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Dual-band Ku-band Scanning Leaky-Wave Antenna For Satellite Communications

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***Abstract*—High gain planar antennas have been investigated using an optimised partially reflecting surface (PRS) placed on a top-open waveguide and fed by a WR-62 waveguide aperture. The PRS consists of an array of switchable slot patches to allow dual-band operation. Initially the reflection phase of the PRS is investigated for the two stages of the switching diode located at the center of a slot cut on the patches proving a suitable performance of the PRS reflection characteristics. The dual-band operation of the 1D antenna has been analysed using full wave 3D electromagnetic simulations showing two frequency bands at [13.67, 14.04GHz] with directivity over 16dBi and 13dBi respectively. Additionally, a mechanical reconfiguration mechanism is incorporated to the antenna that allows modifying the cavity dimension and in turn scanning on the elevation plane up to ~30° at each band.**

***Keywords*— scanning leaky-wave antennas, satellite communications**

I. INTRODUCTION

Leaky-Wave antennas (LWA) have been extensively used to tailor the radiation pattern of low directive sources [1-15]. One can realize these antennas by placing a Partially Reflecting Surface (PRS) over a top-open waveguide forming a type of half-wavelength Fabry-Perot cavity. The cavity, excited by a source embedded within it, is capable of concentrating the radiated power into highly directive frequency dispersive fan beams. In the last few years, these antennas have received significant attention due to their interesting properties, low complexity feeding network, high efficiency and compatibility with established manufacturing technologies. Different technologies have been adopted to design periodic LWA, for instance microstrip lines [1], dielectric grating guides [2], strip-loaded dielectric slabs [3], strip-loaded inset waveguides [4] and many others [5-11]. There has been a significant effort to improve their efficiency, thickness, bandwidth and more recently to provide dual band operation. Generally, the high directivity provided by these antennas typically results in a narrower bandwidth which is a disadvantage in modern communication systems. Different approaches have been adopted to overcome the bandwidth limitation of 1D and 2D LWAs. Some authors proposed the use of tapering designs [5-7]. Others, replace the feeding network by using a sparse array feed rather than a single element unit, increasing the radiating aperture size and thus widening the bandwidth of the antenna for a fixed gain value [6]. However, this design adds complexity in the antenna implementation due to the multiple feeds. Other approaches also involve the use of artificial magnetic conductors [8]. Mateo-Segura et al. [9] proposed a broadband FP antenna design with compact lateral dimensions using double-layer metallo-dielectric PRS with different array element size (i.e. arrays with dissimilar reflectivity). The double-layer array configuration provided a reflection phase response that increased almost linearly with frequency within a frequency range. As a result, the resonance condition of the cavity was satisfied over a wider range of frequencies thus increasing the antenna bandwidth. However these antennas are bulky. Additionally, dual-band antennas have also been investigated as, for instance, they allow to share a common aperture for downlink and uplink operation in SATCOM. 2D dual-band LWA designs are mostly based on dual layer PRSs [10-11]. In particular, [9] recently reported a solution for Ka-band SATCOM On-The-Move.

In this work we present a 1D dual-band FP type LWA at Ku-band incorporatng a mechanical reconfiguration mechanism that allows to scan the beam in the elevation plane by physically modifying the cavity thickness of the LWA at each band. Such antenna could be employed as a mobile user-terminal for tracking in elevation with a hybrid mechanical azimuth tracking, intended to operate in heterogeneous satellite communication networks.

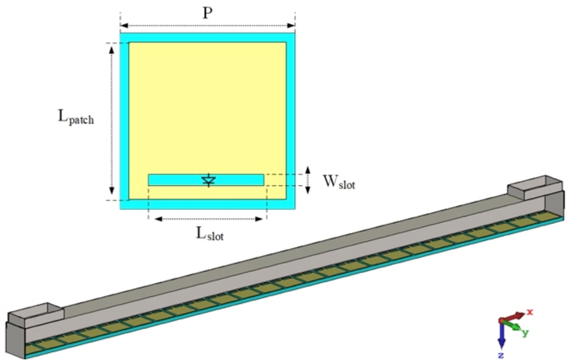


Fig. 1 PRS unit cell consisting of switchable slot patches and dual-band 1D top-open waveguide LWA with slot feed incorporating the detailed PRS.

