Some Useful Background Reading on Current Feedback Amplifiers

July 8, 2017 Walt Jung 9 Comments

Recently, *AudioXpress* published an interesting article on the use of feedback amplifiers. The article is Michael Kiwanuka's "Current Feedback and Voltage Feedback Fallacies" which appeared in June 2017, p32-37. The article purports to clarify certain 'fallacies' regarding four basic feedback configurations, using op amps.

The conclusions reached by the article really are most curious. Quoting directly from the final summation: *'The terms "current feedback amplifier" and "voltage feedback amplifier" as presently used are wholly unfounded.'*

This is a very odd conclusion, as it flies directly in the face of 3-4 decades of current feedback amplifier (CFA) history! In the attachment cited below, the bibliographic references document this point quite well, and will serve as *Useful Background Reading.* After careful study, readers should then be able to draw their own conclusions as to whether the feedback system used in conjunction with a given amplifier architecture employs current or voltage. A couple of CFA data sheets will help immeasurably, of course. *In fact, this exercise should show just how CFAs operate.*

Author MK also is critical of certain book authors on these subjects, namely Professor Sergio Franco and Walt Jung. Accordingly, we have authored a ***technical rebuttal document,*** cited below. This document is supported by other signatories, as noted within. This rebuttal has been forwarded to *AudioXpress,* along with a request that it be made available to their readership. We are hopeful that in time they will honor this request.

> *This is an update to this posting, as of 7/12/2017, including a newly revised technical rebuttal document. This revision includes links to the latest errata information from AudioXpress.*
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> ***See this updated technical rebuttal document for the "Current Feedback and Voltage Feedback Fallacies", Michael Kiwanuka, AudioXpress, June 2017, p32-37.***

Comments on the above are welcome, so address them directly to CFAs@ownmail.net. Indicate if the comment is for publication. Your email address will remain private. All comments are moderated.

Watch these blog pages for additional content of importance.

Walt Jung

Sergio Franco

Michael Steffes
July 17, 2017 at 12:32 PM

Recent Confusing Comments on Current Feedback Amplifiers (CFAs) from Michael Kiwanuka

Hello all,

I was not aware this was going on until a colleague sent it over. Little bit of an odd interpretation MK has on a type of device we have been developing and designing in around the world since the mid-80's. I am actually in the late stages of introducing a new CFA device, I don't see anything in the work by MK that would dissuade me from calling it a current feedback amplifier as was my original intent.

It appears Walt Jung and Sergio Franco covered some of the technical faux pas in the article, but let me comment on how the name current feedback amplifier (CFA) came about. There is certainly a bit of marketing slang involved there, but also very descriptive we believe.

Having worked in the original CFA development group in Comlinear from 1985 on, we were the source for a lot of what came later.

In the late 80's, David Potson (one of several original authors on this topic) and myself were literally circling the globe giving CFA seminars to an initially skeptical design community. I am reminded of that period in MK's article as customers tried to force the topology into the canonical forms. The way I ended up getting past that was to emphasize that the complete solution was really two amplifiers operating together, not a simple one feedback situation – this might be the piece MK has gone past without appreciating its significance.

The input buffer across the inputs operates separately from the high transimpedance forward path and output stage buffer. You can open the external feedback loop and still get a wideband buffer across the inputs – that buffer controls the voltage on the inverting node whether you have feedback or not. At various times I have tried to use this as a simple current controlled comparator. Running a CFA open loop will bang the output against the rails as the polarity of the current in the inverting node (buffer output) flips. Not too useful, as the output saturation recovery time is not controlled.

The real magic of what we have come to call a current feedback op amp is the dual use in the emitter followers at the inverting input. Not only do these transistors provide the voltage follower output function for the buffer across the inputs, but they cascode the "error current" from the feedback network into the inverting node up and down through the current mirrors to the high transimpedance node that is then buffered to the output by the output stage. This "error current" is very real and how the parts operate – hence the current feedback name.

