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# Reconfigurable pyramidal antenna loaded by a cut-off waveguide—application to ARNS/RNSS services

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**Abstract**— A novel reconfigurable and circularly polarized antenna topology for satellite application services, based on a pyramidal geometry, is proposed. Frequency agility is simply obtained by loading the radiating elements by Radio-Frequency switches. The ground plane of the antenna is perforated and loaded by a cut-off and open-ended waveguide. The length of this waveguide is adjusted to achieve a good trade-off between rear radiation and impedance matching. A specific application of this original topology is described in this paper. It consists in the design of a reconfigurable dual-band antenna for Aeronautical Radio Navigation Services (ARNS) and Radio Navigation Satellite Services (RNSS). The computed input return loss is lower than -10 dB in all the considered frequency bands and quasi-hemispheric radiation patterns are obtained. These results are in good agreement with the required Radio Navigation specifications.

**Index Terms**— Reconfigurability, dual-band antenna, circularly polarized fields, pyramidal geometry, radio navigation services.

## I. INTRODUCTION

Multi-band or reconfigurable antennas are often considered on satellite systems to reduce the number of onboard or ground antennas, combining several applications on the same antenna. A design difficulty arises when frequency bands are too close for being considered as different bands but are also too distant to be easily matched on one single band of a multi-band antenna. A typical example is provided by the design of a dual-band antenna that fulfills the frequency plan and technical specifications of the Aeronautical Radio Navigation Services (ARNS) and the Radio Navigation Satellite Services (RNSS) reported in Table I. As indicated in this Table, the ARNS combine E5a/L5, E5b and extended L1, while RNSS combine L2, E6 and extended L1: the E5 and E6 bands are too close for being considered as two different bands of the multi-band antenna, but too distant to be easily matched on one operating band of the antenna (the required bandwidth would be around 13%). Since the extended L1 band is common to the satellite services, the idea exploited in this paper is to

design an antenna that is able to switch between the E5 and E6 bands. The solution developed here is then a dual-band antenna, one of the two bands being switchable.

Few research works have been reported on dual-band reconfigurable antennas with one switchable band [1, 2]. We propose here an original topology, based on pyramidal structures, loaded by cut-off and open-ended waveguide. The length of this waveguide is adjusted for achieving a good trade-off between rear radiation and impedance matching. Trap-loads are used to achieve multi-band operation while frequency agility is obtained by loading the radiating element by Radio-Frequency switches. This paper presents the design of a new version of the multi-band antenna recently reported by the authors in [3, 4]: this original version has frequency flexibility capability to match close operating frequency bands.

An application concerning the design of a reconfigurable dual-band antenna for ARNS and RNSS is described here. Electromagnetic simulation results are reported and confirm the antenna flexibility in terms of input matching. Simulated radiation patterns are also presented and are in a good agreement with required technical specifications.

TABLE I  
TECHNICAL REQUIREMENTS FOR THE ARNS/RNSS RECONFIGURABLE ANTENNA

	Band 1	Band 2	Band 3
Bands	E5a/L5 and E5b	E6	Extended L1
Services	ARNS/RNSS	RNSS	ARNS/RNSS
Center frequency	1.189 GHz	1.280 GHz	1.575 GHz
Bandwidth ( $ S_{11}  < -10$ dB)	50 MHz	40 MHz	32 MHz
Polarization	Right-handed circular		
Minimum directivity	$\theta = 0^\circ$	> 2 dBi	
	$ \theta  < 80^\circ$	> -5 dBi	

## II. ANTENNA DESCRIPTION

The proposed antenna is composed of four radiating elements placed symmetrically around an axis which is perpendicular to a perforated ground plane (Figure 1). In this

figure, these elements are metallic wire monopoles but other types of radiating elements can be chosen (e.g., bow-tie planar antennas).

