Horn Antennas Loaded with Metamaterial For Satellite band Application

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***Abstract*— A Split Ring Resonator (SRR) as Metamaterial has been loaded on pyramidal horn antennas for Ku band or satellite application. The aim of this work is to exhibit the advantage of metamaterial (SRR) use inside horn antenna; this is mainly enhancement of the bandwidth towards lower frequency and improvement of the radiation pattern gain. The horn antenna is feed by a monopole antenna of optimised length. The obtained results from HFSS simulation concerning the constitutive parameters of the (SRR), show that there is a DNG (Double Negative) permeability and permittivity in the frequency of interest. In this work the operating bandwidth of the proposed antenna (notched band) is in the range of 9.80 GHz to 10.30 GHz, and 10.80 GHz to 11.20 GHz as Ku or satellite application.**

***Index Terms*— Metamaterial, Horn antennas, Return loss, constitutive parameters, DNG, Satellite**.

I. Introduction

Metamaterial is well known as artificial material, also known as left hand side, suitable for designing antennas of high absorption. Recently it has been of great interest, both for theoretical development [1,2], and for experimentally works [3,4]. Since ten years ago many research work have been investigated on the effect of dielectric or ferrite object inside the taper of a horn antennas [5, 7]. Here in this paper we are looking at the effect of metamterial (SRR) inside the throat of the horn antennas, just to see the advantage of this application in the satellite band (K_u or X band)

Many combination of dielectric or ferrite layer have been tested but seems that the metamaterial is more interesting [8]. Pyramidal Horn antennas loaded with metamaterial [9], have desirable properties such as increased directivity, reduced side lobe level, wide bandwidth, and ease of fabrication [10,12]. These properties are particularly attractive for applications such as ultra-wideband (UWB) ground penetrating radars (GPR) [13]. However, the characterization of such antennas with increasingly complex designs using analytical techniques is often not possible. On the other hand, a numerical model can provide a virtual test bench to explore different design possibilities before any costly prototyping. Although many numerical techniques can be used to model and study the characteristics of such antennas, the moment method is well known to provide good accuracy [14,15].

This paper deals firstly with the design of unit cell of PCB, as metamaterial operating in the range of 8.20 GHz to 9.50GHz, and from 11.20 GHz to 14.0 GHz as a notched band, the unit cell is designed by HFSS and the obtained S-parameters are used for the extraction of the constitutive parameters of the unit cell. The PCB is inserted at the top of the horn antennas throat, the obtained return loss by simulation show that resonant frequency of the horn antenna is shifted towards the unit cell.

II. Metamaterial Inspiration

A. Theoretical concept

The metamaterial is an artificial material, the extraction of the constitutive parameters needs experimental tests or analytical models. Drude–Lorentz model [16, 17], known as dispersion model is very accurate, in which the magnetic permeability and electric permittivity are extracted analytically. Another well-developed characterization method of metamaterials is the standard retrieval procedure [18,19]. The assigned effective refractive index (n) and relative impedance (z) values of the metamaterial PCB can be extracted from the S-parameters assuming that the unit cell test is symmetric with respect to the (x–y) plane, which means S11 = S22 and S21 = S12. The relative impedance can be given with respect to the S-parameters using the following formulas:

$$Z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \tag{1}$$

And,

$$n = -j.\ln\left(\frac{S_{21}}{1-S_{11}\left(\frac{Z-1}{Z+1}\right)}\right)\frac{1}{k_0 d} \tag{2}$$

Where k_o the free space propagation and (d) is the thickness of the unit cell, here d is chosen to be 5 mm. The constitutive parameters can be derived from the above equation as:

$$\mu_{eff} = n/Z \tag{3}$$

And,

$$\varepsilon_{eff} = n.Z \tag{4}$$

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B. Unit cell Design

The unit cell is realized by utilizing the well-developed printed circuit board (PCB) technology. Figure 1, shows the schematic view of the manufactured metamaterial layers. On the front face, we have the SRRs with geometrical parameters detailed as given bellow.

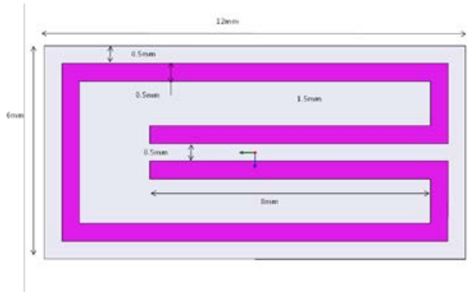


Fig. 1.a, Unit cell of metamaterial

The substrate is an FR4 with relative permittivity $\varepsilon_r = 4.4$ and dielectric loss tangent $\delta = 0.02$, the thickness of the substrate is 0.8 mm.

