A new Class of MET based Tunable Microwave Filters

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Abstract

In this paper, a new class of electronically tunable microwave filter is presented. The Microwave Energy Tunneling (MET) phenomenon is exploited to design a tunable microwave filter for X-band operation. The proposed filter is based on low cost PCB technology and can be tuned to any lower or higher frequency with the help of switches inserted at appropriate positions to achieve a broad tuning range. The proposed technique can be used to design highly high Q, reliable, low cost, and electronically tunable filters for mobile and radar communication systems.

1. Introduction

Microwave filters are widely used in satellites, mobile communication and remote sensing. The performance of the microwave filters is mainly defined by central frequency, return loss, good linearity, quality factor (Q), and insertion losses etc. The growth of modern telecommunication systems standards demand broadband operational frequency width, more controllable response and hence require filters with high Q-values, which can be tuned in the wide range of frequencies. High performance electronically tunable filters have been a topic of research among the researchers from last few decades [1-3]. Different technologies which include semiconductors, ferroelectric materials and MEMS-based devices are potentially used for tuning purposes [4-6]. Drawback of these types of filters is that the tuning element inherits losses and hence affects the Q-factor, tuning speed and range.

Recently, Microwave Energy Tunneling (MET) through narrow channels and bends has been reported which is highly frequency selective [7-11]. This type of frequency selective MET can be potentially used to design microwave filters. MET phenomenon can be achieved by coupling two symmetrical guided structures like waveguides through narrow channel filled with ENZ material or thin metallic wire. At tunneling frequency, the metallic wires behave as medium whose effective permittivity is negative [11]

$$\mathcal{E}_r = 1 - \frac{\omega^2}{{\omega_p}^2} \tag{1}$$

The idea is taken from λ/2 antenna, backed with perfect conducting (PEC) wall. Due to the symmetry of the geometry, impedance is naturally matched at end [9]. The advantage of using MET base filters over conventional microwave filters is that, the filter can be tuned to any desired frequency band by changing the length of the metallic wire and dielectric material around the metallic wire [8, 11].

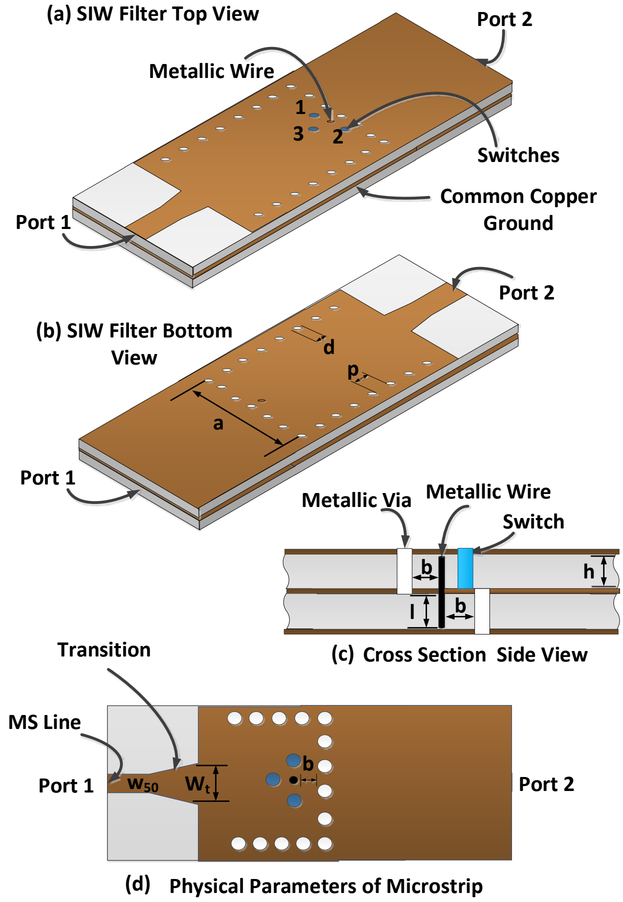

Fig. 1 (a) wire loaded SIW microwave filter Top View; the location of switches are shown as 1, 2 and 3 with blue circles (b) SIW microwave filter Bottom View, Physical parameters of SIW (c) Side view which shows length of the wire l, height of substrate h and location of dielectric sample, b=0.75 mm. (d) Physical parameters of SIW to Microstrip transition

In this work, we proposed a high frequency MET based filter. The proposed filter is based on planar low cost PCB technology and can be tuned to any frequency ranges with the help of switches inserted at appropriate position. This type of filters can be potentially used to design highly frequency selective, reliable, high power electronically tunable microwave filter for mobile, and radar communication systems. The paper is organized as follows. In section 2, filter design procedure is

