Linearized Common-Base Balanced Amplifiers Using Linvill NIC Feedback

by

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Introduction

In the design of wideband active antenna circuitry, the intermodulation distortion (IMD) and noise figure (NF) performance are important design considerations. IMD performance is greatly dependent on the nonlinear behaviour of bipolar transistor base-emitter junctions and the square-law characteristcs of field effect transistors (FETs). NF performance is primarily a matter of device selection and operating bias point as well as the minimization of dissipative devices such as resistors and transformer losses, as well as the proper matching of the antenna to the amplifier. In the matter of active loop antennas, the input impedance of the amplifier needs to be exceptionally low to meet the characteristically low radiation resistance. In this paper we will examine an amplifier having an input resistance of less than 0.10Ω together with exceptional IMD and NF performance.

Input Characteristics of the Common-Base Amplifier

In the common-base amplifier shown in Fig. 1, the base-emitter voltage V_{be} is a function of the total emitter current I_e:

$$V_{be} = V_{BE} + v_{be} = \frac{k\,T}{q}\, ln \frac{I_e}{I_O} \qquad (1)$$

where v_{be} is the base-emitter signal voltage, I_O is the transistor reverse saturation current, q is the electronic charge (1.60219×10^{-19} J), k is Boltzmann's constant (1.380622×10^{-23} J/K), T is the temperature in degrees Kelvin (K), and the total emitter current I_e is the sum of the emitter bias current I_E and the emitter signal current i_e:

$$I_e = I_E + i_e \qquad (2)$$

The emitter input resistance r_e can be approximated by:

$$r_e = \frac{v_{be}}{i_e} = \frac{v_{be}}{I_O \times \varepsilon^{\frac{q\,V_{BE}}{k\,T}}} \qquad (3)$$

In the common-base amplifier shown in Fig. 1, the signal input current i_e is shown as a linear function and the base-emitter signal voltage v_{be} is exagerated for clarity.

Augmentation of the Common-Base Amplifier

In reality, the finite nonlinear emitter input resistance r_e of Eq. 3 disturbs the emitter signal input current i_e. This can be improved by reducing r_e by way of the application of augmentation (1, 2). Shown in basic form in Fig. 2, an inverting augmention amplifier having a voltage gain of A_V

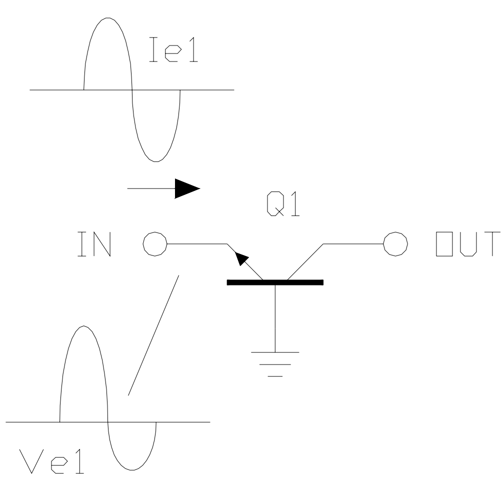

Fig. 1 - Common-Base Amplifier
Input Charcteristics

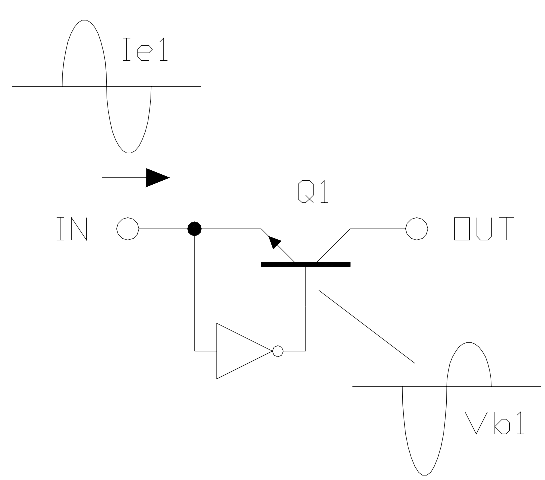

Fig. 2 - Basic Augmentation of the
Common-Base Amplifier

detects the emitter signal voltage v_e, amplifies and inverts it, applying the result to the base of Q_1, resulting in a reduced emitter input resistance r_e':

$$r_e' = \frac{\dfrac{v_{be}}{A_v + 1}}{I_O \times \varepsilon^{\frac{q V_{BE}}{k T}}} = \frac{r_e}{A_v + 1} \qquad (4)$$

As the gain of the augmentation amplifier is increased, the emitter input resistance r_e approaches zero. Numerous realizations of augmentation can be found in the literature cited, and the form making use of a two-winding transformer provides a good compromise of simplicity, NF and IMD perfomance, and input resistance reduction. However, the practical realization of wideband transformers introduces a limit to which the input resistance can be reduced.

