Electronic Steering Antenna Onboard for Satellite Communications in X Band.

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Abstract*— The antenna presented in this article will be developed for satellite communications onboard systems based on the recommendations ITU-R S.580-6 [1] and ITU-R S.465-5 [2]. The antenna consists of printed elements grouped in an array, this terminal works in a frequency band from 7.25 up to 8.4 GHz (14.7% of bandwidth), where both bands, reception (7.25 – 7.75 GHz) and transmission (7.9 – 8.4 GHz), are included simultaneously. The antenna reaches a gain about 31 dBi, and it has a radiation pattern with a beamwidth smaller than 10º and a dual circular polarization. The antenna has the capability to steer in elevation from 90º to 40º electronically and 360º in azimuth with a motorized junction.

***Index terms*— Steering antenna, X band.**

I. Introduction

The aim of this work is the development of an onboard satellite communications system in X band. This printed antenna [3] has the following capabilities: transmitting multimedia data, thanks to its broadband capacity, full steering direction (360º azimuths and 50º elevation) get by electronic and mechanically systems and direct synchronization from the mobile vehicle by signal processing tracking.

The gain offered by the antenna will allow the plane to communicate from every longitude or latitude of the earth. Thorough calculations were made in order to assure coverage under most probable weather conditions. Frequency bands, transmission and reception, are interchangeable by changing the feeding connectors. The radome will be integrated in the fuselage of the structure and will provide weatherproof to the system. A scheme is shown in Figure 1.

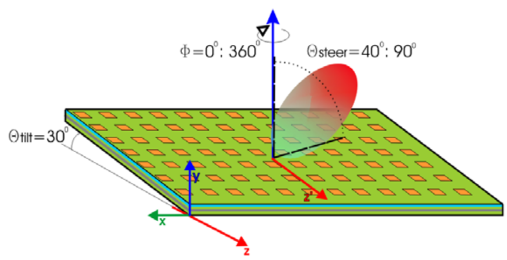

Fig. 1 Usage Stage.

II. Specifications and Architecture

The antenna operates with left hand circular polarization in reception band (7.25-7.75 GHz) and right hand circular polarization in transmission band (7.9-8.4 GHz). The key element is a resonant double stacked patch, which is fed by a miniaturized 90º branch-line coupler to obtain the desired circular polarizations (RHCP or LHCP) and ensures adequate port coupling isolation.

A rectangular structure has been selected formed by an array [4] of 16x24 elements. These elements are treated in two different ways:

A. Rows

First grouped in rows, separated a distance between them of 0.85λ. In case of using an uniform excitation the side lobe levels exceed the limit of the recommendations mentioned before. Due to that restriction, a progressive reduction of the feeding amplitude from the centre to the edges of each row will be implemented with a passive unbalance feeding network.

B. Columns

Thus secondly, 16 rows of 24 elements are grouped and a separation of 0.5λ. The steering direction of the main beam is achieved due to the phase shifting feeding between each row. The terminal will be integrated in the fuselage and because of that, it will be needed to steer close to endfire directions. Therefore to avoid the closer angles to endfire the planar structure is raised. With the installation of a wedge ($\vartheta_{tilt}=30º$) the final steering direction will be from 90º - 40º.

Being the antenna final dimensions: 33cm x 85cm x 20cm.

III. Antenna Design

One of the main features of the system is its big bandwidth. The radiating element (Fig.2) enables to cover 1.15 GHz, therefore, Tx and Rx bands are covered simultaneously. Another of the main features is the capability for electronically steering, which is get by an active feeding network with phase shifters. The last part included in this section will show the passive feeding network.

A. *Radiating element*

The radiating element is composed of two stacked patches, the upper one is fed by electromagnetic coupling, and the bottom one, is fed by two via holes (Fig.3) which get the circular polarization. By using a miniaturized hybrid coupler in two stages, we get to cover the frequency band needed, to use two circular polarizations (RHCP and LHCP) at the same time, and to insulate the both channels (Tx and Rx).

