Low Voltage Tunable Narrow Bandpass Filter using Cross-Coupled Stepped-Impedance Resonator with Active Capacitance Circuit

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Abstract — This paper proposes a tunable bandpass filter using cross-coupled SIRs(stepped-impedance resonators) with active capacitance circuit. To use low varactor bias voltage, the resonator with 36.8 degree(0.1λ) electrical length is used. For good insertion loss, active capacitance circuit is used. For high selectivity and constant bandwidth, cross coupling is utilized and the SIR configuration is used for enhanced stop-band performances. The proposed tunable bandpass filter with 2.54% of fractional bandwidth at 1.85 GHz was fabricated and tested. The measured results show 1.8GHz-1.95GHz tunable range, constant bandwidth, high selectivity, enhanced stop-band and low insertion loss. Bias voltage of the varactors is up to 3.3 V.

Index Terms — varactor, active circuits, cross coupling, selectivity, constant bandwidth, low voltage control

I. INTRODUCTION

Recently, the convergence of the multiband communication systems into a compact mobile terminal requires tunable bandpass filters, in which the characteristics of the conventional filters, such as narrow and constant bandwidth, high selectivity and good stop-band performances, must be included. It is also necessary to have enough frequency tuning range in low voltage.

Varactor-tuned bandpass filter has been studied because of its various merits [1]. For enhanced selectivity in a tunable bandpass filter, structures using an open stub [1] or source/load-multi resonator coupling [2] were proposed. For enhanced stop-band performances, a tunable filter using the resonator of lowpass type was proposed [3]. Moreover, the structures using SIRs [4] or a coupling-controlled varactor [5] were proposed for enhanced selectivity in a tunable filter. However these structures can’t satisfy any conditions in tunable filter for multi-channel.

For multi-channel tunable filter, this paper proposes tunable bandpass filter using cross-coupled SIRs with active capacitance circuit. For wide tuning range by low varactor bias voltage, 36.8 degree resonator at 1.8 GHz is used in Fig.1. As electrical length of the resonator is shorter, wide tuning range can be obtained by low bias voltage [5]. However, short electrical length makes quality factor of resonator low. Moreover, narrow bandwidth bandpass filter requires resonators with high quality factor. Active capacitance circuit in Fig.1 can enhance the quality factor of the resonator [7]-[8]. Therefore, the insertion loss by short electrical length and narrow bandwidth can be improved. Cross coupling structure of this filter makes constant bandwidth and high selectivity. For enhanced stop-band characteristic, SIR structure is used.

II. ENHANCED SELECTIVITY AND STOPBAND CHARACTERISTIC USING CROSSCOUPLING AND SIR

For constant bandwidth of a tunable filter, coupling coefficient of adjacent resonators should be in an inverse proportion to frequency [4]. As shown in Fig. 3(a), \( M_{ij} \) can be inversely proportional to frequency by using the proposed method in [4]. However, \( M_{ij} \) being in inverse proportion to the frequency is difficult, because the arrangement of 1st and 2nd resonators is different from that in [4]. However, the bandwidth of tunable filters can be constantly maintained in the event that \( M_{ij} \) is in proportion to frequency at once as shown in Fig. 2. When the coupling coefficient of adjacent resonators increases, the bandwidth increases 140 MHz to 188
MHz in Fig. 3(a) and 135 MHz to 152 MHz in Fig. 3(b), respectively. Because transmission zeros get nearer to the passband of the filter by the increase of the cross coupling coefficient, the increase of bandwidth by $M_{12}$ is suppressed. Therefore, the bandwidth of the proposed filter in Fig. 1 can be maintained constantly.

SIR structure is used for enhanced stop-band performance. SIR is suitable structure to cross-coupling bandpass filter. Fig. 4 shows the basic structure of SIR. Input impedance of SIR is calculated from (1).

$$Z = jZ_2 \tan \theta_1 + Z_1 \tan \theta_2 \tan \theta_1 \tan \theta_2$$

When Y (inverse of Z) is zero, it is occurred to parallel resonance. Resonance condition is (2).

$$\tan \theta_1 \tan \theta_2 = \frac{Z_2}{Z_1} = R_z$$

In $\theta_1 = \theta_2$, a second harmonic ($f_s$) of the SIR can be presented from (3).

$$\frac{f_s}{f_0} = \frac{\theta_s - \theta_0}{\theta_0} = \frac{\pi}{\tan^{-1}\sqrt{R_z} - 1}$$

By (3), as $R_z$ is smaller, second harmonic frequency ($f_s$) is more far to resonance frequency ($f_0$). Therefore a frequency of a second harmonic of the SIR can be controlled by changing the ratio of two characteristic impedances.

