# PAFSR Reconfigurable Antenna Feed Array Design

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**— This paper outlines THALES ALENIA SPACE activities in the context of reconfigurable missions with channelized amplification in Ku-band. Flexibility in Tx pattern coverage is achieved thanks to an antenna including a shaped reflector and a focal array controlled by Ferrite phase-shifter. This paper focuses on the design of the focal feed array and details the guidelines that allowed to converge on a compact architecture.**

***Keywords: flexibility, focal array, reconfigurable, phase shifter module.***

## I. INTRODUCTION

This paper presents the practical development of the PAFSR antenna concept (Passive Array Fed Shaped Reflector [1]) in the context of the evolution of future satellite payloads [2]. More precisely, the attention is devoted to the most critical point of this antenna, which is the focal feed array design. The concept definition takes into account several requirements as: modularity, flexibility, functionality and overall spatial environment constraints. To ensure these requirements, it is necessary to define the main orientations and derive the design guidelines in order to reach a viable and attractive antenna product. In this paper, the description of the architecture concept and the design of the modules are detailed. The expected performances of this antenna in coverage flexibility scenarios are given for illustration.

## II. ANTENNA DESCRIPTION

This antenna is a lateral sidewall antenna (see Fig. 1)). In his baseline version, this antenna ensures a flexible Tx coverage (H & V) and a fixed Rx beam (H & V).

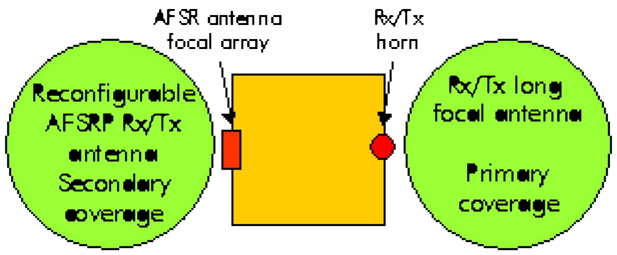



Figure 1. Sidewall antennas

The geometry of this antenna is given in Fig. 2 (a). This antenna is composed of a shaped reflector and a focal array. The operating mode is as follow: first the antenna is oriented toward the reconfiguration area (red in Fig. 2 (b)) and then the phase shifters of the focal array are set to the values corresponding to the desired coverage and power distribution over the polygons of the mission.

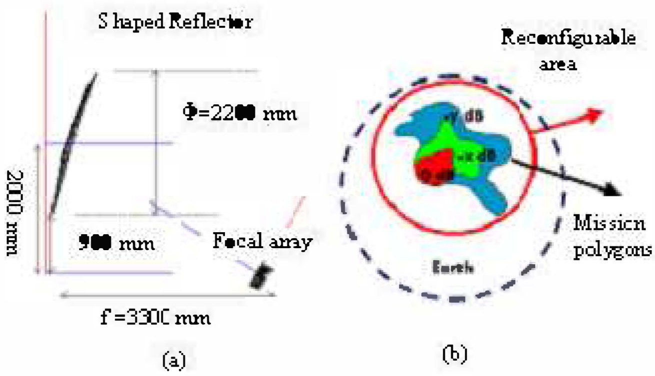



Figure 2. (a) Antenna optics and (b) reconfigurable area definition

## III. ARCHITECTURE FLEXIBILITY

The requirements in term of architecture flexibility, lead to derive these constraints in each module definition.

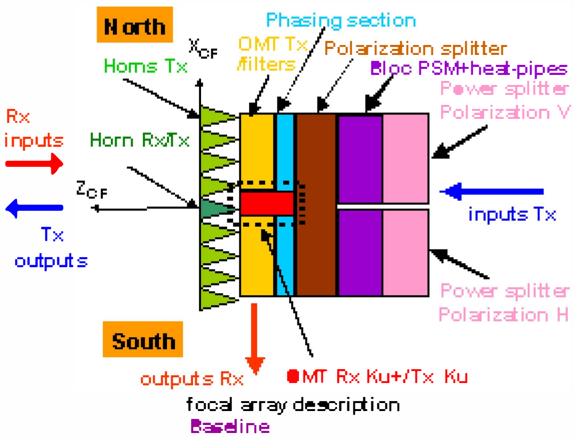



Figure 3. Functional focal feed array description: Baseline

The shaping of the reflector has been performed by taking the centre Rx/Tx horn as the feed (covering [17.3-18.4] and [11.7-12.75] GHz frequency band) and defining a circle area of 7° of diameter as the objective to cover. If the antenna is a Tx only antenna, the shaping is performed with a Tx source in the frequency band [10.7-12.75] GHz. The baseline Rx/Tx Ku+/Ku focal array is illustrated in the Fig. 3 and the other options Tx Ku and Rx/Tx Ku in the Fig. 4.

