GEODESIC CONE ANTENNA

Brian S. Cramer

Lockheed Electronics Company, Inc.
Plainfield, New Jersey

ABSTRACT

The subject of this paper is a novel phased array antenna which is capable of providing 360 degree continuous scanning with low side lobes over a wide band. The antenna consists of a ring of feed elements coupling energy through a coaxial conical waveguide to a circular radiating aperture. Rays from the feed ring are constrained within the conical coaxial waveguide and propagate along geodesic paths in such a way as to be focused in the far field.

A paper presenting a preliminary design of a Geodesic Lens Antenna was presented at this symposium in 1981[1]. Since that time, evaluation has shown performance equivalent to a linear aperture illuminated with a Tchebyshev distribution. Progress achieved in computer aided design and analysis allows tailoring a Geodesic Cone Antenna to the specific needs and constraints of given applications. → next pg

[1] J. McFarland, R. Savage; "A Geodesic Lens Antenna for 360 Degree Azimuthal Coverage"; 1981 Antenna Applications Symposium, Sept 1981, Monticello, Illinois

A brief explanation of the function of the Geodesic Cone Waveguide using geometric optics is presented. Design and analysis techniques utilizing geometric optics and modal analysis are described. A half octave demonstration model of a Geodesic Cone Antenna (GCA) has been built and tested and showed good correspondence with predicted performance.

1.0 INTRODUCTION

Many applications require antennas that can point a beam to any direction over 360 degrees of azimuth. These applications often require phased array antennas to achieve fast beam scanning, beam agility, or elimination of mechanical reliability problems.

The subject of the present paper is a novel circular aperture antenna which requires fewer elements, has more precise pattern control, and has lower loss than many alternative approaches.

The key features of the Geodesic Cone Antenna (GCA) are:

- Precise azimuth pattern control via variable amplitude and phase distribution imposed on the circular input array.
- 360 degree beam steering via commutation of the distribution of the input array.
- Low loss focusing via Geodesic Cone Waveguide.
- Vertical beam formation with a number of alternate aperture configurations.

2.0 CONCEPT

The Geodesic Cone Antenna, Figure 1, consists of a Geodesic Cone Waveguide (GCW) with a ring of input elements at the base

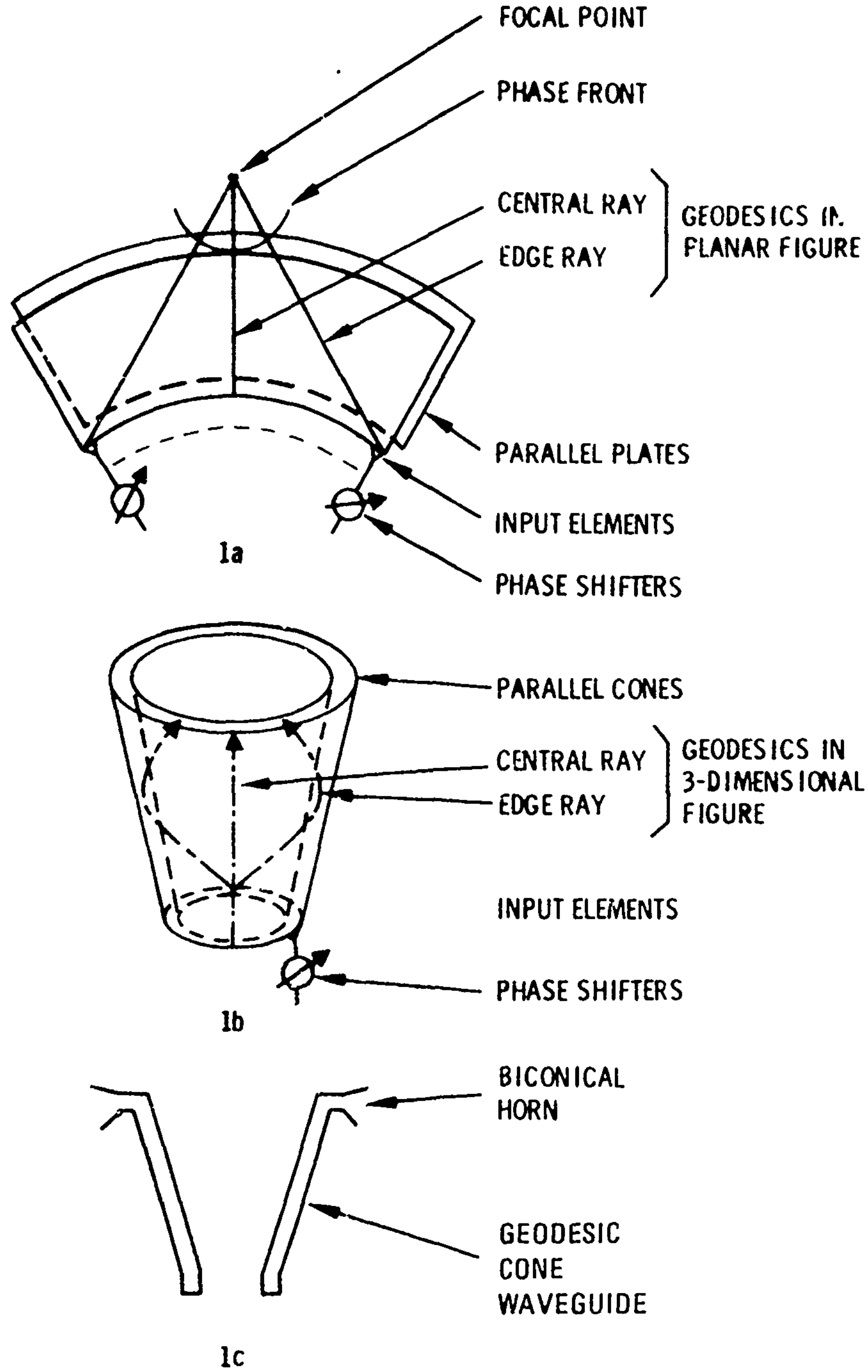

Figure 1. Geodesic Cone Antenna (GCA)

and a radiating aperture at the top. The input elements are fed by a network of phase shifters and power dividers that can provide precise phase and amplitude control to each element.

To form a beam in any direction, energy is applied to all the feed elements simultaneously. The relative amplitude and phase of the signal applied to each element is chosen so that after propagating through the GCW, the energy illuminates a sector (typically 90° to 120°) of the circular radiating aperture. The resulting amplitude and phase distribution provides a low sidelobe pattern focused in the far field.

