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New Harmonic Suppressed Microstrip Ring Bandpass Filters

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Abstract

In this paper, new bandpass filters that are composed of microstrip ring resonators with the center frequency of 5.775 GHz and the bandwidth of 100 MHz are presented. For the suppression of the unnecessary harmonics, lowpass filters are inserted into the feedlines and ring resonator itself, respectively. These bandpass filters show good microwave characteristics with the harmonic suppression ratio of about 39 dB and 35 dB, respectively. Also, the varactor-tuned microstrip ring bandpass filter with harmonic suppression is suggested and the tuning bandwidth of more than 450 MHz is obtained.

I. INTRODUCTION

The microwave filter is a two port network used to control the frequency response at a certain point in a microwave system by providing transmission at frequencies within its passband, and attenuation in the stopband. Typical frequency responses include low-pass, high-pass, bandpass, and band-reject characteristics. These filters have been designed with variable resonators such as coaxial, microstrip, stripline, CPW, and slotline resonator. The microstrip resonator supports the quasi-TEM mode and can be fabricated by photolithography process and easily integrated with other devices[1],[2].

Distributed elements such as microstrip in microwave band have harmonic components, which are unnecessary characteristic in filter application[2]. Therefore, it is required to develop microstrip filters in which only the specific frequency range can be passed with the sufficient suppression of harmonics. Marti, *et. al* recently suggested the ring bandpass filters with these characteristics by inserting low pass filters into the structures[3].

In this paper, new band-pass microstrip ring filters with two lines-to-ring coupling structure, which are applicable to MMIC (Monolithic Microwave Integrated Circuit)/MIMIC(Millimeter-wave Monolithic Integrated Circuit). Also these circuits can be applied to the RF-photonics.

II. MICROSTRIP RING BANDPASS FILTERS WITH HARMONIC SUPPRESSION

Generally, the ring resonator resonates when the mean circumference of the ring is equal to an integral multiple of guided wavelength (λ_g). This is expressed as

$$2\pi r = n\lambda_g \quad \text{for } n = 1,2,3\cdots \tag{1}$$

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{eff}}} \tag{2}$$

When we design the ring resonator with loose coupling structure, the effect of gap capacitance between the feedline and ring has to be considered because this gap capacitance affects the mean circumference of the ring[4],[5]. If the small gap size for the tight coupling is

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adopted, the effective mean circumference becomes large and the resonant frequency becomes lower.

The two lines-to-ring coupling structure was suggested to reduce the insertion loss for the microwave-optoelectronic performance of a ring resonator[6],[7]. This ring has open slits at $\phi = 0°$ and $\phi = 180°$. The open ring with two slits at $\phi = 0°$ and $\phi = 180°$ has same resonant characteristics as the conventional ring resonator. Therefore, the two lines-to-ring coupling resonator supports the resonant frequencies of all modes.

There are two types of bandpass filters from the ring resonator. First, dual mode bandpass filter can be designed by using the asymmetrical ring resonators. In this case the bandpass filter has narrow passband characteristic, large insertion and return losses at the first resonant mode. The second method is a multistage bandpass filter consisting of a couple of resonators. This microstrip ring has a bandpass characteristic at the first resonant mode with low insertion and return losses. In this paper, the bandpass filters are composed of two ring resonators in order to get the dual pole bandpass characteristic at the fundamental resonance.

U. Karacaoglu and J. Marti introduced the bandpass filters with harmonic suppression [3],[8]. In this paper, the new harmonic suppressed microstrip ring bandpass filter with two lines-to-ring coupling structure for tight coupling is investigated. Two topologies for rejection of the harmonics are presented. First one uses lowpass filters at the input and output ports. Second topology inserts the stepped impedance circuits into the ring. Each ring structure of bandpass filter is designed by 8-sided polygon and its 8 sides are connected with microstrip band with 135° of angle. Also, the input and output circuits of every ring resonators consist of two of three coupled lines and open slit. These ring resonators can be modeled by ABCD parameters. Then, LPF is inserted into the feed line and the ring itself, respectively.

