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A Configuration for Realizing Voltage Controlled Floating Inductance and Its Application

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Abstract

A configuration using current feedback amplifiers AD844 and multiplier AD534 has been presented, which is capable of realizing Voltage Controlled Floating Inductance (proportional and inverse proportional). The application of band pass filter in Figure 4(a), notch filter in Figure 5(a) and Hartley oscillator in Figure 6(a) and simulation result in Figures 4(b)-(d), Figures 5(b)-(d), Figures 6(b)-(d) shows the workability of proposed configuration.

Keywords

Inductance Simulation, Voltage-Controlled Impedances, Multiplier, Filter, Oscillator, Current Feedback Operational Amplifier

1. Introduction

Simulation of inductor has been popular area of analog circuit research. Due to the well known difficulties of realizing on chip inductors of moderate to high values and high quality factors, simulated inductors have been the alternative choice for realizing inductor-based integrated circuit. Simulated inductors are also useful in discrete designs in which case they can replace bulky Passive inductors and after the advantages of reduced size, reduced cost and complete elimination of undesirable mutual coupling when several inductors are being used in a circuit.

Electronically controlled inductor such as voltage controlled floating inductance finds application in automatic gain controller, filter and oscillator circuit. A number of configuration using a variety of active elements such as op-amps, operational-mirrored amplifier, current controlled conveyors, OTA and Combination have so far been presented in the literature for realizing such elements in Floating Form [1]-[16].

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Recently, the current feedback op-amps (CFOAs) such as AD844 have attracted considerable attention in literature as alternative building blocks for analog circuit design due to the following advantages

i) Widen bandwidth that is relatively independent closed loop gain.

ii) Very high slew rate (2000 V/us).

iii) Ease of realizing various functions with least number of external passive components.

The main objective of paper is therefore to present a new configuration which is capable of realizing voltage controlled Floating inductance both in proportional and inversely proportional form and its application.

The paper is organized as follow:

Figure 1(a) is the basic terminal equation of CFOA.

Figure 1(b) is the basic structure of multiplier.

Figure 2(a) is the first case of the floating voltage controlled inductance.

Figure 3(a) is the another case of floating voltage controlled inductance

Figure 4(a) explained the application of voltage controlled inductance as BPF.

Figure 5(a) explained the application of voltage controlled inductance as notch filter.

Figure 6(a) explained the application of voltage controlled inductance as an oscillator.

Terminal Equations of CFA:

- $I_y = 0$
- $I_x = I_z$
- $V_x = V_y$
- $V_z = V_0$

As shown in **Figure 1(a)**. The x and y terminal of CFA are denoted by (−) sign and (+) sign respectively. A CFA is equivalent to a plus type conveyor with a voltage buffer and is very suitable building block for realization of active circuit.

MPY534 as MULTIPLIER

Description

The MPY534 is a highly accurate, general purpose four-quadrant analog multiplier. Its accurately laser trimmed transfer characteristics make it easy to use in a wide variety of applications with a minimum of external parts and trimming circuitry. Its differential X, Y and Z inputs allow configuration as multiplier, squarer, divider, square-rooter and other functions while maintaining high accuracy.

2. Proposed Configuration

2.1. Case 1

Implementation of voltage controlled floating inductance which is directly proportional to control voltage (V_c).

The proposed configuration shown in the **Figure 2(a)** where each CFOAs is characterized by $I_y = 0$, $V_x = V_y$, $I_z = I_x$, $V_w = V_z$ and multiplier with two resistance and capacitance is used for realizing the voltage controlled floating inductance.

