



# **Design and Analysis of Circular Waveguide loaded with Split Ring Resonator based MNG Metamaterials**

Prof. Zalak Patel<sup>1</sup>, Prof. Miloni Ganatra<sup>2</sup>, Prof. Hansa Shingrakhia<sup>3</sup>

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmadabad, Gujarat, India

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmadabad, Gujarat, India

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmadabad, Gujarat, India

**ABSTRACT:** A circular waveguide loaded with the magnetically negative filling is designed, modeled & simulated. The effects of inserting split ring resonator as the magnetically negative filling in the circular waveguide are examined through the plots of E field distributions. The placement of split ring resonators are changed along the axis of circular waveguide and the return loss & insertion loss are observed. This work has thoroughly investigated the design of a circular waveguide loaded with metamaterial for achieving multi-band response in X-band of Microwave frequency bands. The results are found to be matched with the theoretical predictions on the basic properties of metamaterials.

**KEYWORDS:** Magnetically Negative (MNG), Circular waveguide, Split Ring Resonator (SRR), Metamaterial (MTM), Return Loss (RL).

## **I. INTRODUCTION**

Several studies of Metamaterial-based waveguides have been published recently. Metamaterials based antennas support multi band response was first reported in [1]. In this paper, we have used the square shaped split ring resonator as an inclusion in the circular waveguide. This SRR provides magnetically negative (MNG) material when it is excited with proper field. Using SRR as MNG filling within circular waveguide, we have obtained the S-parameter response and the E-field plots. By observing these graphs, it can be seen that by inserting SRR based MNG filling within circular waveguide, the number of frequency bands in X-band at which it responses are increased in number as compared to the air filled circular waveguide operating for a single cut off frequency in X-band. Also by changing the locations of SRR on the guiding axis of waveguide, we have different S-parameter responses in terms of no of operational frequency bands. So metamaterials can be of use in the microwave circuits or high frequency antennas which requires producing multi band responses for various wireless and satellite communication applications.

The phenomenon of backward-wave propagation below a cut-off frequency of fundamental TE mode of a rectangular Waveguide loaded with the split ring resonators (SRRs) was reported in [2]. In this paper we have presented the E-field plots of an air filled circular waveguide operating for X-band and the same of MNG Metamaterial filled circular waveguide. The E-field distribution in the circular waveguide filled with the SRR as MNG Metamaterial shows that wave propagates only up to the place where SRR is located and then some energy is absorbed in the SRR material & some energy propagates back towards the incident source side. This may be considered as partial proof to support the property of backward wave propagation of novel metamaterials.

In the simulations first we use SRR structure in the central portion of circular waveguide to fabricate artificial MTM and performed simulation in the frequency range of 0.5-10 GHz. Simulation results are presented in section III. Figure 2 illustrates the geometry of the unit cell comprised of single SRR. A FR4 sheet of 0.8 mm thickness (with relative permittivity 4.4) is used as dielectric substrate material. SRR is made up of copper with conductivity of 5.8.107 S/m. We use Ansoft's High Frequency Structure Simulator (HFSS) software; and analysis technique was finite-element method (FEM). We mainly observe the transmission characteristics (i.e. S11 and S21 – scattering parameter response) for the circular waveguide loaded with SRR based MNG Metamaterial.

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## II. THEORETICAL ANALYSIS OF METAMATERIALS

Existing materials only exhibit a small subset of electromagnetic properties theoretically available. Metamaterials can have their electromagnetic properties altered to something beyond what can be found in nature. These artificial fabricated materials are supposed to exhibit electromagnetic responses generally not found in nature. The unique properties of Metamaterials are listed below:

- Double negativity (DNG): MTMs are the materials which possess simultaneous negative permeability and permittivity i.e.  $\epsilon < 0$  and  $\mu < 0$ . The material which only displays  $\mu < 0$  property then it is referred as magnetically negative MNG Metamaterial.
- Negative Refractive Index (NRI): Due to double negativity of medium parameters, the refractive index in the mediums made up of MTMs is found to be negative exhibiting negative refraction.
- Left-Handedness (LH): The wave propagation (E-field, H-field, and wave vector) in the MTMs does not obey the right-hand rule.
- Back-ward wave propagation: The energy flow and wave vector are anti-parallel showing the backward wave propagation in MTMs.

