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Electrically Reconfigurable Radial Waveguides and Their Potential Applications in Communications and Radars Systems

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Abstract—In this work, different configurations of electrically reconfigurable radial waveguides are presented: a configuration with pass/stop regions, a configuration with tunable narrowband filters and a configuration with integrated phase shifters. Potential applications for the different configurations are also proposed. First, the design and experimental results for a reconfigurable radial waveguide using PIN diodes and operating in the band 5.2–5.8 GHz (11%) are presented and discussed. Then, the principle of radial waveguide with tunable narrowband filters using varactors is described and an application for Frequency Modulated Continuous Wave (FMCW) radars is proposed. Finally, a new radial-line slot array antenna with electrically beam-steering ability is proposed.

1. INTRODUCTION

The radial waveguide structure has been used for feeding circular antenna arrays [1–3] or for designing broadband multiple-port power divider-combiner circuits for power amplifier applications [4–7]. Recent attention has been given to radial waveguides with electrical reconfigurability [10–14]. In this work, three different configurations of electrically reconfigurable radial waveguides are proposed for communications and radars systems. Section 2 presents numerical and experimental results for a reconfigurable radial waveguide with PIN diodes and for a beam switching antenna operating in the WLAN 5 GHz band. A radial waveguide with integrated tunable filters is proposed in Section 3, and a radial line slot array with beam steering ability is described in Section 4. Concluding remarks are given in Section 5.

2. RECONFIGURABLE RADIAL WAVEGUIDES WITH PASS/STOP REGIONS

2.1. Design and Results

Figure 1 presents an optimized reconfigurable radial waveguide using a cylindrical electromagnetic band gap (CEBG) structure of loaded metallic wires [8–10]. E-probes are using for the transitions to the output ports. The main design principle consists in an integrated version of CEBG structures presented in [8, 9]. The printed meandered line in Fig. 1(c) is about a quarter guided wavelength. The radial waveguide operates in the band 5.2–5.8 GHz, Photos of fabricated prototype are shown in Figs. 2 and 4. The S parameters are presented in Figs. 5–7 for the ports which are shown in Fig. 1: the power is mostly divided into two ports (2 and 3) for the considered configuration. If we exclude the losses due to connectors (about 0.4 dB), the measured average insertion loss is about 1.1 dB. Simulated average insertion loss is between 0.35 dB and 0.8 dB for diodes with serial resistance between 0.5 Ω and 5 Ω, respectively (simulated plots in Figs. 5–7 correspond to a serial resistance of 1.5 Ω, which is a value given by the manufacturer).

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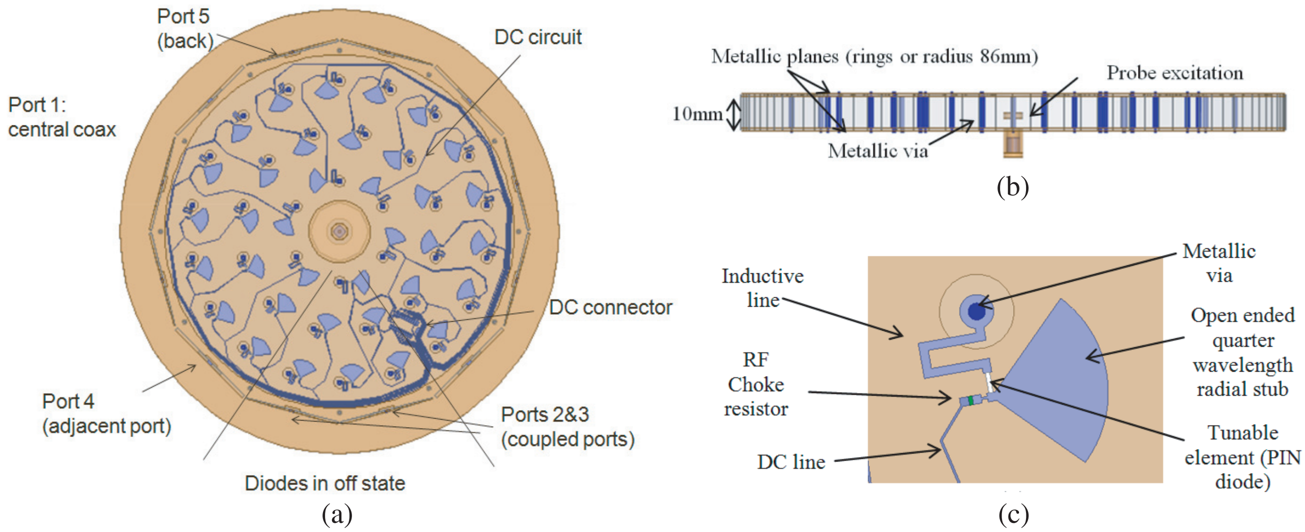


