LOW COST, HIGHLY TRANSPORTABLE, TELEMETRY TRACKING SYSTEM FEATURING THE AUGUSTINE/SULLIVAN DISTRIBUTION AND POLARIZATION, FREQUENCY AND SPACE DIVERSITY

Peter Harwood, Christopher Wilson
Bradley Electronics Ltd,
Neasden Lane,
London, England. NW10 1RR

Arthur Sullivan, Eugene Augustin
Technical Systems Associates, Inc.
1900 Central Florida Parkway,
Orlando, FL 32837-9290

ABSTRACT

The tracking system is part of a telemetry ground station being developed for the UK Ministry of Defence. The design objective is a self-contained transportable system for field use in a vehicle or workshop environment, so that the system components are required to be man portable. Comprehensive facilities are required for the reception, display and analysis of telemetry data from a remote 1430-1450MHz airborne source at ranges of up to 205km. Since tracking over water is a prime requirement the system must accommodate severe multipath fading.

A detailed analysis of the link budget indicates that there is a major conflict between cost, portability, antenna size and the receiver complexity required to achieve a satisfactory performance margin. A baseline system is analysed using a four foot antenna. Methods for improving the performance are then considered including polarisation, frequency and space diversity coupled with alternative antenna types and configurations.

The optimum solution utilises two six foot diameter shaped beam single axis antennas of unique design in conjunction with a receiving system which economically combines the elements of polarisation, frequency and space diversity.

KEY WORDS

Polarisation Diversity, Frequency Diversity, Space Diversity, Single Axis, Shaped Beam, Portability.

INTRODUCTION

The paper describes a new transportable telemetry ground station for the reception, display and analysis of data from an airborne source.

The paper provides a quantitative analysis of the system performance required. Methods for achieving this performance are discussed, followed by a description of the final solution. Emphasis is given to propagation and reception, but a broad description of the ground station includes other aspects.

Sullivan (1) has shown the advantages of diversity for tracking airborne vehicles. Missile antennas characteristically exhibit varying polarisation with aspect angle. Polarisation diversity is required to obtain optimum tracking performance. For tracking aircraft through wide ranges of pitch and roll two antennas (of necessity spaced many wavelengths apart) are required. Frequency diversity is then required for optimum performance. Almost all tracking of missiles and aircraft involves low angle tracking for most missions. Space diversity is required for optimum performance in a strong multipath environment.

The Augustin/Sullivan Distribution (2) allows single axis tracking to be used for most tracking applications, and at less than 50% of the cost of two axis tracking. Full elevation (to zenith) coverage is provided with less than 1 dB loss compared with a pencil beam antenna. A cosecant-squared distribution would only allow tracking to elevation angles of 45 to 50 degrees and has a 3 dB loss from that of a pencil beam antenna because of the beam shaping.

The complete telemetry ground station is a self contained, highly transportable system which is designed to provide complete facilities for the reception, display, and analysis of PCM data from a remote source at ranges up to 205 km. By using two 6 foot diameter Augustin/Sullivan Distribution (ASD) shaped beam single axis antennas of opposite circular polarisation and the minimum number of receivers and combiners to achieve polarisation, frequency and space diversity. An optimum system has been designed giving maximum antenna gain, continuous tracking from horizon to zenith, and maximum range within the constraints of transportability and cost.

LINK BUDGET

The system must operate with a variety of modulation schemes and sources. The worst case source provides 2 watts into a -7dBi transmitting antenna and requires 500kHz bandwidth . The objective is to achieve a carrier to noise ratio of 12 dB at the FM demodulator input of the receiver plus a fade margin allowance of at least 10dB including tolerance to deep fades. The 12 dB ratio is the threshold for signal to noise improvement from the FM demodulation process.

Performance figures for commercially available equipment are used in the following analysis. The fade margin is discussed, and options for improving on this basic system configuration are considered.

The transmission path for the signal is calculated from the output of the airborne transmitter to the input of a low noise amplifier situated close to the receiving antenna feed. Polarisation is essentially linear and of variable attitude.

