Synthesis of Microstrip Filters Using Miniaturized Pentagonal Resonators

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Abstract: This paper presents a study of miniaturized pentagonal microstrip resonators and their application in filter design. Due to their shape, the pentagonal resonators have many coupling topologies in order to achieve couplings of different nature- electric, magnetic, mixed. Each coupling topology is analyzed in full wave electromagnetic (EM) simulator in order to estimate the resonance peaks in the frequency response. Based on the simulation results, coupling coefficient graphs are presented. These design graphs are used in microstrip filter design. Third order microstrip filter for application in GSM900 system is synthesized, simulated, manufactured and measured. There is a very good agreement between the simulated and measured results.

Keywords:, miniaturized pentagonal resonator, coupling coefficient, GSM900.

I. INTRODUCTION

The fast development of the mobile communication systems stimulates the research of microwave filters with symmetrical response [1]. Microstrip filters are preferred for these systems, because of their compact size, low weight, easy integration in integrated circuits, fine adjustment.

Most of the microwave filters are of Chebyshev type. They are equiripple in the passband and maximally flat in the stopband. Such filters can be realized by cascading resonators in series. High filter selectivity requires higher filter order and more resonators. Because of the low unloaded Q factor of the microstrip resonators, the passband loss increases. Alternative way is to use cross-coupled filters with coupling between non-adjacent resonators. Non-adjacent couplings cause transmission zeroes in the stopband or equalization in the group delay.

Among the variety of filter topologies, the classic half-wavelength and hairpin resonator filters are commonly used. Miniaturization is an important requirement for the used resonators. In order to reduce the size of the half wavelength resonator the authors of [2] fold back the ends of the resonator into a "U" shape. The further miniaturization of half wavelength is achieved by the square open loop filters [2]. The resonator is bent in square form. In order to achieve more flexible filter design, the authors of [3] proposed hexagonal structure of the resonator. It inherits the features of the halfwavelength resonator-position of the spur frequency, input impedance and slope parameter.

The authors of [4] propose to use pentagonal open loop resonators in order to achieve compact cascaded quadruplet filter with two symmetrical transmission zeros. The geometrical form of pentagonal resonators allows coupling indifferent coupling schemes, which exhibits various coupling types.

The proposition of cross coupled filters with symmetrical pair of transmission zeros come from the classic papers of Kurzrok [5]. The synthesis of cross coupled filters is based on the early works from Atia and Williams [1], Cameron and Rhodes [6,7] considering waveguide cavity filter design. It is based on the deriving the coupling matrix from the transfer function and its reduction to the corresponding topology form. This technique is found to be useful in the design of microstrip cross-coupled filters. Hong and Lancaster proposed in several papers [2-4], numerical method for cross coupled filter design based on approximation of the low pass filter prototype elements.

This paper proposes miniaturized pentagonal microstrip resonators and a design procedure of all pole Chebyshev type filter. A full wave EM simulator is used for obtaining the coupling coefficients between the resonators. Numerical results for the values of the coupling coefficients are presented. A design example for GSM900 system is manufactured and measured. The frequency responses from full wave EM simulator and measurements are presented and show very good agreement.

II. MINIATURIZED PENTAGONAL RESONATOR COUPLING STRUCTURES

The miniaturized pentagonal resonator is based on the miniaturized resonator proposed in [2,4]. The form of the resonator is shown on Fig.1. Its form helps using the resonator in bigger variety of coupling schemes than using rectangular or square miniaturized resonator. The resonant characteristics of the pentagonal resonator are the same as the characteristics of the rectangular miniaturized resonator.

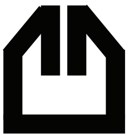

Fig.1. Topology of pentagonal miniaturized microstrip resonator

The coupling mechanism is based on the fringe fields of closely situated resonators. The nature of coupling depends on the resonator configuration. The coupling coefficient for synchronously tuned resonators can be calculated easily by the resonance frequencies of even and odd mode [8]:

$$k = \frac{f_e^2 - f_o^2}{f_e^2 + f_o^2} \tag{1}$$

The necessary condition for observing these resonance peaks is to set the resonator structure in overcoupled mode. In this case the coupling coefficient is larger than the critical coupling value of $1/Q$, where Q is the quality factor of the resonators [6]. A full wave EM simulator based on the Method of the Moments (MoM) is used to identify the

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resonance frequencies. Most of the coupling structures are simulated using the symmetry in their topology for electrical and magnetic wall introducing in-between. When symmetry does not present, the whole structure is simulated. This does not constrain in any way the obtained results. The simulation are carried out for standard FR-4 substrate with $\varepsilon_r = 4.4$, $h = 1.5mm$, $tg\delta = 0.02$.

