An Adaptive Array Antenna for Mobile Satellite Communications

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ABSTRACT

This paper describes the design of an adaptive array antenna for land vehicle operation and its performance in an operational satellite system. Linear and circularly polarized antenna designs are presented. The acquisition and tracking operation of a satellite is described and the effect on the communications signal discussed. A number of system requirements are examined that have a major impact on the antenna design. The results of environmental, power handling and RFI testing are presented and potential problems identified.

INTRODUCTION

The linearly polarized adaptive array antenna consists essentially of a driven $\lambda/4$ monopole surrounded by concentric rings of parasitic elements all mounted on a ground plane of finite size. The parasitic elements are connected to ground via pin diodes. By applying suitable biasing voltages the desired parasitic elements can be activated and made highly reflective. The directivity and pointing of the antenna beam can be controlled both in the elevation and azimuth planes using high speed digital switching techniques.[1] By adding a circular polarizer to the linearly polarized design an increase in gain can be realized at the expense of an increase in antenna height.

The antennas are designed for land mobile applications and provide an angular coverage of 360° in azimuth and between 15° and 60° in elevation over an operating band of 1530 MHz to 1660 MHz. A maximum of 32 beams can be generated in azimuth and 2 to 3 beams in elevation depending on antenna size. The antennas are designed to have low sidelobe levels at low elevation angles to minimize the degrading effects of multipath on the tracking and communications performance. The RF losses are negligible and the measure antenna noise temperature is 60K. The antennas are designed to handle a maximum RF power of 100 watts. The electrical characteristics are simple to measure and are highly repeatable. The antenna manufacturing cost in quantities of 10,000 per year is estimated to be less than $1000. (Can.).

DESCRIPTION

A 5 ring linearly polarized design is shown in Figure 1. The antenna incorporates sufficient electronics to control the radiation patterns and pointing on command. It is designed to be mounted on the metallic roof of a vehicle where the effective ground plane can significantly enhance antenna gain at low elevation angles. The antenna has a diameter of 20", a height of 2" above the ground plane and 1/2" below. It weighs 11 lbs. and requires less than 10 watts of power. The antenna gain varies between 9 and 11 dBic and has a maximum return loss of -12 dB. over the required angular coverage and operating frequency bands. A circularly polarized version of the antenna, shown in Figure 2, is obtained by adding a polarizer to the linearly polarized array. The antenna has a diameter of 24" and a height of 8" and weights 16 lbs. the antenna gain varies between 10 and 13 dBic and has a maximum return loss of -11 dB over the required angular coverage and operating frequency bands. The antenna pattern and return loss measurements are shown in Figures 3 to 8.

ACQUISITION/TRACKING OPERATION

Commands are executed by transmitting to the antenna a serial bit stream, each bit representing the conducting state of a corresponding pin diode and associated parasitic element. Each command defines the switching configuration to point the antenna beam in a particular direction and takes less than 100 micro-seconds to execute. Diagnostic checks are carried out prior to operation.

The satellite is initially acquired by stepping through 16 azimuth beam positions and selecting the beam with the strongest signal. In the event that the signal falls below a given threshold, the acquisition sequence is again initiated until the signal is re-acquired. The speed of operation is determined by the terminal C/No ratio and the signal to noise requirements in the control loop bandwidth. Currently it takes less than 0.1 seconds to acquire the satellite after initial phase lock. The satellite is subsequently tracked using one of 3 modes of operation.

Signal Sensing

A DC signal proportional to the RF signal is derived at the terminal receiver. The satellite is tracked by periodically switching on either side of the current beam position and selecting the beam with the strongest signal. Currently this is accomplished in less than 10 msec. and in normal vehicle operation occurs twice per second. A number of algorithms have been devised to minimize any perturbation of the communications signal to less than 1% of the time. The maximum phase transients when tracking in azimuth can be kept to less than ±10 degrees over the required angular coverage and operating frequency bands.

Signal and Angular Rate Sensing

The tracking operation is similar to the above but the up-dating frequency of the antenna beam position is governed by the angular rate of change of the vehicle as determined by a flux-gate compass. This minimizes the perturbation of the communications signal and provides the necessary up-dating at high angular velocities.

Flux-gate Compass

The flux-gate compass can be used as a primary sensor or as an adjunct or back-up to the signal sensing system.

FIELD TRIALS

Extensive field trials have been conducted using INMARSAT's MARECS B satellite. The three basic tracking modes have been successfully demonstrated. Calibrated duplex tests have been conducted using the Standard "C" transmission for tracking purposes and transmitting CW signals at 24 dBw from the vehicle and recording the transmission at the base station. The measured C/No ratios were within 1 dB of the predicted values. Field trials using ACSSB modulation are presently being conducted and will be extended in near future to include digital modulation.

