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THE EFFECT OF THE METAMATERIAL SUPERSTRATE TO THE VERTICALLY STACKED BANDPASS FILTER ANTENNA PERFORMANCES

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ABSTRACT

The integration of metamaterial superstrate with high-quality cavity 3-poles stacked filter with patch antenna is presented. The metamaterial inspired behavior is obtained using split ring resonators (SRR) printed on the dielectric substrate Rogers 5880 which is located 12 mm from the top of the filter/antenna. The effects of the metamaterial structure on the vertically stacked filter/antenna performances at X-band with resonant frequency 10.18 GHz are investigated. The gain of the filter/antenna system improved from 6.99 dB to 8.22 dB while the radiation pattern become more directive without distorting the filtering response.

Keywords: vertically stacked filter, patch antenna, substrate integrated waveguide, rectangular waveguide, meta material.

INTRODUCTION

Filter and antenna are the important components in many communication systems. Filters are utilized to transmit in band signals and reject out in band noise and interference. A few approaches are implemented to get the high performances of the communications front end. To design high quality resonators filter, various approaches had been done such as based on the waveguide cavities [1], dielectric resonator [2], and substrate integrated waveguide (SIW) [3]. Those techniques gives lower insertion loss which will contributes to increase the efficiency of the system.

Conventionally high-Q filter and antenna are connected by using 50 Ω transmission line. This type of integration renders to bulky size, detuned filter response and more losses [4]. By integrating the filter and antenna into unseparated unit, the 50 Ω transition between both structures are removed which contributes to more compact and efficient system [5, 6].

Patch antenna is widely used in various communications and radar system; it is because of its advantages including the ease in fabrication, low profile and flexibility of design. A few researches have been published on the usefulness of metamaterial to improve the gain and the directivity of the microstrip antenna [7, 8]. In this paper, an array of metamaterial unit cell is used as superstrate to enhance the gain, bandwidth as well as the directivity of the vertically stacked substrate integrated waveguide filter/antenna. The filtering shape and behavior of the reflection coefficient of the stacked filter/antenna is also observed.

Filter/Antenna synthesis

A vertical three-poles cavity filter/antenna is designed as presented in [9] to reduce the footprint. The structures of the filter are shown in Figure-1. The overall systems have three resonators which consist of two cavity resonators and one resonant patch antenna. By acting as another resonator, patch antenna gave additional pole in the filtering response. The sidewalls of the resonator 1 and resonator 2 from the bottom of the designed are formed by closely-spaced metallic vias. The gap between the vias is ~0.7 mm which is small enough compared to wavelength. The substrate used for all three layers was Roger RT/Duroid 5880 (ε_r= 2.2; tan δ = 0.0009). The internal coupling was realized through a slot in the ground plane between the bottom two resonators, k_{12}. The external coupling to the filter/antenna is by using short-ended SMA coaxial connector.

The reported design parameters were

$$k_{12} = k_{23} \tag{1}$$

$$Q_{ext,1} = Q_{ext,2} \tag{2}$$

k_{23} was the coupling between the middle resonator and patch antenna which was realized through a coupling via. Then, the $Q_{ext,2}$ was the radiation Q factor of the patch antenna which also act as another external coupling to the filter/antenna. The coupling via was short ended between the ground plane of the second resonator and the patch antenna. The diameter of the coupling via is 0.64 mm which is similar with the diameter of the metallic vias inside the cavity resonators.

By successfully modeled the coupling via inside the waveguide and the coupling via with the patch antenna, a filter/antenna that contributes the same filtering function of the reference filter was designed. The integrated filter/antenna then simulated using HFSS giving 91.8% overall efficiency of the system. The performances of this design are simulated at the center frequency of 10.16 GHz.

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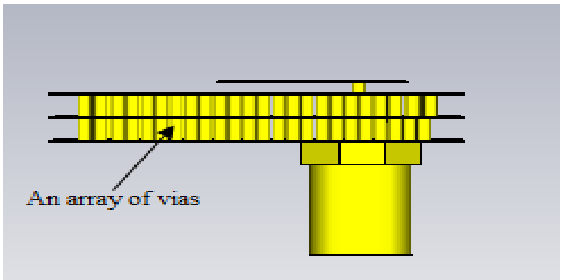

Figure-1. The filter/antenna without metamaterial with hidden substrate.