Reasonable assumptions are made concerning transmitter feed loss and antenna efficiency as follows:

Tx. o/p power at 2 W	33.0 dBm
Feed loss	-0.5 dB
Tx. antenna efficiency	-0.5 dB
Tx. antenna gain	-7.0 dBi
Effective Isotropic Radiated Power (EIRP)	25.0 dBm

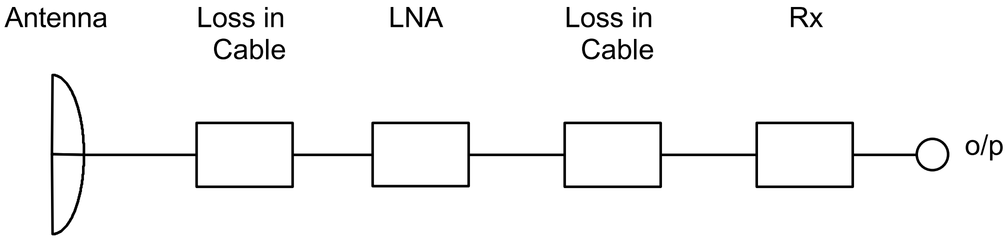
Total calculated path loss is -142.4 dB including an allowance of 0.5 dB for atmospheric attenuation and plume loss.

Antenna gain for a 4 foot diameter pencil beam antenna is typically 22.2 dBi including tracking loss. Cable attenuation from the antenna to the input of the low noise amplifier (LNA) should not exceed 1dB. A circularly polarised receiving antenna is used to ensure reception of the randomly oriented linearly polarised signal. This results in a 3dB polarisation loss.

Using the above figures the signal strength at the LNA input at maximum range is calculated as follows:

EIRP	25.0 dBm
Total path losses at 205 km	-142.4 dB
Cable loss to LNA	-1.0 dB
Polarisation loss	-3.0 dB
Net antenna gain	22.2 dBi
Signal at LNA i/p	-99.2 dBm

In calculating the System Effective Noise Power the following receiving system components are considered:



The effective noise present at the LNA input is considered in two parts; noise originating from items prior to this point, and noise originating from subsequent items. For the system as a whole bandwidth is constant so that the noise power can be normalised to absolute temperature which can then be summed arithmetically.

Noise T_{Ant} at the LNA i/p from all items prior to the LNA i/p is given by:

$$T_{Ant} = \alpha T_{Sky} + (1 - \alpha) T_{amb}$$

where the T_{Sky} is the effective sky temperature, ambient temperature is T_{amb} and cable attenuation ratio is α. A conservative figure for T_{Sky} is 160K for a single axis tracking antenna looking horizontally.

Noise T_L at the LNA input from items subsequent to the LNA input arises from the LNA itself (gain G_{LNA} and noise ratio N_{LNA}), the receiver connecting cable (attenuation ratio β) and the receiver (noise ratio N_{Rx}). Receiver gain is considered to be sufficiently large for there to be no further noise contribution:

$$T_L = (N_{LNA} - 1)T_{amb} + ((1 - \beta)T_{amb})/(\beta G_{LNA}) + ((N_{Rx} - 1)T_{amb})/(\beta G_{LNA})$$

Total system noise T_{Sys} is therefore given by:

$$T_{Sys} = T_{Ant} + T_L$$

The baseline system parameters are as follows:

N_{LNA} at 0.8 dB = 1.2
G_{LNA} at 35 dB = 3162
N_{Rx} at 12 dB = 15.85
α at -1 dB = 0.79
β at -12 dB = 0.063
T_{Sky} = 160K
T_{amb} = 300K

These figures give a T_{Sys} of 274K from which the system effective noise power can be calculated:

Thermal noise	-198.6 dBm/K/Hz
Noise temperature at 274K	24.4 dB
Bandwidth at 500 kHz	57.0 dB
System effective noise power at LNA input	-117.2 dBm

With a minimum signal strength of -99.2 dBm and a system effective noise power of -117.2 dBm as calculated above, the carrier to noise ratio is 18.0 dB. This exceeds the 12 dB carrier to noise performance target by 6dB, but does not provide the required 10 dB fade margin. Also, the effects of deep fades particularly over water cannot be ignored, and some means for improving the performance under these conditions is needed.