Mathematical Analysis

From CFOA (3) applying KCL

$$V_{x1} = V_{y2} = V_0 V_c / V_{ref} \tag{1}$$

From CFOA (4) Applying KCL across capacitor:

$$I_4 = \left(0 - V_{y3}\right) / 1/sC = \left(0 - V_c V_0 / V_{ref}\right) / 1/sC = -\left(V_c V_0 / V_{ref}\right) * sC = I_{x4} \tag{2}$$

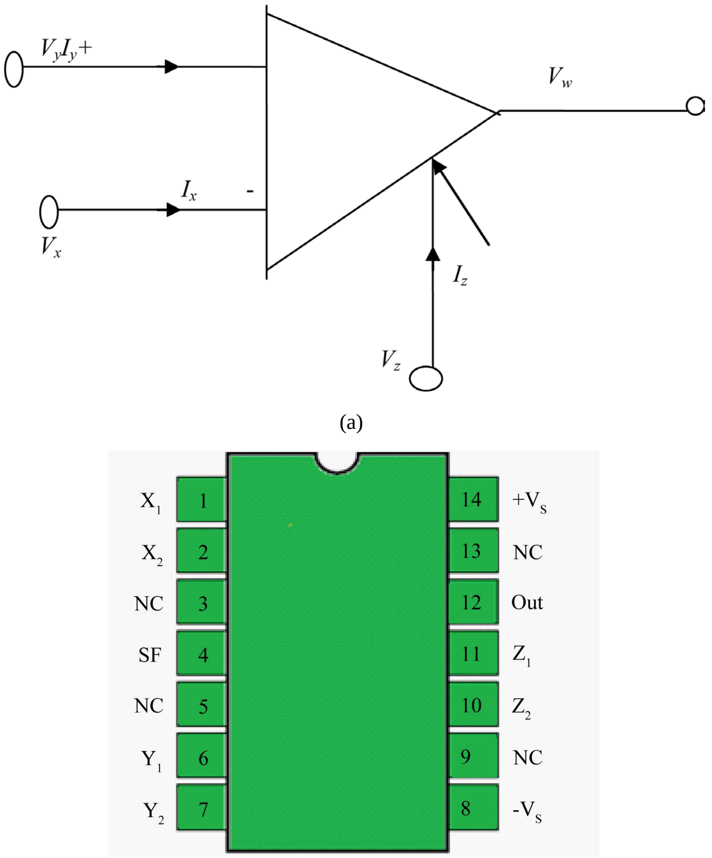
Applying KCL again at input port of CFOA (4)

$$I_{x4} = Y_1 - Y_2 / R_1 = -\left(V_c V_0 / V_{ref}\right) * sC$$

Thus

$$Y_1 - Y_2 = -\left(V_c V_0 / V_{ref}\right) * sCR_1 \tag{3}$$

From CFOA (2)



(b)

Figure 1. (a) CFA Symbol; (b) Multiplier pin diagram.

$$I_2 = I_{x2}$$

Applying KCL

$$I_2 = V_0 / R_3 \tag{4}$$

From CFOA(1)

$$0 - V_{x1} / R_2 = I_1$$

$$I_1 = -V_{x1} / R_2 = V_0 / R_2$$

$$I_1 = -V_0 / R_2 \tag{5}$$

Now subtracting the equation no. (5) from equation No. (4)

$$I_1 - I_2 = -V_0 \left(1/R_2 + 1/R_3 \right) \tag{6}$$

Now from standard floating inductor:

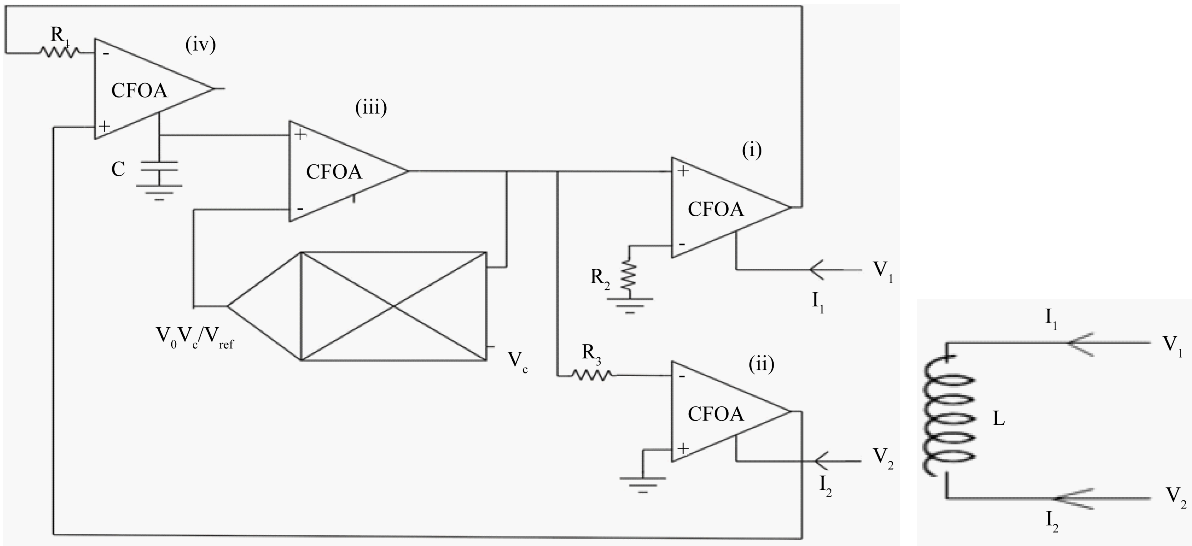
$$Y_1 - Y_2 = SL \left(I_1 - I_2 \right)$$

Putting the value of ($V_1 - V_2$) and ($I_1 - I_2$) from Equation (3) and (6)

$$-R_1 * \left(V_c V_0 / V_{ref} \right) * SC = -V_0 SL \left(1/R_1 + 1/R_2 \right)$$

After simplification we get,

$$L = \left(C R_1 R_2 R_3 / R_2 + R_3 \right) * V_c / V_{ref}$$



(a) (b)

Figure 2. (a) Proposed floating voltage controlled inductance configuration; (b) Realized floating inductor.

Thus inductance (L) is directly proportional to control voltage (V_c)

2.2. Case 2

Implementation of voltage controlled floating impedance with inversely proportional to control voltage.

The proposed configuration shown in the **Figure 3(a)**. where each CFOAs is characterized by $I_y = 0$, $V_x = V_y$, $I_z = I_x$, $V_w = V_z$ and multiplier with two resistance and capacitance is used for realizing the floating voltage controlled inductance.

Mathematical Analysis

Output of the multiplier

$$(V_3 V_c)/V_{ref} = V_{x2} = V_{y1}$$

From CFOA (1)

Applying KCL across capacitor

$$I_1 = 0 - V_{x1}/R_1 \qquad (\text{where } V_{x1} = V_3 V_c / V_{ref})$$

$$= (0 - V_3 V_c / V_{ref})/R_1$$

$$I_1 = -V_c V_3 / R_1 V_{ref} \tag{1}$$

Now from CFOA (2)

$$I_2 = (V_c V_3)/(R_1 V_{ref} - 0)/R_2 = (V_c V_3 / R_1 V_{ref})/R_2 \tag{2}$$

Now subtracting the equation No. (1) from equation No. (2)