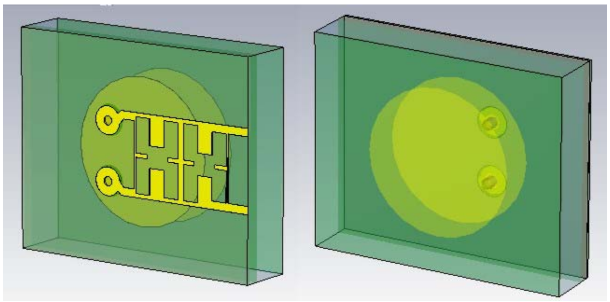

Fig. 2 Radiating element.

In (Fig.3) it can be seen a radiating element layer view. In that figure, we can see how the feeding network and hybrid couplers feed each patch. The structure is composed of an inverted microstrip, a common ground plane and a microstrip on top. one foam layer to move apart the two patches, and a microstrip without ground plane.

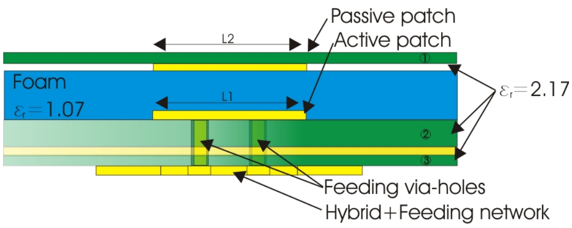

Fig. 3 Radiating element layer view.

The substrate permittivity is 2.17 in order to get a good radiation of the antenna. The thickness of the different layers has been optimize to get the proper radiation pattern and beamwidth. The dimensions of the patches and hybrid couplers have been calculated for low reflection coefficient and insertion losses.

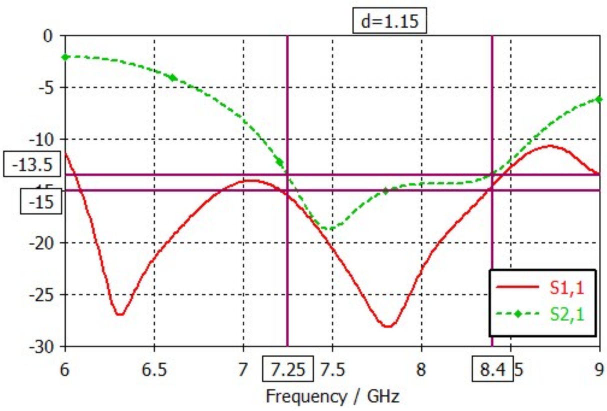

Fig. 4 Radiating element S-parameters.

S-parameters of radiating element are shown in (Fig.4). The reflection coefficient is S_{11} <-15 dB and the hybrid gets an isolation of S_{21} <-13.5. The isolation between the two frequency bands (7.25 – 7.75 GHz) and (7.9 – 8.4 GHz) will assure that the transmission power do not affect the receiving signal.

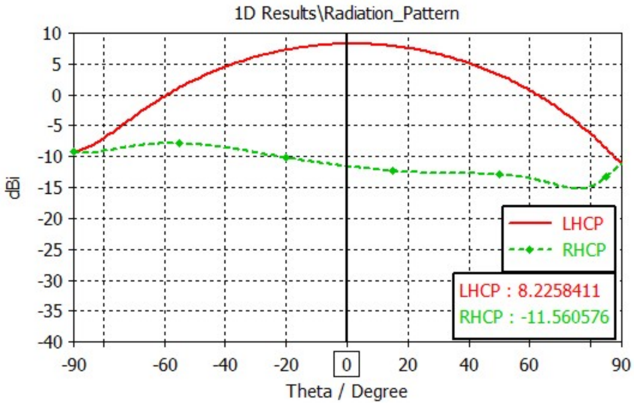

Fig. 5 Radiation pattern of the radiating element f=7.825GHz, φ=0º.

