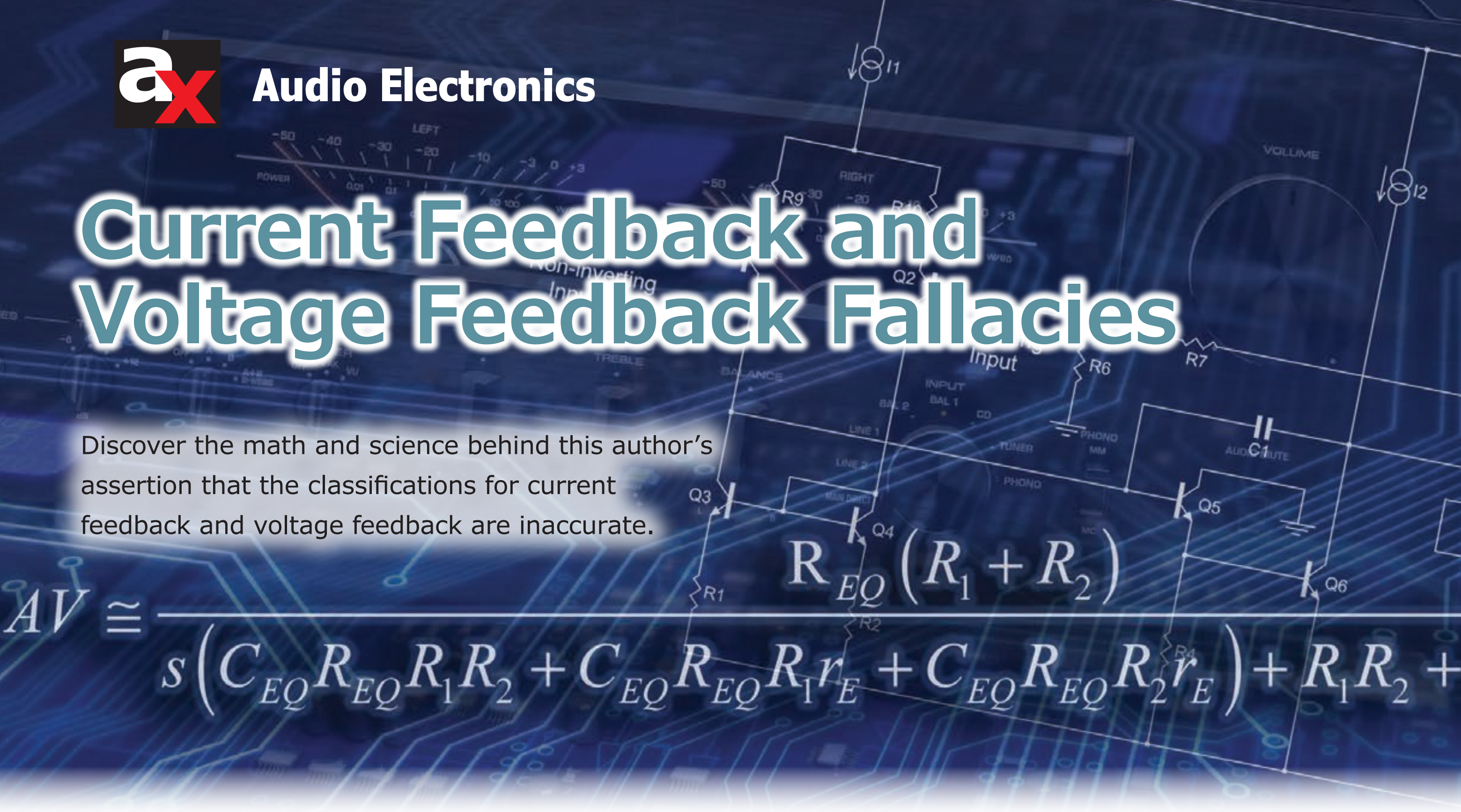

Audio Electronics

Current Feedback and Voltage Feedback Fallacies

Discover the math and science behind this author's assertion that the classifications for current feedback and voltage feedback are inaccurate.

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It is presently almost universally asserted that amplifiers may be classified into two main groups: "current feedback" or "voltage feedback," allegedly depending on whether they respond to current inputs or voltage inputs, respectively.[1] This classification is misconceived and did not exist 35 years ago for sound technical reasons.