Figure 1. Proposed reconfigurable radial waveguide with PIN diodes. (a) Example of configuration showing region with diodes in off state. S parameters are analyzed for the ports shown in the Figure (b) side view showing probe and coaxial feed, (c) details on the tunable load of the metallic vias.

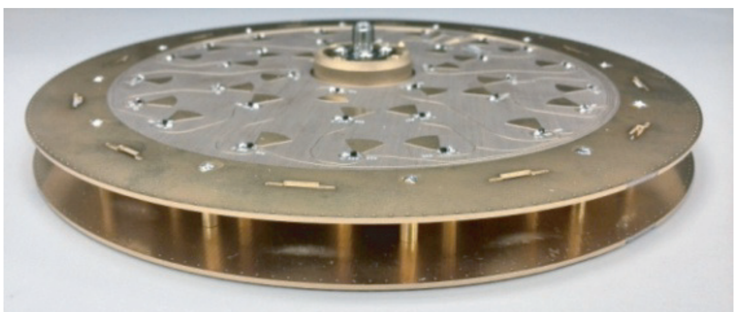


Figure 2. Photo of fabricated reconfigurable radial waveguide made of metallic vias and two printed circuit boards with tunable elements in top board. (a conductive gasket, not shown here, is used for short circuit termination of radial waveguide).

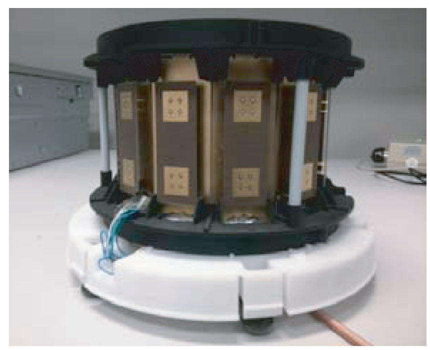


Figure 3. Photo of fabricated beam switching antenna prototype operating in the band 5.2–5.8 GHz.

2.2. Beam Switching Antennas Applications

Using the proposed reconfigurable radial waveguide allows to design and fabricate a beam switching antenna as shown in Fig. 3. The output ports are replaced by capacitively coupled patch antennas. Radiations pattern in H-plane for different diodes states are presented in Figs. 8–9. Fig. 12 shows other possible configurations for different radiation beams. With the designed antenna, there are potentially 2^{18} possible different states. As in the previous subsection, the accordance between measured and simulated results (Fig. 8) validates the proposed concept and model. Although a large number of configurations are possible, a limited number of configurations can be used in practice such that a good impedance matching is obtained at the operating frequency band and sufficiently different radiation patterns are obtained. Examples of possible configurations are shown in Fig. 10. This section has presented a brief description of beam switching application of CEBG reconfigurable radial waveguide. Additional information on the design and performance of the full antenna with dual polarization are presented in [14].

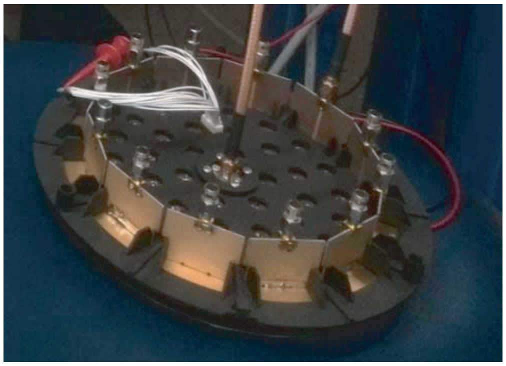


Figure 4. Using a VNA and a dc power supply, setup for the measurements of the S parameters of the reconfigurable radial waveguide. Ports that are not measured are all terminated with 50 ohm loads.

