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Radiation Laboratory

A STUDY OF CB, FM AND AM ANTENNAS FOR AUTOMOBILES

By

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EXECUTIVE SUMMARY

The VSWR and radiation characteristics of various commercially designed CB, FM and AM band antennas mounted on some Ford-built passenger cars have been studied experimentally. The automobiles chosen are 1976 models, Continental Mark IV, Lincoln Continental, Gran Torino and Mustang II. It is believed that the antenna (or antennas) selected on the basis of this investigation are to be used for 1977 and 1978 model cars.

The study program involved the measurement of the horizontal plane radiation patterns of the test antennas, signal strengths received and the VSWR's at the desired input terminals of the antennas mounted at appropriate locations on the selected cars. The relative sensitivities of the test antennas are obtained by comparing the test antenna patterns with the patterns of reference antennas. The CB reference antenna has been a standard quarter wavelength long monopole mounted on the roof of the car and the FM-AM reference antenna has been the FM-AM Ford antenna mounted at its appropriate location. Both VSWR and patterns have been measured by standard techniques.

The antennas tested may be classified as unloaded, center loaded, base loaded and sub-base loaded. Some antennas are meant for use at CB frequencies only, some for use at all the three bands of frequencies. One unloaded tri-band antenna tested is referred to as the fully disguised antenna. Some of the test antennas have provision for tuning.

For each appropriate test antenna mounted on a selected car, some or all of the following results are presented: (1) VSWR vs. CB channel frequencies, (2) horizontal plane patterns vs. three selected frequencies at CB and FM band, (3) field strengths received at three selected frequencies at AM band, (4) relative sensitivity vs. the selected frequencies at CB, FM and AM band. In addition, for some cases similar results are presented when the same test antenna is

mounted on different cars. This has been done to bring out the effects of the size of a car on the performance of an antenna.

After a study of the measured results we make the following observations with regard to the performance of the various antennas:

(1) For better performance at CB, all antennas should be tuned for minimum VSWR at the center of the CB frequencies. Untuned antennas generally have less sensitivity. Also untuned antennas are more sensitive to the type of the car used. For acceptable CB performance an antenna should maintain a VSWR $\leq$ 2 over the CB frequencies.

(2) At the CB frequencies the performance of the power tri-band antenna is comparable to that of the power CB only antenna. At the FM and AM band of frequencies the former antenna is less sensitive.

(3) When properly designed and tuned, both center and base loaded antennas perform equally well at all the three bands. Their performance may be considered acceptable.

(4) The CB and FM band performance of sub-base loaded antennas are similar to (3) but their AM-band performance is poor.

(5) The fully disguised tri-band antennas seem to have acceptable performance at FM and AM band frequencies. However, they have poor performance at CB frequencies.

The goal of the present investigation has been to obtain sufficient experimental data and deduce therefrom some guidelines which may be found useful in evaluating and comparing the relative performance of various candidate antennas for use on Ford-built passenger automobiles. We believe the present study has accomplished this goal. On the basis of measured results we have made some suggestions for selecting a few antennas for use on 1977 and 1978 model cars.

We believe that sub-base loaded and fully disguised antennas be further investigated so that their potentialities may be fully realized. We have also made some recommendations for investigating the electrically short active antenna concept for the present applications.

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I

INTRODUCTION

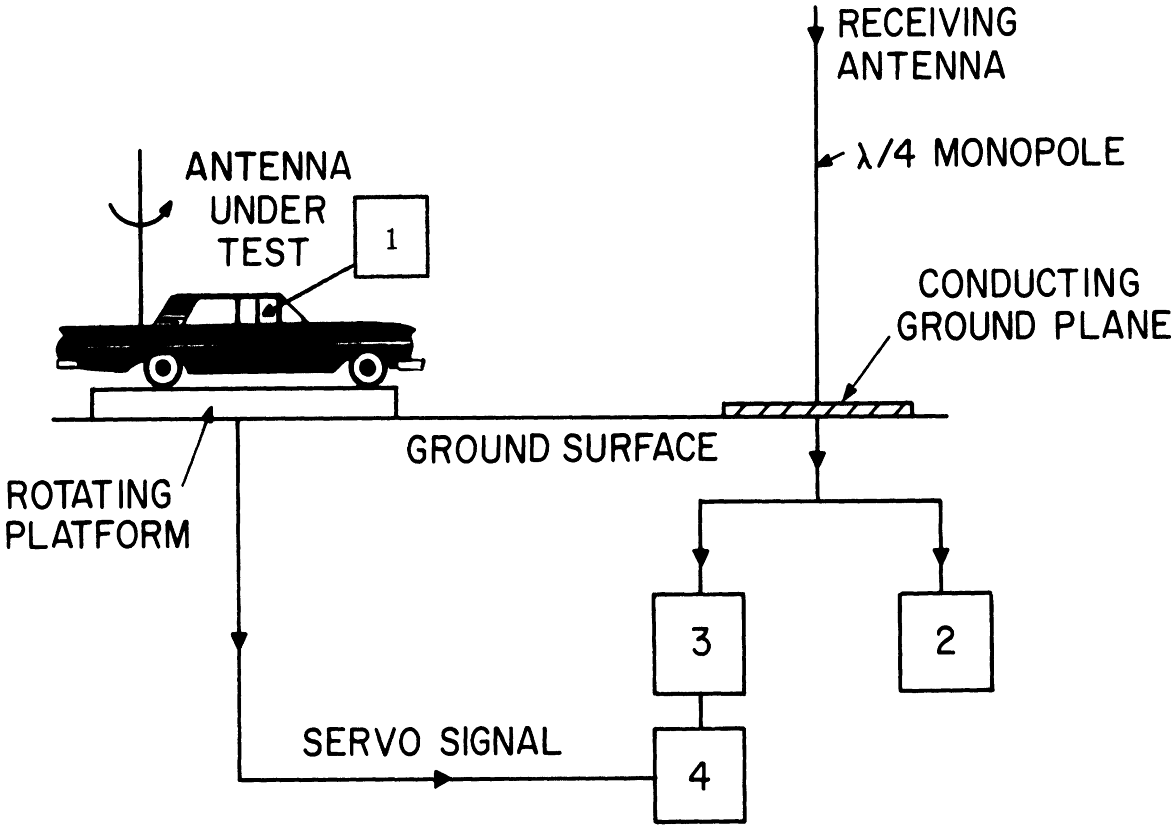
The present report studies experimentally the radiation characteristics of various commercially available CB (Citizen's Band), FM (Frequency Modulation) and AM (Amplitude Modulation) band antennas mounted on automobiles. The automobiles chosen are passenger cars, all manufactured and supplied by Ford Motor Company. The study program mainly involves the measurement of the antenna radiation patterns, the signal strengths received and the VSWR's at the desired locations of the antenna input terminals. The goal of the present investigation is to obtain sufficient experimental data and to deduce therefrom some guidelines which may be found useful in evaluating and comparing the relative performance of various candidate antennas for use on Ford-built passenger automobiles. Wherever possible a limited amount of theoretical interpretation is provided for the observed results.

II

OUTLINE OF THE MEASUREMENT PROCEDURE

Standard measurement techniques are used to obtain the desired results. For pattern measurements the antenna under test is installed at the desired location on a given automobile which is located on a rotating platform. The test antenna radiates signals at the desired CB or FM band frequencies supplied by suitable transmitters located inside the automobile. The CB signals are obtained from the CB transceivers installed in the automobile; signals in the FM band are obtained from a CW General Radio Unit oscillator which has a nominal output power rating of about 325 mw. The signals radiated by the rotating test antennas are received by a monopole antenna located at a distance of approximately 150' from the test antennas. The receiving monopole in each band consists of a metal tubing a quarter wavelength long at the center of the band and mounted vertically at the center of a 4' x 3'10" ground plane placed on the surface of the earth. The lengths of the CB and FM receiving monopoles are 108" and 30" respectively and are made of 3/8" outer diameter aluminum tubings. In general, the output of the receiving antenna is coupled to a spectrum analyzer and to a receiver and polar recorder. The spectrum analyzer is used to monitor the desired signal frequency and amplitude; it may also be used to monitor the nature of the ambient signals. As the automobile is rotated, the polar recorder records the horizontal plane transmitting pattern of the test antenna. By reciprocity theorem the measured pattern will be identical to the receiving pattern of the test antenna. Figure 1 gives the block diagram of the CB and FM band pattern measurement set-up.

Due to the large wavelengths involved in the AM band broadcast frequencies, the existing distance of 150' between the test and the receiving antennas in the above set-up is too small to provide meaningful patterns in the AM frequency band. The block diagram shown in Figure 2 gives the experimental set-up for the pattern measurements of the test antennas in the AM frequency band. As shown in



1 CITIZEN'S BAND TRANSMITTER OR FM BAND GR UNIT OSCILLATOR

2 SPECTRUM ANALYZER HP 8558B

3 MICROWAVE RECEIVER: SCI. ATLANTA 1600

4 PATTERN RECORDER: ANT. LAB POLAR RECORDER

Figure 1: Block diagram of the experimental arrangement for antenna pattern measurements at CB and FM frequencies.

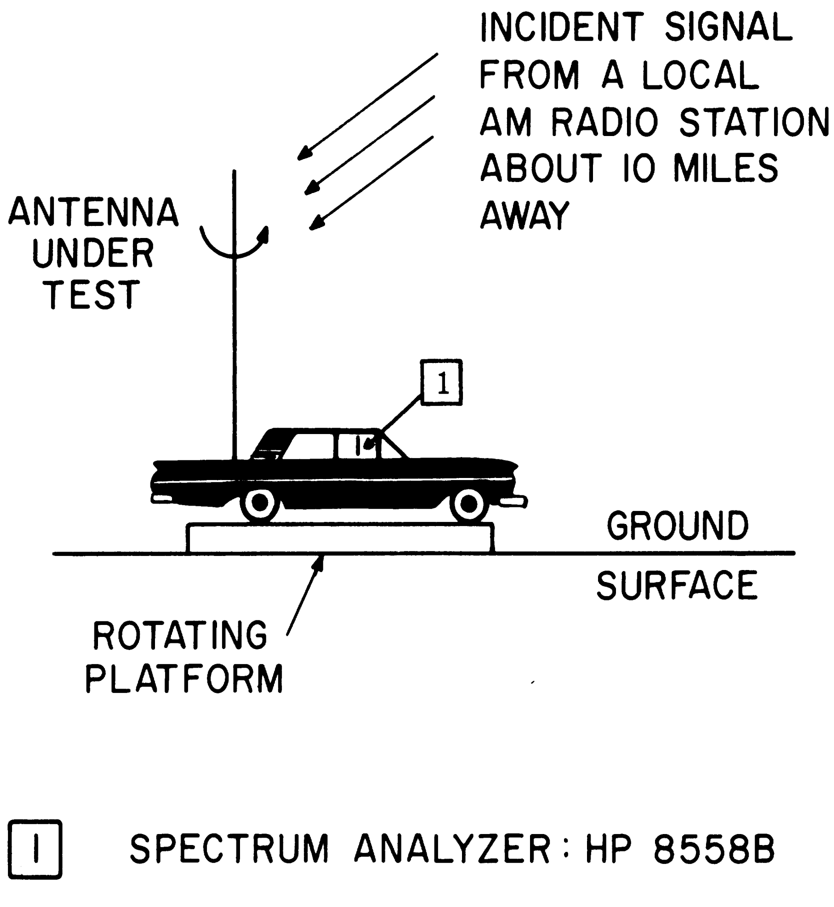


Figure 2: Block diagram of the experimental arrangement for antenna patterns or field strength measurement at AM frequencies.

Figure 2, the test antenna is used as a receiving antenna, receiving signals from a distant AM transmitting station. The horizontal plane pattern of a typical antenna obtained in such a manner has been found to be almost omnidirectional in the entire AM band. Figure 3 shows a typical measured pattern at 0.8 MHz for a test antenna installed on a Mustang II and receiving signals from a local AM radio station located about 10 miles away. The results shown in Figure 3 justify the assumption of omnidirectional horizontal plane pattern of the test antenna in the AM band. For this reason all the AM band field strengths have been obtained from stationary automobiles and at 3 selected frequencies in the AM broadcast band. The signal strength is obtained from the response of the spectrum analyzer which is used as a receiver along with the test antenna.

Two methods have been used to obtain the VSWR results. During the initial part of the program the input impedance at the desired terminals of the test antenna were measured on an RF impedance bridge. The VSWR as a function of frequency was then obtained from the known impedance results. Although the RF bridge method gives the impedance directly, it has been found to be quite time consuming and tedious for the present purpose. For this reason during the latter part of the program we have used a more efficient and quick set-up for VSWR measurements as shown in Figure 4. This uses a vector voltmeter which gives the reflection coefficient from which the desired VSWR data are obtained. VSWR results have been obtained in the CB frequencies for all the test antennas. For some antennas VSWR results have been obtained also for some selected frequencies in the FM band.

During all the measurements the AC power supplies for the test instruments inside the automobiles have been obtained from the automobile battery with the help of an inverter. This has been done to avoid the undesirable effects on the measured patterns and VSWR's produced by long extension cord that would be necessary if the ordinary power source is used.

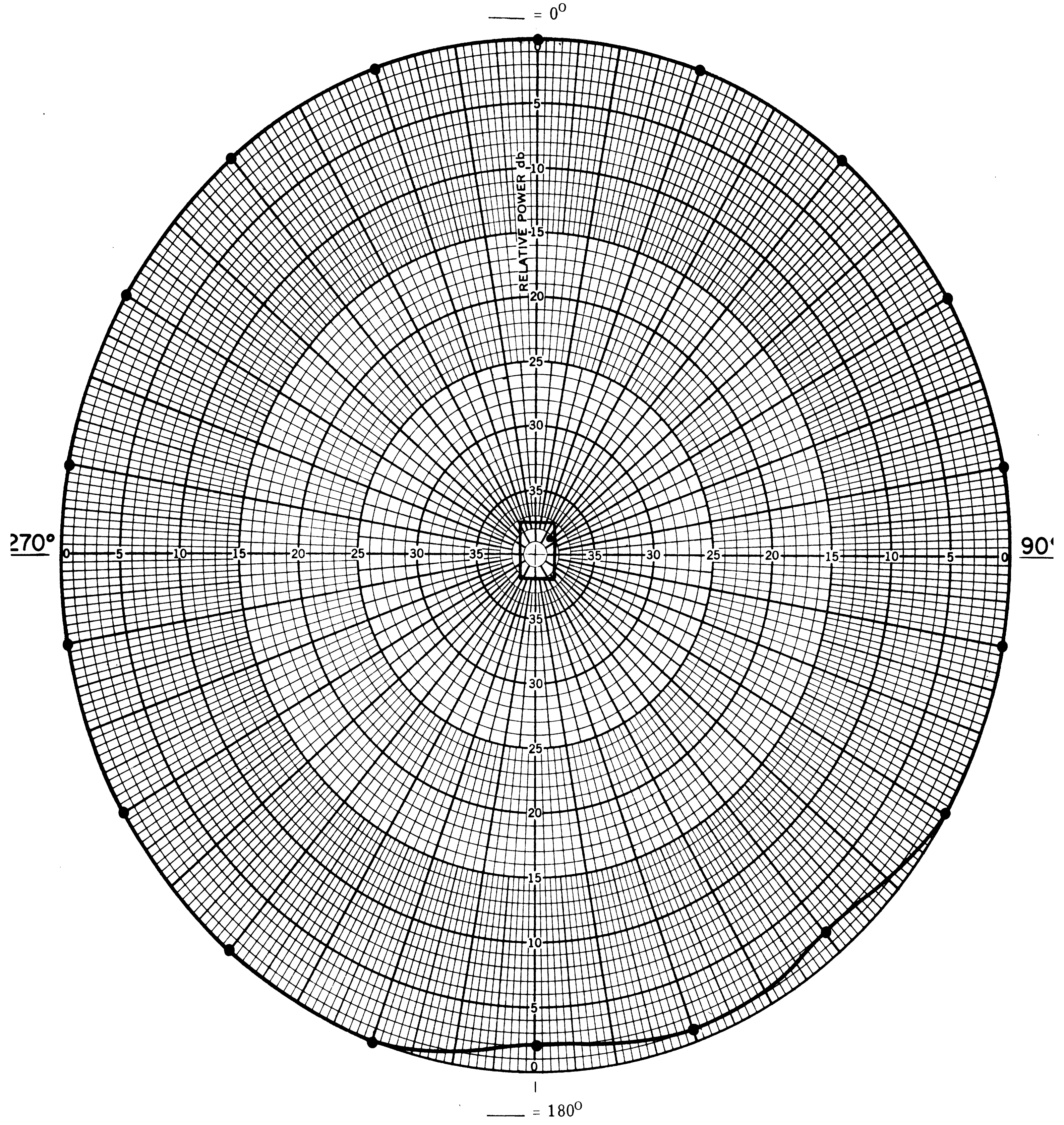
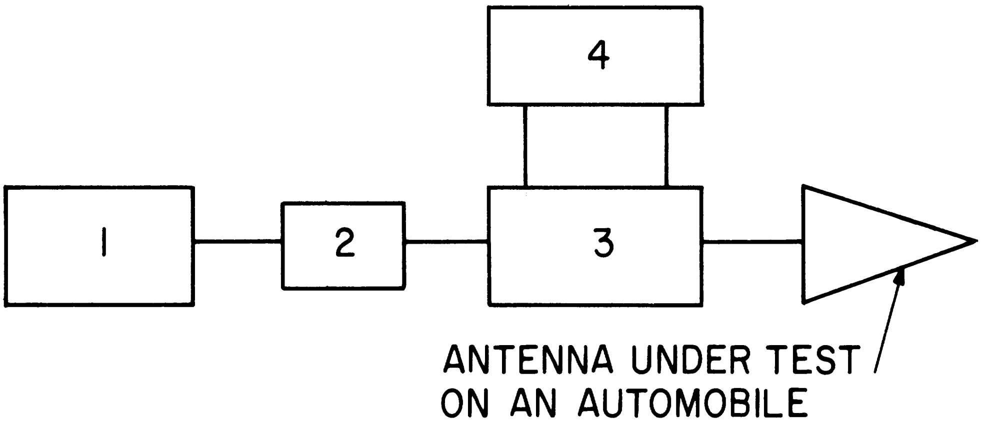


Figure 3: Measured horizontal plane pattern at 0.8 MHz of the Ford AM-FM reference antenna mounted on a Mustang II.



UNIT NO	CB	FM
1	CITIZEN'S BAND TRANSMITTER	FM BAND GR UNIT OSCILLATOR
2	18 dB ATTENUATION	6 dB ATTENUATION
3	DUAL DIRECTIONAL COUPLER ANZAC CH 134	DUAL DIRECTIONAL COUPLER ANZAC CH 134
4	VECTOR VOLTMETER HP 8405 A	VECTOR VOLTMETER HP 8405

Figure 4: Block diagram showing the experimental arrangement for VSWR measurements.

For quick reference the major test instruments used during the program are listed below:

1. CB transceivers - installed in the test vehicles.
2. FM band oscillator - GR unit oscillator model No. 1208
3. Spectrum analyzer - Hewlett-Packard (HP) 8558B
4. Microwave receiver - Scientific Atlanta (SA) 1600
5. Antenna laboratory polar recorder
6. RF impdance bridge
7. Vector voltmeter - Hewlett-Packard 8405A
8. Inverter - Heathkit

III

TEST ANTENNAS

The various test antennas are commercially made and have been supplied by Ford Motor Company. Basically they are all monopole antennas, mounted vertically at some desired locations of a given automobile. The automobiles used are 1976 Continental Mark IV, 1976 Lincoln Continental, 1976 Mustang II and 1976 Gran Torino.

Antennas normally used in Ford cars for AM-FM reception are referred to as AM-FM Ford Reference or entertainment antennas. Some of the test antennas are meant only for CB reception and transmission and will be referred to as CB only antennas. Test antennas meant for use in CB, FM and AM band frequencies will be referred to as tri-band antennas. In some cars the antennas tested were power operated.

A few of the antennas have provisions for tuning so as to obtain optimum VSWR's at the input terminals in the CB frequencies. Tuning is accomplished either by adjusting the antenna length or by adjusting some trimmer capacitor in the loading coil of the antenna. The output from a tri-band antenna goes to a splitter box which directs the signal to FM-AM receiver and the CB transceiver. In general, the antenna splitter box receiver circuit is as shown in Figure 5.

Loading coils are used mainly to improve the base current of a tri-band antenna in the CB frequencies. Some antennas are center loaded where the loading coil is located approximately at the central portion of the antenna. For base-loaded antennas the loading coil is located at the base of the antenna and above the fender of the car, i.e., the ground plane of the antenna. For sub-base loaded antennas, the loading coil is located below the ground plane and cannot be seen from outside. When there is no loading coil, as in the case of the tri-band antenna made by the Antenna Specialists, the antenna is referred to as a fully disguised antenna. Table I lists all the test antennas along with other pertinent information.

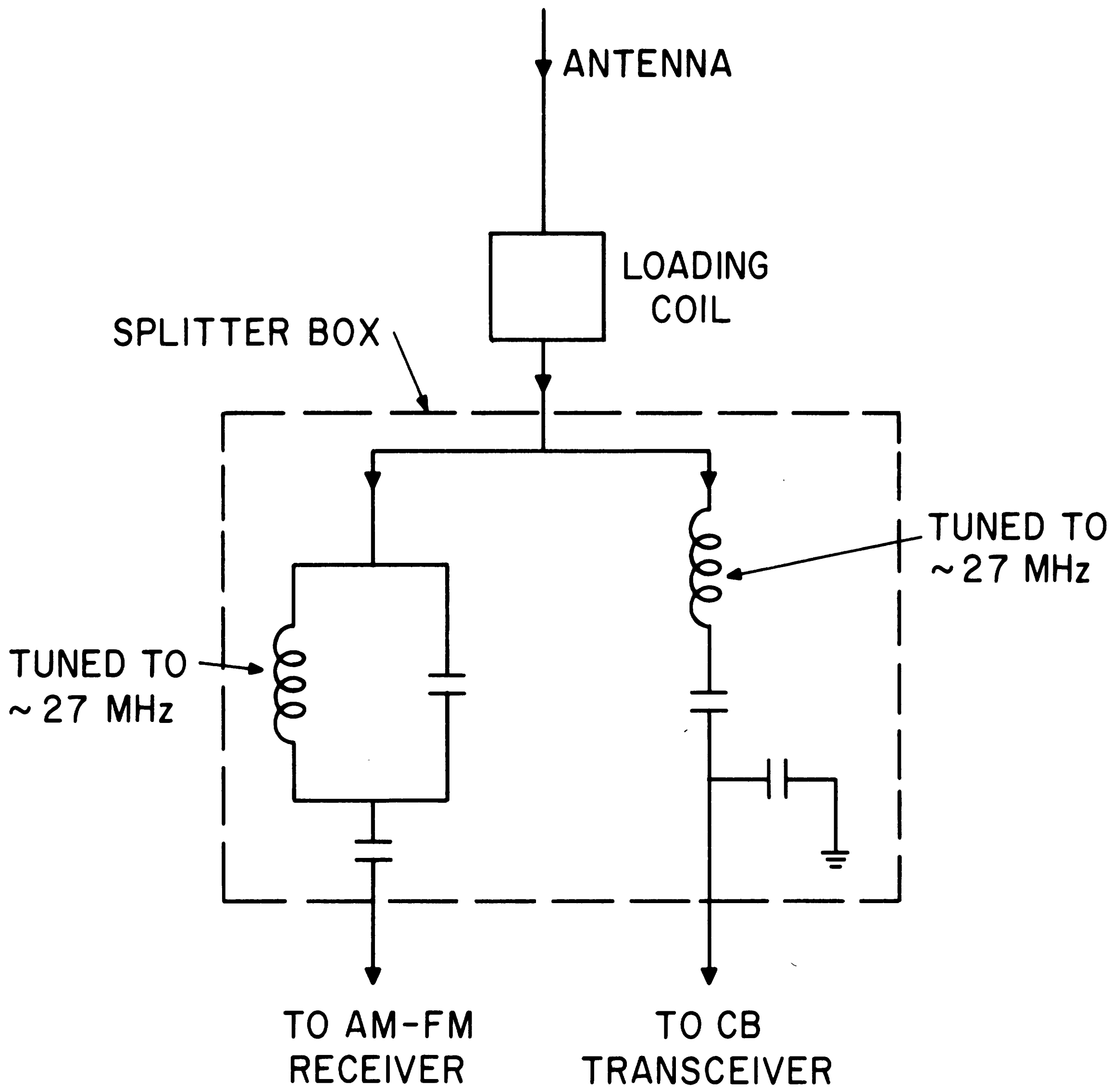


Figure 5: Diagram showing the antenna connections of the CB transciever and FM-AM receiver.

TABLE I. Various Test Antennas

Antenna Type	Nominal length ℓ in inches	Tuning provision	Loading type	Frequency operation	Automobile type	Approximate location in car
CB Only (power)	37-7/8	yes	center	CB	Continental Mark IV	rear right
Entertainment Power	32-1/2	no	none	AM-FM	"	front right
CB Only (power)	37-7/8	yes	center	CB	Lincoln Continental	rear right
Power tri-band	34-7/16	yes	center	CB-FM-AM	Lincoln Mark IV	rear right
Entertainment (power)	32-1/2	no	none	AM-FM	Lincoln Continental	rear left
HY-Gain(426)	35	yes	base	CB-FM-AM	← All or some of these antennas are used on Torino and Mustang II. →	← Right Front Fender →
HY-Gain(426-X1)	35	yes	base	CB-FM-AM		
HY-Gain(426-X2)	35	yes	base	CB-FM-AM		
Turner 4222-2	42	no	sub-base	CB-FM-AM		
Turner 4203-2	42	no	sub-base	CB-FM-AM		
Antenna Specialists	40	no	fully disguised	CB-FM-AM		
Ward	40	yes	base	CB-FM-AM		
Ward RP102-1	40	yes	sub-base	CB-FM-AM		
Antenna Specialists CB only	40	no	base	CB		
Tenna 7-7-701	43	yes	center	CB-FM-AM		
Riverside	43	yes	continuous	CB		

IV

DISCUSSION OF THE MEASUREMENT SCHEME AND THE PERFORMANCE PARAMETER

For a given test antenna mounted on the automobile, VSWR data as a function of CB frequencies are measured. Where there is provision for tuning the antenna, the antenna is tuned so as to obtain minimum VSWR at the center of the band and slightly larger VSWR at the two ends of the band. In the event that such a behavior of VSWR vs. frequency cannot be obtained, the antenna is tuned for an average minimum behavior of VSWR over the band. Under such conditions the antenna is assumed to be tuned. In some cases, VSWR is also measured in the FM band of frequencies - however, the antennas are not tuned for FM frequencies.

Ideally, the pattern of a given antenna should not depend on the VSWR. However, the received field strength at the input terminals depends on the VSWR characteristics at the input terminals of the antenna and hence the relative received field strengths (or the relative sensitivities) of different antennas will be affected by their VSWR characteristics. In general, if the VSWR's within the band is maintained within 2:1 for the antennas, their relative sensitivities will not be appreciably affected by further tuning of the antennas. Figure 6 gives the sensitivity losses associated with the VSWR of the antenna. This graph can be used to account for the extra loss in the sensitivity of an antenna of given length when the VSWR becomes large.

The patterns of the test antennas are compared with those obtained for the reference antennas. The reference antenna for the CB frequencies is a $\lambda/4$ (quarterwave at approximately 27 MHz) monopole of length $\ell \simeq 108''$ mounted on the roof of the car. The reference antenna for the FM-AM band is the usual Ford AM-FM entertainment antenna located at the specified location on the car under test.

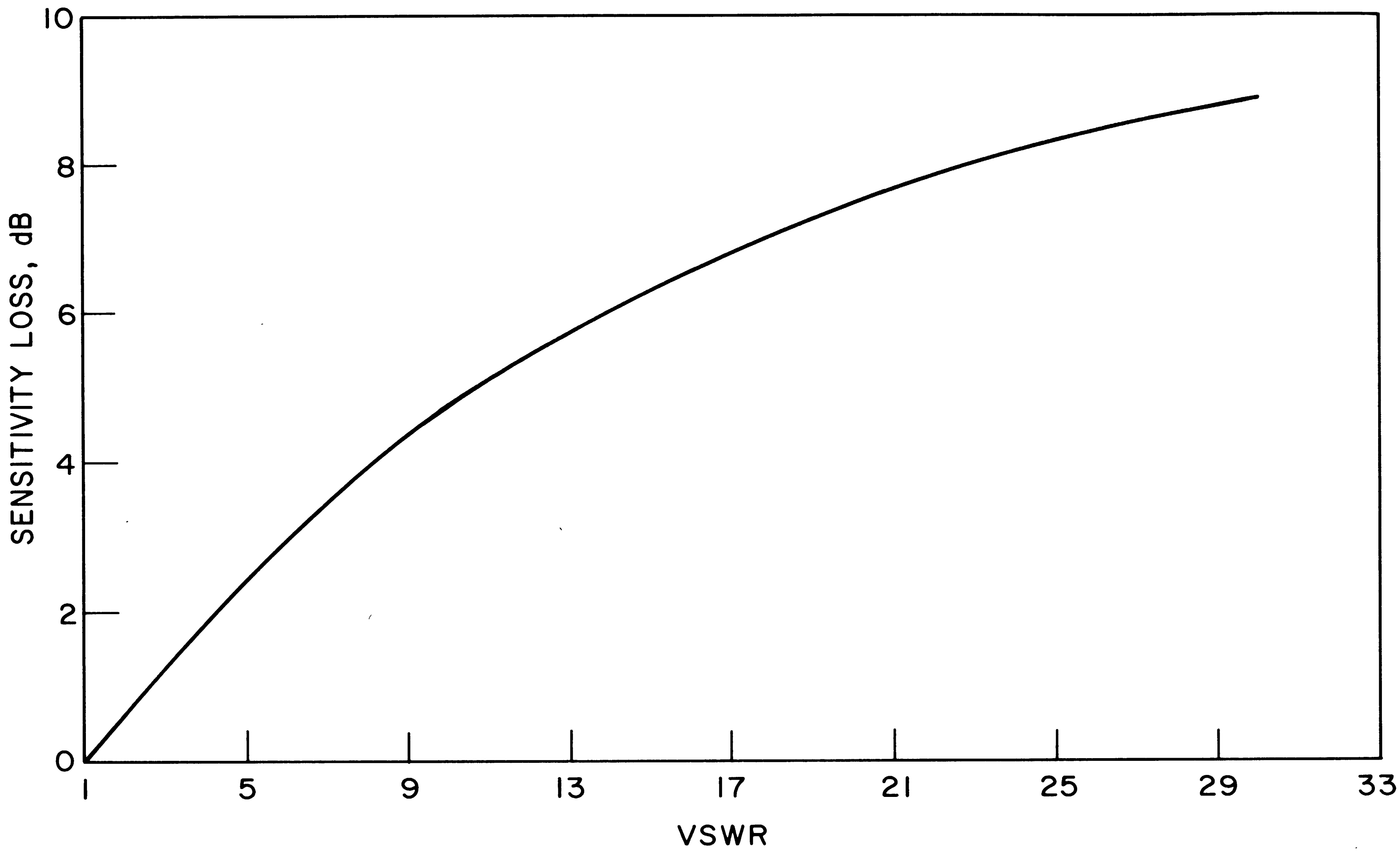


Figure 6: Theoretical variation of the sensitivity loss with VSWR.

Ideally the horizontal plane pattern of all the test antennas are omni-directional. Due to the asymmetric location of the antennas on the car the patterns will be slightly asymmetric. The average radius of the measured pattern can be used as an indication of the sensitivity of the antenna to the incident fields. If E_t and E_r represent the average field strengths in the volts/meter received by the test and reference antennas respectively, then the sensitivity S in dB of the test antenna relative to the reference antenna is defined to be:

$$S = 20 \log_{10} \left(\frac{E_t}{E_r} \right) \quad . \tag{1}$$

Normally, $E_t < E_r$, hence, S in dB as defined above is a negative quantity, i.e., the test antenna is less sensitive than the reference antenna; if $S > 0$ the test antenna is more sensitive.

During the reduction of the measured pattern results for various test antennas we shall be concerned with the loss of sensitivity of a test antenna compared to the reference antenna. The sensitivity loss of a test antenna defined in this manner is the negative of that given by Equation (1). In other words, the sensitivity loss for a given test antenna is positive when it is less sensitive than the reference antenna and is negative when it is more sensitive.

Let ℓ_t and ℓ_r represent the lengths of the test and reference antennas respectively. Assume that the current distributions on the antennas are sinusoidal with base currents I_t and I_r for the two antennas. This is a fair assumption for calculating the patterns of the present antennas. In the ideal case when the two antennas are perfectly matched, it can be shown that the sensitivity loss for the test antenna compared to the reference antenna is given by:

$$S \simeq - 20 \log_{10} \frac{I_t \sin k\ell_t}{I_r \sin k\ell_r} \quad , \tag{2}$$

where, $k = \frac{2\pi}{\lambda}$ is the propagation constant, λ is the wavelength and it is assumed that $\ell_t, \ell_r \lesssim \lambda/4$.

The test antennas are loaded to increase the base current I_t as much as possible, the ideal loading would make $I_t \simeq I_r$. Under this condition and if the reference antenna length $\ell_r = \lambda/4$, the sensitivity loss for a loaded test antenna may be expressed as:

$$S \simeq -20 \log_{10} \sin k\ell_t \quad . \tag{3}$$

Equations (2) and (3) may be used to theoretically estimate the sensitivity loss of a loaded test antenna with respect to a quarter wave antenna. Note that if the antennas are not matched, or tuned, the actual sensitivity loss will be more than that predicted by Equation (2) or (3). The extra loss due to mismatch may be obtained by using Figure 6.

For an unloaded antenna the sensitivity loss, under similar assumptions is given by:

$$S \simeq -20 \log_{10} \frac{1 - \cos k\ell_t}{1 - \cos k\ell_r} \quad . \tag{4}$$

If the reference antenna length $\ell_r = \lambda/4$, Equation (4) reduces to:

$$S = -20 \log_{10} (1 - \cos k\ell_r) \quad . \tag{5}$$

Figure 7 shows the theoretical sensitivity losses of loaded and unloaded antennas as functions of the test antenna length when the reference antenna is a quarter wavelength long. These curves have been calculated for 27 MHz. Note that if the antennas are not matched, the extra loss in sensitivity (due to mismatch) should be taken into account by using Figure 6. The results shown in Figures 6 and 7 may be found useful in estimating theoretically the sensitivity loss of a given

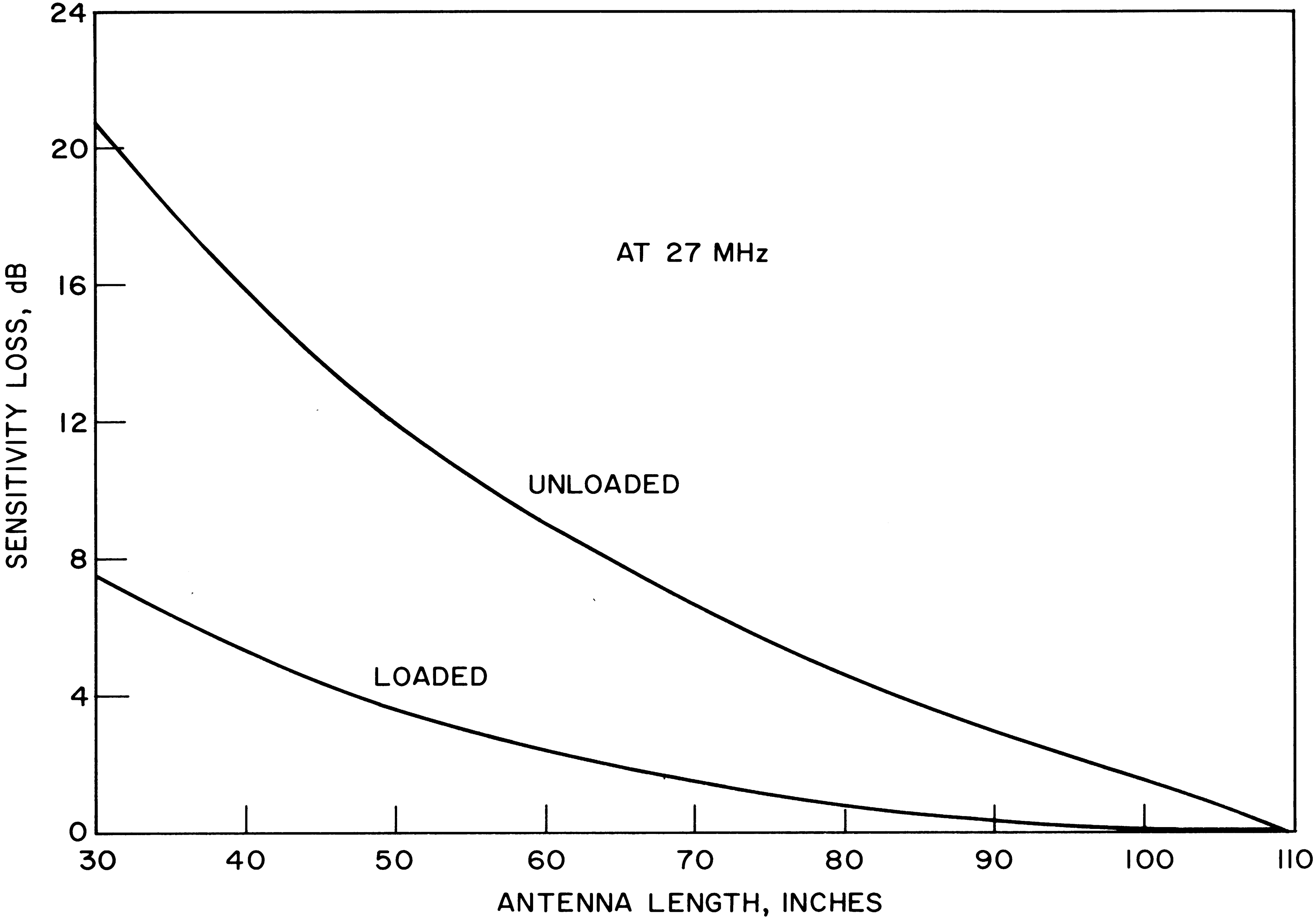


Figure 7: Theoretical variation of relative sensitivity loss with antenna length for loaded and unloaded antennas. Curves are referred to quarterwave length monopoles at 27 MHz.

antenna compared to a quarter-wavelength long similar antenna. Similar theoretical curves may be prepared by using Equations (2) and (4) if the reference antenna length is different than $\lambda/4$.

V

MEASURED VSWR RESULTS

This section gives the measured VSWR results for various test antennas mounted on 1976 Continental Mark IV, 1976 Lincoln Continental, 1976 Gran Torino and 1976 Mustang II cars.

Figure 8 gives the VSWR's as functions of frequencies for the power CB antenna on Mark IV and for the power CB and the power tri-band antennas on Lincoln Continental. Observe that the axis of the abscissa in Figure 8 gives the CB channel numbers and the corresponding frequencies in MHz. The results indicate that all the three antennas are well tuned in the CB frequencies and that the VSWR behavior of the power CB antenna is approximately the same for the two cars. This is not unusual if one considers that the two cars have more or less similar body shapes and structure.

Figure 9 shows the VSWR behavior in the Citizen's Band of a number of test antennas mounted on a 1978 Gran Torino. From these results it is found that the Ward, HY Gain 426 and Tenna antennas have the best VSWR behavior in the CB frequencies. Ward RP102-1 and HY-Gain 426-X1 antennas are fairly well tuned, although their VSWR's are generally higher than those of the first three antennas. Antenna Specialists CB-only antenna (shown in Figure 9 as Ant. Sp.) and the Riverside antenna have fairly high VSWR over the entire CB frequencies. The Antenna Specialists tri-band antenna has a high VSWR at the lower end of the CB channels and is not shown in Figure 9. The two Turner antennas have very high VSWR so that the mismatch losses associated with these antennas will be excessive. These results are also not shown in Figure 9.

Table II and III give the numerical values of measured VSWR results for all the antennas on Gran Torinos. Note that the untuned results were obtained by measuring the VSWR for the antennas as they were supplied to us.

