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AN ANTI-JAM MANPACK ANTENNA FOR GLOBAL POSITIONING SYSTEM APPLICATION

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The GPS Anti-Jam Manpack Antenna (AJMA) system is an ECCM addition to the GPS manpack/vehicular user equipment which will minimize GPS receiver performance degradation due to a jammer by steering a null into the direction of the interference source. Operating strictly at the GPS RF signal level AJMA will easily interface with a GPS receiver without modification and add minimal signal degradation. From results of the experiments described, it is concluded that there exists a feasible method of using null-steering antenna systems to counter CW jammer threats. A number of AJMA configurations were applied successfully and tested practically.

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1. INTRODUCTION

The Navigation Systems Team, Navigation Technical Area, of the Avionics Laboratory was requested by the US Army Satellite Communications Agency to develop an anti-jam manpack antenna (AJMA) system for the NAVSTAR Global Positioning System (GPS) manpack user equipment.[1]

Since GPS is a passive user, radio navigation system, it is subject to jamming when operating in a field environment. It is therefore desirable to protect the receiver from the jammer. One way of accomplishing the objective is in the proper design of the waveform structure of the receiver. Another method, which can be used in concert with waveform design techniques, uses circuitry designed to modify the receiver antenna pattern to achieve the desired insensitivity to interference signals. Using the latter approach, the AJMA system was developed for the GPS manpack user.

The GPS user is required to receive, either simultaneously or sequentially, at least four satellites that are within his field-of-view and properly oriented to achieve a specified accuracy.[2] Such a system requires the user to employ an antenna system that achieves upper hemispherical omni coverage. However, by employing an omni antenna, the user can receive not only the desired satellite signals, but also a wide range of interference signals that could potentially degrade performance. The degree to which this interface could disrupt the GPS user is directly associated with the degree to which it exceeds the present system anti-jam (AJ) capabilities.

The AJMA is a system that uses spatial discrimination by coupling, through a correlator, an omni GPS antenna with a directive antenna to provide substantial AJ margin in addition to that presently provided by system coding.

2. BACKGROUND

The NAVSTAR Global Positioning System (GPS) is a satellite based navigation system currently under development by the Joint Program Office (JPO) at USAF, Space and Missile Systems Organization (SAMSO) Headquarters for the Department of Defense.

Precise three dimensional position, velocity, and time information is derived from signals received from a series of four satellites each in a different orbital plane. Each satellite transmits pseudo-random noise (PRN) codes consisting of protected (P-signal) and clear/acquisition (C/A signal) codes in a composite waveform at two L-band frequencies (1575 MHz and 1227 MHz).

The GPS satellites transmit information to users by means of a spread spectrum modulation technique. Binary navigation data at 50 Hz is combined with the protected or clear/acquisition PRN codes, at approximately 10.23 MHz and 1023 KHz, respectively. The binary waveform, a composite of the PRN code and the data, bi-phase modulates the L-band carrier spreading it in frequency as shown in Figure 1.

[1]SAMSO/YEA letter to USAECOM Avionics Laboratory, Navigation Tech Area, 25 May 1976, subject: AJ and Multipath Tasks.
[2]System Specification for GPS User System Segment, SS-US-101B, 30 September 1974, Code Ident 12436.

The GPS receiver modulates the received spread spectrum signal by an internally generated PRN code (either the P or C/A code) and a sine wave at the L-band carrier frequency. The receiver output is a reconstruction of the binary data input to the satellite transmitter.

By employing a spread spectrum modulation technique, the GPS receiver can discriminate against interference due to jamming signals as shown in Figure 1. Within the receiver, the jamming signal is modulated by a PRN code thus spreading it over a wide range of frequencies. The desired satellite signal, however, is compressed in its frequency spectrum. When the composite signal is passed through a narrowband filter, only a small percentage of the receiver jammer power remains to interface with detection of the binary data.

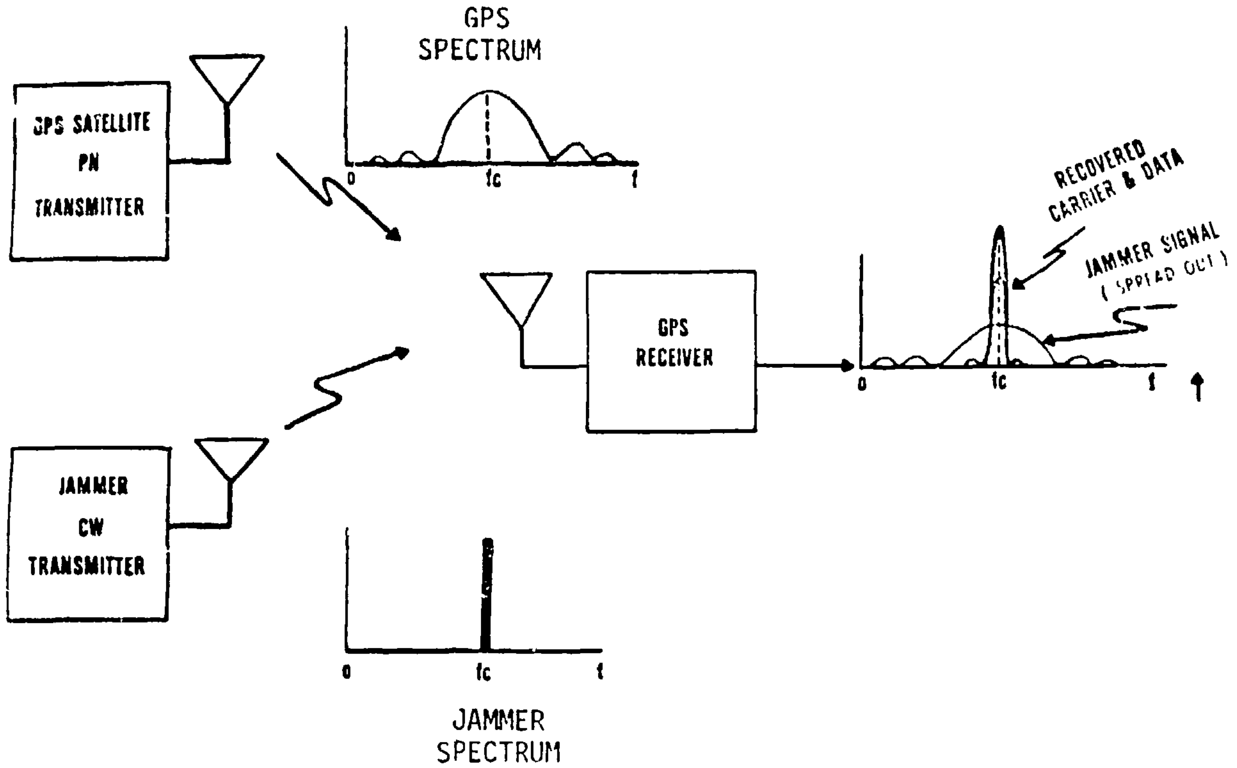


Figure 1. GPS rejection of jamming and noise signal

The jamming signal will look like noise to the receiver and effectively increase the noise power at the receiver input. The jammer will thus decrease the effective signal to noise ratio at the receiver input. This ratio must be above a specified threshold level in order for the receiver to operate in its desired mode, such as initial acquisition, data acquisitions, and signal tracking. Each of these receiver modes of operation has an associated threshold that is a function of the receiver design.

Early Army estimates of tolerable jammer levels are documented 3, 4, and 5, and repeated here in Table 1. To permit GPS operation in a tactical, hostile environment, an improvement in J/S performance is desirable.

TABLE 1. GPS I/S PARAMETERS*

J/S capability of C/A signal acquisition against CW Jammer	12 dB
J/S capability of C/A acquisition against noise jammer	24 dB
J/S capability of P signal tracking against CW or noise jammer	43 dB

*Values based upon received P-signal level = 163 dBW, C/A signal level = -160 dBW. These J/S capabilities are theoretical maximums and are a function of the carrier doppler.

3. DEVELOPMENT OF AJMA CONFIGURATIONS

a. Objective. Design a portable, low cost, manual null steering antenna which will prevent P signal, CW jamming at levels up to the specified P-signal J/S capability within the following constraints:[3, 4, 5]

(1) Effort is restricted to countering a single CW jammer.

(2) Advanced development GPS user equipment should not require modification to work with the AJMA.

(3) Approach should not require extensive development.

(4) Approach should be demonstrable with advanced development GPS user equipment.

[3]SAMSO/YEA letter to YEE, 15 January 1976, subject: Jamming of the C/A Signal.
[4]SAMSO/YEEA Memorandum for Record, 23 February 1976, Subject: Jamming of the C/A Signal.
[5]SAMSO/YEE letter to YEA, 14 May 1976, Subject: Phase I AJ Scheme for Ground Users.

(5) The AJMA elements should have minimum loss to preserve system sensitivity in order to perform its nulling function.

(6) A stationary user is to be assumed for acquisition.

b. Theory of Operation. In addressing the GPS anti-jam problem, the system signal levels and their susceptibility to jamming must be understood. The most important signal characteristic of the GPS system is that the desired GPS signal is always received at a level below receiver noise. This condition is an advantage in designing anti-jam systems for it enables the use of amplitude sensing elements to readily detect signals above noise and identify them as interference.

In order to gain insight into the GPS jamming problem, a quantitative analysis is appropriate. Using the baseline GPS user equipment specification, this system is required to withstand a J/S of 43 dB on the P-signal after acquisition. It is required to acquire the C/A signal in CW jamming for a J/S of 12 dB. Thus, for a successful P-signal acquisition in the face of CW jamming, the jammer power must be reduced to the level acceptable to C/A acquisition operation. These J/S margins were based upon C/A-signal and P-signal amplitudes (received by an omni-directional, 0 dB, right-hand circularly polarized (RHCP) antenna) of -160 dBW and -163 dBW, respectively. The receiver noise is -137 dBW in BW_{3dB} = 2 MHz and -127 dBW in BW_{3dB} = 20 MHz. Thus, the CW jammer described must be greater than -120 dBW (-163 + 43) for the P-signal to be effectively jammed after it has been acquired (i.e., the jammer must be greater than 7 dB above noise). Since the normal sequence of acquisition is to intially acquire the C/A signal, then "handover" to the P-signal, the J/S of 43 dB does not exist until this sequence is completed. For C/A acquisition, the CW jammer must be less than -148 dBW (-160 + 12). If the CW jammer is greater than -148 dBW for the C/A signal, the GPS user is denied access. The intent of the AJMA system is to improve these J/S margins.

The AJMA configuration reduces directional interference by sensing signals in two channels, one containing the desired satellite GPS signals (OMNI) and an unwanted or jamming signal, and the other containing only the unwanted signal (JAMMER). The selectivity to signal types in the JAMMER channel is achieved by using a highly directional antenna which is manually steered into the direction of the jamming signal. The OMNI channel obtains signals from a near-hemispheric coverage antenna. The JAMMER channel contains attenuator and phase controls to produce a signal, which when "added" to the OMNI signal, just cancels the interfering signal in the combined output. The result is a sharp null in the overall radiation pattern of the AJMA in the direction of the jammer. The null depth attainable with the AJMA directly increases the J/S power ratio of the existing GPS receiver.

4. ANTENNA DESCRIPTION (ELECTRICAL/MECHANICAL)

This section describes the antennas used in the various AJMA configurations. These descriptions include electrical, mechanical, and radiation pattern characteristics.

a. GPS Omni-Directional Antenna. This omni-directional antenna is a broadband, conical spiral unit developed by Texas Instruments, Inc. (TI). This antenna was designed to receive RHCP signals. It has an input VSWR (50 Ω) ≤ 3:1, gain (horizon) ≈ 0 dBIC and meets the specifications for the GPS user. Figure 2 shows the TI antenna sitting on top of a wooden platform used to support the AJMA system. This antenna stands 8 inches high, measures 4 inches in diameter (base), and weighs less than 1 pound.

Antenna radiation pattern measurements were conducted in an anechoic chamber to guarantee that the antenna exhibits interference (mechanical/electrical) free patterns. The elevation and azimuth radiation patterns are shown in Figures 3 and 4. As seen in Figure 3, the TI antenna meets the GPS antenna specifications which call for uniform, upper hemispherical coverage (gain ≥ 0 dB) while Figure 4 verifies the omni coverage.

b. Directional Horn Antenna. The horn antenna is the AEL Model H5000. It is a fixed, linearly polarized, broadband (1.0-2.5 GHz) horn antenna. The major characteristics are: VSWR (50 Ω) ≤ 1.4, gain ≈ 11 dB, beamwidth 3 dB = 40° at 1575 MHz, front to back ratio ≈ 25 dB. This directional antenna is shown in Figure 2 as combined in the AJMA system. It is attached to the wooden platform and is spatially in quadrature with the GPS omni antenna. The horn antenna is 16-1/4 inches wide, 12-1/4 inches high, and 17-1/4 inches long with a weight of approximately 10 pounds.

Radiation patterns, as measured in the anechoic chamber are depicted in Figure 5 for elevation, and Figure 6 for azimuth. Figure 6 shows that the gain is approximately 11 dB and it has a beamwidth 3 db ≈ 40°.

c. Directional Array Antenna.[6] An in-house development of a lightweight, portable, RHCP, 1575 MHz center frequency, beamwidth 3 dB ≈ 25° directional antenna was required to make an AJMA system that was, in application, practical.

(1) In deriving the antenna type, an array format was chosen because of its flexibility in design and ease of fabrication. Printed circuit board techniques were used in designing the array antenna. This type of antenna readily meets the lightweight goal of AJMA. The number of antenna elements (aperture size) employed in this array determines the beamwidth, and the excitation determines the directivity of the beam and the sidelobe level.

[6]Munson, Robert E., "*Conformal Microstrip Antennas and Microstrip Phased Arrays,*" IEEE Transactions on Antennas and Propagation, January 1974, pp 74-78.