The Direction of energy flow formed by  $E \times H$  is right-handed only when permeability is greater than zero. This means that when permeability is less than zero, e.g. magnetically negative (MNG), wave propagation is reversed (determined by  $k$ ), and contrary to the direction of energy flow (denoted as  $S$ ). Furthermore, the relations of vectors  $E$ ,  $H$ , and  $k$  form a "left-handed" system - and it was Veselago who coined the term "left-handed" (LH) material, which is in wide use today (2011).

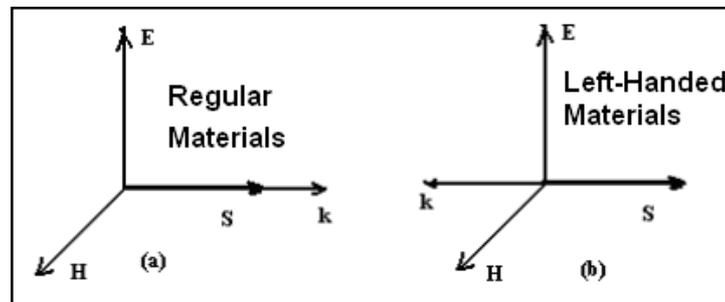


Figure 1: Poynting Vector is anti-parallel to the wave vector in case of Metamaterial

### **Realization of MNG Metamaterial using Split ring resonator:**

The resonance provides oscillation at a particular frequency is the key to achieve negative response and is introduced artificially in a Metamaterial by building small circuits - designed to mimic the magnetic or electrical response of a material. In a split-ring resonator (SRR), for example, a magnetic flux penetrating the metal rings induces rotating currents in the rings, analogous to magnetism in materials. Which induce resonating currents in the loop and generate equivalent magnetic dipole moments, this MTM exhibits a plasmonic-type permeability frequency function which provides negative permeability. Apply a field below this frequency and a normal positive response results. Just above the resonant frequency, however, the response is negative—just as the swing pushed back when pushed faster than its frequency. Thus split rings can provide a magnetic response with negative  $\mu$  over some frequency band. [3]

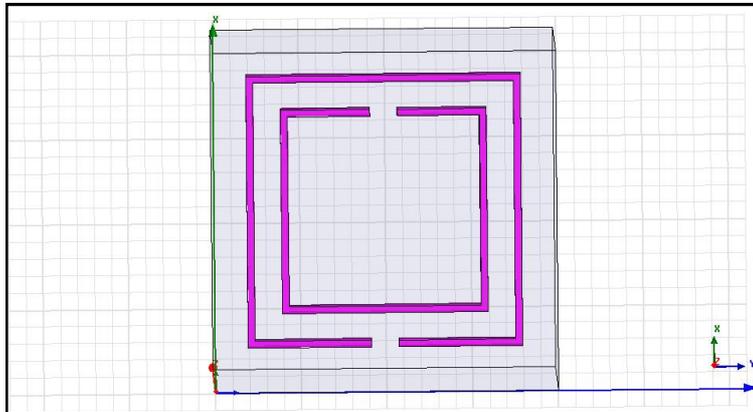


Figure2: The Split-ring resonator (SRR) structure exhibiting negative-permeability as MNG material

### III. SIMULATION RESULTS AND DISCUSSIONS

Figure3 shows the structure of SRR under investigation is placed in a Circular waveguide with dimensions of outer & inner cylinder radii equal to 1.32 cm & 1.17 cm respectively. The square shaped SRR is first placed in the central portion of the circular waveguide along the guiding axis of waveguide (design 1). This setup is first simulated in HFSS modeling as indicated before. Then SRR is located at the load end side along the guiding axis of waveguide and simulated results are observed (design 2).

