RFIT 2022

2022 IEEE International Symposium on Radio-Frequency Integration Technology

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Program Booklet

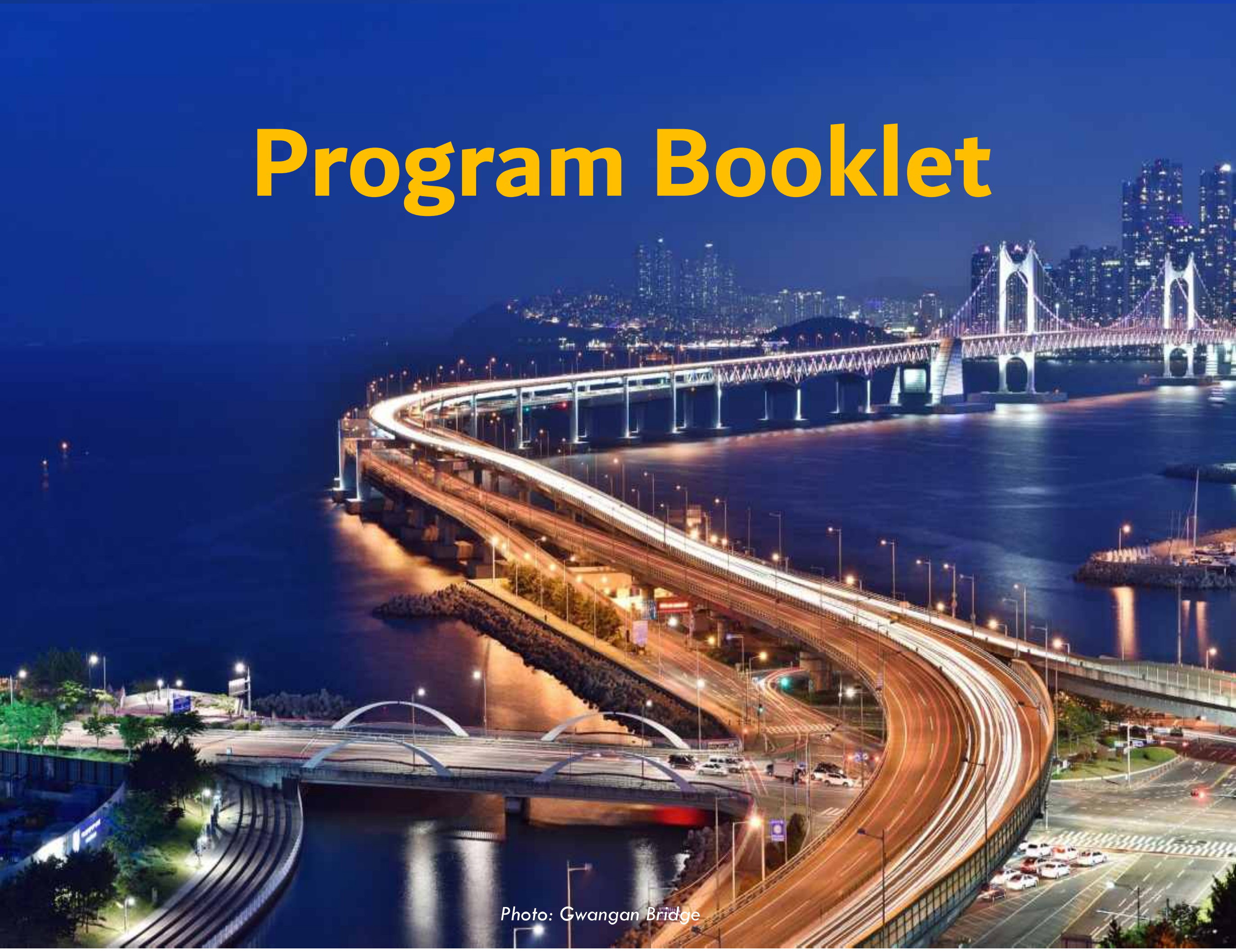

Photo: Gwangan Bridge

W2B: Passive Components

10:40 – 12:00, Wednesday, 31-Aug, Room: Vernazza

Chairs: Minkyu Je, KAIST
Sangkil Kim, Pusan National University

W2B.1 *Invited* **10:40 – 11:00**	**Spatial Separations of Multiple Harmonics** *Gangil Byun (Ulsan National Institute of Science and Technology (UNIST), Korea (South))*
W2B.2 **11:00 – 11:20**	**Multi-Beam Metasurface Scheme Using Polarization Matching for Improving Resource Efficiency** *Sol Kim (Korea Advanced Institute Science and Technology(KAIST), Korea (South)); Hyunyoung Cho, Jeong-Wook Kim, Hyo-Won Lee and Jong-Won Yu (KAIST, Korea (South))*
W2B.3 **11:20 – 11:40**	**Microstrip Line Non-Reciprocal Bandpass Filter With Tunable Center Frequency** *Girdhari Chaudhary, Jaehun Lee and Phanam Pech (Jeonbuk National University, Korea (South)); Yongchae Jeong (Chonbuk National University, Korea (South))*
W2B.4 *Invited* **11:40 – 12:00**	**Study on Loss of Varactor-Loaded Tunable Microstrip Antennas Considering Q Factor** *Eisuke Nishiyama, Ryo Araki and Ichihiko Toyoda (Saga University, Japan)*

