DESCRIPTION OF COMPUTER PROGRAM TO ANALYZE GAIN DISTRIBUTION OF AN ANTENNA PATTERN[1]

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Summary The gain of a radiating antenna is generally a function of the direction in which the antenna is pointing relative to the direction of the received or transmitted signal. The gain distribution over an imaginary sphere surrounding the antenna is called the antenna gain pattern and can be measured experimentally. Under certain circumstances the tolerances associated with the pointing vector make it impossible to determine the antenna gain precisely but rather circumscribe an area on the spherical surface which include a number of different gain values. A computer program called INTGRT has been developed that will determine from measured antenna pattern data the gain distribution within the uncertainty region and will provide a measure of the probability of the gain being above a certain gain value. The boundary of the uncertainty region is described in terms of the. coordinate system used in measuring the antenna patterns. Each gain value contained inside this boundary is compared to some reference gain level and a running total is made of the number of values found to be equal to or greater than the reference value and the total number of values inside the region. After weighting each total by an equal area function, the ratio of the number of values above a reference level to the total number of values in the region gives an estimate of the probability that the gain of the antenna will be equal to or above the reference gain. If the region is analyzed in this way for a number of reference levels, the distribution of gain values within the region is obtained. This information is extremely valuable in determining space communication system performance during periods in which the orientation of the spacecraft's antenna with respect to the earth cannot be determined precisely but is known to be within certain limits.

Introduction In general, when a radiating antenna is placed at the center of a three-dimensional coordinate system, it is found that the amplitude of the radiation varies as a function of position on the surface of an imaginary sphere surrounding the antenna. The radiation amplitude relative to some reference is called antenna gain. The gain of an antenna directly influences the power in a transmitted or received signal incident at the antenna and is, therefore, of prime interest in the analysis and design of communication

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system performance. To determine the effect of the antenna on signal strength it is necessary to know the direction in which the antenna is pointing. The antenna gain is defined as the gain at the point that the vector from the transmitter to the receiver (pointing vector) pierces the surface of the sphere surrounding the antenna. In many cases, the precise direction of the pointing vector cannot be determined due to uncertainties and tolerances associated with the orientation of the antenna. In such cases, instead of piercing the surface of the sphere at a single point, the pointing vector intersects the surface at a number of points determined by all possible combinations of the uncertainties and tolerances of the vector. The locus of these points outlines a region on the surface of the sphere. Since it is only known that the pointing vector is in this region and the antenna gain is, in general, not of equal value everywhere inside the boundary, it is not possible to define the gain of the antenna precisely. The following discussion will be devoted to describing a computer program which will provide statistical information about the distribution of the antenna gain within the uncertainty region. With this information a measure of the confidence of the antenna gain being above or below a particular value can be obtained.

Analysis The computer program which has been developed is called INTGRT. This name is derived from the word “integrate” which best describes the mathematical operation performed by the program.

One common method of measuring antenna gain is to center the antenna in a three-dimensional coordinate system and record the gain level at every point in the 4π steradian field of view of the antenna. The distance from the origin generally remains constant as the measurements are made, such that the locus of all points measured will constitute the surface of a sphere surrounding the antenna. Antenna gain is generally a function of position and will vary in amplitude and phase from point to point on the surface of the sphere. From these measurements the antenna gain variation can be represented graphically by plotting the gain values as a function of position and connecting those of equal amplitude with lines. This figure is commonly called an antenna pattern as shown in Figure 1.

When a signal is being transmitted or received by an antenna, the power of the signal is modified by the antenna gain at the point at which the signal intersects the surface of the sphere. If we define the pointing vector as a vector in the antenna’s coordinate system which directly coincides with the direction of transmission or reception of the signal as shown in Figure 2, the coordinates of the pointing vector and the antenna pattern uniquely determine the effect of the antenna on the signal. In many cases the direction of the pointing vector has associated with it certain tolerances on ϕ and θ due to uncertainties in the orientation of the antenna. The combination of these tolerances result in movement of the pointing vector so as to outline an uncertainty region in the 4π

