Bandpass Filter Using Direct-Coupled Grounded Patch Resonator for Wireless LAN Applications

Vasa Radonic[1], Riana Geschke[2], Vesna Crnojevic-Bengin[1]

Abstract – **In this paper, a new compact bandpass microstrip filter based on grounded patch resonators is proposed. The coupling model of the filter is established and the coupling coefficients of coupled pair of resonators and the external quality factors of basic feeding configuration are investigated using full-wave electromagnetic simulations. As an example, a third order direct-coupled Chebyshev filter that operates according IEEE 802.11b/g/n standard is designed.**

Keywords – **bandpass filter, patch resonator, coupling coefficients.**

I. INTRODUCTION

Compact microwave bandpass filters are in demand for modern communication systems, which demand small size and light weight. High performance narrow-band microstrip filters with low insertion losses in the pass band, high selectivity and spurious response are essential, especially in satellite and mobile communication systems.

Based on well-developed filter theory, [1-3], the direct-coupled filters based on Chebyshev-type characteristic have been developed by various authors in order to meet these specifications. A number of different planar filters have recently been published based on the different shape of resonators, such as square open-loop resonators, [3], the hairpin resonator, [3], triangular open loop stepped-impedance resonators, [4], or fractal resonators, [5].

In this paper, we propose a third order direct-coupled filter based on grounded square patch resonators. The fabrication of the grounded patch is less sensitive to dimension tolerances in contrast to resonators previously reported in the literature, since it does not require narrow conductive lines or small gaps. In the same time, it is very compact in size and exhibits low insertion loss. The grounded patch resonator was initially proposed in the design of two-dimensional high-impedance surfaces, [6], but was seldom used in microstrip filter design. Recently, we have used the grounded patch specifically coupled to the microstrip line to design extremely compact stopband filters, [7], as well as to design a cross-coupled bandpass filter, [8].

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In this paper, we use a square grounded patch to design compact filters following the classical filter design theory and the coupling coefficient method [1-3]. After detail description of the resonator and estimation of equivalent parameters for coupling model, the design curves for coupling coefficient and the external quality factor are presented. As a demonstration, third-order Chebyshev bandpass filter for Wireless LAN (2.4 GHz) applications is designed.

II. GROUNDED PATCH RESONATOR

The grounded patch comprises a metal square etched on the top side of the substrate, connected by a central via to the ground plane on the lower side of the substrate. In the modified version, the via is shifted to the side of the metal patch, Fig. 1. In this way, electric, magnetic and mixed coupling can be achieved between adjacent resonators, [8]. To understand its behaviour, the resonator has been modelled as parallel *LC* equivalent circuit shown in Fig. 1 where L_{via} represents the inductance of via, and C_p is patch capacitance towards the ground.

The values of patch capacitance and via inductance can be obtained using equations (1) and (2), respectively, derived in [9]:

$$C_P = \frac{2.64\cdot 10^{-11}(\varepsilon_r + 1.41)}{\ln(\dfrac{5.98h}{0.8a+t})}, \tag{1}$$

$$L_{via} = 2\cdot 10^{-7} h\left[\ln\left(\frac{4h}{d}\right) + 0.5\left(\frac{d}{h}\right) - 0.75\right], \tag{2}$$

where a denotes the size of the patch, d is the side dimensions of square via, h is the thickness of substrate and t is thickness of metallization. All mentioned variables are in meters.

For the patch realized on a h= 1.27 mm thick Taconic CεR-10 substrate, with ε_r=9.8 and dielectric loss tangent equal to 0.0035, the patch dimension equal to a=7 mm and via size d=0.4 mm, extracted element values are: C_p=8.84 pF and L_{via}=0.474 nH.

A schematic response of the patch resonator capacitively coupled to the feed lines is compared with electromagnetic response obtained using Sonnet, Fig. 2. The resonator exhibits first resonance at f_r=2.41 GHz, while the second one occurs at 2.68f_r. The response of the model, shown in dashed line in Fig. 2, exhibits good agreement with the EM one in the vicinity of the first resonance. Accordingly, the grounded patch is suitable for the design of bandpass filters in the vicinity of the first resonance.

