Defected ground structure based multi-band Band pass filter for wireless applications

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Abstract: - The recent development in wireless communication demands the wireless devices to operate between multiple communication bands. The most important RF module which is supporting the communication band separation between wireless devices is a Filter. The design challenges of any filter circuits are performance, cost and size. In this paper an open circuited stub based method is selected to realize a multiband band pass filter for GSM (1.8 GHZ), UMTS (2.1 GHz), ISM (2.4 GHz), WiMax (3.5 GHz) and LTE Band 3 (1.8 GHz) applications. The concept of defected ground structure is also applied to improve the performance of the filter. The simulated and measured parameters of the proposed filter are presented.

Key-Words: - Transmission zero (TZ), Defected Ground Structure (DGS), and Band Pass Filter (BPF), Wireless communication, microstrip, insertion loss

1 Introduction

Band Pass Filters (BPF) are used primarily in wireless transmitters and receivers. The main function of such filters in the receiver is to reduce image response. This removes any signals at the image frequency, which would otherwise interfere with the desired signal. It also prevents strong out-of-band signals from saturating the input stages.

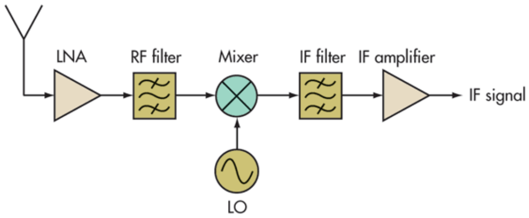

Fig.1 Receiver Front End

The filter performance can be analysed using return loss and insertion loss parameters. When the load and transmission line are mismatched, not all of the available power from the generator is delivered to the load. Instead certain amount of power is returned back to the source side. The amount of power which is reflected towards source side is quantified in terms of the parameter called as return loss (RL). It is defined as the ratio of reflected power to input power and is expressed in decibel (dB). Return loss, $RL = -20\log|\Gamma| dB$, where Γ is the reflection coefficient. Insertion Loss (IL) is the loss of signal power resulting from the insertion of a device in a transmission line or optical fiber and is expressed in decibel (dB). It is defined as the ratio of transmitted power to incident power. Insertion loss, $IL = -20\log|T|$, where T is the transmission coefficient.

Band pass filters can be realized using the open or short circuited stubs attached to J – inverter (transmission line inverter) [1]. The concepts of Defected Ground Structure (DGS) and Defected Microstrip Structure (DMS) also exist [2-4]. These techniques are widely used to improve the stop band characteristics and the out-of-band performance. Dual band filters can be designed easily using stepped-impedance resonators (SIRs) and the spurious responses of the filters can be controlled by adjusting the impedance ratios and electrical lengths. The use of coupling structures provides greater flexibility to adjust the resonant frequency [4]. One of the design challenges in filter is the compactness while achieving multiple pass bands [5, 6]. The Band pass filter designed with Stepped Impedance Resonator (SIR) and Defected Ground Structure (DGS) achieves improved stop band rejection [7, 8]. Band pass filter with multiple bands has been designed using the concepts of SIR and DGS [9, 10]. The concept of DGS also helps in achieving enhanced performance of the filter with compact filter structure [11]. DGS having different slot heads has been designed and compared. Among all the structures, it is concluded that H-DGS has the lowest occupying etched area [12]. To improve the selectivity of the filter, parallel coupled line structures are used [13]. The concept of DGS is also used to achieve wide band filters [14, 15]. The Band pass filter can be designed using short-circuited stubs. The disadvantage of using shortened stubs is the presence of via holes which degrade the signal integrity with ground [16, 17].

The work in this paper, focuses on designing a band pass filter with center frequency of 2 GHz and fractional bandwidth as 50%, as it covers most of the frequency bands of wireless standards such as Global System for Mobile Communication (GSM – 1.8 GHz), Universal Mobile Telecommunication system (UMTS – 2.1 GHz) and certain Long Term Evolution (LTE) channels (1,3, 40, 41 with frequencies 2.1, 1.8, 2.3 and 2.5 GHz respectively). The concept of DGS is implemented to get better stop band performance. The simulation of the designed filter is being done using Advanced Design System 2016.01 and the fabricated filter has been tested using Vector Network Analyzer N9915A.