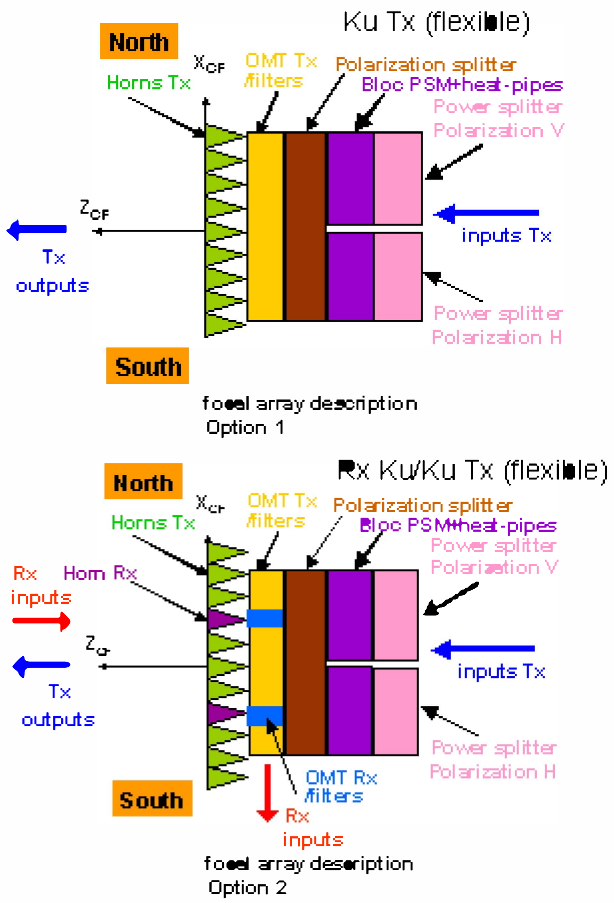



Figure 4. Description of two options: Ku Tx only and Ku Rx/Tx

## IV. FOCAL ARRAY DESIGN (BASELINE)

The schematic view of the focal array is given. (Fig.5)

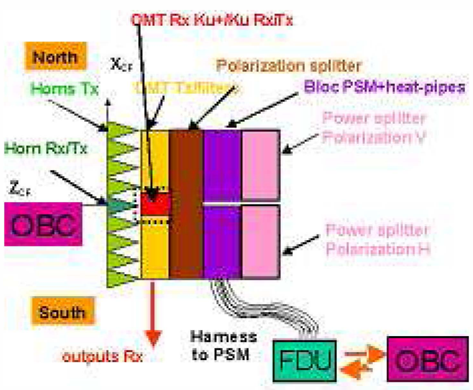



Figure 5. Complete focal array functional description (Baseline)

The FDU (Ferrite driver unit) is interfaced with the OBC (on board calculator) and each PSM.

The considerations as losses/complexity/thermal control make the use of waveguide [3] routing unavoidable (losses and power handling capacity) and to limit the focal array to 25 high directivity horns (one of them is a Rx/Tx horn), a diplexing OMT Rx/Tx Ku, 24 Tx OMT with a filtering and phasing section, one polarization splitter, two identical power splitters (symmetric) and 2x25 phase shifter modules (PSM).

