Metamaterial Transmission Line and Resonator using a new concept of Substrate Integrated Coaxial Line

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Introduction

Metamaterials (MTM) exhibit negative permittivity (ε) and permeability (μ) simultaneously, and hence support waves with antiparallel group velocity (vg) and phase velocity (vp), giving rise to a negative refractive index (n) [1]-[2]. These unique characteristics make them desirable for RF and microwave applications [3]-[5]. For filter applications, metamaterials have the advantages of circuit miniaturization as the MTM zeroth order resonator length is independent of frequency. Also higher Q-values can be obtained and no harmonic generation exists [5]. Several MTM filters have been described in the literature using mainly planar microstrip or coplanar technologies [6]-[8].

For certain applications at microwave and millimeter wave frequencies where high Q filters are needed, coaxial technology, waveguide technology, dielectric slab technology and non radiating dielectric guide can be implemented. However, these technologies are not suitable for low-cost mass-production and integration with other circuits. To overcome this problem a hybrid scheme of planar and non-planar integration scheme has been proposed called Substrate Integrated Circuits (SIC) [9], where Substrate Integrated Slab Waveguide (SISW), Substrate Integrated Waveguide (SIW) and Substrate Integrated Non Radiating Dielectric Guides (SINRD) have been demonstrated. This concept can be further extended to substrate integrate coaxial lines (SICXTL). The SICXTL consists of a three layer structure where the center layer contains the patterned circuit lines and top and bottom layers are ground planes with a series of contiguous metallic via holes interconnecting the top and bottom planes (Figure 1). If the distance between metal vias (D) is much smaller than λ the radiation losses become negligible. For high isolation, D must be smaller than $\lambda/10$, which is less than in SIW [9] as TEM modes propagate rather than TM modes. Compared to stripline structures, in SICXTL more compact circuits can be achieved as ground planes can be much narrower. Also, for integrated MMIC applications SICXTL offers the advantage of good shielding isolation between different components on the same chip.
Metamaterial lines using SIC have been suggested in the literature in SIW technology. In [10] simulations are presented on a CRLH TL based on a monoplanar SIW, where via holes are used to implement the series capacitors and for grounding the shunt inductor of the CRLH LC network. In [11] a left handed transmission line (LHTL) based on multilayer SIW using Split Ring Resonator (SRR) is exhibited. In this paper the novel concept of SICXTL is used to implement a MTM CRLH transmission line and a zeroth order MTM resonator. The via holes that unite the top and bottom layers facilitate the interconnection of the shunt inductor to ground without parasitic through hole interconnect effects since the whole plane acts as a virtual metal wall. Full simulation and experimental results are presented showing good agreement.

Designing of SICXTL and SICX Resonator

A SICXT transmission line consists of a three-layer structure with top and bottom ground planes. In the middle layer the circuit lines are patterned. Along the patterned transmission lines contiguous metallic via holes are placed connecting the ground planes and forming the

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side walls of the structure (figure 1). Two RT Duroid 5880 substrates with permittivity εr = 2.2 and 3.2mm thickness were placed on top of each other to form the three layer structure. The distance between the via holes was 0.35mm and the diameter of the holes was 0.5mm.

To design a zero phase CRLHTL the positive LH phase lead must compensate the negative lag of the RH. The center frequency of the structure is 2GHz. The values for the LH for the series capacitor and shunt inductor are CL = 1.68pF and LL= 4.222nH respectively, which give a 54° phase shift. To compensate them, a –54° conventional RH SICXTL was implemented. The size of the LH unit cell is 15.8mm, which is smaller than $\lambda/6$ at 2GHz, hence fulfilling with the homogeneous media condition [5]. To design the MTM zeroth order resonator this TL was opened at both ends and weakly coupled to a SICXTL. The final structures are shown in figure 2. The circuits were fabricated using standard printed circuit technology.

Simulations and Experimental Results

All simulations were carried out using [12]. The simulation and experimental results for the SICXTL are presented in figure 3. The simulation gives a LH cut off frequency of 1.4GHz and an upper cutoff of 3.8GHz. Which are very similar to the experimental result of 1.45GHz and 4.1GHz respectively. The higher cutoff frequencies are due to higher order modes propagating in the SICXTL as seen in the graph. The experimental insertion losses were about -0.5dB from the lower cutoff up to 3GHz. The return loss is better than -20dB from 1.7 to 3GHz. The experimental phase response is shown figure 3(b), from this graph the CRLH nonlinear characteristic becomes evident. The zero phase was obtained at the designed frequency of 2GHz in the simulation and at 1.73GHz in the experiment. This shift is mainly due to phase shifts in the connector transition that were not considered in the simulation.

