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Microstrip Monopulse Antenna for Land Mobile Communications

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ABSTRACT

Low cost is one of the main requirements in a communication system suitable for mass production, as it is the case for satellite land mobile communications. Microstrip technology fulfills this requeriment which must be supported by a low cost tracking system design. The trade off led us to a prototype antenna composed of microstrip patches based on electromechanical closed-loop principle which design and the results obtained are described below.

INTRODUCTION

This paper describes an antenna and its associated tracking system developed under contract with the European Space Agency (ESA). This development is part of the preparation work to promote a European Mobile Satellite system mainly aimed at the international road transport industry [1].

Presently, satellite land mobile communications are offering low bit data interchange of information, but higher bit rate and/or voice communications are being contemplated.

Voice communication at L band requires a medium gain antenna (≈ 11dBi) which has to be pointed to the satellite. Fixed antennas with hemispherical coverage cannot provide this gain, so a complete antenna system must be composed of two parts strongly related, the aerial and the pointing subsystem [2].

The antenna specifications are similar to those of other programs (e.g. MSAT-X or INMARSAT-M). The operational frequencies at L-band range from 1530 to 1559MHz at Rx and from 1631.5 to 1660.5 at Tx, with a gain of around 10-12dBi in circular polarization (RHC for testing and possibly LHC in production).

The axial ratio requirement is 3dB in the useful beamwidth, including the effect of the car roof, which may cause strong distortions in the antenna pattern. Finally, in order to avoid interference caused by other satellites, a crospolarization isolation of 20dB was specified from 30° to 50° off antenna boresight in the azimuth plane.

The manufacturing technique selected for the antenna was microstrip, which provides the lowest price when compared to other antenna manufacturing techniques, due to the photolitographic processes that this technique allows. It must be acompanied with a careful selection of the materials to be used, which have to perform electrically well, while maintaining a low price. The feed network design must follow also this design approach, minimizing the number of components to reduce the assembly process.

The design of the tracking system is also involved on this low cost requirement, and this imposes also a trade off between tracking performances and price reduction techniques.

TRACKING SYSTEM

The tracking scheme selected was a closed-loop monopulse system which provides both high accuracy and real time response without requiring any additional pointing device for proper operation. The antenna information reaches, after demodulation, to a tracking receiver which commands the motor to correct the position of the antenna to the satellite direction.

A classical monopulse scheme requires two signals (called Sum -Σ- and Difference -Δ- signals) to track the satellite position. The sum signal (which also carries the information) is obtained through in-phase addition of the signals received on each radiator, and the difference signal is obtained through out-of-phase addition of the signals coming from symmetric elements in the array.

The odd characteristic of the Difference signal makes it to be null when the antenna is correctly pointed to the emitter, and the Sum channel receives a maximum in the same situation. Since both channels are independently processed in the receiver, the Sum channel is used for data handling and the Difference channel for tracking purposes, using the signal received in this channel to drive a motor controller.

Actually, the signal used for satellite tracking is not only the Δ signal, but the ratio Δ/Σ, which makes the system to be insensitive to weak fading effects. This signal is compared with a previously stored look-up table of the function values, and the antenna is pointed to the correct position from a single measurement, which makes the system to be extremely fast. Digital techniques allow this fast signal processing and decission of movement.

In a classical Monopulse scheme these two signals are downcoverted and processed through two balanced receiving chains, and an AGC is performed with the sum channel over the difference receiver, which provides the error signal. This scheme has two problems: a dual channel rotary joint and two balanced receiving chains are required.

These two drawbacks made us to consider a Modulated Monopulse scheme which had been proven to work properly in the MSAT program [3]. The block scheme is shown in the figure 1.

