KU-BAND HIGH GAIN ANTENNA

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Almost a year ago, we made a study of the ground antenna required for support of the Tracking and Data Relay Satellite (TDRS). A 16-GHz carrier with 2-GHz bandwidth and a spacecraft EIRP of +84.5 dBm were assumed for this communication link. These parameters, along with a 10-dB margin for unfavorable weather, established a gain requirement of 70 dB. The three alternative antenna configurations considered are shown in Figure 1.

Using current state-of-the-art technology, a single 29-m-diameter single-aperture antenna with 0.76-mm rms surface tolerance can be built to provide 70-dB gain at 16 GHz. The beamwidth of this antenna would be 0.9-mrad. Assuming that the TDRS has an orbit similar to that of ATS 1 with 35-mrad orbit inclination, the angular velocity of the TDRS at synchronous altitude will exceed 0.005 mrad/s. This velocity is significant with respect to the beamwidth of the antenna, and autotracking is therefore a requirement. The surface tolerance of the reflector causes a 1-dB reduction in gain, resulting in an overall efficiency of 44 percent.

The 70-dB gain can also be achieved using a multiaperture array of antennas on separate pedestals. A four-element array would require 13.4-m-diameter elements. For this diameter, a 0.33-mm rms surface tolerance is within the current state of the art. Each antenna would contain a monopulse feed and provide 55 percent efficiency. The spacing required between array elements to prevent shadowing limits the bandwidth of the array to 250 MHz for 0.5-dB loss at band edge. This bandwidth is far below the required 2 GHz. Use of a two-element array of 19.2-m-diameter elements would extend the bandwidth to 330 MHz, but in either case the multiaperture array of antennas on separate pedestals is not a feasible alternative for meeting the requirements of the TDRS.

The third alternative is the limiting case of the second in which the four-element array is mounted on a common pedestal. This configuration has several unique features. The physical arrangement of the elements provides the inherent capability for three-channel phase monopulse tracking with only listening feeds in each element. The requirement for only listening feeds provides at least an additional 10 percent efficiency, and only 12.8-m-diameter elements are required. A coherent receiver combines the outputs of the four elements and simultaneously provides the tracking error channels, which are derived from relative phase measurements.

In combining the array elements, the receiver adjusts the phase of each channel to provide coherent addition. The coherence function serves to scan the array pattern of the antenna to point the main beam at the spacecraft at all times. The 3-dB points for the antenna are therefore determined by the element patterns which have a 3-dB beamwidth of 1.74 mrad. The pointing accuracy requirement for this antenna is one-half that required for the single-aperture antenna.

The bandwidth of the array is 3.5 GHz, more than sufficient for TDRS support. The unused area in the center of the array is sufficiently large to permit the addition of a 5.2-m-diameter antenna. This center element would have a gain of 56 dB and could be used for initial acquisition of the spacecraft. When the full array locks onto the spacecraft, this center element would be used for command uplink to the TDRS.

The cost effectivenss of the two feasible alternatives is shown in Figure 2 as a function of gain. Below the required 70-dB gain, the single-aperture antenna is clearly superior. At 70 dB, the cost effectiveness is approximately equivalent for each configuration, with the array becoming superior as the gain requirement increases further.

The differences between the single-aperture antenna and the array become apparent when considering tracking performance. For an antenna located in the vicinity of GSFC, the gain loss due to wind-induced tracking errors is plotted in Figure 3. The probability that wind conditions are sufficient to cause a 3-dB reduction in gain is eight times greater for the single reflector than for the array. This difference results from the ability of the array to scan its radiation pattern within the 3-dB points of the array elements.

Wind-induced tracking errors can be eliminated entirely by enclosing the antenna in a radome. The use of a radome has two disadvantages: (1) it doubles the total system cost and (2) the water film forming on the surface of the radome under precipitation will reduce the effective gain of the antenna by several decibels. To illustrate this point, the percent probability of exceeding 10 dB reduction in CNR under precipitation is plotted here as a function of elevation of the TDRS (Figure 4). At the minimum elevation angle of concern, the probability is twice as great for the radome enclosed antenna as it is for the exposed antenna. With increasing elevation angle, the difference becomes even greater since the water film losses are essentially constant while the losses due to transmission through the atmosphere decrease rapidly.

In terms of reliability, the array offers significant advantage. If one front end fails or is down for maintenance, the array gain is reduced by only 1.3 dB. With three of the four elements inoperable, the gain reduction is only 4.7 dB. The single-aperture antenna cannot offer such flexibility.

In summary, an exposed four-element array of 12.8-m-diameter elements mounted on a common pedestal is the recommended ground antenna configuration in support of the 2-GHz bandwidth Ku-band downlink from TDRS. The array provides three-channel phase monopulse tracking capability with only listening feeds in each element. The array is as cost effective as a single-aperture antenna and offers significant advantages in tracking and reliability.

