Future Without Feedback?

Martin Colloms, January, 1998

....

As a reviewer for some years, I have tracked the swings of opinion and popularity of various audio ideas and technologies. Amid a sea of advanced designs that achieve powerful technical performance and laudable specifications, I'm reminded of a major blind listening test of 18 power amplifiers that I set up for the long-since-defunct UK magazine *Hi-Fi for Pleasure* back in 1975. We had "advanced technology" then: the transistor amplifier had matured and was well accepted by audiophiles. Prices of the review samples ranged from $300 to $3000 (equivalent to $1000-$10,000 in today's dollars). The auditioning sessions were graced by the presence of many industry leaders, among them the late Spencer Hughes of Spendor, Julian Vereker of Naim, Philip Swift then of Audiolab, Alan Harris then of retailer Audio T., Bob Stuart of Meridian, and John Wright of IMF (now TDL in the UK).

On the suggestion of Alan Harris, a serious tube amplifier fan, I introduced a ringer to those tests: an ancient (over 10 years old) 25Wpc tube amplifier, the Radford STA-25 III, worth perhaps $100 at the time on the used market. I used a selection of master tapes as the source. When the results of the blind test were analyzed, the tubed Radford had come in first, despite showing the poorest measured performance. (Needless to say, its second-hand value soared after the review appeared.)

Almost a quarter-century ago, this result dramatically illustrated that the association between measured performance and sound quality is uncertain. However, unsuspected at that time was the possible benefit of the Radford's relatively low level of negative feedback and the consequent effect on sound quality.

Feedback and the Ferry

The dominant problem in the early days of long-distance telephony was that the harmonic and frequency distortion added to the signal both by the line and by the necessary chain of repeater amplifiers made voices unrecognizable and unintelligible. Harold Black graduated from Worcester Polytechnic Institute in 1921 and took a post as a research scientist at what later became Bell Labs. For six years he struggled with the telephony distortion problem. The solution was the use of negative feedback. Black described how he conceived the theory and the equations for negative feedback in a flash one day in 1927 while commuting to work on the Lackawanna ferry (footnote 1).

To understand the revolutionary nature of Black's idea, consider a device with useful voltage or power gain (μ) that may be compromised by undesirable nonlinearity or distortion. It may also have a non flat frequency response. Prior to Black's flash of insight, all the output of an amplifier was fed to the next stage, be it a transducer or another amplification stage (fig.1). But instead, if a proportion of the output (ß) is fed back into the input of the amplifier and applied in inverted form (fig.2), the fed-back distortion and frequency-response errors will cancel those generated within the device. In addition, the amplifier's output impedance will be lowered. The price to be paid for these performance gains is that the amplifier's overall gain or amplification is reduced in proportion to the amount of negative feedback. But in theory, if the amplifier, operated "open-loop," has a surplus of gain above that which is required, closing the negative feedback loop allows its errors to be reduced to negligible levels.

The concept of negative feedback is hugely valuable both in electronics and in control systems, and is firmly entrenched as a powerful design tool. Many audio engineers see it as a panacea for the ills of practical amplifying devices, using feedback---often with great skill---to engineer amplifiers with superb linearity and consequently low levels of measurable distortion. By and large, negative feedback works. It has made a vast variety of audio products possible and readily manufactured. It is hard to conceive of the world of audio engineering without Harold Black's negative feedback.

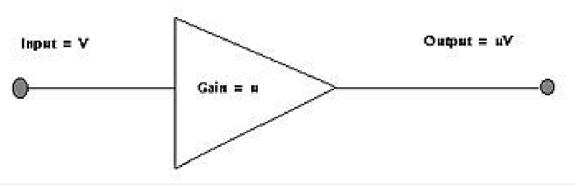

Fig.1 In an amplifier without feedback, the output consists of the input signal multiplied by the gain µ.

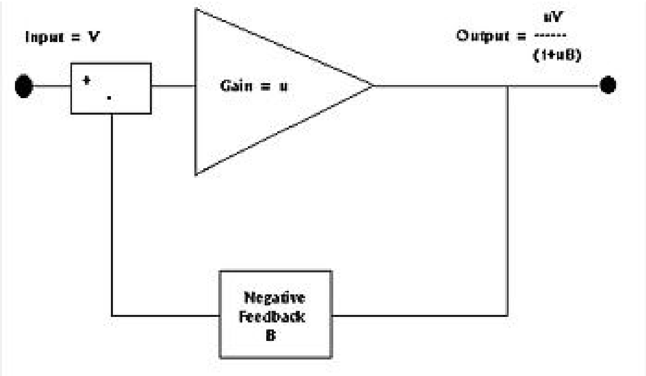

Fig.2 In an amplifier with negative feedback, a proportion of the output (ß) is fed back to the input with inverted polarity. The ratio of the output to the input (the "Amplification Factor") = µ/(1+µß).

