LOWEST COST ALTERNATIVE TO AUTO-TRACKING USING GPS-TRAK, AUGUSTIN-SULLIVAN DISTRIBUTION, & SINGLE AXIS ANTENNA TECHNIQUES

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ABSTRACT

The first telemetry tracking system was desired in 1959 for the space program. Cost was of little concern. The tracking technique used was 3 channel monopulse which is still today, after all these years, the optimum in performance for any type of tracking requirement. Telemetry tracking really got off the ground in the early 1970's with the move from P-Band to S-Band for telemetry. In the design of early tracking systems, performance was on the top of the list, and cost was on the bottom of the list in establishing the design criteria. By the beginning of the 1980's cost was approaching performance in importance. Today, with the demise of the cold war and a considerable reduction in global threats coupled with the state of the world economy, cost has now reached the top of the list.

The cost of a telemetry tracking system can be reduced by more than a factor of two by going to a single axis tracking technique. The lowest cost single axis approach heretofore has been the use of a cosecant squared (CSC^2) distribution. To improve the efficiency of a single axis system and increase the overhead coverage capability, the use of a dual beam antenna has been widely used as another type of single axis approach. The dual beam technique involves additional costs since two tracking antennas are required.

Except for satellite tracking, almost all telemetry tracking is performed at low elevation angles and, like it or not, multipath is there. The multipath fade varies from a few dB, to over 20 dB depending upon the reflecting terrain. Most general purpose systems should be designed for at least a 10 dB multipath fade. For all telemetry tracking applications, the multipath effect is completely negligible at elevation angles

greater than 10 degrees. The Augustin-Sullivan Distribution, in effect, fades away the multipath margin as the multipath effect decreases. Because ofthe multipath phenomenon, an antenna beam should not be shaped at the one dB point as is the case with a CSC^2 distribution, but only needs to be shaped from somewhere between the 15 - 20 dB level based on the mission requirements. This involves a gain reduction from a pencil beam on the order of 1/2 dB or less, rather than the 3 dB reduction associated with the CSC^2 distribution. The Augustin-Sullivan distribution does not start shaping the beam until shaping is retired, and shapes the beam for constant altitude coverage from the horizon to zenith. For the first time, coverage is provided from the peak of the beam to directly overhead with a single antenna and a single axis rotator.

When GPS information is available from the tracked vehicle, the Augustin-Sullivan distribution, with a single axis rotator and using the GPS-TRAK technique, results in the lowest possible cost alternate to autotracking.

KEYWORDS

Low cost tracking, Single axis tracking, Augustin-Sullivan Distribution, GPS tracking

INTRODUCTION

The first telemetry single axis tracking systems used a shaped beam antenna utilizing a CSC^2 distribution. CSC^2 distribution antennas were first developed in World War II for ground mapping from an airborne antenna system. For ground mapping purposes it was desirable to have a constant illumination from the maximum distance to directly below the aircraft. By mathematical analysis this corresponds to a CSC^2 illumination. In the early 1970's when telemetry was moved to S-band, the first S-band systems built were two axis systems since, with the higher space attenuation, considerable directivity was retired. A few years later, in order to save money, shorter range missions were performed with single axis systems. To achieve coverage at the higher elevation angles, the beam was shaped to CSC^2.

Experience in the field with CSC^2 systems has indicated that while the beam has constant illumination with respect to altitude, there is always considerably more signal at the higher elevation angles than required for optimum performance. The reason for this is twofold, at low angles signal fading occurs because of multipath, and low angles imply maximum range with increased space attenuation. The multipath effect is appreciable, ranging from 3 dB over rough, highly vegetated terrain to 20 dB or more over smooth water. At the higher elevation angles, there are no multipath effects. Thus, the system has considerably more gain than required at the higher angles. CSC^2 antennas are shaped from approximately the 1 dB point to usually about 35 degrees elevation. When the energy is taken from this far forward in the main beam, the gain is considerably reduced. Almost all CSC^2 antennas have a gain reduction of at least 3 dB from that of a non-shaped paraboloid.