steradian field of view of the antenna as shown in Figure 3. The uncertainty region R can be considered to be a portion of the surface of the sphere from which the antenna gain pattern was generated. If the tolerances associated with the pointing vector are worst case values, the pointing vector will intersect the surface somewhere within the boundary of the region, and the antenna gain will be one of the values that is contained in R. Although it is not possible to determine the precise value of the antenna gain, due to the tolerances on the pointing vector, the antenna pattern measurements provide information as to the distribution of the gain within the region. By arbitrarily choosing various reference gain levels and assuming that the pointing vector can pass through all points in the region with equal likelihood, the percentage of the region which has gains above each of the reference levels can be determined. This percentage will be a measure of the probability that the antenna will have a gain above the reference level chosen since

$$P_{[G_o]} = \frac{N_{G_o}}{N_G} \quad (1)$$

where

$P_{[G_o]}$ = Probability that the antenna gain will be above G_o

N_{G_o} = Number of gains in R above G_o

N_G = Total number of gains in R.

The calculation of this probability measure is the basic function performed by the program INTGRT.

Program Operation As you recall the antenna gain pattern consists of discrete gain values which are measured at points in the field of view of the antenna and are plotted as a function of position in the antenna's coordinate system. The uncertainty region R shown in Figure 3 can also be represented as a function of position and mapped onto the antenna pattern as shown in Figure 4. Inside the boundary of this region (which, in this case, represents the maximum variation of the pointing vector due to its tolerances) there are a number of points $P(\phi, \theta)$, each of which has associated with it a measured antenna gain value. The spacing of these points depends upon the resolution of the measuring technique used to determine the antenna pattern.

The program INTGRT requires as an input from the user a description of the boundary of the uncertainty region in the antenna pattern coordinate system. To minimize the amount of numbers necessary to describe the boundary, the region was considered to be composed of a number of strips similar to the one in Figure 4. The points P_1 and P_2 are the points at which the strip intersects the boundary of the region and have coordinates

(θ_1, ϕ_2) and (θ_1, ϕ_2), respectively. Thus the entire region can be represented by a number of these strips, as θ is varied from θ_{min} to θ_{max}.

Once the region is described as shown in Figure 4, INTGRT then calculates the percentage of the region above various reference gain levels supplied by the user. This computation involves scanning a strip from ϕ_1 to ϕ_2 and comparing the antenna gain at each point with each of the input reference gain values. If the gain being checked is above a reference value, the index for the reference gain is incremented by one, and if it is not, the index remains the same. This procedure continues until all strips have been scanned. A total of the number of points in the region is also recorded. The ratio of the number of points which have gains above a reference value to the total number of points in the region which has again greater than the reference value. From equation (1), this percentage can be considered a measure of the probability that the antenna will provide a gain greater than the reference value for the case under investigation. If the antenna pattern is derived from measurements made in spherical coordinates, as is generally done, each point in a strip must be weighted by the sine of the angle θ in Figure 1 to normalize the areas over the entire surface.

The previous discussion describes the operation of the program INTGRT. The input data required by the program consists of the following:

1) Antenna gain pattern measurements as a function of position in antenna coordinates

2) A description of the uncertainty region in antenna coordinates

3) A list of the reference gain values to be used for comparison

The user has a number of options he may exercise in operating the program. These options include analyzing any number of uncertainty regions, changing the reference gains for a particular region, and plotting a curve of the gain distribution within a region. An example of the plotting capability is shown in Figure 6.

Conclusions The significance of this computer program lies in its ability to provide an estimate of the probability of achieving a certain gain from an antenna which exhibits uncertainties in its orientation. This problem is often encountered in spacecraft controlled changes in orientation with respect to earth or direction of flight. The dispersions associated with these maneuvers are reflected into the antenna pointing vector, thus causing uncertainties in the performance of the vital communication link to the spacecraft. If the uncertainty regions produced by a number of possible maneuvers are analyzed with INTGRT, the maneuver which provides the highest probability of satisfying communication performance criteria can be readily determined. The main disadvantages of this method of analyzing antennas is that the antenna gain pattern must be measured experimentally, and the accuracy of the analysis is only as good as the accuracy and resolution of the measurements. However, this limitation is inherent in nearly all practical problems, and does not appear to be too great a handicap.

