International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 3, Issue 2 (February 2014), PP.104-114

Novel Compact Microstrip Filtenna Structures

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Abstract:- *In this paper, Microstrip Filter_Antenna structures "MFA" have been proposed, analyzed and investigated in details using the CST_MW Studio. This was carried out using a full parametric study of reconfigure the ground plane along with a rectangular defected patch shape. Reconfigurable ground structure "RGS" includes partial ground "PG" (single ground strip), and Digital ground "DG" (N_Isolated ground strips). Defected patch "DP" includes H_Slot shape and Edge_Slot shape, where the overall patch dimensions are kept constant. The proposed MFA structures are mounted symmetrically on a lossy FR-4 substrate having RGS and arbitrary slots shape near the patch edge. The proposed MFA structures are referred to as H_Slot patch filtenna "HSPF" and Edge_Slot patch filtenna "ESPF". Simulation results showed that the proposed filtennas resonate at multi-frequencies having different operating bands (narrowband, broadband, and ultra-wideband). The presented filtennas are very simple circuits and very compact in size. Furthermore, they cover a wide frequency spectrum for many wireless applications (4G wireless systems).*

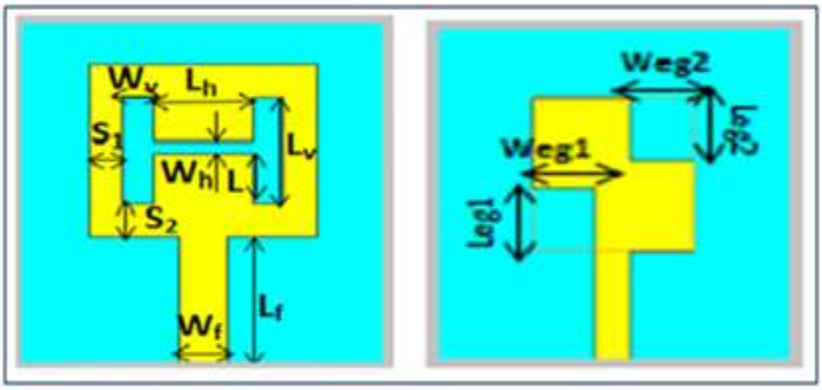
Keywords:- *Microstrip Antenna_Filter, Planar Antennas, Microstrip Filtennas*

I. INTRODUCTION

Microstrip antenna configuration has numerous benefits in wireless communication systems applications. This is due to its small size, low cost, less weight, and easy to fabricate. Furthermore, microstrip antenna has an excellent compatibility with the MMIC planar circuits. Microstrip **Fil**ter_An**tenna** structure "MFA" is a planar antenna circuit having a built-in filter(s), and it is referred to as **microstrip filtenna**. In fact, it is employed in the receiver front end to relieve the necessity of using a band pass and/or band rejection filters. These filters having different specific characteristics which depend upon the antenna patch and ground geometries. Little work has been done to investigate and analyze different MFA structures [1-4]. These structures can be with arrays of bandpass frequency-selective surfaces or with band-rejection elements and or fractal defected ground structure. Other work including MFA structures has been done recently [5-10]. These structures are done by using electromagnetic band gap (EBG) structures, partitioned ground, and double/single T-shaped structures. In addition, MFA structures can utilize an active element to tune their resonance frequencies [11-13]. These active elements can be used by varactor diode to tuned rings fed. In this paper, two proposed and compact microstrip filtenna structures are analyzed, investigated, optimized and presented. These are H_Slot patch filtenna "HSPF" and Edge_Slot patch filtenna "ESPF". The characteristic of theses filtennas is mainly depending on the ground configuration as well as the patch slot geometries. It has been reported that the performance of H_Slot patch filtenna with full and/or defected ground structure depends on the H_slot dimensions, location, and orientation. Such filtenna has multi resonances frequencies having different bands [14]. The presented paper is organized among four sections. A detailed description of the proposed H_Slot patch and Edge_Slot patch microstrip filtenna configurations is presented in section II. Simulation results of the proposed filtenna structures are presented and discussed in section III. Finally, section IV concludes the presented paper.

II. DESCRIPTION OF THE PROPOSED FILTENNA CONFIGURATIONS

Two filtenna configurations are proposed and presented in Fig. 1 (HSPF and ESPF). These Filtennas have been mount on a single FR-4 substrate (ε_r=4.7, and 1.6 mm height with tangential loss of 0.025), and the conductor thickness is 0.035 mm. The dimensions of the substrate are L_{Sub}=30 mm and W_{Sub}=30 mm, while the basic patch dimensions are L_P=13.5 mm and W_P=13.5 mm (conventional patch). A transmission line of 50 Ohm is used to feed the patch with width length L_F=10.0 mm and W_F=2.86 mm. Partial ground "PG" and digital ground "DG" configurations are shown in Fig. 2. The length of partial ground "L_{pg}" has been optimized in case of conventional microstrip patch (without either H_slot or Edge_Slot) and it is equal to 8.5 mm. The digital ground "DG" consists of three isolated strips and it has two parameters. These are the inter-spacing between any two consecutive ground strips (gaps: G_1 & G_2), and the ground strips lengths L_1& L_2 as shown in the Fig. 2b. The H_Slot patch consists of three slots including two vertical slots and one horizontal slot. The dimensions of these slots have been investigated and optimized in case of full ground “FG”, and they are presented in Table 1. The Edge_Slots patch consists of two edges slots including lower left edge slot “LLES” and upper right edge slot “URES”. The dimensions of Edge_Slot patch has been investigated for different slots locations. This include symmetric edge slot “SES”, asymmetric edge slot “AES”, and single edge slot LLES and/or URES. Performance of the proposed filtennas has been investigated and optimized for different slots and/or ground geometries and dimensions. This includes FG, PG and DG for each patch slot type (H_slot and E_Slot). The dimensions of partial and digital grounds are used to control the resonance frequencies of the proposed filtennas.