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Microstrip Line Non-Reciprocal Bandpass Filter With Tunable Center Frequency

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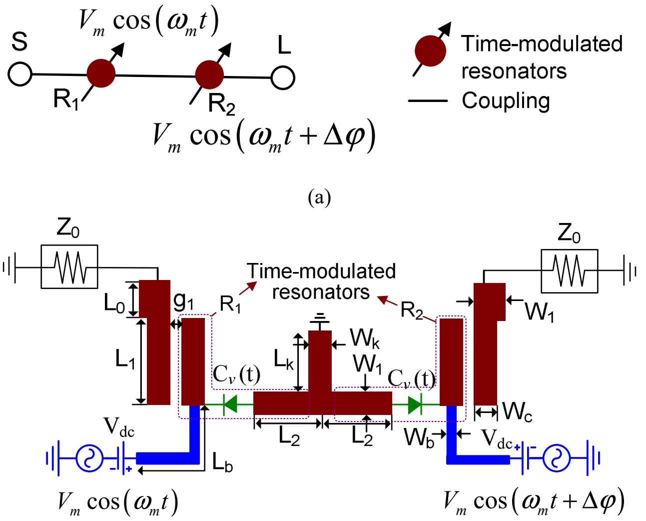
Abstract— **In this paper, we present a design of a magnet-less microstrip line non-reciprocal bandpass filter (BPF) with tunable center frequencies. The proposed non-reciprocal BPF uses quarter-wavelength time-modulated resonators. To achieve a non-reciprocal ($|S_{21}| \neq |S_{12}|$) filter response, a progressive phase shift AC modulation signal is applied to varactors through transmission line, which simplifies the modulation scheme. The center frequency is tuned by changing dc-bias voltage of varactor diode. For experimental validation, a prototype has been designed and fabricated. The measured results confirmed that center frequency is tuned from 1.45 GHz to 1.55 GHz with forward insertion loss variation of 3.71 dB to 3.40 dB and reserve isolation is higher than 10 dB.**

Keywords—Isolator, frequency tunable, magnet-less non-reciprocal bandpass filter, time-modulated resonators.

I. INTRODUCTION

Non-reciprocal components such as circulator and isolator, are crucial to modern wireless communication systems [1], [2]. Non-reciprocal circuits are traditionally almost entirely based on magnetic biasing of ferrite materials. They are cumbersome, costly, and unsuitable for use with integrated circuits [3], [4]. Aactive and non-linear circuits have been attempted with the goal of achieving magnet-less non-reciprocity; however, these approaches suffer from poor noise figure, limited power handling, and small dynamic range [5].

Magnet-less non-reciprocal bandpass filters (BPFs) that allow a signal to travel in only one direction ($|S_{21}| \neq |S_{12}|$) using time-modulated resonators were reported in [6]-[12]. The works [8]-[10] presented lumped element coupled-resonator non-reciprocal BPFs using time-modulated capacitors. A time-varying coupling matrix approach was generalized in [11] to design non-reciprocal BPF. With design, the modulation and RF signals were separated using a low-pass filter (LPF) and a static dc block capacitor and implemented of an additional bias circuit and added duplexing circuits resulted in an increase in overall insertion loss (IL). The work [12] reported a 2-pole microstrip line non-reciprocal BPF based on $\lambda/2$ resonators. Reference [13] extended this design to directly connect an AC voltage modulation signal through a single inductor.



(a)

(b)

Fig. 1. (a) Coupling diagram and (b) proposed microstrip line non-reciprocal BPF using progressive phase shift time-modulated resonators. Physical parameters: $W_1 = 2.38$, $L_1 = 30.7$, $W_c = 1.40$, $g_1 = 0.36$, $L_2 = 13.4$, $L_k = 2$, $W_k = 2.38$, $L_0 = 5$, $L_b = 22$, $W_b = 1$. Dimensions unit: millimeter (mm).

In this work, microstrip line non-reciprocal BPF with tunable center frequency (f_0) is proposed using quarter-wavelength ($\lambda/4$) time-modulated resonators. To achieve non-reciprocal filter response, the modulation signal with progressive phase shift is applied through transmission line.

