FREQUENCY DIVERSITY FOR UHF TELEMETRY

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Summary The use of frequency diversity to allow substantial airborne antenna simplification for L and S band telemetry is described. The system is particularly useful on large, spin stabilized vehicles where omni-directional antenna coverage is required. Typical antenna patterns with and without diversity are presented. A systems block diagram showing dual receivers and diversity combiner is also described. A weight tradeoff is presented for diversity versus non-diversity, with vehicle diameter (at the antenna location) as the variable. It is shown that, at S band, for diameters in excess of about 5 in., frequency diversity represents a favorable approach.

Introduction The switch of telemetry systems from VHF to L and S bands results in rather severe problems in obtaining adequate antenna coverage. Extensive use of spin stabilized vehicles limits the possibility of using directional antennas. An increase of almost one order of magnitude in wavelength implies a corresponding change in the number of antennas needed to provide omni-directional coverage from a given airborne vehicle. Increased cost, complexity, and weight are generally incurred. Although diversity reception systems can provide a significant reduction in airborne vehicle design problems, some increase in ground system complexity is a resultant penalty. The most common diversity system in use is polarization diversity. Although many ranges are equipped for this, frequency diversity systems may prove advantageous for those that are not. It is the purpose of this paper to describe how dual frequency systems may be implemented and to present a comparison with a non-diversity system.

Antenna Coverage by Ordinary Techniques The usual methods of obtaining omni-directional antenna coverage on an airborne vehicle at UHF frequencies are to array many elements around the vehicle waist, or to put an antenna on one end of the vehicle, usually on a boom. For many satellite applications, the boom approach is satisfactory. However, it often must be deployed with an attendant reduction in reliability. Also, in re-entry vehicle or aircraft practice, the use of a boom is usually unacceptable, either aerodynamically, structurally, or thermally. In addition, shadowing of radiation from a boom mounted antenna by the airborne vehicle is inevitable. Thus, arrays around the periphery of the structure are often preferred or required.

Unfortunately, many elements are required to provide acceptably smooth patterns at the higher UHF frequencies. The exact number of elements required is a function of diameter, element (individual antenna) pattern, and the amount of deviation from uniform, smooth, omni-directional coverage that is permissible. The problem has been studied by Chu[1] and has more recently been extended to large cylindrical configurations by Cockrell[2], and Croswell and Knop[3]. A review of this work shows that for directive element patterns and large diameters, a spacing along the circumference of about 0.8 wavelengths is required for low pattern ripple (<3db) and some immunity from small feeding errors in both phase and amplitude. For broader element patterns and smaller structures, the spacing requirement may be as little as 0.5 wavelengths.

As an example of the patterns that are formed when fewer elements are used, two and four slot array patterns are shown in Figures 1 and 2. These were taken on an approximately 9° half-angle cone. The pattern of Figure I was for two longitudinal slots mounted on a diameter of 2.3 wavelengths. Note that deep nulls (~-17 db) are formed due to interference between elements. The situation is not improved by doubling the number of elements and going to sequential phasing and more element directivity as can be seen from Figure 2. This represents a pattern of four circumferential slots fed in 0°, 90°, 180°, 270°, phase progression on the same cone, at about the same diameter. Deep nulls are still much in evidence.

Frequency Diversity Approach Elimination of the antenna interference minima for an array of two elements can be accomplished by feeding each antenna with a different frequency and using separate ground receivers. The outputs of the two receivers can be combined after conversion to IF or baseband frequencies. Rather straightforward ground equipment is required and a very significant improvement in effective airborne. antenna gain or antenna weight can be obtained.

A block diagram of a typical frequency diversity system is shown in Figure 3. Separate airborne transmitters are fed common modulation inputs. The frequencies of the transmitters may be widely different, or as closely spaced as the modulation spectra allow. A single antenna, preferably circularly polarized, is used on the ground to feed a UHF/VHF down converter. Separate receivers are then used for the two different frequencies. Receiver outputs can be put on tape directly for further processing, optimization of detection bandwidths, elimination of doppler effects, etc. They may also be fed to an optimum ratio combiner for real time processing or for the basic flight data record if no optimization is required.