Feedback Amplifier Configurations

Regarding the so-called "current feedback" amplifier topology of **Figure 1**, it is suggested by Sergio Franco in his book *Design with Operational Amplifiers and Analog Integrated Circuits* that the current sunk by the negative feedback network from the inverting input of the amplifier is equal to the current sourced into the impedance at the output of the complementary current mirrors so that:

$$v_{out} = i_N \left(R_{eq} // \left(1/sC_{eq} \right) \right) \tag{1}$$

Franco infers from this equation that the error signal driving the amplifier's forward-path is the current i_N and states that the impedance is the amplifier's "open-loop transimpedance gain." Consequently, he concludes that "current feedback amplifiers" may also be called "transimpedance amplifiers." Franco is far from alone in espousing these views. Derek Bowers also discussed it in Chapter 16 of *Analog IC Design: The Current-Mode Approach*. But, they are, nevertheless, fatally flawed. To see why, a clear appreciation of what really constitutes a current feedback amplifier, a voltage feedback amplifier, and a transimpedance amplifier is required.

There are only four forms of single major-loop electronic negative feedback in existence:[2]

1. Shunt (Current) Applied, Shunt (Voltage) Derived Negative Feedback—In **Figure 2**, the feedback transfer function is a transadmittance, giving rise to a transimpedance amplifier or a transadmittance feedback amplifier.
2. Shunt (Current) Applied, Series (Current) Derived Negative Feedback—In **Figure 3**, the feedback transfer function is a current ratio giving rise to a current feedback amplifier or, simply, a current amplifier.
3. Series (Voltage) Applied, Series (Current) Derived Negative Feedback—With **Figure 4**, the feedback transfer function is a transimpedance,

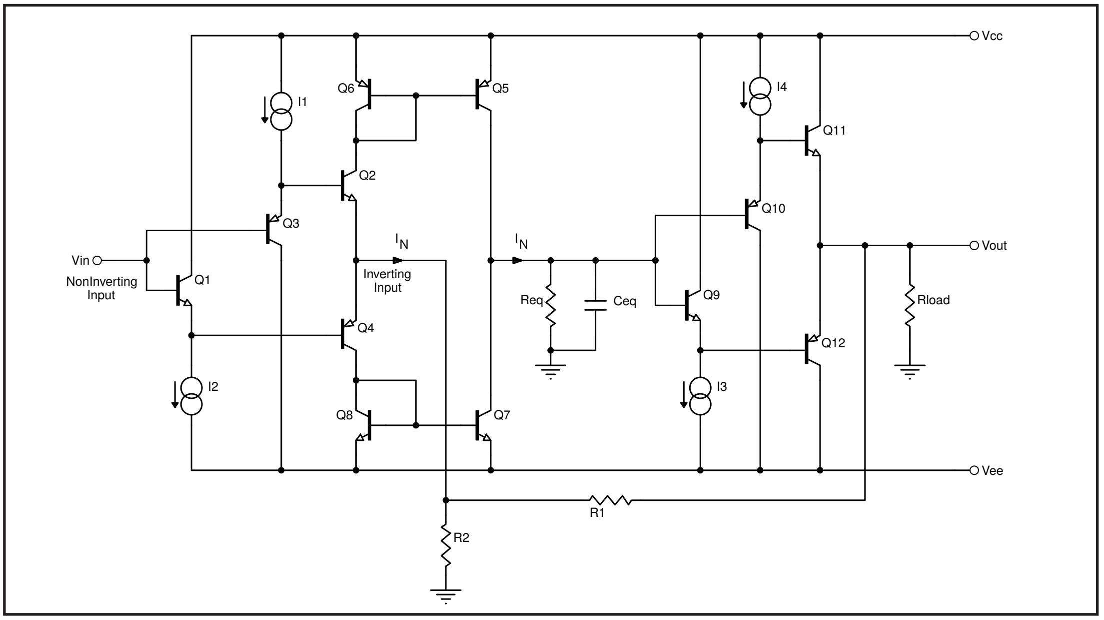

Figure 1: This circuit is almost universally called a "current feedback" amplifier; however, it is simply a voltage amplifier.

which gives a transadmittance amplifier or a transimpedance feedback amplifier.

4. Series (Voltage) Applied, Shunt (Voltage) Derived Negative Feedback—The feedback transfer function shown in **Figure 5** is a voltage ratio resulting in a voltage feedback amplifier or, alternatively, a voltage amplifier.

From the above definitions, it is apparent that the type of amplifier obtained after the application of single major-loop negative feedback is determined by the feedback network's transfer function and not by the topology of the amplifier's forward-path or the current drawn by the feedback network from the amplifier's inverting input in the case of the circuit shown in **Figure 1**.