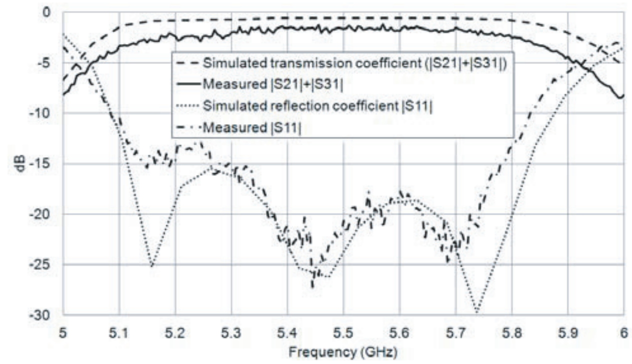


Figure 5. Simulated and measured reflection coefficient and transmission coefficient to coupled ports (simulation is performed with HFSS Ansoft software).

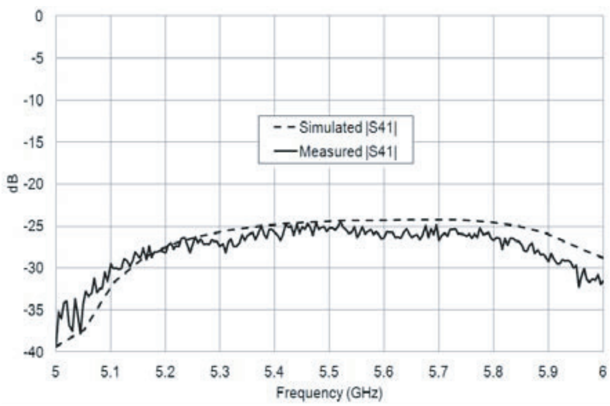


Figure 6. Simulated and measured transmission coefficient to one uncoupled port which is adjacent to coupled port.

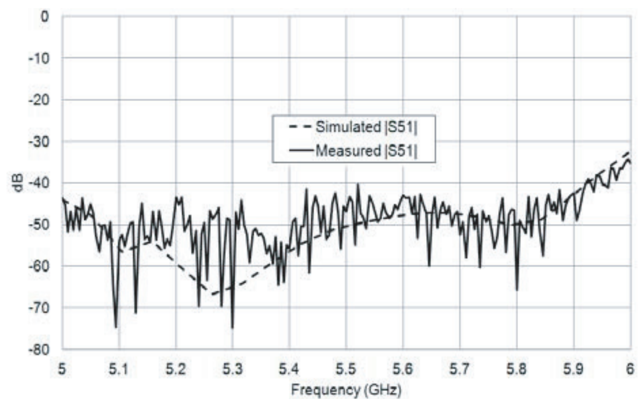


Figure 7. Simulated and measured transmission coefficient to one uncoupled port positioned in the back of the opened region.

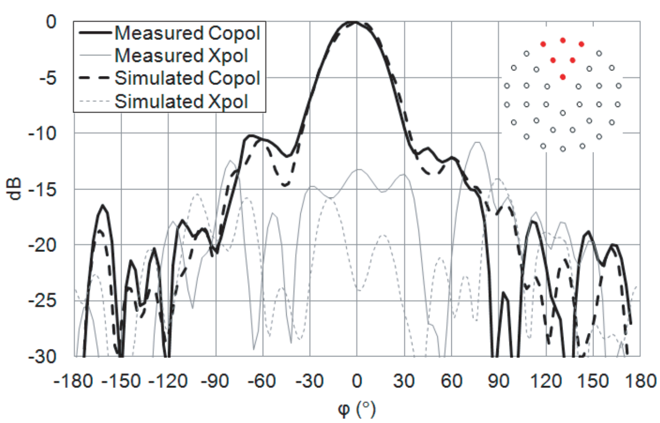


Figure 8. Simulated and measured Copol and Xpol patterns at 5.5 GHz in H plane (Azimuth).

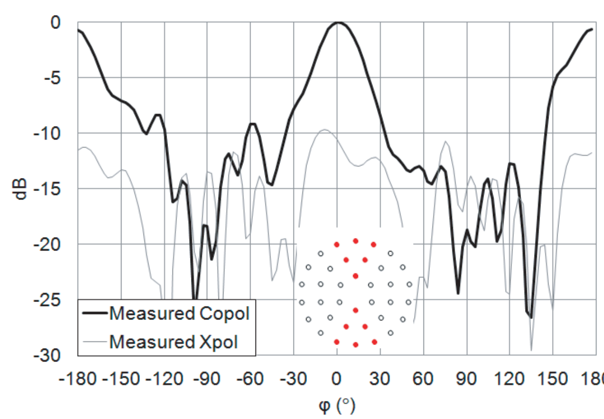


Figure 9. Measured Copol and Xpol patterns at 5.5 GHz in H plane (Azimuth) for two beams configuration.