Figure 4 illustrates the situation from an antenna point of view. A typical longitudinal slot antenna pattern is shown as the solid line. This pattern is rotated 180° and drawn with a dashed line to represent the pattern of an identical slot on the opposite side of the vehicle. (Again a 9° half-angle cone with a 2.3 wavelength diameter at the antenna location is used.) A switch-type combiner that would follow the greater of the two signals as the vehicle spins (for a constant θ look angle) would produce a nearly uniform (4 db ripple) composite signal. Use of an optimum ratio combiner would produce up to 2.8 db improvement, as shown by the dotted line.

The situation for the entire range of look angles is shown in Figure 5. Here the maximum and minimum effective antenna gain around the roll axis is plotted versus angle off nose-on for both the switch combiner and optimum ratio combiner approaches. Right hand circular polarization is used. The poor coverage off the nose is due to the inherent element pattern null of longitudinal slots in this direction. As can be seen, however, the effective coverage is very nearly onmi-directional around the roll axis. Other element designs could be used to eliminate the nose-null, if this were necessary. An attractive candidate would be crossed, or “X” shaped slots. These would have the advantage of not only nose-on gain, but also could be used to achieve circular polarization broadside to the vehicle and, thereby, eliminate the 3 db polarization loss present with the longitudinal slots.

Comparison of Frequency Diversity with a Conventional Array It is apparent that the advantage of using frequency diversity grows as the vehicle diameter required for antenna mounting increases. The best parameter for conducting a tradeoff is airborne vehicle weight. Table 1 shows some typical weight calculations for a frequency diversity system with two transmitters and two antennas. Also shown are the parameters for an array of identical antennas fed by a power divider. An average element spacing at 0.7 wavelengths circumferential distance is assumed. In addition, cascaded, identical two-way hybrids are assumed for the power dividers, so that the number of power dividers = N-1, where N is the number of antennas required. (In general, for m-way power dividers, the total number required is (N-1)/(m-1). Thus, for example, four-way dividers would save six dividers in a ten antenna system, but the four-way devices would be larger than the individual two-way dividers.) The restriction to two-way power dividers limits the number of antennas to powers of two. The results can easily be repeated, however, for other array element numbers.

In order to see the advantages of frequency diversity more directly, the following numbers are substituted for the various parameters:

λ = 5.3 in. (S band telemetry wavelength)
y = 0.5 lb
X = 1.2 lbs
Z = 0.15 lbs
ρ 0.03 lbs/in

These are realistic numbers for an S band telemetry system on a re-entry vehicle. A plot of the weight vs. diameter of the two systems is shown in Figure 6. As can be seen, the advantage of the diversity system is considerable for even moderate vehicle diameter.

References

1. Ta Shing Chu, "On the Use of Uniform Circular Arrays to Obtain Omnidirectional Patterns," iRE Trans. on Antennas and Propagation, vol. AP-7, pp.436-438, October 1959.