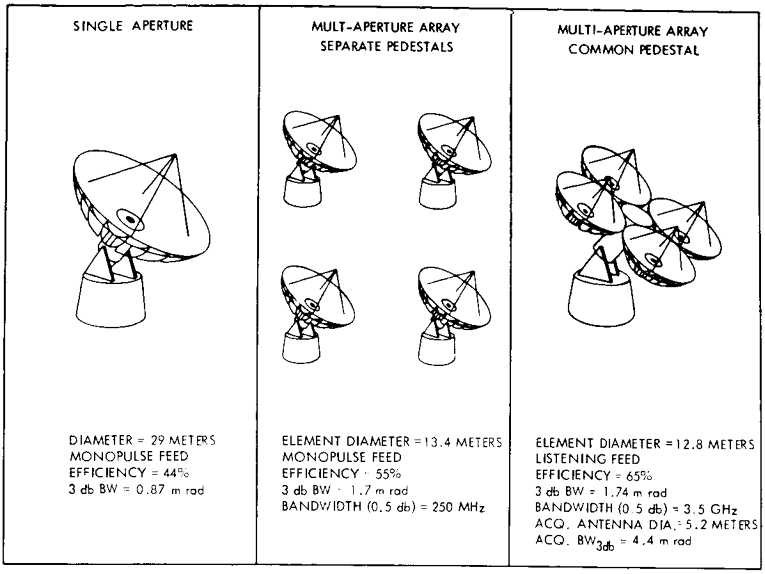

Figure 1–Alternative configurations for TDRS ground antenna.

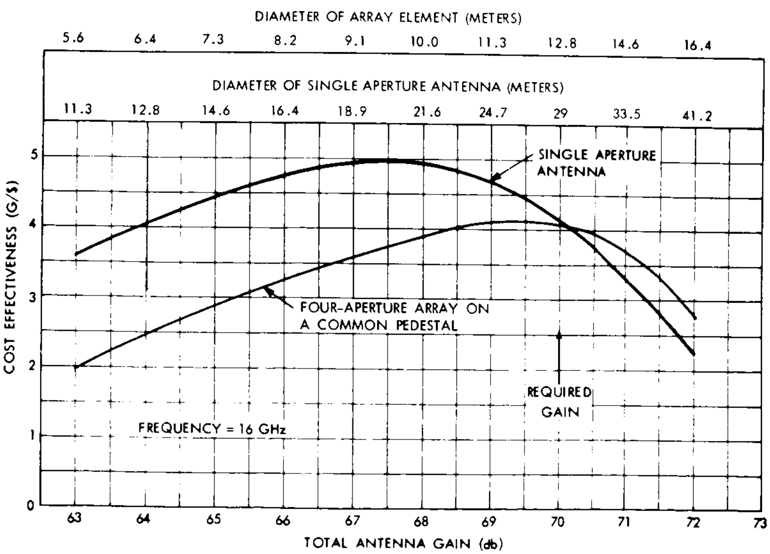

Figure 2–Cost effectiveness.

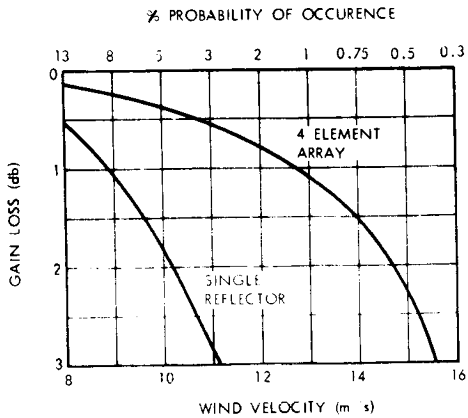

Figure 3--Tracking capability.

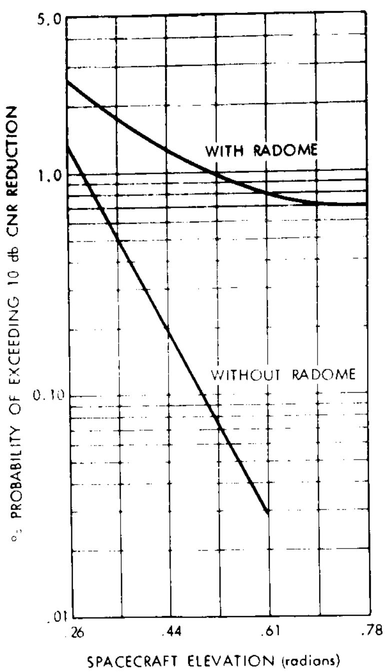

Figure 4--Effects of radome.