A Compact Four-pole Cross Couple Square Open Loop with Asymmetric Feed

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Keywords: Square open loop, Asymmetric feed, Cross couple, Bandpass filter, IMT-2000

1. Introduction

Microstrip bandpass filters can be easily mounted on a dielectric substrate and can provide a more flexible design of the circuit layout. In many applications, keeping RF filter structures to a minimum size and weight is very important. Planar filters would be preferred since they can be fabricated using printed circuit technology with low cost, small size and light weight. Obviously the size of planar filter with parallel-coupled half-wavelength microstrips [1] is too large to be used modern wireless and mobile systems. Thus size reduction has been an important issue in microwave in developing Rf filter. The hairpin filters [2] make progress in size reduction from parallel-coupled line structure. The microstrip square open-loop resonators [3] of lateral size is only a one-eighth
guided wavelength at midband frequency. Further progress in size reduction is made by the compact miniaturized hairpin resonator filters [4]. Using cross coupling for the filter is a good result in a compact topology. Quasi-elliptic function filters [5-7] are able to place transmission zeros near cutoff frequencies of passband so that higher selectivity with less resonators can be obtained.

In this paper, a compact four-pole cross couple square open loop with asymmetric feed is introduced as an alternative for the miniaturization of the filter structure.

![Fig. 1. (a) resonators with symmetric feed and (b) resonators with asymmetric feed.](image)

The square open loop resonator consists of two identical patches which are attached to the inner corner of the square open loop. The use of a capacitive patch reduces the size of the microstrip square open-loop filter. The position of the feeding point has been analyzed for either and out-phase (180°) feed structure or a symmetric feed (Figure 1 top) and in-phase (0°) structure or and asymmetric feed (Figure 1 bottom). The feed position of input/output can be affected on the resonant frequency. The filter is designed at fundamental resonant frequency $f_0 = 1950$ MHz. The filter designed on a RT/Duroid substrate having a thickness $h = 1.27$mm with relative dielectric constant $\varepsilon_r = 6.15$. The filter was designed and simulated by IE3D program [9]. The dimensions of the conventional square open-loop resonator and proposed resonator are $w_f = 1.85$mm, $l_f = 8$mm, $s = 1.04$mm, $t = 1.9$mm, $a = 7.4$mm, $c = 3.9$mm, $w_1 = 0.5$mm, $g_1 = 0.4$mm and $w_3 = 1.35$mm.

In Figure 2, attenuation poles are movable and depending on the offset distance $t$ from the center of resonator [9]. The symmetric feed structure does not have attenuation poles, while an asymmetric feed has two poles beside the passband. The bandpass filter is used as an alternative technique for the implementation of two transmission zeros beside the passband by using asymmetric feed structures and other transmission zeroes are caused by the four-pole cross couplings.

2. Tow-pole filter design

The proposed filter is based upon square open-loop resonator which consists of two identical patches attached to an inner corner of the square open-loop. The use of a capacitive patch reduces the size of the microstrip square open-loop filter. The position of the feeding point has been analyzed for either and out-phase (180°) feed structure or a symmetric feed (Figure 1 top) and in-phase (0°) structure or and asymmetric feed (Figure 1 bottom). The feed position of input/output can be affected on the resonant frequency. The filter is designed at fundamental resonant frequency $f_0 = 1950$ MHz. The filter designed on a RT/Duroid substrate having a thickness $h = 1.27$mm with relative dielectric constant $\varepsilon_r = 6.15$. The filter was designed and simulated by IE3D program [9]. The dimensions of the conventional square open-loop resonator and proposed resonator are $w_f = 1.85$mm, $l_f = 8$mm, $s = 1.04$mm, $t = 1.9$mm, $a = 7.4$mm, $c = 3.9$mm, $w_1 = 0.5$mm, $g_1 = 0.4$mm and $w_3 = 1.35$mm.