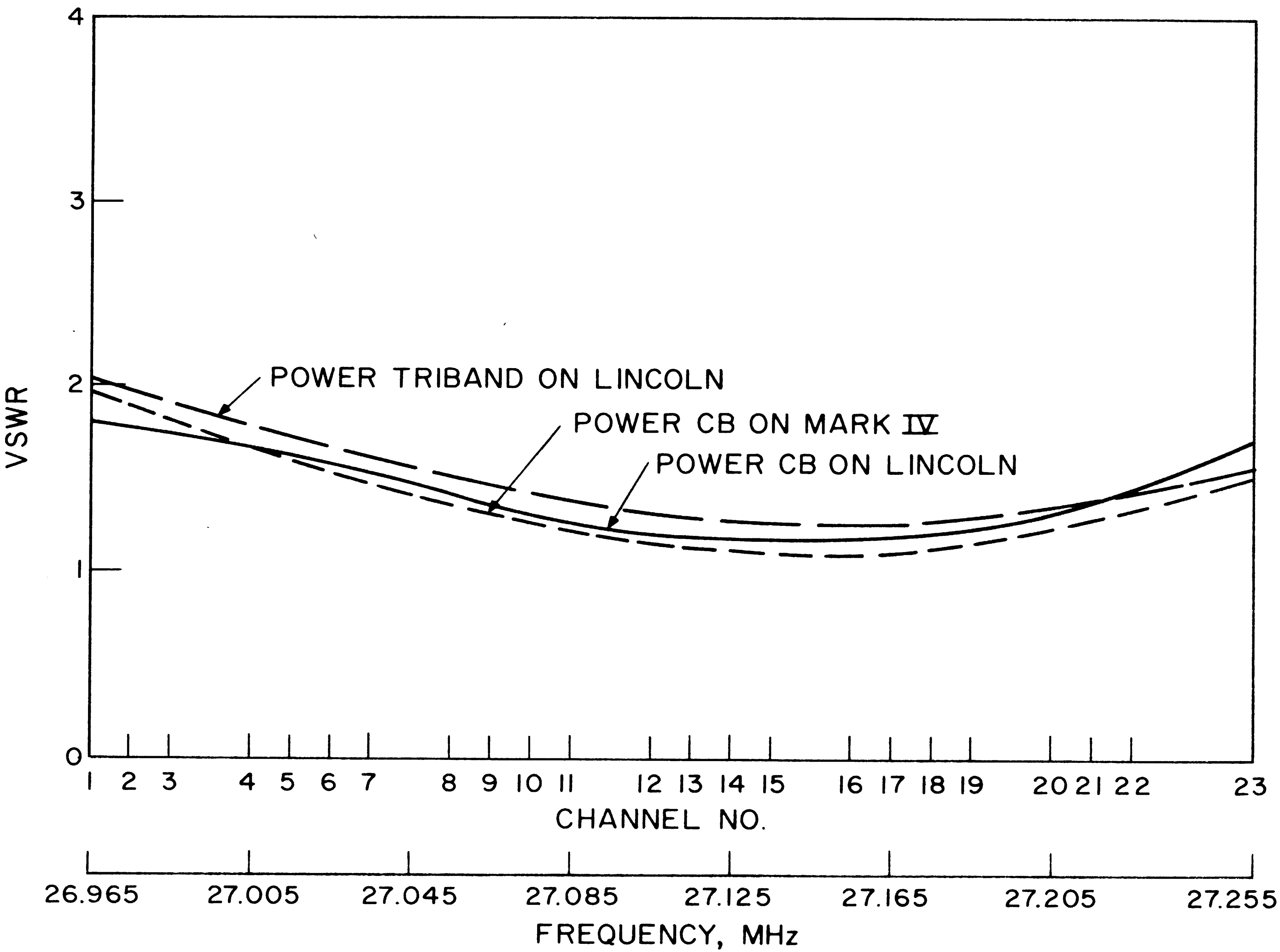


Figure 8: VSWR vs. frequency in the Citizen's Band for CB and tri-badd antennas on

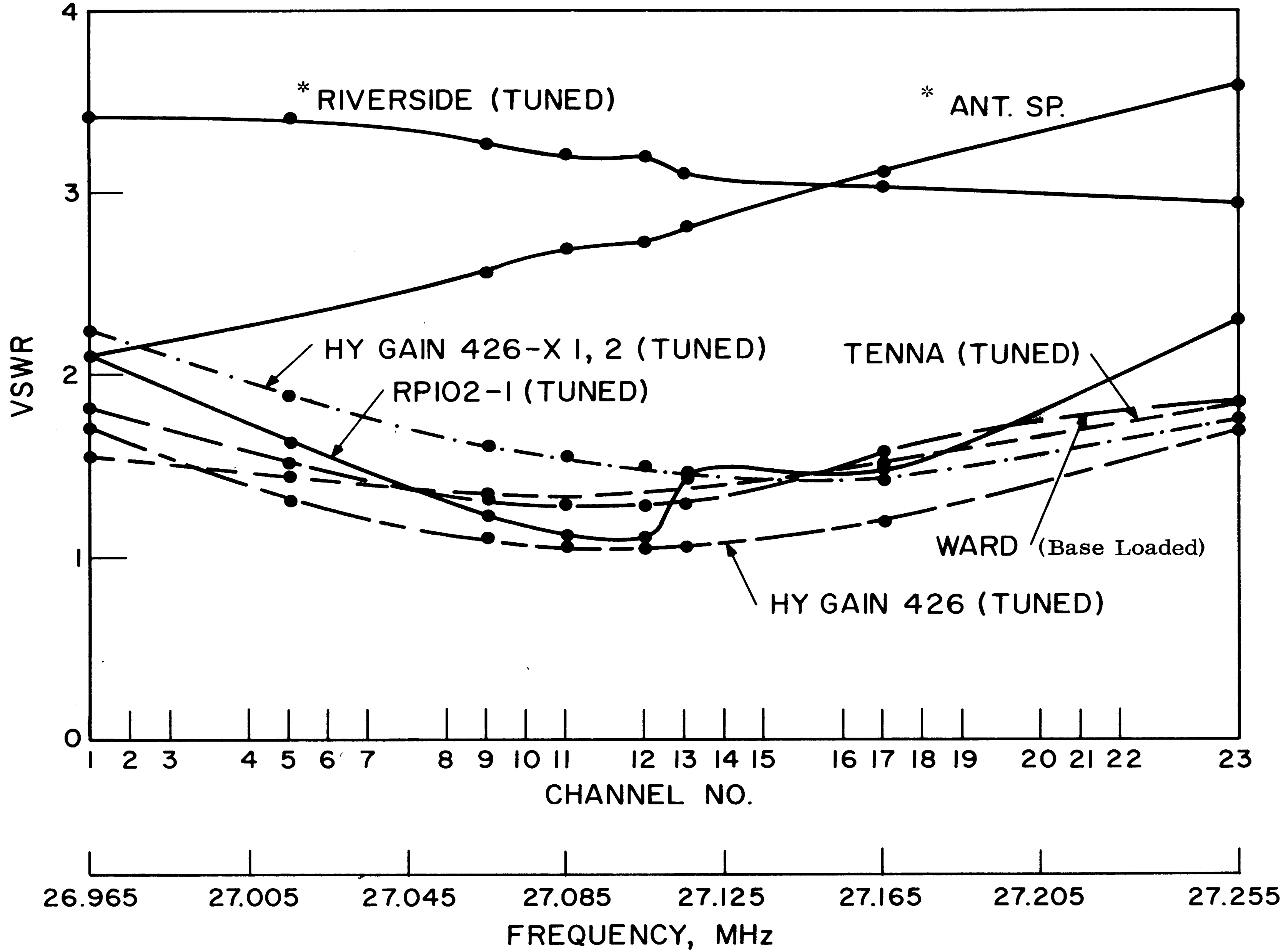


Figure 9: VSWR vs. frequency in the Citizen's Band for various test antennas on the Gran Torino.

* Note: CB only antennas. The others are tri-band antennas.

Table II: VSWR vs. frequency in the Citizen's Band for untuned test antennas on 1976 Gran Torino

Channel No.	Ward Base Loaded	Ward RP102-1	Ant. Spec. Fully Disguised	Turner 4222-2	Turner 4203-2
1	1.20	2.85	> 3	2.9	5.6
5	1.25	1.80	> 3	5.2	9.0
9	1.30	1.30	3.0	8.0	12.8
11	1.60	1.15	2.7	9.4	14.0
12	1.70	1.15	2.4	10.4	14.4
13	1.75	1.05	2.2	10.8	16.0
17	2.30	1.12	1.4	-	23.0
23	> 3	1.95	1.2	-	28.0

Table III: VSWR vs. frequency in the Citizen's Band for tuned test antennas on 1976 Gran Torino

Channel No.	Ward Base Loaded	Ward RP102-1	HY-Gain 426	HY-Gain 426-X1, 2	Tenna 7-7-701	Ant.Sp. CB only	Riverside CB Only
1	1.80	2.10	1.70	2.23	1.59	2.21	3.40
5	1.52	1.61	1.30	1.87	1.45	2.38	3.40
9	1.32	1.23	1.10	1.60	1.38	2.55	3.25
11	1.28	1.11	1.05	1.53	1.38	2.68	3.20
12	1.28	1.12	1.05	1.48	1.39	2.72	3.20
13	1.26	1.45	1.05	-	1.4	2.80	3.10
17	1.58	1.45	1.20	1.42	1.51	3.10	3.05
23	1.85	2.30	1.90	1.74	1.84	3.58	2.92

Note: All test candidates are tri-band antennas, unless otherwise indicated.

Table IV shows the VSWR results for different test antennas mounted on Mustang II. Note that the Ward and Tenna antennas tuned on Gran Torino, show slightly improved VSWR when mounted on Mustang II. No retuning was done for these two antennas when mounted on Mustang II. Ward RP102-1 antenna tuned on Gran Torino, needed slight retuning when mounted on the Mustang II so that minimum VSWR occurs in the middle of the band. The HY-Gain 426 antenna tuning was slightly affected by the Mustang II. As can be seen from Tables III and IV, the VSWR in the upper end of the CB channels are slightly deteriorated for the HY-Gain antenna on the Mustang II. The Turner 4222-2 antenna, when mounted on the Mustang II, has better VSWR than the Gran Torino case (see Tables II and IV). The Ward base-loaded untuned antenna VSWR behavior is found to have been reversed by the Mustang II, i.e., as compared with the Torino impedance results which indicate that the VSWR is a decreasing function of the increasing channel numbers (Tables II and IV). The results given here indicate that the tuned antenna VSWR's are not appreciably affected by the size of the car; however, the untuned antenna VSWR behavior strongly depends on the sizes of the two cars studied. Figure 10 shows graphically the VSWR behavior of the various test antennas mounted on the Mustang II.

Table V gives the VSWR results in the FM band for some selected test antennas on the Mustang II. The important observation is that the HY-Gain antenna tuned at the CB frequency produces a larger VSWR in the FM band.

Table IV: VSWR vs. frequency in the Citizen's Band for different test antennas on the Mustang II

Channel No.	Ward Base Loaded Untuned	Ward Base Loaded Tuned	Ward RP102-1 Untuned	Ward RP102-1 Tuned	Tenna Tuned	Turner 4222-2	HY-Gain 426 tuned	Ant. Spec. Fully Disguised
1	4.0	1.66	2.52	2.25	1.41	1.8	1.7	9.0
5	2.5	1.39	1.97	1.75	1.26	2.0	1.4	9.0
9	1.9	1.18	1.56	1.46	1.15	2.6	1.2	9.0
11	-	1.13	1.43	1.33	1.12	-	-	9.0
12	-	1.11	1.33	1.36	1.13	-	-	9.0
13	1.4	1.13	1.29	1.31	1.14	3.8	1.2	9.0
17	1.3	1.29	1.26	1.52	1.25	3.0	1.5	9.0
21	1.3	-	-			3.4	1.8	9.0
23	1.1	1.73	1.85	2.1	1.52	4.2	2.2	9.0

Table V: VSWR vs. frequency in the FM band for test antennas on the Mustang II.

Frequency MHz	Ward Base Loaded Untuned	Turner 4222-2	Ant. Spec. Fully Disguised	HY-Gain 426 tuned
94	8.0	20	6.0	3.0
102	8.0	8.0	6.0	4.6
108	3.6	4.8	1.7	3.8

Note: All antennas are for tri-band operation.

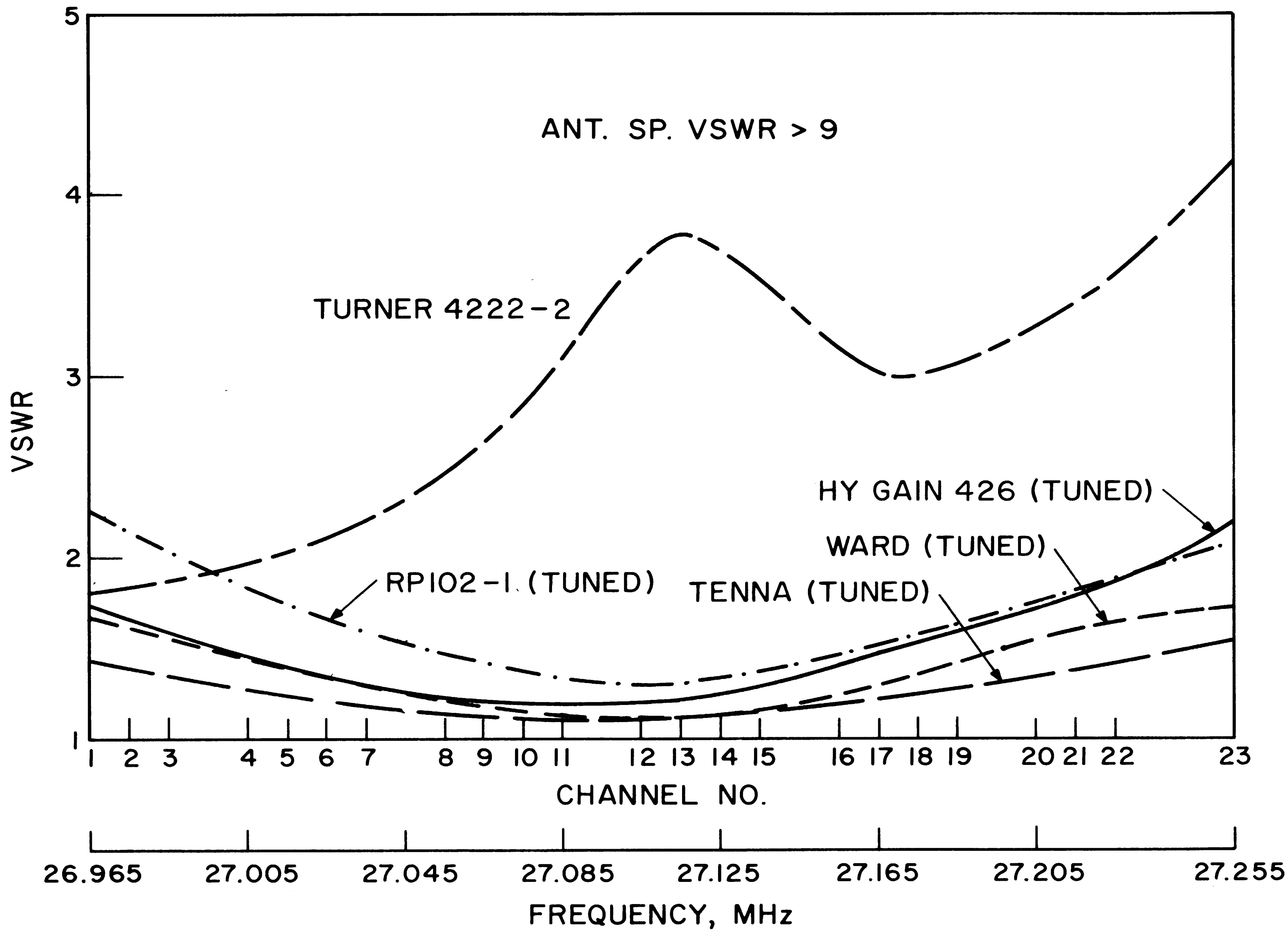


Figure 10: VSWR vs. frequency in the Citizen's Band for various test antennas on the Mustang II.

<u>Note:</u> All antennas are fixed tri-band type.

VI

MEASURED HORIZONTAL PLANE PATTERNS

This section gives the measured horizontal plane patterns at CB and FM frequencies for various test and reference antennas mounted on the selected automobiles. The AM band signal strengths due to known AM radio stations and received by appropriate antennas are also given. As mentioned before the AM band horizontal patterns of the antennas are assumed to be omnidirectional.

6.1 Results for Power Antennas Mounted on 1976 Continental Mark IV and Lincoln Continental

Figures 11 (a)-(c) show the horizontal plane patterns of a roof-top $\lambda/4$ monopole and the power CB antenna mounted on a 1976 Continental Mark IV car and for 3 selected channel frequencies in the CB. The location of the antennas and the 0^{o} reference direction with respect to the car are shown in the inset of Figure 11a. The power CB patterns shown have been taken with the entertainment antenna down all the way. Observe that the roof-top $\lambda/4$ antenna pattern is omnidirectional as it should be. The slight asymmetry in the power CB antenna pattern is attributed to the asymmetrical location of the antenna with respect to the car body. The pattern asymmetry occurs on the side where the antenna is located. Since the power output from the CB transmitter is kept constant, the results shown in Figure 11 can be used directly to estimate the sensitivities of the power CB antenna relative to the $\lambda/4$ monopole.

In order to study the effects of the entertainment antenna on the power CB antenna patterns of the Lincoln Mark IV, a set of CB patterns similar to the above were measured with the entertainment antenna raised up all the way. The results are shown in Figure 12 (a)-(c). The results indicate that the entertainment antenna slightly (within $\sim$ 1dB) affects the CB antenna patterns throughout the band of operating CB frequencies and for practical purposes such effects may be neglected.

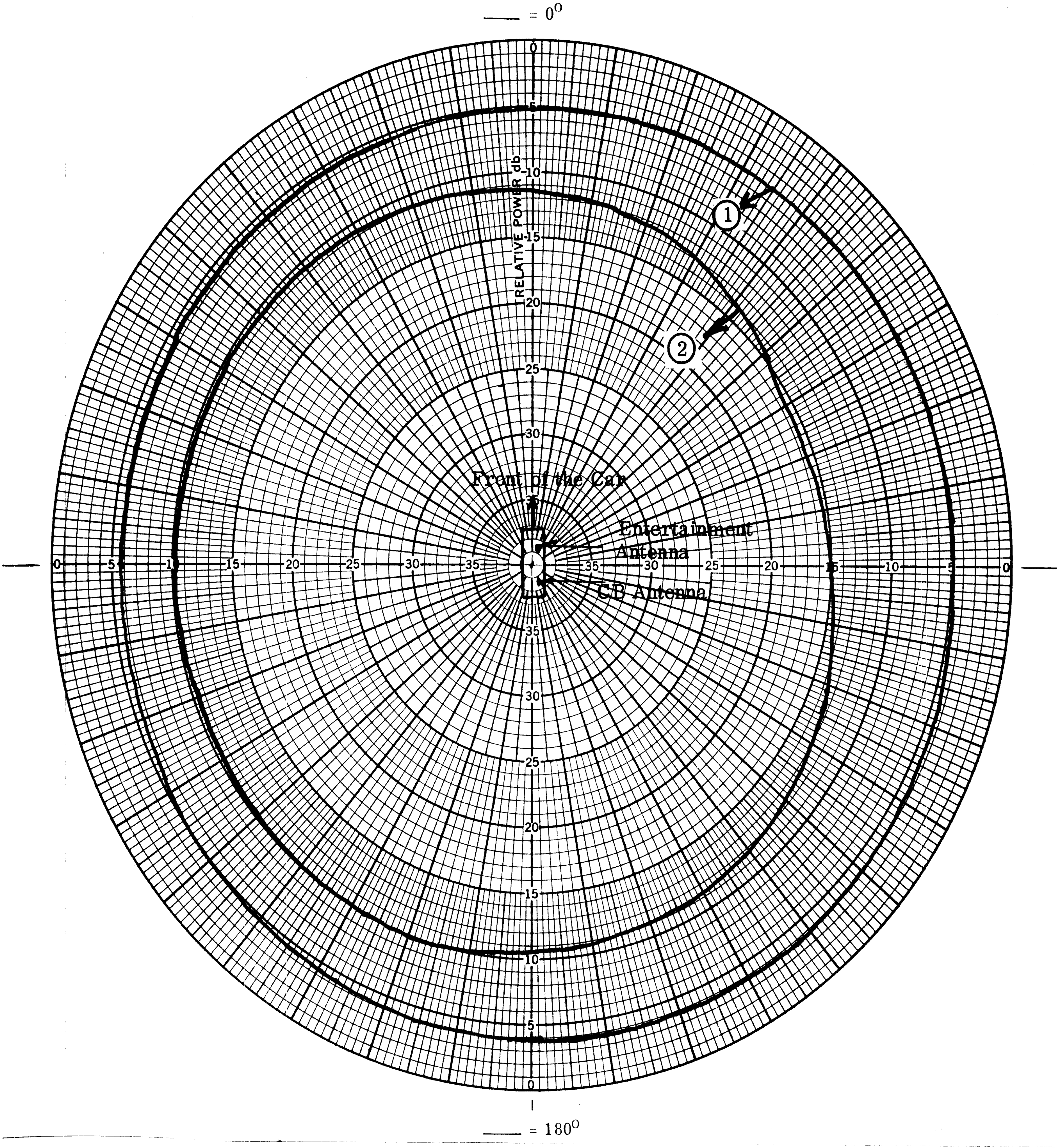


Figure 11 (a): CB Channel 1 patterns of the power CB and λ/4 antennas on 1976 Continental Mark IV. (1) λ/4 - (2) Power CB.

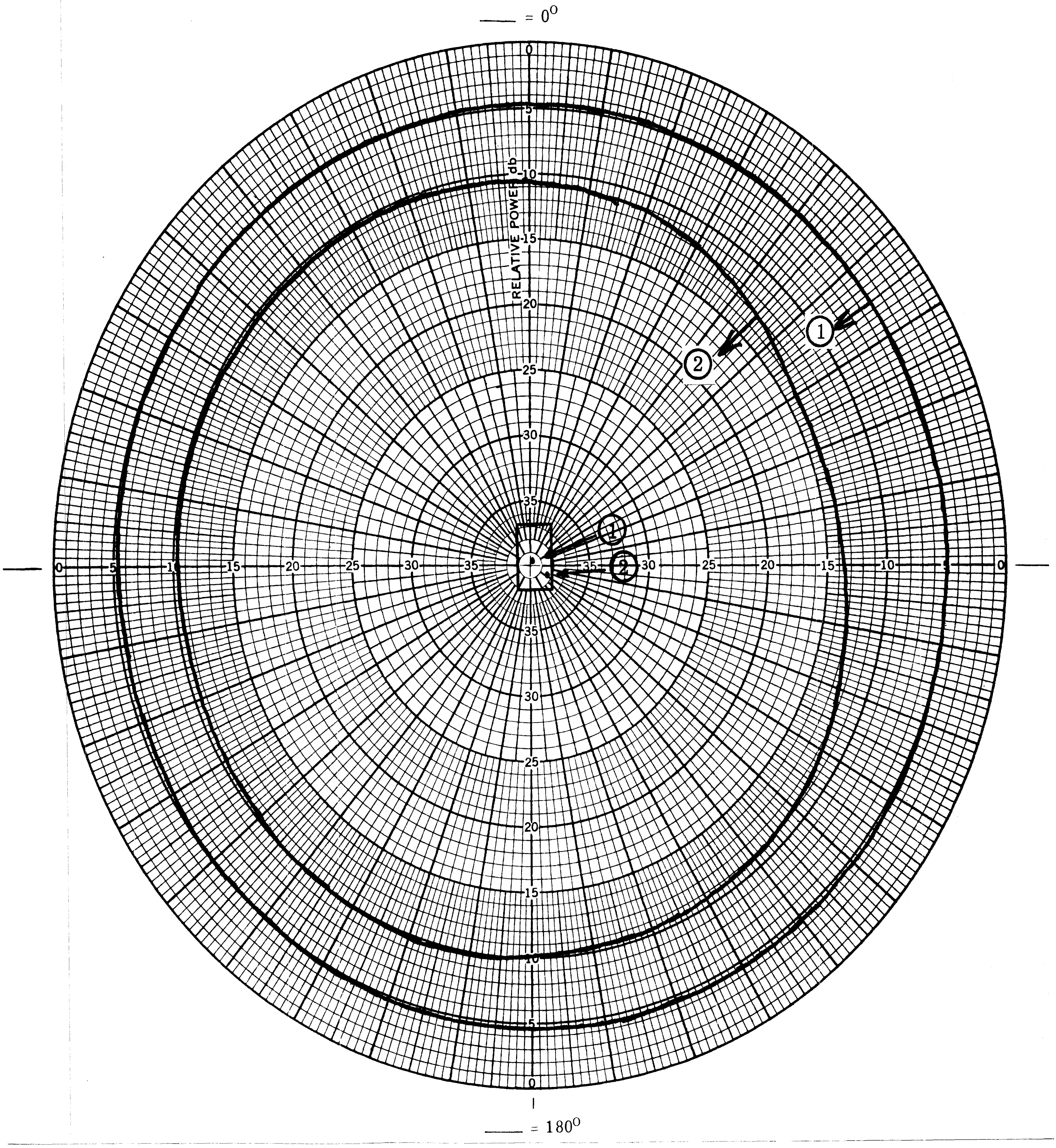


Figure 11 (b): CB Channel 11 patterns of power CB and $\lambda/4$ antennas on 1976 Continental Mark IV. (1) $\lambda/4$ - (2) Power CB.

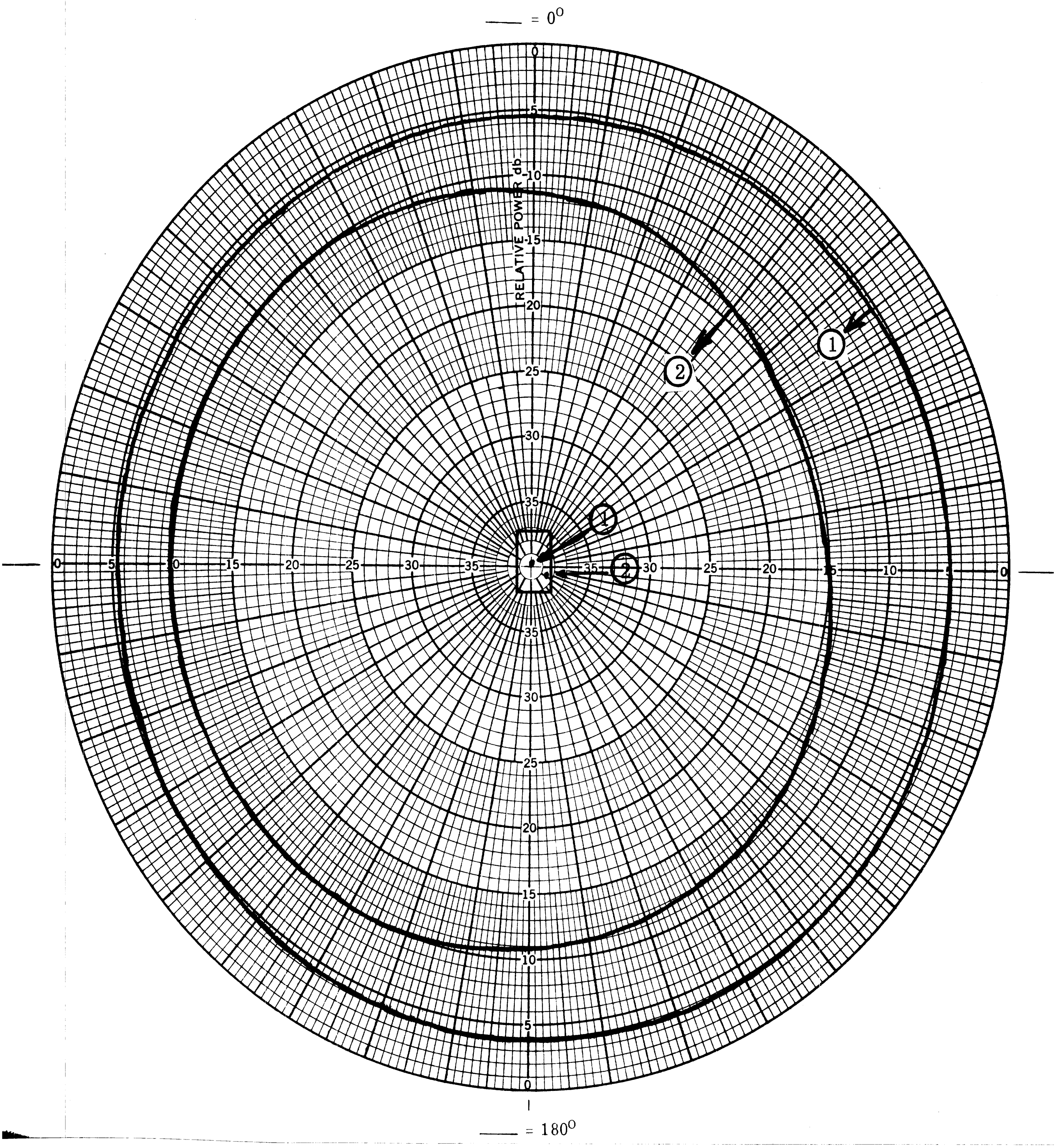


Figure 11 (c): CB Channel 23 patterns of power CB and $\lambda/4$ antennas on 1976 Continental Mark IV. (1) $\lambda/4$ - (2) Power CB.

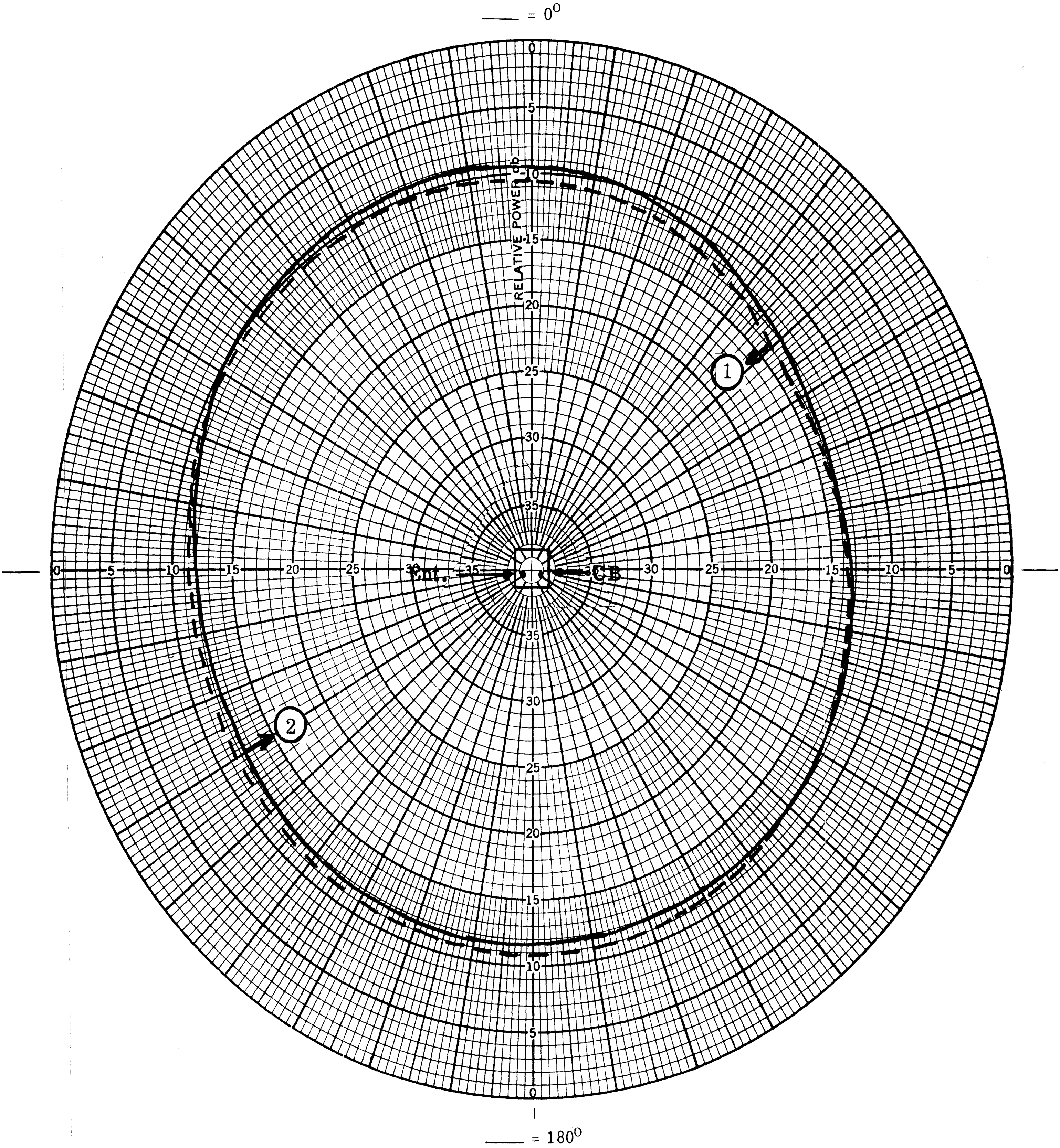


Figure 12 (a): CB Channel 1 patterns of CB antenna with and without entertainment antenna on 1976 Continental Mark IV. (1) CB only - (2) CB antenna with entertainment antenna raised.

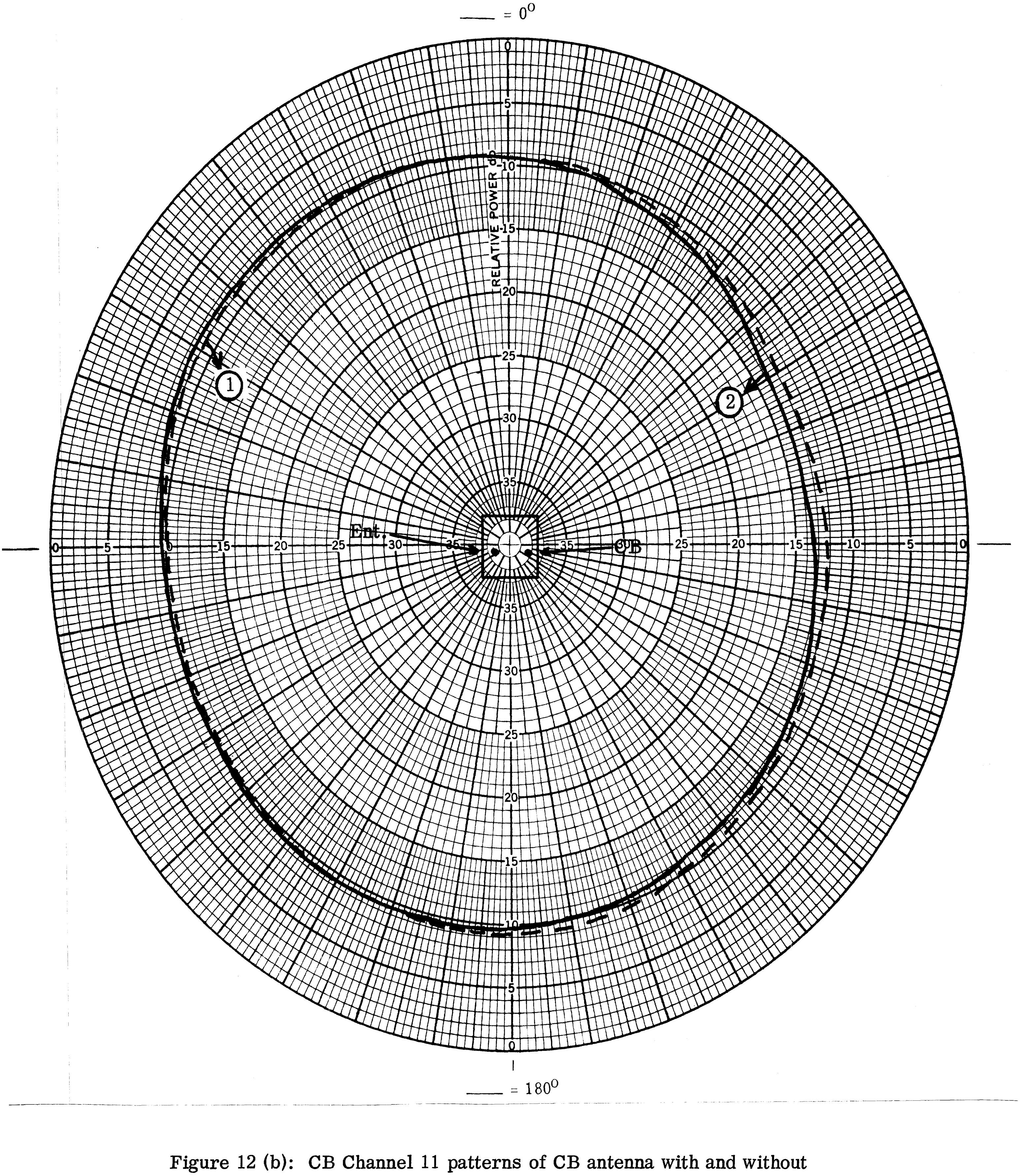


Figure 12 (b): CB Channel 11 patterns of CB antenna with and without entertainment antenna on 1976 Continental Mark IV. (1) CB only - (2) CB antenna with entertainment antenna raised.

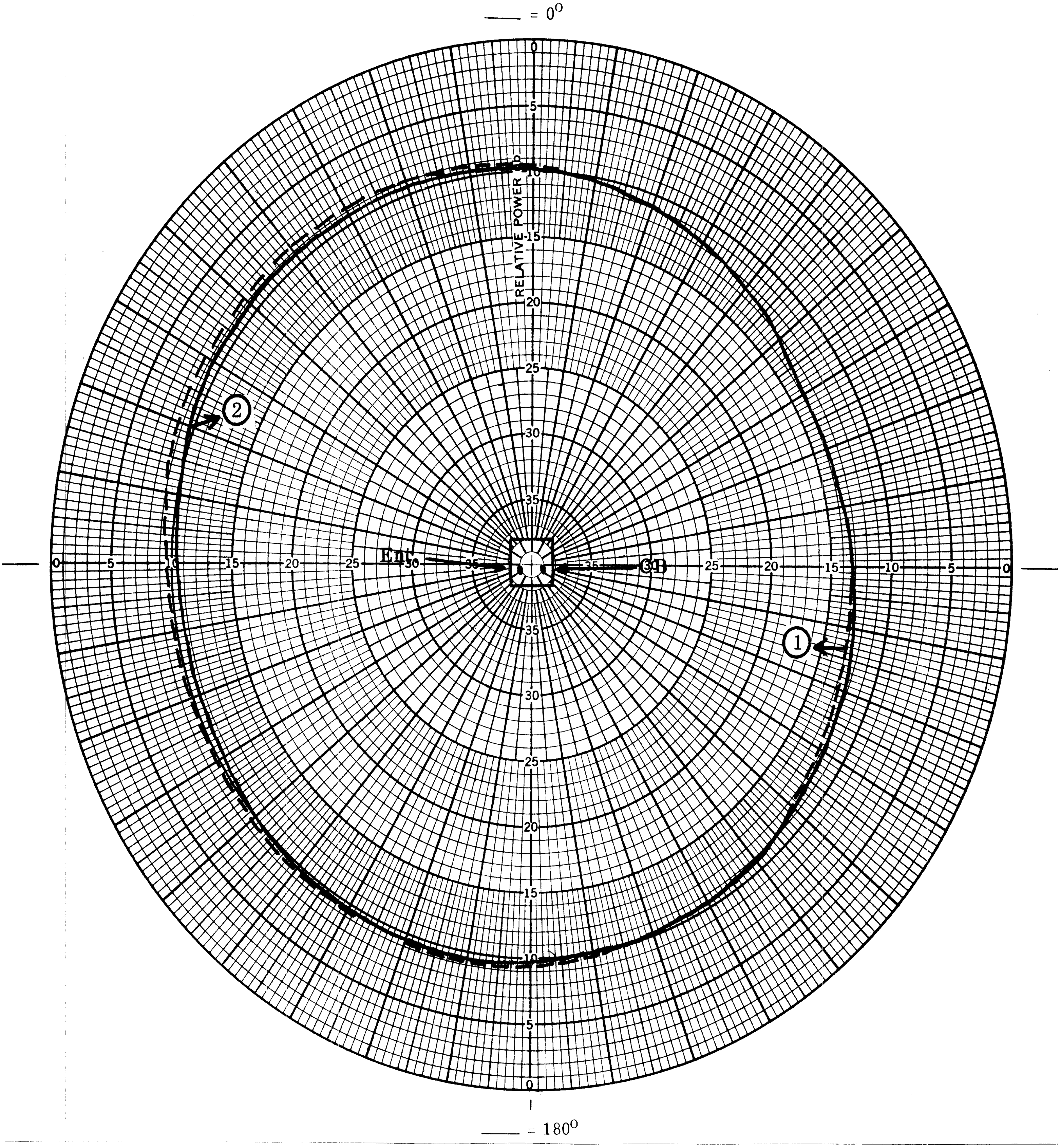


Figure 12 (c): CB Channel 23 patterns of CB antenna with and without entertainment antenna on 1976 Continental Mark IV. (1) CB only - (2) CB antenna with entertainment antenna raised.

Figures 13 (a)-(c) show the patterns in the three CB frequencies for the roof-top $\lambda/4$ monopole, power CB and power tri-band antennas mounted on a 1976 Lincoln Continental car. Observe the correlations of the asymmetrics in the two CB antenna patterns with their locations on the car.

Figures 14 (a)-(c) show the patterns at three selected frequencies in the FM band for the FM reference and power tri-band antennas on the 1976 Lincoln Continental.

Table VI gives the field strengths in three selected AM band frequencies received by the AM-FM reference and the power tri-band antenna mounted on the 1976 Lincoln Continental.

Table VI: AM Band Field Strength for 1976 Lincoln Continental

Frequency → / Antenna	0.8 MHz	1.2 MHz	1.6 MHz
	← Field Strength →		
AM-FM Reference	*-28dB	-37dB	-45dB
Power Tri-band	-34dB	-43dB	-49dB

* Note: Units are arbitrary.

The results indicate that compared to the reference antenna the tri-band antenna performs slightly better at the upper region of the AM band.

6.2 Results for Fixed Whip (Manual) Antenna Mounted On 1976 Gran Torino

Figure 15 (a)-(c) give the patterns for a number of test antennas, as noted; mounted on a 1976 Gran Torino for three selected frequencies in CB. Observe that in this set of test antennas only the HY-Gain 426 is tuned, the rest are untuned. The Antenna Specialists antenna appears to have the poorest sensitivity, the tuned HY-Gain has the best sensitivity.

