Realizable Active Negative Inductors

by

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Introduction

In the design of wideband active loop antenna circuitry, the inductance of the antenna itself is problematic as it makes wideband matching of the antenna to the amplifier difficult, if not impossible (1). Numerous solutions involving remote tuning can be found (2, 3, 4), but overall a wideband solution is highly desireable. One solution would be to implement a negative inductor between the antenna and the amplifier so that the amplifier would only need to be matched to the low radiation and bulk resistance of the antenna. Such a circuitry block is elusive and often unstable, but here we will examine some traditional approaches as well as the adaptation of an approach used in monolithic circuitry that has some promise.

The Linvill Negative Impedance Converter

Probably the best-known approach to active negative impedances is the simple two-transistor negative impedance converter (NIC) circuit deviced by Linvill (5). Many variations of the circuit can be found in the literature, and the form shown here in Fig. 1 is one of those. Here, a pair of NPN transistors Q_1 and Q_2 see linear input currents at there emitters. These currents are pass to a pair of 1:1 wideband transformersT_1 and T_2 that are cross-coupled to the opposite transistor base terminals. Thus forms a balanced positive feedback amplifier, and the impedance Z connected between the two base terminals is reflected to the input terminals as a negative impedance of -Z.

This seems fairly straightforward until the nonlinear charcteistics of the base-emitter junctions are taken into account. Referring back to Fig. 1, the mapping of the base signal voltages v_{b1} and v_{b2} is exagerrated for clarity. It can be readily seen that these two voltages are not only assymetrical about signal ground, but they are also not balanced. This makesit necessary to use two separate transformers,. In addition, the unbalanved nature of the two base signal voltages makes the circuit unattractive for use with anything other than resistors for the impedance Z.

The Linearized Linvill Negative Resistance Converter

A partial solution to the nonlinearity problem of the Linvill NIC was proposed by A.H. Marshak in 1965 (6, 7). His solution, shown in Fig. 2, is to use a complementary NPN/PNP pair