Footnote 1: Black published his work on feedback in "Stabilized Feed-Back Amplifiers" in the January 1934 issue of *Electrical Engineering*, published by the American Institute of Electrical Engineering. See James E. Brittain, "Scanning the Past: Harold S. Black and the Negative Feedback Amplifier," *Proceedings of the IEEE*, Vol.85 No.8, August 1997.---*JA*

Fun in sound reproduction

Engineering can explain much about the audio world. However, it is when it can't explain something that the real fun begins. Some aspects of perceived sound quality are not explained by established theory. There is a growing suspicion that some of these aspects---a loss in natural timbre; a duller, less expressive performance; increased aural fatigue; and missing life and energy in reproduced sound---may be consequences of the application of negative feedback.

It would be a mistake to demonize any particular philosophy. To do so forces people into entrenched positions and encourages the adoption of unhelpful defensive reactions, thus missing the opportunity for constructive dialog. Consider some of the contentious subjects that have been debated recently in these pages: analog vinyl and tape vs digital; one-box CD players vs separate transports and DACs; tubes vs solid-state; single-ended vs push-pull amplifiers; monoblock vs stereo amplifiers; class-A vs class-A/B or any other class of amplifier operation; pentodes vs triodes; and integrated amps vs pre- and power amps. Audiophiles have debated the merits or otherwise of cables ad nauseam. And in the high country of the tube purists, discussions rage about the virtues and vices of various types of triodes, even individual brands of triodes.

In my opinion, such debates have been valuable, though in some cases the importance of what differences do exist has been blown up out of all proportion. But the fact that a given difference or sonic error is detectable and audible doesn't mean that all is lost, that you can't adjust to and live with some of these transgressions.

Measuring

Many of us working in the audio industry have long been aware that measurements do not fully describe sound quality. Moreover, it seems that measurements fail to describe some of the more important aspects of subjective perception. For example, we may guarantee that an amplifier will have a perfectly flat frequency response under normal conditions of use, yet we cannot explain why it may still sound duller or brighter than another comparably "flat" amplifier. We can measure crosstalk, channel separation, distortion, and noise to incredibly low levels, yet we cannot explain why some amplifiers have greater perceived stereo depth, resolution of detail, and low-level ambience than others. While we know that 0.3-0.5% of third-harmonic distortion is just audible in the midrange, how can the overall sound of a tube amplifier be judged "just fine" when we can measure 1.5% of second harmonic and 0.8% of third at a moderately high listening level?

Still more intriguing is the matter of dynamics. Some electronics sound flattened and dulled in terms of musical expression; others may be wonderfully revealing of this quality even at quiet sound levels. Or consider rhythm and timing: One power amplifier gets your foot tapping, another leaves you reading the sleeve notes. I can identify no measurement associated with rhythm or musical dynamics.

How can an amplifier produce superbly low measured treble distortion, yet give the aural impression that there's sand in the tweeter? How can an amplifier that in theory should have great low frequencies (for example, it has a DC-coupled topology, a big power supply, and a high damping factor) have soft, slow-sounding bass?

Some engineers have been developing an awareness of how we've got some of it wrong. Glimpses of audio heaven have been observed and reported with a number of exotic single-ended creations. More precisely, the SE units' sound over the broad midrange---in point of fact, over most of the significantly audible frequency range---reaches a level of purity and intrinsic musicality that inspires near-religious fervour. Such quality shows the rest of the industry what they're missing.

This isn't the place to expand upon the SE power-amplifier technology's strengths and, in some instances, audible weaknesses. Suffice it to say that the problems, often located at the extremes of the audio range, are in this context relatively harmless, and won't confound the following argument.

Art...

One aspect of sound quality reached a focus recently when I received a sample of the Conrad-Johnson ART for review in the UK magazine *Hi-Fi News & Record Review*. This preamplifier's $15,000 price tag is irrelevant; what's important in this context is its overall attainment.

The ART is a technically uncompromised design---by which I mean it has no significant weakness observable by established technical precepts---which should gladden the heart of a measurement diehard. Consider its moderate output impedance, minimal noise, negligible distortion, and the wide, flat frequency band pass. And don't forget the highly accurate volume control. It does invert signal polarity but his may be corrected at the loudspeaker terminations. Then note that it comprises just one stage: a zero-feedback, common-cathode amplifier employing paralleled 6DJ8/6922 triodes. Tube purists might argue that C-J's choice of tube isn't optimal, but no matter. The truth lies in the listening result. The sound is excellent. However, that global superlative encompasses something special, which I have come to understand as the sound of zero negative feedback.