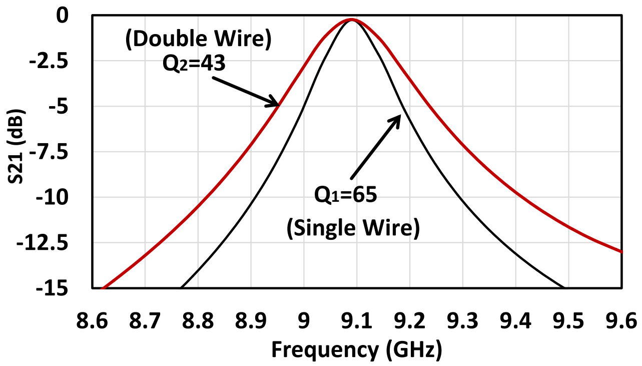

Fig. 3. Effect of single and double wires of equal length of 2.4 mm on the Quality Factor

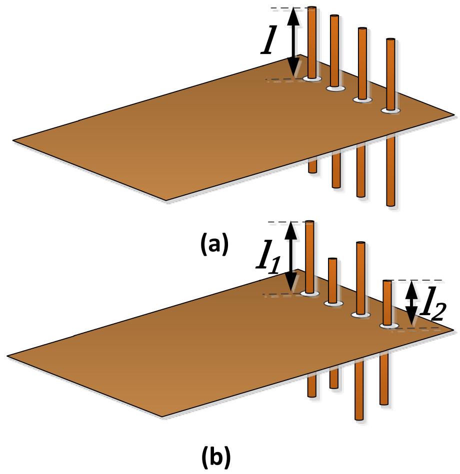

Fig. 4. a) Multiple wire of the same length; b) Multiple wires of the different lengths.

discussed. Filter working is given in section 3. The conclusion is summarized in Section 4.

2. Filter Design Procedure

Multilayer MET based microwave filter is shown in the figure 1. The top and bottom view are given in figure1 a, b. Multilayer filter consists of two Substrate Integrated Waveguides (SIW), coupled through thin metallic wire as shown in the figure1c. Where l is the length of the metallic wire, h is thickness of the substrate and b is the position of the metallic wire as shown in figure 1c. The Metallized holes at the boundaries provide strong faraday caging. The SIW, only supports TE dominate modes due to the specific geometry and discontinuity at side walls, SIWs supports do not supports TM modes. The important physical parameters of the design are shown as below,

$$a_{eq} = a_{con}/\sqrt{\mathcal{E}} \tag{2}$$

There are many different ways to calculate ‘a’ which is center to center distance, one is given below,

$$a = a_{eq} + \frac{d^2}{0.95p} \tag{3}$$

Where p is the spacing between the vias and d is the diameter of the vias. The ratio of p, d and h are $p \le 2d$ and $d / h < 0.4$ [12, 13]. Where the length of microstrip can be calculated by following relation,

$$L_t = \frac{n\lambda_g}{4} \quad, n = 1,2,3,4 \ldots\ldots \tag{4}$$

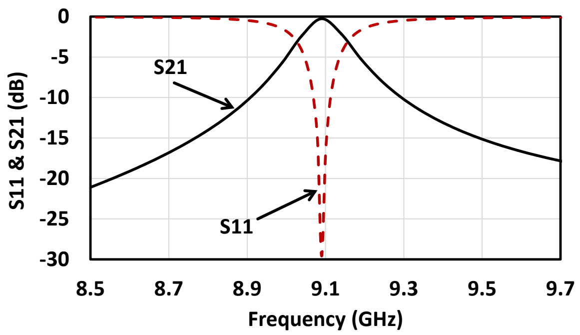

Fig. 2. S11 and S21 parameters for Substrate Integrated Waveguide (SIW).

