Miniaturized Printed Filtering Antenna

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ABSTRACT

A new co-design approach is used to synthesize and design the new printed Bandpass Filtering Antenna. For the purpose of miniaturization and enhancing the overall performance of the circuit, a multi-function module is designed. It performs filtering and radiating, simultaneously with the help of co-design approach. The parallel half wavelength coupled microstrip lines and inverted-L antenna is used for synthesizing the bandpass filtering antenna. The inverted-L antenna acts as a last resonator and provides load impedance of the bandpass filter. The equivalent circuit components of inverted-L antenna are acquired by comparing with the simulation results and then used for synthesis of Filtering Antenna. A complete design methodology is then described after the synthesis process. Here, third-order Chebyshev bandpass filter with center frequency 2.45 GHz and 0.1 equal-ripple response is designed as an example. The designed structure is compact and provides good design accuracy.

General Terms

Bandpass Filter, Antenna design

Keywords

Filtering Antenna, Filter Synthesis, Co-design approach, Inverted-L antenna.

1. INTRODUCTION

Microwaves are the signals whose frequencies ranges from 300 MHz to 300 GHz, which implies the electrical wavelength from 1 m to 1 mm. Use of microwave energy for transmission purpose provides more bandwidth (which is critically important at present stage), miniaturization of system.. Microwave Power Transmission provides various advantages over the traditional system by facilitating the interconnection on large scale [12]. Microwave signals are used for wireless communication systems, as they are not bent by upper layers of atmosphere. In wireless communication system, microwave filters holds great importance. Microwave filters are used to suppress the unwanted signals in stopband, and provide transmission of wanted frequencies in passband. As the electromagnetic spectrum is limited, frequencies should be shared and reused, which is done with the help of microwave filters. At present, the challenges and stringent requirements for microwave filters in communication system is raising high, which leads us to further developments in filter design technologies [12][14].

Microwave communication system is developing very rapidly, which corresponds to need of challenging highly efficient systems. In almost all wireless communication systems, antenna is a necessary component for receiving or transmitting microwave signals along with bandpass filters for suppressing unwanted signals. The impedance mismatch between the individually designed antenna and filter causes interference and thus affecting the performance of the circuit. Integration of two or more functions together leads to multi-function module miniaturizing the circuit size and leading to improved circuit performance. Radiating and Filtering are the most important functions of the communication system, integrating these functions into a single module will reduce the additional circuit and enhance the overall performance of the circuit. This module is Filtering Antenna, performing both the functions at the same time. Filtering Antenna provides shaping of frequency response [1],[11],[12].

Many efforts have been carried out in past for synthesis and designing of Filtering Antenna[3]-[8]. In [3], filtering function was integrated in an electromagnetic horn. The filtering function was developed by inserting discontinuities with the help of metal posts in an electromagnetic horn antenna. To achieve their aim of separately specifying filtering and radiating functions, a mixed simulation electromagnetic-circuit was used. But standard method was not followed and also cross polarization was slightly detorioted. In [4], cavities were created in leaky waveguide so as to control the bandwidth and hence, develop the filtering function. Leaky waveguide area along with the cavities provided radiating and filtering functions simultaneously. Due to cavities, bandwidth of antenna is limited and also matching between the structures is improved. This design did not consider the filter?s or antenna?s specifications. In [5], to control the bandwidth of antenna, the bandpass filter was directly inserted at the feed point of patch antenna. But they faced problems in mounting of two structures together along with less controlled bandwidth and low radiation efficiency. In [6], Co-design approach was used to enhance the performance parameters of the circuit. 3-pole compact CPS structure is used as an filter, while CPS fed loop is used as an antenna and both are designed by co-design approach. For combining these two structures, a high impedance transmission line is used which needs extra additional circuit area. Also the frequency response was not as per the expectations. In [7], multilayered (ceramic/foam) technology resulting in the composite structure made of high and low permittivity layers was used for the purpose of integrating filtering and radiating functions together. The foam layer facilitated the larger bandwidth and ceramic layer minimized the size and impedance level. But such a complicated design led to various design constraints. In [8], a sin-