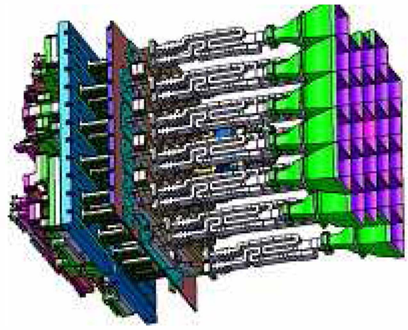


Figure 6. CAD view of the focal array

## V. MODULES DESCRIPTION

### A. *Rx/Tx Ku+/Ku OMT*

The design of the OMT Rx/Tx covers [11.7-12.75] GHz for Tx and [17.3-18.4] GHz for Rx. The functional description and the manufactured view of this OMT are given respectively in the Fig. 7 and Fig. 8.

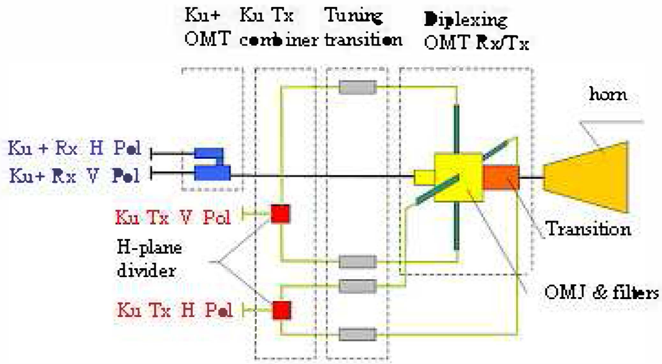



Figure 7. Functional description of the Rx/Tx Ku+/Ku OMT

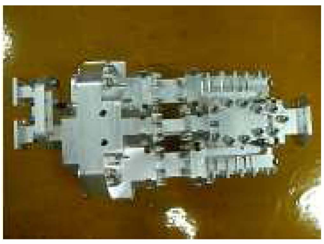


Figure 8. Manufactured OMT

This OMT has a matching of 23 dB and losses in order of 0.1 dB. The diameter is 100 mm (to be compatible with the focal array), a length of 180 mm in his short version (without the tuning transitions) and a mass of 765 g.

### *B. Ku Tx horns*

These horns are optimized in the full Tx band [10.7-12.75] GHz and have a spline profile and a square aperture (see [5] and [6])) of 2.6 $\lambda$ at the centre frequency. The matching is better than 24 dB, the losses around 0.05 dB, a XPI > 30 dB over 10° of solid angle and the efficiency between 80.5 to 85 % in the frequency band. This horn has been manufactured by milling and electro eroding process and is silver coated to limit the losses. The mass is around 100 g and has a length of 129 mm.

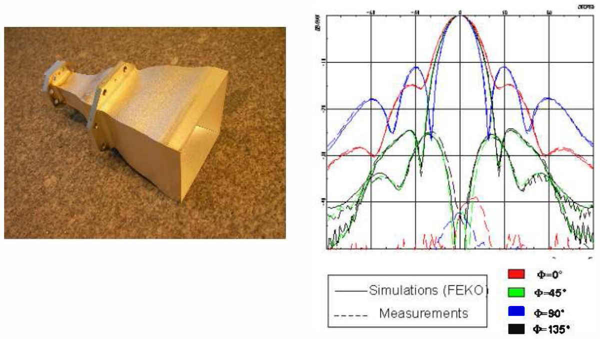



Figure 9. Ku Tx horns : manufactured horn and radiating pattern at central frequency

### *C. Ku+/Ku Rx/Tx horn*

This horn covers the [11.7-12.75] & [17.3-18.4] GHz frequency band and has excellent Rx performances (> 85 %) and almost 80 % in the Tx band. This horn has been manufactured by using the same process used for Tx horns. The mass is around 125 g for a length of 150 mm.