The sum and difference signals are generated in the RF Monopulse beamformer, and they are routed to the monopulse modulator, composed of a 180° phase shifter and a directional coupler. The difference signal goes through the shifter which is switched at a constant frequency f_c, and a signal $\Delta(t)*p(t)$ is generated at the output, where p(t) is a square wave signal. This AM modulated difference signal is added through a directional coupler to the sum signal. Since the coupling factor gives place to a path loss of $(1-C^2)^{1/2}$ in the sum channel, the output signal is:

$$V(t) = (1 - C^2)^{1/2}\, \Sigma(\theta,t) + C\, \Delta(\theta,t)\, p(t)$$

The modulation of the difference port frequency-multiplexes the Sum and the Difference signals. Both signals are included in V(t) independently: its spectrum has the sum signal at f_{Rx}, and the difference signal at $f_{Rx} \pm f_c$. This signal is downconverted and splitted; one of the channels is lowpass filtered and the Sum information signal is obtained, and the other branch is synchronously detected with a delayed replica of the modulating signal p(t). A ratio device provides a signal proportional to Δ/Σ used to control the antenna movements through the tracking processor.

The receiver used in this project was manufactured by SNEC(France), and it performed the detection and demodulation processes, providing two output signals which were handled by the tracking processor. The integration time of the receiver was 50ms and the output signals ranged from 0 to 3volts and from -2.5 to 2.5 volts for the sum and difference channels respectively.

The tracking processor is based in the general purpose microprocessor Z80, with three parallel I/O programmable controllers 8255 which provide a TTL-compatible interface between the data interfaces and the CPU, RAM and ROM memories for the source code and process operations, and a minimum of additional logic.

The signals supplied by the tracking receiver are routed to two identical PMI-ADC912 Analog to Digital converters of 12 bits. The sampling frequency is 3.2 kHz, and the conversion time is 12 microseconds.

The step angle of the motor was 7.5° with a reduction ratio of 1:7. The maximum angular speed of the antenna was 40°/sec. The use of a stepper motor allows the system not to require any kind of encoder, since the microprocessor counts the number of steps to control the antenna movements.

The algorithms are stored in EPROM memory. Two 12 bits ports are inputs to the CPU which acquire the data supplied by the A/D converters. One 8 bits digital port is configured for I/O control data going to, and coming from the CPU. The data to the motor drivers is composed of the motion direction and the number of steps that the motor has to move.

The tracking receiver may also include additional pointing devices such as solid state turn rate sensors in order to maintain the link in special fading environments or when the signal coming from the satellite disappears (in a tunnel, for instance). These devices have a fast response, so they could be used as the prime tracking process, checking periodically with the open loop system in order to correct the possible drift error.

Acquisition and Tracking processes

In the initial acquisition, the processor commads the antenna to perform a 360° scan looking for the satellite. The number of steps in acquisition mode is given by the antenna beamwidth rounded to an integer number of motor steps. Then, the antenna moves in 15° steps looking for the maximum. In each step the signal level is read and averaged.

The channel used in the acquisition is the sum pattern. Once the system recognizes the maximum, the antenna is commanded to move to the indicated position. The antenna follows the minimum path length to move to the indicated position.The value of the maximum is stored and used to calculate a threshold level which is 7dB below.

Once the antenna has been roughly pointed to the satellite direction in the initial acquisition, the system switches to the tracking algorithm to keep the antenna correctly pointed.

The signal level of the sum channel controls the system state: if its value is greater than the threshold level it remains in tracking mode, but if its value is lower than the threshold, after 5 seconds, it goes into reacquisition.

DESCRIPTION OF THE ANTENNA

In order to reduce the number of elements needed to obtain the specified gain (10-12 dBi), and to reduce also the mass and the inertia of the aerial, a low permittivity substrate ($\varepsilon \approx 1.1$) was selected, giving place to a larger size with higher gain in a single element.

Three square patches were needed to meet the gain requirement, and to comply with the intersatellite isolation specification, the lateral elements were fed with an amplitude taper of 3dB.

A substrate thickness of 5mm was taken; the initial selection of 10mm made the patch to have a quite large port to port coupling, which affected the crospolarization level. This height reduction does not affect seriously the gain of the radiator since the patch size is almost unaltered by the substrate thickness.

The VSWR bandwidth of the patch element is about 55MHz (≈3%) with a port to port decoupling better than 30dB. Two matching networks with double-stub tuners are connected at both inputs of each radiator and to the 3dB branch coupler required for circular polarization. The circularly polarized elements are connected to the RF comparator which provides the sum and difference signals. It also provides the amplitude taper to the lateral elements in the sum pattern. Sum and difference channels are isolated more than 35dB at Rx and about 25 at Tx. Figure 2 shows the antenna and the beam forming network layouts.