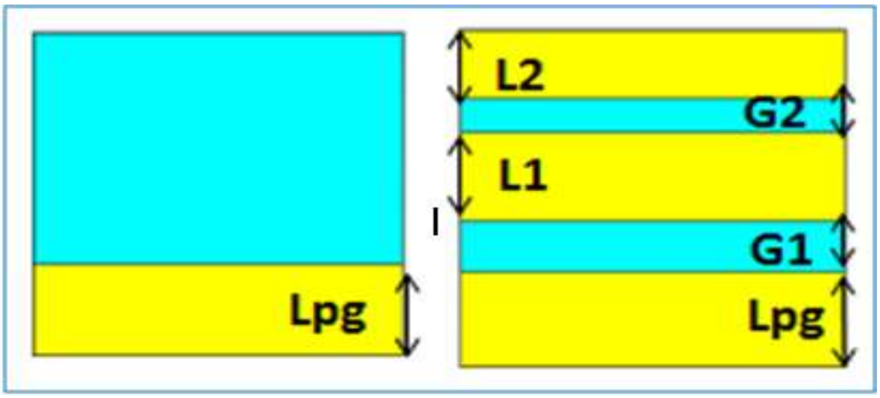


(a) “HSPF” (b) “ESPF”

Fig.1 Top view of two proposed filtenna structures

Table 1 The dimensions and locations H_slot

Symbol	Value (in mm)	Symbol	Value (in mm)
W_v	1.8	L	4.0
L_v	8.5	S_1	2.0
W_h	1.0	S_2	2.5
L_h	5.9	-	-



(a) Partial Ground “PG” (b) Digital ground “DG”

Fig.2 Bottom view of two ground configurations

III. SIMULATION RESULTS AND DISSCIONS

Performances of the two proposed filtenna structures have been evaluated in details for three different RGS configurations. First, in case of full ground configuration, the performance of H_Slot patch filtenna “HS” has been evaluated and compared to conventional patch antenna “CP” (has no slots), and the results are presented in Fig. 3. It is clear from the figure that the H_Slot patch creates multi resonances frequencies. These resonances start from 7.0 GHz to the higher frequencies up to 14.0 GHz. One of these resonances is narrowband (7.0 GHz) and the other are broadband (9.3, 12.2 and 14.2 GHz). On the other hand CP antenna has only a single resonance frequency at 9.7 GHz. Therefore, the number of resonance frequencies and their bands depend on dimensions, location, and orientation of the H_Slot. Moreover, the minimum and maximum resonance frequencies are fully determined by the overall patch and H_Slot dimensions. Second, effects of PG configuration (L_{pg}= 8.5 mm) on the filtration characteristic of CP antenna and H_Slot patch have been evaluated and the results are illustrated in Fig.4. In this case as expected an ultra-wideband start from 3.5 GHz to 8.6 GHz has been obtained in case of CP antenna. Unlike CP antenna, H_Slot patch filtenna has been achieved an extended UWB with multi resonances frequencies and single stopband (UWB: 3.0 - 10.2 GHz, resonances: 3.3, 5.5, 6.8, and 9.7 GHz and stopband: 3.9 - 4.9 GHz). The multi resonances frequencies and the stop band are mainly depending upon the dimensions, locations and orientations of the H_Slot. In addition, the length of the partial ground (L_{pg}=8.5 mm) is mainly affect the overall filtenna bandwidth (7.0 GHz band). Third, performances of H_Slot patch filtenna and CP antenna in case of digital ground are presented in Fig. 5. A digital ground is assumed to be consists of three discrete and isolated ground strips having lengths "L_{pg}, L_1 & L_2", gaps "G_1 and G_2" and widths the same as the substrate width W_{Sub} (see Fig. 2 (b)). These strips along their gaps create more stop bands and pass bands within the filtenna UWB. The number of gaps between the isolated ground strips and their widths control the number of stopbands and their bandwidths. Again, in case of H_Slot patch filtenna, digital ground creates multi resonance frequencies within the UWB range and two stopbands (UWB: 2.8 - 9.5 GHz, resonances: 4.6 & 8.3 GHz and two stopbands: 3.2 - 4.0 GHz & 5.7 - 7.7 GHz). On the other hand, in case of CP antenna, the same results have been obtained as compared to the H_Slot patch filtenna but with different values (UWB: 3.0 - 9.6 GHz, resonances: 3.8, 6.0 & 9.2 GHz and two stopbands: 5.1 - 5.9 GHz & 6.0 - 6.6 GHz).Therefore, CP and the H_Slot patch antennas have an adjustable filtration characteristic using a RGS (partial and digital grounds). To understand the impact of reconfigurable ground structure as well as the H_Slot patch on the antenna_filteration characteristic, distribution of current density on patch and ground should be investigated. In this study, the conventional patch antenna with full ground structure has been used as reference antenna (has no filtration property).Therefore, the current distributions of H_Slot patch and CP for three different RGS are presented in Fig. 6. These current distributions were computed at some selected resonance frequencies presented in table 2. As it is clear from Fig. 6, the H_Slot patch changes the current distribution pattern as compared to the CP antenna. Consequently, the equivalent effective electric length of the H_Slot patch is changed which leads to new resonance frequencies. Moreover, the number of these resonances is equivalent to "N" different CP antenna each with its own effective electric length. This number is mainly depending upon the dimensions, locations, and orientation of the H_Slot patch. The total filtenna efficiency and the gain of the proposed HSPF have been evaluated for three different ground structures at some selected resonance frequencies and then compared to CP antenna. The results are summarized and presented in **table 2**