Cascade Linearization of the Common-Base Amplifier

To realize a practical substantial reduction in the emitter input resistance r_e, a cascade of two common-base amplifiers can be employed, detecting the emitter signal voltage of the second amplifier (v_{e2}), and then using a simple 1:1 wideband transformer to invert v_{e2} and conduct it to the base of the first amplifier. Shown in Fig. 3, this method results in a substantial reduction in the amplifier input resistance:

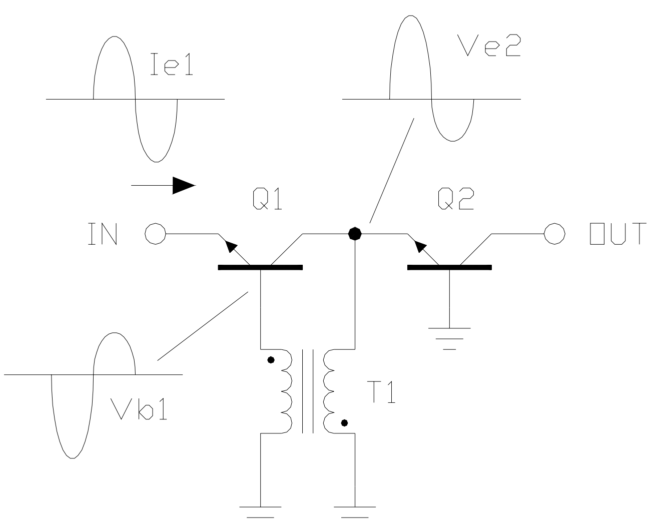

Fig. 3 - Cascade Linearization of the Common-Base Amplfier

$$r_e' = \frac{r_{e1}}{h_{fe1} - 2} \qquad (5)$$

where r_{e1} is the emitter input resistance of transistor Q_1 and h_{fe1} is the small signal current gain of transistor Q_1. This is an exceptionally low input impedance that would typically require the use of active augmentation.

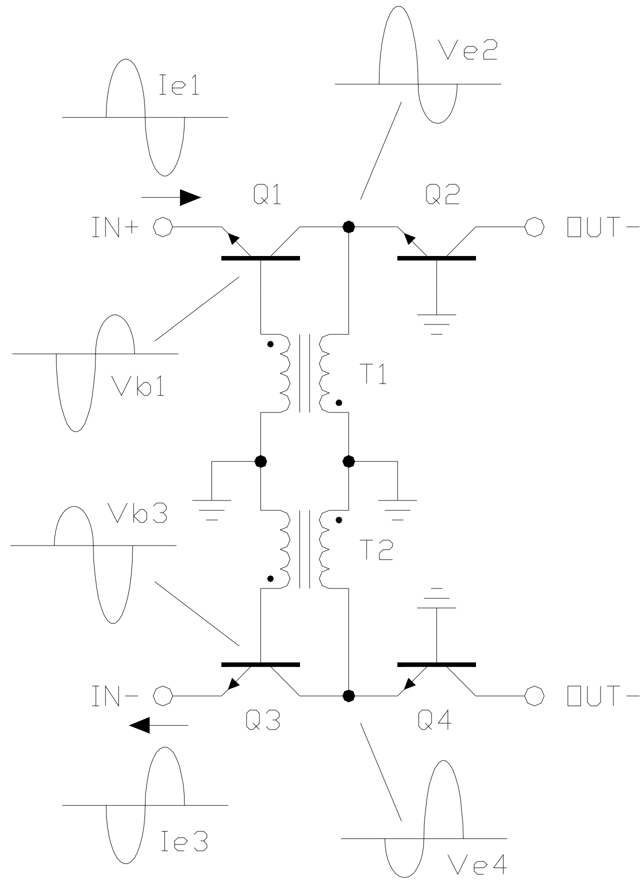

Fig. 4 - Balanced Common-Base Amplifier Using Cascade Linearization

The currents and voltages shown in Fig. 3 show that the base voltage of Q_1 is the same in both approaches, and in Fig. 3 this is accomplished with a simple 1:1 wideband transformer and a second transistor. This method can be extended to push-pull amplifiers, as shown in Fig. 4.

