Optimal Design of a Compact filter for UWB applications using an Improved Particle Swarm Optimization

Seung-Hun Oh[1], Seung-Jae Lee[1], Sungtek Kahng[2], Kyung Choi[3], and Hyeong-Seok Kim[1]

[1]School of Electrical and Electronics Eng., Chung-Ang Univ., Seoul 156-756 Korea, Kimcaf2@cau.ac.kr
[2]Dept. of Info. & Telecomm. Eng., Incheon National Univ., Incheon 406-772 Korea, s-kahng@incheon.ac.kr
[3]Department of Electronics Engineering, Kangwon National Univ., Chuncheon 200-701 Korea, kyunchoi@kangwon.ac.kr

This paper shows an improved particle swarm optimization (PSO) to design a novel compact ultra wideband (UWB) filter. The filter consists of an only one-cell composite right and left handed-transmission line (CRLH-TL) resonator, stepped impedance (SI), and two spurlines. The one-cell CRLH-TL resonator has a compact size and forms a wide passband. An SI and two spurlines are employed to reject both the harmonics out of the UWB and the wireless local area network (WLAN, 5.15-5.825GHz) band. In order to optimize efficiently the filter, the design of the proposed filter is performed by an improved PSO which takes a suppression of the ripple effect in the passband. During the proposed procedure, the objective function converges only after 96th iteration, while the characteristic of the filter is optimized in acceptable results. The proposed filter has the overall size of 14 x 15mm2(0.63λg x 0.53λg), a bandwidth of 105% for a return loss > 10 dB, an insertion loss < 0.98dB, and stopbands at 11.5~22GHz and WLAN band. Moreover, the ripple in the passband is minimized by the improved PSO.

***Index Terms*—UWB filter, WLAN, Harmonic band, CRLH-TL, Stepped Impedance, Spurline, PSO, Ripple, Improved PSO.**

I. Introduction

Many studies have been conducted on the UWB components and systems since the Federal Communication Commission (FCC) released a band from 3.1 to 10.6GHz as UWB in 2002. Compact microstrip bandpass filters are very good candidate for UWB systems, because of their advantages of low profile and compact size [1].

Most of the previous UWB filters were based on the quarter-wavelength, which restricts size reduction. This problem of size reduction was resolved by introducing the concept of CRLH-TL [1]. But they suffer from a fundamental limitation; namely, the absence of stopbands at the WLAN and harmonic band of the UWB. This limitation can degrade the quality of the UWB system, when exposed to noise interference [2].

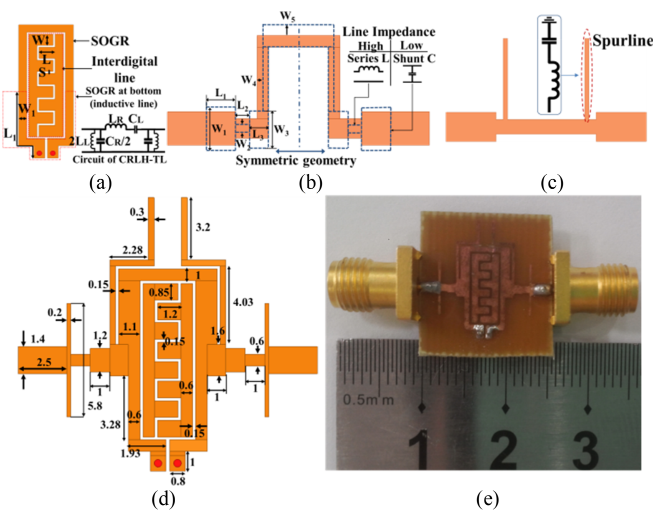


Fig. 1. Proposed UWB filter (a) π-type unit-cell circuit of CRLH-TL (b) Stepped impedance (c) Two spurlines (d) Shape of optimized filter (e) Fabrication of optimized filter

The filter consists of a CRLH-TL resonator and the additional structure blocking the WLAN frequency band and the harmonic in the passband. This filter generates the higher order coupling. This complicated structure needs a long design process and causes many ripples in a passband due to the impedance mismatch. The ripple is an unstable insertion loss, which degrades the overall system performance [2], [3]. Furthermore, the objective function does not converge to zero due to the ripple. Thus, the filter with complicated structure should be designed by an accurate optimization process.

In this paper, an improved PSO for a novel compact filter design is proposed. The proposed filter consists of a one-cell CRLH-TL resonator, SI, and two spurlines. The CRLH-TL resonator forms the wide passband. An SI and two spurlines are used as the additional structure to avoid the interference. The optimization of the filter is performed using an improved PSO to suppress the ripples. The final design is fabricated and tested.

II. Design of the Proposed Filter

The geometry of the proposed filter and detailed dimensions are shown in Fig. 1. The filter is fabricated on a 1 mm-thick low- cost FR4 substrate ($\varepsilon_r = 4.4$) of size 14 × 15 mm^2. Fig. 1(a) shows a circuit and the physical realization of the one-cell CRLH-TL resonator. The C_R, L_R makes an RH-TL for the upper frequency, the C_L, L_L constitutes an LH-TL for the lower frequency in the balanced condition [4].