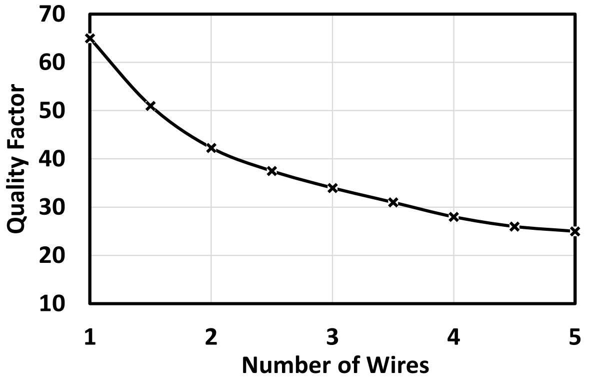

Fig. 5. Effect of multiple wires of equal length l on the Quality Factor

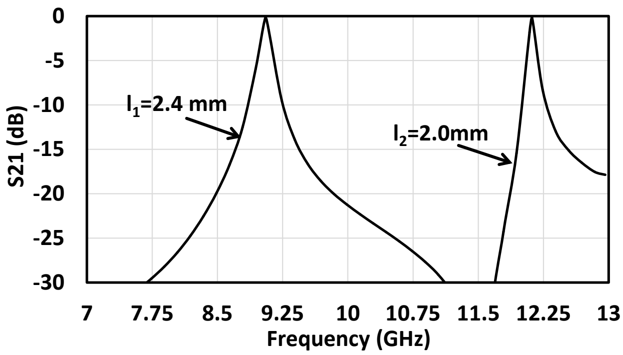

Fig. 6. Effect of two wires of different lengths on the tunneling frequency

The width of microstrip taper can be calculated by following expression [14, 15].

$$\frac{120\pi}{\eta h\left[\frac{w}{h} + 1.393 + 0.667 ln\left(\frac{w}{h} + 1.444\right)\right]} = \frac{4.38}{a_{eq}} e^{-6.27\left(\frac{\frac{\varepsilon_r}{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2\sqrt{1+12\frac{h}{w}}}}}{}\right)} \tag{5}$$

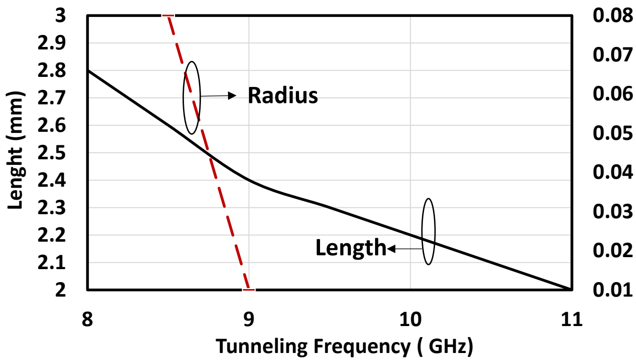

Fig. 7. Effect of length and Radius of metallic wire on tunneling frequency

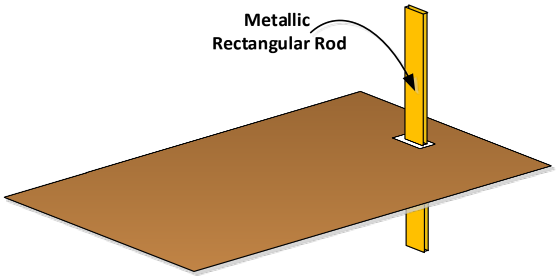

Fig. 8. Wide cossectional rectangular rod for tunneling

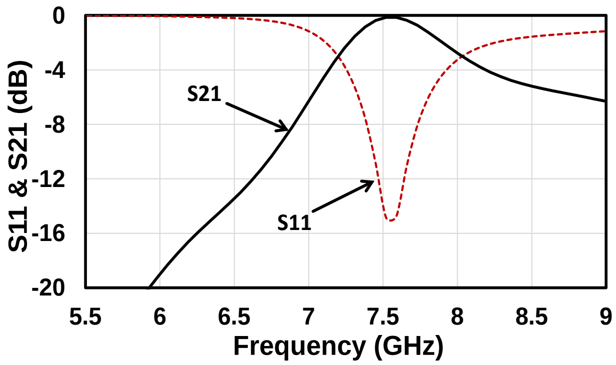

Fig. 9. S11 and S21 parameters for rectangular wide rod

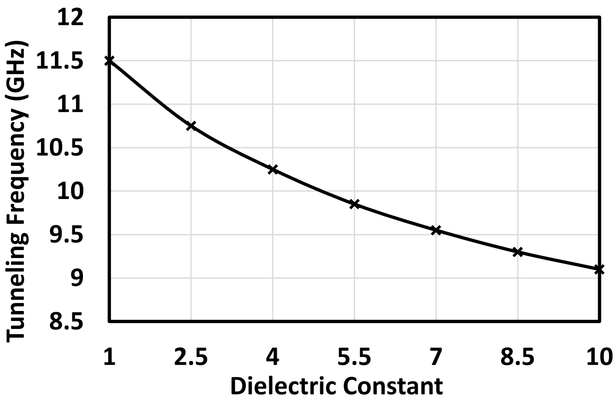

Fig. 10. Effect of permittivity on tunneling frequency

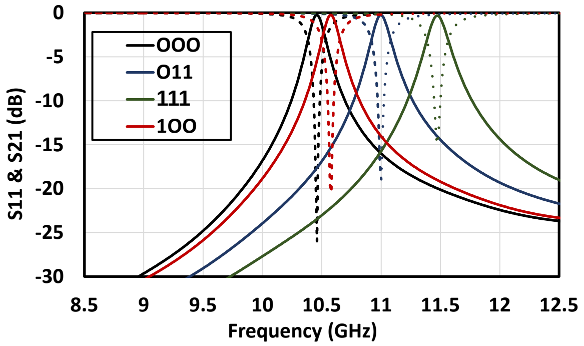

Fig.11. Tuning possibilities for different combinations of the switches.

