A Compact Micro-strip λ/4-SIR Dual-Band Band-pass Filter Design

Chang Soon Kim\textsuperscript{1} and Tae Hyeon Lee\textsuperscript{1} and Kwang Seob Shin\textsuperscript{2}

\textsuperscript{1}Graduate school, Dept of holography 3D content, Kwangwoon University, 20 Kwangwoon-Ro, Nowon-Gu, Seoul, 01897 hl1stt@hanmail.net, leeth0555@empas.com, ks.shin@ecarplug.com

\textsuperscript{2}Graduate school, Dept of plasma biodisplay, Kwangwoon University, 20 Kwangwoon-Ro, Nowon-Gu, Seoul, 01897

Bhanu Shrestha\textsuperscript{3} and Kwang Chul Son\textsuperscript{*}

\textsuperscript{3}Dept. of Electronics Engineering, Kwangwoon University, Graduate School of Information and Contents, Kwangwoon University, 20 Kwangwoon-Ro, Nowon-Gu, Seoul, 01897

hl1stt@hanmail.net, leeth0555@empas.com, ks.shin@ecarplug.com, bnu56@kw.ac.kr, kcson@kw.ac.kr

Abstract—In this paper, we proposed a dual-band band-pass filter using three microstrip λ / 4 Stepped Impedance Resonator (SIR). In the design, the first and the second bandpass is composed of λ / 4 SIR and the middle λ / 4 SIR that helps to improve the passband characteristics. The characteristic impedance ratio and the electrical length ratio in an intermediate λ / 4 SIR structures are used. It has the advantage of being able to adjust the 1st band easily and accurately. Further, we increased the capability of the rejection band and reduced the insertion loss between the two pass-bands. Specially, the first band and the second band frequencies can be operated at 3.52 GHz and 6.30 GHz respectively. The experiment results show that the insertion loss (S21) of the first band and the second band were 3.97 dB and 3.3 dB, and the reflection coefficients (S11) were 15.1dB and 15.47 dB respectively.

Keywords—Dual-Band Band-Pass Filter; SIR Filter; Microstrip Line; Impedance.

I. INTRODUCTION

Recently, wireless communications systems using multiple bands of radio communication service have been increasing. For example, IEEE502.11 standard of WLAN (Wireless Local Area Network) using the 2.4~2.45 GHz, 5.15~5.85 GHz band and IEEE.16 standard of WiMAX (Worldwide Interoperability for Microwave Access), are using the 2.3~2.7 GHz, 3.3~3.9 GHz, 5.15~5.85 GHz band. Therefore, the demand for multiple bands in the RF front end is increasing which is very important part of the wireless communication systems. Many studies have been carried out for the dual-band band-pass microstrip filter. And there are also notch filters that can be used to sharpen the transmission zero at band-pass filter, wide-band band-pass filter with two passbands [1-3]. Then, λ / 4-SIR (Stepped Impedance Resonator) utilizes the electrical length ratio and impedance ratio of transmission line which can be generated at each frequency to the desired dual-band. The advantages of the designed filter are the improved stop-band characteristics at high selectivity in the pass-band, and small size [4-6]. In this paper, we use three λ / 4-SIRs to design a dual-band band-pass filter of the micro-strip line. In the design, we used the input and middle λ / 4-SIRs for the first band of the dual band filter and for the second band, we used output and the middle λ / 4-SIRs using the characteristic impedance ratio and the electrical length ratio. It has the advantage of being able to adjust the 1st band pass band easily and accurately. By designing and fabricating a dual-band filter operating at 3.52-GHz and 6.30-GHz, to verify the validity of the proposed structure.

II. DESIGN AND SIMULATION OF DUAL-BAND BAND-PASS FILTER

Fig. 1 (a) shows the typical SIR structure. This is a resonator consisting of two parts in the middle of the high impedance with low impedance in both sides. The first band and the second band resonance frequency can be adjusted by selecting the appropriate proportions of high impedance and the low impedance. The ratio of the impedances, R can be defined as the equation (1) [7].

\[ R = \frac{Z_2}{Z_1} \quad (1) \]

The length of the SIR is a half wave as depicted in the Figure 1 (a), however, it is possible to change the λ / 2 to λ / 4 SIR as shown in the Figure 1 (b).