The operation of the Geodesic Cone Waveguide can be described in terms of a two dimensional model. the conical section (Figure 1b) can be cut along a line from the base of the edge rays to the aperture and unrolled to become a sector of a radial waveguide (Figure 1a). By placing a circular phase distribution on the radiating elements, the energy can be focused to a point in the planar geometry. The ray paths that are linear in the two-dimensional representation follow geodesic paths in the three dimensional Geodesic Cone Waveguide. The ray paths beyond the parallel plate region, that focus to a point in the two-dimensional representation, result in a collimated beam focused in the far field in the fully formed cone (Figure 2).

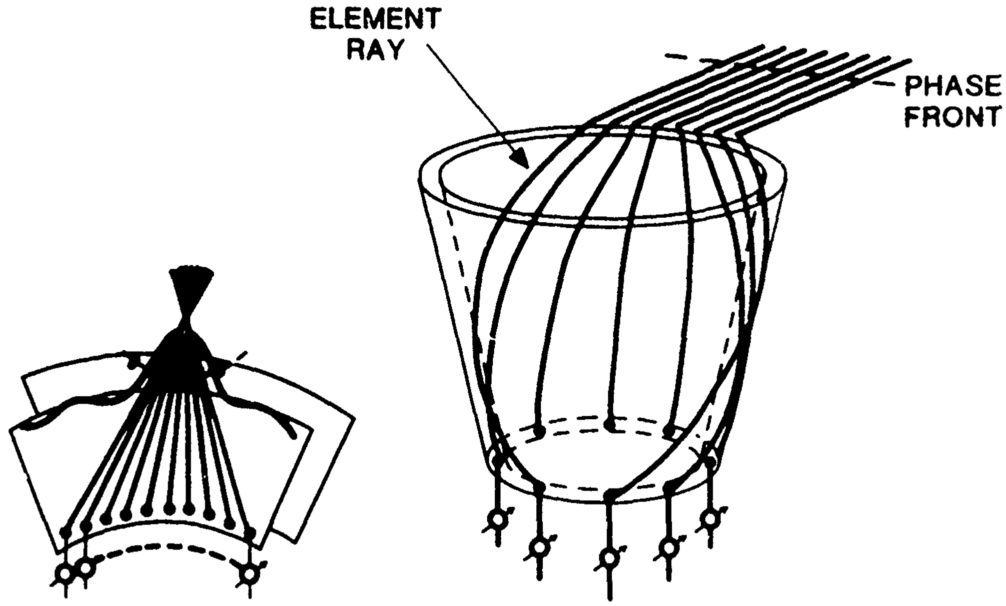

Figure 2. Geodesic Cone Waveguide Concept Development

All of the feed elements are utilized in forming any beam. In order to scan the beam to any azimuth position, the signal distribution to the feed elements is commutated around the base. By modifying the signal distribution at the feed elements of a Geodesic Cone Antenna, many beam shapes can be obtained. Beamwidth is continuously variable from the narrowest beam (design limit) to very broad beams and omni patterns. Also achievable are difference patterns and multiple beam patterns. By dividing the input array into segments with separate feed networks, it is possible to form independently controllable beams.

3.0 DESIGN APPROACH

The design of a Geodesic Cone Antenna involves the following steps:

- Selection of an Equivalent Linear Aperture (ELA) necessary to meet the beamwidth and sidelobe level requirements.
- Selection of the GCA dimensions based on trade-offs of size and degrees of aperture illuminated.
- Synthesis of the optimum input element phase and amplitude values using a modal analysis computer program.
- Synthesis of far field patterns incorporating selected levels of error using a modal analysis computer program.

A GCA has a continuous circular aperture, the performance of which can be exactly related to the performance of an Equivalent Linear Aperture (Figure 3). The length of the Equivalent Linear Aperture is equal to the projection of the illuminated portion of the aperture. In the initial step of the design process the linear aperture required to meet the performance specifications (at broadside) is determined. Figure 4 shows the beamwidth vs. sidelobe trade-off for a linear aperture with a Tchebyshev distribution. For an example application the equivalent linear length is derived from such a figure.

Using design curves generated from a geometric optics analysis, the preliminary dimensions of a GCA are determined. The input diameter of the GCA is related to the ELA by a proportionality factor called the Aperture Utilization Factor (AUF). The AUF is related to the maximum scan angle of the feed elements (α) as follows:

$$AUF = \sin\alpha \qquad (1)$$

The required minimum input diameter of the GCA is:

$$D_{IN} = ELA/AUF \qquad (2)$$

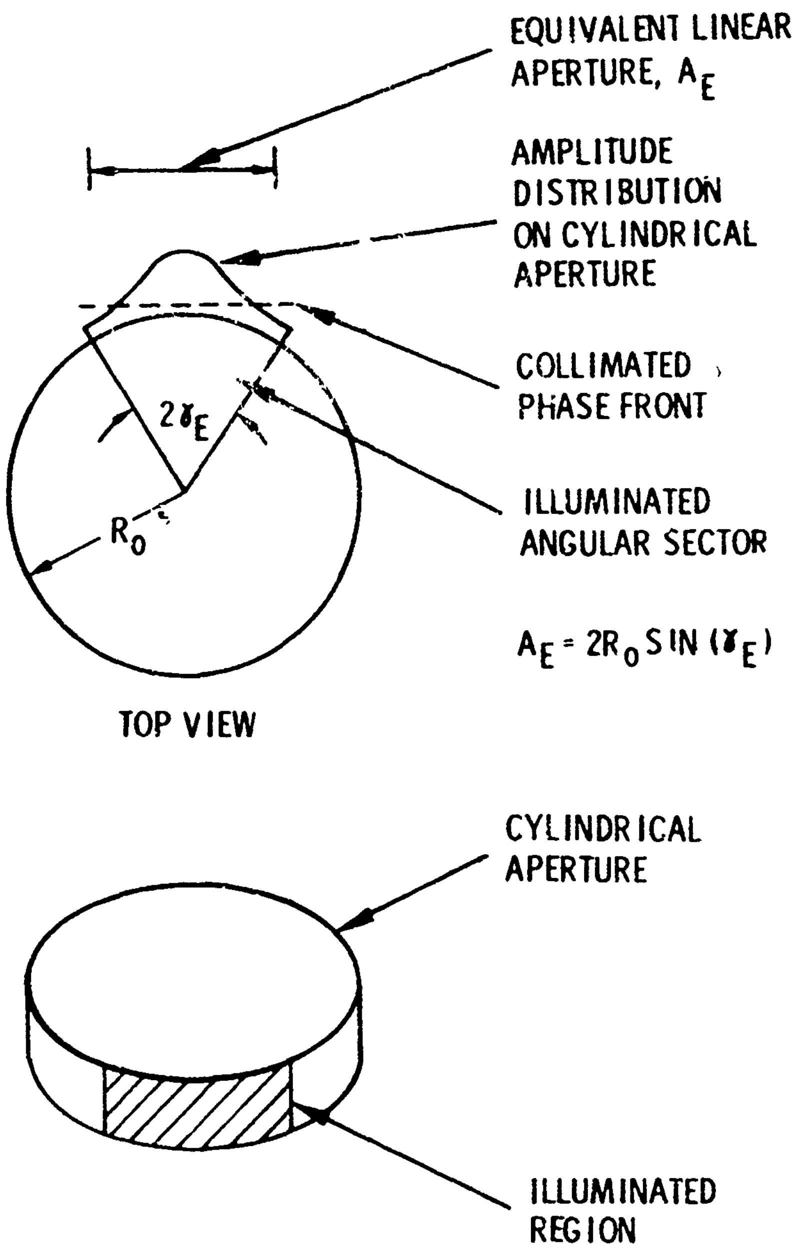

Figure 3. Radiation from a Collimated Illumination of an Angular Sector of a Cylindrical Aperture can be Related to Radiation from an Equivalent Linear Aperture

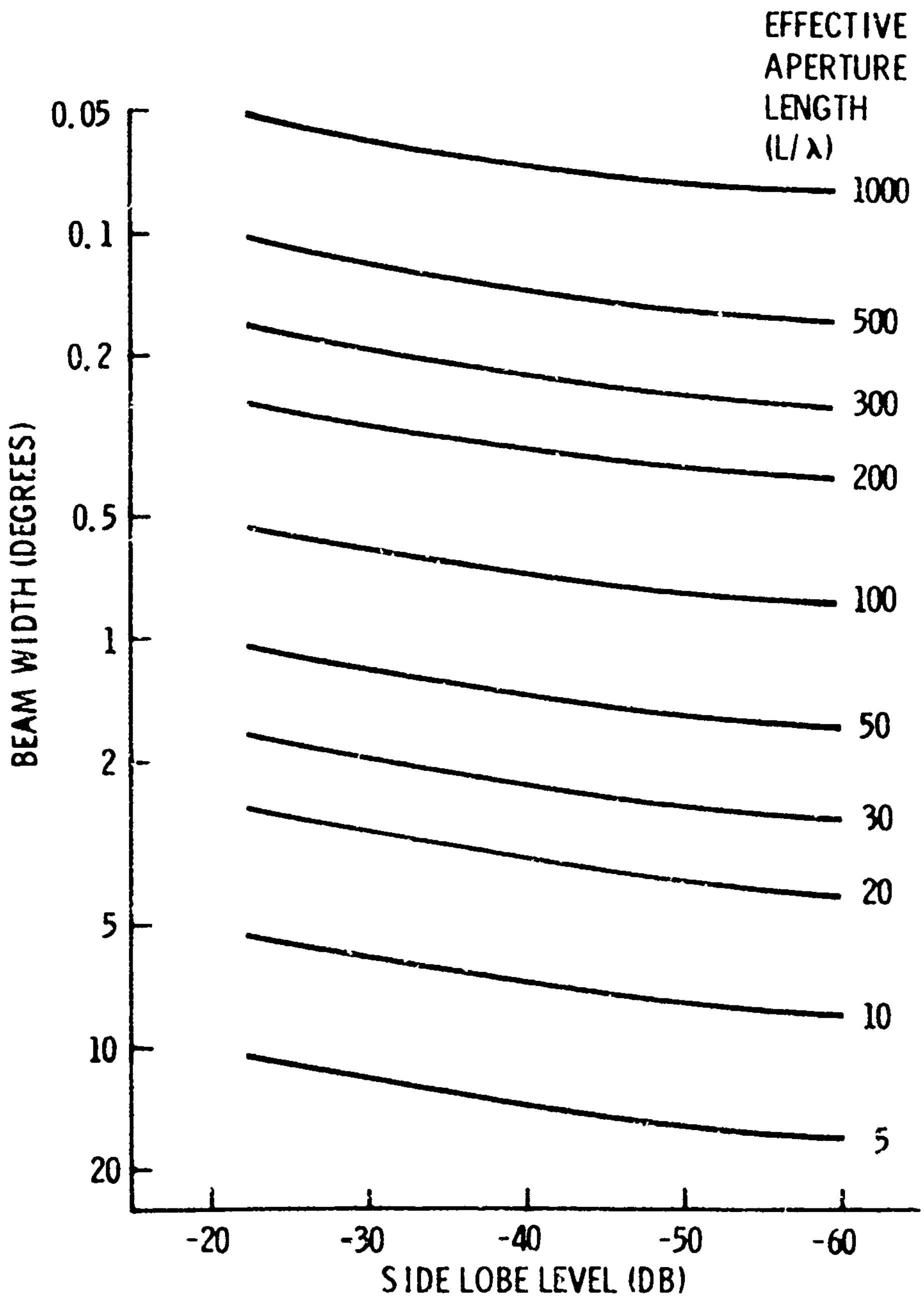

Figure 4. Beamwidth versus Sidelobe Level for a Tchebychev Distribution

Figure 5 is used to determine cone height, output diameter and the illuminated angular sector of the aperture given the input diameter and the maximum element scan angle. For each set of inputs, there is a family of possible solutions defined by the line corresponding to the maximum scan angle. It is at this point that geometric constraints on the size and shape of the Geodesic Cone Antenna are taken into account. Each of the possible solutions will provide the required performance so the most convenient combination of dimensions can be chosen; however, to maintain low-reflection aperture performance, the illuminated sector is normally limited to less than 120°. This limits the angle of existing waves to a maximum of 60 degrees from the normal.