$$I_1 - I_2 = -(V_c V_3 / V_{ref})(1/R_1 + 1/R_2)$$

From CFOA (3) Applying KCL across capacitor we get

$$I_3 = (0 - V_3)/1/sC$$

$$I_3 = -V_3 sC \tag{3}$$

Again applying KCL at input node

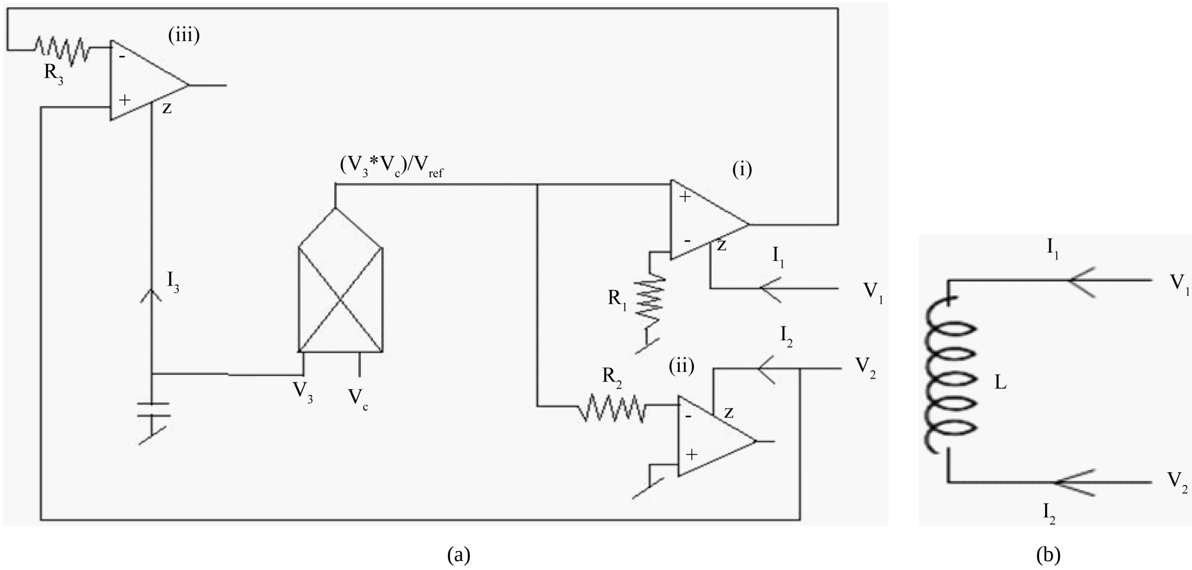


Figure 3. (a) Proposed floating linear voltage controlled inductance configuration; (b) Realized floating inductor.

$$I_3 = (V_1 - V_2)/R_3$$

rearranging the equation we get,

$$V_1 - V_2 = I_3 R_3 \tag{4}$$

Now from standard floating inductor:

$$V_1 - V_2 = sL(I_1 - I_2)$$

Putting the value of $(V_1 - V_2)$ and $(I_1 - I_2)$ from Equation (3) and (4)

$$I_3 R_3 = sL\left(-V_c V_3 / V_{ref}\right)\left(1/R_1 + 1/R_2\right)$$

Putting the value of I_3

$$-V_3 sCR_3 = sL\left(-V_c V_3 / V_{ref}\right)\left(1/R_1 + 1/R_2\right)$$

After simplifying we get,

$$L = CR_1 R_2 R_3 \left(V_{ref} / V_c\right) / \left(R_1 + R_2\right)$$

Thus inductance (L) is inversely proportional to control voltage (V_c)

$$-V_3 sCR_3 = \left(-sLV_c V_3 / V_{ref}\right) * \left(\left(R_1 + R_2\right)/R_1 R_2\right)$$

$$R_2 \gg R_1, \quad R_1 + R_2 = R_2$$

$$L = CR_1 R_3 V_{ref} / V_c$$

Thus inductance is inversely proportional to control voltage (V_c).

3. Application of Floating Inductor Realized in Figure 2(a) and Figure 3(a)

3.1. Band Pass Filter

In **Figure 4(a)**, we realized a Band pass filter using voltage controlled floating inductance and resistance, capacitance.