FADING EFFECTS

The above calculations use worst case figures throughout so that the calculated Carrier to Noise performance at maximum range should be comfortably achieved. However these figures leave little margin for further signal loss which will occur due to fading which results from interference between received signals arriving along different paths. The two major causes are Atmospheric Multipath Fading and Reflection Multipath Fading.

Atmospheric Multipath Fading is caused by refraction through the atmosphere which results in multiple 'direct' paths. This creates relatively rapid fades, and published figures indicate that typical worst case conditions give:-

3 dB fades for 20% of the time
10 dB fades for 2.0% 0f the time
20 dB fades for 0.1% of the time

Reflection Multipath Fading occurs due to interference between direct and reflected signals. When the difference in path length is $\lambda/2$, or 0.1 metres in this case, the multipath fading becomes prevalent over water under calm conditions.

Under calm conditions and with horizontal polarisation the reflection coefficient of the sea surface is close to -1 at all angles of incidence (Fig.1). This results in very deep fades as can be seen from the calculated results with typical transmitter and receiver altitudes of 25,000 and 500 feet respectively (Fig.2). As the sea state increases there is a rapid reduction in the effective reflection coefficient which causes a corresponding improvement in multipath fading (Fig.3).

METHODS FOR IMPROVING SYSTEM PERFORMANCE

With a nominal 6 dB fade margin the telemetry link is very susceptible to fading, and would require careful and informed selection of operating conditions. A number of methods are available for improving performance:

Polarisation Diversity. A loss of 3dB has been included in the above calculations to allow for transmitter attitude and the need for a circularly polarised antenna. By utilising parallel LHCP and RHCP feeds this 3 dB can be recovered.

Space Diversity. This technique is aimed specifically at reducing multipath effects by optimal selection of the signal from two separate antennas. To overcome Atmospheric Multipath Fading the ideal antenna separation given in the literature is 150 to 200 wavelengths corresponding to 30-40 metres. This ensures that paths with different reflection characteristics are selected and will give a very considerable improvement with this type of fading. To reduce Reflection Multipath Fading the antennas are positioned at different heights. For typical transmitter and receiver heights of 25000 ft and 500 ft respectively and under worst case fading conditions the situation is enormously improved in a 140 - 205 km range window by antennas with a vertical separation of five feet (Fig.4). Over this range the strength of the received signal actually exceeds the direct signal strength indicated by the solid line. Furthermore at these typical Rx/Tx heights an adjustment in vertical separation from 0 - 5 feet moves the window to any range.

Frequency Diversity. The user requirement for two frequency working effectively provides frequency diversity.

Antenna gain. This increases with diameter broadly as follows in relation to the 4 foot antenna:

6 ft	3.5 dB
8 ft	6.0 dB
10 ft	8.0 dB
20 ft	14 0 dB

An increase to 8 feet diameter is a major step with the dish alone weighing over 200 kg and requiring a substantial pedestal, foundation, and separate radome. Also the narrow beam width would be incompatible with single axis tracking.

THE OPTIMUM SOLUTION

Antenna diameters of four and six feet are considered to be the maximum for man portability. Calculated performance at maximum range with increasing system complexity is given below:

No.	Antenna size	Receiver Arrangement	Fade Margin (dB)
1	4 ft	Basic	6
2	4 ft	Polarisation Diversity	9
3	4 ft	Space Diversity	9
4	4 ft	Space and Polarisation Diversity	12
5	6 ft	Basic	9.5
6	6 ft	Polarisation Diversity	12.5
7	6 ft	Space Diversity	12.5
8	6 ft	Space and Polarisation Diversity	15.5

In practical terms a 10 dB fade margin should be the minimum objective, and appears to be met by configurations 4, 6 ,7 and 8, and almost met by 5. However, the table is inadequate in comparing the merits of polarisation and space diversity as regards fading. Space diversity is effective in the presence of deep fades and is therefore considerably better than polarisation diversity in maintaining an acceptable carrier to noise ratio. Also, by utilising left hand polarisation in one antenna and right hand polarisation in the other some of the merits of polarisation diversity are obtained at no increase in cost or complexity.

