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초소형 40 GHz Hairpin 대역통과 여파기

Compact 40 GHz Hairpin Band-Pass Filter

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[요 약]

본 연구에서는, 밀리미터파 무선 통신 시스템 응용을 위하여 hairpin 구조를 응용한 40 GHz 대역통과 여파기 (BPF; band pass filter)를 설계 및 제작하여 그 특성을 측정하였다. 3차원 전자계분석 툴과 hairpin BPF 설계 수식을 이용하여, 비유전율 2.2와 5 mil 두께의 Duroid (RT5880) 기판에 BPF를 설계하였다. 입•출력단에서 U-shape 공진기의 tapping 위치(t)는 external Q-factor (Q_e)를 추출하여 결정하였고, 다른 공진기들 사이의 커플링 계수는 필터 특성을 고려하면서 물리적 치수를 조정하여 결정하였다. 제작된 hairpin BPF는 probe station에서 probing 방법으로 측정하였고 , 중심 주파수와 대역폭은 각각 41.61 GHz 그리고 7.43 %으로 나타났다. 측정된 입력 및 출력 반사 손실은 통과 대역에서 -10 dB 이하 이고 측정된 삽입손실은 -3.94 dB이다. 제작된 여파기의 크기는 9.1 x 2.8 mm^2 이다.

[Abstract]

In this study, a 40 GHz band pass filter(BPF) employing a hair-pin structure has been designed, fabricated, and characterized for millimeter-wave wireless communication applications. Using the 3 dimensional(3-D) electromagnetic(EM) tool and design equations of the hairpin BPF, the BPF was desgned on the 5 mil-thick Duroid substrate(RT5880) with a relative dielectric constant (ε_r) of 2.2. The tapping point (t) of the U-shape resonator in the input and output port has been determined using extracted an external Q-factor (Q_e). The coupling coefficients between the other resonators are calculated by adjusting the physical dimensions for the desired response of the BPF. The fabricated BPF was characterized using probing method on a probe station. Its measured center frequency(fc) and fractional BW are 41.6 GHz and 7.43 %, respectively. The measured return loss is below −10 dB at the pass band and the insertion loss is 3.87 dB. The fabricated BPF is as small as 9.1 x 2.8 mm^2.

Key word : Band-pass filter, Hair-pin structure, Electromagnetic analysis, Millimeter wave, Wireless communications.

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Ⅰ. Introduction

Recently, the increasing demands for uncompressed data transmission have accelerated realization of broadband wireless systems using millimeter-wave(mm-wave) band because of more available spectrum. Therefore, various systems like a mm-wave imaging, a car radar as well as wireless communications have been proposed and realized. These evolutions have required easy and low-cost implementation technology of millimeter-wave modules. In particular, a compact and low-loss BPF implementation is definitely one of these technical challenges.

In general, mm-wave filters have been developed using a printed circuit board (PCB), a low temperature co-fired ceramic (LTCC)[1] or a liquid crystal polymer (LCP) technology in the past 10 years. The conventional planar filter using PCB always offers advantages such as shorter development period and easier filter synthesis. A hairpin-structured filter [2-5] is a coupling structure which is originated from a parallel-edge coupled filter that is folded to minimize the size [6]. It is very popular for the RF and microwave applications, because of compact topology and easy design. In addition, it satisfies the standard PCB fabrication process.

In this paper, a 40 GHz hairpin BPF has been presented for mm-wave applications. The hairpin structure on a 5 mil Rogers RT5880 substrate is designed using an commercial electromagnetic (EM) analysis tool and is characterized in terms of transmission losses and fractional BW.

Ⅱ. Filter Design

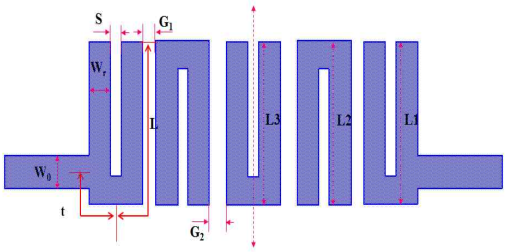


Fig. 1. Schematic layout of symmetric microstrip hairpin BPF (L: the conductor length, Wx: the conductor width, S: spacing of resonator arms, Gx: the gap between resonators).

그림. 1. 대칭 마이크로 스트립 hairpin BPF의 회로도 레이아웃 (L: 도체 길이, Wx : 도체 폭, S : 공진기 arm의 간격, Gx : 공진기 간극)

The low-loss hairpin microstrip BPF was designed to realize the fifth-order Chebyscheff prototype response having a fractional bandwidth (FBW) of 4.87 % at the center frequency of 42 GHz with 0.01 dB ripple. Fig. 1 shows the schematic diagram of a symmetric hairpin microstrip BPF.