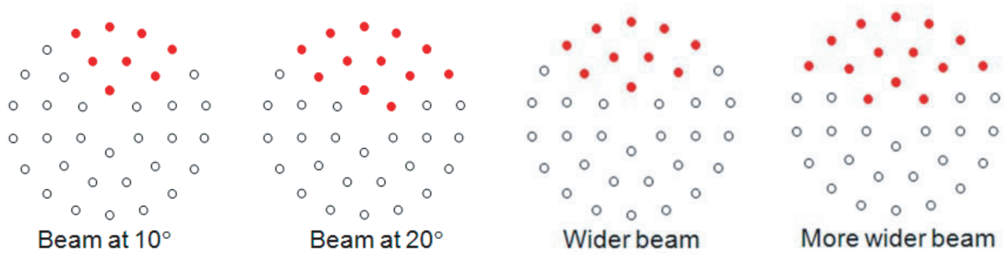


Figure 10. Configurations of the radial waveguide for different radiation pattern characteristics in azimuth plane.

3. RECONFIGURABLE RADIAL WAVEGUIDES WITH TUNABLE NARROWBAND FILTERS

3.1. Principle and Design

This structure is inspired by the reconfigurable radial waveguide described in Section 2 except that the cell of the radially and circularly periodic structure is modified as shown in Fig. 11, using another integrated frequency selective surface. With varactors, this structure allows to tune a narrow frequency band of transmission as shown in Fig. 13.

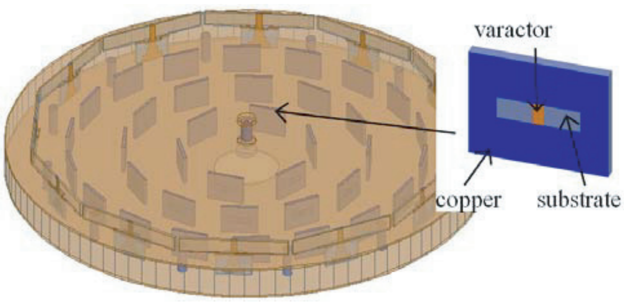


Figure 11. Proposed reconfigurable radial waveguide using varactors for tunable narrowband filtering.

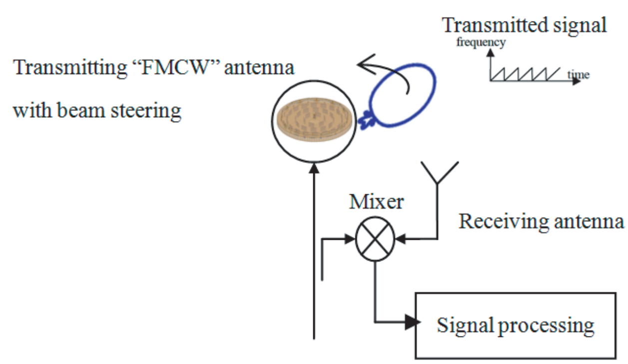


Figure 12. Proposed block diagram of an FMCW radar using reconfigurable radial waveguide.

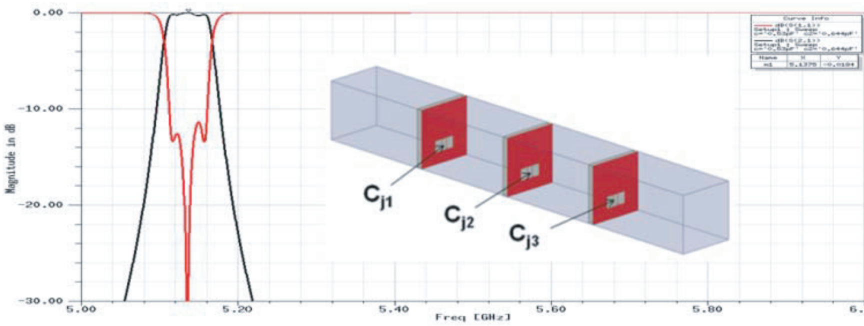
It is also possible to integrate the varactor outside the radial waveguide using similar technique than the technique presented in previous section (*c.f.* Fig. 1). The proposed concept is protected by a patent [13].

