METAMATERIAL ANTENNA ON MAGNETICALLY POLARIZED FERRITE SUBSTRATE

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In this paper we present a mm-wave metamatarial Composite Right / Left Handed (CRLH) CoPlanar Waveguide (CPW) Zeroth-Order Resonating (ZOR) antenna having a magnetically polarized ferrite as supporting substrate. The antenna was designed, experimentally processed and measured at 30 GHz. The measurements emphasize a frequency shift of about 1.1 GHz due to the variation of the ferrite substrate effective permeability following the magnetic biasing.

Keywords: metamaterials, mm-wave antenna, ferrite, frequency shift

1. Introduction

In recent years the area of metamaterials has been getting a lot of attention from the scientific community. Although Veselago enunciated the theory of Left-Handed (LH) materials more than 50 years ago [1], structures mimicking these properties were developed only about 10 years ago [2].

Considering the transmission line (TL) parameters, metamaterials were introduced as the concept of Composite Right/Left-Handed (CRLH – TL). The CRLH is an artificial TL that can be obtained by combining the RH behavior of the classical TL modeled by a transmission line loaded with series connected inductors and parallel grounded capacitors, with the LH behavior modeled by series connected capacitors and parallel connected grounded inductors. Such a transmission line exhibits both right-handed (RH) and left-handed (LH) behavior. The first presentation of this type of transmission line was made in [3].

This particular frequency characteristic of the CRLH TL has been exploited in the development of many types of devices such as coupled-line directional couplers, filters and resonators and various types of antennas [4] –

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[14]. A complete description of the most practical leaky wave and ZOR antennas was done in [4].

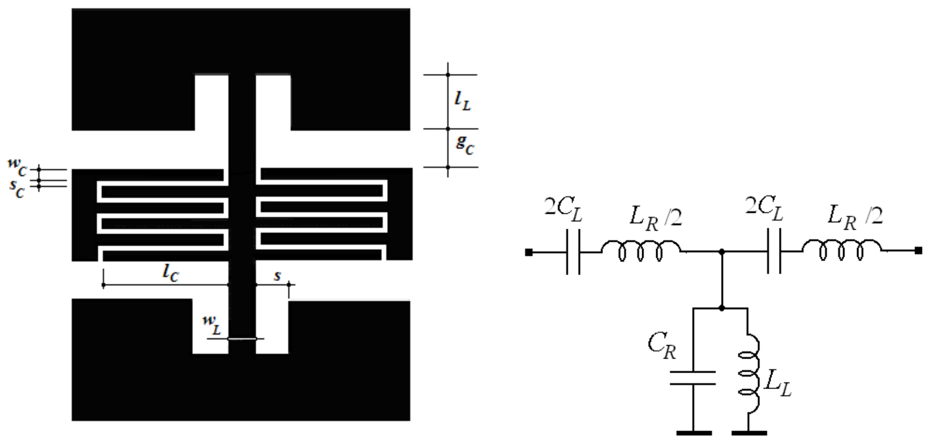
A special and very promising class of microwave and millimeter wave CRLH components consists of devices supported on magnetically biased ferrite. In literature there are very few contributions concerning this class of devices. A tuning metamaterial antenna on ferritic material was reported in microwave frequency domain [15], [16], demonstrating a $\Delta f = 450$ MHz tuning capabilities at a frequency f = 13.5 GHz.

Based on previous experience, in this contribution we present a sample of CRLH CPW ZOR antenna tunable in the mm-wave frequency domain (30 GHz), having magnetically biased ferrite as supporting substrate. The interesting results concerning the tuning capabilities of these antennas entitle us to consider the manufacturing and characterization of other CRLH devices processed on ferritic substrate.

