

AN OVERVIEW OF COMPRESSOR / LIMITERS AND THEIR GUTS

Gain Control Devices, Detectors, Side Chains & Audio "make-up" Amplifiers

© 1999 by Eddie Ciletti and David Hill with comments by Paul Wolff at API

SEE VU PLAY

Every compressor / limiter review reminds me that the subject of dynamics processing is very four-dimensional and not-so-well understood. Conversations with a manufacturer-designer can often be revealing, as was recently the case with Greg Gualtieri of Pendulum Audio. His physicist background literally shed some light on the subject of optical limiters, specifically how he overcame the idiosyncrasies of the devices used in his OCL-2.

I tend to be heavy-handed when testing compressor / limiters, slamming the meters just to see how "bad" things can sound when abused. (To me, the better boxes don't sound that bad under aggressive settings.) My approach did not make the Pendulum 6386, Variable-Mu "sing" until taking into consideration the VU meter's slow response time. By adjusting for less than a full dB of (displayed) Gain Reduction, the "6386" came alive, making me realize that older products with VU meters (Fairchild, UREI, Teletronics or Neve) might also benefit from a kinder and gentler approach. (Translation: more is going on inside than meets the eye outside.)

- **PW:** I do the same thing. Being "heavy handed" is an easy way to see what the features do at their extremes, then you can easily imagine what they would sound like at a lower level. I also make comparisons by summing "dry" and "processed" sounds together, but out-of-phase. Once you identify the "differences," you can then go back and listen for those things *within the sound*. It has really increased my ability to perceive the "little" things, making me feel like I really am good...

For any device with a mechanical VU meter — from analog tape machines to signal processors and pre-amps — the meter's response time must be a consideration, especially when processing "transient rich material." While my goal is to assist in the process of user-education, my own process of evaluation was "adjusted" simply by the good fortune of finding people who are patient enough to answer questions.

I re-learned that it is important to listen — the eyes, a stubborn brain and an ego can easily get in the way of sonic perception — yet it is equally important for products to accurately display the work that is being done. (My other soapbox is ease of parameter access, especially with digital gear).

- **PW:** Ego? What !@\$ing ego? Are you accusing me of having a large, over-blown ego? Well !@\$ you. I don't have a \$#@ing ego. Oh>>>sorry>>>errrrr back to work...

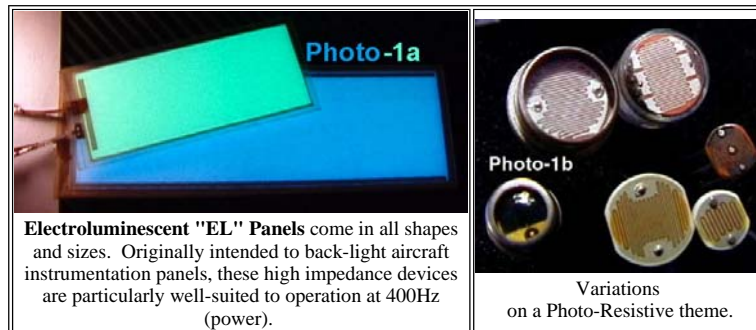
With all of that in mind, I welcomed an e-mail that came from Crane Song's David Hill (former designer of Summit gear) and now creator of the STC-8 and Trakker (dynamics manipulators). As a designer-manufacturer, David is not alone in feeling that educated consumers make better customers and so with his permission, his "detailed correspondence" was used as the foundation for this column.

OOPS!

An investigation into our vintage audio heritage is helpful both for the "happy accidents" that occurred (and endured) as well as gaining a greater knowledge of what made these great boxes tick. This article is an overview, with another planned to cover "just" the supporting amplifier technology and its affect on the "sound." If you're new to compressor - limiters and just wanna get a leg up, skip to the paragraph labeled "[Questions.](#)"

DEARLY BELOVED

Surely the Teletronix LA-2A is the most famous and beloved Optical Compressor / Limiter. A close second is its transistorized successor, the LA-3A. The heart of both units is the T4 "optical attenuator," consisting of an Electro-Luminescent (EL) panel as light source and a light dependent resistor (a.k.a. photo-resistor or photocell) as optical receiver (as shown in **Photo-1a** and **Photo-1b**, respectively).





EL Panels are sold commercially as "Nite-Lites" under several brand names.

The "other" Gain Control topologies include a vacuum tube / circuit called "Variable-Mu," the Field Effect Transistor (FET) and the Voltage Controlled Amplifier (VCA). (See **Table One** for a quick comparison.) All will be discussed in this article, "Optical" first, because it's easiest to understand.