II. DESIGN THEORY

Fig. 1(a) depicts a coupling diagram of the proposed non-reciprocal BPF, where circled represents time-modulated resonators. Fig. 1(b) shows microstrip line implementation of the proposed non-reciprocal BPF. The source and load impedances of the non-reciprocal BPF are terminated with

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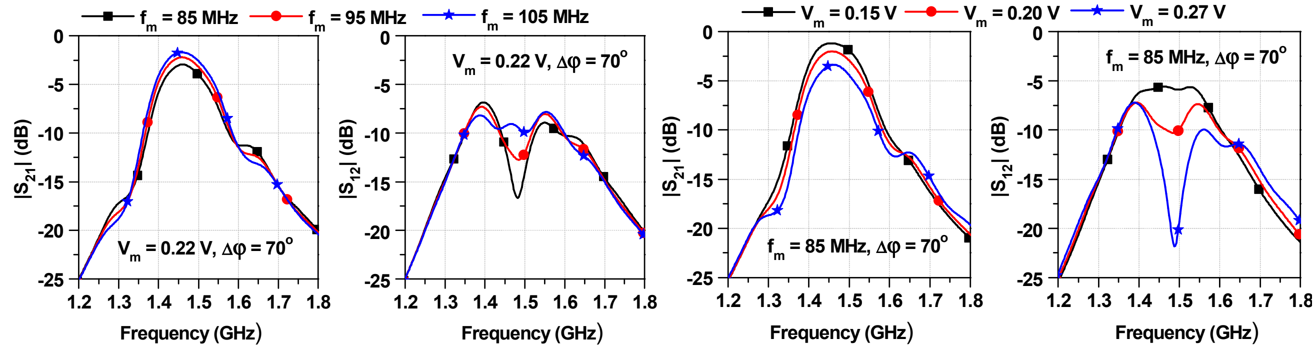

(a) (b)

Fig. 2. Simulation results with different modulation parameters: (a) different modulation frequency f_m, and (b) different modulation amplitude V_m

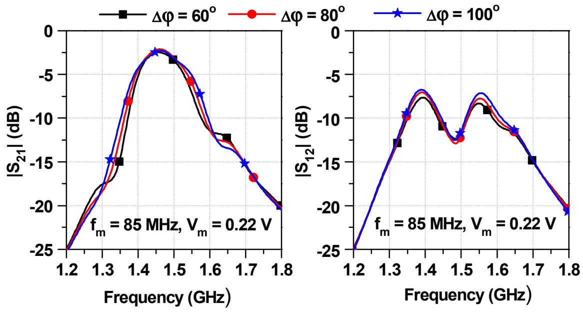

Fig. 3. Simulation results with different progressive phase shift Δφ.

port impedance of $Z_0 = 50\ \Omega$. Time-modulated resonators are coupled through a T-type short-circuited (length L_k and width W_k) and coupled line (length L_1, Width W_c and gap g_1). To achieve a magnet-less non- reciprocal BPF ($|S_{21}| \neq |S_{12}|$), the resonators are modulated in time and space with progressive phase shift AC signal as follows:

$$C_v(t) = C_0 + \Delta C \cos\left(2\pi f_m t + \Delta\varphi\right) \qquad (1)$$

where C_0 is nominal capacitance, ΔC is modulation depth, f_m is modulation frequency, and $\Delta\varphi$ is the progressive phase shift of the modulation signal [8].

When proper modulation parameters ($\Delta C, f_m, \Delta\varphi$) are used, the powers at intermodulation products can be collected at the RF carrier frequency to provide a small forward transmission loss or destructively added up in the reverse direction to create high isolation.

To find the required modulation parameters for achieving non-reciprocal filter response, we performed the parametric studies of modulation parameters (f_m, V_m, $\Delta\varphi$). For this purpose, we used a varactor SMV-1233 SPICE model manufactured by Skyworks [14]. The proposed non-reciprocal BPF is designed on substrate with dielectric constant of 2.2 and thickness of 0.787 mm for Chebyshev response with a center frequency of 1.45 GHz. The physical parameters are shown in Fig. 1(b).

Figs. 2 and 3 shows the simulated results of the proposed non-reciprocal BPF. The proposed filter exhibits non-reciprocal BPF response during various combinations of f_m, V_m, and $\Delta\varphi$.

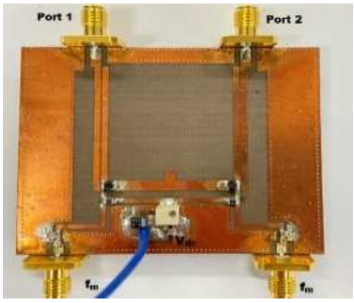

Fig. 4. Photograph of fabricated non-reciprocal BPF.