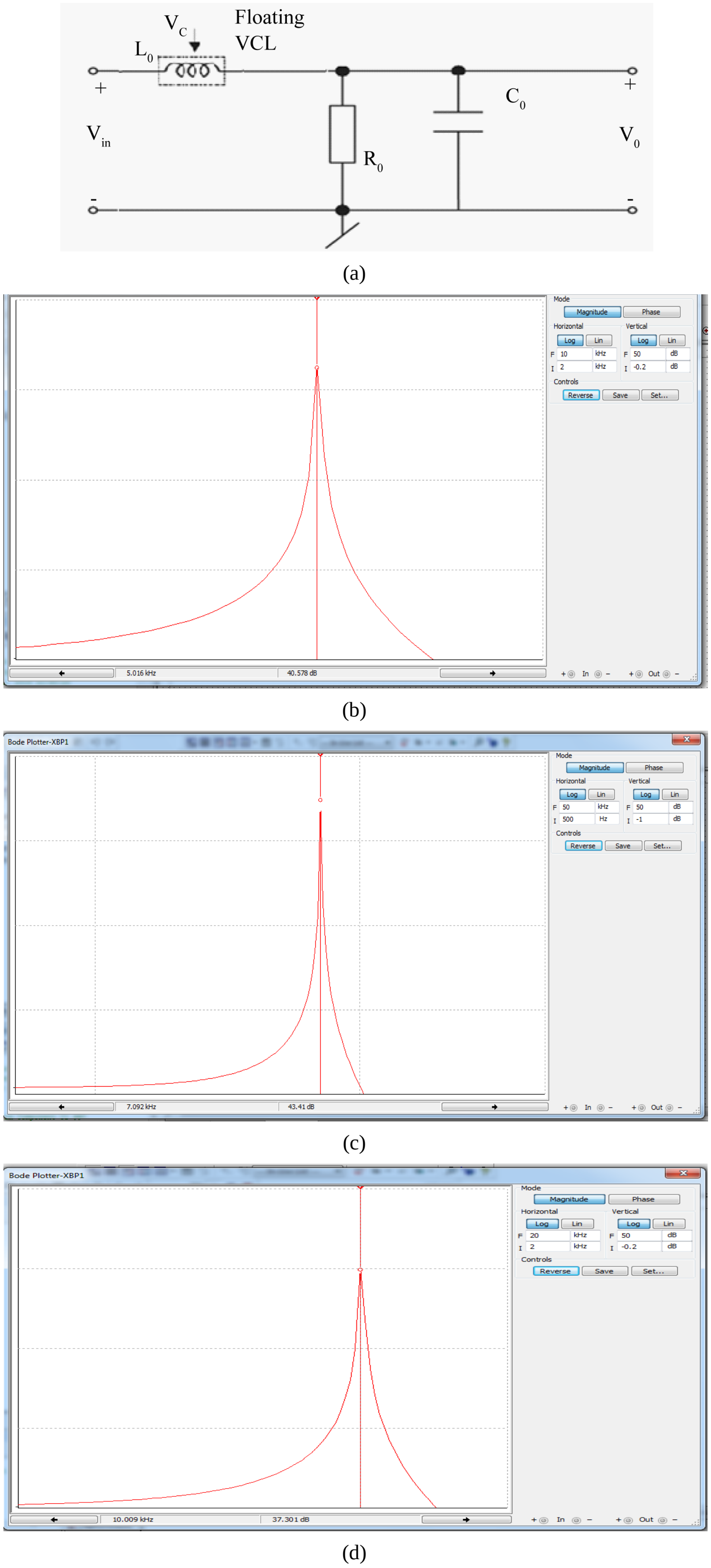


Figure 4. (a) A passive prototype RLC band pass filter; (b) Frequency response of the band pass filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 1 V, L_0 = 0.1 mH); (c) Frequency response of the band pass filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 2 V, L_0 = 0.05 mH); (d) Frequency response of the band pass filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 4 V, L_0 = 0.025 mH).

3.1.1. Simulation Results
Please see **Figures 4(b)-(d)**.

3.1.2. Result
In the above simulation result, we show the frequency response of band pass filter made from voltage controlled floating inductance, a resistance and a capacitor. The band pass filter was designed for frequency f_0 = 5 kHz, 7.1 kHz and 10 kHz with different value of inductance as given in **Table 1**. The center frequency of filter was found to be electronically tunable from 5 kHz to 10 kHz with V_c varying from 1 to 4.