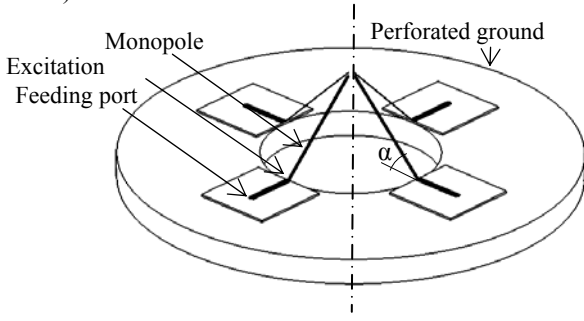


Fig. 1 The pyramidal antenna with monopoles as radiating elements and its perforated ground plane

The circular polarization is obtained when the monopoles are fed with a progressive  $90^\circ$  phase difference and equal amplitudes. The excitation points are located at the edge of the perforation and the monopoles form a non-zero inclination angle  $\alpha$  with the ground plane. By varying this angle the antenna radiation pattern can be shaped to achieve various required specifications. As a matter of fact, tuning this angle allows bringing the excitation points more or less closer to each other and hence, the radiation pattern can be set either quasi-hemispheric or directive. The feeding ports are connected to the excitation points via  $50\Omega$  planar transmission lines. Each monopole contributes to the overall radiation patterns whatever the considered direction. A frequency transparent material (e.g., foam or polystyrene) may be placed under the substrate boards forming the pyramid in order to obtain a rigid radiating structure. The radius of the ground plane influences the antenna gain and axial ratio and it has to be chosen sufficiently large for limiting the reflection effect at the outer edge. Moreover, we have observed that the hole in the ground plane improves the matching at the excitation points. However, it generates an undesirable rear electromagnetic radiation. This rear radiation can be reduced by loading the ground plane by a cut-off and open-ended metallic waveguide (see Figure 2).

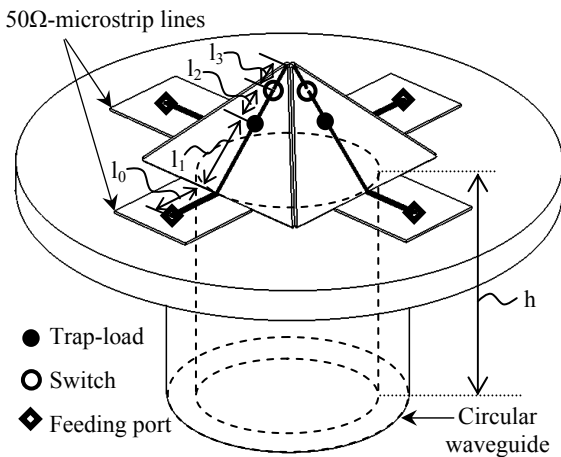


Fig. 2 Reconfigurable pyramidal antenna loaded by a cut-off and open-ended metallic circular waveguide

The metallic waveguide may be viewed as the continuity (or prolongation) of the already existing one that is naturally created by the finite thickness of the ground plane together with the perforation. This waveguide is designed in such a way that no mode is propagating inside at the operating frequencies of the antenna (a lossless circular waveguide is considered cut-off when its radius is lower than the maximum allowed radius ensuring the evanescence of the first (fundamental) mode in the circular waveguide). The length of this waveguide has to be adjusted in order to achieve a good trade-off between rear radiation and the antenna matching.

