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Composite Lowpass Filter Realized by Image Parameter method and Integrated with Defected Ground Structures

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ABSTRACT

An asymmetric DGS consisting of two square headed slots connected transversely with a rectangular slot is etched in the ground plane underneath a high-low impedance microstrip line. It provides a band-reject filtering characteristics with sharp transition. Thus, it may be modeled as m-derived filter section. Accordingly, T-type LC equivalent circuit is proposed and LC parameters are extracted. A planar composite lowpass filter is designed by image parameter method and implemented by different DGS units. A composite filter requires at least three filter sections, of which two m-derived sections and one constant k-section. In proposed scheme, one such m-derived section is directly replaced by proposed DGS unit, whose cut-off frequency is same as that of designed m-derived section. The other m-derived section implemented by proposed DGS unit divided into equivalent two L-sections which will act as a termination for impedance matching. A constant k-section has been realized by a dumbbell shaped DGS having same cutoff frequency. Here lumped LC parameters are directly replaced by the equivalent LC values of the DGSs and therefore, produce almost ideal filter characteristics by overcoming the limitations of microstrip technology

General Terms

DGS, image parameter, lowpass, m-derived section, composite filter, high-low microstrip line.

INTRODUCTION

We A defected structure etched in the metallic ground plane of a microstrip line effectively disturbs the shield current distribution in the ground plane and thus, introduces high line inductance and capacitance of the microstrip line. Thus, it obtains wide stopband and compact size, which meet emerging application challenges in wireless communication. Planar microstrip filter design using DGSs are very much challenging. Dumbbell shaped DGS explored by D. Ahn offers the lowpass characteristic with one finite transmission zero [1-2]. Using such elements, lowpass and bandpass filters are implemented in recent time [3-6]. A filter with high selectivity has a good demand for designing communication systems within finite spectrum resources. Most conventional approaches are Butterworth or Chebyshev type designs in insertion loss method. But they require a high order design to ensure a good selectivity near the passband since they do not have attenuation zeros. Elliptic function filter may be a candidate. They have finite attenuation zeros close to attenuation pole, which make them very attractive for such applications. In this line, few DGSs with quasi-elliptic lowpass responses are reported [7-11] recently. However, the design should also ensure flat responses in the passband and deep attenuations at stopband for wide band of frequency. Therefore, designing a planar lowpass filter within a limited space (compact) is still a challenge.

In this paper, an asymmetric DGS pattern with respect to transmission line is proposed. Its unit cell consists of two square headed thin slots connected with a rectangular slot underneath a microstrip line transversely. The insertion loss introduced in the microstrip line by DGS has been reduced with the inclusion of high-low impedance line. It is modeled as a T-type LC resonant circuit and equivalent parameters are extracted for a given dimension of the DGS.

Design of a lowpass composite filter by image parameter method requires minimum three filter sections: one constant-k section and two m-derived sections. One m-derived section is cascaded to the constant-k section and other m-derived T section is divided into two L sections to act as a terminator on both sides for impedance matching. Here, proposed DGS unit is modeled as m-derived filter section and popular dumbbell DGS unit as constant-k section. By combining all three sections, a filter has been designed at cut-off frequency of 4.5 GHz with desired attenuation and matching properties. The lumped LC parameters for each section are directly replaced by the equivalent LC values of the DGSs. Therefore, produces almost ideal filter characteristics by overcoming the general limitations of microstrip technology.

ASSYMMETRIC DGS UNDERNEATH A HIGH-LOW IMPEDANCE LINE

All The schematic diagram of a proposed DGS unit is shown in Fig. 1(a). It consists of two square headed slots of side length ‘a’ connect a rectangular slot of width ‘a’ and length ‘b’ by transverse slots of width ‘g’ underneath a high-low impedance line. The transverse slots increase the effective capacitance and other rectangular/square slots attached to transverse slots loaded inductance to the line. The high-low impedance line is used to reduce the insertion loss, introduced by DGS unit.

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

In order to investigate of the DGS, it is simulated here by the MoM based IE3D EM-simulator. The different dimensions are considered as b=10 mm, a = 4 mm, d = 2 mm, and g = 0.4 mm. The substrate with a dielectric constant of 3.2, loss tangent 0.0025 and thickness 0.79 mm is chosen. The low impedance (Lo) has a width (w_c) of 4.1 mm, which corresponds to 30Ω and high impedance line has width of 1.92 mm, corresponds to 50 Ω.

