A Dual Band Bandpass Filter Using Capacitively Loaded and Cross-Coupled Resonators for WLAN Systems

P. Chomtong and P. Akkaraekthalin

Department of Electrical Engineering, Faculty of Engineering
King Mongkut’s University of Technology North Bangkok,
1518 Pibulsongkram Rd., Bangsue, Bangkok 10800, Thailand
Phone:+662-9132500 Ext.8519 , Fax:+662-5857350,
E-mail:tonkmutnb@hotmail.com, prayoot@kmutnb.ac.th

Abstract

This paper proposes a dual band bandpass filter using capacitively loaded and cross-coupled resonators for WLAN systems. The proposed filter is designed on a fundamental frequency of 2.4 GHz and its first harmonics at 5.2 GHz. By using the capacitively loaded resonators, the lengths can be reduced from $\lambda/2$ to about $\lambda/4$. Four resonators are taken to connect in a cross-coupled structure forming the dual band bandpass filter, resulting in a compact size of 2x3 cm. The proposed filter has an insertion loss less than 3.0 dB and a return loss more than 10 dB at the operating frequency bands.

Keywords: capacitively loaded, dual band bandpass filter, cross-coupled.

1. Introduction

Recently, the great demand of communications with connection to the internet has been developed continuously. Wireless LAN (WLAN), which translates data rapidly and conveniently based on standards of IEEE, has used more frequency bands between 2.4 GHz and 5.8 GHz. In all wireless communication systems, a bandpass filter is one of key components. Most of bandpass filters have been developed on micro strip structures due to ease for design, low cost, and compact size. At the present day, the multiband filters have been designed using resonator harmonics. A step-impedance technique has been employed to control the harmonic frequencies by changing values of the impedance ratio. In addition, the capacitive load technique has been proposed for reducing the resonator sizes [1-5]. Also, the coupling resonator structures have been used to construct the bandpass filters, resulting in improved characteristics. These techniques include parallel coupled line, hairpin line, and cross-coupled resonators [6-10]. Especially, the cross-coupled structures can provide superior characteristics for the bandpass filters including high shape factor due to the formation of transmission zeroes in the insertion loss response.

In this paper, capacitively loaded hairpin resonators have been developed to resonate at the fundamental frequency of 2.4 GHz. With this capacitively loaded structure, the first harmonics is at 5.2 GHz. Four resonators have been then arranged into a cross-coupled structure, resulting in a dual band bandpass filter with compact size and good performance.

2. Filter design

A. Open-loop resonators with capacitively loaded structure

![Diagram](image)

Fig. 1. The capacitively loaded resonator (a) geometrical diagram and (b) an equivalent circuit.

Fig. 1 (a) shows a geometrical diagram of the capacitively loaded resonator. Fig. 1 (b) shows equivalent circuit of the resonator, when $\theta_\ell$ is electrical length of transmission line and $Z_t$ is impedance value of transmission line. The couple-line at the end of the resonator is formed to be capacitive load ($C_\ell$), when $Z_a$ and $\theta_a$ are impedance and electrical length of the couple-line, respectively. The frequency responses at fundamental frequency and first harmonics can be shown in term of the relationship between $C_\ell$ and internal parameter values of the resonator in equation (1)-(2). [1-2]
\[ \theta_{s1} = 2 \tan^{-1} \left( \frac{1}{\pi f_0 Z_s C_L} \right) \]  

(1)

Where \( f_0 \) is fundamental frequency value and \( \theta_{s1} \) is electrical length which has been resonant at fundamental frequency. From equations seen, \( C_L \) has an affect to control size of \( \theta_{s1} \) when experiment \( f_0 \) is stable. The increase \( C_L \) made decrease \( \theta_{s1} \) and resonant frequency at first harmonic. This can be calculated from equation (2)

\[ \theta_{s2} = 2\pi - 2 \tan^{-1} \left( \pi f_1 Z_s C_L \right) \]  

(2)

Where \( f_1 \) is the first harmonic frequency and \( \theta_{s2} \) is the electrical length which resonate at the first harmonics frequency. When the resonator is resonated at the first harmonic frequency from equations (1) and (2), \( C_L \) can be calculated from equation (3) [1],[3].

\[ C_L = \frac{\tan \theta_{s2}}{Z_s \omega} \]  

(3)

The capacitive loaded resonator can be designed using the equations (1)-(3). The designed resonator parameters can be obtained as follows: \( W_1 = 0.5 \) mm, \( W_2 = 1.255 \) mm, \( L_1 = 7.6 \) mm, \( L_2 = 7.2 \) mm, and \( L_3 = 6.41 \) mm. The simulated return loss (S11) of the capacitively loaded resonator can be then determined, as a result shown in Fig.2. It can be seen that the resonator resonates at frequencies of 2.4 and 5.2 GHz.