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3. Four-pole Cross Coupled Filter with Asymmetric Feed

In implementing of a filter with a passband response, to properly place the resonators so that a coupling in the structure $K_{ij}$ can be established. The coupling coefficient $K_{ij}$ and the external quality factor $Q_e$ meeting these specifications can be obtained as follows:

$$Q_e = \frac{g_{ij}g_{12}}{FBW}$$  \hspace{1cm} (1)

Fig. 2. Frequency responses of the resonators for a symmetric and an asymmetric feed.

Fig. 3. A typical frequency response of a resonator pair for extracting the coupling coefficient.
Fig. 4. The three basic coupling structure (a) electric coupling, (b) magnetic coupling, (c) mixed coupling.

Fig. 5. The coupling coefficient $K$ versus the spacing.
where FBW is the fractional bandwidth of the bandpass filter, element value $g_0$ is 1.0, $g_1$ is 0.95449 and $g_2$ is 1.38235 for Chebyshev lowpass prototype filter. The negative sign coupling is due to the required magnetic coupling between adjacent resonators. The prototype filter for IMT-2000 band, the corresponding external quality factor $Q_e$ is 42.882. The coupling coefficient $K_{12} = K_{34}$ is 0.0217, $K_{14} = -0.002$ and $K_{23} = 0.023$ for the four-pole filter. The desired external quality factors and coupling coefficients are determined empirically by varying the spacing (s). External quality factors and coupling coefficients are calculated using the EM simulator IE3D.

Fig. 6. Structure of four-pole cross couple square open loop with asymmetric feed.

\[
K_{12} = K_{34} = \frac{FBW}{\sqrt{g_1g_2}}
\]

\[
K_{14} = \frac{FBW \cdot J_1}{g_1}
\]

\[
K_{23} = \frac{FBW \cdot J_2}{g_2}
\]

Fig. 7. Photograph of the four-pole cross couple square open loop with asymmetric feed.
The coupling coefficient between resonators i and j \( (K_{ij}) \) can be calculated as

\[
K_{ij} = \pm \frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2}
\]

(5)

where \( f_{p1} \) and \( f_{p2} \) are the lower and higher spilt resonant frequencies of a pair of coupled resonators when they are decoupled from the remainder. These values could be found in the typical response, as shown in Figure 3. Fig. 4 shows the three basic coupling structures. The coupling structure in Fig. 4(a) is for electric coupling because the electric fringe fields are stronger near the open ends of resonators. By similar reasoning, the structure in Fig. 4(b) provides a magnetic coupling because the magnetic fringe fields are stronger near the center of the resonators. Fig. 4(c) provides both electric and magnetic coupling. The structure of four-pole cross couple square open loop with asymmetric feed is shown in Fig. 6. Therefore, the implementation of the square open loop with stepped impedance
resonators filter is pictured in Fig. 7. The frequency response of the filter is portrayed in Fig. 8 validating the agreement of simulation and measurement results. The 3-dB fractional bandwidth of the filter is 3.07%, the insertion loss is better than 3.0 dB and the return loss is greater than 10 dB in the passband. The bandpass filter is used as an alternative technique for the implementation of two transmission zeros beside the passband by using asymmetric feed structures and other transmission zeroes are caused by the four-pole cross couplings.

The measurement of wide-band response is shown in Fig. 9. Unlike the conventional square open loop structure filter, the filter exhibits a wide stopband due to two identical patches at the inner corner of the square open loop and proposes the first spurious resonance frequency of the dispersion effect.

4. Conclusion

A compact four-pole cross couple square open loop with asymmetric feed is proposed here. The resonator consists of two identical patches which are attached to the inner corner of the square open loop. The bandpass filter is used an alternative technique for the implementation of two transmission zeros beside the passband using asymmetric feed structures and four-pole cross couplings. A prototype filter is designed at 1950 MHz. The filter is 3.07% fractional bandwidth. The measured insertion losses is about 3.0 dB. It is very useful for the mobile communication systems.

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