Optimum Design of Wideband Bandpass Filter with CSRR-loaded Transmission Line using Evolution Strategy

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Abstract — In this paper, a planar wideband bandpass filter with complementary split-ring resonator (CSRR) - loaded transmission line is optimized taking into account multi objective function. Eight physical dimensions are set to be design parameters of the filter structure, and the Evolution Strategy (ES) algorithm is adopted to optimize this multi-parameter problem.

The result shows that a simple gap capacitance model can make a wideband bandpass filter and accomplish the design goal well with a smaller size by the proposed optimization technique.

I. INTRODUCTION

The wideband bandpass filter (WBPF) is one of the essential components in modern broadband wireless communication system. A planar type WBPF, which can be composed on a printed circuit board (PCB) pattern, is very attractive technique in practical use. The planar WBPF is usually formed by transmission line and proper resonator, which may require a spacious area. Complementary split-ring resonators (CSRRs) have been proposed as new constitutive elements for the synthesis of negative permittivity and left handed (LH) metamaterials in planar configuration [1]. The attractive features of CSRRs are their compact size, low cost, high quality-factor (Q) and low radiation loss for wireless communication systems [2].

A number of compact filters using CSRRs with stepped impedance resonator and open-circuited stub [3], coupled square loop [4], parallel microstrip-line [5] have been successfully reported to exhibit wide passbands. In such studies, the researchers investigated circuit models equivalent to their structure and utilized the models as references for the design and analysis. Although they tried to establish better structures for WBPF by changing design parameters, the parameters do not seem to be selected in a systematic manner, which can be accomplished by an optimizing process.

In this paper, an optimal design technique is proposed for the implementation of the planar WBPF with CSRR. The Evolution Strategy (ES) method is adopted for multi-parameter optimization. In addition the adopted structure of WBPF is more simplified one, which is enough to get the design goal by the optimization procedure, and it is even more compact in size than conventional design.

II. CSRR-LOADED TRANSMISSION LINE WITH GAP

According to the analysis of electromagnetic properties of SRRs and CSRRs in the literature [1]-[2], CSRRs behave as and *LC* resonator that can be excited by an external magnetic flux.

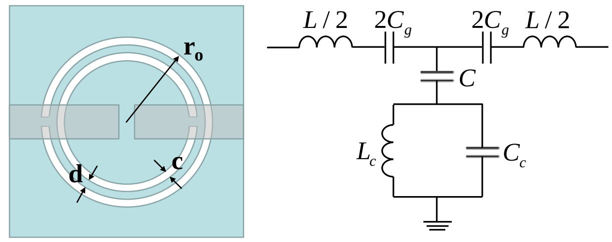

Figure 1. Lumped-element equivalent circuit for the CSRR loaded microstrip line.

The lumped-element equivalent circuit for the CSRR loaded microstrip line is shown in Fig. 1, where the CSRRs are described by the resonant tank L_c and C_c, L models the line inductance, C_g the gap capacitance of line and C the electric coupling between the line and the CSRRs [5].

In this CSRR circuit, L_c is the parallel inductance of two ring, i.e., $L_c=L_o/4$. Each inductance is given by $L_o/2$, where $L_o=2r_o\pi L_{pul}$ can be obtained by that of a single ring with averaged radius r_o and width c. L_{pul} is the per unit length inductance of the coplanar waveguide (CPW) connecting the inner disk to the ground. The capacitance C_c can be approximated by r_o, c and dielectric substrate [1]. In addition, C_g can be expressed in terms of C_s and $C_{par}(=C_f+C_L)$ as follows;

$$C_g = 2C_s + C_{par} \tag{1}$$

where, C_L is the line capacitance, C_f is the fringing capacitance of the gap and C_s is the series capacitance of the gap.

III. SUGGESTING MODEL AND ES OPTIMIZATION

In Fig. 1, the equivalent circuit model shows wideband characteristics as C_g increases. Accordingly, it is desirable to have a structure with a high capacitance of C_g. Therefore, as an initial prototype, a novel structure with an elongated facing length of the gap of the line is proposed.

The schematic of the initial design model with enhanced gap capacitance is illustrated in Fig. 2, where eight design parameters are notated as out_r (outer radius), stub_w (capacitance stub width), stub_l (capacitance stub length), ring_w (ring width), ring_d (ring to ring distance), ring_gap (gap of the ring), t_line_w (transmission line width) and t_line_gap (gap of the transmission line).