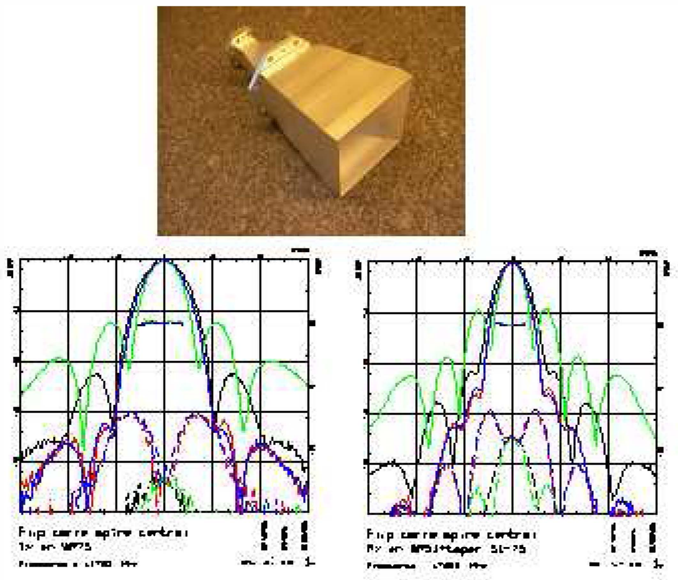


Figure 10. Ku+/Ku Rx/Tx horn : manufactured horn and radiating patterns : central Rx frenquency and central Tx frequency

The Fig. 11 gives the view of the manufactured horn and the Rx and Tx diagrams at the central frequency of each band.

### *D. Polarization splitter*

The polarization splitter ensures the function to separate the V and the H accesses spatially from the outputs of the OMT (see Fig. 11). The routing is performed in WR 75 (b/2) waveguides with H & E plane bents and cover the full Tx+Rx Ku band [10.7-14.5] GHz. The expected performances (simulations) are a matching of <51 dB, losses of 0.1 dB and a maximum phase dispersion of around 1°. The technologies used for this module are: double face machined shells (3 shells) and aluminum vacuum brazing process for the assembly. This module estimated mass is around 4-5 kg and occupies a volume of 400x400x60 mm$^3$.

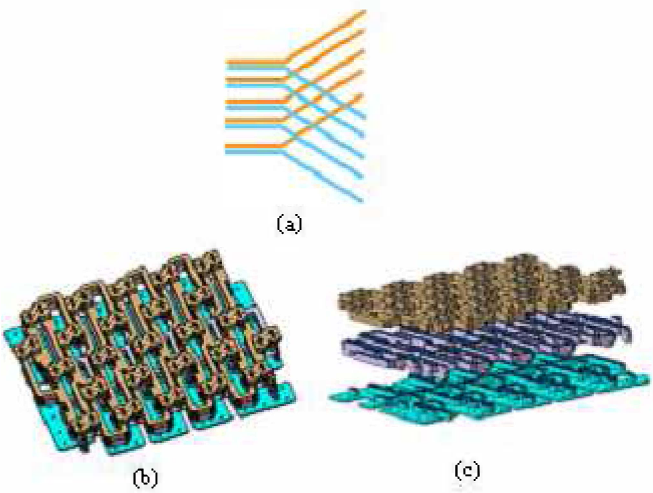
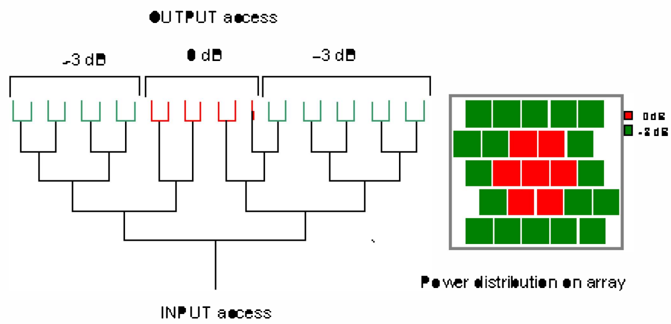



Figure 11. Polarization splitter: (a) functional description, (b) CAD view, (b) CAD shells view

### *E. Power splitter*

The power splitter function is to ensure the power distribution over the 25 accesses as defined in Fig. 12. The power splitter presents two levels of power (7 accesses at 0 dB and 18 accesses at 3 dB) and covers the full Tx band [10.7-12.75] GHz band. The routing is performed in WR75 (b/2) with H and E planes bents and Riblet type 3 dB couplers and SIC loads.




(a) (b)

Figure 12. Functional description and power distribution on the array

The design is made in 5 layers (see Fig.13) and the technology process is the same as the one used for the polarization splitter (double face machined shells and vacuum aluminum brazing). The estimated losses is around 0.4 dB with an amplitude/phase dispersions of 0.5 dB/ 2° with an estimated mass around 5-6 kg and occupies a volume of 400x230x100 mm$^3$.