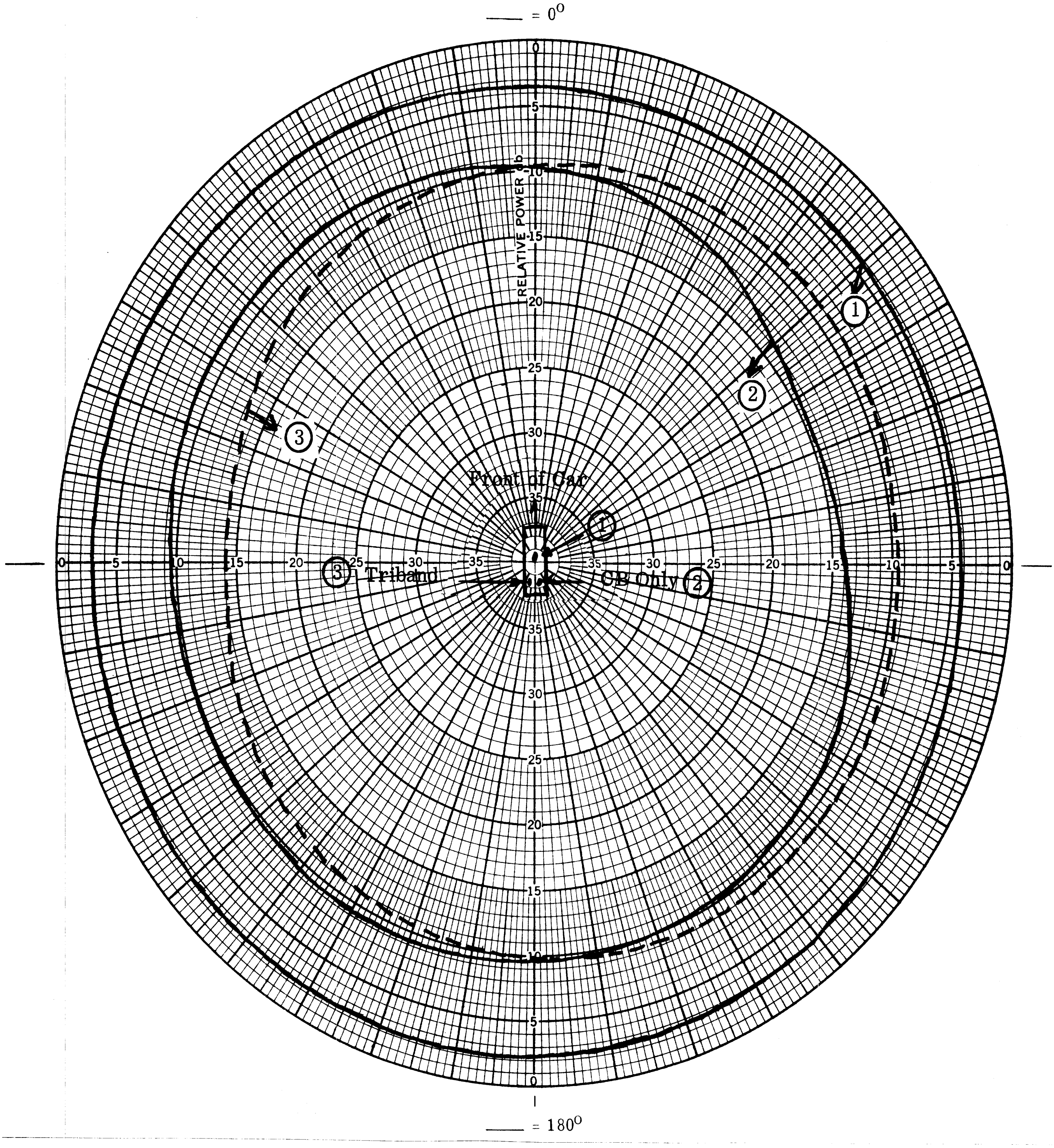


Figure 13 (a): CB Channel 1 patterns of $\lambda/4$, power CB and power tirband antennas on 1976 Lincoln Continental.
(1) $\lambda/4$ - (2) Power CB - (3) Power Tri-band.

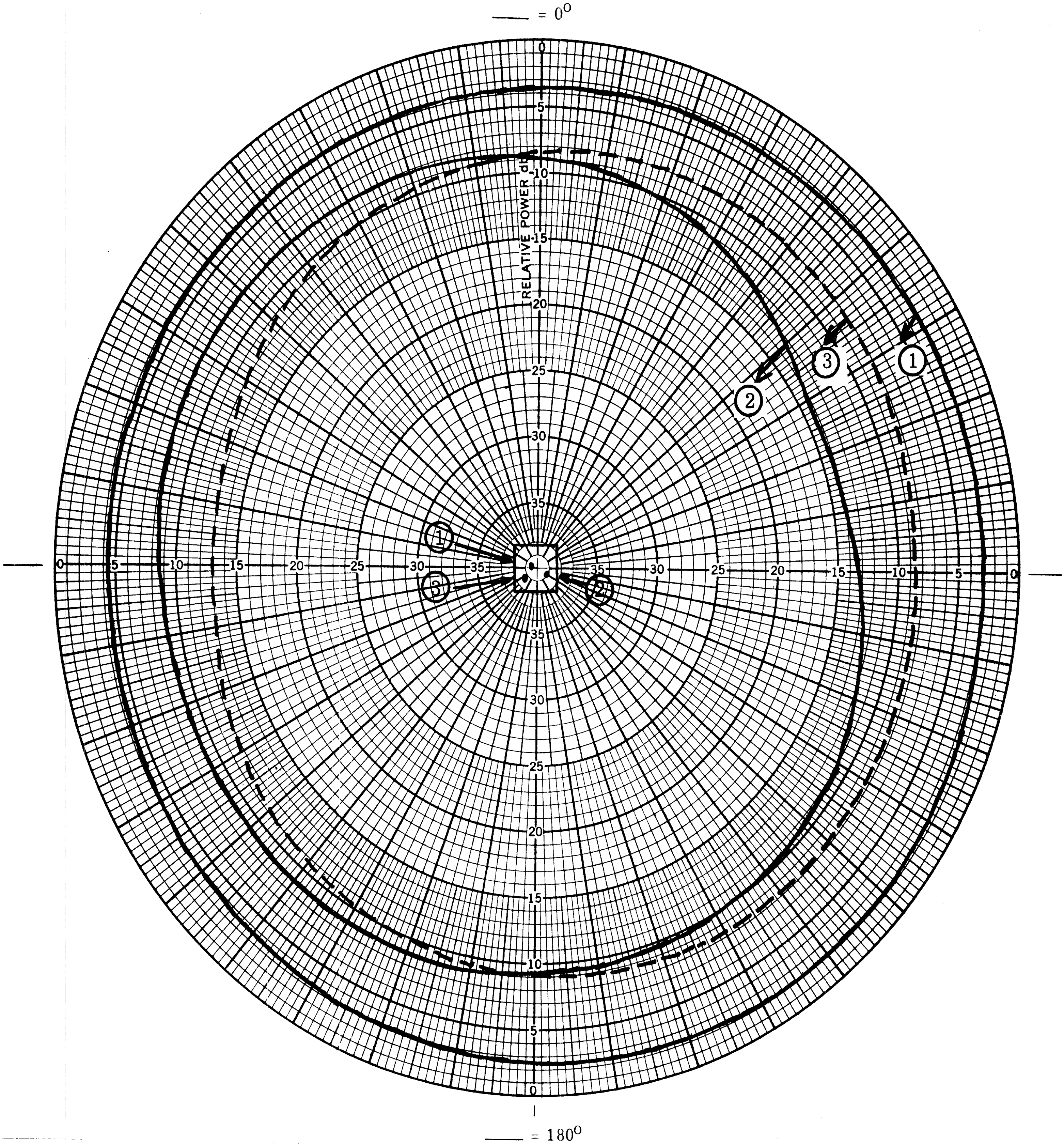


Figure 13 (b): CB Channel 11 patterns of $\lambda/4$, power CB and power triband antennas on 1976 Lincoln Continental. (1) $\lambda/4$ - (2) Power CB - (3) Power Tri-band.

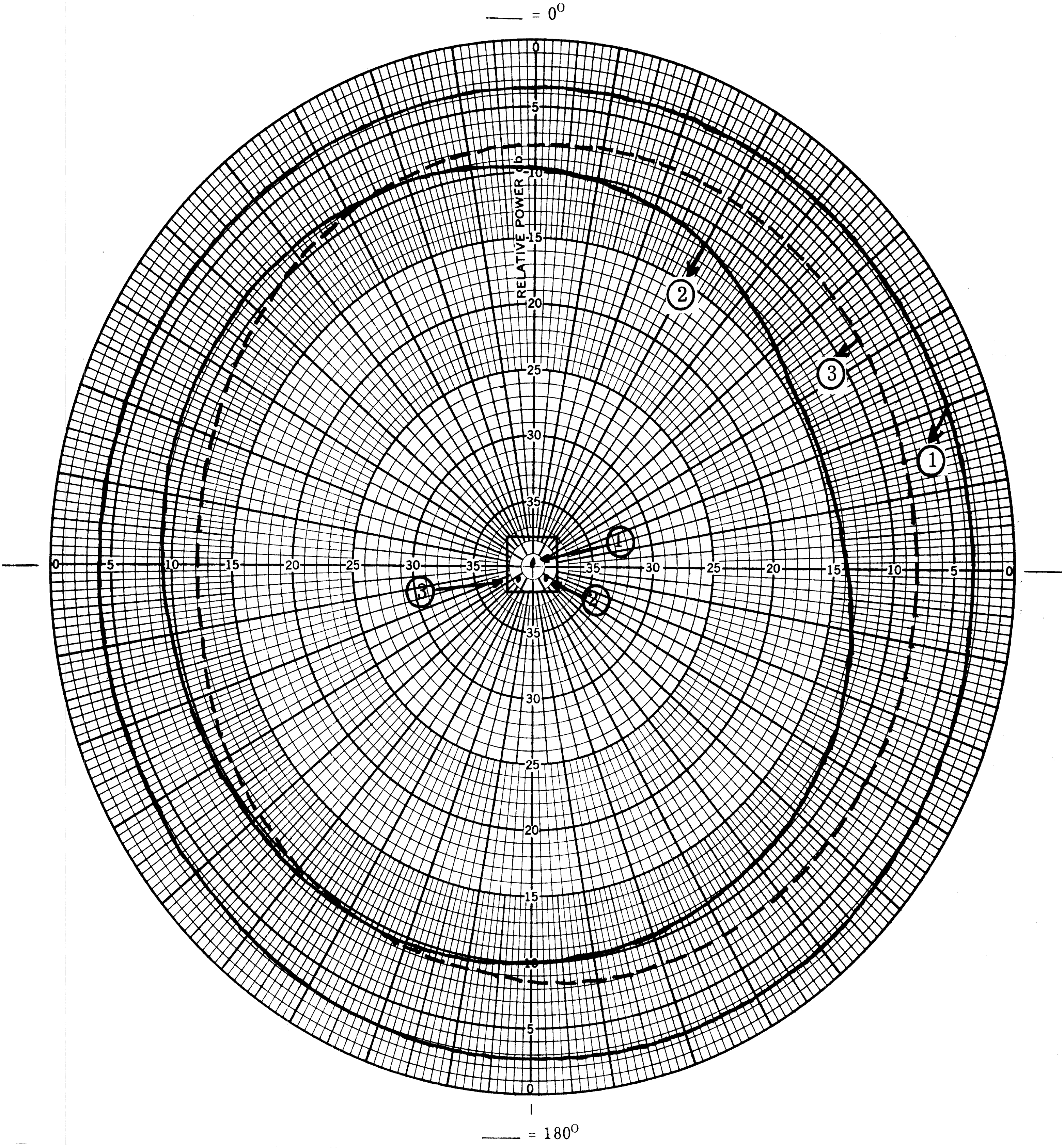


Figure 13 (c): CB Channel 23 patterns of $\lambda/4$, power CB and power tri-band antennas on 1976 Lincoln Continental.
(1) $\lambda/4$ - (2) power CB - (3) power tir-band.

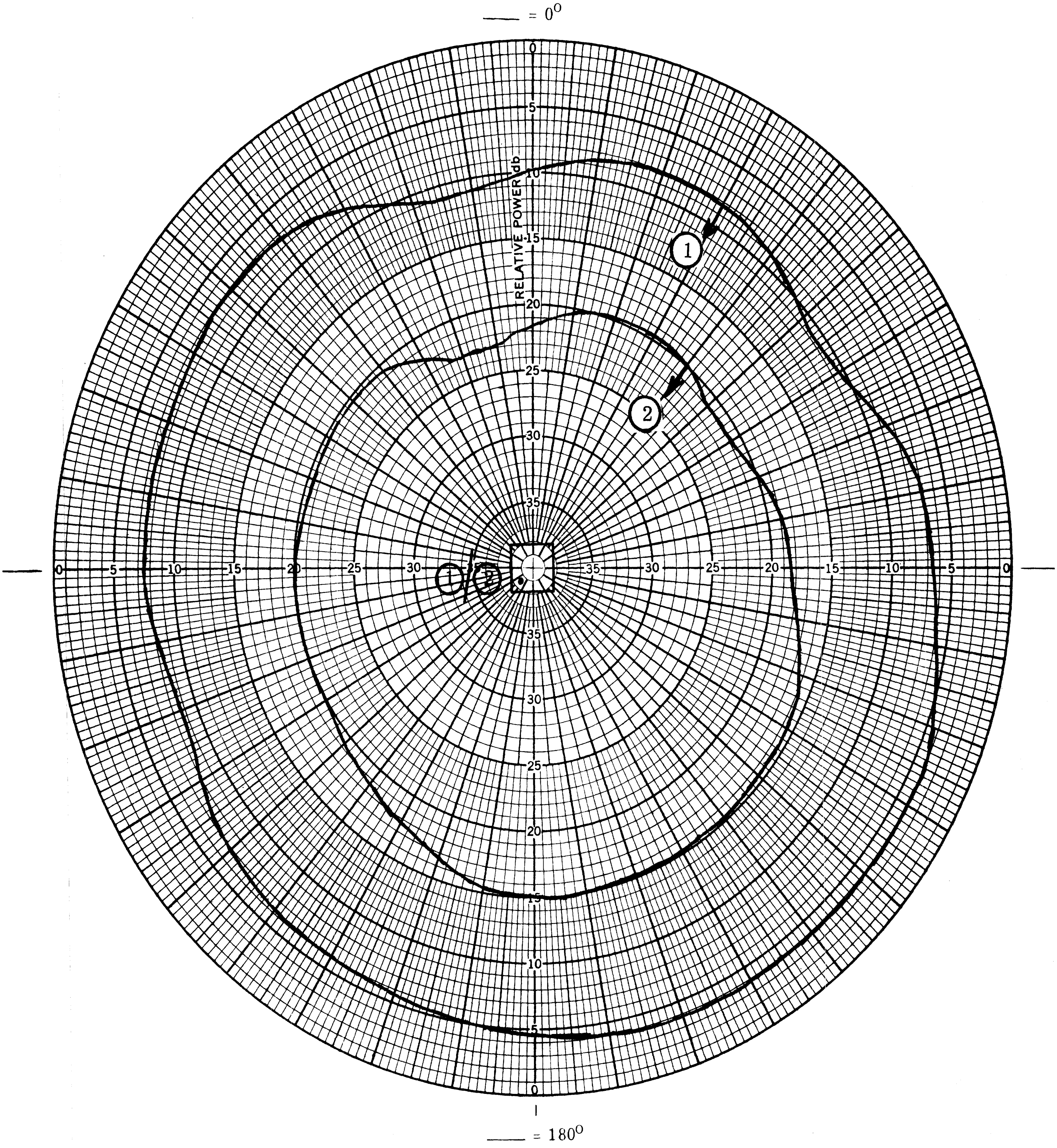


Figure 14 (a): Patterns at 93.7 MHz for FM reference and power tri-band antennas on 1976 Lincoln Continental. (1) FM reference - (2) power tri-band.

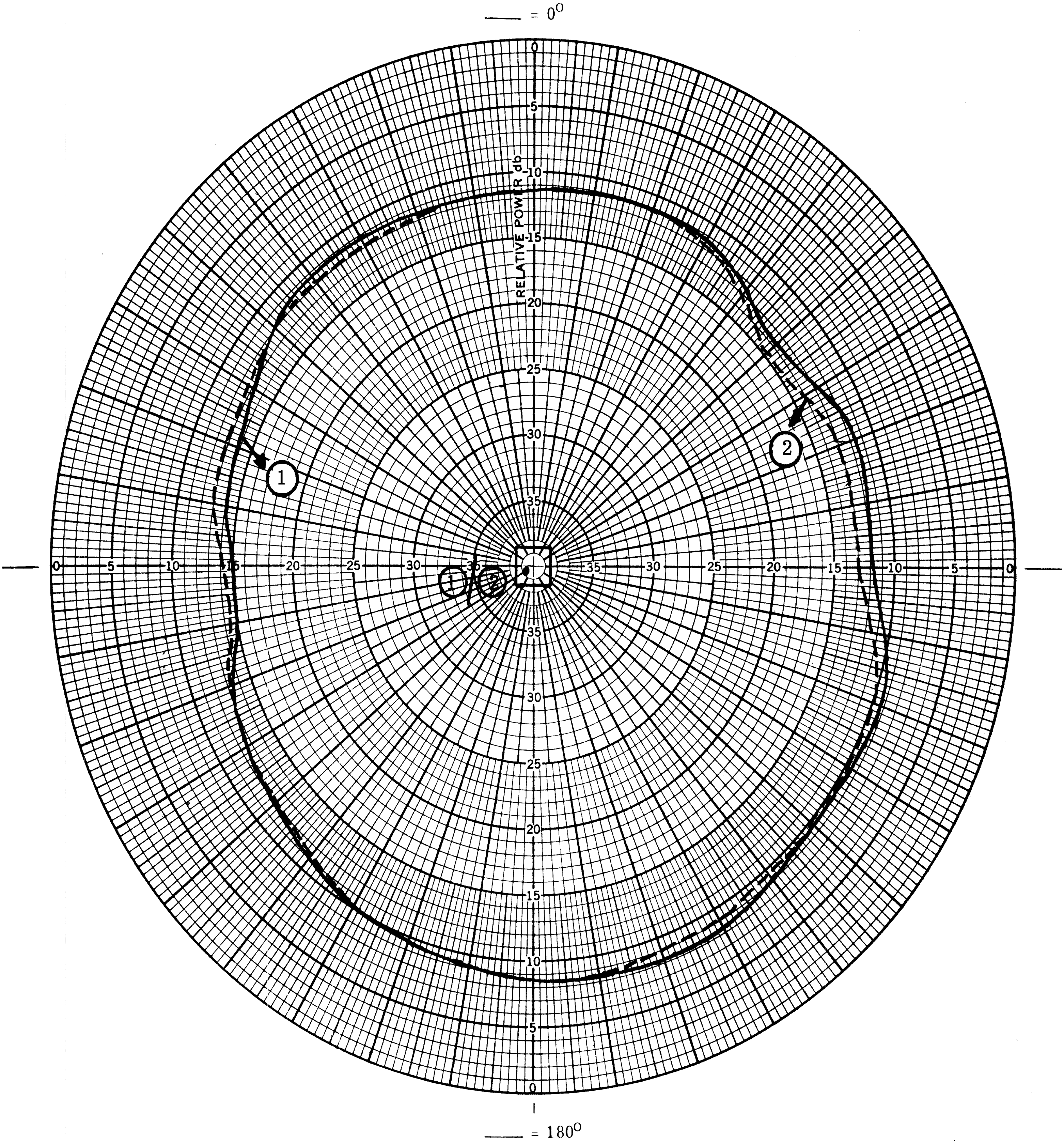


Figure 14 (b): Patterns at 102.8 MHz for FM reference and power tri-band antennas on 1976 Lincoln Continental. (1) FM reference - (2) Power tri-band.

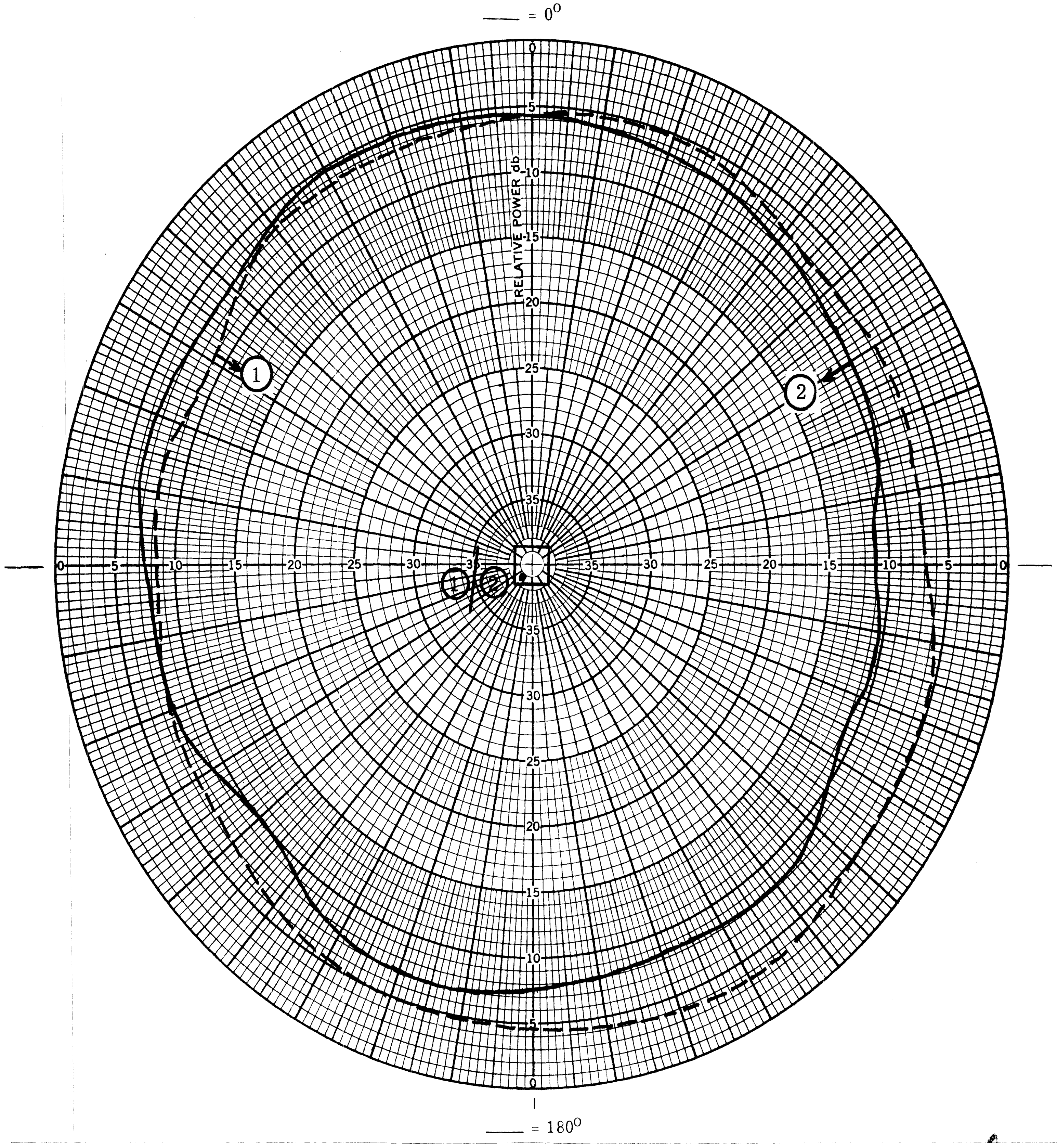


Figure 14 (c): Patterns at 108 MHz for FM reference and power tri-band antennas on 1976 Lincoln Continental. (1) FM reference - (2) Power tri-band.

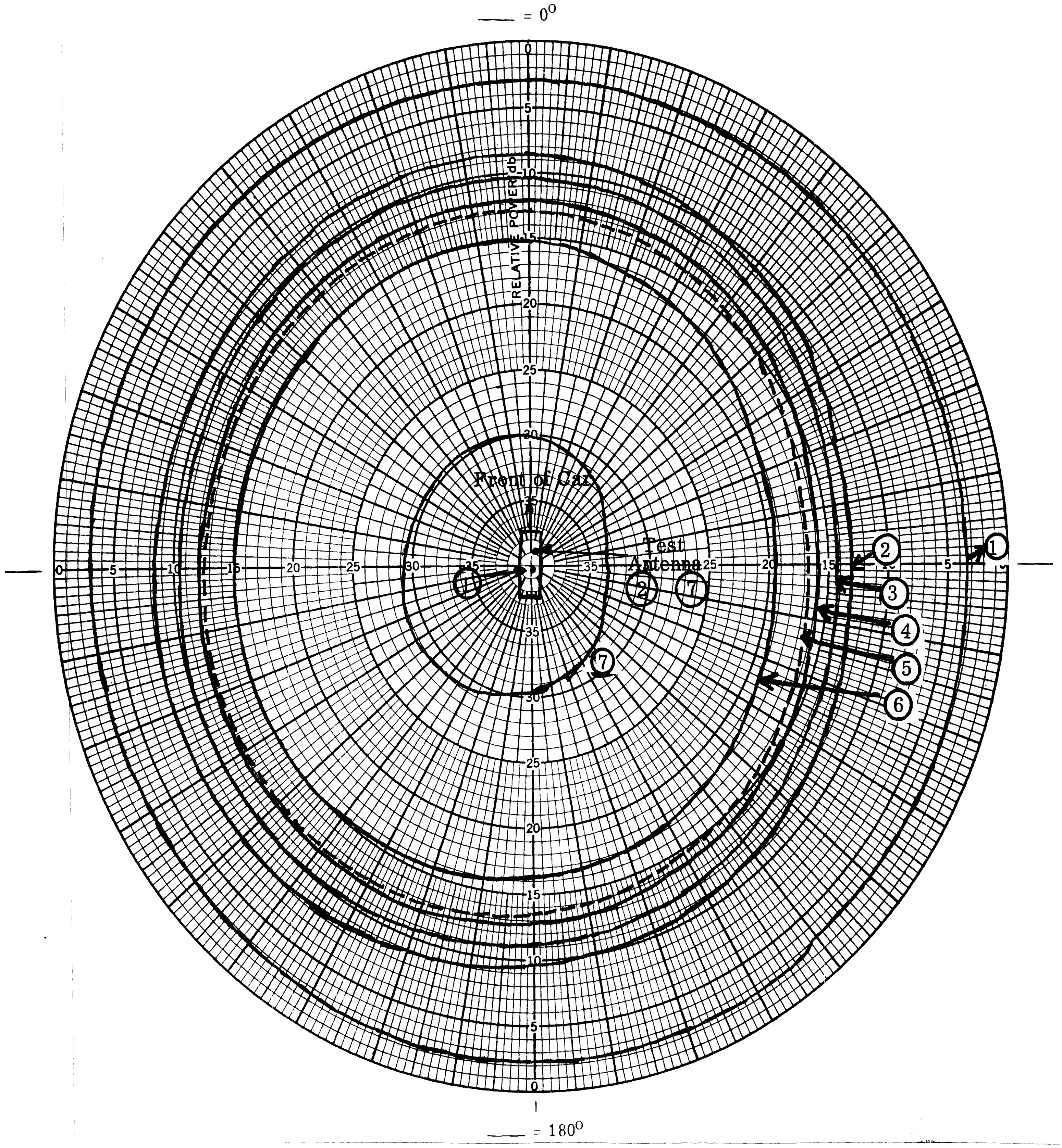


Figure 15 (a): CB Channel 1 patterns of various test antennas on 1976 Gran Torino. (1) $\lambda/4$ - (2) HY-Gain 426 (tuned) - (3) Ward Base-Loaded (untuned) - (4) Turner 4203-2 - (5) Ward RP102-1 (untuned) - (6) Turner 4222-2 - (7) Antenna Specialists Fully Disguised.

<u>Note:</u> Test antennas (2) through (7) are fixed tri-band type.

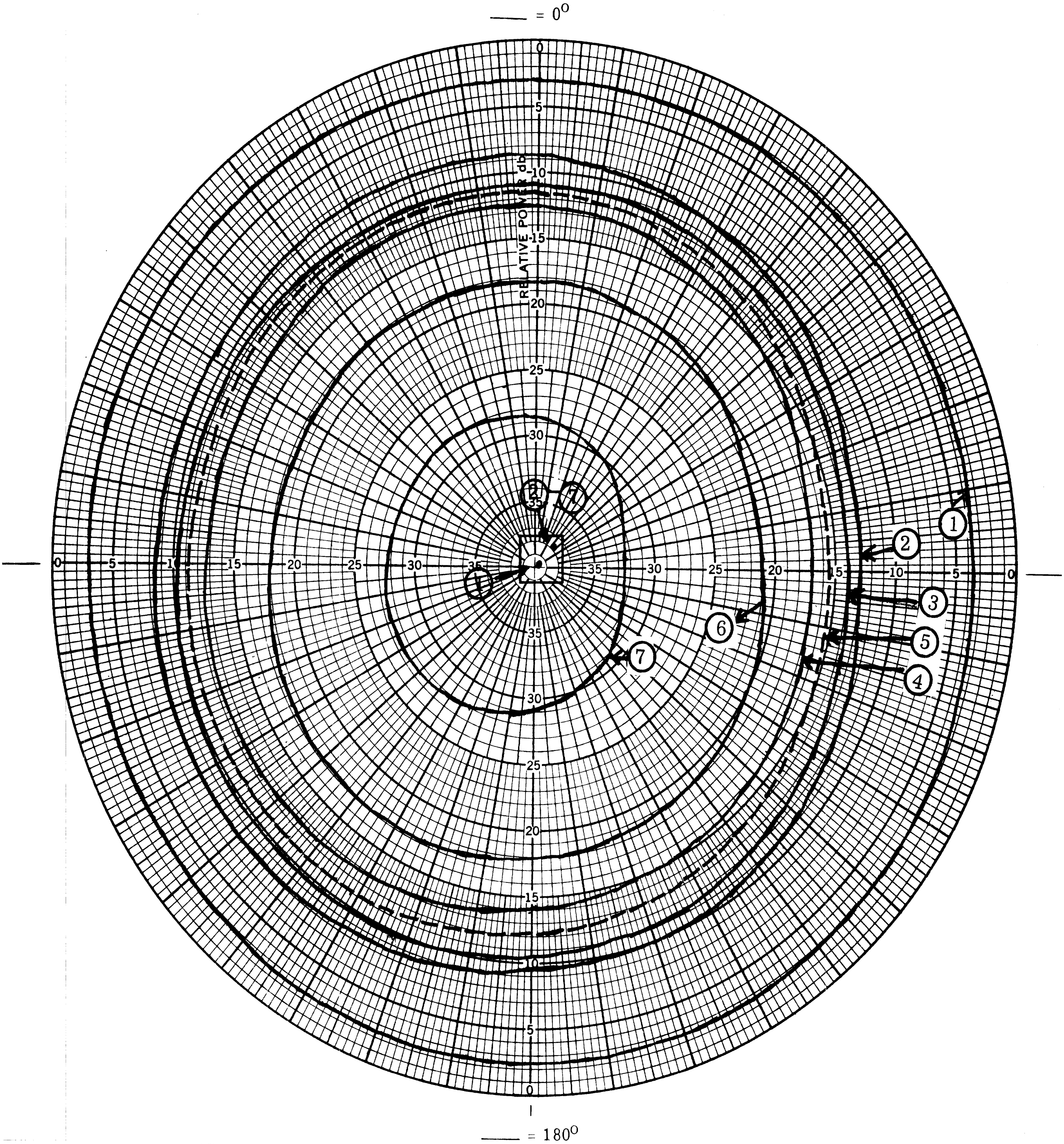


Figure 15 (b): CB Channel 11 patterns of various test antennas on 1976 Gran Torino. (1) $\lambda/4$ - (2) HY-Gain 426 (tuned) (3) Ward Base-Loaded (untuned) - (4) Turner 4203-2 - (5) Ward RP102-1 (untuned) - (6) Turner 4222-2 - (7) Antenna Specialists Fully Disguised.

Note: Test antennas (2) through (7) are fixed tri-band type.

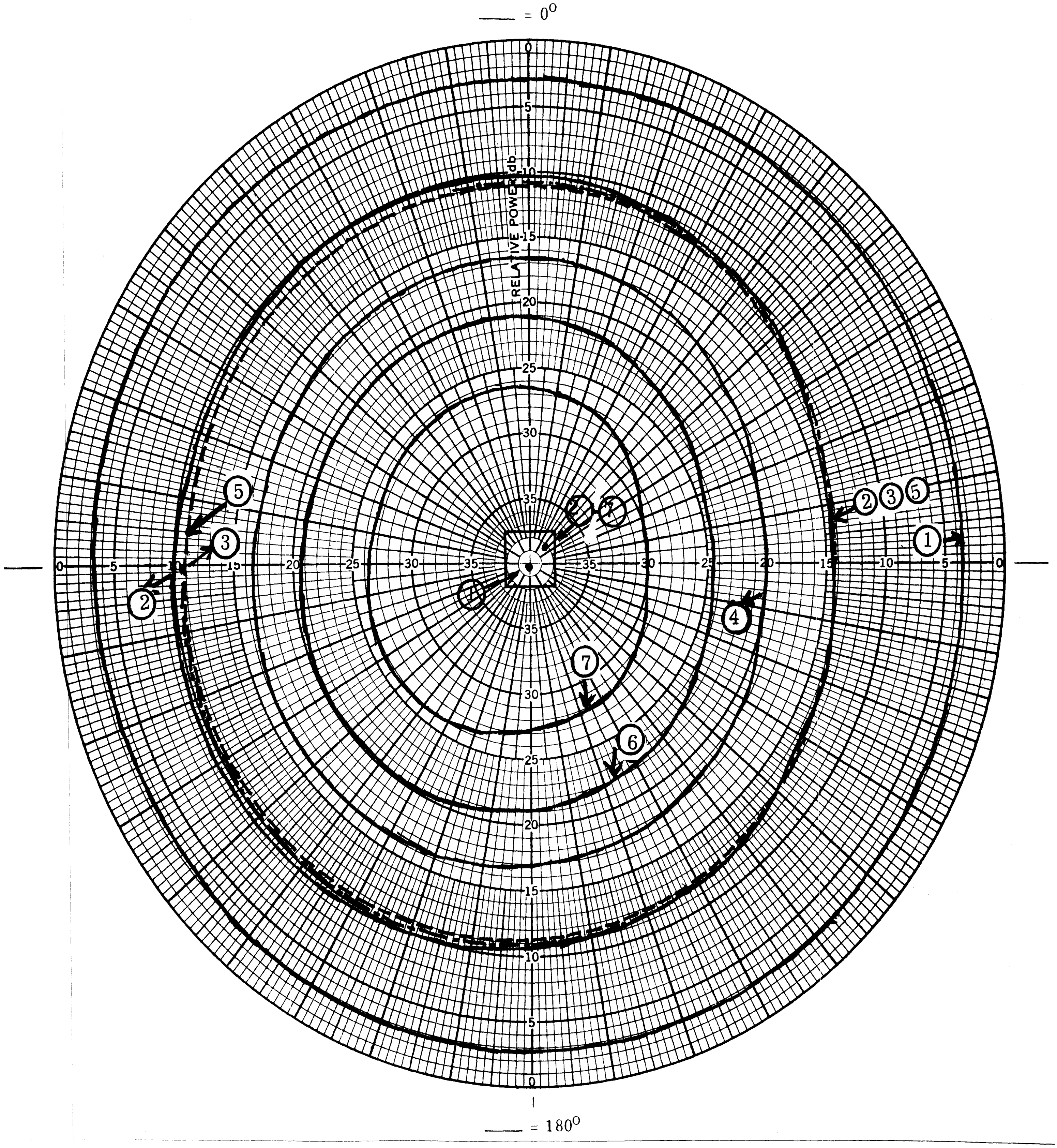


Figure 15 (c): CB Channel 23 patterns of various test antennas on 1976 Gran Torino. (1) $\lambda/4$ - (2) HY-Gain 426 (tuned) (3) Ward Base-Loaded (untuned) - (4) Turner 4203-2 - (5) Ward RP102-1 (untuned) - (6) Turner 4222-2 - (7) Antenna Specialists Fully Disguised.

Note: Test antennas (2) through (7) are fixed tri-band type.

Figure 16 (a)-(c) gives similar results for the two tuned antennas Ward Base-Loaded and Ward RP102-1.

Figure 17 (a)-(c) show the patterns for four tuned antennas at three CB frequencies. The improved performance of the tuned antennas are evident from the results shown.

The FM band patterns at 96 MHz for various antennas are shown in Figure 18. Note that only the Ward Base-Loaded antenna is tuned here. Figures 19 (a)-(b) give the corresponding results for the same antennas for 102.3 MHz. The results for 108 MHz are shown in Figure 20 (a)-(b).

The results for tuned antenna Ward RP102-1 for the three selected frequencies in the FM band are shown in Figure 21 (2)-(c).

The patterns for the tuned Tenna 7-7-201 and HY-Gain 426-X antennas are shown in Figures 22 (a)-(c).

The measured field strengths in the AM band for various antennas are shown in Table VII. Observe that in Table VII, the groups of antennas in each box should be compared with the reference antenna in the corresponding box.

6.3 Mustang II Results

The pattern for the Ward untuned antenna for the 3 CB frequencies are shown in Figure 23 (a)-(c). Figure 24 (a)-(c) show similar results for their test antennas. During measurements of results shown in Figures 24 and 25, a different detection characteristic of the receiver was used. Hence, the dB difference between the results of the test and reference antennas shown in Figures 23-24 must be divided by 2, to obtain the correct relative sensitivity of the test antennas.

Figure 25 (a)-(c) show the patterns for 3 tuned antennas at 3 CB frequencies.

The 3 FM patterns for the untuned Ward antenna along with the patterns of the corresponding reference antenna are shown in Figure 26 (a)-(c).

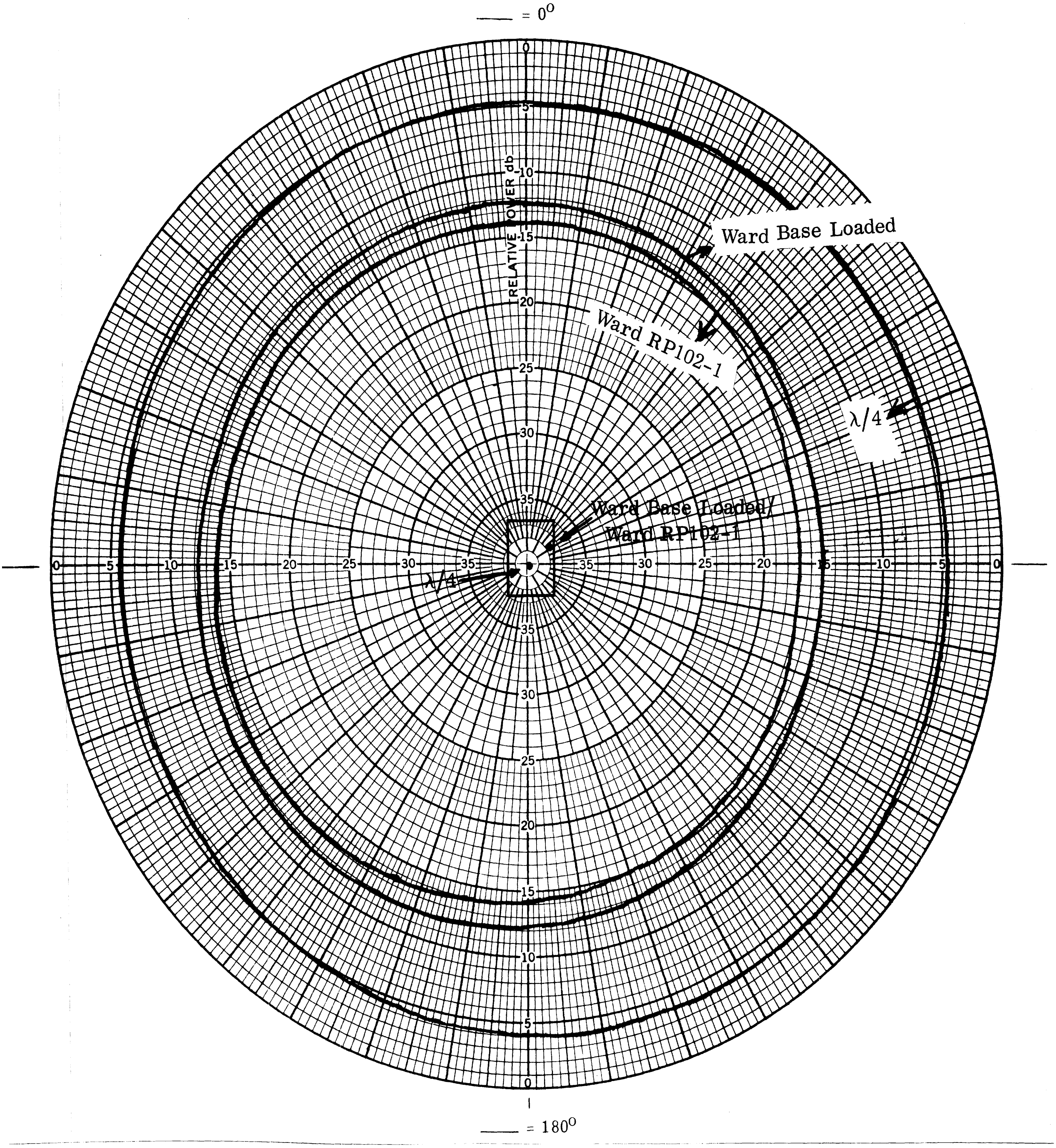
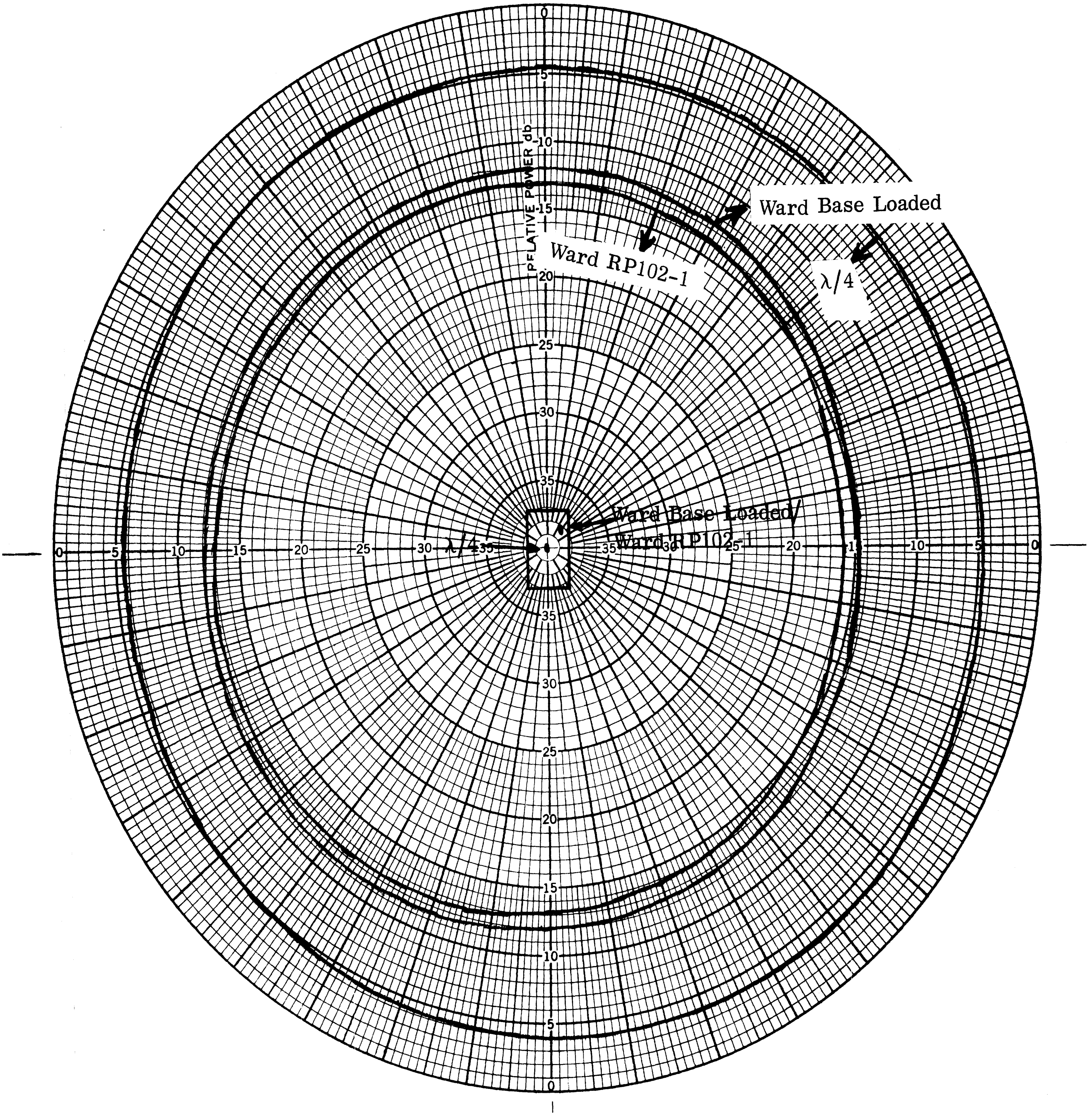


Figure 16 (a): CB Channel 1 patterns of λ/4, tuned Ward Base Loaded and tuned Ward RP102-1 antennas on 1976 Gran Torino.