Fig.1 illustrates two stepped impedance lowpass filters at the input and output feedlines. This ring bandpass filter is fabricated on Chukoh CGP500 substrate with $\varepsilon_r = 2.6$, thickness $h = 0.504$ mm, metal thickness $t = 0.018$ mm, and loss tangent $\delta = 0.0022$. The width of a ring is determined as to have characteristic impedance of 50 Ω. In order to obtain a fundamental resonant frequency of 5.775 GHz, the mean radius is calculated as 5.63 mm by using equation (1). The coupled line length (θ) is 45°, coupling gap (s) is 0.18 mm and the coupled structure width (W_c) is optimized to 0.4 mm for impedance matching.

Fig. 1. The new microstrip two-stage two lines-to-ring bandpass filter with lowpass filter at feedlines.

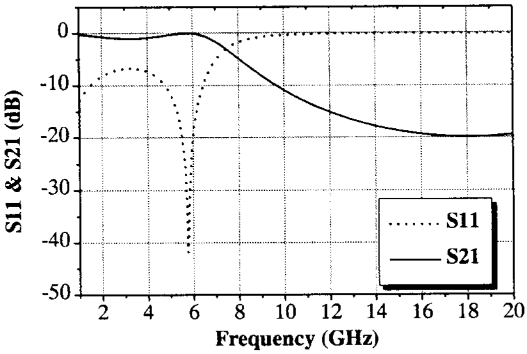
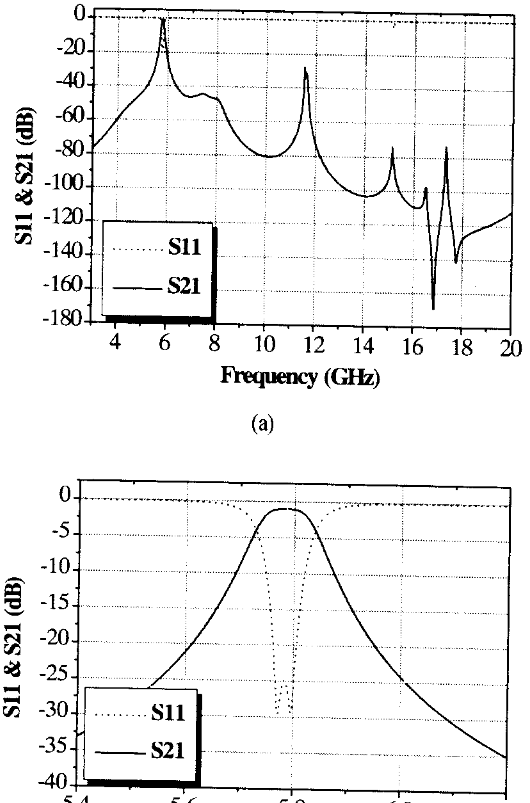


Fig. 2. The simulation results for the lowpass filter.

The frequency response of the lowpass filter is shown as Fig. 2. Because the center frequency of a two-stage ring filter can be passed and unwanted modes are attenuated by this lowpass filter, its cutoff frequency is fixed to 7.7 GHz. The insertion losses for the lowpass filter are 0.28 dB at 5.88 GHz, and 14 dB at near the third resonant mode, respectively as shown in Fig. 2.

Fig. 3 shows the characteristics of the ring filter with lowpass filter when coupling gap size between two resonators is 0.75 mm. As shown in Fig. 3, the insertion losses of harmonics are lower than 25 dB.