![Figure 2](image-url)  

**Figure 2.** The simulation result of return loss (S11) to examine resonant frequencies of the capacitively loaded resonator.

---

**B. Cross-couple using capacitively loaded resonators**

Fig. 3. The proposed cross-coupled bandpass filter.

Figure 3 shows the structure of cross-coupled bandpass filter, consisting of four capacitively loaded resonators. By using capacitively loaded technique, the sizes of resonators can be reduced. Normally, the resonators using hairpin line structure has the electrical length of \( \lambda/2 \). However, the capacitively loaded technique can reduce the size of electrical length to \( \lambda/4 \).

By using theory of cross-coupling [7-9], the next step is to determine proper places of the resonators in Fig. 3, so that four appropriate coupling coefficients can be evaluated corresponding to the Chebyshev response using following equations (4)-(5) [7].

\[ K_{12} = K_{34} = \frac{FBW}{\sqrt{g_1 g_2}} \]  

(4)

\[ K_{23} = \frac{FBW j_2}{g_1} \]

\[ K_{14} = \frac{FBW j_1}{g_1} \]

(4)

\[ Q_{el} = Q_{eo} = g_0 g_1 \frac{FBW}{FBW} \]  

(5)

Where \( FBW \) is the fractional bandwidth and the element values are \( g_1 \) and \( g_2 \). The fractional bandwidth at fundamental frequency of 83 MHz (3.45%) and the fractional bandwidth at the 5.2 GHz of 200 MHz (3.84%) are used to calculate the coupling coefficient.
In the equivalent circuit of the low-pass prototype filter, the admittance inverters $J_1$ and $J_2$ can be determined from the ripple of Chebyshev set to be 0.001dB. The external quality factors $Q_{ei}, Q_{eo}$ are to calculate $K_{1,4}$ and $K_{2,3}$ and then to find $D_{1,4}$ and $D_{2,3}$, respectively. The proposed resonators have been designed on GML-1000 with $\varepsilon_r = 3.2$, thickness of 0.762, loss tangent of 0.004. We can obtain a low pass prototype of the proposed filters [7-8]: $g_0 = 1$, $g_1 = 0.7533$, $g_2 = 1.16552$, $J_1 = -0.4513$, $J_2 = 1.05789$. The external quality factors are $Q_{ei} = Q_{eo} = 21.5225$. The coupling coefficients between the adjacent resonators can be found to be $K_{1,2} = K_{3,4} = 0.037353$, $K_{2,3} = 0.03176$ and $K_{1,4} = 0.020974$, which the coupling coefficients of $K_{1,2}$, $K_{1,4}$, $K_{2,3}$, and $K_{1,4}$ at the resonant frequency 2.4 GHz and 5.2 GHz are identical. Alternatively, the couplings between resonators $i$ and $j$, $K_{ij}$, can be calculated by equation (6) [7-8].

$$K_{ij} = \frac{g_j^2 - f_0^2}{g_j^2 + f_0^2}$$  

(6)

The lower and higher of resonant frequency from connection with resonators are $f_a$ and $f_b$ respectively. Coefficient of coupling between resonators can be simulated from program IE3D, resulting in a response of frequency between resonators shown in Fig.4.

Fig. 4. coupling coefficients between the adjacent resonators by simulation

From simulation of IE3D program and equation (6), we can plot coupling coefficient graphs of electric, magnetic and mixed coupling, as shown in Fig.5. In order to determine the distance D, the coupling coefficients $K_{ij}$ are selected at the sufficiently intersection point between the coupling coefficients $K_{ij}$ line of 2.4 GHz and 5.2 GHz.

Fig.5. (a) Electric coupling coefficients. (b) Magnetic coupling coefficients. (c) Mixed coupling coefficients.

Figure 5 shows the increase of coupling coefficient of electric, magnetic, and mixed coupling affecting from the decrease of parameter d. From the calculated $K_{1,2} = 0.010974$ that is electric coupling as follows in Fig.5 (a) can be calculated to distance $D_{1,4}$ approximately 0.67 mm. If $K_{2,3} = 0.03176$ that is
magnetic coupling as follows in Fig.5 (b) can be calculated distance $D_{2,3}$ approximately 0.76 mm. Then $K_{1,2} = K_{3,4} = 0.037353$ that is mixed coupling as follows in Fig.5(c) can be calculated to distance $D_{1,2} = D_{3,4}$ which is approximately 0.56 mm.

4. Conclusions
A dual band bandpass filter using capacitively loaded and cross-couple resonators has been proposed to operate at frequency bands of 2.4 and 5.2 GHz. The proposed filter has compact size. The results show good agreement between simulation and measurement with insertion loss less than 3.0 dB and return loss more than 10 dB. The proposed filter also demonstrates good performances, which can be applied for WLAN systems and other interesting frequency operation bands.

References