Thus from the above result it can be seen that by varying the control voltage (V_c) center frequency (F_c) of the band pass filter can be changed . Thus we can control the center frequency by varying V_c.

3.2. Notch Filter
In **Figure 5(a)**, we realized a RLC notch filter using voltage controlled floating inductance and resistance, capacitance.

3.2.1. Simulation Results
Please see **Figures 5(b)-(d)**.

3.2.2. Result
In the above simulation result, we show the frequency response of notch filter made from voltage controlled floating inductance, a resistance and a capacitor. The notch filter was designed for frequency f_0 = 5 kHz, 7.1 kHz and 10 kHz with different value of inductance as given in **Table 2**. The center frequency of filter was found to be electronically tunable from 5 kHz to 10 kHz with V_c varying from 1 to 4.

Thus from the above result it can be seen that by varying the control voltage (V_c) center frequency (F_c) of the notch pass filter can be changed .Thus we can control the center frequency by varying V_c.

3.3. Hartley Oscillator
In **Figure 6(a)**, we realized an op-amp Hartley oscillator using voltage controlled floating inductance and, capacitance.

3.3.1. Simulation Results
Please see **Figures 6(b)-(d)**.

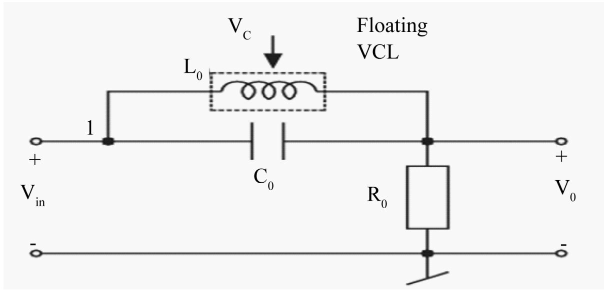
3.3.2. Result
In the above simulation results, we show the frequency response of Hartley oscillator made from voltage controlled

Table 1. Effect of variation in control voltage (V_c) on center frequency (f_c) of band pass filter.

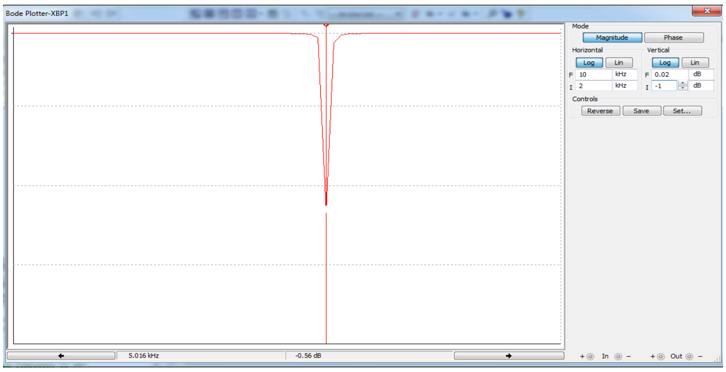
V_{REF}/V_C	Inductance (L)	Capacitance (C)	Center frequency (f_c)
1	0.1 mH	10 uF	5 kHz
0.5	0.05 mH	10 uF	7.1 kHz
0.25	0.025 mH	10 uF	10 kHz

Table 2. Effect of variation in control voltage (V_c) on center frequency (f_c) of notch filter.

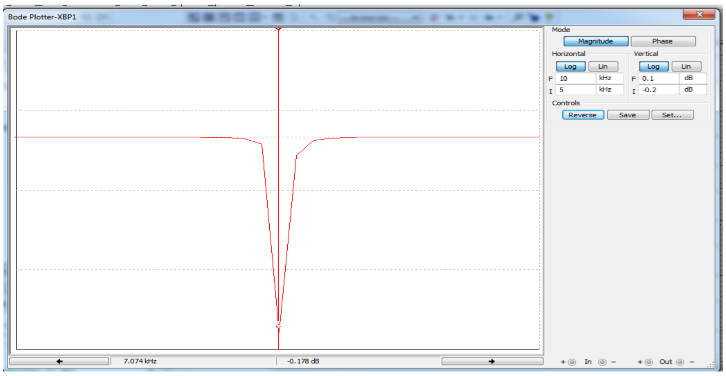
V_{REF}/V_C	Inductance (L)	Capacitance (C)	Center frequency (f_c)
1	0.1 mH	10 uF	5 kHz
0.5	0.05 mH	10 uF	7.1 kHz
0.25	0.025 mH	10 uF	10 kHz



