Cross-coupled Combline Bandpass Filter using Active Capacitance Circuit

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Abstract — In this paper, a cross-coupled combline bandpass filter with active capacitance circuit using BJT is presented. The proposed active combline bandpass filter is composed of 2 normal microstrip resonators and 2 microstrip resonators with active capacitance circuits. The negative resistance of the active capacitance circuit compensates the loss of the microstrip resonator. According to the Q distribution method, we arranged the 2 active resonators with high Q in the middle stages of the filter. The proposed active bandpass filter has very good insertion loss and selectivity with 2 transmission zeros. Moreover, it has good noise figure with common-emitter configuration. Therefore, it can be applicable to the modern wireless communication systems. The measured performance of the proposed filter has center frequency of 1.77 GHz, 5.1 % fractional bandwidth, and maximum 2 dB insertion loss. The measurement shows good agreement with the simulated results.

Index Terms — cross-coupled, active capacitance circuit, Q distribution, insertion loss, selectivity.

I. INTRODUCTION

In recent mobile communication systems, many efforts have been performed to integrate a transceiver system on one chip. However, integrating a RF bandpass filter is a problem to do this. Modern communication system requires a small and high selective bandpass filter which needs a high-Q resonator. To achieve this, several technologies were developed, like MMIC, RFIC and RF MEMS. These technologies could make highly integrated circuit, but it is still difficult to realize a high selective RF bandpass filter due to small volume.

For high-Q bandpass filter, dielectric resonators [1] and SAW (surface acoustic wave) resonators [2] have been widely used. However, they need large dimension. In order to make a bandpass filter small and highly selective at the same time, there have been many researches about negative resistance to compensate a loss of a resonator [3][4]. Despite of small size and high-Q, it cannot have been used in commercial products because of its instability, high noise-figure, and low power handling capacity.

A novel negative resistance circuit which has enhanced the stability and noise performance was presented in [5]. In this paper, the negative resistance circuit was used with a microstrip resonator which is a quarter-wave length. By doing this, the quality factor of the microstrip resonator was enhanced.

When resonators with different Q are used in a filter, a bell-shaped Q distribution is proposed to achieve the optimal passband response [6]. Therefore, we designed a 4 stage combline bandpass filter and used the negative resistances to the second and third resonators to obtain the optimal passband response.

Also, we introduced a new structure of cross-coupled combline bandpass filter [7]. The new cross-coupled combline bandpass filter has good selectivity with two transmission zeros on the both sides of the passband.

In this paper, we propose a design procedure of the cross-coupled combline bandpass filter and the negative resistance circuit, and present an experimental filter to verify this method. The proposed filter has center frequency at 1.77 GHz and 5.1 % fractional bandwidth (FBW).

II. ACTIVE CAPACITANCE CIRCUIT DESIGN

We will introduce design procedures of active capacitance circuit in this part. Fig 1. shows the active capacitance circuit we used. BJT was used to the active capacitance circuit. The active capacitance circuit was used to compensate the loss of the microstrip resonators.

Fig. 1. Active capacitance circuit : (a) Block diagram (b) equivalent circuit

The $R_{neg}$ in Fig. 1 cancels the resistance in microstrip resonator to compensate the loss of the microstrip resonator and this method can improve the Q of a filter. Therefore, we need to know what the exact value of $R_r$ is. The value of $R_r$ can be calculated from (1)[8].
\[ R = \frac{Z_0}{\alpha^l} \]  

In (1), we need the value of \( \alpha \) and can find it as follows.

\[ \alpha = \alpha_d + \alpha_c \]

\[ \alpha_d = \frac{k_0 \varepsilon_r (\varepsilon_r - 1) \tan \delta}{2 \sqrt{\varepsilon_r (\varepsilon_r - 1)}} \]

\[ \alpha_c = \frac{R_s}{Z_0 W} \]

\[ R_s = \sqrt{\frac{\alpha \mu_0}{2 \sigma}} \]  

In (2), \( \alpha_d \) is attenuation due to a dielectric loss, \( \alpha_c \) is attenuation due to a conductor loss, \( k_0 \) is wave number, \( \varepsilon \) is dielectric constant, \( W \) is width of the microstrip line and \( R_s \) is the surface resistivity of the conductor. We calculated the \( R_r \) which is resistance of a quarter-wave length resonator.

After calculating the value of \( R_r \), we have to design a active capacitance circuit which have a negative resistance whose magnitude is same as \( R_r \). The active capacitance circuit should have the negative resistance value at least in a region of frequency we targeted, for this case, 1.725 GHz to 1.825 GHz. To do this, we have to know the value of minimum and maximum frequency when the resistance of the active capacitance became negative and the maximum value of negative resistance. We can find these by analysis of the circuit in Fig 2.[5]

![Fig. 2. Small signal equivalent circuit of active capacitance circuit for high frequency](image)

Otherwise, we can simulate the active capacitance circuit to find the values of components. We used ADS to simulate this circuit and find the values. We can see a negative resistance of the proposed circuit in the appropriate region of frequency, about 1.4 GHz to 1.9 GHz, in Fig 3.

