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A simple impedance converter.

internal report by

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(July 1967)

abstract:
In the following a device is given, which converts an impedance into its dual. It can be used to simulate grounded inductances.
Introduction.

As far as we know, up till now every active device with gyrator properties consisted of at least two differential amplifiers [1], or four operational amplifiers [2], or contained two negative impedance convertors [3], all these circuits requiring a lot of components for proper action.

Recently W. Jost [4] has realised a gyrator with only two operational amplifiers in connection with a resistance network, in which tolerances of the resistance-values must be kept very small to guarantee good operation.

In some aspects, the circuit given here borrows from the various circuits of the references mentioned above.

It basically consists of only one negative resistance convertor and one emitter follower.
Consider the T-circuit of figure 1. After transforming it into its equivalent delta-network, the circuit of fig. 2 is obtained.

\[ R \quad Z \quad \text{fig. 1} \]

\[ R + 2Z \text{ \quad \quad \quad \quad \text{fig. 2} \quad 2R \quad R^2/Z \quad R + 2Z } \]

If now an ideal emitter follower is placed between points 1 and 3, these two points will achieve the same potential, and therefore, in the equivalent configuration of fig. 2, obviously no current will flow from point 1 to point 3.

Thus, looking into the circuit between points 1 and 2 of fig. 2, what remain will be the impedance \( 2R + (R^2/Z) \).

Finally, by adding a negative resistance \(-2R\) in series with the impedance between 1-2, to compensate the \(+2R\), only \(R^2/Z\) will be left, which is precisely the dual of the original impedance \(Z\).
The complete circuit is depicted in figure 3.

![Circuit Diagram]

This circuit has the advantage, that apart from the negative resistance, it can easily be built in integrated circuit form, because stability is evident and furthermore, element tolerance cannot disturb proper action.

The negative resistance has to be constructed in such a way, that it can be controlled from the outside.

The overall circuit is stable, if the absolute value of the negative resistance is smaller than \(2R\).

If \(Z\) of fig.3 is taken to be a capacitor, the input impedance will be an inductance in series with a small amount of resistance, which can be compensated with the negative resistance. In this way, inductor values from 5 millihenry to 1 henry with quality factors of 800 and more has been obtained in the range from zero to a few hundred kiloc./sec. at stable circuit operation.
Practical realisation.

The practical circuit is shown in fig. 4.

![Circuit Diagram]

The transistor $T_1$ is used as a current-source to bias the negative impedance convertor formed by $T_2$ and $T_3$. Transistor $T_4$ is the emitter follower. The circuit can be improved by replacing $T_4$ with a darlington-connection, a field-effect transistor or a combination of both; but for almost every practical application one transistor $T_4$ will prove sufficient.

For verification, we have constructed a first-order Tchebycheff-filter, first with a conventional wire-wound inductor with quality-factor 200 at the pole frequency and then replacing the inductor with the above simulator circuit.

The lastmentioned case gave equal or even better characteristics, especially at the pole frequency, due to the higher $Q$ (about 900) of the simulated inductance.
Conclusions.

An active device is given to generate dual impedances, for instance to convert a capacitive impedance into an inductive impedance with high Q-factor; with few components needed, thus facilitating future integrated-circuit realisation.

Moreover, if we consider the emitter-follower and the negative resistance of fig. 4 to be ideal; then a simple proof, as privately communicated to us by Prof. A. Fettweis, shows, that the circuit of fig. 4 indeed represents an ideal gyrator with gyration-resistance $R$ (here $R = 1$ k$\Omega$) and loaded at the output by the arbitrary impedance $Z$.

At the moment, work is in progress on a modified form of the above gyrator, which we hope will be more suitable as simulation for the ungrounded inductance. For this we have in mind a balanced-bridge configuration, in which the balancing is again maintained by an emitter-follower, similar to the one we used here.
References

("Electronics Letters", 1967, no.2, pp.50-51)


(Proc. of the Symp. on Modern Network Synthesis, Polytechnic Institute of Brooklyn, 1955.)


The negative resistance realisation as used in fig.4 is due to "Western Electric".
(Dutch Patent pending, no.6608223, Dec.15, 1966.)