II. PRS DESIGN

The structure under investigation consists of a highly reflective PRS printed on a dielectric substrate. The PRS is formed by an array of patches with switchable slot. In order to provide high reflectivity, the PRS typically operates close to the array resonance. For this reason, square patches with dimensions of the order of half wavelength are employed. By locating a switching diode at the center of a slot cut on the patch PRS, one may control the PRS operation status using dc bias. A schematic drawing of the PRS unit cell is shown in Fig. 1. The working example consist of patches with edge 8.0 mm (L_{patch}) and periodicity P=9.0 mm printed on a dielectric slab of thickness h_s=1.5mm and relative permittivity ε_r=2.55. The slot-cut dimensions, considered in this example, have been optimised to produce the reflection magnitude and phase presented in Fig. 2. These dimensions are L_{slot}=6.08 and W_{slot}=0.5mm, with the cut positioned at 1.08mm from the lower edge of the patch. The reflection magnitude and phase for normally incident plane wave in the vicinity of 14 GHz are shown in Fig. 2 for the ON/OFF status of the switch. The transparency of the PRS controls the amount of energy that reaches the top aperture of the antenna and therefore it determines the radiation rate of the leaky mode (α/k_0). Here, we can see that within 13.67 and 14.1GHz, the reflection magnitude changes slightly, from 0.85 to 0.98 for the ON and OFF status respectively. More importantly the reflection phase is the same. In the following, the 1D LWA incorporating the PRS with the response in Fig. 2 is designed.

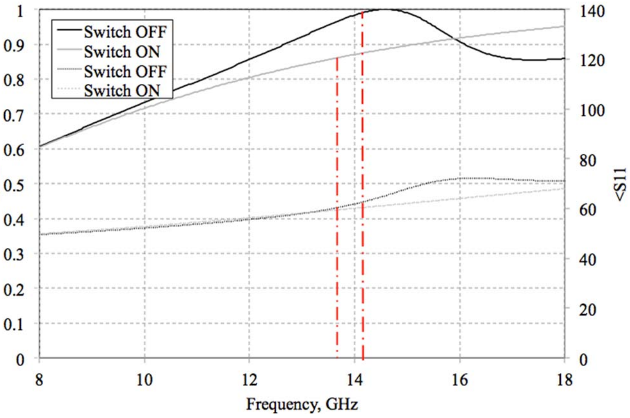


Fig. 2 Reflection coefficient (magnitude and phase) by PRS with switchable slot for ON/OFF status of the switch.

A. *1D Leaky Wave Antenna*

As a proof of concept, Fig. 1 shows the 1D FP cavity, which consists of a top-open waveguide loaded with the previous PRS; total antenna dimension is approximately 10λ along X. The structure is simply fed by a WR-62 slot positioned at one of the corners. A terminated port at the other antenna end is used to absorb the guided energy reaching the LWA far end. The radiation mechanism of these type of antennas is well known and described in detail in [12]. Here, the proposed LWA has been analyzed using 3D full-wave electromagnetic simulations, CST Microwave Studio. Our structure provides dual-band operation for the ON/OFF status of the switch; this is shown in Fig. 3 where it appears superimposed the LWA pointing angle and the directivity of the antenna at e.g. 5° from broadside versus frequency for the two stages of the switch. One can see that at θ=5°, the maximum directivity is 13.58dBi and 14.52dBi which appear at 13.8GHz and 13.62 for the ON/OFF state of the switch respectively (red and blue arrows in Fig.3). Leaky-wave theory suggests that LWAs with lower leakage rates produce larger radiating apertures and therefore more directive patterns. It is therefore expected that antennas formed by more reflective PRSs (Switch OFF, Fig.2) will produce lower leakage rates and therefore higher directivity. This can easily be corroborated in Fig. 3 by inspection of the directivity vs. frequency, right-hand axes for the two cases where larger directivities are achieved for Switch OFF stage (with maximum directivity of 16.7dBi at 8°). Additionally, it is expected that lower directivities allow for larger bandwidths. In particular, the 3dB directivity pattern fractional bandwidth, defined as the frequency range within which the directivity of the antenna at a certain direction (θ) varies within 3 dB of its maximum value, is calculated; Fig. 3 shows a change from 0.8% to 5.5% when the switch is OFF/ON respectively. The spectral distance between the two bands for the different stages of the switch (distance between the two directivity maxima) correspond to 370MHz [13.67-14.04GHz].