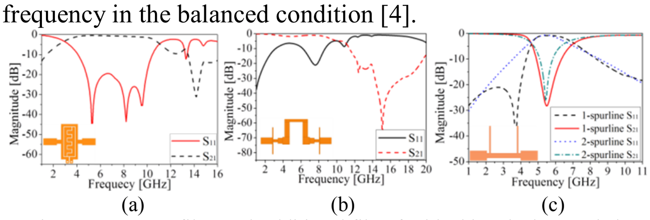


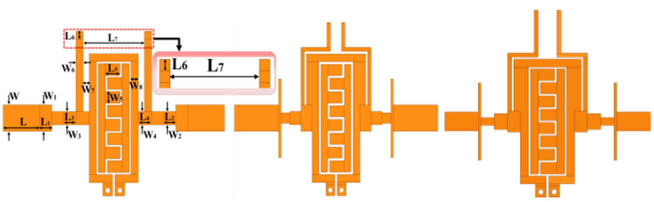
Fig. 2. CRLH-TL filter and Additional filter for blocking the harmonic band and WLAN band (a) S-parameter of CRLH-TL (b) S-parameter of SI (c) S-parameter of two spurlines

The interdigital line implements the C_L, C_R and L_R. The inductive lines of the shorted open gap ring (SOGR) at the bottom form the C_R, L_L [5]. The one-cell CRLH-TL resonator provides the acceptable UWB passband but the harmonic band out of the UWB and the WLAN band also exists as shown in Fig. 2(a).

The harmonic band is eliminated by modifying the upper segment of the SOGR and ports to an SI path, which works as a lowpass filter [2]. The SI, alternating sections of high and low characteristic impedance lines, is implemented as shown in Fig. 1(b). The frequency response of the SI is shown in Fig. 2(b). The harmonic band of the UWB(11.5–22GHz) is suppressed by tuning the widths and lengths of the SI.

The WLAN band can be rejected by the spurline in Fig. 1(c) [6]. The width and length of the two spurlines are adjusted for creating the stopband at the WLAN band. Fig. 2(c) shows the stopband formed by the spurlines. The stopband at the WLAN band (5.15–5.825GHz) is obtained by tuning the widths and lengths of the two spurlines.

III. Optimization and Results



(a) (b) (c)

Fig. 3. Filter optimized by PSO (a) Initial shape of filter (b) Shape of filter optimized by PSO (c) Shape of the filter optimized by improved PSO

The proposed filter consists of two spurlines, CRLH-TL resonator, the SI as shown in Fig. 3. The performance of the initial filter is varied due to electrical interference among the structures. To improve the performance, the optimization algorithm (e.g., Evolution Strategy, PSO) can be applied for the optimal design of the filter [7]. But, the objective function of the standard PSO does not converge to zero due to the ripple that is 1.3dB in Fig. 5(b).

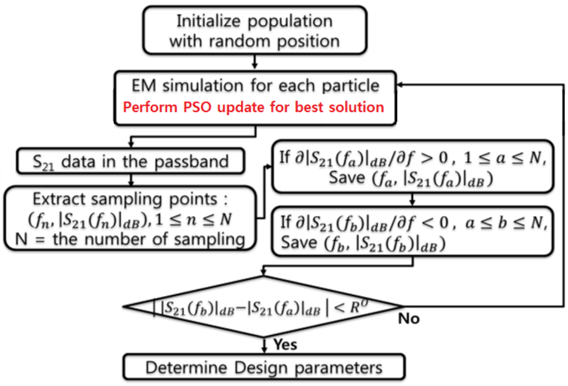
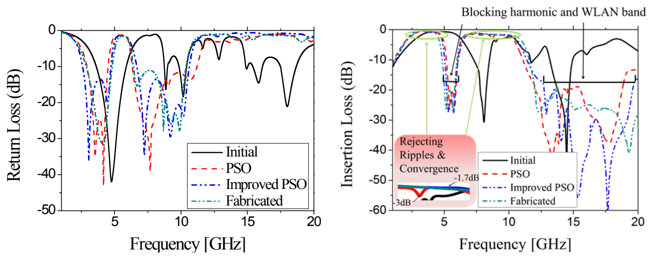


Fig. 4. Process checking and suppressing the ripple

Fig. 4 shows the process handling the ripples. In Fig. 4, f is frequency and $|S_{21}(f)|_{dB}$ is the magnitude of S_{21} at f. This process obtains the data of S-parameter in the simulation results and set the sampling points in the passband. The slope data of S_{21} is computed at each sampling point. The sign of the basic slope is minus due to the loss tangent. When a ripple is generated in the passband, the sign of the slope changes to plus and then returns to minus. This process searches the two points where the sign changes. The ripple is the difference between the magnitudes of S_{21} at the two points. The magnitude of the ripples can be applicable as a portion of the objective function to enhance the convergence.

The PSO is improved with ripple handling process for the filter optimization process. The filter design and optimization were performed using commercial EM simulation tool (HFSS) in conjunction with our own program using visual basic in EXCEL. In process of the improved PSO, the shape of the optimal filter is changed as shown in Fig. 1(d), (e). The performance of the optimized filter is shown in Fig. 5. This results confirm that the proposed filter design exhibits the right UWB response from 2.85 to 10.67 GHz, with a bandwidth of 105% for a return loss > 10 dB and an insertion loss < 3 dB. The filter forms the stopbands removing the harmonic over 12–20GHz and the WLAN over 5.15–5.825GHz. In particular, the ripples are smoothed in the passband. The measured results show some deviation from the simulated results; this may be due to fabrication imperfection.

The objective function of the improved PSO was converged at the 96th iteration. But the PSO is not converged. The improved PSO performs the optimal solution search with faster convergence speed than the existing PSO algorithm. The convergence rate, the number of optimization iterations to obtain a final value, and comparison between the PSO and improved PSO will be presented in extended paper.



(a) (b)

Fig. 5. Result of optimized filter (a) Return Loss (b) Insertion Loss

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