The rest of the paper is organized as follows: Section 2 deals with designing the multi-band BPF. Section 3 explains the proposed design using DGS concept. The simulation and measurement results are discussed in Section 4 and finally Section 5 concludes the work.

2 Design of the Multi-band BPF

In general, the design specifications of the filter include the center frequency, fractional bandwidth and pass band ripple. In this paper, the filter is designed for center frequency of 2 GHz with fractional bandwidth of 50 %. The allowable pass band ripple is 0.1 dB. The designed filter design is carried out using 5th order Chebyshev polynomial coefficients. The substrate is chosen as RT duroid 6010 with high dielectric constant of 10.2 and having small thickness of 0.635 mm, which leads to the reduction of filter size. The normalized coefficients of the 5th order prototype filter are given as $g_0 = g_6 = 1, g_1 = g_5 = 1.1468$, $g_2 = g_4 = 1.3712$, $g_3 = 1.975$.

The Band pass filters are usually designed using quarter wavelength resonators [18, 19]. In this paper, the multi-band BPF is mainly designed using half-wavelength open circuited stubs. This eliminates the use of via holes in case of short circuited stubs.

The structure of the proposed open circuited stub based band pass filter is shown in Fig.2.

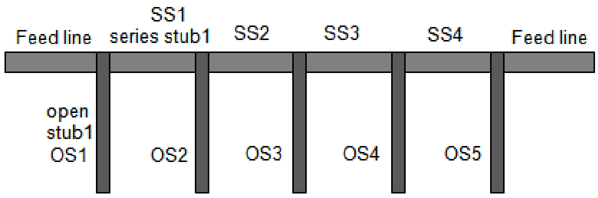

Fig.2 Structure of the open circuited stub Band pass filter

The proposed filter structure has five open circuited stubs indicating that the order of the filter is 5. The feed lines of the filter are designed for the characteristic impedance of 50 Ω and dimensions of the series stubs are calculated using the admittance values as given in Table 1. The reciprocal of the admittance gives the impedance values, with which the width and length of the series stubs are calculated.

The design equations for open circuited stubs are found using the characteristic admittance of the transmission line.

$$Y_{ia} = \frac{Y_i\left(\alpha_i \tan^2\theta - 1\right)}{\left(\alpha_i + 1\right)\tan^2\theta} \qquad (1)$$

where, $\alpha_i = \cot^2\left(\frac{\pi f_{zi}}{2 f_0}\right)$ and f_{zi} is the assigned transmission zero at the lower edge of pass band.

The width and length values for the series stubs and open circuited stubs are calculated with the help of the admittance values [20]. For the substrate with dielectric constant of 10.2 and transmission line characteristic line impedance of 50 ohm, $\frac{w}{h} < 2$,

$$\frac{w}{h} = \frac{8e^A}{e^{2A} - 2} \qquad (2)$$

where,

$$A = \left(\frac{2\pi Z_0}{Z_f}\right)\sqrt{\frac{\varepsilon_r - 1}{2}} + \left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \qquad (3)$$

w is the width of the microstrip line, h is the height of the substrate and $Z_f = 377\Omega$.

The length of the microstrip line is calculated using the equations,

Electrical length, $$\phi = \beta l = \frac{2\pi}{\lambda_g} l \qquad (4)$$

Guided wavelength, $$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{eff}}} \qquad (5)$$

Effective dielectric constant,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{-0.5} \qquad (6)$$

where, f is the operating frequency, ε_r is the dielectric constant of the substrate, $\phi = \frac{\pi}{2}$ when l is of quarter wavelength and $\phi = \pi$ when l is of half wavelength.