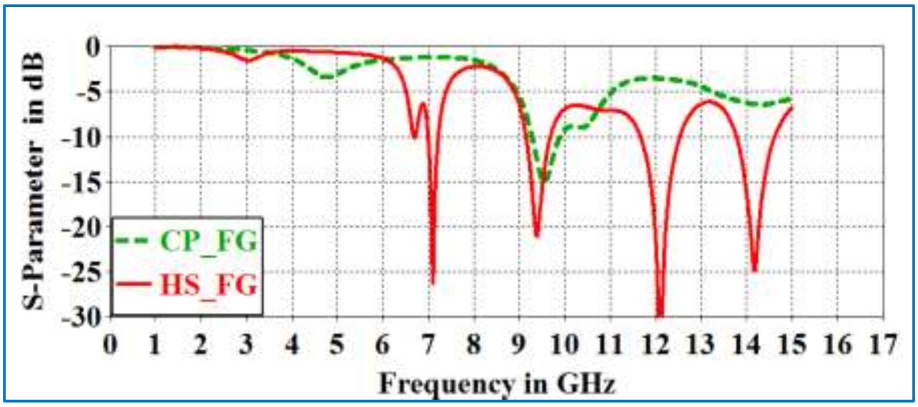


Fig.3 |S11| of H_slot filtenna for FG configuration versus CP antenna

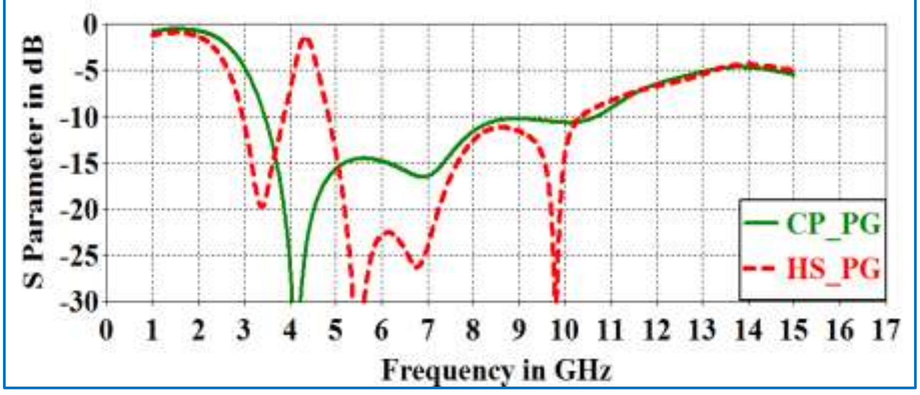


Fig.4 |S11| of H_slot filtenna for PG configuration with (L_{pg} =8.5mm) versus CP antenna

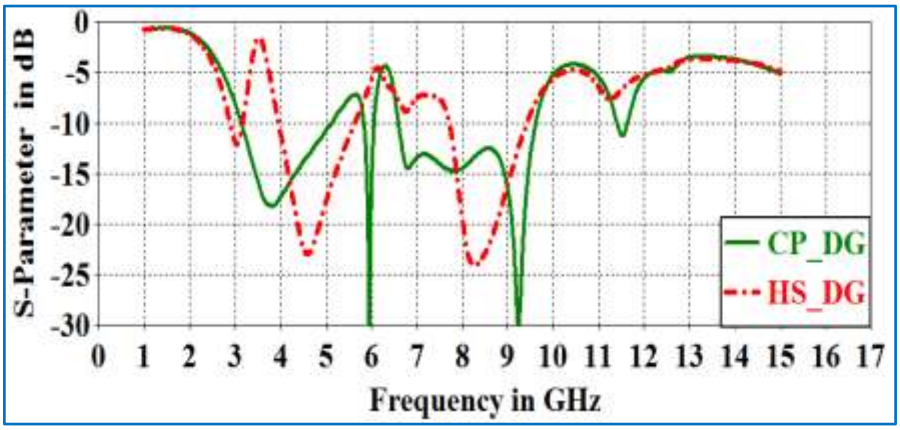
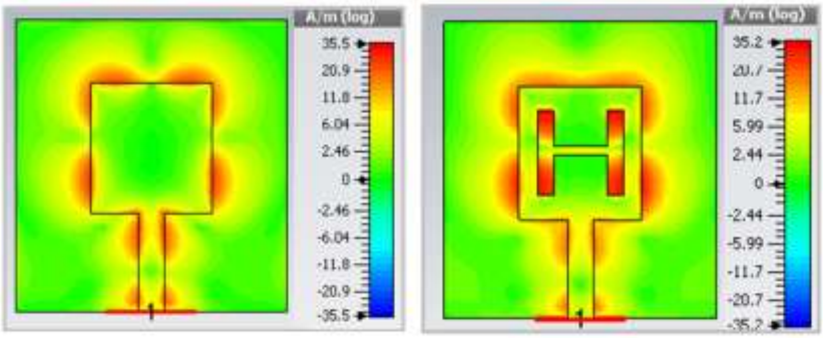
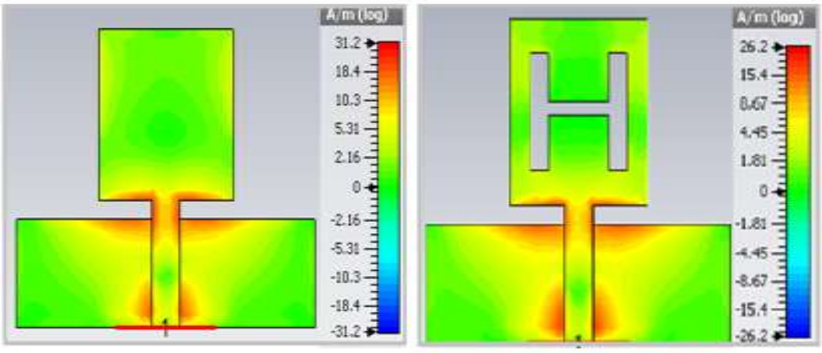