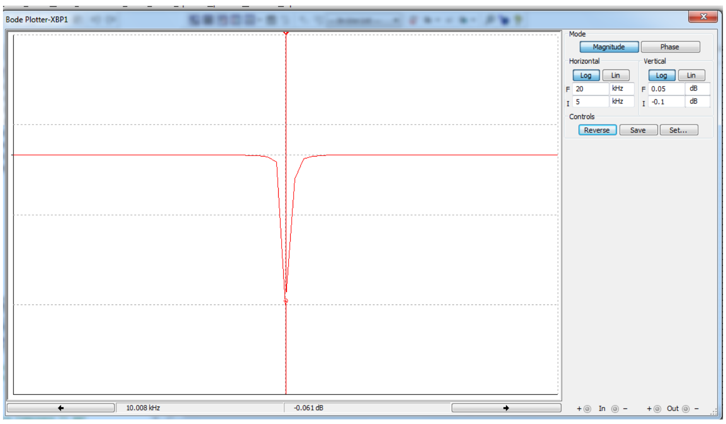
(a)



(b)



(c)



(d)

Figure 5. (a) A passive prototype RLC notch filter; (b) Frequency response of the notch filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 1 V, L_0 = 0.1 mH); (c) Frequency response of the notch filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 2V, L_0= 0.05 mH); (d) Frequency response of the notch filter (with C_0 = 10 uF, R_0 = 1 K, V_c = 4 V, L_0 = 0.025 mH).