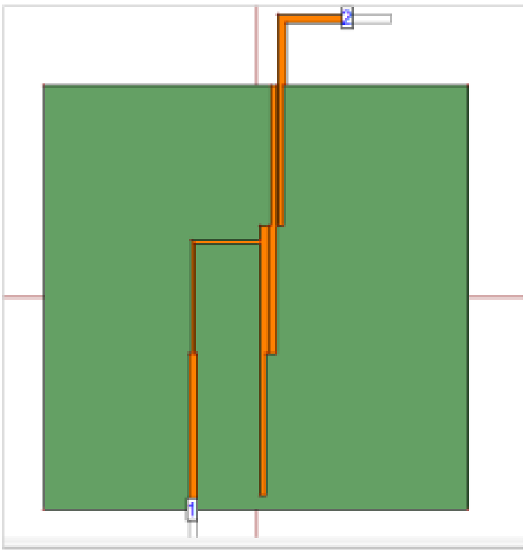

Fig. 1. Geometry of Filtering Antenna

gle material technology was used and co-design approach was used for integrating 3rd order filter with microstrip antenna which uses same substrate for both. In this structure, the last resonator and load impedance was provided by the antenna. The most important parameters for this module were the thickness and permittivity of the substrate material used. The antenna exhibited the series or parallel RLC equivalent circuit. However, for all the analysis and designing, only the centre frequency was considered and not the entire bandwidth. Also circuit and antenna losses were not considered.
In this study, we have examined the synthesis and design of new printed filtering antenna. Fig. 1 contains the Third order Chebyshev Bandpass Filter. The 2 filter resonators are provided by the parallel half wavelength microstrip lines and the 3rd by inverted-L antenna. The inverted-L antenna is printed on 0.508mm thickness substrate with $\varepsilon_r = 3.38$ and loss tangent of 0.0027. The ground plane of the whole circuitry has a size of $L \times W = 60mm \times 60mm.$ A 50Ω microstrip line of width 1.17mm is used to feed the antenna. For synthesis of Filtering Antenna, the printed inverted-L antenna used with its equivalent circuit is extracted over the entire desired bandwidth. For simple fabrication and good circuit behaviour, a quarter-wave admittance inverter is used in the synthesis and designing[1]
.

2. SYNTHESIS

Synthesis refers to specifying the desired parameters for the structure and then using combination of systematic methods to achieve the parameters which are approximately equal to desired parameters. Here, Filtering Antenna is to be synthesized and designed. The inverted-L antenna is to be desgined as the last resonator and load impedance of the Bandpass Filter. So firstly, we have to synthesis inverted-L antenna to obtain the antenna's equivalent circuit model and the values of circuit components. Thus synthesis is acquired in two steps,

(1) Synthesis of inverted-L antenna.

(2) Synthesis of Filtering antenna.

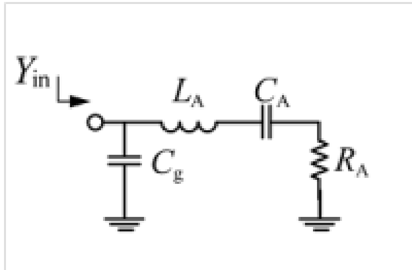

Fig. 2. Equivalent Circuit of Inverted-L Antenna

2.1 Synthesis of inverted-L antenna

The inverted-L antenna is a monopole antenna and it exhibits series R-L-C resonance. Resonance occurs when average stored magnetic and electric energies are equal. The equivalent circuit of inverted-L antenna is as shown in Fig.
The components are, $L_A = Resonant \quad Inductance$
$C_A = Resonant \quad Capacitance$
$R_A = Antenna \quad Radiation \quad Resistance$
$C_g = Parasitic \quad Capacitance$
$Y_{in} = Input \quad Admittance \quad looking \quad at \quad the \quad feed \quad point \quad of \quad antenna$
Here, the shunt capacitance C_g is included due to accumulation of charges at antenna feed point. The equivalent circuit components of the inverted-L antenna are obtained by optimization method using the IE3D electromagnetic simulator. The last resonator of the bandpass filter to be synthesized is contributed by the series $L_A - C_A$ circuit, giving the centre frequency as,

