

## COMPACT ANTENNAS FOR MOBILE SATELLITE COMMUNICATION

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## 1. Introduction

There is a need for small earth station antennas for satellite communications in the 1.5/1.6 GHz band not only for aircraft and land mobile terminals, but also for shipboard terminals. For these purposes, many kinds of compact antennas are being studied. Report 921 considers potential new ship earth-station systems and their applications, and in particular new concepts for the INMARSAT Standard-B and Standard-C systems and their possible variants.

Two classes of compact antennas are being considered for mobile satellite applications and are discussed in this Report. The first consists of low-gain antennas with omni-directional azimuth antennas patterns and gains in the range 0-6 dBi. The other consists of medium-gain directional antennas whose directionality is in azimuth, but may also be in elevation. Gains in the range 7-15 dBi are representative. In the latter type, since the beam is directional, steering is required either by mechanical rotation or by electronic steering or switching in order to track the satellite.

Low-gain antennas are expected to cost less because they are simple structures and do not require beam steering when the mobile unit is in transit. However, because of their omni-directional coverage, they will offer potential interference (to other satellites) or receive interference.

Medium-gain antennas may provide some degree of discrimination against external interfering sources. In addition, in multi-satellite systems which are sufficiently separated, orbital reuse may be possible with satellites using the same frequency. This is because the antenna's low sidelobes will receive less interference from the adjacent satellite, and also radiate less in its direction.

## 2. Antenna characteristics

Various types of antennas systems for mobile satellite applications have been studied [Heckert 1972], and Table I indicates preferred antenna types for the gain range 0-15 dBi.

TABLE I

Preferred antenna types for mobile satellite earth stations

|             | Gain range (dBi) | Antenna type                                                                                                                                                                                                         | Pointing in azimuth (Az)/elevation (El) | Stabilization         |
|-------------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------|
| Low Gain    | 0-3              | Hemispherical coverage:<br>- quadrifilar helix /Kilgus, 1975/<br>- turnstile<br>- microstrip patch<br>- flat spiral<br>- drooping crossed dipole<br>- Lindenblad dipole configuration<br>/Lindenblad, 1941/          | No                                      | No                    |
|             | 4-6              | Optimized for a given elevation sector with bifolium (near toroidal) pattern:<br>- conical spiral (normal mode)<br>- turnstile on ground plane<br>- quadrifilar helix on ground plane (Note 1)<br>- microstrip patch | No                                      | No                    |
| Medium Gain | 7-10             | - helix<br>- horn<br>- linear array<br>- planar array of 4 crossed dipoles<br>- archimedian spirals, microstrip patches, etc.<br>- conical spiral (beam mode)                                                        | Yes in Az and El                        | Yes (simple gravity?) |
|             | 11-15            | - short backfire<br>- helix<br>- linear or planar array of 4, 8, or 16 elements<br>- array of microstrip patches                                                                                                     | Yes in Az and El                        | Yes                   |

2.1 Low-gain antennas

The types of low-gain antenna that have been considered for mobile satellite applications are listed in Table I.

All of these antennas provide circular polarization. Some provide this intrinsically, but others require an external quadrature hybrid. They also provide omni-directional or quasi-hemispherical coverage. Where a low antenna profile is necessary, the microstrip patch(es) and the flat spiral have the greatest application. The characteristics of certain of these antennas are discussed below.

### 2.1.1.1 Omni-directional type

The quadrifilar helix antenna can achieve circularly polarized and conically shaped radiation patterns with full azimuthal coverage and directional elevation beam [Kilgus, 1975]. Therefore, this antenna requires no additional tracking system.

The various helix parameters (number of turns, pitch, diameter and so on) have effects on the radiation patterns and on the axial ratios. This antenna has a conical radiation pattern and provides a good axial ratio over wide elevation angles. Table II provides the main electrical performance characteristics of the 5-turn quadrifilar helix antenna whose pitch and length are 0.48 and 0.72, respectively, for one turn of helix (normalized by wavelength) [Terada *et al.*, 1987].