When you step through the transfer function using these simple pieces, you end up with a simple transfer function that shows that the frequency response part of the Loop Gain is partially de-coupled from the signal gain (gain bandwidth independence) – the feedback resistor is the compensation element. As Sergio Franco and Walt Jung noted, making the impedance lower

looking into the inverting input (buffer output impedance) will move towards ideal gain bandwidth independence – that was the idea behind the closed loop input buffer I put into the OPA684 and OPA683 products. Closing the loop locally in the buffer across the inputs vastly reduces the impedance looking into that pin.

Some of the original app notes I wrote back then, and still very popular with customers, cover CFA loop gain development in simple form.

This one says it is obsolete, but only because all the devices are discontinued – the steps are there and simple to follow.

This is OA-12 in the original Comlinear databooks

http://www.ti.com/lit/an/snoa366b/snoa366b.pdf

This one came from all the customer calls we took as the first source of commercially available CFA. I still see designers wanting to bandlimit the response with a cap across the feedback, so I send this one out to them as that is a really bad idea for current feedback parts.

This is OA-15 in the original Comlinear databooks.

http://www.ti.com/lit/an/snoa367c/snoa367c.pdf

For a circuit-block-naming purist, current feedback may be a little odd, but it describes exactly how the amplifier operates. We at Comlinear starting using that name early on – and, in fact, when ADI introduced their first versions, ADI tried to call them “transimpedance amplifiers” presumably to be different (this is just naming the part for how we get the open loop gain). We at Comlinear objected strenuously as that seemed to confuse the field, given that there was already a closed loop architecture (photo-diodes amplifiers for instance) using that name. ADI saw the wisdom in that and switched over to current feedback. The “transimpedance amplifier” in fact remains a large area of activity for us where I send out this application note a couple of times/week.

http://www.ti.com/lit/an/sboa122/sboa122.pdf

It is unlikely there are too many folks in the component vendor world that have prepared and presented more CFA vs. VFA seminars than I have. There are very real differences and we exploit those for different needs. My simple summary these days is that CFA’s normally show up leading away from a DAC (the most ubiquitous being DSL line drivers) while VFA type parts (op amps and FDA’s now) show up leading up to an ADC. In fact, the original genealogy for the CFA started from David Nelson’s work doing HP ARB output stage designs. If you wanted to actually buy the output stage amplifier using the CFA design from a circa 1980’s HP ARB, you can get that as the CLC142 (originally called the CLC102 – maybe only on eBay now). That one has the same input buffer stage cascoding an error current in the buffer output transistors. But then only a current mirror gain stage to the output for what we called a “Norton” output stage – later implemented in the CLC560 and later still the KH560. That last one might be the only remaining documented one –

https://www.exar.com/content/document.ashx?id=21434

There is still new product working going on with CFA's where some of my recent work shows up in this example 4-channel DAC output demo platform. The Output Power Stage (OPS) in the THS3217 applied here is one of the first new CFA line drivers for AWG or ARB apps done in quite some time. The 20Vpp driver with the THS3091 CFA op amps shown in this example document is being upgraded soon to a vastly improved device. I can guarantee you that new device will be called a "Current Feedback Amplifier" since I am writing the datasheet and am very comfortable with that name being both accurate and well understood in the design community for what benefits it brings. This latter is probably most important. When I am talking to AWG designers, they know immediately what I mean by current feedback amplifiers and why they belong right behind the output jack on their boxes.

http://www.ti.com/lit/ug/tiduc44/tiduc44.pdf

Michael Steffes
Sr. Member of Technical Staff
Tucson, AZ.

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Steve Taranovich
July 19, 2017 at 11:03 AM

In reply to Michael Steffes.

In 1989 when I was a Burr-Brown NY Apps engineer, one of my first exciting products was the new ADC603, a 12-bit, 10 MHz ADC in a .600 wide, hermetic metal DIP package that was the first of its kind to replace an ADC board-product design. There were two companies that I called on in Long Island, NY: Fairchild Weston Systems in Syosset, NY and Grumman Aerospace in Great River, NY.