In Figure 2 the dimensions  $l_1$ ,  $l_1+l_2$  and  $l_1+l_2+l_3$  are approximately the lengths of quarter-wavelength monopoles operating at the three desired frequencies. Trap-loads and Radio-Frequency (RF) switches are inserted on the surface of the radiating elements to achieve the multiband behavior, frequency reconfigurability or the combination of the two. For a first rapid design the trap-loads are assumed to be perfect short- or open-circuits, depending on the frequency. Next, in order to perform an accurate design, trap-loads are modeled by a LC parallel circuit. At its resonant frequency  $1/(2\pi\sqrt{LC})$ , the trap-load is equivalent to an open circuit; at lower frequencies, the trap-load presents low reactive impedance that can be compensated by a slight change in the length of the radiating elements. The desired rejection frequency and bandwidth allow deriving the pertinent values of L and C. The use of trap-loads requires a minimum separation between two successive operating frequency bands. When two bands are too close and the bandwidth of the radiating elements are not wider enough to cover them simultaneously, it is preferable to use RF-switches instead of trap-loads. Due to their compactness, easy integration and reduced effect on the antenna radiation patterns, the chip components (capacitors and inductors) are very suitable for the practical realization of the trap-loads. However, the impedance matching and the bandwidth of the antenna are quite dependent on the performances of these chip components. Concerning the switches, RF Micro-ElectroMechanical switches can be used (examples of such integration in antennas may be found in [5-7]). Besides their compactness, these devices can outperform their semiconductor counterparts such as transistors and diodes in lower insertion loss [5, 6], lower power consumption during operation and higher Q, which inherently fits the antenna requirements.

### III. APPLICATION: RECONFIGURABLE DUAL-BAND ANTENNA FOR ARNS/RNSS SERVICES

The application considered here concerns the design of a dual-band antenna that fulfills the frequency plan and technical specifications summarized in Table I. Since the ARNS and the RNSS are sharing the same L1 band, the designed antenna is a dual-band antenna able to switch between E5 band and E6 band.

The first design of the antenna has been achieved by using IE3D electromagnetic simulation tool while fine optimizations have been performed by means of CST Microwave Studio software. The resulting pyramidal antenna is shown in Fig. 2.

The four radiating elements that constitute the antenna are metallic strips of width 1mm printed on a NELTEC substrate (ref. NY9208ST0762CTCT: relative permittivity of 2.08 and thickness of 0.762mm). The same substrate is used for the design of the 50Ω microstrip lines that place the four feeding ports at 20mm from the edge of the ground plane perforation. These 50Ω-microstrip lines have a width of  $w = 2.39\text{mm}$  and are printed on a 30mm x 30mm boards. The lengths  $l_1$ ,  $l_2$  and  $l_3$  (see Figure 2) are equal respectively to 35.7mm, 4.6mm and 1mm. The outer radius of the ground plane is 85mm. The cut-off and open-ended circular metallic waveguide, used for controlling the rear radiation and impedance matching, presents an inner radius equal to one of the ground plane hole (33mm) and a length  $h$  of 70mm. This length has been chosen to have a minimum of rear radiation and a good impedance matching at all operating frequencies. A pyramidal inclination of 45° is chosen as a good trade-off between the expected radial and axial radiation performances.

As above-discussed the agility between frequency bands 1 and 2 is achieved using RF-switches placed along the radiating strips while the dual-band behavior of this antenna is obtained using trap-loads. The operating frequency bands and associated services versus the ON/OFF state of the RF-switches are reported in Table II. Once the strip dimensions defined, the trap-loads are replaced by ideal optimum parallel LC circuits ( $L=9.68\text{nH}$  and  $C=1.06\text{pF}$ ). Consequently, the lengths of the strips need to be slightly adjusted accordingly for the lower bands.

TABLE II  
FREQUENCY BAND SELECTION VERSUS SWITCH STATE

Switch State	Services	Selected bands
ON	ARNS	1 and 3
OFF	RNSS	2 and 3

Simulated return losses are displayed in Figure 3 over the three considered bands. It can be observed that simulation results are in good agreement with the nominal required specifications. As expected the band 3 (extended L1) is available with the two ON/OFF switch states. Nevertheless, depending on the ON/OFF states either band 1 or 2 is selected. The return loss is lower than -10 dB over E5a/L5, E5b, E6 and extended L1. From the scattering parameters analysis, it appears that the impedance matching level in the lower bands is degraded, when compared to the band 3, due to electromagnetic coupling effects between the quarter-wavelength monopoles (between two adjacent monopoles the coupling level at lower bands is found to be around -6 dB). This coupling may be reduced by modifying the monopole inclination angles.

