Design of Hexagonal Open Loop Filters on FR-4 Substrate

Marin V. Nedelchev, Ilia G.Iliev

Abstract - **This paper presents a design of microstrip hexagonal open loop resonator filter. The hexagonal form of the open loop resonator reduces the area on the PCB. Because of their structure, the hexagonal open loop coupled resonator offers wide variety of coupling schemes and different in value and sign coupling coefficient. The coupling schemes are electrical, magnetic and mixed. The paper presents a Chebyshev filter design of third order with tapped input/output lines. There is a good agreement between the theoretical and EM simulation results.**

Keywords - **Microstrip bandpass filter, hexagonal resonator, External quality factor, coupling coefficients.**

I. Introduction

In the modern communication systems, high selectivity and low passband loss are the main requirements for the microstrip filters. Low passband loss increases the system sensitivity and the high selectivity decrease the guard interval between two channels in a communication system. On the other hand it is important to reduce the filter size and weight in order to integrate them in MIC or MMIC. The problem for miniaturization is very important for the lower microwave range.

In order to reduce the size of the half wavelength resonator the authors of [1] fold back the ends of the resonator into a "U" shape. The hairpin resonator filter is one of the most popular microstrip filter configurations used in the lower microwave frequencies. It is easy to manufacture and adjust, because it has opencircuited ends that require no grounding. The hairpin resonator filter has the same design procedure as the parallel resonator filter.

The further miniaturization of half wavelength is achieved by the square open loop filters [2]. The resonator is bent in square form. This resonator configuration allows additional couplings and design of cross coupled filters [2-4]. These filters have quasi-elliptic response. The formulae for the coupling coefficient for different topologies are given in [2] using curve approximation of simulation results. Theoretical formulae for the coupling coefficients are derived in [5,6].

In order to achieve more flexible filter design, the authors of [7] proposed hexagonal structure of the resonator. It inherits the features of the halfwavelength resonator-position of the spur frequency, input impedance and slope parameter. There are two main topologies of hexagonal resonators shown on Fig.1.

Hexagonal resonators offer different coupling topologies with different in value and sign coupling coefficients (Fig.2). Both configurations allow filter topologies with non-adjacent resonator couplings, performing quasi-elliptical response. More over, the hexagonal resonator makes easier the coupling for triplet and cascaded triplet filters than using square open loop resonators.

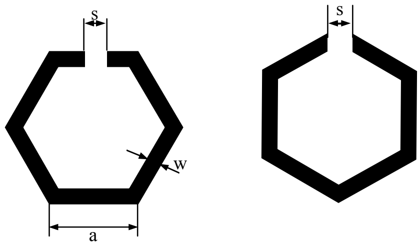

Fig.1. Topologies of hexagonal open loop resonators.

Due to the short length of the coupled lines, the realization of loose couplings is possible with reasonable gap between them. This makes suitable the hexagonal resonator applicable in narrow and very narrow bandwidth microstrip filters.

The microstrip filter synthesis includes calculating the coupling coefficients for a given approximation (a method for Chebyshev approximation is presented in [2,7] and their realization. The theory of coupling for tuned resonators is given in [2].

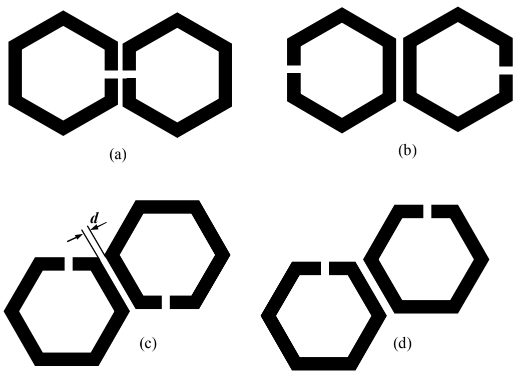

Fig.2 Coupled resonator topologies. (a) electrical (b) magnetic (c) and (d) mixed.

A full-wave electromagnetic (EM) simulator is used to calculate the couplings in the papers [2-4,7], which is an time-consuming, but reasonably accurate method. Closed form formulas are derived for the basic couplings in the CQ filters in [5,6].