In the late 1970's, Sullivan (1) devised a dual beam approach which eliminated the gain reduction problem but was more costly since two tracking antennas were required.

To achieve the maximum gain realizable from a single axis system with constant altitude coverage to high angles, including an overhead pass, the authors have derived the optimum distribution called the Augustin-Sullivan Distribution. While the Augustin-Sullivan Distribution can be used for many applications including complete auto tracking systems, the combination ofthe GPS-TRAK technique (2) and the Augustin-Sullivan Distribution results in the lowest cost telemetry pseudo tracking approach. In addition, because of the simplicity of the system, reliability is enhanced by an order of magnitude.

DEVELOPING THE CONCEPT

In many ways the design of a two axis tracker is very simple compared to a single axis tracker. For a two axis tracker, one performs a link budget analysis and determines the gain, or preferably the gain divided by the temperature (G/T). One then only has to concern himself with the velocities and accelerations required to perform the mission. With single axis tracking, the gain or G/T still has to be calculated. After this, the maximum altitude, dictated by the mission, must be considered. When one determines the gain or G/T, then a minimum beamwidth is determined. For most missions, single axis tracking is usually not possible for beamwidths less than 4 degrees.

The majority of telemetry tracking missions today are for tracking aircraft and missiles, and usually the maximum altitude is less than 50,000 feet. The profile of most missions allows single axis tracking for antenna gains below 32 dBi. For a dual beam or multi-beam single axis system, the system must be custom designed based on the worst case conditions of the mission requirements. This is also the case for the Augustin-Sullivan Distribution.

To illustrate the technique, an example is chosen of tracking an airborne vehicle with a maximum altitude of 50,000 feet, at a frequency of 2250 MHz, an EIRP of 10 watts, a multipath fade of 10 dB, and a polarization loss of 3 dB. This assumes vertical polarization of the airborne vehicle and circular polarization on the ground. For a 1 MHz data bandwidth and a 15 dB C/N, assuming a general purpose system, which would necessitate allowing 10 dB reduced margin for multipath, a 4 foot diameter antenna would allow a range of 200 miles on the horizon.

The multipath phenomenon, with respect to a single axis tracking system, has been discussed in detail by Chandler (3). Figure 1 is a graph from Chandler's paper showing the severe multipath effect on the pattern of a 6 foot reflector at L-Band operating over smooth water. This is a worst case situation; however, a general purpose system must be expected to perform with multipath fades of at least 10 dB. The structure and number of multipath nulls will vary as a function of several parameters, especially the height of the antenna over the reflecting terrain. The multipath effect on the pattern in figure 1 is completely eliminated for elevation angles greater than 6 degrees. For the 4 foot antenna of our example, mounted between 10 and 20 feet above the surface and based on typical conditions, the multipath effects will be eliminated for angles greater than 10 degrees. To illustrate the Augustin-Sullivan Distribution concept, and simplify the illustrations, we will assume a flat earth and choose a coordinate system with the ordinate in feet (altitude) and the abscissa in miles (range).