Compared with many of its colleagues, the ART fairly breathes tonal accuracy, dynamic expression, clarity, and natural musical vitality. Conrad-Johnson's designers told me that, during the preamplifier's development, and with their minimalist single-stage objective firmly in sight, they still could not conceive of using *zero* feedback. Instead, the initial design featured just a few dB of feedback, but a few dB nonetheless. When a circuit idea emerged late in the day that allowed negative feedback to be reduced virtually to zero, with what feedback remaining being merely local degeneration (something generally considered to be harmless), they were forced to concede that the sound quality was improved in precisely the area where the production ART is now so admired.

The ART provides a logical meeting place for objectivists and subjectivists. The former cannot accuse the latter of being fooled by measurable errors. The latter may express and explain what they hear without fear of attack.

What they and I hear is an aspect of sound quality that transcends the general experience of reproduced audio; a quality that cannot be specifically addressed by system matching, cables, or speaker substitutions. In the context of the ART, and to a significant degree one or two related solid-state preamplifiers that use a single FET as an amplifying stage (the XTC PRE in the UK and the Pass Aleph P in the US), this quality can be considered as an absence of previously unidentified, almost unsuspected degradation present in much established amplification. I invite you to keep a sense of proportion when I claim that, compared with worthy zero-feedback designs, conventional amplifiers impose a significant "graying" of dynamic expression, a falsification of timbre, a shift of truly natural tonality, and a smearing of temporal definition. There may also be an associated loss of rhythm, and a blurring of the delicate nuances of the leading edges of natural sounds.

Science...

Then I received review samples of the Cary CAD-805C monoblock power amplifier. I wanted to try the single-ended 805C because it is sufficiently powerful to produce credible loudness and fair bass with my Wilson WITT speakers. Much to my relief, the 805C was a seriously good-sounding amplifier. (See Dick Olsher's review of the earlier 805 in the January 1994 *Stereophile*.)

Despite this amplifier's obvious competence, however, there were still some allowances to be made. Its intrinsic frequency response is not perfectly flat, especially at the band extremes. In addition, its relatively high output impedance significantly alters the effective frequency response of the speaker. Both of these factors required some mental adjustment and acclimatization. For an old speaker hand, this wasn't too difficult; true, my Wilson WITTs weren't quite the same as before, but they still possessed their trademark qualities of good dynamics, fine clarity, and good rhythmic expression. And in combination, the ART and 805C showed an immediate association---a commonality of expression and harmonic line with no apparent concession in low-level detail, focus, or stage width or depth.

At this point the proceedings took on an educational dimension, as the big Cary offers the fascinating feature of user-adjustable variable negative feedback. In fact, the degree of negative feedback can be reduced right down to zero.

With the Cary's control set to its maximum of "10dB feedback"---(when measured, this in fact turned out to be 6dB, a factor of 2x for the 8 ohm output and with the 8 ohm feedback switch position) ---you could certainly hear a more accurate frequency response, the benefits of a greater damping factor, tighter bass, and a mid band more like that of the familiar Wilson WITT. However, much of the magic was lost. That particular degree of perfectly timed involvement, of convincing transient edges, of natural tonality and expression, was lost. Now what we had was just another very good tube amplifier with a particularly pleasing mid band.

Reduce the feedback to a factor of only 3dB (as measured)---negligible by the standards of the majority of most modern amplifiers---and the sound improves a little. Reduce it to 1.5dB and the light begins to dawn. Turn it completely off (0dB) and musically you know where you ought to be.

Without feedback, both I and my friends and colleagues who shared the listening, found that reproduced sound could really be different from the usual expectation, that a pervasive greying of expression and false tonal colour had been swept away without dire consequences for other important aspects of sound quality.

I can hear the arguments already: "This amplifier is probably so wrong that it can't use feedback successfully...it's one of those rare cases where negative feedback makes it worse."

Somehow I don't think so. An analysis of the approximately 700 amplifier reviews that I've undertaken over the years indicates that, if there has been any trend associated with improving sound quality, it has largely been associated with reductions in global negative feedback. Even the majors---Mark Levinson, Krell, Audio Research, Conrad-Johnson---have consistently moved toward more elegant, more linear circuitry, allowing lowered feedback levels for the same closed-loop linearity. Are these designers unconsciously and instinctively seeking a safe route toward designs with minimal or no negative feedback?

Unmusical?

The combination of the Conrad-Johnson ART and the Cary CAD-805C forcefully supports the contention that there is a region of aural perception that is not quantified by measurements---a region powerfully related to musicality, to how real audio replay sounds in terms of vividness, expression, micro dynamics, rhythm, and timbre. It was almost uncanny how this zero-feedback pairing allowed more of the natural vitality and characteristic signatures of notes to be replayed, especially their beginnings and endings. It's as if other components blur these nuances. Well, they may be nuances, but they somehow tell us so much more about the quality of the instrument and of its playing.