Both of these companies wanted the ADC603. The front-end amplifiers of choice at that time was the CLC203 or CLC231 from Comlinear — both were current feedback amplifiers. Just about every customer I had visited back then, with a high speed interest in the ADC603, wanted the Comlinear front end amp. There were many other high speed op amps on the market at that time by other vendors such as Burr-Brown and ADI, who were the most prominent, but Comlinear dominated the current feedback arena.

Fairchild Weston Systems had just acquired the CCD image sensor team from Ford Aerospace in 1989 just as Loral Corp. was acquiring Fairchild Weston, and they were working on a military space-borne camera at the time and Grumman was revamping the Navy's E-2C Hawkeye Phased-array RADAR dish atop that aircraft. These were the designs that employed the ADC603 and the CLC203/231 amplifier front ends in the initial development.

Best regards,
Steve Taranovich
Aspencore
Editor-in-chief, Planet Analog
Senior technical editor, EDN Analog and Power

Soufiane Bendaoud
July 22, 2017 at 10:53 AM

CFA's by Michael Kiwanuka

I was very surprised to read the Michael Kiwanuka article on CFA's, and noted his persistence to essentially discredit decades of work and analysis for what seems to be a desperate search for notoriety.

If he only knew who you two gentlemen (Sergio and Walt) really were! Along with Derek Bowers, Michael Steffes, and several others party to this dialogue.

As an anecdote, I still remember the very first time I got to present op amp stability to a large audience of then ADI FAE's in Boston, as part of the 2002 amplifier seminar. Walt Jung, Walt Kester, James Bryant, Bruce Homan were all in the audience, and just the thought of presenting to these big names technical information was frankly quite intimidating. In my book, this is called respect.

If nothing else, MK should have done his research on these names, to find out what contributions these great minds have made to the industry. Some of Derek's designs are still ADI's best sellers after more than 20 years.

It was an honor for me to have worked with you Walt, Derek, Michael, etc. And it was a blessing to have had Professor Franco teach me everything I know today (which is still very little compared to all of you). I genuinely feel proud just being able to communicate with you.

Thanks to you both, Professor Franco and Walt, and to all the other contributors on CFA knowledge.

The French have a saying "silence kills insolence"

Soufiane Bendaoud
TI development manager for precision amplifiers
former Sergio Franco student at SFSU

Walt Jung
August 5, 2017 at 10:37 AM

CFA Updates

Updated information has been received from AudioXpress on the controversy associated with Michael Kiwanuka's "Current Feedback and Voltage Feedback Fallacies". The thrust of it is repeated just below, and it is italicized here for clarity. This post also links to a revised online version of MK's original piece.

Most unfortunately, this revised version of the article still repeats (within the 'Resources' section) the use of an active link to "Op Amp Applications Handbook". This link is one which directs people to an unauthorized download of the copyrighted version. **Note that a free and legal download of "Op Amp Applications" is available here.**

Further update of 8/7/2017

There is also strong proof that CFA type topologies have been with us for some time. Related to the ADI link above, see specifically Section One of the Op Amp Applications book. Navigate down to sub-section 1-2, 'Op Amp Topologies' then peruse Figures 1-17 through 1-19 and their associated text. Wow! CFAs in 1937 and 1941?

Comments on the above are welcome, so address them directly to CFAs@ownmail.net. Indicate if the comment is for publication. Your email address will remain private. All comments are moderated.

We suggest monitoring these blog pages for further updates.

Walt Jung

Received from AX (unedited):

The article revolves around the question whether the term 'current feedback' is correctly applied to a 'CFA opamp'. MK recalls that the term 'current feedback' used to denote a feedback configuration where the feedback signal was derived from the output load current. With the advent of the 'CFA architecture', however, this term has obtained a different meaning, to indicate not how the output signal sample was obtained, but rather how the output sample is thought to be fed back. This happens often in fast-paced technological fields; but you can't turn back history so it has to be accepted.