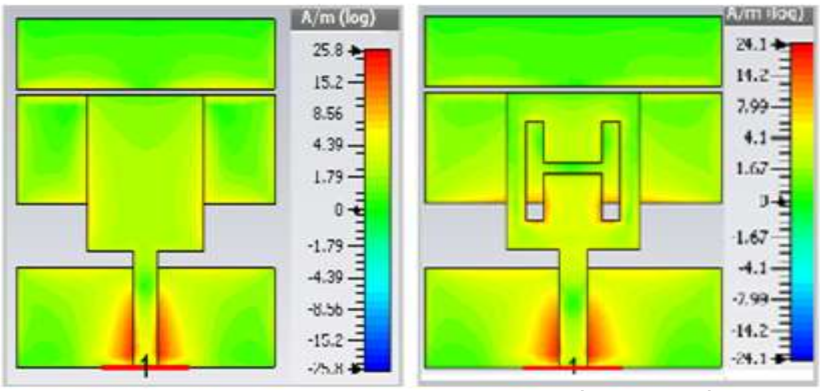
Fig.5 |S11| of H_slot filtenna for DG configuration with (L_{pg}=8.5 mm) versus CP antenna (L_1= 9.5 mm, L_2= 6.0 mm, G_1=5.5 mm, & G_2= 0.5 mm)



(a) Conventional patch versus H_Slot patch for FG configuration



(b) Conventional patch versus H_Slot patch for PG configuration



(c) Conventional patch versus H_Slot patch for DG configuration

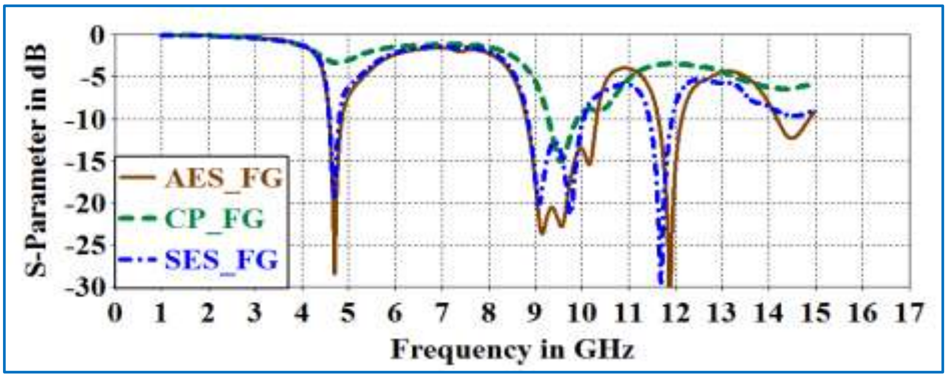
Fig.6 Current distributions of CP and HS for FG, PG and DG at the frequencies listed in TABLE 2

Table 2 Gain and Efficiency of H_Slot filtenna versus CP antenna for the current distributions presented in Fig.6

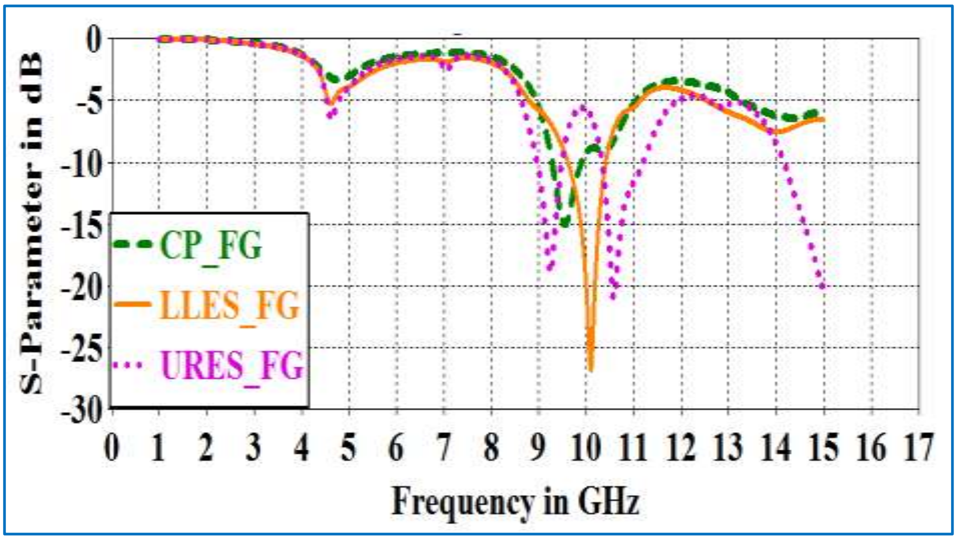
	CP	HS
FG	F=9.70 GHz, Eeff=70 % Gain=2.0 dB, BW=500 MHz	F=9.387 GHz, Eeff=52 % Gain=5.3 dB, BW=600 MHz
PG	F=6.88 GHz, Eeff=88 % Gain=3.3 dB, BW=3.5-8.6 GHz	F=6.76 GHz, Eeff=90 % Gain=2.85 dB, BW=3.0-10.2 GHz
DG	F=3.760 GHz, Eeff=91 % Gain=2.42 dB, BW=2000 MHz	F=4.6 GHz, Eeff=93 % Gain=2.76 dB, BW=1800 MHz

