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Microstrip Passive Low Pass Filter (MPLPF) for Maximally Flat Response

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***Abstract*—Technology is a way to live life differently. Filters are frequently used in communication systems as it helps in plummeting degradation in communication channel. Microstrip technologies are well-known, that are commonly utilized due to their small size and ease of implementation on printed circuit boards. In this manuscript, a microstrip passive low band pass filter (MPLPF) of measurement (20x15x1.6) mm^3 for maximally flat response by using stepped impedance technique is presented. The framework of the filter is simulated and analyzed in Ansys HFSS software. It provides fine performance for 1 GHz – 4.72 GHz frequency range antennas. It has the fabulous results. The low VSWR value guarantees that it performs well. The MPLPF is designed such that it can be operate at sub-6 GHz frequency ranges.**

Keywords—filter, low band pass filter, microstrip, maximally flat response

I. INTRODUCTION

In electronics, filter is a circuit that permit some frequency range to pass (or amplify) while terminate others. A filter may withdraw some essential frequencies from signals that also contain redundant frequencies. Filters are categorised in two parts, first one is passive filter and second one is active filter. Components that are comprises in making of passive filter are resistors, inductors and capacitors. On the other hand components that are comprises in making of active filter are op-amps, resistors, capacitors where as inductors are not used in active filter circuits. Radio frequency and microwave filters are a type of electrical filter that operates on signals with frequencies ranging from megahertz to gigahertz. This frequency range is utilised by most television, broadcast radio and wireless communication system such as cell phones, and Wi-Fi [1] - [3].

The radio frequency filters are generally two port network and having the condition which must be satisfy i.e. when the input current is given to one end point must equal to the current promising from the other end point on the same port and this essential required condition is known as port condition. The ports are the points where the other system is subjected to establish the connection, as well as the terminating point at which signals are functional or outputs are occupied [4].

The cellular network technology is evolved up to fifth generation. In 5G, there are two categories of frequency bands. First is sub-6 GHz band and second is millimetre wave (mmWave). The sub-6 GHz is very similar to 4G, where the radio frequencies are transmitted from cell phone towers are less than 6 GHz. The greater speeds that truly distinguish 5G from any of the 4G LTE variants, on the other hand, necessitate mmWave (over 24 GHz) high frequency bands. So because of these high frequencies have such enormous bandwidths, and are good for establishing communication in congested areas like stadiums.

From last decade many researches are done and some are discussed here. A tunable microwave bandpass filter which is having cut-off frequency range of 610 MHz to 930 MHz and with a insertion loss of 1.14 dB for usage in WIFI, Bluetooth, and GSM applications. It also acts as a low pass filter for cut of frequency range. In this a varactor diode is used to change the resonance frequency, the filter is intended to function for these applications. The suggested filter is build with stub technique and is a maximally flat third order filter [5].

To offer a sufficient passband and sharp response, filters are discovered having different characteristics and operating frequency ranges. For example one of them is having symmetrical triangle-shaped resonators in which suppressing unit is made up of many suppressing cells which leads to a strong rejection band and a low insertion loss in the passband, and when this LPF is manufactured it is found that it has cut off frequency 5.15 GHz at -3dB. Also the rejection band is improved from 5.51 GHz to 43.2 GHz; with a maximum flat return loss [6].