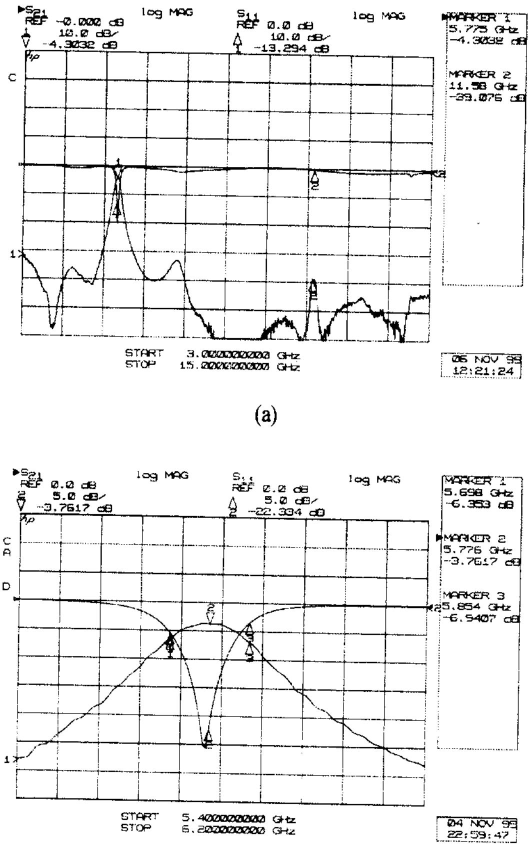


(a)

(b)

Fig. 3. The simulation results for two-stage two lines-to-ring bandpass filter using lowpass filters in input/ output feedlines. (a) wide span, (b) narrow span.

Fig. 4 shows the measurement results of the actual two-stage two lines-to-ring bandpass filter using a HP 8510C network analyzer. As shown in the figure, this circuit has the bandpass characteristic with the center frequency of 5.776 GHz and the bandwidth of 156 MHz. Also, the second harmonic is successfully attenuated to 39 dB. Table 1 summarizes the data comparison between the design and measurement values for the new microstrip ring bandpass filter with lowpass filter inserted at the feedlines. The differences between the simulation and measurement values come from the reason that the ring is analyzed as an 8-sided polygon in the simulation while it is implanted by a circular ring. Also, when it is simulated, the lengths of inner and outer coupled lines are the same while they are different in the real ring circuits because of electrical



(a)

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Fig. 4. The measurement results for two-stage two lines-to-ring bandpass filter using lowpass filters in input/ output feedlines. (a) wide span, (b) narrow span.

Table 1. The comparison of designed and measured values for two-stage two lines-to-ring bandpass filter inserted LPFs at feedlines.

Parameters	Designed value	Measured value
Center frequency	5.775 GHz	5.776 GHz
3 dB Bandwidth	100 MHz	156 MHz
Return loss	25 dB	22.334 dB
Insertion loss	1.036 dB	3.7617 dB
Harmonic suppression	< 25. 9 dB	< 39 dB

length of 45°. To reduce this error, the schematic structure of simulation is needed to make it circular. If the size of the ring is enlarged by using lower dielectric substrate, the error can be reduced owing to the reduction of curvature effect of the ring[10].

To get the harmonic suppressed filter with ring structures, two mode suppression ring resonators can be used. For the case of microstrip bandpass filter with lowpass filter at the feedlines, the harmonics are attenuated under 39 dB but the size of circuit becomes large because of two lowpass filters at the input and output feedlines. In order to reduce the size of the two-stage ring bandpass filter with harmonic suppression, the stepped impedance circuit is integrated into the ring resonator.

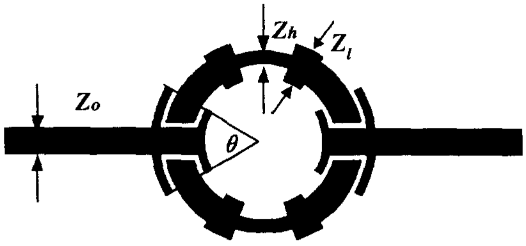


Fig. 5. The mode suppression ring resonator with two lines-to-ring coupling structure.

