Microstrip Bandpass Filters for Ultra-Wideband (UWB) Wireless Communications

Ching-Luh Hsu¹, Fu-Chieh Hsu² and Jen-Tsai Kuo²

¹ Department of Electronics Engineering, Ta Hwa Institute of Technology
1 Dahua Rd., Qionglin, Hsinchu, 307, TAIWAN

² Department of Communication Engineering, National Chiao Tung University
1001 Tahsueh Rd., Hsinchu, 300, TAIWAN

Abstract — A new technique is developed for designing a composite microstrip bandpass filter (BPF) with a 3-dB fractional bandwidth of more than 100%. The BPF is suitable for ultra-wideband (UWB) wireless communications. The design utilizes embedding individually designed highpass structures and lowpass filters (LPF) into each other, followed by an optimization for tuning in-band performance. The stepped-impedance LPF is employed to attenuate the upper stopband and quarter-wave short-circuited stubs are used to realize the lower stopband. Two such BPFs are fabricated and measured to demonstrate the performance.

Index Terms — Bandpass filters, microstrip filters, ultra-wideband, wideband filters.

I. INTRODUCTION

The requirement of wideband bandpass filters (BPFs) has emerged from advance of the ultra-wideband (UWB) wireless communications [1-2]. For the UWB purpose, the fractional bandwidth of BPFs usually exceeds 100%. Based on the traditional parallel-coupled line structure, very strong coupling structure will be a must for such a wide bandwidth. The tolerance of a microstrip fabrication process, however, imposes an upper limit upon coupling levels for coupling structures. To increase the coupling, special arrangement such as three-line structure [3] can be incorporated into the filter structure for wideband design. The relative bandwidths of the filters presented in [3], nevertheless, are still no more than 70%. Furthermore, filters synthesized using conventional method [4] show a smaller bandwidth than theoretical prediction, since the synthesis procedure is formulated only for relatively narrow band purposes [5]. Even the bandwidth prediction by sophisticated Q value distribution method [6] is promising; the implementation of the microstrip coupled stages with a very high coupling level is still limited by the resolution of fabrication process.

Alternatively, a wideband BPF can be constructed by a direct cascade of an LPF and an HPF. Both upper and lower transition bands can be determined individually as long as the input and output impedances of both filters are matched. In this paper, the HPF and the LPF are combined together, or equivalently one is embedded into the other, so that the circuit area of entire circuit can be greatly saved. A stepped-impedance structure is used to design the LPF because it is easier to design and occupies less space [5]. Its design is readily available if the order, cutoff frequency, and in-band specification are specified. For realizing the HPF characteristic, i.e., the lower stopband, short-circuited stubs are tapped to the high-impedance microstrip sections of the LPF, so that attenuation poles are inserted at DC. Optimization is then employed to fulfill the specification over a wide bandwidth. Two filters with 3dB bandwidths of 51% and 127% are designed and measured.

II. BPF CONFIGURATION AND DESIGN PROCEDURE

Fig. 1 shows the configurations of a directly cascaded BPF and the proposed composite BPF. Obviously, the latter uses an area much less than the former. Both BPFs consist of a hi-Z, low-Z LPF and an HPF structure designed with shunt quarter-wave short-circuited stubs separated with λ_e/4 sections, acting as impedance inverters. The variable λ_e is the guided wavelength at a proper frequency f_o which will be addressed shortly.

Fig. 2(a) and 2(b) show the layouts of the microstrip LPF and HPF of our initial designs. The LPF has a cutoff frequency at 10 GHz, and the HPF at 3 GHz for fulfilling the UWB requirement. Note that the HPF shows a periodic response due to its distributive nature and possesses a bandpass characteristic from DC to 2f_o. Its center frequency f_o should be large enough so that the passband performance of...
the composite BPF is not destroyed by the notch of the HPF at 2\(f_0\). Fig. 2(c) shows the respective simulated performances of the LPF and HPF. Both filters have return losses better than 20 dB in their respective passbands. The full-wave software package IE3D [7] is used for fine tune of the circuit dimensions.