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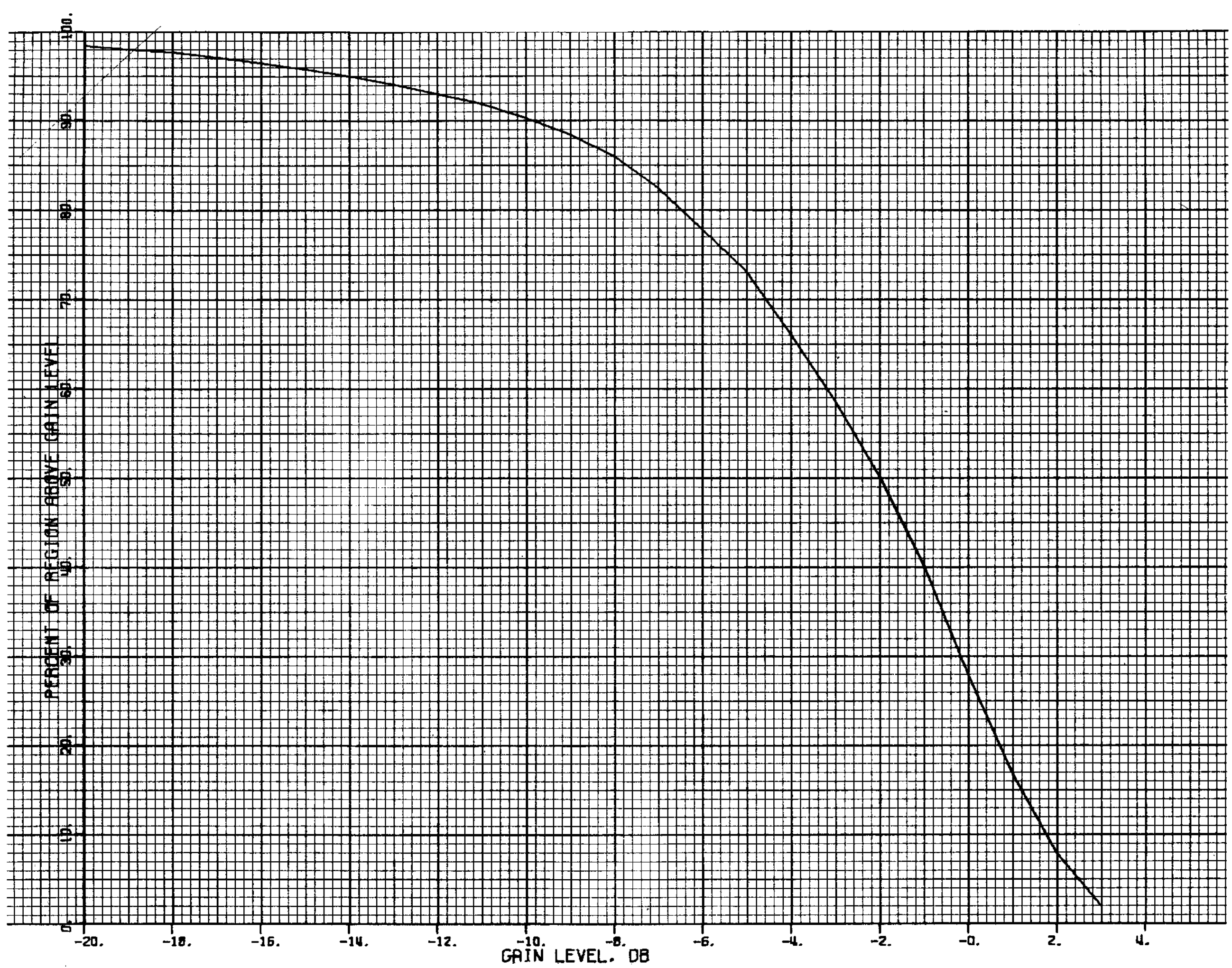