Table 1 Dimensions of the Series stubs

Transmissi--on line	Admittance of the series stub (mho)	Width of the series stub (mm)	Length of the series stub (mm)
SS1	0.02587	0.9694	14.0495
SS2	0.02787	1.0998	13.9712
SS3	0.02787	1.0998	13.9712
SS4	0.02587	0.9694	14.0495
Feed line	0.02	0.5957	14.3373

Table 2 Dimensions of the Open circuited stubs

Position of the stub	Admittance of the stub (mho)	Width of the stub (mm)	Length of the stub (mm)
OS1	0.0146	0.2815	14.7194
OS2	0.0287	1.1565	13.9397
OS3	0.0283	1.1258	13.9566
OS4	0.0287	1.1565	13.9397
OS5	0.0146	0.2815	14.7194

The dimensions of the series and open circuited stubs are calculated using the operating frequency, impedance values, dielectric constant and height of the substrate. The calculated values of series stubs and open circuited stubs are indicated in Table 1 and Table 2. The simulation is done using Advanced Design System 2016.01 and the layout of the band pass filter is shown in Fig.3.

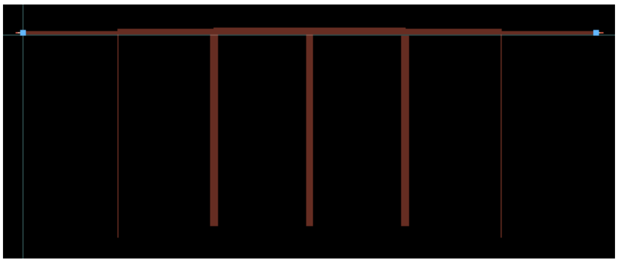

Fig.3 Layout of the Multi-band BPF design using open circuited stubs

In Fig.3, the five open circuited stubs corresponds to the 5th order filter which results in multi-band filter response. The simulated response of the filter is shown in Fig.4.

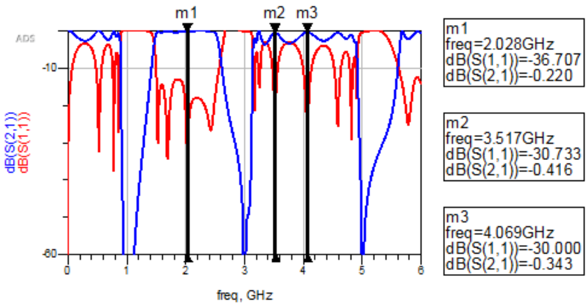

Fig.4 Simulated response of the Multi-band BPF

From the response, it is observed that at the center frequency of 2 GHz, the obtained return loss is 36 dB and the pass band range is obtained as 1.466 GHz – 2.55 GHz with a bandwidth of 1.08 GHz. The second band produces a bandwidth of 370 MHz (3.37 – 3.74 GHz) with return loss and insertion loss values as 30 dB and 0.4 dB. The filter also resonates to produce third pass band is centered at 3.5 GHz having return loss of 30 dB and insertion loss of 0.3 dB with a bandwidth of 590 MHz (3.78 – 4.37 GHz).

3 Proposed Filter Design

In the proposed filter design, the concept of DGS is implemented. The concept of DGS is originated from photonic band gap structures (PBG) in the optical field. The DGS is realized by etching simple shapes in the ground plane of microstrip line. The etched pattern disturbs the current path in the ground plane which changes the performance of microstrip line. The DGS has two main characteristics: one is slow wave effect and the other is band stop characteristics.

A DGS cell is equivalent to an LC resonant circuit [21]. The classic microwave low pass filter (LPF) is implemented either by all shunt stubs or by series connected high-low (Hi-Lo) stepped impedance microstrip line sections. However, these designs suffer from few limitations such as the fabrication difficulties associated with the high impedance lines and the appearance of spurious bands. In order to overcome these limitations, a method has been proposed, which uses both DGS resonators and a compensated microstrip line to design the desired LPF.

The slot in the ground plane acts as a parallel resonant circuit; it can be modelled by an LC resonant circuit. The values of L, C and R can be computed using,

$$Y = \frac{1}{R} + j2\pi\left(fC - \frac{1}{4\pi fL}\right) \quad (7)$$

$$|s_{12}| = \left(1 + (2Z_0)^{-2}\left(\frac{1}{\omega L} - \omega C\right)^{-2}\right)^{-0.5} \quad (8)$$

At resonance frequency, the relationship between LC and ω_0 are defined as follows:

$$L = \frac{1}{\omega_0{}^2 C} \quad (9)$$

Using equation (9),

$$L = \frac{2Z_0}{\omega_0{}^2}\left(\frac{\omega_0{}^2 - \omega_c{}^2}{\omega_0}\right) \quad (10)$$

$$C = \frac{1}{2Z_0}\left(\frac{\omega_c}{\omega_0{}^2 - \omega_c{}^2}\right) \quad (11)$$

where, ω_c is the cut-off frequency (radians) and ω_0 is the attenuation pole frequency (radians).

