Frequency Suppression by Metamaterial

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***Abstract* — in this research, an artificial or metamaterial was fabricated by printing *I*-shaped metal patterns periodically on a dielectric host medium to demonstrate frequency blocking property. The research was conducted by 3D electromagnetic simulation software first and then verified by several experiments. Experimental results showed that center frequency of blocked band could be controlled by adjusting the size and shape of *I*-shaped metal patterns.**

Keywords— frequency suppression, artificial material, metamaterial, I-shaped metal patterns, focused beam free space material measurement

I. INTRODUCTION

In 2002, Smith [1] and Wu [2] in 2005, demonstrated that if infinitely long and thin metal wires are placed in space periodically, lower frequencies are blocked by the structure when electric field is polarized along the direction of the wire length. This phenomenon could be explained by lumped element circuit point of view by considering long thin wires as inductances which offer lower impedance at lower frequencies to bypass. Conversely, it could be predicted that if infinitely thin and long wires could be replaced by very short and thin wires, higher frequencies could be blocked or bypassed due to the fact that series capacitances developed by the thin and very short metal wires offer lower impedance at higher frequencies. However, thin wires with infinitely long or very short are not practical. So, in this research, *I*-shaped metal strips with finite length and width were printed periodically, as shown in Fig. 1, to demonstrate the property of signal suppression of particular band.

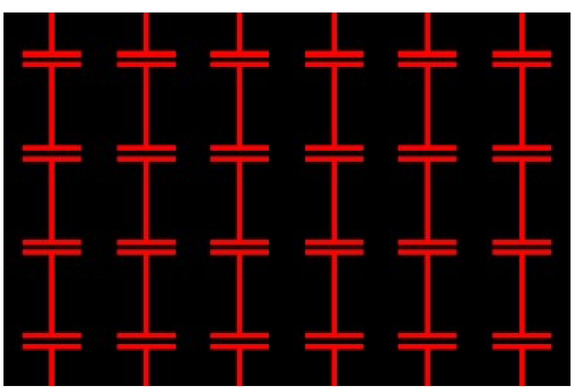

Fig. 1. Periodic array of *I*-shaped metal strips on FR4 dielectric substrate

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The phenomenon of signal suppression could be explained by the fact that length of metal strips could be considered as inductance (*L*) and gap between the strips or fins as capacitance (*C*). As a result periodic array of metal strips gave rise to *L-C* series circuit which caused resonance or zero impedance at a particular frequency to bypass or block that frequency. In fact, this resonance frequency was the center frequency of the suppressed band.

II. MATERIAL & METHOD

A. Simulation

First of all, a random frequency 11 GHz was chosen at which complete signal suppression or non-transparency was intended to be observed. In order to achieve this, several simulations were conducted with 3D electromagnetic simulation software HFSS. In the simulation, FR4 dielectric substrate with 0.78 mm thickness and *I*-shaped metal patterns on it were modeled. According to the simulation, the dimensions of *I*-shaped metal patterns were as follows: strip length 2.3mm, strip width 0.20mm, fin length 1.8mm, fin width 0.20mm, gap between two neighboring fins 0.20mm, and distance between strips in horizontal direction 2.8mm as shown in Fig.2. The sample was modeled with 0.78mm thickness FR4 dielectric sheet with metal patterns on it and sandwiched with another empty FR4 board to make a symmetric structure as shown in Fig.3. Simulation result of transmission coefficient (S_{21}) was displayed in Fig.4 with blue color line to show *L-C* series resonance or complete non transparency or full signal blocking at the frequency of 11 GHz.

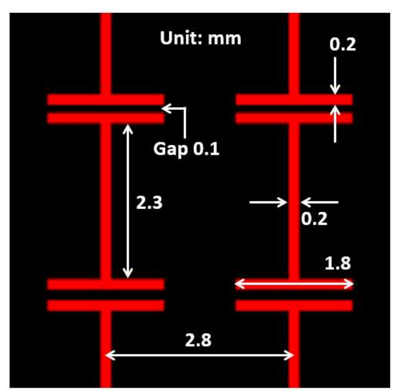

Fig.2. Dimensions of *I*-shaped metal patterns

B. Experiment

To validate the simulation result, an experiment was conducted with focused beam free space material measurement system equipped with a Vector Network Analyzer as shown in

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Fig.5. The samples were fabricated with 355.6mm x 355.6mm x 0.78mm FR4 dielectric sheet and metal patterns with appropriate dimensions and periodicity as described above. Fabricated sample was placed between transmitting and receiving antennas as shown in Fig.5 to measure the transmission coefficient (S_{21}).

Experimental result of transmission coefficient (S_{21}) was shown in Fig. 4 with gray color line where complete non transparency of signal was observed at the frequency of 15.5 GHz.