Let's consider the outrageous proposition that corrective feedback is fundamentally unmusical. In my reviews, I have observed that high-feedback amplifiers---which have an inherently limited open-loop bandwidth---suffer what is commonly called "midrange glare": a hardening of and forwardness in the upper midrange. Amplifiers with wider open-loop bandwidths have less of this, or their "projection" moves up to the mid-treble. Low-bandwidth, high-feedback designs can end up sounding "dark," even significantly ‘coloured’ in the midrange.

With feedback disconnected, a typical amplifier may have 20% of complex distortions. Closing its negative feedback loop---60dB of feedback is not unusual---will reduce the level of that distortion to a level suitable for the printed specification, but perhaps not for good sound quality. Investigation has suggested that the open-loop break frequency is involved here---the point at which, without any negative feedback, an amplifier will begin to filter out the upper frequencies (fig.3, top trace). Without feedback, the open-loop break frequency could be as low as a few hundred Hz; these days it is typically 500Hz to 1kHz, and may be as high as 5kHz in wide-band designs. Normally you can't see this low-pass "filter," as it's buried by negative feedback: with its feedback loop closed, the amplifier may have a measured bandwidth 100 times greater (fig.3, bottom trace). Yet I reckon that the buried filter comes back to haunt us in the form of "glare"---a colouration centred around the amplifier's intrinsic open-loop, low-pass function, perhaps due to the nonlinearity of the feedback technique itself.

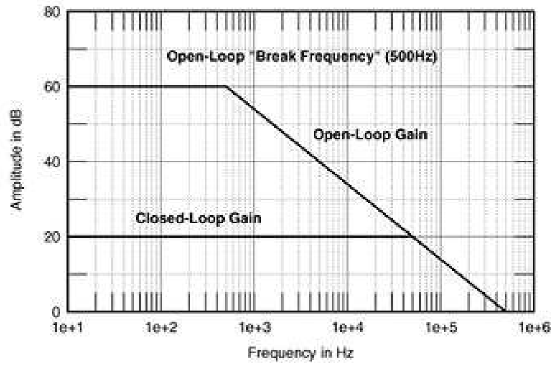

Fig.3 Gain plotted against frequency of a typical solid-state amplifier with 40dB negative feedback and an open-loop "break frequency" of 500Hz: operated open-loop (top), closed-loop (bottom). Note that, without feedback, the amplifier's output would be -35dB at 20kHz. With feedback, it is flat to 480kHz. (10dB/vertical div.; 10Hz-1MHz frequency scale.)

Consider the proposition that a pure input signal is subjected to the usual nonlinear amplification, and is then applied with all the subsequent errors back to the input, to be amplified again. In theory, the errors are subtracted at the feedback connection, but inevitably there is some error in this subtraction. No problem, says the textbook: the wide bandwidth of the closed-loop amplifier will ensure that the signal and errors, and *their* errors, will go many times 'round the loop, reducing the distortion to below audible levels.

Or will it? Audiophile pundits know only too well that making a single audio stage perform to a truly high standard is not a trivial matter. Almost by inspection you can see that the more complex high negative feedback amplifier has the capacity to go on compounding its error residual. When an amplifier is processing a complex, harmonically rich input signal---music---and not a steady-state single sine wave tone in a lab test, something could well go wrong. That cascade of residual errors will mix or intermodulate at low levels, and will do so in a fantastically complex manner.

Subjectively, the effect of increased negative feedback is generally that of increased compression, in addition to the midrange colouration noted above. This loss of dynamic expression suggests that additional energy is indeed filling in the natural spaces in the original spectrum and thus blurring musical expression.

A Future Without Feedback?

When Black proposed negative feedback in 1927, he was trying to solve a specific problem: the long cascading of imperfect, transformer-coupled tube amplifiers. But in the absolute sense has anyone explored the implications of negative feedback for reproduced sound quality?

Based on my experience of the cited pairing of a zero-loop-feedback preamplifier and amplifier, and supported by the evidence that amplifier designers consciously or unconsciously do attempt to reduce negative feedback to improve subjective quality---even if this means worsening the measured performance---we need to reconsider the subject.