Crosstalk between sum and difference ports is an important factor in a Monopulse system since a lack of isolation gives place to errors in the difference signal, which affects the pointing error information. The isolation level obtained with our comparator (≈35 dB) assured a minimum error due to coupling.

Sum and difference radiation patterns measured at midband Rx frequency are shown in the figure 3. Gain and axial ratio performances vs. frequency of the isolated antenna are shown in the figure 4.

A constraint associated to this antenna design is the broad elevation beam of the array, affected by the closely situated car roof, which acts as a ground plane. A GTD study of the ground plane effects on the antenna performances made us to select an antenna height over the ground plane of 0.5λ (≈ 90 mm) to minimize the axial ratio deterioration.

The modulator which generates the difference over sum signal is used to provide the error voltage to move the antenna. It is composed of a directional coupler and a continously switched 180° phase shifter which multiplexes the sum and difference signals, providing the signal $\Sigma \pm \Delta$, routed to the receiver, where a special circuitry at IF level is used to recover the sum signal and the difference over sum signal to control the antenna.

The design of the $0\text{-}\pi$ phase modulator is based on a 180° rat race hybrid coupler. An analysis of the operation shows that the required phase shift is obtained with two diodes, oppositely biased, placed on the balanced ports of the hybrid. When one diode is biased on its forward conduction state, the other is reverse biased with the junction voltage of the first one (≈ 0.85V). This operation limits the RF power handling when the system transmits. An evaluation of the power handling capability of the modulator gave 36.7dBm at Tx for the diode selected (MA/4P404).

The complete modulator network (coupler and phase shifter) is sketched in the figure 5. Sum and difference path lengths are phase balanced in order to have a correct sum ($\Sigma + \Delta$) and difference ($\Sigma - \Delta$) operations. The additional length of line was included in the direct (Σ) path of the coupler, giving place to higher losses in this channel (≈ 1dB). The coupling level between the difference and the input port was 10dB, and the isolation between channels was better than 20dB over the band. The rest of the RF circuitry is isolated from the DC signal with several DC blocking capacitors.

The input match of the complete outdoor unit (antenna and difference over sum modulator) measured at the rotary joint port is better than 20dB at 1550MHz and better than 13dB at 1650MHz.

MECHANICAL DESIGN

The materials used for the specific components are nylon (gears) and aluminium (supporting structures). This lowers the weight of the moving parts and reduces the required motor torque. The aluminium pieces have been thought to be press machined. The required antenna height (90mm) is included inside the radome design, which also acts as external enclosure and interface, providing installation both on a car roof or in a mast in the case of trucks.

Just two output connectors exist, one for the RF and DC line and one for the motor bias and control. This minimizes the complexity of the interfaces between the antenna and the mobile. This design allows an estimated cost in mass production of 1200US$.

The general drawing of the antenna is shown in the figure 6. The dimensions of the antenna with the radome are 27x59cm(diameter).

FUNCTIONAL TESTS

The tests done were dedicated to evaluate the tracking accuracy and the mobile to satellite link mainteinance for different environments. The antenna was mounted in a van where all the required equipment for piloting the results had been placed. The spacecraft used for this measurements was the INMARSAT satellite, which transmits a PRODAT carrier signal at 1547.8 MHz.

Figure 7 plots one course of the mobile, where the gyrocompass reading and the antenna indication are shown. Table I shows the performances of the system in terms of signal fluctuation and pointing error, measured by comparison with the signal of a reference gyrocompass.

CONCLUSIONS

A low cost, medium gain microstrip antenna for L-band mobile communications has been shown. It is one of the first prototypes of mobile satellite antennas developed in Europe.

The operational basis of the tracking system have been presented, and the tracking and acquisition processes have been outlined. The antenna and associated RF parts have been described, and finally they have been presented relevant results on field tests.