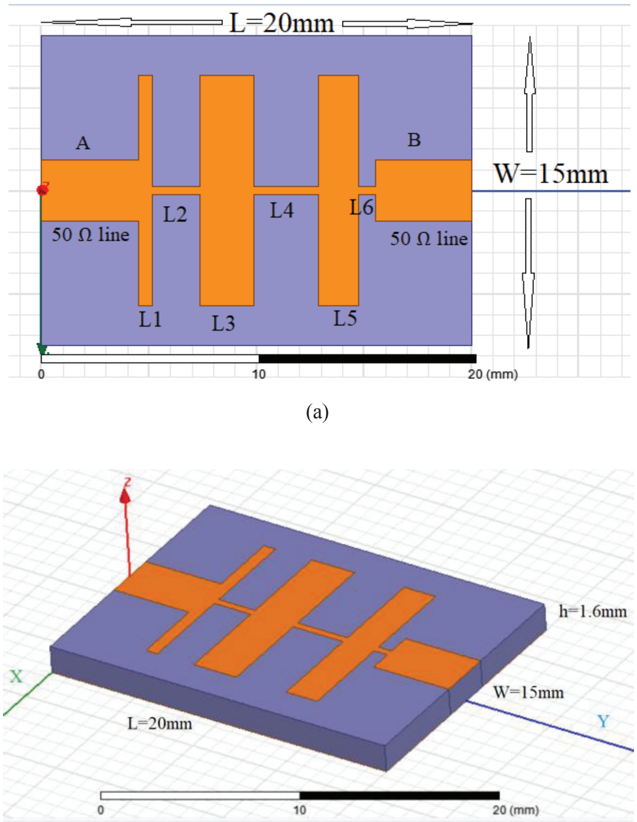
Microwave filters are two-port network, passive, reciprocal, and linear devices that reduce undesirable signal frequencies while allowing desired frequencies to flow through. One of the filters is microwave low pass filter based on complementary split ring resonators (CSRRs). A unique low-pass filter with transmission zero control and keen rejection that use CSRRs discovered with stepped impedance low pass filter used and it has a cut-off frequency of 1.6 GHz and an insertion loss of 10 dB at 3 GHz [7].

In this manuscript, a microstrip passive low pass filter (MPLPF) is proposed. We are enhancing the cut-off frequency performance so that it brings quite noise free signal to the antenna which can be operate at sub-6 GHz 5G frequency range. The results are very fabulous. We know that filters are two port networks and this filter has two ports of 50 Ω input impedance matching network. It has the cut-off frequency of 5.18 GHz at which the insertion loss is -5.89 dB. The VSWR(1) and VSWR(2) results very lower value as 3.68 and 3.06 at 5.18 GHz respectively. This filter is working fine in the range of 1 GHz – 4.72 GHz.

II. CONFIGURATION AND DESIGHN

The projected MPLPF configuration and design are addressed in this part. A ground sheet, a FR4 substrate, and a rectangular patch make up the MPLPF. The dimensions of the MPLPF are as follows:

The intended dimension of the projected MPLPF is depicted in Figure 1. The MPLPF's dimension is (20x15x1.6) mm^3 where L = 20 mm, W = 15 mm, and h = 1.6 mm. The patch is printed over the top of FR4 substrate, and which has the relative permeability of 1, dielectric loss tangent of 0.02, relative permittivity of 4.4, and mass density of 1900. The MPLPF is supplied using a microstrip line inset feed method with an input impedance i.e. Z_{in} = 50 Ω. The intended MPLPF is designed and successfully simulated in Ansys HFSS software. The FR4 substrate is put over the ground sheet, which has a thickness of 0.035 mm. A perfect electric is allocated to the top patch and ground. Figure 1 (a), (b) clearly show all of the dimensions.



(a)

(b)

Fig. 1. (a) Top view and (b) side view of the planned MPLPF

Before designing the MPLPF in Ansys HFSS software tool, it has to be prototyped. So now to design a prototype of MPLPF, consider it has the cut-off frequency f_c = 7.5 GHz having the input impedance Zin = 50 Ω and at least having insertion loss IL = 15 dB at f = 10 GHz. To find the number of elements for designing MPLPF we need to find the order of the filter which can be find by below given formula:

$$N = \frac{\log\left(10^{IL/10}-1\right)}{2\log\left(\omega/\omega_c\right)} \qquad (1)$$

Where, IL = Insertion loss = 15 dB and, $\omega/\omega_c = f/f_c = 10/7.5$

Now, substituting the values in equation (1), and we get:

$$N = 5.94$$

Here, the insertion loss value should be at least 15 dB at 10 GHz. So, to have this larger value of insertion loss we must have larger value of N. So, we cannot take lesser value than N = 5.94 and N is always integer, so the nearest integer will be 6.

Therefore, N ≈ 6 and it means that in MPLPF, there will be 6 elements.