The CP/XP is higher than 19 dB in the middle of the frequency band (f_c= 7.825 GHz), the directivity is over 8 dBi (Fig.5).

Furthermore, in (Fig.6) it can be seen the purity of the circular polarization, in the centre of the working bands, f_{c1}=7.5 GHz and f_{c2}=8.15 GHz. Axial ratio value is above 3 dB for $\Delta\vartheta$=70º.

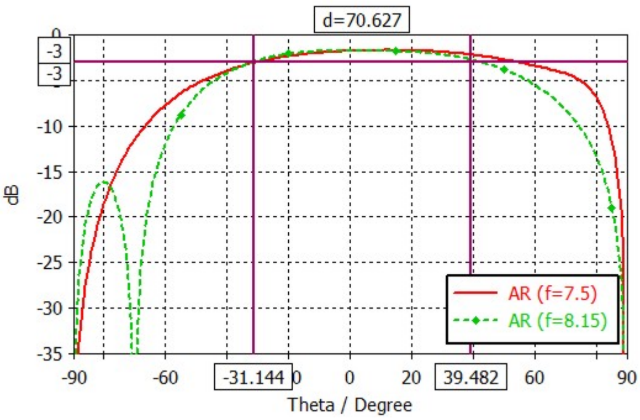

Fig. 6 Axial ratio of the radiating element.

B. *Active feeding network*

The active feeding network is presented in (Fig.7) and (Fig.8). Each subsystem will be the responsible for adapting the signal in amplitude, noise or phase. In both cases, transmitter and receiver, the subsystem in charge for beam steering will be the phase shifters, these, can be digital or analogical, but in both cases TTD (true-time-delay) in order to cover the whole frequency operation band.

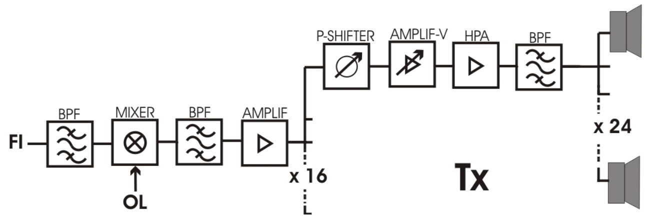

Fig. 7 Transmitter diagram.

In receiver system, another filter is added after the antenna in order to minimize the power transmitted, coupled in the receiver system.

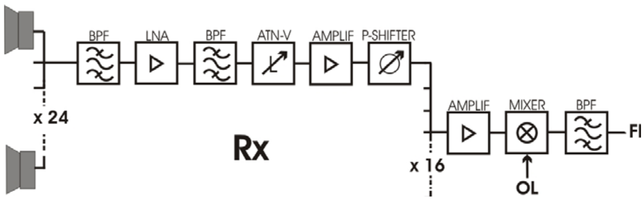

Fig. 8 Receiver diagram.

The steering range needed in elevation goes from 10º until 60º above the horizon. However, the plane in which the antenna is supported is tilted, thus, the new steering range will be from 40º to 90º. Electromagnetic simulations (in dashed line) and the analytic simulations (continuous line) for the different steering directions are presented in (Fig.9). The simulations were carried out with a structure of 16x1 elements.

I would like to emphasize, the directivity losses of 3 dB between the perpendicular steering direction (90º, or broadside) and the worst steering angle case (40º). This is due to the non isotropic properties of the radiating element and the array effect.

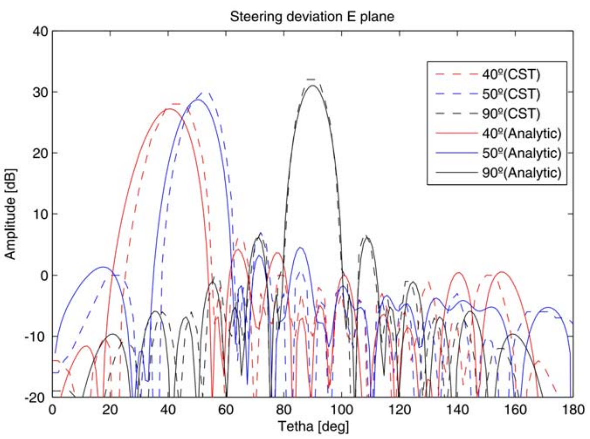

Fig. 9 Radiation pattern of 16x1 array φ=0º.

