Synthesis of a High-performance Ultra-Wideband Bandpass Filter

***Chun-Ping Chen*[*1], *Noriki Kato*[1], *Tetsuo Anada*[1], *and Zhewang Ma*[2]**

[1]Department of Electrical, Electronics and Information Engineering, Kanagawa University
3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama, 221-8686, JAPAN
chen@kanagawa-u.ac.jp

[2] Graduate School of Science and Engineering, Saitama University
225 Ookubo, Saitama-ken, 338-8570, JAPAN

Abstract

An Ultra-wideband bandpass filter (BPF) prototype consisting of SIRs and short-circuited stubs with Chebyshev characteristics is proposed. As an example, a UWB filter(3.1~10.6GHz) with an FBW of 110% is synthesized based on the microstrip line. The circuit parameters and corresponding geometrical dimensions are worked out and confirmed by a microwave circuit/EM simulator. The good agreement between the simulated and theoretical results validates the effectiveness of newly-proposed theory.

1. Introduction

Since Federal Communication Committee (FCC) authorized the unlicensed commercial application of ultra-wideband (UWB) communication systems in microwave frequency band, UWB bandpass filters (BPFs) have attracted a lot of interests from many researchers and scientists, due to the important performance benefits associated with UWB communication systems.

A number of works on the UWB filter design have been published [2]-[11]. In [2], a UWB filter was developed to have a fractional bandwidth (FBW) of about 86% by the idea of generating two stopbands on both sides of the passband with the open-stubs-loaded ring resonators. In [3], an UWB filter is designed by the microstrip-coplanar-waveguide combinational structures, whereas [4] proposed another type of UWB filters using suspended striplines. In [5], a compact UWB filter was designed with a cascade of the short stubs based on an optimum distributed filter prototype. In [6], a new UWB filter using a parallel-coupled three-mode stepped impedance resonator (SIR) is successfully developed, whereas that composed of a parallel-coupled four-mode one is proposed in [7]. Furthermore, two types of general synthesis theories for the filters consisting multistage multi-mode SIRs are proposed in [8] and [9] respectively. However, one of the disadvantages of this type of UWB filters is that the gap sizes between the coupled lines are usually smaller than 0.1mm to obtain a very strong coupling coefficient (For example, the coupling gap size of the UWB filter designed in [6] is 0.05mm, whereas that of the UWB filter in [7] is 0.06mm). As well known, the processing limitation of the minimum gap size is about 0.1mm when the most popular and low-cost processing technology, etching technology, is used to fabricate the filter. Accordingly, for the filter that has a gap size smaller than 0.1mm, some other processing technology with a higher-precision as well as the higher-cost is required for the fabrication of the filter. To lower the requirement on fabrication precision, a DGS structure is applied in [8], whereas, in [9], asymmetric SIRs are used to introduce an extra degree of freedom in design.

In this paper, another class of UWB filters composed of stepped-impedance resonators and short-circuited stubs will be presented with an emphasis on the synthesis theory. After the derivation of real and theoretical transfer functions of the filter, the design equations are given. As an example, a UWB with an FBW of 110% is designed to validate the proposed filter structure and the corresponding synthesis theory. To be highlighted here, the minimum gap size of the filter is bigger than 0.1mm.

2. Filter Structure and Synthesis Theory

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The structure of the proposed UWB filter is illustrated in Fig. 1. The filter is electrically symmetrical in whole and consists of 3-stage parallel-coupled (or edge-coupled) SIRs and two shunt short-circuited stubs. Each resonator is composed of a cascade connection of three transmission lines, that is, a lower impedance transmission line in the middle with an electrical length of 2θ and two higher-impedance ones located at both sides with that of θ. The SIRs are positioned such that adjacent resonators are parallel to each other along a section of higher-impedance line, whereas two shunt short-circuited stubs are located at input- and output- ports symmetrically.

The new wideband filter will be synthesized in terms of a design/characteristic equation system [9]. The design equation system can be derived by the comparison of the real and theoretical transmission function of the proposed

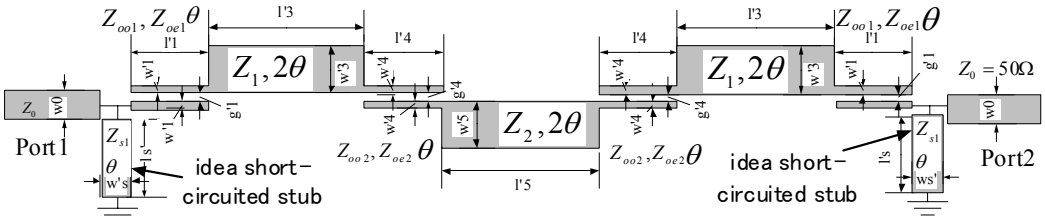


Fig.1 Configuration of the proposed UWB filter comprised of stepped impedance resonators and short-circuited stubs.

filters as follows:

2.1. Derivation of the Real Transfer Function

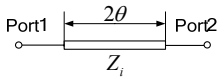
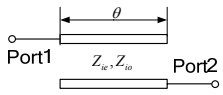
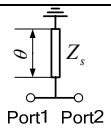
To obtain a real transfer function of the filter, the ABCD-matrix of the proposed filter in Fig.1(a) might be derived by the multiplication of those of short-circuited stubs, parallel-coupled lines and those of the U.E.(Unit element) in sequence as:

$$T_t = T_s \cdot T_{c1} \cdot T_{u1} \cdot T_{c2} \cdot T_{u2} \cdot T_{c2} \cdot T_{u1} \cdot T_{u1} \cdot T_{c1} \cdot T_s \tag{1}$$

where subscript c denotes coupled-lines, u denotes a unit element, s denotes short-circuited stubs. T_s, T_c, T_u are shown in Table I.