It is also self-evident that the term "current feedback" only applies to an amplifier in which the negative feedback transfer function is a current ratio—that is, one in which the negative feedback is shunt applied and series derived, giving a current amplifier or current-controlled current source.

Additionally, the amplifier shown in **Figure 1** is a voltage amplifier and not a transimpedance amplifier because its negative feedback transfer function is a voltage ratio (that is, one in which the feedback is series applied and shunt derived by means of a simple voltage divider) irrespective of the topology of the amplifier or of the loading of the feedback summing node (the inverting input) on the feedback network.

Greater insight into why the circuit shown in **Figure 1** really isn't a current feedback amplifier can be gleaned by consideration of the fact that, in the first instance, the current flowing in the negative feedback network for a given output voltage is not a function of the current flowing through the amplifier's load. In other words, the load current is not controlled by the negative feedback, as it should with a current feedback amplifier. Instead, the negative feedback network in the circuit shown in **Figure 1** is a voltage divider draped across the output of the amplifier which implies, clearly, that it is the output voltage that is sampled by the divider which then applies a fraction of that output voltage to the inverting input of the amplifier. The current flowing through the negative feedback voltage divider is, therefore, completely irrelevant.

A transimpedance amplifier, on the other hand, possesses transadmittance feedback (that is, an amplifier with shunt applied and shunt derived negative feedback) and is, in fact, a current-controlled voltage source. The circuit shown in **Figure 1** is, therefore, most certainly not a transimpedance amplifier, regardless of its assumed internal workings.

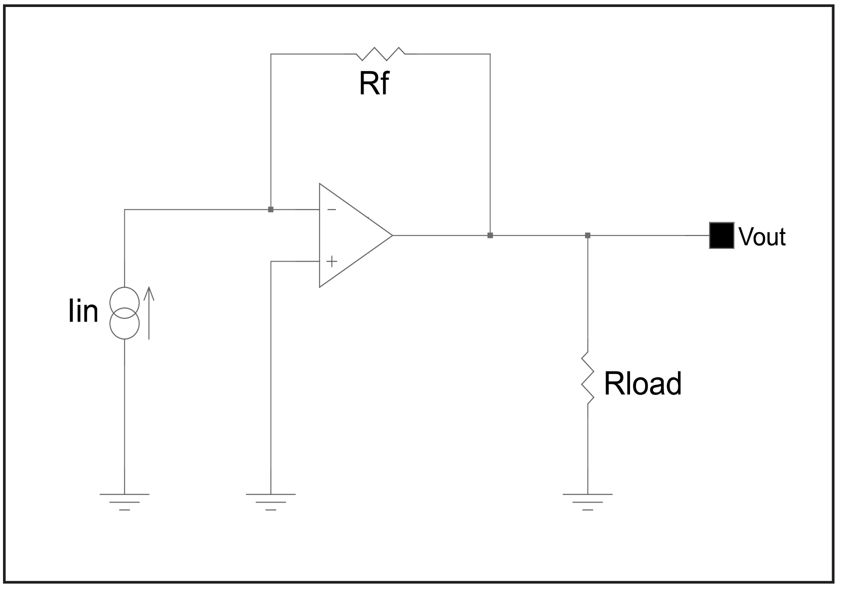

Figure 2: Transadmittance feedback gives rise to a transimpedance amplifier or a current-controlled voltage source (CCVS).

How So-called "Current Feedback" and "Voltage Feedback" Amplifiers Really Work

The critical error in Franco's **Equation 1** is that it does not account for the amplification occasioned by the complementary pair of input transistors Q2 and Q4 (see **Figure 1**), which operate in common-emitter mode with respect to the amplifier's forward-path and common-base mode as far as the loop-transmission path is concerned. In both modes, it is the voltage gain of these transistors that is relevant, irrespective of the fact that significant current flows between the inverting input and the feedback network due to the loading of the former on the latter.