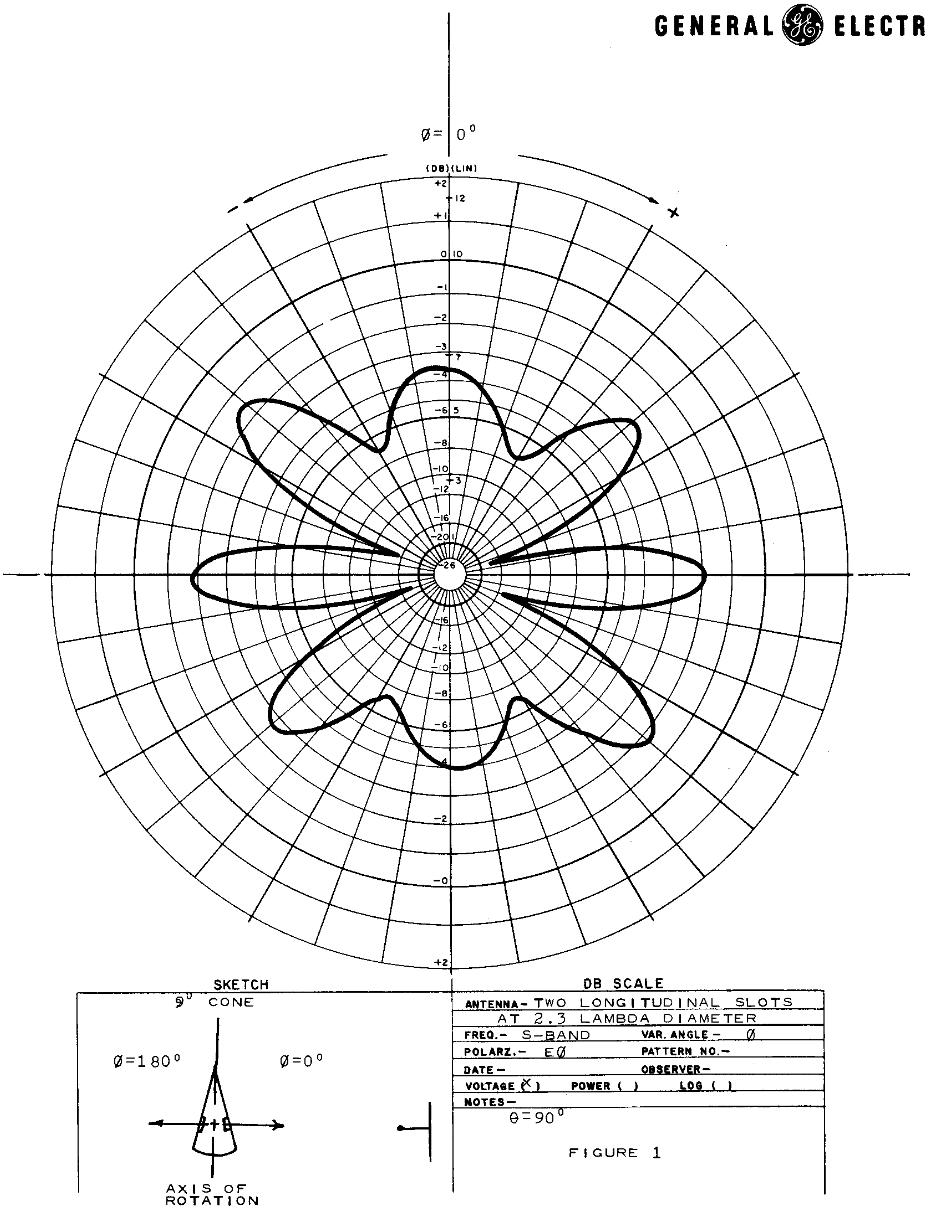
2. C. R. Cockrell, "Computations for Larger Uniform Circular Arrays with Typical Element Patterns," NASA, Hampton, Va., Tech. Note NASA TN D-2105, October, 1964.

3. W. F. Croswell and C. M. Knop, "On the Use of an Array of Circumferential Slots on a Large Cylinder as an Omni-directional Antenna," IEEE Trans. of Antennas and Propagation, vol. AP-14, pp. 394-396, May 1966.

TABLE 1. WEIGHT VS. AIRBORNE VEHICLE DIAMETER TRADE OFF

	Weight of Frequency Diversity System	Weight of Non-diversity Multiple Element Antenna System
Transmitter	2 X (each with half power)	X
Antennas	2 Y	ny
Cables	$\rho\frac{\pi D}{2}$	$\rho\frac{\pi Dn}{4}$
Power Divider	0	(n - 1) z
Battery	← Assume constant for both →	

ρ cable weight per unit length
D = vehicle diameter
X = single transmitter weight
Y = antenna element weight
Z = weight of single hybrid power divider
λ wavelength
n number of antennas

