CHAPTER 7

Synthesis of analog filters, oscillator and tuned amplifier using the newly proposed SUJA simulated inductor *

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7.1 Introduction

Inductor protracts applications in all the analog circuits. But the usage of inductors near to the ground frequencies is very much bordered. A solution to this is the use of simulated L obtained from GIC. Many applications of simulated inductor using GIC have been presented which includes the analog filters, oscillators, amplifiers etc. The inductors used for replacing the physical inductor are considered to be an ideal one. But normally the inductors have losses due to resistance and this decreases the quality factor. The present method is used for replacing the practical inductor (with internal resistance) by ideal one. An alternate elucidation is the use of newly proposed SUJA simulated inductor acquired by using two active elements and six passive elements. In this chapter, the newly proposed SUJA simulated inductor is presented. This makes use of negative resistance to compensate the loss in the simulated L to make it as an ideal L and hence offers high Q [94]. It has many applications. One such application is the use of newly proposed SUJA simulated L in analog filters, tuned amplifier and oscillators. The frequency response of those filters, tuned amplifier and the oscillator output are presented. The simulation is done in PSPICE. There are number of ways of realizing the simulated inductor [95-99].
7.2 Basic circuit to simulate L

The circuit shown in Figure 7.1 is a form of integrator which is equivalent to an inductor in parallel with a resistor. The simulated L is a lossy inductor. This can be made ideal by adding a negative resistance of suitable value in parallel or in series with the circuit.

Figure 7.1 Basic lossy simulated inductor circuit

7.3 Concept of negative resistance

The negative resistance [100] is obtained by making use of one op-amp and three resistors as shown in Figure 7.2. The op-amps are assumed to be ideal ones with the basic assumption that no current are drawn by both the terminals of the op-amp and the differential input voltage across the terminal is zero.
Figure 7.2  Negative resistance circuit

By applying the basic KVL and KCL for the circuit given in Figure 7.2, the following equations are obtained from which the negative resistance is obtained.

\[ I = \frac{V - V'}{R_3} \]  \hspace{2cm} (7.1)

\[ \frac{V' - V}{R_4} = \frac{V}{R_5} \]  \hspace{2cm} (7.2)

On solving the above equations (7.1) and (7.2), the impedance of the circuit is obtained as

\[ Z = \frac{V}{I} = -\frac{R_5 R_3}{R_4} \]  \hspace{2cm} (7.3)

which is a negative resistance.

7.4 Simulation of the newly proposed SUJA simulated inductor using negative resistance

The circuit used for realizing the ideal inductor makes use of two op-amps, five resistors and one capacitor as per the connections given in Figure 7.3. Without the first op-amp,
the impedance offered by the circuit is a non-ideal inductor with a resistor in parallel with the ideal inductor.

The first op-amp produces a negative resistance and thus cancels the positive resistance offered by the second op-amp, leaving only the ideal inductor as the impedance. By properly selecting the values of resistors and capacitors, the values of the inductance will be in the range of henry which is impossible with the passive component L. So, the newly proposed SUJA simulated inductor is used for providing such high value of L and it replaces the grounded L and not floating L.

![Figure 7.3 Newly proposed SUJA simulated inductor circuit](image)

The mathematical derivation of SUJA simulated L obtained from Figure 7.3 is given below.

\[
I = \frac{V - V'}{R} + \frac{V - V_B}{R} \tag{7.4}
\]

\[
\frac{V' - V}{\frac{R}{2}} = \frac{V}{R} + \frac{V - V_A}{R} \tag{7.5}
\]
\[
\frac{V - V_A}{R} = \frac{V_A - V_B}{\frac{1}{j\omega C}}
\]  \hspace{1cm} \text{(7.6)}

On solving the equations (7.4), (7.5) and (7.6) the impedance obtained for the circuit is

\[
Z = \frac{V}{I} = j\omega CR^2 = j\omega L
\]  \hspace{1cm} \text{(7.7)}

Hence the impedance provided by the circuit is an ideal L.

7.5 Application of the newly proposed SUJA Simulated inductor in analog filters

The proposed SUJA simulated L can be used in all analog circuits for varied applications particularly at low frequencies where L is grounded and where there is a need to replace the lossy inductor by an ideal inductor by nullifying its internal resistance. One such application is the implementation of Butterworth filters. These filters are basically obtained from the basic LCR resonator circuit. The use of simulated inductor for realizing high pass, band pass and notch filter is presented because the inductors used in these filters are grounded.

7.5.1 Synthesis of high pass filter

The circuit shown in Figure 7.4 is the high pass filter which is designed for the cut off frequency of 160 Hz. The requirement of L for this frequency is in the order of Henry. Hence the proposed SUJA simulated L is used. The transfer function of the high pass filter is given by

\[
T(s) = \frac{s^2}{s^2 + s\left(\frac{1}{CR}\right) + \frac{1}{LC}}
\]  \hspace{1cm} \text{(7.8)}
The frequency response of the high pass filter circuit is shown in Figure 7.5. The PSPICE simulation circuit using simulated L is given in appendix A.

Figure 7.4  High pass filter circuit using the newly proposed SUJA simulated inductor circuit.