The second part of the present study is the performance evaluation and analysis of the proposed Edge_Slot patch filtenna “ESPF”. The edge slot patch consists of lower left and upper right slots having dimensions L_{eg1} &W_{eg1} and L_{eg2} &W_{eg2} respectively. Also, these slots may be either symmetric or asymmetric. Symmetric slots mean that they have the same dimensions while asymmetric slots have different dimensions. In addition, the edge slot patch may have only a single slot (upper right or lower left). Performance of ESPF has been evaluated and investigated for the three RGS’s and then compared to the CP antenna. The assumed dimensions of the edge slots are illustrated in Table3. In case of full ground, the simulated S-parameters for different edge slot geometries are presented in Fig. 7. It is clear from the figure that SES creates multi resonance frequencies each with different bandwidth. On the other hand, AES has multi resonance at lower & higher frequencies. Also, it is clear from the figure that the ESPF resonances can be moved along the frequency axis using a single slot (LLES or URES).The second ground configuration is the partial ground strip with length L_{pg} and width W_{sub}. The same dimensions of the edge slots are assumed (presented in table 3). The simulated S-parameters are presented in Fig. 8. The SES and LLES increase the total antenna bandwidth by a factor of 34.6% as compared to the CP antenna. In addition, dual resonances have been obtained at 4.0 & 7.6 GHz, and 4.3 & 6.89 GHz for SES and LLES respectively. This is due to the effect of the patch lower edge slot near ground plane behind the feeder. On the other hand, the AES and URES increase the antenna bandwidth by a factor of 41.37% and having resonances at 4.06, 7.7 &10.8 GHz and 4.3 & 6.9 GHz respectively (compared to CP antenna). The third ground configuration is the digital ground. In this case, the simulated S-parameters of the proposed ESPF are compared to the CP antenna and they are presented in Fig. 9. The dimensions of the digital ground configuration are summarized in Table 4. The performance of CP antenna using digital ground has multi-passbands and multi-stopbands. Therefore, the digital ground along with the square patch acts as a bank of filter having adjustable characteristic (gaps: G_1 & G_2). Consequently, the CP antenna acts as filtenna circuit. Finally, performances of the SES and AES in case of digital ground have also multi-passbands and multi-stopbands. Again, the digital ground along with Edge_Slots acts as bank of filter. Similar performances have been obtained for the other slot geometries of the ESPF (LLES and URES). Table 5 summarizes the main parameters of the proposed filtenna structures as compared to the CP antenna for some selected resonance frequencies.

Again, to understand the impact of reconfigurable ground structure as well as the Edge_Slot patch on the antenna_filteration characteristic, distribution of current density on patch and ground should be investigated. The current distributions of the Edge_Slot patch for three different RGS are presented in Fig. 10 and Fig. 11. These current distributions were computed at some selected resonance frequencies presented in table 5. It is clear from the figure that Edge_Slot patch filtenna have different current distribution patterns for the three ground configurations. Again, this leads to different effective electric lengths and in turn, multi-resonance frequencies having different bands are achieved.