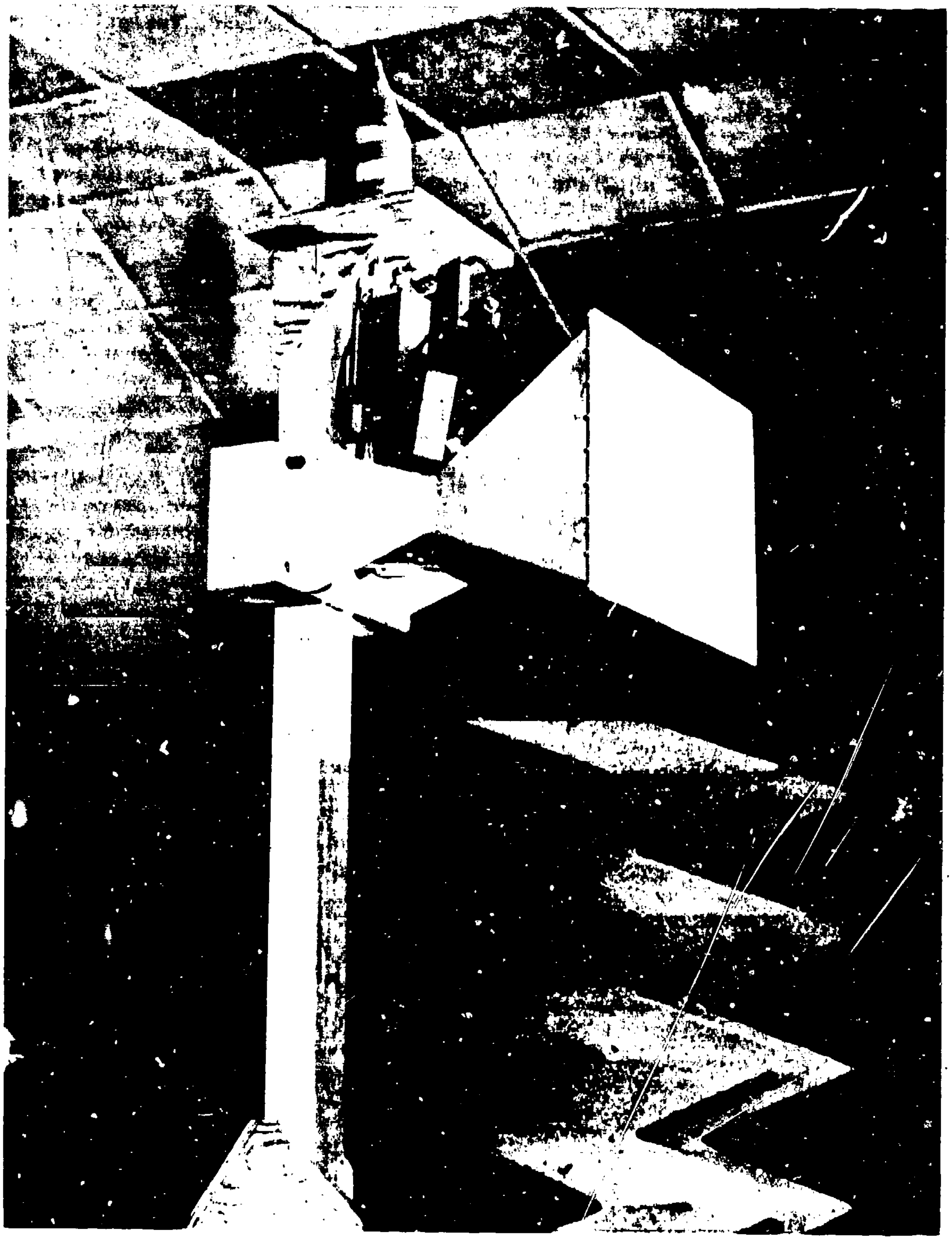


Figure 2. GPS AJMA experimental model

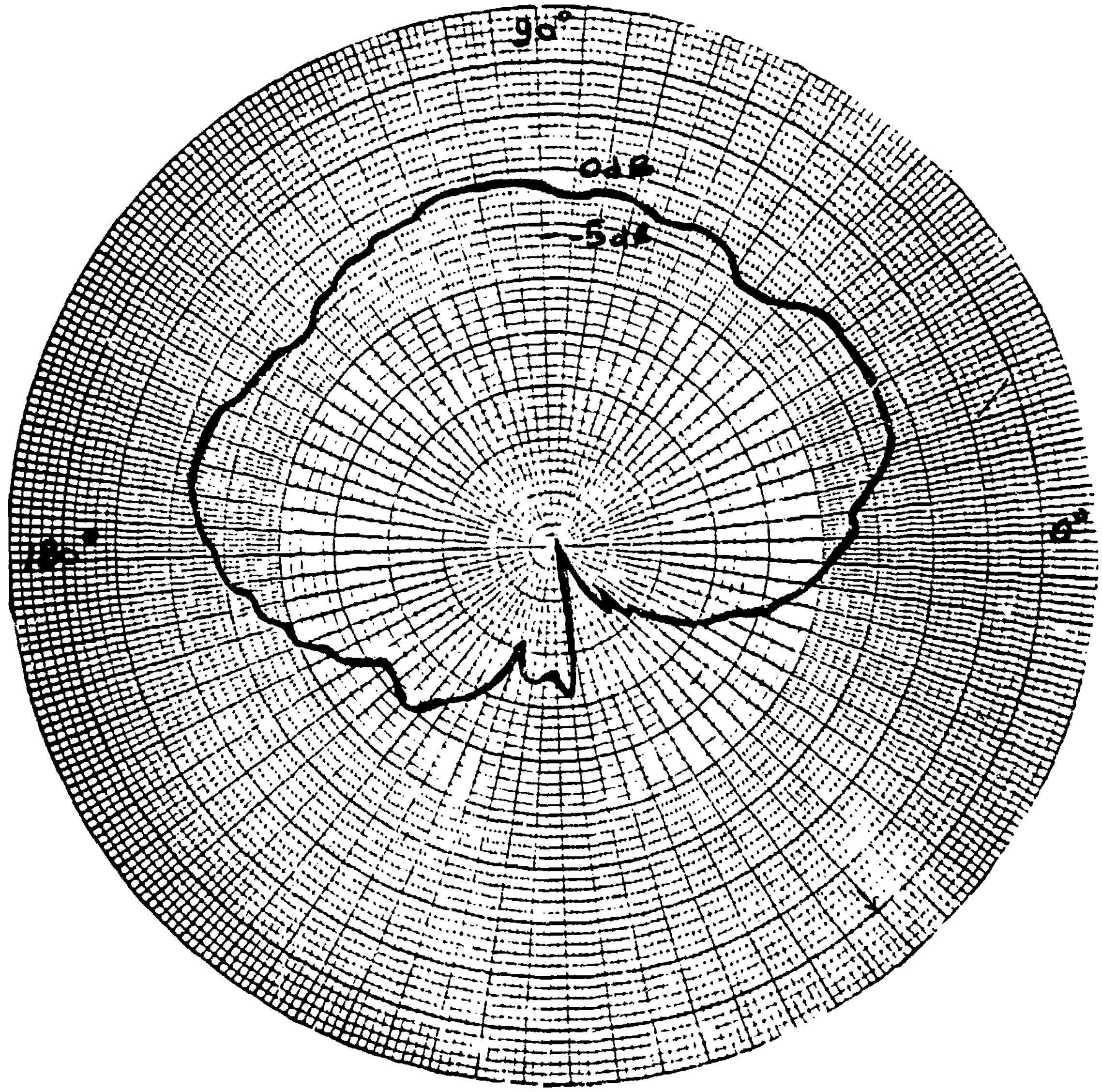


Figure 3. Measured radiation pattern, Texas Instruments omni antenna 1575 MHz, elevation plane

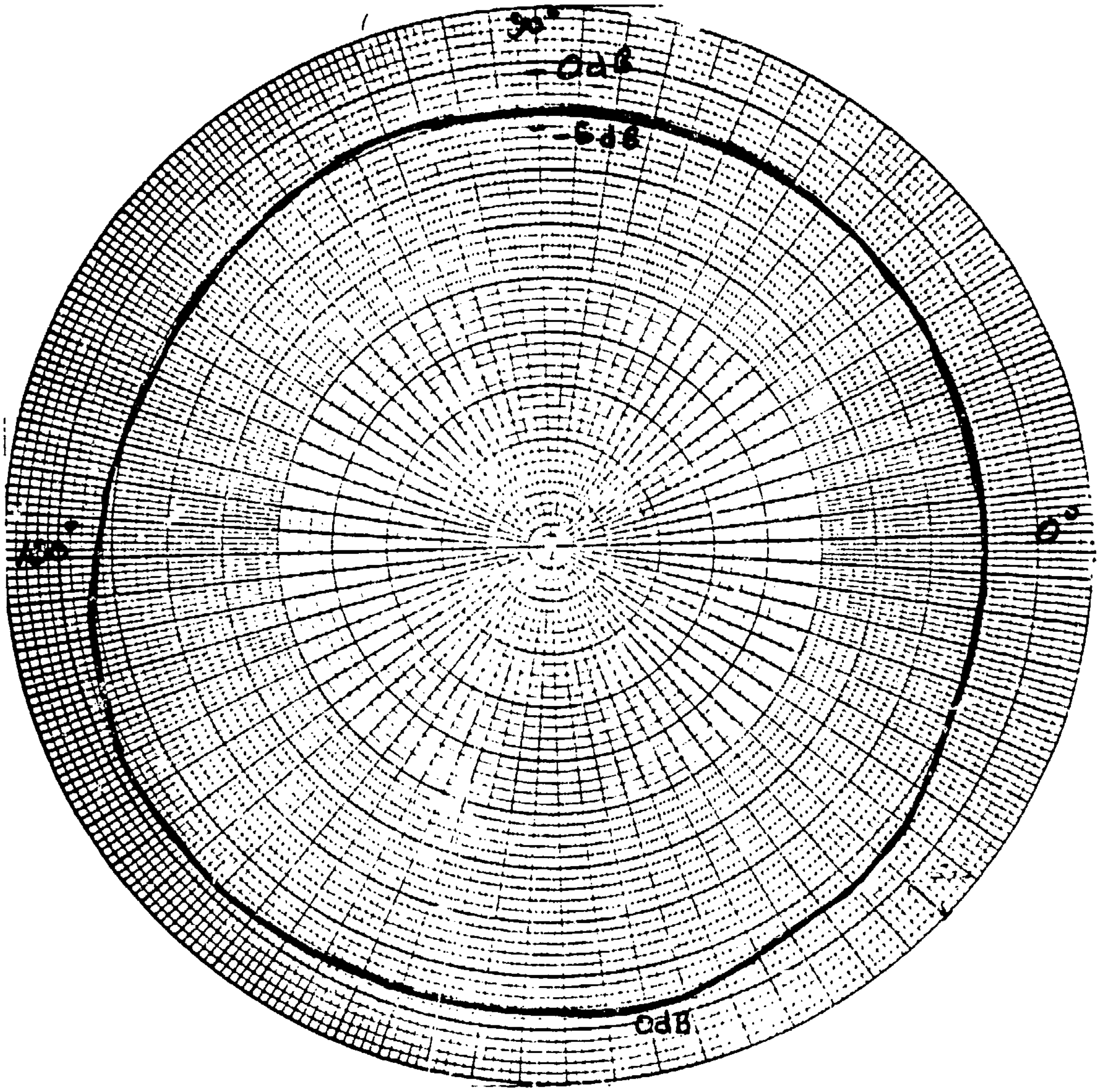


Figure 4. Measured radiation pattern, Texas Instruments omni antenna 1575 MHz, azimuth plane

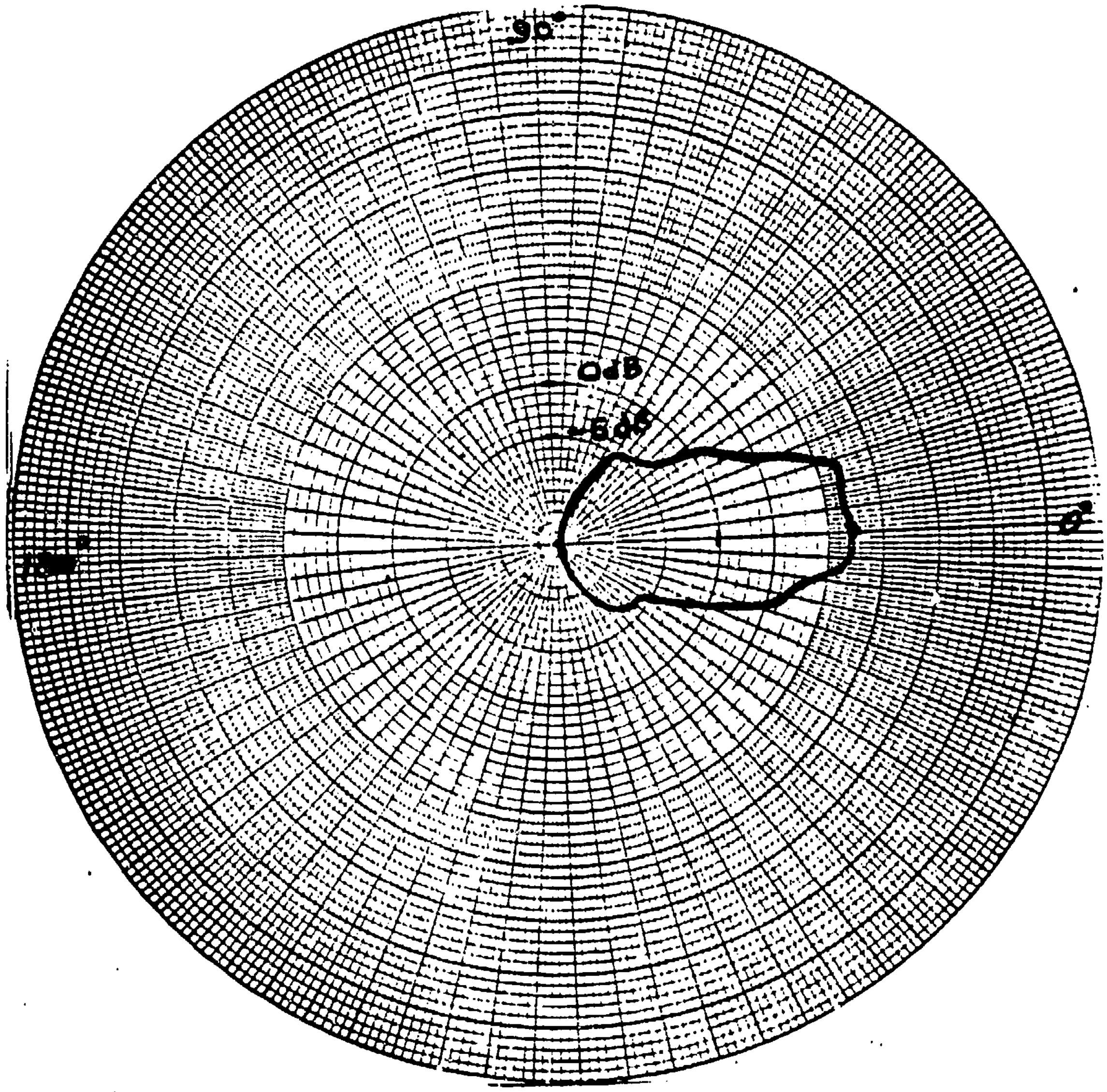


Figure 5. Measured radiation pattern, AEL horn antenna 1575 MHz, elevation plane

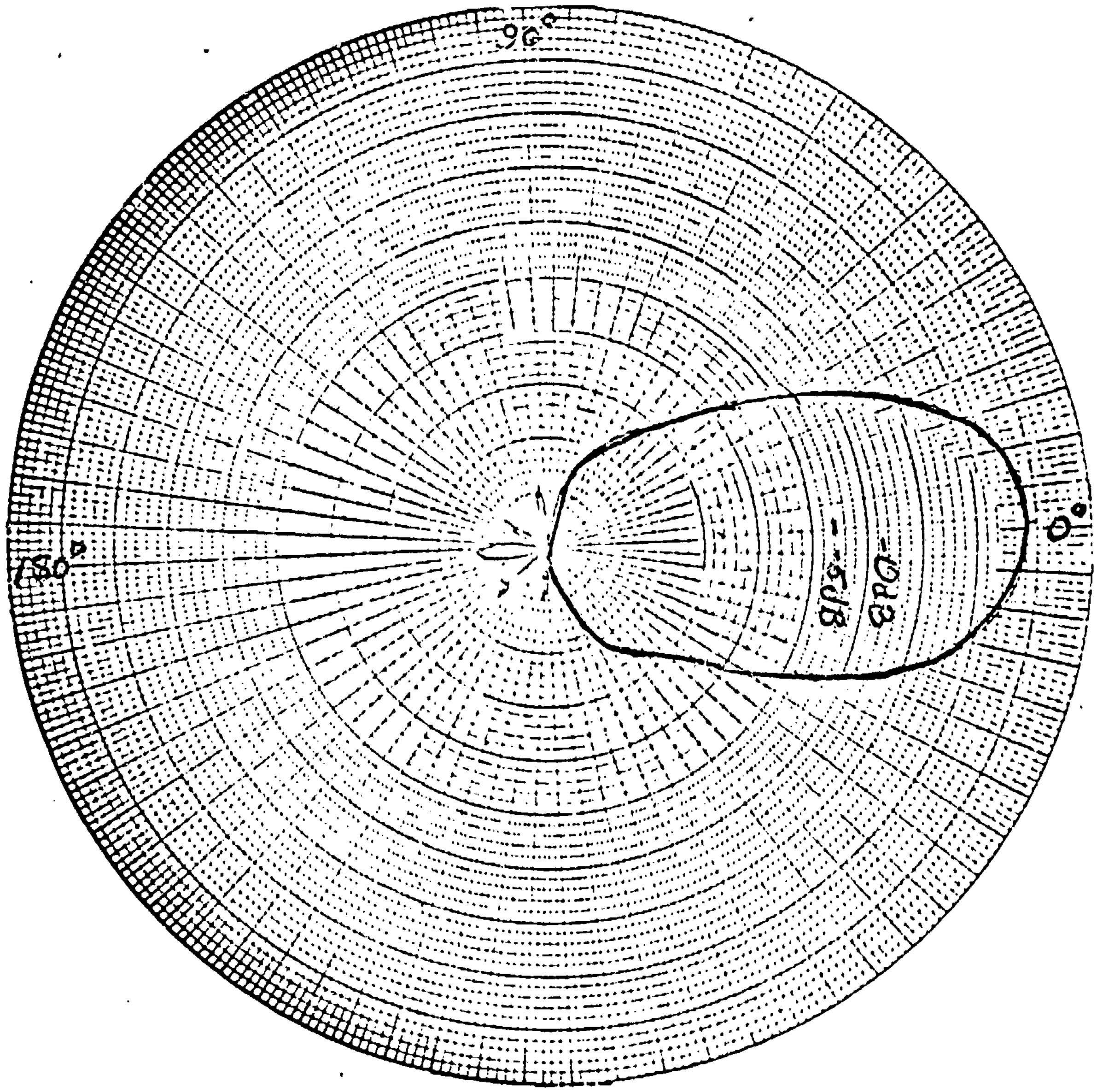


Figure 6. Measured radiation pattern, AFL horn antenna 1575 MHz, azimuth plane

The design of the array began by fabricating several single element, microstrip linear antennas for the higher GPS frequency (f = 1575 MHz). Figure 7 shows a typical array element, and a typical radiation pattern is shown in Figure 8. Each of the array elements has a similar radiation pattern.

The first array that was tested consisted of two antenna elements. Radiation patterns shown for two different element spacings in Figures 9 and 10, show that the beamwidth and directivity were unacceptable for the AJMA application.

In order to produce an antenna with a narrower beam and higher directivity than the two element array, while maintaining lightweight and reasonable size, a four element stacked array was designed[7] (Figure 11). The array is etched on a printed circuit board whose dimensions are 8 by 16 by 1/8 inch and weighs less than 1 pound.