Filter/Antenna with metamaterial synthesis

Ordinarily, Split Ring Resonator (SRR) consists of two split ring situated oppositely and share the same center. These SRRs are made from conductive material. The function of splits is to allow SRR unit to resonate at wavelength much longer than the physical dimension of the rings [10]. In this design, as shown in Figure-3, the 6x8 arrays of unit cells of conventional Split Ring Resonator (SRR) are located 12 mm from the filter/antenna and aligned together on the Rogers 5880 substrate, the thickness of the substrate is 0.787 mm. Each unit cell of SRR consists of two rings, outer and inner rings. The gap between these two rings is 0.3 mm. The slots in each of them and the thickness of the SRRs are 0.3 mm and 0.035 mm respectively.

Figure-2 demonstrates the side and top view of 3-poles filter/antenna with metamaterial.

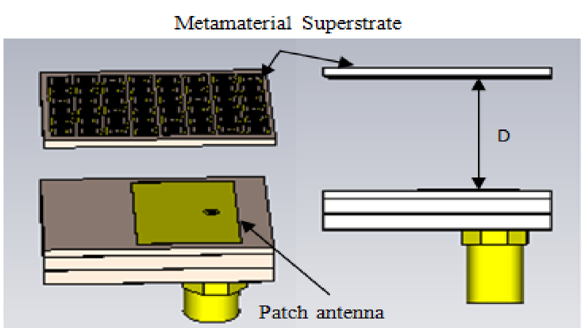

Figure-2. The filter/antenna with metamaterial.

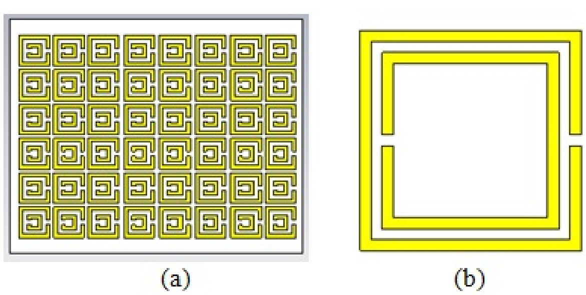

Figure-3. Split Ring Resonator (SRR) (a) An array of SRR (b) One unit cell of SRR.

RESULTS AND DISCUSSIONS

The parametric study of the return loss, S_{11} as a function of frequency for varying the air gap 'D' between the antenna and the metamaterial has been carried out. As in Figure-4, by increasing the air gap, *D* between the metamaterial and the filter/antenna, the filtering shape is getting better with the return loss is below -10 dB at the center frequency 10.16 GHz. From Figure-4 the optimized value of D=12 mm is achieved through simulation which is able to produce good filtering shape for 3-poles Chebyshev filter and higher gain.

Figure-5 shows the simulated return loss versus frequency graph of the filter/antenna without and with metamaterial. The simulated frequency ranges of filter/antenna without and with metamaterial for below -10 dB return loss with corresponding resonant frequencies of 10.18 GHz and 10.186 GHz are from 9.76-10.62 GHz and 9.75-10.62 GHz respectively. This gives the calculated fractional bandwidth of 8.7% for both.

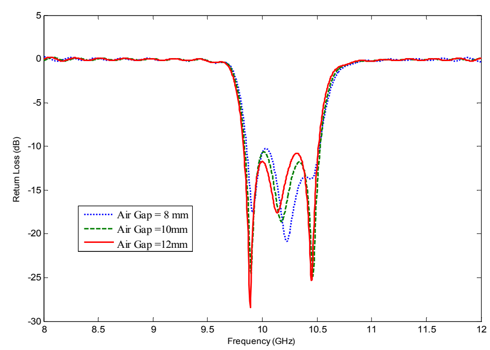

Figure-4. Simulated return loss versus frequency plots of filter/antenna with superstrate metamaterial for varying gap, *D*.