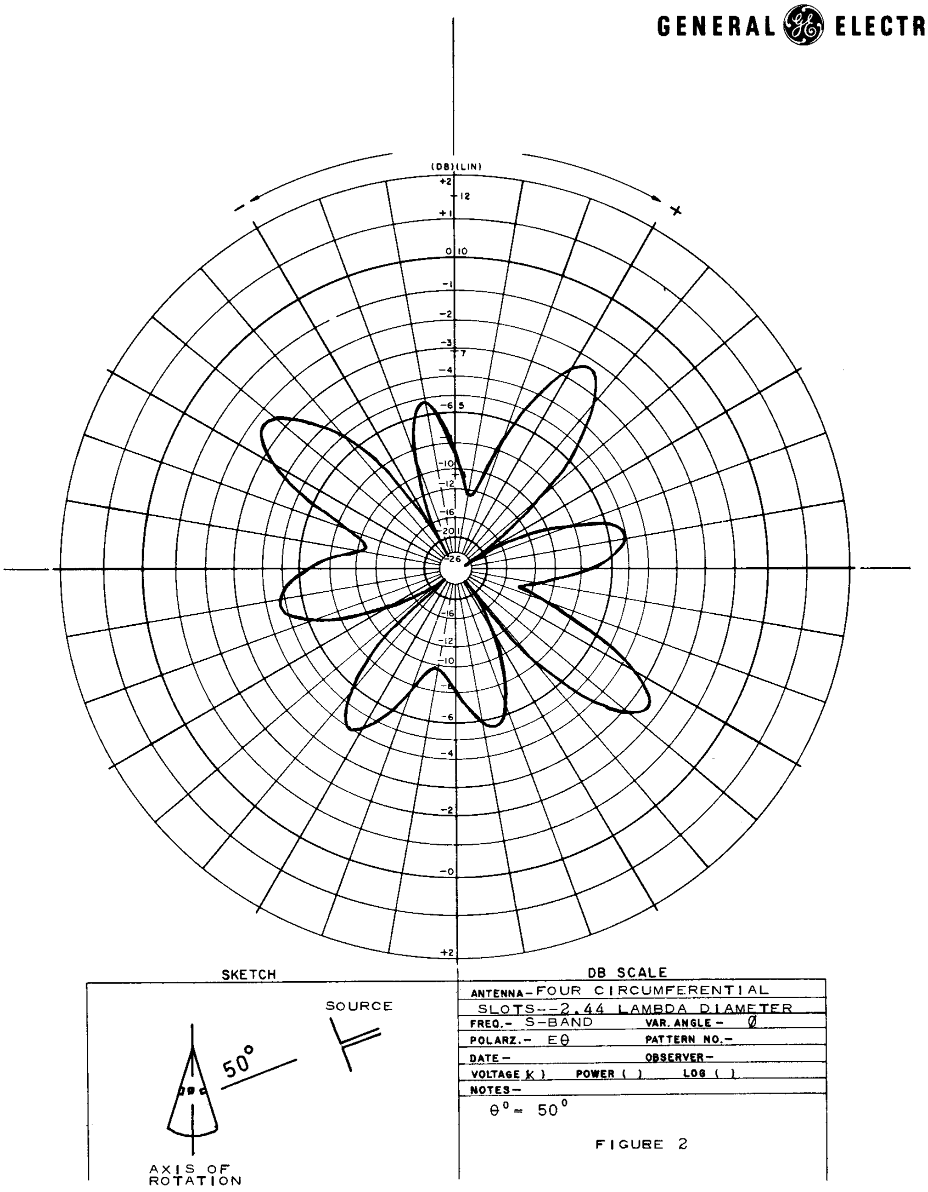


ANTENNA- TWO LONGITUDINAL SLOTS
AT 2.3 LAMBDA DIAMETER
FREQ.- S-BAND VAR. ANGLE - Ø
POLARZ.- EØ PATTERN NO.-
DATE- OBSERVER-
VOLTAGE (X) POWER ( ) LOG ( )
NOTES-
θ=90°

FIGURE 1

Figure 1. Two Longitudinal Slots at 2.3 λ Diameter, 90 Half-Angle Cone, ϕ Variable Pattern, E ϕ Polarization, $\phi = 80^{\circ}$

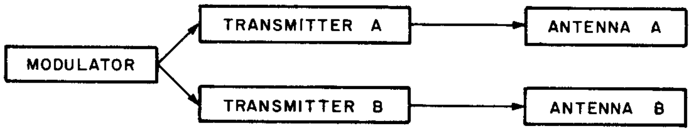
MISSILE AND SPACE VEHICLE DEPARTMENT
GENERAL ELECTRIC