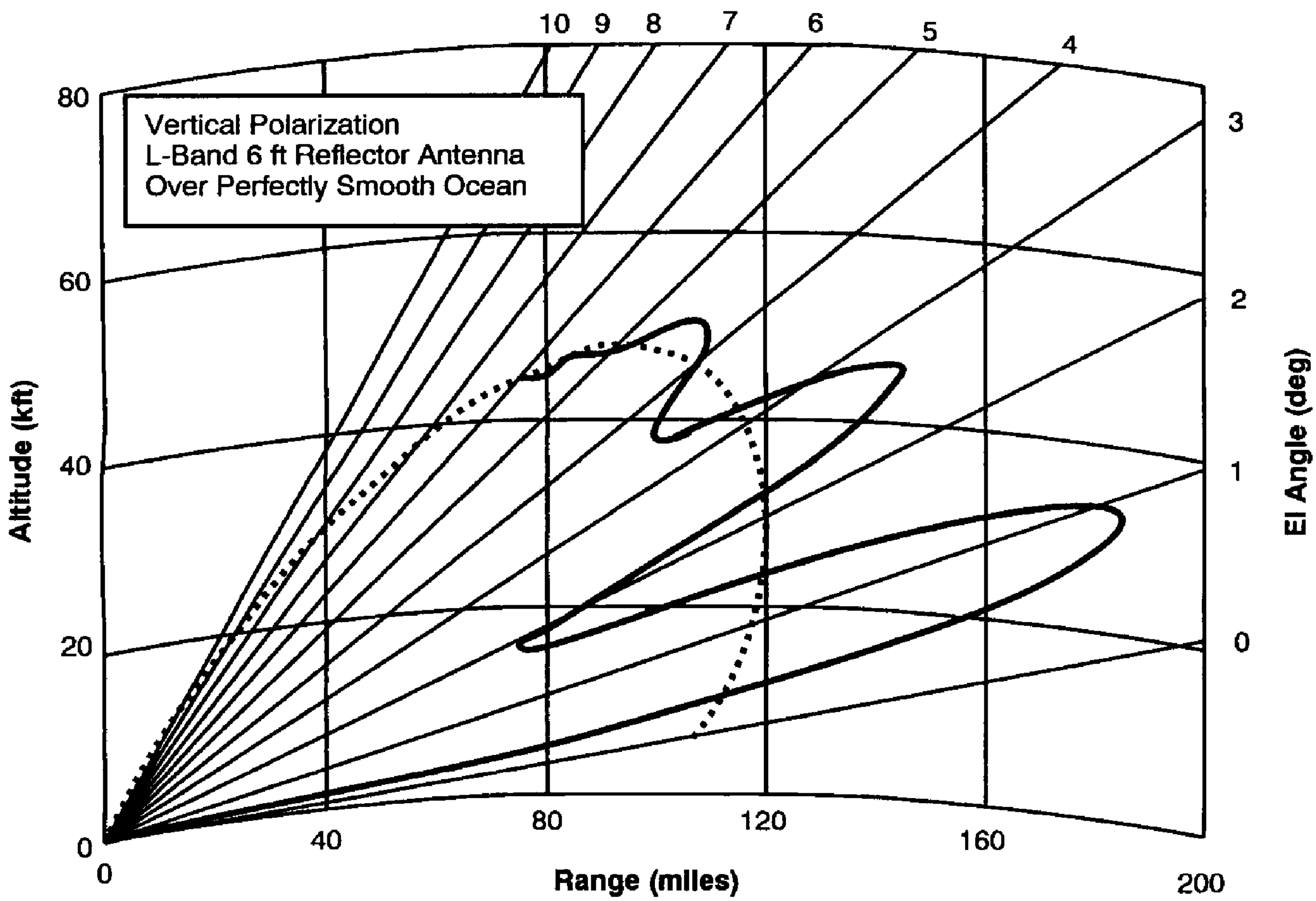

Figure 1. Severe Multipath Effect on the Pattern of a 6-foot Reflector at L-band Operating over Smooth Water.

For our example, figure 2 shows the antenna pattern coverage for a four foot non-shaped parabolic reflector antenna (pencil be am) with the peak of the beam on the horizon. The dotted line represents the antenna coverage with 10 dB allowed for multipath. The solid line shows the worst case coverage envelope of the reflector antenna with a 10 dB multipath fade margin with the multipath faded out from the horizon to 10 degrees.