Figure 4 shows the simulated Right Handed (RH-) and Left Handed (LH-) Circular Polarization (CP) directivity patterns of the antenna at the three operating center frequencies (1.189GHz, 1.280GHz and 1.575GHz) for  $\varphi = 0^\circ$  and  $\varphi = 45^\circ$ . As it can be observed from this figure, the radiation patterns of the antenna are quasi-hemispheric at all operating frequencies, allowing a maximum reception of signals from the satellites in sight.

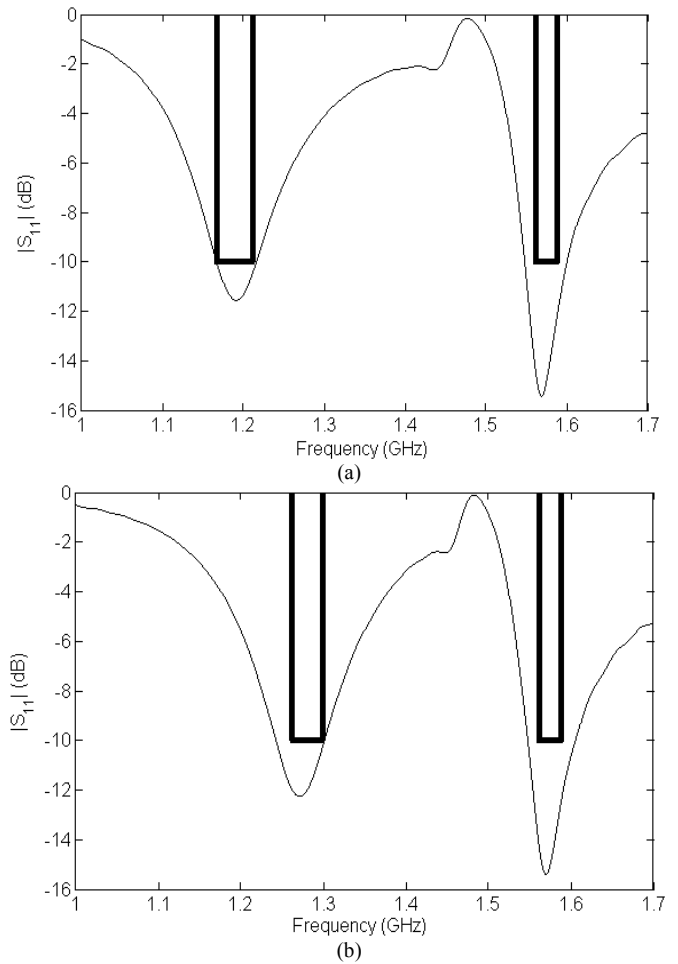
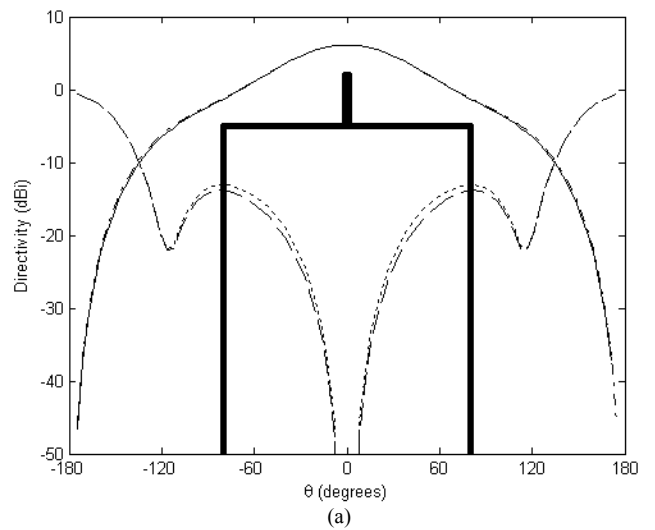


Fig. 3 Simulated return loss (in dB) when : (a) the switch is ON and (b) the switch is OFF. (■) Nominal required specifications

The shape of radiation patterns of the figure 4 is appropriate for satellite navigation reception antennas. The cross-polarization obtained by electromagnetic simulation is lower than -10 dB in the half space of interest, thus ensuring a necessarily purity of polarization for a nominal antenna operation.