A. Magnetic Coupling

Both resonators are arranged according to Fig.2. In this case magnetic coupling exists. There presents a line of symmetry and the point **A** has zero potential for the resonant frequency. In this point the electrical field has minimum, but the magnetic field has maximum. This determines the magnetic character of the coupling. The mutual inductance between both coupled lines characterizes the magnetic coupling. The mutual capacitance of coupled lines is negligible because of the minimum of the amplitude of electric field.

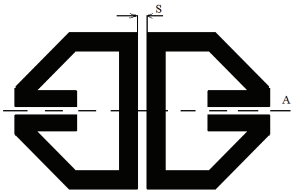


Fig.2. Topology of magnetic coupled pentagonal miniaturized resonators

The coupling coefficient when magnetic coupling presents is with positive sign, because the even mode frequency is higher than the odd mode resonant frequency.

Fig.3. shows the results derived from the full wave EM simulations for the magnetic coupling coefficient dependence with respect to the distance between the coupled lines –*s*.

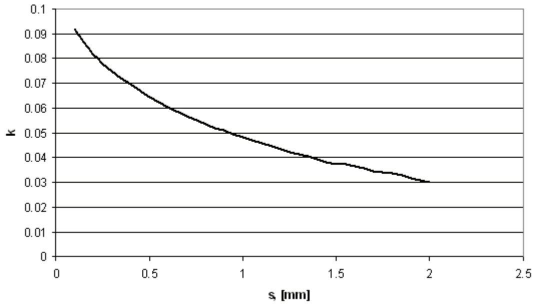


Fig.3 Magnetic coupling coefficient dependence with the distance ***s*** between the coupled lines.

The geometric parameters of the pentagonal resonator are as follows- arm length $l = 13mm$, width of the main transmission line $w = 2.8mm$, width of the symmetrical coupled lines $w_1 = 3.1mm$, distance between the coupled lines $s = 0.3mm$.

When analyse overcoupled resonators, two resonance peaks for even and odd mode are observed in the response. Both frequencies are read and the coupling coefficient is calculated according to Eq.1. The dependence of the coupling coefficient in respect to the distance between the coupled lines is shown on Fig.3.

The topology of magnetic coupled resonators is applicable in realization of positive coupling coefficients in classical or cross-coupled filters.

B. Electric Coupling

The topology of electric coupling between pentagonal microstrip resonators is shown on Fig.4

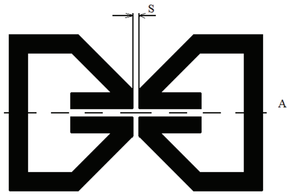


Fig.4. Topology of magnetic coupled pentagonal miniaturized resonators

The nature of coupling is assumed as electrical because the maximum of the electrical field is in the middle of the resonator. In this point the electrical field is predominant over the magnetic field for the resonant frequency. The coupling is defined by the mutual capacitance. The mutual inductance is negligible because of the minimum of the magnetic field. Fullwave EM simulations are carried out over the electrically coupled resonators and the coupling coefficient is computed according to Eq.1. The dependence of the coupling coefficient with respect to the distance between the coupled lines is shown on Fig.5.

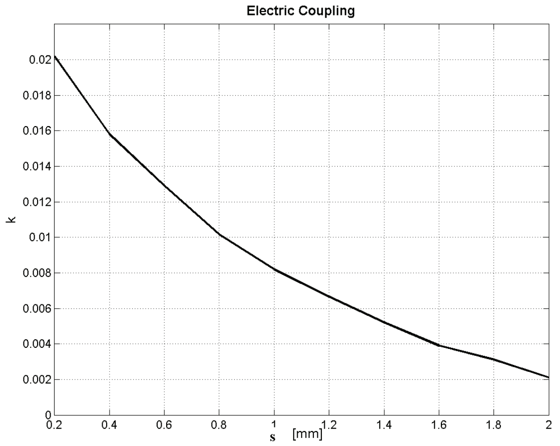


Fig.5 Electrical coupling coefficient dependence with the distance ***s*** between the coupled lines.

The electric coupling coefficient is with negative sign. The coupling between the non-adjacent resonators should be out-of-phase the other couplings. In the case of pentagonal coupled resonators, the coupling is not strong enough. This leads to transmission zeros in the frequency response away from the passband.

The application of the electrically coupled resonators is constrained to realization of negative coupling coefficients for cross-coupled filters.

C. Mixed Coupling

The mixed coupling presents in the coupling structure shown on Fig.6. The currents in the coupled lines are equal in amplitudes, and in-phase.

