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Comparison of Sinuous and MAW Spiral Antennas for Wideband, Dual Polarized Multi-Arm Applications

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Abstract

Recent requirements for wideband dual polarized antennas with good pattern circular symmetry have centered on two feed candidates: cavity backed Modulated Arm Width (MAW) spiral and Sinuous antennas.

Both of these antennas are capable of arbitrarily wide bandwidth operation; practical bandwidths are limited by photo-etching and feedpoint considerations.

The properties of these antennas appear not to be widely known and to date the useful range of design parameters have not been published. This paper will show and compare the properties of two corresponding models of the multi-arm MAW spiral and Sinuous antennas.

The feeds will be compared for the four-arm case which yields dual circular polarization or orthogonal linear operation as well as six-arm versions which can provide both sum and difference mode operation.

Introduction

In this paper we will compare the characteristic performance of the Modulated Arm Width (MAW) spiral antenna and the Sinuous antenna (or as we will show, a "folded" spiral) with those of the corresponding parent spiral. Both the MAW spiral and Sinuous antennas can provide arbitrarily wideband performance with excellent pattern characteristics in planar cavity backed configurations. The two antennas achieve dual polarization operation using completely different mechanisms ,yet both are capable of essentially identical pattern performance and impedance. Both antennas can also provide wideband orthogonal linear polarization operation. In the linear polarization mode, the polarization angle properties as a function of frequency of both antennas are fundamentally different. Neither antenna provides a fixed polarization angle with frequency. The MAW spiral antenna provides an orthogonal linear response whose polarization angle (τ) changes linearly with frequency (with respect to the log of the spiral wrap angle), while the τ angle of the Sinuous antenna demonstrates an oscillating behavior with frequency. In six arm versions, both antennas can provide dual polarized sum and difference mode of operation for tracking and angle of arrival (AoA) applications.

Modulated Arm Width Spiral Antenna

The modulated arm width spiral was first introduced in 1971 [1,2] The performance capability of this antenna was a significant improvement over other Log Periodic (LP) planar configurations, in that it could provide the radiation patterns and input impedance characteristics of logarithmic spirals but with dual senses of polarization over an arbitrarily wide bandwidth.

The swept pattern characterizatics reveal none of the central feed line resonances that the planar LP trapezoidal tooth or circular tooth structures exhibited. (See for example Reference 3, Figure 17, for the "Interlog Antenna")

The four arm MAW spiral antenna concept was extended to six arms, where dual polarized sum and difference modes of operation were demonstrated, but not published, a few years later.

Spiral antennas normally provide radiation characteristics dependent on the direction of the wrap of the arms. That is, placing the thumb in the direction of radiation, Right Hand Circular Polarization (RHCP) would be a counter clockwise wrap direction and left hand would be clockwise. When the N arms of a normal spiral are progressively fed with an integer multiple M of ($2\pi/N$) phase, all the radiation patterns are polarized in the sense of wrap of the spiral. For a counter clockwise wrapped spiral, only the M = +1 mode with a $+2\pi/N$ clockwise phase progression from arm-to-arm produces radiation normal to the aperture plane. All other modes produce patterns with nulls, if the structure is of a large enough diameter to support the mode's active region.

For M greater than 1, essentially no radiation takes place along the arms until the currents are properly phased in the appropriate active region. If the diameter of the antenna is smaller than that required for a given mode, the energy is reflected at the end of the arms and on traveling back along the arms is phased to radiate efficiently. Since the energy is traveling inward the sense of polarization is reversed. The bandwidth of this mode of operation is typically much less than 2:1.

The modulated arm width spiral in effect just provides a structural stopband, by means of the arm impedance modulation, to block the energy before the appropriate active region and reflect it inward to provide the opposite polarization sense. If the modulation scales in a log periodic fashion with the appropriate scale factor, the relative stopband location with respect to the active regions will remain fixed and frequency independent bandwidth performance is obtained.

Since the maximum reflection occurs when the length of a wide and narrow section is approximately 1/2 wavelength, the number of modulations around a circumference are chosen to place the stopband before the selected active region. For example to place the stopband after the M = 1 mode active region and before the M = 3 mode for a four arm spiral requires four modulation bands at the two wavelength circumference. To obtain two modes, from a six arm MAW spiral antenna, the stopband is placed after the M = 2 mode and ahead of the M = 4 mode. This results in six modulation bands.

Sinuous Antenna

The Sinuous antenna is a new antenna concept patented by R. H. DuHamel in 1987. As described in his patent [4] the Sinuous antenna comprises an N arm antenna with angular coordinates of each arm having an oscillatory function of radius between two angular limits. Each arm has a rotational symmetry such that a rotation of 360/N degrees about its axis leaves the structure unchanged.

One important embodiment of this antenna is most easily understood as a folded log spiral. That is, a near optimum performance sinuous antenna can be designed by using the parameters of a conventional spiral for the sinuous generatrix. Using the parametric equation form of a log spiral.

$$X = r_0 e^{a\phi} \cos\phi \qquad \text{where} \qquad \phi_{initial} \leq \phi \leq \phi_{final}$$
$$Y = r_0 e^{a\phi} \sin\phi \qquad \text{and} \qquad r_0 = \text{initial radius} \qquad (1)$$

The corresponding sinuous antenna becomes

$$X = r_0 e^{a\phi} |\cos\phi|$$
$$Y = r_0 e^{a\phi} \sin\phi \qquad (2)$$

This generatrix line spiral is then rotated $\pm\ \delta/2$ to provide the edge lines of the sinuous antenna. For a self complimentary geometry of an N arm antenna δ is given by:

$$\delta = \frac{360}{2N} \text{ degrees} \qquad (3)$$

The arms are then progressively rotated by 360/N degrees from each other.

This method of sinuous antenna generation gives near optimum parameters for 4, 6, 8 or higher numbers of arms.

If one views the spiral arm operation in the transmitting case as having an outward traveling wave, it is clear that the phasing along each segment is essentially the same as that of a regular spiral since the total path length along the arms is identical. It then is plausible to understand the sinuous antenna as a combination of segments from RH and LH spirals.

When the wrap angle is tight enough to provide several segments in the active region, the result is the sum of RH and LH radiation which is linear. In the case of a four arm antenna, onc can also consider obtaining linear by exciting the sum and difference of RH and LH arm excitations. This is identical to just feeding one pair of opposite arms 180 degrees out of phase.

Pattern Comparisons

Typical patterns of the parent RHCP spiral, Sinuous, and MAW spiral antennas are shown in Figures 1, 2 and 3. These were all measured over a midband frequency segment using the same absorber filled cavity with a cavity and spiral diameter of 7.5 inches. The corresponding antennas are shown in Figure 4.

Figures 5, 6 and 7 show the corresponding swept pattern (averaged) beamwidth. All the antennas showed highly circularaly symmetrical patterns. The beamwidths plotted in Figures 5 thru 7 are averages from several pattern cuts.