REFERENCES

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[2] "SMALL STEERABLE LAND MOBILE ANTENNA" Final Report. ref TDC-LMA-200. Dec 92. Estec contract no. 8598/89

[3] MSAT-X Quarterly. no.13 Jet Propulsion Laboratory. Jan.88

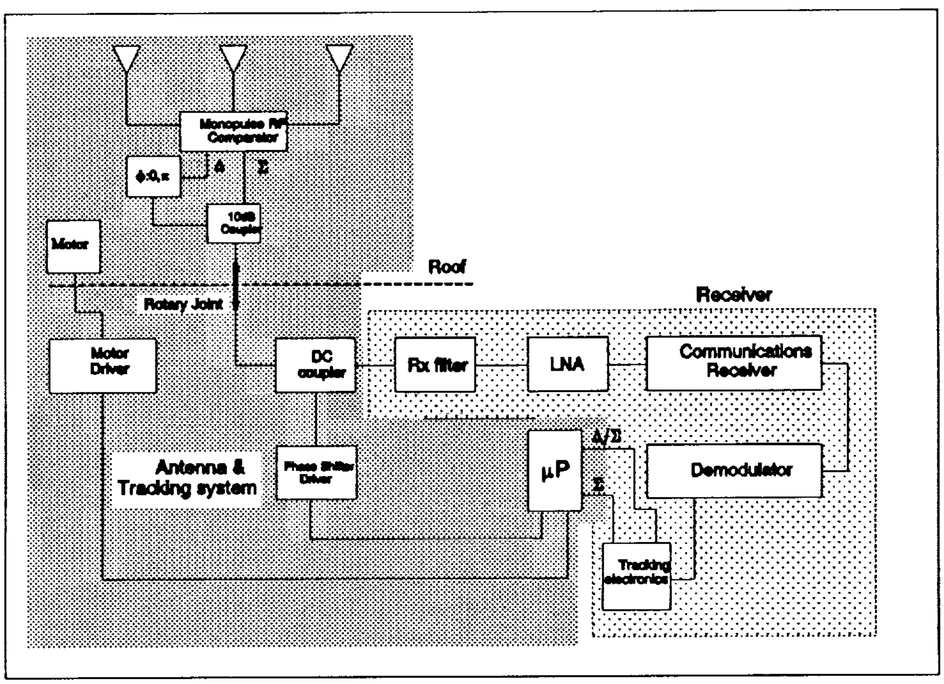

Figure 1.- Modulated monopulse schematics

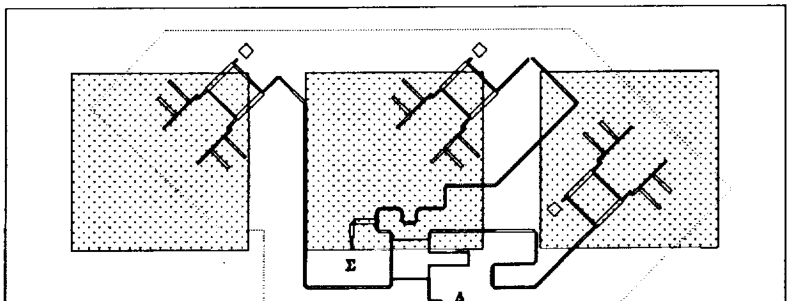

Figure 2.- Layouts of the antenna and RF components showing the dual-band matching network and the monopulse RF beamformer.

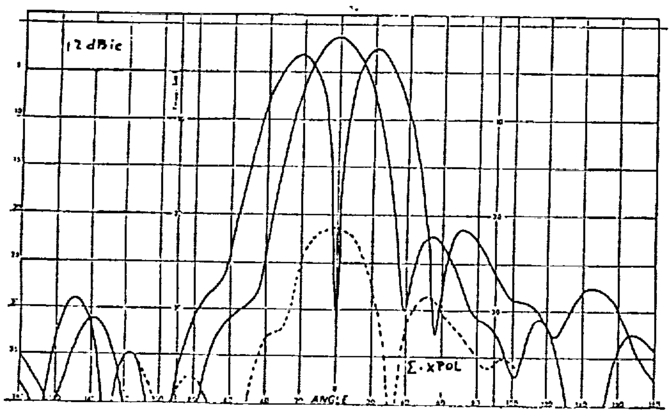

Figure 3.- Sum and Difference Radiation Patterns of the Antenna isolated from the Ground Plane. Operational Frequency: 1550MHz.