$$f_0 = \frac{1}{2\pi\sqrt{L_A C_A}} \tag{1}$$

This center frequency is chosen to be 2.45GHz. Due to the presence of parasitic capacitance C_g, the antenna frequency f_A has to be slightly greater than the center frequency. The antenna's reflection coefficient S_{11}has it's minimum value at the location of f_A, and is given by,

$$S_{11} = 20log\left[\frac{Y_{in} - Y_0}{Y_{in} + Y_0}\right] \tag{2}$$

Where, Y_{in} is derived from the equivalent circuit as,

$$Y_{in} = j2\pi f C_g + \frac{1}{R_A + j2\pi f L_A + \frac{1}{j2\pi f C_A}}$$

$$Y_{in} = j2\pi f C_g + \frac{1}{R_A + j2\pi f L_A + \frac{1}{j2\pi f \frac{1}{L_A (2\pi f_0)^2}}}$$

$$Y_{in} = j2\pi f C_g + \frac{1}{R_A + j2\pi f L_A + \frac{L_A 2\pi (f_0)^2}{jf}}$$

$$Y_{in} = j2\pi f C_g + \frac{1}{R_A + j2\pi f L_A - j2\pi f L_A (\frac{f_0}{f})^2}$$

$$Y_{in} = j2\pi f C_g + \left[R_A + j2\pi f L_A \left(1 - \frac{f_0^2}{f^2}\right)\right]^{-1} \tag{3}$$

By first extracting the equivalent circuit components and then the antenna is resonated at centre frequency f_0, we can obtain the an-

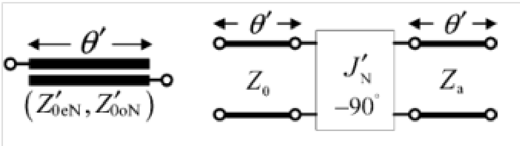

Fig. 3. Geometry of the Nth coupled line section and the corresponding equivalent circuit.

tenna frequency f_A. And then, by substituting all the values in above equation, we can obtain the physical dimensions. Quality Factor is the important parameter of the resonant circuit and it is defined as,

$$Q = \frac{average \quad energy \quad stored}{energy \quad loss \quad per \quad second} \tag{4}$$

Higher value of quality factor corresponds to lower loss in the resonant circuit[12]. The quality factor of the antenna can be used for synthesizing the filtering antenna, given by

$$Q_A = \frac{2\pi f_0 L_A}{R_A} \tag{5}$$

The effect of parasitic capacitance has not been considered in Q_A and hence, it's not the whole quality factor of the antenna. It can be seen that quality factor of antenna decreases as the radiation resistance increases. The dimensions of the inverted-L antenna are $l_1 = 10mm$, $l_2 = 17.25mm$, and $w = 1.17mm$. The extracted equivalent circuit components are $L_A = 14.2nH$, $C_A = 0.30pF$, $R_A = 28.6\Omega$ and $C_g = 0.37pF$ with antenna resonant frequency, $f_A = 2.53GHz$[1].

2.2 Synthesis of Filtering antenna

We have to synthesis and design 3rd order Chebyshev Bandpass Filter in which, first two orders(filter resonators) are provided by the parallel coupled lines sections and the last order is contributed by the inverted-L antenna. The synthesis of 3rd coupled line section is different from the other two, as it has to match to the low radiation resistance of the inverted-L antenna. Consider the below diagram, in which the Nth(3rd) coupled line section having the even mode characteristics impedance (Z'_{0eN}) and odd mode characteristics impedance (Z'_{0eO}) are shown. The actual response of a circuit can be obtained by the sum of the response of the circuit to even and odd mode excitations. In even mode, voltage potentials are same and it replicates the magnetic wall, where as, in odd mode, voltage potentials are opposite and it replicates electric wall. The equivalent circuit of the Nth coupled line section is also shown in the same diagram, at center frequency f_0.