(a) Symmetric and Asymmetric edge slots for FG configuration

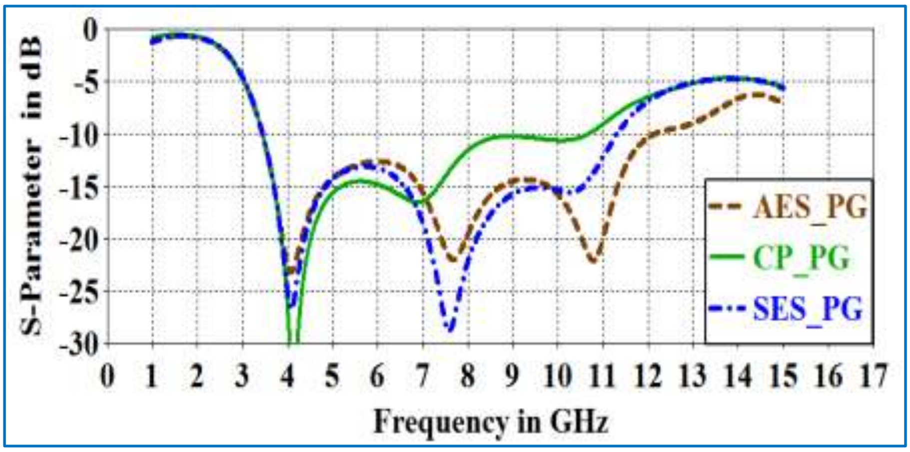


(a) Lower and Upper edge slots for FG configuration

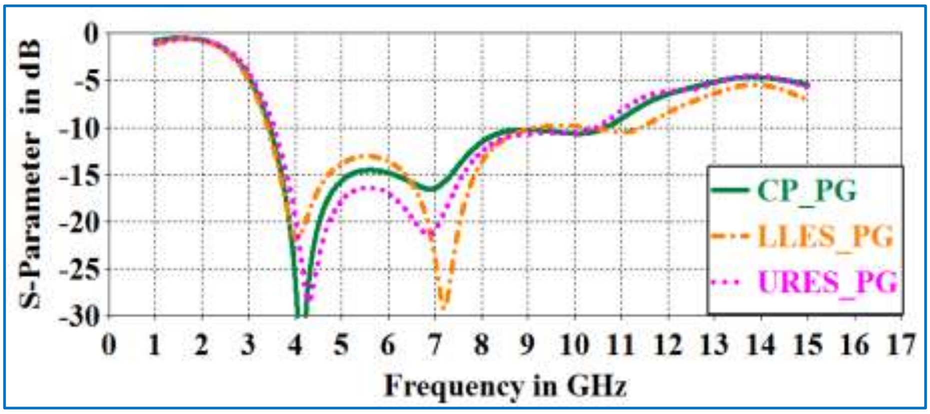
Fig.7 |S11| of Edge_Slot filtenna for FG configuration versus CP antenna

Table 3 Slots dimensions of SES, AES, LLES, and URES

	Value (in mm)
SES	Leg_1= Leg_2=2, & Weg_1=Weg2=3.32
AES	Leg_1= 4 & Leg_2=2, Weg_1=2.32, & Weg_2=3.32
LLES	Leg_1=2 & Weg_1=3.32
URES	Leg_2=2 &Weg_2=3.32