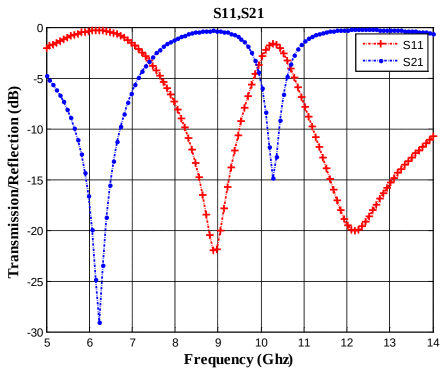
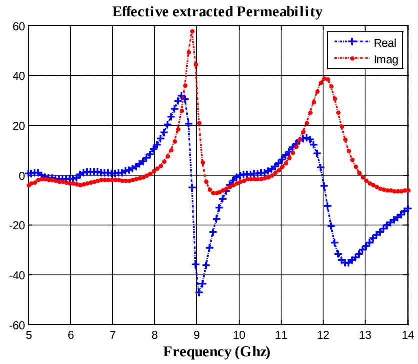
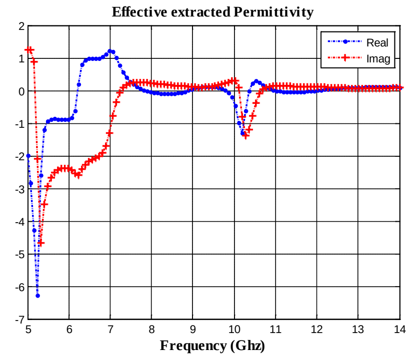


Fig. 1.b The Transmission and Reflexion coefficient

The transmission and reflexion coefficient of the unit cell is presented by figure 1.b.The simulated unit cell on HFSS has shown very interesting results, figure 2.a and figure 2.b present the imaginary and real parts of respectively the permeability and the permittivity, two resonant frequencies are observed, the first one is on 9 GHz and the second one on 12.2 GHz, both the permittivity and the permeability have negative real parts from 6.2 GHz up to 8.8 GHz, and from 10.2 GHZ to 12.0 GHz, this is also valid for the refractive index in figure 3.a.

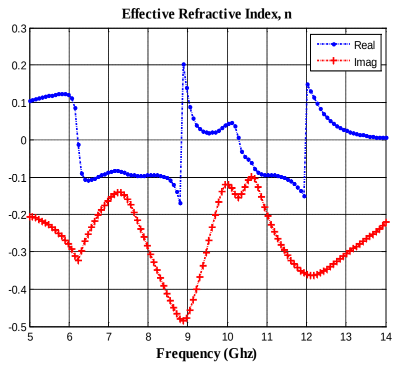


(a)

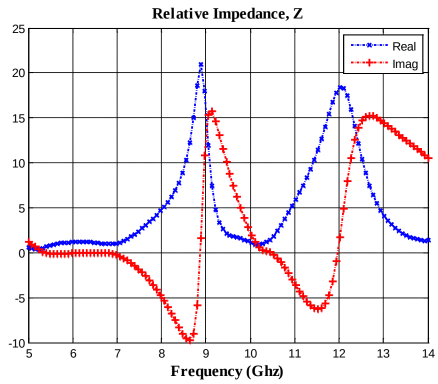


(b)

Fig. 2, (a) Real and Imaginary parts of the unit cell permeability.
(b) Real and Imaginary parts of the unit cell permittivity.



(a)



(b)

Fig. 3, (a) Real and Imaginary parts of the unit cell Refractive index
(b)Real and Imaginary parts of the unit cell relative impedance.

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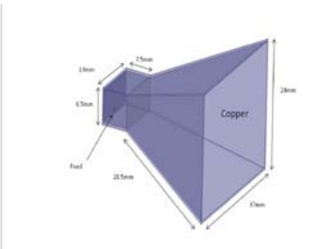
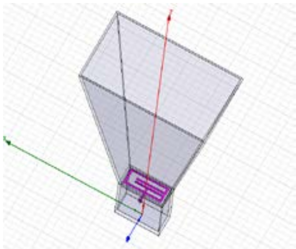
In the literature [19], this is a clear DNG media (Double Negative, $\varepsilon_r \langle 0$, $\mu_r \langle 0$), which involve application in the electromagnetic phenomena of reflection, absorption, radiation, cloaking, refraction, and subwavelength imaging. The relative impedance (z) has a positive real part in figure 3.b, but still the resonant frequencies observed in the same given frequencies of the PCB.

