Application of a Symmetrical Type Current Pump to realize Ungrounded Inductors.

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Abstract

This letter describes the realization of ungrounded inductor using a differential integrator and a symmetrical current pump. Stable low-frequency Q-factors of approximately 800 are easily obtained. Using the symmetrical current pump, variation of the inductance (L) value is easily obtained with a single potentiometer.

Introduction

The inductor without coils, using operational amplifiers or transistor circuits, has been reported. But, in its floating form, it has seen few realizations, because of the difficulty of designing 'floating' gyrators[1-4].

Several years ago we pointed out that an inductor could be realized by means of a current pump driven by the integrated voltage across the terminal-pair of the required inductor[5]. Since this publication, we have developed a new form of floating indnctor[6], similar in principle to earlier forms, but requiring two integrators and two single-ended input push-pull outputs. The earlier networks utilised NIC's for loss compensation ; this incurred the disadvantage of accurate resistance matching. The present system replaces the NIC action with a current pump, hence overcoming the matching problem.

Inductor Simulation and the Model Circuit

An ungrounded inductor can be replaced by two gyrators and a capacitor, as in Fig. 1A. Then we may redraw Fig. 1A using pairs of controlled current sources, as in Fig. 1B. We consider Fig. 1B as a three-port circuit, the Parameters of which may be represented by the equation :

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = g \begin{bmatrix} 0 & 0 & -1 \\ 0 & 0 & 1 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \qquad \cdots\cdots(1)$$

where g is the transfer conductance of the two gyrators in Fig. 1A. with a load consisting of a capacitor C connected across the terminals of port 3 :

$$I_3 = -V_3\ CP \qquad \cdots\cdots(2)$$

The variables of the network between the two ports 1, 2 are related by the equation :

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{g^2}{CP} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad \cdots\cdots(3)$$

The resulting equation, as show in (3), defines a simple ungrounded series inductor of value $L = C/^2g$.

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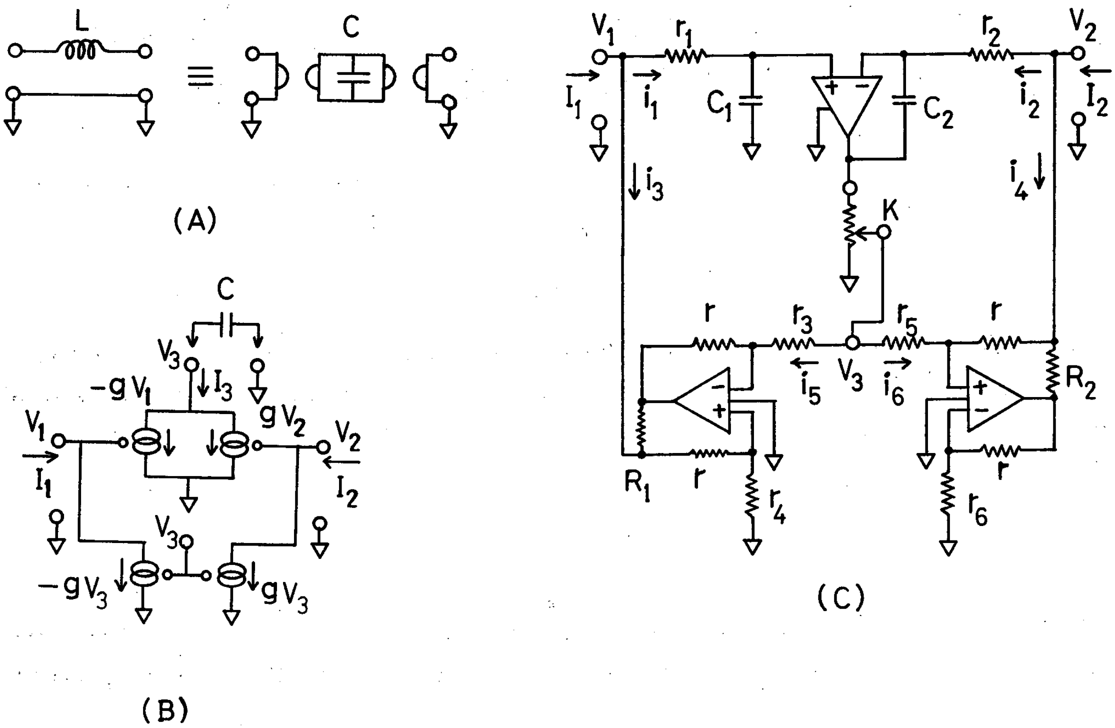