2. Resonating CRLH antenna

The antenna is an array of three CRLH cells, each one having a T circuit topology consisting of two series connected CPW interdigital capacitors and two parallel connected short-ended CPW transmission lines. The CPW technology was preferred due to an easier technological approach and also due to a straightforward measurement procedure using an on-wafer characterization installation. This is, upon the authors' knowledge, the first realization of a millimeter wave CRLH antenna on ferrite substrate for effective use in mm-wave integrated circuits.

The layout of the CRLH cell and the equivalent circuit is presented in Fig. 1 where symbols and notations are those used in literature [4], [5]. The CRLH circuit was designed to be balanced, with the series resonance frequency equal to the shunt resonance frequency. The CRLH antenna layout, shown in Fig. 1 was designed for a resonant frequency f_{sh} = 30 GHz. In this respect, the following interdigital capacitor and inductor dimensions were used: l_L = 212 μm; w_L = 42 μm; s = 10 μm; l_C = 250 μm; w_C = 10 μm; s_C = 5 μm; g_C = 65 μm and number of capacitor digits: 10. The layout of the CRLH cell was designed and optimized using IE3D – Zeland software.



(a) (b)

Fig. 1. CPW CRLH elementary cell used in ZOR antenna construction (a) and the equivalent circuit (b)

The substrate was a 1.2 mm thickness / 22 mm diameter polycrystalline ferrite wafer of type G84SK having the saturation magnetization $4\pi M_S = 840$ Gs, permittivity $\varepsilon = 13.5$, resonance linewidth $\Delta H = 16.8$ kA/m. The wafer surface to be metalized was mirror polished. The antenna layout was designed for an external applied field $H_{appl} = 0$ T. When the ferritic substrate is biased by a DC magnetic field (H_{appl}) applied normally on the ferrite substrate, the permeability changes its values from non polarized state. The effective permeability μ_{eff} of the magnetically biased ferrite substrate was computed by inserting the relations (1)…(4), (no comma) [17].

$$\mu_{eff} = \frac{\mu'^2 - K'^2}{\mu'} \tag{1}$$

with:

$$\mu' = 1 + \frac{\omega_M \omega_L \left[\omega_L^2 - \omega^2\left(1-\alpha^2\right)\right]}{\left[\omega_L^2 - \omega^2\left(1+\alpha^2\right)\right]^2 + 4\omega^2\omega_L^2\alpha^2} \tag{2}$$

$$K' = \frac{\omega_M \omega \left[\omega_L^2 - \omega^2\left(1+\alpha^2\right)\right]}{\left[\omega_L^2 - \omega^2\left(1+\alpha^2\right)\right]^2 + 4\omega^2\omega_L^2\alpha^2} \tag{3}$$

where:

$$\gamma|4\pi M_S| = \omega_M; \quad \gamma|H_i| = \omega_L; \quad \alpha \cong \Delta H/2H_i \qquad (4)$$

The physical significance of the terms is: ΔH = resonance linewidth; $4\pi M_S$ = saturation magnetization of the ferrite substrate and H_i = internal magnetic field in the ferrite substrate.

For a thin wafer with the biasing magnetic field applied normally on its surface, the internal magnetic field is:

$$H_i = H_{appl} - 4\pi M_S \qquad (5)$$

A preliminary computing was done showing that for a frequency f ≅ 30 GHz, with the applied magnetic field changing from H_{appl} = 0 T to H_{appl} = 0.265 T, the effective permeability (μ_{eff}) of the ferrite substrate decreases from $\mu_{eff} \cong 1$ to $\mu_{eff} \cong 0.98$ and the resonating frequency of the CRLH antenna changes about 1 GHz as it is shown in Fig. 2.