Fig. 1 - Example of Antenna Gain Pattern

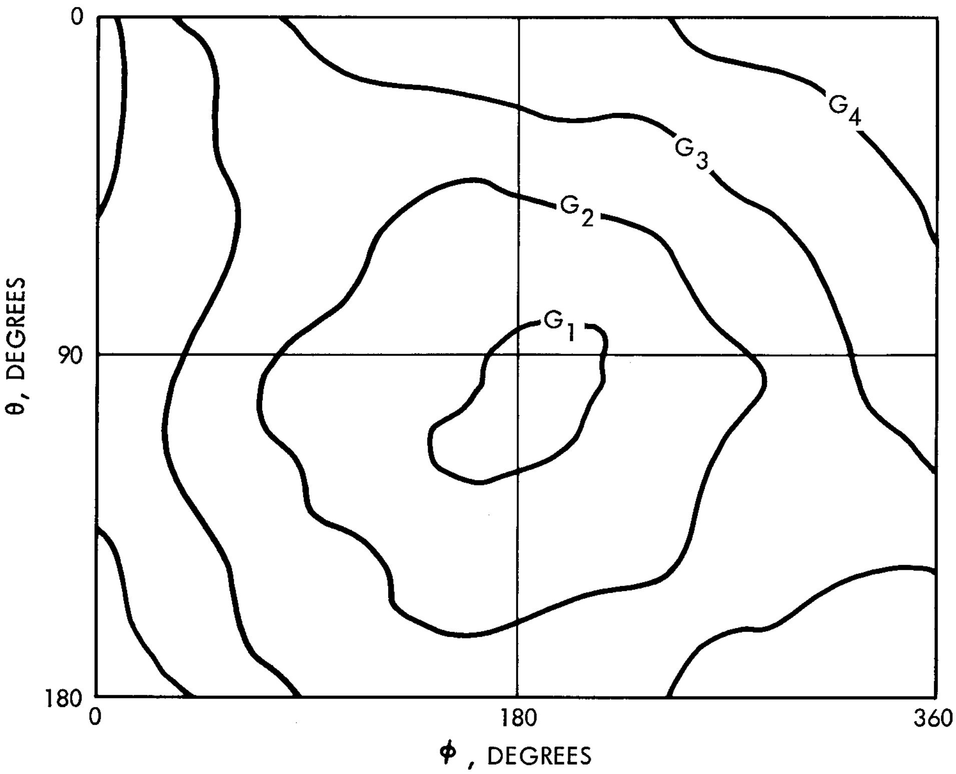

Fig. 2 - Pointing Vector Representation in Antenna Coordinate System

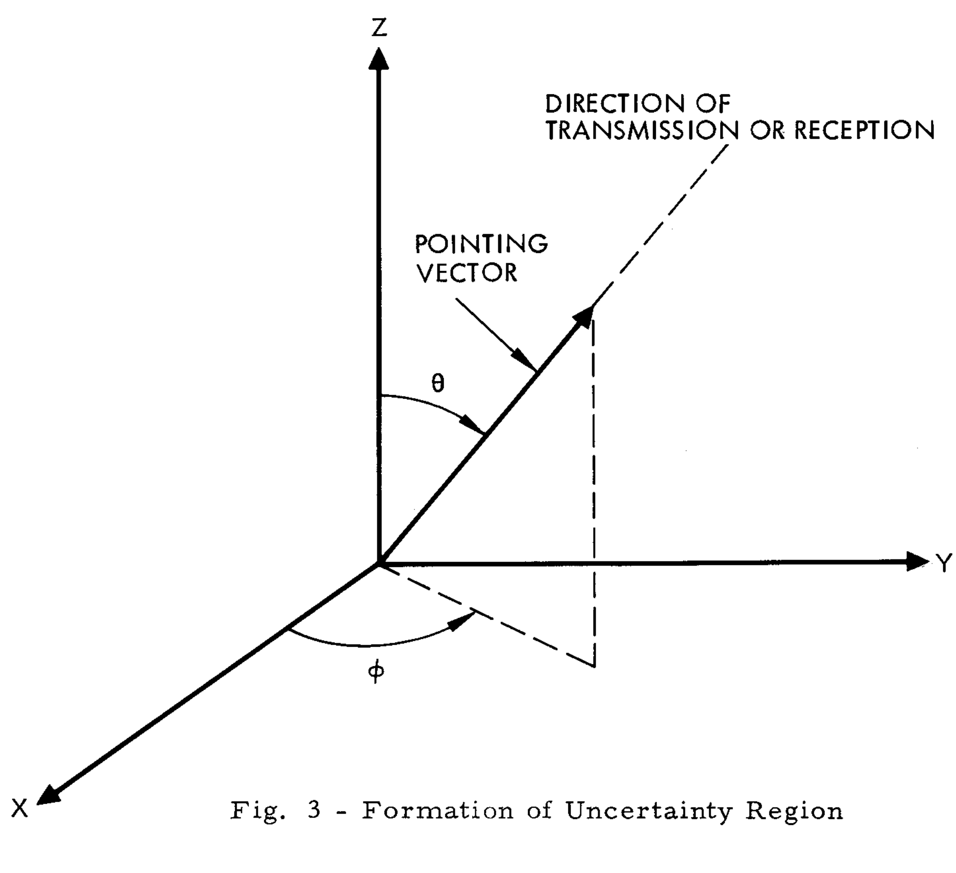

Fig. 3 - Formation of Uncertainty Region

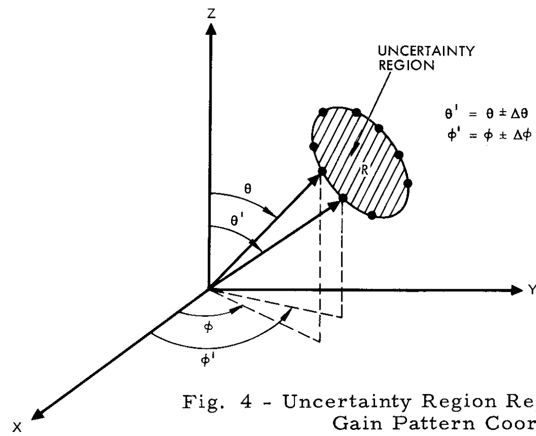