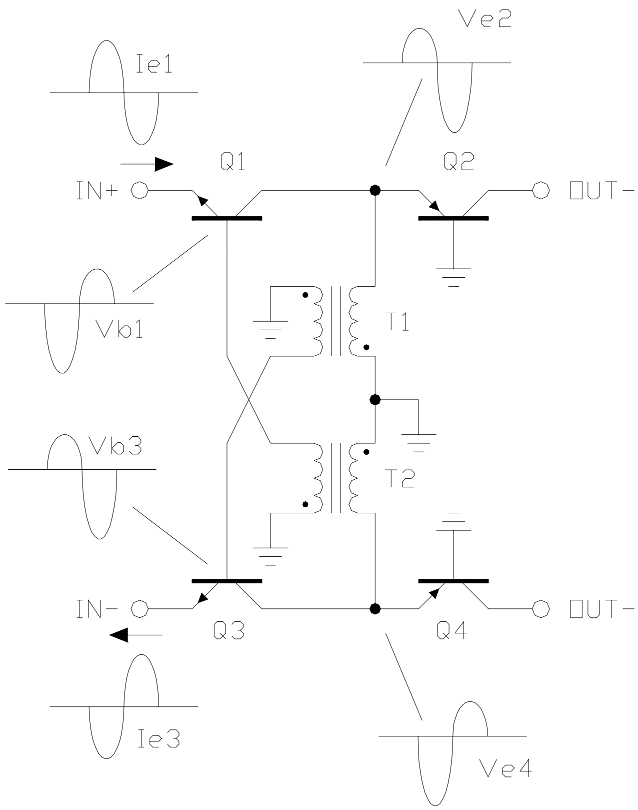

Fig. 5 - Linearized Common-Base Balanced Amplifier Using Linvill NIC Feedback

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The balanced amplifier of Fig. 4 suggests an interesting innovation if the emitter signal voltage v_{e2} of transistor Q_2 was conducted to the base of transistor Q_3 and the emitter signal voltage v_{e4} of transistor Q_4 was conducted to the base of transistor Q_1. However, as the signal voltages shown in Fig. 4 illustrate, the asymmetry of the emitter signal voltages v_{e2} and v_{e4} prevents this from being a practical approach when compared to the signal voltage requirements of Fig. 2 and Fig. 3, and it would result in a substantial reduction in IMD performance.

The incompatibility of these signal voltages can be remedied by changing transistors Q_2 and Q_4 from NPN to PNP, as shown in Fig. 5. Now, the secondary winding of transformer T_1 is connected to the base of transistor Q_3 and the secondary winding of transformer T_2 is connected to the base of transistor Q_1. In this configuration, transistors Q_1 and Q_2 together with transformers T_1 and T_2 constitute a Linvill negative impedance converter (NIC). If all four transistors have similar characteristics, the balanced amplifier of Fig. 5 is unconditionally stable and has a balanced input resistance that is very close to zero.

Practical Realization of the Linvill Feedback Amplifier

Fig. 6 shows a practical realization of the Linvill feedback amplifier of Fig. 5. This configuration is intended to be used with loop antennas such as the Meobius Strip loop that has connections to ground (3). This simplifies the coupling of the loop antenna to the amplifier as well as the biasing of the amplifier.

Vcc is any suitable DC supply voltage between 8V and 15V.

Transistor Q_5 provides a current mirror reference for transistors Q_1 and Q_3, while transistor Q_6 provides a similar current mirror reference for transistors Q_2 and Q_4. 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. T_3 is a 1:1:1 wideband transformer made with trifilar twisted wire on a similar binocular core (4, 5).

Closing Remarks

The Linvill feedback amplifier described herein provides an exceptionally low input impedance 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 lossy components.