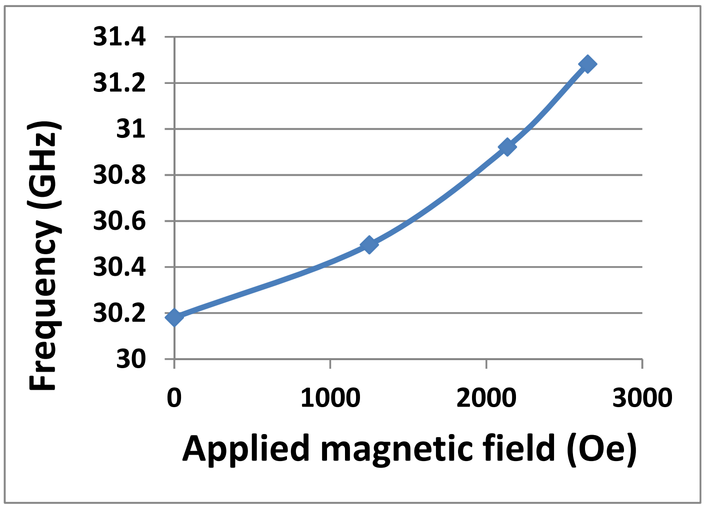
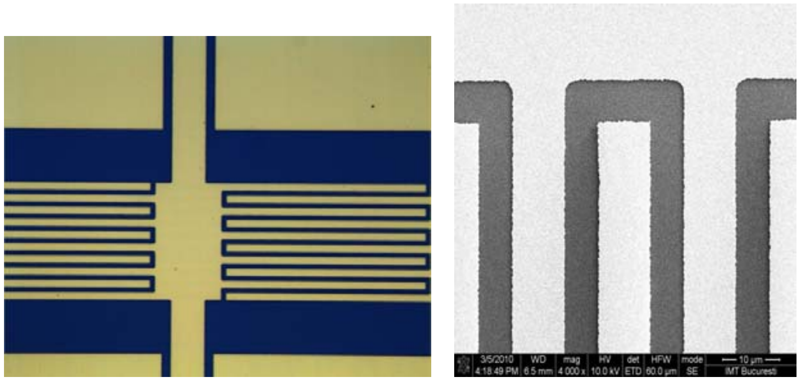


Fig. 2. Computed variation of the antenna resonant frequency following increasing the applied magnetic field from 0 T to 0.265 T

3. Experimental results

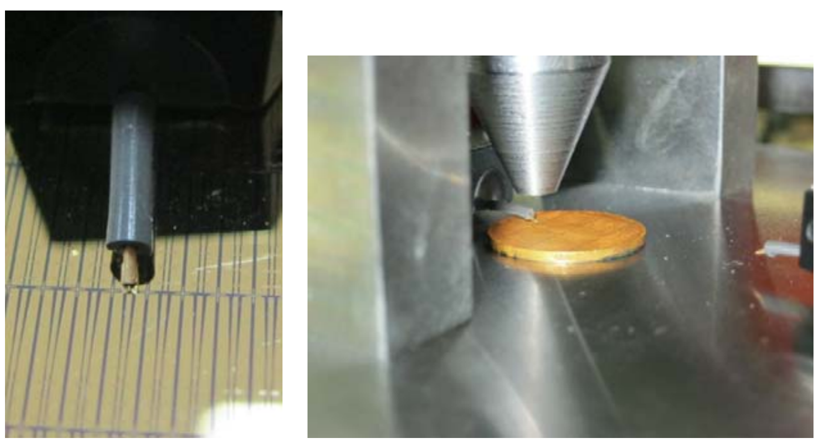
A 500Å Cr / 0.6 µm Au layers were evaporated on the mirror polished side of the ferrite wafer and then processed by an one mask positive photolithography. A microscope photo with the configuration of the interdigital capacitors and part of the inductor lines is given in Fig. 3 (a). In Fig. 3 (b) there is presented a scanning electron microscopy (SEM) image showing a detail of an interdigital capacitor.