Configuration 7 stands out as the preferred solution providing acceptable performance at reasonable cost. There is an added advantage in that the use of two antennas provides a built-in buffer against antenna failure, as reasonable performance is still achieved with the remaining unit.

A block diagram of the selected system (Fig.5) shows direct and multipath reception at LHCP and RHCP antennas, followed by two receiver channels with full pre-detection phase combining to recover telemetry signals A and B for processing by the monitoring sub-system. A further combiner would be needed to provide frequency diversity, giving a total of four receivers and three combiners. By comparison, full space, frequency and polarisation diversity requires more complex antennas with a total of eight receivers and seven diversity combiners. This is not considered to be cost effective for the performance improvement gained.

SELECTION OF ANTENNA

In terms of both low cost and simplicity single axis tracking is the preferred approach provided that the resulting limitations in elevation coverage and antenna gain can be tolerated. Elevation coverage of 45 to 50 degrees may be obtained by the use of a cosecant-squared distribution, but the consequent 3dB loss cannot be tolerated in this application. In the late 1970s, Sullivan (3) devised a dual beam approach which eliminated the gain reduction problem but was more costly since an additional low gain broad beam antenna was required to provide elevation coverage. This adds cost and complexity and is more susceptible to damage in the transportable role. In the present application a durable arrangement is needed which retains antenna sensitivity.

In 1992 Sullivan and Augustin conceived the Augustin/Sullivan Distribution to solve the gain problems of the cosecant-squared distribution. Very little antenna gain is in fact needed at high elevation as target range is small. By correctly redistributing less than 1dB from the peak of the beam the Augustin/Sullivan Distribution gives satisfactory gain from horizon to zenith. The first 6 foot systems have now been built and tested, and exhibit excellent performance. Overhead tracking can now be accomplished with a single axis antenna. Figure 6 is a measured antenna pattern at L Band. Superimposed on the measured pattern is the theoretical Augustin/Sullivan Distribution.

A very clean 'clam shell' construction encloses the feeder and front face of the reflector in an integral radome, so that a separate radome is not required. Two of the antennas undergoing final test are shown in Figure 7.

PRACTICAL DETAILS

Each antenna is provided with a trailer both for transportation and as a stable easily levelled platform for the antennas when deployed in the field.

The remainder of the system is housed in rugged transportation cases with integral shock mounts for the constituent assemblies. These cases can be rapidly deployed in a vehicle or building, and have detachable front and rear covers. A standard IBM compatible PC in ruggedised format provides extensive 'Windows' based display and monitoring capability. It also provides overall control and logging features for the receiver system. Other features of the system as deployed will include magnetic tape recording, spectrum display facilities, an off-air time standard, an oscilloscope and chart recorder.

CONCLUSIONS

The design of a portable ground telemetry station has been realised using two antennas with a minimum of four receivers and two diversity combiners. The system combines space, frequency, and polarisation diversity to provide good performance while tracking airborne sources at long range over water. When missions require tracking in the presence of multipath, the system described provides:

- Highest level of transportability
- Optimum performance
- Maximum reliability
- Complete elevation coverage
- Overhead pass capability
- Logistics simplification
- Lowest cost

ACKNOWLEDGEMENTS

The authors gratefully acknowledge permission given by the UK Ministry of Defence to publish this paper.

REFERENCES

(1) Sullivan, Arthur, "Dual Beam Single Axis Tracking Antenna for Tracking Telemetry Instrumented Airborne Vehicles", Proceedings of the International Telemetering Conference, San Diego, California, 1979.

(2) Sullivan, Arthur and Augustin, Eugene, "Lowest Cost Alternative to Auto-Tracking using GPS-Trak, Augustin/Sullivan Distribution, & Single Axis Antenna Techniques", Proceedings of the European Test & Telemetry Conference, Arcachon, France, 1993 and the International Telemetering Conference, Las Vegas, Navada, 1993.

(3) Sullivan, Arthur, "Dual Beam Single Axis Tracking Antenna for Tracking Telemetry Instrumented Airborne Vehicles", Proceedings of the International Telemetering Conference, San Diego, California, 1979.

