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Specific Kind Of Meta-Material Application On High Frequency Structures And Waveguide Antennas

Mahdi JALALI[1] Tohid SEDGHI[2]

[1] Department of Electrical Engineering, Naghadeh Branch, Islamic Azad University, Naghadeh, Iran.
[2] Department of Electrical Engineering, Urmia Branch, Islamic Azad University, Urmia, Iran.

*Corresponding author:
E-mail: Jalali.mahdi@gmail.com

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Abstract

A novel technique was employed to miniaturize the open-ended radiator using electromagnetic meta-materials (MTM). In this paper, an open - ended rectangular waveguide antenna loaded with Back to Back Square Broad Side Coupled Meta-Material Split Resonator (BBSCMM-SR), radiating below the cut-off frequency of the waveguide are designed is proposed. This work has investigated design development, simulation, miniaturization and are comparing with these different types of Ring Resonators of an open end a waveguide dual band antenna. The antenna is capable of radiating below the cutoff frequency of the waveguide by supporting backward waves. Comparing previous work of miniaturization of waveguides, a better bandwidth about 550 MHz, good matching, dual band and low profile antenna is obtained.

Keywords: ***Index Terms*—meta-materials, Split ring resonator, waveguide Antenna.**

INTRODUCTION

In the last few years, there have been several new ideas which may to the miniaturization of waveguides [1]. Recently, a very unusual waveguide was proposed. in [2] and then extensively studied by in [3]. [2]-[3] proposed a rectangular metallic waveguide periodically loaded with resonant magnetic scatterers, so-called split - ring resonators (SRR's) [3]-[10]. The design of split rings is very important to construct a new type of MTMs. Numerous types of different ring and ring-like structures such as circular, square, Ω-shaped, U-shaped, S-shaped and others are used to create new MTMs [7]. In the light of the known structures we decided to use a new MTM which consist of a Back to Back Square Broad Side Coupled Meta-Material Split Resonator which has been proposed in [8]. We use this structure in an open ended waveguide antenna and do simulation in the frequency range of 5-9 GHz. Simulation results are presented below. This kind of resonator has negative permittivity and permeability in the used frequency band. An X-band, open ended waveguide antenna loaded with unit cells which is radiating below the cutoff frequency with a good bandwidth and better impedance matching, is designed and simulated.

Theoretical Analysis And Simulation

In the part, first we use combination of SRR (Split Ring Resonator) and WS (Wire Strip) structures to fabricate artificial MTM. Figure 1 illustrates the geometry of the unit cell comprised of BBSCMM-SR and WS. Optimal parameters of the proposed Unitcell: W_{sub} = 13 mm, L_{sub} = 10.16 mm, W = 4 mm.

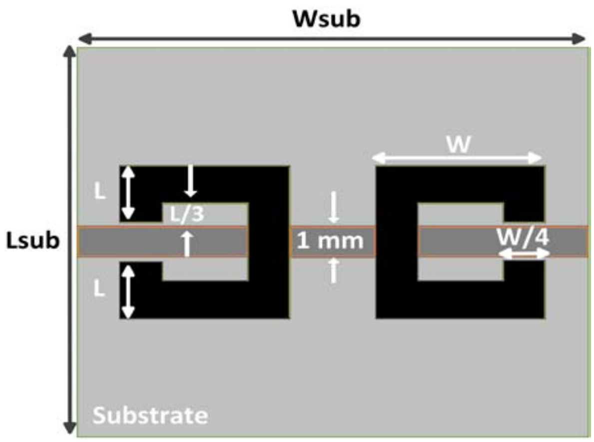


Figure 1. Unit cell of new metamaterial

A FR4 sheet of 1mm thickness (with relative permittivity 4.4) is used as substrate for each configuration. BBSCMM-SR and WS are made of copper with conductivity of 5.8×10^{7} S/m. the width of all unit cells is 0.4 mm. SRRs are located on one face of FR4 and WSs are etched on their opposite face. We use HFSS Ver. 13 software; based on finite-element method (FEM).The width of WS is chosen 0.5 mm. The base and height of SRR are 8 and 7 mm respectively. The gap in each SRR is 0.6 mm and space between SRRs is 0.5mm. Left handed medium is simulated by a regular array of five SRR-WS placed in the symmetry plane of 60mm long. In a lossless case, the longitudinal propagation factor of this waveguide is given by the simple set of equations [4]:

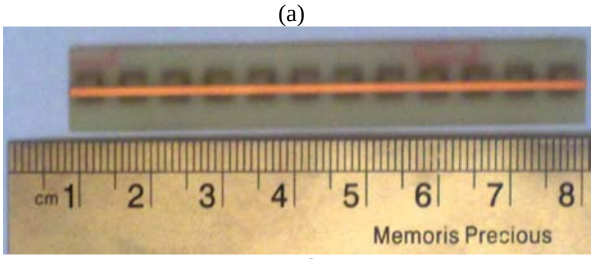
$$k_z = \pm k_0\sqrt{\varepsilon_r\mu_{tr}\left[1-\left(\frac{f_c}{f}\right)^2\right]},\ f_c = \frac{f_{c0}}{+\sqrt{\varepsilon_r\mu_{lr}}},\ f_{c0} = \frac{mc}{2a} \qquad m = 1,2,3,\cdots$$

(1)

Here, k_z stands for waveguide propagation factor, k_0 is a free space propagation factor, ε_r is relative permittivity and μ_{tr} and μ_{lr} stand for relative permeability in transversal(x) and longitudinal (z) directions of the waveguide, respectively. The symbol f stands for frequency of the signal, whereas f_{c0} and f_c are the cut-off frequency of an empty waveguide and the waveguide filled with a material respectively. The X-band waveguide loaded with SRR-WS is excited by a C-band waveguide-to-coaxial transition (cutoff frequency 4.3 GHz). To ensure the excitation of the first SRR in the array, the first ring was partially placed out from the X-band waveguide; and to improve the radiation, the last ring was partially placed out from the open end of the waveguide along with an extra ring. As shown in figure 2the fabricated and realized unit-cell has printed commercially available on FR4 substrate with array of six unit-cells.

Reflection coefficient S_{11} at the input port for antenna is plotted in figure 3. From the plot, one can notice that the propagation pass band is located well below the cut of frequency of X-band waveguide with the bandwidth 550 MHz. Minimum return loss computed is 18 dB. Comparing this to previous works of miniaturization of waveguides in [2], [3], a larger bandwidth obtained with low profile and the less number of cells.

(a)



(b)

Figure 2. fabricated BBSCMM-SR (a) top view of (b) bottom view.

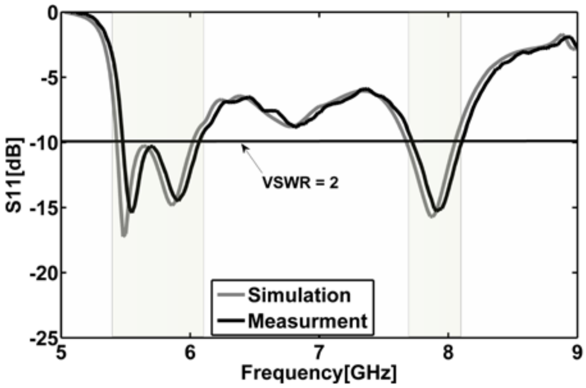
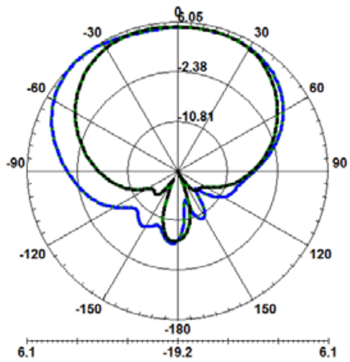


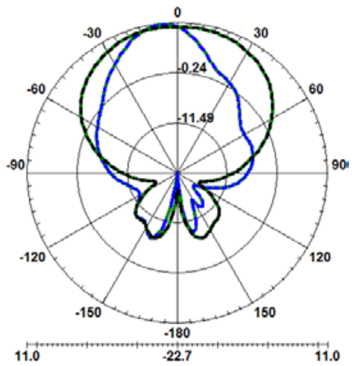
Figure 3. Measured and simulated S_{11} plot for Antenna with 6 unit cells for FR4 substrate.