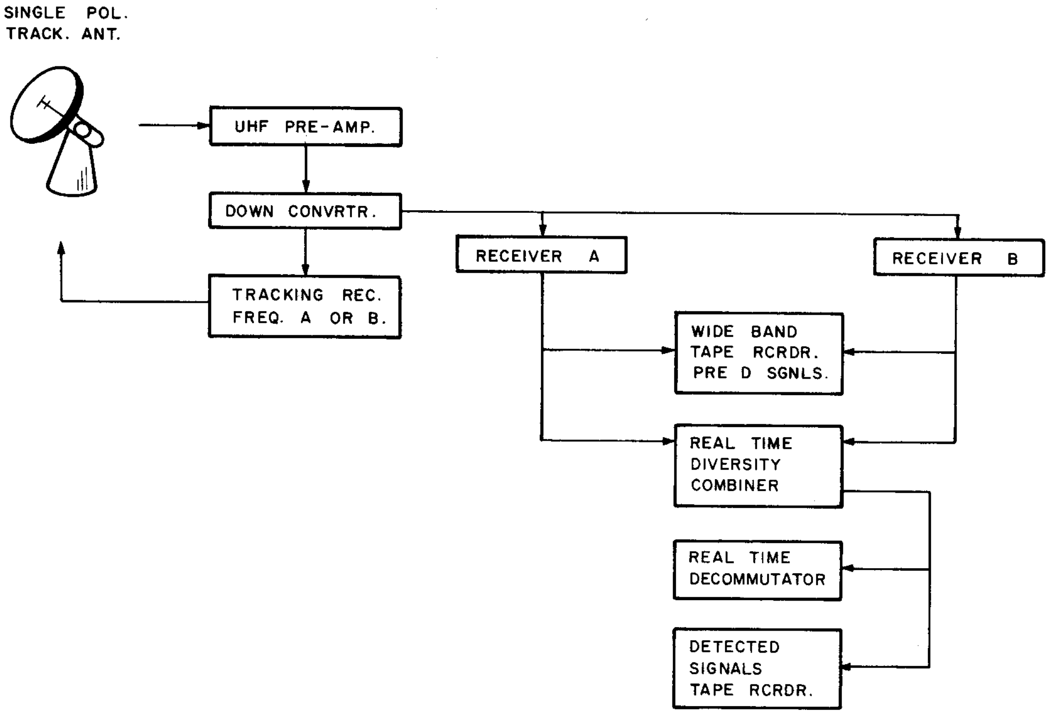
ANTENNA- FOUR CIRCUMFERENTIAL SLOTS--2.44 LAMBDA DIAMETER
FREQ.- S-BAND VAR. ANGLE - Ø
POLARZ.- Eθ PATTERN NO.-
DATE- OBSERVER-
VOLTAGE (K) POWER ( ) LOG ( )
NOTES-
θ° = 50°

FIGURE 2

Figure 2. Four Circumferential Shots at 2.44 λ Diameter, 9° Half-Angle Cone, ϕ Variable Pattern, E ϕ Polarization, ϕ = 50°