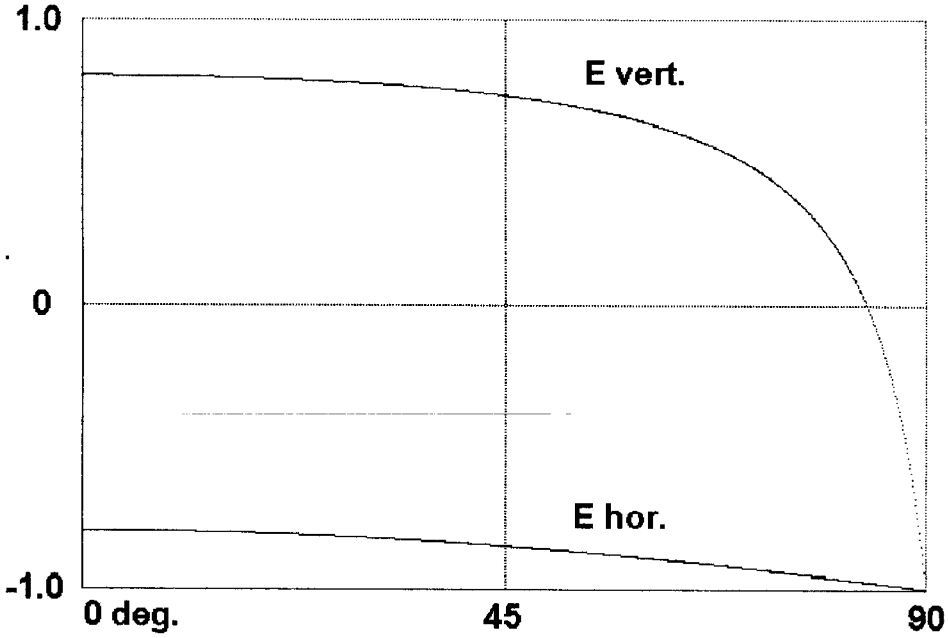


Fig. 1. Reflection Coefficient of Calm Sea at 1.45GHZ.

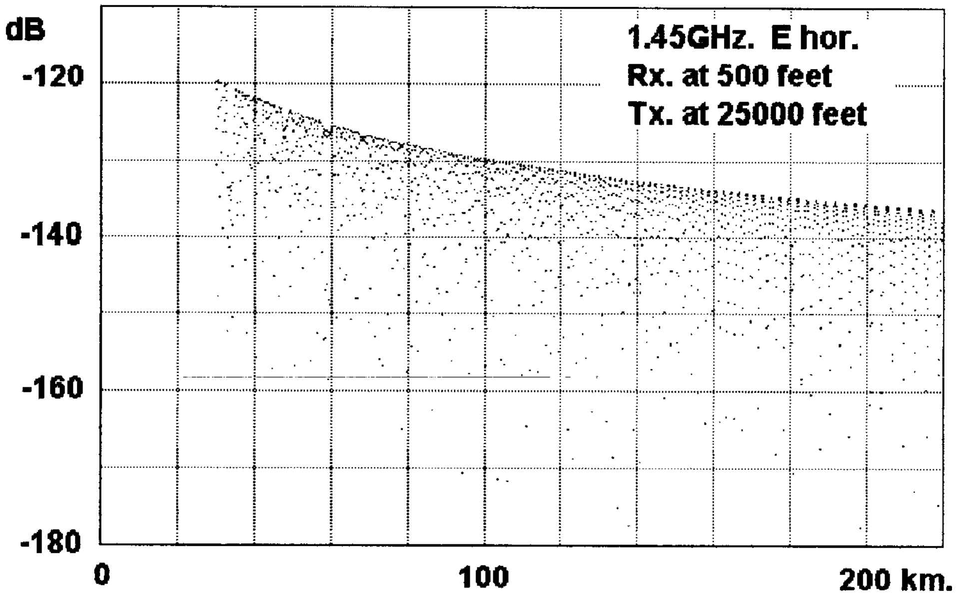


Fig. 2. Signal Variation Due to Multipath Effects over Calm Sea.

