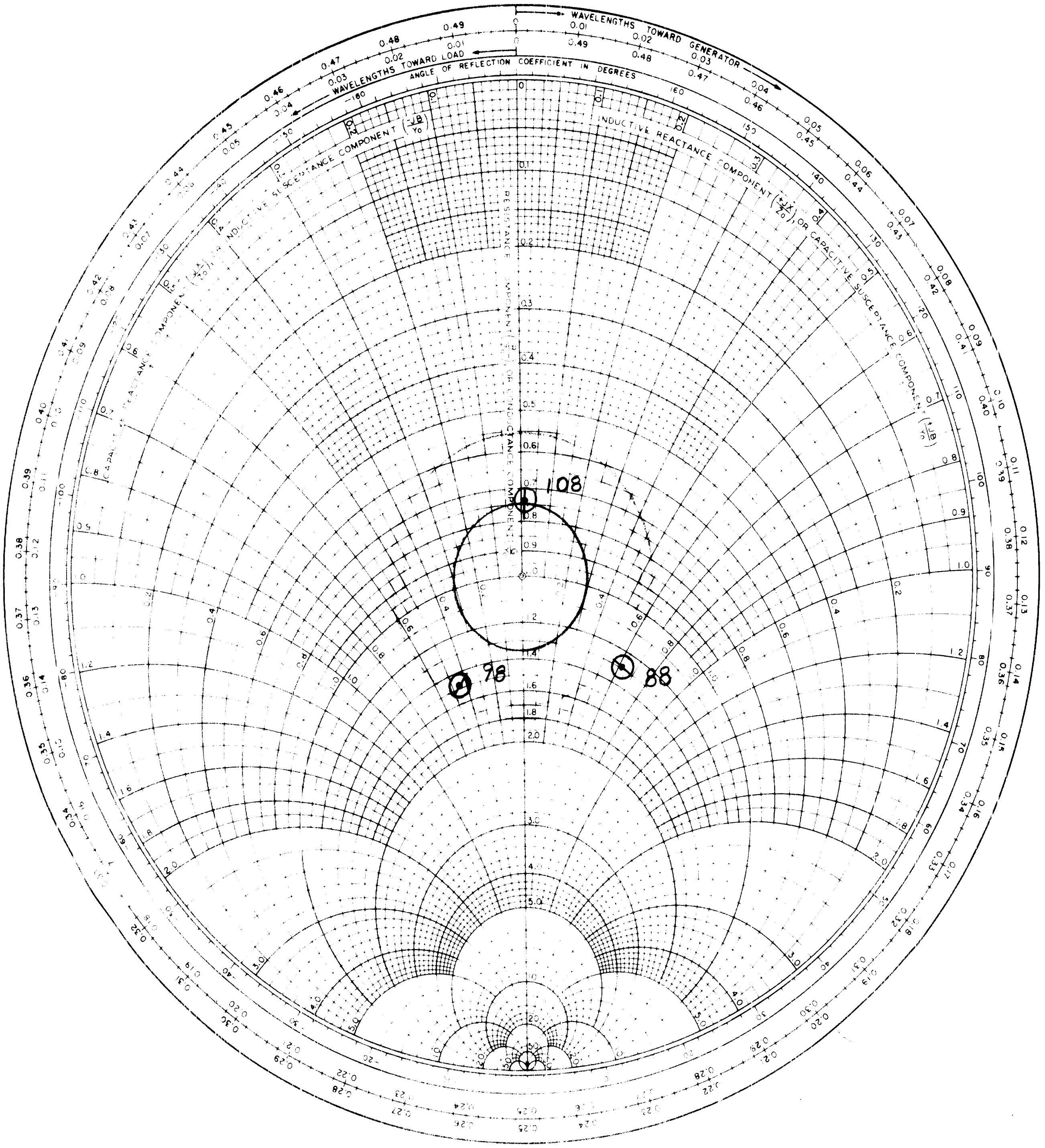


Figure 13A. Impedance data for whip antenna on Ford Thunderbird.
f = 88, 98, and 108 MHz (Z_n = 50Ω).