An U-shape resonator can be obtained by folding the resonators of parallel-coupled half-wavelength resonator filters.

Due to the reduced length of folded coupled-line resonators, the coupling between them should be taken into account. therefore, a design approach employing full-wave EM simulation is considered to design this hairpin filter [7]. The element values of the low-pass prototype given for a normalized low-pass cutoff frequency f_c = 1 are $g_o = g_6 = 1$, $g_1 = g_5 = 1.1468$, $g_2 = g_4 = 1.3712$, and $g_3 = 1.975$. Using the obtained element values, the BPF design parameters can be calculated by using following equations;

$$Q_{e1} = \frac{g_0 g_1}{FBW} \tag{1}$$

$$Q_{en} = \frac{g_n g_{n+1}}{FBW} \tag{2}$$

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \tag{3}$$

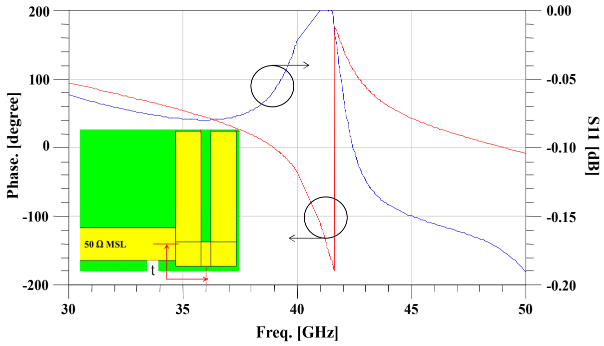
$$\text{for } i = 1$$

Where Q_{e1} and Q_{en} are external quality factors of the resonators at the input and output, and $M_{i,i+1}$ are coupling coefficients between the adjacent resonators. The calculated parameters are $Q_{e1} = Q_{e5} = 23.502$, $M_{1,2} = M_{4,5} = 0.039$, and $M_{2,3} = M_{3,4} = 0.030$.

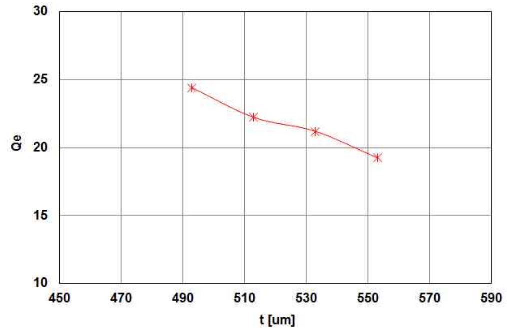
$$t = \frac{2L}{\pi} \sin^{-1}\left(\sqrt{\frac{\pi}{2}\frac{Z_o/Z_r}{Q_e}}\right) \tag{4}$$

The input and output transmission line is tapped from resonators, hence the tapping point (t) needs to be specified. The equation (4) provides the estimation for the tapping point. In which Z_r is the characteristic impedance of the hairpin line. Z_o is the terminating impedance, and L is about a quarter wavelength long. At the center frequency of 42 GHz, L=1,466 ㎛. Because this design equation ignores the effect of discontinuity at the tapped point as well as coupling effects between two folded arms, it just give the estimated value and more accurate value can be obtained by using full-wave EM simulation. In this work, a commercial EM tool [8] is utilized.

Using the EM tool, the tapped line input and output are designed on the 5 mil-thick Duroid substrate (RT5880) with a relative dielectric constant (εr) of 2.2 to estimate the tapping point (t). Considering the minimum spacing between conductor lines in the PCB foundry company, S is fixed to 100 ㎛. Values of Z_r and Z_o are 70 and 50 Ω, respectively. For Z_r, its conductor width is 263 ㎛.



(A)



(B)

Fig. 2. Simulated phase and return loss results (A) of the tapped line input and output at the t = 200 ㎛ and calculated external quality factor (B) (an inset: the designed model to calculate t).
그림. 2. t = 200 ㎛에서 계산된 tap 라인의 입출력의 반사손실 및 위상 (A)과 계산된 외부 품질 계수 (B) (삽입: t를 계산하기 위한 설계 모델).

Fig. 2 (A) shows the simulated phase and return loss (S_{11}) at the t = 200 ㎛. At 41 GHz, the resonance (ω_o) is observed and its phase response is also presented. Using these results, the external quality factor (Q_e) can be calculated by a below equation;

$$Q_e = \frac{\omega_o}{\Delta\omega_{\pm 90^o}} \quad (5)$$

Where ω_o is a resonant frequency and $\omega \pm 90^o$ is a bandwidth of phase difference of $\pm 90^o$ at ω_o. Changing the tapping point (t), the tapped line input and output are simulated and the external quality factor (Q_e) is extracted as shown in Fig. 2 (B). Q_e of 23.502 corresponds with the tapping point (t) of 500 ㎛.