Now, calculating the value of elements by using order number N = 6 and we know that the formula as:

$$g_k = 2\sin\left(\frac{(2k-1)\pi}{2N}\right) \qquad (2)$$

Where, N = Number of order, and k = 1, 2, 3, 4, 5, 6

Now, substituting the value of N and k and we get:

g_1 = 0.517, g_2 = 1.414, g_3 = 1.931, g_4 = 1.931, g_5 = 1.414, g_6 = 0.517

To design microstrip passive low pass filter in Ansys HFSS, we need to consider lower impedance value as 20 Ω for capacitor and higher impedance value as 120 Ω for inductor then we will calculate top patch dimension of MPLPF with the help of "em:talk microstrip line calculator". Here, note that for designing the MPLPF, the lower impedance should be less than input impedance and higher impedance should be higher than the input impedance i.e. Z_{in} = 50 Ω.

Lower and Higher impedance can be denoted as:

Z_{low} = 20 Ω, Z_{high} = 120 Ω

Now, for calculating the length, width, and electrical length of the top patch, let us consider L1, L2, L3, L4, L5, and L6 are be the lengths of the element. Let $W_{20\Omega}$, $W_{120\Omega}$ be the width of the element. And let the electrical lengths of the elements are βl_1, βl_2, βl_3, βl_4, βl_5, and βl_6.

In telecommunication engineering, the electrical length is also called phase length. It is defined as the length of an electrical conductor produced by transmission across the conductor at certain or desired frequency. Now, for calculating the electrical length, we will use below given formula:

For capacitor,

$$\beta l_m = \frac{g_m * Z_{low} * 180}{Z_{in} * \pi} \qquad (3)$$

Where βl_m is in degree, and m = 1, 3, 5

For inductor,

$$\beta l_n = \frac{g_n * Z_{in} * 180}{Z_{high} * \pi} \qquad (4)$$

Where βl_n is in degree, and n = 2, 4, 6

So, now the final prototyped calculation is shown in table 1, and with the help of table I we can easily design the planned MPLPF.

TABLE I. PROTOTYPED CALCULATION CHART

S. No.	Impedance (Z)	Electrical length (degree)	Length (mm)	Width (mm)
1	20 Ω	βl_1 = 11.84	L1 = 0.68	11.1
2	120 Ω	βl_2 = 33.75	L2 = 2.18	0.408
3	20 Ω	βl_3 = 44.25	L3 = 2.54	11.1
4	120 Ω	βl_4 = 46.09	L4 = 2.98	0.408
5	20 Ω	βl_5 = 32.4	L5 = 1.86	11.1
6	120 Ω	βl_6 = 12.34	L6 = 0.79	0.408

By using “em:talk microstrip line calculator” we get $W_{20\Omega}$ = 20.71 mm and $W_{120\Omega}$ = 23.30 mm. And to design 50 Ω line we have to subtract total element length from substrate length i.e. (20 – 11.03) mm = 8.97 mm then dividing it by 2, that results 4.485 mm and width will be 3 mm calculated by using “em:talk microstrip line calculator”.

Therefore, with the help of prototyped calculation, we can easily design MPLPF in Ansys HFSS software.

III. Methodology And Experimentation

The intended MPLPF’s theoretical analysis, software analysis, experimentation, synthesis, characterization, and material selection are all covered in detail in this part.

MPLPF is calculated, designed, and simulated successfully in Ansys HFSS software. HFSS is one of numerous commercial tools used to design antennas and sophisticated radio frequency electrical circuit elements such as filters, transmission lines, and packaging. The first general-purpose software package to tackle arbitrary three-dimensional electromagnetic field issues was HFSS. It pioneered a variety of novel computational electromagnetic methods, including as automated adaptive mesh creation, tangential vector finite elements, transfinite elements, and reduced-order models [8], [9].

To design it in Ansys HFSS, first step is draw a rectangular ground plane of dimension (20x15) mm^2 then after a substrate of dimension (20x15x1.6) mm^3 is dawn over the ground plane. FR-4 epoxy material is very common and easily available, it has the characteristic of adaptability of high pressure thermoset plastic laminate grade which has a high strength to weight ratio. FR-4 is most typically employed as an electrical insulator with high mechanical strength. In both dry and humid circumstances, the material is famous to keep its tough mechanical and electrical insulating characteristics respectively. These qualities, along with superior manufacturing capabilities, make this grade useful for a broad range of electrical and mechanical practices [10].