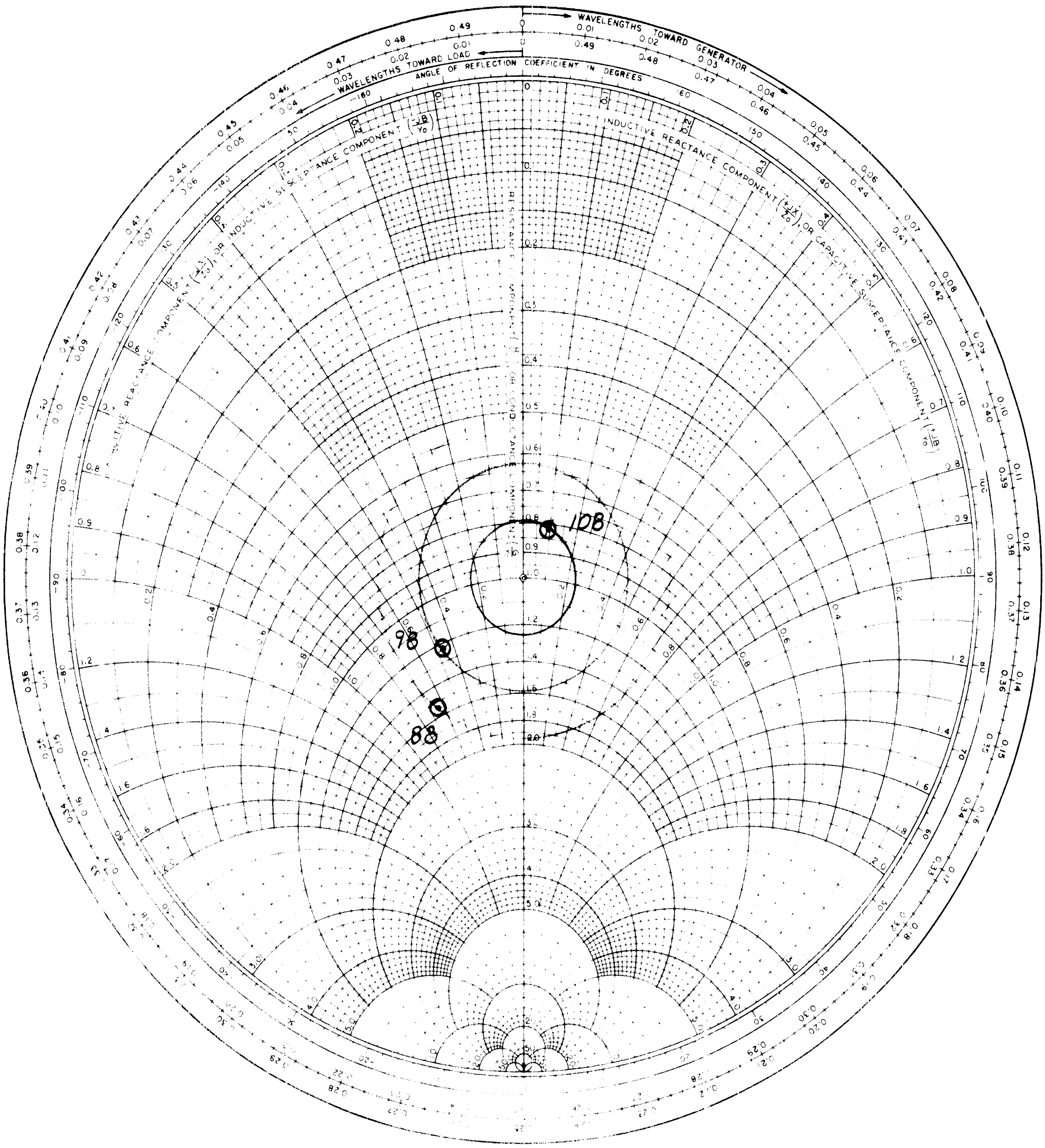


Figure 13B. Impedance data for whip antenna on Ford LTD II.
f = 88, 98, and 108 MHz (Z_n = 50Ω).