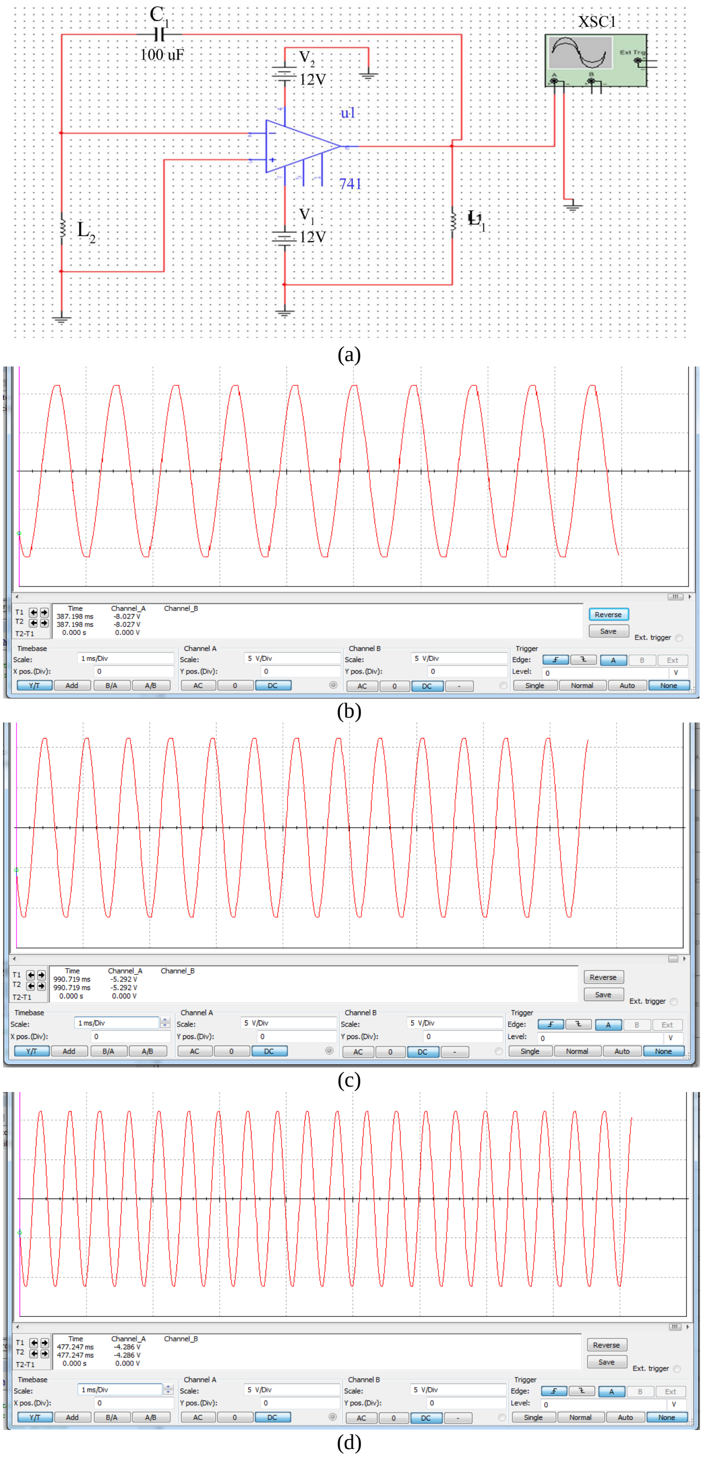


Figure 6. (a) A prototype of op-amp Hartley oscillator; (b) Frequency response of the oscillator (with C = 100 uF, V_C = 1 V, $L_1 = L_2$ = 0.1 mH) Center frequency = $\left\{(1)/\left(2\times 3.14\times (LC)^{0.5}\right)\right\}$ = 1.125 kHz (where $L = L_1 + L_2$)); (c) Frequency response of the oscillator (with C = 100 uF ,V_C = 2 V, $L_1 = L_2$ = 0.05 mH) Center frequency = $\left\{(1)/\left(2\times 3.14\times (LC)^{0.5}\right)\right\}$ = 1.59 kHz (where $L = L_1 + L_2$)); (d) Frequency response of the oscillator. with C = 100 uF ,V_C = 4 V, $L_1 = L_2$ = 0.025 mH Center frequency = $\left\{(1)/\left(2\times 3.14\times (LC)^{0.5}\right)\right\}$ = 2.25 kHz (where $L = L_1 + L_2$)).

Table 3. Effect of variation in control voltage (V_c) on center frequency (f_c) of Hartley oscillator.

V_{REF}/V_C	Inductance (L)	Capacitance (C)	Center frequency (f_c)
1	0.1 mH	100 uF	1.125 kHz
0.5	0.05 mH	100 uF	1.59 kHz
0.25	0.025 mH	100 uF	2.25 kHz

Table 4. Comparison of results of reference [17] and proposed realization.

		Proposed realization	
	Reference [17]	Case 1	Case 2
CFOAs	4	4	3
FET	1	0	0
Multipliers	0	1	1
Capacitor	0	1	1
Resistor	6	3	3

floating inductance, an op-amp and a capacitor. The Hartley oscillator was designed for frequency f_0 = 1.125 kHz, 1.59 kHz and 2.25 kHz with different value of inductance as given in **Table 3**. The center frequency of oscillator was found to be electronically tunable from 1.125 kHz to 2.25 kHz with V_c varying from 1 to 4.

From the above result, it can be seen that by varying the control voltage (V_c) center frequency of oscillation of Hartley oscillator can be changed .Thus we can control the frequency of oscillation by varying V_c.

4. Conclusion

The proposed circuit in **Figure 2(a)** and **Figure 3(a)** realized and compared with reference [17]. In **Table 4**, we have used less number of CFOAs and less number of passive components. The use of multiplier nullifies the effect of non linearity of FET. The application of BPF, notch filter a Hartley oscillator have been discussed.

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