About implementing an inductor by the means of gyrators

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Abstract ***–Take into account the entrance equivalent impedance of gyrators, by connecting a condenser to output is possible simulate a lossless inductor, which can be grounded inductor or floating inductor. The gyrators behavior of a class of two-ports structured on operational amplifiers and resistors is studied. The paper presents some aspects regarding performances characteristics of gyrators with different circuit topology. In order to verify the theoretical predictions, the analytical inductivities are linked with the experimental one numerical by the means of a PSpice simulation.***

Keywords: ***antireciprocal quadripol, gyrator,***

I. INTRODUCTION

The gyrator as an ideal, lossless nonreciprocal two-port circuit element has been introduced by the B. D. H. Tellegen [1]. The main property of the gyrator, namely the conversion of the network connected at the output port into its dual, as seen from the input port, was supposed by Tellegen to help synthesizing various electrical filters in the field of signal processing.

There are many ways to physically implement a gyrator. In the quest for physical gyrators it has been discovered that the Hall effect can be used to build gyrators that could operate in a very broad range of frequencies [2]. Unfortunately, Hall effect based gyrators do not imposed as inductance emulators due to their large ohmic dissipation. Practical applications of the gyrator at low frequencies occurred with the development of active semiconductor device technology, especially due to the need to integrate large values of inductances. Based on transistors and operational amplifiers, many practical gyrator circuits have been proposed and used [3].

An antireciprocal two-port circuit is a special case of a nonreciprocal two-port circuit whose parameters satisfy a certain condition, usually referred as the antire-ciprocity condition. For example, if the two-port's equations are expressed via the short-circuit admittances,

$$\underline{I}_1 = G_{11}\underline{U}_1 + G_{12}\underline{U}_2 \qquad \underline{I}_2 = G_{21}\underline{U}_1 + G_{22}\underline{U}_2 \qquad (1)$$

then the antireciprocity condition is [4]

$$G_{12} = -|G_{21}| \qquad (2)$$

where the passive rule for U and I at both ports has been assumed (fig. l).

The physical meaning of eq.(2) is as follows: if a voltage source, connected at the input port, determines a current $\underline{I}$ at the short-circuited output port then, the same voltage source, if connected at the output port, will determine, at the short-circuited input port, a current of the same amplitude but of opposed phase, $-\underline{I}$. A similar anti-reciprocity condition for the two-port is used:

$$G_{12}G_{21}<0 \qquad (3)$$

thus the schematic behaves like a gyrator

For an ideal gyrator, which is a lossless passive antireciprocal two-port network, eqs. (1) become

$$\underline{I}_1 = G_{12}\underline{U}_2 \qquad \underline{I}_2 = -|G_{21}|\underline{U}_1 \qquad (4)$$

where parameter G_{12} and G_{21} are transfer conductance of the gyrator. The circuit symbol for a gyrator is shown in fig.1.

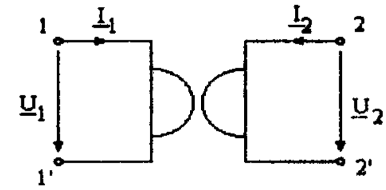


Fig. 1 Circuit symbol for a gyrator

II. EQUIVALENT INPUT OF ANTIRECIPROCAL QUADRIPOLS

Expressions equivalent input impedances (admittances) with a quadripol feed at terminals $11^{/}$ if the rule for receiving terminals applies to both the are pairs of [5, 9]:

$$\underline{Z_{e1}} = \underline{Z_{11}} - \frac{\underline{Z_{12}}\ \underline{Z_{21}}}{\underline{Z_S} + \underline{Z_{22}}} = \underline{Z_{10}} - \frac{\underline{Z_{12}}\ \underline{Z_{21}}}{\underline{Z_S} + \underline{Z_{20}}} \quad (5)$$

$$\underline{Y_{e1}} = \underline{Y_{11}} - \frac{\underline{Y_{12}}\ \underline{Y_{21}}}{\underline{Y_S} + \underline{Y_{22}}} = \underline{Y_{1k}} - \frac{\underline{Y_{12}}\ \underline{Y_{21}}}{\underline{Y_S} + \underline{Y_{2k}}} \quad (5^{/})$$

in which $\underline{Y_S} = 1/\underline{Z_S}$.