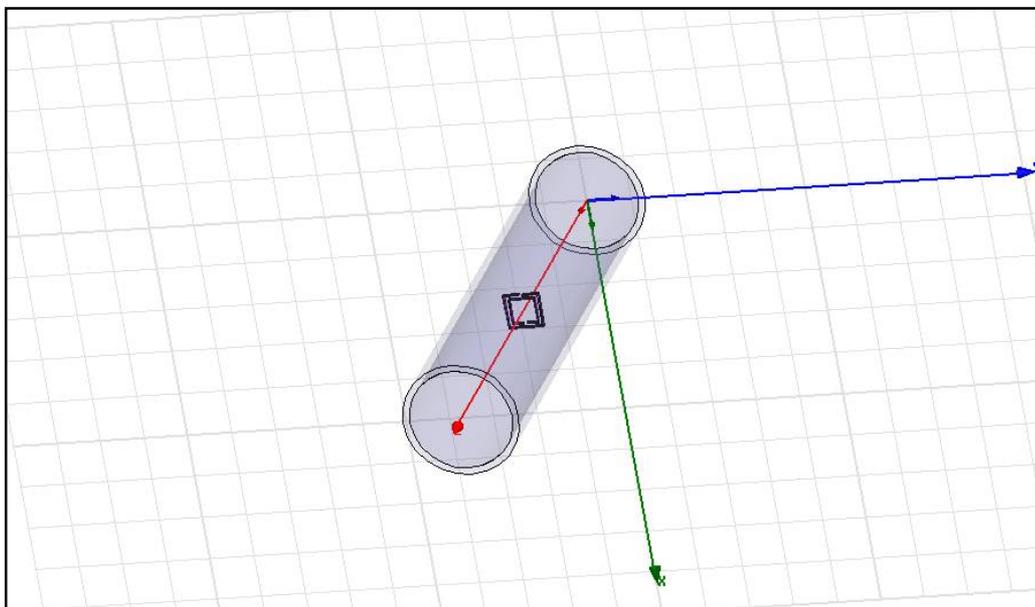


Figure 3: Design 1 - Model of unit cell waveguide loaded with SRR as MNG Metamaterial in the central portion

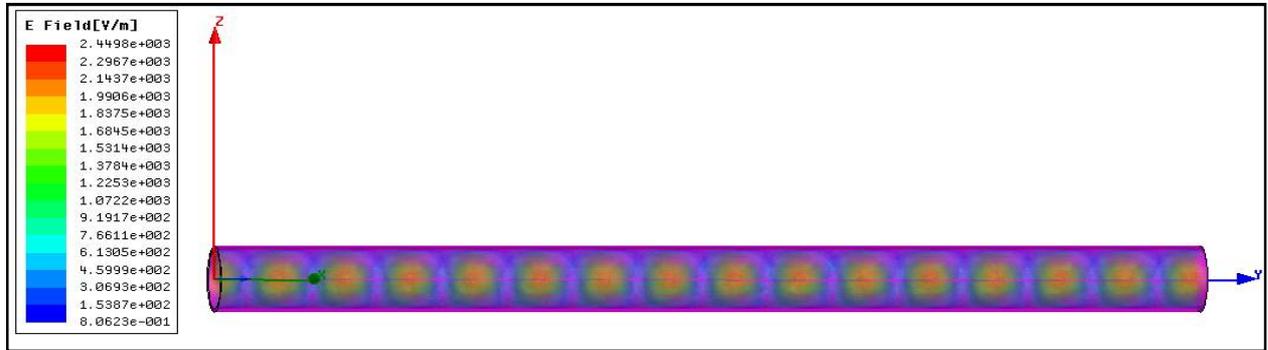


Figure4: E-field distribution in the circular waveguide filled with vacuum as dielectric



Figure5: E-field distribution in the circular waveguide filled with the SRR as MNG Metamaterial

Result analysis: Figure4 shows the E- field distribution of the circular waveguide filled with vacuum as dielectric. Fig. 5 shows the E-field plot for the circular waveguide loaded with the SRR as MNG filling. This result displays that E-field is obstructed at resonator ring within waveguide that presents the backward wave propagation property of the metamaterials.

