LOW COST ELECTRONICALLY STEERED ANTENNA AND RECEIVER SYSTEM FOR MOBILE SATELLITE COMMUNICATIONS

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Abstract. *The design, construction and basic characteristics of an electronically steered, adaptive phased array antenna for land mobile satellite communications are described. The antenna system includes an array of six microstrip stacked patch antennas, each connected to an RF channel, which include an MMIC Low Noise Amplifier and a commercial silicon monolithic I-Q modulator. A 6-way microstrip combiner adds the six channels so that the resulting signal is introduced in a GPS receiver, constructed with two commercial ASICs. This receiver has a PC interface which include control boards, specifically designed for this application, that allow to set the amplitude and phase of each RF channel. Acquisition and tracking algorithms have been programmed in C-language for working in real time using as input data the signal levels provided by the receiver. The work involved in the antenna RF subsystem design, calibration and tracking algorithms and some field tests is reported.*

I. INTRODUCTION

In the field of satellite communications, serious attention is actually being paid to land-mobile services. It is hardly surprising because, although there are a few reliable ways of communicating with ships in the middle of an ocean, the land-dweller generally has a choice of methods of communications. These might include telephone, cellular radio, microwave links and CB radio. Land mobile needs are currently satisfied mostly by cellular radio, but there are plenty of applications where satellite communications are preferable or perhaps the only solution. Mobile communications in sparsely-populated areas or between distant locations are the first two examples of this. Nowadays, the potential market for mobile communications provided by satellite systems has triggered the development of a wide variety of future integrated communications and navigation systems, like IRIDIUM, IMMARSAT-P, GLOBALSTAR, ODYSSEY and GPS as well [1].

On the other hand, there is a currently considerable interest in the use of adaptive array antennas for applications in the field of mobile satellite communications [2][3][4], because they offer advantages over conventional antennas with a fixed pattern, such as flexible communication zones, or an antenna pattern for the actual signal situation.

This paper presents the planar array design, radiation pattern measurements, the RF subsystem performances and design, the GPS commercial receiver and the digital circuitry needed to make the main beam scan for satellites and track them into the space. The system also includes several algorithms to maximize the received signal in urban environments, which are actually being developed and tested. The experimental characterization has been realized using the signal transmitted by GPS (Global Positioning System) satellites due to good hardware availability. Fig. 1 shows a photograph of the developed adaptive antenna system.

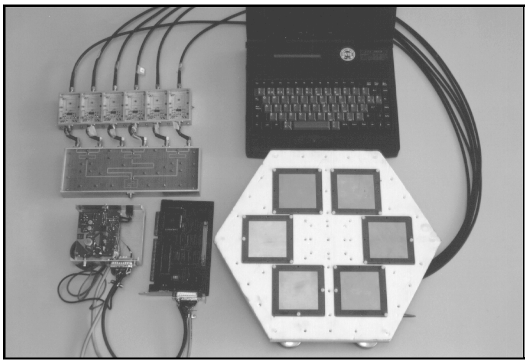

Fig. 1. Adaptive antenna system.

II. SYSTEM DESCRIPTION

II.1. Array antenna design.

Microstrip antennas have demonstrated to be adequate for mobile communications due to their many advantages, such as low profile and weight, easy integration with printed circuits (both in monolithic and hybrid technologies), photolithic process of fabrication, etc [5]. To suit the requirements of gain and bandwidth, a 6-element array was developed using six microstrip square patches in stacked configuration. Each one was placed in the corner of a regular hexagon of side equal to 10.59cm ($0.55\lambda_0$ for f=1.558Ghz). Two orthogonal probes were used to connect the patch to the inputs of a 3dB-90º hybrid in order to receive circularly polarized waves. The output of the hybrid is followed by a MMIC Low Noise Amplifier (LNA), specifically developed for this application.

A) Stacked microstrip patch array element.

The stacked patch antenna overcomes the inherent narrow bandwidth of the conventional microstrip antenna. This is done by placing a parasitic patch above the driven one, thus symmetry of the antenna is retained and no extra space is needed in the array for the parasitic element. A computer code based on a rigorous Green's function technique [6] has been developed to design the stacked element. The final design consists of square upper and lower patches of side 6,62cm. and impressed on a CuClad substrate of ε_r of 2.27 and h=3.175mm. Fig. 2 shows the metallic plate and the foam layer with the patches.