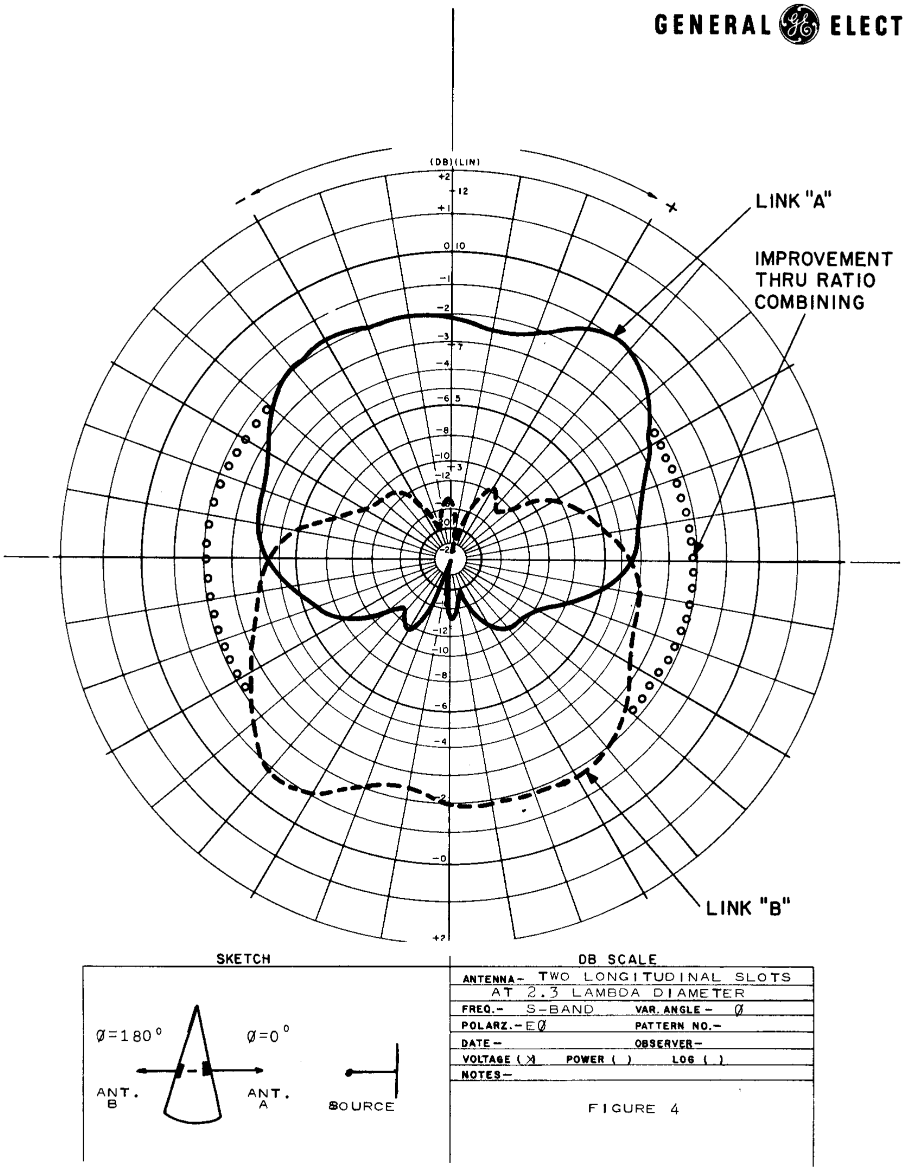


AIRBORNE SYSTEM



GROUND SYSTEM

Figure 3. Block Diagram - Frequency Diversity System



ANTENNA – TWO LONGITUDINAL SLOTS AT 2.3 LAMBDA DIAMETER

FREQ. – S-BAND VAR. ANGLE – Ø

POLARZ. – EØ PATTERN NO. –

DATE – OBSERVER –

VOLTAGE (X) POWER ( ) LOG ( )

NOTES –

FIGURE 4

Figure 4. Two Longitudinal Slots at 2. 3 λ Diameter, 9° Half-Angle Cone, ϕ Variable Pattern, E ϕ Polarization