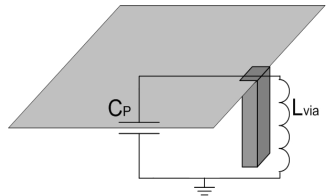

Fig. 1. Proposed grounded patch resonator

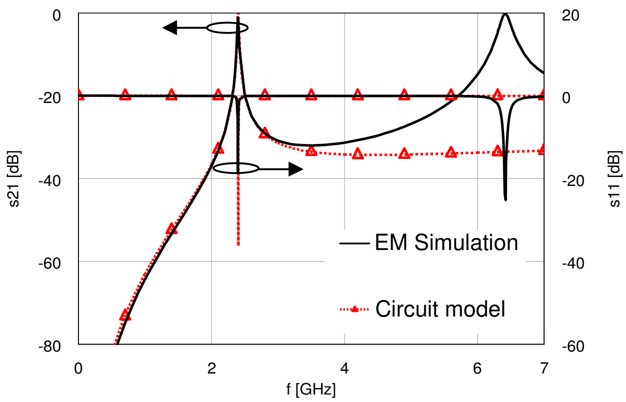

Fig. 2. Full-wave simulated response of the grounded patch resonator and the response of the equivalent circuit model

III. Filter Design

The proposed configuration of third-order direct-coupled filter is shown in Fig. 3. The filter has been specified to exhibit a Chebyshev response centered at 2.4 GHz, with pass-band transmission ripple equal 0.05 dB and the fractional bandwidth equal to FBW=3.96 %.

The coupling coefficients and external quality factors can be determined from coupling model shown in Fig. 4, where J_{ij} represent frequency-independent admittance inverters. Each resonator is modeled by a parallel *LC* circuit, while the parallel R_p model the effect of a finite resonator unloaded Q-factor. The coupling between resonators is modeled by frequency independent *J*-inverters. It should be noted that these models are only accurate in the vicinity of the resonant frequency.

The filter parameter values for the prototype, found in [2], are:

$$g_0 = g_4 = 1 \qquad g_1 = g_3 = 1.031 \qquad g_2 = 1.147.$$

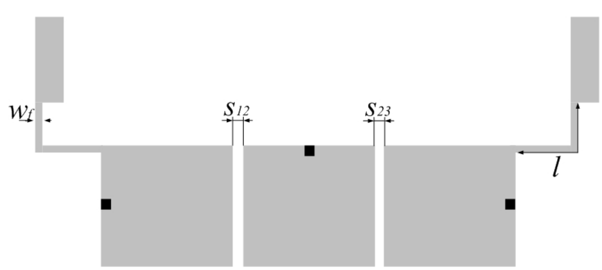

Fig. 3. Configuration of the proposed third-order direct-coupled filter

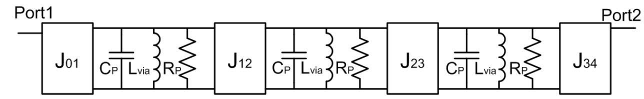

Fig. 4. The prototype of the third-order band pass filter

The related coupling coefficients and external quality factors of the direct-coupled filter can be determined by equations:

$$k_{ij} = \frac{FBW}{\sqrt{g_i g_j}} \tag{3}$$

$$Q_{e1} = \frac{g_0 g_1}{FBW} \tag{4}$$

$$Q_{e4} = \frac{g_3 g_4}{FBW} \tag{5}$$

The coefficients k_{ij} specify the coupling between adjacent resonators *i* and *j* of the filter. Because of the symmetry of the structure, two coupling coefficients must be equal, $k_{12} = k_{23}$. The external quality factors Q_{e1} and Q_{e4} that specify the input and output couplings, respectively, are also equal. For the defined filter specifications the following values have been obtained:

$$k_{12}=k_{23}=0.0363846$$

$$Q_{e1}=Q_{e4}=26.046.$$

Characteristic admittances of the frequency independent inverter are:

$$J_{01} = \sqrt{\frac{FBW \cdot b}{Z_0 g_0 g_1}}, \tag{6}$$

$$J_{04} = \sqrt{\frac{FBW \cdot b}{Z_0 g_0 g_4}}, \tag{7}$$

$$J_{ij} = \frac{FBW \cdot b}{\sqrt{g_i g_j}}, \tag{8}$$

where Z_0 is a characteristic line impedance of the resonator and *b* is the susceptance slope.