Note: Both the Ward test antennas are fixed tri-band type.

______ = 0°



______ = 180°

Figure 16 (b): CB Channel 11 patterns of λ/4, tuned Ward Base Loaded and tuned Ward RP102-1 antennas on 1976 Gran Torino.

Note: Both the Ward test antennas are fixed tri-band type.

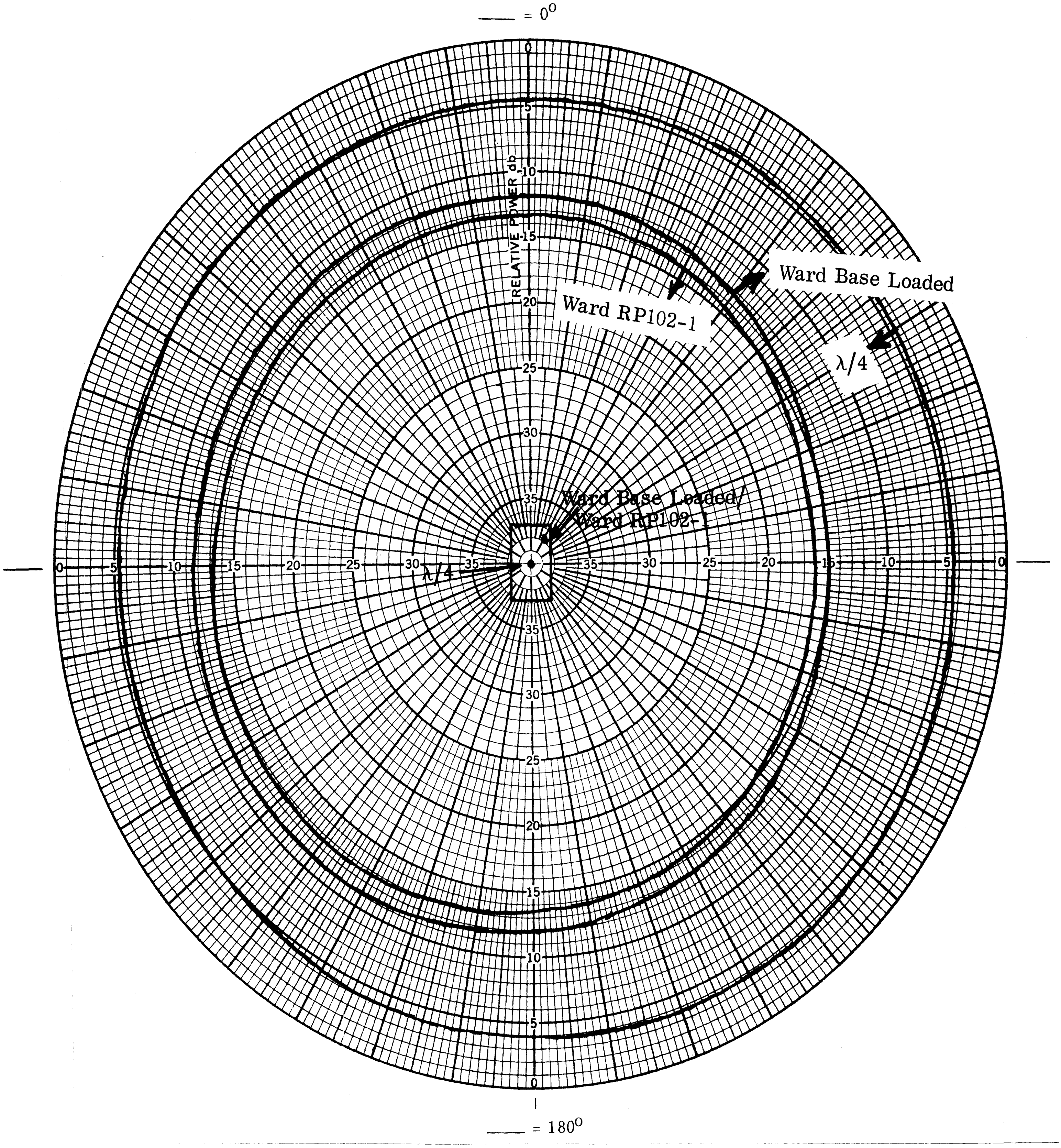


Figure 16 (c): CB Channel 23 patterns of λ/4, tuned Ward Base Loaded and tuned Ward RP102-1 antennas on 1976 Gran Torino.

Note: Both the Ward test antennas are fixed tri-band type.

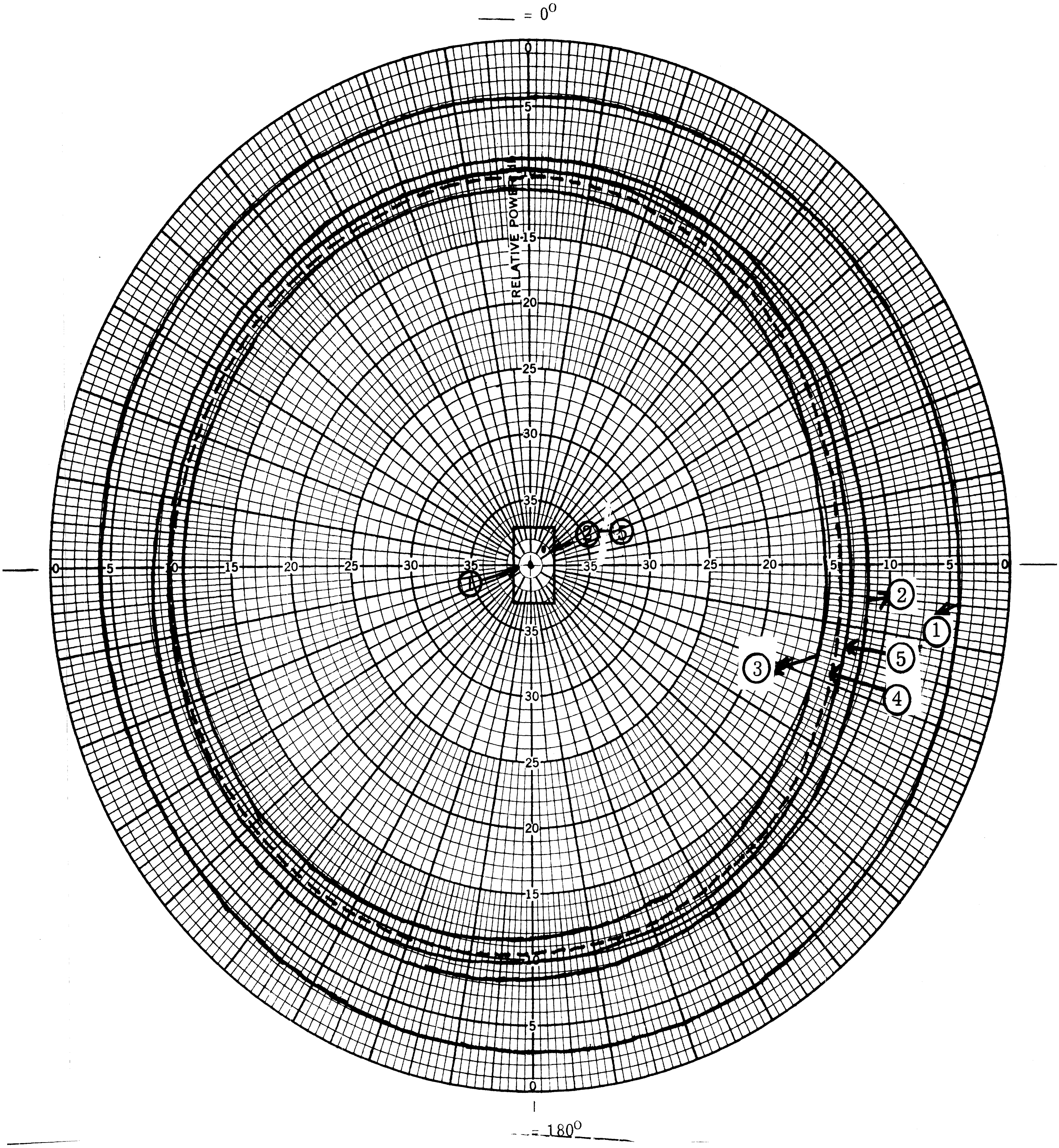


Figure 17 (a): CB Channel 1 patterns of λ/4 and four tuned test antennas on 1976 Gran Torino. (1) λ/4 - (2) Tenna 7-7-201 - (3) HY-Gain 426-X - (4) Riverside - CB only (5) Antenna Specialists CB only.

Note: Test antennas (2) and (3) are fixed tri-band type.

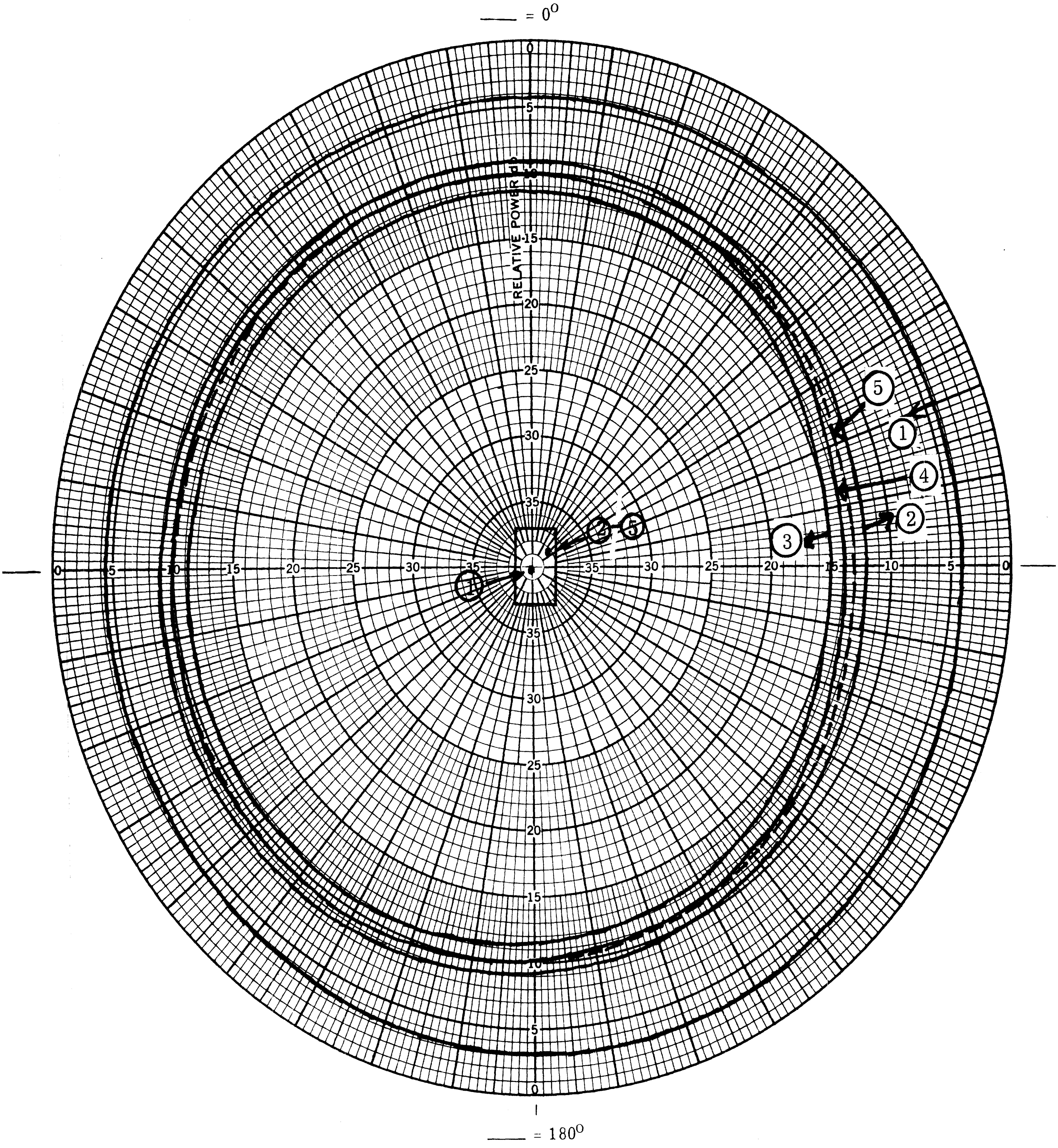


Figure 17 (b): CB Channel 11 patterns of $\lambda/4$ and four tuned test antennas on 1976 Gran Torino. (1) $\lambda/4$ - (2) Tenna 7-7-201 - (3) HY-Gain 426-X - (4) Riverside CB only (5) Antenna Specialists CB only.

Note: Test antennas (2) and (3) are fixed tri-band type.

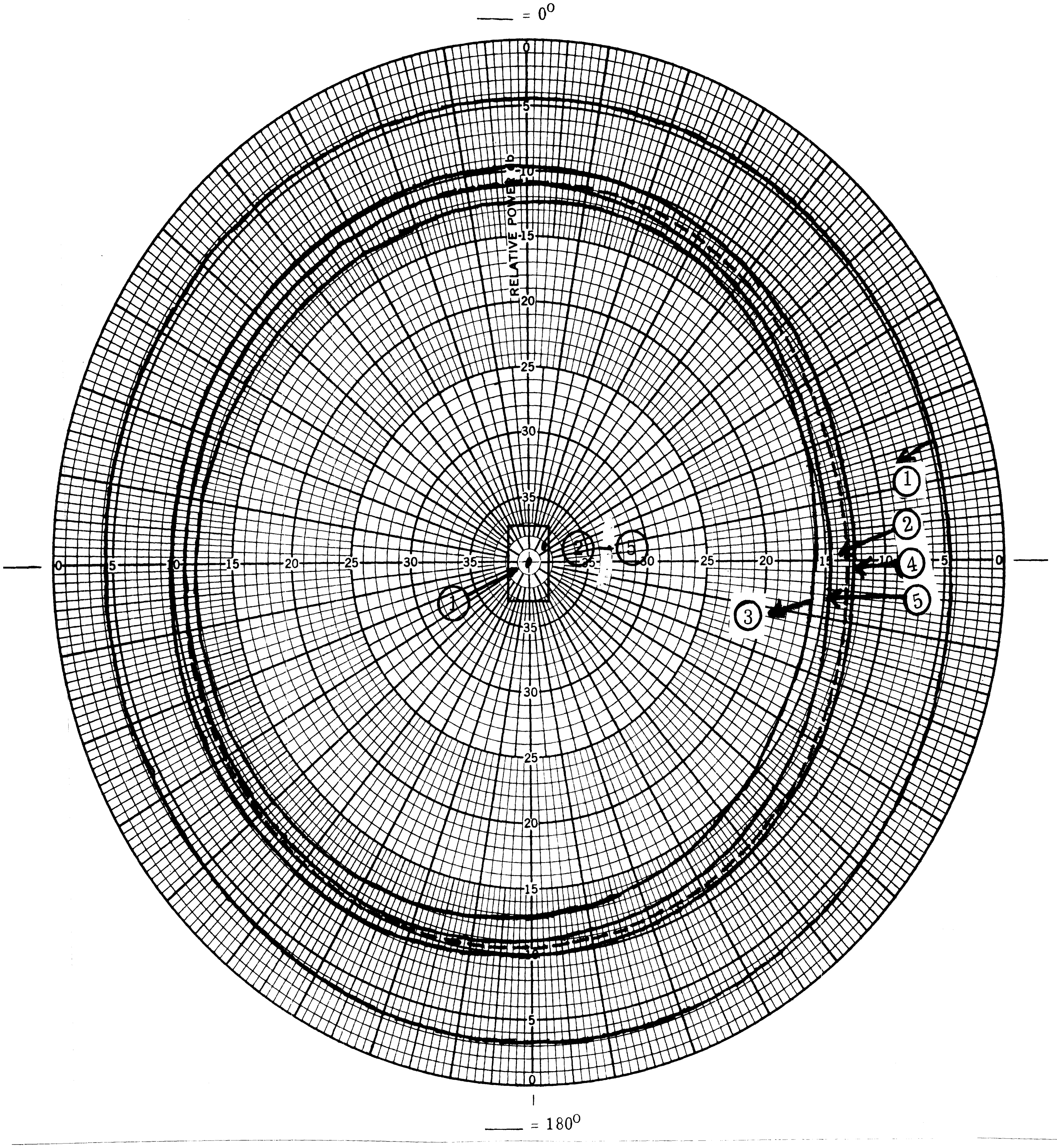


Figure 17 (c): CB Channel 23 patterns of $\lambda/4$ and four tuned test antennas on 1976 Gran Torino. (1) $\lambda/4$ - (2) Tenna 7-7-201 - (3) HY-Gain 426-X - (4) Riverside CB only - (5) Antenna Specialists CB only.

Note: Test antennas (2) and (3) are fixed tri-band type.

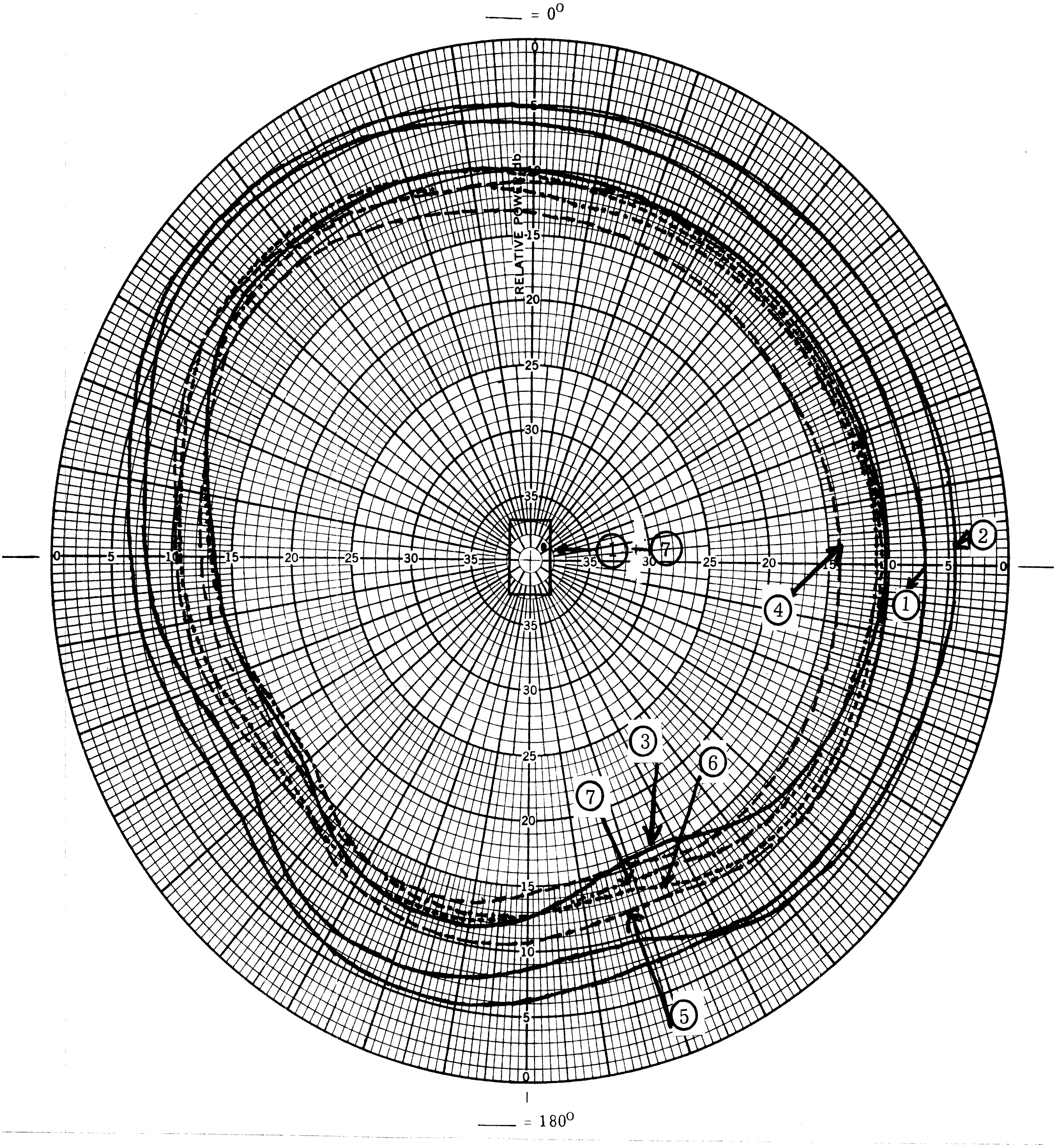


Figure 18: FM patterns at 96 MHx for various test antennas on 1976 Gran Torino. (1) FM Reference - (2) Antenna Specialists fully disguised - (3) HY-Gain 426 (tuned) - (4) Turner 4222-5 - (5) Turner 4203-2 - (6) Ward Base-loaded - (7) - RP102-2 (untuned).

Note: Test antennas (2) through (7) are fixed tri-band type.

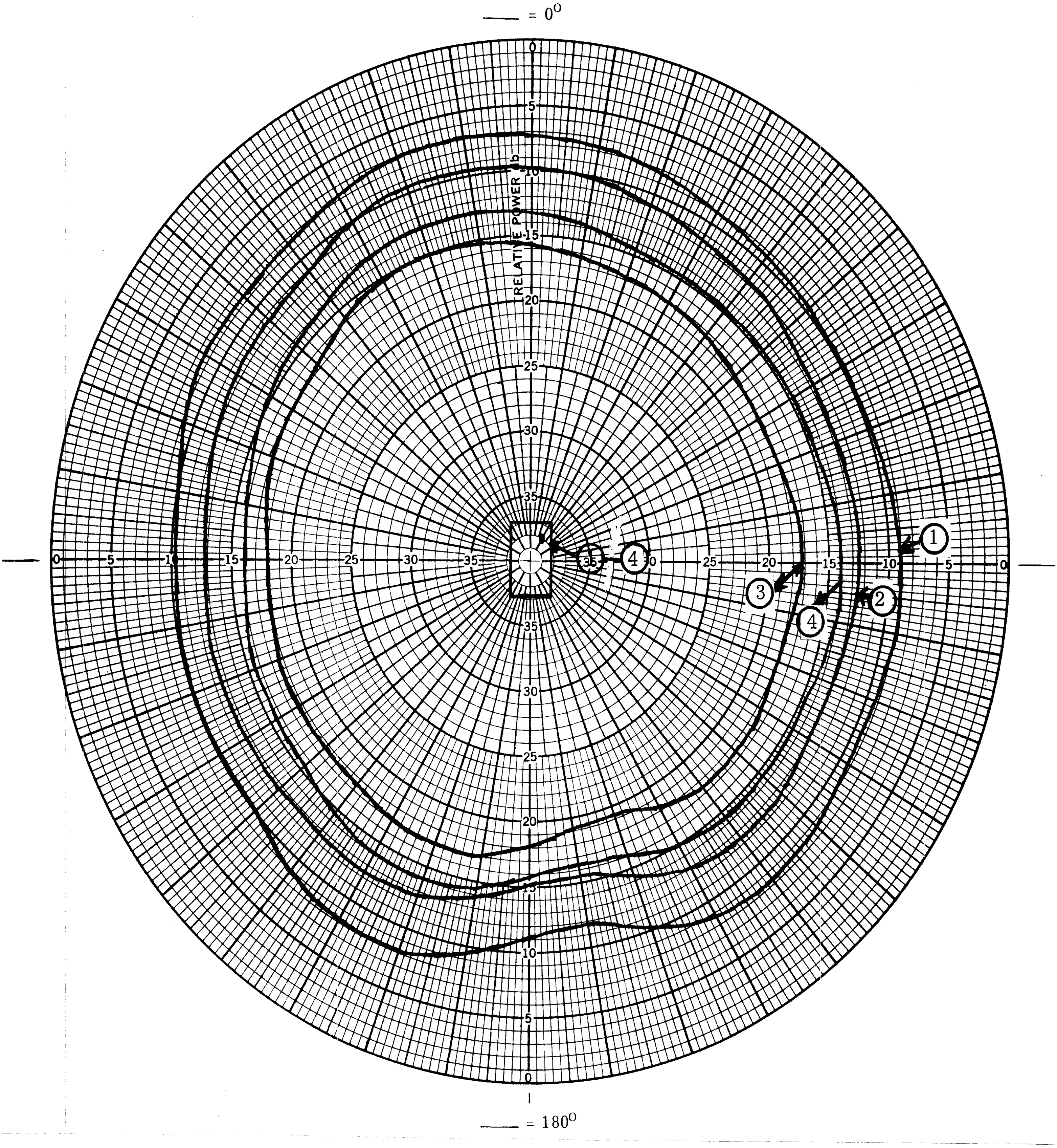


Figure 19 (a): FM patterns at 102.3 MHz for various test antennas on 1976 Gran Torino. (1) FM reference - (2) Turner 4222-2 - (3) Turner 4203-2 - (4) Ward base-loaded tuned.

Note: Test antennas (2) - through (4) are fixed tri-band type.

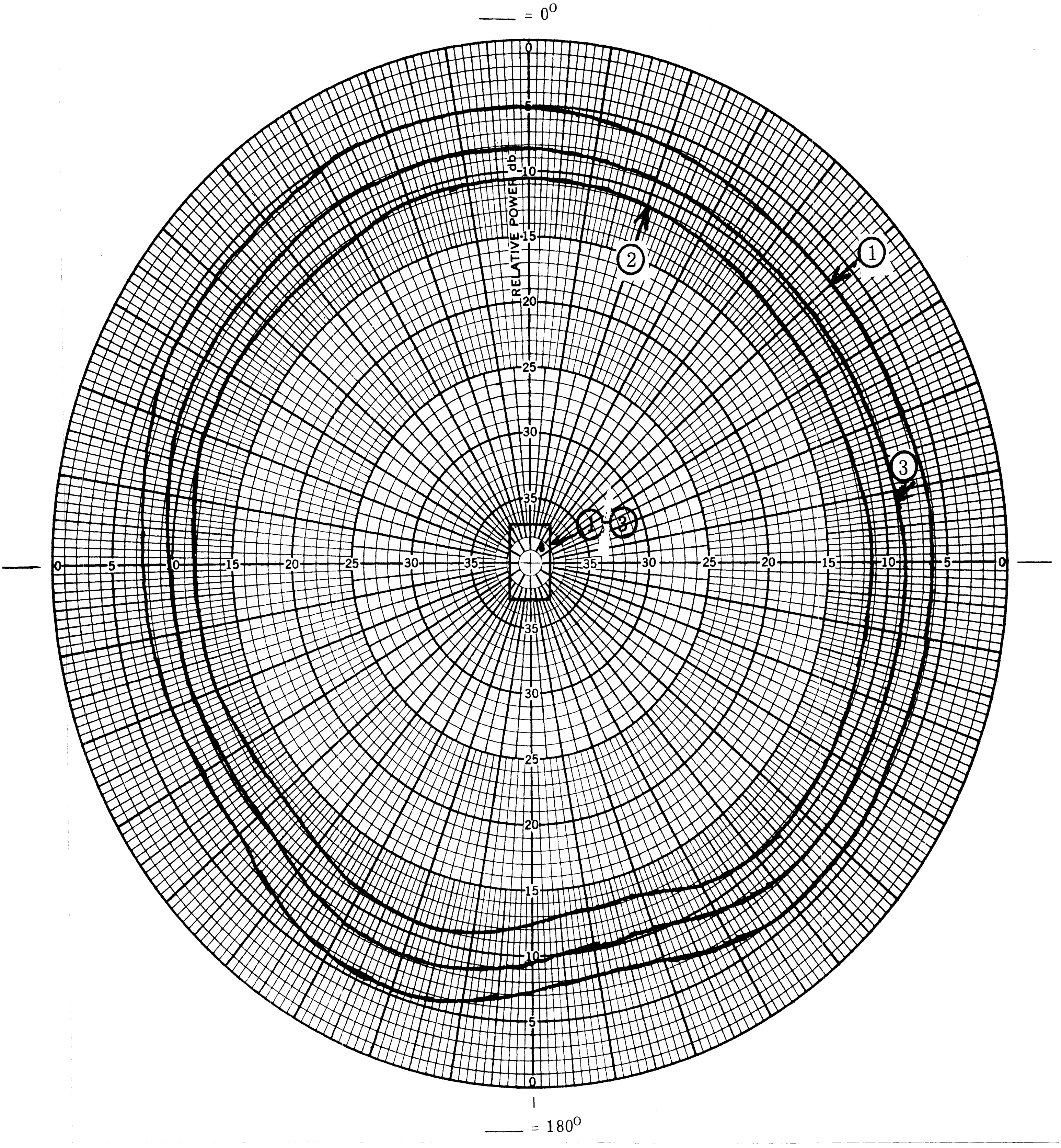


Figure 19 (b): FM patterns at 102.3 MHz for various test antennas on 1976 Gran Torino. (1) FM reference - (2) Ward RP102-1 (untuned) (3) Antenna Specialists fully disguised.

Note: Test antennas (2) and (3) are fixed tri-band type.

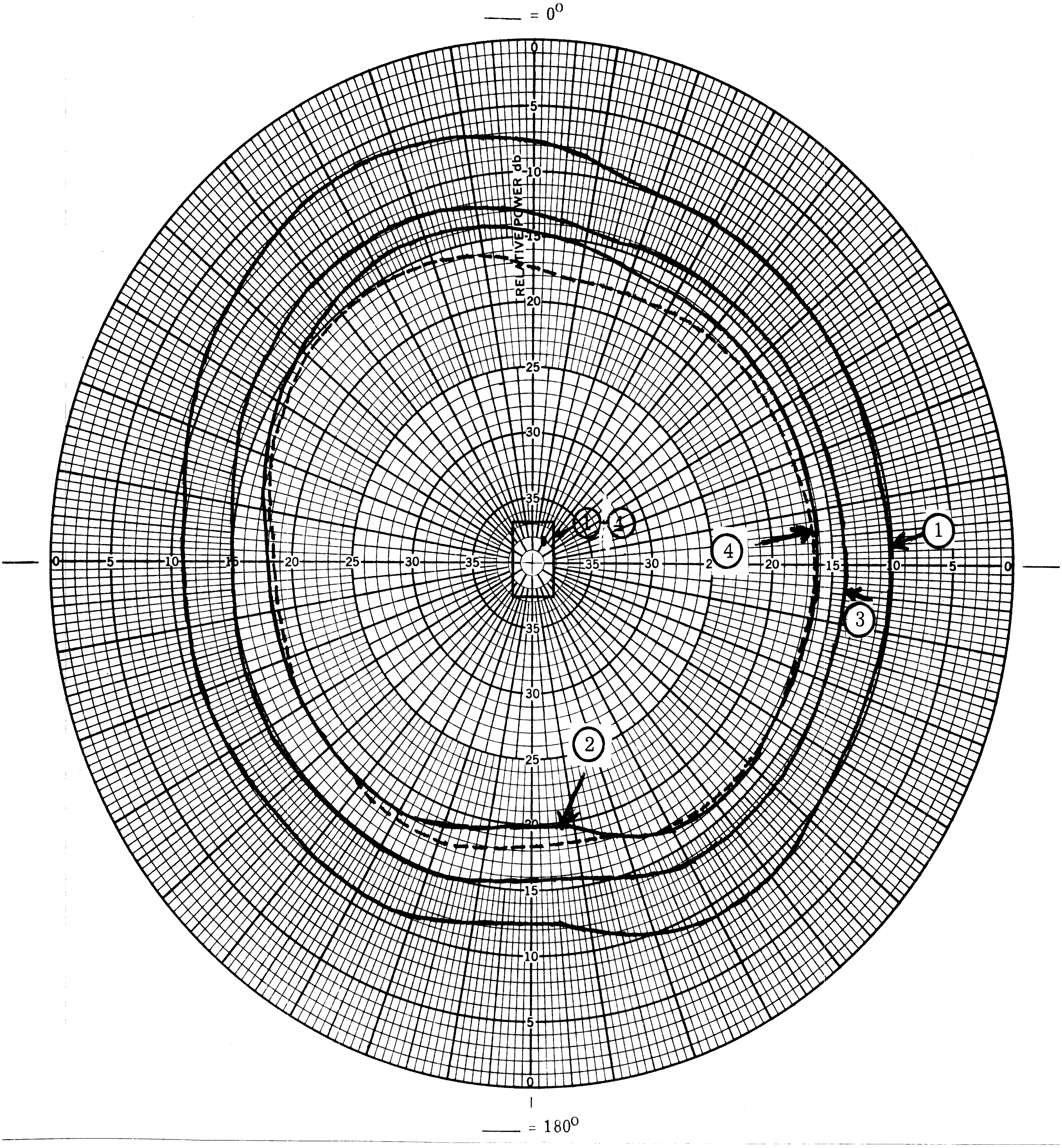


Figure 20 (a): FM patterns at 108 MHz for various test antennas on 1976 Gran Torino. (1) FM reference - (2) Ward base-loaded (tuned) - (3) Turner 4222-2 - (4) Turner 4203-2.

Note: Test antennas (2) through (4) are fixed tri-band type.

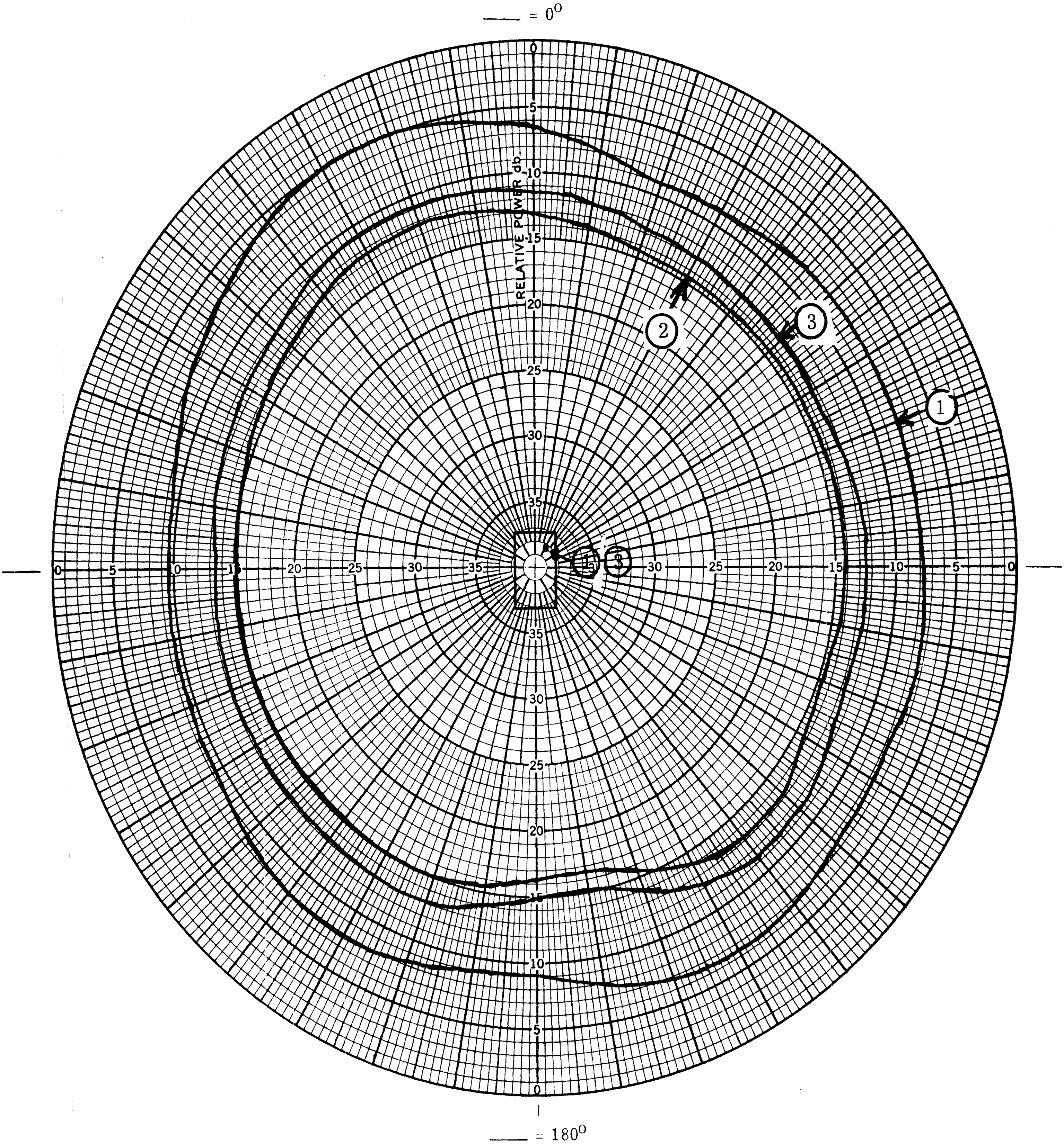


Figure 20 (b): FM patterns at 108 MHz for various test antennas on 1976 Gran Torino. (1) FM reference - (2) RP102-1 (untuned) (3) Antenna Specialists fully disguised.

Note: Test antennas (2) and (3) are fixed tri-band type.

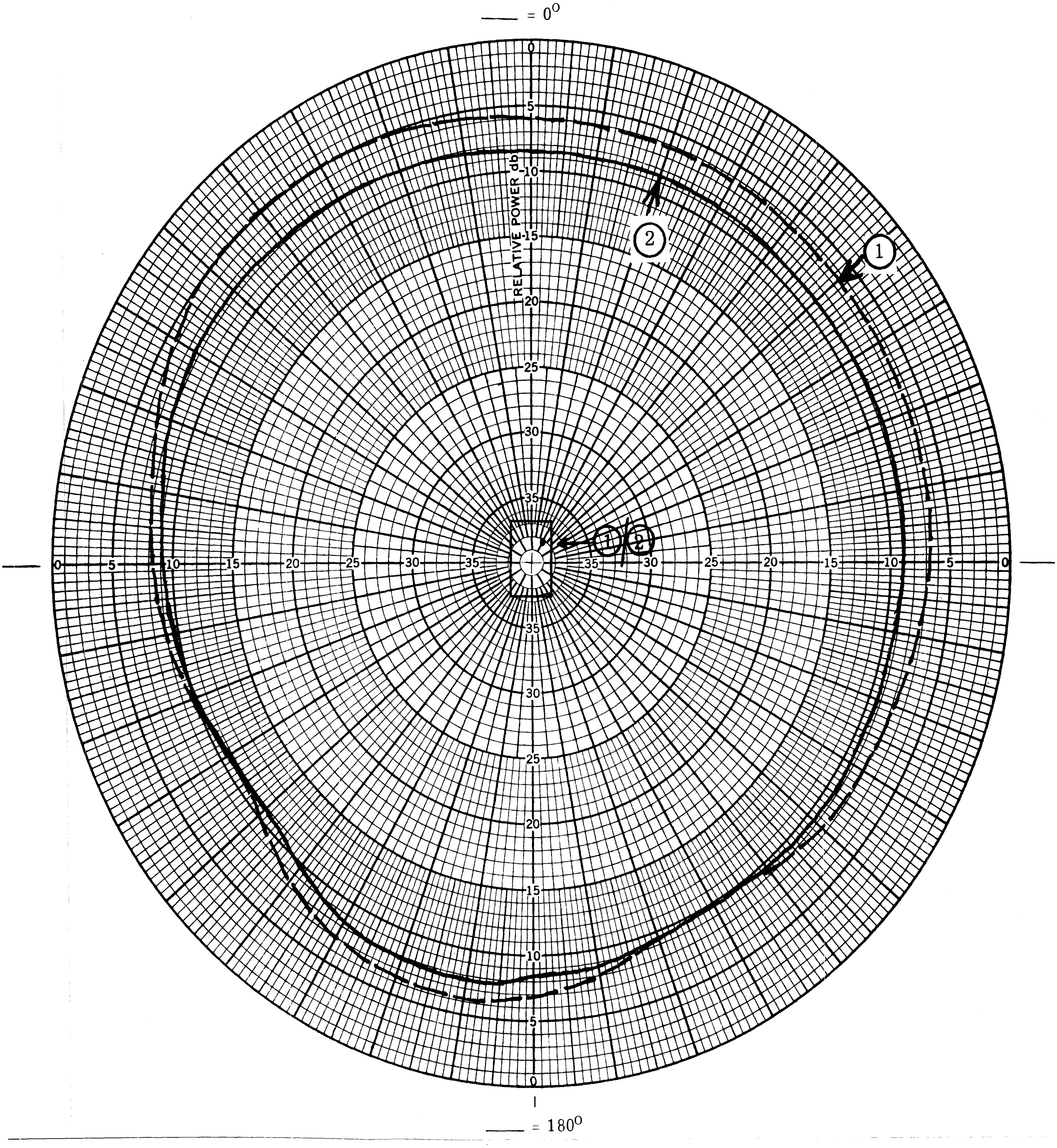


Figure 21 (a): FM patterns at 94 MHz for the FM reference and tuned Ward RP102-1 antennas on 1976 Gran Torino. (1) FM reference - (2) Ward RP102-1 (tuned).