Fig. 5 shows the layout for the mode suppression ring resonator with two lines-to-ring coupling structure. The lowpass filters are placed at the maximum field point of certain frequencies and the S-parameter characteristics are affected by them. Fig. 6 and 7 show the simulation and experimental results for widths of the feedlines and rings (W) = 1.369 mm, width of coupled lines (W_c) = 0.4 mm, all gaps (s) = 0.18 mm, electrical length of coupled lines (θ) = 45°, the highest practical line impedance in the ring (Z_h) = 68.83 Ω, and the lowest line impedance in the ring (Z_l) = 33 Ω. From

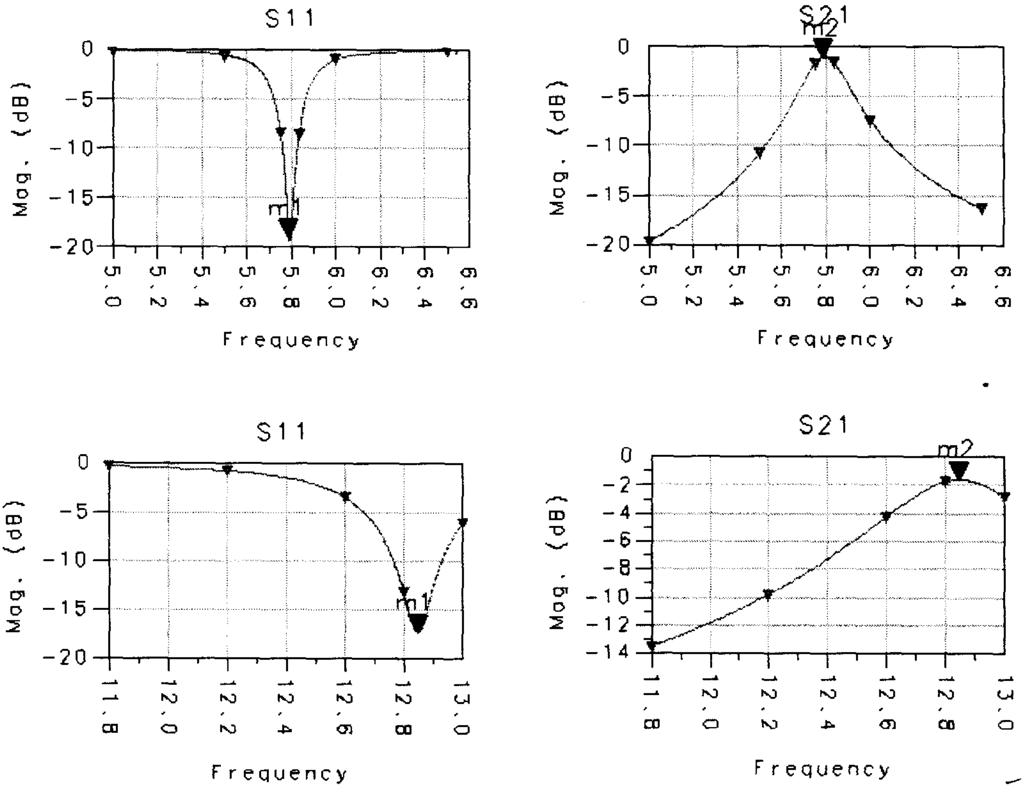


Fig. 6. The simulation results for the mode suppression ring resonator with two lines-to-ring coupling structure.

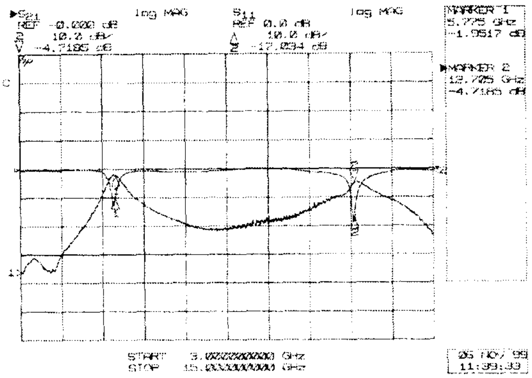


Fig. 7. The measurement results for the mode suppression ring resonator with two lines-to-ring coupling structure.