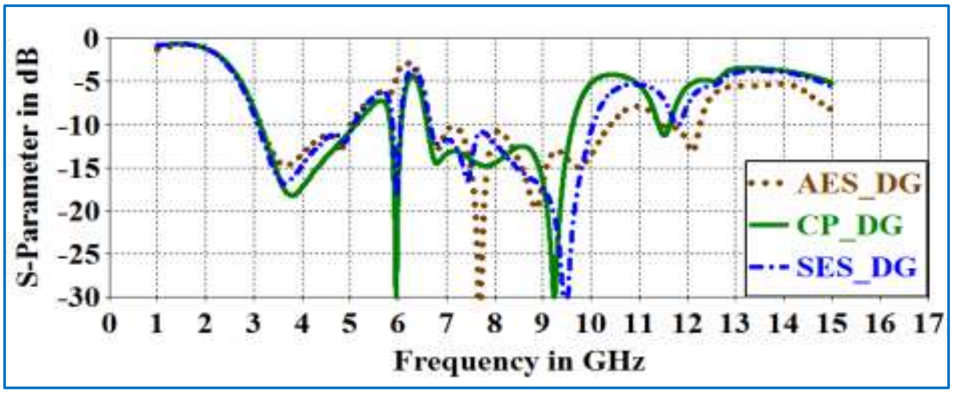


(a) Symmetric and Asymmetric edge slots for PG configuration

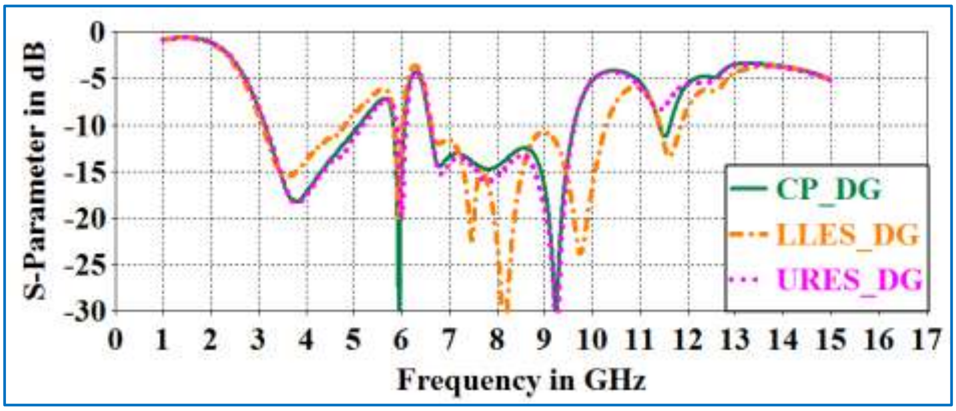


(b) Lower and Upper edge slot for PG configuration

Fig.8 |S11| of Edge_Slot filtenna and CP antenna for PG configuration



(a) Symmetric and Asymmetric edge slots for DG configuration

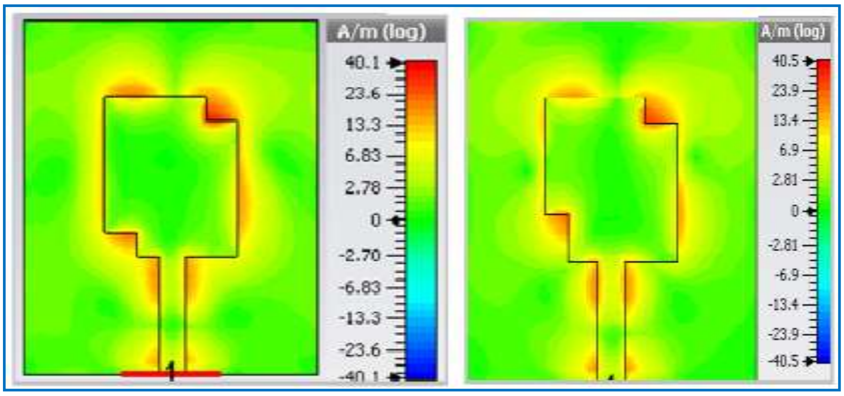


(b) Lower and Upper edge slot for DG configuration

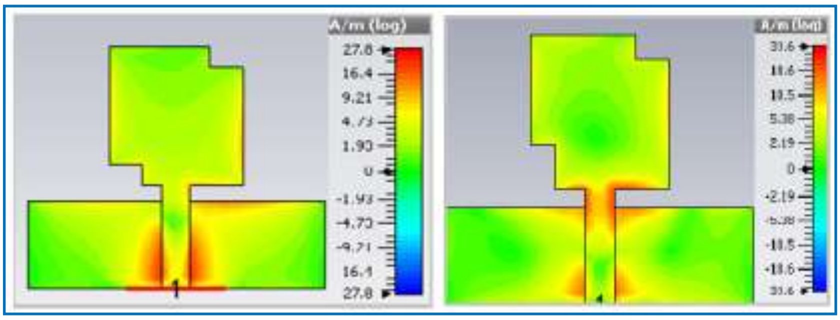
Fig.9 |S11|of Edge_Slot filtenna in case of DG configuration

Table 4 Dimension of slots of DG configuration

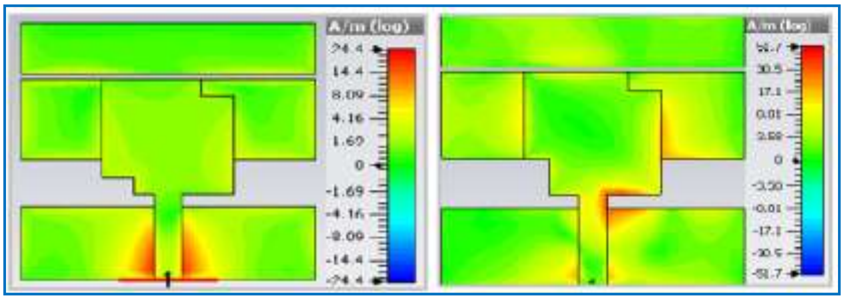
	Value (in mm) & (Lpg=8.5mm)
CP (Ref.)	L1= 9.5, L2= 6 , & G1= 5.5, G2= 0.5
SES	L1= 9.5, L2= 6 , & G1= 5.5, G2= 0.5
AES	L1= 9.5, L2= 6 , & G1= 5.5, G2= 0.5
LLES	L1= 9.5, L2= 6 , & G1= 5.5, G2= 0.5
URES	L1= 9.5, L2= 6, & G1= 5.5, G2= 0.5



(a) Symmetric and Asymmetric edge slots for FG configuration

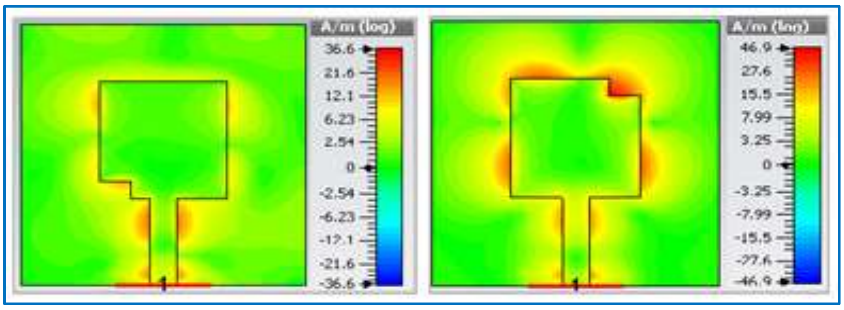


(b) Symmetric and Asymmetric edge slots for PG configuration

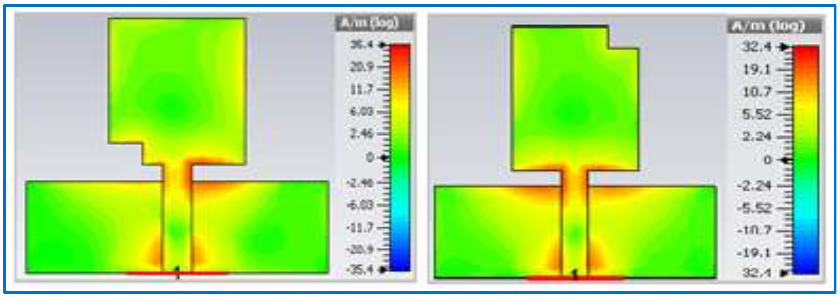


(c) Symmetric and Asymmetric edge slots for DG configuration

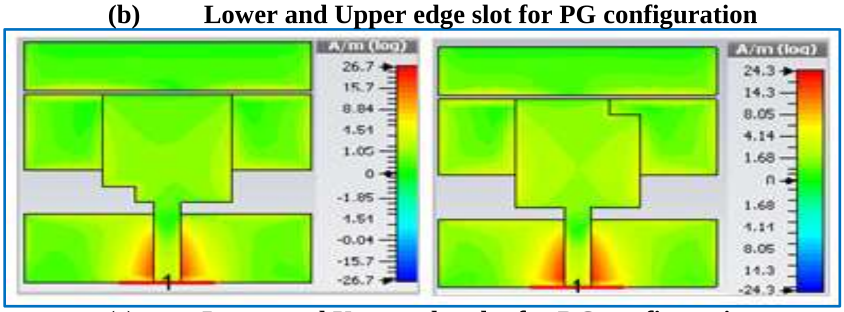
Fig.10 Current distribution of SES and AES Filtennas for FG, PG and DG at the frequencies listed in TABLE 5