Linear Mode Polarization Properties

The polarization angles, τ, for both the Sinuous and MAW spiral antennas are not constant with frequency. The τ angle of the Sinuous antenna oscillates back and forth with a period directly related to the spiral wrap angle parameter a.

$$f_N = f_0 \, e^{2Na\pi} \qquad N = \pm 1, \pm 2, \ldots \qquad (4)$$

This is shown in Figure 8 along with the axial ratio for a four arm sinuous with a scale factor of 0.63 or 1.5 turns per octave (T/O), measured over a midband segment. Figure 9 shows similar performance of a 6 arm Sinuous antenna.

The corresponding polarization angle of a MAW spiral changes linearly with frequency when plotted with respect to the log period of the antenna as shown for the corresponding 6 arm MAW spiral in Figure 10.

Tracking and Angle of Arrival (AoA)

Both the Sinuous and the MAW spiral can be extended to 6 or 8 arm versions shown in Figure 11 giving dual polarization sum (Σ) and difference (Δ) performance. To use these feeds for tracking or AoA applications, the key parameters of interest are the relative phase of the sum to difference patterns and the amplitude ratio of the difference to sum signals. As with conventional spirals, the relative phase angle between the Σ and Δ patterns gives signal direction (clock angle) relative to the difference pattern null while the ratio of the Σ to Δ signals are proportional to the angular separation of the signal from the pattern null. The proportionality factor is called the scale factor. While actual achievable performance requires inclusion of changes with respect to incident polarization and beamformer errors, Figures 12 and 13 illustrate that both antennas can provide well behaved clock angle phase and scale factor performance for both senses of polarization.

References

1. Ingerson, P.G., "The Modulated Arm Width (MAW) Spiral Antenna ," *Abstracts of the 20th Annual Symposium USAF Antenna Research and Development Program* , Oct 13, 14, 15, 1970.

2. Ingerson, P. G. Inventor "Modulated Arm Width Spiral Antenna," U.S. Patent 3,681,772, August 1, 1972.

3. Hoffer, D. A., Kesler, O. B., Loyet, L. L., "Compact Multi-Polarization Broadband Antenna," *Antenna Applications Symposium,* Sept. 20, 21, 22, 1989.

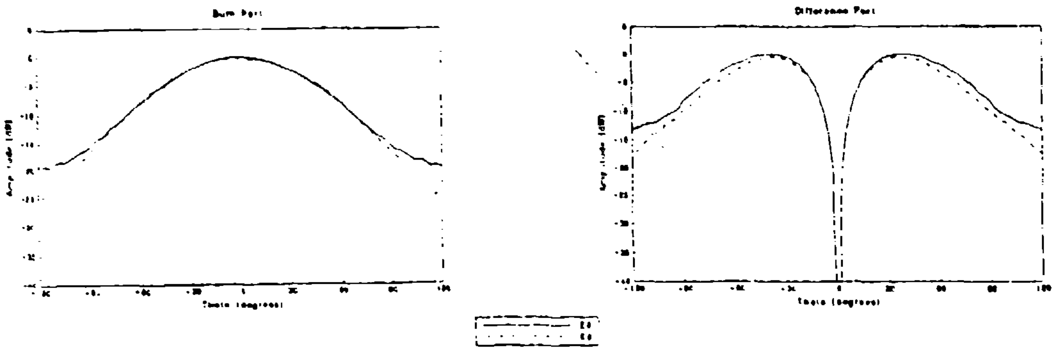
4. DuHammel, R. H., Inventor, "Dual Polarized Sinuous Antennas," U. S. Patent 4,658,262, April 14, 1987

5. Chu, T. T. and Oltman, H. G. Jr.,"The Sinuous Antenna," *M.S.N. Communications and Technology*, Vol. 18 No. 6, June 1988.

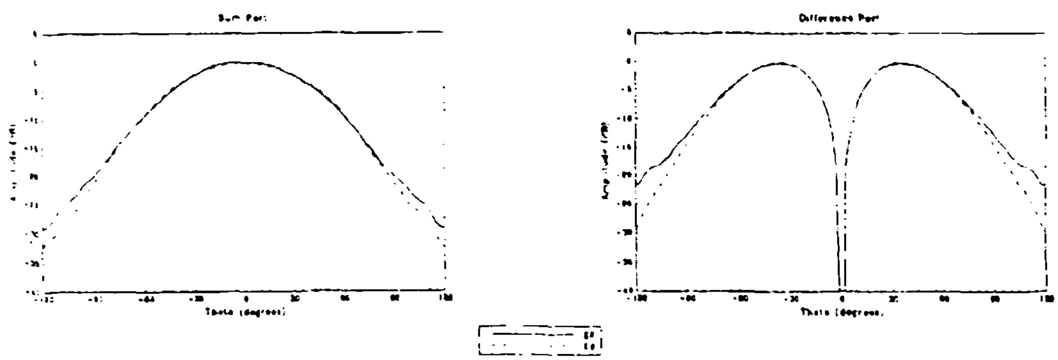
4 Arm RHCP Planar Spiral Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN

RHCP Response to Eθ and Eϕ Incident Signals

Frequency = 2.0 GHz



Frequency = 4.0 GHz



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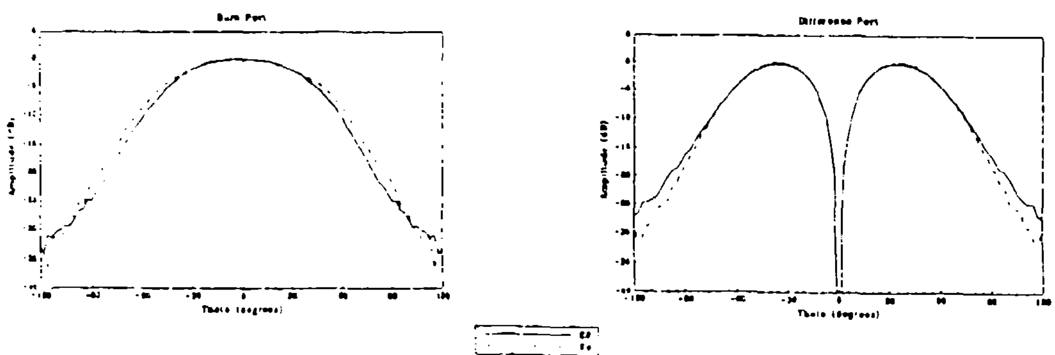
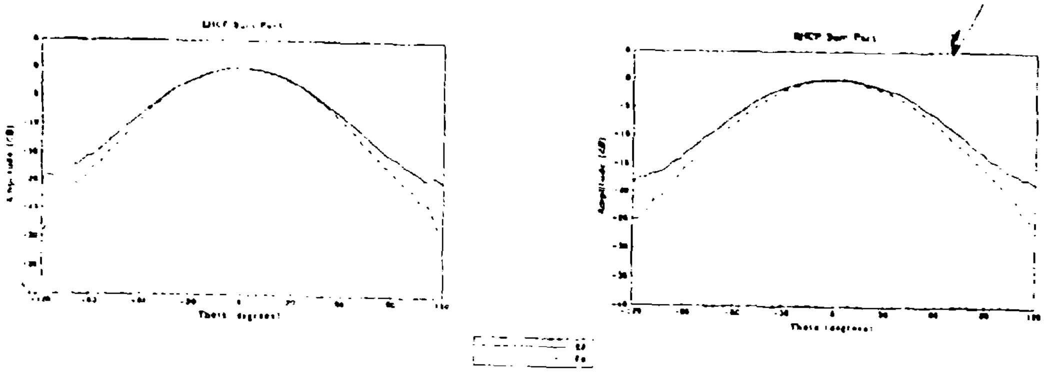