SYSTEM CONSIDERATIONS

Current antenna specifications for vehicle antennas are tentative and subject to change. There are a number of uncertainties that have a major impact on the antenna design.

Cost

The cost of the antenna for airborne applications is not likely to be a major consideration. In the case of land vehicles and to a lesser extent maritime applications, the cost of the antenna, when manufactured in quantity, must be low enough to be commercially viable. A manufacturing cost of less than $1,000. (Can.) is the design goal for the Canadian MSAT program.

Polarization

Satellite operation at L-band uses circular polarization to overcome the effects of Faraday rotation and to eliminate the problem of polarization alignment at the mobile terminals. A requirement that the land vehicle antenna be circularly polarized is based in part on the premise that by alternating the sense of polarization of adjacent satellites, a degree of isolation is achieved between satellites (20 dB), that permits the re-use of the available RF spectrum. When the mobile terminal antenna points at the desired satellite, the adjacent satellites are illuminated by the antenna sidelobes. Most electronically steered array designs have difficulty in controlling cross-polarized sidelobe levels over the relatively large angular coverage and operational frequency bands. In some cases the cross-polarized levels can be as high as the co-polarized sidelobes. This limitation together with the depolarizing effects of scattering by objects in close proximity to the antenna, fading and other propagation effects, questions the feasibility of using orthogonal circular polarizations to enhance inter-satellite isolations.

Terminal G/T

The current MSAT and Inmarsat minimum G/T requirements for land mobile terminals are -17 dB/°K and -12 dB/°K respectively with corresponding nominal antenna gains of 8 dBic and 12 dBic respectively. The G/T requirements have been arrived at after allowing for a systems operational margin. A dominant contribution is an allowance for the degrading effects of multipath and fading which occur at low elevation angles in land mobile operation. A directional antenna pointing at high elevation angles, will experience less multipath and fading and will have a lower antenna temperature than when pointing close to the horizon. A relaxation in G/T requirements at high elevation angles of between 1 and 2 dB vis `a vis low elevation angles may be possible for land mobile operation.

ENVIRONMENTAL TESTING

Vibration

The antenna has been subjected to vibration testing and meets land vehicle MIL specification 810C.

Thermal.

Solar simulation tests have been conducted. The highest temperatures recorded within the radome and electronic enclosure were 50°C and 70°C respectively well within the component design limits. No measurable shift in antenna boresight was observed. No problems were experienced during field trials in the winter months when temperatures were as low as -20°C.

Power

High power testing was conducted by sweeping an 80 watt CW signal across the transmit band via a diplexer and monitoring the receive band. There was no observable increase in noise level or evidence of spurious responses.

RFI

There is the possibility of VHF transmitters (70 - 130 MHz) mixing with the L-band transmit frequencies to produce interference in the receive band. Tests were conducted in the Ottawa area where there are about 10 VHF transmittters within a 10 mile radius with EIRP's of 50 dBw that could cause potential interference. The antenna, radiating 40 watts of CW power in the transmit band, was pointed in direction of the VHF transmitters and the received band monitored. Although no measurable interference was observed, it can be expected that when operating in close proximity to VHF transmitters, interference may occur using even passive antenna designs.

ACKNOWLEDGEMENTS

The author is grateful for the support provided by Martial Dufour, Bert Schreiber and Keith Elms in designing the tracking software and hardware and the magnetic sensor.

REFERENCES

1. Milne, R. 1988. An Adaptive Array Antenna for Mobile Satellite Communications. NASA/JPL Mobile Satellite Conference, Pasadena.