![Diagram of SIR structure](a) λ/2-SIR
The first spurious (FS_sir) and the basic (F0_sir) which is maximum ratio of the resonance and it is possible to obtain θ1 = θ2 = θ0. The resonance ratio is given by equation (2).

\[
\frac{FS_{sir}}{F0_{sir}} = \left( \frac{\pi}{\tan^{-1}} \right) - 1 \ldots \ldots \ldots \ldots \ldots (2)
\]

where R = 1, FS_sir = 3F0_sir, This can be calculated in the case of typical λ / 4 unit of impedance resonator (UIR-Unit Impedance Resonator). We can change and adjust the value of R by using the equation (2). It is found that a higher rate than the low R value. Furthermore, the first spurious resonance with SIR is basically considered which are standardized and the UIR is given by the equation (3), (4).

\[
\frac{FO_{sir}}{FO_{uir}} = \frac{4 \tan^{-1} \sqrt{R}}{\pi} \ldots \ldots \ldots \ldots \ldots (3)
\]

\[
\frac{FS_{sir}}{FS_{uir}} = \frac{4(\pi - \tan^{-1} \sqrt{R})}{3\pi} \ldots \ldots \ldots \ldots \ldots (4)
\]

The stop bandwidth is extended as shown in the above equations (3) and (4) and that assists to reduce the size of the resonator simultaneously. It is necessary to select a low R value for maximum stop bandwidth.

However, the manufacturing tolerance limits the width of the transmission line that makes difficult to realize the microstrip line with small value of R. In order to suppress the high-order resonance, we can use the λ / 4 SIR to obtain the effective dual bandpass characteristics with a small insertion loss. Therefore, we designed a dual-band band-pass filter based on the SIR theory using three λ / 4 SIRs and the pattern of the layout of the designed filter is shown in the Figure 2. The dual bandpass filter is designed and simulated using FR4 PCB with dielectric constant of 4.5 and thickness of 1.6 mm. The designed dual band pass filter has a center frequency of 3.55 GHz and 6.16 GHz for the first and the second band respectively.

![Figure 1. Structure of λ/2-SIR and λ/4-SIR](image1)

![Figure 2. Schematic of the compact and dual BPF](image2)

![Figure 3. Equivalent circuit of the integrated Dual BPF](image3)

In particular, it plays an important role in the adjustment of the center frequency of the 2Z1 and 2Z2 as in Figure 2 that indicates high band pass filter and the low band pass filter. And, 1Z1, 1Z2, 3Z1, and 3Z2 act an important role for improvement of the insertion loss and bandwidth and bandwidth stop-band characteristics. In addition, 1Z2, 2Z1, 2Z2, 2Z3, and 3Z2 have the binding force that makes a very low insertion loss. These binding effects has enabled to improve the bandstop characteristics to generate a transmission zero at both ends of the pass-band. The equivalent circuit of this filter is depicted as in Figure 3.

As in the Figure 3, C1, L1, C1, L2, C2, C2, indicate the first band that resonates at 3.56 GHz representing the low pass band and the L2, C2, C3, L3, C2, indicate the second band that resonates at 6.08 GHz representing the high pass band. It has an input and output port represented by Port 1 and Port 2 respectively. The C1 and C2 represents the parasitic capacitors. The simulated transmission coefficient and the reflection coefficient of the dual bandpass filter are shown in Figure 4.

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*Corresponding author: Kwang Chul Son.*
Figure 4. Transmission and reflection coefficients

The center frequency of the 1st band pass filter is 3.56 GHz, and the transmission coefficient, S21, is 0.8 dB. The input reflection coefficient is 19 dB, and the 3 dB pass band-width is about 200 MHz. Further, the center frequency of the 2nd band pass filter is 6.08 GHz, and the transmission coefficient, S21, is 0.4 dB. The input reflection coefficient is 27 dB, and the 3 dB pass band width is about 520 MHz. Figure 5 shows the distribution of the current density of the dual band pass filter during the random simulations.