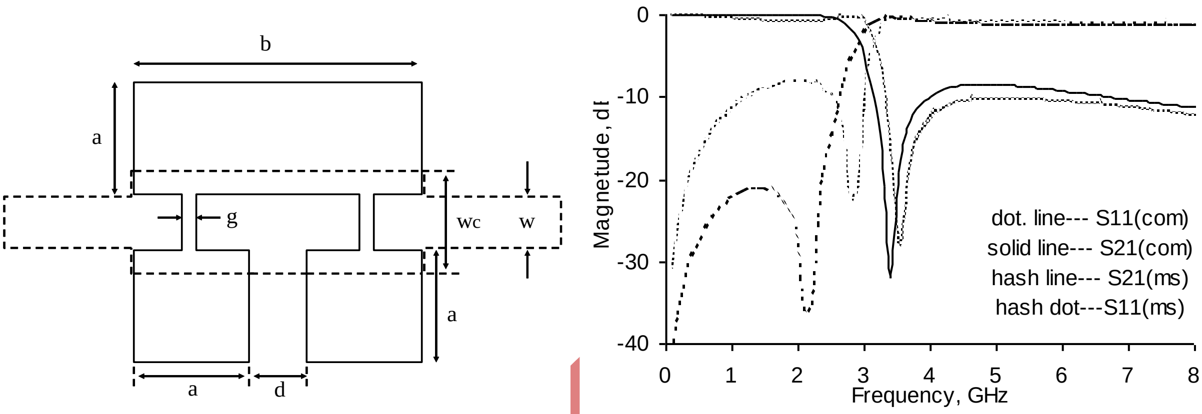

Fig 1: (a) schematic diagram of a DGS underneath a high-low line, (b) their simulated S-parameters

In simulated result, the cutoff is observed at 2.9 GHz and pole at 3.4 GHz as shown in Fig. 1(b). The insertion loss is obtained, as 0.06 dB and return loss is 22 dB. An attenuation zero at 2.7 GHz is clearly indicated in the frequency response. Both finite attenuation pole and zero observed in its frequency response, ensure a 3rd order elliptic filter and thus, it is modeled by a equivalent circuit represented by a T-network composed of an inductance L_1, L_2 and capacitance C_2 connected in series with a transmission line 50 Ω as illustrated in Fig. 2(a). Losses are not considered here.

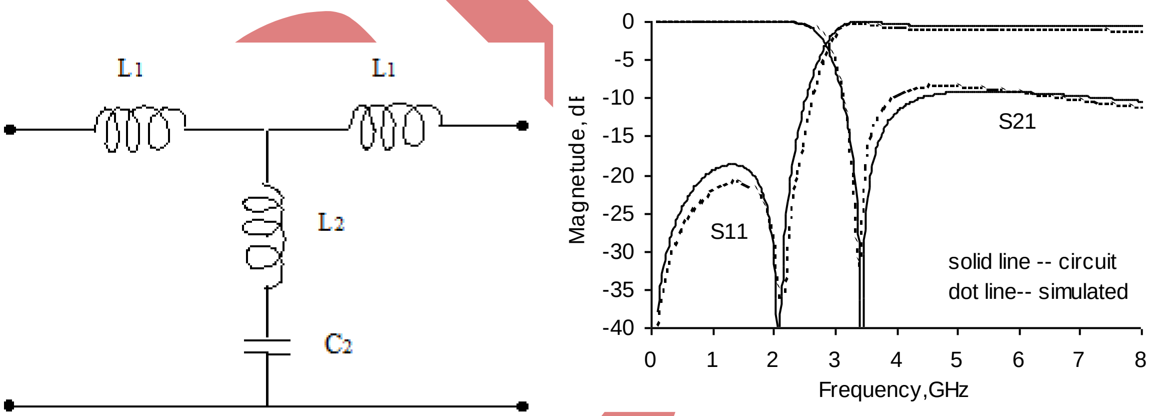

Fig 2: T-network as equivalent circuit (b) S-parameters from circuit and EM-simulations

For the dimensions of the DGS unit as mentioned earlier, we can extract the parameters, L_1 =1.76 nH, L_2 =3.32 nH and C_2 =0.66 pF respectively using FilterSim software. The same LC parameters are also estimated by prototype element value of the 3rd order elliptic lowpass filter function and they are obtained as L_1 =1.97 nH, L_2 = 3.1 nH and C_2 = 0.56 pF. The circuit-simulated s-parameters are compared with EM-simulated results in Fig. 2(b) and good agreements have been obtained.

INFLUENCE OF THE SLOT DIMENSION

The shape of the DGS is optimized against filter parameters like the stopband ratio, stopband attenuation and passband insertion loss and obtained a relation between different dimensions as given by: a=e; d=c=e/2; b=2a+d=2.5d. Four DGS unit with different set of dimension are simulated maintaining that relationship, keeping the width of the connecting slots (g) constant to 0.4 mm. For case A, b is chosen to be 15 mm and obtained a=e= 6 mm, and d=c=3 mm. For case B, b is chosen to be 10 mm and obtained a=e= 4 mm, and d=c=2 mm. For case C, b=7.5 mm and for case D, b=5 mm are chosen and obtained other dimensions. As the etched area of the unit lattice increases, the attenuation pole reduces, as shown in Fig. 3(a). It is also observed that the stopband ratio, stopband attenuation and pass band insertion loss are maintained almost constant values of 1.12, 10 dB, and 0.1 dB respectively for all four cases. The cutoff and pole frequencies are plotted against length (b) of rectangular slot in Fig. 3(b). Thus, the dimensions of the DGS operated at any pole or cutoff frequency may be obtained from this plot.