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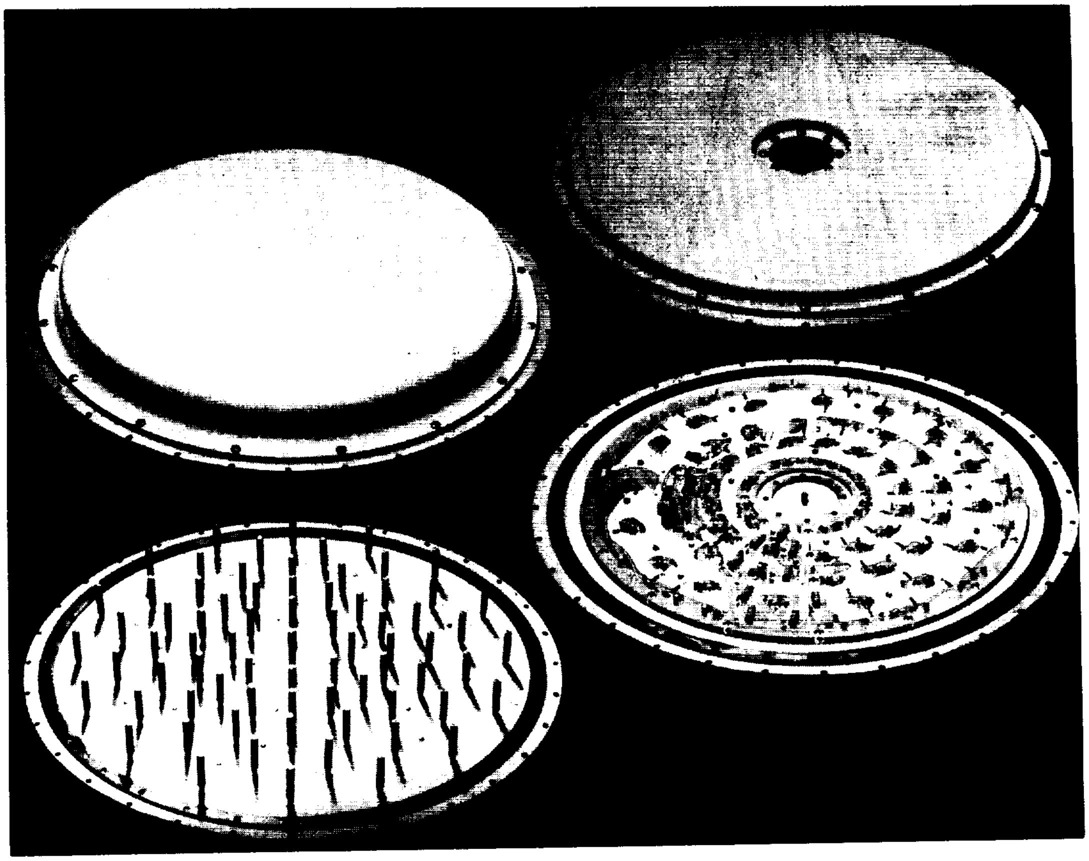