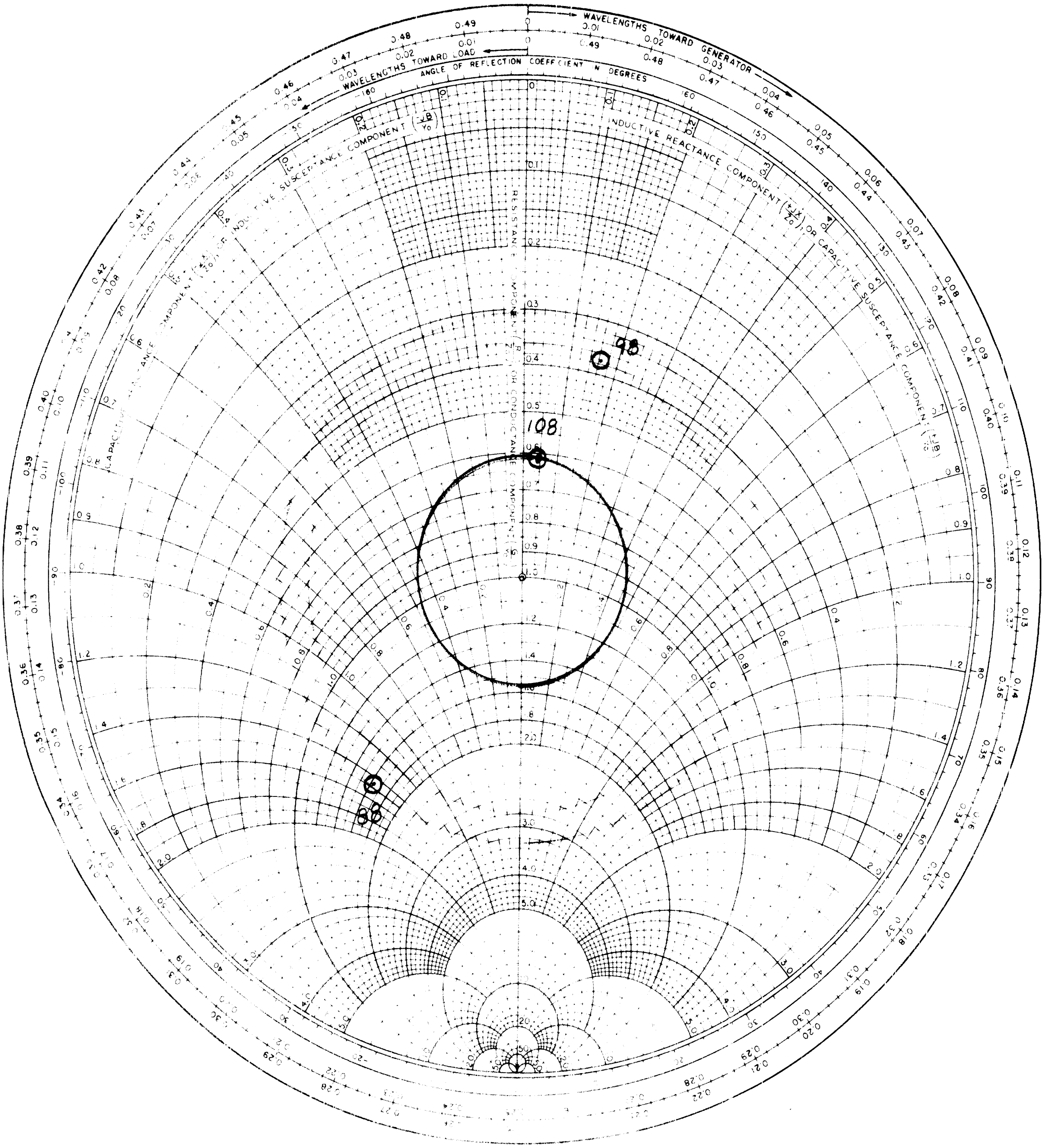


Figure 13C. Impedance data for windshield antenna Configuration #1 on Ford LTD II. f = 88, 98, and 108 MHz (Z_n = 50Ω).