Several theoretical radiation patterns were calculated for various spacings D_1 and D_2, with the individual radiating elements of the array excited in phase and with equal amplitude currents. Two of the more favorable designs are shown in Figure 12. These patterns were calculated using the following equation:

$$E = 2\, E_o\, [\cos\,(k\, D_1 \cos\,\theta) + \cos\,(k\, D_2 \cos\,\theta)]$$

where

E_o = amplitude of electric field

$k = 2\pi/\lambda$

θ = polar angle

A radiation pattern of an experimental array based on the "A" design of Figure 12 is shown in Figure 13. This is the elevation plane pattern; the corresponding azimuth pattern is similar to the pattern of Figure 8. It can be seen that the theoretical and experimental patterns are in excellent agreement.

Since the polarization of the jamming signal could be either linear or circular to be effective, it was decided to make the array responsive to RHCP signals. If the jammer was linearly polarized, the array would then be capable of receiving that signal with only a 3 dB reduction in gain, but more important, it would not have to be rotated for maximum response. Thus, a CP array was constructed based on design A of Figure 12, and the measured radiation pattern, in linear plotting format, is shown in Figure 14. The curve shows the axial ratio of the array as well. Results show that a gain of 9 dB and a beamwidth of 18 degrees was achieved. The 3 dB bandwidth of the array is shown in Figure 15 to be 35 MHz. Comparing Figure 14 with the expected simulation pattern shown in Figure 13, it can be seen that in the practical design model, the sidelobes are somewhat greater than in the simulation; however, they are sufficiently below the main lobe, and as will be observed in the test results, have a negligible effect on the overall AJMA pattern when combined with the omni antenna.

[7]Global Positioning System (GPS) Monthly Status Report, USAECOM Avionics Laboratory, Navigation Tech Area, 30 March 1977.

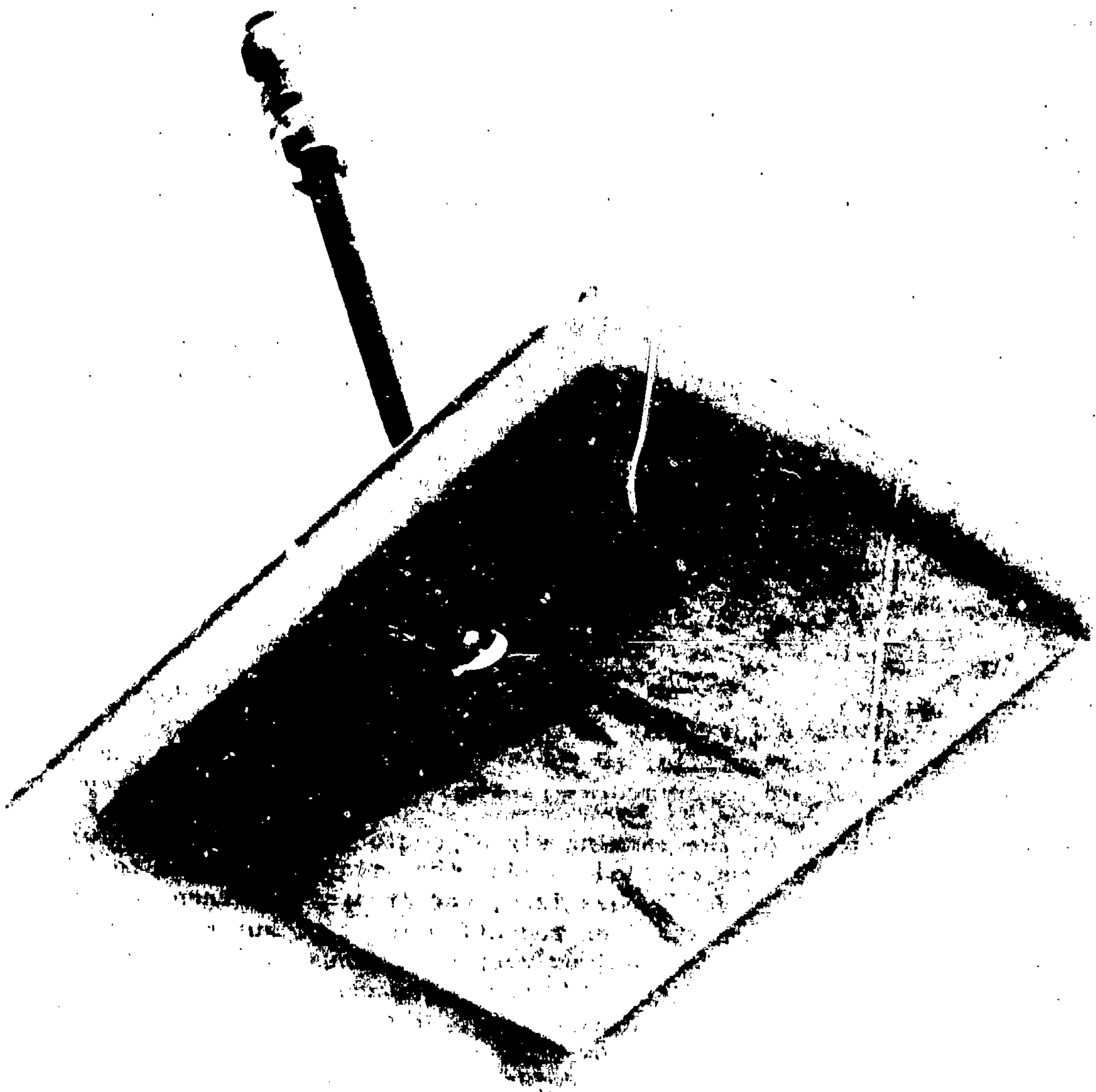


Figure 7. Single GPS antenna array element (f = 1575 MHz)

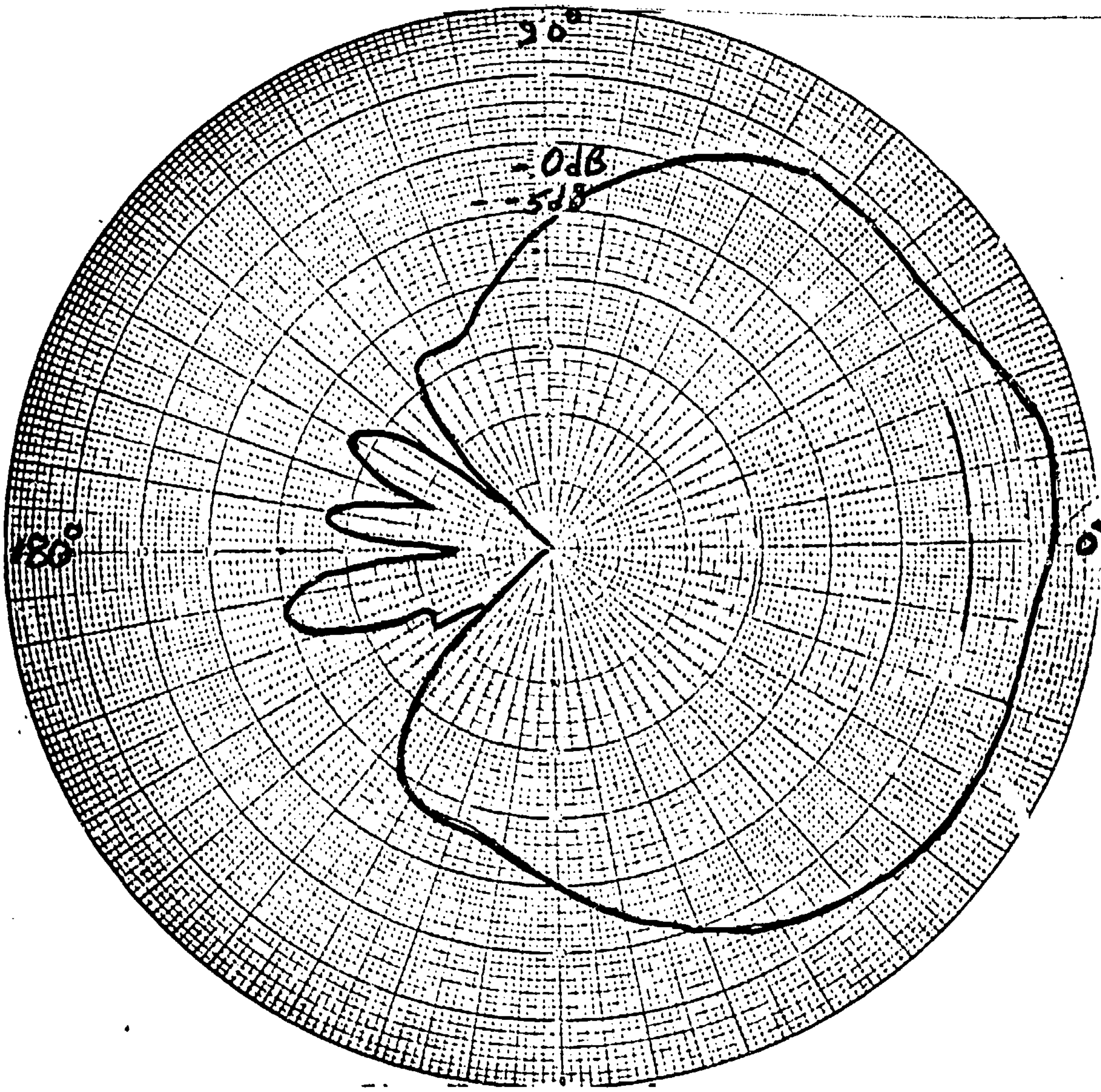


Figure 8. Measured radiation pattern single GPS antenna array element, 1575 MHz, in phase

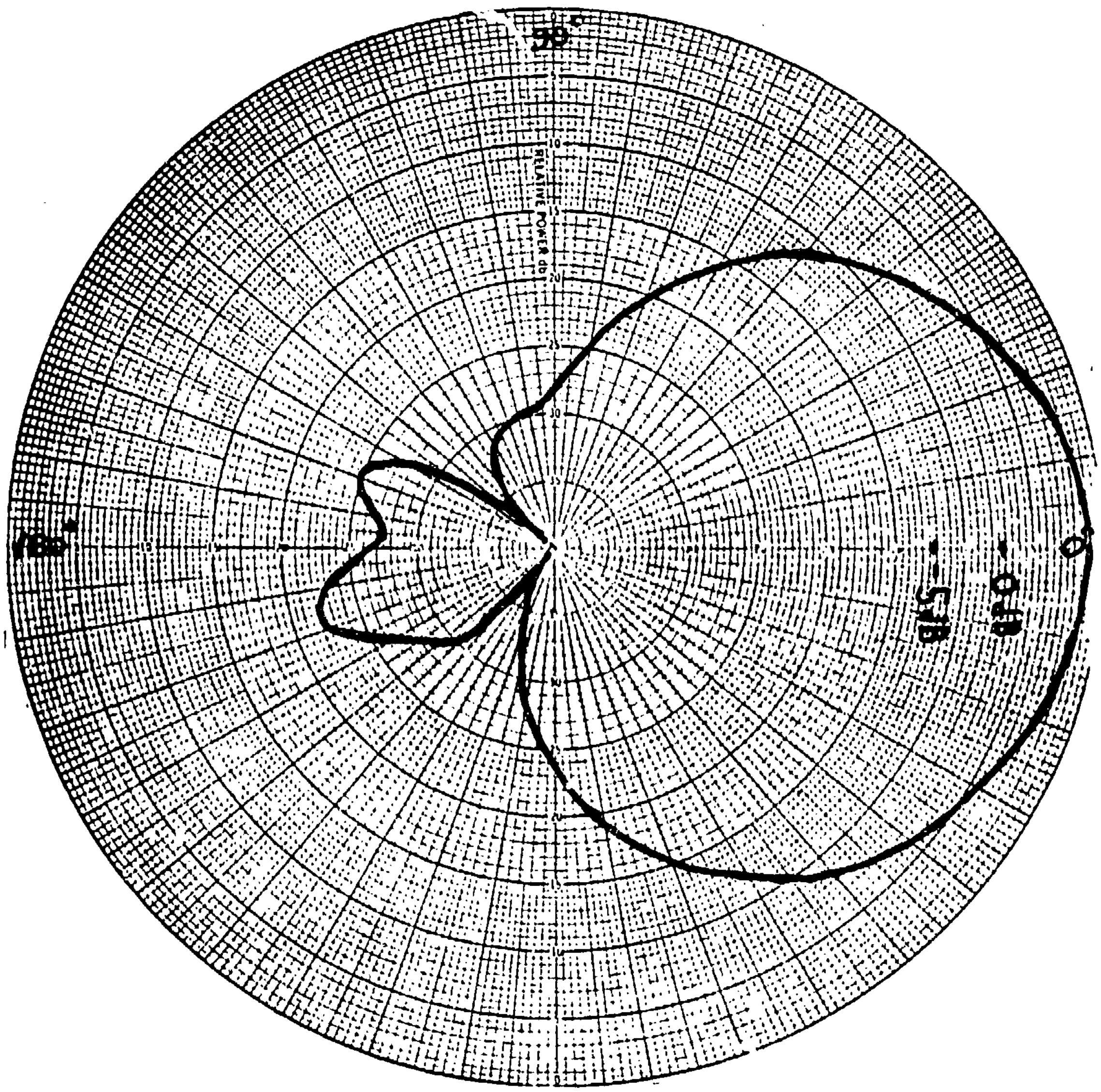


Figure 9. Measured radiation pattern dual GPS antenna array elements 1575 MHz, in phase 3-1/4 inch spacing

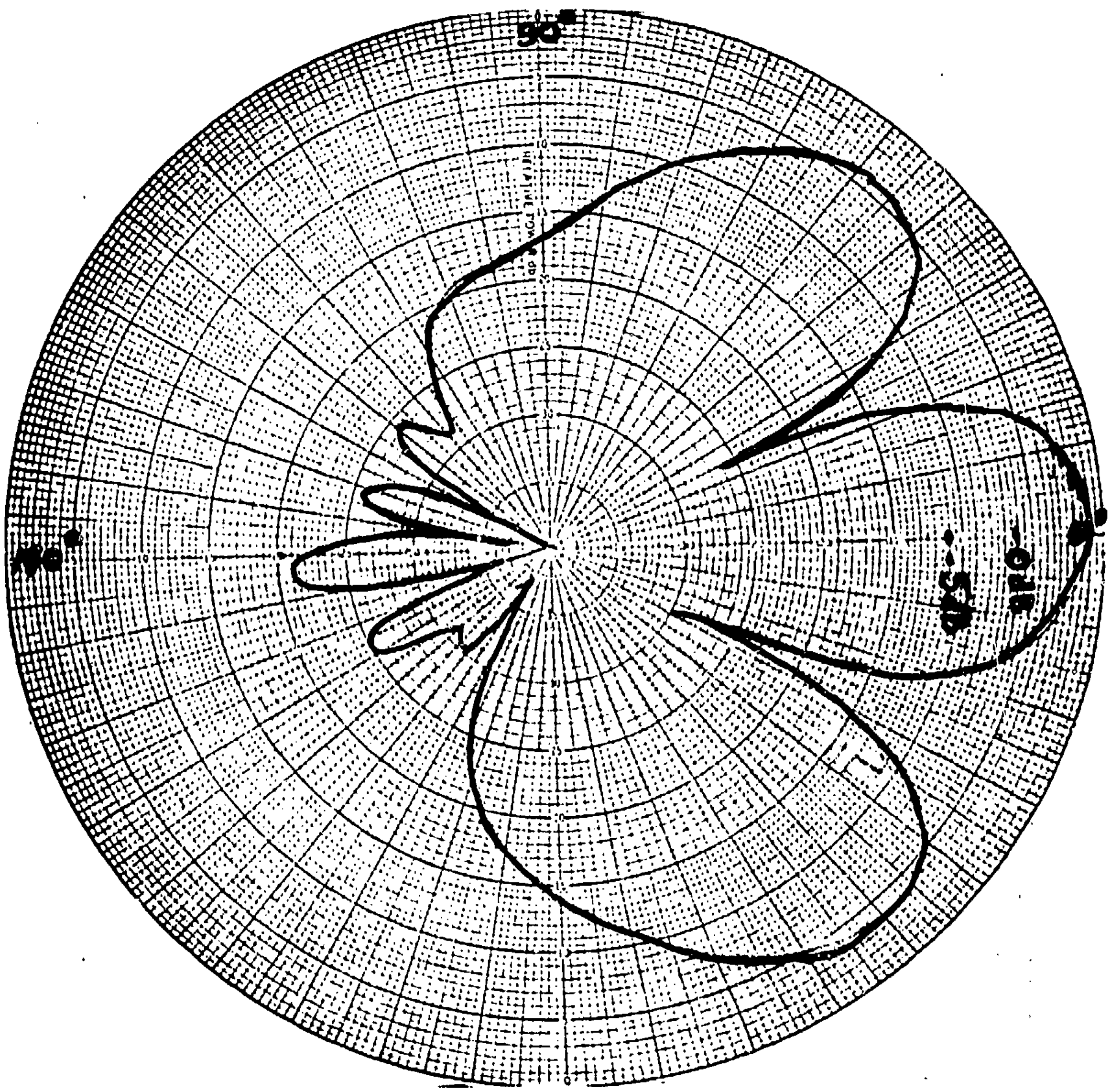


Figure 10. Measured radiation pattern dual GPS antenna array elements 1575 MHz, in phase 6-5/8-inch spacing