In this paper is demonstrated a design of third order hexagonal open loop resonator filter. The filter is of Chebyshev type with tapped input/output lines with center

Marin Veselinov Nedelchev and Ilia Georgiev Iliev –are with Dept. of Radiocommunication and Videotechnologies in Faculty of Telecommunication in TU –Sofia, N8, Kliment Ohridski bul., 1700 Sofia, Bulgaria. E-mail: mnedelchev@tu-sofia.bg, igiliev@tu-sofia.bg.

frequency 1080MHz and fractional bandwidth 4.7%. The size of the designed filter is two times shorter than the parallel edge coupled resonator filter, but remains the same selectivity. The coupling coefficient for mixed coupling and the external quality factor are extracted by EM simulation results.

II. HEXAGONAL RESONATOR AND COUPLING COEFFICIENT

Hexagonal open loop resonator is half wavelength long microstrip line with open ends (Fig.1). When the form of the resonator is symmetrical, there are two possible topologies. The hexagonal form of the resonator is derived from the square open loop resonator. Two adjacent faces join to an angle of 120°. In order to avoid the coupling between the open ends of the resonator the distance ***s*** between them should be bigger than the width oh the line ***w***. The perimeter of the resonator is *(6a+s)* and should be equal to 180 degrees for the center frequency of the filter. The open ends are supposed to be shortened, because of the fringe capacitance by [1]:

$$\frac{\Delta l}{h} = 0.412\left[\frac{\varepsilon_{reff}+0.3}{\varepsilon_{reff}-0.258}\right]\left[\frac{w/h+0.264}{w/h+0.8}\right], \quad (1)$$

where ε_{reff} the effective dielectric permittivity and h is the substrate height.

The different orientations of the resonators on the substrate lead to different kinds of coupling structures (Fig2). Obviously the coupling is achieved by the fringe fields, when the resonators are close one another. Taking into account the field distribution along the hexagonal resonator it is possible to distinguish four main couplings. The electrical filed is stronger than the magnetic near the open end of the resonator. Consequently the coupled structure on Fig2a is dominantly electrical in nature and negative in sign. The maximum of the magnetic field is in the center of the resonator. The coupling is magnetic (Fig.2b) and positive in sign. The strength of the electrical field and magnetic field decays rapidly with the distance from the open end and the center of the resonator respectively. Then the coupling structures on Fig2c and Fig.2d perform mixed coupling. It is not possible to determine which field is dominant. The resonators on Fig.2c exhibit stronger coupling, because the currents in the coupled lines are equal and in-phase. The value of the coupling coefficient of the coupled resonators on Fig.2d is much lower, because the currents are out-of-phase. This topology is applicable in narrow bandwidth filters.

The filter demonstrated in the paper is fed by a tapped line.

III. THIRD ORDER CHEBYSHEV BANDPASS FILTER

Since all six arms of the hexagonal resonator are available for coupling, the filter design is very flexible. The topology of third order Chebyshev type bandpass filter is shown on Fig.3.

The filter design methodology is described in [2]. Following this procedure, a third order filter is designed. The filter specification is:

Order: *3*;
Approximation: *Chebyshev type*;
Center frequency: $f_0 = 1080MHz$;
Bandwidth: $\Delta f = 50MHz$;
Ripple: $0.1dB$

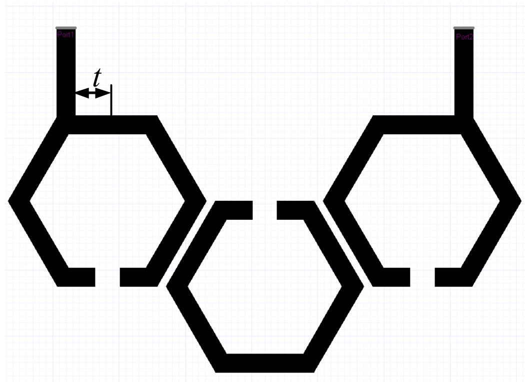

Fig.3 Filter topology

The coupling coefficients and the external quality factor of the bandpass filter are found to be:

$$k_{12} = k_{23} = 0.04 \quad (2)$$

$$Q_e = 20.79 .$$

Ansoft Designer SV is used for extraction the coupling lines parameters and the parameters of the hexagonal resonators.

Using FR-4 dielectric substrate with dielectric permittivity $\varepsilon_r = 4.5$, height $h = 1.5mm$ and tangent loss $tg\delta = 0.02$, the 50Ω hexagonal resonator dimensions are found to be $a = 13mm$, $s = 3.8mm$ and $w = 2.8mm$ for center frequency $f_0 = 1080MHz$. In comparison with it, the 50Ω halfwavelength resonator is $73.78mm$.

There are two resonant peaks in the response are observed if the coupled resonators are over-coupled, which occurs when the coupling coefficient is bigger than the value 1/Q, where Q is the quality factor of the resonator circuit. It is convenient to use full wave EM simulator to find the mode splitting resonance frequencies.