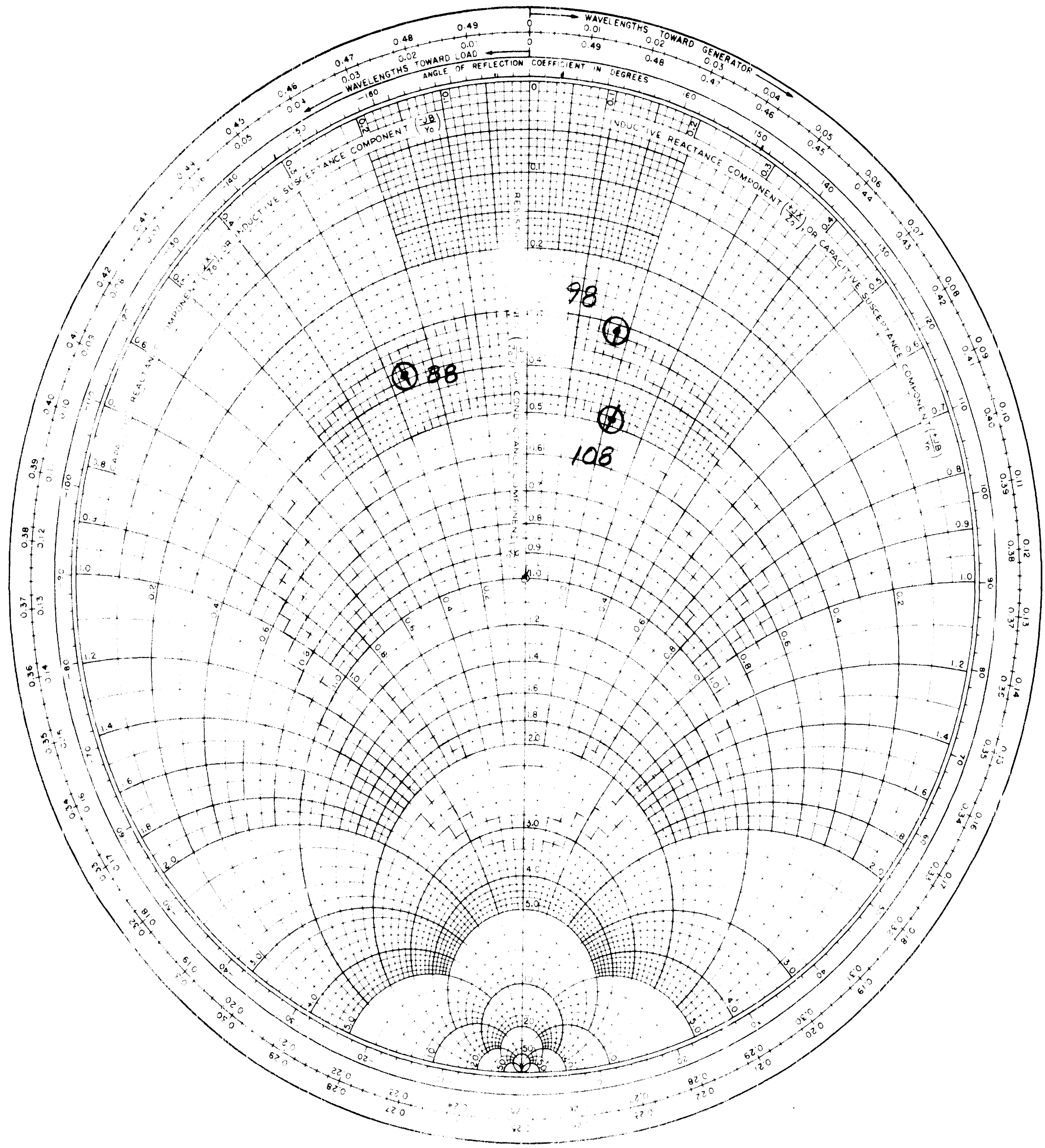


Figure 13D. Impedance data for windshield antenna Configuration #2 on Ford LTD II. f = 88, 98, and 108 MHz (Z_n = 50Ω).

