Mechanically Frequency Reconfigurable Cavity-Backed Slot Antenna based on ENZ Medium for Millimeter Waves

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***Abstract*—This work proposes a mechanical frequency reconfigurable waveguide-fed cavity-backed slot antenna based on ENZ medium for millimeter wave operation. The antenna air-filled metallic cavity is doped by FR4 dielectric slabs enclosed by four metallic rods to achieve an ENZ medium and fed by a commercial single waveguide-to-coaxial transition through a standard WR28 waveguide. The cavity is semi-cylindrical, providing a semi-omnidirectional radiation pattern at the H-plane. An external sleeve mechanically actuated allows reconfiguring the antenna bandwidth using different slot lengths. The antenna full-wave numerical analyses show reconfigurability from 24.41 to 26.88 GHz, with a gain ranging from 4.80 to 5.15 dBi for eight different slot lengths.**

***Index Terms*—antenna, ENZ medium, geometry-independent antenna, millimeter wave, frequency reconfigurable antenna.**

I. Introduction

Electromagnetic devices have been manufactured based on the research findings in physics, which are devoted to studying and understanding the properties of materials and the phenomena circumventing their intrinsic structures. Hence, materials are exploited by their electromagnetic properties, such as permittivity (ε) and permeability (μ) [1], [2]. For instance, the epsilon-near-zero (ENZ) medium uses dielectric materials to set the ε parameter close to zero [3], [4]. ENZ-based medium devices have recently achieved geometry-independent operating frequency, including antennas [5]–[7]. Radiators with one-dimensional size-invariant frequency and two-dimensional geometry-independent were designed using ENZ materials [8], [9]. The latter was demonstrated through a cavity-backed slot antenna operating at a microwave frequency.

The geometry-independent antenna operates based on material dispersion phenomena, which is realized by doping a metallic cavity with a dielectric rod, forming the ENZ medium whose permittivity follows the Drude model, $\varepsilon_h(f) = f_p^2 - f^2$ [5]–[9]. The medium behaves like a homogeneous ENZ medium with a relative permeability, ensuring uniformity of the magnetic field across the ENZ region. The full wave analysis indicated that the antenna's geometry shape could be modified while the operating frequency remained unchanged and tied to the material's dispersive constitutive parameters [9].

This work was partially funded by CNPq (Grant Nos. 403612/2020-9, 311470/2021-1, and 403827/2021-3), by Minas Gerais Research Foundation (FAPEMIG) (Grant Nos. APQ-00810-21 and APQ-03162-24) and by the project XGM-AFCCT-2024-2-5-1 supported by xGMobile – EMBRAPII-Inatel Competence Center on 5G and 6G Networks, with financial resources from the PPI IoT/Manufatura 4.0 from MCTI grant number 052/2023, signed with EMBRAPII.

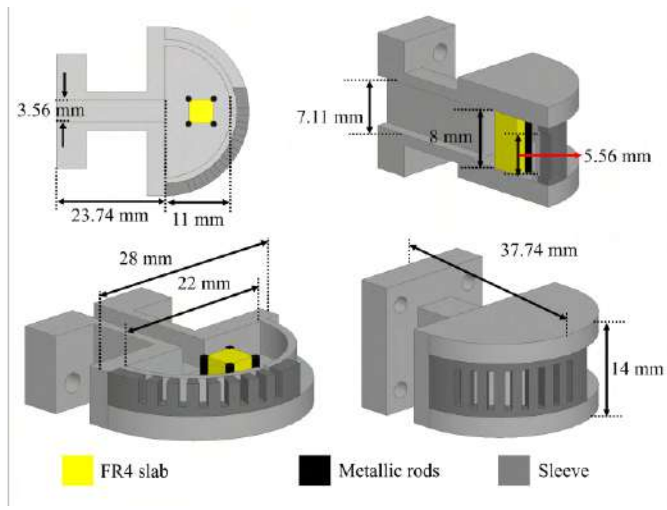

Fig. 1. Antenna structure and dimensions.

Based on this concept, we propose a waveguide-fed cavity-backed slot antenna mechanically reconfigurable to tune its frequency bandwidth using a metallic sleeve, as seen in Fig. 1. The radiator has a reduced size and operates in millimeter waves (mm-waves). It allows for reconfiguring different bandwidths related to eight slot positions that a stepper motor can easily adjust. To the best of the author's knowledge, this is the first mechanically frequency reconfigurable radiator based on the ENZ medium working principle proposed to operate at mm-waves. The paper is organized as follows: Section II introduces the waveguide-fed cavity-backed slot antenna design and the full-wave numerical results. In contrast, Section III addresses the conclusions and future work.