Since the complementary common-emitter pair Q2 and Q4 is biased in Class-B (with the transistors forward-biased alternately) courtesy of emitter followers Q1 and Q3, the forward-path voltage gain of the amplifier with respect to its non-inverting input is that of a single common-emitter amplifier with (R_{EQ}//(1/sC_{EQ}) as its load. The latter is simply divided by the sum of the parallel combination of the feedback resistors (R1//R2) and the emitter intrinsic resistance r_E to obtain the approximate forward-path voltage gain A_V:

$$AV \cong \frac{R_{EQ}\left(R_1+R_2\right)}{s\left(C_{EQ}R_{EQ}R_1R_2+C_{EQ}R_{EQ}R_1r_E+C_{EQ}R_{EQ}R_2r_E\right)+R_1R_2+R_1r_E+R_2r_E} \quad (2)$$

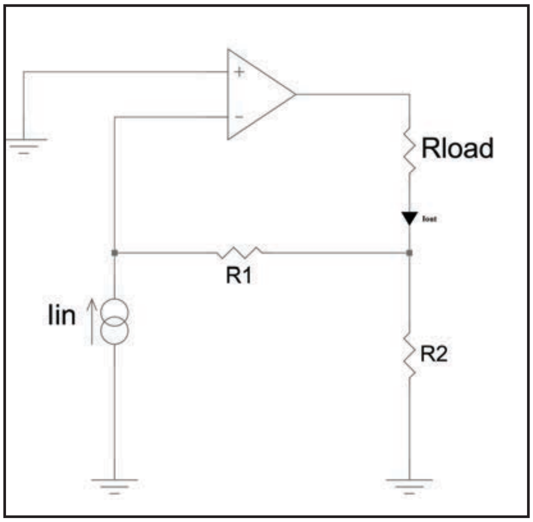

Figure 3: Current feedback gives rise to a current amplifier or a current-controlled current source (CCCS).

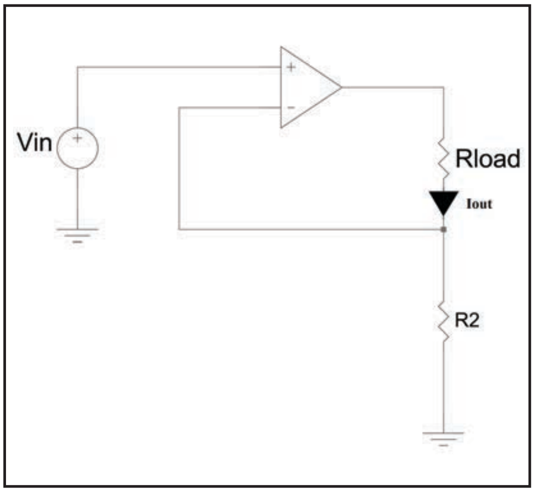

Figure 4: Transimpedance feedback gives rise to a transadmittance amplifier or a voltage-controlled current source (VCCS).

Note that the complementary current mirrors in **Figure 1** do not generate voltage gain but merely provide phase inversion and level shifting.

The method we used earlier to determine the forward-path gain of a voltage feedback amplifier in which the feedback summing node (the inverting input) of the amplifier significantly loads the feedback voltage divider is ably explicated by D. H. Horrocks in his book *Feedback Circuits and Op Amps*. The loading effects of the feedback network on the output of the amplifier are here deemed negligible.

As indicated above, the fact that the complementary common-emitter pair in the circuit shown in **Figure 1** source significant current to the negative feedback network is merely indicative of the loading of the amplifier's inverting input on the feedback network, and it certainly does not imply that the circuit is a current feedback amplifier.

The feedback voltage divider places a fraction of the amplifier's output voltage at the inverting input where it is then subtracted from the input voltage at the non-inverting input to generate the error voltage which drives the amplifier's forward-path. Therefore, contrary to opinions from Franco and from Walt Jung in his book *Op Amp Applications Handbook*, the negative feedback does not act to drive the current from the inverting input to zero because the error signal is a voltage and not a current. Indeed, the negative feedback does not act to drive this error voltage to zero either because, in a physically realisable amplifier, a finite error voltage is required to drive the amplifier's forward-path in order to cause it to generate the demanded output voltage. This is a common misconception. Therefore, to reiterate this important point, the amplifier from **Figure 1** responds to voltages rather than currents at both its inverting and non-inverting inputs, and, consequently, the error signal driving its forward-path is a voltage and not a current.

This is also true of the topology shown in **Figure 6**, which is erroneously and almost universally referred to as a "voltage feedback amplifier" even when its feedback connections do not justify it. Of course, it is evident that in this specific case, the circuit shown in **Figure 6** is, in fact, a voltage feedback amplifier because it possesses series (voltage) applied, shunt (voltage) derived negative feedback, and, therefore, its feedback transfer function is a voltage ratio. But, crucially, this will not be true if either of the other three forms of negative feedback is applied instead. Clearly, in the absence of major loop negative feedback the circuits shown in **Figure 1** and **Figure 6** are simply voltage amplifiers.