Fig. 4 - Uncertainty Region Represented in Antenna Gain Pattern Coordinates

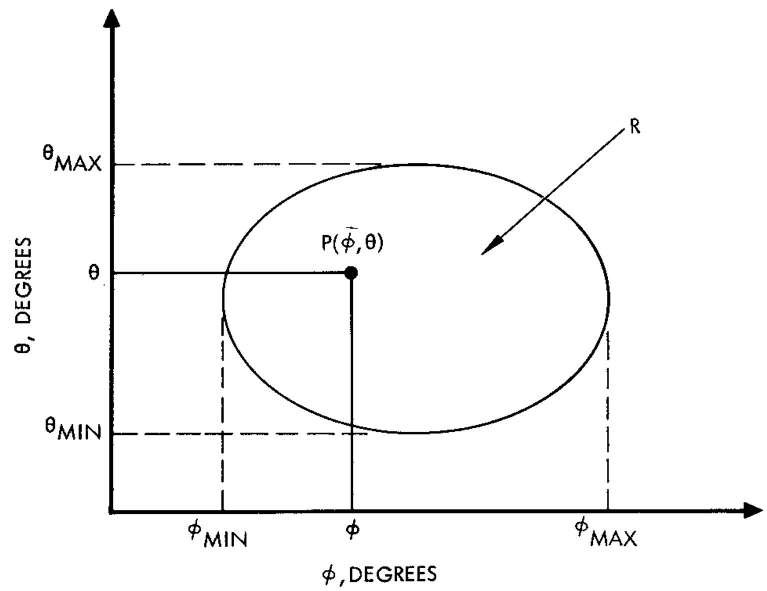

Fig. 5 - Uncertainty Region's Decomposition for Input to INTGRT Program

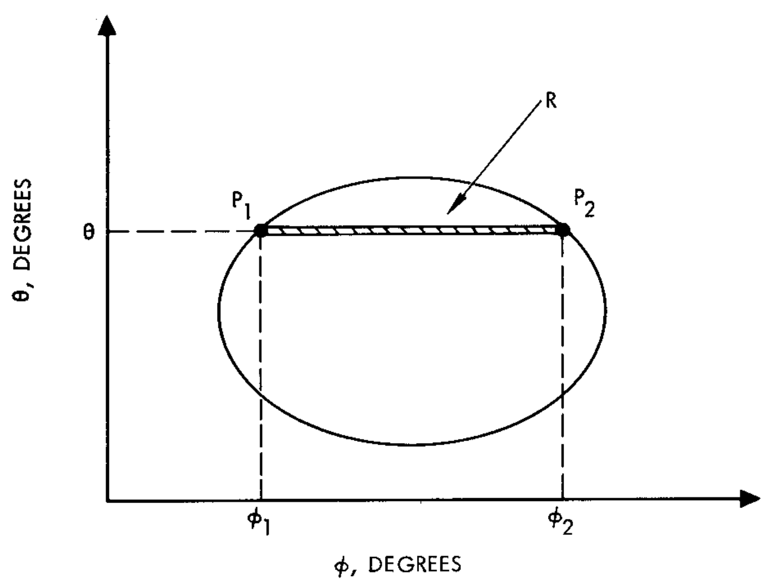

Fig. 6 - Gain Distribution of a Sample Uncertainty Region