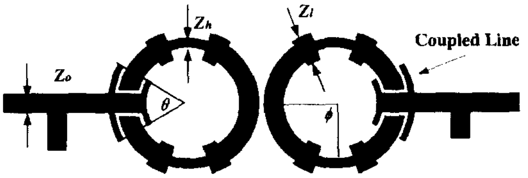


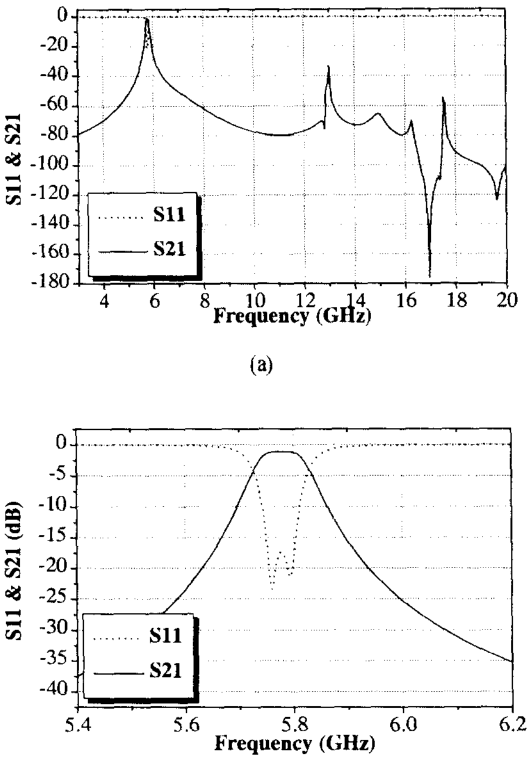
Fig. 8. The new microstrip ring bandpass filter with two mode suppression ring resonator.

the figure, it can be observed that the second harmonic is effectively suppressed by the inserted lowpass filters.

Fig. 8 shows the layout for the bandpass filter with two-stage mode suppression ring resonators. The coupling space between two ring resonators is determined to 0.65 mm and the lengths of two $\lambda/4$ open stubs at input and output feedlines which are chosen for attenuation of unwanted frequencies, are 3.88 mm and 2.75 mm, respectively. The insertion loss and return loss for this ring filter are shown in Fig. 9. As shown in the figure, the bandpass filter is centered at 5.775 GHz with 100 MHz bandwidth and the insertion loss for other harmonics is lower than 32 dB.

In Fig. 10, frequency response for the bandpass filter is observed with the center frequency of 5.752 GHz and 3 dB-bandwidth of 158 MHz. Furthermore, the second harmonic suppression of near 35.17 dB is achieved. Table 2 gives a comparison data between simulation and measurement. As summarized in Table 2, the minimum insertion loss is 3.9448 dB and return loss is 14.9 dB in its passband. Since the ring resonator was predicted as an 8-polygon resonator, the errors between simulation and measurement can be occurred. Therefore, the coupling effects between two ring resonators are not sufficient in the experiment. Also, high insertion loss is due to the radiation loss from discontinuity in the mode suppression ring. This high insertion loss can be reduced by using another types of resonator such as a loop resonator or elliptical resonator with the two lines-to-ring coupling structure.

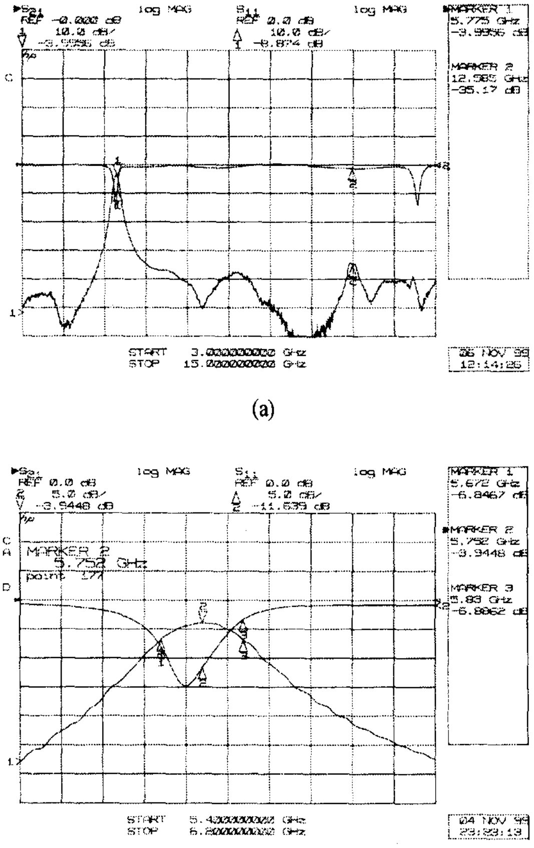
To suppress undesirable harmonics, two new microstrip ring bandpass filters are presented in this paper. These ring bandpass filters are expected to contribute to the suppression of the spurious signal in a microwave