In the design, four rectangular slots are etched in the ground plane. The ground plane is left undisturbed in the place of the stubs, so that there is no radiation from the ground plane. The DGS helps to attain the better stop band characteristics.

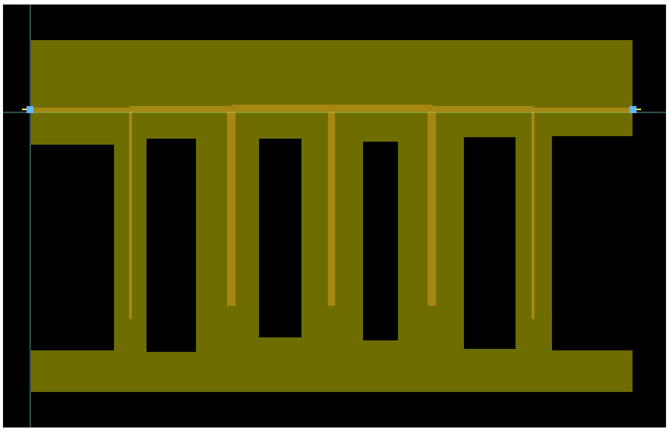

Fig.5 Layout of the proposed filter design with DGS

Fig.5 shows the defected ground structure based Multi-band BPF and its response is shown in Fig.6.

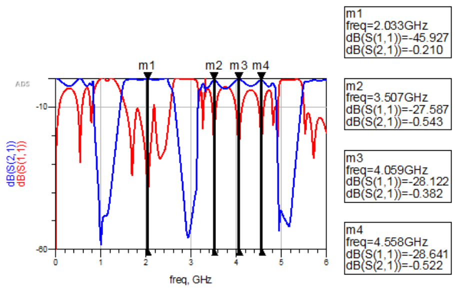

Fig.6 Simulated response of DGS based filter

From the response, it is observed at center frequency of 2 GHz, the return loss is near to 45 dB and the pass band range is 1.48 GHz – 2.55 GHz (i.e.) bandwidth of 1.07 GHz. The successive bands are due to the presence of open stubs, and the next band is centered at 3.5 GHz, having return loss of 27 dB and insertion loss of 0.5 dB. The bandwidth of the second band is 350 MHz (3.35 GHz – 3.7 GHz). The second transmission zero is at 3 GHz. The third band is at 4 GHz with return loss of 28 dB, insertion loss of 0.3 dB and bandwidth of 560 MHz (3.79 GHz – 4.35 GHz). The fourth band is obtained at 4.56 GHz with the return loss of 28 dB, insertion loss of 0.5 dB and the bandwidth of 350 MHz (4.38 GHz – 4.73 GHz).

4 Experimental results

The designed Multi-band BPF with DGS is fabricated using the RT Duroid 6010 substrate of thickness 0.635 mm. The snapshots of the fabricated design are shown in Fig.7 and Fig.8.

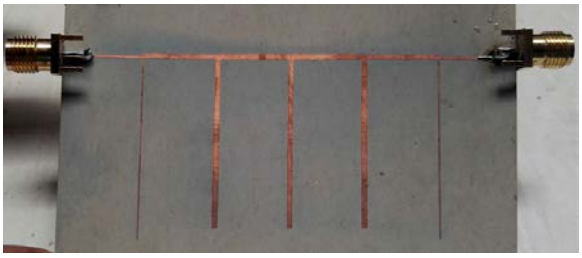

Fig.7 Top view of the designed filter

Fig.7 shows the top view of the fabricated 5^{th} order band pass filter with five open circuited stubs connected across horizontal series stubs. The bottom surface of the design has finite ground in which copper layer has been deposited to act as ground.

Fig.8 Bottom view of the designed filter

The designed band pass filter is tested using the Vector Network Analyser N9915A. Fig.9 shows the experimental setup for testing the filter.