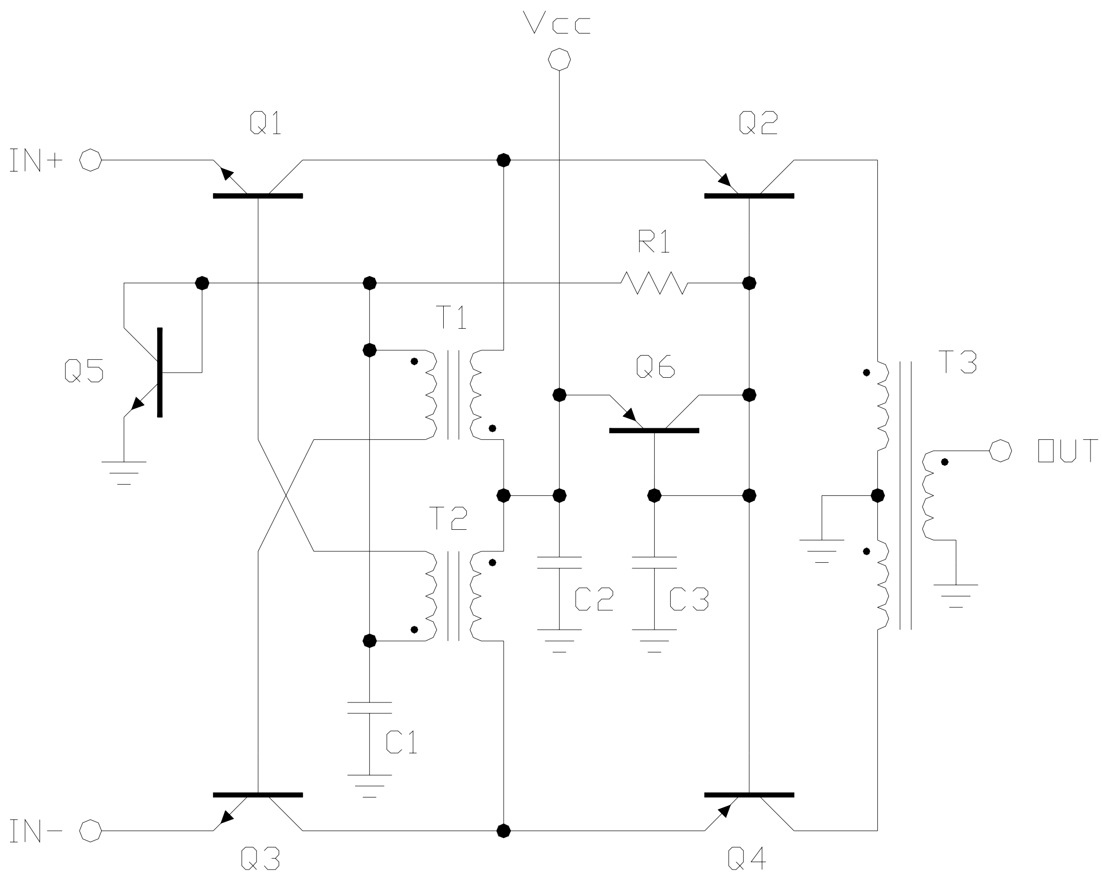

Fig. 6 - Practical Linvill Feedback Amplifier

C1, C2, C3 - 0.1uF	R1 - See text
Q1, Q3, Q5 - 2N2222	T1, T2 - 1:1 Transformer (see text)
Q2, Q4, Q6 - 2N2907	T3 - 1:1:1 Transformer (see text)

Table 1 - Parts List

References

1. Trask, C., "Common Base Amplifier Linearization Using Augmentation," *RF Design*, October 1999, pp. 30-34.
2. Trask, C., *Common-Base Amplifiers with Linearity Augmentation*, US Patent 6,271,721, 7 August 2001.
3. Trask, C., *Mastering the Art of Shielded Loop Aerials*, 20 March 2010 (online resource).
4. Trask, C., “Designing Wide-band Transformers for HF and VHF Power Amplifiers,” *QEX*, May/April 2005, pp. 3-15.
5. Walker, John L.B., Daniel P. Meyer, Frederick H. Raab, and Chris Trask, *Classic Works in RF Engineering: Combiners, Couplers, Transformers, and Magnetic Amplifiers*, Artech House, 2006.