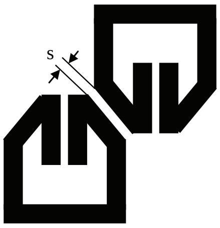


Fig.6. Topology of mixed coupled pentagonal miniaturized resonators

This fact supposes high value of the coupling coefficient. It cannot be estimated which component of the field- electric or magnetic is predominant in this coupling structure. However, the electrical filed decays more rapidly with the distance from the open ends, than the magnetic field. The value of the coupling coefficient is with positive sign.

The coupling structure is simulated in full wave EM simulator according to the above described method and the resonance peaks' frequencies are obtained. The graphical results are presented on Fig.7.

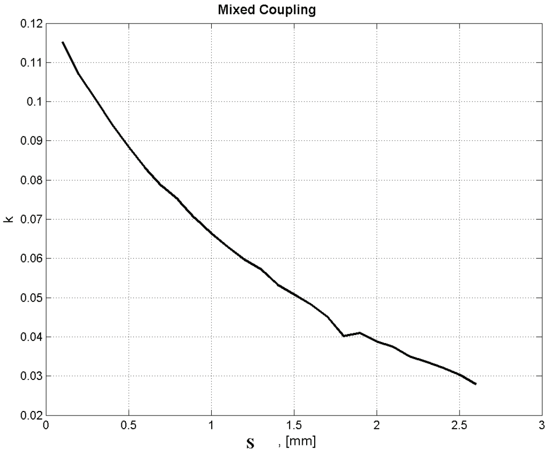


Fig.7 Mixed coupling for the structure shown on Fig.5.

III. SIMULATION AND MEASUREMENT RESULTS

In order to prove the applicability of the proposed pentagonal miniaturized microstrip resonators, a third order classical Chebyshev filter is designed, manufactured and measured.

The filter is realized on the FR-4 substrate with the following parameters:

- Relative dielectric permeability $\varepsilon_r = 4.4$;
- Substrate height: $h = 1.5mm$
- Copper foil thickness $t = 17.5\mu m$;
- Dielectric loss tangent: $tg\delta = 0.02$.

The center frequency of the filter is $f_0 = 902.5MHz$, the bandwith is $\Delta f = 75MHz$ with maximum return loss in the passband $RL = -20dB$.

Fig.8 shows the structure schematic of the filter consists of three cascaded resonators.

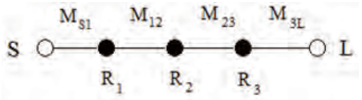


Fig.8. Structure schematic of cascaded three resonator filter. R_i are the resonators, S- Source, L-load, M_{ij} – the coupling coefficients

For the realization of the parameters of the filter, miniature pentagonal microstrip resonators are utilized. Their topology is very convenient for realizing the form of the filter shown on Fig.9. The geometric dimensions of the resonators are: length of the arm $l = 13mm$, width of the main line $w = 2.8mm$, which corresponds to characteristic impedance $Z_c = 50\Omega$, width of the symmetrical coupled lines $w_1 = 3.1mm$, distance between the coupled lines $d = 0.3mm$.

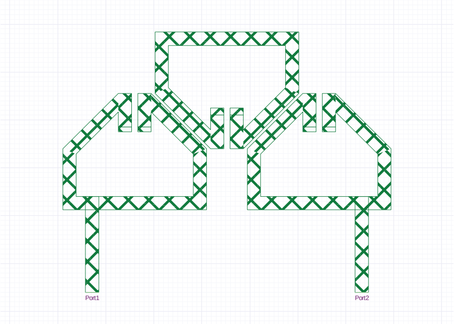


Fig.9. Topology of three resonator microstrip filter with pentagonal resonators.

The topology of the filter requires mixed coupling between the resonators. The coupling coefficient is $M_{12} = M_{23} = 0.081$.The distance between the coupled lines is found to be $s = 0.75mm$, according to the results shown on Fig.6.The results of the fullwave EM simulation of the designed filter are shown on Fig.10.

