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Design and prototyping of a low-cost parasitic element antenna for a telemetry-telecommand link on Ariane 6 space launcher

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Abstract— This work presents a first prototype of a TMTC (telemetry-telecommand) S-band reconfigurable antenna, validating the architecture of ESPAR (Electronically steerable parasitic array radiator) in terms of performances, integration and power handling for use on space launcher environment. The originality of this work is based on the design of high efficiency-high power handling reflective phase shifters with reduced size and their association with a large radiating surface.

Index Terms—ESPAR, beam steering antenna, reflective phase shifter, power handling, S-band, embedded antenna, space launcher, parasitic antenna.

I. INTRODUCTION

In order to improve the TMTC (Telemetry-Telecommand) link between space launcher and base stations or relay satellites, ArianeGroup wishes to equip the Ariane 6 launcher with a reconfigurable antenna. Indeed, the current antenna with a fixed radiation pattern does not allow the maintenance of an optimal RF link whatever the position of the launcher in relation to its interlocutors.

This work focuses on the development of a beamforming antenna for use on a space launch vehicle. For this application, the radiation specifications are a gain greater than 10dBi for any steering angle up to $\theta_0=45^\circ$ in directive mode. The active reflection coefficient must be less than -14dB in a bandwidth between 2.2 and 2.29 GHz and the antenna should be able to handle up to 40W of input power. The area occupied by the antenna should be less than 30 cm x 30 cm.

Given the moderate gain requirements and the goal of low-cost manufacturing, the design was based on an ESPAR architecture. This paper describes the design and measurement of this antenna.

The ESPAR architecture is based on the work of Harrington [1] who explained this concept through a study of six dipoles surrounding a central element. Only the central element is then powered. The distribution of energy between all the radiating elements of this array is done by the proximity coupling. Harrington demonstrated that the radiation pattern of such a system depends on the impedance values charging the ports of each unpowered element. The advantage of such

an architecture is to avoid the transmission lines constituting the beamforming network and the fact that the matching constraint is only on the single powered element.

Post-Harrington work has focused on arrays of limited size with fewer than ten elements leading to gains of no more than 8 dBi. Most of them have made pattern reconfiguration possible by using a PIN diode or a switch to tune the load connected to the ports of unpowered elements. These elements can then be selectively charged by a single impedance or shorted (state ON/OFF).

This degree of reconfigurability allows the freedom to choose between several radiation pattern configurations depending on the ON or OFF state of each of these tuning elements. This is for example the case in [2] where the authors worked with an array of 9 patches. The ESPAR thus had a variety of 8 directive radiation patterns with gains up to 7.5dBi at 2.45 GHz. Many recent developments involving technological improvements propose to realize the switchable reactive loads with MEMS [3] or to replace the radiating elements with dielectric-resonator antennas [4]. Since Harrington's original paper, increasing computational power has also enabled larger problems involving tens or hundreds of radiating elements to be solved [5,6].

Most of the published work on ESPAR antennas has focused on the use of monopoles as radiating elements [7], since coupling between elements is favored by their radiation pattern. However, some research has focused on diversifying the nature of these elements. For example, the use of slot antennas [8] makes possible to create a very compact antenna for the beam steering in azimuthal directions. There is also research on the use of patches to form larger arrays [9], or to enable circularly polarized radiation [10].

This paper presents the development of technological blocks to achieve the objectives of radiation pattern reconfiguration and power management. These blocks have been combined to form a linearly polarized antenna demonstrating the viability of the ESPAR concept to meet the most critical specifications.

II. DEVELOPMENT OF A SINGLE POLARIZED ESPAR ANTENNA

This section presents the development of a reflection-type phase shifter (RTPS) and a linearly polarized radiating panel. These two elements will form a first ESPAR antenna demonstrating the validity of this architecture to validate the main requirements of the specifications.

A. Definition of the ESPAR architecture

The ESPAR configuration developed in this work is shown in Figure 1. It consists of the combination of several radiating elements loaded by reactive loads that act as RTPS.

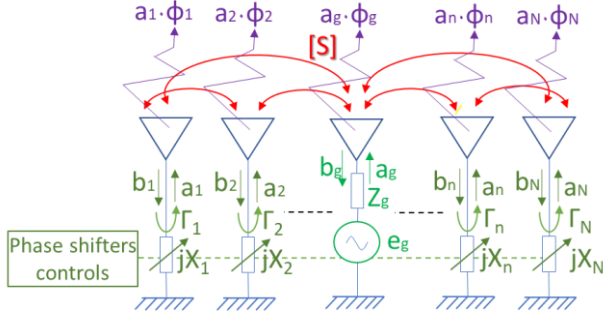


Figure 1 ESPAR architecture

The tunability of reactive loads allows for a various sets of radiation patterns, increasing with both the number of elements and the number of states available. The phase shifter and the radiating panel are therefore the two complementary technological blocks forming the ESPAR. They must be optimized to offer the best possible performance according to the specifications.