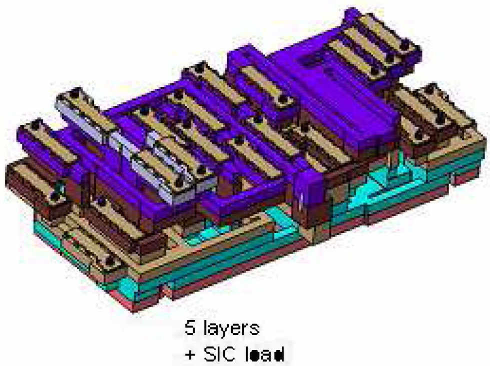



Figure 13. Power splitter CAD design

*F. Phase shifter module (PSM)*

The phase shifter module design is based on the concept of twin toroids assembly [6] (see Fig. 14) issued from ARTES 3 trade-off and with TEMEX© ferrites. The objective was to develop a generic module compatible with numerous Ku applications and also for the PAFSR antenna.

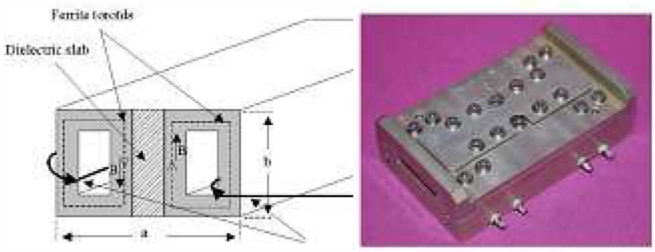



Figure 14. Phase shifter concept and manufactred PSM

An EQM model has been developed with following goals: frequency band 17.5 % [10.7-12.75] GHz, T° [-25°C to 80°C], VWSR <20 dB, phase slope dispersion 6° and a mass <80 g, a phase set-up of a least 360° and qualified in thermal and mechanical environment (40 g). A power handling capacity of 50 W ( T=25°) and a level of PIMP order 3 less than –105 dBc with 2 carriers of 10 W.

The measured results of the PSM are given in Fig. 15. A phase adjustment over 400° and an average losses of 0.4 dB is achieved over the full Tx band and the temperature range.