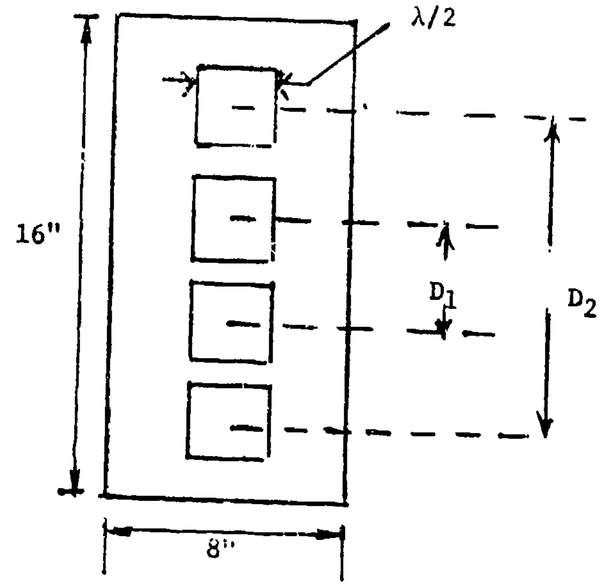


Figure 11. Four element planar antenna array dimensions

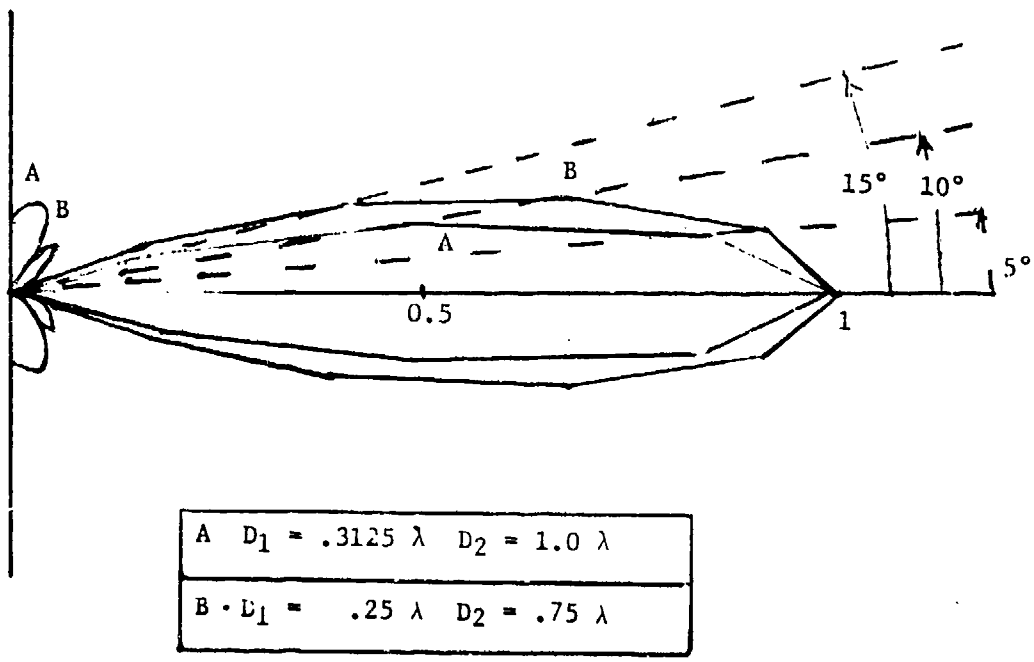


Figure 12. Four element antenna array computer simulation optimal radiation pattern

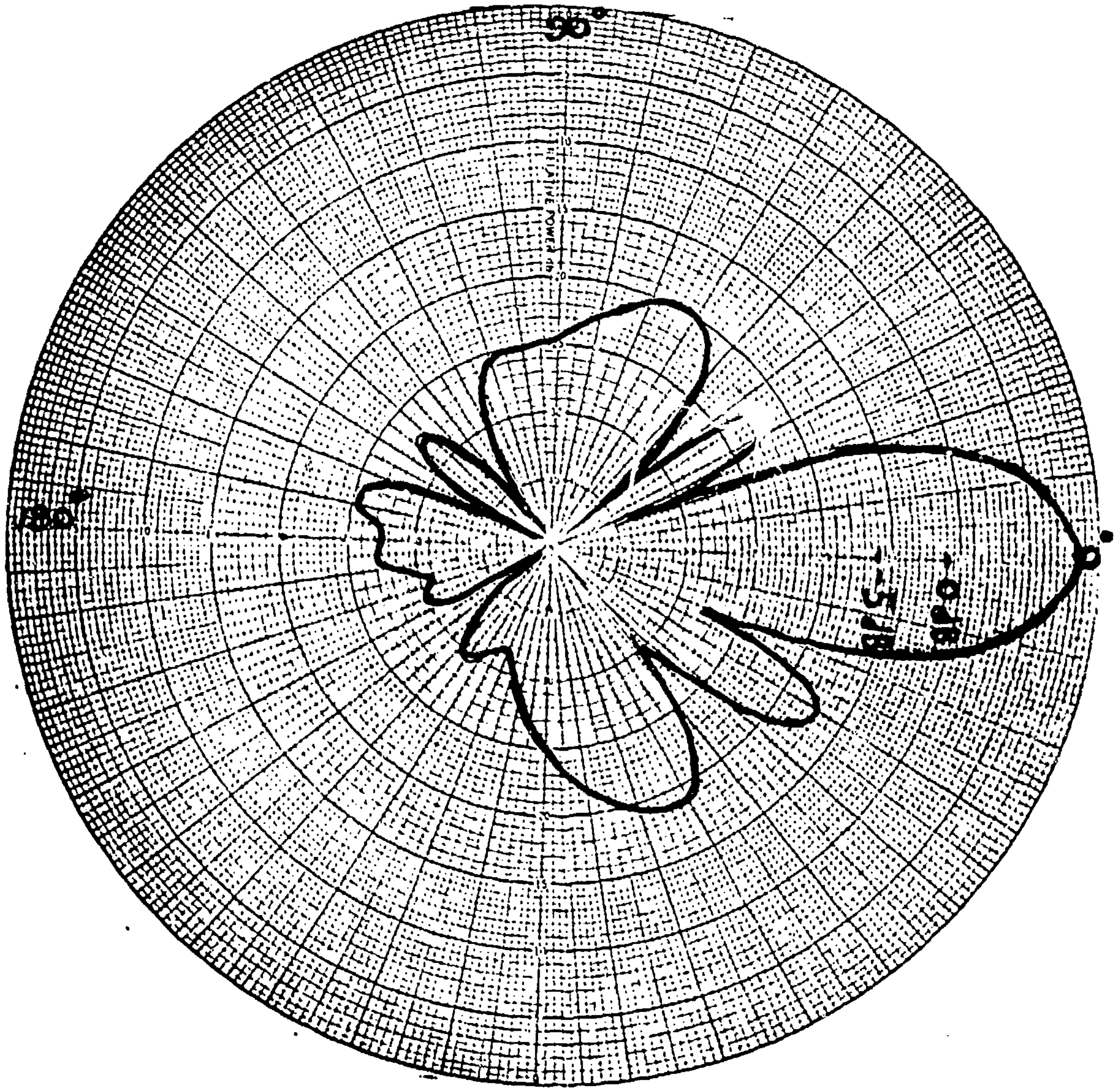


Figure 13. Measured radiation pattern GPS four element antenna array 1575 MHz, linear polarization

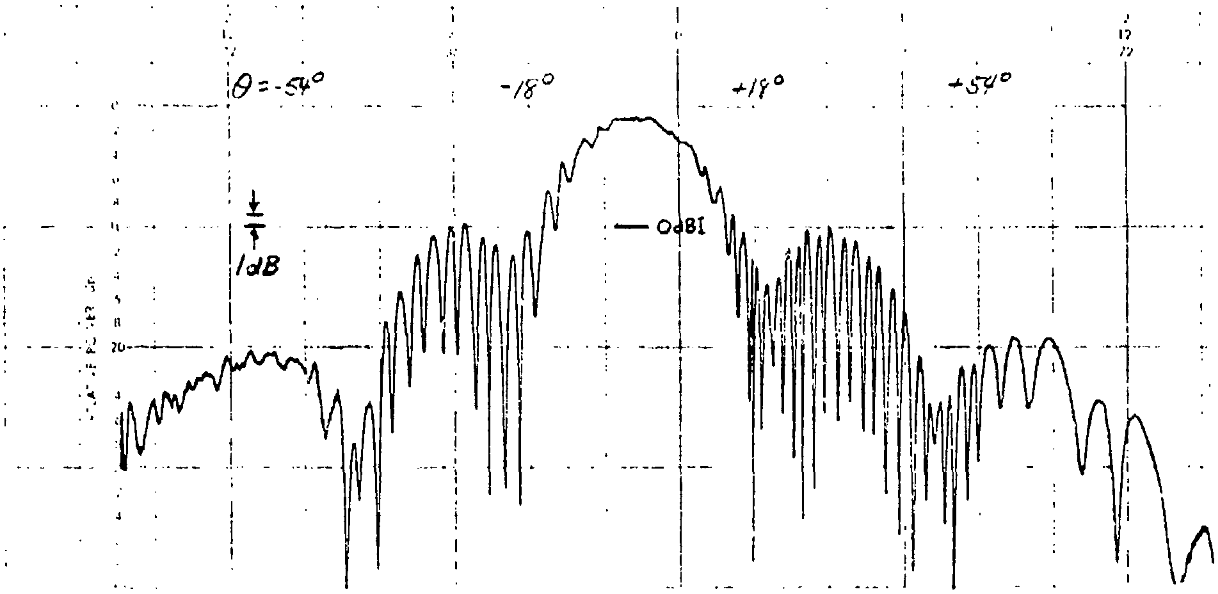


Figure 14. Measured radiation pattern GPS four element antenna array 1575 MHz, circular polarization

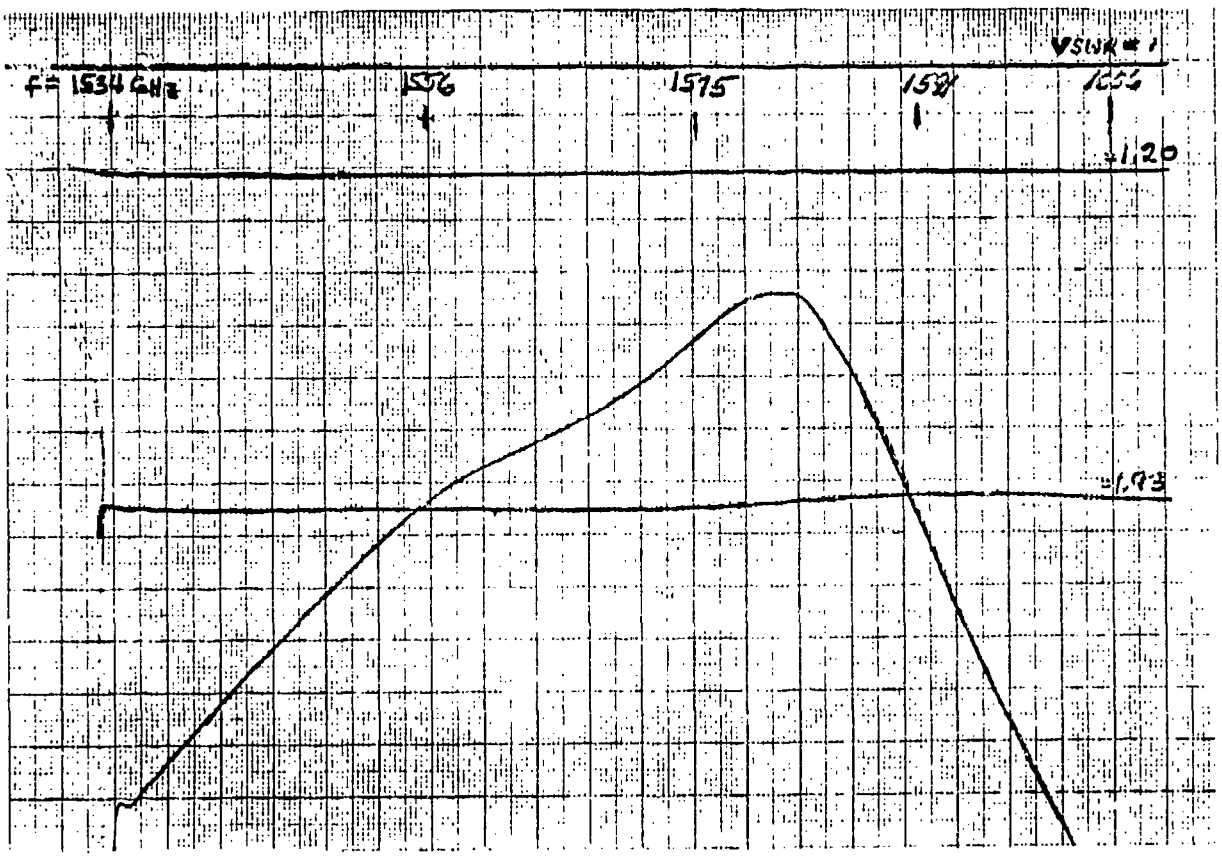


Figure 15. GPS four element antenna array input VSWR versus frequency pattern

5. AJMA LAB TESTS

The initial experimental AJMA model developed was shown previously in Figure 2. The TI omni antenna was mounted on top of a wooden stand. The directive antenna used for this model was the AEL horn antenna. These antennas are combined through a correlator system consisting of a vector multiplier and a 180° hybrid coupler. The signal vector multiplier, connected to the directional antenna, adjusts the phase and amplitude of the signal received by this antenna. The phase rotation is selectable from 0 to 2 π. The magnitude is continually adjustable over a 6 dB to 60 dB range. The signals received by the directional and omni antennas are combined through a 10 dB directional coupler. The correlator system adjusts the shape of the AJMA pattern, positioning a pattern null in the direction of an unwanted signal while retaining gain in the direction of the desired signals.

Operation of the AJMA system requires that the jammer signal sensed by the directional antenna be adjusted through the vector multiplier so that it is equal in amplitude to the jamming signal sensed by the omni antenna and 180° out of phase with it. It is then "added" by the directional coupler to the omni channel. Theoretically, it should be possible to obtain complete cancellation of the jamming signal along the line-of-sight of the directional antenna. The phase shifter of the vector multiplier is adjusted to compensate for the different lengths in the RF circuitry, and to afford some control of the location of the null in the overall elevation plane pattern of the AJMA model.[8]

Radiation patterns obtained during lab tests were run in the anechoic chamber shown in Figure 16. During these tests, the AJMA system was placed upon a rotating turntable. The turntable was servo-linked to a polar plot recorder. The AJMA system was turned through 360° and the radiation patterns were made at the 1575 MHz test frequency. The transmitting antenna, during this test, was a broadband log-periodic antenna. Prior to running these tests, the polar plot recorder system was calibrated using a standard gain horn at 1575 MHz

The system response to both linearly and RHCP signals were recorded. Ideally, a perfect RHCP antenna would induce all the available voltage out of a RHCP wave; would completely reject one of the opposite sense; and would respond to half of the available voltage from a linear wave. The elevation and azimuth AJMA system response to linearly polarized (LP) signals, with the directive antenna completely attenuated, is shown in Figures 17 and 18, respectively. By properly adjusting the vector multiplier, for this LP case, the elevation and azimuth AJMA system response is significantly altered as shown in Figures 19 and 20. Comparing Figures 17 and 18 with Figures 19 and 20, respectively, a null depth of 38 dB was observed to occur using the directive antenna while retaining nearly 0 dB azimuthal coverage. The system response to right-hand circularly polarized (RHCP) signals in the elevation plane,

[8]Global Positioning System (GPS) Monthly Status Report, USAECOM Avionics Laboratory, Navigation Tech Area, 3 March 1977.