Furthermore, the scattering parameters can be derived by the well-known formulae [10]

Table I ABCD-matrix of each circuit component [10].

Circuit component			
ABCD-Matrix	$T_u = \begin{bmatrix} \cos 2\theta & jZ_i \sin 2\theta \\ \frac{j\sin 2\theta}{Z_i} & \cos 2\theta \end{bmatrix}$	$T_c = \begin{bmatrix} \frac{K_1}{K_2}\cos\theta & j\frac{K_2^2 + K_1^2\cos^2\theta}{2K_2\sin\theta} \\ j\frac{2\sin\theta}{K_2} & \frac{K_1}{K_2}\cos\theta \end{bmatrix}$ where $K_1 = Z_{ie} + Z_{io}; K_2 = Z_{ie} - Z_{io}$	$T_s = \begin{bmatrix} 1 & 0 \\ \frac{-j}{Z_s \tan\theta} & 1 \end{bmatrix}$

$$\mathbf{S_{11m}} = \mathbf{S_{22m}} = \frac{A_t + B_t/z_0 - C_t z_0 - D_t}{A_t + B_t/z_0 + C_t z_0 + D_t}$$
$$\mathbf{S_{21m}} = \mathbf{S_{12m}} = \frac{2\left(A_t D_t - B_t C_t\right)}{A_t + B_t/z_0 + C_t z_0 + D_t} \tag{2}$$

where z_0 is characteristic impedance of the ports whereas A_t, B_t, C_t, D_t are the elements of ABCD-matrix and defined in (1).

2.2. Approximating Transfer Function for the UWB Filter

The Chebyshev-type transfer function is derived to approximate the bandpass characteristics of the filter as follows:

$$\left|S_{21}(\theta)\right|^2 = \frac{1}{1+\varepsilon^2 \cdot H_3^2(\theta)} \tag{3}$$

where ε is the ripple constant associated to a given passband ripple L_{Ar} in dB by

$$\varepsilon = \sqrt{10^{L_{Ar}/10} - 1} \tag{4}$$

where $H_3(\theta)$ is a equiripple function and plotted in Fig.2(b) for an intuitive understanding.

2.3. Design Equations

Based on the synthesis theory in [9], the design equations for the proposed filter structure can be obtained by equaling the real transfer function (2) to the theoretical one (3) as

$$\begin{cases} \left|q_0(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_0(\theta_c)\right| \\ \left|q_2(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_2(\theta_c)\right| \\ \left|q_4(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_4(\theta_c)\right| \\ \left|q_6(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_6(\theta_c)\right| \\ \left|q_8(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_8(\theta_c)\right| \\ \left|q_{10}(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_{10}(\theta_c)\right| \\ \left|q_{12}(Z_{oo1}, Z_{oe1}, Z_{oo2}, Z_{oe2}, Z_1, Z_2, Z_{s1})\right| = \varepsilon \cdot \left|g_{12}(\theta_c)\right| \end{cases} \tag{5}$$

where the coefficients q_i and g_i can be derived by the procedure proposed in [10]. Because of the limitation of the length of the paper, the formulae will be introduced in presentation.

3. Design Example

To validate the proposed synthesis technique and newly-developed design equations, a UWB filter is designed to satisfy the FCC's outdoor spectrum mask [1] shown in Table II, in terms of the proposed filter prototype,

Table II Specifications of the UWB filter based on FCC outdoor limit.

Passband	3.1 ~ 10.6 GHz (f_0 = 6.85GHz)
Passband ripple	L_{Ar} = 0.01dB
Cutoff frequency	f_c = 3.43GHz (θ_c = 44.1°)
Out-of-band (FCC outdoor limit)	C1: $\lvert S_{21}\rvert \le$ -20dB@3.0GHz
	C2: $\lvert S_{21}\rvert \le$ -34dB@0.96 ~1.61GHz
	C3: $\lvert S_{21}\rvert \le$ -20dB@10.7 ~ 14 GHz

By the substitution of the specification of the UWB filter into (5), the parameters of the filter shown in Fig.1 can be obtained. Furthermore, we check the above values using a microwave-simulator AWR MWO [11] based on a microstrip model shown in Fig.2(a). The simulation results are illustrated in Fig.2(b) to compare with the theoretical ones. A very good agreement between the simulation and theoretical results validates our model and synthesis theory. (Because of the limitation of the length of the paper, the details will be introduced in the presentation.)

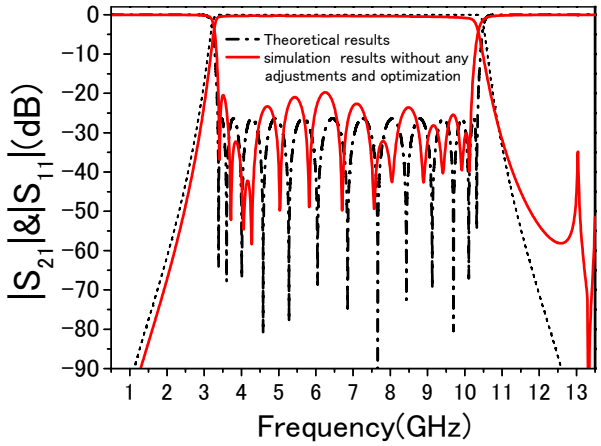


Fig. 2 Theoretical and simulation Characteristics of UWB filter in Fig.1 with FBW@-20dB = 110 %. (θ_c = 44.1°, L_{Ar} = 0.01dB).

4. Conclusion

A UWB filter composed of stepped impedance resonators and short-circuited stubs are proposed with a corresponding synthesis theory. The good agreement between the simulation and synthesis results validates the effectiveness of newly-derived design formulae.

5. Acknowledgments

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