If we take into account the physical meanings of quadripolar parameters in accordance with the rule of association it results:

$$\underline{Z_{e1}} = \underline{Z_{10}} - \frac{(\underline{Z_{t0}})_1 (\underline{Z_{t0}})_2}{\underline{Z_S} + \underline{Z_{20}}} \quad (6)$$

$$\underline{Y_{e1}} = \underline{Y_{1k}} - \frac{(\underline{Y_{tk}})_1 (\underline{Y_{tk}})_2}{\underline{Y_S} + \underline{Y_{2k}}} \quad (6^{/})$$

Given the resistive behaviour of antireciprocal quadripols analyzed in the paper, expressions equivalent input impedances (admittances) will be written as follows:

$$\underline{Z_{e1}} = R_{10} - \frac{R_{12}\ R_{21}}{\underline{Z_S} + R_{20}} \quad (7)$$

$$\underline{Y_{e1}} = G_{1k} - \frac{G_{12} G_{21}}{\underline{Y_S} + G_{2k}} \quad (7^{/})$$

It will also consider expression of the antireciprocity condition for the same rule. Antireciprocity is highlighted by the inequalities $R_{12}R_{21}<0$, respectively $G_{12}G_{21}<0$, resulting:

$$\underline{Z_{e1}} = R_{10} + \frac{|R_{12}R_{21}|}{\underline{Z_S} + R_{20}} \quad (8)$$

$$\underline{Y_{e1}} = G_{1k} + \frac{|G_{12}G_{21}|}{\underline{Y_S} + G_{2k}} \quad (8^{/})$$

We note that in the second term of the relations occurs the module of quadripolar transfer parameters. Expression equivalent input impedance of an antireciprocal quadripol clearly reveals the propriety of these types of quadripol of impedances inversion

In the case of, lossless gyrator, the relation (8) customization is achieved by the expression:

$$\underline{Z_{e1}} = \frac{|R_{12}R_{21}|}{\underline{Z_S}} \quad (9)$$

$$\underline{Y_{e1}} = \frac{|G_{12}G_{21}|}{\underline{Y_S}} \quad (9^{/})$$

In this particular case may be added that $\underline{Z_{e1}} = \underline{Z_{e2}}$.

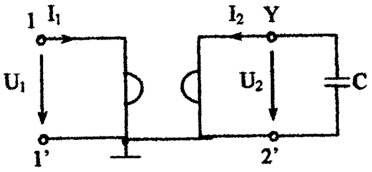
Given the expressions by the relations 8 and $8^{/}$ and that $\underline{Z_{e1}} = 1/\underline{Y_{e1}}$, it results:

$$\frac{R_{11}(\underline{Z_S} + R_{20}) + |R_{12}R_{21}|}{R_{20} + \underline{Z_S}} = \frac{G_{2k} + \underline{Y_S}}{G_{11}(G_{2k} + \underline{Y_S}) + + |G_{12}G_{21}|} \quad (10)$$

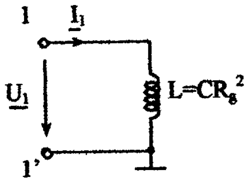
which make known the connection between $|R_{12} R_{21}|$ and $|G_{12} G_{21}|$. It can be seen that in the case of a lossy gyrator this relation is relatively complicated. The equation is dramatically simplified if the considered that the gyrator is ideal, in which case it becomes: $R_{12}R_{21} = 1/G_{12}G_{21}$.

III. FLOATING INDUCTOR BY THE MEANS OF GYRATORS

Typically, the inductivity (L) simulated by a practically ideal operational amplifier (OA) with resistance (conductance) of gyration R_g (G_g) and purely capacitive load (C) is $L = CR_g^2 = C/G_g^2$. Must, however, be noted that such inductivity achieved is related to mass, grounded inductor as shown in fig.2.



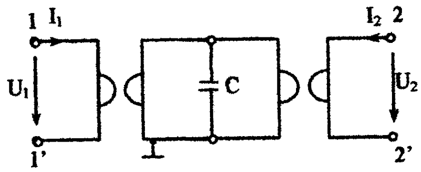
a)



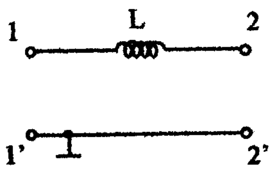
b)

Fig. 2 Explanatory implementation of grounded inductivity endorsed with an ideal gyrator

In order to design a floating inductor two gyrators are utilized as is can be seen in fig.3, [4].



a)



b)

Fig. 3 Floating inductor implementation by the means of ideal gyration

To justify this result (fig.3), in a more general framework will be considered a quadripol in T between two gyrators, assumed identical for simplicity (fig.4), questioning the quadripol equivalent (dual) assessment of the global scheme.