Note: Test antenna No. 2 is fixed tri-band type.

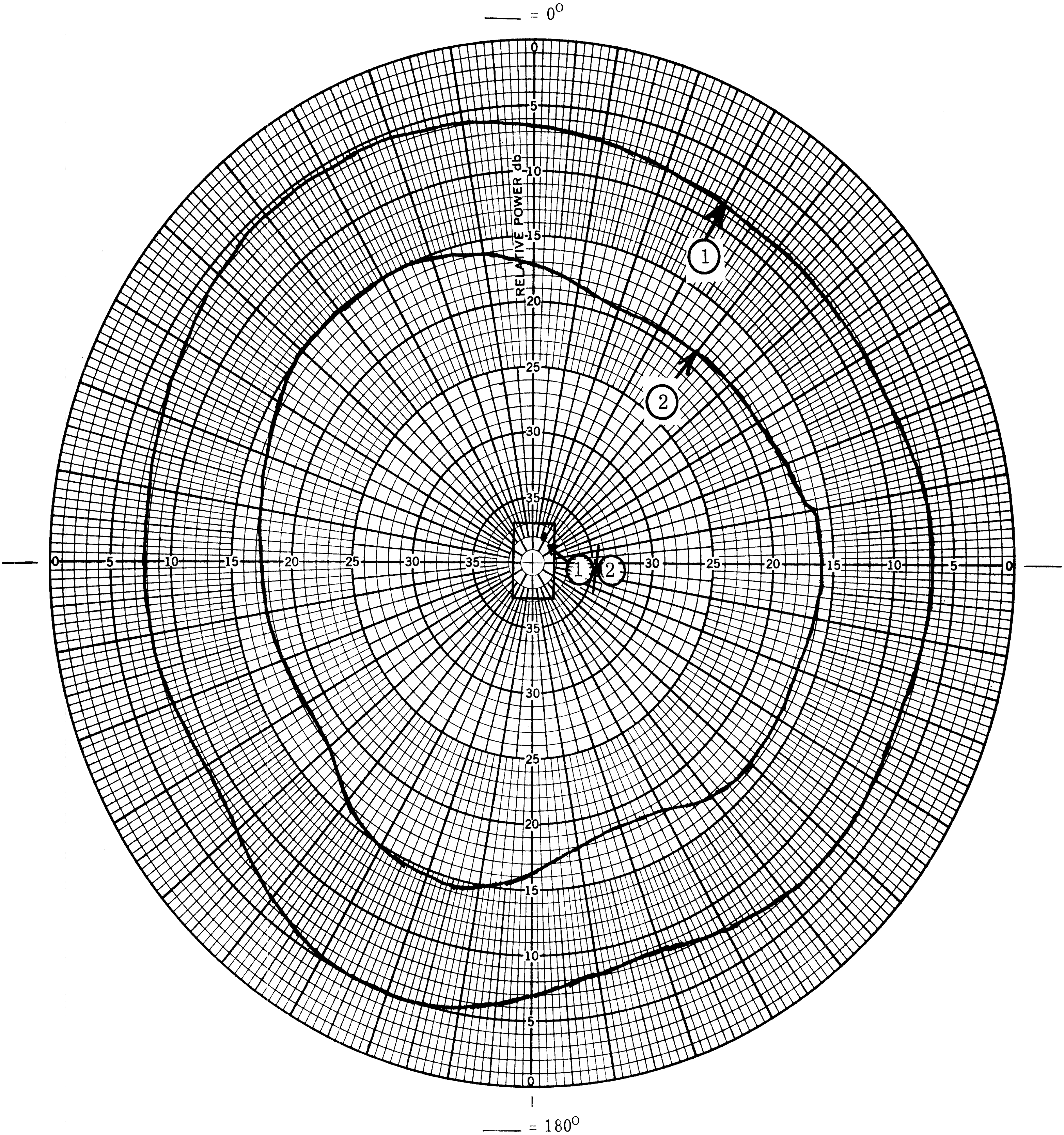
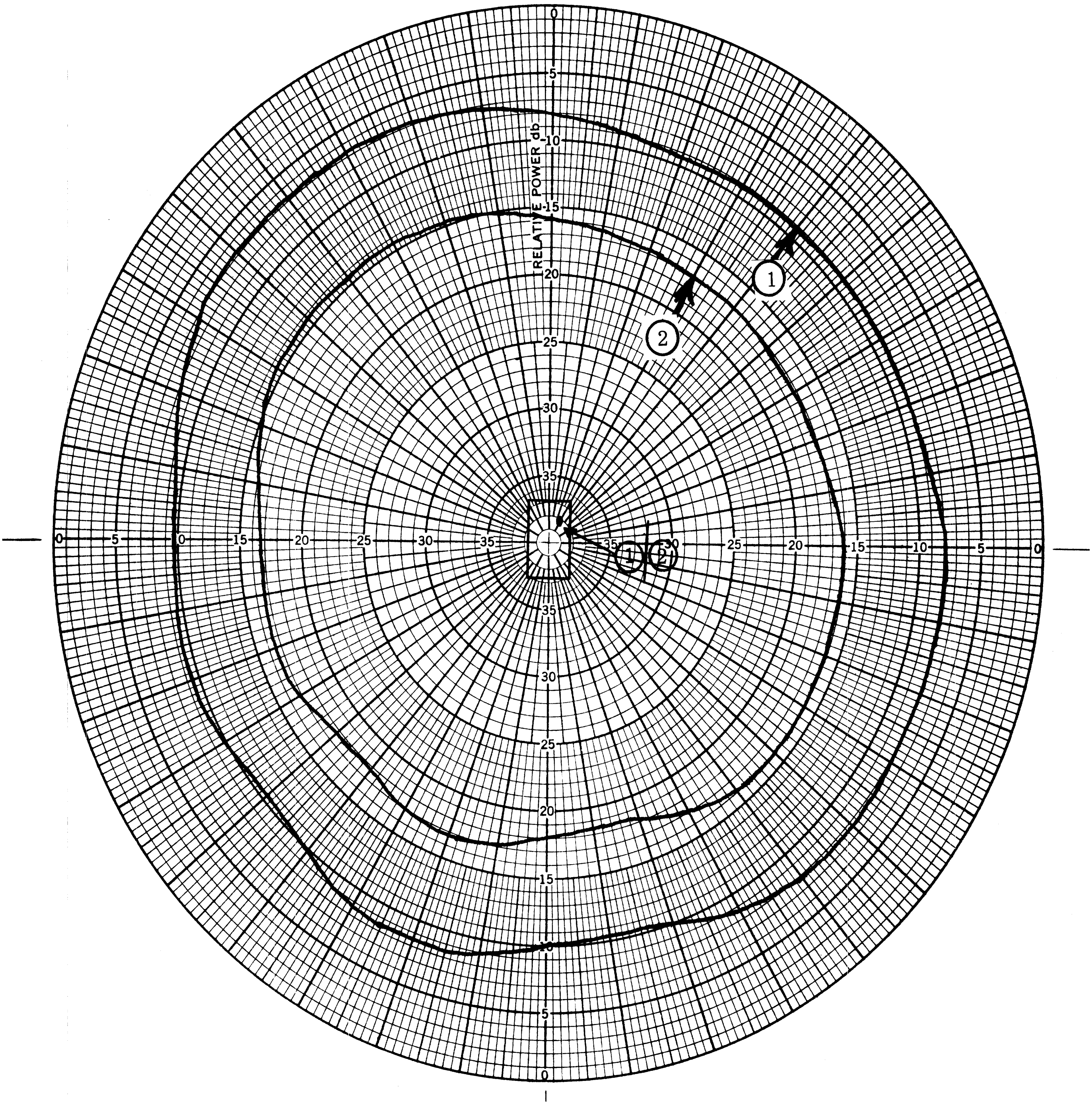


Figure 21 (b): FM patterns at 102.4 MHz for the FM reference and tuned Ward RP102-1 antennas on 1976 Gran Torino. (1) FM reference - (2) Ward RP102-1 (tuned).

Note: Test antenna No. 2 is fixed tri-band type.

—— = 0°



—— = 180°

Figure 21 (c): FM patterns at 108 MHz for FM reference and tuned Ward RP102-1 antennas on 1976 Gran Torino. (1) FM reference (2) Ward RP102-1 (tuned).

<u>Note</u>: Test antenna No. 2 is fixed tri-band type.

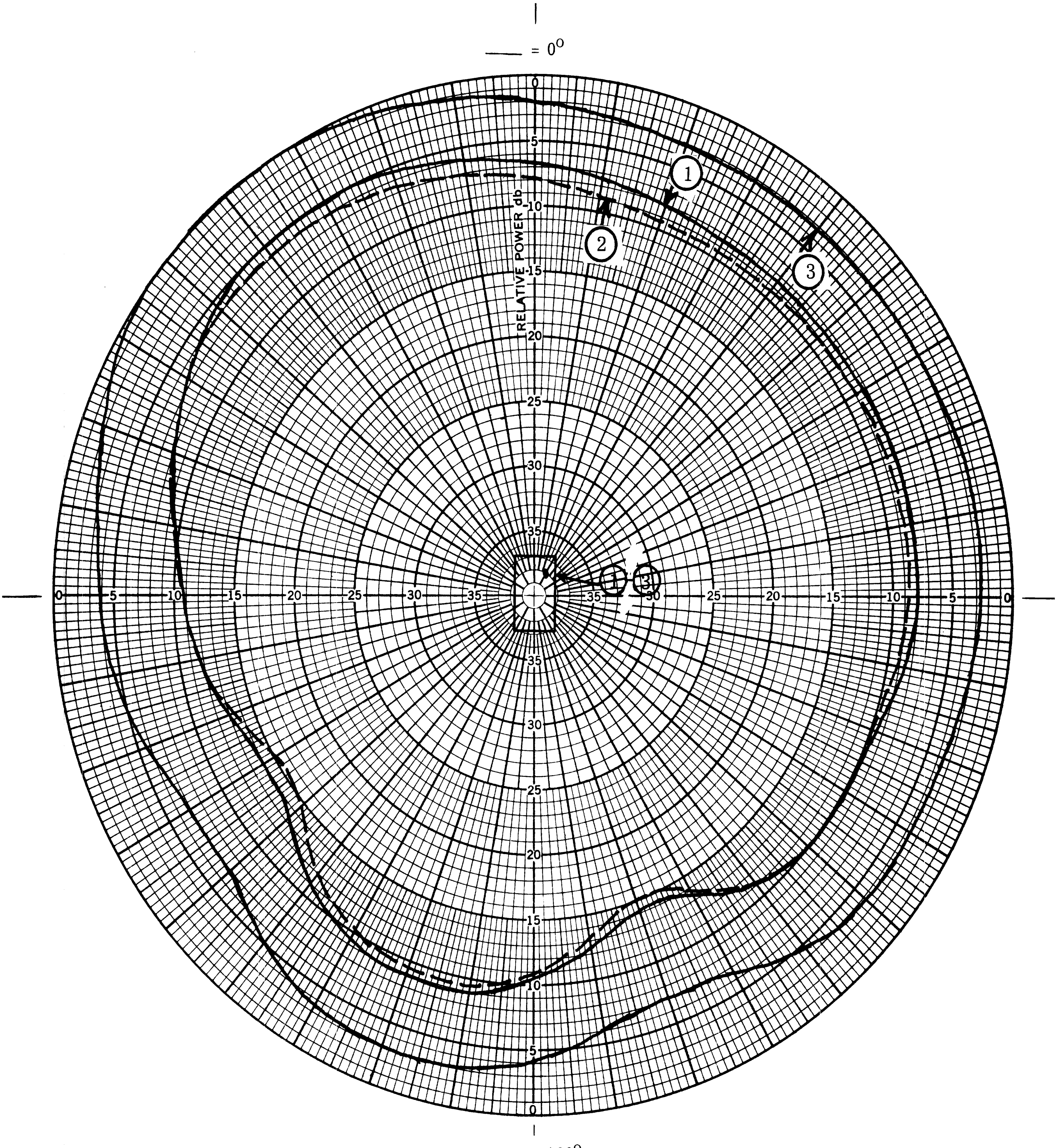


Figure 22 (a): FM patterns at 94.9 MHz for FM reference and two tuned antennas on 1976 Gran Torino. (1) FM reference, (2) Tenna 7-7-201 - (3) HY-Gain 426-X (tuned). Note - Subtract 10dB from the pattern level (3).

Note: Test antennas (2) and (3) are fixed tri-band type.

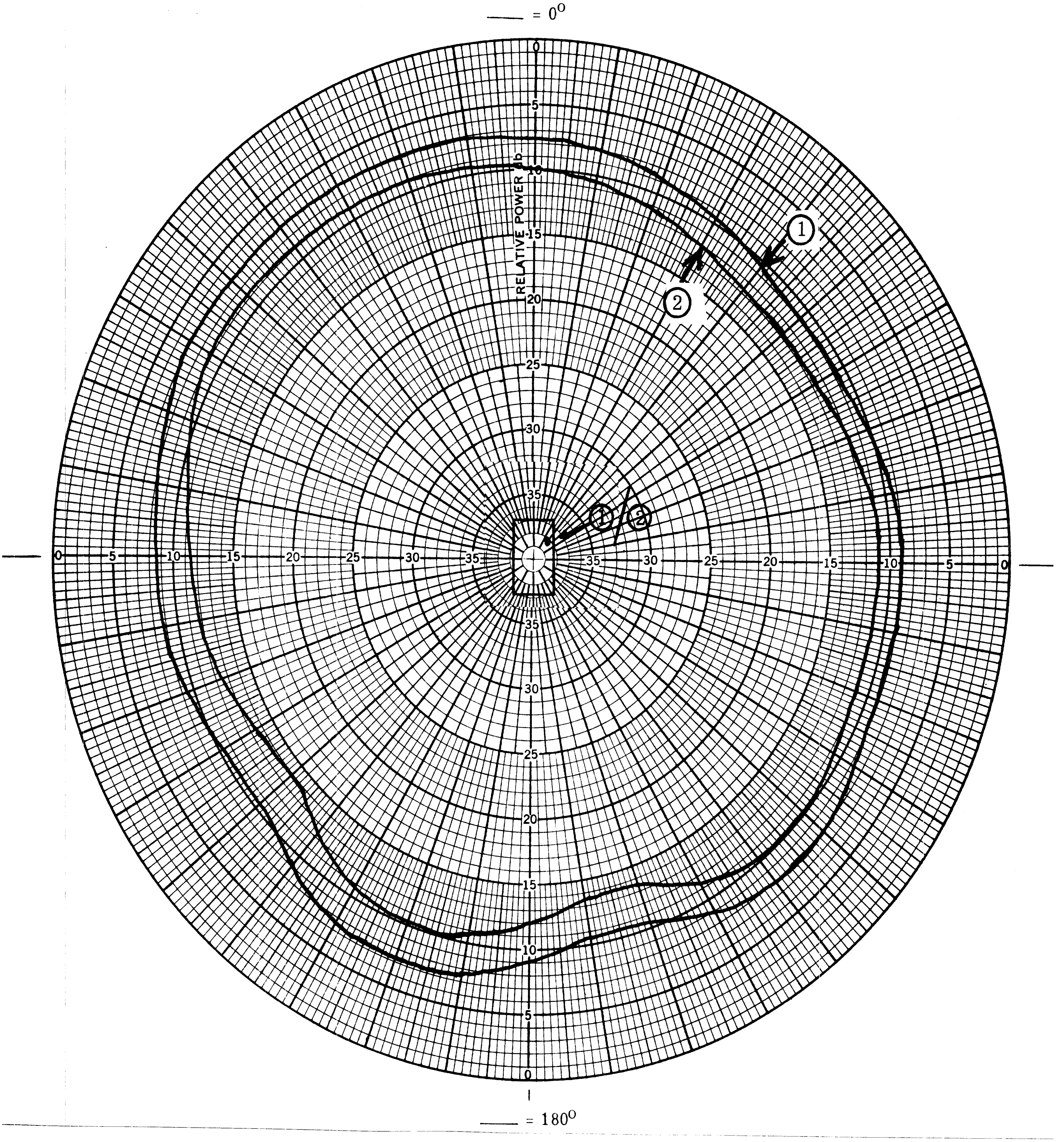


Figure 22 (b): FM patterns at 100.6 MHz for FM reference and tuned Tenna antennas on 1976 Gran Torino. (1) FM reference - (2) Tenna 7-7-201 (tuned).

Note: Test antenna No. 2 is fixed tri-band type.

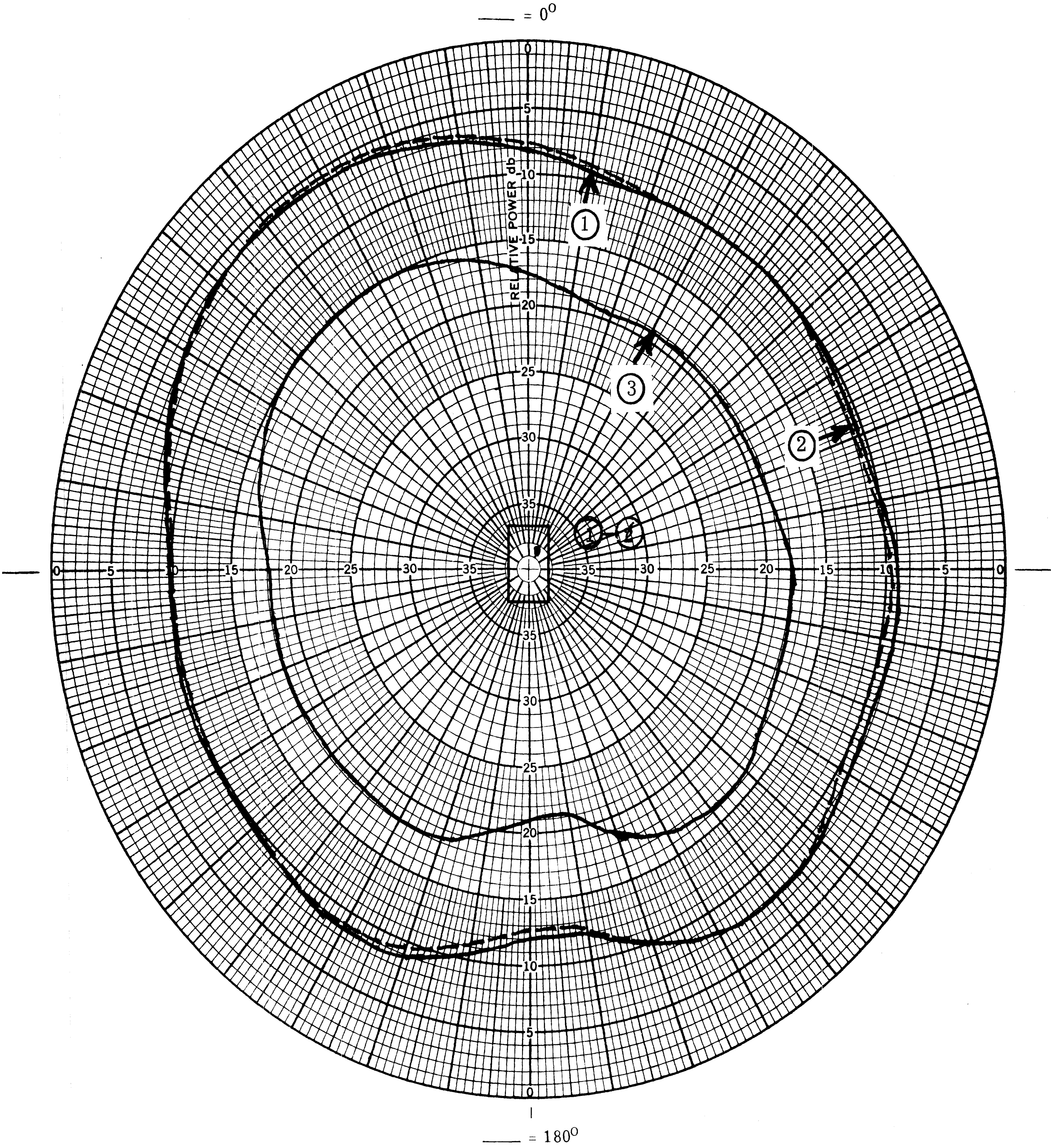


Figure 22 (c): FM patterns at 109 MHz for FM reference and two tuned test antennas. (1) FM reference - (2) Tenna 7-7-201 (tuned) (3) HY-Gain 426-X (tuned). Note from (3) subtract 10dB from the pattern level.

Note: Test antennas (2) and (3) are fixed tri-band type.

TABLE VII: AM band field strengths for antennas on the 1976 Gran Torino

Frequency → / Antenna ← Field Strength →	0.8 MHz	1.2 MHz	1.6 MHz
Ref	-28dB	-36dB	-43dB
Tenna 7-7-201 (tuned)	-26dB	-35dB	-41dB
HY-Gain 426-X (tuned)	-33dB	-40 dB	-47dB
Ref	-26dB	-35dB	-40dB
Ward RP102-1 (untuned)	-32dB	-40dB	-46dB
Ward Base-Loaded (tuned)	-24dB	-33dB	-38dB
Turner 4222-2	-32dB	-41dB	-46dB
Turner 4203-2	-39dB	-39dB	-44dB
HY-Gain 1426 tuned	-30dB	-39dB	-44dB
Antenna Specialists Fully Disguised	-30dB	-40dB	-45dB
Ref	-31dB	-40dB	-44dB
Ward RP102-1	-38dB	-47dB	-50dB

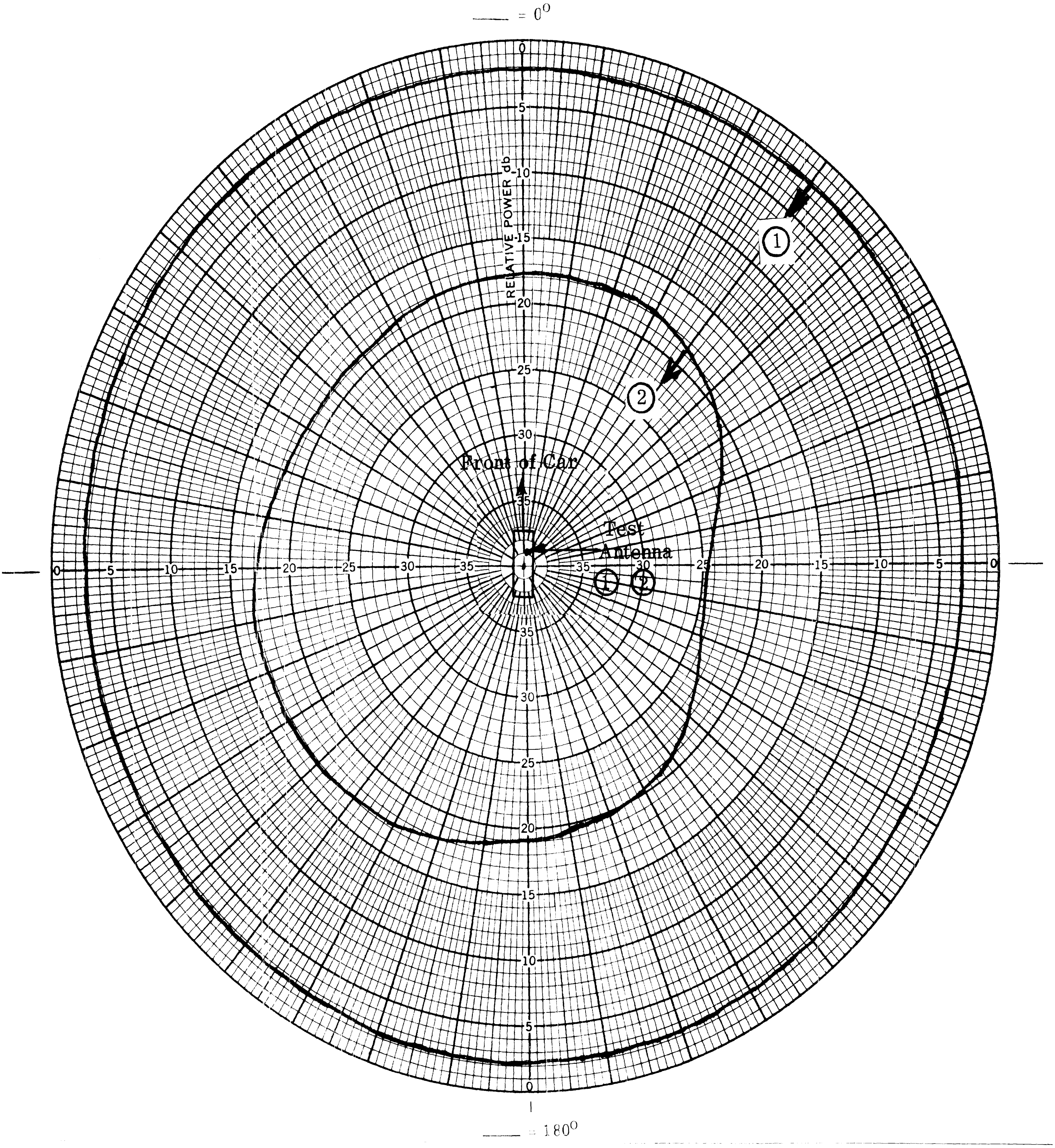


Figure 23 (a): CB Channel 1 patterns for λ/4 and Ward base loaded untuned antennas on 1976 Mustang II. Note - Divide the results by 2. (1) λ/4 - (2) Ward base loaded (untuned).

Note: Test antenna No. 2 is fixed tri-band type.

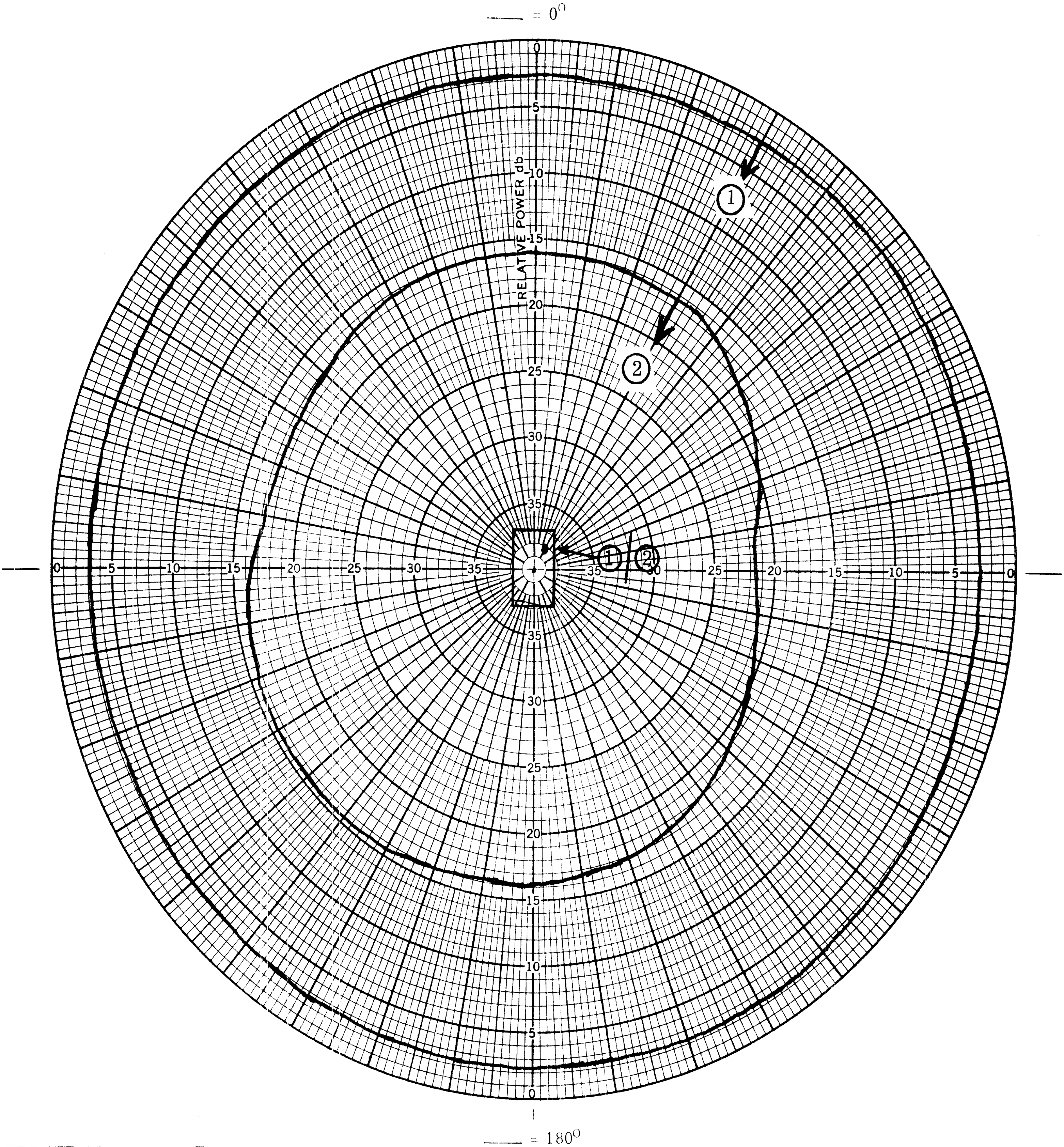


Figure 23 (b): CB Channel 11 patterns for $\lambda/4$ and Ward base-loaded untuned antennas on 1976 Mustang II. (1) $\lambda/4$ - (2) Ward Base loaded (untuned). Note- Divide the results by 2.

Note: Test antenna No. 2 is fixed tri-band type.

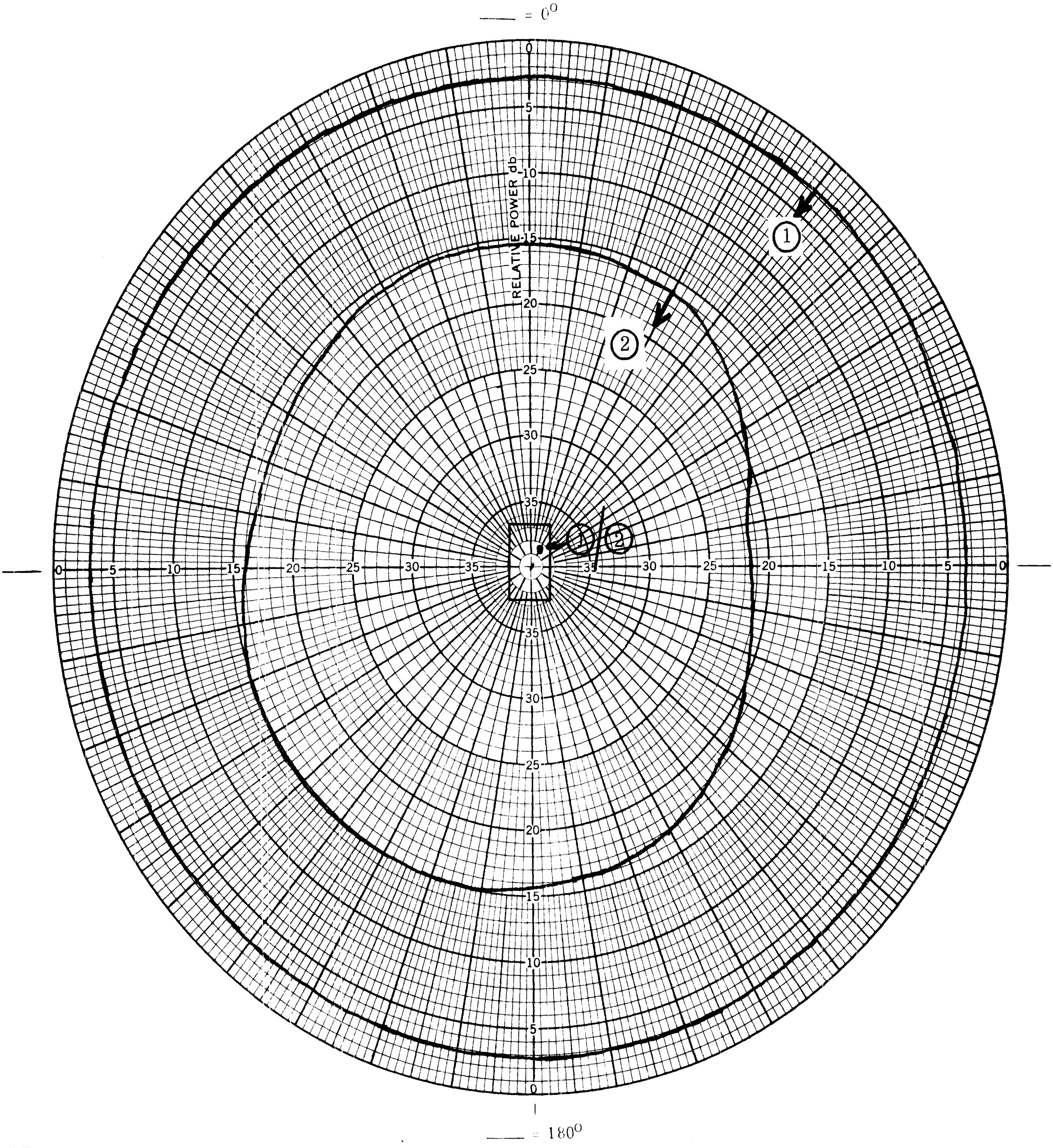


Figure 23 (c): CB Channel 23 patterns for $\lambda/4$ and untuned Ward base loaded antennas on 1976 Mustang II. (1) $\lambda/4$ - (2) Ward base loaded (untuned). Note- Divide the results by 2.

Note: Test antenna No. 2 is fixed tri-band type.

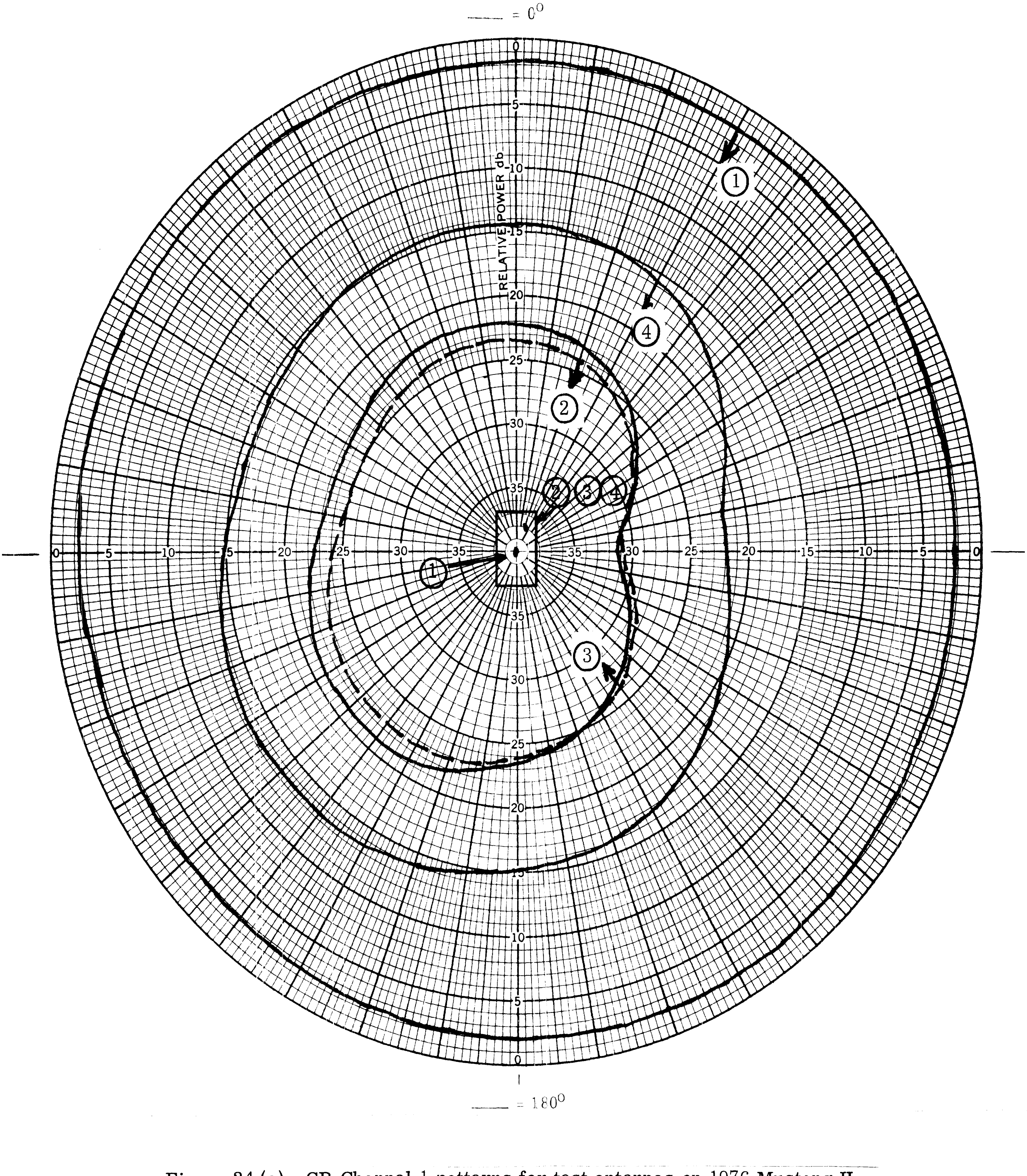


Figure 24 (a): CB Channel 1 patterns for test antennas on 1976 Mustang II. (1) λ/4 - (2) Antenna Specialists fully disguised - (3) Turner 4222-2 - (4) HY-Gain 426 (tuned). Note - Divide the results by 2.

Note: Test antennas (2) through (4) are fixed tri-band type.

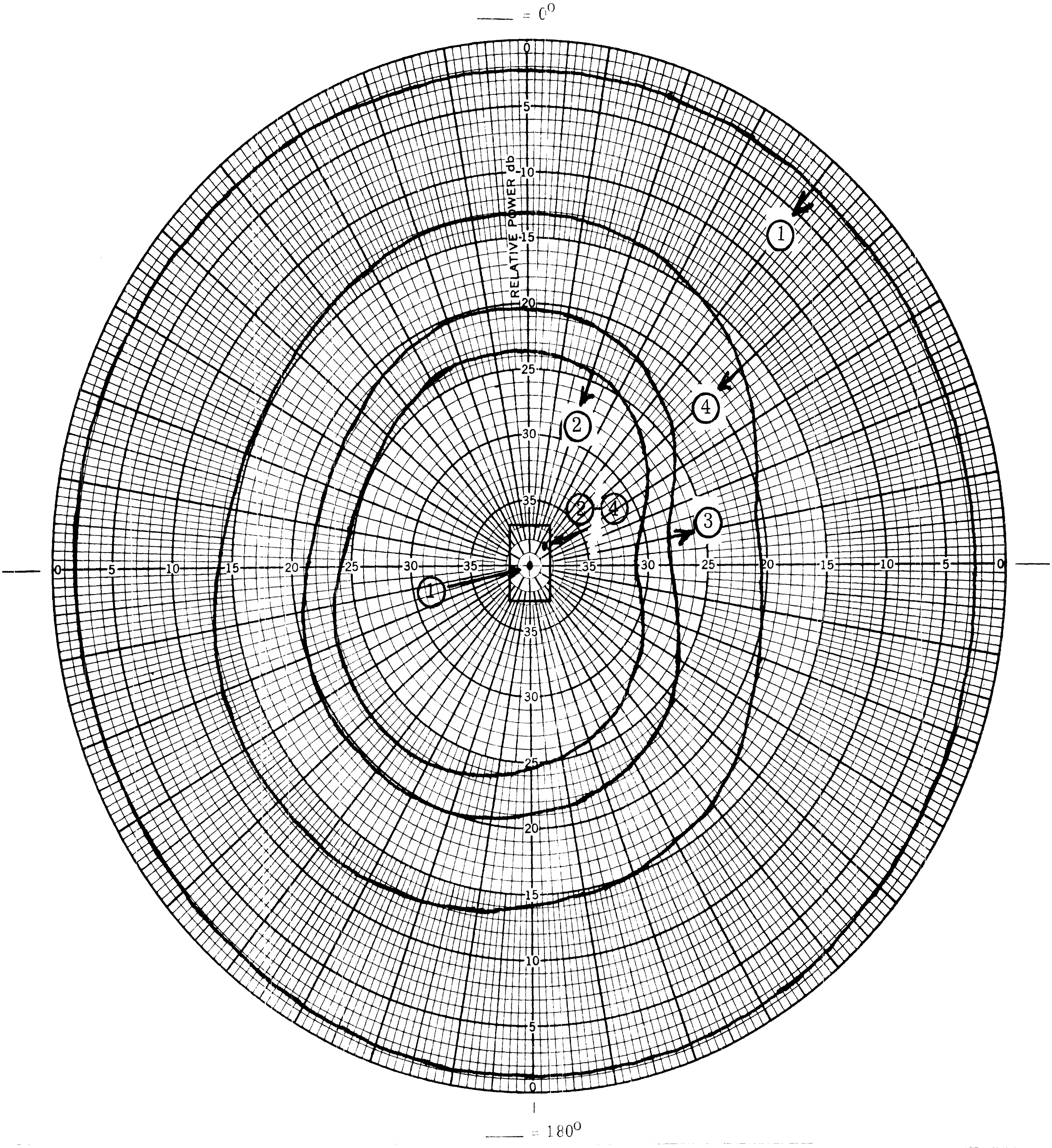


Figure 24 (b): CB Channel 11 patterns for test antennas on 1976 Mustang II (1) λ/4 - (2) Antenna Specialists fully disguised - (3) Turner 4222-2 - (4) HY-Gain 426 (tuned).