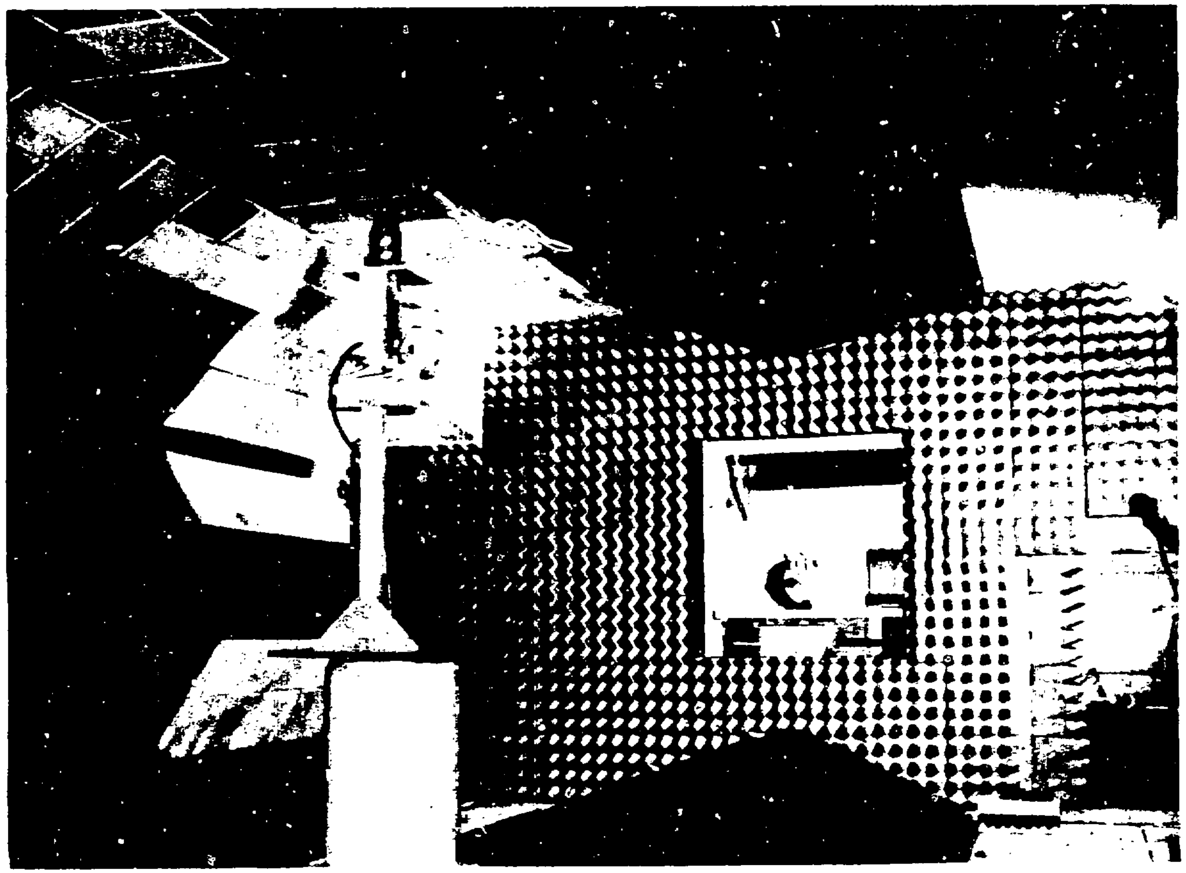


Figure 16. AJMA anechoic chamber test facility

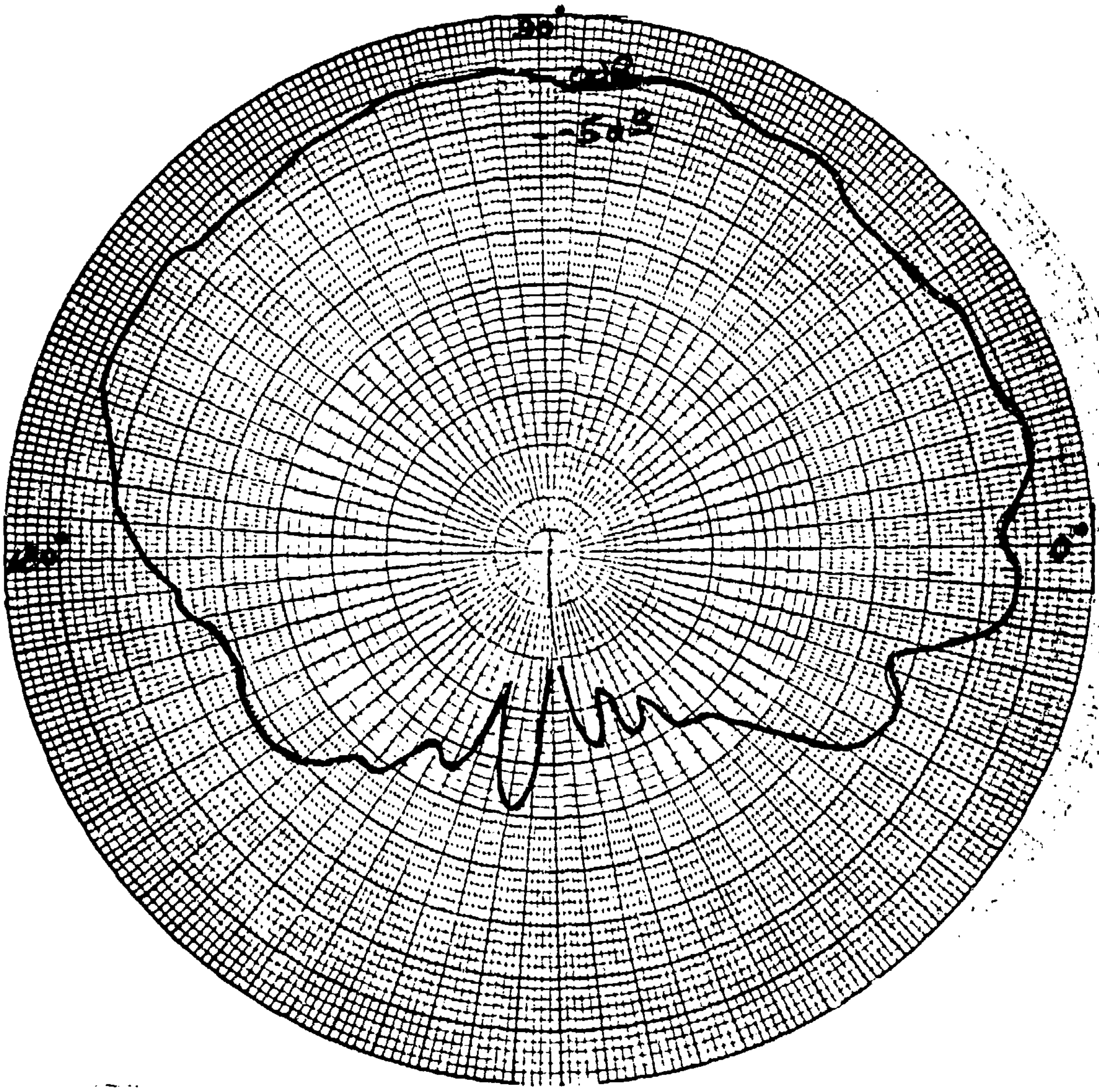


Figure 17. Measured radiation pattern, AJMA (GPS four element antenna array completely attenuated), 1575 MHz, linear polarization, elevation plane

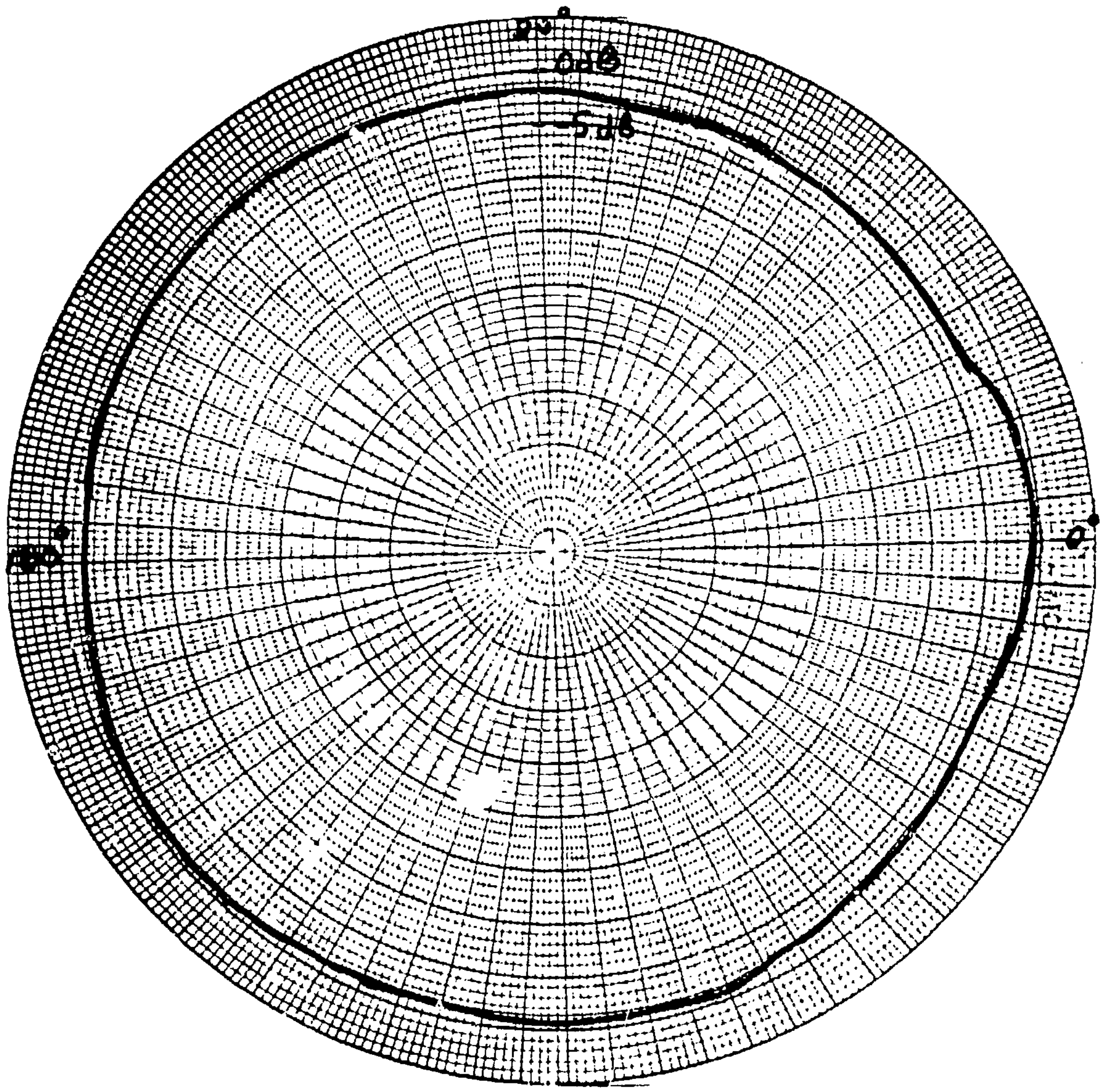


Figure 18. Measured radiation pattern, AJMA (GPS four element antenna array completely attenuated), 1575 MHz, linear polarization, azimuth plane

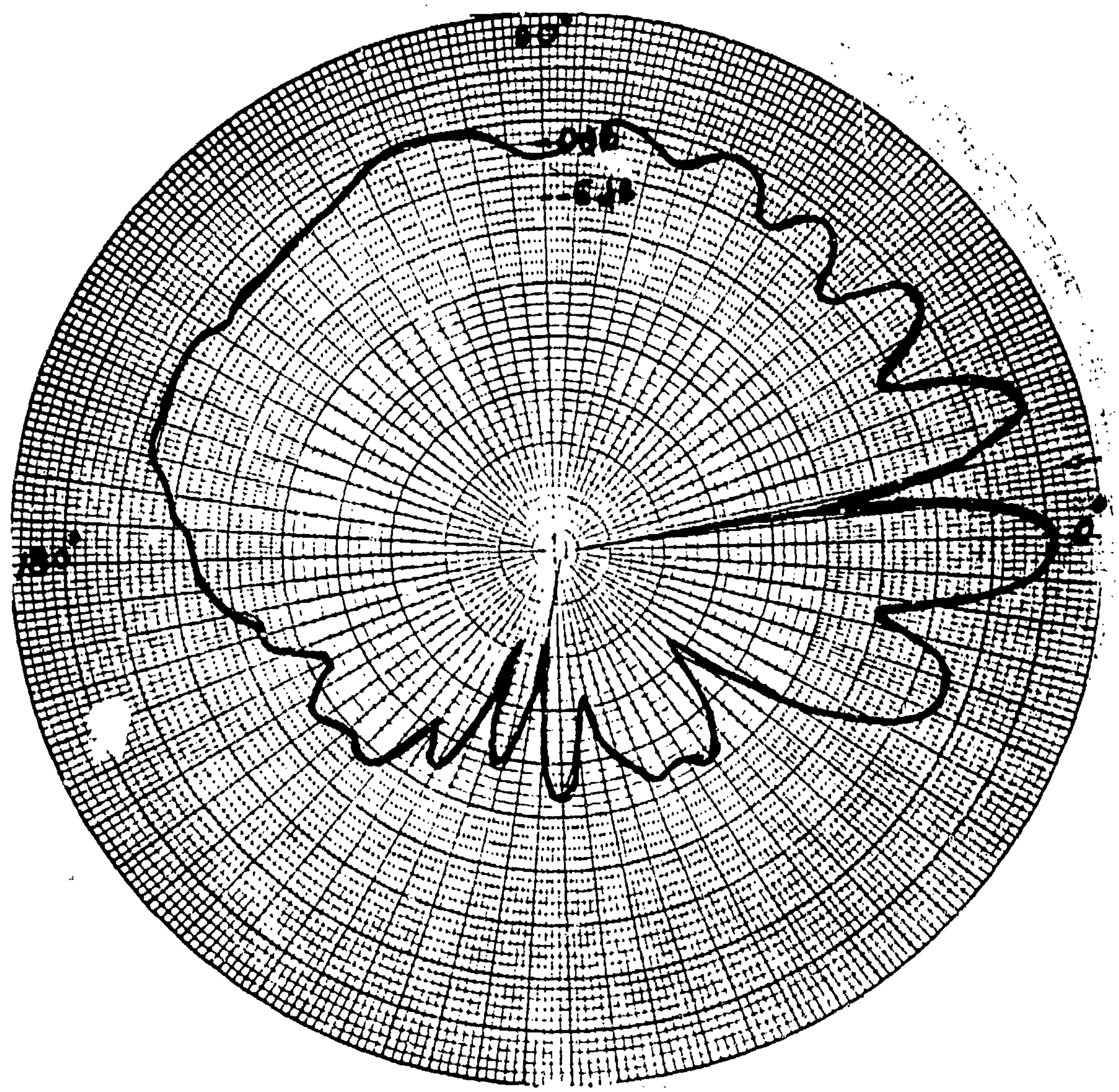
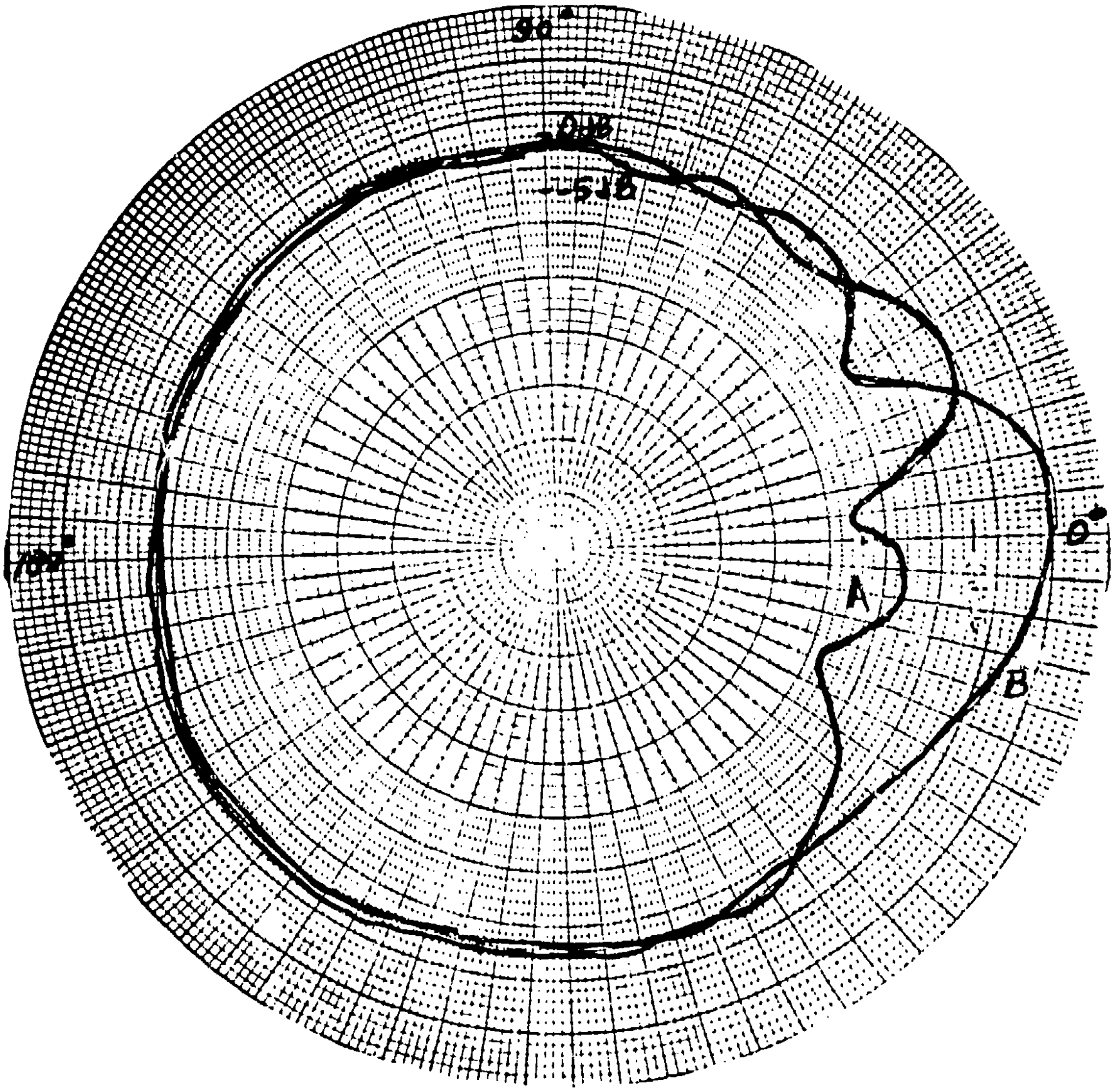


Figure 19. Measured radiation pattern, AJMA, 1575 MHz, linear polarization, elevation plane



A. 0° phase shift inserted B. 199° phase shift inserted

Figure 20. Measured radiation pattern, AJMA, 1575 MHz, linear polarization, azimuth plane

with the directive antenna completely attenuated, is shown in Figure 21. When the vector multiplier is properly adjusted, a null of approximately 13 dB is attainable, as shown in Figure 22.