This provides all the basic dimensions of the GCA. Some other considerations are that the spacing between the conical plates must be less than half a wavelength at the highest operating frequency to prevent crossed modes, and that the feed elements should be spaced at or near a half wavelength at the high end of the band. The design of the aperture is not considered in this paper.

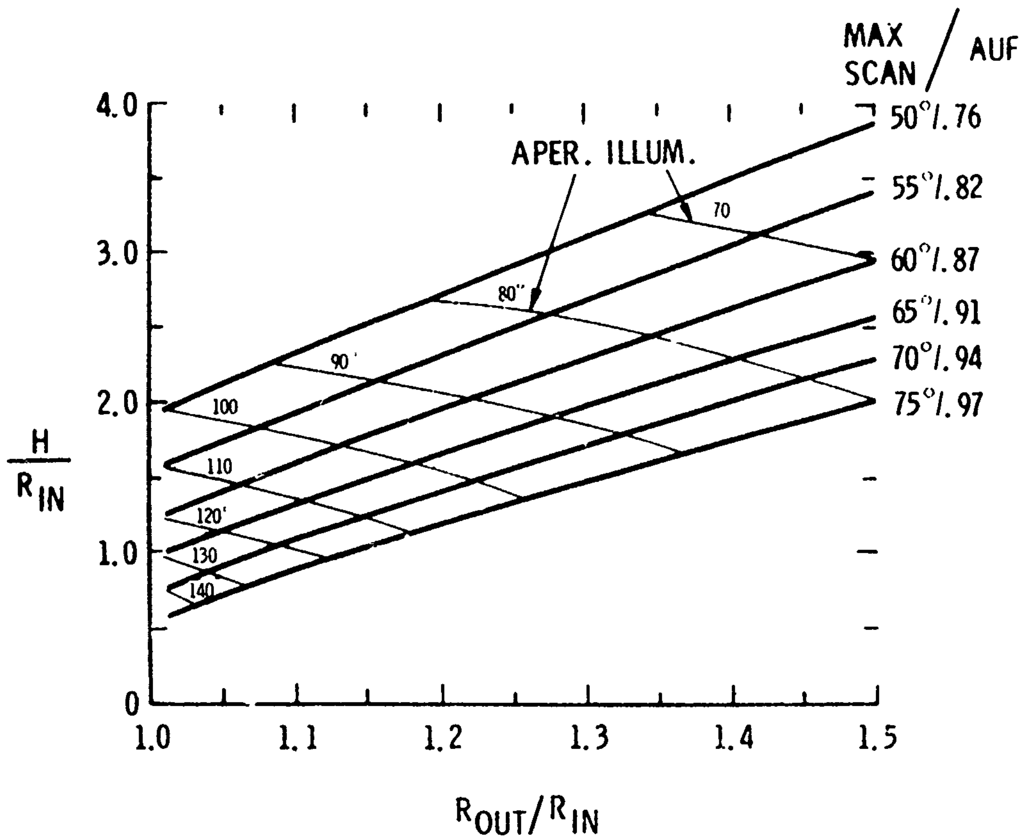

Figure 5. Geometric Optics Relationships in Geodesic Cone Waveguide

Modal Analysis techniques in a computer simulation are used to derive the optimum input feed distribution to form a desired beam shape on a Geodesic Cone Antenna. A computer program has been written that relates the input and output of a GCA in terms of TE_{NO} waveguide modes. This enables synthesis of an input distribution from a desired pattern. The computer program can also derive a far field pattern from an input distribution. A beam pattern based on the optimum input distribution would be an upper bound of performance. The program has the capability to insert selected error levels and quantization parameters at the feed elements prior to the modal derivation of the aperture distribution and the far field patterns.

4.0 EXAMPLE DESIGN PROBLEM

As an illustrative example of the design approach, consider the following requirements:

Maximum operating frequency - 12 GHz

Maximum azimuth beamwidth - 3° (at 12 GHz)

Maximum sidelobe level - 40 dB (at 12 GHz)

The resulting GCA dimensions assuming maximum element scan of

60 degrees and an illuminated aperture of 90 degrees are:

Input radius - 13.2 inches

Output radius - 16.1 inches

Height - 26.4 inches

Number of feed elements - 166

Figure 6 is the calculated far field pattern for this example GCA given RMS amplitude error of 0.5 dB and RMS phase error of 2 degrees. The resulting bandwidth of 3.2 degrees and the peak sidelobe level of -38 dB are consistent with the design goals.

To meet the same performance requirements over 360 degrees using a group of linear arrays would require 35 to 45 percent more active elements then a GCA (Figure 7). The reduced number of active elements in a GCA results in substantial decreases in size and cost.

5.0 DEMONSTRATION MODEL

Figure 8 shows a 64 element Ku-band Geodesic Cone Antenna demonstration model which was designed and evaluated at LEC. The antenna is fed by a network of power dividers with manually adjustable attenuators to provide the amplitude taper and manually adjustable phase shifters to create the required phase distribution. A simple biconical horn was used for the aperture and the Geodesic Cone Waveguide is constructed of aluminum.