A. Stepped-Impedance LPF

In realization of a stepped-impedance LPF, the length of each line section is given as [5]:

\[
\ell_L = \tan^{-1}\left(\frac{\omega L}{Z_{hi}}\right) \frac{v_c}{\omega \sqrt{\varepsilon_{hi\text{eff}}}}
\]  

(1)

and

\[
\ell_c = \sin^{-1}\left(\frac{\omega CZ_{low}}{v_c} \right) \frac{v_c}{\omega \sqrt{\varepsilon_{low\text{eff}}}}
\]  

(2)

where \(L\) and \(C\) are respectively the inductance and capacitance values of the LPF prototype scaled by the port impedance and cutoff frequency, \(v_c\) is the speed of light in free space, and \(\omega_k\) represents the 3-dB angular frequency. The effective dielectric constants \(\varepsilon_{hi\text{eff}}\) and \(\varepsilon_{low\text{eff}}\) are for the hi-Z and low-Z microstrip sections, respectively. The formulas can be simplified if each section is electrically short and the results are

\[
\ell_L = \left(\frac{L}{Z_{hi}}\right) \frac{v_c}{\sqrt{\varepsilon_{hi\text{eff}}}}
\]  

(3)

and

\[
\ell_c = \frac{CZ_{low}v_c}{\sqrt{\varepsilon_{low\text{eff}}}}
\]  

(4)

Note that all formulas (1) through (4) are derived with approximation. For initial design, one can use either (1) or (2) to implement \(L\) and either (3) or (4) to realize \(C\). It is found that, based on our experience in this particular design, the synthesized LPF will have an accurate cutoff frequency and better agreement with an ideal LPF response by using (1) and (4). It could be due to the parasitic components existing in the impedance junctions.

B. High-Pass Filters

For the HPF in Fig. 2(b), the \(ABCD\) parameters of the impedance inverters and the shunt stubs are given as [5]:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}_{inv} = \begin{bmatrix}
\cos\left(\frac{\pi f}{2 f_c}\right) & jZ_{inv}\sin\left(\frac{\pi f}{2 f_c}\right) \\
jY_{inv}\sin\left(\frac{\pi f}{2 f_c}\right) & \cos\left(\frac{\pi f}{2 f_c}\right)
\end{bmatrix}
\]  

(5)

and

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}_{stub} = \begin{bmatrix}
1 & \frac{\pi f}{2 f_c} \\
-j Y_{stub}\cos\left(\frac{\pi f}{2 f_c}\right) & 1
\end{bmatrix}
\]  

(6)

where \(Z_{inv}\) and \(Z_{stub}\) are the characteristic impedances of the inverter and stub, respectively. The stub length is determined by choosing \(f_c = 9\) GHz, which will give a sufficiently wide passband for our particular design. The passband performance of the HPF relies on the values of \(Z_{inv}\) and \(Z_{stub}\). When \(Z_{inv} = 50\) \(\Omega\), design data of the stub admittances for a maximally flat response can be found in [8]. It is known that the 3dB point of the HPF, \(f_{3\text{dB}}\), is inversely proportional to \(Z_{stub}\). If it is below 2 GHz, provided \(f_c = 9\) GHz, value of \(Z_{stub}\) will exceed 150 \(\Omega\) which is difficult to implement by the microstrip structure. By comparing coefficients of the insertion loss function derived from the final \(ABCD\) matrix with designated Chebyshev or Butterworth function, \(Z_{stub}\) and \(Z_{inv}\) can be determined. It is found that, however, the 3dB frequency is still dominated by \(Z_{stub}\). Therefore, the desired value of \(Z_{stub}\) can be found by choosing \(Z_{inv}\) a value between 45 \(\Omega\) and 50 \(\Omega\).
C. The Composite BPF and Optimization

The LPF and HPF shown in Fig. 2 can be directly cascaded or embedded each other to form a wideband BPF. Fig. 3 compares the performances of these two BPFs. No optimization is applied to the directly cascaded filter, and its performance is used as a benchmark. Of the directly cascaded BPF, the upper and lower transition bands agree well with its counterparts shown in Fig. 2.