Figure 1

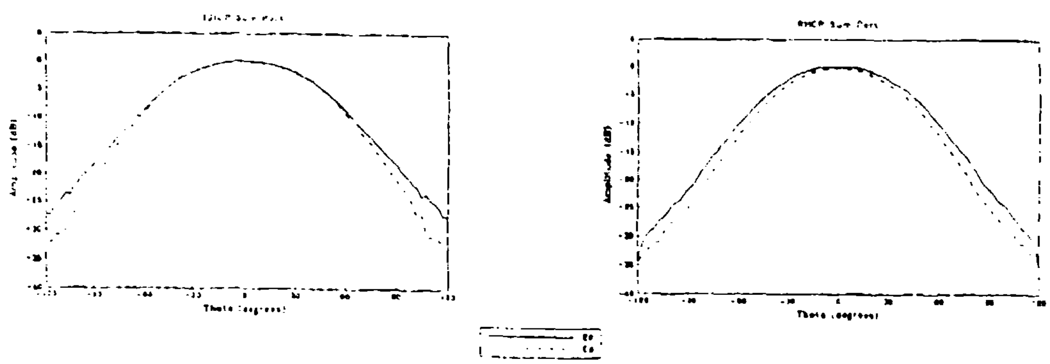
4 Arm Planar Sinuous Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN

LHCP & RHCP Responses to Eθ and Eϕ Incident Signals

Frequency = 2.0 GHz



Frequency = 4.0 GHz



Frequency = 0.0 GHz

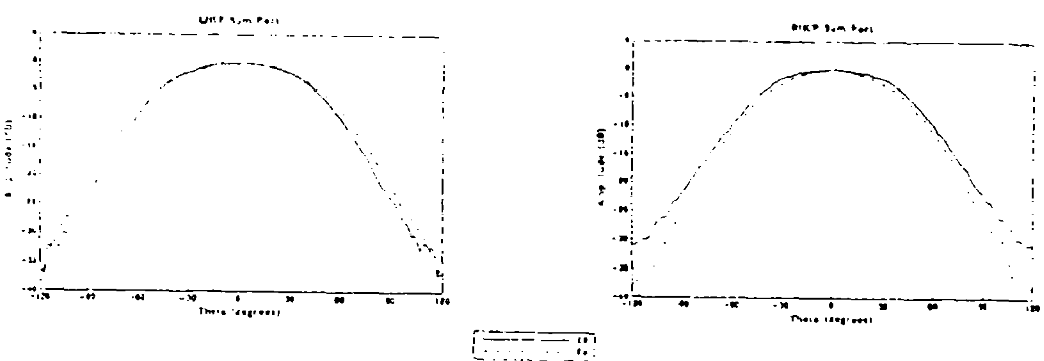


Figure 2

4 Arm Planar MAW Spiral Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN

LHCP & RHCP Responses to Eθ and Eφ Incident Signals

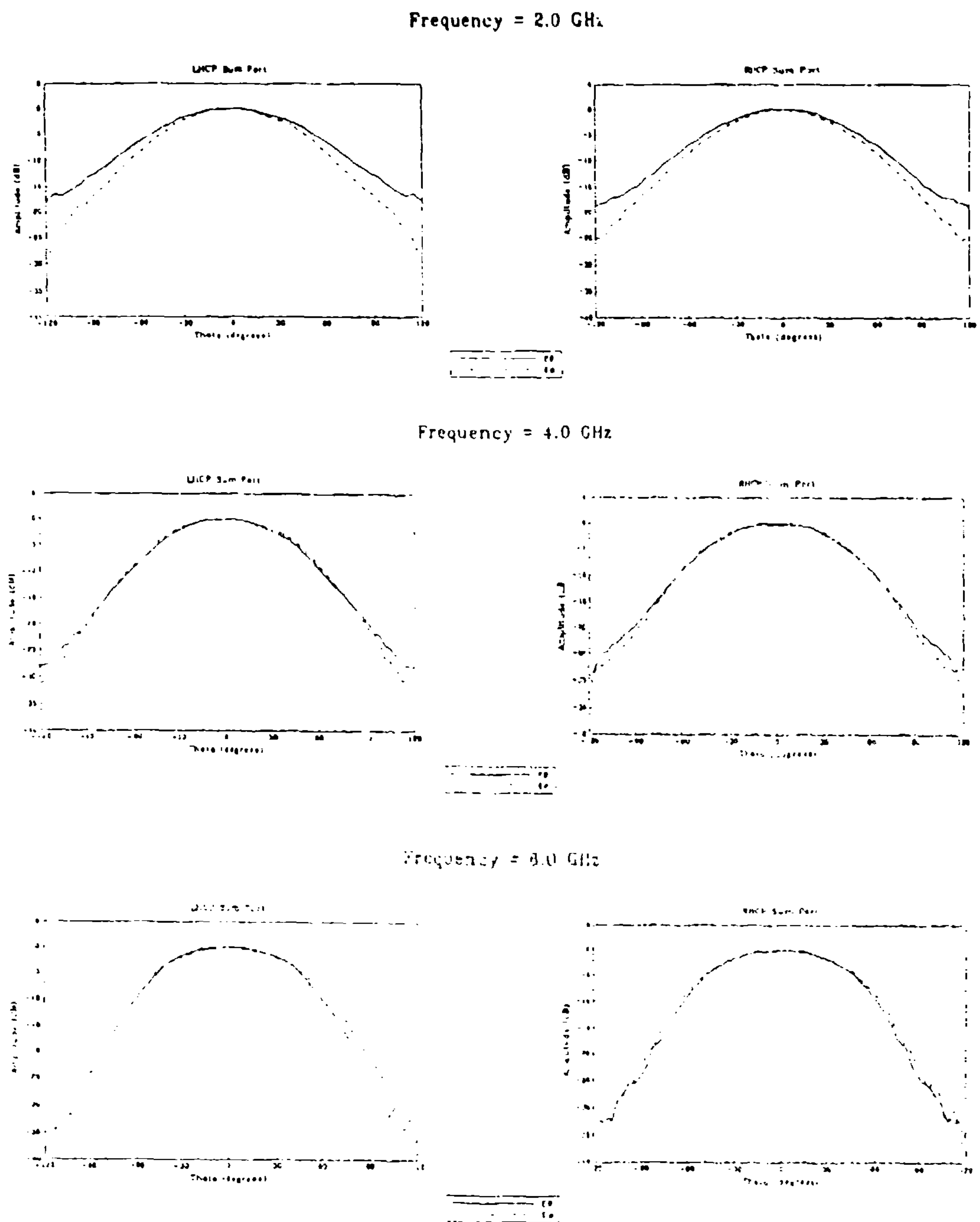


Figure 3

Four Arm Antenna Geometries

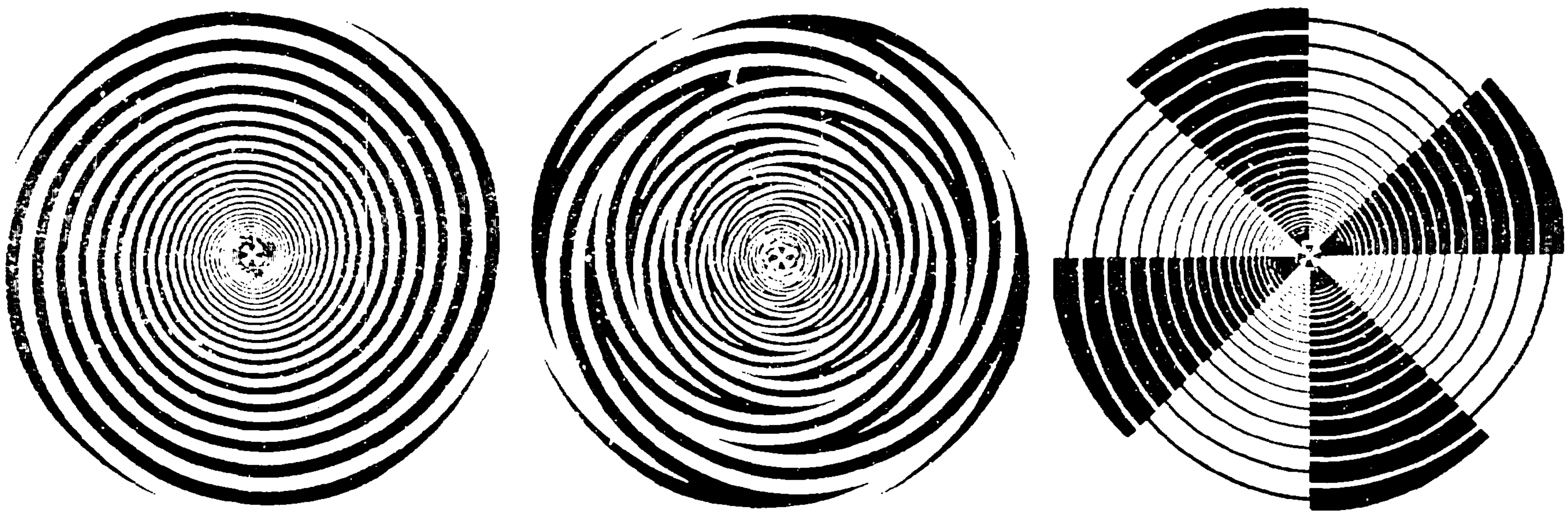
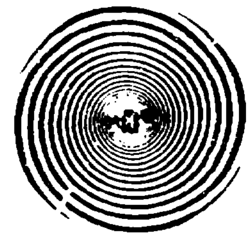
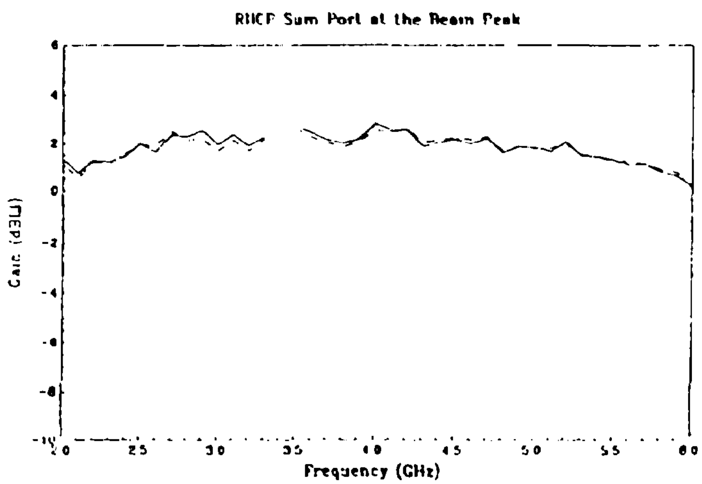


Figure 4

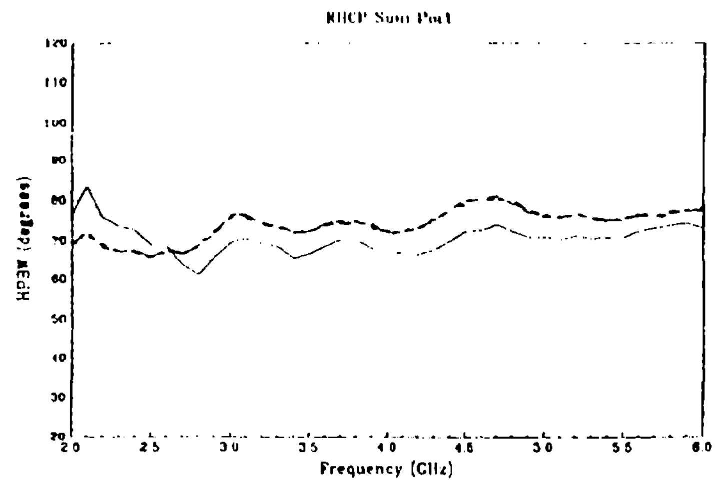
4 Arm RHCP Planar Spiral Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN