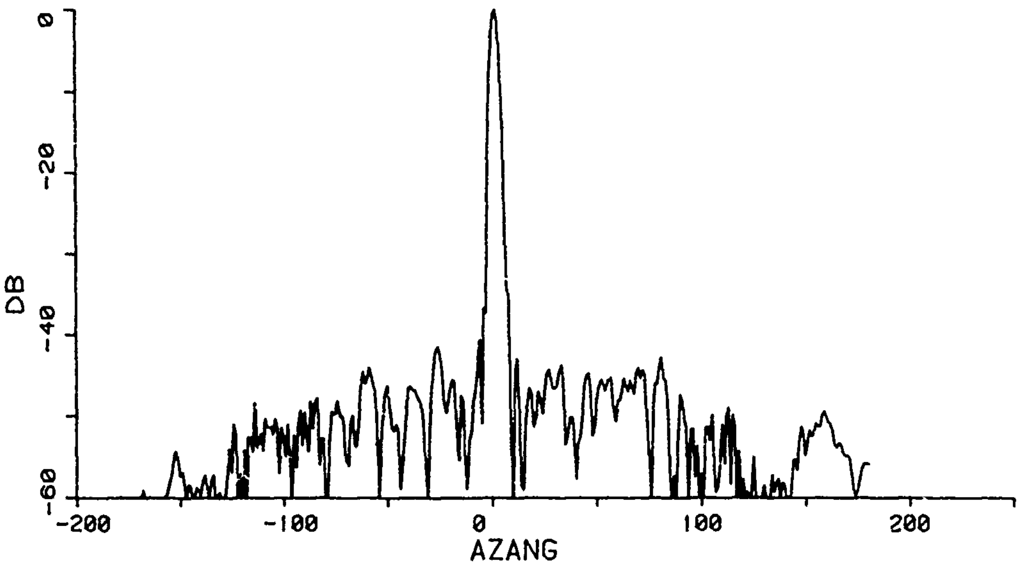

Figure 6. Calculated Farfield Pattern

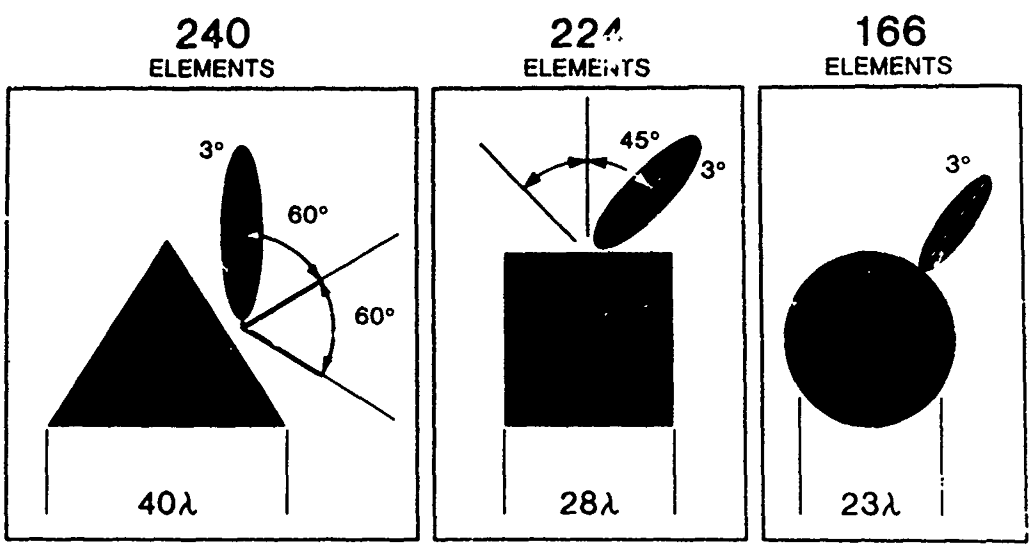

Figure 7. Number of Elements-Comparative Techniques

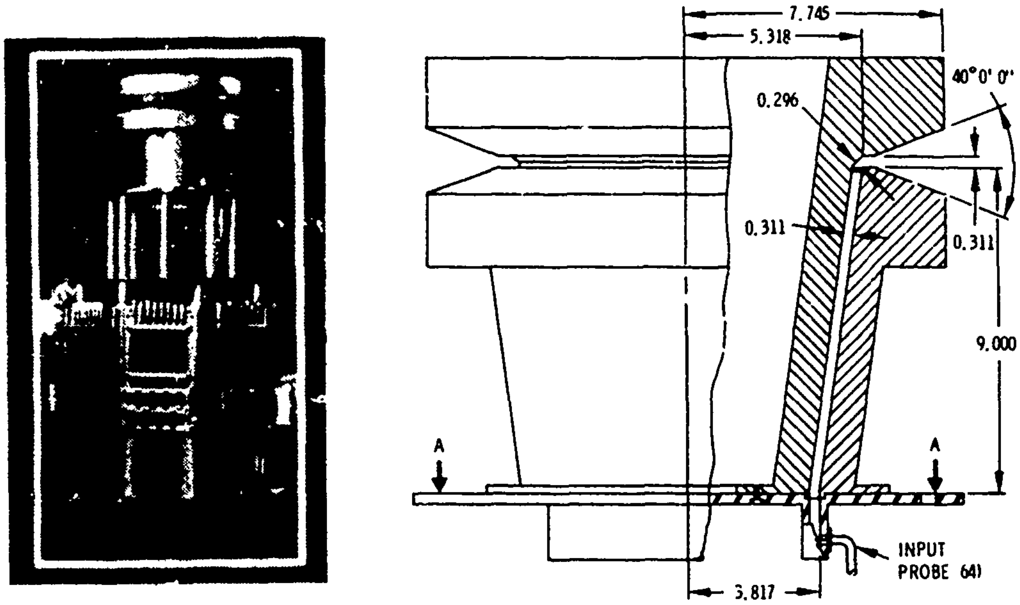

Figure 8. Geodesic Cone Antenna Demonstration Model

The Demonstration Model operates from 12 to 16 GHz. The Geodesic Cone Waveguide and aperture are designed to operate over the full octave from 8 to 16 GHz, but the feed elements currently implemented are only matched over the half octave.

The Demonstration Model was designed to perform as follows (without feed error):

Characteristic	Frequency (GHz)				
	8	12	14	15	16
Beamwidth (degrees)	14	10.4	8.7	7.8	7
Peak Sidelobe Level (dB)	-25	-27.6	-28.8	-29.4	-30

Figures 9, 10 and 11 show the calculated and measured beam patterns at 14, 12, and 15 GHz. The calculated patterns include random errors imposed on the feed element distribution. The magnitude of the error (one dB RMS amplitude error and five degrees RMS phase error) was (1) determined through evaluation of the accuracy, repeatability, and resolution specifications of the mechanical attenuators and phase shifters, and (2) confirmed by laboratory testing of the components. These feed errors increase the sidelobe levels of the patterns. As can be seen from these