Obtaining pass-band below the cutoff frequency of the waveguide is not proof of a backward wave. In figure 3, which shows the phase and magnitude of the guided wave, it is clearly seen that in the pass-band, the phase of the wave increases unlike as in an ordinary waveguides where phase decreases. Thus, physically longer waveguides exhibit larger phase of S_{11}. This is because the direction of the phase velocity is opposite to the energy flow. This proves that there is a phase advance in such waveguides unlike phase delay in an ordinary waveguide. With this, one can conclude, physically longer backward wave waveguide appears electrically shorter with phase advance.

In the figure 4 E-plane and H-plane patterns of the antenna in resonance frequencies are depicted. The patterns show that the antenna works like an directional antenna on resonance frequencies.



(a)



(b)

Figure 4. Measured E-plane and H-plane of antenna with 6 unit cells in (a) 5.48GHz (b) 5.88GHz

Parametric Analysis

There are parameters that affect on the antenna characteristics such as return loss and bandwidth. To see the effect of the parameters, there are some parametric analyses below.

Analysis of waveguide antenna for different methods

For analysis of the antenna characteristics for different methods, we use some kind of methods, in the antenna and do simulation. The S_{11} is presented in figure 5. results shows that the bandwidth is fully depend on the techniques used in the antenna. Also it is obvious that a larger band width with the respect of cut-off frequency of the waveguide is obtained when we use of proposed method in the antenna.

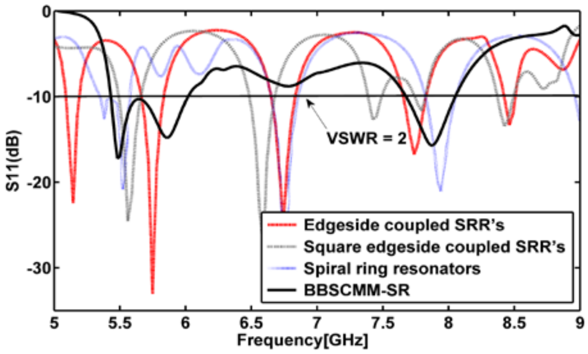


Figure 5. Return loss plot for Antenna with different Methods

Analysis of waveguide antenna for different dielectric substrate

To see the effect of using different dielectric substrates in the waveguide antenna structure we use a Rogers RT/duroid 5870 with relative permittivity of 4.4 and dielectric loss tangent of 0.0012. Simulation results are presented in figure 6. As it is obvious using a substrate with lower relative permittivity cause a shift in bandwidth frequency range for lower band and a smaller bandwidth for higher band. So choosing FR4 as a proper dielectric substrate to have a lager bandwidth and less return loss is suitable.

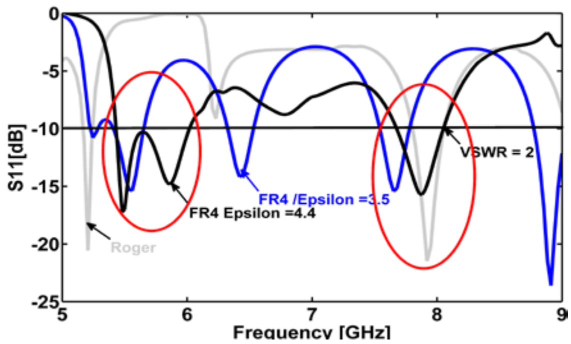


Figure 6. Return loss plot for Antenna with different Substrates

CONCLUSION

Simulation of Back to Back Square Broad Side Coupled loaded X-band waveguide antenna radiating below the cutoff frequency was successfully carried out. According to simulations, the antenna operated about 5 GHz, 1 GHz below the cut off frequency of the waveguide. The antenna had a bandwidth of 550 MHz. The primary goal of the research was to miniaturize a waveguide antenna using novel electromagnetic meta-material rather than classical dielectric inclusion. The radiation property of the antenna does not depend on the cross section of the waveguide, but on the inclusion. Transverse width of such a waveguide can be, in principle, arbitrarily small. The lowest frequency of radiation, and therefore the miniaturization, is dictated by feasibility of fabrication of the meta-material at the frequency of interest. We design a smaller, compact, and low profile antenna with better bandwidth from previous works.

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