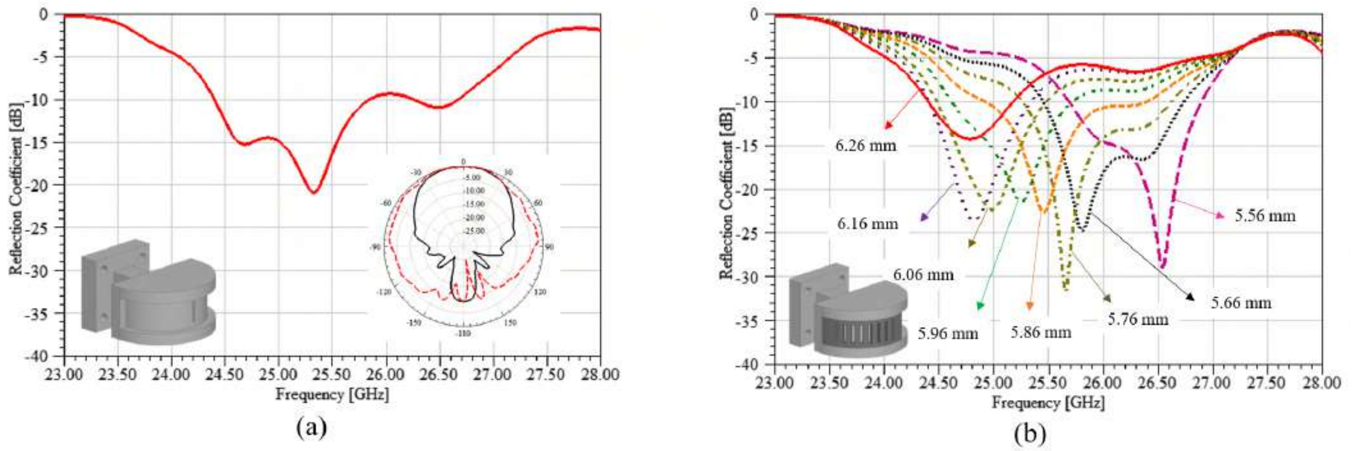

Fig. 2. Antenna's simulated reflection coefficient (a) without the sleeve, (b) with the sleeve at different positions.

II. Antenna Design

This section discusses the antenna design and the mechanical sleeve added to provide frequency reconfigurability in mm-waves. The prototype is fed by a commercial single waveguide-to-coaxial transition operating at the fundamental mode TE_{10}, modeled and included in the simulations for proper design. The antenna performance is discussed based on full-wave numerical analysis from ANSYS HFSS software.

A. Cavity-backed Slot Antenna

The antenna comprises a metallic waveguide-fed cavity-backed slot with a semi-cylindrical shape and a semi-omnidirectional radiation pattern in the H-plane. The air-filled cavity is photonically doped with an FR4 rectangular slab enclosed by four metallic rods to provide an ENZ medium. The dielectric slab has dimensions equal to 3.2 mm $\times$ 4mm while the rods have a diameter of 1 mm, being inserted to prevent mode coupling from the TE_{10} to TM_{10} mode. The cavity's cross-section area and height were numerically modeled to achieve a wide bandwidth for further frequency reconfigurability. Fig. 2(a) shows the cavity-backed slot antenna without the sleeve and its simulated reflection coefficient with values below or near -10 dB from 24.50 to 26.50 GHz.

B. Mechanically Frequency Reconfigurable Antenna

A metallic sleeve was introduced on the antenna structure overlapping the initial slot with a length equal to 5.56 mm. Eight slots with different lengths were milled into the sleeve and spaced by 10^o with values displayed in Table I. Moving the slots upon the fixed one made the antenna impedance bandwidth reconfigurable between 24.41 and 26.88 GHz, as seen in Fig. 2(b). The 10 dB impedance bandwidth was around 1 GHz, while the gain ranged from 4.79 to 5.17 dBi to the central frequency (f_c) of each bandwidth, as shown in Table I.

TABLE I
Antenna performance at each slot length.

Slot's lenght [mm]	Impedance bandwidth [GHz]	Gain[dBi]@ f_c[GHz]
6.26	0.77 (24.41 to 25.18)	4.79 @24.8
6.16	0.93 (24.41 to 25.34)	5.25 @ 24.87
6.06	1.00 (24.48 to 25.48)	4.87 @ 24.98
5.96	1.08 (24.63 to 25.71)	4.73 @ 25.17
5.86	1.47 (24.93 to 26.40)	5.13 @ 25.66
5.76	1.34 (25.27 to 26.61)	4.80 @ 25.94
5.66	1.27 (25.46 to 26.73)	5.17 @ 26.16
5.56	1.20 (25.68 to 26.88)	5.15 @ 26.30

III. Conclusion

This work proposed the first mechanically frequency reconfigurable waveguide-fed cavity-backed slot antenna based on ENZ medium to operate in mm-waves. The reconfigurability was accomplished by inserting a metallic sleeve with eight slots overlapping the fixed one, setting different operating bandwidths between 24.41 and 26.88 GHz due to different lengths. Future work will address the antenna's prototyping and characterization.

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