Note: Test antennas (2) through (4) are fixed tri-band type.

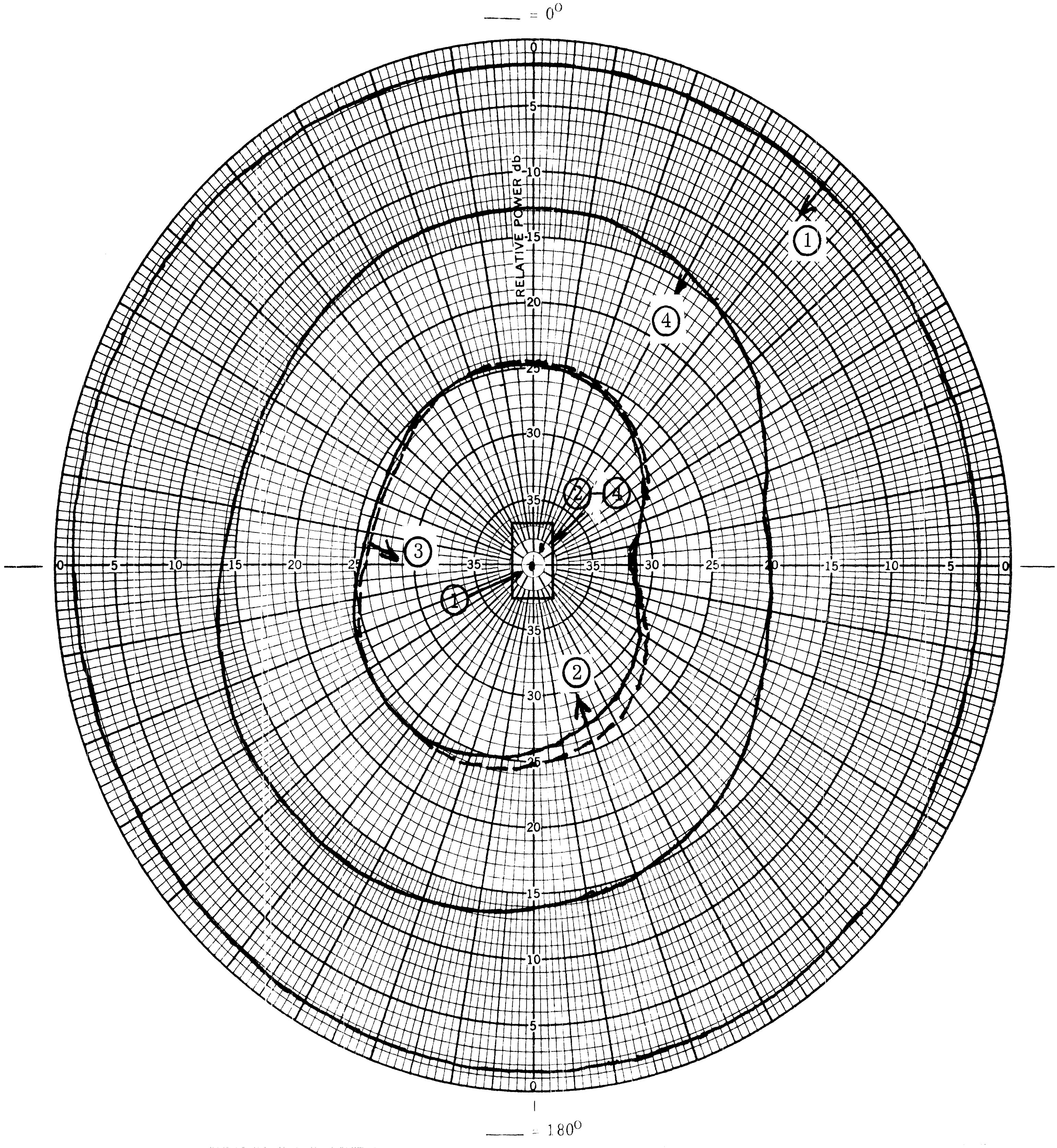


Figure 24 (c): CB Channel 23 patterns for test antennas on 1976 Mustang II. (1) λ/4 - (2) Antenna Specialists fully disguised - (3) Turner 4222-2 - (4) HY-Gain 426 (tuned). Note - Divide the results by 2.

Note: Test antennas (2) through (4) are fixed tri-band types.

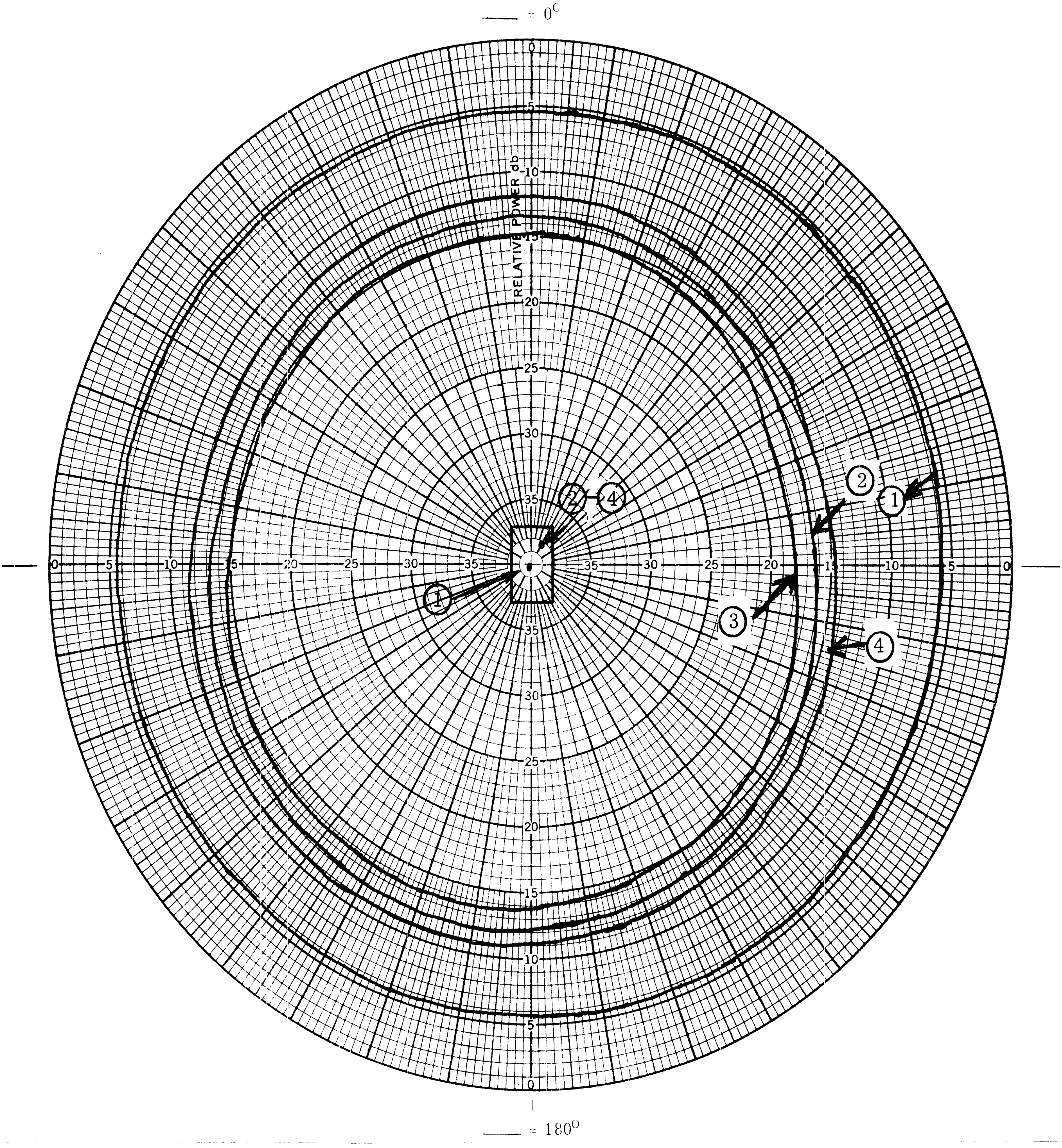


Figure 25 (a): CB Channel 1 patterns for $\lambda/4$ and three tuned test antennas on 1976 Mustang II (1) $\lambda/4$ - (2) Ward base-loaded - (3) Ward RP102-1 - (4) Tenna 7-7-201.

Note: Test antennas (2) through (4) are fixed tri-band type.

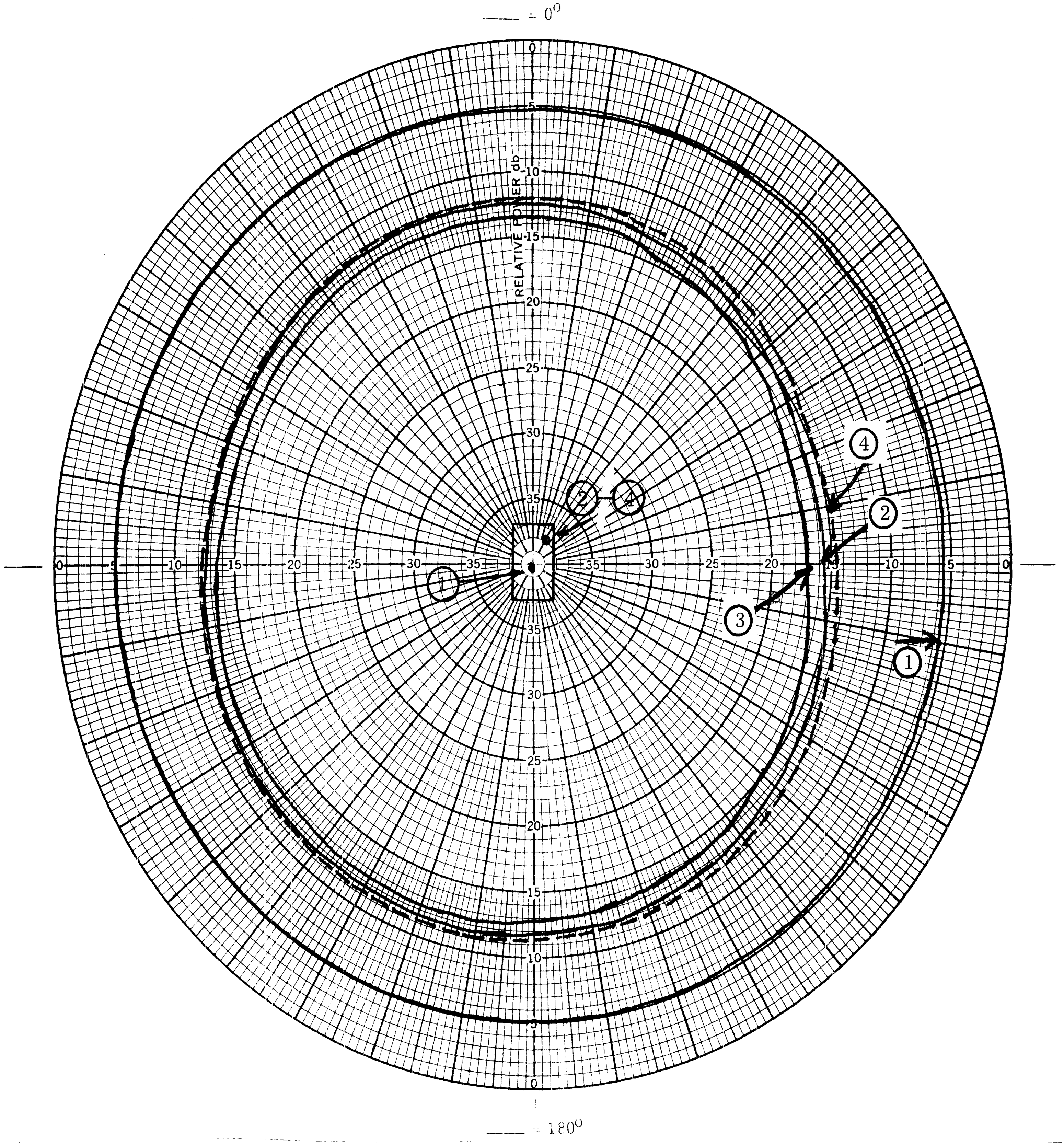


Figure 25 (b): CB Channel 11 patterns for λ/4 and three tuned test antennas on 1976 Mustang II (1) λ/4 - (2) Ward base loaded - (3) Ward RP102-1, (4) Tenna 7-7-201.

Note: Test antennas (2) through (4) are fixed tri-band type.

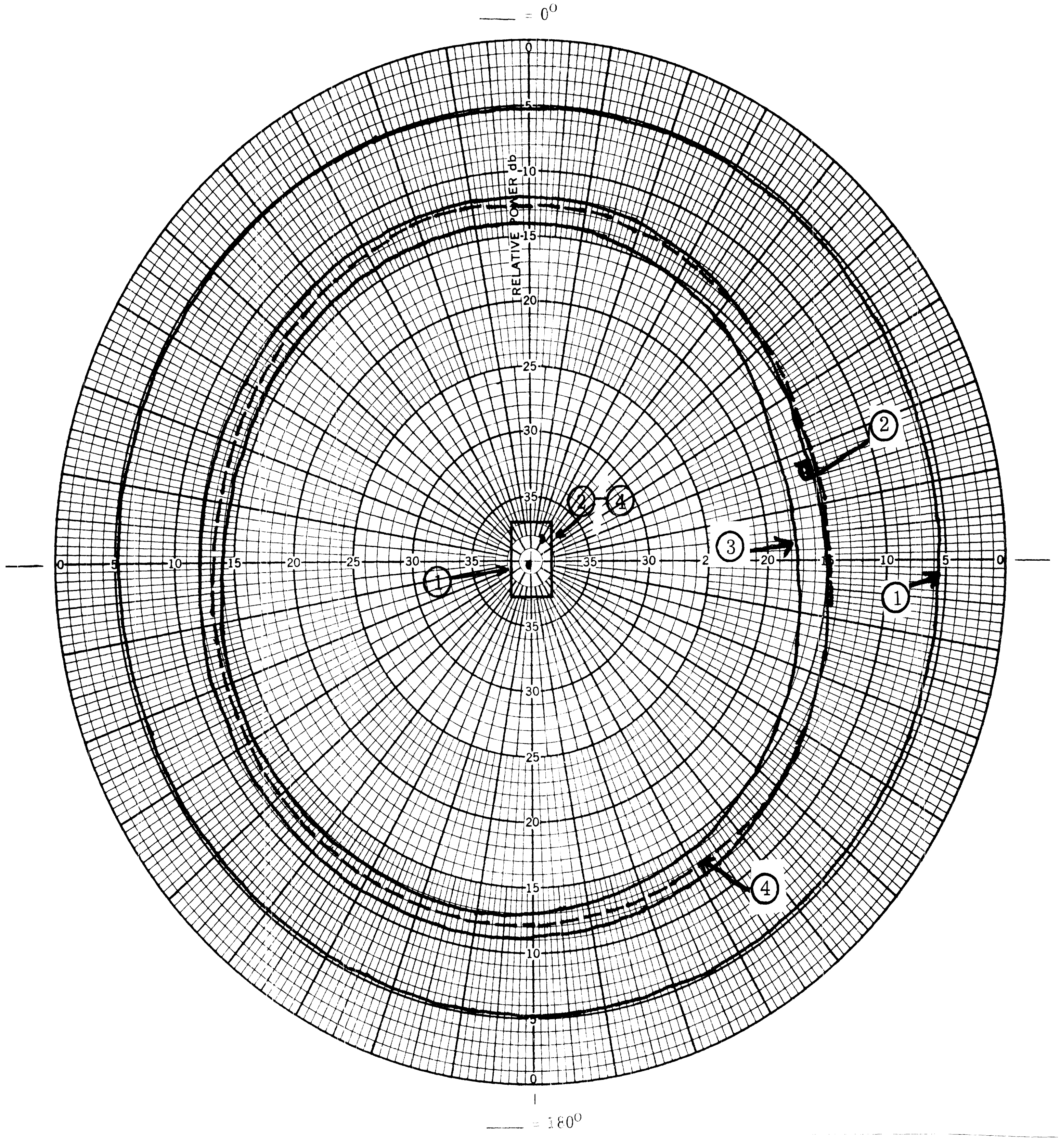


Figure 25 (c): CB Channel 23 patterns for λ/4 and three tuned antennas on 1976 Mustang II. (1) λ/4 - (2) Ward base-loaded - (3) Ward RP102-1 - (4) Tenna 7-7-201.

<u>Note:</u> Test antennas (2) through (4) are fixed tri-band type.

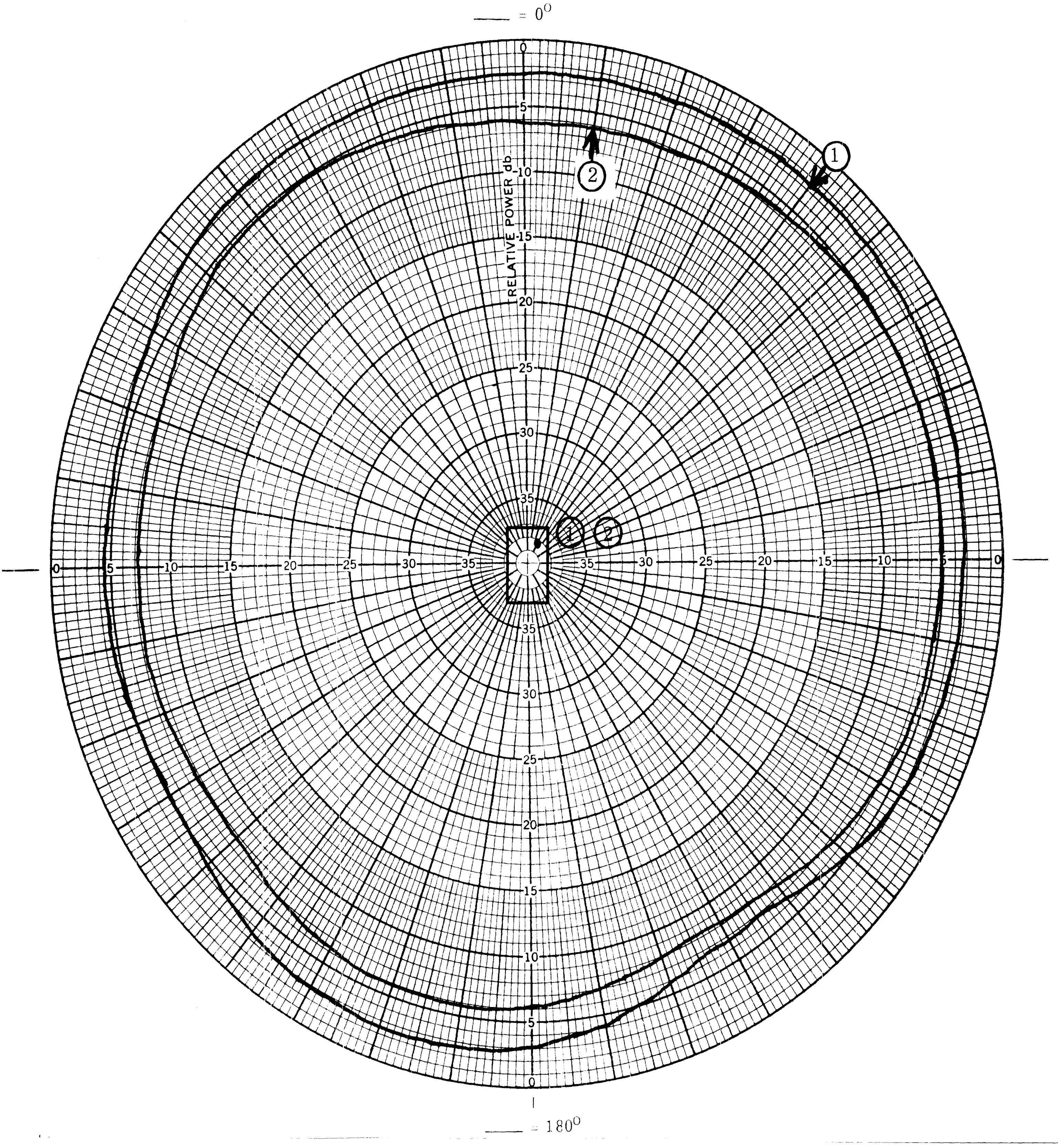


Figure 26 (a): FM patterns at 93.8 MHz for the FM reference and untuned Ward base-loaded antenna on 1976 Mustang II. (1) FM reference - (2) Ward base-loaded (untuned).

Note: Test antenna No. 2 is fixed tri-band type.

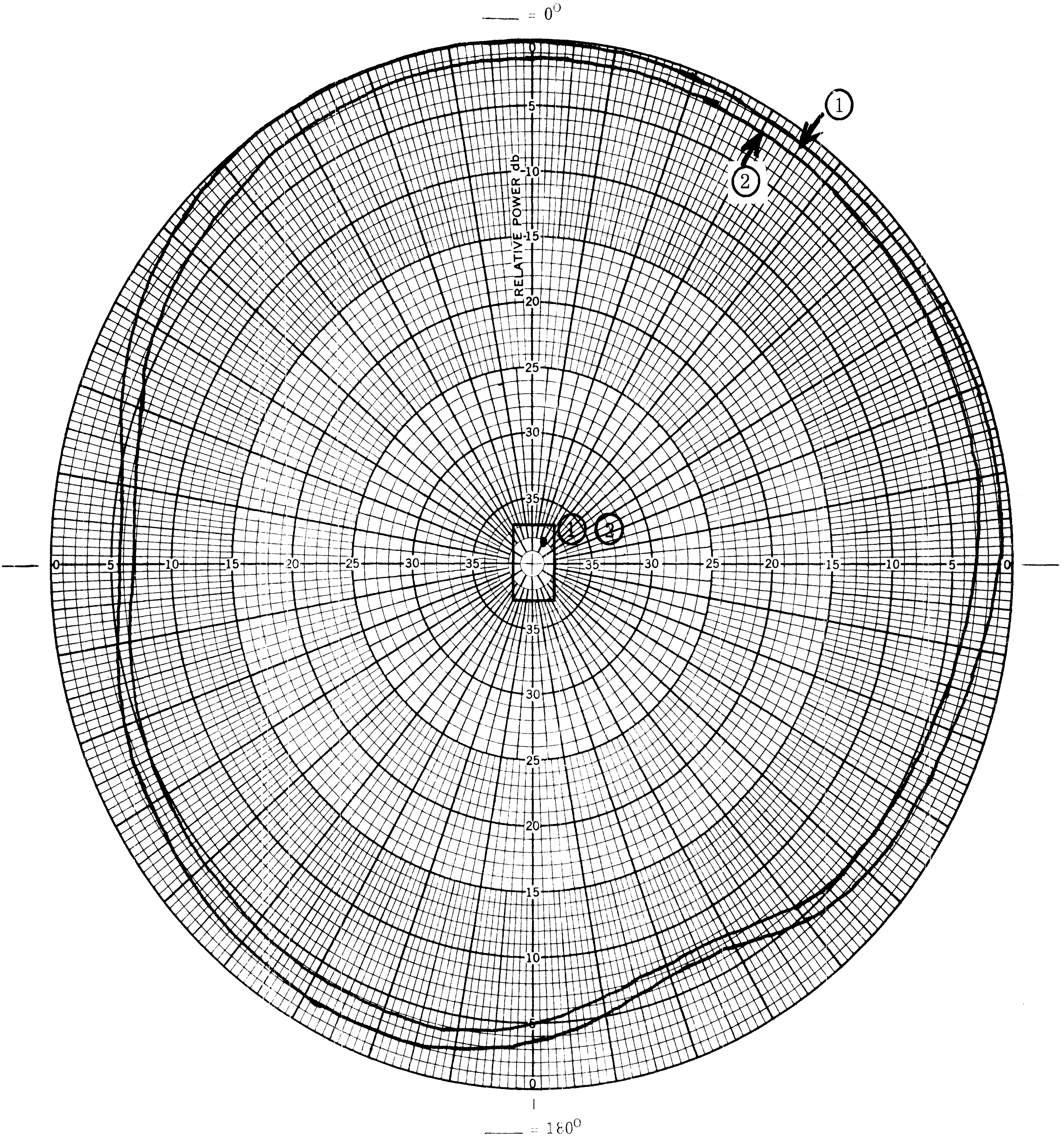


Figure 26 (b): FM patterns at 102.3 MHz for the FM reference and untuned Ward base loaded antennas on 1976 Mustang II. (1) FM reference - (2) Ward base loaded (untuned).

Note: Test antenna No. 2 is fixed tri-band type.

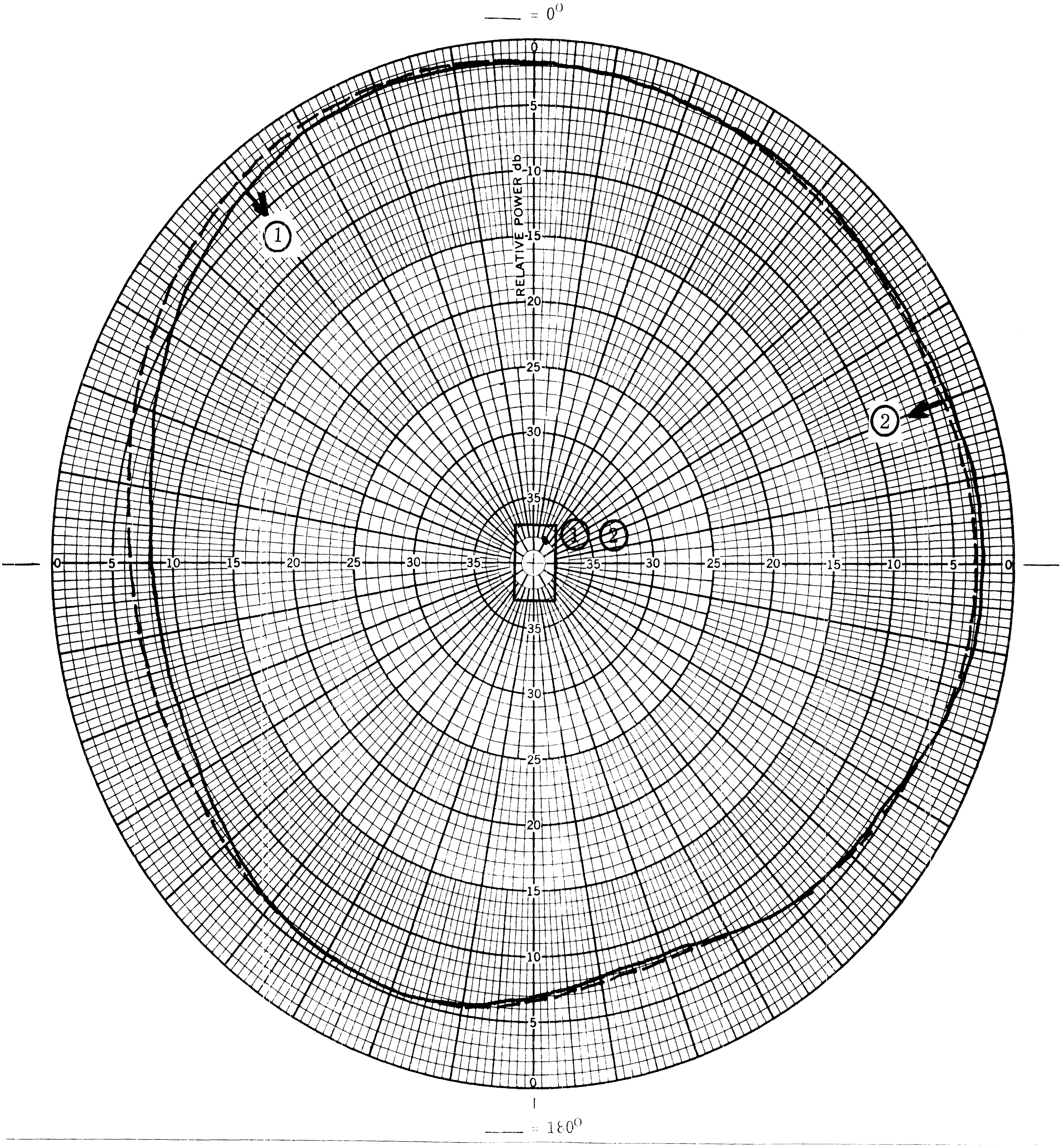


Figure 26 (c): FM patterns at 108 MHz for the FM reference and untuned Ward base loaded antennas on 1976 Mustang II. (1) FM reference - (2) Ward base-loaded (untuned).

<u>Note</u>: Test antenna No. 2 is fixed tri-band type.

Figure 27 (a)-(c) show the corresponding results for three other test antennas. Note that HY-Gain 426 antenna is tuned.

Figure 28 (a)-(c) show the FM patterns of three tuned antennas. Note that with the Ward RP102-1 in 28 (b), we were unable to measure the pattern due to low level of the received test signal compared to ambient FM signals.

The measured field strengths in the AM band for various antennas are shown in Table VIII.

Note the improved response of the Ward base-loaded antenna when tuned. In terms of the AM gain the test antenna made by Tenna appears to be best - this might be due to the longer length and better matching characteristics of the Tenna antenna.

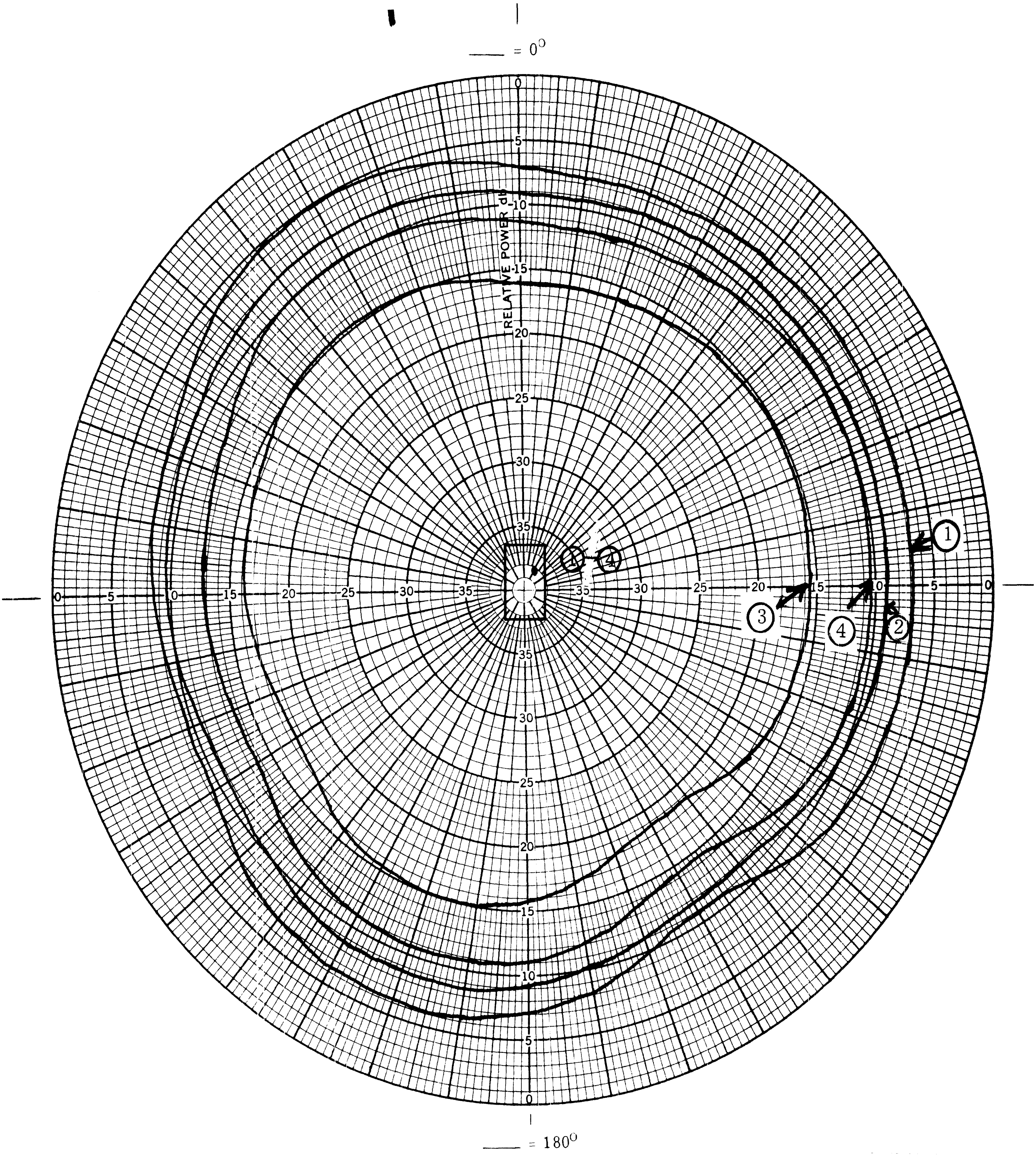


Figure 27 (a): FM patterns at 94 MHz for the FM reference and three test antennas on 1976 Mustang II. (1) FM reference - (2) Antenna Specialists fully disguised (untuned) - (3) HY-Gain 426 (tuned) - (4) Turner 4222-2.

Note: Test antennas (2) through (4) are fixed tri-band type.

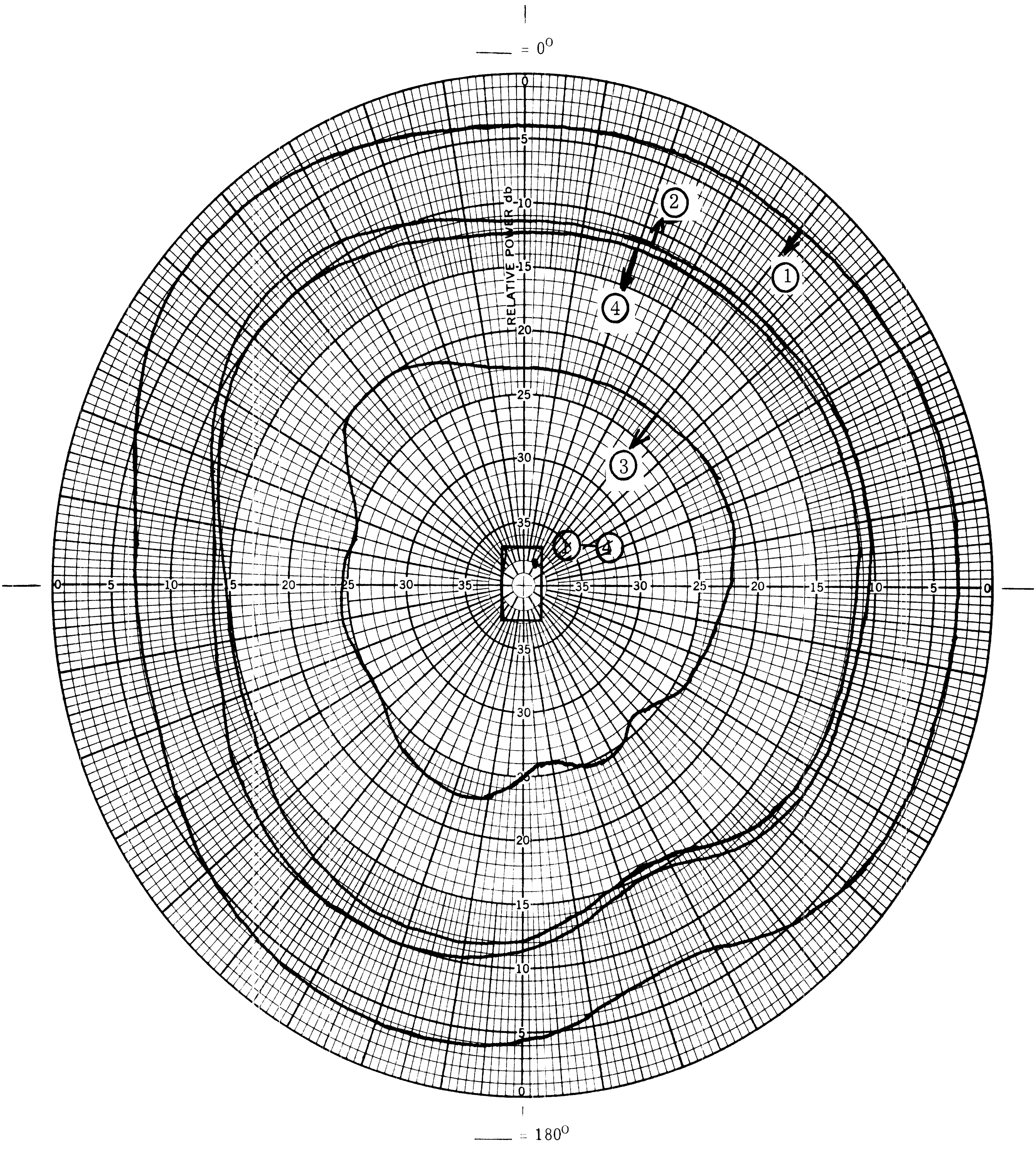


Figure 27 (b): FM patterns at 102 MHz for the FM reference and three test antennas on 1976 Mustang II. (1) FM reference - (2) Antenna Specialists fully disguised (untuned) - (3) HY-Gain 426 (tuned) (4) Turner 4222-2.

Note: Test antennas (2) through (4) are fixed tri-band type.

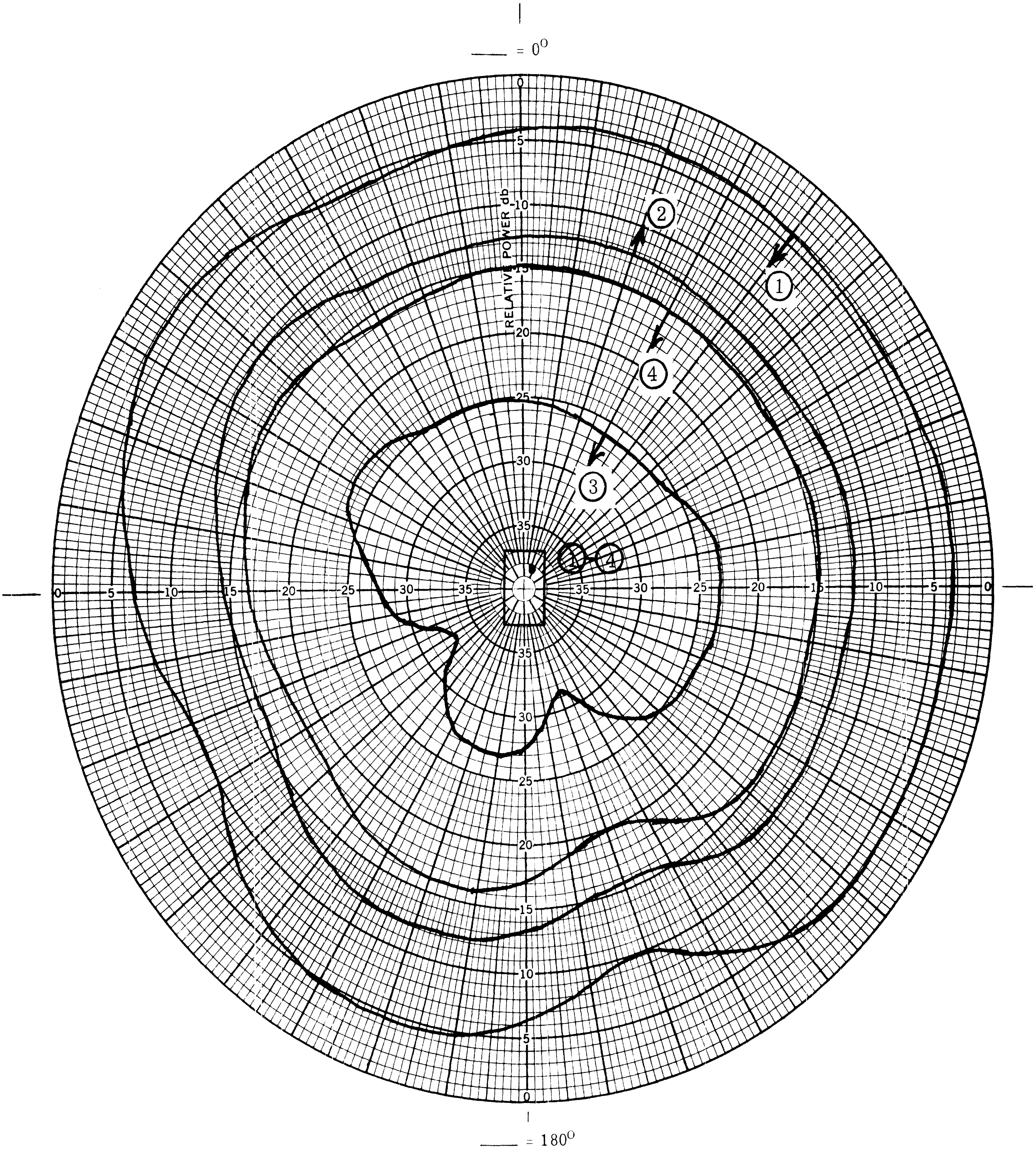


Figure 27 (c): FM patterns at 108 MHz for the FM reference and three test antennas on 1976 Mustang II. (1) FM reference - (2) Antenna Specialists fully disguised - (3) HY-Gain 426 (tuned) - (4) Turner 4222-2.