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

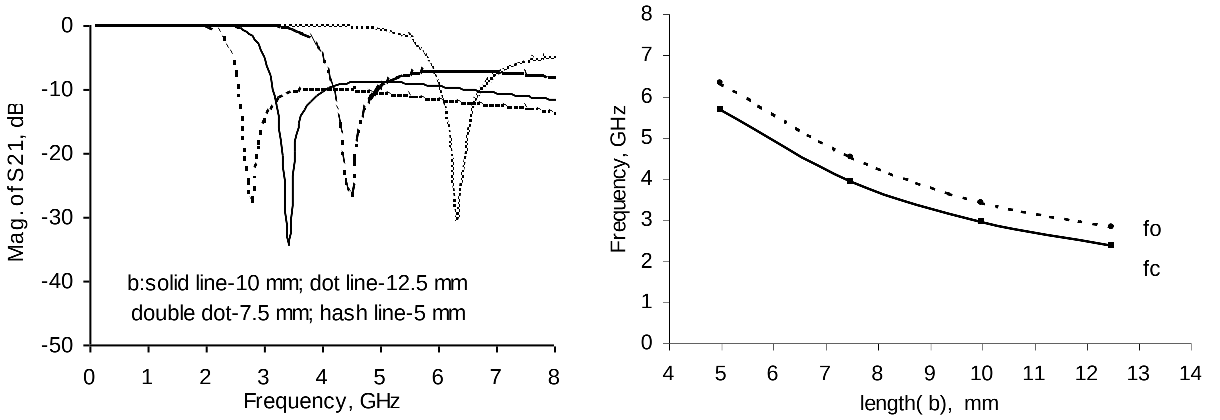

Fig 3: (a) S_{21} for different set of dimensions (b) cutoff and pole frequencies vs. b plots

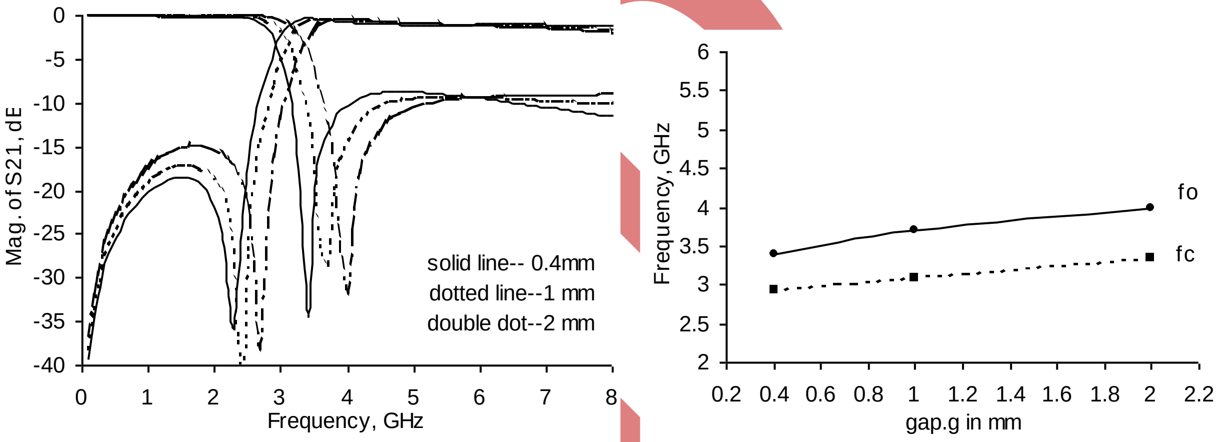

Fig 4: (a) Simulated for different set of g-value (b) cutoff/ pole frequency vs. g plots

For investigated the influence of the width (g) of the connecting slot, it is varied to 0.4, 1 and 2 mm, keeping other dimensions fixed as a=e=4 mm, d=c=2 mm, and b=10 mm. The simulated S-Parameters in Fig. 4(a) show that the attenuation pole location moves up to higher frequency with increasing the connecting slot width. The cutoff and pole frequencies are plotted against g-values in Fig. 4(b). The variation of both frequencies here are less in comparison to variation in Fig. 3(b). Therefore, the variation of the width (g) may be useful for fine-tuning of the stopband.

COMPOSITE LOWPASS FILTER USING IMAGE PARAMETER

There are two methods (a) insertion-loss and (b) image parameter available for synthesize passive filters. The insertion loss method provides a specified response of the filter. Image parameter method provides a design that can pass or stop a certain range of frequency band, but its frequency response cannot be shaped. A lowpass composite filter requires minimum three filter sections: one constant-k filter section and two m-derived filter sections. One m-derived section is cascaded to the constant-k section and other m-derived T section is divided into two L sections to act as a terminator on both side of this composite filter structure for impedance matching as shown in Fig. 5. The cutoff frequencies of all three sections should be same as the cutoff frequency (f_c) of the designed composite filter. The pole frequencies (f_0) should be different but they should be close enough to cutoff frequency for getting sharp transition. The sharpness of the composite filter is determined by m values of m-derived sections, which are normally taken near to 0.5.