Fig.9 Experimental setup for testing the filter

The frequency response of the filter has been observed in the frequency range of 1 GHz-6 GHz. The plot of s_{11} in dB with respect to frequency is used to obtain the behaviour of the filter for the entire frequency range. The plot of s_{21} in dB with respect to frequency is used to determine the insertion loss in the filter and also the pass bands of the filter.

The two port S-parameter measurement results of the proposed filter are shown in Fig.10 and Fig.11.

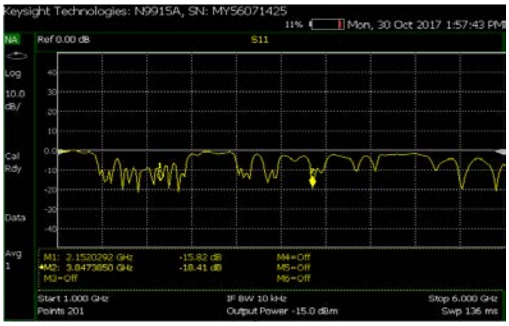

Fig.10 Return loss measurements of the filter

It is observed from the Fig.10, that the return loss of 15.82 dB is obtained at 2.15 GHz (shifted from center frequency of 2 GHz) indicating that 2.618 % of input power gets reflected and the return loss of 18.41 dB is obtained at 3.85 GHz (shifted from center frequency of 4 GHz) indicating that 1.442 % of input power is reflected.

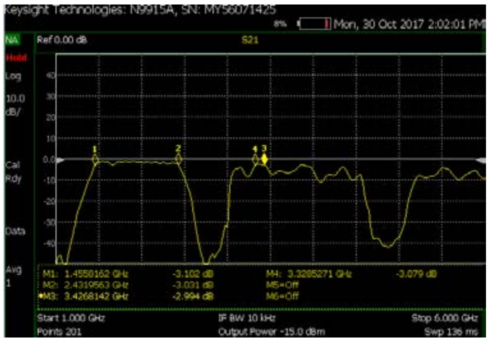

Fig.11 Insertion loss measurements of the filter

The result of Fig.11 indicates that the first pass band occur in the frequency range of 1.4581 GHz – 2.4319 GHz with less than 0.3 dB insertion loss and having the bandwidth of 974 MHz. The second pass band occurs in the frequency range of 3.328 GHz – 3.426 GHz covering the minimum bandwidth of 100 MHz which has to be improved.

5 Conclusion and Future work

In this paper, a Multi-band band pass filter has been designed using open circuited stubs. It eliminates the complexity of using conventional short circuited stubs. The defected ground structure is included in the open circuited stub based filter. The dimension of the proposed filter is 80 x 50 mm^2, which can fit into any wireless devices like Wi-Fi terminals, satellite receivers and radar receivers. The designed filter has the advantage of compact size. It also exhibits the performance in multiple bands to support many of the wireless standards such as GSM, Wi-Fi, LTE, RFID, etc. The future work can be extended to attain tunability in the designed band pass filter.

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References:

[1] Wenjie Feng, Xin Gao, Wenquan Che, Band pass filters with multiple transmission zeros using open/shorted stubs, *IET Microwaves, Antennas & Propagation*, Vol. 9, No. 8, 2015, pp. 769–774

[2] Arjun Kumar, M.V.Kartikeyan,Design and realization of microstrip filters with new defected ground structure (DGS), *Engineering Science and Technology, an International Journal*, Vol. 20, 2017, pp. 679–686

[3] Mukesh Kumar Khandelwal, Binod Kumar Kanaujia, Sachin Kumar, Defected Ground Structure: Fundamentals, Analysis, and Applications in Modern Wireless Trends, *International Journal of Antennas and Propagation*, Article ID 2018527, 2017, 22 pages

[4] Feng Wei, Pei-Yuan Qin, Y. Jay Guo, Xiao-Wei Shi, Design of multi-band band pass filters based on stub loaded stepped-impedance resonator with defected microstrip structure (SL-SIR-DMS), *IET Microwave Antennas Propagation*, Vol. 10, No. 2, 2016, pp. 230–236

[5] Z. Zhang, Q. Chu, F. Chen, Compact dual-band bandpass filters using open-/short-circuited stub-loaded resonators, *IEEE Microw. Wireless Compon. Lett.*, Vol. 25, No. 10, 2015, pp. 657-659