It is possible that engineers need to rethink how audio systems should be designed. Before the introduction of transistors which were limited to low voltages, and which forced the speaker industry down to 8 and 4 ohm impedances, loudspeakers were typically 8 to 16 ohms impedance, did not need super thick cable to wire them up, achieved maximum electromagnetic utilization at good efficiency, and were well matched to tube amplifiers. Higher efficiency spells better dynamics, reduced thermal compression, and the potential to use smaller, more perfect power amplification. And if speakers were designed to have smoother impedance curves, to be relatively uncritical of amplifier or cable matching, and to offer higher sensitivity, we would have greater freedom to examine the feedback question and the validity of the low-power, short-path, zero-feedback approach to power amplification.

We still have much to learn about the art of sound reproduction; ultimately, our responsibility is to our ears, not to established precepts.

End.

Many letters in response appeared in the March, April, and May 1998 issues of *Stereophile* illuminating several fascinating aspects andobservations.

Thanks, Martin
Editor:
Many thanks to Martin Colloms for his most interesting article on negative feedback and amplifier design in the January '98 issue (Vol.21 No.1, p.87). *Stereophile* readers, I am confident, will be interested in reading a similar article by Jan Didden that was published in the Six:1997 issue of *Audio Electronics* (published by Audio Amateur Publications).
---Ray Segura, New Orleans, LA, Segurar@nctamslantdet.nola.navy.mil

Mr. Didden's article mentioned research by the later Peter Baxandall that showed that while loop negative feedback applied to a simple amplifier circuit reduced the level of the second and third harmonics as expected, it actually increased *the level of the subjectively harmful high-order harmonics compared with the circuit used without feedback.-*
--JA

Feedback & Martin
Editor:
After reading Martin Colloms' article on amplifiers without feedback in January, I must comment.

Without feedback, a power amplifier becomes load-sensitive. *Stereophile*'s own measurements show the frequency response into a simulated load. These measurements show the audio expansion/compression that zero-feedback amplifiers exhibit---often as much as 2dB. This is indeed audible, and while it may enhance perceived performance, it cannot be considered accurate. There are plenty of products out there to "process" audio---expanders, compressors, bass-impact enhancers, spectrum harmonic enhancers, spatial enhancers, etc. However, an amplifier should never behave as a signal processor!

Feedback, used properly, is a good thing. However, it should never be relied upon to compensate for poor power-supply design, nor can it be trusted to control radical nonlinearity, as in class-B operation. Unfortunately, it is called upon to do this more often than not. And that, too, is audible.

There is a lot more to this debate than simply feedback or no feedback. Audio design is more complicated than that. It would be a shame to see high-end designs distilled down to this level.
---Kevin A. Barrett, President, KAB Electro-Acoustics, www.KABusa.com

Feedback & Audio Research
Editor:
Martin Colloms' recent article in *Stereophile* described the history of negative feedback in amplifier design and detailed in some length the effect that it can have on component sound. Intrigued by this, I did some research of my own. The Audio Research VT100 was recently auditioned by *Stereophile* (March '97), and the reviewer was quite taken by its sound. The VT130 was also recently auditioned (November '96), but the reviewer was not so impressed by its audio merits.

The VT100, VT130, and VT150 [*reviewed in August '94---Ed.*] share similar tube complements and internal architectures.

One area where they differ is in their use of negative feedback. The VT100 uses half the negative feedback of the VT150 and one third less negative feedback than the VT130. The higher level of negative feedback in the VT130 would appear to have an effect on listeners.

I hope that manufacturers will begin to take to heart the effect that negative feedback has on their creations' sounds, and will begin to design components that use less, or ideally zero, negative feedback.

While the 1980s were an era of less than notable improvements in the audio realm, with the hopefully soon-to-be-adopted improvements in digital standards and landmark components such as the Pass Labs two-gain-stage amplifiers, the '90s will turn out to have been a great decade.
---*Dave Brown, dmbrown@bechtel.com*

Feedback & Measurements
Editor:
Martin Colloms raised the question of measurements *vs* sonic performance in his interesting article on negative-feedback amplifier design in the January issue. I keep reading about this subject, and I begin to be bothered that the real issue is not that measurements cannot reliably predict the sound of a piece of equipment, but that the *wrong* measurements cannot do so.

We know that there is no magic involved---these are all physical devices whose physical properties can be known and described, if only we take the care to first figure out what the complete set of relevant properties are. For example, I have auditioned various speakers whose measured high-frequency responses extend out to 20kHz, 26kHz, 35kHz, and 40kHz, yet I have found that one sounds dull at the top of the spectrum and another sounds bright, with no correlation between these observations and the HF specs...