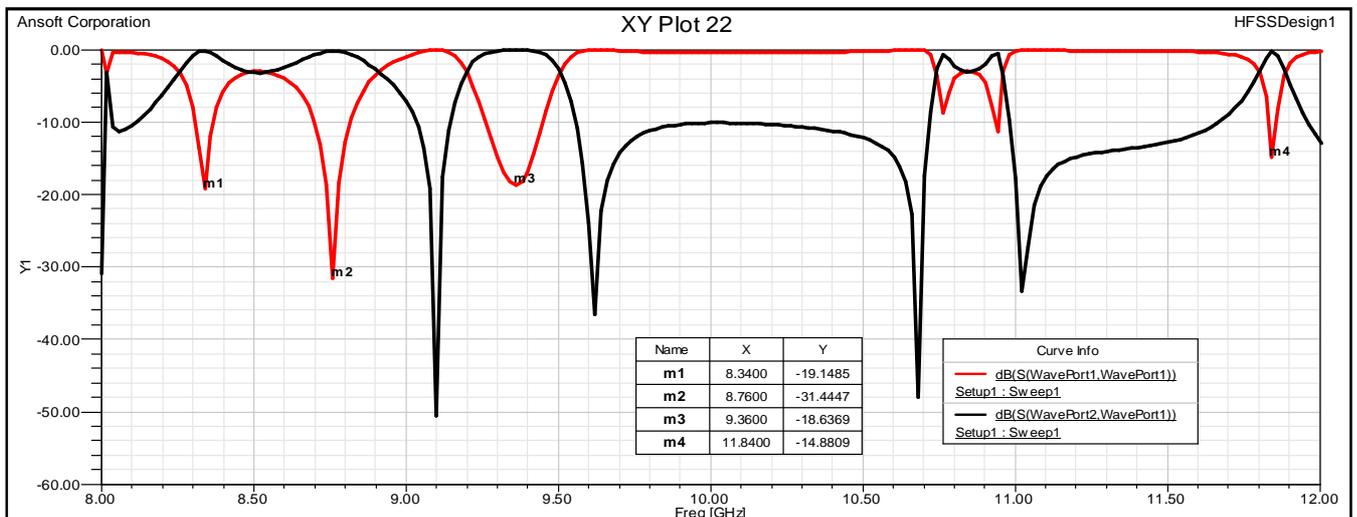


Figure6: Transmission spectra ( $S_{11}$  and  $S_{21}$  parameters) for the proposed design 1