The admittance inverter shown in the fig, is basically an ideal quarter wave transformer, it enables us to use identical resonators throughout the network and it is more convenient for implementation of filter at microwave frequency. J_N is the real and characteristic admittance of the inverter. To obtain the same performances of the coupled line section and it's equivalent circuit, we have to show that ABCD matrices of both the circuits are approximately equal at $\theta = \frac{\pi}{2}$. ABCD paramters are the transmission parameters, useful for defining circuit performance when more cascaded sections are used. The image impedance and propogation constant of both the circuits are calculated and equated to obtain the even- and odd-mode characteristics impedances , given by

$$Z'_{0eN} = Z_a \left[\frac{Z_0}{Z_a} + J'_N Z_0 + (J'_N Z_0)^2 \right] \tag{6}$$

$$Z'_{0oN} = Z_a \left[\frac{Z_0}{Z_a} - J'_N Z_0 + (J'_N Z_0)^2 \right] \tag{7}$$

The above equations can be derived as follows. The ABCD matrix of the equivalent circuit is obtained as,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} cos\theta' & jZ_o sin\theta' \\ \frac{jsin\theta'}{Z_o} & cos\theta' \end{bmatrix} \begin{bmatrix} 0 & \frac{-j}{J'_N} \\ -jJ'_N & 0 \end{bmatrix} \begin{bmatrix} cos\theta' & jZ_a sin\theta' \\ \frac{jsin\theta'}{Z_a} & cos\theta' \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} J'_N Z_o sin\theta' & \frac{-jcos\theta'}{J'_N} \\ -jJ'_N cos\theta' & \frac{sin\theta'}{J'_N Z_o} \end{bmatrix} \begin{bmatrix} cos\theta' & jZ_a sin\theta' \\ \frac{jsin\theta'}{Z_a} & cos\theta' \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} sin\theta' cos\theta' (J'_N Z_o + \frac{1}{J'_N Z_a}) & j(J'_N Z_o Z_a sin^2\theta' - \frac{cos^2\theta'}{J'_N}) \\ j(\frac{sin^2\theta'}{J'_N Z_o Z_a} - J'_N cos^2\theta') & sin\theta' cos\theta' (J'_N Z_a + \frac{1}{J'_N Z_o}) \end{bmatrix}$$

The below two parameters are useful for deriving the above equations,

—**Image Impedance**

(1) Image Impedance is given as, $Z_i = \sqrt{\frac{AB}{CD}}$

but, for symmetric network, $A = D$ and so $Z_i = \sqrt{\frac{B}{C}}$

$$Z_i = \sqrt{\frac{j(J'_N Z_o Z_a sin^2\theta' - \frac{cos^2\theta'}{J'_N})}{j(\frac{sin^2\theta'}{J'_N Z_o Z_a} - J'_N cos^2\theta')}} \tag{8}$$

Here, $\theta' = \pi/2$, so we have, $sin\theta' = 1 \& cos\theta' = 0$

$$Z_i = J'_N Z_o Z_a \tag{9}$$

(2) Image Impedance for the Nth coupled line section is given as,

$$Z_i = \frac{\sqrt{(Z'_{0eN} - Z'_{0oN})^2 - (Z'_{0eN} + Z'0oN)^2 cos^2\theta'}}{2sin\theta'} \tag{10}$$

$\theta' = \pi/2$

$$Z_i = \frac{Z'0eN - Z'0oN}{2} \tag{11}$$

Equating equations (4.10) and (4.12) , we get

$$Z'0oN = Z'0eN - 2J'_N Z_0 Z_a \tag{12}$$

—**Propagation Constant**

(1) Propagation Constant for the equivalent circuit is

$$cos\beta = A \tag{13}$$

$$cos\beta = sin\theta' cos\theta' \left(J'_N Z_0 + \frac{1}{J'_N Z_a} \right) \tag{14}$$

(2) Propagation constant for Nth coupled line section is given as,

$$cos\beta = cos\theta' \left[\frac{Z'_{0eN} + Z'0oN}{Z'_{0eN} - Z'_{0oN}} \right] \tag{15}$$

Equating equations for propagation constant, At $\theta' = \pi/2$

$$J'_N Z_0 + \frac{1}{J'_N Z_a} = \frac{Z'_{0eN} + Z'_{0oN}}{Z'_{0eN} - Z'_{0oN}} \tag{16}$$