The audiophile community ought to be devising new and more meaningful measurements that we could then use to better predict how gear will sound and how it will interact with other gear. It is not enough simply to say that measurements don't always correlate to sonic results---we need to focus on taking the *right* measurements. Why doesn't *Stereophile* solicit suggestions from its readership, and try some out in the lab to see if they correlate with the sonic results?
---*Agim Perolli, meistertrinker@juno.com*

Feedback & Transient Response
Editor:
I read with interest Martin Colloms' discussion of negative feedback in the January *Stereophile*, and something occurred to me as I digested the article. I was wondering if there has been much thought given to the differences between steady-state *vs* transient response. It is relatively easy to think about the positive effects of negative feedback---sorry---during steady-state conditions, such as reproducing a sinusoidal waveform. The distortion components are somewhat static, and can be cancelled out in real time.

However, during transient events there could be instantaneous conditions when the distorted feedback is not cancelling anything out, but simply building on itself. If all the measurements are made with swept sinewaves, then this phenomenon would be missed in the measurements---which might account for the disparity between the subjective perception and the objective.

I have seen plenty of measurements using square wave responses. While these provide a useful evaluation of overall dynamics, they excite frequencies only at odd harmonics of the fundamental, and the measurements do not give any indication of linearity, just dynamic response.

This leads me to a question: Does the audio industry ever measure frequency-response functions with white-noise excitation? If so, are partial and multiple coherence analyses performed to provide direct measures of linearity (and hence distortion) within and between channels under more realistic conditions?-
--*Nigel A. Linden, Burnsville, MN, Nigel.Linden@MTS.com*

Feedback & IM Distortion
Editor:
I think Martin Colloms, in his January article, touched on a neglected subject:

intermodulation distortion. It has long been recognized that spot frequency measurements, such as second- or third-order harmonic distortion, while indicators of amplifier linearity, are insufficient to explain audible performance. Similarly, two-tone difference tests for intermodulation also may fail to correlate with subjective tests.

I would like to suggest a more sophisticated intermodulation test that might go a long way toward correlating measured performance with audible effects.

Years ago, when the world was analog, designers and users of wideband telephone transmission equipment (of the type Harold Black worked with when he developed negative feedback) recognized the failure of single- and two-tone frequency tests to fully characterize their systems. Eventually a test method was developed that correlated well with system performance, a method known as "white-noise loading." This test, while simple in concept, takes into account all orders of intermodulation products that may be present.

Noise loading may be described in the following way: The test signal consists of white noise, limited to the bandwidth under test. The amplitude is chosen to remain just under hard clipping. A narrow frequency segment of the test signal is removed with a band-stop filter. At the output of the amplifier, a narrow bandpass filter is used to measure the signal present within the stop band of the test signal. Any energy within this passband is due to the presence of a mixture of idle noise and intermodulation products. The IM component can be removed by removing the test signal. The difference between these two readings is an indication of the level of intermodulation products.

I don't know if the noise-loading technique has ever been implemented for audio amplifiers, but it seems to me that it should be. Perhaps this technique could help explain why some amplifiers sound poorer than others that measure, by conventional means, as good or better.
---*Lee Stephens, mstephen@mack.rt66.com*

Both Belcher at the BBC and the late Deane Jensen have suggested using a signal with a comb like spectrum to test amplifier performance, the idea being that any component that appears in the gap between the discrete test tones is due to intermodulation and noise. I have done some testing using this kind of technique--- Stereophile*'s* Test CD 3 *contains some suitable signals---but have come up with enigmatic results.*
---JA

Amplifiers & Feedback
Editor:
The following question surfaced after reading Martin Colloms' thought-provoking article about negative feedback in January ("A Future Without Feedback," Vol.21 No.1, p.87).

How bad can feedback designs be when Mr. Colloms could achieve a "dawning" of such fine sounds from zero-feedback amplifiers when he used recordings bearing the imprint of any number of feedback circuits? Most likely the sound survived all those feedback circuits in the recording chain. It seems unlikely that a zero-feedback amp would erase the imprint.

I guess the next step is to make a live recording using all zero-feedback electronics as an experiment.
---*Tony DeLuca, Frankford, DE*

Feedback & Sympathy
Editor:
I read Martin Colloms' indictment of feedback (Vol.21 No.1) with great interest and more than a little sympathy.

Martin's article was not based on any scientific "research" into the use of feedback in audio amplifiers. Rather, it was a simplistic generalization based on MC's exposure to a limited number of commercially available products. I am familiar with the products MC has mentioned in *Stereophile* and *HFN/RR* and can understand his feelings.

I'm sure that MC is well aware of the weakness of such an *ad hoc* argument, and surely this is why he offers his experience with the variable-feedback Cary 805C amplifier in an attempt to buttress his argument with something a little more rigorous.

At first glance, comparing the same amplifier with various amounts of feedback applied appears to be reasonable. However, a quick look at the test reports of the Cary 805 in the January 1994 issue of *Stereophile* reveals that when feedback is applied, this amplifier exhibits gross ringing that would be considered unacceptable by any standard (Vol.17 No.1, p.108, fig.2). (There really is a place for such reports in high-end magazines.)