The resistance R_p can be determided from unloaded quality factor as:

$$R_p = \frac{Q_u}{w_0 C_P} \tag{9}$$

where Q_u is the external quality factor of the resonator given by:

$$Q_u = \frac{f_0}{BW_{3dB}}. \tag{10}$$

In (10) BW_{3dB} denotes the 3 dB bandwidth of the single grounded patch resonator. It should be mentioned that the proposed resonator has very high unloaded quality factor equal to Q_u=350.

The coupling coefficient k can be calculated from two split resonant frequencies f_1 and f_2, obtained from full-wave EM simulations of two identical coupled resonators, [3], using:

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \tag{11}$$

Due to the specific resonator design, where the via is shifted to one side of the metal patch, several basic coupling scenarios can be realized. They result from different orientations of otherwise identical grounded patch resonators, which are separated by spacing s and may be shifted for a lateral offset. The influence of the nature and the intensity of the fringing fields to the type and the strength of the coupling in those geometrical arrangements were investigated in [8].

The obtained coupling coefficient as a function of resonator-to-resonator distance s is shown in Fig. 5, for the orientation chosen in the proposed filter.

Similarly, the external quality factor was determined as a function of the feed line length l for line width fixed to w_f=0.1 mm, Fig. 6.

Using the obtained design curves given for coupling coefficient and Q-factor, initial dimensions of the filter were determined, such as resonator-to-resonator spacing and the feed length. Spacing between the resonators was set to s_{12}=s_{23}=1.1 mm and lengths of feeds to l=6.3 mm. This filter was simulated in Sonnet and it exhibited larger bandwidth and passband ripple than expected. In order to obtain required response, a numerical tuning procedure based on the filter model was performed, in which the filter and the corresponding model were divided into individual elements and analyzed separately. We have concluded that the type of the used feed slightly influences the resonances of the patches. The first and the third patch have to be larger, in order to resonate on the same frequency as the middle one. In addition, Q-factor has to be higher, therefore the length of the feeds has to be longer.

Final dimensions of the filter are: dimensions of the first and third patch are 7.3 mm x 7 mm, while the middle one is 7 mm x 7 mm; the distances between patches are s_{12}=s_{23}=1.05 mm and the length of the feeds is l=6.4 mm. The overall size of the filter together with feeds is only 0.31λ_g x 0.64λ_g, where λ_g denotes guided wavelength.

In Fig. 7. comparison of electromagnetic and the model response is shown, where a very good fit with the theoretical model can be observed. The electromagnetic response of the filter in the wide frequency range is shown in Fig. 8. The filter is characterized by small insertion loss in the passband equal to 1.25 dB, and passband ripple smaller than 0.07 dB. The fractional bandwidth is 3.91 %, which confirms well to the specifications. Furthermore, the filter exhibits wide stopband up to 6.25 GHz, with a more than 60 dB rejection in the stopband.

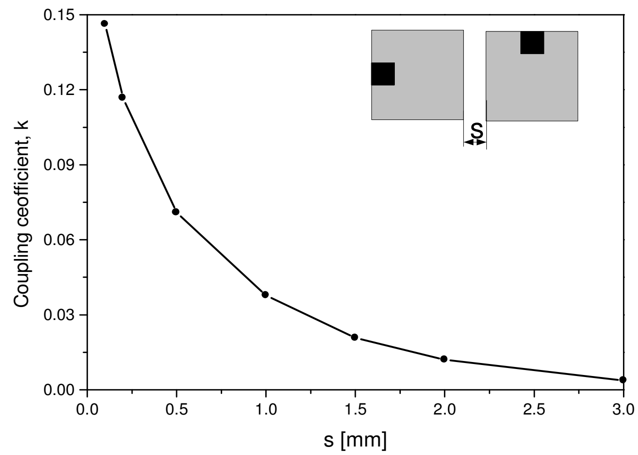

Fig. 5. Coupling coefficients versus resonator-to-resonator distance s for selected orientation.