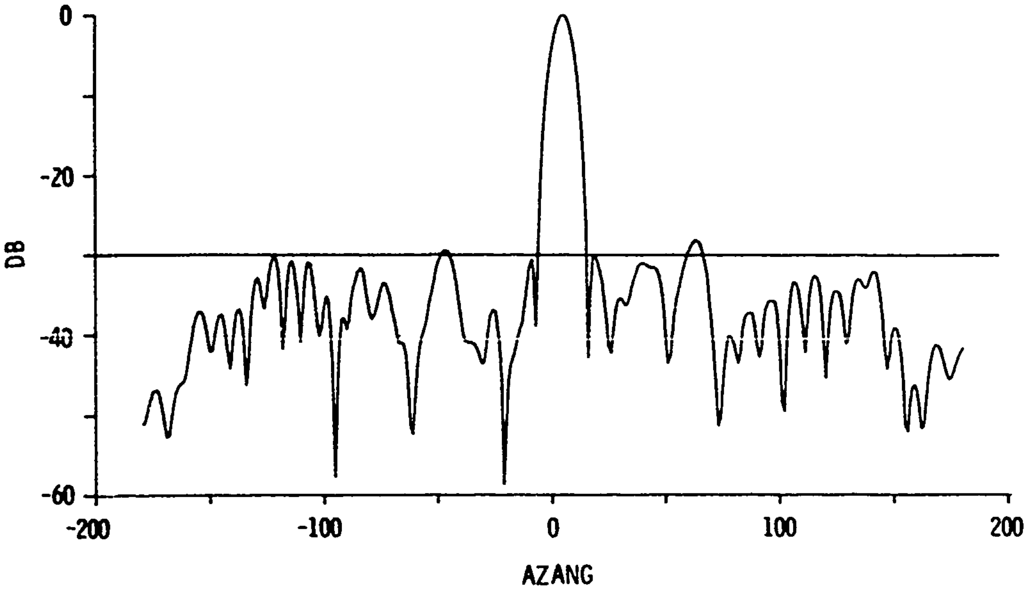

Figure 9a. Calculated 14 GHz Sum Pattern

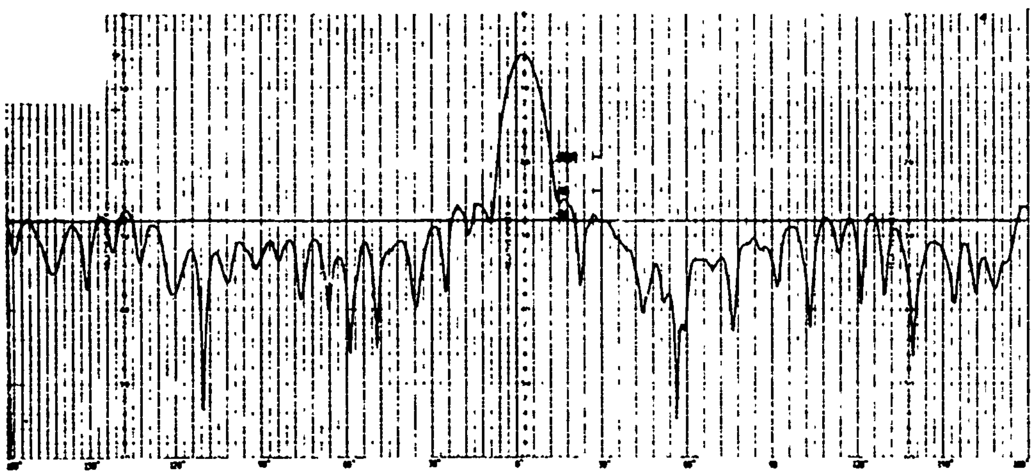

Figure 9b. Measured 14 GHz Sum Pattern

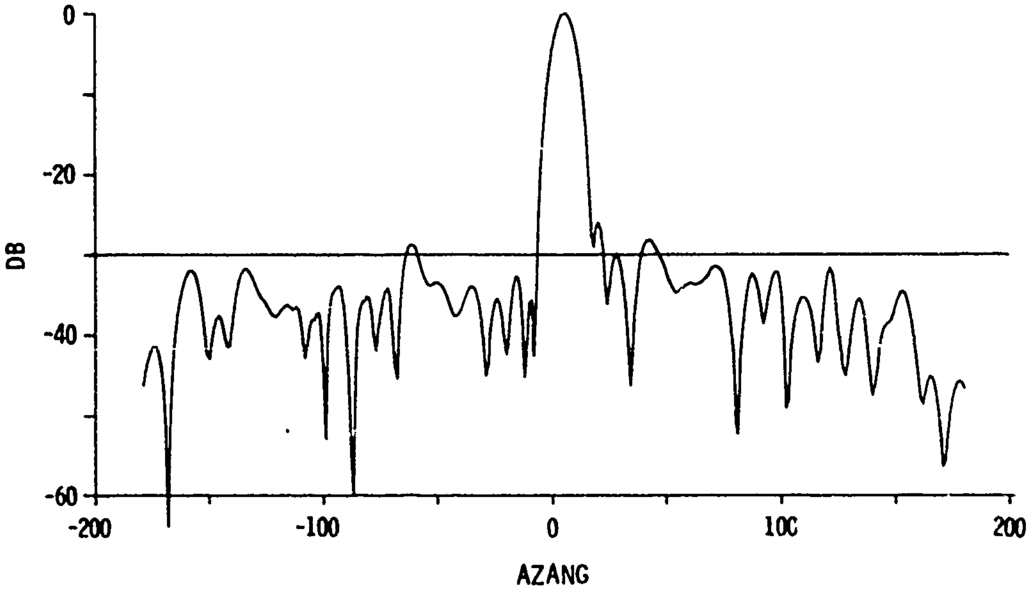

Figure 10a. Calculated 12 GHz Sum Pattern

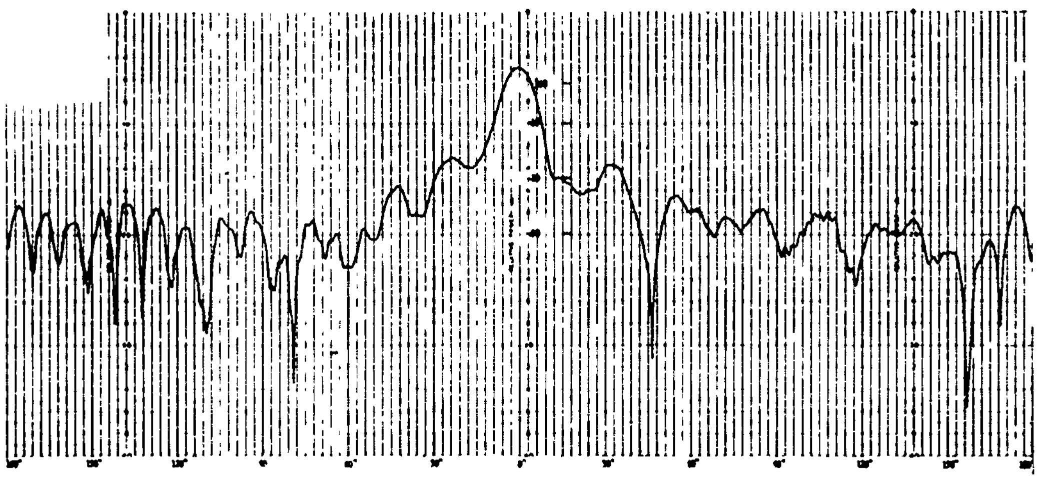

Figure 10b. Measured 12 GHz Sum Pattern

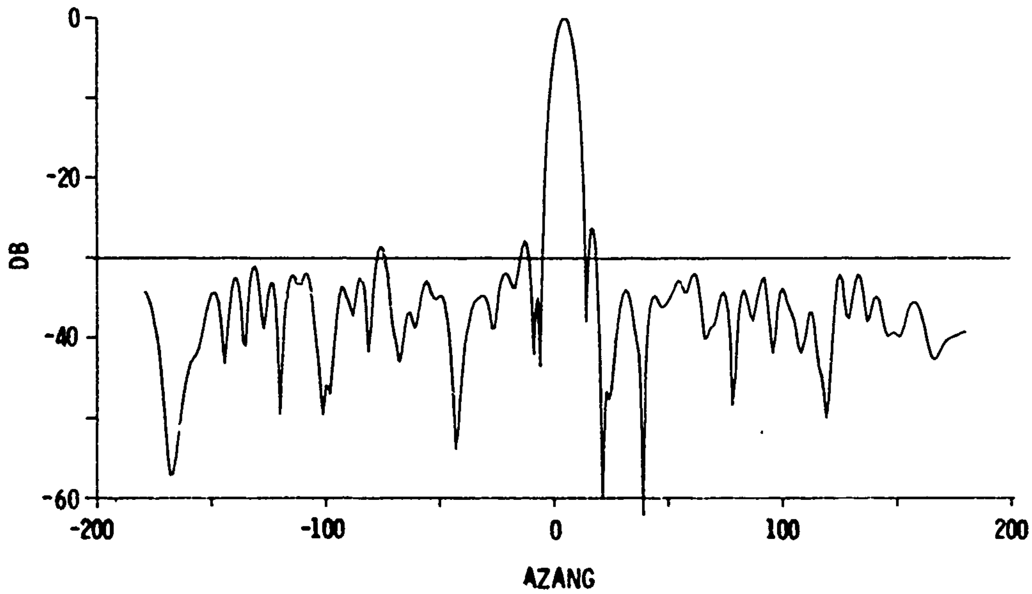

Figure 11a. Calculated 15 GHz Sum Pattern

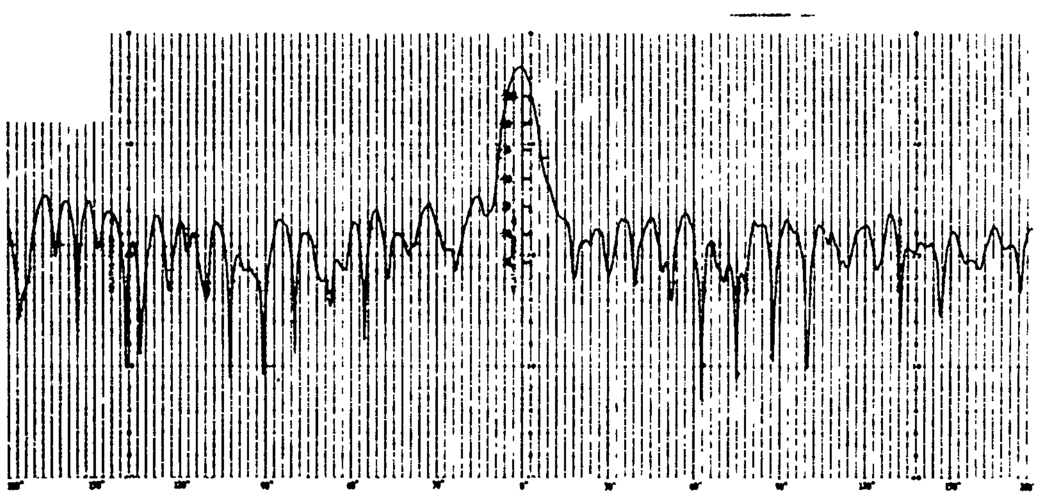

Figure 11b. Measured 15 GHz Sum Pattern

figures, the calculated patterns correlate well with the measured patterns. Figures 12 and 13 show both the calculated and measured omni and difference patterns. These results clearly verify the predicted performance of the 64-element demonstration model.

6.0 CONCLUSIONS

The Geodesic Cone Antenna is an approach which offers size, weight, cost and performance advantages for many 360 degree applications. Analytic methods for design and analysis have been developed and verified empirically. The GCA offers excellent beam control with low sidelobes and multiple independent beam capability. A GCA can be used as an azimuth scanning feed to a vertical beam scanning aperture resulting in a pencil beam scannable in azimuth and elevation. Applications for the GCA range from radar and ECM to communications systems.