Gain vs. Frequency



Half-Power Beamwidth vs. Frequency



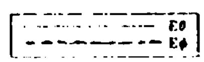


Figure 5

4 Arm Planar Sinuous Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN

Half-Power Beamwidth vs. Frequency

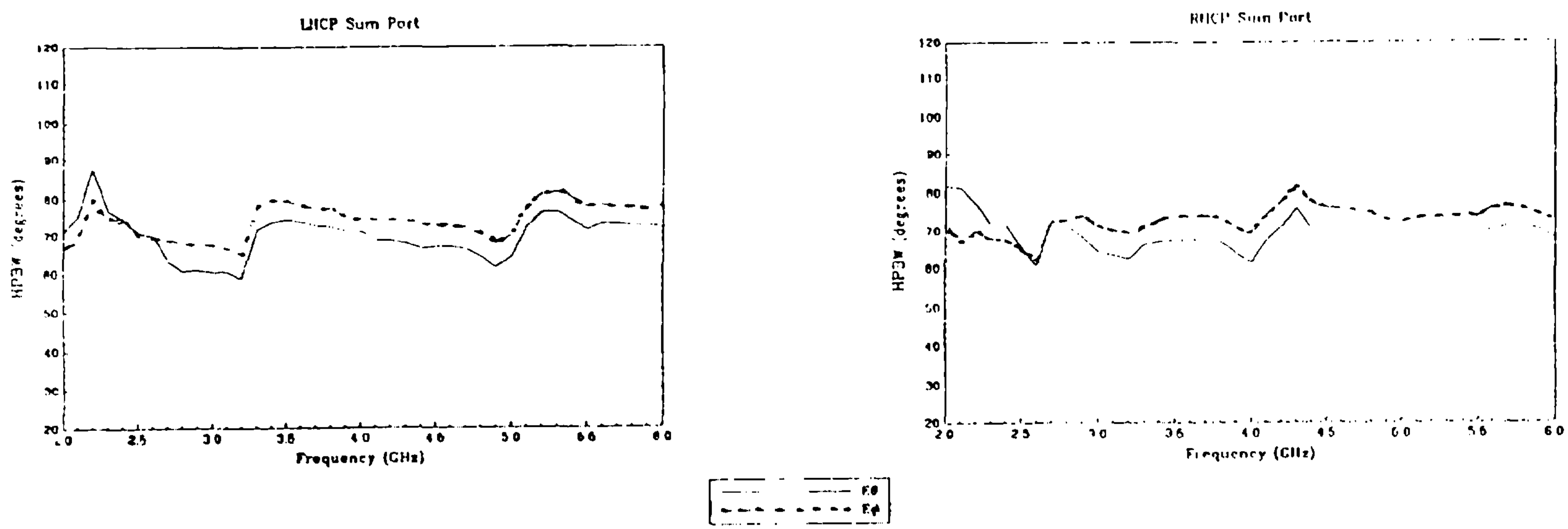
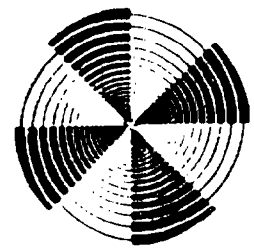


Figure 6

4 Arm Planar MAW Spiral Antenna (1.5 Turns/Octave) Mounted over a Lossy Cavity with an Ideal BFN

Half-Power Beamwidth vs. Frequency



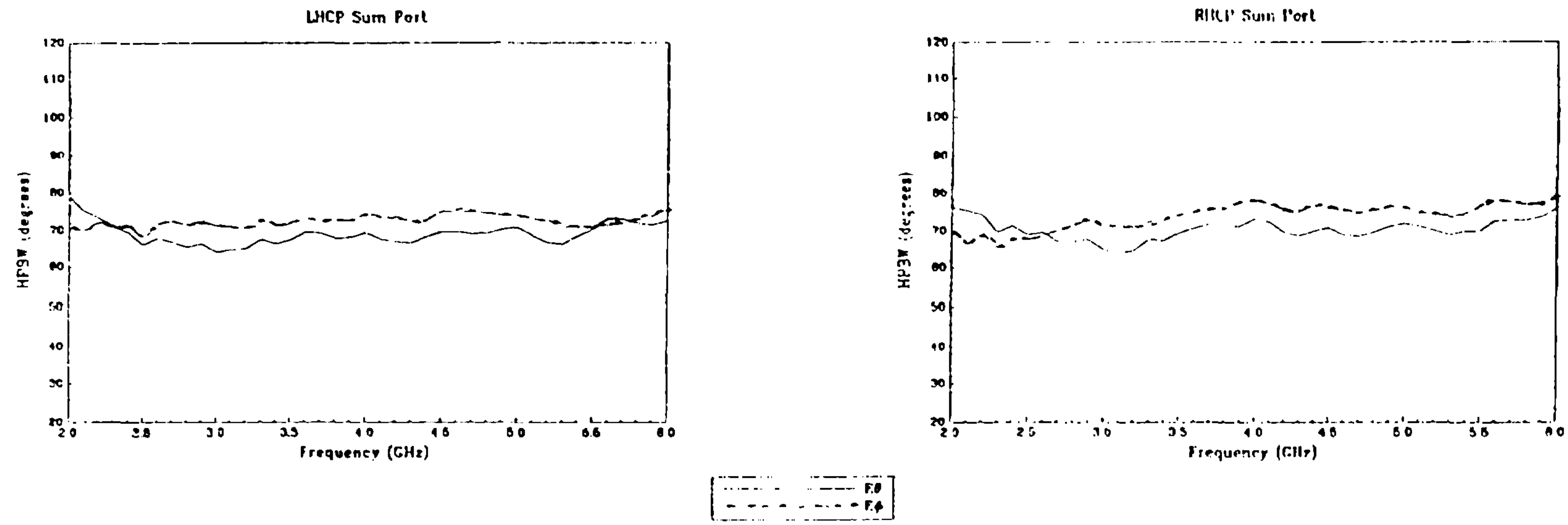


Figure 7

Polarization Properties of a 4 Arm Sinuous Antenna in Orthogonal Linear Mode Operation

