**Multi band microwave circuits with metamaterial effects**

**Abstract:**

In the past few decades, there has been an increase in the use of high speed wireless communication systems. The devices are realized with dedicated wireless applications. However it is convenient to have a single compact portable device which can access most of the wireless applications. To accomplish this, multi band components (like multi band filter and multi band antennas etc) can be used. These circuits can operate in more than one frequency band, so they can reduce the size and the complexity of the devices. In this thesis, multi band components are realized by exploiting the electromagnetic metamaterial effects.

The electromagnetic metamaterials are artificial structures with abnormal characteristics. The conventional materials have the phase and group velocities in the same direction, so they are right handed (RH) materials. The left handed (LH) materials on contrary have anti parallel phase and group velocities ('Backward Propagation'). The left handed materials are also called as Double negative materials since they have negative permittivity and negative permeability. The left handed properties are achieved here using transmission line approach. The conventional transmission line has a series inductor and a shunt capacitor, by duality the left handed transmission line should have a series capacitor and a shunt inductor. Since left handed materials are not readily available in the nature, they should be implemented in a host medium which naturally has RH properties. So, a pure LH Transmission line cannot be implemented, only Composite Right and Left Handed transmission line (CRLH TL) can be realized. Mostly CRLH TL is implemented by interdigital capacitor and short circuited stub. This CRLH TL is not an ideal transmission line so they are made effectively homogeneous by making phase shift of the unit cell less than $\pi/2$.

Before going to design of double negative material, single negative material design is discussed. Substrate integrated waveguide (SIW) is defined as planar implementation of conventional metallic waveguide, but it can also be visualized as negative permittivity or epsilon negative (ENG) transmission line. The unit cell of epsilon negative TL is similar to CRLH TL except the former do not have series capacitor in the unit cell. The phase constant obtained using both the theories (waveguide and negative epsilon) are compared. A triple band antenna is designed using open circuited SIW. The antenna is designed by including two slots to have three bands at 3.3 GHz, 4 GHz and 4.8 GHz.

After seeing the single negative material design, next double negative material design is focused. The double negative material considered here is Double periodic CRLH (DPCRLH) TL. DPCRLH unit cell is formed by concatenating two different CRLH unit cells. Two symmetric unit cells of DPCRLH TL are proposed. The DPCRLH symmetric unit cells are analysed using ABCD matrix. The dispersion diagram of DPCRLH has two left and two right handed regions. The important frequency points in the dispersion diagram are analysed. The closing condition of attenuation gap at $\beta d = 0$ in the dispersion diagram is derived. A DPCRLH symmetric unit cell is designed and fabricated with closing condition of attenuation gap at $\beta d = 0$ at 3.39 GHz. The measured results are compared with the simulated results. The DPCRLH TL has an additional LH and RH regions compared to CRLH TL. So DPCRLH has more number of resonance points. The DPCRLH symmetric unit cell is converted to resonator by open circuiting the ends. The resonator has five resonate points out of which the last three resonant points are selected to design a triple band filter at 3.6 GHz, 6 GHz and 9 GHz. The filter has different fractional bandwidths on all three bands. The order of the filter is three and it is designed using coupling coefficient and external quality factor. The filter is designed and fabricated with microstrip as host line.

The short circuited stub is used to create shunt inductance in CRLH and DPCRLH TLs and it is implemented as via hole in the microstrip form. The fabrication of via hole is relatively difficult. So, in order to avoid via holes, coplanar waveguide (CPW) is chosen as host line to create DPCRLH in the next design. A DPCRLH symmetric unit cell is designed in CPW and its characteristics are analysed. The open circuited resonator is formed from DPCRLH unit cell. As in the previous case it has five resonance points. A triple band antenna is designed at 3.6 GHz, 4.9 GHz and 6 GHz and measured results are compared with the simulated results.

**List of publications:**

Manoj Prabhakar Mohan, A. Alphones and M. F. Karim, "Triple Band Filter Based on Double Periodic CRLH Resonator," in IEEE Microwave and Wireless Components Letters, vol. 28, no. 3, pp. 212-214, March 2018.

Manoj Prabhakar Mohan, A. Alphones and F. Karim, "Triple band SIW cavity backed slot antenna," 2017 IEEE Asia Pacific Microwave Conference (APMC), Kuala Lumpur, 2017, pp. 698-701.

Manoj Prabhakar Mohan and Arokiaswami Alphones, “Double Periodic CRLH Transmission line for Wideband Performance," 2016 Asia-Pacific Microwave Conference (APMC), New Delhi, 2016, pp. 1-4.

Manoj Prabhakar Mohan, A Alphones and MF Karim, “CPW Triple Band Antenna based on DPCRLH resonator” (submitted to IEEE Antennas and Wireless Propagation Letters).

Manoj Prabhakar Mohan, A Alphones and MF Karim “Design guidelines of multi band Microwave Circuits” under preparation to be submitted to IEEE Microwave Magazine.