The feeding amplitude and phase coefficients were calculated (Fig.10) for reducing the side lobe levels, and get the desired steering angles.

Further developments in the project, will include a genetic algorithm. This algorithm will calculate in real time the best coefficients.

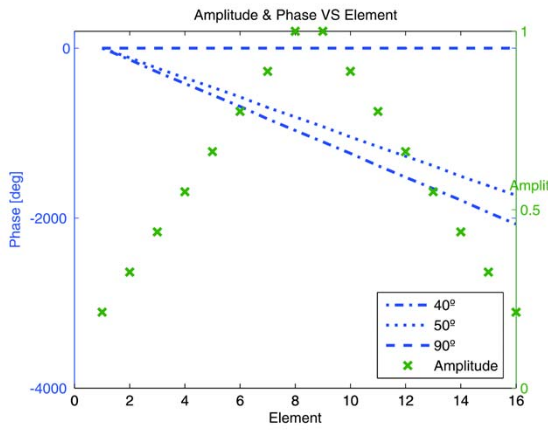

Fig. 10 Amplitude and phase of the active network elements.

C. *Passive feeding network*

To construct an unbalanced feeding network is the only way to reduce the side lobe level. Therefore the array 1x4 shown in (Fig.11) is a sub array that will compound the final antenna.

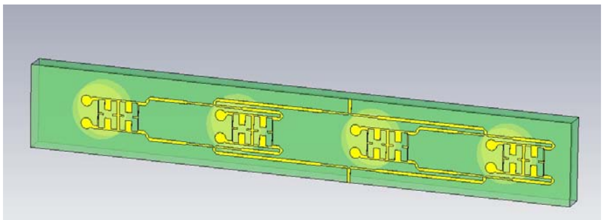

Fig. 11 Array patch antenna 1x4.

The radiation pattern is shown in (Fig.12), it has a beamwidth of 30º and a directivity of 14 dBi. Thus, 6 sub arrays in horizontal will be group, each sub array will be fed with an specific amplitude in order to obey the ITU-R required.

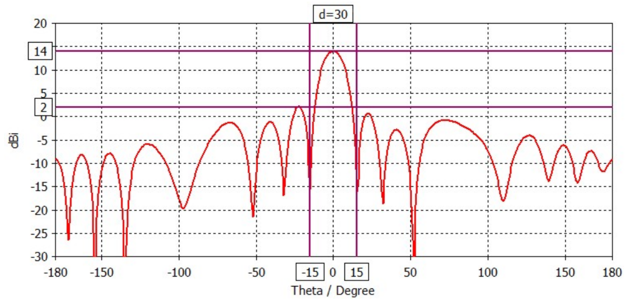

Fig. 12 Array patch antenna 1x4 radiation pattern H plane, f=7.825GHz.

IV. Prototype

The available space in the passive feeding network is one problem for this kind of antenna, because the vertical separation between the elements is 20.68 mm (0.5λ @ 7.25 GHz). For this reason, a miniaturized hybrid coupler was design. Basically, the reduction consists in substitute each line in the model of a branch line for its equivalent quarter – wavelength transmission line of T- model [5].

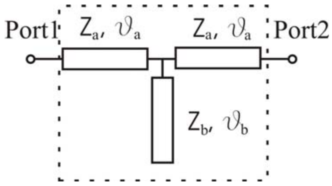

Fig. 13 Equivalent quarter – wavelength transmission line of T-model.

$$Z_a = \frac{Z_0}{\tan\theta_a} \quad (1)$$

$$Y_b \tan\theta_b = \frac{2}{Z_a \tan 2\theta_a} \quad (2)$$

A hybrid coupler was designed, simulated and constructed following these guidelines. Final dimensions are less than 8mm x 10mm (Fig.14).