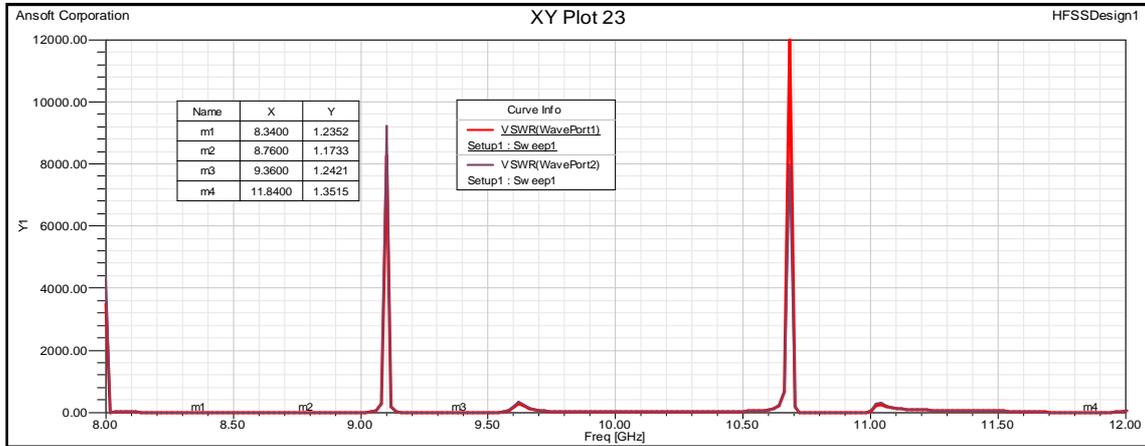


Figure7: VSWR plot for the proposed design 1

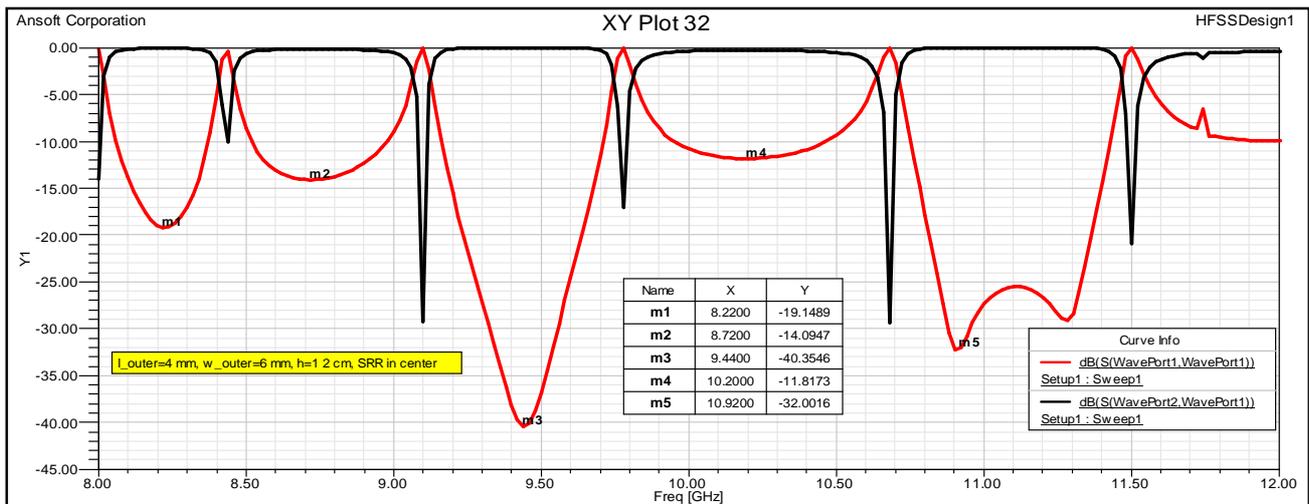


Figure8: Transmission spectra ( $S_{11}$  and  $S_{21}$  parameters) after the parametric variations of the geometry of SRR in design 1

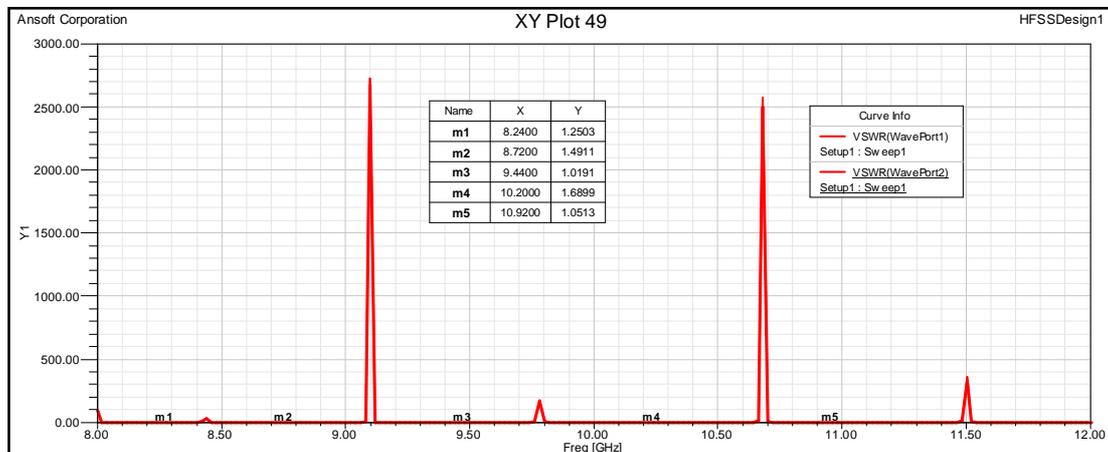


Figure 9: VSWR plot for the optimized version of design 1

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Results	$f$ (GHz)	RL (dB)	Bandwidth (MHz)	VSWR
<b>Band1</b>	8.22	-19.15	308	1.25
<b>Band2</b>	8.72	-14.1	451	1.49
<b>Band3</b>	9.44	-40.35	540	1.01
<b>Band4</b>	10.2	-11.42	510	1.68

Table 1: Results of return loss, bandwidth & VSWR at the operating frequencies of Design 1

Result Analysis: Figure 6 shows the S-parameter response for waveguide loaded with SRR in the central portion along the guiding axis, which demonstrates multi bands at 8.34 GHz, 8.76 GHz, 9.36 GHz and 11.84 GHz frequencies of X-band. As illustrated, return losses are above -10 dB and narrowband operations have been achieved. The VSWR are found to be in between 1 to 2 for all the operating frequencies. After parametric variations of the design values of length and width of SRR, S-parameter response of optimized design is analyzed shown in figure 8. This optimized design provides better responses in terms of return loss and bandwidths.