The optimum design procedure starts with seeking the global minimum of design function. For this kind of multi-parameter optimization, the Evolution Strategy (ES) algorithm provides a straightforward and reasonable solution [6]. In this study, (1+1) ES is applied.

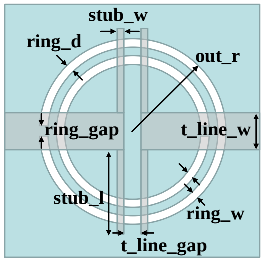

Figure 2. A proposed wideband bandpass filter with CSRR.

The multi objective function for general purpose in ES with constraints on the insertion loss S_{21} is defined as (2);

$$F = \sum_{i=1}^{n} (S_{o1} - S_i)^2 + \sum_{j=1}^{n} (S_{o2} - S_i)^2 + \sum_{k=1}^{n} (S_{o3} - S_i)^2 \quad (2)$$

where S_i is the insertion loss computed at each design iteration and n is the number of sampling point. S_{o1}, S_{o2} and S_{o3} are the target insertion loss value respectively. We set the values as described in the equation (3) to get the wide pass-band from 2 to 5 GHz.

$$\begin{aligned} S_{o1} &= -15dB, \quad at \ \ 0.1 \sim 1.5GHz \\ S_{o2} &= -3dB, \quad at \ \ 2 \sim 5GHz \\ S_{o3} &= -15dB, \quad at \ \ 6 \sim 10GHz \end{aligned} \quad (3)$$

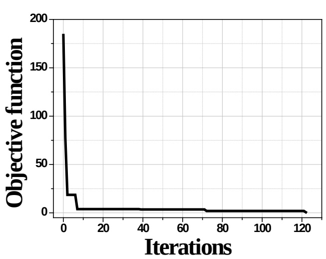

Figure 3. The convergence of objective function.

The convergence characteristics of the objective function are shown in Fig. 3. It shows that a few iterations are enough to get a good convergence. Finally a wideband bandpass filter with CSRR is fabricated as shown in Fig. 4. The predicted and the measured insertion loss are compared in Fig. 5, where the design goals are denoted with bars, S_{o1}, S_{o2} and S_{o3}. The measured bandwidth is from 2 to 4.9 GHz, which shows a good agreement with the simulation results and the design goal. It is observed that the performance of the optimized design accomplishes the design goal well by only 8 parameters. The initial and final values of design parameters are denoted in Table I. As noted in Table I, the variation of the parameters, stub_w, stub_l, t_line_w, t_line_gap affects C_g most significantly. It is positively expected that the whole size of the WBPF is less than 15x15 mm, which is quite smaller than the conventional filter with CSRR.

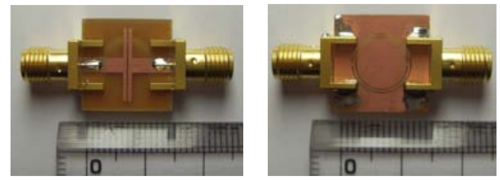

Figure 4. Fabricated wideband bandpass filter with CSRR

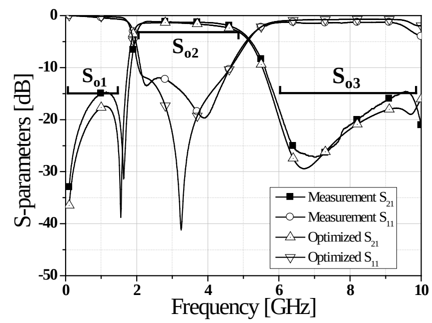

Figure 5. Measurement and ES optimized insertion loss

TABLE I
Transition of Design Parameters and Performance

Parameters	Unit	Initial Value	Opimal Value
out_r	mm	4.00	4.70
stub_w	mm	0.20	0.42
stub_l	mm	5.00	4.90
ring_w	mm	0.20	0.30
ring_d	mm	0.20	0.24
ring_gap	mm	0.20	0.38
t_line_w	mm	2.00	2.20
t_line_gap	mm	0.20	0.42
3dB bandwidth	GHz	2.59~5.64	1.93~4.82

IV. CONCLUSION

An optimum design of a novel WBPF with CSRR-loaded transmission line was successfully conducted. Eight design parameters are extracted from the filter structure and optimized with ES algorithm.

The results reveal that the multi-objective function converges very well with ES optimization algorithm and the performance of the optimized design successfully accomplishes the design goal.

V. REFERENCES

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