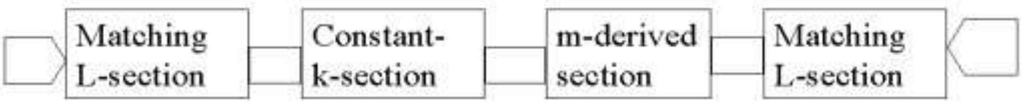

Fig 5: block diagram of a composite filter

For, constant-k filter section the energy does not attenuated rapidly beyond cut-off and characteristics impedance varies widely over the passband, therefore, satisfactory impedance match is not possible. The constant-k filter section suffers from the disadvantages of relatively slow attenuation rate beyond cut-off and non-constant characteristics impedance. This m-derived filter section is used to sharpen the attenuation at stopband. Physically it is done by creating resonance of the series LC resonator in the shunt arm of T section. The position of pole may be controlled with the value of m. The sharpness of m-derived filter section is related to $m = (1-f_c^2 / f_0^2)^{1/2}$. One of the m-derived sections is bisected into two L-sections and used to match the constant-k section to the input while the other side will be used to match the m-derived

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

section to the output. Here, a composite filter has been designed at cutoff frequency of 4.5 GHz. So the m-derived filter sections have cut-off frequency at 4.5 GHz but attenuation pole frequencies of m-derived sections are taken to be 5 GHz (directly cascaded to the constant-k section) and 5.2 GHz (used as a terminator) respectively. Here dumbbell DGS is taken to realize constant-k filter section. The m-derived filter section provides both attenuation pole and zero and they are close enough to get sharp response. Therefore, proposed DGS is taken for realizing m-derived filter sections. The second DGS unit has been divided into two equal sections for realizing L sections.

CONSTANT-K FILTER SECTION USING DUMBBELL SHAPED DGS

The schematic diagram of a dumbbell shaped DGS consisting of two rectangular headed slots (of length b and width a) connected by a transverse slot (of length c and width g) underneath a microstrip line is shown in Fig. 6. The transverse slot increases the effective capacitance and rectangular slots attached to transverse slot loaded inductance to the line. The different dimensions are considered as b=4 mm, a= 4 mm, c=2 mm, and g = 0.4 mm. The same substrate is considered here.

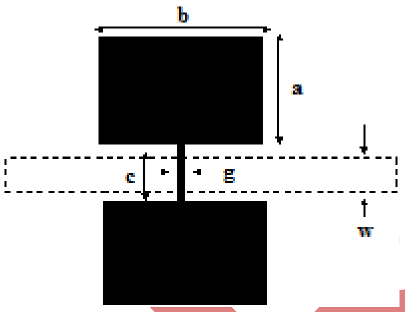

Fig 6: Schematic views of dumbbell shaped DGS unit (solid area is etched area in ground plane and dotted area is metal strip on signal plane)

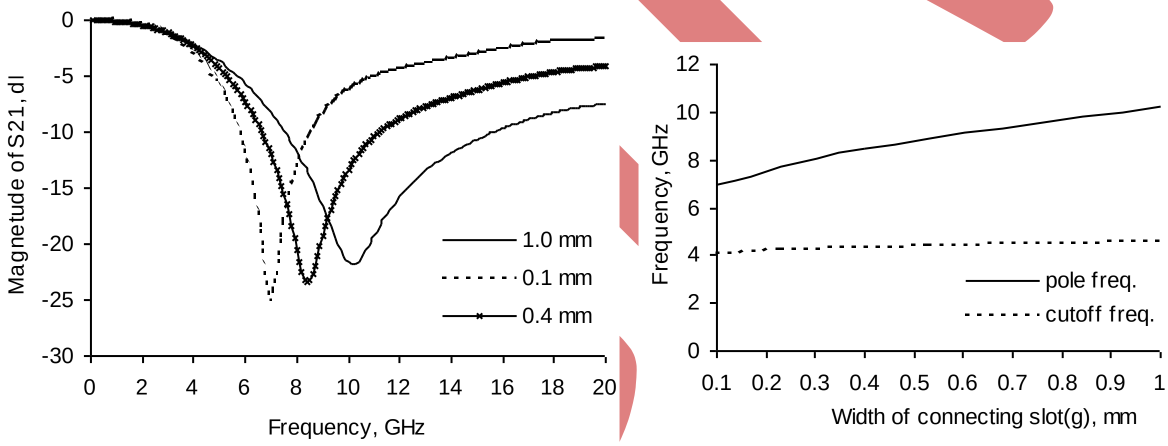

Fig 7: (a) S-parameters for different width of connecting slot (g) (b) Pole/cutoff freq vs g-plot

The width (g) of the connecting slot is varied keeping the area of slot head and the length of the connecting slot (c) fixed. The simulated S_{21} results are plotted in Fig. 7(a). Due to the fixed slot head dimension, the effective series inductance is constant for all cases and no change in cutoff frequency is observed. As the width of the connecting slot increases, the effective capacitance decreases so that the attenuation pole location moves up to higher frequency.

In order to investigate the influence of the slot-head, the area of the slot head is varied to 4, 16 and 36 square mm, keeping width and length of connecting slot fixed. As the area of the square head increases, lowering of cutoff frequency is observed as seen in Fig. 8(a). The capacitance values are identical for all cases due to identical connecting slot width. However, the attenuation pole location becomes lower because the series inductance increases.