The coupling coefficients between other resonators are calculated adjusting the physical dimensions for the desired response. For easy design, all widths and gap sizes (S) of the U-shape resonators are the same as 263 and 100 ㎛, respectively. Because of the symmetrical structure of the BPF, gaps of G_1 and G_2 between the resonators were optimized to 100 and 130 ㎛, respectively. Finally lengths of the U-shape resonators were adjusted at a minimum value. Each physical dimension of the hairpin BPF shown in **Fig. 1** is summarized in **Table 1**.

Table 1. Physical dimensions of the BPF [㎛].
표 1. BPF의 물리적 치수

W_o	W_r	S	L1	L2	L3	G_1	G_2
320	263	100	1,466	1,477	1,477	100	126

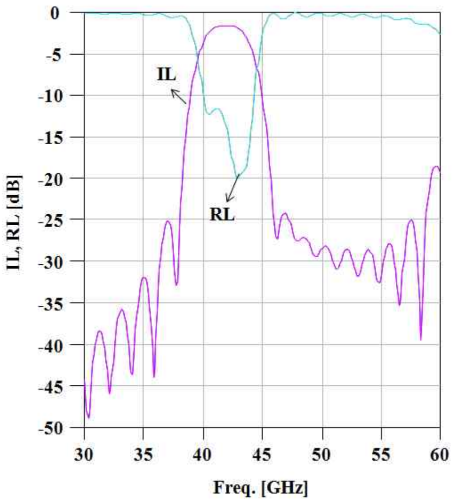
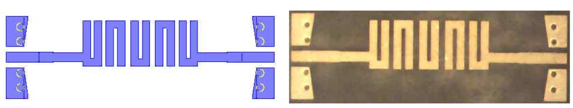


Fig. 3. Simulated results of the 40 GHz hairpin BPF.
그림. 3. 40 GHz hairpin BPF의 시뮬레이션 결과

Fig. 3 presents the designed results of the hairpin BPF. The 3-dB bandwidth ratio is 8.11 % from 40.2 to 43.6 GHz. An insertion loss (IL) of the designed filter is 1.2 dB and its return losses (RL) are below 10 dB for the pass band.

Ⅲ. Fabrication and Measurement



(A) (B)

Fig. 4. Layout of the BPF (A) and fabricated one (B).
그림. 4. BPF의 레이아웃(A)과 제작된 BPF (B)

To characterize the designed filter using probing method, probing pads at the input and output port were designed as shown in Fig. 4 (A). The designed BPF was fabricated on the 5 mil-thick RT5880 substrate. The whole size is 9.1 x 2.8 x 0.125 mm^3. The fabricated BPF is shown in Fig. 4 (B).

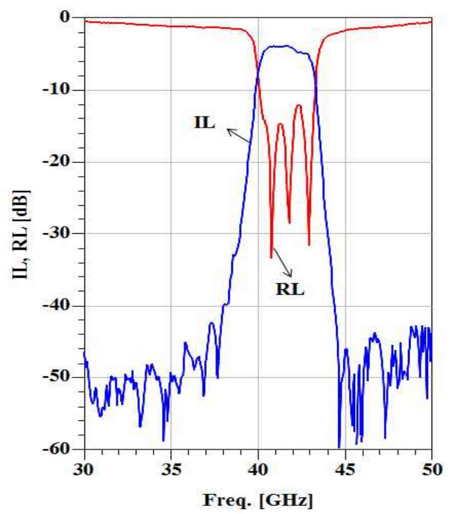


Fig. 5. Measured results of the fabricated BPF.
그림. 5. 제작된 BPF의 측정 결과

The fabricated BPF was measured from 30 to 50 GHz using GSG probes on the probe station. Figure 5 shows the measured results of the fabricated BPF. The 3-dB bandwidth is 3.09 GHz from 40.06 to 43.15 GHz and its fractional ratio is 7.43 %. at the center frequency of 41.605 GHz. The insertion loss (IL) and return loss (RL) are －3.87 dB and less than －10 dB in the pass band, respectively.

Ⅳ. Conclusion

In this work, a compact 40 GHz hairpin band pass filter (BPF) has been presented for millimeter wave applications. The BPF was designed and realized on the 5 mil Rogers RT5880 substrate. Its measured center frequency and fractal bandwidth are 41.6 GHz and 7.43 %, respectively. The measured return loss and insertion loss are below －10 dB at the pass band and 3.87 dB, respectively. The fabricated BPF is as small as 9.1 x 2.8 mm^2.

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