The length of taper Lt is taken such that, it is between the wavenumber of wave guide and its half i.e.

$$\lambda_g < L_t < \lambda_g/2. \quad (6)$$

Where $\lambda_g$is guide wavelength of the SIW. The permittivity of the substrate used is 10.2 and other physical dimensions are taken as p=1.5mm; d=1mm; h=2.54mm; a= 12mm; Wt = 4.4mm; l=2.4mm and b=0.75 mm. In figure 2, the S11 and S21 parameters of MET based microwave filter are shown.

At tunneling frequency, the electromagnetic energy tunnels from SIW 1 to SIW2 without any losses. The central frequency and tuning bandwidth ([f1, f2]) are necessary criteria for filter design. The filter is designed such that it couples the energy at 9.1 GHz. The bandwidth in that case is 0.14 GHz and quality factor is 65. More than one metallic wire can also be used for MET as shown in figure 4. Figure 3 shows the comparison of Q factors for the case of one and two metallic wires. Solid line is for the case when filter is loaded with single wire while dotted line is used for two lines. Figure 5 shows change in quality factor for up to five metallic wires. The quality factor changes from 65 to 25 as the number of metallic wires used for energy tunneling increases from 1 to 5. The drop in the quality factor shows increase in the operational band wide of the proposed microwave filter. Wires of different lengths can be used for energy tunneling as shown in the figure 4b. In that case the energy tunnels at multiple frequencies as shown in figure 6 [14]. The lower tunneling frequency is due to metallic wire of large length and higher tunneling frequency is due to the wire of smaller length. The effect of change in length and radius of the metallic wire on tunneling frequency is shown in the figure 7. A remarkable shift of 3 GHz is noticed when the length of the wire is changed from 2.0 mm to 2.8 mm. 0.5 GHz shift in the tunneling frequency by increasing the radius eight times which shows that tunneling frequency mainly depends upon the length of the metallic wire not on the radius of the metallic wire. Operational bandwidth can also be increased if the area of the wire increases as shown in figure 8. The Figure 9 shows the transmission coefficient when SIWs are coupled through the rectangular shaped metallic road. The quality factor in this case is 8.52. The tunneling frequency is also shift by changing the permittivity of the material placed close to the tunneling wire as shown in the figure 10 [9, 11, 15]. This property can be potentially used to design electrically tunable microwave filters.

3. Electronically Tunable

The electronic tuning of energy tunneling based microwave filter can be achieved by inserting different dielectric materials (switches) in the area around / close to the tunneling wire. The tunneling frequency is highly dependent on the dielectric material around the metallic wire. The position of the switches made of dielectric cylinders are shown in the figure 1a indicated with number 1, 2 and 3. The length of each cylinder is 2.56 mm and radius of each cylinder is 0.2 mm. The desired response can be achieved by changing the state of the switches. The four different states of switches are given in the table 1.

Table1. Position of dielectric material

State	SWITCH 1	Switch 2	Switch 3
000	Empty	Empty	Empty
100	Filled	Empty	Empty
011	Empty	Filled	Filled
111	Filled	Filled	Filled

The transmission responses for four different states listed in the table 1, are shown in figure 11. It can be seen that the remarkable shift 1.0 GHz in the tunneling frequency can be achieved by changing the state from 000 to 111. In case of 000 state, tunneling frequency is 10.5 GHz and in the 111 state, the tunneling frequency is 11.5 GHz. The permittivity of the material used as switch is taken as 1. Tuning range can be increased by increasing the number of switches arround the wire or by using material with difference dielectric constants.

4. Conclusion

A new class of high frequency wide band electronically tunable filter was proposed in which microwave energy tunneling phenomenon was being used to design electrically tunable microwave filter for X-band operation. The proposed filter has an ability to tune to any lower and higher frequency by the help of switches inserted at appropriate position so that a broad tuning range is possible. The proposed model can be potentially used to design highly frequency selective, reliable, high power electronically tunable filter for mobile, and radar communication systems.

5. Acknowledgment

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6. References

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