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DUAL-BAND FILTER USING NON-BIANISOTROPIC SPLIT-RING RESONATORS

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Abstract—This work proposes the use of Non-Bianisotropic Split Ring Resonators (NB-SRRs) as building blocks for dual-band response filters. Design parameters will be evaluated in order to characterize coupling mechanisms for both the particle and filter structure. A ready-to-use dual-band filter for a multiconstellation Galileo/GPS global positioning receiver is manufactured in order to validate and test the proposed design. The device transmission response measurement agrees with both circuital and electromagnetic simulations, as well as with theoretical insertion losses, which are 2.4 dB and 3.5 dB at center passbands for L_5 and L_1 bands respectively.

1. INTRODUCTION

In recent years, there has been a growing interest in multi-band wireless communication systems. Specifically, major effort has been put into the development of dual-band filters both in terms of their analytical algorithms and in the physical mechanism of creating the dual-band behavior.

For the synthesis of planar dual-band filters, several approaches have previously been reported in the literature. A few of them that could be mentioned are the use of the fundamental and harmonic frequency response of resonators, structures composed by combining two filters with simpler responses, or devices formed by cascading stop-band elements tuned at different frequencies that shape the required pass bands.

A more interesting approach was used in [1] to implement a band-pass filter with a dual-band response using Split Ring Resonators

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(SRRs) or Edge-Coupled SRRs (EC-SRRs). SRRs or EC-SRRs are well known as they were one of the first particles proposed for the implementation of effective media [2]. These structures have also been widely reported as resonators to construct miniaturized band-pass filters, where miniaturization is achieved by taking advantage of the well-known subwavelength effect [3]. That is to say, the first resonance is achieved at a lower frequency than a half-wavelength resonator.

Furthermore these particles also create an upper resonance which has led recent papers to propose them as basic building blocks for dual-band filters [1]. This work exploits that idea by means of a different kind of SRR particle, the Non-Bianisotropic SRR (NB-SRR) which is formed by symmetrically interweaving both rings. The NB-SRR introduces some new and appealing characteristics that simplify the filter design procedure. Finally, a ready-to-use dual-band filter for a Galileo/GPS positioning receiver is fabricated in order to validate and test the proposed design.

2. RESONATOR THEORY

Conventional EC-SRRs are made up of two concentric open rings with their slits on opposite sides. This geometry could be seen as two open-loop microstrip resonators with a strong electromagnetic interaction between them. Therefore overcoupling resonator behavior is present, leading to a frequency split where two resonances appear one below and one above the resonant frequency of isolated rings. In a first approximation these resonances will depend directly on the strength of the coupling and on the length of the open loops.

In order to equalize resonant frequencies with the desired design frequencies, a meandrous line could be added to the inner ring in order to increase its effective length and therefore equalize the resonances of both isolated rings [1]. A symmetric split or a synchronous coupling is obtained by doing such a procedure. However there is already a

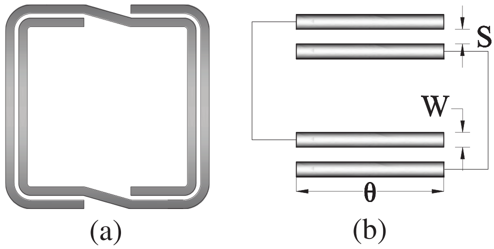


Figure 1. (a) NB-SRR drawing. (b) Simplified equivalent circuit [1].

particle with a synchronous split behavior, the NB-SRR (Fig. 1(a)).

In order to understand this dual mode resonator, the following results can be gathered from its electromagnetic analysis: In the lower resonance a circular counterclockwise current is induced, which generates a magnetic dipolar momentum, hence an axial magnetic field ($\vec{H}$) is created on the particle. In the upper resonance an electric dipolar momentum is created throughout the longitudinal direction. In other words, the Non-Bianisotropic behavior implies the excitation of each resonance by only an $\vec{E}$ or $\vec{H}$ field in a given direction avoiding anisotropic behaviour [4].

Using this 180° symmetrical particle, in comparison to those presented in [1], makes its design parameters easier to tune. However it also leads to a slightly bigger particle since the behavior of the meandrous line is absorbed by the entire resonator structure.

As known not only the gap between rings but also the width of the strips have influence on both: the frequency separation and the quality factor of the resulting resonances. For this reason, simultaneously to the split analysis, the unloaded quality factor (Q) of each of the resonances must be evaluated in order to minimize in-band filter losses.

Like [1] an equivalent model has been implemented using two sections of straight edge-coupled parallel lines. The coupled microstrip lines are of the same electrical length and have two open ends at crossed locations. The remaining terminals of each section are connected to each other in the same way as the NB-SRR (Fig. 1(b)).

By means the aforementioned model, the frequency split and the quality factor will be evaluated by the characteristic parameters of a pair of edge-coupled parallel lines in good agreement with electromagnetic simulation results.

As mentioned, split resonances have to be equalized to the design frequencies of the dual-band response. The characterization of the NB-SRR particle frequency split is studied by means of the synchronous coupling factor between rings [5]. Figs. 2(a) and (c) shows the coupling factor as a function of gap and width, for a fixed value of width and gap, respectively.