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

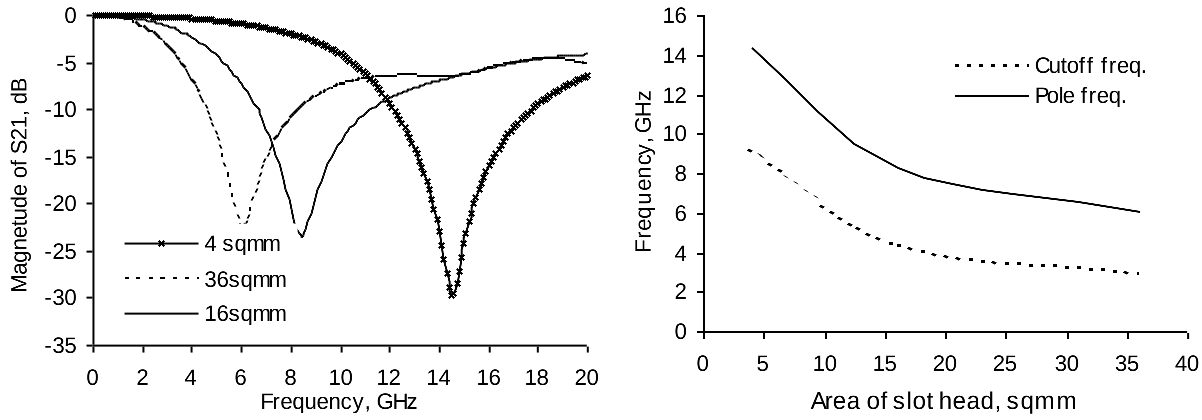

Fig 8: (a) S-parameters with different area of slot head (b) Pole/cutoff freq vs slot area-plot

Therefore, the DGS unit may be fully described by the area of head slots and connecting slot dimensions. The cutoff frequency mainly depends on the etched area of the slot head. If a dumbbell DGS is designed such that cutoff frequency should be at designed cutoff frequency of the composite filter and pole at quite high frequency, it may produces responses like'constant-k type filter section' at lower frequency range. The pole/cutoff frequency vs. area of head-slot and g plots as shown in Fig. 7(b) & Fig. 8(b) are used to design such a filter-section.

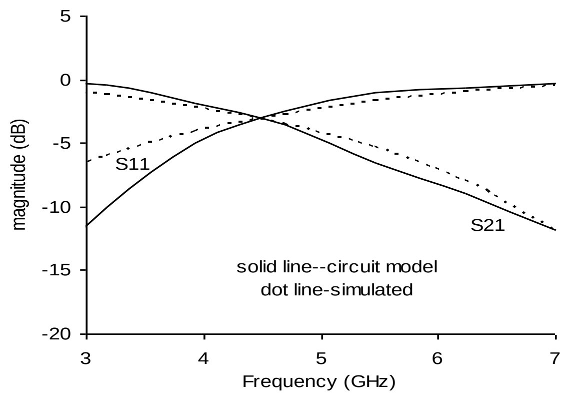

Fig 9: EM-simulated and circuit-simulated S-parameters of dumbbell DGS

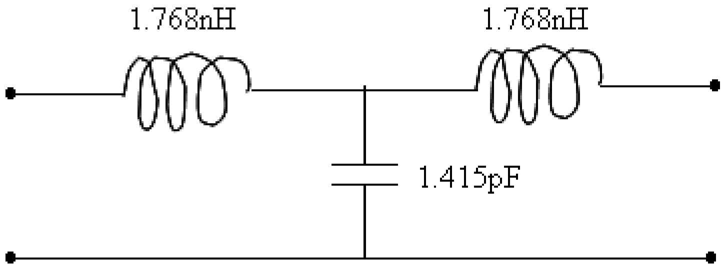

Fig 10: Circuit model of dumbbell DGS with extracted LC values

For getting cut-off frequency at 4.5 GHz, the dimensions of a dumbbell DGS are obtained as b= 6.5 mm, a= 2.5 mm, c= 2 mm, and g = 0.5 mm. The pole is observed at 10 GHz. So the DGS shows the characteristics like 'constant-k type filter section' upto 8 GHz as shown in Fig. 9. Then circuit model of the DGS represents as 'constant-k type filter section' at low frequency as shown in Fig. 10 and LC parameters are extracted accordingly.

m-DERIVED T-SECTION BY PROPOSED DGS

An m-derived lowpass filter section provides an attenuation pole and attenuation zero which is very similar to the 3rd order elliptical lowpass filter response, except insertion loss, which is zero for m-derived section. As we have seen that proposed DGS underneath a HI-LO line produces attenuation zero close to the pole frequency, and passband insertion is almost zero value (0.065 dB), it can easily be modeled as m-derived filter section. For given dimensions of DGS in section 3, the LC values are extractedas L_1=1.76 nH, L_2 =3.32 nH and C_2 =0.66 pF from Filter-Sim software and L_1=1.97 nH, L_2 = 3.1 nH and C_2 = 0.56 pF from elliptic prototype filter design.