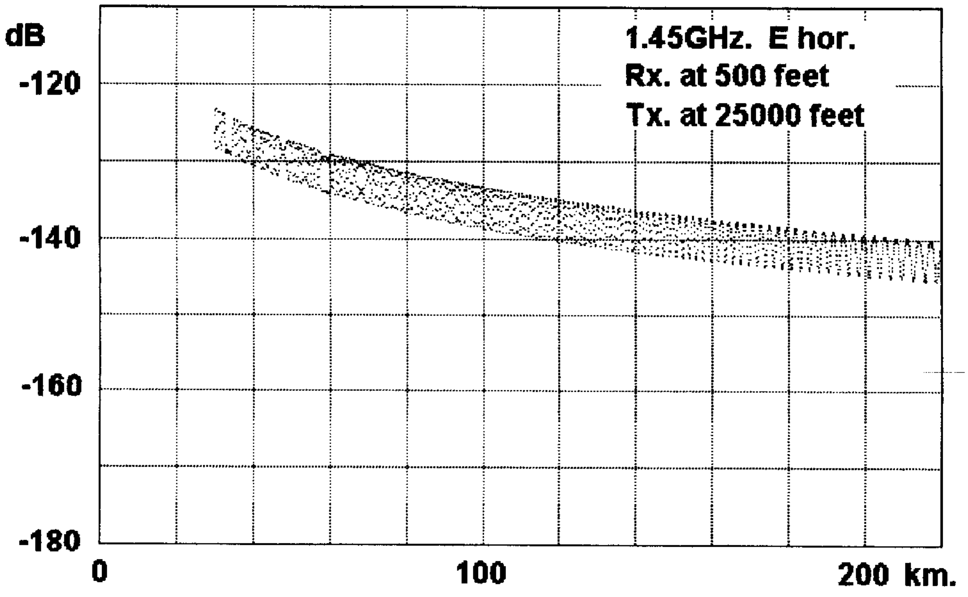


Fig. 3. Signal Variation Due to Multipath With 30% Reflection.

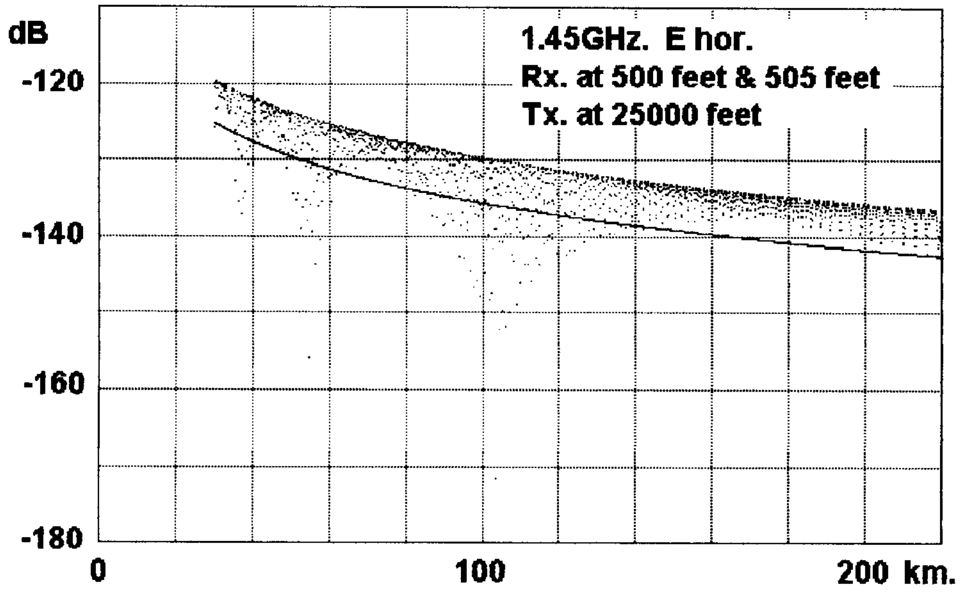


Fig. 4. Multipath Improvement with Space Diversity.