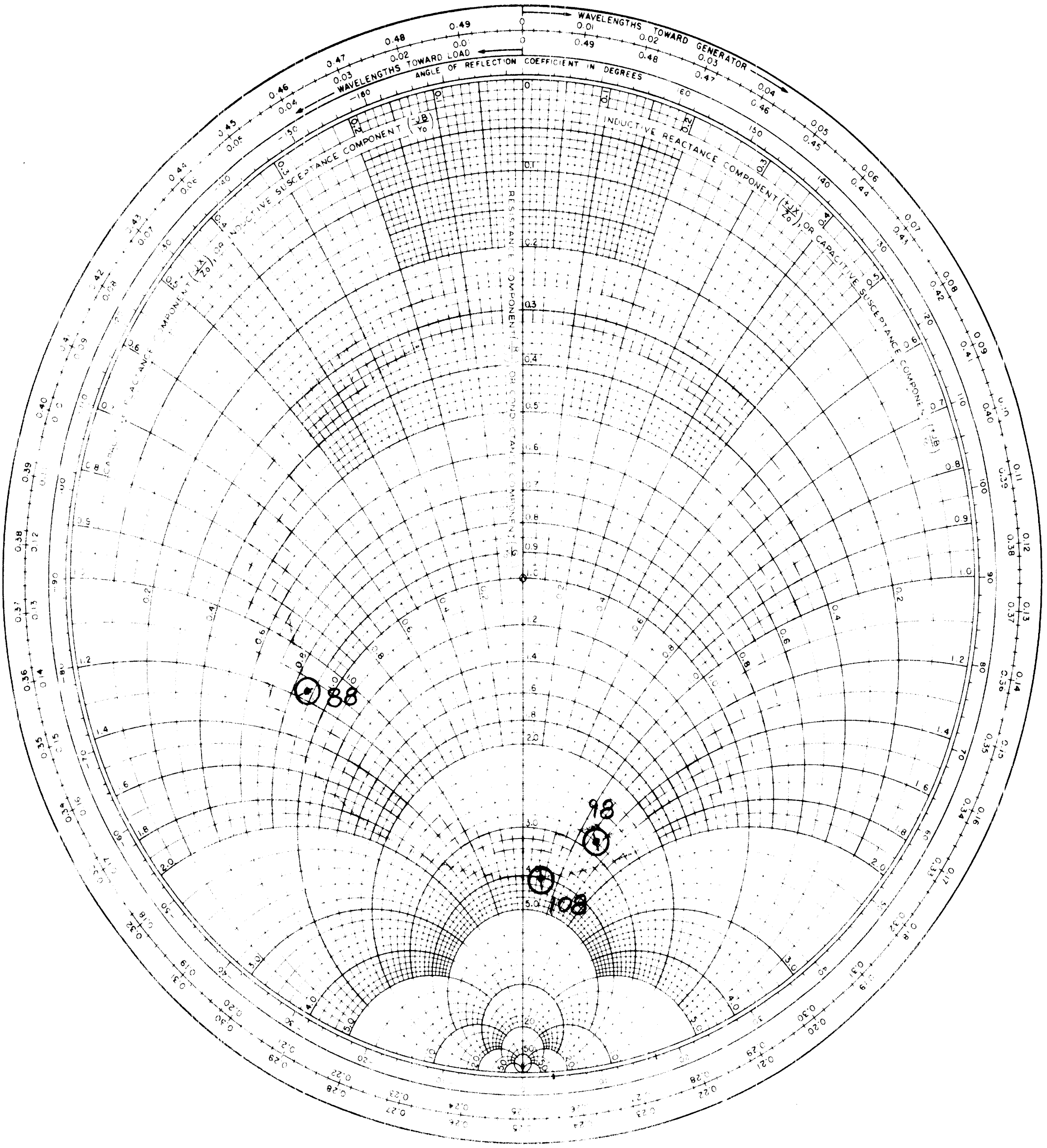


Figure 13E. Impedance data for windshield antenna Configuration #3 on Ford LTD II. f = 88, 98, and 108 MHz (Z_n = 50Ω).