International Journal of Computers & Technology
Volume 4 No. 2, March-April, 2013, ISSN 2277-3061

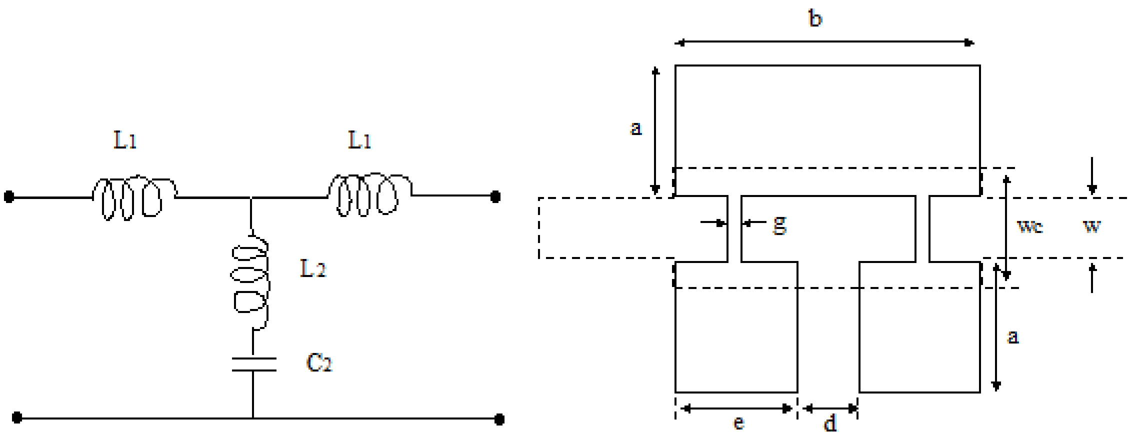

Fig 11: (a) equivalent circuit model and (b) schematics diagram of proposed DGS unit

For, m value of m-derived section is obtained as m= $(1-f_c^2 / f_0^2)^{1/2}$ = 0.522. for cutoff freq. (f_c) = 2.92 GHz and pole freq. (f_0) = 3.4 GHz, taking match load as R= 50 Ω and LC values are obtained from the m-derived filter formula as given by: L_1= m/2 *(R/π f_c) = 1.43 nH; L_2 = $(1-m^2)$/4m *(R/π f_c) =1.912 nH; C_2 = $1/4\pi^2 f_0^2 L_2$ =1.14 pF

Table 1. Comparison of LC-values obtained from FilterSim, Prototype & m-derived section

Causers T-section	circuit simulation using Filtersim	prototype 3rd order elliptic function	m-derived section
L_1	1.76 nH	1.97 nH	1.43 nH
L_2	3.32 nH	3.1 nH	1.912 nH
C_2	0.66 pF	0.56 pF	1.14 pF
ripple	.06 dB	0.06 dB	0 dB

The LC values obtained from obtained from FilterSim, and elliptic prototypes are compared with m-derived filter section in table-1 and good agreements among them have been noticed. The m values of the m-derived sections represented by proposed DGS with b = 5 mm, 7.5 mm, 10 mm and 12.5 mm as illustrated in Fig. 6 are estimated and compared in table-2. It is observed that the value of m varies between 0.44 to 0.54, which is quite good for composite filter.

Table 2. m-value for different dimensions of proposed DGS

b	fc	fo	$m=(1-fc^2/fo^2)^{1/2}$
5 mm	5.65 GHz	6.3 GHz	0.4424
7.5 mm	3.9 GHz	4.5GHz	0.4988
10 mm	2.9GHz	3.4GHz	0.5220
12.5 mm	2.35GHz	2.8GHz	0.5437

Here, the m-derived section connected in series with the constant-k section has cut-off frequency at 4.5 GHz and attenuation pole at 5 GHz. It is implemented by proposed DGS unit and its dimension are obtained as b=7.5 mm, a=e= 3 mm, d=c= 1.5 mm, and g=0.4 mm from Fig. 6. Low impedance line has a width of 4.0 mm. The extracted LC parameters are given in equivalent circuit in Fig. 12.

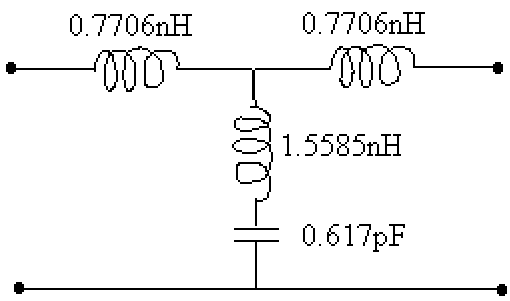

Fig 12: m-derived section implemented by proposed DGS

The m-derived section acted as terminator has the same cutoff frequency and slightly higher pole frequency (5.2GHz). It is implemented by proposed DGS unit and its dimension are obtained as b=7.5 mm, a=e= 3 mm, d=c= 1.5 mm, and g=0.6 mm from 5(b). Here we changed only the g-value to shift the pole frequency from 5 GHz to 5.2 GHz. The equivalent LC values are shown in Fig. 15(a). Then, the T-section is converted into equivalent Π-section (Fig. 13(b)) and finally divided into two equivalent L sections to act as a terminator at both ends as shown in Fig. 13(c).