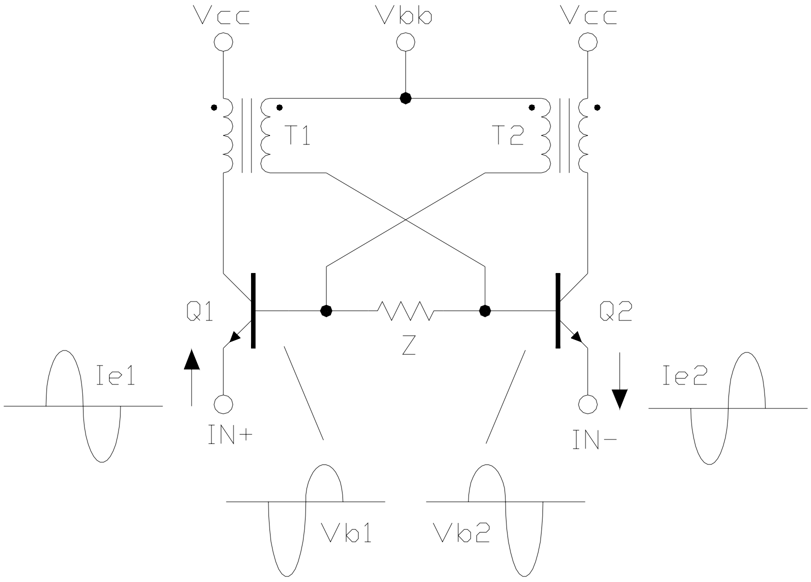

Fig. 1 - The Linvill Negative Impedance Converter

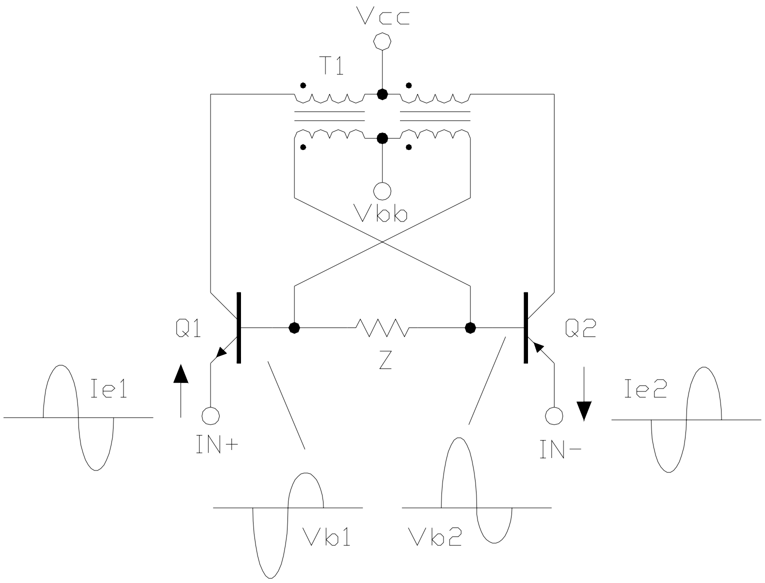

Fig. 2 - The Lineaized Linvill Negative Resistance Converter (from Marshak1965)

of transistors. As the voltage mapping of he base signal voltages v_{b1} and v_{b2} shows in Fig. 2, these two voltages are now balanced, which allows combining the 1:1 wideband transformers T_1 and T_2 of Fig. 1 into a single 1:1:1:1 wideband transformer. This provides an improvement in the balance of the Linvill NIC, however, the assymetry of the two base voltages about signal ground remains, so the circuit remains suitable only for resistors for the impedance Z.

The CMOS Negative Impedance Converter

Many additional solutions for NIC circuitry exist (8), and the vast majority have some problem with nonlinearities, transistor gain, temperature sensitivity, and conditional stability. One notable exception is that of the CMOS NIC (9), shown in functional form in Fig. 3. This and a few other circuitry blocks that hae evolved recently can be found in commercial electronics products as solid-state tuners for consumer television receivers.

Basically, the circuit consists of two current mirrors. The P-channel devices MM1 and MM2 reflect the input signal current I_1 seen by N-channel device M1. The reflected signal current I_2 is passed to the second N-channel device M2, which acts as the reference device for the second current mirror formed by M1 and M2.

The reflected signal current I_2 is conducted to an impedance Z connected across port 2. The voltage generated across port 2 is conducted to the input port, where it is seen as being 180° out of phase with the input signal current. Thus, the impedance seen at the input port is -Z.

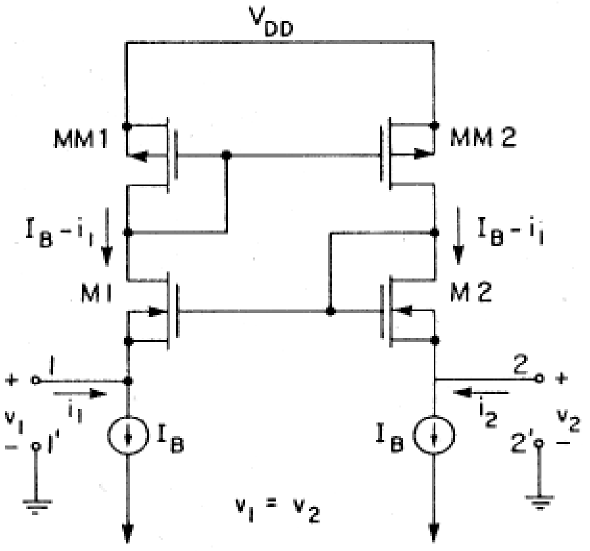

Fig. 3 - The CMOS Negative Impedance Converter (from Brennan *et al* 1988)