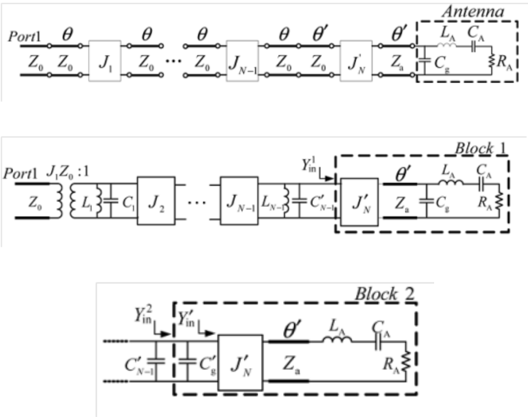

Fig. 4. Modified Circuit of Filtering Antenna

Substitute the value of Z'_{0oN}, from(4.13)

$$\frac{1 + J_N'^2 Z_0 Z_a}{J'_N Z_a} = \frac{Z'_{0eN} + Z'_{0oN}}{Z'_{0eN} - Z'_{0oN}} \tag{17}$$

$$\frac{1 + J_N'^2 Z_0 Z_a}{J'_N Z_a} = \frac{Z'_{0eN} + Z'_{0eN} - 2J'_N Z_0 Z_a}{Z'_{0eN} - Z'_{0eN} + 2J'_N Z_0 Z_a} \tag{18}$$

$$\frac{Z'_{0eN} - J'_N Z_0 Z_a}{Z_0} = 1 + J_N^2 Z_0 Z_a \tag{19}$$

$$Z'_{0eN} = Z_a \left[\frac{Z_0}{Z_a} + J'_N Z_0 + (J'_N Z_0)^2 \right] \tag{20}$$

Now, we wil determine Z'_{0oN}

$$Z'_{0oN} = Z'_{0eN} - 2J'_N Z_0 Z_a \tag{21}$$

$$Z'_{0oN} = Z_0 + J'_N Z_0 Z_a + J_N'^2 Z_0^2 Z_a - 2J'_N Z_0 Z_a \tag{22}$$

$$Z'_{0oN} = Z_a \left[\frac{Z_0}{Z_a} - J'_N Z_0 + (J'_N Z_0)^2 \right] \tag{23}$$

Where,Z_a is the characteristic impedance of the right side transmission line of equivalent circuit.
As we have obtained equivalent circuits of coupled line sections and inverted-L antenna, the filtering antenna structure can be expressed as in fig 4. The two transmission line sections in between the admittance inverters can be replaced by a parallel LC resonator as shown in fig 5.
frequencies near f_0 and $\theta' = \pi/2$, the input admittance Y_{in}^1 of Block 1,

$$Y_{in}^1 \approx (J'_N Z_a)^2 \left(j2\pi f C_g + \frac{1}{j\sqrt{\frac{L_A}{C_A}}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) + R_A} \right) \tag{24}$$

For better implementation and flexibility of this circuit, the placement of antenna's parasitic capacitance C_g should be done as shown in fig 6.

$$Y_{in}^2 = j2\pi f C'_g + Y'_{in} \tag{25}$$

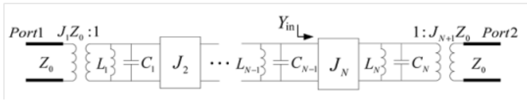

Fig. 5. Final Circuit of Filtering Antenna

where,

$$Y'_{in} = \frac{(J'_N Z_a)^2}{j\sqrt{\frac{L_A}{C_A}}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) + R_A} \tag{26}$$

Substituting the value of Y'_{in} in Y_{in}^2,

$$Y_{in}^2 = j2\pi f C'_g + \frac{(J'_N Z_a)^2}{j\sqrt{\frac{L_A}{C_A}}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) + R_A} \tag{27}$$

Equating (4.25) and (4.27) for C'_g

$$(J'_N Z_a)^2 \left(j2\pi f C_g + \frac{1}{j\sqrt{\frac{L_A}{C_A}}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) + R_A} \right) = j2\pi f C'_g + \frac{(J'_N Z_a)^2}{j\sqrt{\frac{L_A}{C_A}}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) + R_A}$$

$$C'_g = (J'_N Z_a)^2 C_g \tag{28}$$

If a resonator with it's adjacent couplings is removed from the filter and tested under singly loaded conditions then, with shunt type resonance the dual equation is,[14]