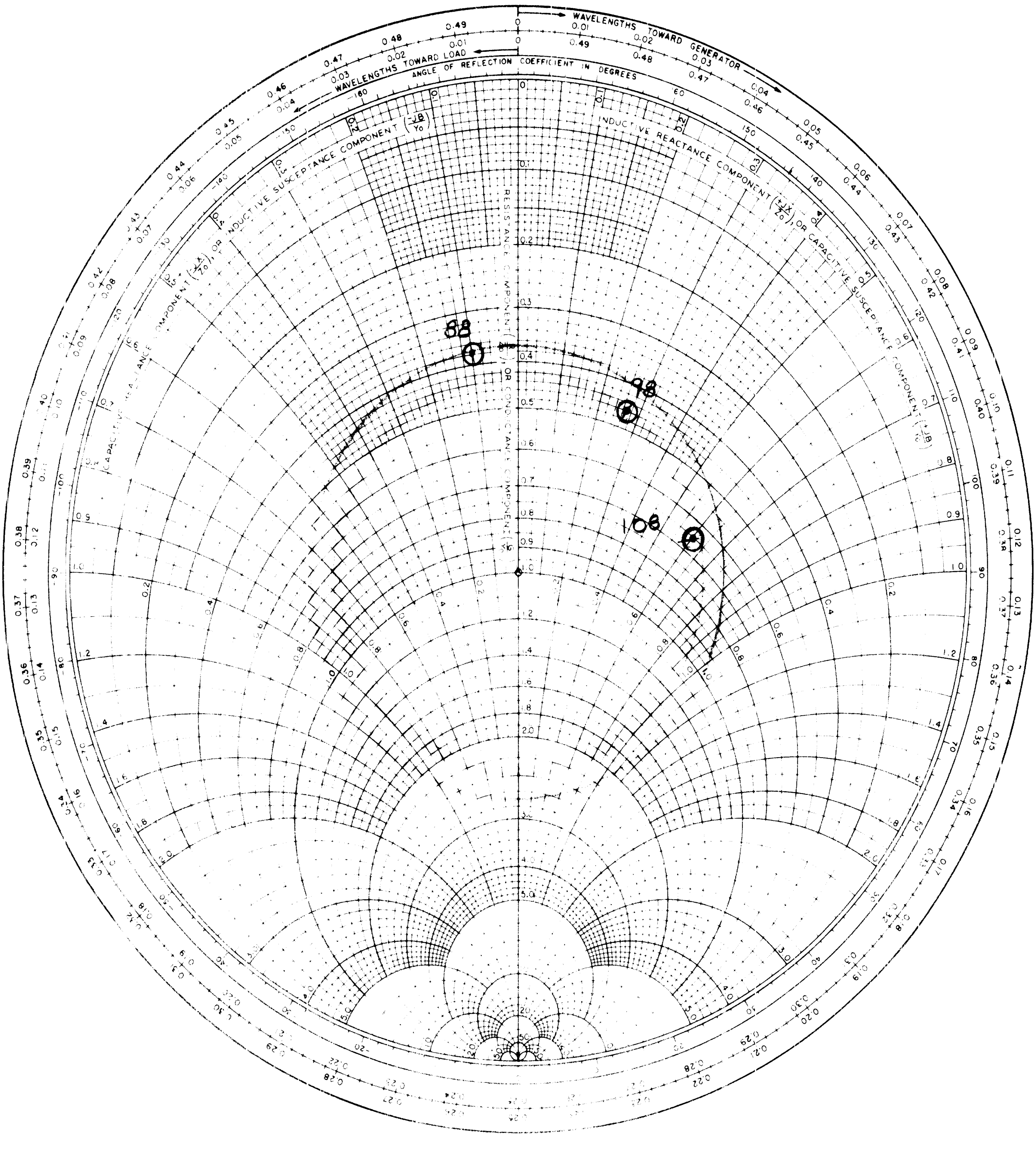


Figure 13F. Impedance data for windshield antenna Configuration #4 on Ford LTD II. f = 88, 98, and 108 MHz (Z_n = 50Ω).