Fig. 1 Realization of an ungrounded inductor.
(A) Two-gyrator realization
(B) Principle of our circuit
(C) Model circuit diagram

According to the above-mentioned principle, the model circuit is constructed as in Fig. 1C using three operational amplifiers. Now, with ideal amplifiers in this circuit, the parameters are defined by the equation as follows:

$$\begin{bmatrix} V_3 \\ i_5 \end{bmatrix} = \begin{bmatrix} \dfrac{r\,r_4 - r_3\,(r+R_1)}{r\,(r+r_4)} & \dfrac{r_3}{r}R_1 \\ \dfrac{r+R_1}{r\,(r+r_4)} & \dfrac{1}{r}R_1 \end{bmatrix} \begin{bmatrix} V_1 \\ i_3 \end{bmatrix}$$

$$\begin{bmatrix} V_3 \\ i_6 \end{bmatrix} = \frac{-1}{r^2 + r_6(r+R_2)} \begin{bmatrix} r\,r_5 - r_6\,(r+R_2) & R_2 r_6\,(r+r_5) \\ r & r_6 R_2 \end{bmatrix} \begin{bmatrix} V_2 \\ i_4 \end{bmatrix}$$

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} \dfrac{C_1 P}{1 + r_1 C_1 P} & 0 \\ \dfrac{1}{r_2 + r_1 r_2 C_1 p} & \dfrac{1}{r_2} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad \cdots\cdots(4)$$

and

$$V_3 = \frac{K}{r_2 C_2 P}\left\{ \frac{1 + r_2 C_2 P}{1 + r_1 C_1 P} V_1 - V_2 \right\} \qquad \cdots\cdots(5)$$

By adopting the following set of relationships:

$r,\ r_1,\ r_2,\ \cdots\cdots,\ r_6 \gg R_1,\ R_2$

$r_1 C_1 = r_2 C_2$

$$\frac{r}{R_1 r_3}=\frac{1}{R_2}\left\{\frac{r\ (r+r_6)}{r_6\ (r+r_5)}\right\}\equiv\frac{1}{R} \qquad \cdots\cdots(6)$$

the equations of (4), (5)become: −

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \doteqdot - \begin{bmatrix} 0 & 0 & -\frac{1}{R} \\ 0 & 0 & \frac{1}{R} \\ \frac{K}{r_2} & \frac{K}{r_2} & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \qquad \cdots\cdots(7)$$

and

$$I_3 = -\ v_3\, C_2\, P \qquad \cdots\cdots(8)$$

we have

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \doteqdot \frac{K}{R\, r_2\, C_2\, P} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad \cdots\cdots(9)$$

The resulting equation, as shown in (9), defines an inductor of value $L = R r_2 C_2/K$.

We have used this circuit with r, r_1, r_2, ···, r 6 = 1 Mohms, C_1, C_2=100 pF, R_1, R_2=5.1 Kohms (all of 1 % tolerance) , and with solidstate differential amplifiers (Philbrick EP 85AU) of transfer function= $5\times10^4/\ (1+0.0008\ P)\ \ (1+0.00013\ P)$. In this case the value of ungrounded inductor was 0.51 H with K= 1 .