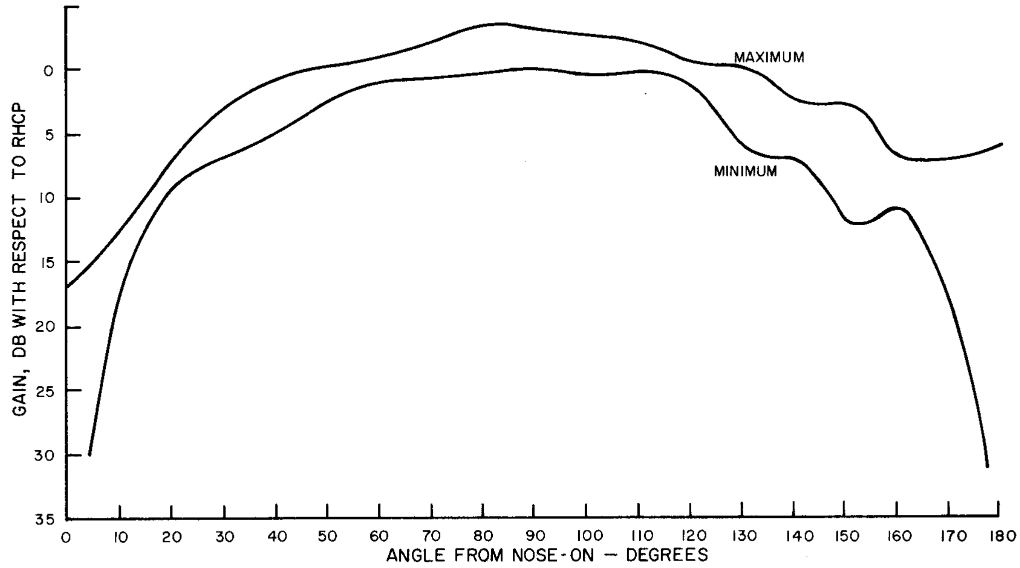


Figure 5. Longitudinal Slots Composite on Frequency Diversity Basis

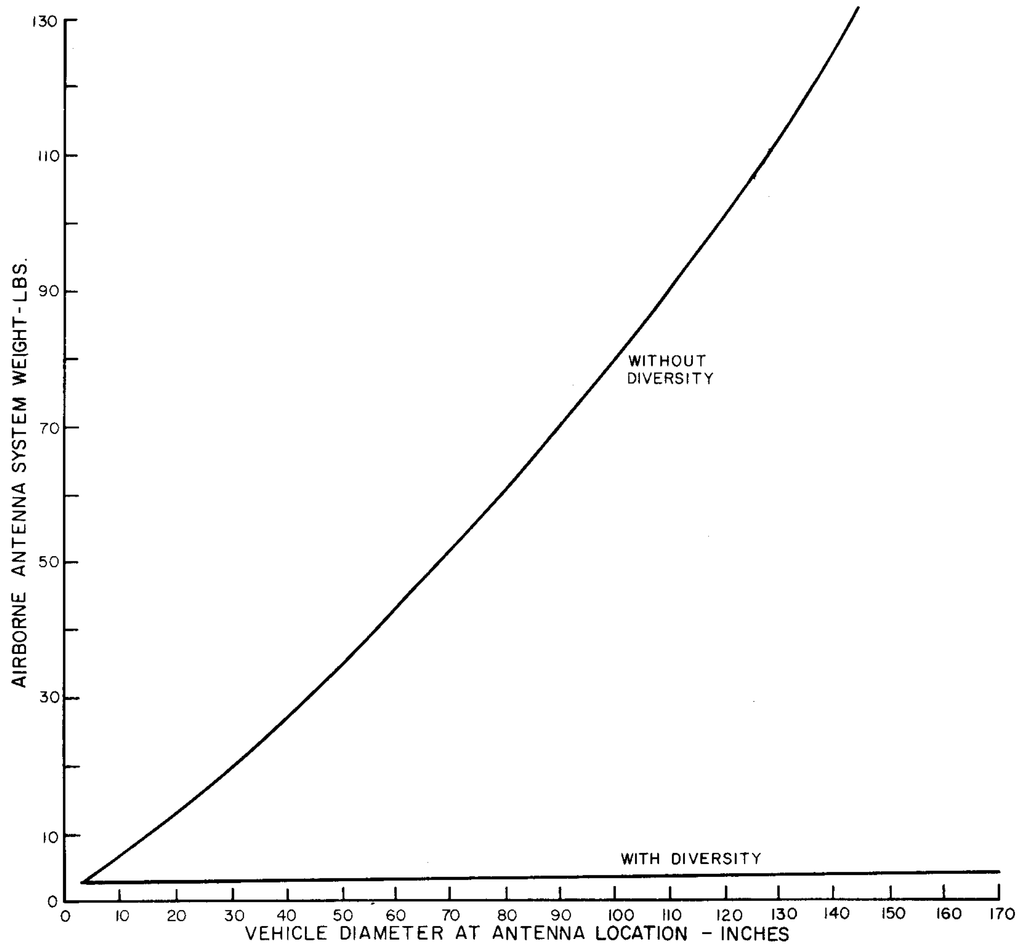


Figure 6. Airborne Vehicle RF System Weight - Frequency Diversity vs. Non-Diversity Systems