In developing the Augustin-Sullivan Distribution, it was determined that the exact nature of the multipath nulls are not important since there will be a worst case coverage envelope in the multipath environment that defines the range of the system. Using the worst case coverage envelope, for a general purpose system, the multipath can be faded out from the horizon to the angle at which the multipath effect disappears. To achieve coverage to an altitude of 50,000 feet from the horizon to zenith, figure 2 shows that beam shaping is not required until a range of less than 70 miles is reached. Based on this fact, the required C/N ratio would be met or exceeded for all ranges between 70 and 200 miles for all altitudes above the line of sight to 50,000 feet. The 70 mile point correlates to approximately the 15 dB point of the antenna radiation pattern. Thus, beam shaping is not required until 15 dB below the peak of the antenna radiation pattern. Since greater than 90% of the energy in the pattern is contained between the 15 dB points, very little gain reduction is realized in shaping after the 15 dB point. For this example, the gain reduction amounts to less than 1/2 dB.

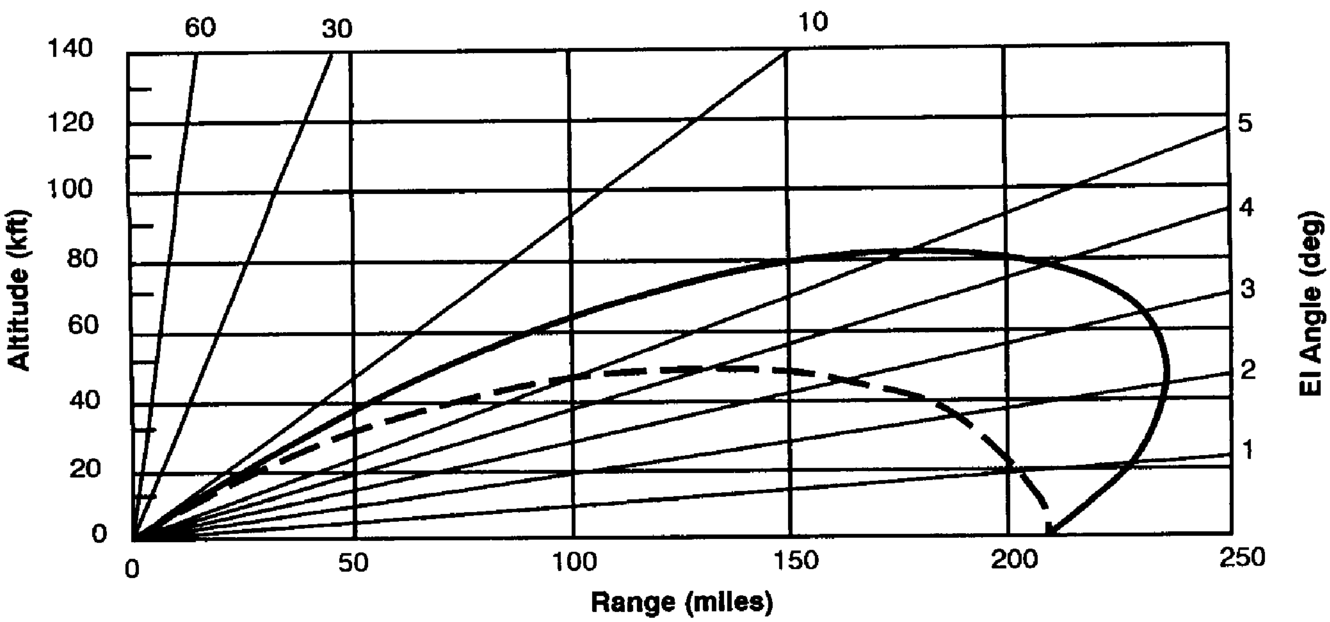

Figure 2. Paraboloidal Reflector Antenna Coverage
(Dashed Line) Antenna Coverage with Built-in 10 dB Multipath
(Solid Line) Antenna Coverage with 10 dB Multipath Faded Out

Shaping the beam in elevation so that constant coverage is realized from the 15 dB point to the 90 degree elevation angle results in the optimum distribution for maximum gain from the reflector while still providing coverage to zenith. This optimum distribution, called the Augustin-Sullivan Distribution, is shown in figure 3. The dashed line of figure 4 shows the antenna radiation pattern required to produce the Augustin-Sullivan Distribution shown in figure 3. Figure 4 also shows the radiation patterns of a non-shaped paraboloidal reflector (solid line) and a cosecant squared antenna (dotted line).