III. TUNING RANGE CONTROL BY LENGTH OF RESONATOR

Tuning range of tunable filter using microstrip and varactor such as combline or interdigital structure is related with capacitance of varactor as well as length of microstrip line. Generally, as length of microstrip is shortened, filter has wide tuning range and increases insertion loss [9]-[10]. Relation between tuning range and length of microstrip can be derived by condition of resonance of resonator. Input admittance of resonator that has combline or interdigital structure and narrow bandwidth can be presented as (4) [9]-[10]. If $Y_{in}$ is 0, it is occurred to resonance.

$$Y_{in} = -jY_{oe} \cot \theta + j\omega C_v$$

Where, $Y_{oe}$ is even mode characteristic admittance of microstrip line, $\theta$ is electrical length of microstrip line, $C_v$ is equivalent capacitance of varactor respectively. And (5), (6) is derived from (4).

$$\omega_{\text{max}} C_{\text{min}} = Y_{oe} \cot \theta_{\text{max}}$$

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Where

$$\omega_{\text{max}} = 2\pi f_{\text{max}}, \quad \omega_{\text{min}} = 2\pi f_{\text{min}}$$

Where, $f_{\text{max}}$, $f_{\text{min}}$ are maximum and minimum frequency in tuning range, $\theta_{\text{max}}$, $\theta_{\text{min}}$ are electrical length of microstrip line in $f_{\text{min}}$ and $f_{\text{max}}$ respectively. And $C_{\text{min}}$, $C_{\text{max}}$ is equivalent capacitance of varactor in $f_{\text{max}}$, $f_{\text{min}}$ respectively. Tuning range, $\alpha$, is derived from (5), (6).

$$\alpha = \frac{f_{\text{max}}}{f_{\text{min}}} - 1 = \frac{C_{\text{ratio}} \tan \theta_{\text{min}}}{\tan(\alpha - 1) \theta_{\text{min}}} - 1$$

Where
In (8), $\alpha$ is tuning range. From (9), as length of microstrip line is shortened, tuning range increases. Since the weakest point of tunable filter using varactor is large insertion loss, using varactor with large capacitance ratio is not good manner. Hence, in this paper, we used 36.8 degree electrical length resonators for wide tuning range.

IV. ACTIVE CAPACITANCE CIRCUIT WITH VARACTOR DIODE

Fig. 5 shows BJT active capacitance circuit connected varactor. This circuit compensates insertion loss of tunable filter because it has negative resistance characteristic. Varactor is connected to active capacitance circuit as in Fig. 5. Because total capacitance of $Z_{in}$ in Fig. 5 can be intensely changed by bias voltage of varactor [5]. Fig. 6. is simulated and measured results of Fig. 5.

Fig. 5. BJT active capacitance circuit with varactor.

Fig. 6. The simulated and measured result of active capacitance circuit with varactor(MA46H201-1088). Bias voltage at the varactor is 1.8V-3.3V.

Fig. 6 shows that active capacitance circuit has negative resistance and capacitor characteristics [8]. The negative resistance compensates insertion loss caused by varactor.

V. SIMULATED AND MEASUREMENT RESULTS

The proposed filter was designed with 2.54% of fractional bandwidth at 1.85 GHz. The used varactor is MA46H201-1088 of TYCO electronics and the substrate used in the design is RO3003 of Rogers with 30 mil thickness. As the length of the resonator in Fig. 1 is 11mm, the electrical length is 36 degree at 1.8GHz. As shown in Fig. 7, the insertion loss of the tunable filter without active capacitance circuit is 12dB due to 36 degree electrical length of the resonator. However, 9dB is improved in the tunable filter with active capacitance circuit as shown in Fig. 7. Bias voltage of the varactors is up to 3.3 V.

As shown in Fig. 8, the center-frequency tunable range is 1.8 GHz-1.95 GHz and 3dB bandwidth of the filter is 30 MHz (@ 1.8 GHz)-50 MHz(@ 1.95 GHz). As shown in Fig. 10, the stop-band rejection is greater than -15 dB up to 10 GHz. The insertion and return losses are 0.7~2.5 dB and -23~ -14dB, respectively.

Fig. 7. Measured result of loss compensation by active capacitance circuit.

Fig. 8. Measured and simulated result of $S_{21}$ of proposed filter in tuning range; bias voltage and capacitance of varactor is 1.8V (2pF) to 3.3V (1.5pF).
VI. CONCLUSION

In this paper, the cross-coupled SIR bandpass filter with active capacitance circuit using BJT has been presented. It employs resonators that have 36.8 degree electrical length at 1.8GHz for low voltage control. For enhanced selectivity, the proposed filter applies the cross-coupled structure. And SIR structure is used for enhanced stop-band performances.

The microstrip resonators with active capacitance showed good insertion loss performance because the negative resistance of the active capacitance circuit compensates it. The insertion loss of the proposed filter is maximum 2.5 dB. Therefore, it has good performances as bandpass filter which can be used in channel selecting system.

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