MK explains (correctly) the historical meaning of the term, but then proceeds to argue that this is not correct, based on the definition of current feedback not in the context of a CFA but when viewed from the context of feedback configuration classifications. But as noted, the terms 'CFA' and 'VFA' in the context of 'CFA opamps' have a different, widely understood and accepted meaning and as such are, by definition, correctly applied.

*We regret that editing errors have crept into the article. Specifically, eq (1) was printed incorrectly; the original equation was of the correct form Vout = iN * Req//(1/sCeq). Also, fig 2 was inadvertently replaced by a copy of fig 6; the correct fig 2 appears at the corrections link given above. We offer our apologies to author Kiwanuka and our readers alike. A complete correct version of the article is now available here, together with a sample of the exchange between Walt Jung et al and Michael Kiwanuka, posted below.*

AX

Walt Jung
August 23, 2017 at 11:06 AM

Further CFA Updates of 8/23/17

Professor Sergio Franco's new CFA article is now available, on the EDN website. There is also a lively discussion on this general topic, on DIYaudio.

Walt Jung
August 27, 2017 at 4:41 PM

Further CFA Update of 8/27/17

Some recent postings of Aug 27, 2017 are available, as noted below.

Chris Paul (Itis Strange) and Michael Kiwanuka (Moo Koo or MK) have had a continuing series of exchanges on CFA operation. Recently Jan Didden of AX has entered the discussion (08/25). On Aug 27, 2017, in a reflective moment, MK offers his *"Apologies to all concerned"*. **See posted comments of Aug 25, 2017 and forward.**

Michael Kiwanuka has also posted a similar comment of apology to the "Comments" attached to Sergio Franco's EDN blog on CFAs. **See posted comment of Aug 27, 2017.**

Also on Aug 27, 2017, Michael Kiwanuka sent a private email apology to a number of individuals following this topic. Among these recipients are Sergio Franco and Walt Jung (authors of the 7/11/17 rebuttal to his article – available here), plus all of the supporting signatories.

We take all of these developments as a positive step.

Walt Jung
Sergio Franco

Bob Cordell
August 30, 2017 at 1:32 PM

The CFA is as old as dirt!

I was thinking of a simplified and direct way of characterizing a CFA vs. a VFA yesterday, with the following generalization (I know there will be exceptions).

Consider a simple flat-gain amplifier with negative feedback. It has a feedback resistor R1 connected from the output to what I'll call the feedback node. The feedback network includes a second resistor, R2, that is a shunt from the feedback node to signal ground. An active amplifying

device, like a BJT, is connected to the feedback node. Typically, the feedback node would be connected to the base or emitter of the device.

If the impedance seen looking into the active device (input stage) is much lower than the impedance of the feedback network (R1 || R2 in this simple case), then we have a CFA. This would typically be the case when the feedback node is connected to the emitter.

If the impedance seen looking into the active device is much higher than the impedance of the impedance of the feedback network, then we have a VFA. This would typically be the case when the feedback node is connected to the base.

If the impedance seen looking into the active device is similar to the impedance of the feedback network, we have a crappy amplifier :-).

I think that these simple generalizations tend to avoid much of the potential confusion that can arise when more complex variants of a CFA are discussed.

So, the CFA is as old as dirt!

CFA is a broad umbrella of feedback circuit arrangement and function, which covers arrangements as simple as two or three transistors (or tubes!) to sophisticated amplifier arrangements. Even the classic two-stage RIAA phono preamp can be seen as a form of CFA (albeit with a frequency-dependent feedback impedance and a non-flat loop gain).

We need not argue about or analyze complex amplifier circuits to understand the fundamentals of CFAs. One key advantage of the CFA architecture is that, to the feedback loop signal path, the input stage transistor acts like a cascode. In a 3-transistor CFA, the feedback loop thus sees a cascode input stage, a CE voltage amplification stage (VAS) and a CC output stage buffer.

Even a 2-transistor complementary feedback pair (CFP) with gain is a form of CFA.