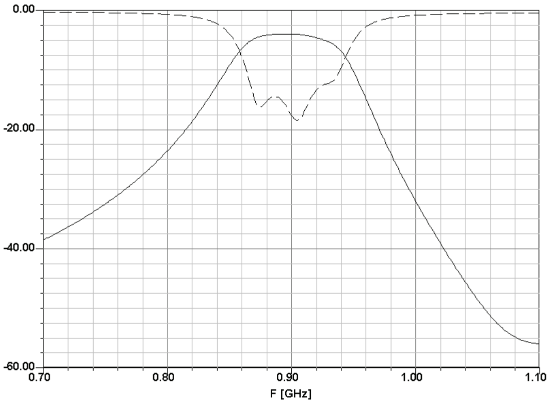
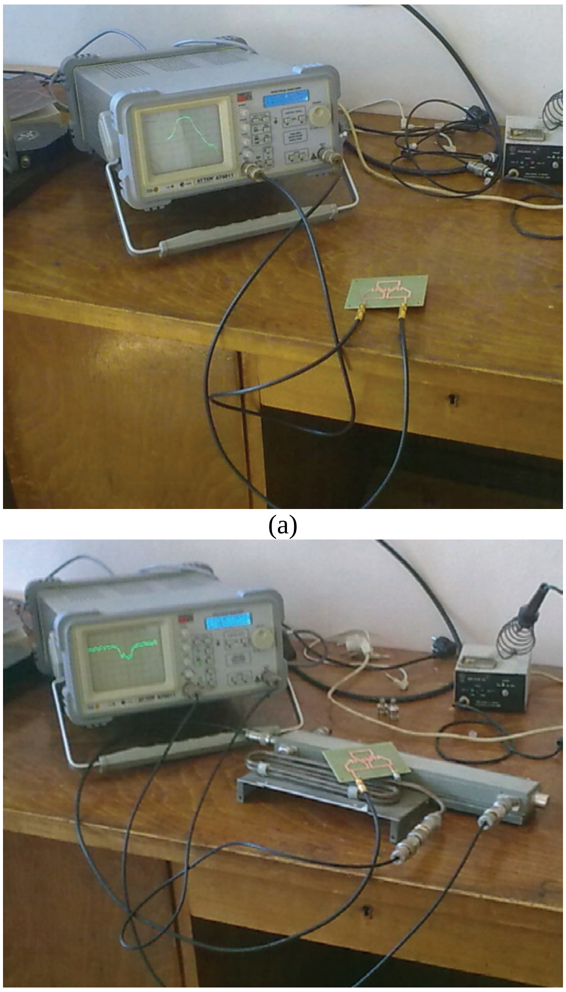


Fig.10 Frequency response from the EM simulation. Solid- transmission coefficient, dashed- reflection coeficient

From Fig.10 is clearly seen that the filter response is of Chebyshev type with equiripple response in the passband. The bandwith is 72MHz and the center frequency is 895MHz. The insertion loss in the passband is less than 4dB. The reflection coefficient is lower than -14dB.

The synthesized filter is manufactured on FR-4 substrate with standard etching technique. The measurement equipment for transmission and reflection coefficients is shown on Fig.11.



(a)

(b)

Fig.11 Measurement equipment for (a) transmission coefficient S_{21} and (b) reflection coefficient S_{11}

The measurements are carried out on spectrum analyser ATTEN AT6011with tracking generator. For the reflection coefficient measurement is used directional coupler Hewllet-Packard. The measurement results are shown on Fig.12.

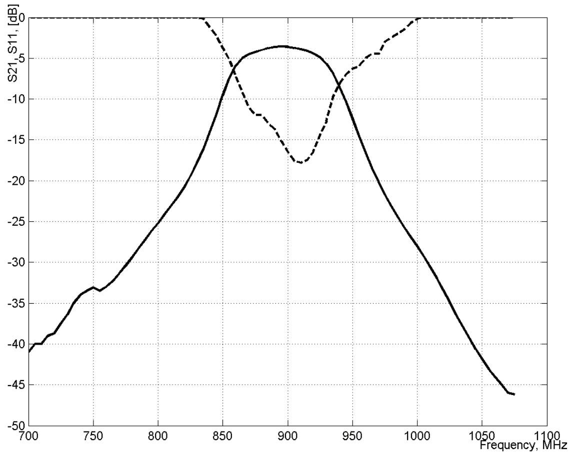


Fig.12 Measured frequency response. Solid- transmission coefficient, dashed- reflection coeficient

The measured results show very good agreement between the simulated and measured results. The measured center frequency is 895MHz, and the bandwidth is 65MHz measured on -3dB. The minimum insertion loss in the pass band is -3.5dB and is due to the very high dielectric loss of the substrate FR-4. The conductor loss is relatively low in comparison to the dielectric loss. The reflection coefficient is less than -12dB with minimum value of -17.5dB. The filter size is 69x55mm and it is 30% less than the same filter using pentagonal open-loop resonators

V. CONCLUSION

The paper proposes miniaturized pentagonal microstrip resonators and their usage in filters for mobile communication systems like GSM 900. The topology of the resonator yields more flexibility in the possible couplings between the resonators in the structure of the filter. Three coupling topologies are investigated and the coupling mechanism is described. Based on fullwave EM simulations, the coupling coefficient is computed and graphical results are presented. Based on the research of topologies of coupled pentagonal resonators, it is synthesized third order Chebysev filter. The designed filer is manufactured and its frequency responses are measured. There is very good agreement between the theoretical, simulated and measured results.

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