(a) (b)

Fig. 3. Configuration of the active part of the CRLH antenna – interdigital capacitors and part of the inductor lines – (a) and a SEM image showing a detail of an interdigital capacitor (b)

The Süss Microtec probe-tip contacting one antenna structure supported by the ferrite wafer can be seen in Fig. 4 (a). The electromagnet providing the applied magnetic field mounted on Süss Microtec measuring equipment is visible in photo in Fig. 4 (b). A Hall probe intended to measure the applied magnetic field was put close to the fixed armature. The surface of the antenna active area is 2.1×0.8 mm^2, having a size reduction of ~30%, compared with a standard $\lambda/2$ patch antenna.



(a) (b)

Fig. 4. Süss Microtec probe-tip contacting an antenna structure supported by the ferrite wafer (a) and the electromagnet providing the magnetic biasing field (b).

The electrical measurements of the antenna resonant frequency and return loss were done with a set-up composed of an ANRITSU 37397D Vector Network Analyzer (VNA) with a 110 GHz maximum working frequency combined with a PM5 on-wafer characterization equipment from Süss Microtec. The measurement result on antenna resonant frequency and return loss following the biasing magnetic field variation is shown in Fig. 5.

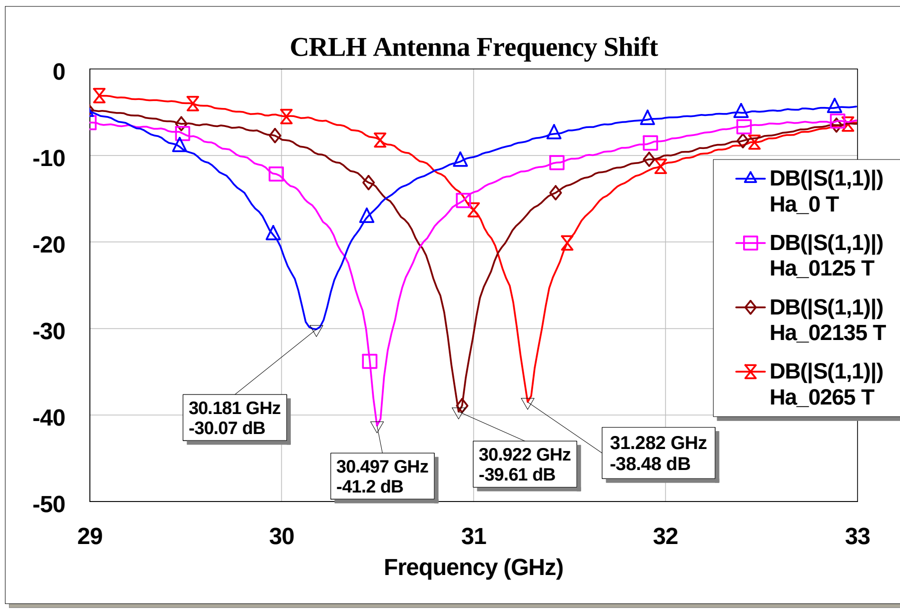


Fig. 5. Antenna resonant frequencies following the biasing magnetic field variation

The measured return losses at resonance show S_{11} = -30.07 dB at f = 30.181 GHz in absence of the magnetic biasing field. Also the low field losses characteristic to the non magnetized ferrite substrate are visible. At higher values of H_{appl}, the resonant frequencies of the antennas increase, as it may be seen in Fig. 5. For magnetic biasing fields H_{appl} = 0.125 T, 0.2135 T and 0.265 T successively, the resonances occur as follows: S_{11} = -41.2 dB at f = 30.487 GHz, S_{11} = -39.61 dB at f = 30.922 GHz and S_{11} = -38.48 dB at f = 31.282 GHz, respectively.

4. Conclusions

In this contribution we present a CRLH CPW zeroth-order antenna having a magnetically polarized ferrite as supporting substrate. A frequency shift of about 1.1 GHz due to the variation of the effective permeability of the ferrite substrate following the magnetic biasing was obtained from experiments. The measured frequency shift is consistent with the calculated values for particular magnetic biasing field. Also, the return loss decrease due to eliminating of low field loss in the ferrite substrate.

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