(a) Lower and Upper edge slot for FG configuration



(b) Lower and Upper edge slot for PG configuration



(c) Lower and Upper edge slot for DG configuration

(d) Fig.11 Current distribution of LLES and URES Filtennas for FG, PG and DG at the frequencies listed in TABLE 5

Table 5 Gain & Efficiency of Edge_Slot filtenna configurations

	CP (Ref.)	SES	AES	LLES	URES
FG	F=9.70GHz Eeff =70% Gain=2.0dB BW=500MHz	F=9.10GHz E_{eff}=60% Gain=3.05dB BW=500MHz	F=9.3GHz Eeff=60% Gain=3.55dB BW=1500MHz	F=10.01GHz E_{eff}= 46% Gain=3.90dB BW=800MHz	F= 9.24GHz E_{eff}= 55% Gain=4.50dBB W= 500MHz
PG	F=6.88GHz Eeff=88% Gain=3.3dB BW=3.5-8.6GHz	F=5.49GHz E_{eff}=88% Gain=2.14dB BW=3.5-11.3GHz	F=7.7GHz Eeff= 89% Gain=5.75dB BW=3.4-12.1GHz	F=7.21GHz E_{eff}=90% Gain=4.57dB BW=3.4-11.3GHz	F= 6.90GHz E_{eff}= 90% Gain=3.87dB BW=3.5-9.0GHz
DG	F=3.760GHz Eeff=91% Gain=2.42dB BW=2000MHz	F= 3.66GHz E_{eff}= 90% Gain= 2.59dB BW= 1500MHz	F= 7.6GHz Eeff= 51% Gain= 5.56dB BW= 760MHz	F= 3.62GHz E_{eff}= 96% Gain= 2.7dB BW=1700MHz	F=3.81GHz E_{eff}=96% Gain=2.82dB BW=1900MHz

Table 6 presents a comparison between H_Slot patch and Edge_Slot patch Filtennas for RGS. A conventional microstrip patch is also used as reference antenna in the presented table. A final conclusion is presented at end of the table. All values of the resonance frequencies presented in the table are in gigahertz.

Table 6 Performance comparison of the proposed Filtennas for different ground configurations

	CP (Ref.)	HS	SES	AES	LLES	URES
FG	Single resonance 9.7	Multi resonances 7.0, 9.3, 12.2, & 14.2	Multi resonances 4.8, 9.0, 9.7, &11.7	Multi resonances 4.7, 9.1, 9.5,10.1 & 11.8	One resonance 10.1	Dual resonances 9.2, 10.5, &15.0
PG	UWB 3.5-8.6	UWB 3.0 -10.2 Stopband 3.9- 4.9 Multi resonances 3.3, 5.5, 6.8, & 9.7	UWB 3.5- 11.3 Dual resonances 4.0 & 7.6	UWB 3.4-12.1 Tribal resonances 4.06, 7.7, &10.8	UWB 3.4-11.3 Dual resonances 4.3 & 6.89	UWB 3.5-11.5 Dual resonances 4.3 & 6.9
DG	Two resonances 6.0 & 9.2 Two Passbands 3.0-5.1 & 6.6-9.6 Two Stopbands 5.1-5.9 & 6.0-6.6	Two resonances 4.6 & 8.3 Wide Passband 2.8-9.5 Two Stopbands 5.1-5.9 & 6.0-6.6	Passband 3.0-5.0 Wide Passband 3.0-10.0 Narrowband 6.0 Stopbands 5.0-5.9, 6.1-6.6, & 10.0-15.0	Passband 3.1-5.0 Wide Passband 3.1-10.4 Stopbands 5.0-6.6 & 10.4-15.0	Passband 3.0 - 4.8 Narrowband 6.0 Wide Passband 3.0-10.2 Stopbands 4.8-5.7, 6.0-6.6, 10.2-11.3, & 11.9-15.0	Passband 3.1-5.1 Narrowband 6.0 Wide Passband 3.1-9.6 Stopbands 5.1-5.6, 6.1-6.6, & 9.6-15.0
Conclusion: The main features of these proposed filtennas are: max gain of 2 up to 5.5 dB, antenna efficiency 50% - 90%, the radiation pattern can be either directive or Omni directive, and the resonances frequencies cover a wide spectrum of many wireless applications for the 4G.						

IV. CONCLUSION

The presented paper demonstrates how to design a microstrip Filter_Antenna structure “MFA” to achieve the required operating passbands and stopbands within a wide frequency spectrum. This was carried out through two main steps. The first step is to use arbitrary slots located near the edge of the selected patch with a full ground plane. The dimensions and the orientation of these slots control the patch resonance frequencies. The number of these resonances is mainly depending upon the slots dimensions and locations. The second one is to reconfigure the microstrip ground plane to control the filtenna operating passbands and stopbands. This includes partial ground “PG” and digital ground “DG”. Thus, two filtenna structures (HSPF and ESPF) have been proposed, investigated, and analyzed using the CST_MW Studio to verify this design methodology. Simulation results show that reconfiguring the ground plane and the patch slots can be used to tune and control the desired filtenna specifications. This includes the passbands and the stopbands of filtenna under investigation. Therefore, defected patch as well as digital ground is equivalent to a built-in bank of rejection filters. Future work will include design, analysis and evaluation of a filtenna chip module mounted on a microstrip motherboard.

ACKNOWLEDGEMENT

I am grateful to my advisor associate professor Dr. Hussein Hamed Ghouz who strongly encourages and help me to present this work. Also I would like to grateful my parents that encourage me for go forward and never give up.

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