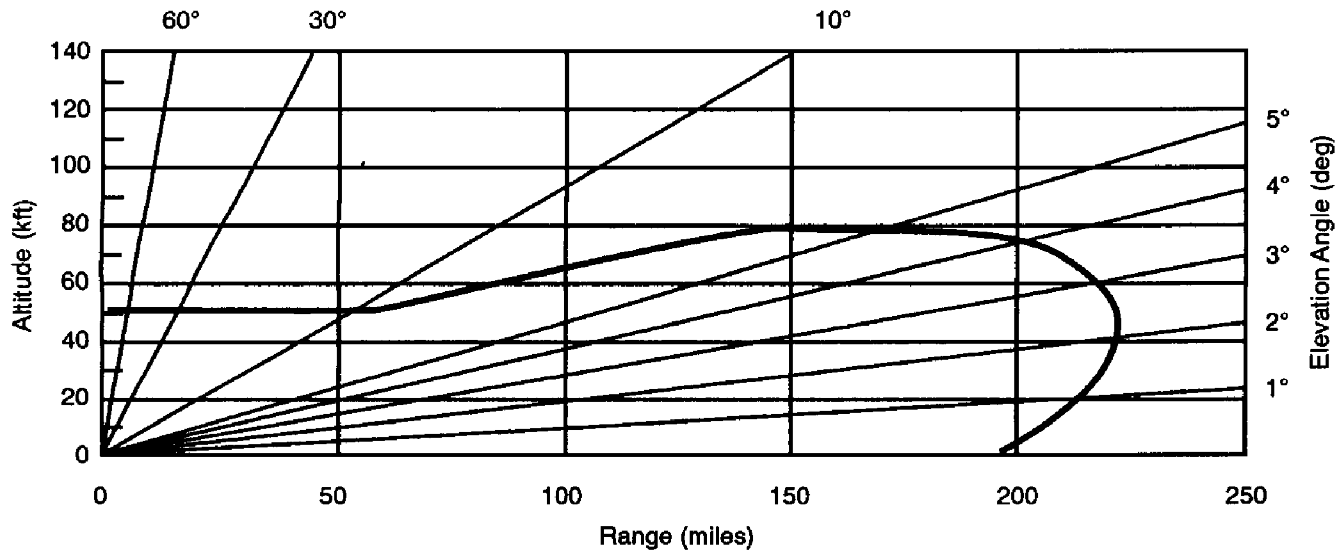

Figure 3. Augustin-Sullivan Distribution Shaped Antenna Coverage with 10 dB Multipath Faded Out

APPLICATION OF THE CONCEPT

The authors have developed the following computerized programs:

1. Multipath Analysis

2. Link Budget Analysis

3. Reflector Shaping Program

The Multipath Analysis Program is similar to that developed by Chandler (3). The Link Budget Analysis Program is a computerized version of the system developed by Sullivan (4). The Reflector Shaping Program is a proprietary program developed by Augustin, and allows one to quickly derive the coordinates of a reflector to generate a shaped beam to within less than 1 dB of the desired shape for beams that are shaped starting from a pencil beam generated by a paraboloid. Most ofthe shaped beam reflectors built from this program have exhibited conformance to better than 1/2 dB.

Based on these computer programs, one can take the worst case parameters for a required mission scenario and develop the lowest cost, most efficient tracking system to yield the required C/N for quality data. This approach can be used with any type of auto tracking feed.