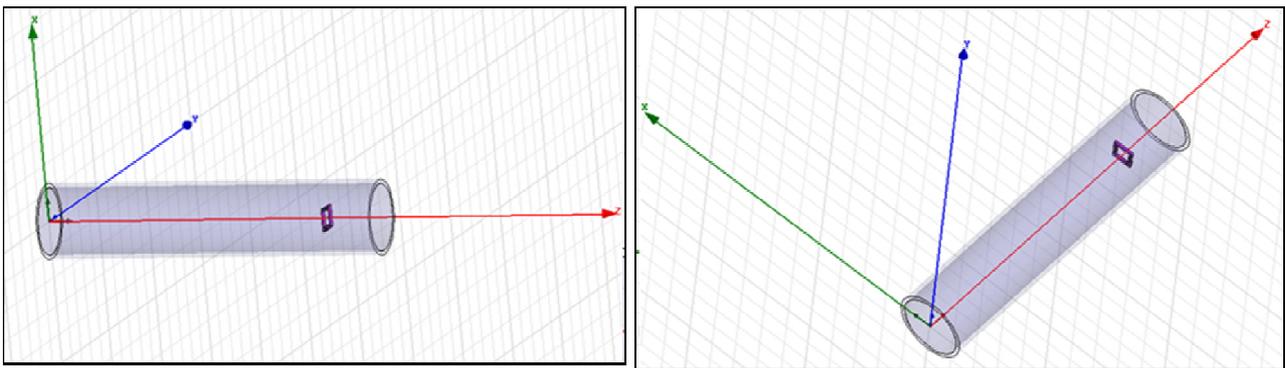


Figure10: Design 2- Model of unit cell waveguide loaded with SRR as MNG Metamaterial at load end side

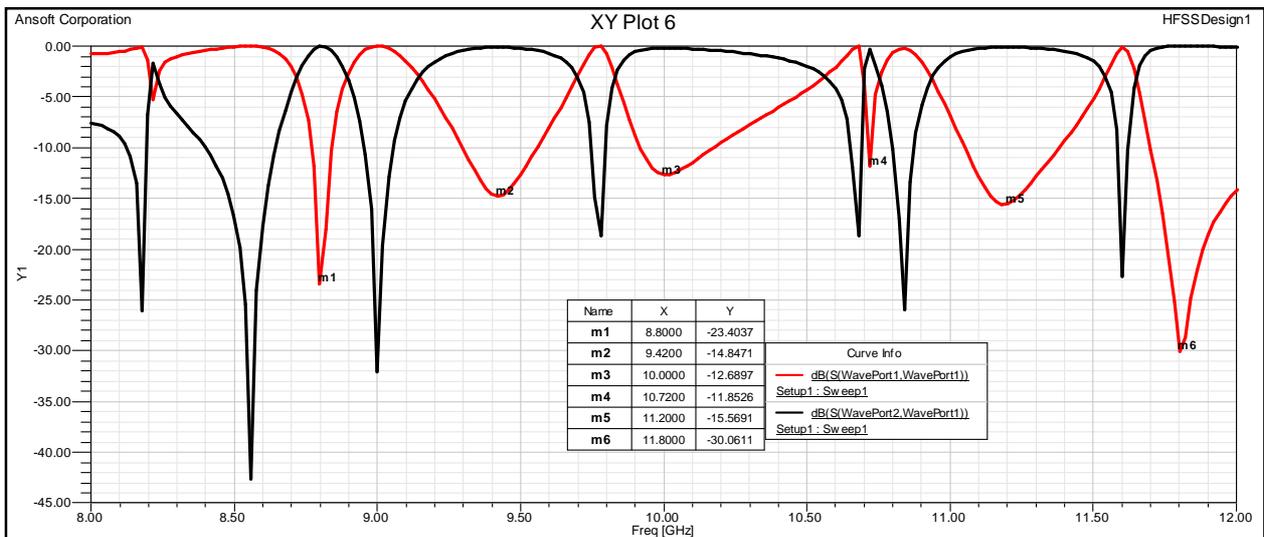


Figure11: Transmission spectra ( $S_{11}$  and  $S_{21}$  parameters) for the proposed design 2