After that by using prototyped calculation chart we can easily draw a top patch including 50 Ω line for providing input to the filter by using inset feed technique via lumped port. Lumped ports are used to excite or terminate passive circuits, as well as to calculate device frequency responses such as impedance matching and insertion loss.

The planned MPLPF is simulated under the radiation box which is assigned as “air” material in Ansys HFSS. The solution setup is given for 7.5 GHz as it designed to operate up to 7.5 GHz cut off frequency, and then after frequency sweep is given from 1 GHz to 10 GHz and then MPLPF is analyzed and simulated at interpolating mode to get the final result.

IV. Results And Discussions

The outcomes of the intended MPLPF are mentioned in this part.

S-parameters elucidate the input-output link connecting electrical structure ports (or end points). For example, consider two ports (named Port 1 and Port 2), S(1,2) indicates the power transmitted from Port 2 to Port 1. S(2,1) denotes the amount of power transmitted from Port 1 to Port 2 [11].

The figure 2 depicts the S(1,2) parameter of the planned MPLPF which clearly shows the cut-off frequency is 5.18 GHZ at -3dB insertion loss and at 7.5 GHz, the insertion loss value is -34.05dB. The plot shows that MPLPF passes low frequency i.e. less than or equal to 5.18 GHz and it blocks the frequency larger than the cut-off frequency.

Analysis of cut-off frequency is the main result of any filter. Cut-off frequency of any LPF is the frequency at which the load voltage value (or output voltage value) equals to 70% of the source voltage value (or input voltage value). The load voltage is less than 70% of the source voltage which should be above the cut-off frequency, and vice versa. As a consequence, we can acquire the suitable filter range.

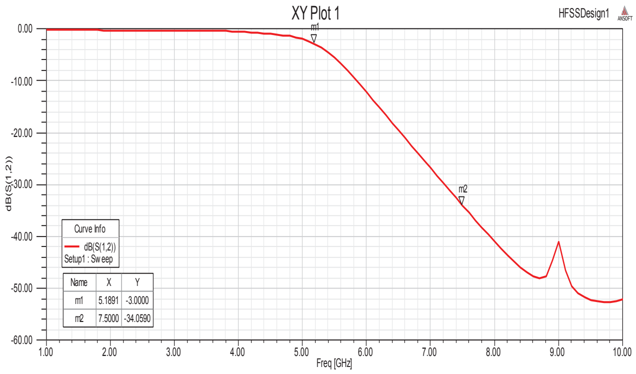


Fig. 2. S(1,2) Parameter of the planned MPLPF

S(1,1) is the most usually reported antenna parameter, also for other electronic circuits such as filters. S(1,1) represents the quantity of power reflected by the system and it is also called as reflection coefficient. If S(1,1) is 0 dB, means there will be no power is reflected or emitted by the system. If S(1,1) = -10 dB, this means that if 3 dB of power is given to the system, the reflected power is -7 dB. The remaining power was either "received by" or "sent to" the system. This received power is radiated or it may be engrossed as system losses. Because systems like antennas are normally built to be low loss, the mainstream of the power given to the system should ideally be radiated.

Figure 3 depicts the S(1,1) parameter in which it is clearly shows a curve i.e. below -10 dB for up to 4.72 GHz that means MPLPF can work finely for the frequency range from 1 GHz to 4.72 GHz antennas. And at cut-off frequency i.e. 5.18 GHz the insertion loss is -5.89 dB.