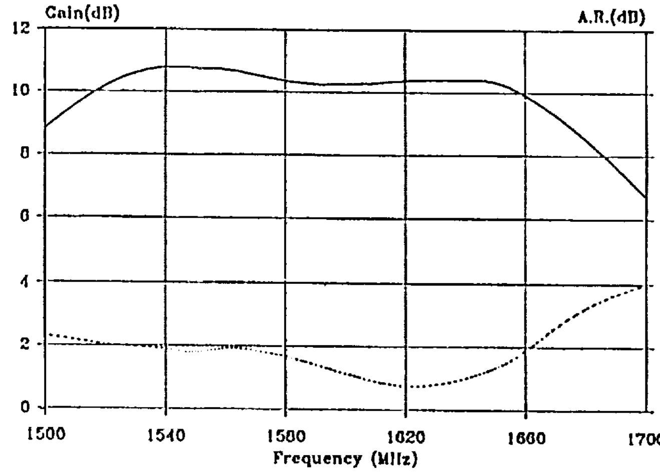

Figure 4.- Gain and Axial Ratio variation vs. frequency of the antenna, isolated from the Ground Plane.

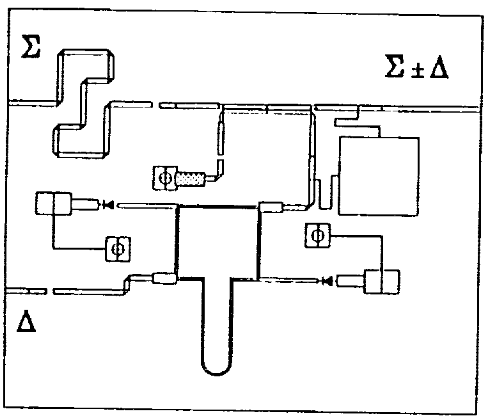

Figure 5.- Layout of the modulator component for multiplexing the difference signal over the sum channel. The antenna is isolated with DC-blocking capacitors.

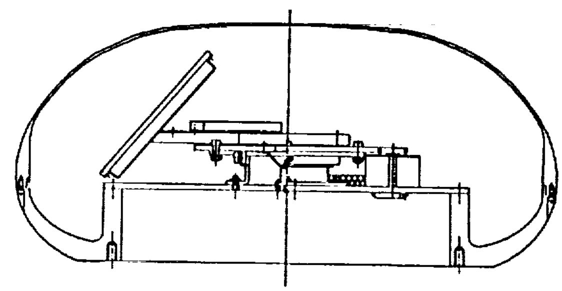

Figure 6.- Pictorial view of the antenna with the radome.

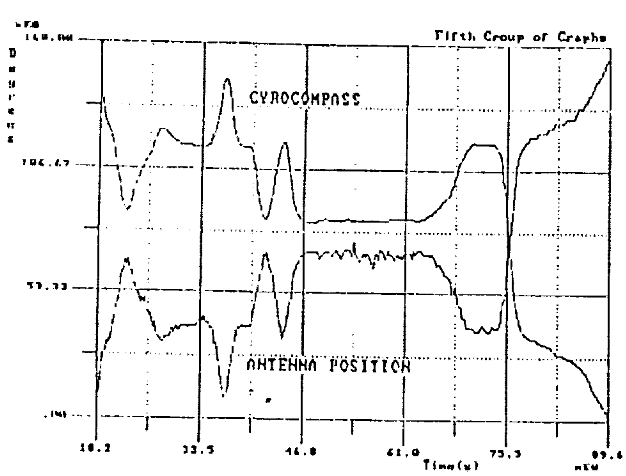

Figure 7.- Functional Test: course plot of the antenna under real conditions. Operational Frequency: 1547.8 MHz.

Table I

Course	Pointing error (degrees rms)	Signal level (dB rms)	Sample duration (sec)
Straight	0.74	-0.30	10
	1.86	-2.59	15
	1.37	-1.09	15
	3.50	-3.90	25
	1.07	-1.59	30
	1.24	-0.33	10
With turns	3.14	-0.5	42
	2.37	-1.7	30
	2.07	-1.47	30
	3.74	-1.76	20
	2.91	-1.52	45