These tests were run such that the spatial distance between the omni antenna and the directive antenna was maintained at 15 inches. Measurements for longer spatial distances proved to slightly reduce field coupling of the antennas.[8]

6. AJMA FIELD TESTS

The lab tests were run to determine the feasibility of the AJMA system. Having successfully shown this feasibility, a practical, lightweight AJMA system was developed, which used the same correlator system as was used in the lab tests, however, replacing the AEL horn with an in-house developed four element linear antenna array. This new AJMA configuration is shown in Figure 23.

The AJMA is attached to a wooden structure and consists of an omni antenna (standing upright), a directive antenna (in quadrature to the omni), and associated electronics. The height of the AJMA system (excluding wooden stand) is 28 inches.

Field radiation pattern measurements were conducted to observe the patterns in a non-ideal field environment. The relative amplitude response properties of the AJMA were measured as a function of azimuth and elevation space coordinates. This data will provide the basic information for determining the anti-jam capabilities of the AJMA.

The antenna range facility and AJMA field test setup is shown in Figure 24. The AJMA is located on top of a column attached to an antenna rotator. A log-periodic RHCP antenna positioned 30 feet from the AJMA served as the GPS transmitting antenna. A parabolic dish antenna located 30 feet from the AJMA and 5. away from the GPS signal source served as the far field linear CW jammer source. An underground cable connected the AJMA system to the recording instrumentation housed in the antenna range building. The AJMA signals were received by a Scientific Atlanta recorder and plotted on a strip chart recorder which was synchro-coupled to the antenna rotator. Since a GPS signal generator was unavailable for these tests, a right-hand circular polarized, pulse modulated (10 MHz), binary phase shift keyed (BPSK), single frequency (1575 MHz) signal source was used and designated as the GPS signal.

In the field AJMA configuration, the insertion loss of the system is only 1 dB. This low insertion loss was achieved by using impedance mismatch coupling between the GPS omni antenna and the directive antenna array.

A sketch of the jamming configuration used in the AJMA field test is shown in Figure 25. Using this setup, the first test was run to determine the elevation radiation pattern of the omni only portion of the AJMA using the satellite signal (GPS) transmitter. The resulting pattern (Figure 26) shows approximately a uniform 0 dB hemispherical coverage, except for -4 dB level* at $\alpha = 135°$ (equivalent to 45° above horizon).

*Scattering at field test site. Anechoic chamber measurements showed no variation in this direction.

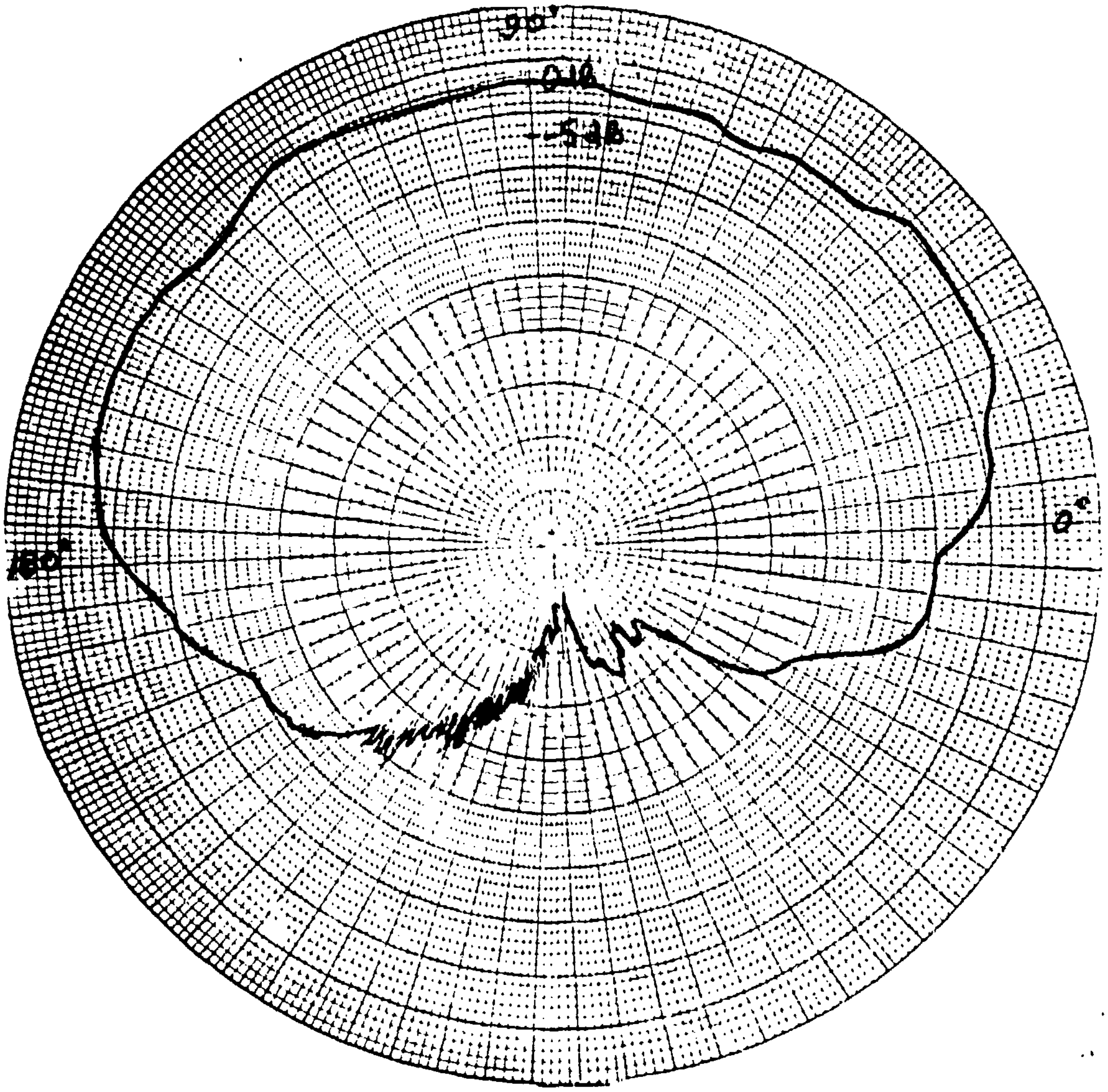


Figure 21. Measured radiation pattern, AJMA (GPS four element antenna array completely attenuated), 1575 MHz, right-hand circular polarization, elevation plane

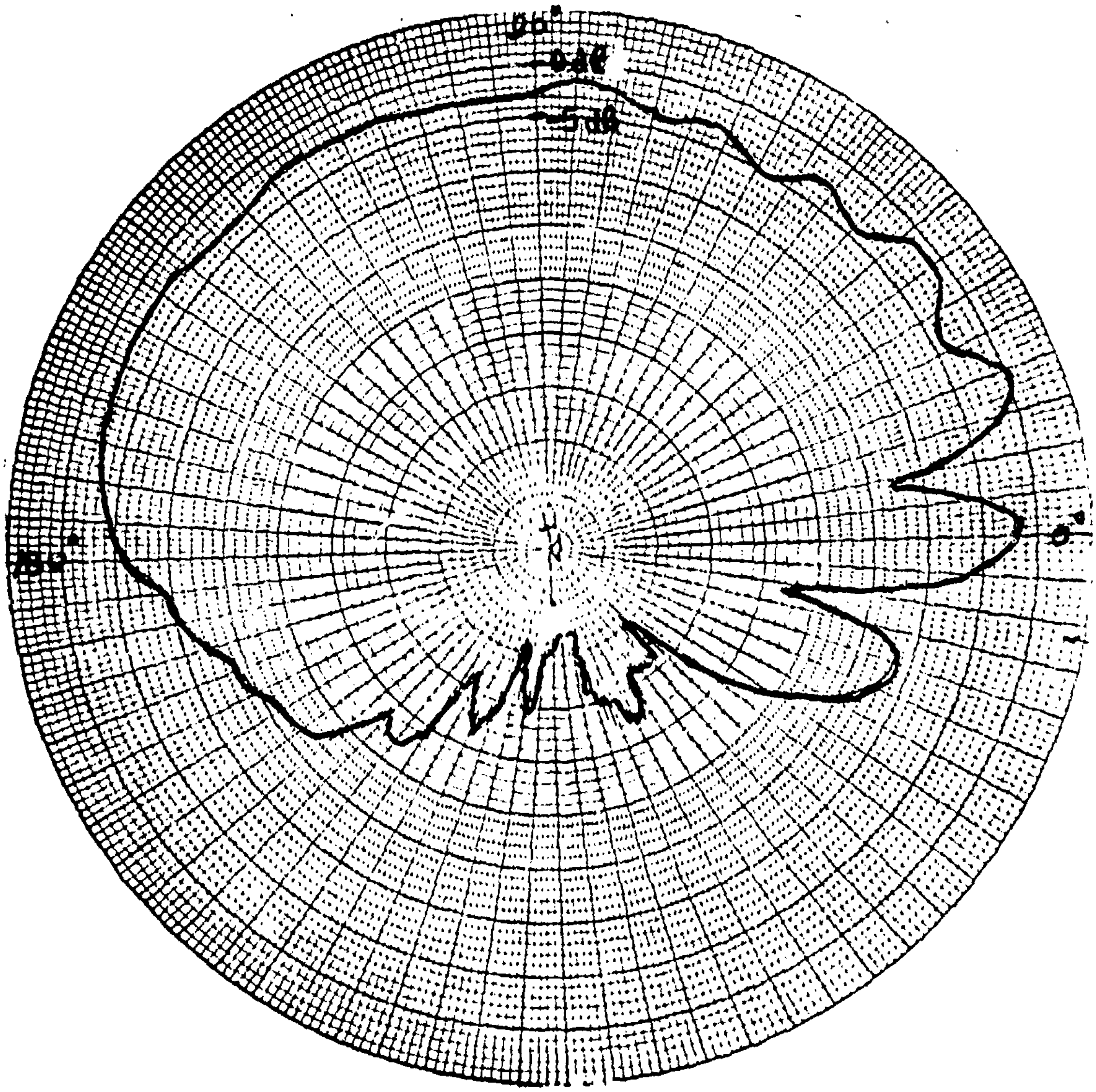


Figure 22. Measured radiation pattern, AJMA, 1575 MHz, right-hand circular polarization, elevation plane