(a)

(b)

Fig. 9. The simulation results for the new microstrip ring bandpass filter with two mode suppression ring resonators. (a) wide span, (b) narraw span.



(a)

(b)

Fig. 10. The measurement results for the new microstrip ring bandpass filter with two mode suppression ring resonators. (a) wide span, (b) narrow span.

Table 2. The comparison of designed and measured values for the new microstrip ring bandpass filter with two mode suppression ring resonators.

Parameters	Designed value	Measured value
Center Frequency [GHz]	5.775	5.752
3dB Bandwidth [MHz]	100	158
Return Loss [dB]	17	14.9
Insertion Loss [dB]	1.046	3.9448
Harmonic Suppression [dB]	< 32.19	< 35.17

amplifier. When the bandpass filter using mode suppression ring resonator compares to the two-stage microstrip ring bandpass filter with lowpass filter at feedlines, the former has an advantage of a compact size while the performance is a little worse than the latter.

Ⅲ. VARACTOR-TUNED MICROSTRIP RING BANDPASS FILTER

The varactor diode is a nonlinear device and provides a voltage-dependent variable junction capacitance. Varactors are generally semiconductor p-n junctions, Shottky-barrier junctions, or point-contact diodes made from gallium arsenide or silicon. Varactor diodes are usually operated under reverse bias conditions since forward biased voltage results in a large leakage current and low Q[9].

The junction capacitance can be expressed as

$$C_j(V) = C_{j0}\left(1-\frac{V}{V_{bi}}\right)^{-\gamma} \qquad (3)$$

where C_{j0} is the capacitance at zero bias voltage, V_{bi} is the built-in potential of 1.3 volts for GaAs, and γ is a parameter depending on the PN junction doping profile.

In this paper, the new varactor-tuned microstrip ring bandpass filter with harmonic suppression is studied. This ring filter is realized using varactor diodes into the ring bandpass filter with two mode suppression rings. Fig. 11 shows a two-stage tunable bandpass filter with harmonic suppression. In the varactor diode, a variable junction capacitance is used as tuning element.

The varactor diode provides a voltage-dependent variable capacitance. When this varactor is mounted in series with the microstrip ring, the variable capacitance values can affect the resonant frequency. Large capacitance will result in large circumference and thus lower the resonant frequency[10].

For the application of the varactor diodes into the ring circuits, the small gaps at ϕ = 90° are introduced in the each ring as shown in Fig. 11 and the photograph of the circuit is shown in Fig. 12. The varactor-tuned microstrip ring bandpass filter with harmonic suppression has been fabricated on Teflon substrate (Chukoh CGP 500). The design parameters are given as following: relative dielectric constant (ε_r) = 2.6, height of substrate (h) = 0.504 mm, effective radius (r) = 5.23 mm, widths of the feedlines and rings (W) = 1.369 mm, width of coupled lines (W_c) = 0.4 mm, all gaps (s) = 0.18 mm, electrical length of coupled lines (W_c) = 45°, the highest practical line impedance in the ring (Z_h) = 68.83 Ω, the lowest line impedance in the ring (Z_l) = 33 Ω. A design CAD tool, HP ADS ver. 1.1 and HP EEesof Libra ver. 6.1 are used for the design of the new varactor-tuned microstrip ring bandpass filter with harmonic suppression.