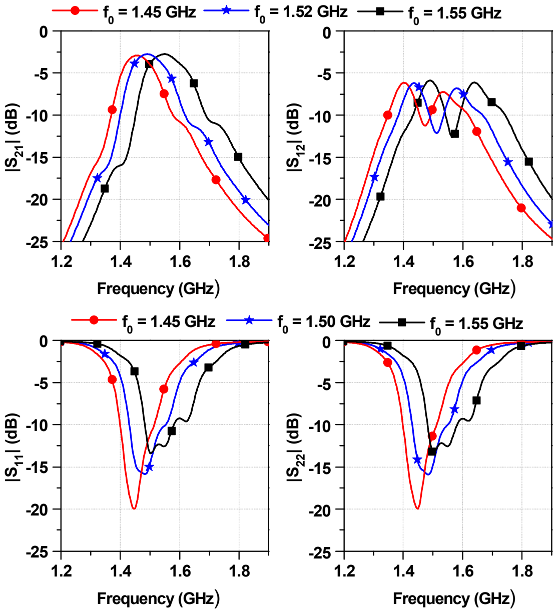

Fig. 5. Simulation results with tunable center frequencies. Modulation parameters: f_m = 85 MHz, V_m = 0.20 V and Δφ = 70°.

When f_m is 105 MHz, the bandwidth of the reverse isolation ($|S_{12}|$) increased, but isolation magnitude at f_0 decreased. When f_m is 85 MHz, reserve isolation is high at f_0, however, isolation bandwidth decreased. Likewise, a large V_m exhibits high reverse isolation, but the forward insertion loss ($|S_{21}|$) slighly degraded. The proposed non-reciprocal BPF exhibits strong reverse isolation when $\Delta\varphi$ is between 60° and 100°.

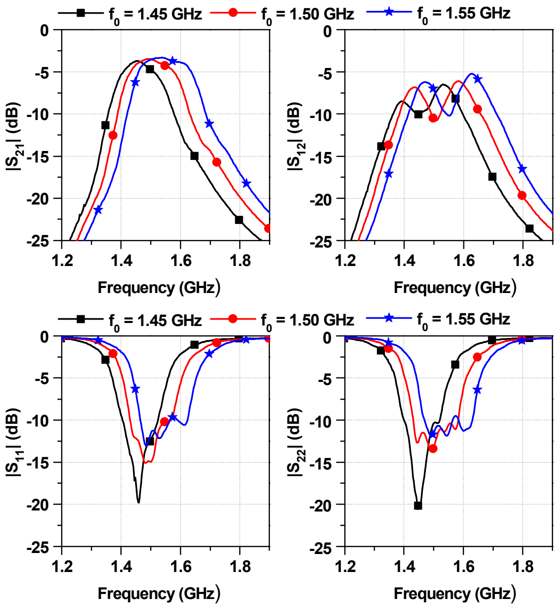

Fig. 6. Measurement results with tunable center frequencies. Modulation parameters: f_m = 85 MHz, V_m = 0.25 V, and $\Delta\varphi$ = 70°.

III. EXPERIMENTAL RESULTS

To experimentally validate, a prototype of non-reciprocal BPF at f_0 of 1.46 GHz was designed and fabricated. Fig. 4 shows a photograph, of the fabricated non-reciprocal BPF. The simulation was performed using ANSYS HFSS and Keysight ADS in conjunction with a large signal scattering analysis module. The time-varying capacitor was implemented by modulating varactor SMV 1233-079LF. According to the previously described parametric studies, the modulation parameters of f_m = 85 MHz, $\Delta\varphi$ = 70°, and V_m = 0.2 V are chosen for non-reciprocal BPF response.

Fig. 5 shows the simulated results of the proposed non-reciprocal BPF. The center frequency of non-reciprocal BPF is tuned from 1.45 GHz to 1.55 GHz with forward insertion loss ($|S_{21}|$) variation of 2.62 dB to 3.12 dB. The backward isolation ($|S_{12}|$) is higher than 10.5 dB at tuning state center frequency. The input and output return losses are higher than 10 dB.

Fig. 6 shows measurement results of the non-reciprocal BPF. The measured forward insertion loss ($|S_{21}|$) varied from 3.71 dB to 3.40 dB while tuning center frequency from 1.45 GHz to 1.55 GHz. Likewise, the measured reserve isolation ($|S_{12}|$) was higher than 10 dB at each tuning state center frequency. The input and output return losses are higher than 10 dB.

IV. CONCLUSION

In this paper, we demonstrated the microstrip line non-reciprocal bandpass filter with tunable center frequencies using time-modulated resonators. The non-reciprocal bandpass filter response is achieved when resonators are modulated with progressive phase AC signal and proper modulation parameters. As proof of concept, a prototype of microstrip line non-reciprocal bandpass filter was designed and fabricated and measured results were agreed well with simulation.

ACKNOWLEDGMENT

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