3.2. Potential Radars Applications

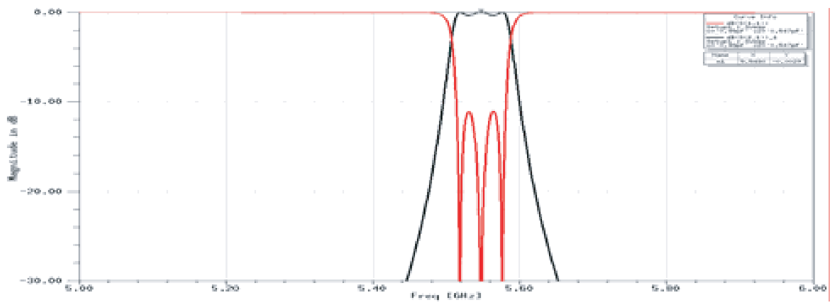
Frequency Modulated Continuous wave (FMCW) radar is a popular technology that is being employed very often in modern radar applications, mainly because of its good performance, low cost and low power consumption [15–17]. Fig. 14 presents the general schematic of an FMCW radar system.

In Fig. 15, the beat frequency is used to obtain information on the target range whereas the Doppler frequency gives information on the moving target speed.

A potential application of the reconfigurable radial waveguide presented in the previous subsection consists in designing a smart antenna for emitting an "FMCW" beam that turns in 360°, as shown in Fig. 12. The proposed system can allow obtaining the information on the target direction angle in addition to usual information. The main advantage is that the FMCW functionality would be integrated within the antenna.



(a)



(b)

Figure 13. Transmission coefficient analysis is of a rectangularly periodic structure (using Floquet Boundary conditions) for different values of the capacitances. (a) $C_{j1} = 0.53\,\text{pF}$, $C_{j2} = 0.64\,\text{pF}$, $C_{j3} = 0.53\,\text{pF}$. (b) $C_{j1} = 0.45\,\text{pF}$, $C_{j2} = 0.55\,\text{pF}$, $C_{j3} = 0.45\,\text{pF}$.

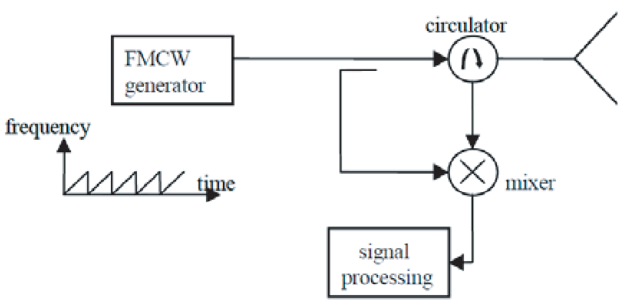


Figure 14. Block diagram of an FMCW radar.

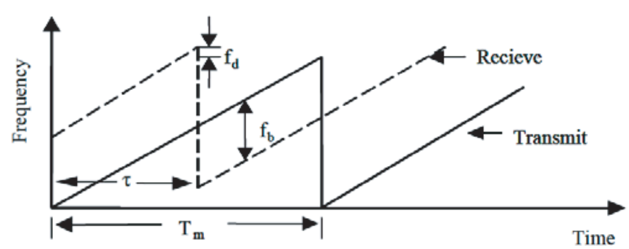


Figure 15. Transmitted and received frequencies as a function of time showing beat frequency f_b and Doppler frequency f_d.

4. RECONFIGURABLE RADIAL WAVEGUIDES WITH SLOT ANTENNAS AND PHASE SHIFTING

This structure is also inspired by the reconfigurable radial waveguide described in Section 2. The PIN diodes are replaced by variable capacitances (such as varactors) and the transitions to antenna radiators are replaced by radiating slots. The proposed structure is illustrated in Figs. 16–18. As a proof of concept, an example of radiation pattern is presented in Fig. 19 for a given configuration of the capacitances, obtaining a tilted beam. Changing the variation of the capacitances changes the direction of the beam. A further analysis of the effect of the capacitances in the phases and the effect of the phase distribution in the radiation patterns will be performed in the future. Furthermore, the number of rings of slots could be increased in the future to obtain higher gain.