TOPOLOGY	** Approximate Range of Gain Reduction **
Variable-Mu	12~25 dB
Optical	25~30 dB
pwm-FET	30 dB
FET	40~50 dB
VCA	100 dB

Table One: Topology Gain Reduction "Window"

**** Note:** The "approximate" range of Gain Reduction is typical for what is practical for each topology.**

- **PW:** Notice that all feedback type compressors have a max reduction of *about* 30 dB. That is because you can never get a feedback-based device to compress with a ratio of more than 5:1. If you take the FB circuit and turn it into an FF circuit — optimize it for 20:1 ratio, then switch it back to FB mode — it will never get over 5:1 because of the gain riding FB does.
- **PW:** The units that go over 5:1 typically have gain in the control voltage. If you were to take this control design and turn a 20:1 FB circuit into an FF circuit, the ratio would be over inf:1 and would be doing negative reduction. (The dbx 160X had this feature.) I discovered this while designing the 225. As far as I know, I am the only person to make it — FB and FF — a selectable option.
- **PW:** As an experiment, I added gain to achieve a 20:1 ratio, but because of the speed, it was on the edge of becoming unstable. The sonically strange thing is that a 5:1 ratio in FB mode sounds more compressed than 5:1 should. That's because you can't really accurately correlate ratios on FB compressors because they act differently with tones as compared to program material. It's a "dynamic" thang!

SPEED OF LIGHT

A photocell, responding to light, decreases its resistance as the amount of light increases. The time it takes for this resistance change to occur varies with optical device design and typical production tolerances. Photocells have a built-in "Attack" time-constant limiting their ability to quickly respond to transient signals. When used as a "Limiter," optical devices are not fast enough for overload protection — especially in digital-land — where there's nowhere to go beyond 0 dB Full-Scale (0-dBFS).

In response to a transient, the photocell's recovery is non-linear (initially fast, then slow). When constantly bombarded with light — as would be the case with heavy compression — the Release time increases, developing a "memory" that in essence contours the release curve to be "program dependent." Most users would consider these anomalies "the happy accident," for it is nearly impossible to make a classic optical compressor / limiter sound bad.

- **PW:** The API 525 FB compressor had a circuit called "release time over-ride" that allowed transients to recover quickly and overloads to recover slower. The reason was to "prevent the unit from sounding bad with overuse". I think in those days there were more "tone police," because the engineers could actually design.

The response-time limitations mostly work in the optical device's favor, though as a gain control device, the photo-resistor is much less flexible than its competitors. It is nearly impossible to speed up the response time of a photo-resistor short of testing and selecting the fastest devices. Temperature and time affect these components more than others, making it difficult to achieve and maintain accurate stereo tracking. One exception is the Pendulum Audio OCL-2, which uses a proprietary approach to speed up and "tame" the optical device.

OPTICAL TRANSITION

Recent products — both analog and digital — may have more signal-processing ability, but in many cases the interface obfuscates the user's ability to take advantage of the available power. By contrast, the LA2-A and LA3-A are simple two-knob devices that are, in many cases, just right for vocals and bass guitar.

They serve as a reminder that *less* truly is *more*. Inside, the aforementioned "classics" are as basic as they appear on the outside. Only minimal circuitry is needed, one amplifier to drive the EL panel and another amplifier to "make-up" (recover) the gain lost by processing. Oh yeah, let's not forget the power supply!

Later, in the neo-IC age, the designers of the UREI LA-4 substituted an LED for the EL Panel. In order to drive the "transmitting" LED, a "detector" circuit must be added. The perfect lead-in to a more global concept...

THE BLACK BOX

All Gain-Control topologies can be modeled as a three-terminal "black box" with input, output and control connections. In order to establish "control," it is first necessary to convert the AC signal (via rectification) into a DC Control Voltage (CV) that corresponds to the variations in signal amplitude. This circuit can be designed to "detect" RMS or "peak" information plus the ability to manipulate parameters such as Attack, Release, Ratio and Slope (HEY---MY WIFE IS ASIAN...). For more information, see the [Sidebar: Detection and Side-Chain](#).

VARIABLE-MU

The highly treasured Fairchild 670 is one vintage example of the "Variable-Mu" circuit. More recent versions include the Manley Labs "Variable-Mu" and the Pendulum Audio "6386." In the latter instance, the model number refers to the vacuum tube used for the task. No longer in production, the "6386" is a Five-Star military-grade dual-triode vacuum tube made only by General Electric (GE). All products currently manufactured are using "New Old Stock" (NOS) tubes, so the supply is obviously limited.