Note: Test antennas (2) through (4) are fixed tri-band type.

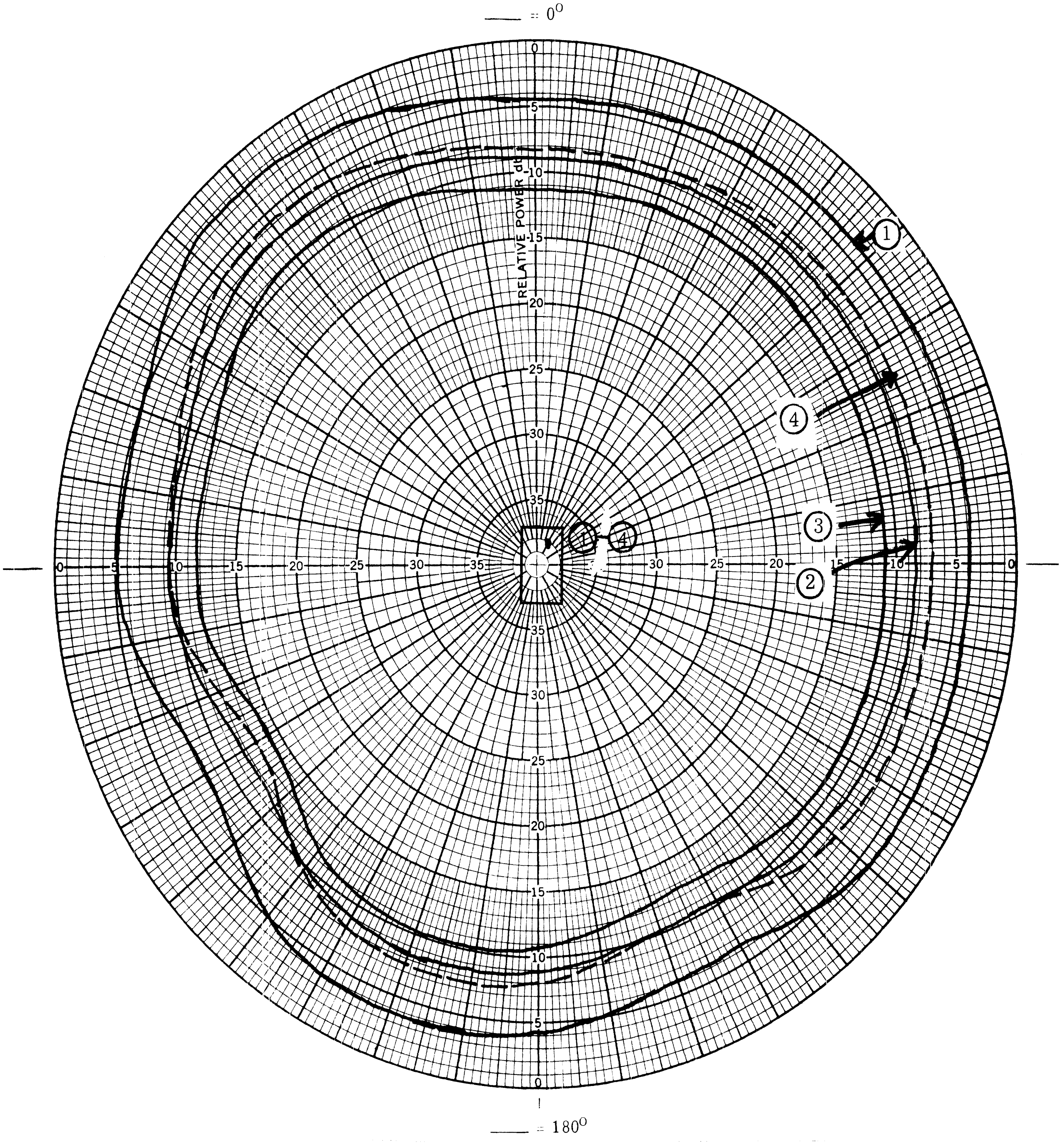


Figure 28 (a): Patterns at 95 MHz for the FM reference and three tuned test antennas on 1978 Mustang II. (1) FM reference (2) Ward (tuned) - (3) RP102-1 (tuned) - (4) Tenna 7-7-201 (tuned).

Note: Test antennas (2) through (4) are fixed tri-band type.

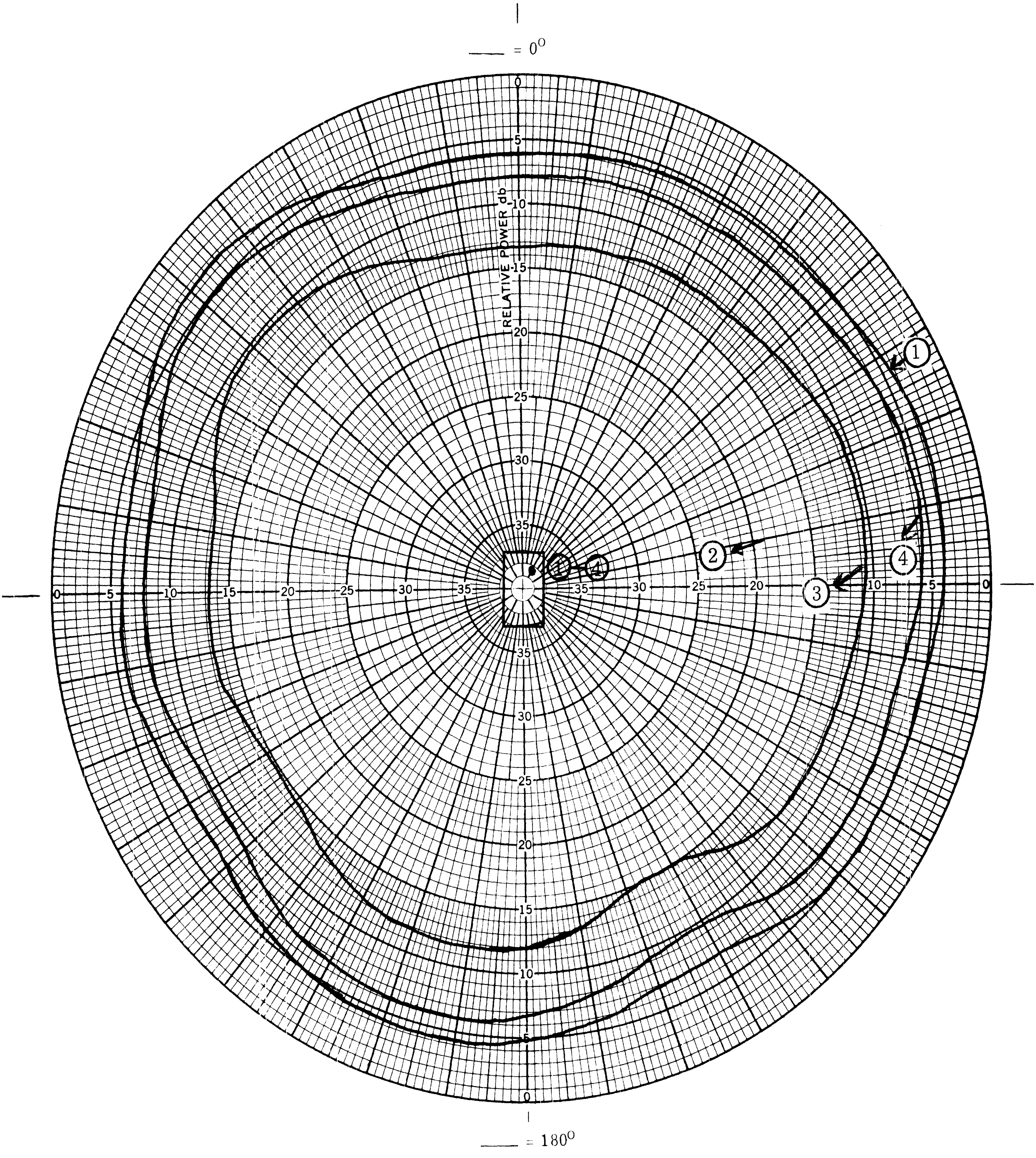


Figure 28 (b): FM patterns at 102.7 MHz for the FM reference and three tuned test antennas on 1976 Mustang II. (1) FM reference - (2) Ward base loaded (tuned) - (3) Ward RP102-1 (pattern not possible to take) - (4)Tenna 7-7-201 (tuned).

Note: Test antennas (2) through (4) are fixed tri-band type.

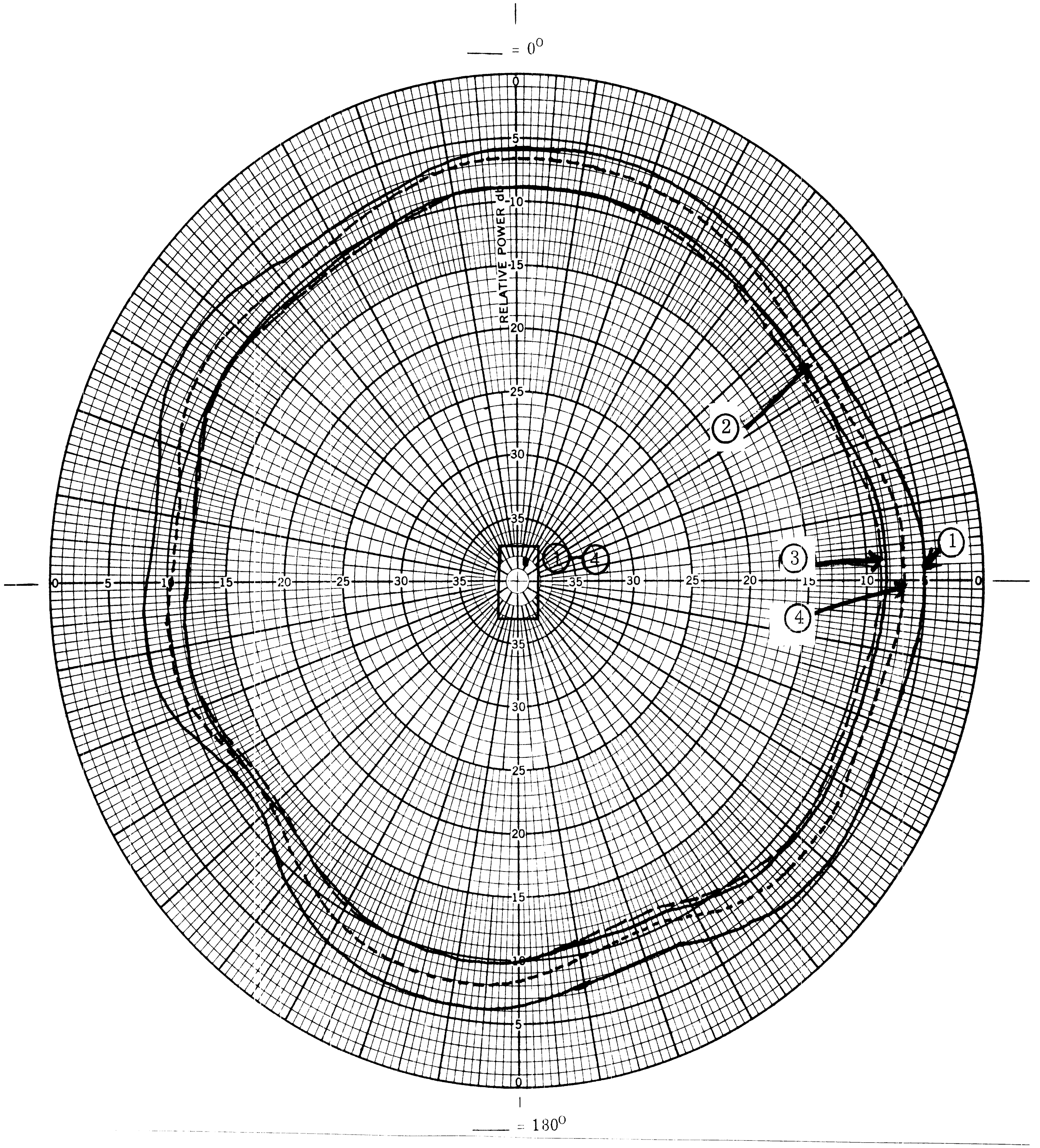


Figure 28 (c): FM patterns at 108 MHz for the FM reference and three tuned test antennas on 1976 Mustang II. (1) FM reference - (2) Ward base-loaded (tuned) - (3) Ward RP102-1 (tuned) - (4) Tenna 7-7-201 (tuned).

Note: Test antennas (2) through (4) are fixed tri-band type.

Table VIII: AM field strengths received by antennas in the 1976 Mustang II.

AM Frequency → / Antenna ↓	0.8 MHz	1.2 MHz	1.6 MHz
	← Field Strength →		
Ford Reference	-22 dB	-31dB	-40dB
HY-Gain (426-X1) (tuned)	-28dB	-36dB	-42dB
Ward RP102-1 (tuned)	-37dB	-44dB	-52dB
Ward Base Loaded (tuned)	-22dB	-31dB	-40dB
Tenna 7-7-201 (tuned)	-20dB	-26dB	-34dB

	0.8 MHz	1.1 MHz	1.6 MHz
Ford Reference	-30dB	-36dB	-32dB
HY-Gain 426 tuned	-36dB	-50dB	-48dB
Ant. Spec. Fully Disguised (tuned)	-36dB	-50dB	-48dB
Ward Base Loaded (untuned)	-30dB	-45dB	-42dB
Turner 4222-2	-40dB	-55dB	-53dB

VII

RELATIVE SENSITIVITY OF TEST ANTENNAS

In this section we discuss the sensitivity of various test antennas relative to standard reference antennas. The method of obtaining the sensitivity loss of a given antenna from the measured patterns has been discussed in Section IV and will not be repeated. For convenience we use the convention that if the relative sensitivity loss is a positive quantity, it signifies that the test antenna is less sensitive than the reference antenna, and vice versa if the sensitivity loss is negative. Note that the reference antenna for the CB results is $\lambda/4$ monopole and for the FM and AM results the reference antenna is the Ford entertainment radio antenna.

7.1 1976 Continental Mark IV and 1976 Lincoln Continental Results

The sensitivity losses of the various CB antennas on the 1976 Continental Mark IV and 1976 Lincoln Continental cars are shown in Table IX.

Table IX: Sensitivity losses of test antennas on 1976 Continental Mark IV and 1976 Lincoln Continental cars

Car ↓	Frequency → / Antenna ↓	CB Channels No. 1	CB Channels No. 11	CB Channels No. 23	FM Frequency MHz 93.7	FM Frequency MHz 102.8	FM Frequency MHz 108	AM Frequency MHz 0.8	AM Frequency MHz 1.2	AM Frequency MHz 1.6
		← Relative Sensitivity Loss (dB) →								
Mark IV	Power CB	6.63	6.30	6.83	-	-	-	-	-	-
Lincoln Continental	Power CB	7.27	6.60	7.25	-	-	-	-	-	-
Lincoln Continental	Power Tri-band	7.25	6.35	5.93	11.60	0.95	1.47	6	6	4

Some of the results in Table IX are shown graphically in Figures 29 and 30. The performance of the power CB antennas on the two cars appears to be quite similar although the loss in the Continental appears to be slightly more. This may be attributed to the longer cable length used for the antenna input in the Continental.

7.2 1976 Gran Torino Results

Table X summarizes the sensitivity losses of all the test antennas mounted in the 1976 Gran Torino and for CB, FM and AM bands. The results in this table may be used to make a comparative judgement of any antenna performance at different bands and also for comparing the performance of different antennas; a gap signifies that no data was collected. For FM bands note that the frequencies of measurement were slightly different for some groups of antennas. (This was due to the fact that results were taken during different periods of time). Also some FM results do not appear because that antenna sensitivity was so low so that meaningful patterns could not be obtained due to the interference of local ambient FM signals.

Figures 31 and 32 show the plots of CB sensitivity results for tuned and untuned antennas on the 1976 Gran Torino. Figures 33 and 34 show the FM and AM sensitivity of test antennas on the 1976 Gran Torino.

7.3 1976 Mustang II Results

Table XI summarizes the sensitivity losses of all the test antennas mounted on the 1976 Mustang II and for CB, FM and AM band frequencies.

The CB sensitivity losses of four tuned antennas on the 1976 Mustang II are shown in Figure 35. Figures 36 and 37 show the FM and AM sensitivity losses associated with test antennas mounted on the 1976 Mustang II.

The results indicate that the Ward and Tenna antennas perform uniformly better in all the three bands. The Ward RP102-1 antenna appears to have comparable performance at CB and FM frequencies but it is inferior at the AM frequencies. In general, all the antennas except Antenna Specialist fully disguised and Turner antennas appear to have comparable sensitivity at CB frequencies.

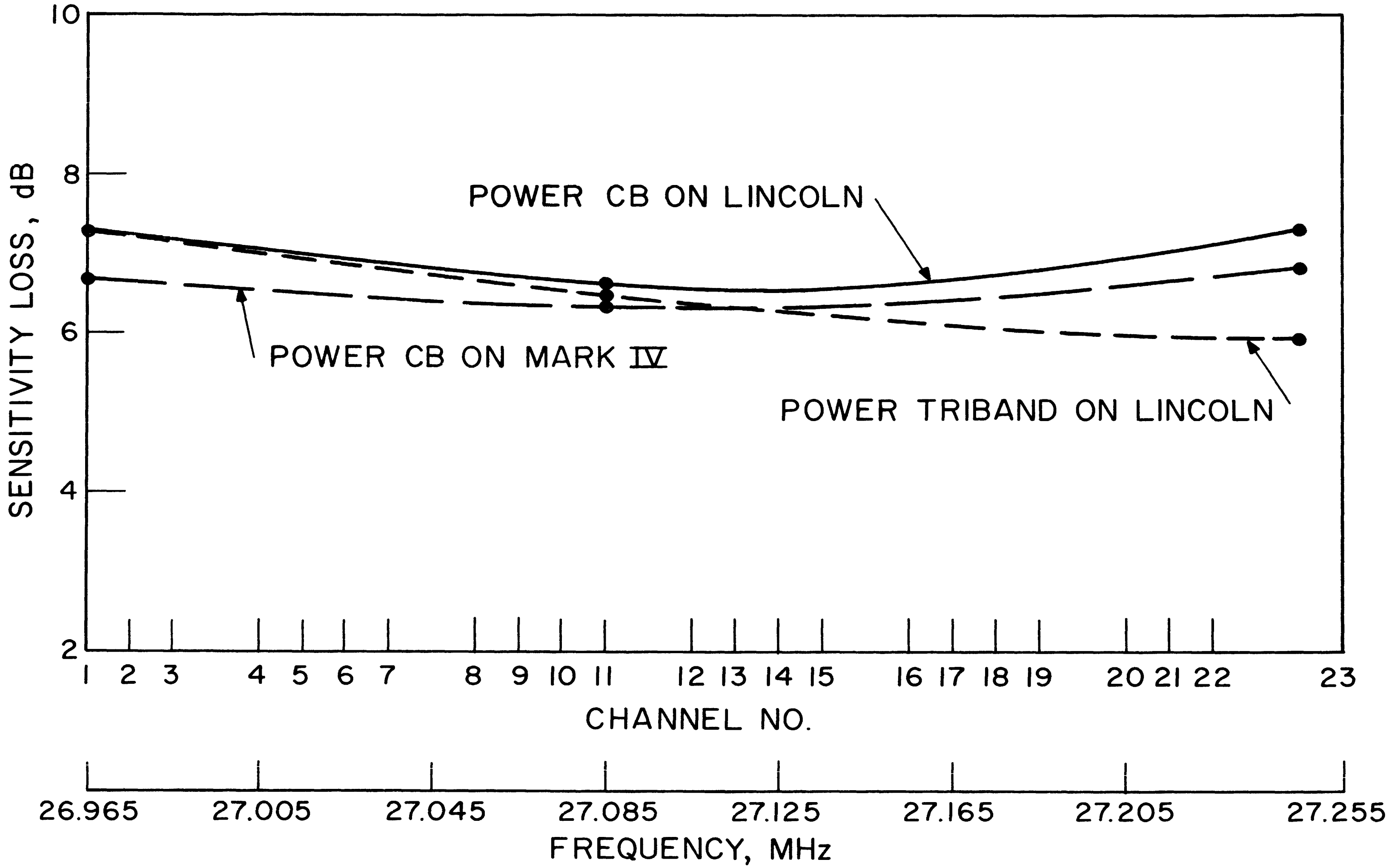


Figure 29: CB sensitivity loss of test antennas on 1976 Continental Mark IV and 1976 Lincoln Continental.

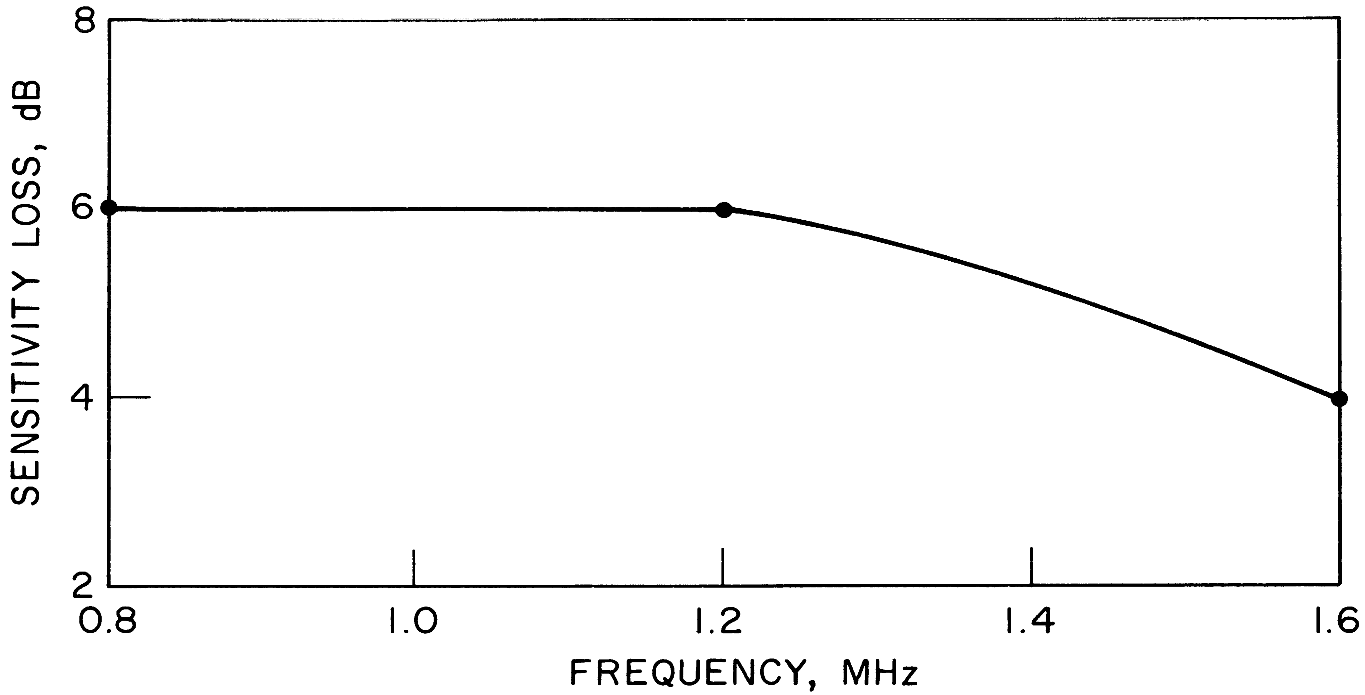


Figure 30: AM sensitivity loss of power tri-band antenna on Lincoln Continental.

Table X: Sensitivity loss at CB, FM and AM band mounted for test antennas on the 1976 Gran Torino

Antenna Type	Sensitivity Loss (dB) At CB Frq. MHz			At FM Freq. MHz			At AM Freq. MHz		
	Ch.1	11	23	96	102.3	108	0.8	1.2	1.6
Ward Base Loaded (untuned)	8.58	8.43	8.73	-	-	-	-	-	-
Ward Base Loaded (tuned)	8.18	8.28	7.77	3.95	3.45	6.90	-2	-2	-2
Turner 4222-2	13.50	15.85	18.73	6.30	5.60	4.17	6	6	6
Turner 4203-2	10.25	11.10	14.18	3.40	8.2	7.6	13	12	12
		FM Frequency		95.8	102.8	108			
Ward RP102-2 (untuned)	10.98	9.60	8.58	5.35	5.23	6.37	6	5	6
HY-Gain 426 (tuned)	6.93	6.95	8.2	4.78			4	4	4
Ant. Spec. Fully Dis.	27.88	26.55	24.08	-1.52	2.43	4.82	4	5	5
		FM Frequency		94	102.4	108			
Ward RP102-2 tuned	9.9	9.4	9.35	1.28	8.58	7.75	7	7	6
		FM Frequency		94.9	100.6	109			
Tenna 7-7-201	5.73	5.72	6.80	0.68	2.50	0.23	-2	-1	-2
HY-Gain 426-X tuned	8.23	8.15	8.93	4.33			5	4	4
Riverside CB only	7.33	6.75	6.25	-	-	-	-	-	-
Antenna Spec. CB only	6.90	6.92	7.65	-	-	-	-	-	-

Note: All test antennas are fixed tri-band type, unless designated as "CB only".

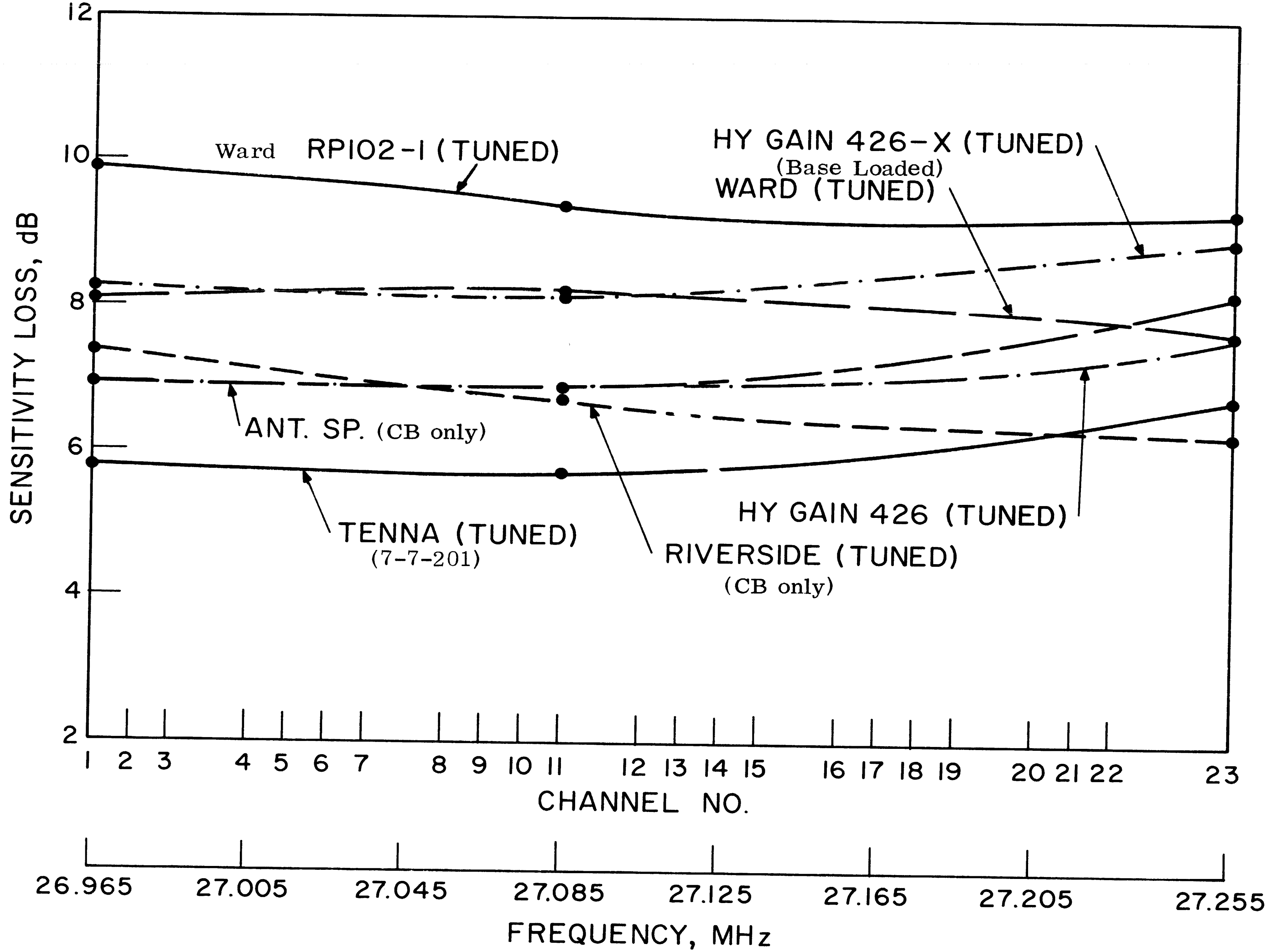


Figure 31: CB sensitivity losses of tuned antennas on the 1976 Gran Torino.

Note: All test antennas are fixed tri-band type, unless noted otherwise.

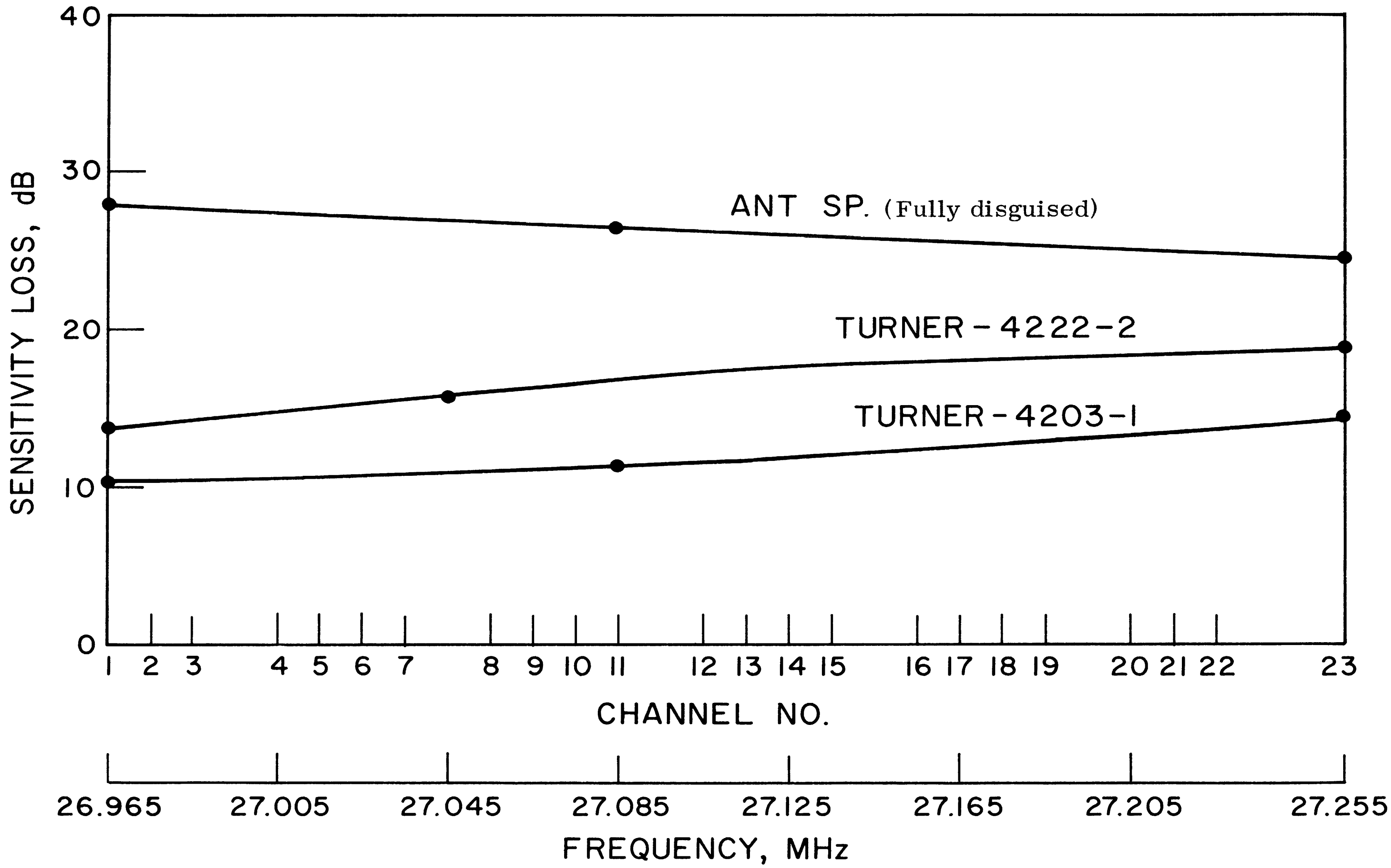


Figure 32: CB sensitivity loss of untuned antennas on the 1976 Gran Torino.

Note: All test antennas are fixed tri-band type.

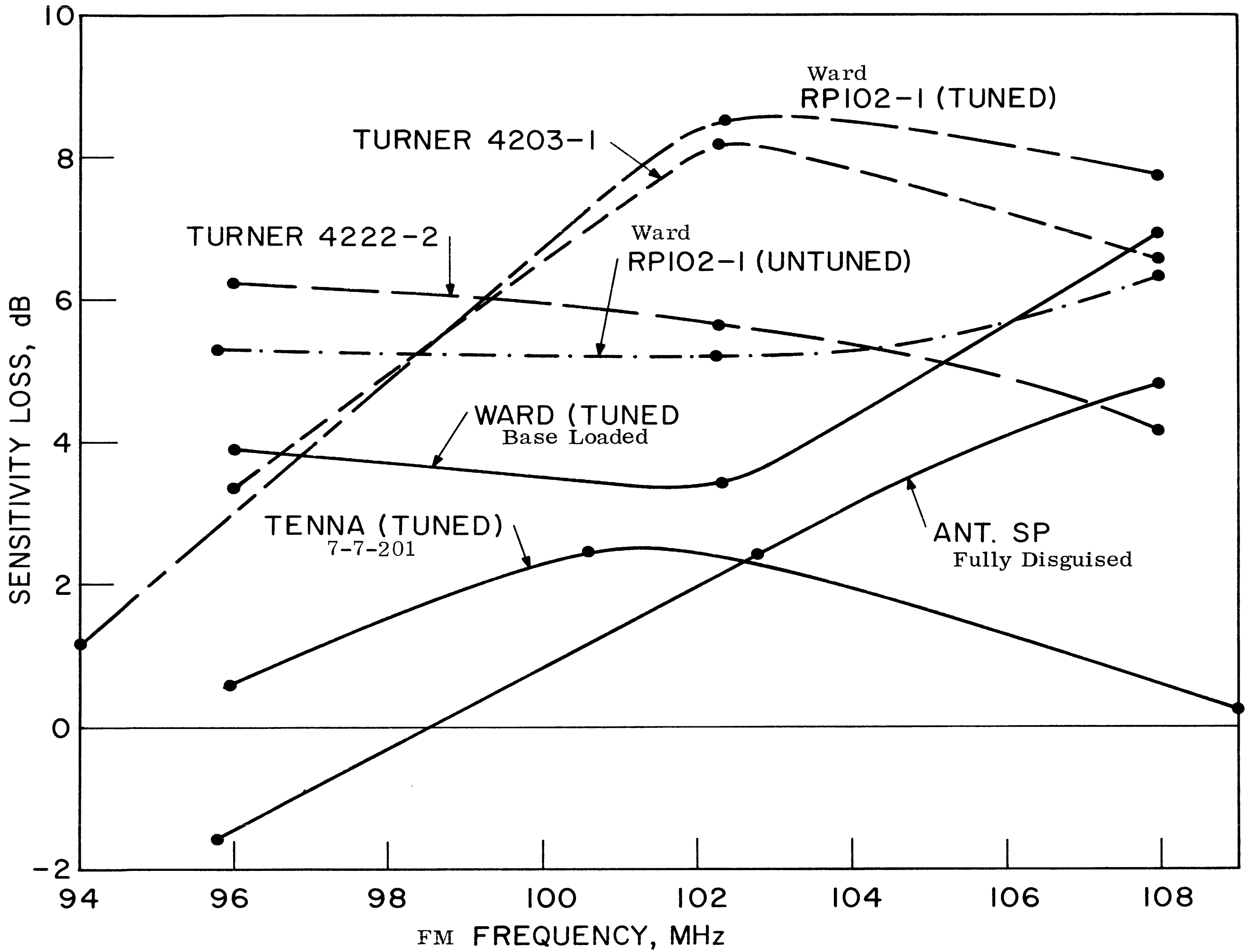


Figure 33: FM sensitivity losses of test antennas on the 1976 Gran Torino.

Note: All test antennas are fixed tri-band type.

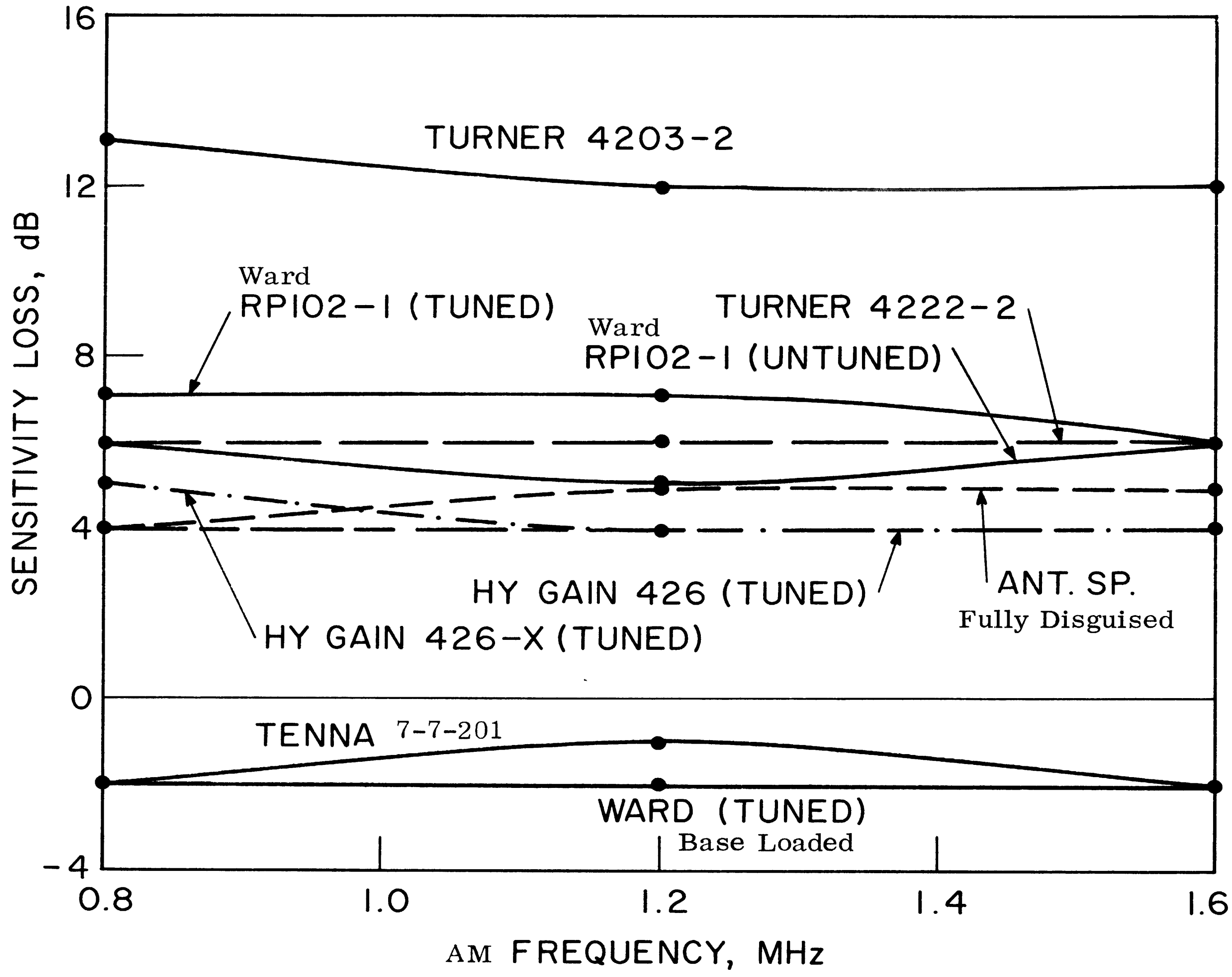


Figure 34: AM sensitivity losses of test antennas on the 1976 Gran Torino.

Note: All test antennas are fixed tri-band type.

Table XI: Sensitivity loss of CB, FM and AM band for Test antennas on the 1976 Mustang II.

Antenna	At CB Frequency			FM Frequency MHz			AM Frequency MHz		
	Ch.1	11	23	95	102.7	108	.8	1.2	1.6
Ward Base Loaded (tuned)	8.12	7.33	7.27	4.47	7.10	3.40	0	0	0
Ward RP102-2 (tuned)	9.75	8.93	10.37	6.75		3.50	15	+13	12
Tenna 7-7-201	6.77	7.25	7.95	3.67	1.83	1.80	-2	-5	-6
HY-Gain (426X-2)	-	-	-	-	-	-	+6	+5	2
				4	102	108	0.8	1.1	1.61
Ward Base Loaded (untuned)	8.5	7.5	7.5	4	0	-3	0	9	10
Ant. Spec. Fully Dis.	21.5	22.5	22.5	4	8	8	6	14	16
HY-Gain (426) tuned	7.5	6.5	6.5	10	20	21	6	14	16
Turner 4222-2	11.5	10.5	12.5	5	9	12	10	19	21

Note: All test antennas are fixed tri-band type.