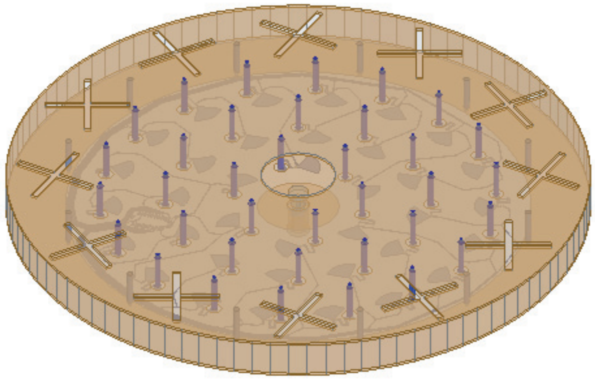


Figure 16. Proposed reconfigurable radial-line slot array.

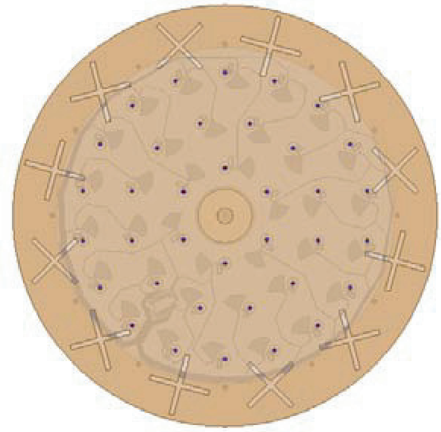


Figure 17. Top view of reconfigurable radial-line slot array.

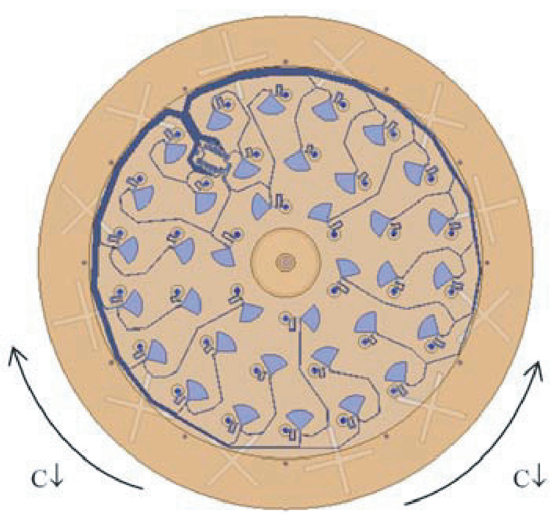


Figure 18. Bottom view of reconfigurable radial-line slot array. The capacitances are varied to obtain a directive beam at one direction.

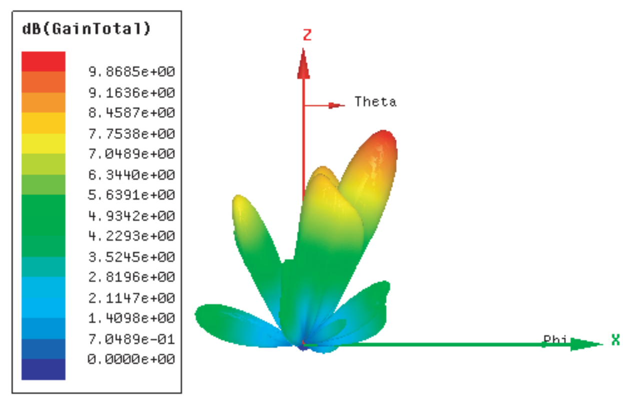


Figure 19. Example of directive beam obtained with the reconfigurable radial-line slot array for a variation configuration of the capacitances.

5. CONCLUSION

This work presents a review and new designs, techniques and results for reconfigurable radial waveguides. The experimental results for the first radial waveguide and a beam switching antenna application validate the proposed concept and model. Then, the same model is used to develop other reconfigurable radial waveguides or reconfigurable antennas which can found potential applications in communications and radars systems. The presented analysis shows that, by using different configurations, the proposed reconfigurable radial waveguide can be used for beam switching, frequency and direction reconfigurability and for beam steering in two planes.

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