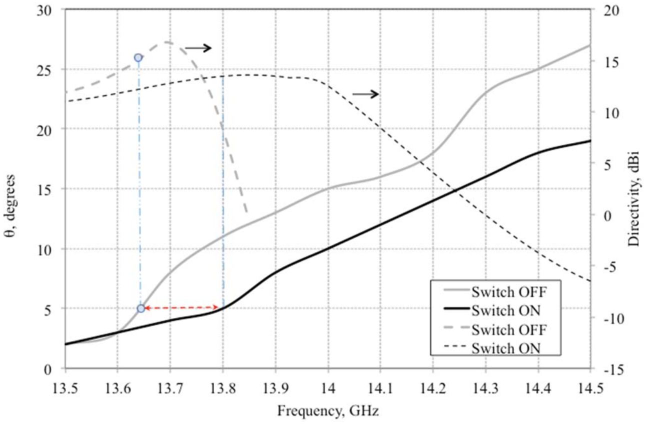


Fig. 3 Pointing angle and directivity at θ=5°of the LWA shown in Fig.1 over frequency for ON/OFF status of the switch.

III. MECHANICAL RECONFIGURATION DESIGN

The top-open waveguide is loaded with the PRS described in section II. The LWA profile, *h*, representing the distance between the top PRS and the waveguide lower wall is approximately λ/2. The position of the PRS is fixed to the structure. The bottom waveguide wall, shown in green in Fig. 4, is allowed to move independently from the main body structure (i.e. displaced up and down and thus modifying, *h*). This type of LWA is known to operate at a mode which is a perturbation of the first order TE_{10} of the waveguide modes formed between the PRS and the lower ground plane. By substituting the top metallic wall of the waveguide by a PRS, the fast waveguide modes are allowed to radiate. At the frequency of operation of the antenna the distance between the PRS and the lower waveguide wall is equal to half wavelength, leading to a resonant Fabry-Perot type cavity model. By modifying the position of the lower waveguide wall, the transverse resonance condition changes and thus the frequency of operation of the LWA mode. This in turn will be used in section III to modify the angle of the main radiated beam. The lower waveguide wall holds the two waveguide ports at its edges and two cylinder pistons, that will unsure a vertical displacement of the structure. As a proof of concept, each piston is controlled by a rotor, which, depending of the sense of rotation, will lengthen or shorten the effective length of the two piston's arms. The two pistons have the same length and are controlled by the same rotor to maintain an accurate alignment between the PRS and the lower waveguide wall.

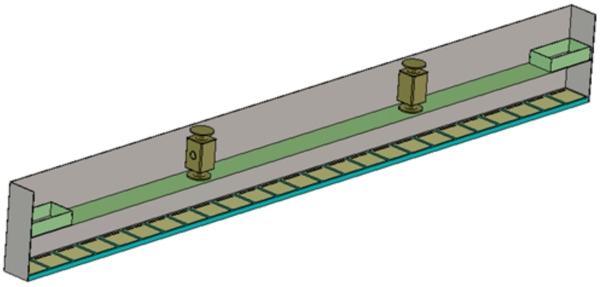


Fig. 4 Mechanical design for beam scanning, 1D LWA in Fig1b.