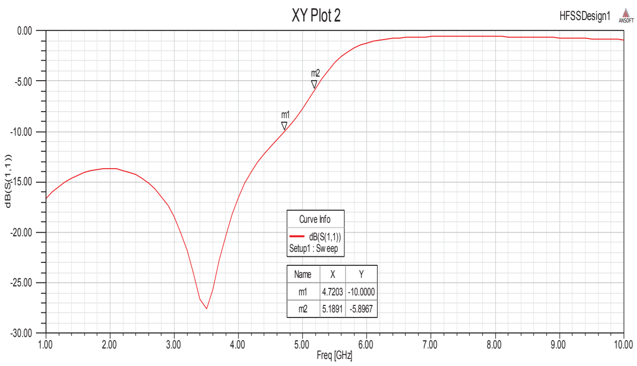


Fig. 3. S(1,1) Parameter of the planned MPLPF

There is one more major important factor that ensures the stability of the filter i.e. “Voltage Standing Wave Ratio”, or VSWR. The minimum value of VSWR parameter ensures that the system is stable and performs well. The VSWR parameter is a numerical metric which explains how effectively the system is impedance matched to the broadcast line to which it is attached. The VSWR is always a true and positive value. The lower the VSWR, the better suited the system is to the broadcast line and the further power is provided to the system.

Figure 4 depicts the VSWR parameter of the intended MPLPF. The figure 4 clearly indicates the lower value in the frequency range of 1 GHz to 5.18 GHz. The value of VSWR(1) is 3.68 at 5.18 GHz and value of VSWR(2) is 3.06 at 5.18 GHz. So that this result shows that MPLPF operate finely from frequency range 1 GHz – 5.18 GHz.

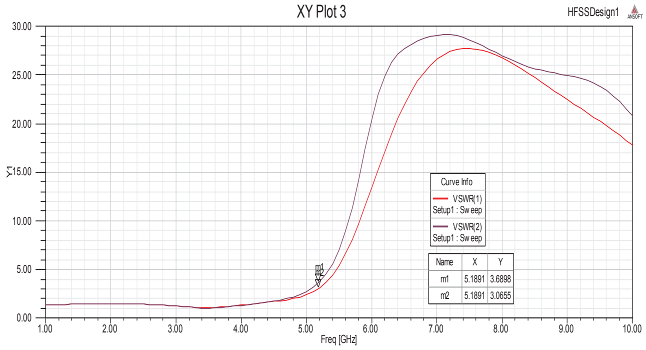


Fig. 4. VSWR Parameter of the planned MPLPF

The input impedance is the computation of the opposition to current entering the load network i.e. external to the electrical source, both static and dynamic. Here 'static' term is used for resistance and 'dynamic' term is used for reactance. The figure 5 depicts the input impedance and the plot clearly verifies the result as we designed MPLPF for 50 Ω input impedance. The plot overlapped each other for both ports i.e. port 1 and port 2.

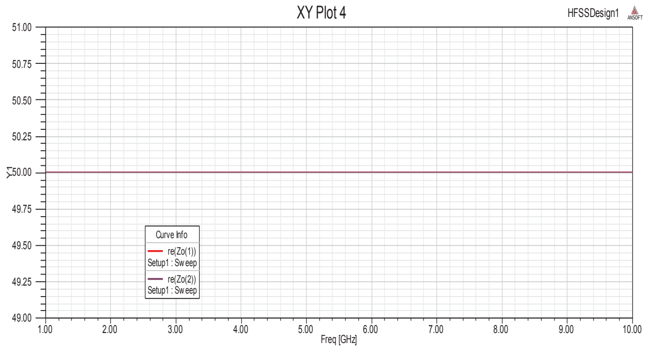


Fig. 5. Input impedance plot of the planned MPLPF

Therefore, results are very fabulous as desired. MPLPF successfully designed and simulated in Ansys HFSS software. Also it possesses good high frequency rejection capability. The performance of MPLPF is to yield good quality RF signals suitable for a 5G wireless Wi-Fi systems.

V. Conclusion

In this manuscript, a microstrip passive low pass filter (MPLPF) by using stepped impedance technique with low frequency selectivity has been investigated and designed. Detailed design methods and steps have also been presented. The MPLPF successfully simulated and analyzed in Ansys HFSS software tool. Along with the enhanced performance, fabrication easiness, cost and time savings are easily achievable with MPLPF. Due to the huge frequency ratio, integrating sub-6-GHz and millimeter-wave (mmWave) bands to retain the compactness of future sub-6GHz 5G wireless systems is a difficult issue. The MPLPF is compact and having great performance results which can help in such 5G wireless systems.

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