The coupling coefficient may be calculated by the resonance frequencies f_1 and f_2 as:

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \quad (3).$$

Fig.4 shows the dependence of the coupling coefficient against the distance between the coupled resonator topology shown on Fig2c. The coupling coefficient decreases with the increase of the distance between the resonators. This is due to the exponential decay of the fringe field against the distance. The coupling coefficient has a low value and decreases faster than the coupling coefficient between square open loop resonators [2]. This makes the hexagonal open loop resonators more suitable for narrowband filters than the square open loop resonators.

For the design example, the distance between the resonators should be $d = 1.05mm$ in order to realize the coupling coefficient.

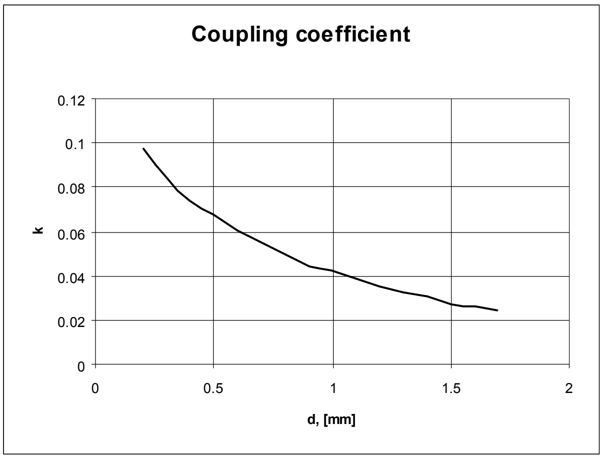

Fig.4 Coupling coefficient versus the distance between the resonators.

In order to determine the exact tapping position of the input/output lines, it is necessary to derive the external quality factor Q_e. The mathematical expression for it is [2]:

$$Q_e = \frac{f_0}{\Delta f_{\pm\frac{\pi}{2}}} \quad (4),$$

where f_0 is the resonance frequency of the resonator, and $\Delta f_{\pm\frac{\pi}{2}}$ is the bandwidth at which the phase of the s_{11} shifts to $\pm\frac{\pi}{2}, rad$ with respect to the phase at the resonance frequency.

Using Ansoft Designer SV, it is extracted the external quality factor. The results are shown on Fig.5.

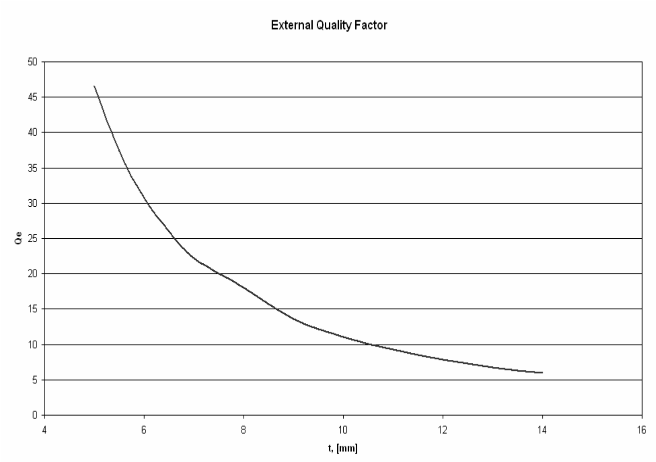

Fig.5 Coupling coefficient versus the distance between the resonators.

The external quality factor decreases with the distance from the center of the resonator. For narrow bandwidth filters Q_e is bigger and he tapping position is closer to the center of the resonator. This leads to bigger sensitivity of the filter's response against the tapping position. Consequently the passband reflection coefficient will degrade. The tapped position is found to be t=7mm.

A full wave EM simulation of the designed is performed in Ansoft Designer. The filter's passband response is shown on Fig.6.

