Active C Simulated RLC resonator

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Abstract: In this paper a novel active-C circuit is proposed which realizes all the three basic filter functions in current mode. It uses only two OTAs. It is electronically tunable, the tuning range being linear over four decades. Since grounded capacitors are used, it is suitable for IC implementation in CMOS technology. This circuit is basically a resonator and is an active equivalent of passive RLC network.

Key words: Active-C, Current mode, electronic tenability, CMOS technology, resonator, current mirror.

1. Introduction

Active resonators circuits have been in use in the past in filters circuits, which were operational amplifier (OA) based [1,2,5]. In such circuits control could be obtained either using external passive components such as resistors/capacitors or using internal dynamics of OAs which was carried out by changing the supply voltage of the circuit. This is not always convenient to do so. Further such tuning arrangements are not suitable for circuits when it is to be implemented in IC form. Moreover, in such approaches the limitation of range is another problem. Proposed circuit uses OTAs which have electronic tunability [6,7]. In [3], an RLC resonator using OTA was reported but it was in voltage mode. Another RLC resonator was reported in [4] which used three OTAs. More over it used programmable integrators which employed additional capacitors and buffers which add to the hardware. The proposed circuit is in current mode, which has some additional advantages. The mathematical operations (such as addition, multiplication etc) become easy as compared to voltage mode. Moreover, other advantages include low voltage requirements, low power consumption, suitability of implementation in micro- miniaturization [8,9,10,11]. Moreover, the proposed circuit is active C type, which makes it suitable for IC implementation in CMOS technology.

2. Circuit Description

2.1. RLC with passive elements

A parallel RLC circuit is shown in Fig.1(a) and it behaves as filter giving all three basic responses in current mode. The routine analysis of circuit of Fig.1(a) yields the current mode transfer functions, which show that the current mode response at resistance is band pass, across inductance it is low pass and across capacitance it is high-pass.
Eqn. (i), (ii) and (iii) realize band pass, low pass and high pass responses respectively.

The pole frequency of this current mode filter of Fig.1(a) is:

\[ f_o = \frac{1}{2\pi \sqrt{LC}} \]  

The values of L=100\mu\text{H}, C = 10\text{nF} and R = 100 \Omega were used in simulation. With these values the pole frequency works out to be 159.23 KHz. This can be seen in the simulation result of Fig.1(b).

### 2.2. Proposed Active-C Simulated Resonator

This structure is simulated using active components OTAs (single output). The proposed circuit is shown in Fig.2. The straight forward analysis in current mode gives input impedance:
The equivalent s-domain form is:

\[ Y = G + \frac{1}{sL} + sC \] ..............................................(vi)

Comparing (v) and (vi) we have:

\[ G = g_{m2}; \quad L = \frac{C_2}{g_{m1}g_{m2}} \quad \text{and} \quad C = C_1 \] ..............................................(vii)

This shows that the circuit behaves as parallel RLC network in which conductance and inductance are circuit parameters in simulated form. It can be seen that conductance and inductance are electronically tunable. Again the analysis of the circuit of Fig.2 yields the following current mode transfer functions:

\[ \frac{I_i(s)}{I_i(s)} = \frac{s^2}{s^2 + s \frac{g_{m2}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}} \] ..............................................(viii)

This realizes high pass operation.

\[ \frac{I_i(s)}{I_i(s)} = \frac{s \left( \frac{g_{m2}}{C} \right)}{s^2 + s \frac{g_{m2}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}} \] ..............................................(ix)

This realizes band pass response.

These responses are shown in Fig.4(a).

The current is input at node A. Since it is current mode approach, the node A and node B may be treated different and current division may be applied at A (this cannot be done in voltage mode as point A and B will be at the same potential). The current can be obtained from here using a current mirror. At A it divides into two branches i.e. into C1 and towards node B. Looking into the network from point B (i.e. ahead of capacitor C1), by routine analysis its input impedance is given by:

\[ \frac{I_i(s)}{V_i} = \frac{g_1g_2}{sC_1} + g_2 \] ..............................................(x)

This means that looking into node B, it simulates an inductor alongwith a conductance. Further the current mode transfer function at the node B yields,
\[
\frac{I_2(s)}{I_1(s)} = \frac{g_1g_2 + g_2s}{C_1C_2} - \frac{g_1g_2}{C_1C_2}s^2 + s \frac{g_2}{C_1} + \frac{g_1g_2}{C_1C_2} \quad \text{(xi)}
\]

This is a mixed low pass and band pass response as could be anticipated in the light of Eqn.(ix). By appropriate design values, the low pass response can be made dominant. For the values chosen, the circuit gives low pass response as shown in Fig.4(b). The simulation results confirm this and the dominant low pass response is obtained.

2.3. Filter Parameters
The pole frequency \((\omega_o)\) and pole quality factor \(Q\) of the circuit are:

\[
\omega_o = \sqrt{\frac{g_1g_2}{C_1C_2}} \quad \text{………………………………………………………………} \quad \text{(xii)}
\]

\[
Q = \sqrt{\frac{g_mC_1}{g_mC_2}} \quad \text{…………………………………………………………..} \quad \text{(xiii)}
\]

3. Simulation Results
To confirm theoretical analysis, the proposed circuit was simulated using Pspice with the following values of the components: \(g_{m1}=g_{m2}= 2 \text{ mS}; \ C_1 = C_2 = 10 \text{ nF}.\) An input current of 10 mA was used. The simulation results are shown in Fig.4(a) and (b). The theoretical results are in good agreement with the simulation results. Theoretical frequency is 31.8 KHz and the frequency obtained from simulation is 31.8KHz.

![Fig.4(a): Band pass and Highpass responses of the proposed resonator](image-url)
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5. References