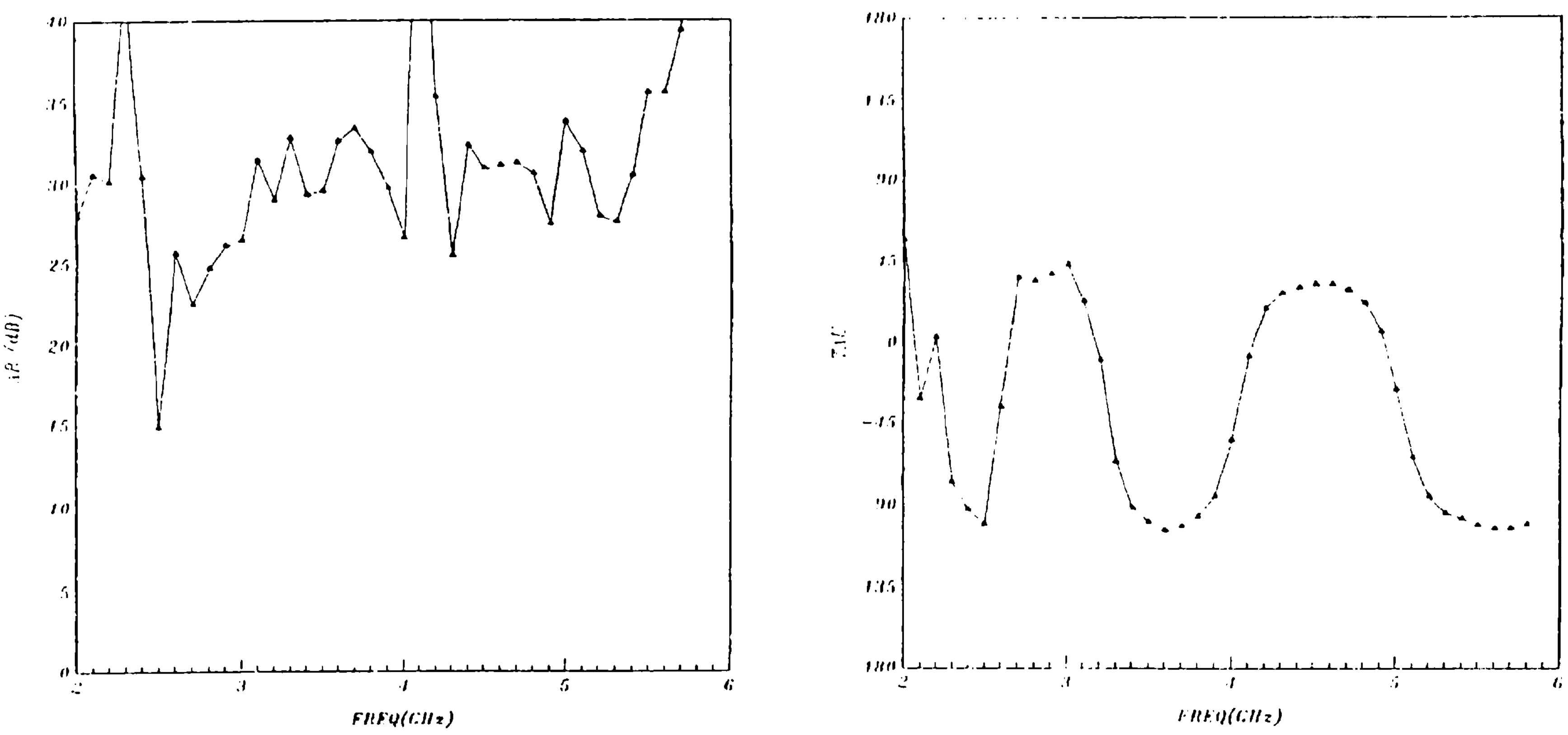


Figure 8

Polarization Properties of a 6 Arm Sinuous Antenna in