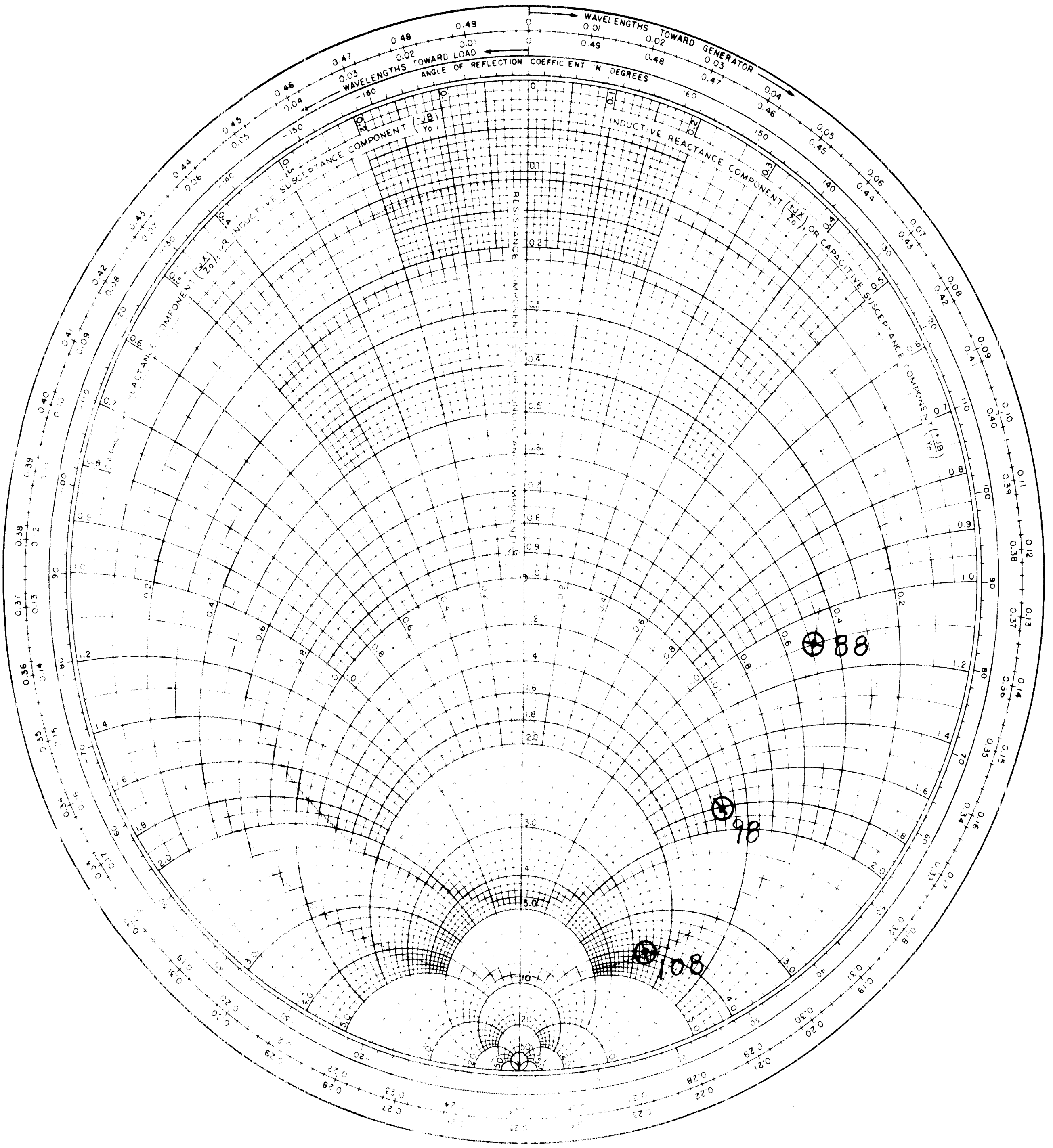


Figure 13G. Impedance data for windshield antenna on Chevrolet Caprice. f = 88, 98, and 108 MHz (Z_n = 50Ω).