This is about as fair as comparing the sound of a push-pull amp as supplied by the factory with the sound of the same amp with half the output tubes removed and claiming that this is a valid comparison between push-pull and single-ended! Or how about taking a low-feedback amp (like the CAT JL1) and simply removing the feedback to "prove" the reverse of MC's assertion? Indeed, the loss of directness, vibrancy, life, and harmonic purity when *decreasing* feedback is similar to MC's claimed losses in the Cary when *increasing* feedback!

Additionally, even if the feedback were properly compensated to produce a good-looking squarewave, it could still be a sub-par feedback representative. Every circuit has an optimum amount of feedback, and sometimes this amount is zero. Further, as one who has experimented extensively with feedback and nonfeedback circuits, I can tell you that there are numerous ways to go about phase-compensating a feedback amplifier to produce equally good measuring results, but each way sounds very different. Would you believe that a 10-picofarad compensation capacitor can have profound sonic consequences across the entire audio band, including the bass? It doesn't make textbook sense and can't be measured by any standard technique, but it sure is easy to hear!

Martin Colloms' "A Future Without Feedback" is the kind of article that drives certain types of audiophiles, the type who thinks too much and listens too little, to make very poor purchasing decisions. Fifteen years ago this type was convinced that super-low THD was the answer. (Who believes that now?) Ten years ago they thought slew rate and TIM distortion was the answer. (Does any manufacturer even specify TIM distortion these days?) Five years ago we were told that fully balanced circuitry was the answer. (And now now we have the backlash: fully single-ended circuitry!) Now MC would like to usher in a zero-feedback craze! The trouble is that we've had zero-feedback practitioners, both tube and solid-state, with us for many years, and they have made both very good and very bad products, just like their feedback-using colleagues. (Although it seems that both the very best and very worst designs use feedback.)

Yes, Martin, I hope you are unsuccessful, but I know that the audio press has to latch on to some "new" idea even if it's recycled, so why not "no feedback"? Maybe it will be followed up by a "high-feedback" craze! The "think-rather-than-listen" audiophiles will lose either way.

Now I don't want Martin to get mad at me for accusing him of making "simplistic generalizations." Perhaps he'll feel better if I do the same thing. How about this one: "High-voltage tubes don't have any magic." To prove my point, first I should say that I've heard many amps that use high-voltage tubes, including some that cost more than a nice house, and none have had "magic."

But MC might want something a little more rigorous than my personal experiences, and so I encourage him to compare his beloved Cary 805 (which uses high-voltage tubes) to the cheaper, albeit lower-powered, Cary 300SE (which uses medium-voltage tubes). Both amps are made by the same manufacturer; presumably, both are made to the same quality level and designed by the same person, who, I'm sure, must be equally adept with both high- and medium-voltage tubes. If this doesn't prove my point, I don't know what will!

Semi-sincerely,-
--*Ken Stevens, President, Convergent Audio Technology*

Voigt, Not Black

Editor:
I was surprised to find Martin Colloms---and John Atkinson in his footnote---perpetuating the notion that Harold Black

"invented" feedback (January '98, p.87). As I recently pointed out elsewhere (Hi-Fi World, April 1997), that honor belongs to the British engineer Paul Voigt, a pioneer of high fidelity, who had incorporated it in his Motional Feedback Patent 231,972, dated January 29, 1924. Over 70 years later, motional feedback as applied to loudspeakers has made little further progress, and Voigt's use therein of selective negative feedback, which he regarded as obvious and not worthy of special attention, is the first reliably documented use of which I am aware---many years before the Black disclosure. I enclose a copy of Voigt's circuit in the patent, and a description of its operation in his own words that shows that he fully understood its application. The latter is taken from papers in my possession, typed and annotated by him in August 1970, and reads as follows:

"As you will see from the circuit, it makes the loudspeaker one arm of an AC bridge. The arm that balances...inductance is a choke, with no parts supposed to move at any frequency. So long as the program frequencies were those on which the 'speaker behaved as a pure choke, the bridge remained in balance and nothing special happened. At those frequencies, however, at which the 'speaker drive portion or the diaphragm or horn resonated, the bridge became unbalanced. The 'floating' audio transformer then fed back into the grid circuit a signal due to the imbalance of the bridge.

"It was possible to make the connection in such a way that the fed-back signal provided negative feedback at the resonant frequencies, thus diminishing the effect of the resonant peak. By suitable juggling of the exact values of the bridge arms, it was possible to unbalance the bridge slightly at both high and low frequencies in such a way that the feedback was positive, thus boosting the ends of the scale where the 'speaker's response was poor.