Figure 7.5  Frequency response of high pass filter using the newly proposed SUJA simulated inductor circuit.
7.5.2 Synthesis of band pass filter

Similarly the band pass filter is designed for the centre frequency of 160 Hz using the simulated L and is shown in Figure 7.6. The transfer function is given by

\[ T(s) = \frac{s(1/CR)}{s^2 + s\left(\frac{1}{CR}\right) + \frac{1}{LC}} \]

(7.9)

The frequency response of the band pass filter is given in Figure 7.7. The PSPICE simulation circuit using simulated L is given in appendix A.

Figure 7.6 Band pass filter circuit using the newly proposed SUJA simulated inductor circuit
7.5.3 Synthesis of notch filter

The notch filter cannot be obtained directly. Hence the concept of subtracting the band pass filter from the original input signal is used. This concept is shown as schematic diagram in Figure 7.8. The notch filter is designed to have a notch frequency of 160 Hz whose transfer function is given in the equation 7.10. The response of the notch filter is shown in Figure 7.9 which also show the input signal (straight line) as well the band pass response (bell shape). The PSPICE simulation circuit using simulated L is given in appendix A.

\[
T(s) = K \frac{\frac{1}{LC} + s^2}{s^2 + s\left(\frac{1}{RC} + \frac{1}{LC}\right)}
\]  

(7.10)
Figure 7.8 Notch filter circuit obtained using band pass filter using the newly proposed SUJA simulated inductor circuit

Figure 7.9 Frequency response of notch filter using the newly proposed SUJA simulated inductor circuit
The proposed simulated L cannot be used for other types of filters like the low pass filter, all pass filter etc in which the inductor is floating.

### 7.6 Design of the filters using the newly proposed SUJA simulated inductor

Circuit design for High pass and band pass filter:

\( f_0 = 100 \text{ Hz}, L = 2.536 \text{H}, C = 1 \mu\text{F}, R = 1.125 \text{K} \Omega \)

**For Simulated L:**

\( R = 1.592 \text{K} \Omega, C = 1 \mu\text{F} \)

Circuit design notch filter:

\( f_0 = 50 \text{ Hz}, L = 10.14 \text{H}, C = 1 \mu\text{F}, R = 2.252 \text{K} \Omega \)

**For Simulated L:**

\( R = 3.184 \text{K} \Omega, C = 1 \mu\text{F} \)

### 7.7 Application of the newly proposed SUJA Simulated inductor in Oscillator

An oscillator is a circuit which generates an output without an input. Oscillators can be classified as audio frequency (AF) oscillator and radio frequency oscillator (RF). Radio oscillators like Hartley and Colpitts cannot be used at low frequency due to large value of L required. This drawback can be eliminated by using the newly proposed SUJA simulated L. Another way of realizing an oscillator using newly proposed SUJA simulated L is shown in Figure 7.10. The corresponding output waveform is shown in Figure 7.11.
Figure 7.10 Oscillator circuit using the newly proposed SUJA simulated inductor circuit

Figure 7.11 Output waveform of the oscillator using the newly proposed SUJA simulated inductor circuit

7.8 Design of the oscillator using the newly proposed SUJA simulated inductor

Circuit design for oscillator:

\[ f_0 = 100Hz \quad L = 2.536H \quad C = 1\mu F \quad R_1 = R_2 = 1K\Omega \quad C = 1\mu F \quad R = 4.55K\Omega \]

For Simulated L: \( R_4 = R_6 = R_7 = R_8 = R = 1.59K\Omega, R_5 = 795\Omega, C = 1\mu F \)

\( C_3 = 1\mu F, \quad R_3 = 4.78K\Omega \)
7.9 Application of the newly proposed SUJA simulated inductor in tuned amplifier

Tuned amplifier is a circuit which tunes to a particular frequency or a narrow band of frequencies. Normally these tuned filters are not used at low frequencies due to hefty value of L required. By using simulated inductor tuning the amplifier to low and very low frequencies is possible. The circuit shown in Figure 7.12 using the newly proposed SUJA simulated L shows the amplifier tuned to a frequency of 100Hz. The frequency response is shown in Figure 7.13.

Figure 7.12 Circuit diagram of tuned amplifier using the newly proposed SUJA simulated inductor circuit.
Figure 7.13 Frequency response of the tuned amplifier using the newly proposed SUJA simulated inductor circuit

7.10 Design of the tuned amplifier using the newly proposed SUJA simulated inductor

Circuit design for tuned amplifier:

\[ f_0 = 100 \text{Hz} \quad L = 2.536H \quad C = 1\mu F \]

\[ R_1 = 5.96K\Omega, R_2 = 1.22K\Omega, R_3 = 1K\Omega, R_c = 4.77K\Omega, C_1 = 20\mu F, C_2 = 50nF \]

\[ R_4 = 4.78K\Omega, C_3 = 1\mu F \]

For Simulated L: \( R = 1.59K\Omega, C = 1\mu F \)

7.11 Conclusion

The applications of L at low frequency is narrowed due to its large value. This is due to more number of turns requirement which makes the size massive. So there is a need for an alternate method of simulating a lossless inductor. It is achieved by introducing the combination of an inductor which has loss with a negative resistance. This improves the quality of L since it behaves as an ideal inductor. This new approach finds its applications in the simulation of analog filters, oscillators and tuned amplifier and the results are presented. The
application is used not only for analog filters but can be extended for all other analog circuits like power amplifiers, regulators and many more circuits which operates at low frequencies.