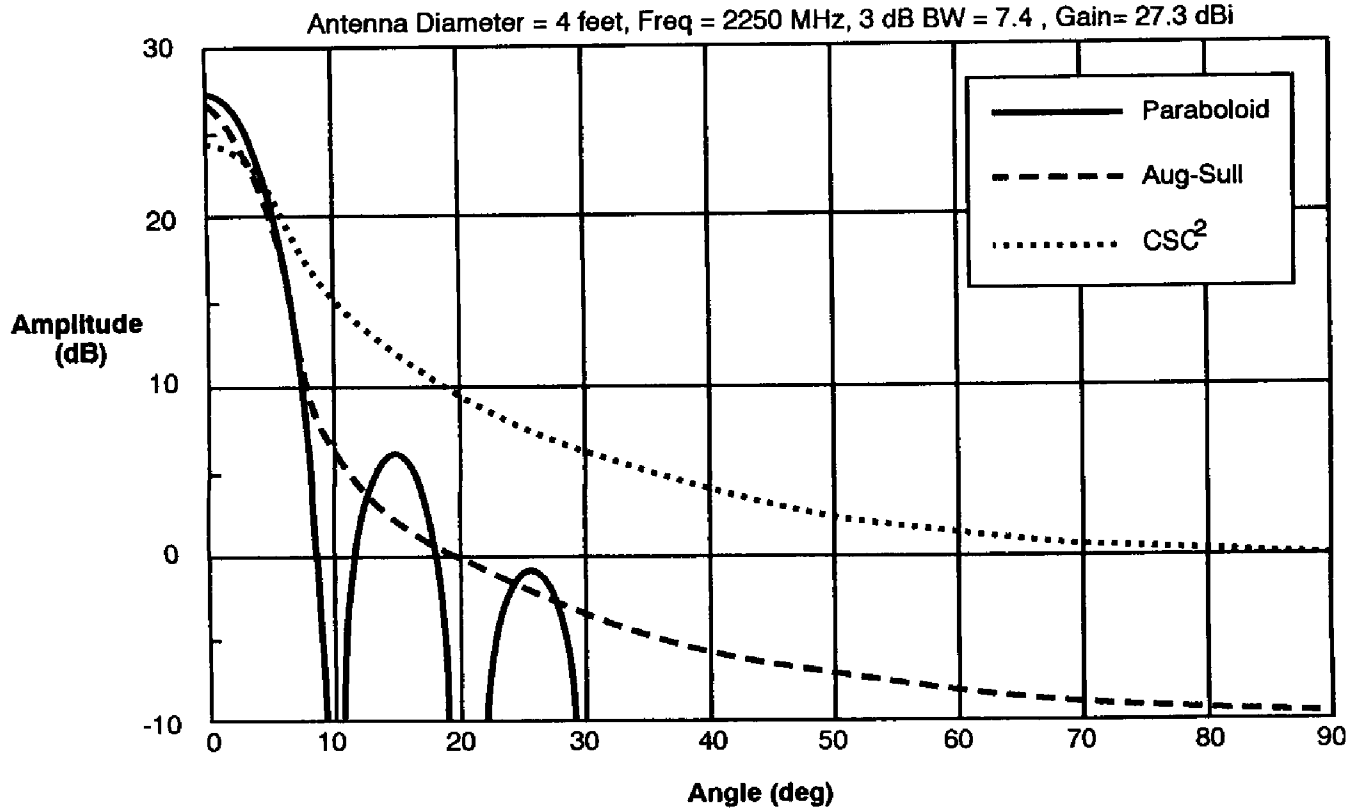

Figure 4. Antenna Radiation Patterns for a Paraboloidal Reflector, the Augustin-Sullivan Shaped Antenna Distribution, and a CSC^2 Antenna.