TABLE II

|                                  |                          |
|----------------------------------|--------------------------|
| Maximum antenna gain             | more than 7 dBi          |
| Beamwidth in elevation direction | 3 dB = 32°<br>1 dB = 18° |
| Axial ratio                      | less than 2 dB           |

Another omni-directional antenna which is being considered for mobile satellite earth station applications is the drooping crossed dipole. This is depicted in Figure 1 with its co-pol and cross-pol radiation patterns. The co-pol pattern is quasi hemispherical.

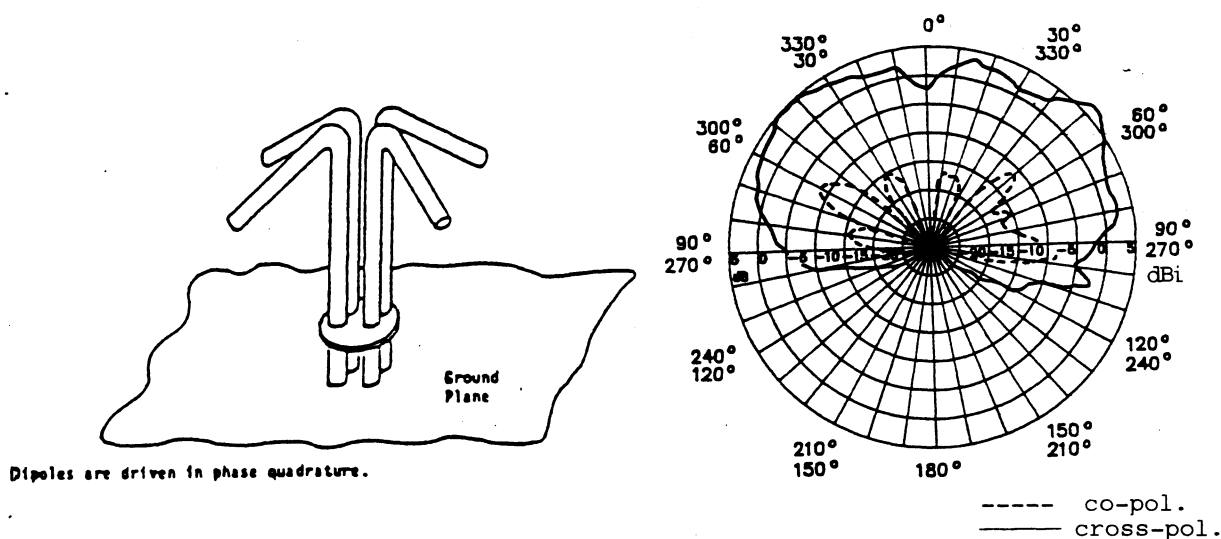


FIGURE 1 - Drooping crossed dipole antenna and typical radiation patterns

### 2.1.2 Electronically switched - directional type

To achieve a directional antenna using a simple tracking system, a beam-switching antenna has been proposed [Hori *et al.*, 1987]. This antenna consists of 6 radially placed microstrip patch antennas and can point to a satellite in the azimuth angle by switching from one element to another. Though it can achieve a wide beamwidth in elevation direction compared with a conically shaped beam antenna of the same gain, it requires a simple tracking system. Table III provides the main electrical performance characteristics of this antenna.

TABLE III

|                      |                          |
|----------------------|--------------------------|
| Maximum antenna gain | more than 8 dBi          |
| Beamwidth            | 3 dB = 70°<br>1 dB = 38° |
| Axial ratio          | less than 3 dB           |

The configuration for the antenna is shown in Figure 2. Six microstrip patches are evenly deployed on the conical dome. Full azimuth coverage is realized by switching from one microstrip patch to another, by the switch shown on the left.