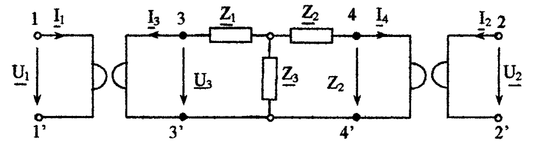


Fig. 4 Connecting a T quadripol between two identical gyrators

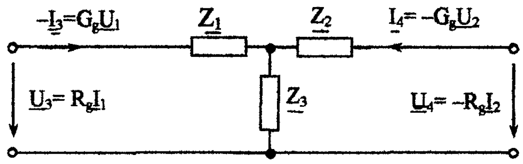


Fig. 5 The variables at the terminals of T quadripol

Given equations of ideal gyrator, with notation in fig. 3, can write

$$\begin{aligned} \underline{I}_3 &= -G_g \underline{U}_1 \\ \underline{U}_3 &= R_g \underline{I}_1 \\ \underline{I}_4 &= G_g \underline{U}_2 \\ \underline{U}_4 &= -R_g \underline{I}_2 \end{aligned} \qquad (11)$$

With these expressions of variables, voltages and currents, from the quadripol component in T terminals (fig.5), the quadripolar equations thereof become:

$$\begin{aligned} R_g \underline{I}_1 &= G_g \underline{U}_1 \underline{Z}_1 + \left(G_g \underline{U}_1 - G_g \underline{U}_2\right) \underline{Z}_3 \\ -R_g \underline{I}_2 &= -G_g \underline{U}_2 \underline{Z}_2 + \left(G_g \underline{U}_1 - G_g \underline{U}_2\right) \underline{Z}_3. \end{aligned} \qquad (12)$$

which take into account that are ideal gyrators, $R_g = 1/G_g$. Equations (8) may be written under the form:

$$\begin{aligned} \underline{I}_1 &= \left(\underline{Z}_1 + \underline{Z}_3\right) G_g^2 \underline{U}_1 - \underline{Z}_3 G_g^2 \underline{U}_2. \\ \underline{I}_2 &= -\underline{Z}_3 G_g^2 \underline{U}_1 + \left(\underline{Z}_2 + \underline{Z}_3\right) G_g^2 \underline{U}_2. \end{aligned} \qquad (13)$$

It can be noted that these equations in fact correspond to the whole scheme of between $11'$ and $22'$ (fig.3) and they are the equations of each quadripol.

If we consider now a quadripol in Π (fig.6) which is the dual of T quadripol, quadripolar equations are the following:

$$\begin{aligned} \underline{I}_1 &= \left(\underline{Y}_a + \underline{Y}_c\right) \underline{U}_1 + (-\underline{Y}_c) \underline{U}_2 \\ \underline{I}_2 &= (-\underline{Y}_c) \underline{U}_1 + \left(\underline{Y}_b + \underline{Y}_c\right) \underline{U}_2 \end{aligned} \qquad (14)$$

From the comparison of relations (13) and (14), it results in conditions that the ∏ scheme, in fig.6 and schema in fig.5 are equivalent. These expressions are:

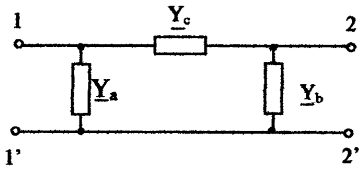


Fig. 6 Π Quadripol

$$\begin{aligned} \underline{Y}_a &= \underline{Z}_1 G_g^2 \\ \underline{Y}_b &= \underline{Z}_2 G_g^2 \\ \underline{Y}_c &= \underline{Z}_3 G_g^2 \end{aligned} \qquad (15)$$

Considering the particular case: $\underline{Z}_1 = \underline{Z}_2 = 0$, it results $\underline{Y}_a = \underline{Y}_b = 0$ and remains only $\underline{Y}_c = \underline{Z}_3 G_g^2 \neq 0$.

If $\underline{Z}_3 = 1/j\omega C$, it results $1/j\omega L$ meaning that $\underline{Y}_c$ corresponds to an inductivity L with given expression $L = C/G_g^2$. In the fig.3 are shown the gyrators corresponding to a floating inductivity.

The result may be generalized to the case when resistances (conductances) of gyrators have two values are different (R_{g1} and R_{g2}). Considering a T quadripol made only in the capacitors (C_1, C_2, C_3) and placed between two gyrators (fig.7) results in a ∏ quadripol composed only with inductivities (L_a, L_b, L_c) having the expressions:

$$\begin{aligned} L_a &= R_{g1} \cdot R_{g2} \cdot C_1 \\ L_b &= R_{g1} \cdot R_{g2} \cdot C_2 \\ L_c &= R_{g1} \cdot R_{g2} \cdot C_3 \end{aligned} \qquad (16)$$

Analogously may be established and other examples of dual quadripolar schemes arranged between the two gyrators. Getting scheme using dual gyrators is an important feature of them.