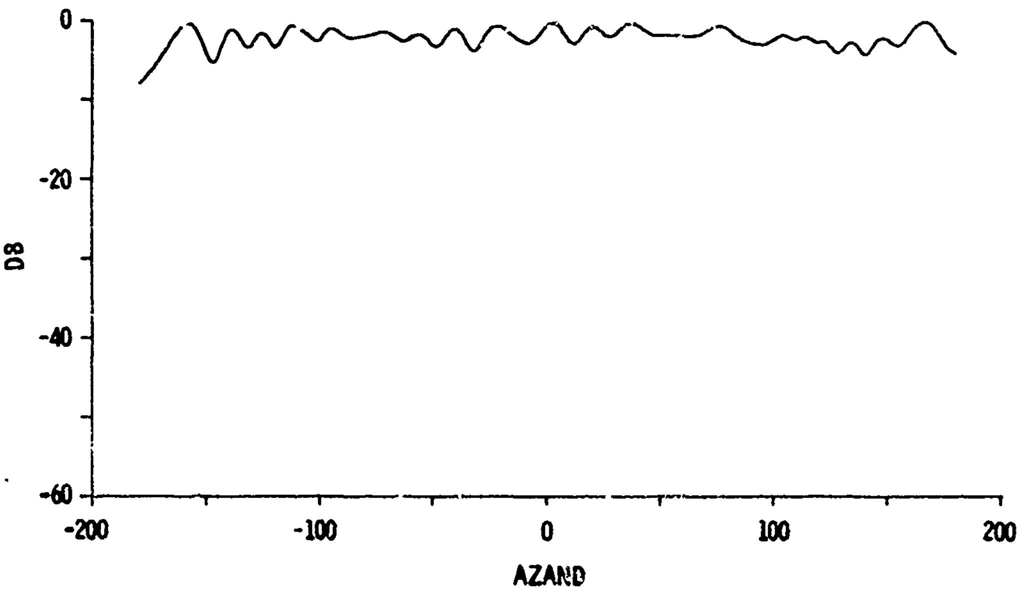

Figure 12a. Calculated 14 GHz Omni Pattern

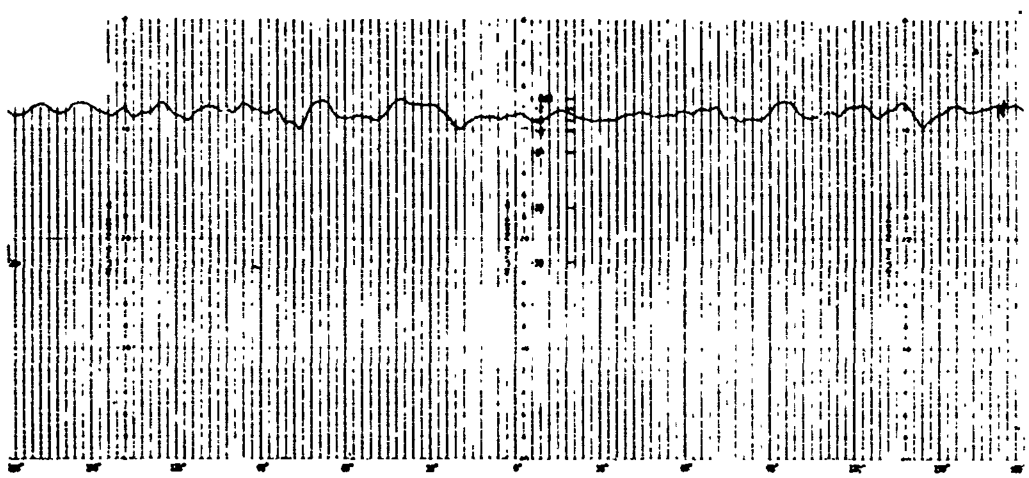

Figure 12b. Measured 14 GHz Omni Pattern

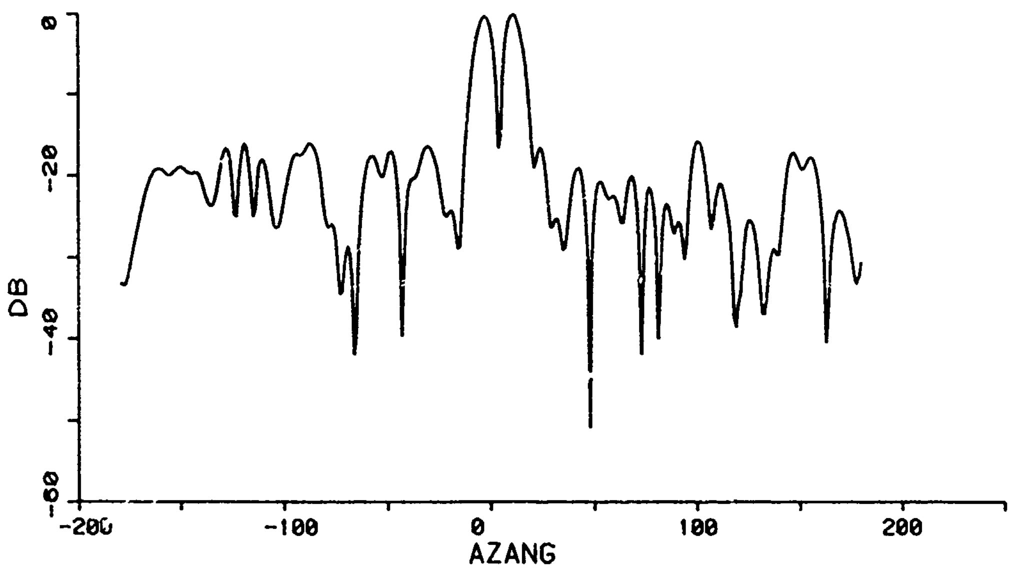

Figure 13a. Calculated 14 GHz Difference Pattern

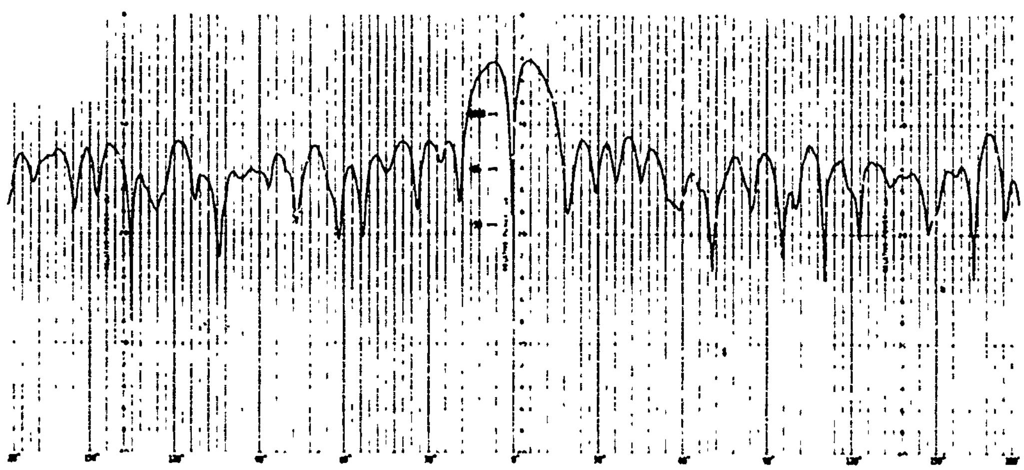

Figure 13b. Measured 14 GHz Difference Pattern

ACKNOWLEDGEMENTS

The author wishes to thank J. Becker, J. Margolin and O. Fahrenfeld for their valuable contributions in this program.