If the airborne target is equipped with a GPS receiver, and the GPS data added to the telemetry data, the GPS-TRAK technique described by Sullivan (2) can be used in conjunction with the Augustin-Sullivan Distribution to afford the lowest possible cost alternative to autotracking. Figure 5 is a block diagram of a GPS-TRAK system using the Augustin-Sullivan Distribution. The Antenna Control Unit can now be a simple low cost personal computer (P.C.) The P.C. receives signal strength from the receiver and GPS target coordinate data. The coordinates of the Ground Receiving Antenna System are stored in the P.C. The P.C. then calculates the azimuth angle and range of the target. The azimuth servo command to the rotator is generated by the P.C. The P.C. monitor displays a rotating vector. The angle of the vector corresponds to azimuth and the length of the vector corresponds to range. Azimuth angle, elevation angle, range, and signal strength are also digitally displayed.

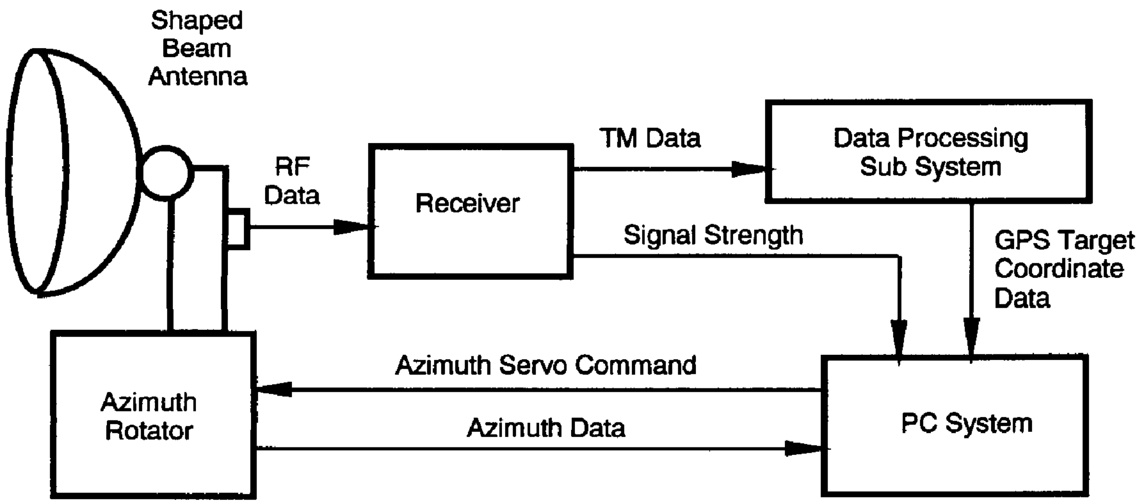

Figure 5. GPS-TRAK Block Diagram

CONCLUSION

Whenever single axis tracking is practical, the Augustin-Sullivan Distribution yields the optimum performance for the lowest cost. The Augustin-Sullivan shaped reflector can be manufactured for the same cost as a CSC^2 shaped reflector. The tracking system, using the Augustin-Sullivan shaped reflector, will have gain in excess of 2 1/2 dB more than the CSC^2 system, and elevation coverage to zenith. The Augustin-Sullivan Distribution will yield results comparable to a dual beam single axis antenna approach to within 1/2 dB, at considerably less cost. Since only a single tracking antenna is required, the cost of the Augustin-Sullivan system will be at least $25,000.00 less than the dual beam system. For $25,000.00, it is easy to find 1/2 dB in other areas such as a slightly larger antenna size, lower noise figure pre-amplifier, etc.. To equal the gain of an efficient dual beam 48 inch diameter parabolic reflector antenna one would only have to increase the Augustin-Sullivan shaped antenna diameter by 3 inches.

By using the Augustin-Sullivan Distribution, a single axis tracking system can be purchased with hemispherical coverage (for a reasonable altitude) for less than half the cost of a two axis tracking system. Reliability is increased by more than a factor of two.

When the tracked vehicle is instrumented for GPS, a single axis tracker, using the Augustin-Sullivan Distribution and the GPS-TRAK technique, can be purchased for approximately 1/3 to 1/4 the cost of a two axis tracking system for systems up to 8 feet in diameter.

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