Constant-Absolute-Bandwidth Frequency-Tunable Half-Mode SIW Filter Containing No Tunable Coupling Structures

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***Abstract*—A new half-mode frequency-tunable SIW (substrate-integrated waveguide) bandpass filter with a constant absolute bandwidth is presented in this paper. For achieving the constant bandwidth, we have developed new external and internal coupling structures capable of exhibiting specified coupling values over the frequency tuning range of the presented filter. Hence, the presented filter employs no tuning components in the coupling structures and this avoids the insertion loss increase due to tuning components. For verification, a second-order filter has been designed, fabricated, and measured. The filter has the insertion loss smaller than 2.0 dB over the frequency tuning range from 1.85 GHz to 2.3 GHz. The bandwidth slightly varies from 136 MHz to 142 MHz.**

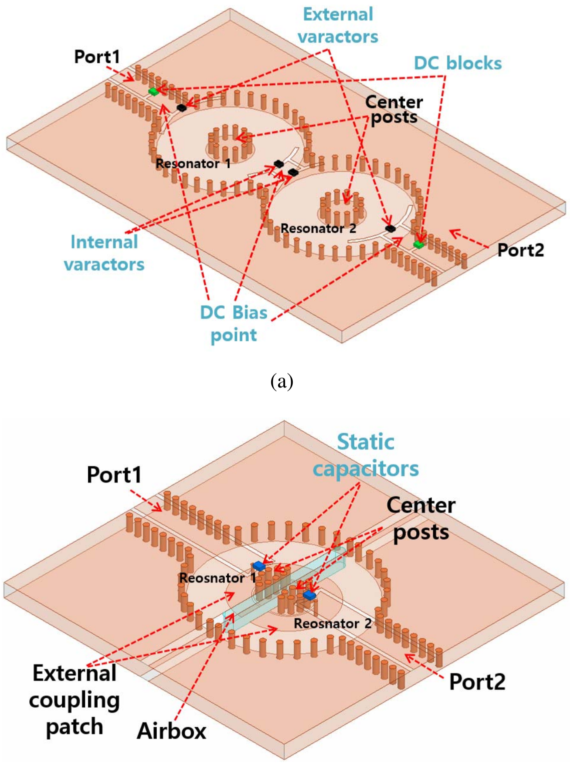
***Index Terms*—Half-mode, SIW, Tunable filter, Bandpass filter, Absolute bandwidth**

I. INTRODUCTION

As wireless communications systems evolve into tunable ones, the design of tunable RF/microwave filters has become a great interest. In general, tunable filters employ tunable resonators and tunable coupling structures so that center frequencies and bandwidths can be adjusted. For instance, a half-mode reconfigurable SIW filter is presented in [1]. This filter uses varactors to control both the center frequency and the bandwidth. [2] and [3] show the varactor-loaded compact filter with a constant absolute bandwidth by using the corrugated coupled-line concept and the modified coupled line concept, respectively. In addition, there exist a number of studies on tunable filters containing varactors that can keep the bandwidth constant [4]-[5]. In [6], a tunable half-mode SIW filter containing RF MEMS switches is presented.

The aforementioned tunable filters have tuning devices such as varactor diodes and MEMS switches, and they augment the insertion loss. In addition, they must be accompanied by DC bias circuits that may increase the insertion loss and the total size of filter structures. Hence, reducing the number of tuning components is important in view of reducing the insertion loss, the complexity, and the total size of frequency-tunable filters.

Hence, this work newly presents a new frequency-tunable half-mode SIW filter structure that can exhibit a constant bandwidth without using lossy tuning component on the coupling structures. To avoid using tuning components on the coupling structures, we have developed new static coupling structures capable of having specified coupling values over the frequency tuning range. The second-order filter fabricated for demonstration shows an almost constant bandwidth (136-142 MHz) when it is tuned from 1.85 GHz to 2.3 GHz.



(a)

(b)

Fig. 1. (a) conventional second-order frequency-tunable SIW filter (b) proposed second-order tunable SIW filter

II. THEORY AND DESIGN

Fig. 1 shows a conventional second-order frequency-tunable SIW filter and the one proposed by this work. The conventional one has a number of tuning devices for controlling coupling structures. Hence, a constant bandwidth can be obtained by adjusting the coupling values when the center frequency varies. The filter proposed by this work has two half-mode frequency-tunable SIW resonators. It contains new static external and internal coupling structures that make the filter have a constant bandwidth over its frequency tuning range.