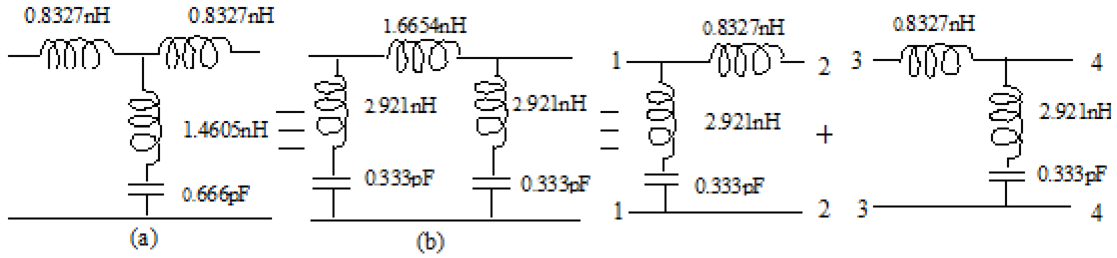

Fig 13: (a) Equivalent T circuit of proposed DGS used as terminator, (b) its Π model, (c) equivalent L sections used as terminal of both input and output side.

CIRCUIT MODEL OF THE COMPOSITE FILTER

This equivalent circuit of each section is cascaded and obtained the combined lowpass filter as shown in Fig. 16. The circuit-simulated S-parameters are compared to the EM-simulated result as illustrated in Fig. 17. The cut-off frequency and attenuation pole frequency of the EM-simulated results match the circuit-simulated results to some extent. The difference observed as the LC value of small line section between DGS cells are not considered here.

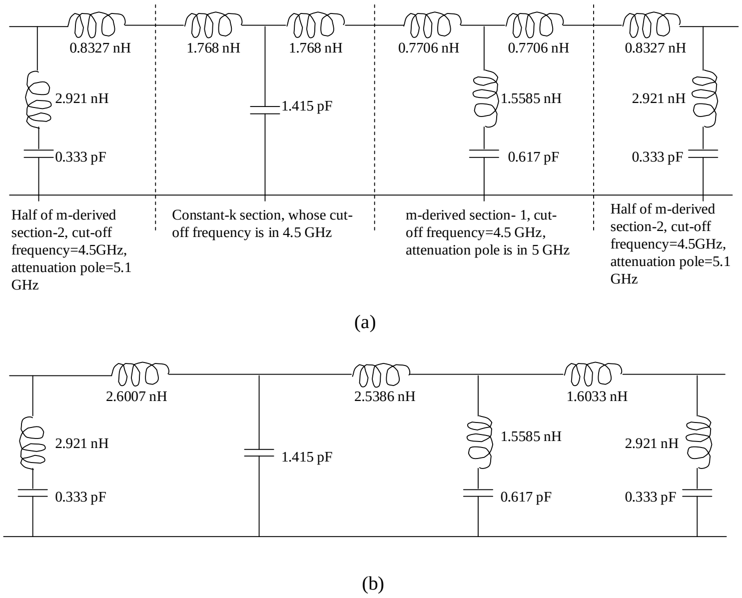

Fig 14: (a) equivalent circuit of each section (b) combined circuit of the filter

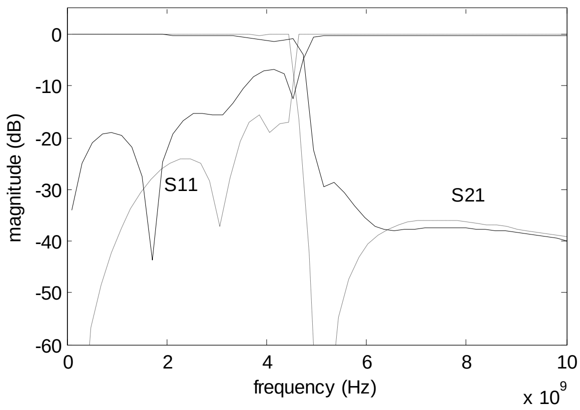

Fig 15: S-parameter of composite filter: dotted line for circuit-simulation, solid line for EM-simulation

EXPERIMENTAL MEASUREMENT OF PROTOTYPE FILTER

The photographic views of the composite filter are shown in Fig. 16. The prototype has been fabricated with Arlon substrate with a dielectric constant of 3.2, loss tangent 0.0025 and thickness 0.79 mm. The experimental measurement is carried out with Agilent make vector network analyzer.

Fig 16: photographic views of (a) ground plane (b) top plane of composite lowpass filter

The cut-off and pole frequencies are observed at 4.68 GHz and 5.01 GHz (29.5 dB) in measurement result where as, they are 4.76 GHz and 5.1 GHz (33 dB), respectively, in simulated results as shown in Fig 19. The insertion losses are obtained as 1.68 dB in measurement and 1.18 dB in simulated results. The stopband attenuation of more than –35 dB is observed from 5 GHz to 10 GHz.

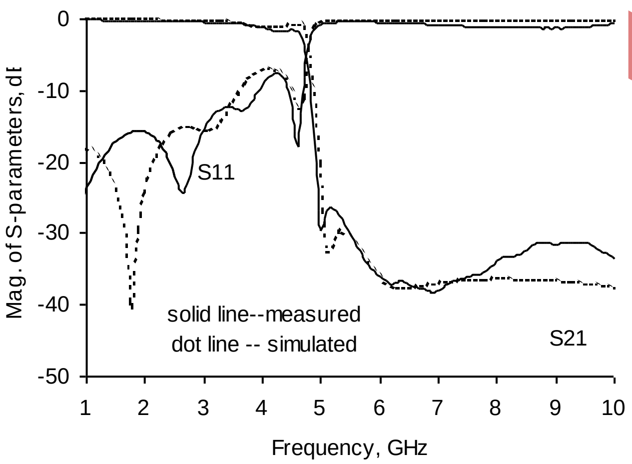

Fig 17: S-parameter of the EM-simulation and experimental measurement

The response of the constructed lowpass filter offers very sharp cutoff (>60 dB/GHz) as well as ultra wide bandwidth (>100%) with acceptable insertion loss in the passband.