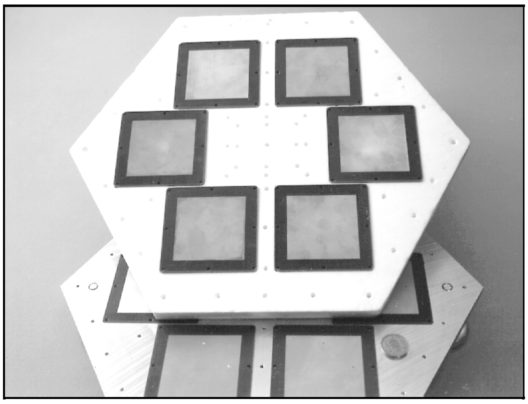

Fig. 2. Array antenna with upper and lower patches.

The separation between the upper and lower patches is provided by placing a foam between them. Varying the thickness of this foam layer, the separation between the lower and upper patches changes and the coupling between them, and so input impedance. Fig. 3 shows a measurement of the return losses of the stacked patch element for different thicknesses of foam. Bandwidths up to 230MHz (SWR=2:1) have been observed for the present design. For 15mm. thick foam the measured directivity goes to 8 and 9dB. over the frequency bandwidh. An efficiency around 65% and a cross-polar component below -20dB have been measured.

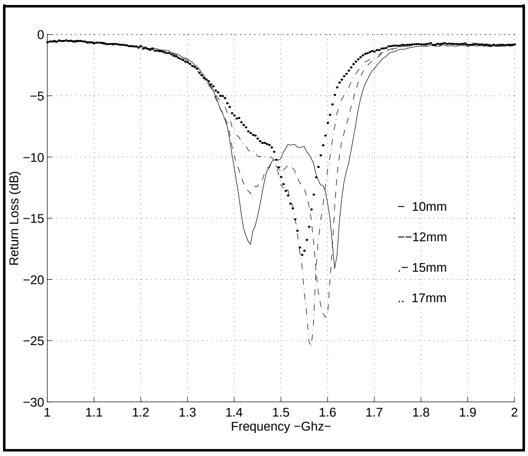

Fig. 3. Input impedance of stacked patch element.

B) MMIC Low Noise Amplifier.

The LNA monolithic is a two-stage circuit with input, output and interstate matching circuits. A source inductor is used in the first stage to achieve low noise figure and good input matching simultaneously. For the second stage, RC feedback is used to improve the stability in the band DC-20GHz and to increase the gain of the whole amplifier. The performance of the circuit in a 250MHz band centered at 1.575GHz can be summarized as follows: the input and output matching is better than -10 dB., the gain is better than 23dB and the noise figure is less than 2.7dB. The power consumption is 60mW. Fig. 4 shows a photograph of the chip described above.

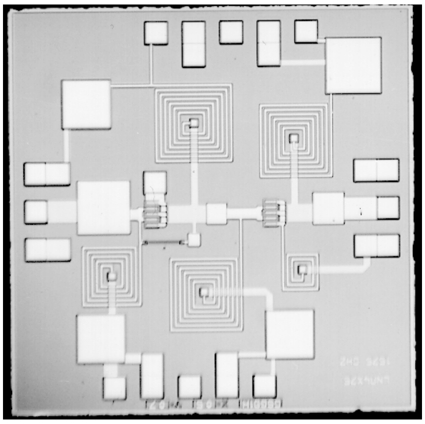

Fig. 4. Photograph of MMIC low noise amplifier.

C) Measurements.

The array was measured in an anecoic chamber. The radiation pattern of the whole array is easily obtained by combining the pattern of the six elements. The weights employed in each antenna were obtained assuming non-coupling between elements. Fig. 5 displays the radiation pattern of the array looking at broadside where each element pattern has been normalized. A maximum value of 15.35dB can be observed. The θ_{3dB} is equal to ±15.5º. The crosspolar component with the array at broadside is 25.33dB below the copolar one for any angle (θ,ϕ).

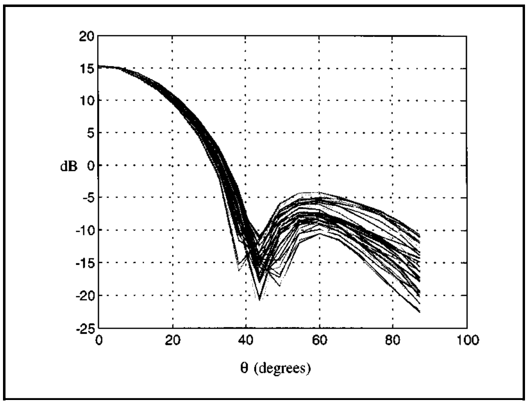

Fig. 5. Radiation pattern of array at broadside.