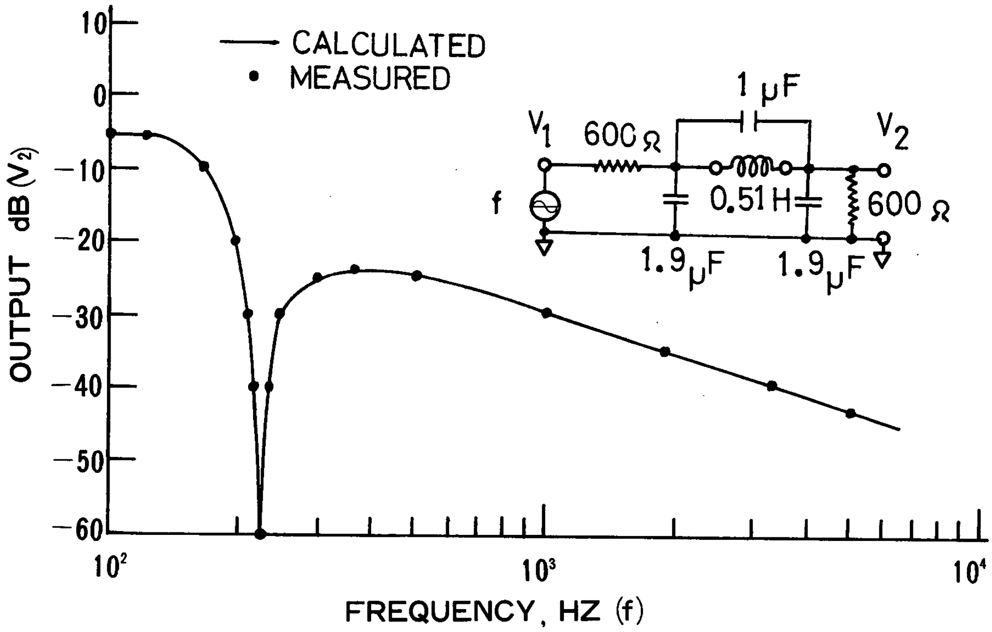

Fig. 2 Measured filter response.

To demonstrate the use of these techniques the simple 600 ohm notch filter shown in Fig. 2 (inside) was constructed. The experimental result of this filter is shown in Fig. 2, from which it can be seen that the attenuation value at the notch frequency is−60 dB. The Q−factor of the inductor L with $r_1C_1 = r_2C_2$ is approximately 800 in the experimental case. However, in the theoretical case it is $Q = 2.4/\omega RC_2$, and with $r = r_1 = r_2 \cdots = r6 = 1$ Mohms, $R_1 = R_2 = R = 5.1$ Kohms in this circuit, the Q is approximately 4000 at a frequency of 220 Hz.

Here, we take two interesting circuits, in order to compare their stability with the stability of our circuit. One of them is Deboo's circuit[3], which is lossless in theory, and another is K. P. 's circuit[2], which is simple. Both of these networks utilise NIC action for loss compensation and may therefore under certain circumstances become unstable. The present system however is potentially more stable as it does not comprise NIC subsystems.

We conclude with a simple comparative sensitivity and stability study of the three networks having component tolerances of 1 %. One parameter is the incremental change $\triangle$ dB of the regulation of the −14 dB point on the attenuation curve in Fig. 2, when each one of the resistors is changed by 1 %, and another is given in the change of each resistance required to cause oscillation to commence. The resulting largest values are $\triangle$ dB=−2 %, −2 % and −4 % and $\triangle$ R=−2.4%, −2.2% and −84.0% for the Deboo, K. P. and our circuit respectively.

Conclusion

We have indicated that the present configuration is potentially more stable than those proposed in references (2) and (3), and comparative sensitivities of gain at the cut−off frequencies corroborate the superiority of the proposed system.

We have given a simulation procedure for a stable ungrounded inductor with high Q-factor and readily variable inductance. We believe that this technique will considerably facilitate systematic solution of active and passive network problems.

References

1) ARAI, I., SUZUKI, T. : "Realization of Series Inductance using RC Active Circuit", (in Japanese), Trans. IECE Japan, Vol. 55—A, No. 9,479 (1972—9) .

2) KEEN, A. W., PETERS, Jacquelline L. : "Nonreciprocal representaton of the floating inductor with grounded-amplifier realizations", Electronics Letters, 3 (8), August 1967.

3) DEBOO, Gordon J. : "Application of a gyrator-type circuit to realize ungrounded inductors", I. E. E. E. Trans. on CT—14, March 1967.

4) MIZOGUCHI, T. : "Realization of a Floating Inductance Connected to an Input Signal Voltage", (in Japanese), Trans. IECE Japan, Vol. 59—A, No. 1, 77 (1976—1).

5) USUI, G. : "Bilateral converting circuit betweenvoltage and current and its applications", Trans. IEEJ, Vol. 86, No. 937, 1726 (1966—10) .

6) FORD, R. L., GIRLING, F. E. J. : "Active filters and oscillators using simulated inductance", Electronics Letters, 2 (2), February 1966.

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