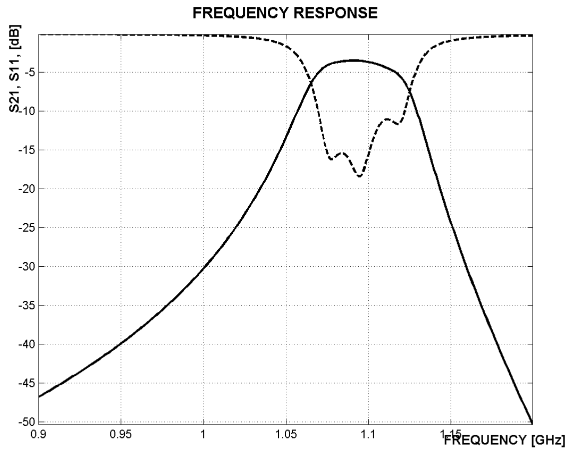

Fig.6 EM simulated filter's passband response. Solid line-S_{21}, dashed line- S_{11}

The designed filter size is reduced to the dimensions 0.497λ_g by 0.352 λ_g. The simulated 3dB passband is 47MHz at center frequency 1090MHz. It is clearly seen the three reflection zeroes in the passband to prove the Chebyshev response. The reflection coefficient in the passband is better than -11.4dB. The asymmetrical transmission coefficient is due to two factors-bad characteristics of the substrate FR-4 and the frequency dependent coupling coefficient. The minimum passband insertion loss is around 2.7dB. This is mainly due to the high dielectric loss of the substrate and the conductor loss.

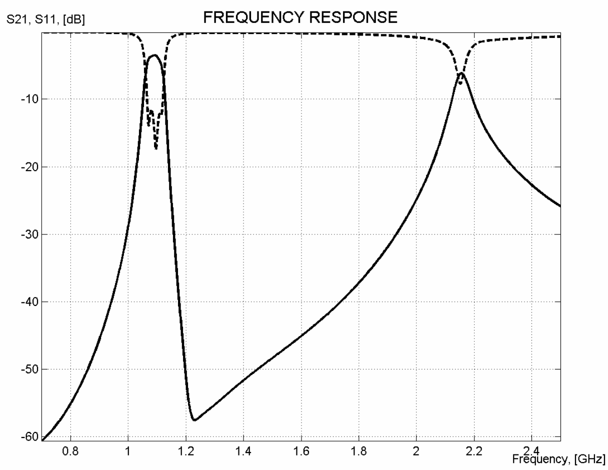

Fig.7 Wideband EM simulated filter's passband response. Solid line- S_{21}, dashed line- S_{11}

Fig.7 shows the wideband frequency response of the designed and EM simulated filter. As it is expected, the first spurious passband of the filter is around $2f_0$ as the hexagonal resonator length is half of the wavelength.

Further improvement of the reflection loss of the filter could be done by replacement of the tapped lines with coupled lines. Thus, a very loose coupling could be realized and the designed filters are narrow band.

IV. Conclusion

The paper demonstrates a design of third order hexagonal open loop resonator filter. The filter is of Chebyshev type with tapped input/output lines with center frequency 1080MHz and fractional bandwidth 4.7%. The size of the designed filter is two times shorter than the parallel edge coupled resonator filter, but remains the same selectivity. The coupling coefficient for mixed coupling and the external quality factor are extracted by EM simulation results. The paper presents the EM simulated responses of the designed filter. There is a very good agreement between the filter specification and the simulation results.

References

[1] Morikazu Sagawa, Kenichi Takahashi, and Mitsuo Makimoto, "Miniaturized Hairpin Resonator Filters and Their ApplicationsTo Receiver Front-End MIC's," IEEE Transactions on Microwave Theory & Techniques, Vol. 37, No. 12, pp. 667-670, December 1989.

[2] J.S.Hong, Couplings of Asynchronously Tuned Coupled Microwave Resonators, IEE Proc. Microwave, Antennas, Propagation 147, Oct. 2000, pp.354-358

[3] J.S.Hong, Lancaster, M, Microstrip Cross-Coupled Trisection Bandpass Filters with Asymmetric Frequency Characteristics, IEE Proc.-Microwave, Antennas, Propagation 146, Feb, 1999, pp.84-90

[4] J.S.Hong, Lancaster, M, Theory and Experiment of Novel Microstrip Slow-Wave Open Loop Resonator Filters, IEEE Trans. On MTT-45, Dec.1997, pp.2358-2365

[5] J.S.Hong, Lancaster, M, Cross-Coupled Microstrip Hairpin-Resonator Filters, IEEE Trans on MTT-46, Jan.1998, pp.118-122

[6] Iliev, I, Nedelchev, M, CAD of Cross-Coupled Miniaturized Hairpin Bandpass Filters, ICEST, Nis, Yugoslavia, 2002

[7] Chang, Tam, Choi, Martins, Novel Quasi-Elliptic Microstrip Filter Configuration Using Hexagonal Open Loop Resonators, www.fst.umac.mo/en/staff/documents/rtorpm_pdf/43-SCAS2002.pdf