III. Horn Antennas

The horn antennas used in this study (without metamaterial) is operating in the range of 11.80 GHz to 12.80 GHz as K_u band, feed by a monopole antenna of 4.5 mm long as shown by figure 4.a. The PCB considered as metamaterial is placed at the top of the throat as shown by figure 4.b.



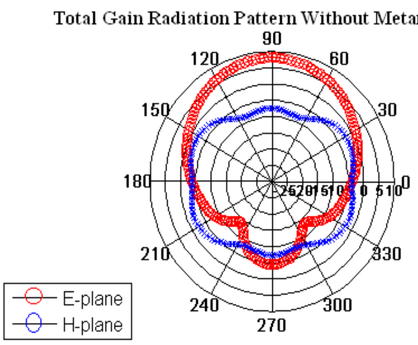
(a)



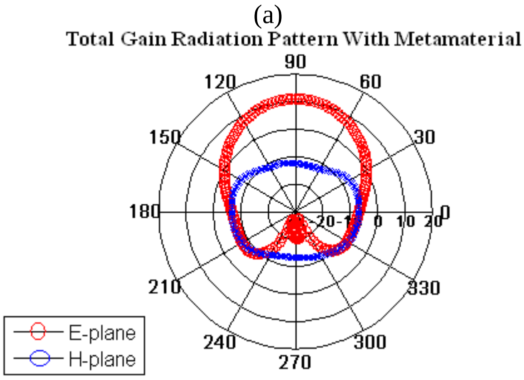
(b)

Fig. 4, (a) Pyramidal horn in 3D
(b) Horn Antenna Loaded with PCB unit cell designed by HFSS.
(c) Physical horn

The excitation is considered to be TE_{01}, only the fundamental mode (oy axis) is allowed, the position of the feed is also optimized as shown by figure 4.a, (4.5 mm to the (z) axis and 3.5 mm to the (x) axis). The total gain shown in figure 5, is recorded only for the frequency 10 GHz as the resonant frequency of the horn antenna after metamaterial placement. The maximum total gain without metamaterial is 8 dB and 11 dB with metamaterial, an improvement of the gain more than 30%.



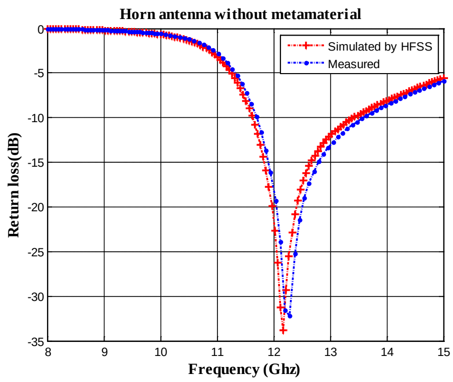
(a)



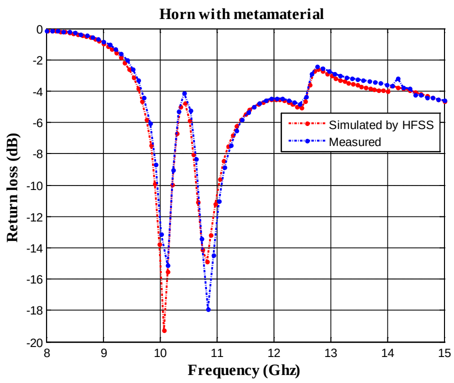
(b)

Figure 5, Total Gain Radiation Pattern At frequency F = 10 GHz
(b) without Metamaterial, (b) with Metamaterial

The return losses shown in figure 6, present two cases, without metamaterial and with metamaterial, it is clear that, the resonant frequency is shifted from 12.25 GHz to 10.10 GHz, a displacement of 17%, the bandwidth is slightly reduced from (12.8-11.8 = 1 GHz) to (10.30-9.80 = 0.5 GHz), say there is reduction of 50%.



(a)



(b)

Fig.6, Return loss of the horn with and Without Metamaterial

Regarding the resonant frequency of the unit cell, it was expect to see the resonant frequency of the horn equal to the unit cell; however there is a difference of (10.10-9.0 = 1.1 GHz), say 10% of difference, this difference could be due to the fact that the unit cell is studied in PML condition, when

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placed inside the horn antennas the conditions are not the same.

CONCLUSION

In this paper, SRR Metamaterial for satellite application has been designed by HFSS and the constitutive parameters are retrieved by the standard procedure. The obtained results show that both the permeability and the permittivity have negative real parts; this means that the PCB can produce resonant frequency in any medium placed in. The results obtained by simulation and experimentally, show that, when loading the horn antennas with metamaterial, the resonant frequency is shifted of 17% towards lower frequencies and the bandwidth is reduced to 50%, whereas the gain is increased to 30%.

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