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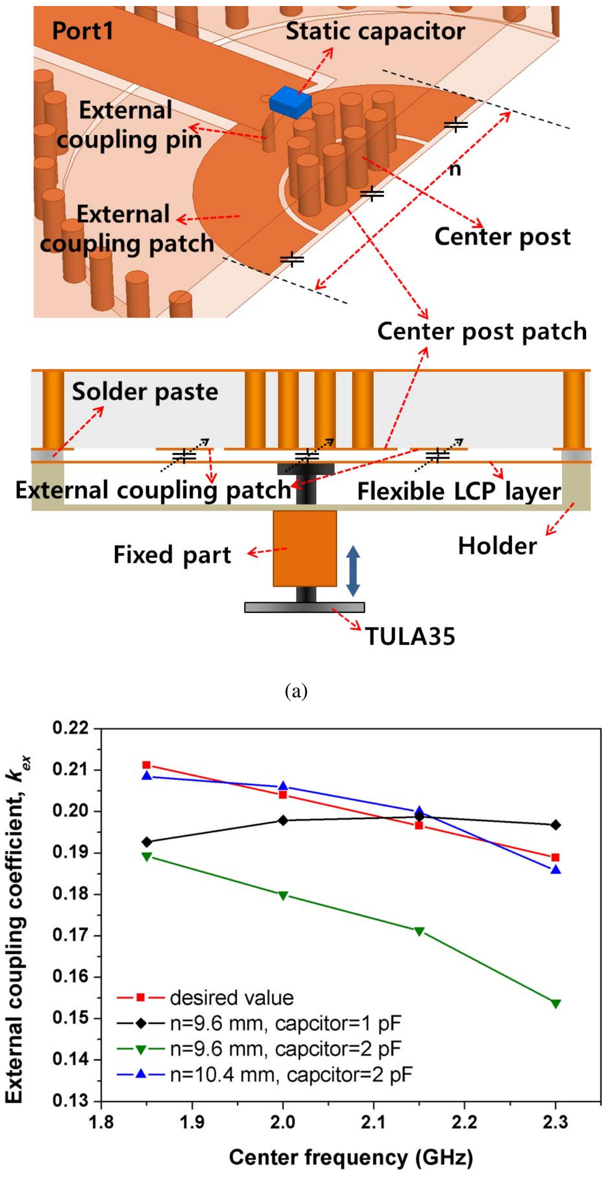

(a)

(b)

Fig. 2. (a) 3-D view and the cross-sectional view of the new external coupling structure and the resonator (b) external coupling coefficient

In this work, the filter is designed to have a 15 dB Chebyshev response with the constant bandwidth of 140 MHz over the frequency range from 1.85 GHz to 2.30 GHz. The specified response mandates the coupling structures to have the physical external and internal coupling values of

$$\begin{aligned} k_{ex} &= \sqrt{fbw} \cdot M_{ex} \\ k_{in} &= fbw \cdot M_{in} \end{aligned} \tag{1}$$

where fbw denotes the fractional bandwidth, and where M_{ex} and M_{in} are the normalized external and internal coupling values, respectively. For the 15 dB Chebyshev response, M_{ex}=0.7712 and M_{in}=0.7719. Since fbw decreases as the center frequency increases, the coupling structures are required to have a smaller coupling value at a higher frequency.

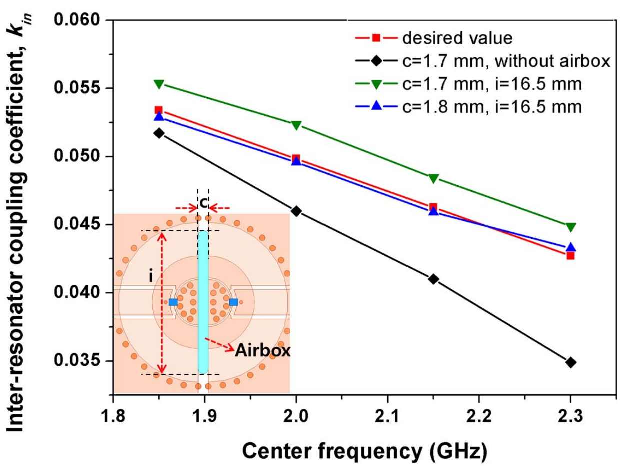

Fig. 3. Inter-resonator coupling structure and the relationship between the coupling coefficient and the center frequency