Orthogonal Linear Mode Operation

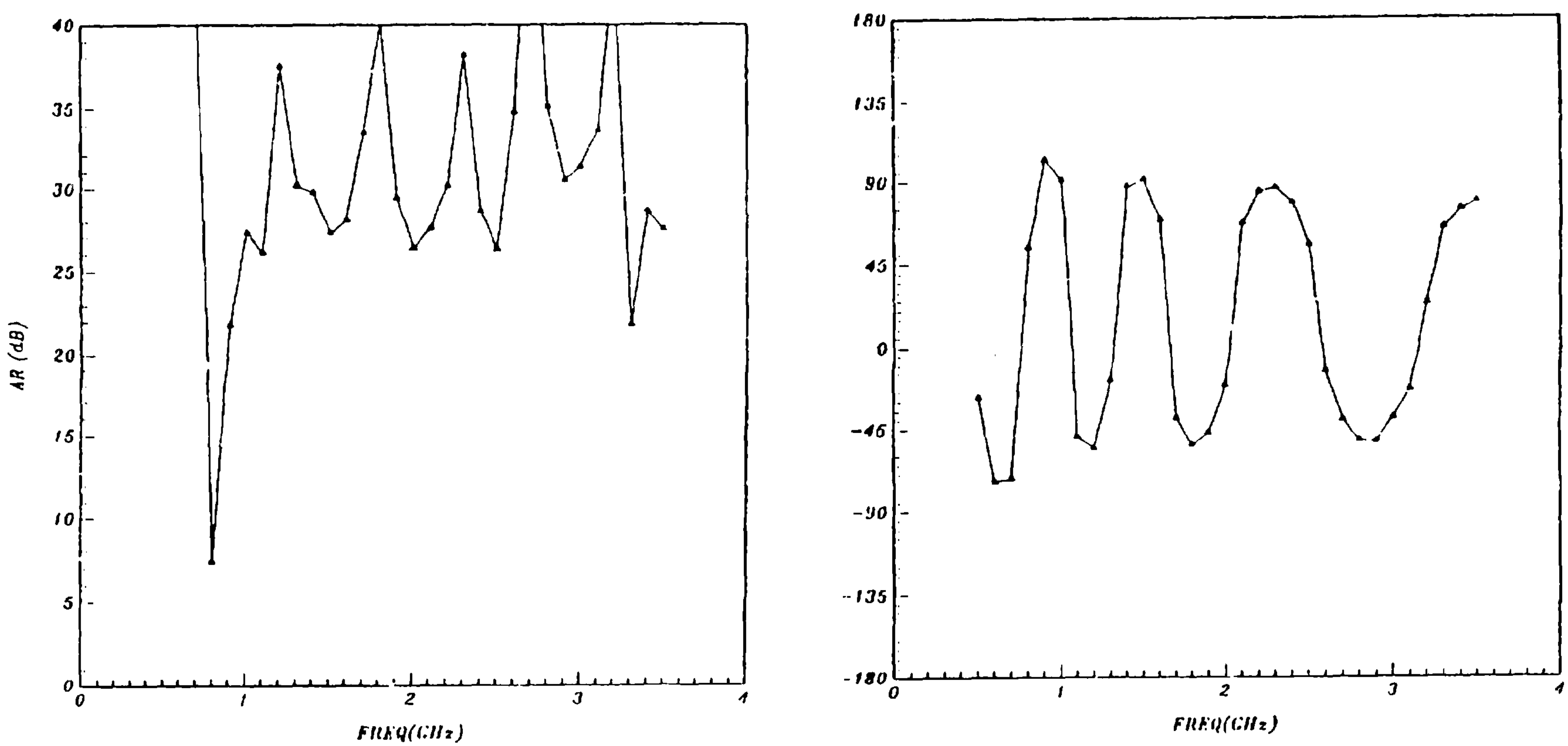
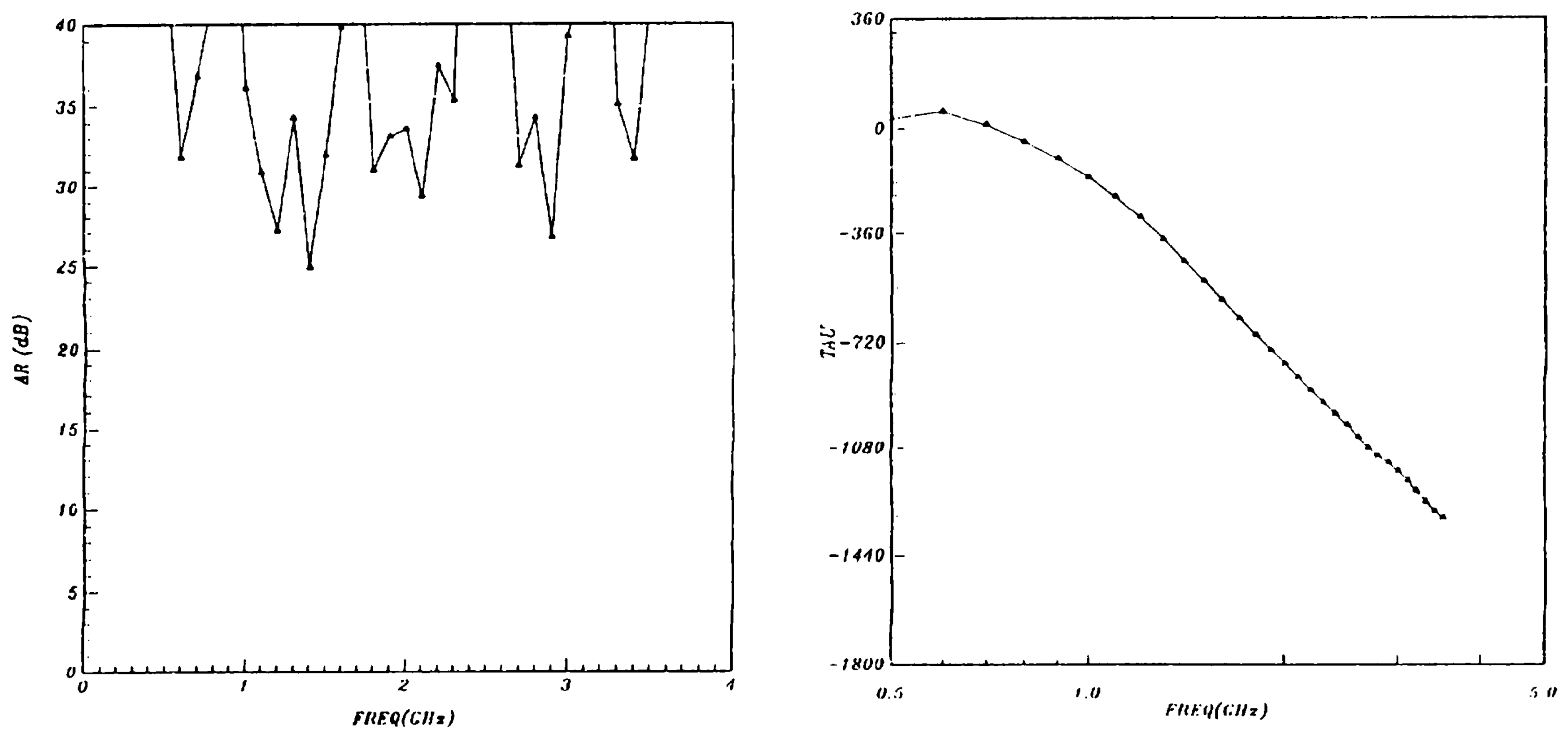