FIG. 5 (a) shows the simulation result of the current density at 3.55 GHz of the first band and the Figure 5 (b) shows the results of current density of the second band at 6.13 GHz. As we can see, the input stage and the output stage have weak current flows, while the maximum current is flowing around the central part of the filter. This also confirms that the current flow is maximum in the input stage and the output stage, and the maximum current density is displayed in each of the center of the high-impedance part and the low-impedance part of the λ/4 SIR filter in the middle.

III. FABRICATION AND EXPERIMENT RESULT

The fabricated dual bandpass filter is characterized using the Agilent (HP) 8510C Vector Network Analyzer (VNA). Figure 6 shows the fabricated dual band pass filter.

We used the Sonnet simulator to design the filter and fabricated on the PCB substrate (FR4 glass fiber) which has a dielectric constant of 4.5. The size of the PCB is 30 X 30 X 1.6 mm, and the thickness of the copper plate is 35 μm.

Figure 7 shows the result of the measured transmission coefficient and the reflection coefficient.

In fact, the measurement results show the center frequency of the first band is at 3.52 GHz with the transmission coefficient of 3.97 dB, the input reflection coefficient of 15.1 dB, and the 3dB bandwidth of about 120MHz. In the same way,
the second band has the transmission coefficient of 3.3 dB, the input reflection coefficient of 15.47 dB, and 3dB bandwidth of about 300MHz at 6.30 GHz. We compared the simulation and measurement results in terms of the transmission coefficient and the reflection coefficient as shown in Figure 8. The center frequency of the first band has been changed from 3.54 GHz to 3.52 GHz. The transmission coefficient has been changed from 0.6 to 3.97 dB, and the input reflection coefficient reduced by 3.57 dB (i.e. from 19 dB to 15.47 dB). And, 3dB bandwidth has also been changed from 160 MHz to 120 Hz. The center frequency of the second band has also been changed from 6.14 GHz to 6.3 GHz. The transmission coefficient has been changed from 0.2 to 3.3 dB, and the input reflection coefficient reduced by 11.53 dB (i.e. from 27 dB to 15.47 dB). And, 3dB bandwidth has been changed to 300Hz in 5200 MHz.

Figure 8. The simulation and actual measurement characteristics results

There were three transmission zeros point, which has been changed to four points in the measurement results. For detailed information, they are shown in Table 1.

<table>
<thead>
<tr>
<th>Transmission Zero</th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>TZ1</td>
<td>1.1 GHz / 77.6 dB</td>
<td>1.12 GHz / 43.1 dB</td>
</tr>
<tr>
<td>TZ2</td>
<td>3.84 GHz / 45.0 dB</td>
<td>3.72 GHz / 29.1 dB</td>
</tr>
<tr>
<td>TZ3</td>
<td>7.76 GHz / 31.2 dB</td>
<td>7.18 GHz / 25.0 dB</td>
</tr>
<tr>
<td>TZ4</td>
<td>-</td>
<td>7.56 GHz / 27.0 dB</td>
</tr>
</tbody>
</table>

There are a small difference between simulation and measurement results due to wet etching process and soldering effect in the input and output ports and also there are some parasitic elements in the two ports.

IV. CONCLUSION

In this paper, a dual bandpass microstrip \( \lambda / 4 \) SIR (Stepped Impedance Resonator) filter is proposed which is composed of two \( \lambda / 4 \) SIRs. The second band characteristics is improved by utilizing the intermediate \( \lambda / 4 \) SIR and the first band can be adjusted by utilizing the characteristic impedance ratio and the electrical length ratio in an intermediate \( \lambda / 4 \) SIR structure of three \( \lambda / 4 \) SIR. The measurement results showed that that the transmission losses were 3.97 dB and 3.3 dB at 3.52 GHz and 6.3 GHz respectively. Their reflection coefficients were 15.1 dB and 15.47 dB, and the bandwidth was 120MHz and 300MHz. The first band can be used in satellite communication systems, earth stations and geostationary satellites, it can be easily to communicate with the earth station and the LEO(low earth orbit) satellites while the second band can be applied to earth station and a geostationary orbit satellite in the satellite communication system, It can be used and the application of a fixed Microwave relay system too.

REFERENCES