In the proposed composite BPF, the tap positions, impedance inverters and stub lengths can be different from those of the HPF. First, in Fig. 4(a), two hi-Z sections with a low-Z section in between can definitely be equivalent to a $\lambda_g/4$ line as an impedance inverter, and have a high-pass function. It can be proved that the $\pi$-network in Fig. 4(b) also possesses a high-pass characteristic, and the $Z_{stub}$ and $Z_{inv}$ values can be derived in a similar fashion to the method given in [8]. Note that the values of $L_a$ and $L_c$ have been specified by the LPF, thus only $L_{stub}$ and $L_b$ have to be determined by a root-searching program. In the program, $L_{stub}$ is chosen first and then $L_b$ is calculated from the 3dB point. The iteration finishes if the in-band return loss of the composite BPF achieves a satisfactory level. It is found that the case in Fig. 4(a) works well for a bandwidth of about 50%, and the two-patch case in Fig. 4(b) can show a good performance over a bandwidth up to 100%. The composite BPF needs further optimization since the LPF part of the composite BPF structure is perturbed. After optimization, in-band return loss can be further improved up to better than 20 dB as shown in Fig. 3.

III. MEASUREMENTS

Two composite filters, built on a substrate with $\varepsilon_r = 2.2$ and thickness $h = 20$ mils, are designed to demonstrate the proposed idea. Circuit simulation is done before they are fabricated, since parasitic effects of step discontinuities, T-junction and grounding via holes have to be taken into account.
Fig. 5(a) plots the geometry of BPF A which has three low-
Z patches and four short-circuited stubs. The passband is
designed from 6 GHz to 10 GHz, complying with the upper
frequency set of the UWB wireless communications. The
characteristic impedances corresponding to line sections with
widths $W_h$ and $W_o$ are 130 $\Omega$ and 30 $\Omega$, respectively. Fig. 5(b)
shows the simulation and measurement responses. The
measured return loss is better than 15 dB. In the lower
transition band the measurement agrees very well with the
simulation. In the upper transition, the measured data have
deviations from the simulation. The discrepancy may attribute
to the inaccurate modeling of via holes in simulation, since
each via may have a strong radiation at these frequencies. The
photograph of the circuit is in Fig. 5(c).

Fig. 6(a) plots the geometry of filter B. In this circuit, two
short-circuited stubs are used. In the final circuit optimization
for the composite BPF, $L_2$ is increased and $L_3$ decreased by
20%, while the other dimensions have relatively small
changes. The passband is designed from 3 GHz to 10 GHz.
The simulation and measurement data are presented in Fig.
6(b). The experimental circuit has not only a return loss better
than 15 dB from 5 GHz to 9.5 GHz, but also a good rejection
in the upper stopband. Fig. 6(c) shows the photo of the circuit.

IV. CONCLUSION

A new technique for designing microstrip BPFs suitable for
the UWB wireless communications is proposed. The BPF is
designed with a composite structure by embedding an HPF
and an LPF to each other. The HPF is realized by coupled
short-circuited stubs and the LPF is by the well-known
stepped-impedance structure. Although the high-pass and low-
pass structures in a composite BPF are perturbed by each other,
the entire design shows a satisfactory bandpass characteristic
over a wide bandwidth. Two experimental filters are designed
to have bandwidths complying with the upper frequency set
and full-band of the UWB specifications. The measured data
show a good passband characteristic and a good agreement
with the simulated results.

ACKNOWLEDGEMENT

This work was supported in part by the National Science Council,
TAIWAN, under Grants NSC 93-2213-E-009-095 and NSC 93-2752-
E-009-002-PAE.

REFERENCES

pass filter for ultra wideband (UWB) communication systems,”
2003 IEEE Conference on Ultra Wideband Systems and
International Workshop on Ultra Wideband Systems,
three-line microstrip structures,” 2001 IEEE MTT-S Int.
Microwave Symp. Dig., pp. 1593-1596.
synthesizing microstrip bandpass filters with relatively wide
bandwidths,” IEEE Microwave and Guided Wave Letters,
wave-length-coupled transmission-Line filters using Q
distribution,” IEEE Trans. Microwave Theory Tech.,
filters using shorted quarter-wave stubs,” IEEE Trans.