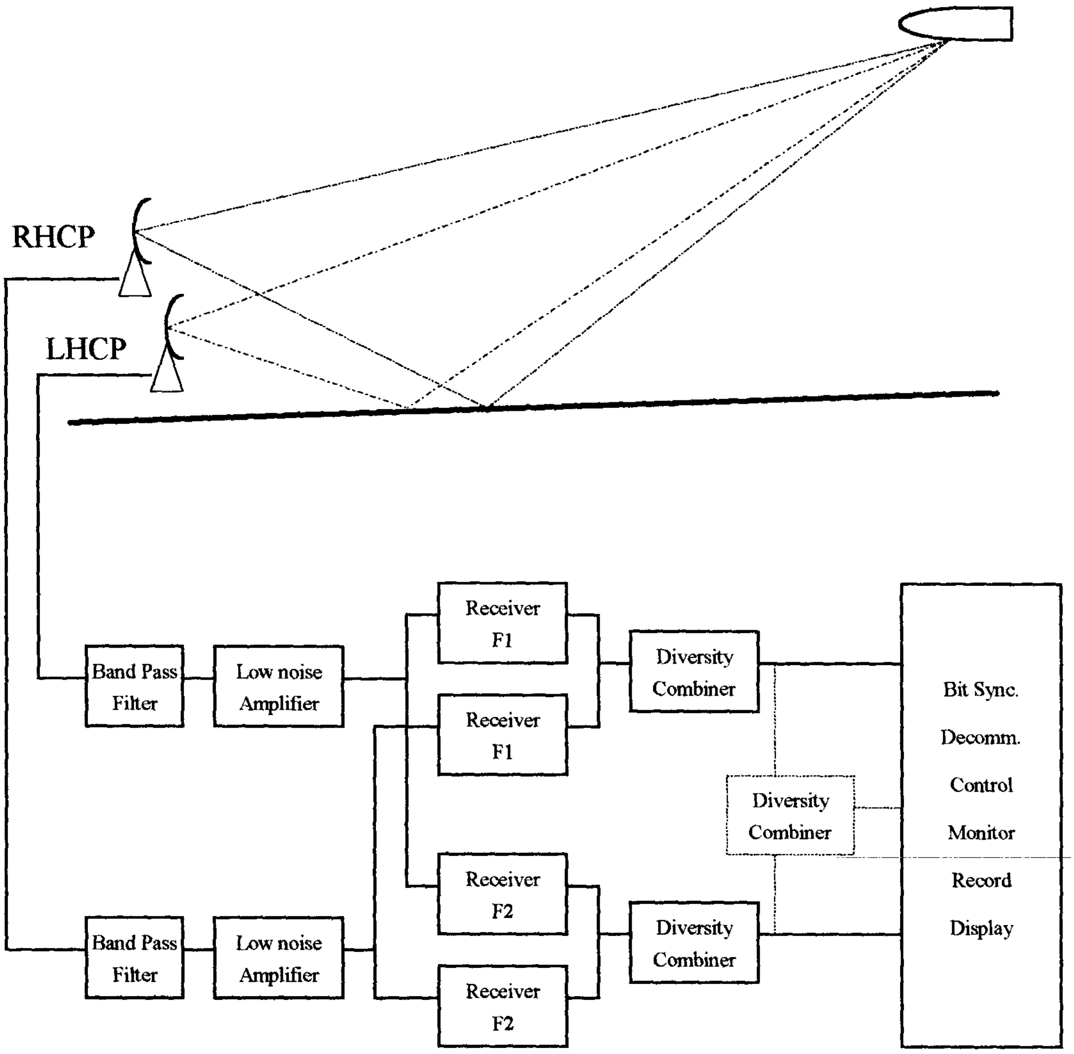


Fig. 5 System Block Diagram

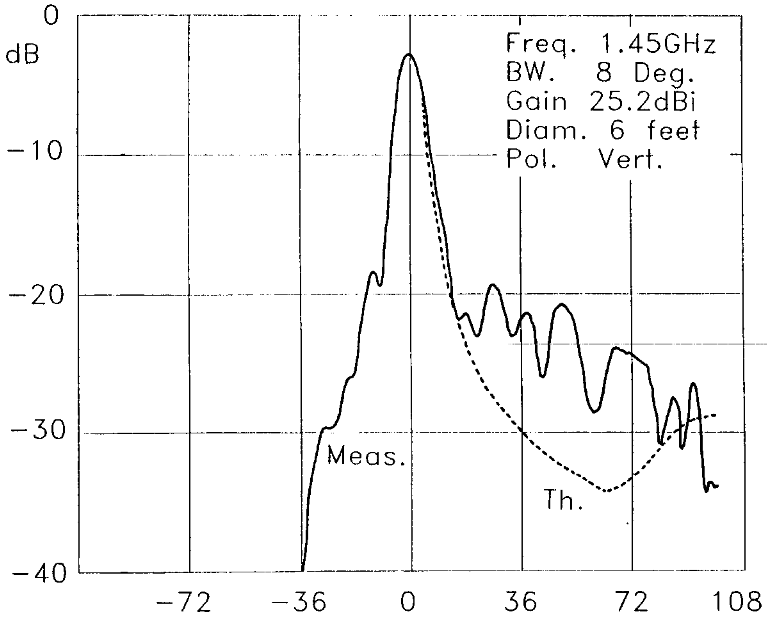