For the SICX resonator, the simulated resonant frequency was 1.93GHz and experimentally it was 1.95GHz (Figure 4). The simulated Qo was 126 and the measured one was 100. A second resonance appears at about 3.5GHz due to the effect of the capacitive fingers acting as distributed resonant elements.

Conclusion

A novel metamaterial transmission line and a zeroth order resonator structures have been presented using a new concept of SIC called Substrate Integrated Coaxial (SICX). Simulated and experimental results have been exhibited showing good agreement.

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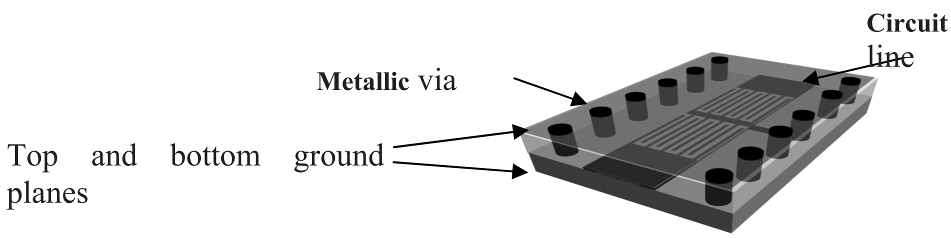


Figure 1. Substrate Integrated Coaxial Transmission Line

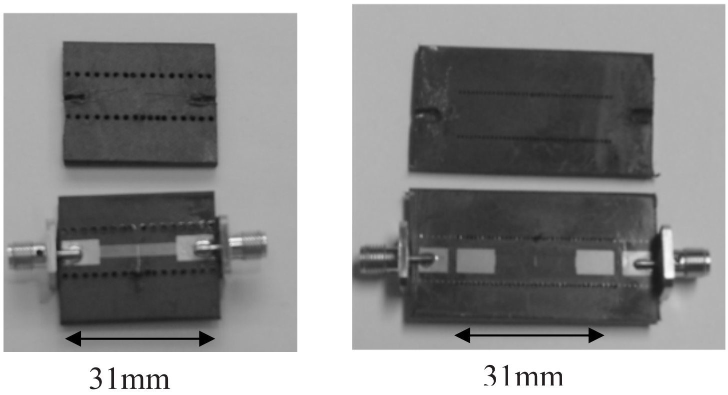
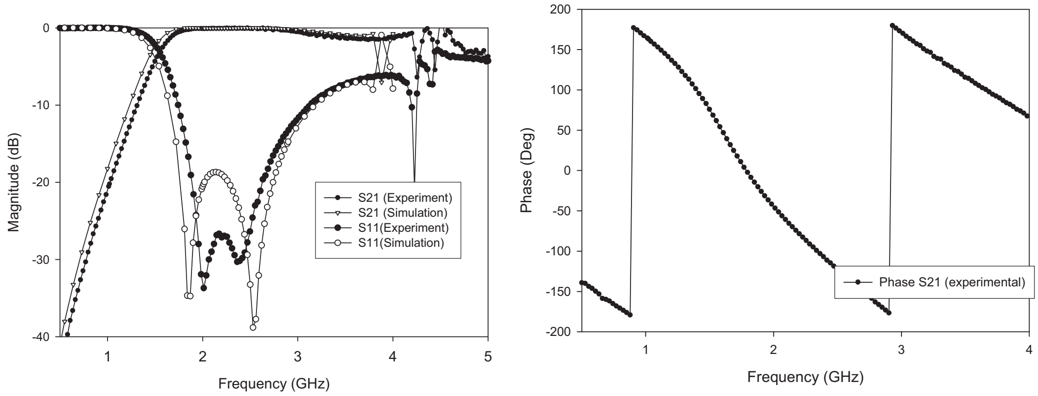


Figure 2. Layout of SICX TL and weakly coupled SICX Resonator



(a) (b)

Figure 3. (a) Magnitude simulation and experimental results of SICX MTM TL. (b) Phase response of SICX MTM TL.

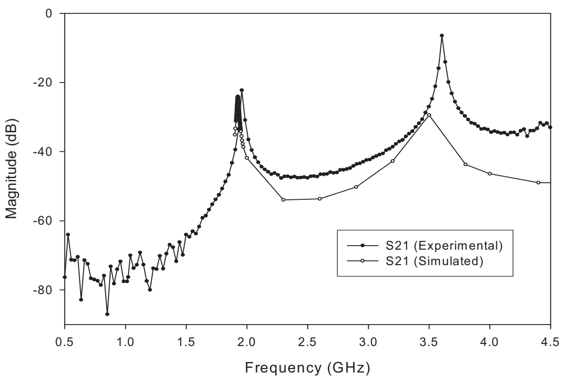


Figure 4. (a) Magnitude simulation and experimental results of SICX MTM TL. (b) Phase response of SICX MTM TL.