One of the most important functions of major loop negative feedback is to convert a basic voltage amplifier into one of the following configurations: a voltage-controlled voltage source (VCVS), a voltage-controlled current source (VCCS), a current-controlled current source (CCCS), or a current-controlled voltage source (CCVS). This is achieved by the negative feedback modifying the amplifier's input and output impedances, with shunt negative feedback connections reducing the impedance, while series negative feedback connections increase the impedance. Note, however, that the low impedance at the inverting input of the voltage amplifier of **Figure 1** broadly precludes its use in inverting applications with shunt applied negative feedback; such applications require a voltage amplifier with a differential-pair input stage as used in the circuit shown in **Figure 6**.

A significant difference between the circuits shown in **Figure 1** and **Figure 6** is in the

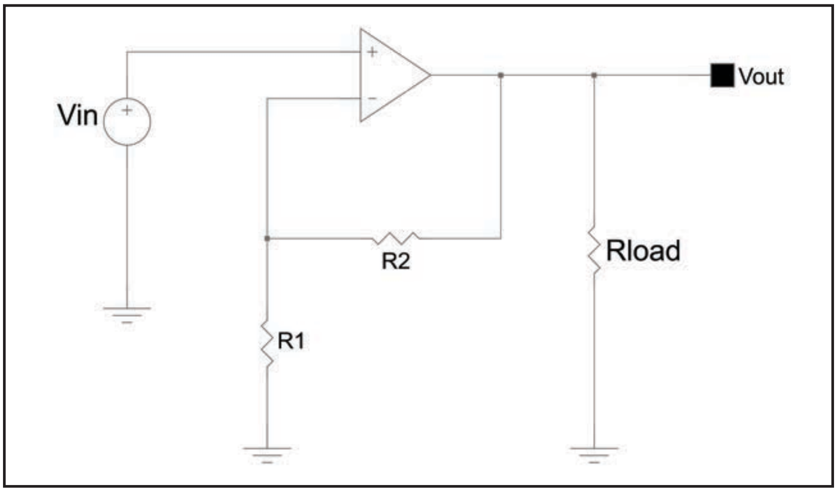

Figure 5: Voltage feedback gives rise to a voltage amplifier or a voltage-controlled voltage source (VCVS).