Fig 1 Linearly Polarized Antenna

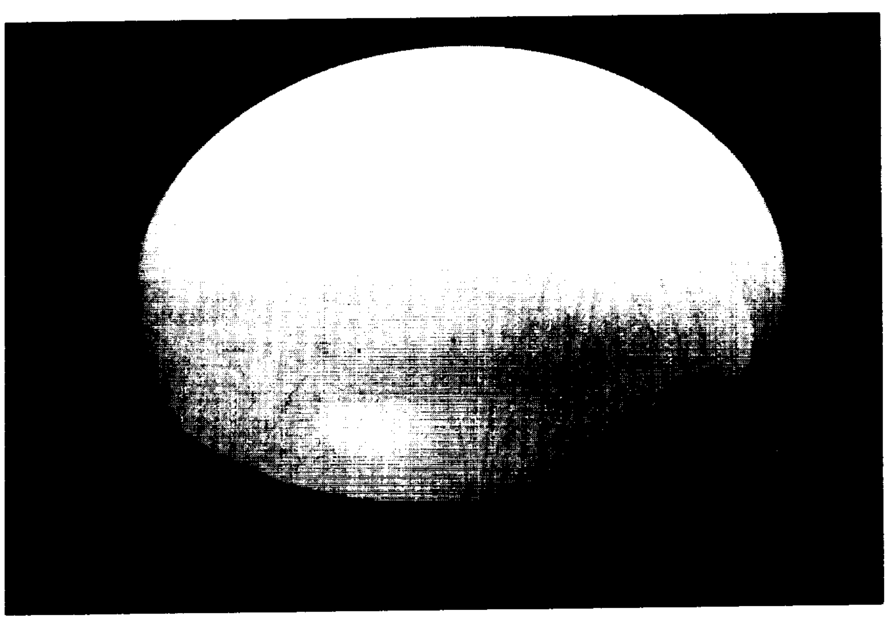

Fig 2 Circularly Polarized Antenna

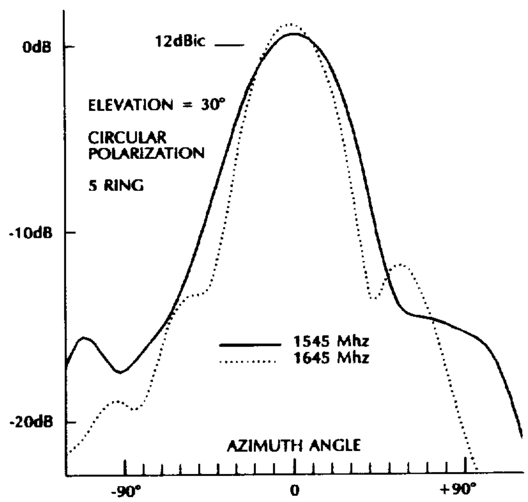

FIG. 3 AZIMUTH PATTERN - LOW BEAM

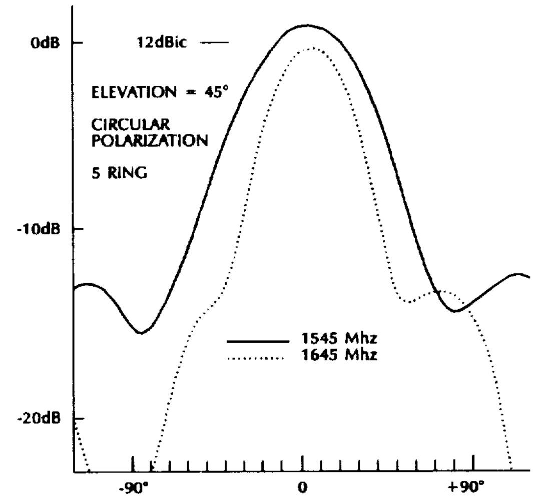

FIG. 4 AZIMUTH PATTERN - INTERMEDIATE BEAM

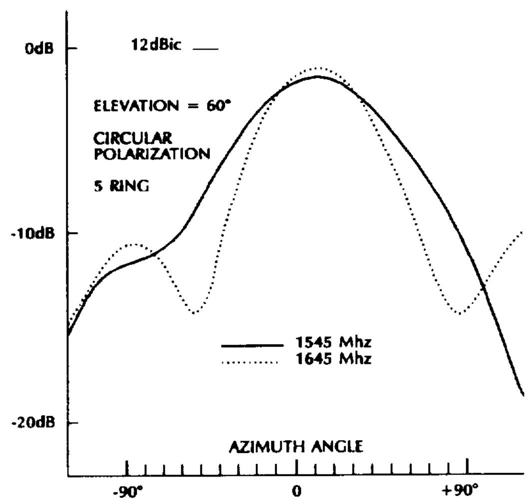

FIG. 5 AZIMUTH PATTERN - HIGH BEAM

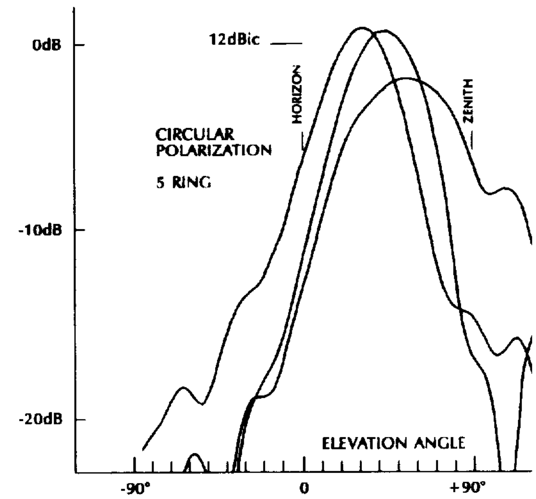

FIG. 6 ELEVATION PATTERNS - 1545 Mhz

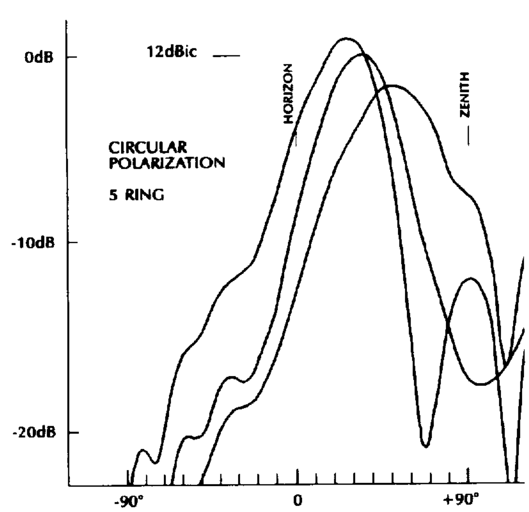

FIG. 7 ELEVATION PATTERNS - 1645 Mhz

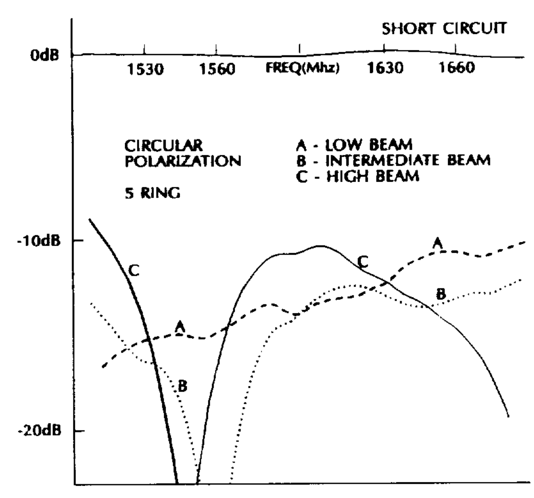

FIG. 8 RETURN LOSS VERSUS FREQUENCY