$$\frac{J_{N+1}}{G_A} = \sqrt{\frac{b}{G_A Q_A}} \tag{29}$$

$J_{N+1} = Admittance \quad inverter \quad parameter$
$G_A = Generator \quad conductance$
$b = Susceptance \quad slope \quad parameter$
By considering,
$G_A = Y_0$ and $b = \frac{\pi}{2} Y_0$
Above equation can be written as,
$\frac{J_{N+1}}{Y_0} = \sqrt{\frac{b}{Y_0 Q_A}}$
$(Z_0 J_{N+1})^2 = \frac{b}{Y_0 Q_A}$

$$Q_A = \frac{\pi}{2\,(Z_0 J_{N+1})^2} \tag{30}$$

From (27) and (31), we get

$$J'_N Z_0 = \frac{J_N Z_0}{Z_a} \left(\frac{2 Q_A R_A Z_0}{\pi} \right)^{1/2} \tag{31}$$

2.3 Preliminaries for designing of Filtering Antenna

The synthesis of some important parameters is as followed[15],[16] The dielectric constant of substrate is 3.38 and it?s height is 0.508mm.

—**Synthesis of $\frac{W}{h}$**
If only height of the substrate is given, we can find out $\frac{W}{h}$ and hence width.
$\frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - ln\,(2B-1)\right\}$
$+\frac{2}{\pi}\left\{\frac{\epsilon_r - 1}{2\epsilon_r}\left[ln\,(B-1) + 0.39 - \frac{0.61}{\epsilon_r}\right]\right\}$

$$B = \frac{60\pi^2}{Z_0\sqrt{\epsilon_r}} \tag{32}$$

$B = \frac{60\pi^2}{Z_0\sqrt{3.38}}$
$B = 6.44$
Thus, now
$\frac{W}{h} = \frac{2}{\pi}\{(5.44) - ln\,(2\times 6.44 - 1)\}$
$+\frac{2}{\pi}\left\{\frac{3.38-1}{2\times 3.38}\left[ln\,(6.44-1) + 0.39 - \frac{0.61}{3.38}\right]\right\}$

$$\frac{W}{h} = 2.31 \quad (33)$$

$$W = 1.17mm \quad (34)$$

—**Effective Dielectric Constant** ϵ_{reff}

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left\{1 + 12\frac{h}{W}\right\}^{-0.5} \quad (35)$$

$$\epsilon_{reff} = \frac{3.38+1}{2} + \frac{3.38-1}{2}\left\{1 + 12\frac{0.508}{1.17}\right\}^{-0.5} \quad (36)$$

$$\epsilon_{reff} = 2.7175 \quad (37)$$

—**Characteristic Impedance** Z_0

$$Z_0 = \frac{\eta}{\sqrt{\epsilon_{reff}}}\left\{\frac{W}{h} + 1.393 + 0.677ln\left(1.44 + \frac{W}{h}\right)\right\}^{-1} \quad (38)$$

$$\eta = 120\pi \quad (39)$$

$Z_0 = \frac{120\pi}{\sqrt{2.7175}}\left\{\frac{1.17}{0.508} + 1.393\right\}^{-1}$
$+\left\{0.677\frac{120\pi}{\sqrt{2.7175}}ln\left(1.44 + \frac{1.17}{0.508}\right)\right\}^{-1}$

$$Z_0 = 49.828\Omega \quad (40)$$

In this way, synthesis of filtering antenna is accomplished.

3. DESIGNING OF FILTERING ANTENNA

Designing of Filtering Antenna is carried out in 5steps as explained below.

—**Step 1**
At start, state the specifications of filter to be designed. With the help of these specifications, admittance inverters $J_nZ_0(n = 1, 2...N+1)$ and the parallel resonators $L_nC_n(n = 1, 2...N)$ can be obtained. Specifications of Bandpass Filter to be synthesized are,

—A third-order Chebyshev bandpass filter with a 0.1 dB equal-ripple response, N= 3.
—$f_0 = 2.45GHz$
—Fractional Bandwidth is 0.14.
—Characteristic Impedance, $Z_0 = 50\Omega$

As all the specifications are now obtained, we can determine inverter constants, given by formulae,

$$Z_0J_1 = \sqrt{\frac{\pi\Delta}{2(g_1)}} \quad (41)$$

$$Z_0J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}}, n = 2, 3, ...N \quad (42)$$