Fig. 2(a) shows the new external coupling structure used in our filter design. There exists a coupling patch surrounding the post patch on the bottom side of the resonator. This differentiates the new external coupling structure from the conventional one. The resonant frequency of the resonator can be adjusted by changing the gap between the post patch and the flexible LCP (Rogers Ultralam 3850) layer with copper cladding, since the the capacitance between them varies. Meanwhile, the capacitance between the coupling patch and the LCP layer also varies. Controlling this capacitance allows us to obtain the desired external coupling values for a constant absolute bandwidth. Adjustment of these capacitance values is possible by using a piezoelectric actuator (TULA35 from Piezotech), which makes the LCP layer move in the vertical direction. The details of the application of the aforementioned actuator to SIW resonator structures can be found in [7]. Fig. 2(b) shows the external coupling value, k_{ex}, for various capacitors and diameters of the coupling patch. The capacitor placed at the top of the filter can adjust the rate of the decrease of k_{ex} with the frequency. When the static capacitor is 2 pF, k_{ex} is inversely proportional to the frequency, and we can control the magnitude of k_{ex} by changing the diameter of the coupling patch. 10.4 mm and 2 pF have been chosen for the diameter of the external coupling patch and the static capacitor respectively, and these values give the desired coupling value over the frequency tuning range.

According to (1), the inter-resonator coupling value, k_{in}, has to be inversely proportional to the center frequency in order to obtain the absolute constant bandwidth. The inset of Fig. 3 shows the new inter-resonator coupling structure invented by this work. The two resonators are placed close to each other, and the separation between them is denoted by c. We first investigated k_{in} when the two resonators were separated by 1.7 mm, and it is depicted by the black line in Fig. 3. It is shown that the rate of the decrease of k_{in} with the frequency is much larger than that of the desired one depicted by the red line. This rate can be controlled by removing the dielectric material between the two resonators. This task is equivalent to inserting an air box between them. The green line shows the

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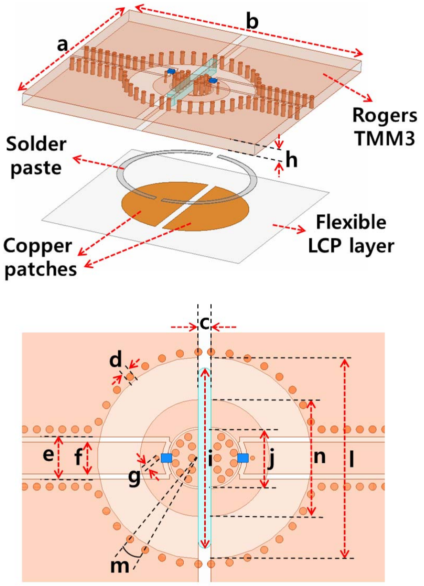


Fig. 4. Physical dimensions of the proposed SIW second-order filter.(a= 40 mm, b= 40 mm, c= 1.8 mm, d=0.75 mm, e=4 mm, f=3 mm, g=0.4 mm, h=1.905 mm, i=16.5 mm, j=5.4 mm, l=20 mm, m=10°, n=10.4 mm)

case that the separation between the two resonators is 1.7 mm and the air box with the length of 16.5 mm is inserted. It can be concluded that the rate of the decrease of k_{in} with frequency is almost identical to the desired one. However, the magnitude of k_{in} still needs to be adjusted, and this can be carried out by adjusting the separation between the two resonators. When the separation is 1.8 mm (blue line in Fig. 3), k_{in} agrees well with the desired one.