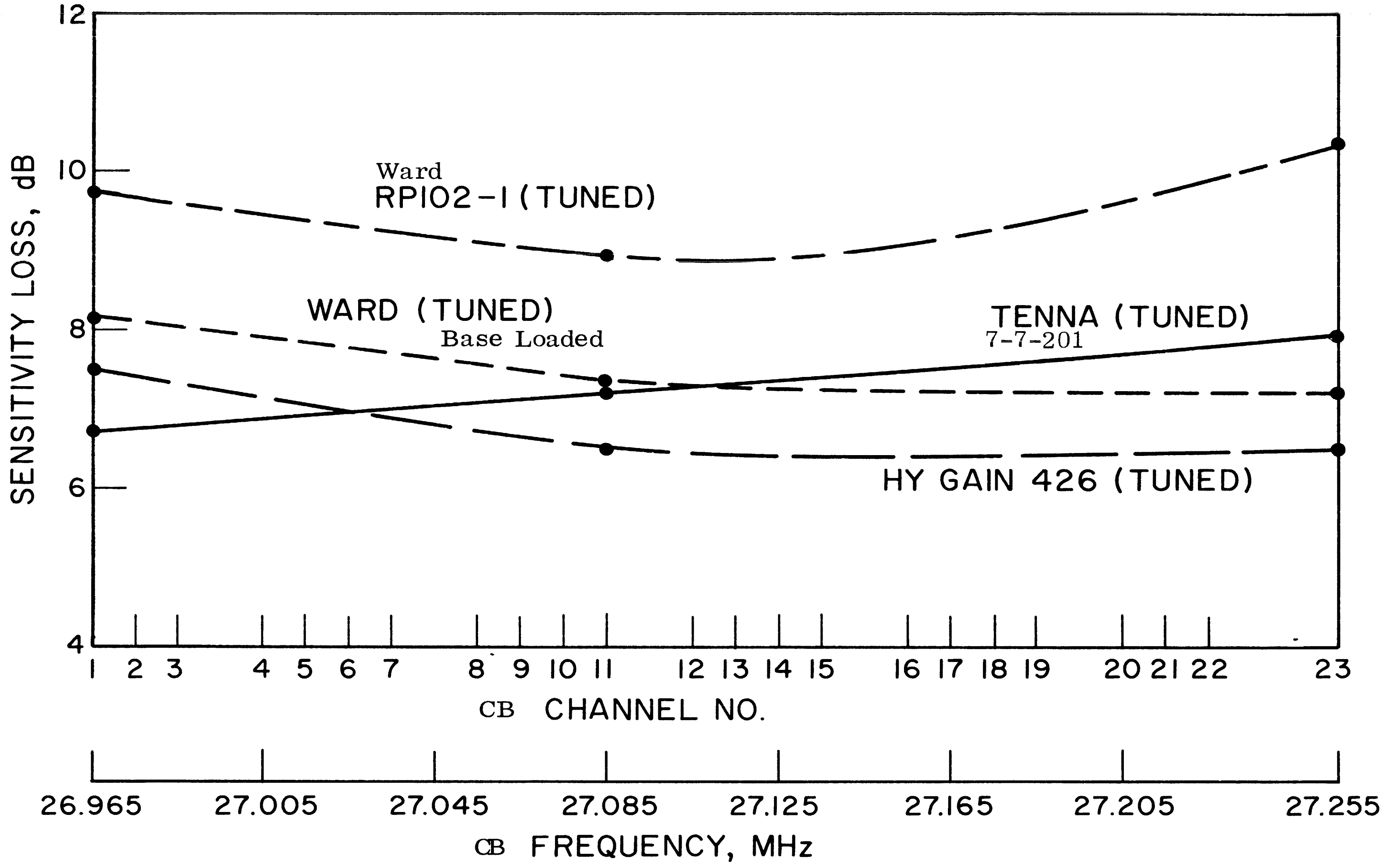


Figure 35: CB sensitivity losses of tuned antennas on the 1976 Mustang II.

Note: All test antennas are fixed tri-band type.

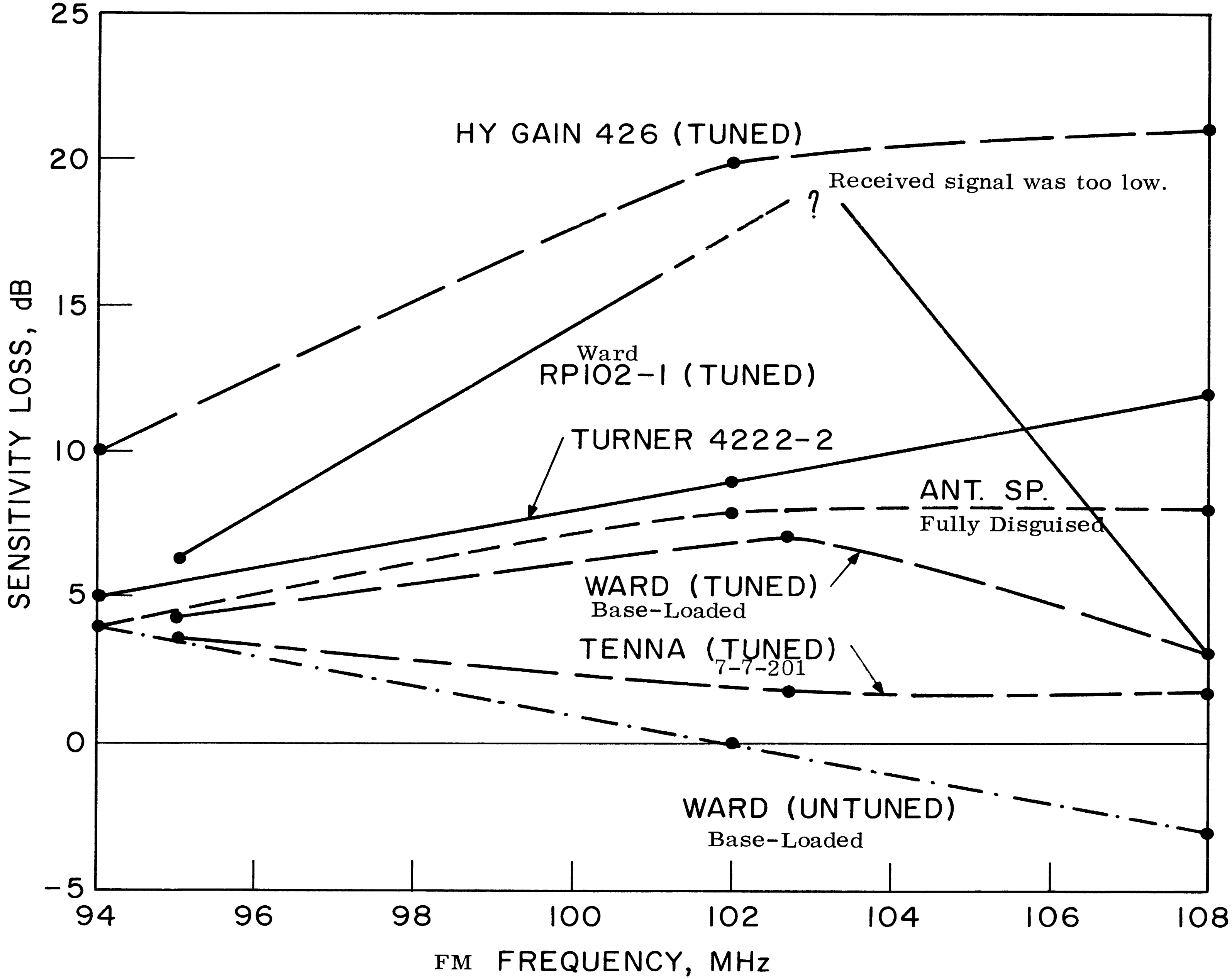


Figure 36: FM sensitivity losses of various test antennas on 1976 Mustang II.

Note: All test antennas are fixed tri-band type.

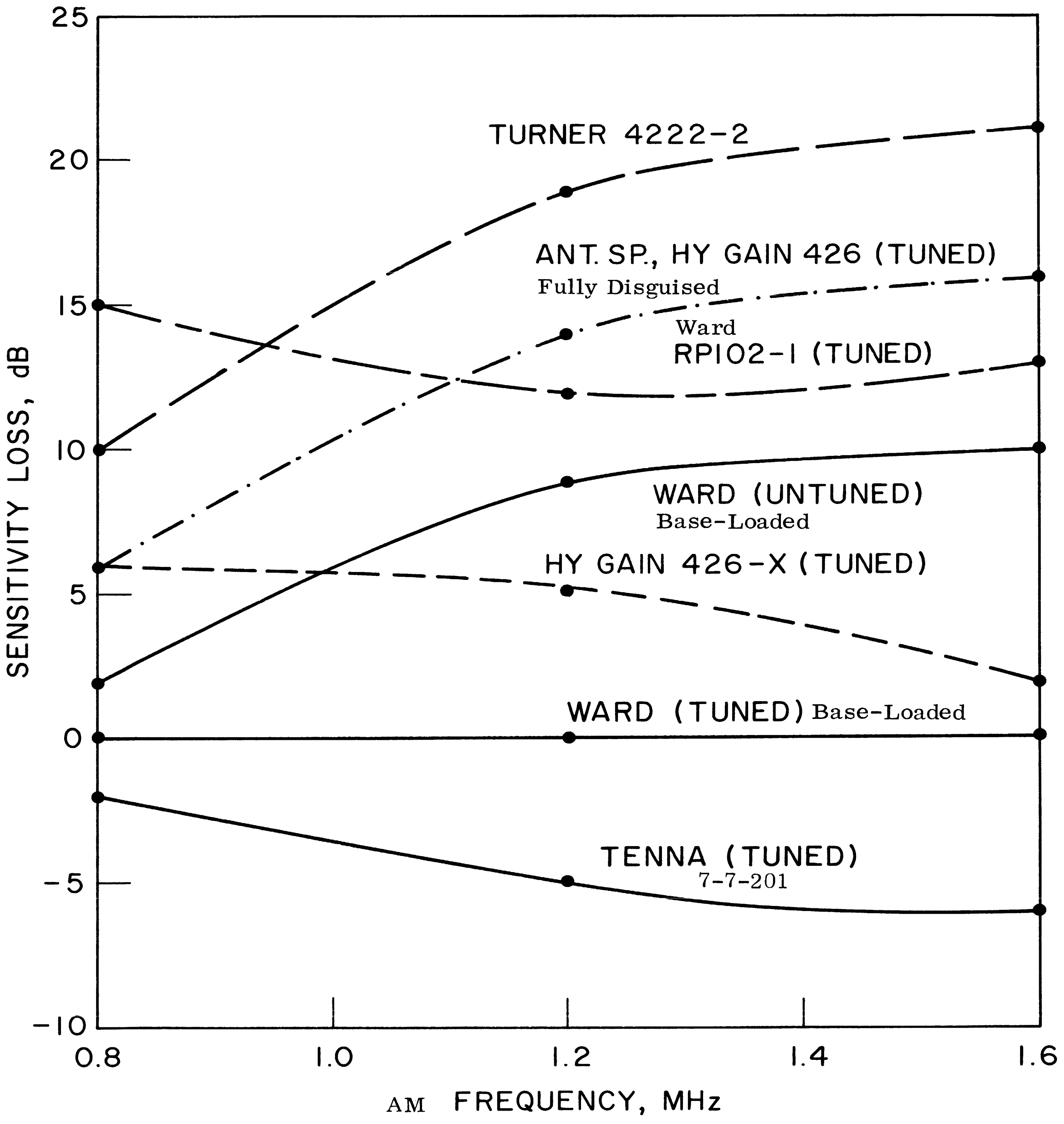


Figure 37: AM sensitivity of test antennas on 1976 Mustang II.

Note: All test antennas are fixed tri-band type.

VIII

EFFECT OF THE AUTOMOBILE

It may be of interest to know the performance of a given test antenna when used in different cars. To this end we have done some limited investigation and the results are discussed in this section.

The antennas tested were Ward base loaded, HY-Gain, Tenna and Ward RP102-1 on the 1976 Gran Torino and 1976 Mustang II. The measured VSWR characteristics at the CB frequencies are shown in Table XII

In Table XII the Ward base-loaded, HY-Gain 426 and Tenna 7-7-201 antennas were all tuned when mounted on the 1976 Gran Torino. The first column under each antenna gives the VSWR results obtained for this situation The second column under each of the three antennas gives the VSWR obtained when these antennas (tuned for the 1976 Gran Torino) were mounted on the 1976 Mustang II. Comparison of the results indicate that the tuning of these three antennas are not appreciably changed by changing the car.

The results for the Ward RP102-1 antenna seem to indicate that the tuning of the antenna is affected by the car. Ward RP102-1 needed slight retuning when mounted on the 1976 Mustang II.

Detailed comparison of the patterns of the above antennas when mounted on different cars may be made by studying the results given in section VI. For comparison we give in Table XIII the results of the sensitivity losses at various frequencies for the test antennas.

The results indicate that CB performance of the tuned antennas are not appreciably affected by changing the car from the 1976 Gran Torino to the 1976 Mustang II. The AM sensitivities deteriorated in going to a smaller car for all the antennas.

No such general behavior pattern of the FM sensitivities can be made from the results.

Table XII: VSWR of test antennas on 1976 Gran Torino and 1976 Mustang II.

Ch. No. or Frequency	Ward Base Loaded tuned on Torino		HY-Gain 426 tuned on Torino		Tenna 7-7-201 tuned on Torino		Ward RP 102		
	Torino	Mustang II	Torino	Mustang II	Tornio	Mustang II	Tuned on Torino	Tuned on Tor. and mtd. on Mstg.	After re-tuning on Mstg II.
1	1.8	1.66	1.7	1.7	1.59	1.41	2.1	2.52	2.25
5	1.52	1.39	1.3	1.4	1.45	1.26	1.61	1.97	1.75
9	1.32	1.18	1.1	1.2	1.38	1.15	1.23	1.56	1.46
11	1.28	1.13	1.05		1.38	1.12	1.11	1.43	1.33
12	1.28	1.11	1.05		1.39	1.13	1.08	1.33	1.36
13	1.26	1.13	1.05	1.2	1.40	1.14	1.12	1.29	1.31
17	1.58	1.29	1.20	1.5	1.51	1.25	1.65	1.26	1.52
23	1.85	1.73	1.9	2.2	1.84	1.52	2.3	1.85	2.1

Note: All test antennas are fixed tri-band type.

Table XIII: Sensitivity losses of test antennas on 1976 Gran Torino and 1976 Mustang II.

Frequency	Ward Base Loaded Torino	Ward Base Loaded Mustang	HY-Gain 426 Torino	HY-Gain 426 Mustang	Tenna 7-7-201 Torino	Tenna 7-7-201 Mustang	Ward RP102-1 Torino	Ward RP102-1 Mustang
CB Ch. 1	8.18	8.12	6.93	7.5	5.73	6.77	9.9	9.75
CB Ch. 11	8.28	7.33	6.95	6.5	5.72	7.25	9.4	8.93
CB Ch. 23	7.77	7.27	8.20	6.5	6.80	7.95	9.35	10.75
FM 96 MHz	3.95	4.47	4.33	10	0.68	3.67	5.35	6.75
FM 102.3 MHz	3.45	7.10	-	20	2.50	1.83	5.23	-
FM 108 MHz	6.90	3.40	-	21	0.23	1.80	6.37	3.5
AM 0.8 MHz	-2	0	5	6	-2	-2	6	15
AM 1.2 MHz	-2	0	4	14	-1	-5	5	13
AM 1.6 MHz	-2	0	4	16	-2	-6	6	12

Note: All test antennas are fixed tri-band type.

IX

PERFORMANCE OF WARD AND HY-GAIN ANTENNAS

In this section we single out the above two tuned antennas and compare their performance when mounted on the 1976 Gran Torino and 1976 Mustang II cars. As discussed in Section VIII, the antennas were tuned when mounted in the Torino and their tuning does not change appreciably when mounted on the Mustang II.

The VSWR characteristics vs. CB Channel frequencies for the two cars are shown in Figure 38. The results indicate that the two antennas maintain comparable VSWR, except that the HY-Gain 426 on the 1976 Mustang II tends to have slightly longer VSWR at the high end of the band.

Figures 39, 40 and 41 give CB, FM and AM sensitivity losses associated with the antennas for the two cars. The CB performance of the two antennas seem to be comparable (Figure 38). The FM performance of the HY-Gain 426 antenna is inferior to that of the Ward base-loaded antenna. HY-Gain 426 on the 1976 Mustang II has more losses. The single result for the HY-Gain 426 on the 1976 Gran Torino shown in Figure 40 is comparable with that of the Ward base-loaded. The other readings for the HY-Gain 426 on the 1976 Gran Torino could not be taken due to low signal level and the interference from the local station. Figure 41 indicates that the HY-Gain 426 sensitivity loss in the AM band is larger than those of the Ward base-loaded antennas.

The results of this section conclusively indicate that the overall performance of the Ward base-loaded antenna is better than the HY-Gain 426 antenna.

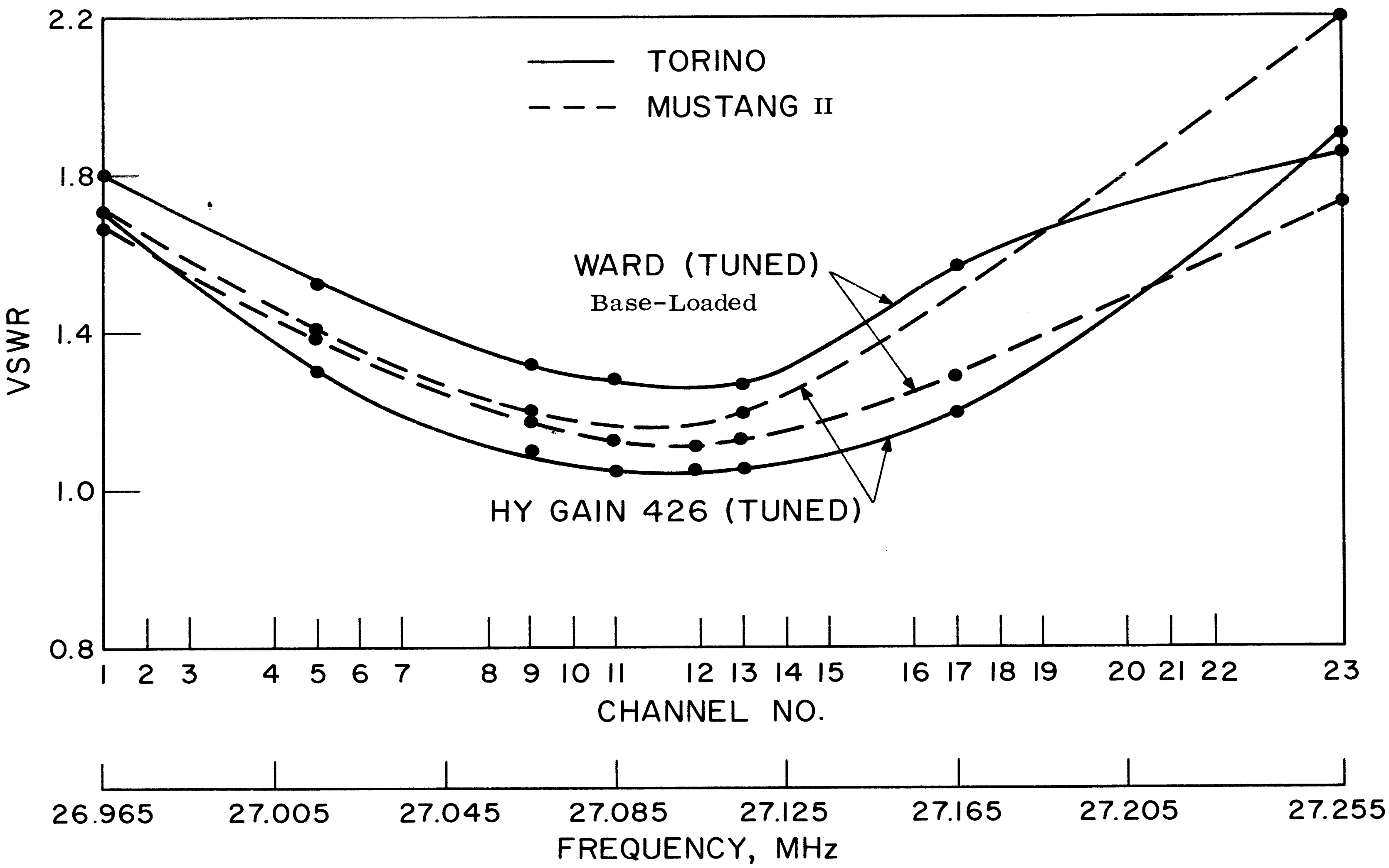


Figure 38: VSWR results for Ward base-loaded and HY-Gain 426 antennas on 1976 Gran Torino and 1976 Mustang II.

Note: Both the test antennas are fixed tri-band type.

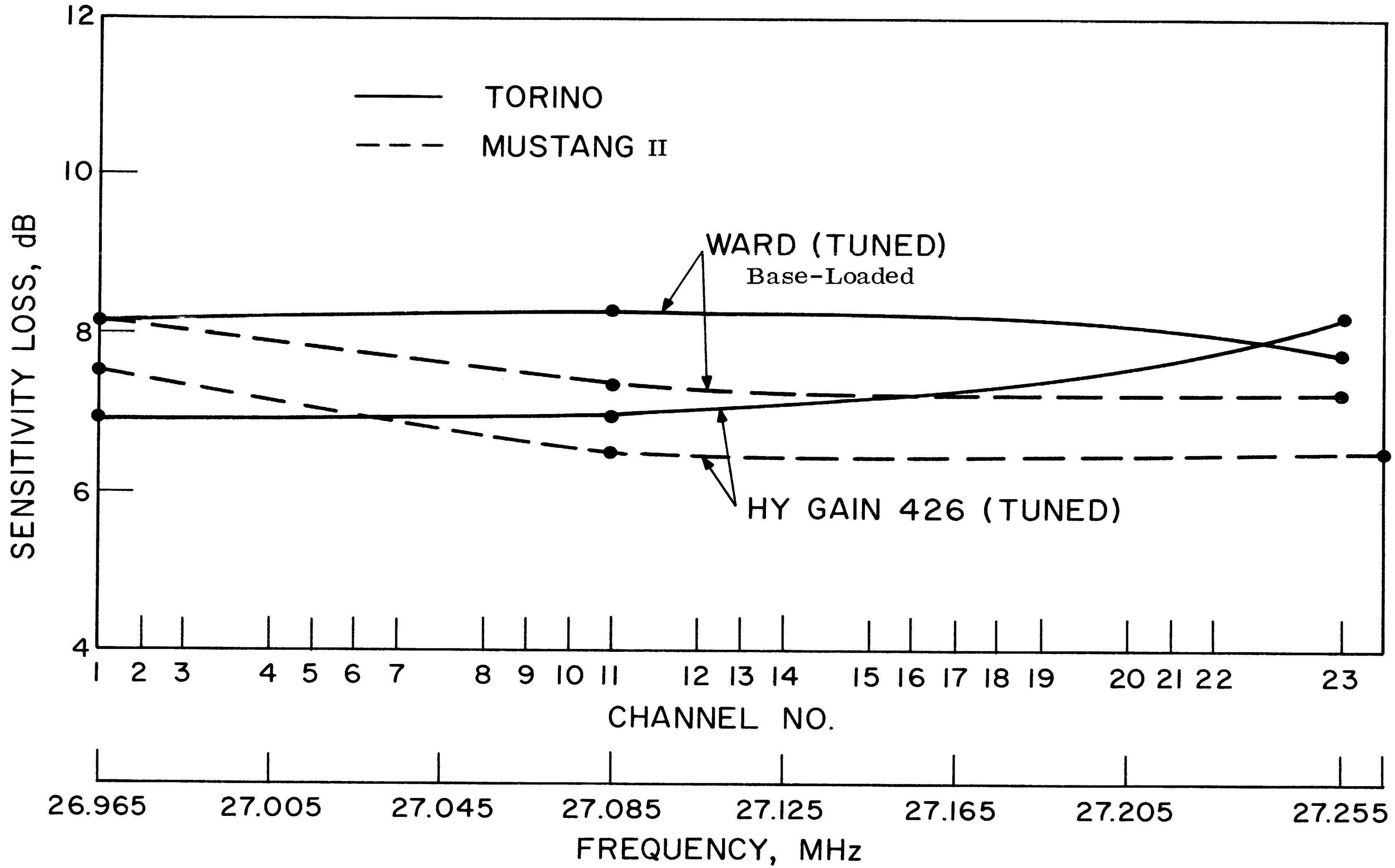


Figure 39: CB sensitivity of Ward base-loaded and HY-Gain 426 antennas on 1976 Gran Torino and 1976 Mustang II.

Note: Both thc test antennas are fixed tri-band type.

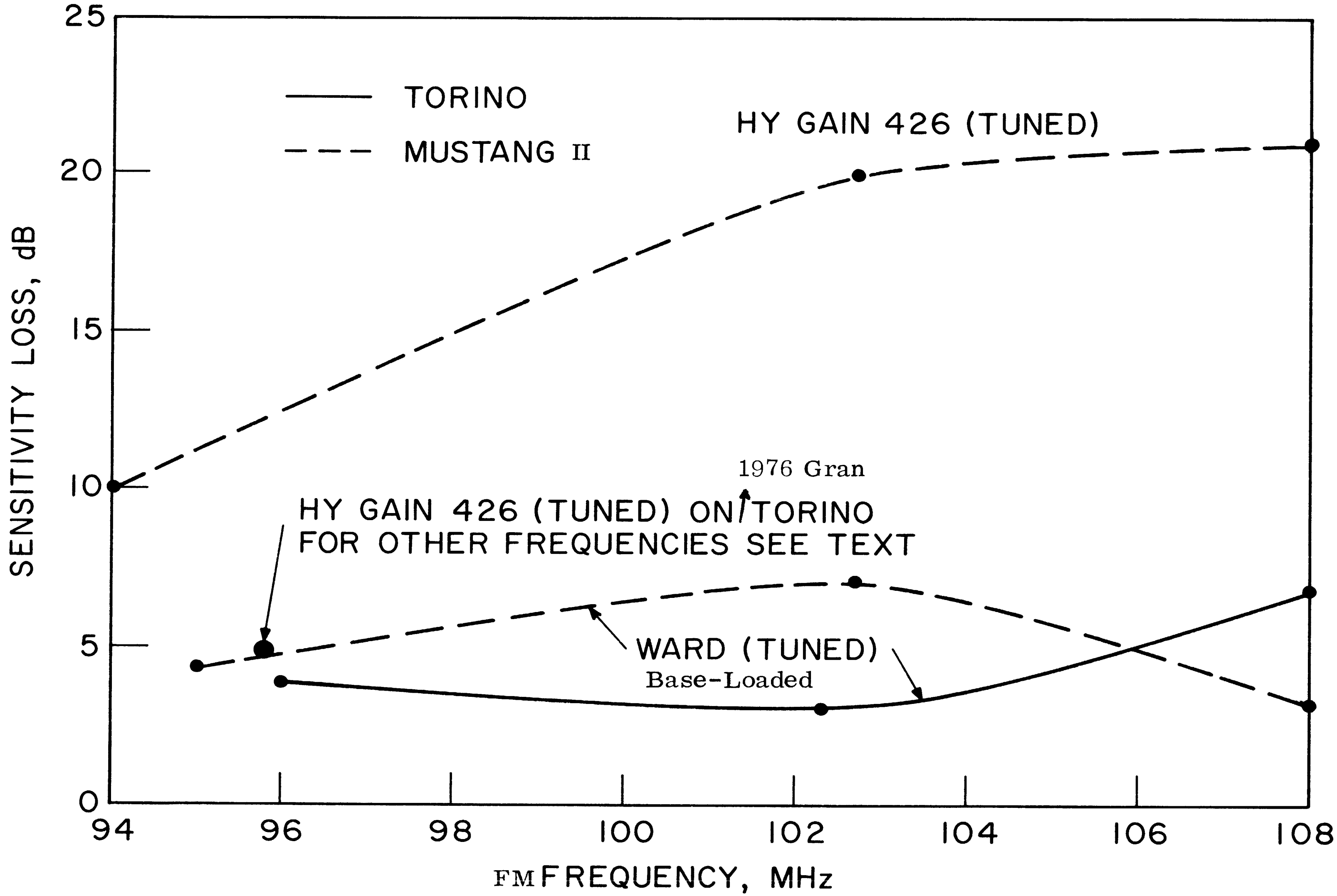


Figure 40: FM sensitivity of tuned Ward base-loaded and HY-Gain 426 antennas on 1976 Gran Torino and 1976 Mustang II.

Note: Both the test antennas are fixed tri-band type.

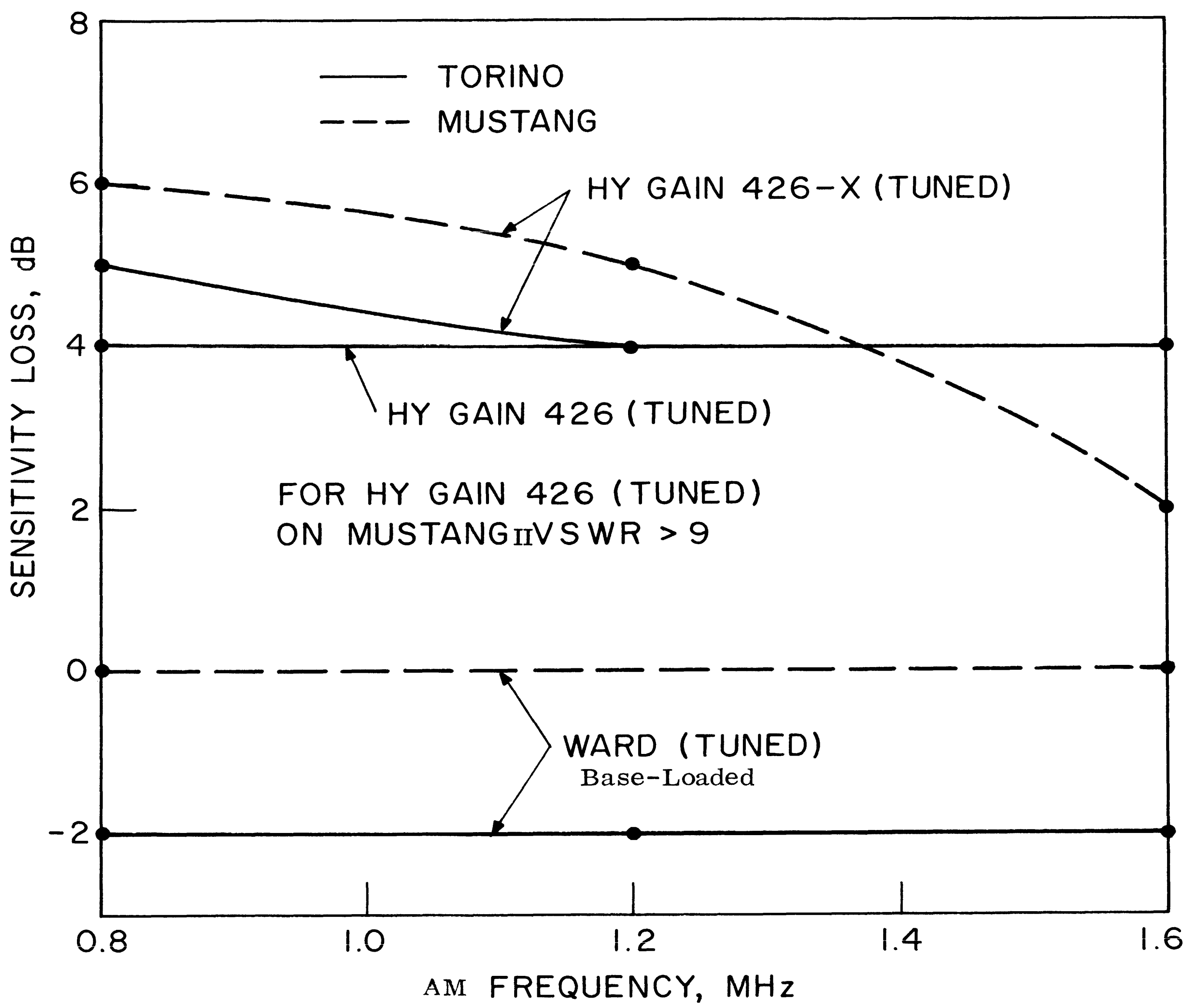


Figure 41: AM sensitivity of Ward base-loaded and HY-Gain 426 antennas on 1976 Gran Torino and 1976 Mustang II.

Note: All the test antennas are fixed tri-band type.

X

GENERAL DISCUSSION

On the basis of the results discussed in earlier sections the following general observations are made with regard to the performance of various types of automobile antennas:

(1) Mismatch losses are more serious at the CB frequencies because transmission efficiency will become unacceptable if the input VSWR is high. For this reason all tri-band antennas should be tuned at the CB frequencies; of course CB only antennas should also be tuned for low VSWR. This implies that the tri-band antennas may have fairly high VSWR in the FM and AM band. Generally for acceptable performance the antenna should be tuned so that the VSWR stays within 2:1 at the CB frequencies.

(2) A tuned antenna performance does not vary too much from car to car, however, the tuning of an antenna may vary particularly if the size of the car is changed significantly.

(3) Both center and base loaded antennas perform equally well when properly designed and tuned.

(4) Sub-base loaded antennas seem to perform well at the CB and FM band frequencies but have poor sensitivity at the AM band frequencies.

(5) The fully disguised antenna like the Antenna Specialists tri-band antenna appears to have acceptable performance at the FM and AM band frequencies. Its performance has been found to be poor at the CB frequencies. This is due to the fact that the antenna has large VSWR at the CB frequencies and there is no provision for tuning the antenna. If the disguised tri-band antenna is properly tuned, it is believed that its performance will be acceptable.

XI

FINAL EVALUATION

The set of candidate antennas tested for 1976 Continental Mark IV and the 1976 Lincoln Continental is different from the set tested for 1976 Gran Torino and the 1978 Mustang II. For this reason we discuss separately the evaluation and final choice of antennas for use on the two sets of cars.

At the CB frequencies the performance of the power tri-band antenna on the 1976 Lincoln Continental is comparable to that of the power CB antenna. At the FM and AM band of frequencies, the tri-band antenna is less sensitive than the FM-AM entertainment antenna. If the sacrifice in the sensitivity in the FM-AM band is acceptable, then the power tri-band antenna should be a good choice for use in both the Lincoln and Mark IV car lines.

For the 1976 Gran Torino and the 1976 Mustang II both Tenna 7-7-201 and Ward base-loaded antennas have comparable performance in all the three bands of frequencies. Tenna 7-7-201 is center loaded and has a length $\ell \simeq 43''$ while Ward is base-loaded with $\ell \simeq 40''$. If a choice has to be made between these two antennas it has to be made on the basis of these differences. If smaller length is a desirable feature then the Ward antenna will be a good choice. The HY-Gain 426X antenna has $\ell \simeq 35''$ and it performs equally well at CB and AM frequencies but its performance at FM has been found to be poor. The reason for its poor performance at FM may have been the malfunction of some components. If this is corrected, the HY-Gain 426X antenna should also be a good choice.

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RECOMMENDATIONS FOR FURTHER WORK

At the present time automobiles use separate CB and FM-AM antennas. On the basis of our study it is found that base-loaded tri-band antennas can serve both functions.

Antennas of another type that may be used with advantage are the sub-base loaded tri-band antennas. Our investigations indicate that the CB and FM band performance of such antennas are comparable to those of base-loaded tri-band antennas, but their sensitivity is poor at AM band frequencies. This aspect should be further investigated.

From the user's point of view fully disguised tri-band antennas are desirable. The fully disguised tri-band antenna that we have tested showed acceptable performance at FM and AM band of frequencies and poor performance at CB frequencies. This may have been due to poor VSWR characteristics of the antenna at CB frequencies, and it is believed that with proper design the performance levels of fully disguised antennas can be made competitive with those of the previous two types. Further work should be carried out to achieve this.

Recently the number of CB channels has been increased to 40. As indicated earlier, we have investigated all the test antennas over the first 23 CB channels. In view of the increase in the number of CB channels it is desirable that the candidate antennas be tested for both VSWR and patterns over the increased band of CB frequencies. The tuning of the antennas should be adjusted for minimum VSWR at Channel 23. The implications of this need further investigation.

It is believed that the physical length of an automobile antenna should not exceed 40". It is conceivable that with proper design, antennas of shorter length may provide acceptable performance. The techniques used in electrically-short active antennas may be useful for this purpose, and should be investigated in connection with automobile antennas.

On the basis of the discussion of this section it is recommended that further research be done on the following problems:

(i) Redesign the matching and other associated circuitry of the sub-base loaded and fully disguised tri-band antennas whose present performance is not optimum. Perform VSWR and pattern measurements and analyze the results for these antennas at CB (all 40 channels) FM and FM frequencies.

(ii) In general tri-band antennas tuned at CB frequencies show large VSWR at FM and AM band frequencies. The matching and splitter box circuitry should be studied further with the goal of improving the overall VSWR characteristics.

(iii) Investigate the concepts of electrically short active antennas for developing automobile antennas of lengths shorter than those presently in use.

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APPENDIX

EQUIVALENT CIRCUITS FOR MONOPOLE ANTENNAS

The equivalent circuit representation of an antenna is useful in designing the matching of an antenna to a given system and also in evaluating the overall efficiency of the antenna-to-system coupling. In this section we discuss the equivalent of a monopole antenna mounted on an infinite ground plane. For finite ground plane the circuit parameters of the antenna are difficult to obtain analytically. However, the circuit and the parameters given here may be used to estimate the input VSWR and other characteristics of the antenna connected to a given system.

The antenna is a two-terminal device, as shown schematically in Figure A1., which is usually connected to the remainder of the system by a transmission line.

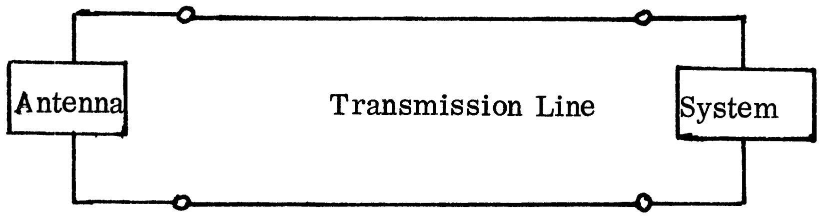

Figure A1: Schematic representation of the antenna connected to a system.

The simple equivalent circuit of a receiving antenna is shown in Figure A2. Here the two-terminal antenna impedance is denoted by Z_A and the system impedance termin-

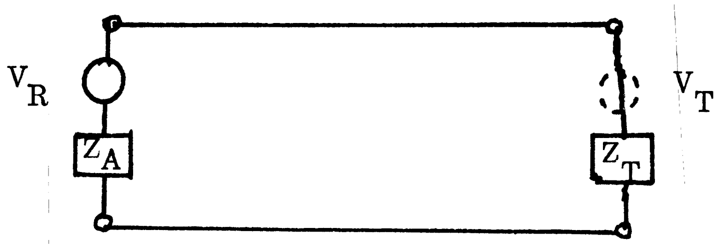

Figure A2: Equivalent circuit representation of Fig. A1 for the receiving case.

ating the transmission line by Z_T. The voltage induced in the receiving antenna by the incoming electromagnetic waves is represented by the voltage generator V_R. For the transmitting antenna case, $V_R = 0$, and the equivalent transmitter output voltage V_T is instead in series with Z_T as shown dotted in Fig. A2; in this case the field produced by the antenna and its efficiency may be obtained from a knowledge of the voltage across Z_A and their circuit parameters shown in Fig. A2.

In general both Z_A and Z_T are complex and hence for maximum power transfer between the antenna and the system some kind of impedance matching is required.

The input impedance of an antenna may be written as

$$Z_A = R_A + j\,X_A \tag{A1}$$

where R_A is the radiation resistance of the antenna when the antenna is perfectly conducting, X_A is the reactance of the antenna. Both R_A and X_A are complicated functions of the antenna length ℓ and the radius 'a' of the antenna element. For a monopole made of their circular conducting cylinders and mounted on an infinite ground plane, the following approximate expressions may be used to obtain the input resistance and reactance of the antenna for $\ell \leq \lambda/4$, where λ is the wavelength,

$$R_A = 15\left[\left\{2 + 2\cos(2k\ell)\right\} S_1(2k\ell) - \cos(2k\ell)\, S_1(4k\ell) - 2\sin(2k\ell)\,\mathrm{Si}(2k\ell) + \sin(2k\ell)\,\mathrm{Si}(4k\ell)\right], \tag{A2}$$

$$X_A = -15\left\{\sin(2k\ell)\left[-0.5772 + \ln\left(\frac{\ell}{ka^2}\right) + 2\,\mathrm{Ci}(2k\ell) - \mathrm{Ci}(4k\ell)\right] - \cos 2k\ell\left[2\,\mathrm{Si}(2k\ell) - \mathrm{Si}(4k\ell)\right] - 2\,\mathrm{Si}(2k\ell)\right\} \tag{A3}$$

where,

$k = 2\pi/\lambda$ is the propagation constant,

$$Si(x) = \int_0^X \frac{\sin V}{V} dv \quad , \qquad (A4)$$

$$Ci(x) = -\int_x^\infty \frac{\cos V}{V} dv \, , \qquad (A5)$$

$$S_1(x) = \int_0^x \frac{1 - \cos v}{v} dv \, . \qquad (A6)$$

The functions defined by Equations (A4)-(A6) are well tabulated in the literature and hence R_A and X_A for a given monopole may be obtained by knowing ℓ and a.

For example, when $\ell = \lambda/4$, $\sin 2k\ell = 0$, $\cos 2k\ell = -1$, under these conditions we obtain:

$$R_A = 15\, S_1\,(4k\ell) = 15\, S_1(2\pi) = 15 \times 2.4377 \simeq 36.57 \text{ ohms.}$$

$$X_A = 15\, Si\,(4k\ell) = 15Si\,(2\pi) = 15 \times 1.4182 \simeq 36.57 \text{ ohms.}$$