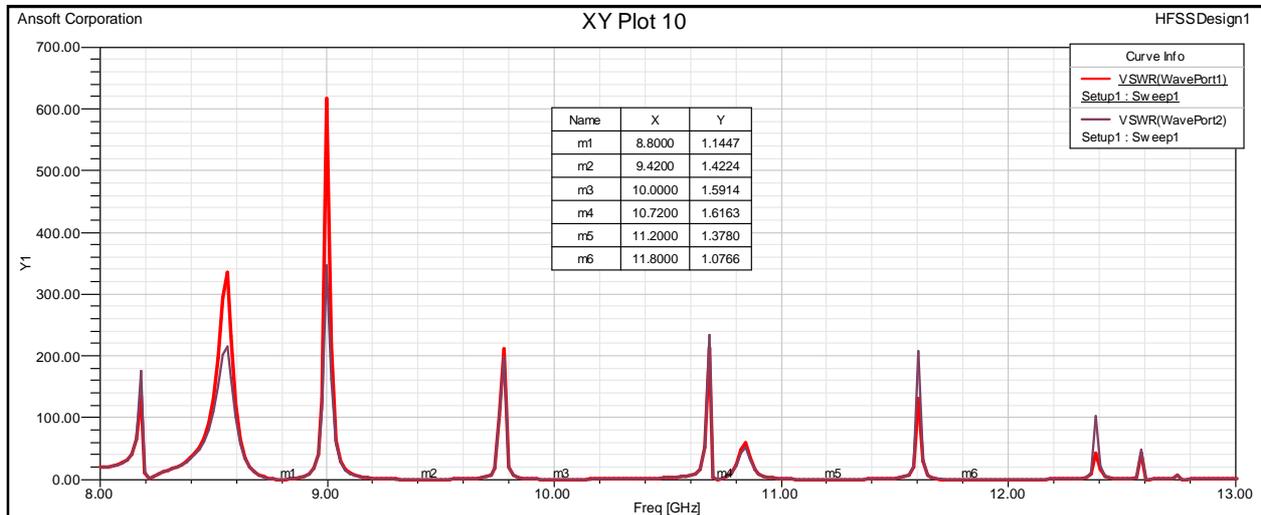


Figure12: VSWR plot for the proposed design 2

Results	$f$ (GHz)	Return Loss (dB)	Bandwidth (MHz)	VSWR
Band1	8.88	-23.43	87	1.15
Band2	9.42	-14.84	260	1.42
Band3	10.0	-12.65	260	1.59
Band4	11.2	-15.56	330	1.37
Band5	11.8	-30.06	480	1.07

Table 2: Results of return loss, bandwidth & VSWR at the operating frequencies of Design 2

Result Analysis: Figure 11 shows the S-parameter response for the waveguide loaded with SRR at the load end side. This provides the multi band response at the 8.88 GHz, 9.42 GHz, 10 GHz and 11.2 GHz. The VSWR are found to be in between 1 to 2 for all the operating frequencies. As illustrated, total resonating frequencies increases compared to the design1 which gives better options to tune the center frequency for applications operational in X band.

#### IV. CONCLUSION AND FUTURE WORK

It is demonstrated that the X-band circular waveguide loaded with split ring resonator exhibits the multi band operation property, which provides effectiveness for various satellite & wireless communication systems. The basic properties such as insertion & return loss, backward wave propagation & field distribution of circular waveguides filled with spit-ring-resonator based MNG Metamaterial are investigated experimentally and numerically. MTM based microwave circuits are presumed to be more compact than the conventional, so it is preferred to reduce the size of circular waveguide by loading it with metamaterials and with the design of the array of SRRs filled in waveguide, the improvements in results of return loss, bandwidth and compactness can be realized.

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## BIOGRAPHY

**Zalak Patel** has pursued her B.E Electronics and Communication from Charotar Institute of Technology & Engineering, change. (Gujarat University) .She has pursued her M.Tech in communication Systems engineering from Charusat University, Changa. She has research work in the area of microwave engineering, especially in metamaterials inspired microwave circuits. She is currently working as an Assistant Professor at Indus Institute of Technology, INDUS University. She has teaching experience of 5 years.

**Miloni Ganatra** has pursued her B.E Electronics and Communication from Ahmadabad Institute of Technology, Ahmadabad (Gujarat University). She has pursued her M.Tech. in VLSI Design from Nirma University. She is currently working as an Assistant Professor at Indus Institute of Technology, INDUS University. She has teaching experience of 5 years.

**Hansa Shingrakhia** has pursued her B.E Electronics and Communication from V.V.P Engineering College, Rajkot. She has pursued her M.Tech. in Communication Systems engineering from L.D. Engineering college, Ahmadabad. She is currently working as an Assistant Professor at Indus Institute of Technology, INDUS University. She has teaching experience of 6 years.