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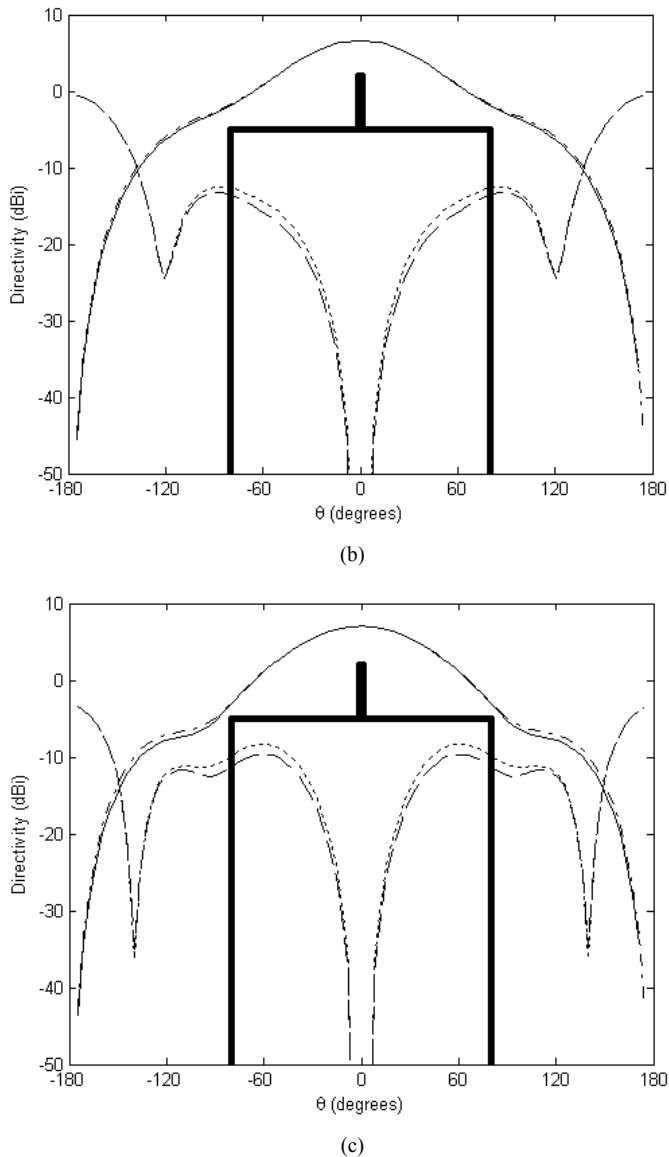


Fig. 4 Simulated radiation patterns at: (a) 1.189GHz, (b) 1.280GHz and (c) 1.575GHz.  $\phi = 0^\circ$ : (—) RH-CP, (- - -) LH-CP;  $\phi = 45^\circ$ : (- · - ·) RH-CP, (- - -) LH-CP; (█) Minimum required RH-CP

## IV. CONCLUSIONS

A novel reconfigurable antenna based on pyramidal structures loaded by cut-off and open-ended waveguide was presented and applied to the design of a dual-band reconfigurable antenna for Aeronautical Radio Navigation and Radio Navigation Satellite Services. The ground plane of the radiating element is perforated and loaded by a cut-off hollow and metallic waveguide. This original configuration leads to a good trade-off between rear radiation and impedance matching. By the simple structure feature of the antenna described here, various possible adjustments (inclination angles, geometry of the metallic radiating elements and ground plane, switches) contribute to a multi-application use.