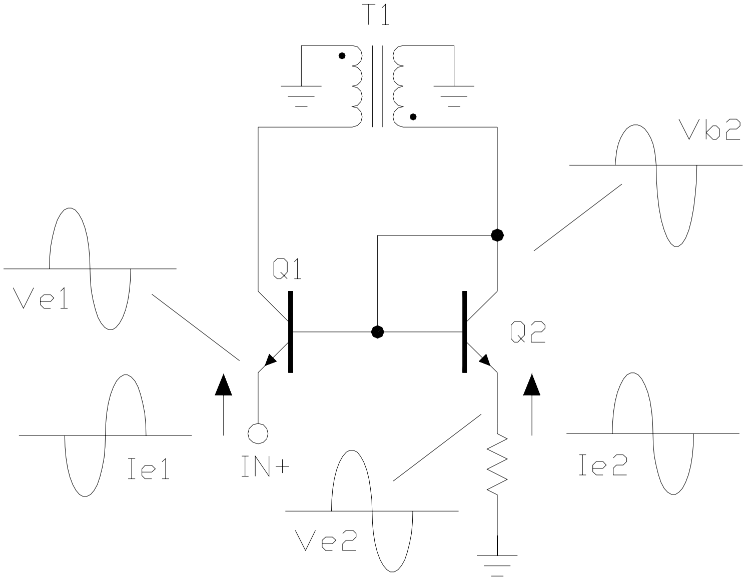

Fig. 4 - Functional Diagram of the Bipolar Negative Impedance Converter

The Bipolar Negative Impedance Converter

Of course, hobbyists do not have access to CMOS fabrication foundaries that would be required to reproduce the CMOS NIC circuit of Fig. 3. However, as shown in Fig. 4 the function of the P-channel current mirror pair MM1 and MM2 can be duplicated with a simple 1:1 wideband transformer, and the function of the N-channel current mirror pair M1 and M2 can be closely duplicatedwith a current mirror consisting of a pair of NPN bipolar transistors.

The voltage and current mapping shown in Fig. 4 shows that an input signal current i_{e1} at the emitter of Q_1 is reflected to the NPN current mirror reference transistor Q_2. A slightly smaller signal current i_{e2} is conducted to the reference impedance Z at the emitter of Q_2, creating a signal voltage v_{e2}. This same voltage then appears as v_{e1} at the emitter of Q_1, and it is 180° out of phase with the input signal current, just as with the CMOS NIC circuit of Fig. 3.

Since the signal current i_{e2} has remained virtually free of distortion, the emitter signal voltages v_{e1} and v_{e1} aare also virtually free of distortion, so the circuit is suitable for use with impedances consisting of reactive and non-reactive components as well as any combination, so the impedance Z could potentially be a lumped element model of a loop antenna (1, 2).

Practical Realization of the Bipolar Negative Impedance Converter

Fig. 5 shows a practical realization of the bipolar NIC circuit of Fig. 4, being used with an inductance for the reference impedance. This configuration makes it easy to conduct the input signal by way of a second wideband 1:1 transformer T_2. The circuit can be used for both single-ended and floating negative inductances, he absolute value of which is slightly higher than that of the reference nductance L..

Vcc is any suitable DC supply voltage between 5V and 15V. Resistor R_1 is selected to set the bias current that provides the best compromise of IMD and NF performance.

T_1 and T_2 are wideband 1:1 transformers made with bifilar twisted wire on a suitable binocular core such as the Fair-Rite 2843002402 (10, 11).

Transistors Q1 and Q2 are listed in Table 1 as being 2N2222, which should be fairly closely matched so that bias currents and small-signal characteristics are similar. It is, however, advantageous to make use of monolithic dual transistors, such as those offered by Panasonic and NEC (aka CEL, California Eastern Labs) which are readily available from popular distributors such as Digi-Key.

The Single Transistor Negative Impedance Converter

An interesting negative impedance converter circuit consisting of a single transistor and transformer is suggested by Hayakara and Nakamura (12). Shown in functional form in Fig. 6, an input current is applied to the input winding of a 3-winding wideband transformer T_1. The base winding of T_1 couples the input current to the base of transistor Q_1 in reverse phase, which then generates an amplified current through inductor L. The amplified current is passed to the collector of Q_1 and then to the collector winding of T_1. To achieve balance, the collector current of Q_1 becomes approximately equal to and opposite of the input current, and the voltage across the input winding is approximately that of the voltage across inductor L but in opposite phase from the input current. Therefore, the input winding produces an inductance approximately equal to -L.