Since the split is set by the desired design frequencies, the required gap and width that satisfy the coupling factor have to be chosen in order to maximize both high and low band quality factors. As shown in Figs. 2(b) and (d) by means of the electrical model the following results could be extracted. For a fixed gap between rings the quality factor increase with the strip width for both low and high resonances.

On the other hand for a fixed strip width the quality factor increases with the gap for both low and high resonances. Moreover with a growing gap both quality factors tends to the quality factor of

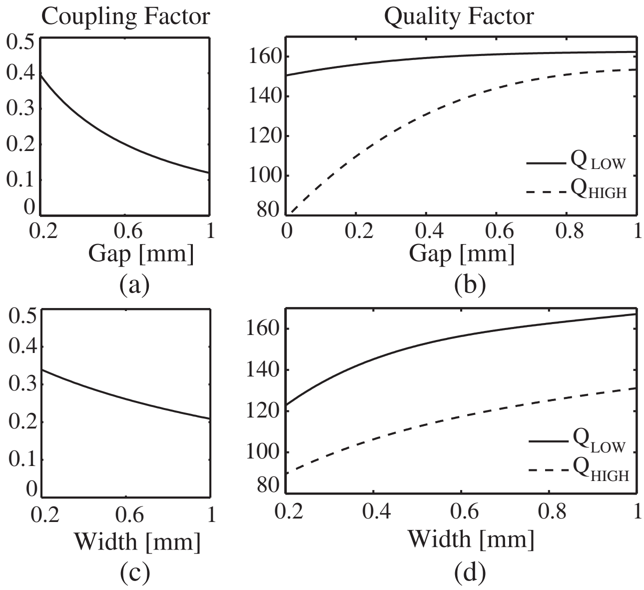


Figure 2. Trend behaviour of geometrical edge-coupled line model parameters on the quality factor for both low band (L_5) and high band (L_1), for: (a) Fixed line width of 0.55 mm, and (b) fixed gap of 0.3 mm. Substrate: $\varepsilon_r = 10.2$, thickness $= 0.635$ mm.

an isolated ring since increasing the gap decouples both rings. This asymptotic value must be optimized according to the constraints of an independent open loop in order to maximize the quality factor.

For this reason an optimization procedure for the quality factor of an isolated ring was previously carried out [6]. A study of conductor, dielectric and radiation losses has been developed against substrate parameters and electric impedance.

Starting on the NB-SRR particle evaluation, it is now possible to design an isolated dual-resonance particle, since the central frequency of the synchronous split is determined by the electrical length of an isolated ring and the resonance split could be controlled by the synchronous coupling factor. It is also important to wisely choose design parameters leading to a particle with a high quality factor in order to later obtain low in-band losses with a suitable dual-band resonator [5].

3. DESIGN PROCEDURE

The filter design procedure is based on the coupled-resonator method. This method employs two design parameters: the loaded or external quality factor (Q_e) and the coupling factor between particles (M_{ij}) [5]. Those parameters could be computed from the coupling matrix or extracted from the common filter responses such as the Chebyshev response from following equations:

$$M_{ij} = \frac{\Delta}{\sqrt{g_i, g_{i+1}}}, \quad Q_{e_i} = \frac{g_0 g_1}{\Delta}, \quad Q_{e_o} = \frac{g_n g_{n+1}}{\Delta} \tag{1}$$

where Δ is the relative bandwidth and g_0, $g_1 \ldots g_n$ are the lowpass prototype immitances.

From the symmetrical nature of NB-SRR particles, neither electric nor magnetic coupling is realizable, so the only possible coupling is a hybrid one. In Fig. 3 the coupling coefficient between two NB-SRRs and the loaded quality factor are mapped as a function of the gap and the distance for the access tap (presented in the figure diagrams). This simulation has been carried out with *momentum* of *Agilent*.

As it is shown in Fig. 3(a) a relation between coupling coefficients of both high and low resonances is extracted which imposes a bandwidth constraint between both filter bands. Some strategies could be followed in order to reach other bandwidth relations such as placing the particles out of line, setting up different sized NB-SRRs or constructing different filter schemes of NB-SRRs [7]. From (1) both high and low band couplings are set, hence determining the distance S gap between particles.

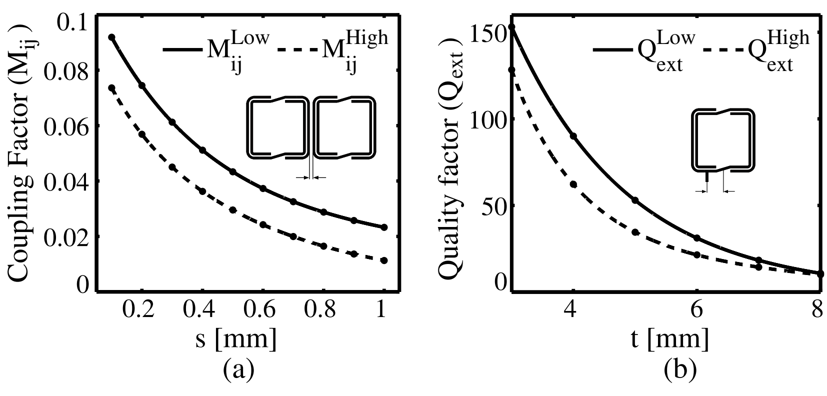


Figure 3. Mapping of the (a) coupling coefficient, and (b) loaded quality factor. For both low (L_5) and high (L_1) band.