Figure 23. Anti-jam manpack antenna (AJMA) field test model

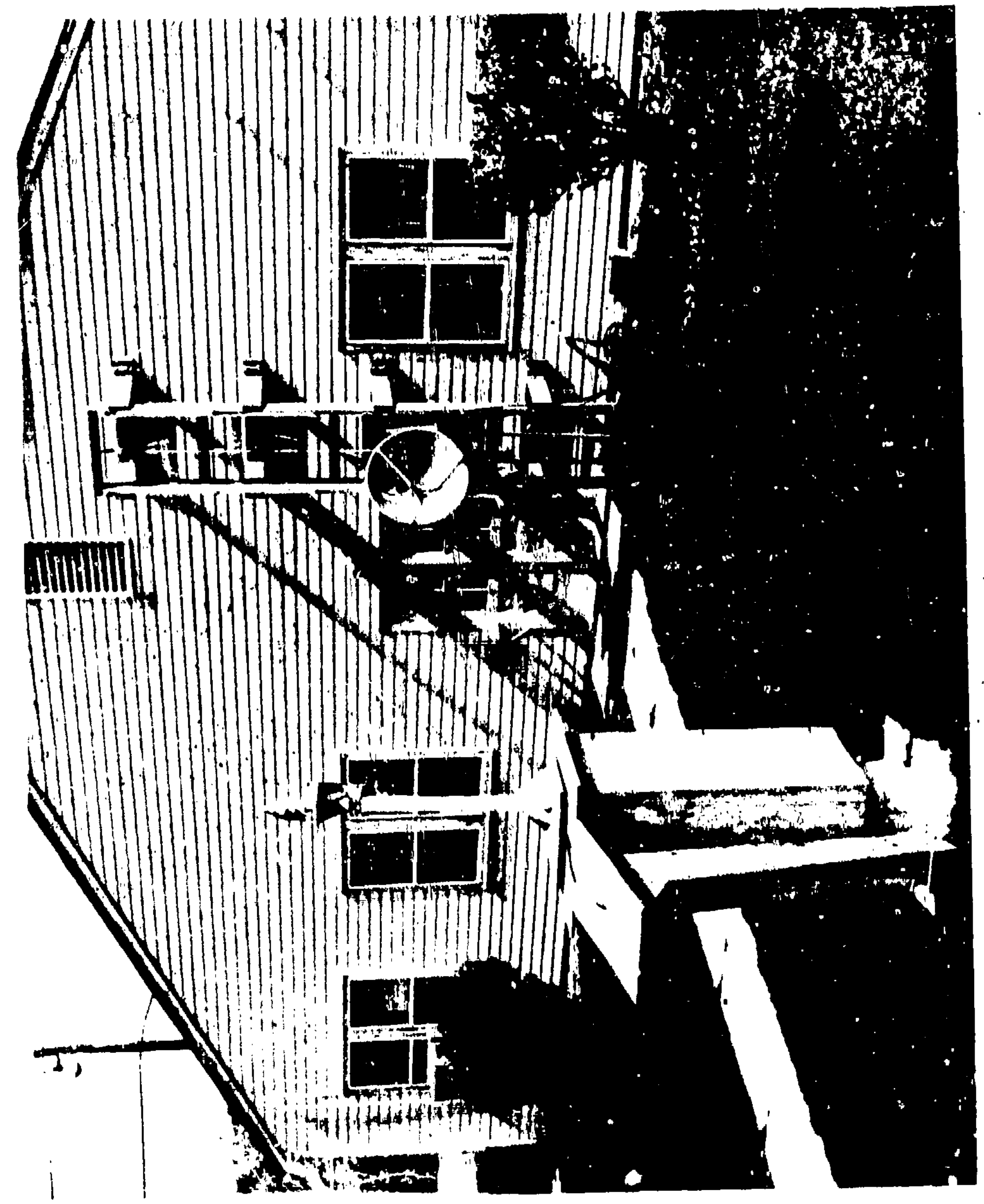


Figure 24. AJMA field test facility

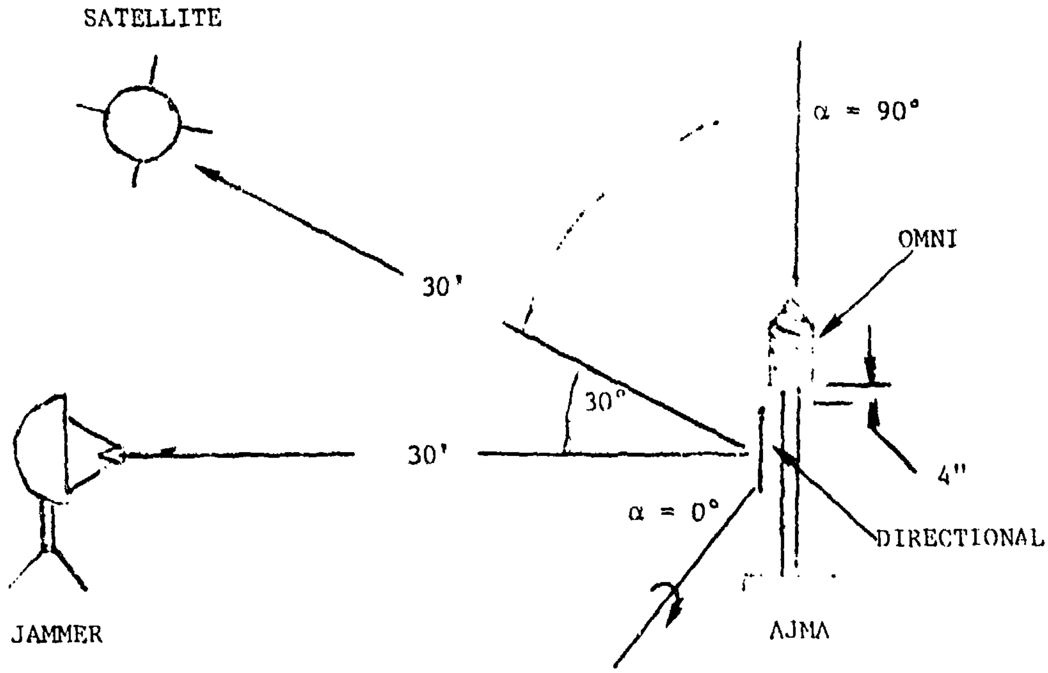


Figure 25. AJMA jamming test configuration

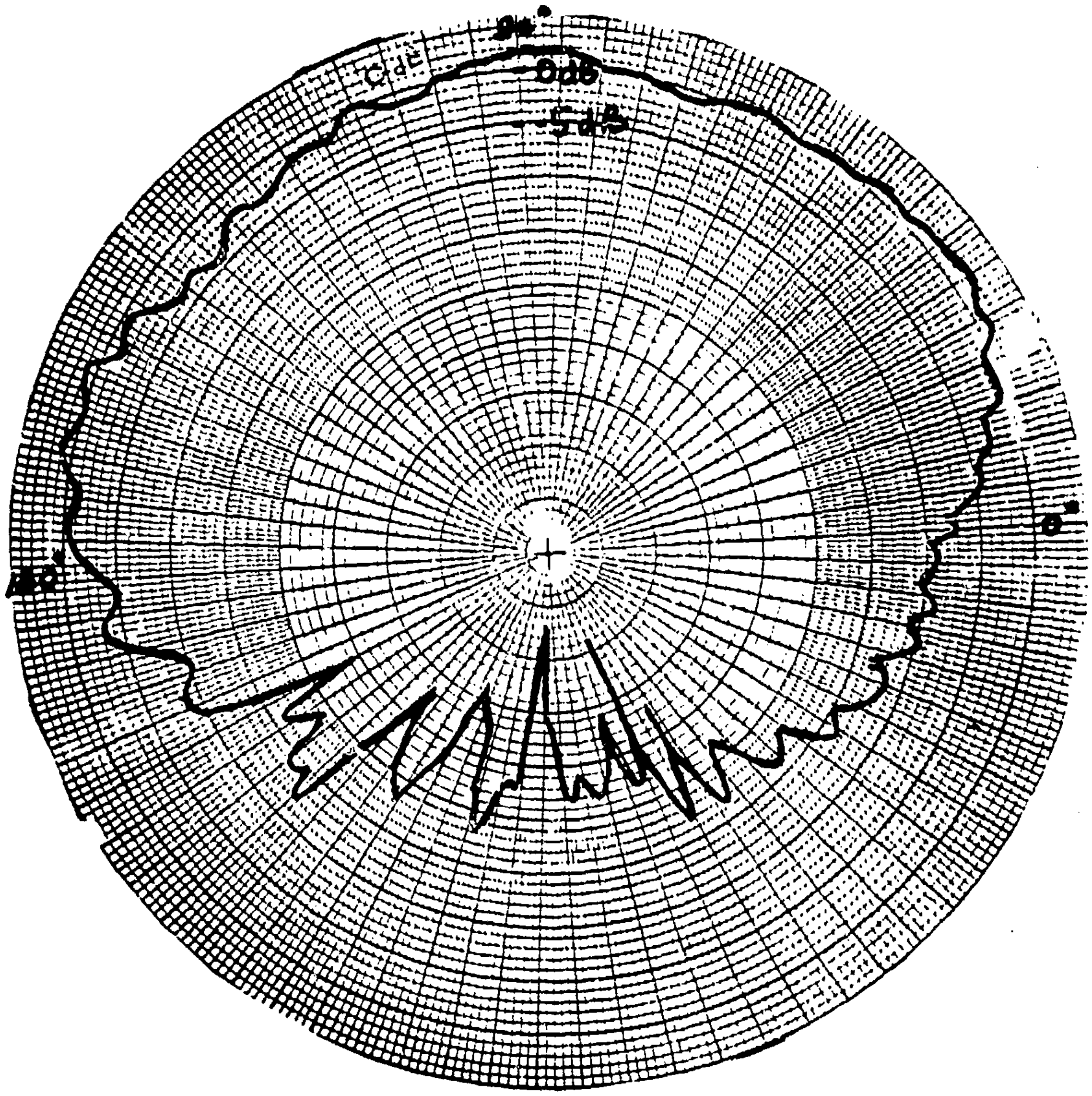


Figure 26. Measured radiation pattern, AJMA omni antenna only response to satellite signal (1575 MHz, 10 MHz pulse modulation, BPSK), elevation plane

The second test was run to determine the elevation radiation pattern of the AJMA using the jammer as transmitter. This pattern (Figure 27) shows a major null near the horizon at α = -4° (-16 dB).

The third test was critical since it represented the elevation radiation pattern of the AJMA to the satellite signal (Figure 28). Aside from a -4.5 dB attenuation at α = 135°, the pattern is uniform for upper hemispherical coverage and shows the nulling effect of the directional antenna at α = 0° (13 dB).

The elevation radiation pattern shown in Figure 29 was made to determine the change in the AJMA radiation pattern shown in Figure 28 as a result of spacing the directional antenna ≈ 21 inches further from the omni. The overall effect was to increase the number of nulls, e.g., at α = 6° (-12 dB), α = -4° (-21 dB), α = -12° (-27 dB).

Azimuthal radiation patterns of the AJMA system for vertically polarized and horizontally polarized CW jammers are shown in Figures 30 and 31, respectively. Although deep nulls are seen to occur in both cases (> 20 dB for vertical polarization and > 10 dB for horizontal polarization), the expected 0 dB, circular pattern was not realized. Both patterns experience an anomaly which degrades the lower left-hand corner of the polar plot by nearly 10 dB. It must be assumed that the measurement range is causing scattering effects on these patterns. This scattering effect upon the patterns would also explain the unexpected attenuation on the elevation patterns above the horizon.

Since the null in Figure 31 is not as deep as for Figure 30, this particular directive antenna is more effective against vertical polarization than horizontal polarization simply because the gain of the circularly polarized array is different from each polarization.*

Following the radiation pattern tests, jamming tests were run, whereby the AJMA was subjected to both the satellite signal (RHCP, 1575 MHz, 10 MHz modulation, BPSK) and the CW jammer (1575 MHz, $BW_{3\ dB}$ = 1 MHz). Since actual GPS signals would be at a level below noise (-163 dBW, P-code, and -160 dBW, C/A code) and not detectable by presently available commercial equipment, tests were run at levels which could be detected by a spectrum analyzer (noise level -100 dBW). The AJMA's operation is based upon the relative signal levels in the omni and directional antennas and requires that the signal levels be of equal amplitude in both antennas for complete cancellation of the jammer to occur. This equalization of amplitude is achieved through manual adjustment of the vector multiplier. Since the AJMA system performance is not dependent upon absolute signal levels, the successful performance of the AJMA at one signal level would necessarily make it successful for all signal levels.

Using the radiation pattern measurement test scenario, a series of photographs (Figure 32) were taken on a spectrum analyzer of nonjammed and jammed

*Due to the coupling coefficient of the directional coupler used in the experiments, the gain of the directive antenna should be ≈ 9 to 10 dB. Apparently, in this particular antenna, the gain for a horizontally polarized signal was slightly less than this value, and, therefore, perfect cancellation was not achieved.

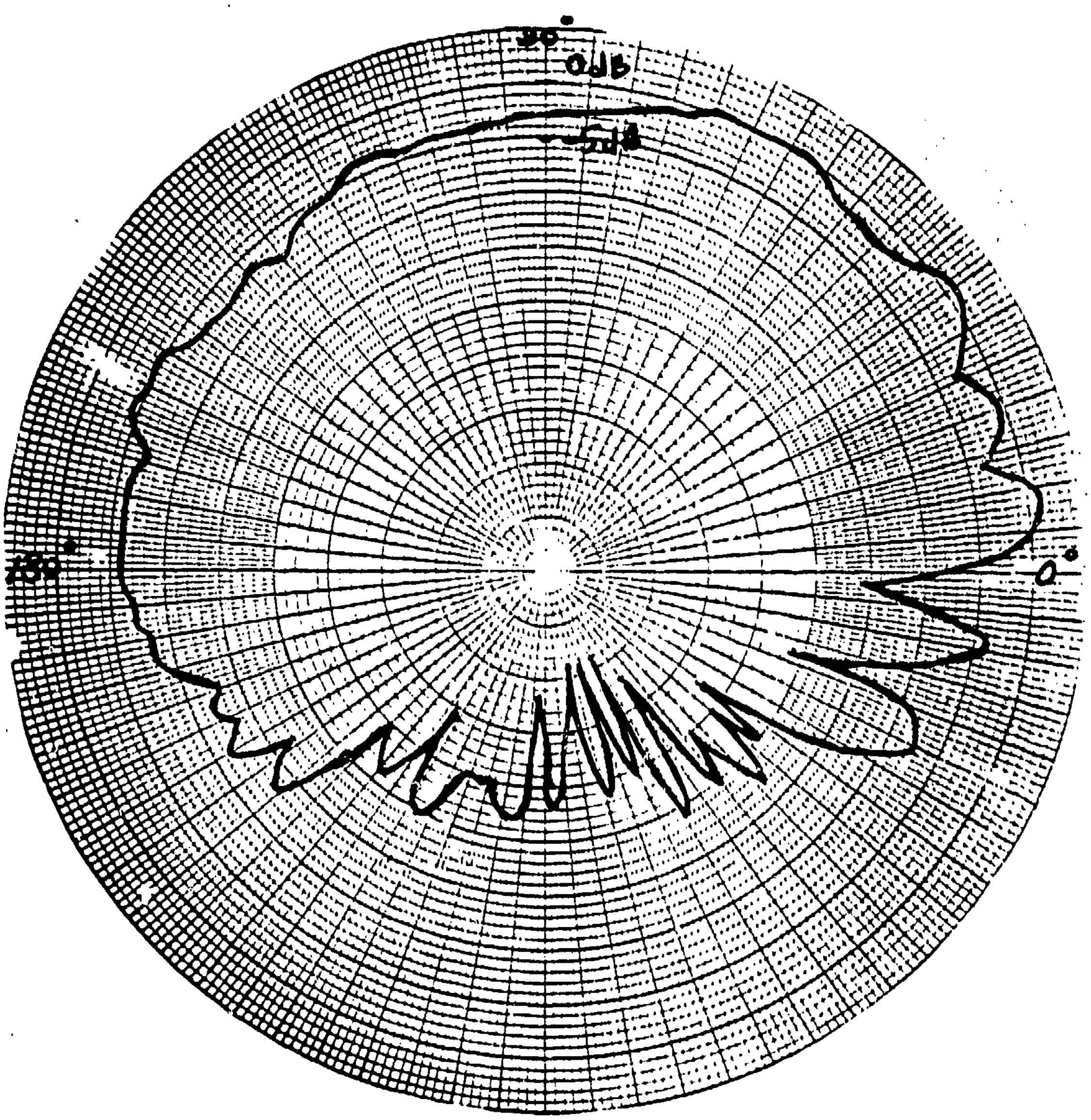


Figure 27. Measured radiation pattern, AJMA response to linearly polarized CW (1575 MHz) jammer, elevation plane

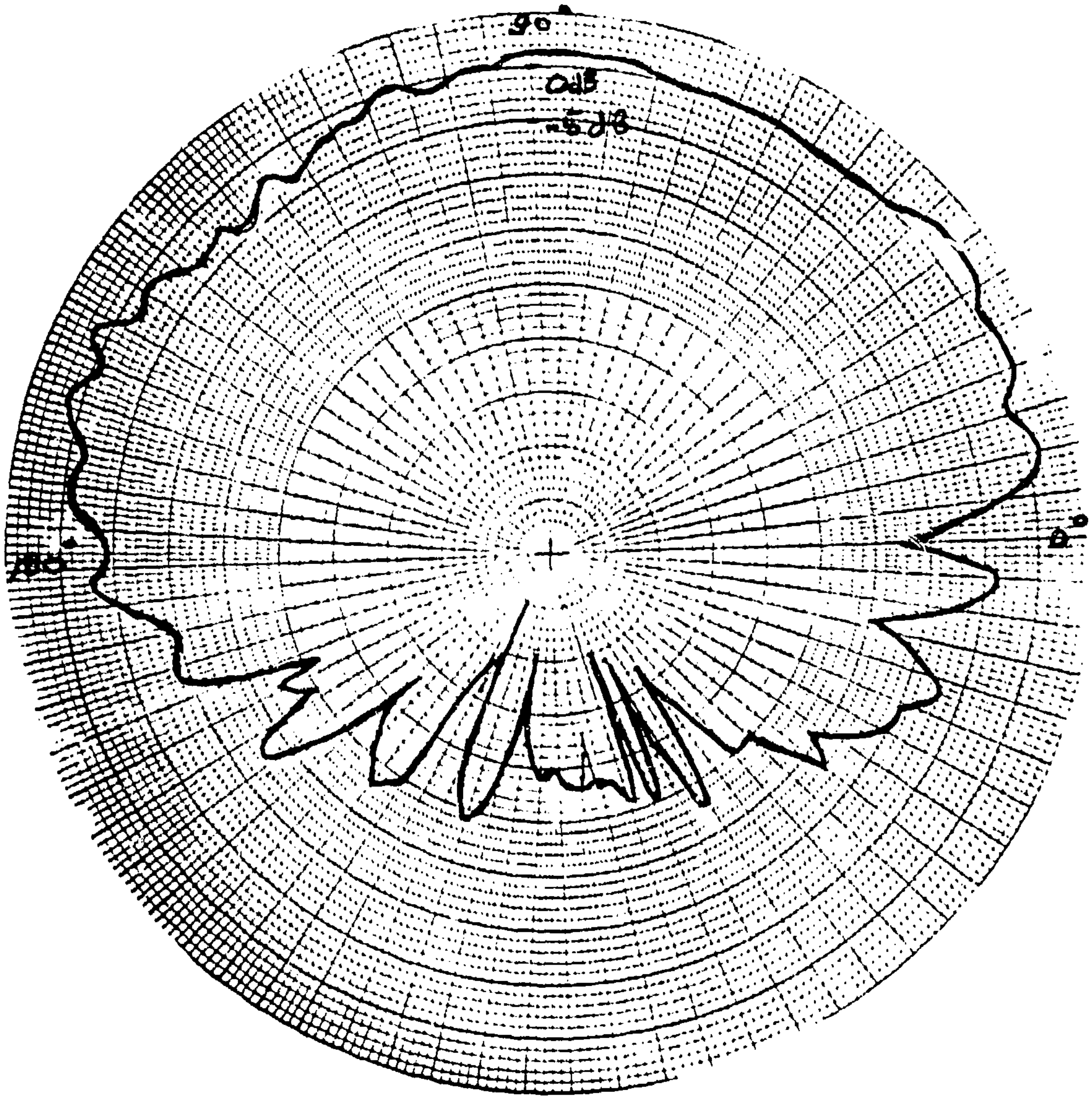


Figure 28. Measured radiation pattern, AJMA response to satellite signal (1575 MHz, 10 MHz pulse modulation, BPSK), elevation plane