To predict the frequency response for the bandpass filter, an RLC - equivalent circuit can be substituted for the varactor diode as shown in Fig. 13. In this experiment, varactor diodes made from M/A COM (model 46609 and 276 case type) are used. This varactor for equation (3) has a C_{j0} of 2.37 pF, V_{bi} of 1.3 V for GaAs, and γ of 0.5 for the abrupt junction. In this case style, case parasitic value, L_p and C_p are given from a data book as the values of 0.4 nH and 0.13 pF, respectively and the series resistance associated with the semiconductor (R_s) is given approximately as the value of 1 Ω. Also, gap capacitance (C_2) of the equivalent L-network, which is suggested by C. C. Yu, is calculated as 0.013 pF, while the parallel capacitance is neglected [5]. The soldering inductance and the lead of varactor (L_s) is given approximately as 0.2 nH. The junction capacitance (C_j) can be obtained in high frequency according to this equivalent circuit model for the varactor diode. With these parasitic values of varactor, the junction capacitance can be expected to be from 0.4 pF to 5.3 pF. When the varactors are mounted

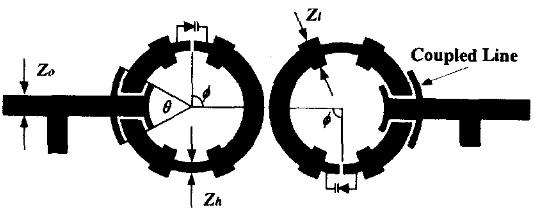


Fig. 11. The varactor-tuned microstrip ring bandpass filter with harmonic suppression.

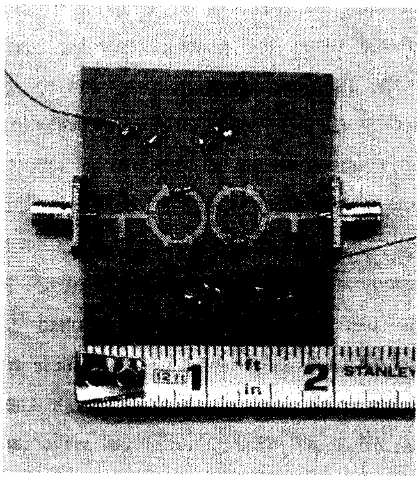


Fig. 12. Photograph of the varactor-tuned ring bandpass filter with harmonic suppression.

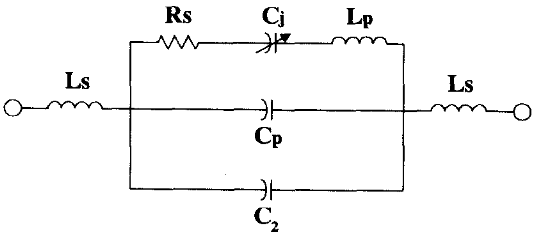


Fig. 13. Equivalent circuit for the packaged varactor diode.

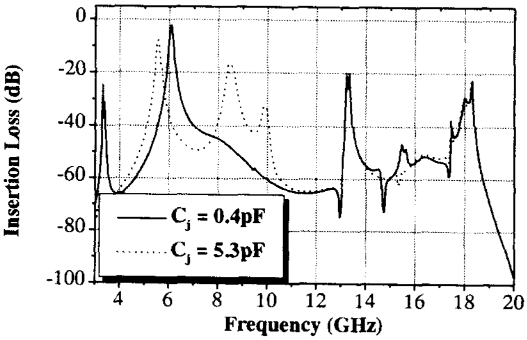


Fig. 14. The simulation result for the varactor-tuned ring bandpass filter with harmonic suppression.

at gap ϕ = 90° into the each ring, the simulation results for this tunable filter are shown in Fig. 14. The tuning bandwidth for the center frequency is approximately predicted from 5.55 GHz to 6.06 GHz.