[6] Wu, H.-W., Chen, G.-S., Chen, Y.-W, New compact triple-passband bandpass filter using multipath-embedded stepped impedance resonators, *IEEE Microwave Wireless Components Letters*, Vol. 24, No. 3, 2014, pp. 158–160

[7] Gi-Rae Kim, Design of Coupled Resonators Bandpass filter with Defected Ground Structure, *International Journal of KIMICS*, Vol. 9, No. 2, 2011, pp. 150-154

[8] Pragya Singh, Raghuvir tomar, The use of defected ground strucutres in designing microstrip filters with enhanced performance characteristics, *Procedia Technology*, Vol. 17, 2014, pp. 58-64

[9] Maryam Jaldi and Majid Tayarni, Design of Ultra Wideband Bandpass Dual Band Filter Using Defected Ground Structures, *International Journal of Information and Electronics Engineering*, Vol. 3, No. 1, 2013, pp. 59-62

[10] Emad S. Ahmed, Design of Tri-Band Bandpass Filter Based On Quad-Sections SIR Resonator for Wireless Applications, *WSEAS Transactions on Communications*, Vol. 12, Issue 12, 2013, pp. 641-650

[11] Adel Abd Elrahman, Adel Zein Eldein, Ahmed Abd Elmonem, Hesham Fathi, Small Size Defected Ground Structure (DGS) Coupled Resonator Band Pass Filters with CapacitorLoaded Slot Using FDTD Method, *WSEAS Transactions on Communications*, Vol. 10, Issue. 3, 2011, pp. 88-99

[12] Ahmed Boutejdar, Abbas Omar, Edmund P. Burte, Reinhard Mikuta, An Improvement of Defected Ground Structure Lowpass/Bandpass filters using H-slot resonators and coupling matrix method, Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 10, No. 2, 2011, pp. 295-307

[13] D. Piscarreta and S.-W. Ting, Microstrip parallel coupled-line bandpass filter with selectivity improvement using U-shaped defected ground structure, *Microwave and Optical Technology Letters*, Vol. 50, No. 4, 2008, pp. 911–915

[14] H.-J. Chen, T.-H. Huang, C.-S. Chang et al., A novel cross shape DGS applied to design ultra-wide stopband low-pass filters,*IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 5, 2006, pp. 252–254

[15] G. M. Yang, R. Jin, J. Geng, X. Huang, and G. Xiao, Ultra wideband bandpass filter with hybrid quasi-lumped elements and defected ground structure, *IET Microwaves, Antennas*

and Propagation, Vol. 1, No. 3, 2007, pp. 733-736

[16] Mohammad Shahrazel Razalli, Alyani Ismail, Mohd Adzir Mahd, Mohd Nizar Hamidon, Compnact Configuration Ultra- Wideband Microwave Filter Using Quarter-Wavelength Short-circuited stub, *Proceedings of Asia-Pacific Microwave Conference*, 2007

[17] Kavita, Sandeep Kumar, Anupma Gupta, Design of UWB Microstrip Filter Using Quarter Wavelength Short Circuited Stubs, *International Journal of Innovative Research in Computer and Communication Engineering*, Vol. 2, Issue. 11, 2014, pp. 6735-6741

[18] Xin Dong, Mengze Li, Yanli Li,Dual-Band Bandpass Filters Using Open-/Short- Circuited Stub-Loaded Quarter-Wavelength Resonators, *Advanced Materials and Processes for RF and THz Applications, International Microwave Workshop Series*, 2016.

[19] Cheng-Chung Chen, Yi-Ru Chen, and Chi-Yang Chang, Miniaturized Microstrip Cross-Coupled Filters Using Quarter-Wave or Quasi-Quarter-Wave Resonators, *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 1, 2003, pp.120-131.

[20] Pozar, *Microwave engineering*, John Wiley & Sons, Inc., 2012.

[21] Jia-Sheng Hong, Bindu M Karyamapudi,A General Circuit Model for Defected Ground Structures in Planar Transmission Lines, *IEEE Microwave And Wireless Components Letters*, Vol. 15, No. 10, 2005, pp. 706-708.