II.2. RF Receiver Architecture.

A) RF Channel.

The signal from each element of the array antenna is applied to the RF subsystem, where beam conformation will be done.

The RF subsystem consists of six identical channels, one for each array antenna element. The RF chain has been designed in hybrid technology and each channel includes a 3dB-90º hybrid and the IC HPMX2001 from Hewlett-Packard [7]. The device is a Quadrature Phase Shift Keyed (QPSK) modulator which consists of two double balanced mixers, a summing circuit to combine the output and an amplifier as the output stage. The use of this analog device as a vector control function is a key element of this design [8-9]. The obtained structure can be controlled by two DC voltages, obtained with specifically developed control boards an a PC. If θ_n is the phase shift and k_n (in dB) is the attenuation needed in the *n*-element of the array, the values required in the inputs i and q for its phase-shifter are calculated as:

$$V_{i,n} = 10^{(k_n/20)} \cdot \cos(\theta_n) \quad , \quad V_{q,n} = 10^{(k_n/20)} \cdot \sin(\theta_n)$$
$$n = 1,2,...,6$$

Therefore, twelve control values are needed for the whole system, which will be converted into voltages through 8-bit D/A converters and its asociated latches, placed in two PC specifically developed boards. With an appropiate bias setup a precision of ±0.5 dB in amplitude and ±1º in phase can be obtained in the worst case. Fig. 6 depicts the response in amplitude and phase for an I-Q modulator at 0 and 10 dB attenuation values.

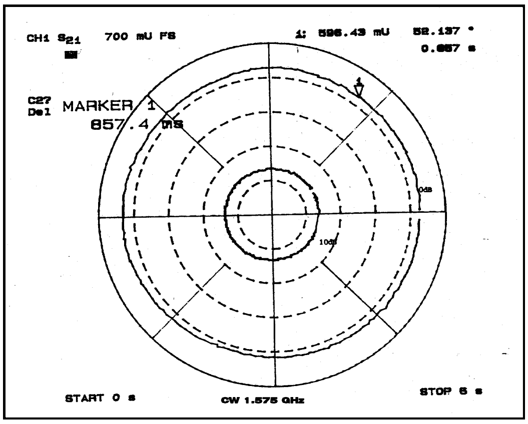

Fig. 6. Attenuation and phase control in RF channel.

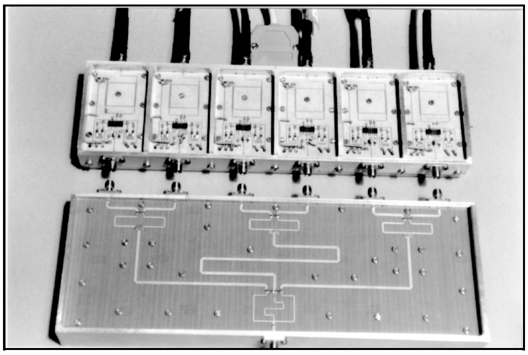

Fig. 7 I-Q modulators and 6-way combiner.

Finally, a 6-way microstrip combiner [10] adds the RF outputs signals from each RF channel. A balance of 0.5dB in amplitude and 1.5º in phase for all inputs was obtained. This phase errors have weak influence because it will be corrected in a subsequent calibration process. A photograph of the RF subsystem can be seen in figure 7. Once the signals have been added they will be processed by the GPS receiver.

B) Commercial GPS Receiver.

The designed and implemented GPS receiver consists of a standard DS-SS receiver which is composed of two basic stages: the downconversion from RF to IF and the IF processing to get the base band signals.

The commercial ASICs GP1010 and GP1020 from GEC Plessey Semiconductors [11-12] are used in the implementation of the receiver. The first one converts the input frequency in three stages to get a final IF signal centered at 4.32MHz. The output of the last mixer is sampled at 5.71 Mhz and coded with only two bits. The second ASIC, a six-channel parallel correlator, acomplishes the following tasks: Down conversion to base band with the necessary Doppler cancellation, decorrelation or matched filtering with the code assigned to each satellite, bit synchronization and decision over the symbol of the constellation (BPSK).