Both are developed on a substrate with a permittivity close to 3.5. The radiating panel will consist of a lattice patch printed on 3 layers, while the phase shifters are fabricated on a single layer. As shown in Figure 2, they will both share the same ground plane, forming a fully integrated antenna.

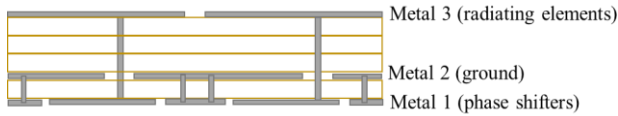


Figure 2 ESPAR PCB stacking

B. Development of the optimized reflective phase shifter

As shown in Figure 3, the architecture of the RTPS consists of a hybrid coupler whose 3 ports are loaded by short-circuited analogic tunable capacitors. The fourth port of the hybrid coupler is the access to the phase shifter realized. The total phase shift and the loss level of this circuit can be adjusted by setting the lengths of the lines connecting the tunable capacitor to the hybrid coupler (lengths TL_2 , TL_3 and TL_4 on Figure 3) and to the short circuit (length L_{cc} on Figure 3).

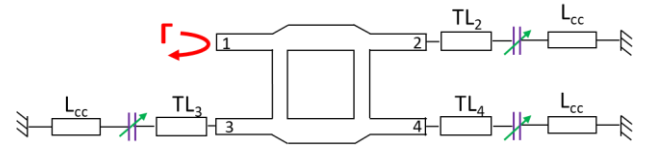


Figure 3 Reflective phase shifter architecture

A phase shift of 356° with losses below 1.8 dB was obtained by adjusting the line lengths. Figure 4 shows the measured and modeled performance of this circuit at 2.25 GHz. The Smith chart represents the reflection coefficient when the three tunable capacitors receive the same bias voltage varying from 0V to 24V.

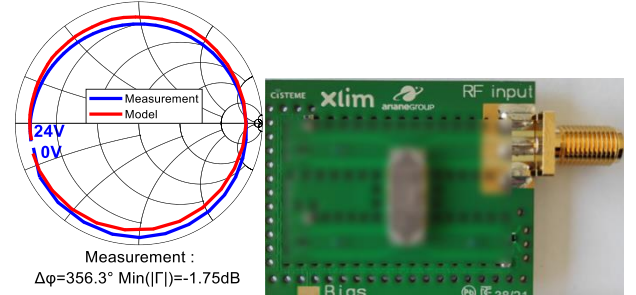


Figure 4 Realized reflective phase shifter

The RF power handling of this circuit was determined experimentally at 14 W, the value at which the breakdown of the chosen tunable capacitor occurs.

C. Development of the radiating panel

The radiating panel consists of 37 circular patch antennas array with a triangular lattice. For the ESPAR configuration, only the central patch is powered while other elements are loaded by RTPS.

Figure 5 shows the matching of the central element and some coupling levels of the scattering matrix. Those coupling levels up to 11 dB will be sufficient to spread the energy between all the antenna elements.

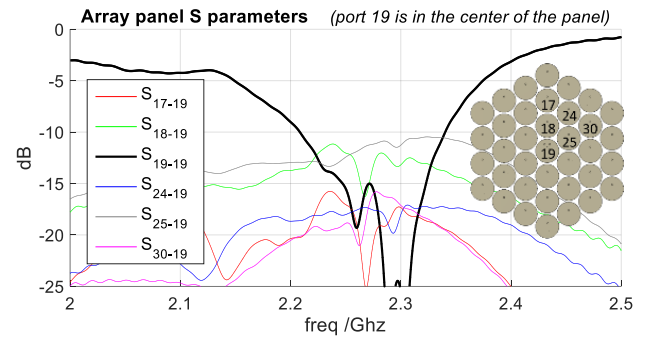


Figure 5 Simulated S parameters of the array panel

Such coupling levels would lead to a power level in the phase shifters lower than 4 W when the antenna feed power is 40 W.