![Fig. 3. The simulated results of negative resistance of the proposed active capacitance circuit.](image)

III. CROSS-COUPLLED COMBLINE BANDPASS FILTER WITH ACTIVE CAPACITANCE CIRCUIT

In this paper, we used a new cross-coupled combline bandpass filter structure. The structure of the filter with 4 pole characteristic is introduced in Fig. 4.

![Fig. 4. Structure of new cross-coupled combline bandpass filter.](image)

To design the proposed 4-pole cross-coupled combline bandpass filter with active capacitance, first, we have to decide coupling coefficients which are proper to characteristics of bandpass filter we desire. A set of transmission zero can be made by cross-coupling between non-adjacent resonators of a filter [9]. The cross-coupled combline bandpass filter is designed at 1.77 GHz and has 5.1 % FBW and we can find the lowpass prototype elements appropriate to the specifications from tables in [8]. After choosing the lowpass prototype elements, we can decide coupling coefficients needed to synthesize the filter. The coupling coefficients can be calculated from (3).
In (3), $M$ is coupling coefficient, $FBW$ is fractional band width, $J$ is the characteristic admittance of the inverter, and $n$ is the degree of the filter.

Next, we should find the dimension of the filter with full wave simulator like ADS. Here, it is an important point that we will use resonators with the active capacitance circuit like in Fig 5. The Q of normal microstrip resonator with 3.0 dielectric constants and 20 mil thickness is about 200, but the Q of microstrip resonator with active capacitance is over 5000 in simulation. We can see it in Fig. 6.

![Microstrip resonator with active capacitance](image)

Fig. 5. Microstrip resonator with active capacitance : (a) Block diagram (b) equivalent circuit.

![Q of microstrip resonator](image)

Fig. 6. Q of microstrip resonator with the active capacitance.

We used the active capacitance circuit to enhance the Q of the microstrip resonator, but we did not use it to all resonators of the proposed filter to reduce the size of the filter. As we said in the introduction, the Q distribution of the resonator affects performance of a filter, and the bell shaped distribution is optimal.

Hence, we applied the active capacitance circuit to second and third stage of the proposed 4 stage bandpass filter to optimize the passband characteristic of filter like in Fig 7.

![New cross-coupled combline bandpass filter](image)

Fig. 7. (a) new cross-coupled combline bandpass filter (b) new cross-coupled combline bandpass filter with active capacitance circuit.

### IV. SIMULATION AND MEASUREMENT RESULTS

The cross coupled combline bandpass filter with active capacitance is designed at 1.77 GHz with 5.1 % $FBW$ and is fabricated on ROGERS RO 3003 with dielectric constant of 3.0 and 20 mil thickness. For the implementation of active capacitance circuits, Infineon’s BFP620 is used. We used ADS 2005 to perform simulations.

The simulated results of the cross-coupled combline bandpass filter without active capacitance and the proposed filter is shown in Fig. 8, and the design parameter is given in Table I.

![Simulated results of the proposed filter](image)

Fig. 8. Simulated results of the proposed filter.
Table I

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<th>g1</th>
<th>C1</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>dx</th>
<th>dy</th>
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<td>0.32 mm</td>
<td>1 pF</td>
<td>2 mm</td>
<td>3.75 mm</td>
<td>16.06 mm</td>
<td>1.53 mm</td>
<td>1.25 mm</td>
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<td>21 Ω</td>
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</table>

Fig. 9. Measured results of the proposed filter.

One can see the difference of the insertion loss and the selectivity between the proposed filter without active capacitance and with active capacitance in Fig. 9. The measured results show good agreement with the simulated ones.

V. CONCLUSION

In this paper, the cross-coupled combline bandpass filter with active capacitance circuit using BJT has been presented. The design procedures of active capacitance circuit and cross-coupled combline bandpass filter were introduced. According to the Q distribution method, we could reduce the size of the proposed filter with optimal performance. The microstrip resonators with active capacitance showed very good Q because the negative resistance of the active capacitance circuit compensates the loss of the resonators.

An active bandpass filter was designed and tested to verify the proposed method. The measured results show very good performance in the insertion loss as well as the selectivity in comparison with the filter without active capacitance circuit. The insertion loss of the proposed filter is maximum 2 dB. Furthermore, it employs a common-emitter configuration which can generate a better noise performance. Therefore, it has very desirable characteristics which can be applicable to modern wireless communication system.

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REFERENCES