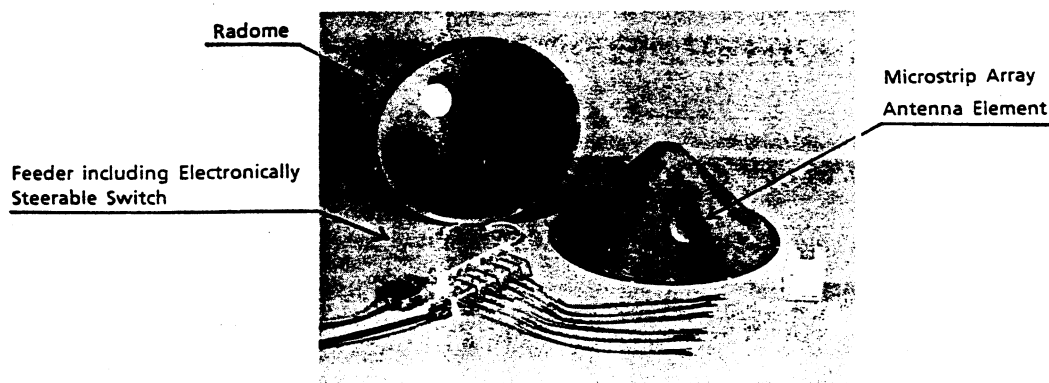


Fig. 2 Electronically Switched Array Antenna

## 2.2 Medium-gain antennas

Medium-gain antennas, with gains in the range 7-15 dBi, have the following advantages over low-gain antennas:

- o Reduces spacecraft EIRP requirements
  - increases earth station G/T
- o Potentially lowers ground receiver system noise temperature
  - if antenna system losses are reasonably low.
- o Reduces multi-path effects
  - because of lower sidelobes at low elevation angles, thus reducing input signal caused by specular reflected signal and diffused component. This is augmented by using circular polarization and taking advantage of odd bounce rejection, if axial ratio is reasonably low.
- o Contributes to orbital reuse
  - For satellites serving the same area, two or more satellites can use the same frequency if they are separated by an amount which is dictated by the frequency used and the size of the antenna.

However, medium-gain antennas are more expensive to produce than single element low-gain antennas.

### 2.2.1 Short backfire antenna

A short backfire (SBF) antenna is considered a candidate for mechanically-steered, directional, medium-gain antennas in the range of 12-15 dBi for small ships and vessels.

The conventional short backfire antenna consists of two planar reflectors of different diameters, the main reflector and the sub-reflector separated by one-half wave length. They act as a shallow leaky cavity resonator with the radiation beam normal to the sub-reflector. The antenna, originated by Ehrenspeck [Ehrenspeck, 1965], is fed by a crossed dipole antenna at the midpoint between the two reflectors.

Recently, two types of new SBF antennas have been proposed which improve the electrical characteristics by modifying the shapes of the main and small reflectors and that of the primary exciter. The first type is a SBF antenna that has dual small reflectors and a non-flat main reflector. Another SBF antenna has dual small reflectors and a conical main reflector by which the frequency characteristics of the VSWR is considerably improved [Ohmori et al., 1983]. The latter has a step configuration on the main reflector which improves the gain of the SBF antenna by about 1-1.5 dBi [Shiokawa et al., 1983].

### 2.2.2 Array antenna systems

There are basically two types of arrays which have been considered for mobile satellite applications. The first is an assemblage of antenna elements on a linear or planar surface in which the generated beam is steered by mechanical means. The other is an array of elements whose beam is steered by electronic means by phase shifting or time delay devices usually located in each element path. This latter type of array is generally called a phased array. Examples of the array antennas are depicted in Figure 3.

Figure 3a shows an array consisting of two separately driven arrays (back-to-back) with each having two-element tiers (paired elements) and driven by eight phase shifters each. The elements are microstrip patches driven by quadrature hybrids to produce left-hand circular polarization. The structure is mounted on top of the fuselage of an aircraft, and the array which is in operation depends on the east-west flight direction of the aircraft [Ohmori, 1986]. The array is scanned  $\pm 60^\circ$  in the horizontal direction. Experiments have been conducted using the Japanese ETS-5 communication satellite located at  $150^\circ\text{E}$  longitude and aircraft on trans-Pacific flights.

Figure 3b shows a simplified version of a mechanically-steered linear array using circularly polarized microstrip patches. The array is partitioned to offer single plane monopulse sensing for closed-loop satellite tracking. Satellite tracking accuracy is affected by the fading signal level received from the satellite. Signal absence or deep fade can be coped with by reverting to open-loop tracking scheme. A practical implementation of a mechanically-steered array is described by Pattan [Pattan, 1987]. The array produces circular polarization, and the beam forming network is weighted for sidelobe control. The array is divided into two halves and phase monopulse is used. The two phase centers are located at the center of each sub-array. The monopulse comparator gives a sum and difference output.