For the measurement of S-parameter characteristic for the varactor-tuned microstrip ring bandpass filter with harmonic suppression, a HP 8510C network analyzer is used. Fig. 15 shows the experimental results for the ring filter with harmonic suppression. The center frequency for the microstrip ring filter is varied from 5.58 GHz at the bias voltage of +3 V to 6.03 GHz at −17.5 V. This corresponds to the tuning bandwidth of approximately 450 MHz. Also Fig. 15 shows the good characteristic of the harmonic suppression. Fig. 16 shows the plot of center frequency for this filter as a function of bias voltage. This varactor-tuned ring bandpass filter was tested in the bias voltage range from −17.5 V to +3 V. However, if the reverse bias voltage of −30 V, which is the maximum reverse bias value for the varactor, is applied for the diodes, the tuning bandwidth will be broader than 450 MHz. Also, the insertion loss of this filter can be improved by a smaller gap for the integrated varactor diode and by using the resonators with the sufficient coupling effect.

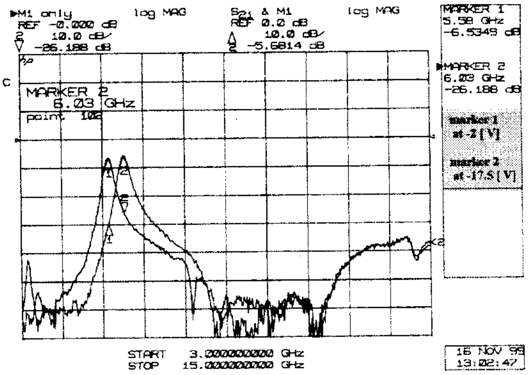


Fig. 15. The experimental result for the varactor-tuned ring bandpass filter with harmonic suppression.

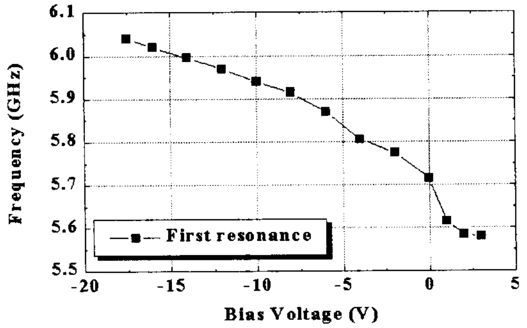


Fig. 16. The center frequency values for the applied bias voltages for the varactor-tuned ring bandpass filter.

Ⅳ. CONCLUSIONS

The new microstrip ring bandpass filters with harmonic suppression characteristic have been suggested in this paper. One is the two-stage microstrip ring bandpass filter with lowpass filter at feedlines. The other is the two-stage microstrip ring bandpass filter with two mode suppression ring resonators. These filters with 100 MHz bandwidth at 5.775 GHz was designed, fabricated, and successfully demonstrated. The new microstrip ring bandpass filters are attractive for high performance filters with harmonic suppression and good flatness within the passband. If a model which can describe for the characteristics for two lines-to-ring coupling structure, will be suggested, then the ring and filter including the effects of this coupling structure can be analyzed using the general resonator and filter theory. The insertion and return losses can be expected to reduce by using the modified ring resonator to obtain sufficient coupling effects between two resonators. Also, the varactor-tuned microstrip ring bandpass filter was designed and demonstrated with high harmonic suppression ratio and tuning bandwidth of 450 MHz.

These planar structures can be applied for the MMIC, RFIC and RF-photonic devices. These types of circuits can be easily fabricated with slotline and CPW structure which are used in millimeter-wave range. If the microstrip ring bandpass filters with harmonic suppression are fabricated on HTS (High Temperature Superconductor), it is expected to be enhanced in insertion and return loss characteristics with narrow bandwidth.

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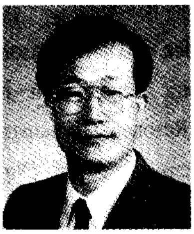

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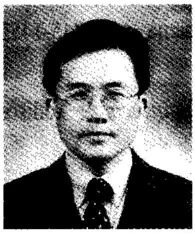

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