Figure 9

Polarization Properties of a 6 Arm MAW Spiral Antenna in Orthogonal Linear Mode Operation



Figu . 10

Six Arm Antenna Geometries

Sinuous Antenna
1.5 Turns/Octave

MAW Spiral Antenna
1.5 Turns/Octave

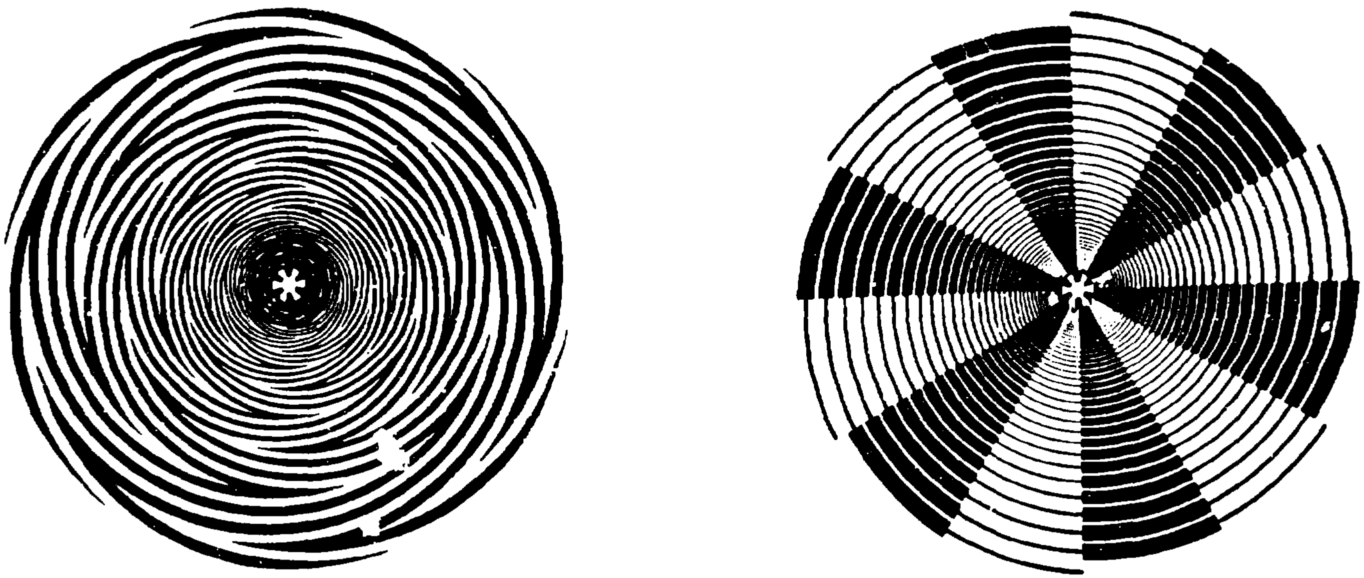


Figure 11

Δ/Σ Pattern Behavior of a 6 Arm Sinuous Antenna

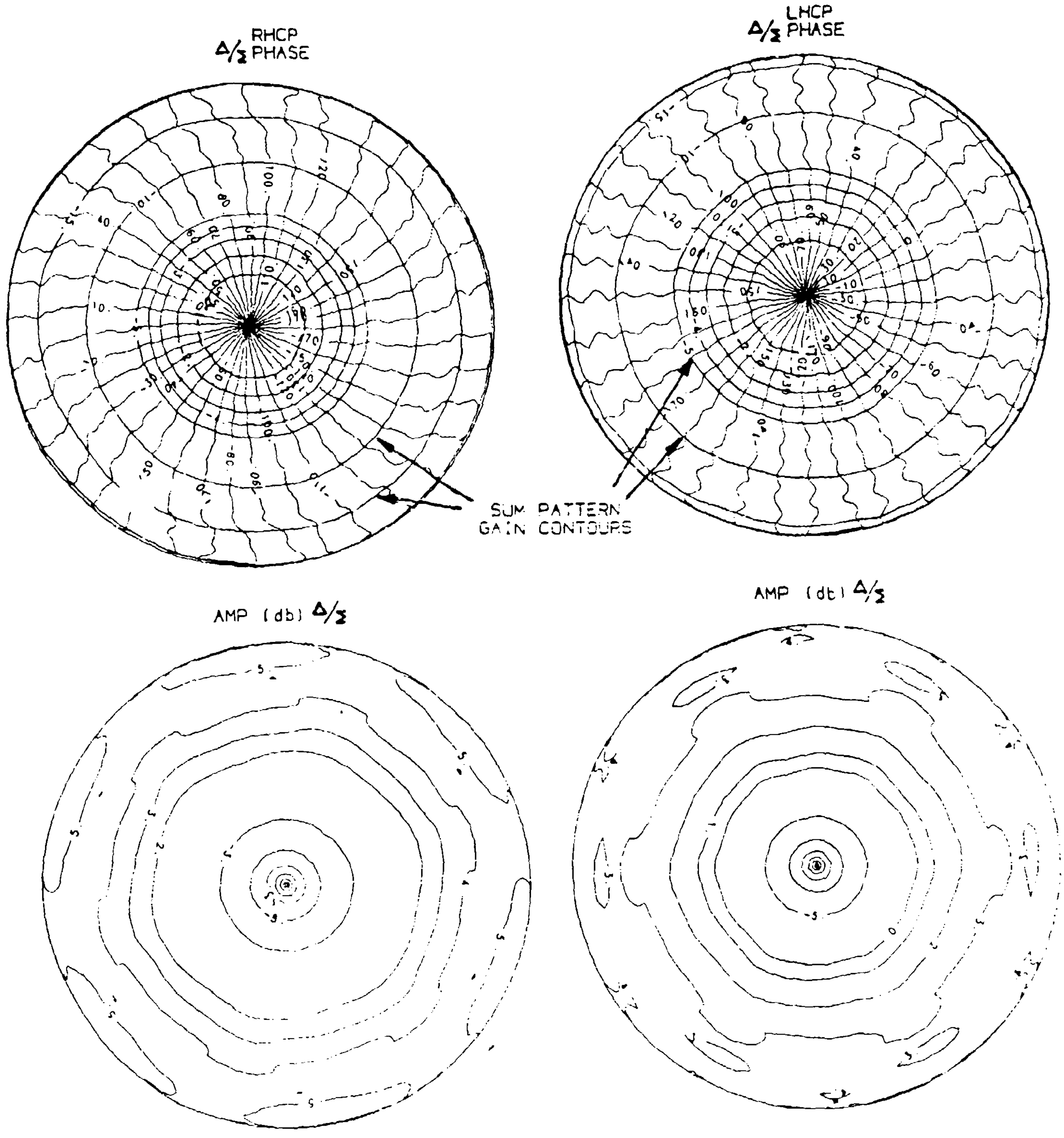


Figure 12

Δ/Σ Pattern Behavior of a 6 Arm MAW Spiral Antenna

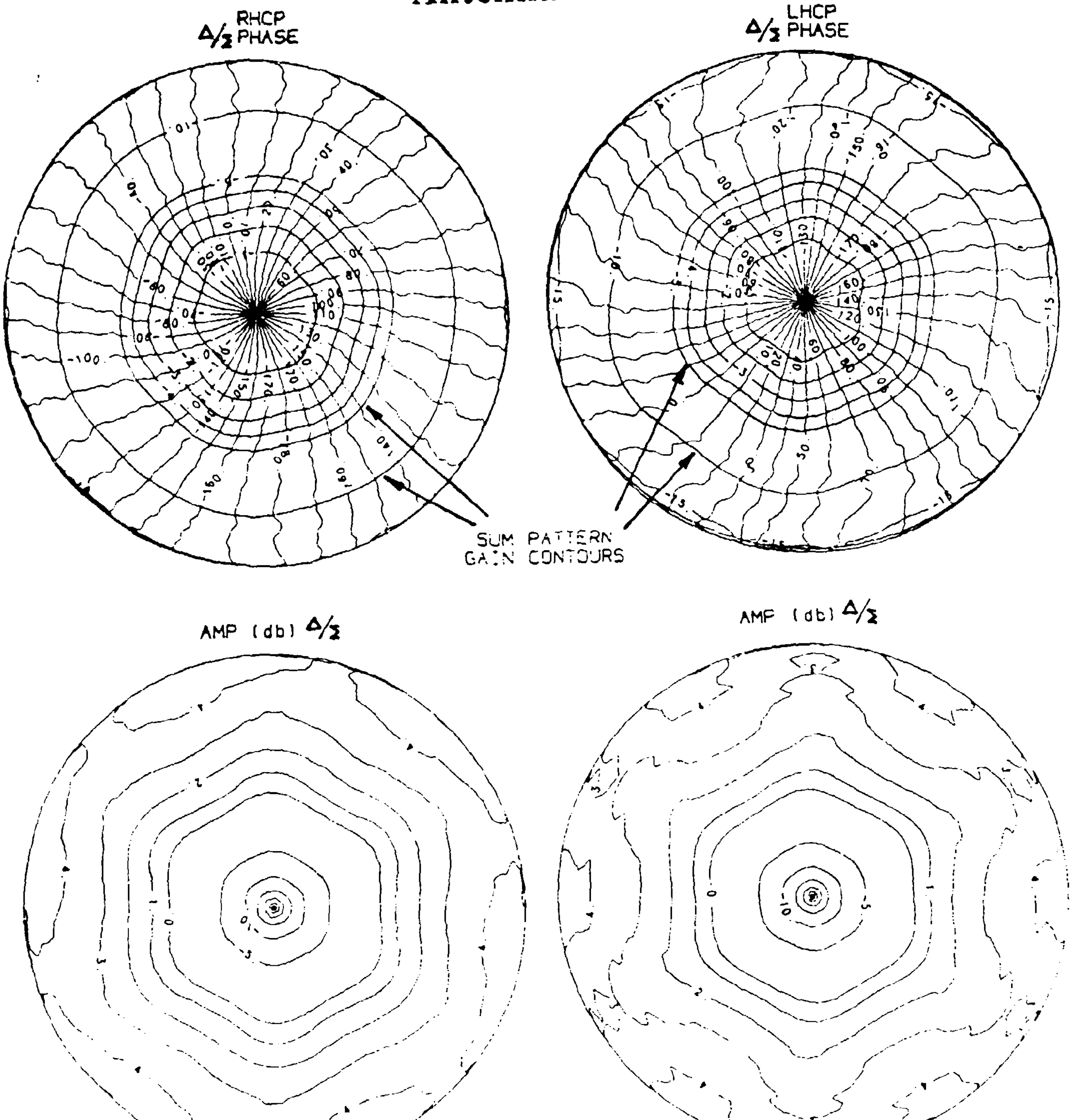


Figure 13