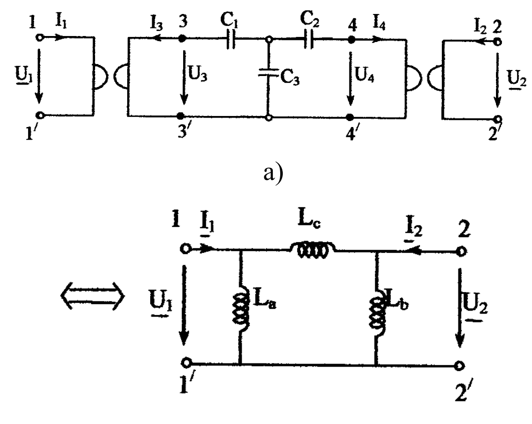


Fig. 7 Quadripol in T between two gyrators (a) and equivalent dual scheme in Π (b)

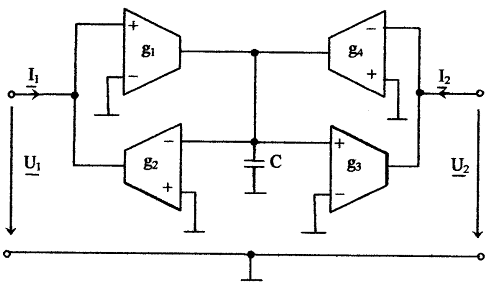


Fig. 8 Implementation of floating inductivity using operational transconductance amplifiers (OTA)

In fig.8 we may follow the implementation of floating inductivity using operational transconductance amplifiers, OTA, [10].

IV. PSPICE SIMULATION VALIDATION OF EQUIVALENT INDUCTIVITY

For ideal gyrator with AO type Antoniou, by choosing appropriate resistances, the scheme will analyze two cases. A first set $R_1=R_2=\ldots=R_7= =R=2k\Omega$. In this situation is ideal gyrator with transfer conductances equal ($G_{12}=-\left|G\right|=0{,}5mS$). Another set of values chosen for passive circuit elements of the scheme correspond gyrator in case (b) where the parameters transfer quadripolar values are not equal. It is considered as follows: $R_1=R_2=R^{/}=2k\Omega$; $R_3=R_4=R_5=R^{//}=3k\Omega$; $R_6=R_7=R^{/}= =2k\Omega$; Transfer conductances values are: $G_{12}=0{,}5mS$, $G_{21}=-0{,}333mS$.

For the two cases of gyrators considered ideal (a, b) is important to underline which is the equivalent inductivity (L_{e1}) completed at the input terminals of gyrators, assuming that at their output terminals is connected a condenser of capacity C=10nF. Referring to the relation 9 is obtain a corresponding ideal gyrator in the first case follows directly by calculation L_{e1}=40mH, and for the second case is obtained L_{e1}=60mH. Using PSpice numerical simulation of gyrator we have obtained the results shown in fig.9, which shows that at 1kHz, equivalent inductivity is L_{e1}=40.27mH for the first case, and L_{e1}=60.29mH for the second case. States that PSpice simulation takes into account a real model of AO, which in our case corresponds to the type of integrated AD 712.

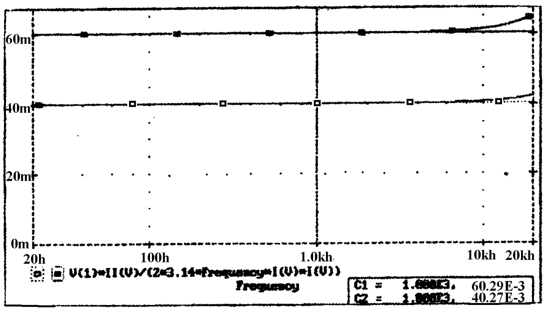


Fig. 9 Equivalent inductivities variations obtained by PSpice simulation: □ – case a, ■– case b

V. CONCLUSIONS

Simulation of inductor with gyrators is an important technique and the widely used in practical applications [10, 11, 12].

With this solution were made steps in the replacement circuit of RL circuit with the RC type, more efficient which can have a integrated form. On advantage of this RC circuit is added the high reliability and relatively low cost of integrated circuits with modern elements.

It is observed in this case (fig.9), a good concordance between results obtained by PSpice simulation, in terms very close to a real operation, the results obtained by calculation on the simplifying assumptions of the study. Concordance is particularly good at the frequency considered 1kHz.

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