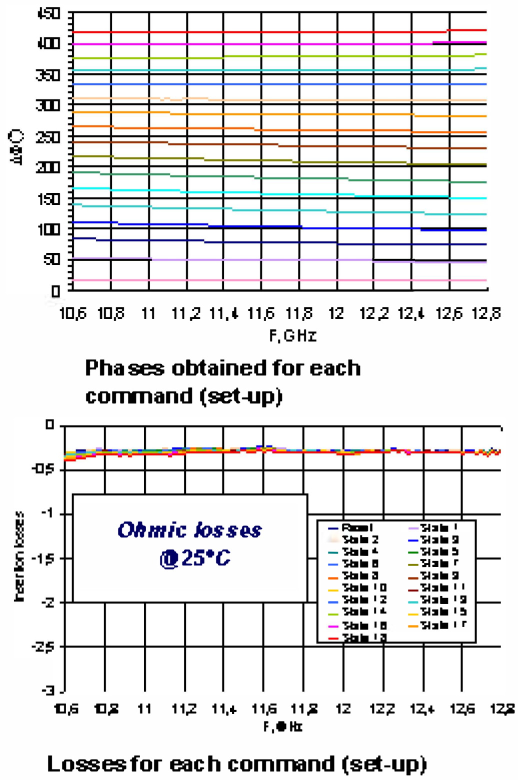



Figure 15. PSM Performances phases and losses

*G. Ferrite driver unit (FDU)*

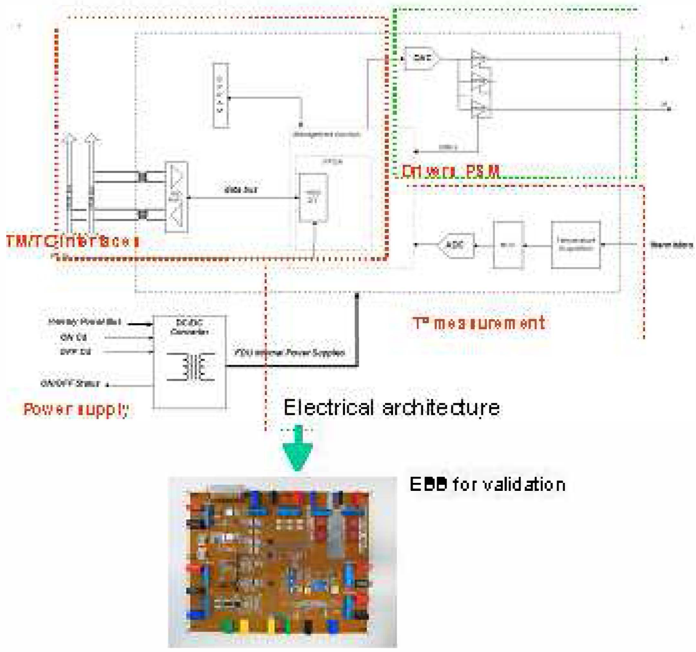



Figure 16. FDU Functional description and EBB view

Trade-offs between different driver architectures allowed to define an architecture based on the magnetic flux control as the best compromise for the need of this antenna. This architecture is illustrated in Fig. 16. A breadboard has been built in order to verify the accuracy of this architecture in term of performances. The FDU under development will have the following characteristics: a capacity to control up to 64 PSM, an accuracy of 1.5 % over the 360° phase set-up, a set-up time of 25 µs and a expected consumption less than 40 W.

### *H. Thermal control device*

The objective of the thermal control device is to maintain the PSM temperature around ± 5 °C over the operating temperature interval (typically 45°C-65°C) in order to limit the phase dispersion. To reach these requirements (see Fig.17), the solution converged to a device composed of thermal insulators (Peek) and an aluminum plate in which heat pipes (Cu/$H_2$0 with a diameter of 6 mm) are integrated by brazing (Fig. 18). This architecture is flexible and could be adjusted according to the input power: for instance the thermal device could be interfaced with an OSR plate or a LHP and the insulators could be removed if not necessary.

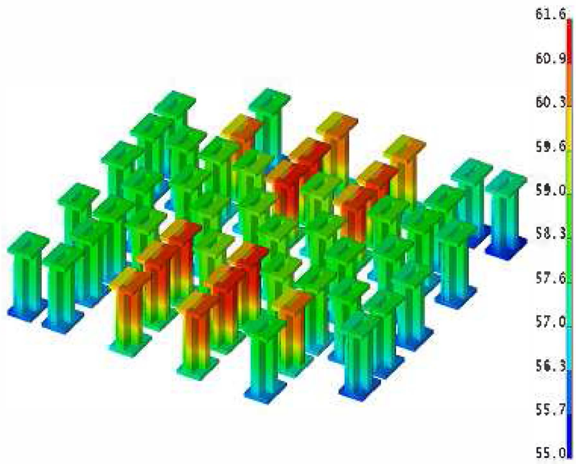



Figure 17. Thermal gradient on the PSM

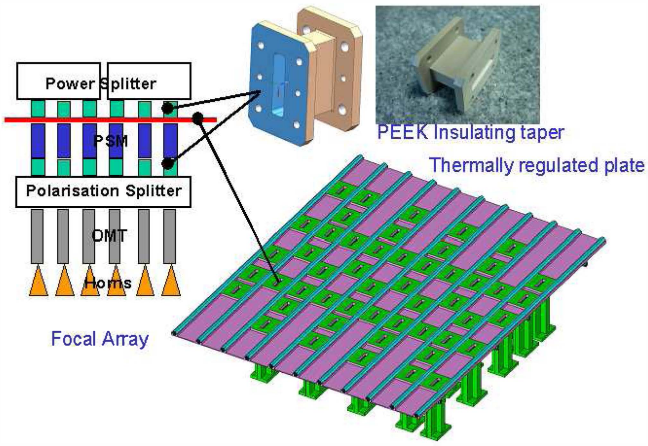



Figure 18. Focal array thermal control device

## VI. COVERAGE FLEXIBILITY

For illustrate the ability of this antenna in beam forming efficiency, this part gives an example of coverage flexibility. In Fig. 19, the reflector is pointed toward two possible missions ( South Africa or Caribbean coverage ). The ADPM (antenna deployment and pointing system) allows to concentrate the energy around the desired region. The phase set-up of each PSM allows to synthesize the diagram according to the goals (directivity /polygons).