D. Manufactured ESPAR

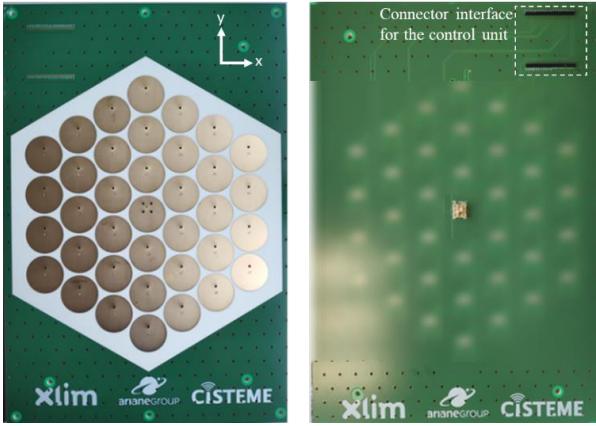


Figure 6 Manufactured ESPAR

Figure 6 shows the ESPAR fabricated. Each of the 36 phase shifters printed on the back of the panel is connected to a patch through a metalized via. The control unit is plugged into an interface in one corner of the antenna providing 36 independent bias voltages to each phase shifter through printed lines. The central element is fed by a SMA connector. The antenna has been measured for several beam steering, Figure 7 and Figure 8 shows a configuration for the control unit to achieve beam steering in E-plane [$\theta_0=40^\circ$; $\phi_0=90^\circ$]. It compares the modeling with the measurement for realized gain and impedance matching.

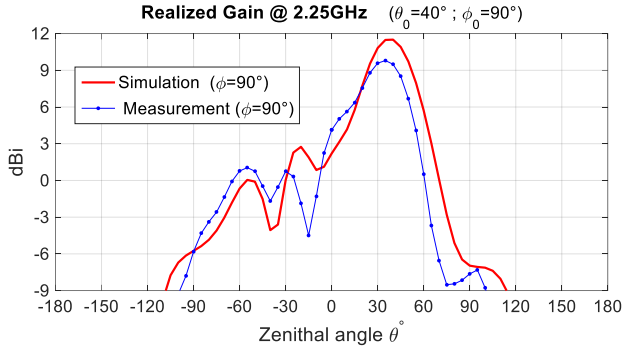


Figure 7 Realized gain in plane $\phi_0=90$

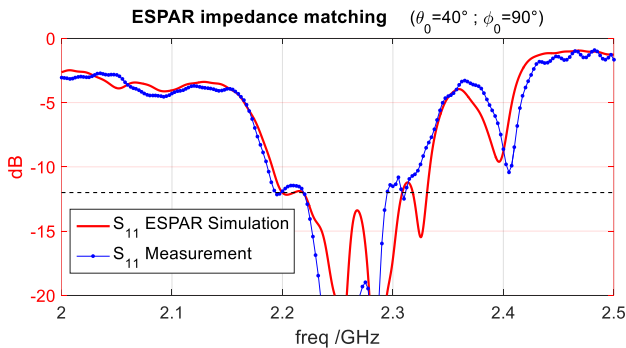


Figure 8 Impedance matching

The measured impedance matching corresponds to the simulation, showing a level below -12dB over the bandwidth.

The beam steering is done in the desired direction but the gain level does not meet the specifications, reaching 9.5dBi instead of the 11.5dBi predicted by the simulation. A loss of gain is also observed for the other measured radiating modes.

E. Assessment of the realized antenna

After various investigations, it appears that several tunable capacitors of the ESPAR have weld defects. They seem to originate from an unevenness in the thermal profile of the tunable capacitor footprint. The right part of Figure 9 shows the solution chosen to solve this problem: The access lines to the DC bias will now have a similar shape to the one connecting the tunable capacitor to the RF lines.

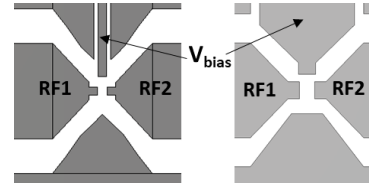


Figure 9 Tunable capacitor footprint: First version (left) and modified version (right)

This antenna has nevertheless demonstrated the viability of the ESPAR architecture for the realization of directional beams for different steering angles. Power handling tests of the antenna have been performed up to an input power of 40W without causing any component destruction.

III. CONCLUSION

This paper describes the design of an ESPAR antenna for a space launch vehicle TMTTC link. The development meets the requirements of compactness, power consumption, antenna gain, bandwidth and RF power handling.

This antenna is capable of radiating gains greater than 10dBi regardless of the pointing direction. It has been built with technology blocks that allow 40W RF power. This antenna allows an electronic control of the beam with low-cost solutions.

Three main novelties emerge from this study compared to the ESPARs present in the literature:

- The large number of radiating elements allows to reach relatively high gain values for an ESPAR.
- The power handling of the phase shifters allows the antenna to transmit high power signals.
- The wide phase excursion range of analogic phase shifters combined with the large number of radiating elements allows an important versatility of the beamsteering coverage.

Other improvements are in progress, such as circularly polarized radiation and the implementation of a switchable omnidirectional radiation mode.

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