Fig. 6. Elevation Plot of Augustin/Sullivan Antenna

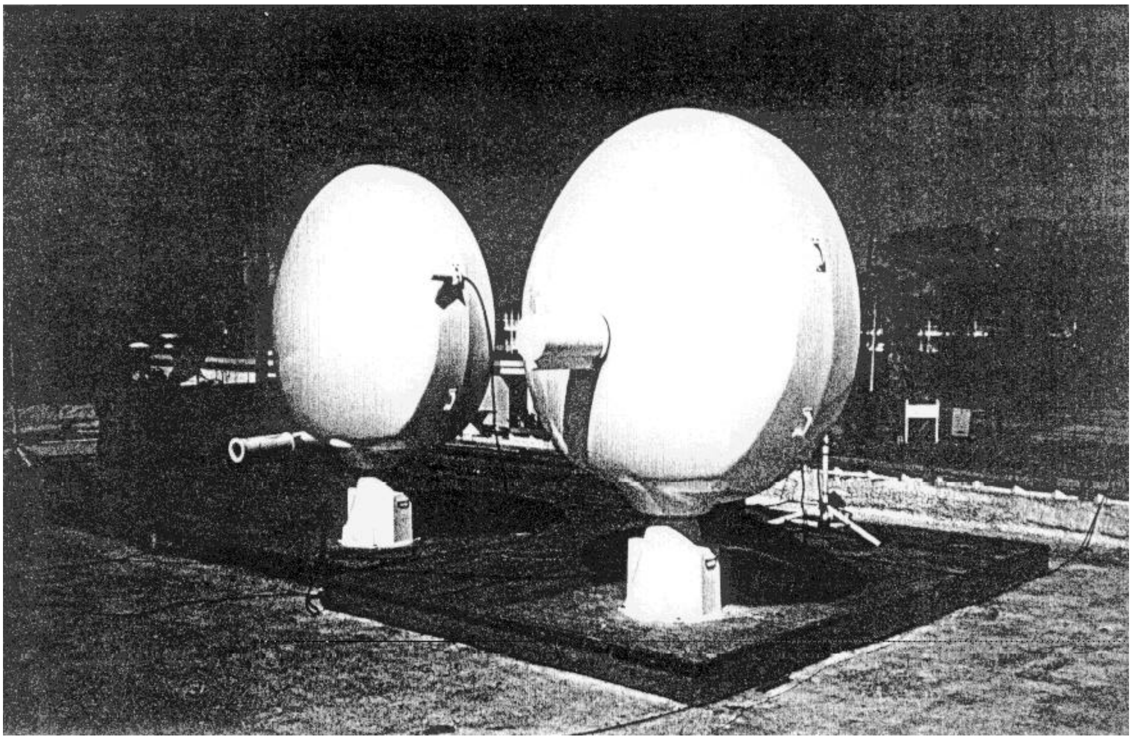


Fig. 7. Two Augustin/Sullivan Antennas Under Test