All the Digital Signal Processing involved is driven by a low cost microprocessor. The task carried out by the microprocessor comprises the estimation of the satellite-user distance, acquisition of the Universal Coordinated Time (UCT), decoding of the navigation message sent by the satellites and the computation of the users location. In addition, the microprocessor has to control the digital ASIC. This architecture of the receiver allows a great flexibility and robustness.

II.3. Software Description for Beam Control.

An specifically developed control and processing software is installed in the computer, which allows to control the system and makes it work according to the implemented algorithms.

The software offers some facilities to the user, who can choose between manual (for special purposes) and automatic ways of working. The manual mode lets collect received signal data in conditions freely chosen by the user; in this way, any situation can be tested. In automatic mode three main functions can be performed: searching, tracking and position parameters determination.

Searching runs automatically before tracking. The vertical beamwidth (3dB.) is about 60º, large enough to determine the satellite azimuth in just an azimuthal sweep at a medium steady elevation (say 50º). Relative elevation of the satellite is then calculated in a single pseudomonopulse operation, pointing beams to zero and ninety degrees. The vertical monopulse function has been calculated and successfully tested.

Tracking is made on an azimuth pseudomonopulse basis. Having an expected position of the satellite, beams are directed sequentially right and left from this position; signal levels received are used to give the monopulse function (level difference divided by level sum) and so a predicted position of the satellite. A further filtering finally gives the new expected position. This process is repeated while tracking.

III. MEASUREMENTS AND FIELD TESTS

In figure 8 a comparison between a simulated and an actual azimuthal sweep can be seen. It is to point out the fact that both plots match significantly. Given that searching is made through azimuthal sweep, this figure gives an idea of the good accuracy in determining the satellite azimuth.

Tracking performances are shown in figure 9 for some different satellites having low and medium elevations. Corresponding elevation graphics are disposed to see that signal levels grow according to the satellite elevation, due mostly to the fact that non omnidirectional antennas are used. There are also included the signal levels obtained with only an antenna, to make easier to appreciate the difference with the whole array.

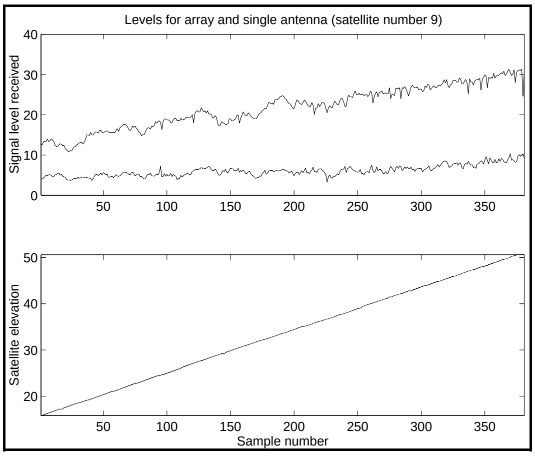

Fig. 9. Level signals while tracking.

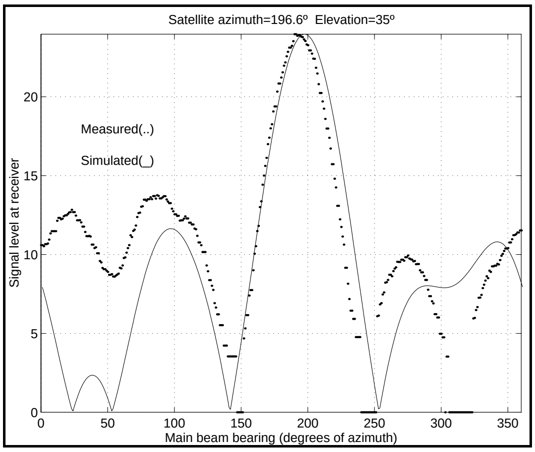

Fig. 8. Complete azimuthal scanning.

IV. CONCLUSIONS

The design and basic characteristics of an electronically steered adaptive array antenna for land vehicle operation are described. The aim with the reported antenna has been to obtain a system allowing to perform experiments in order to evaluate a possible solution to the mobile antenna segment of a mobile satellite communication system.

The work involved in the RF subsystem design, the use of commercial and low cost components, the calibration and tracking algorithms and some field tests have been reported.

V. ACKNOWLEDGEMENTS

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