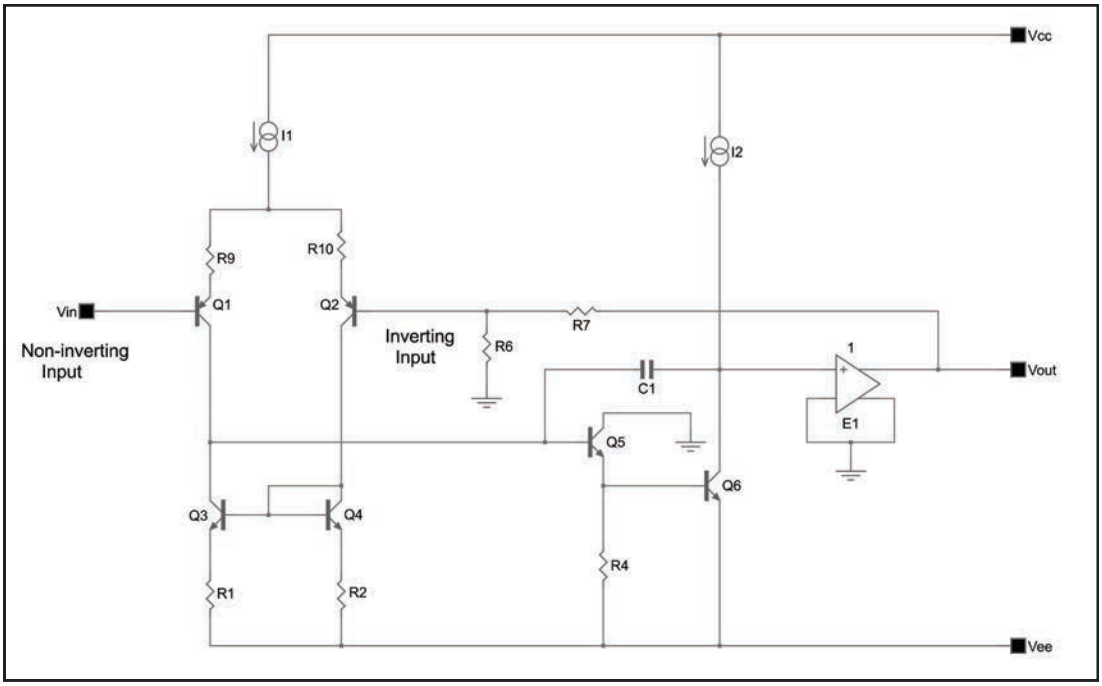

Figure 6: The rudiments of a voltage amplifier of the Thompson topology; the input stage is a differential transadmittance stage (TAS) while the second stage is a transimpedance stage (TIS). The unity-gain voltage-controlled voltage source E1 represents the output stage of the amplifier, and this is usually a complementary Class-B emitter-follower arrangement.

amplifier of **Figure 6**—the feedback network is buffered from the feedback summing node by the emitter follower Q2 that is part of the input differential pair. Thus, the forward-path gain and forward-path dominant pole of the circuit shown in **Figure 6** do not vary significantly with changes in the values of the feedback network. The workings of the circuit shown in **Figure 6** are further elucidated in an article I wrote called "Variations on the Complementary Folded Cascode Transimpedance State in Discrete Audio Frequency Power Amplifiers" (*Electronics World*, 2013).

In contrast, and in accordance with **Equation 2**, the forward-path dominant pole and forward-path gain of the so-called "current feedback" amplifier of **Figure 1** vary appreciably with changes in the values of the components comprising the feedback network. This is due to the voltage coupling factor between the feedback network and the conjoined emitters of the complementary common-emitter input stage being much less than unity. The poor voltage coupling factor is simply another way of saying the amplifier's inverting input severely loads the feedback network. The compromised voltage coupling factor also severely reduces major-loop gain in the voltage amplifier of **Figure 1** compared to that obtainable with the conventional circuit shown in **Figure 6** for the same feedback network component values. Major-loop transmission is not helped by the fact that the execrable circuit shown in **Figure 1** possesses only one common-emitter gain-generating stage

References

[1] S. Franco, *Design with Operational Amplifiers and Analog Integrated Circuits*, pp. 315-321, 4th edition, McGraw-Hill Education, 2014.

[2] T. M. Frederiksen, *Intuitive Operational Amplifiers: From Basics to Useful Applications*, pg. 80-85, McGraw-Hill, 1988.

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D. F. Bowers, "Applying 'Current Feedback' to Voltage Amplifiers," Chapter 16 in *Analogue IC Design: The Current-mode Approach*, C. Toumazou, et al. (editors), Peter Peregrinus, Ltd., 1990.

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A. C. Russell, "CFA vs VFA: A Short Primer for the Uninitiated," hifisonix.com, January 2014, http://hifisonix.com/wordpress/wp-content/uploads/2014/01/CFA-vs-classic-Lin-VFA-topology.pdf.

in its forward-path compared to two stages in the arrangement shown in **Figure 6**, which consists of a transadmittance stage driving a transimpedance stage.

Therefore, contrary to the comments by Andrew C. Russell in his article "CFA vs VFA: A Short Primer for the Uninitiated," the voltage amplifier of **Figure 1** is of no use whatsoever in audio frequency applications because its significantly low major loop gain (compared with that generated by the circuit shown in **Figure 6**) is insufficient to satisfactorily mitigate the non-linearity generated by its forward path. The performance of the circuit shown in **Figure 1** is further degraded by the fact that its complementary common-emitter input stage operates in Class-B. It's bad enough that crossover distortion arising from Class-B operation has to be tolerated in the output stage, but extending it to the input stage as well is downright perverse, at least as far as audio frequency applications are concerned. Although the push-pull Class-B operation of the complementary common-emitter input stage of the circuit shown in **Figure 1** makes very high slew rates possible by supplying a relatively large amount of current to charge and discharge the capacitance at the output of the current mirrors, this is not a significant advantage in audio frequency applications.

Conclusion

The terms "current feedback amplifier" and "voltage feedback amplifier" as presently used are wholly unfounded. It has been demonstrated that the correct application of these terms is entirely dependent on the manner in which major loop feedback is applied around the forward-path of an amplifier, irrespective of the workings of its internal circuitry.

About the Author

Michael Kiwanuka has had an abiding fascination for audio electronics since he was a teenager. This interest eventually led to the pursuit of a BTEC HNC in Electronic Engineering and a BSc (Honors) degree in Electronic Engineering. He is presently involved in the research and development of novel feedback error correction strategies for audio frequency power amplifiers.