CONCLUSION

A new asymmetric DGS structure with respect to microstrip line produces attenuation zero near to pole frequency and yields a very sharp lowpass filtering characteristics. A considerable improvement in insertion loss has been achieved by replacing standard line by a Hi-Lo impedance line. It is modeled by 3rd order lowpass elliptic- function filter and m-derived filter section. The equivalent circuit is represented by Causer's T-network. At the end, a composite lowpass filter has been designed at 4.5 GHz cutoff frequency and implemented by dumbbell and proposed DGSs. In conventional design of microstrip filter, equivalent inductance or capacitance is realized by short microstrip line section. This method incurred a lot of inaccuracy and affected by spurious frequencies. Thus, the responses of microstrip based filter differ a lot from ideal responses. In composite filter design, the lumped L and C parameters are directly replaced by the equivalent LC values of the DGSs. Therefore, it produces almost ideal filter characteristics by overcoming limitations of microstrip technology.

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REFERENCES

[1] C.S.Kim, J.S.Park, D.Ahn and J.B. Lim, "A novel one dimensional periodic defected ground structure for planar circuits," IEEE Microwave and Guided wave Letters, vol. 10, no. 4, pp.131-133, 2000.

[2] D. Ahn, J.S.Park, C.S.Kim, J.Kim, Y Qian and T. Itoh, "A design of the lowpass filter using the novel microstrip defected ground structure,"IEEE Trans. on Microwave Theory and Techniques, vol. 49, no. 1, pp. 86-93, 2001.

[3] Lim J., Kim C., Lee Y., Ahn D., and Nam S., "Design of lowpass filters using defected ground structure and compensated microstrip line," Electronics Let, vol. 38, no.25, pp.1357-1358, 2002.

[4] A. Abdel-Rahman, A.K. Verma, A. Boutejdar, and A.S. Omar, "Control of bandstop response of Hi-Lo microstrip lowpass filter using slot in ground plane," IEEE Trans. On Microwave Theory Tech., vol .52, no. 3, pp. 1008-1013, March 2004.

[5] H-M Kim and B. Lee, "Band gap and slow/fast-wave characteristics of defected ground structures (DGSs) including left-handed features," IEEE Trans. on Microwave Theory Tech., vol 54, no. 7, pp.3113-3120, 2006.

[6] S.K.Parui and S. Das., "A New Defected Ground Structure For Different Microstrip Circuit Applications" Radio engineering Journal, vol. 16, no 1, pp16-22, 2007.

[7] Chen J.-X., Li J.-L., Wan K.-C. and Xue Q., "Compact quasi-elliptic function filter based on defected ground structure," IEE Proc.-Microwave Antennas propagation., vol . 153, no. 4, pp. 320-324, Aug. 2006.

[8] S. K.Parui, and S. Das, "A new Defected Ground Structure with elliptical response and it's application as lowpass filter," International Journal of Electronics and Communications (AEU), ELSEVIER, vol 63, pp.483-490, 2009.

[9] Susanta Kumar Parui and Santanu Das, "Modeling of Split-ring Type Defected Ground Structure and It's Filtering Applications," Journal of Microwaves, Optoelectronics, Electromagnetic applications, vol 8 no 1, pp.6-12, June 2009.

[10] Susanta Kumar Parui and Santanu Das, "Modeling of Modified Split-ring Type Defected Ground Structure and Its Application As Bandstop Filter," Radio engineering Journal, vol 18, no 2, pp.149-154, June 2009.

[11] A. Boutejdar A. El-Sherbini and A. S. Omar, "Method for Widening the Reject-Band in Lowpass/Bandpass Filters by Employing coupled C-Shaped Defected Ground Structure (DGS)," IET Microwaves, Antennas & Propagation, Vol. 17, No. 12, pp. 1405-1408, December 2008.

Author' biography with Photo

Chandan Kumar Ghosh received the B.Sc (Hons) degree in Physics and B.Tech. degree in Radio physics and Electronics from University of Calcutta in the year 1987 and 1990 respectively. He did M. Tech. degree in Microwave Engineering in the year 2003, from Burdwan University, India. From 1991 to 1995, he worked as Development Engineer in Sonodyne Electronics Co. Pvt. Ltd. and from 1996 to 1999 he worked as Assistant Manager (R&D) in Sur Iron & Steel Co. Pvt. Ltd. From 2000 to 2009 he was associated with the department of Electronics & communication Engineering of Murshidabad College of Engineering & Technology and from Aug'10 he is in Dr. B. C. Roy Engineering College, Durgapur, India and presently holds the post of Assistant Professor. He published more than 10 contributory papers in referred journals and international conference proceedings. His current research interests include the Array antenna, MIMO antenna,

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