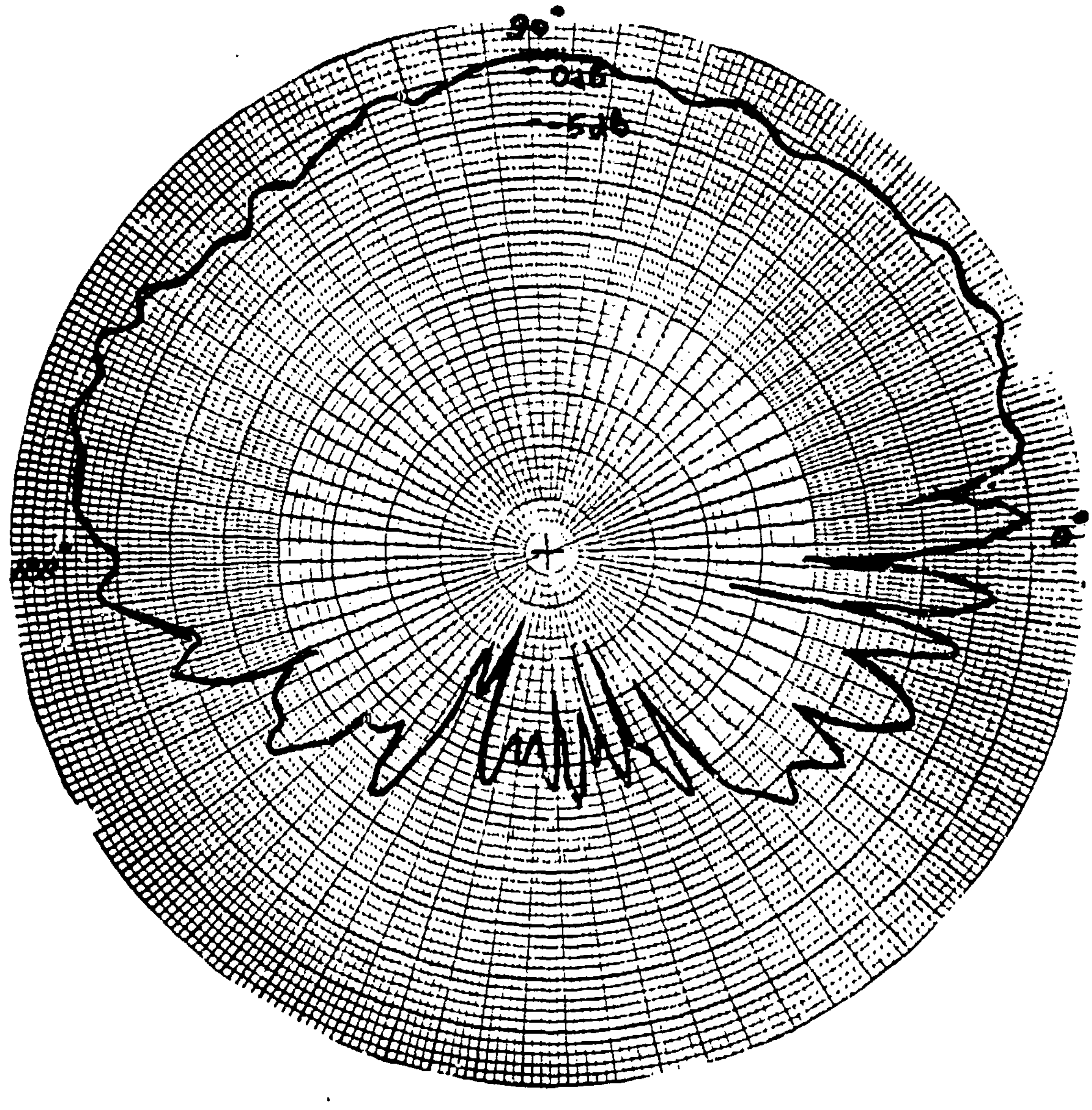


Figure 29. Measured radiation pattern, AJMA response to satellite signal (1575 MHz, 10 MHz pulse modulation, BPSK), 21 inch separation of GPS four element array from omni antenna, elevation plane

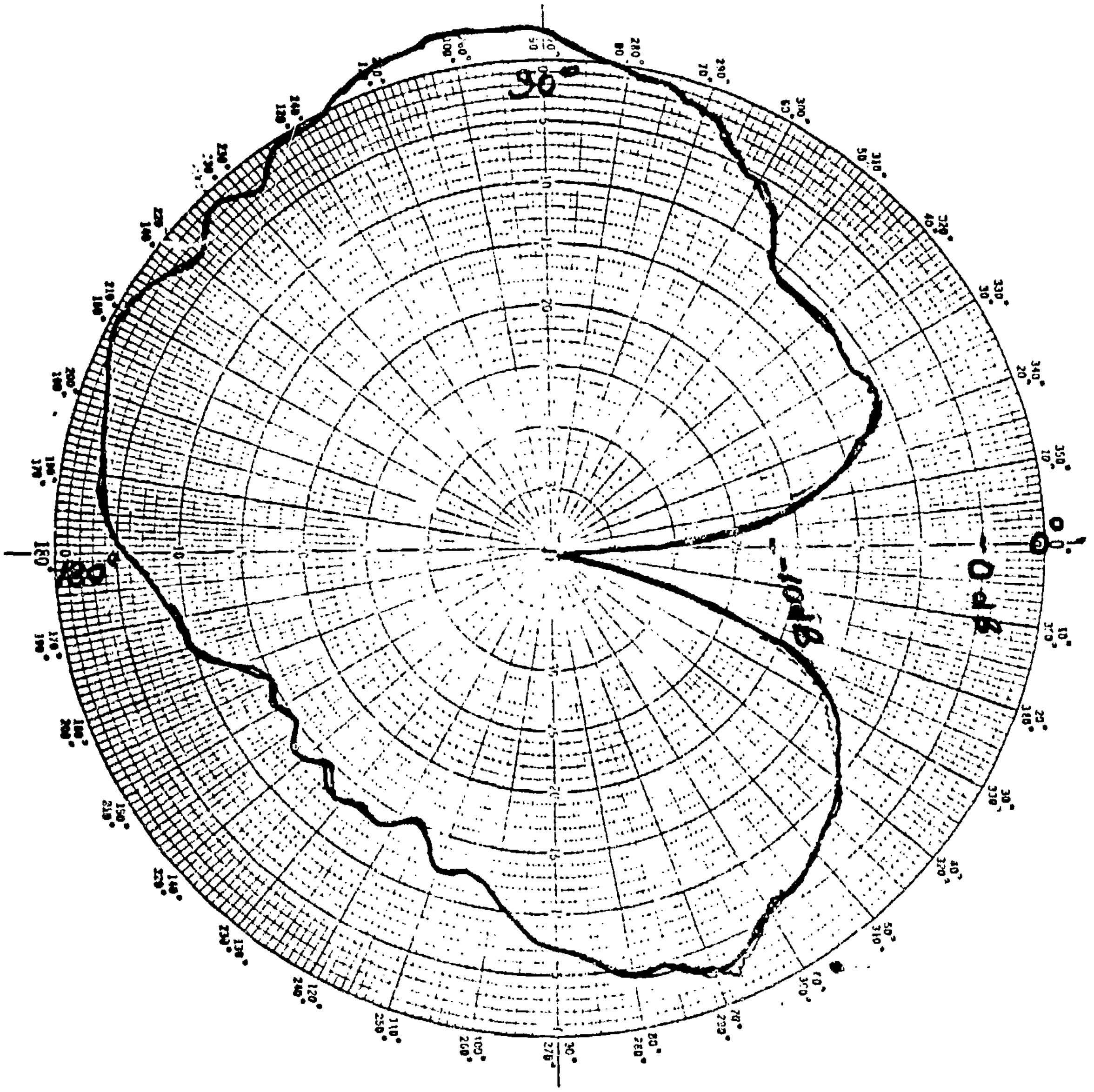


Figure 30. Measured radiation pattern. AJMA response to CW (1575 MHz) jammer, vertical polarization, azimuth plane

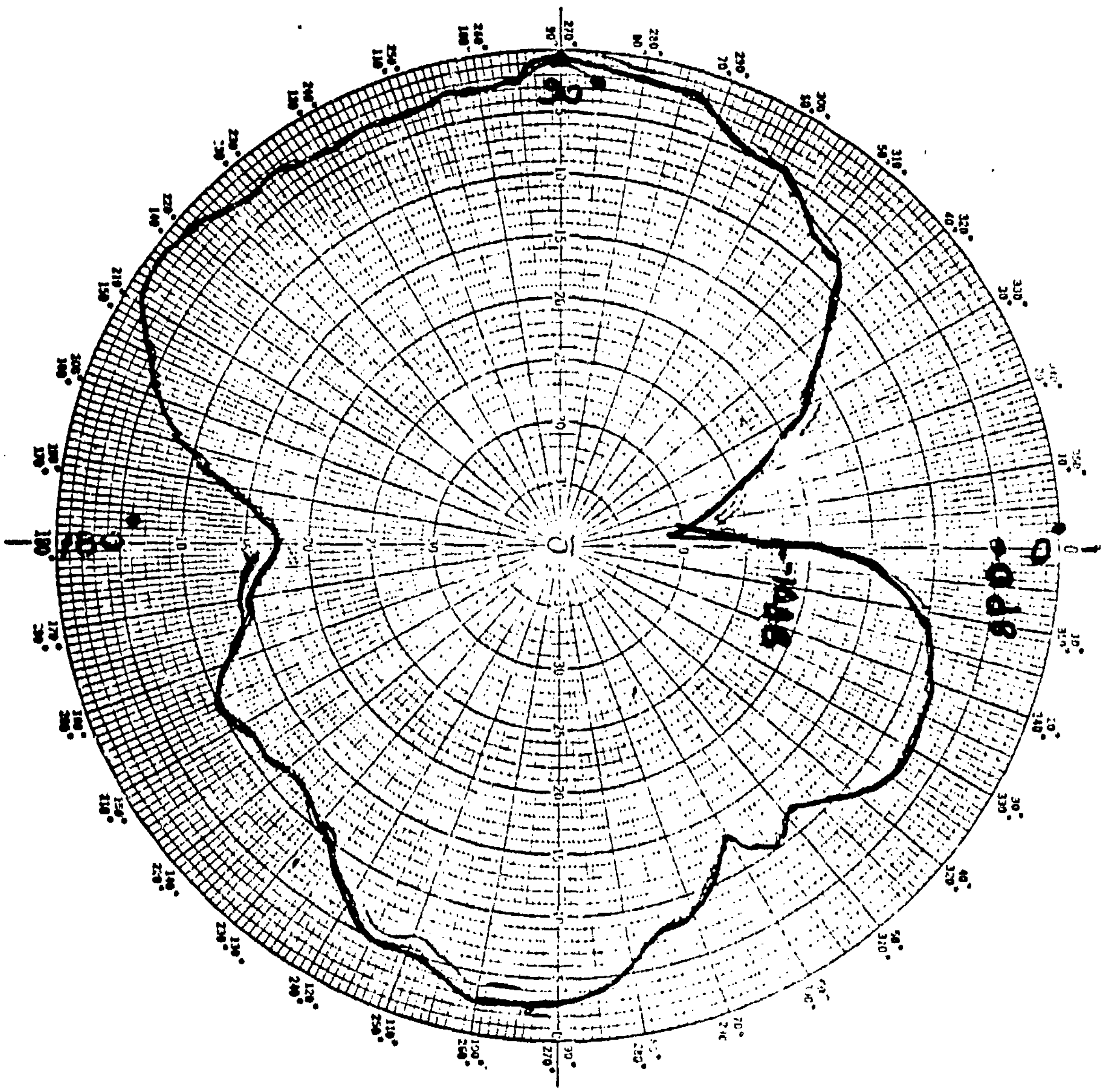


Figure 31. Measured radiation pattern, AJMA response to CW (1575 MHz) jammer, horizontal polarization, elevation plane

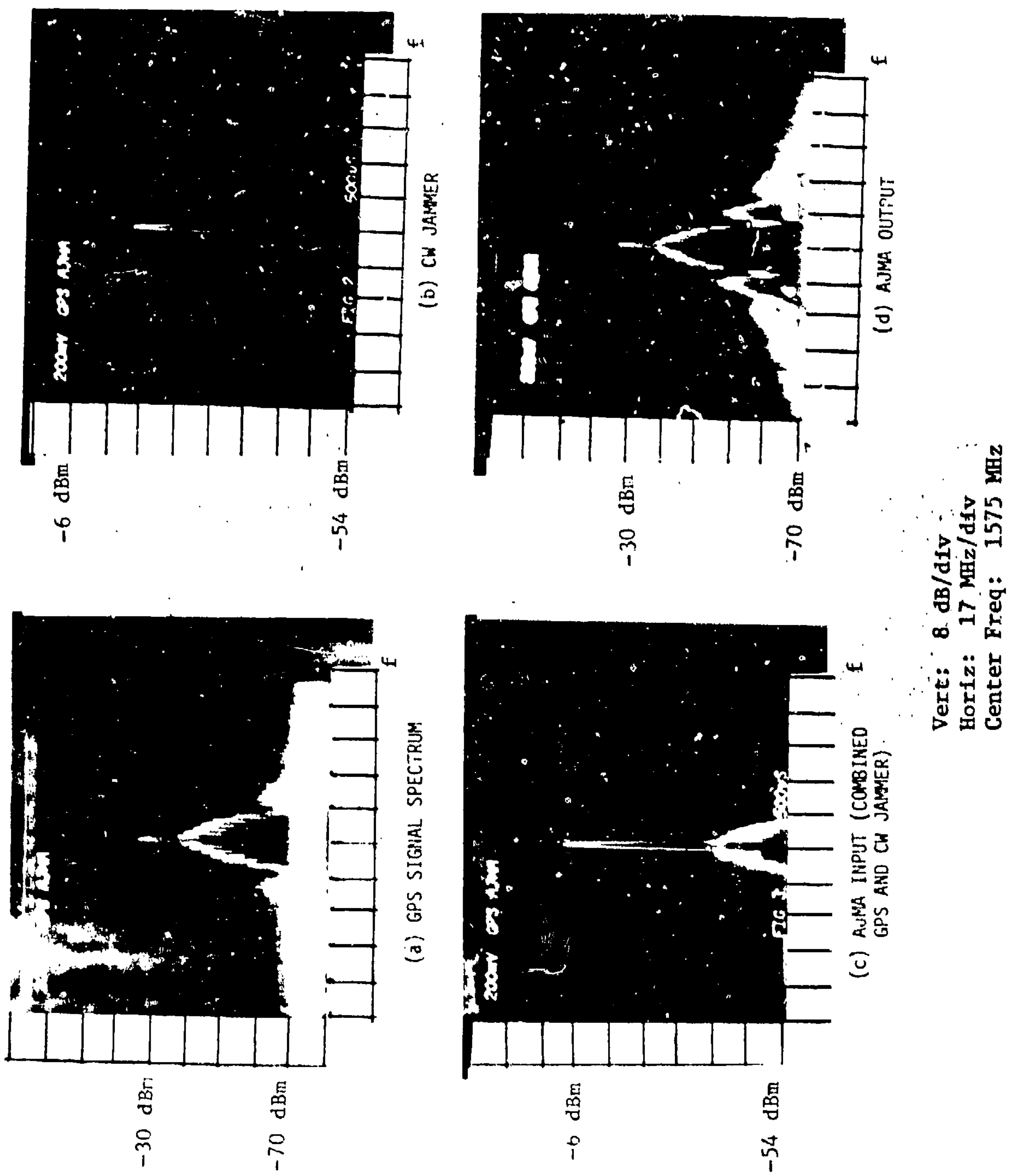


Figure 32. AJMA jamming test results

GPS signals received by the AJMA system. Figure 32a shows the GPS signal as received by the AJMA. Signal levels are 8 dB/div (vertical) and frequency levels are 17 MHz/div (horizontal). Figure 32b is the jammer only signal as received by the AJMA. The combined GPS signal and CW jammer signal (Figure 32c) is shown, in this sample run, to be 24 dB greater than the GPS signal alone (the AJMA controls not adjusted). By properly adjusting the vector multiplier controls, the jammer (Figure 32d) was effectively "notched" to within 2 dB of the GPS signal without distorting the desired signal. Repeated tests for stronger jammer signals produced identical results. The 2 dB limitation can be overcome by using a directive antenna having an additional 2 dB of gain over the present AJMA directive antenna.

7. CONCLUSIONS

The work described in this report has shown the effectiveness of an anti-jam manpack antenna against a CW jammer and its applicability to GPS. This system utilizes a straight forward, low noise, low loss, microwave correlator system to null interference while retaining most of the required GPS elevation and azimuthal coverage. Tests have revealed nulls $\gtrsim$ 20 dB against linearly polarized CW jammers. While these values represent the results of an experiment, it should be emphasized that there exists no fundamental limit to the rejection capability of this system against a single-frequency, CW jammer.* It is only necessary that the gain of the directive antenna be greater than the coupling of the combiner and that the directivity be great enough to minimize cross-coupling in the two channels.

8. RECOMMENDATIONS

It is recommended that further field tests be run to determine the effects of scattering of the GPS signal on the overall AJMA radiation patterns. As was indicated during field tests, anomalies did exist in the AJMA patterns due to reflections from nearby objects.

Although, for the purposes of these AJMA tests, a GPS like signal was sufficient to show the effectiveness of the system, the final validation of the AJMA requires testing with the actual GPS signal. These tests should include bit-error-rate recording equipment to determine if the AJMA corrupts any GPS data. The signal levels used for these tests should be comparable to the actual GPS signal levels which will require GPS user equipment to detect these signals.

The present AJMA system requires manual scanning in azimuth and manual controlling of the correlator to sense, then null, the jammer, respectively. Automating the system, although adding cost and complexity, is recommended because of its independence from user errors and applicability to a dynamic user.

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*Figures 19 and 30 show a deep null into the noise level of the measurement system ($\approx$ 40 dB dynamic range).

9. ACKNOWLEDGEMENT

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