Obviously, in the real world, it takes a lot more circuitry to implement a really good CFA, and to mitigate the CFA's shortcomings… especially if we implement CFAs with push-pull-like complementary arrangements. Nevertheless, I think that the fundamentals of the CFA remain the same.

Cheers, Bob

Follow up by Walt Jung

Thanks for those cogent thoughts, Bob. I'm sure that many may not realize just how long the CFA concept has been with us. Around 80 years? Your post reminded me of the Op Amp Topologies section of Op Amp Applications. This section is reprised here with permission from ADI (see links within for full book content).

Some useful words on modern CFA topologies, then the historical goodies. Neat "old as dirt" stuff it is!

Walt Jung

Walt Jung
September 21, 2017 at 12:08 PM

Ah, but here's some *real* rubbish:

As a comment on Professor Sergio Franco's *EDN* blog, "In-defense-of-the-current-feedback-amplifier " On Sept 6, 2017 4:56 AM EDT Moo Koo said this (quoting directly):

"The fact is I have proved that the forward path gain of a so-called "current feedback" amplifier is simply that of a single degenerated common emitter stage; this makes the circuit rubbish because a single common emitter stage cannot generate anywhere near enough forward path gain, and, by implication, major loop gain, to mitigate against the non-linearity of the forward path."

Alas, some may have doubts as to the so-called "proof". It is helpful in understanding everything to place this into a historical context, with some references truly germane to the topic.

Take for example the operation of current-source-based mirroring stages, which have been in standard use since at least 1965 or 1966. As shown by Bob Widlar (see Figs 1 and 3 of: Some Circuit Design Techniques for Linear Integrated Circuits, *IEEE Transactions on Circuit Theory*, Dec. 1965). Moreover, Russel and Solomon credit this type of mirror to Jim Thompson, from 1966, within A High-Voltage Monolithic Operational Amplifier, *IEEE Journal of Solid-State Circuits*, December 1971.

Beyond the mirror basics, of particular interest is how the Wilson current mirror operates (See Fig 6 of: A Monolithic Junction FET-n-p-n Operational Amplifier, *IEEE Journal of Solid-State Circuits*, Dec. 1968).

The point here is that with use of very high gain-node impedance(s) (i.e., Req ~1meg or more), there is no problem in producing a net high gain overall within a CFA. Or with any other bipolar CE stage, for that matter. For example, see the 1970's quad Norton op amp LM3900, which achieves a gain of 2.8 V/mV within a single CE gain stage. But, that's just an aside, to show that this circuit methodology has been a fait accompli for 40+ years. Now, back to CFAs.

Prof Franco's Fig. 2a uses a simple push-pull current mirror driving the gain node, while Fig. 1 uses the Wilson type. Either functions, but the Wilson variety of mirror allows for a higher Req, and thus a higher overall CFA gain. For example, if gain-set resistance Rg is open, and Rf then takes a value of 1k, with a CFA internal Req ~ 1meg, the forward path open loop gain in V/V will be 1000x, which is simply the ratio of these two impedances (this is in first order terms, and assumes rn < < Rg || Rf ... *note these Rf and Rg clarifications over original website wording).*

So, we'd all be better served by looking at this topic globally, leaving strawmen arguments aside. *Speaking more specifically, a 4.5k resistor simply has no place whatsoever at the gain node of a CFA structure, as it will simply ruin the voltage gain characteristics!*

If anyone insists on placing such a low resistance there, they aren't dealing with a CFA structure, but something else entirely. A separate discussion.

It is a tangential obfuscation to insist that such an unrealistic condition is relevant to useful CFA analysis. Let us now move away from this fecklessness. Any further “So-called CFA” comments are closed for this thread.

Thanks to all of our contributors above!

Walt Jung

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Walt Jung
June 4, 2018 at 10:43 AM

Related to the above thread, Professor Sergio Franco has posted another blog on CFAs, in his EDN series on CFAs. And, Michael Steffes has also reported on a new CFA with exceptional performance in regard to distortion and load drive.

Thanks to both Professor Franco and to Michael Steffes for these useful CFA updates!