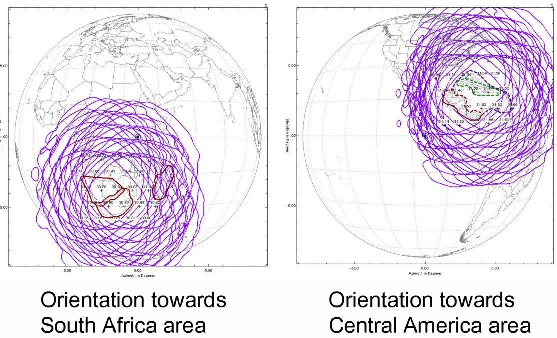



Figure 19. Beam forming capacity: orientation toward the reconfigurable area (elementary diagrams towards South Africa and Russia)

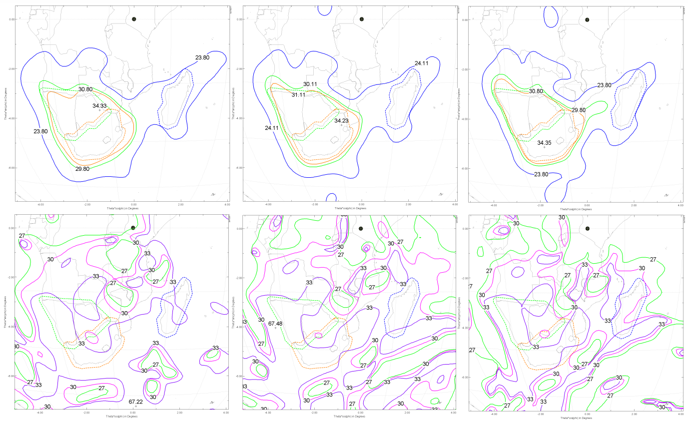


Figure 20. South Africa (Co-Pol and X-Pol) f=10.7 GHz, 11.7 GHz & 12.75 GHz

In the Fig. 20, the synthesized patterns for 3 frequencies are given for South Africa missions. The XPD is around 27 dB as expected. This level depends on the objective given for the reflector shaping. The estimated losses of the array is around 1.dB in Tx and the beam efficiency is around –2 dB.

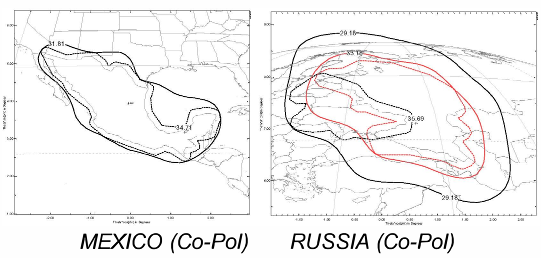



Figure 21. Mexico mission and Russia mission: Co-pol. Patterns

Two other missions synthetis are given in Fig.21 to complete the illustration: the Mexico coverage (one polygon) and the Russia mission (two polygons with 2 levels of power distribution). Due to the limited number of feeds (25), the beam forming efficiency in Tx is strongly dependent on the number of the polygons and the shapes, the dimension and the power level of each of them.

## VII. CONCLUSIONS

The design of a focal feed array for a PAFSR reconfigurable antenna has been proposed. This focal array allowed to ensure flexibility in Tx beam forming and gives a fixed Rx coverage. Moreover, the architecture of this focal array by itself includes the possibility to be modified by adding or removing modules to respond to a specific need. An extreme compact design has been achieved thanks to several technological developments (PSM, square horns, vacuum Aluminum brazing). By limiting the number of elements and the losses of the RF chains, the performances of this antenna has been optimized. As a consequence, this antenna becomes efficient and compensates his major drawbacks (losses and beam forming efficiency) when high degrees of flexibility in term of mission coverage and power distribution are required.

## ACKNOWLEDGMENT

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