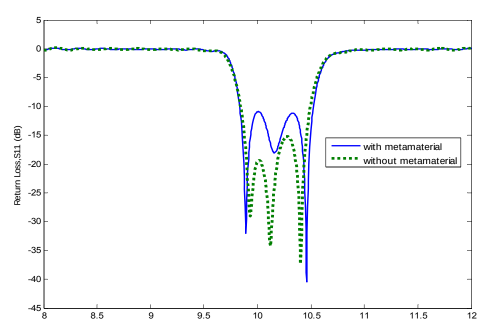

Figure-5. Simulated return loss versus frequency plots of filter/antenna with and without metamaterial. The air gap, *D*=12 mm.

Figure-6 shows the simulated gain of the filter/antenna with and without metamaterial over the frequency range from 8 GHz to 12 GHz. Simulated variation of gain with frequency of the structures was obtained through CST Software. The simulated gain for

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filter/antenna without metamaterial is 6.99 dB and with metamaterial is 8.22 dB. The simulated results clearly indicated that with the use of metamaterial, significant improvement in gain is obtained.

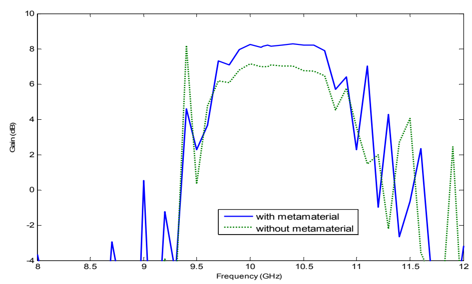
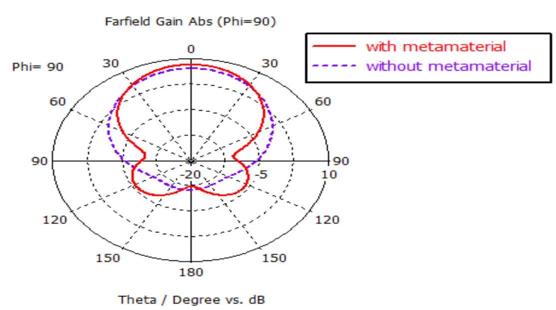
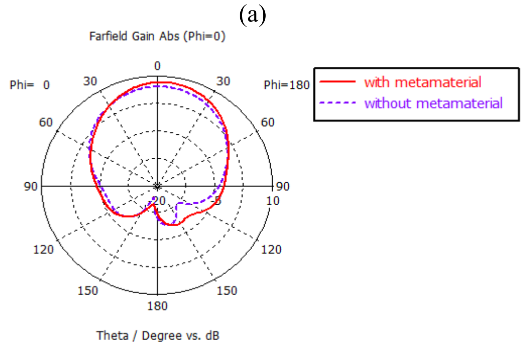


Figure-6. Simulated gains versus frequency for with and without metamaterial for filter/antenna.

The simulated farfield patterns for both filter/antenna with and without metamaterial for Φ=0° (x-z plane or H-plane) and Φ=90° (z-y plane or E-plane) were obtained by using CST software. Figure-6(a) and (b) give the comparison of the 2-D radiation patterns of the filter/antenna with and without metamaterial at the frequency of 10.18 GHz. From these figures, it can be seen that broadside radiation pattern is converted into directive radiation pattern with reduced beam width when the metamaterial is used.



(a)



(b)

Figure-7. Radiation patterns of the proposed filter/antenna for with and without metamaterial (a) E-plane (b) H-plane

CONCLUSIONS

A vertically stacked 3-poles filter with patch antenna inspired metamaterial has been simulated and presented. The effect of air gap between filter/antenna to the return loss, gain and radiation pattern was also discussed. The results shown by using metamaterial, the return loss is below -10 dB without distorting the filtering shape for 3-poles filter. The radiation pattern is more directives and the antenna gain improved from 6.99 dB to 8.22 dB.

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