Value of n	g_1	g_2	g_3	g_4	g_5	g_6
1	0.3052	1.000				
2	0.8430	0.6220	1.3554			
3	1.0315	1.1474	1.0315	1.000		
4	1.1088	1.3061	1.7703	0.8180	1.3554	
5	1.1468	1.3712	1.9750	1.3712	1.1468	1.000

Fig. 6. Element values

$$Z_0J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_Ng_{N+1}}} \quad (43)$$

—The element values are numbered from g_0 at the generator impedance to g_{N+1} at the load impedance for a filter having N reactive elements.[14]
—g_0 = Generator Resistance.
—g_k = Capacitance for Shunt Capacitance.
—g_{N+1} = Load resistance

$$J_1Z_0 = \sqrt{\frac{\pi\Delta}{2g_1}} = \sqrt{\frac{\pi\times 0.14}{2\times 1.0315}} = 0.462 \quad (44)$$

$$J_2Z_0 = \frac{\pi\Delta}{2\sqrt{g_1g_2}} = \frac{\pi\times 0.14}{2\sqrt{1.474\times 1.0315}} = 0.2021 \quad (45)$$

$$J_3Z_0 = \frac{\pi\Delta}{2\sqrt{g_2g_3}} = \frac{\pi\times 0.14}{2\sqrt{1.474\times 1.0315}} = 0.2021 \quad (46)$$

$$J_4Z_0 = \sqrt{\frac{\pi\Delta}{2g_3g_4}} = \sqrt{\frac{\pi\times 0.14}{2\times 1.0315\times 1}} = 0.462 \quad (47)$$

—The values of parallel resonators, for $n = 1, ...4$ are given by

$$L = \frac{2Z_0}{\pi f_0} = \frac{2\times 50}{\pi\times 2.45GHz} = 2.068nH \quad (48)$$

$$C = \frac{1}{Lf_0^2} = \frac{1}{2.068n\times(2.45G)^2} = 2.041pF \quad (49)$$

—**Step 2**
As antenna is used as a last resonator and load impedance of the bandpass filter, specify the antenna structure to be used. Here, the printed inverted-L antenna is used for this purpose.

—**Step 3**
At this step, obtain all the dimensions of the inverted-L antenna. For this, calculate the antenna quality factorQ_A given by,

$$Q_A = \frac{\pi}{2(Z_0J_{N+1})^2} \quad (50)$$

here, N=3

$$Q_A = \frac{\pi}{2(Z_0J_4)^2} \quad (51)$$

$$Q_A = \frac{\pi}{2(50\times 0.4617)^2} = 7.37 \quad (52)$$

Now, the strip length l_1 and radiation resistance R_A can be obtained from the graph. Thus strip length $l_1 = 10mm$ from the

$Q_A - l_1$ relationship of the graph, and similarly, $R_A = 28.6\Omega$. For obtaining all the antenna parameters,

$$Q_A = \frac{2\pi f_0 L_A}{R_A} \quad (53)$$

$$L_A = \frac{Q_A R_A}{2\pi f_0} \quad (54)$$

$$L_A = \frac{7.37 \times 28.6}{2\pi 2.45G} \quad (55)$$

$$L_A = 14.24nH \quad (56)$$

$$C_A = \frac{1}{14.24nH(2\pi 2.45G)^2} \quad (57)$$

$$C_A = 0.312pF \quad (58)$$

At this step, all the dimensions of inverted-L antenna are obtained.

—**Step 4**
At this step, select the appropriate characteristic impedance Z_a as the line width and gap between the microstrip lines of 3rd coupled lines are dependent on Z_a. If $Z_a > 50\Omega$, then the gap between the microstrip lines of 3rd coupled line will be too small and hence, difficult for practical realization. Hence, let $Z_a = 30\Omega$. Now we can obtain the inverter constant $J_3' Z_0$ by using,

$$J_3' Z_0 = \frac{J_3 Z_0}{Z_a} \left(\frac{2 Q_A R_A Z_0}{\pi} \right)^{1/2} \quad (59)$$

$$J_3' Z_0 = \frac{0.2021}{30} \left(\frac{2 \times 7.37 \times 28.6 \times 50}{\pi} \right)^{1/2} \quad (60)$$

$$J_3' Z_0 = 0.5515 \quad (61)$$

—Following, the even and odd mode characteristic impedance Z_{0e3}' and $Z'0o3$ of the 3rd coupled line section for the designed filtering antenna can be calculated.