IV. MECHANICALLY ACTUATED BEAM SCANNING

In this section, the scanning capability of the LWA is investigated. The frequency dispersive innate behaviour of LWAs has limited their applications especially in modern communication systems. Most of these systems require fixed frequency operation for effective channelization. Significant efforts have been followed in order to develop LWAs with scanning operation at a fixed frequency. For instance, PIN diodes were used as switches in [13] to electrically change the radiation angle by controlling the guided wavelength. This solution, however, only allows for two discrete radiation angles, for the biased and unbiased state of the switch. Other solutions investigate magnetically scannable LWAs over ferrite slabs [14] or the use of tunable piezoelectric high impedance surfaces [15] which is associated with larger losses.

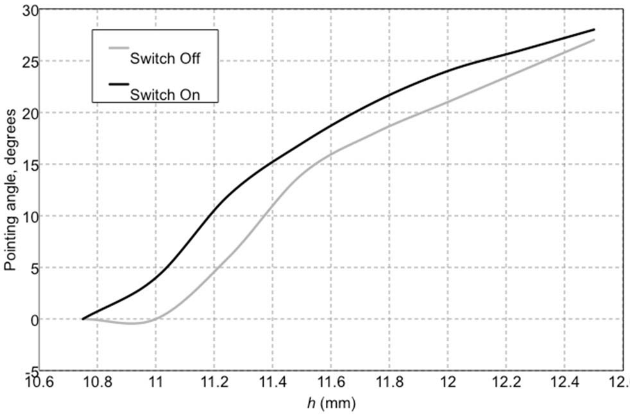
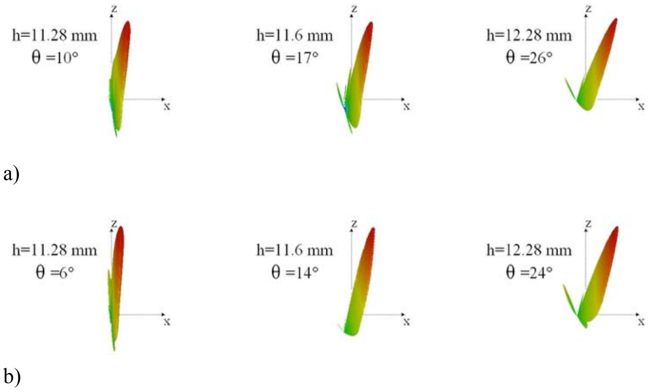


Fig. 5 Pointing angle for varying *h* of the LWA shown in Fig.1 for ON/OFF status of the switch at 14GHz.

Here, the mechanical design introduced in section III is incorporeted to the LWA in order to allow mechanical actuation of the beam scan at a fixed frequency. In particular, the lower plate of the waveguide, located at distance *h* from the top PRS, is allowed to mechanically move up and down changing the LWA profile and in turn the pointing angle of the main beam. The mechanical reconfiguration approach provides a large degree of freedom of positions, *h*, and have lower cost than other reconfigurable technologies. Additionally, further substrates of electro-active polymers can be included in the design to allow for more rigidity in the design. Fig.5 depicts the pointing angle of the LWA with PRS, Switch ON and Switch OFF, for different positions of the waveguide back-wall, *h,* at 14GHz. The antenna scanning capability is up to ~30°. Additionally, 3D radiation pattern obtained using full-wave simulation for three different positions, namely *h*=11.28, 11.6 and 12.28mm are shown in Fig. 6 for Switch ON/OFF stage at 14GHz. The SLL is below 13dB.



a)

b)

Fig. 6 3D directivity radiation pattern for different positions of h a) Switch ON and b) Switch OFF at 14GHz

V. CONCLUSIONS

A dual-band 1D Fabry-Perot Leaky-wave antenna with a mechanically actuated beam scan mechanism is studied in this paper. The top-open waveguide is loaded with a patch PRS with switchable slot to achieve the dual-band operation of the antenna. It has been proved a shift of 370MHz for the two stages of the PRS cut slot switch. The mechanically actuated waveguide allows modifying the profile of the antenna, *h*, and in turn the resonant condition of the LW mode. This allows for a scan of the LWA beam up to 30°. Some examples have been included throughout to prove the antenna performance.

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