"The values of the components of the bridge arms were chosen so that they 'stole' only a small amount of the audio energy. By means of a switch, the system could be made to behave like a normal amplifier, and it was enlightening to switch over from 'Normal' to 'Compensated.' Apart from the improvement in frequency response, it had the effect, when several voices or instruments were involved at the same time, of 'disentangling' their sounds (no doubt due to better transient response). The sensation was that the sound came through the loudspeaker rather than originating at its mouth."

Voigt, a month short of his 20th birthday, had joined the English Edison Bell Company (J.E. Hough Ltd.) straight from college on November 1, 1922, to work on "wireless," into which they wished to diversify, as it was then widely believed that broadcasting would kill off the gramophone record. However, on February 9, 1924 he had made an experimental electrical recording on a disused cylinder machine of an evening radio program. Mischievously, he left the result on the boss's desk; this resulted in an immediate instruction to develop this "new" recording method. By 1927, Voigt had invented and produced moving-coil cutters, feedback amplifiers to drive them, and the slack-diaphragm condenser microphone. There followed high-efficiency horn loudspeakers, and later the long-coil MC pickup. By the 1930s he had taken this gear to major middle European cities and sent back some 600 wax masters.

I got to know Voigt in the late 1930s when Edison Bell had gone to the wall (1933) and he had started his own company, Voigt Patents Ltd. Unfortunately, the war, which for us began in 1939, put paid to his business dreams, and in failing health he emigrated to Canada in 1950 and ceased his work in audio.
---Geoffrey Horn, Oxford, England

Feedback Forever
Editor:
It was instructive to read Martin Colloms' thoughts on negative feedback after he reviewed his 701st amplifier, the Cary CAD-805C ("A Future Without Feedback?," January '98, p.87). But is it true to say that it is improperly designed amplifiers that are allergic to negative feedback? I discovered this phenomenon for myself almost 28 years ago when I heard a whistle from my first hi-fi system. It later became clear that a generic amplifier has a nonlinear phase response; moreover, the latter varies with the amplitude of the input signal. Such a system is hard to control with negative feedback, as Professor Kalman has said.

The main problem of a real closed-loop system is stability. Any amplifier stage built with an active element (tube or transistor) has always got some negative-feedback loops, either intrinsic and parasitic or a circuit for operating-point stabilization. A resistor introduced in series with the tube's cathode, a bipolar transistor's emitter, or a FET's source causes negative feedback. A cathode/emitter follower is an amplifier with 100% negative feedback. Therefore, all kinds of amplifiers have negative feedback. The Encyclopedia Britannica says that feedback is a basis of nature. Why, then, must designers avoid using feedback? In the two centuries since Watt's use of a governor in a steam engine (1768), and Maxwell's formulation of feedback (1868), negative feedback has been working for mankind.

I am sure that 25 years ago a tube amplifier designed by an "old man" with 45 years of experience sounded better than any transistor design from a novice. But 25 years ago Robert Widlar had already created his legendary LM101 op-amp chip, and fast silicon power transistors were about to appear on the scene. It was time for the solid-state amplifier. (Though CD has recently returned tubes from their dusty shelves.) And designers continue to think about a distortion-free amplifier. I made one in 1984 (theory and circuit diagram published in 1987).

All things are measurable---even light pressure, which was measured by Petr N. Lebedev early in the century. With harmonically rich pink noise as an input signal and using DSP-based modern statistical methods, it's quite practicable to measure any spectrum modifications in an amplifier's output signal.

Martin Colloms is right about there being a "thermal compression" phenomenon in loudspeakers. (Why do good loudspeakers have sensitivities below 90dB?) However, I have observed thermal intermodulation in low-voltage (10-15V) stages with currents of only a few milliamperes. In general, thermal effects are the main difficulty in precision-analog/mixed-circuit design.

Any amplifier stage is a low-pass filter (described with gain, time constant T, and output resistance). In an ideal case, that filter is first-order (T1 only). As the loop is closed with non delay negative feedback, the amplifier is stable without a load! But since a real amplifier stage isn't a first-order filter and also has to drive a complex load, it becomes clear that the application of negative feedback is far from trivial. Hence, we see "designers...seeking a safe route toward designs with minimal or no negative feedback," in Martin's words.

The coloration mentioned in the Colloms article results from negative feedback being applied to a relatively stable amplifier. A typical negative-feedback circuit consists of two carbon or metal-film resistors, and it can't be nonlinear. Dynamic nonlinearity is caused by transient feedback breaking under varying signal conditions in improperly designed amplifiers. Since any nonlinearity causes intermodulation distortions, coloration appears.

There is no mysticism in amplifier design, just serious science.
---Andrey A. Danilov, nfq@orc.ru

End of correspondence