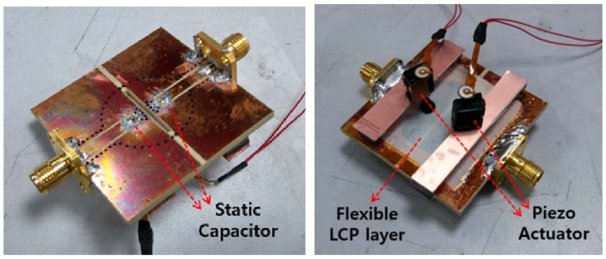
Fig. 4 shows the physical dimensions of the proposed second-order SIW filter. It has been fabricated by the fabrication method described in [8]. The airbox at the center is created by routing process. On the bottom side of the filter, a flexible 25 μm-thick LCP layer with copper cladding (Rogers Ultralam) is laminated with solder paste for tuning the center frequency. It should be noted that this structure does not necessitate any varactors, MEMS switches, DC blocks or RF chokes.

The presented design method can be applied to higher-order filter designs. More specifically, the presented structure can be cascaded for achieving higher-order constant-bandwidth responses and the details will be presented at the symposium.

III. MEASUREMENT

The second-order half-mode SIW filter has been fabricated for verifying the design method for obtaining the constant bandwidth without using tunable coupling structures. Fig. 5 shows the photograph of the fabricated filter. The two piezoelectric actuators are attached to the bottom side of the filter for the center frequency tuning.

Fig. 6 shows the measured frequency response of the fabricated filter and the simulated one centered at 2.3 GHz. There is good agreement between the measurement and the simulation. The center frequency varies from 1.85 GHz to 2.3 GHz with (136-142 MHz) bandwidth. The minimum insertion loss is 1.3 dB at 1.85 GHz and the maximum insertion loss is 2.0 dB at 2.3 GHz. It can be concluded that the presented filter has almost constant absolute bandwidth over the frequency range. Table I summarizes the comparison between previous similar works and this work for the reader's convenience.



(a) (b)

Fig. 5. Photograph of the fabricated filter (a) top-view (b) bottom- view.

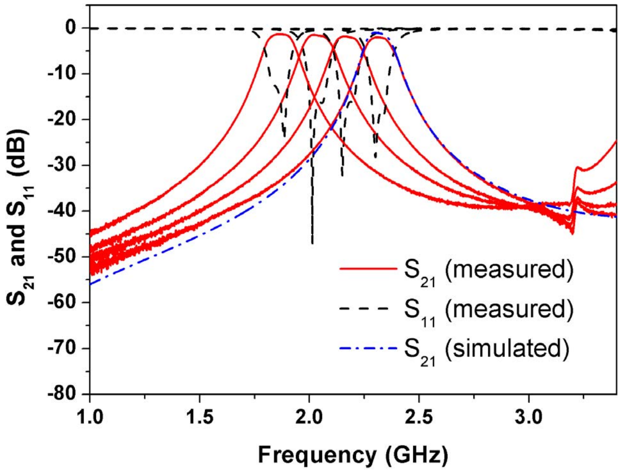


Fig. 6. Measured frequency responses of the fabricated second-order SIW filter and a simulated frequency response.

TABLE I
COMPARISON OF TUNABLE FILTERS

	Number of varactors or MEMS	Insertion loss (dB)	Tuning range	Size (mm)
[1]	6	7-2.6	1.11-1.5 GHz	95×24
[2]	2	2.5-2.9	1.45-1.89 GHz	(>10)
[3]	3	2.4-2.8	0.95-1.55 GHz	30×25
[4]	6	3.2-4.4	0.55-1.9 GHz	35×47
[5]	3	6.8-4.3	1.1-1.88 GHz	40×35
[6]	6	1.2-3.4	1.2-1.6 GHz	74×50
this work	0	1.3-2.0	1.85-2.3 GHz	40×40

IV. CONCLUSION

A new varactorless half-mode tunable filter with a constant absolute bandwidth has been introduced in this paper. During the center frequency tuning, the proposed external and internal coupling structures allow the filter to have a constant bandwidth without using lossy tuning devices. In other words, the filter is able to tune the center frequency without varactors or MEMS switches on the coupling structure, implying that the proposed structure can remove the loss of tuning components. In addition, DC bias circuits do not need to be adopted in this filter design. The measurement has verified the new filter structure.

ACKNOWLEDGMENTS

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