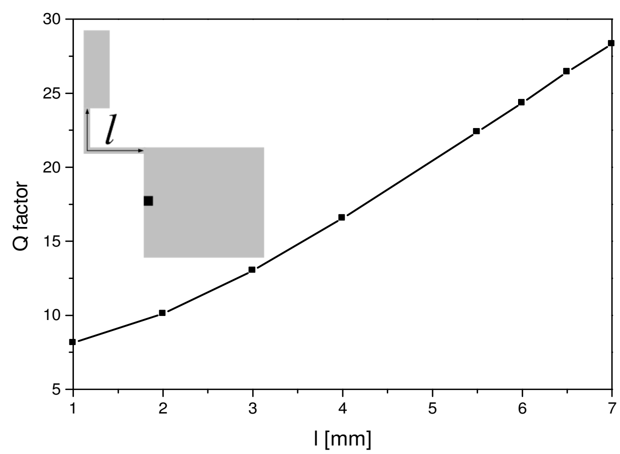

Fig. 6. External quality factor as a function of the coupling line length l.

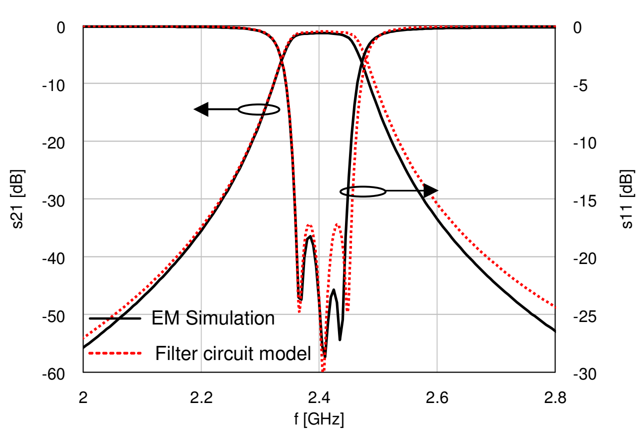

Fig. 7. Comparison of electromagnetic response and response of coupling model.

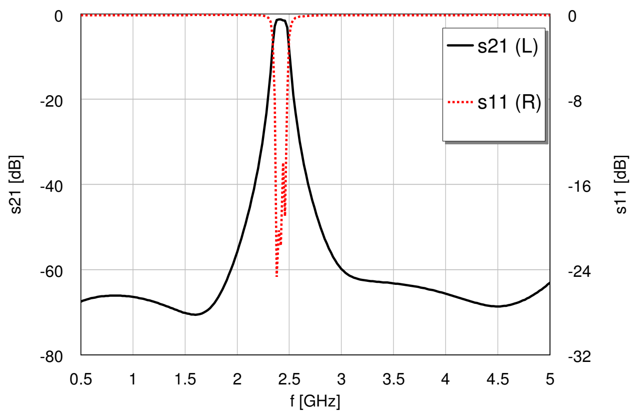

Fig. 8. Electromagnetic response of the proposed filter in wide frequency range.

IV. CONCLUSION

In this paper, square grounded patch resonator was used in the design of direct-coupled bandpass filters. The filter synthesis procedure is shown in detail. To demonstrate the potential of the grounded patch resonator, bandpass filter of the third order has been designed that operates according to IEEE 802.11b/g/n standard.

The filter conforms well to the given specifications: it exhibits small insertion loss in the passband equal to 1.25dB, ripple less than 0.07 dB, and it has very compact dimensions, equal to $0.31\lambda_g$ x $0.64\lambda_{g,}$ where λ_g is the guided wavelength. In addition, the filter exhibits stopband rejection of more than 60 dB up to 6.25 GHz.

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