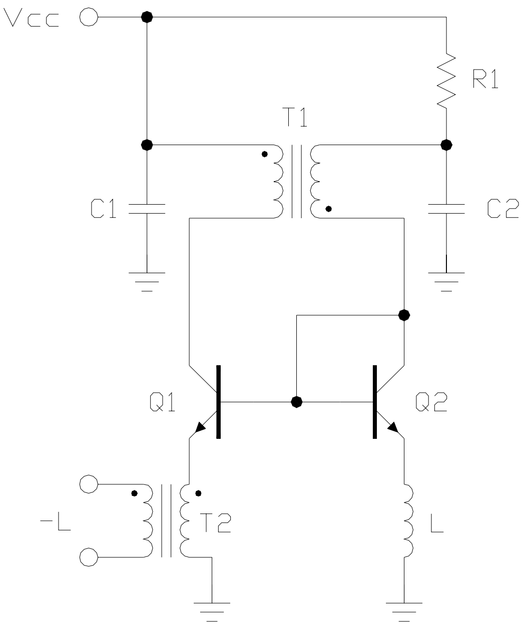

Fig. 5 - Realizable Form of the Bipolar Negative Impedance Converter

Table 1 - Parts List for Bipolar Negative Impedance Converter

C1, C2 - 0.1uF
Q1, Q2 - 2N2222 (see text)
R1 - See text
T1, T2 - 1:1 Transformer (see text)

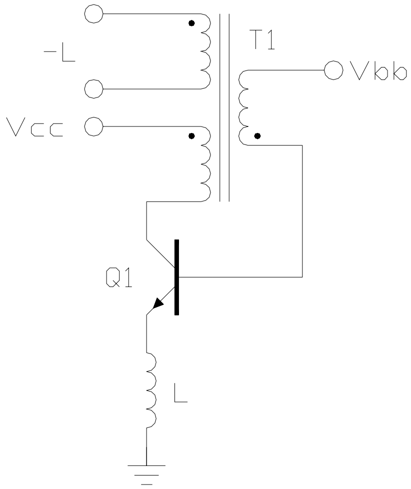

Fig. 6 - Functional Diagram of the Single Transistor Negative Impedance Converter

This circuit has a NF advantage over that of Fig. 4, however the IMD performance is less. In Fig. 4, the nonlinear emitter resistance r_{e2} of transistor Q_2 is reflected as $-r_{e2}$ at the emitter of transistor Q_1, where it is cancelled by the emitter resistance r_{e1} of Q_1. In the single transistor negative impedance converter of Fig. 6, the nonlinear emitter resistance r_{e1} of Q_1 is reflected to the input winding of T_1 as $-r_{e1}$, which results in a degraded IMD performance.

The discussion of the parts listed for the practical realization of the single transistor NIC circuit shown in Fig. 7 is much the same as that for Fig. 5, except that T1 is now a 1:1:1 wideband transformer.

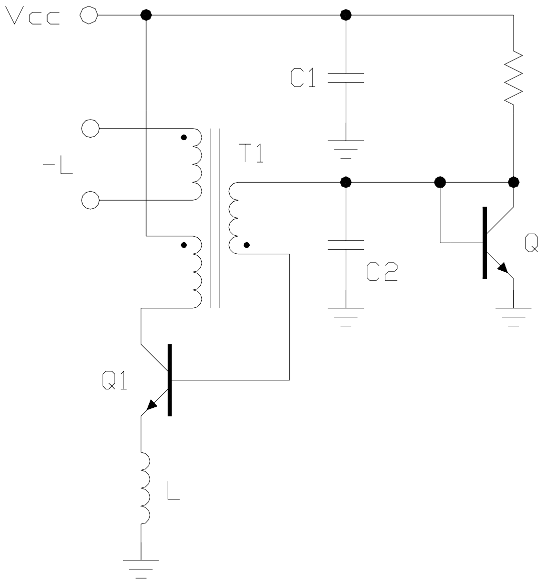

Fig. 7 - Realizable Form of the Single Transistor Negative Impedance Converter

Closing Remarks

The Bipolar NIC circuit described herein provides astable negative impedance converter that is well suited for use with wideband active loop antennas. It also provides good IMD performace by virtue of the feedback topology employed as well as good NF performance by minimizing the number of components. The single transistor NIC circuit described herein also provides a stable negative impedance converter, with a lower NF but with lesser IMD perforance.

Table 2 - Parts List for Single Transistor Negative Impedance Converter

C1, C2 - 0.1uF
Q1, Q2 - 2N2222 (see text)
R1 - See text
T1 - 1:1:1 Transformer (see text)

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