Once the required gap between particles has been obtained, the loaded quality factor must be satisfied by means of the input/output feed lines. In this case a tapped-line approach is implemented. From the mapping of the loaded quality factor, Fig. 3(b), we could locate the position of the tap points at the input/output resonators.

With the chosen architecture satisfying the coupling for both bands leads to a response by which the loaded quality factor could not also be fully satisfied. Therefore a relaxation of the aforementioned Chebyshev responses must be performed by means of an optimization.

At this point it is already possible to design a dual-band filter since main design parameters are already known and characterized.

4. EXPERIMENTAL RESULTS

The design procedure detailed in the previous section is applied to the fabrication of a dual-band filter for a Galileo/GPS real receiver application for bands E_5/L_5 (1165–1215 MHz) and E_1/L_1 (1559–1591 MHz) with fractional bandwidths of 4.19% and 2.03%, respectively.

The first step consists of designing a dual resonator with its resonances in the center frequencies of the desired pass-bands ($k = 0.27$). From Fig. 2 we chose a gap of 0.3 mm and a width of 0.55 mm.

The second step consists of the design of two mono-band filters, with a three order Chebyshev response and $L_{Ar} = 0.04321$ dB ripple, the design of the dual-band filter is carried out by a three inline equal NB-SRR structure as shown in Fig. 4. Using the results from (1) and Fig. 3, the separation between particles is 0.5 mm.

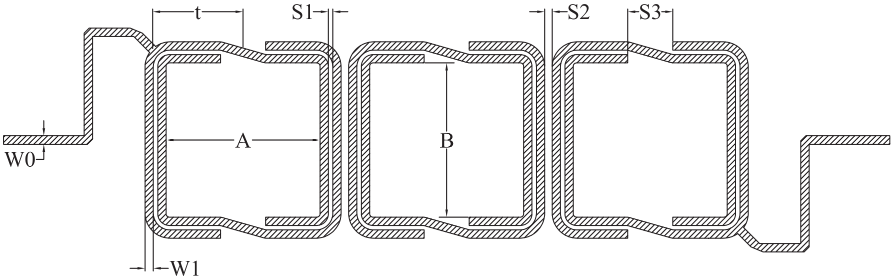
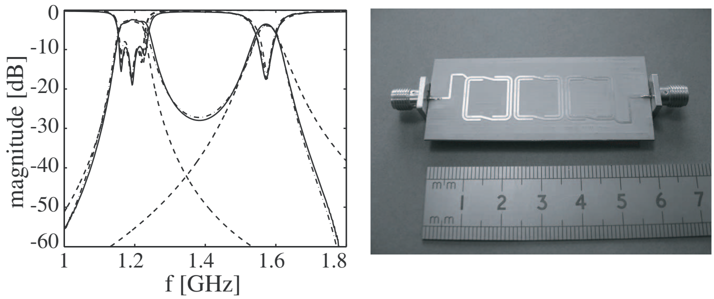


Figure 4. Circuit layout of a three in-line equal NB-SRR. Substrate parameters: $\varepsilon_r = 10.2$, thickness $= 0.635$ mm. Dimensions: $A = B = 10.25$ mm, $W_0 = 0.56$ mm ($50\,\Omega$ line), $W_1 = 0.55$ mm, $S_1 = 0.3$ mm, $S_2 = 0.5$ mm and $S_3 = 3$ mm, $t = 6$ mm.



(a) (b)

Figure 5. (a) Measurement (solid), circuital simulation (dashed) and electromagnetic simulation (dot-dashed) of the proposed filter. (b) Photograph of manufactured dual-band filter.

In order to satisfy the loaded quality factor for both bands a high impedance quarter-wavelength transformer would be useful to control the external quality factor along with the location of the insertion point [1]. However an straightforward approach using a direct $50\,\Omega$ tap on an optimized insertion point has been used in order to validate the structure despite a variation in filter response. In this case, the optimum solution entails a lower matching of both pass-bands.

Figure 5(a) shows the measured results along with two computer simulations: The circuital response of both isolated mono-band filters and the full electromagnetic simulation. Measured results of the fabricated circuit agrees well with both circuital and electromagnetic simulations, as well as with theoretical losses with 2.4 and 3.5 dB at center pass-bands.

5. CONCLUSION

A planar coupled-resonator dual-passband response filter employing NB-SRR particles is presented. NB-SRRs symmetry enables an easier design and tuning of both the particle and the filter in exchange for a slightly bigger particle and the exclusion of some coupling configurations (electric and magnetic coupling). A circuit with three equal geometric NB-SRRs is designed and fabricated. Its measured result shows a good agreement with both circuital and electromagnetic simulations.

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