$$Z_{0e3}' = Z_a \left[\frac{Z_0}{Z_a} + J_3' Z_0 + (J_3' Z_0)^2 \right] \quad (62)$$

$$Z_{0e3}' = 30 \left[\frac{50}{30} + 0.5515 + (0.5515)^2 \right] = 75.67\Omega \quad (63)$$

—Odd mode characteristic impedance of 3rd coupled line section is given as,

$$Z_{0o3}' = Z_a \left[\frac{Z_0}{Z_a} - J_3' Z_0 + (J_3' Z_0)^2 \right] \quad (64)$$

$$Z_{0o3}' = 30 \left[\frac{50}{30} - 0.5515 + (0.5515)^2 \right] = 42.579\Omega \quad (65)$$

—**Step 5**
Now, obtain the even- and odd- mode characteristic impedance of 1st and 2nd coupled line sections as,

$$Z_{0e1} = Z_0 \left[1 + J_1 Z_0 + (J_1 Z_0)^2 \right] \quad (66)$$

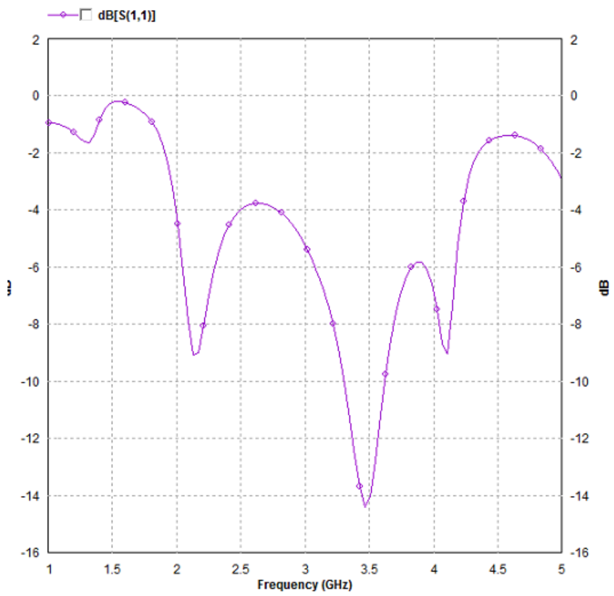

Fig. 7. Return Loss of Designed Filtering Antenna

$$Z_{0e1} = 50 \left[1 + 0.462 + (0.462)^2 \right] = 83.77\Omega \quad (67)$$

$$Z_{0o1} = Z_0 \left[1 - J_1 Z_0 + (J_1 Z_0)^2 \right] \quad (68)$$

$$Z_{0e1} = 50 \left[1 - 0.462 + (0.462)^2 \right] = 37.57\Omega \quad (69)$$

Accordingly, $Z_{0e2} = 60.125\Omega$ and $Z_{0o2} = 41.937\Omega$. In this way, the designing of Filtering Antenna is achieved.

4. EXPERIMENTAL VERIFICATION

Simulation of the studied design is carried out on the IE3D electromagnetic simulator. IE3D is an integral full-wave electromagnetic simulation and optimization package for the analysis and design of 3D and planar microwave circuits. Basically, it solves the Maxwell's Equation in an integral form. The important parameter from design point of view is,

Return Loss
It is the measure of power reflected by the transmission line. Return loss is the measure of how well the devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in lower insertion loss. The S-parameter S_{11} from the 2-port network theory is frequently also called return loss. Return loss with a negative is more properly called reflection coefficient. replace by

5. CONCLUSION

The new printed Filtering Antenna is synthesized and designed by co-design approach. The equivalent circuit components of the inverted-L antenna were first extracted and then used for synthesis of Bandpass Filter. The 3rd order Chebyshev Bandpass Filter was designed in which the last resonator and load impedance was provided by the inverted-L antenna. By integrating the filtering and radiating functions, we obtained a compact sized structure with less insertion loss. The design is approximately accomplished.

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