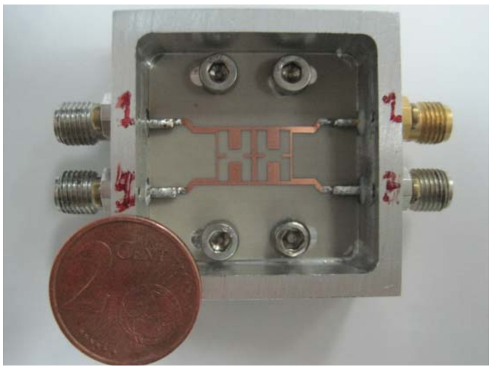

Fig. 14 Miniaturized hybrid coupler photograph.

Electromagnetic optimizations and simulations were carried out. These simulations and measurements can be seen in (Fig.15) module of S-parameters and (Fig.16) phase of S-parameters.

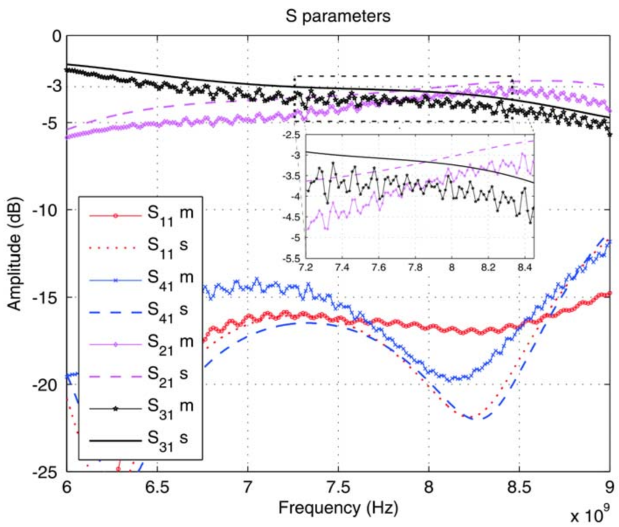

Fig. 15 Hybrid coupler S-parameters (module) m=measured, s= simulated.

Reflection coefficient is $S_{11} < -15$ dB and isolation is $S_{41} < -15$ dB) and transmission coefficients approximately are -3.5 dB (S_{21}, S_{31} =-3.5 ±0.5 dB) (Fig.15).

In (Fig.16) it can be seen the difference between the phases of S_{21} and S_{31} is ~90º ± 5º.

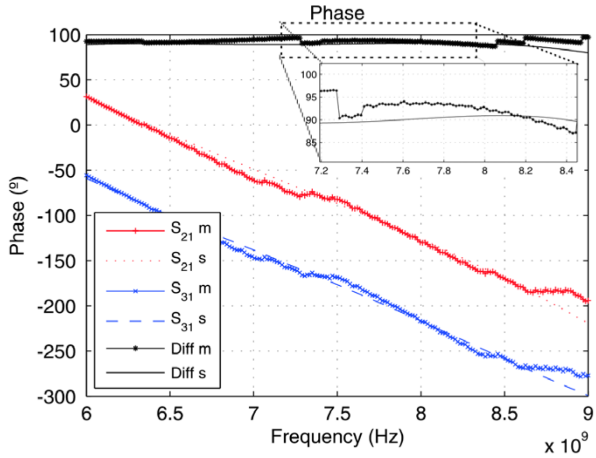

Fig. 16 Hybrid coupler S-parameters (phase) m=measured, s= simulated.

V. Conclusions

In this work a printed antenna with electronic steering capability for onboard systems has been presented. Its parts have been developed in order to get wideband, two circular polarizations (RHCP and LHCP) and a good isolation between them. In addition a reduction of the passive feeding network was carried out and the measurements were presented.

Further results and prototypes of this antenna will be presented in EuCAP 2011, Rome.

Acknowledgment

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