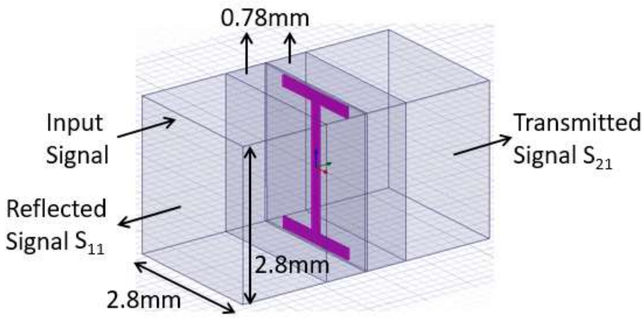

Fig. 3. Simulation arrangement of *I*-shaped metal pattern on FR4 dielectric substrate backed by another bare FR4 board to maintain symmetry

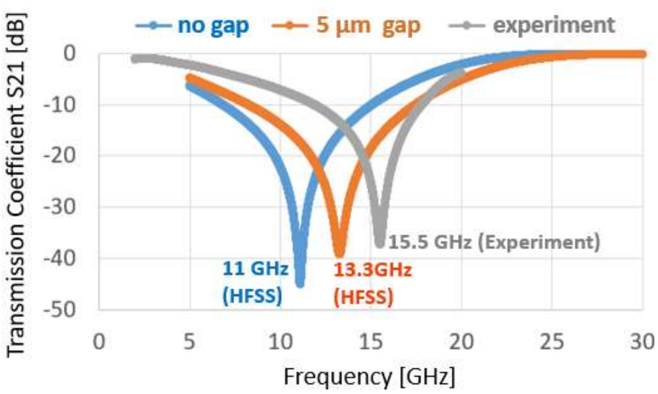

Fig.4. Experimental demonstration of signal non-transparency evolved from *I*-shaped metal patterns and comparison with simulated response with fin length 1.8mm

It is obvious that there was some discrepancy between simulated and experimental result. This could be attributed to the fact that simulation was conducted assuming no gap between printed circuit board (FR4 dielectric sheet + metal patterns) and empty FR4 board.

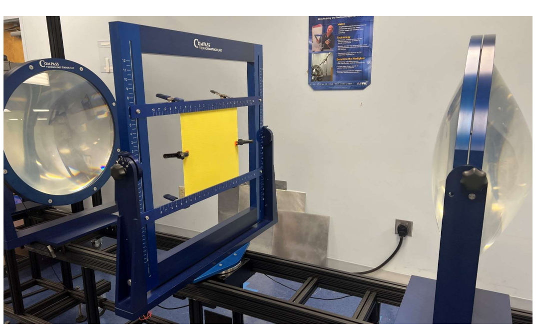

Fig.5. Focused beam free space material measurement system with test sample in the middle

So, when same simulation was conducted again with introducing a 5μm gap between two layers, complete band stop frequency was seen to occur at 13.3 GHz which was closer to the experimental value of 15.5 GHz as shown in Fig.4 with orange color line.

C. Parametric Study

To observe the effect of fin length on stop band behavior, previous simulations were repeated reducing the fin length from 1.8mm (Fig.2) to 0.8mm. Simulated transmission coefficients were displayed in Fig.6 along with experimental results.

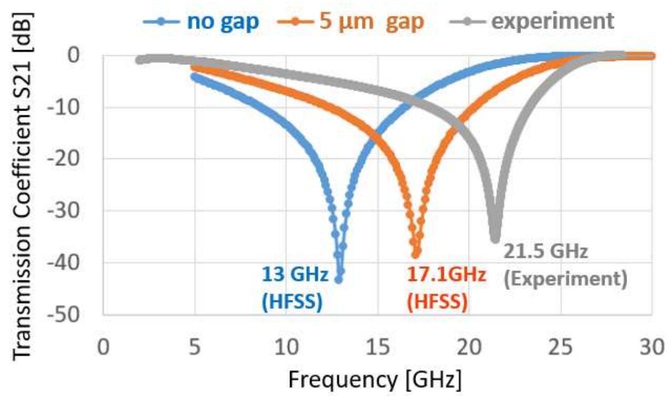

Fig.6. Experimental demonstration of signal non-transparency evolved from *I*-shaped metal patterns and comparison with simulated response with fin length 0.8mm

A decrease in fin length induced less capacitance between metal patterns and shifted the *L-C* series resonance frequency to a higher value as predicted from the resonance equation $f = 1/(2\pi\sqrt{LC})$. Reduction of fin length from 1.8mm to 0.8mm resulted in shifting of band stop frequency from 15.5 GHz to 21.5 GHz as evidenced in the experimental results shown in Fig.4 and Fig.6 with gray color lines.

III. Conclusion

Metal strips printed periodically on a host medium exhibited frequency suppression behavior which was demonstrated by simulations and validated by experiments. The center frequency of the suppressed band literally could be set to any value by adjusting dimensions of the strip or by choosing a host material with appropriate thickness and dielectric constant. The outcome of this research may find application in protecting human bodies or sensitive electronic devices from harmful electromagnetic radiations.

Acknowledgment

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References

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