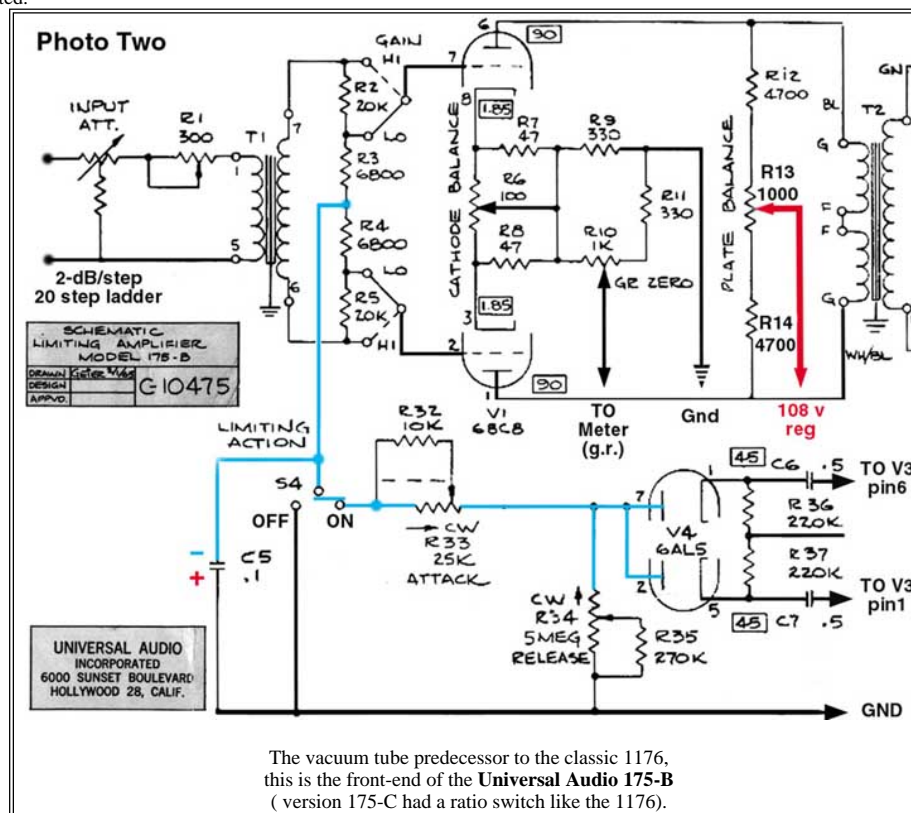


Photo Two is a simplified schematic of the front end of the Universal Audio 175 "Limiting Amplifier," the vacuum tube predecessor to the "solid state" 1176 and a Variable-Mu device. Changing the grid-to-cathode voltage results in a corresponding change in "mu," (μ) the gain of the circuit. In this case, the BLUE line indicates the path of the Control Voltage (CV) — from the detector and side-chain through a voltage divider — to vary the bias of each half of the tube.

For "good" performance over its useable range, adjustments are provided so that each half of the Variable-Mu tube can be balanced to minimize the amount of CV "feed-through" into the audio path (the red arrow). From a purest point of view, CV feed through is bad, though it can also be part of the "sound" that is desired in some cases. One example would be putting some "attack" back into a kick drum (something that also happens with noise gates). Although the total amount of Gain Reduction is limited for Variable-Mu when compared to the alternatives, it is easier than optical to make a balanced stereo compressor.

FET CONTROL ELEMENTS

Like optical, the Field Effect Transistor (FET) acts as a voltage dependent resistor. Although it might sound like the perfect answer to a photo-resistor, it's not. As a gain control element, the FET is level sensitive. Very large signals can modulate the device resistance causing a gain-modulated distortion that is independent of the control voltage used to manipulate the gain. (Translation: overload the input of a FET-based device and expect some funky, most likely undesirable sound.)

- **PW:** in the API 525, the signal is padded down 30 dB and then boosted back up with the FET going to ground on the "—" input of the input op-amp, controlling the gain to minimize the effect of gain-modulated distortion. Another reason that that FB compressors were "limited" to 30 dB of Gain Reduction is that they could only attenuate as much as they were set up to lose. A reasonable point considering that 30 dB of gain did not add a whole lot of "extra" noise.

1176: A Very Good Year

The Universal Audio (later UREI) 1176 is a vintage FET compressor / limiter that is extremely popular with vocalists. The most favored of versions include an input transformer (eliminated in later production runs, both black- and silver-faced), a discrete audio path and an output transformer. The early Allison Research

Gain Brain is also an FET compressor / limiter that is both transformer-less and unbalanced.

REALITY CZECH

To make the FET work as a gain control element, the signal level must be kept low requiring more than the usual amount of gain from the "make-up amplifier." One example is the Input control on a Universal Audio 1176 — a dual-pot configured as a constant-impedance attenuator. To satisfy the input transformer, the attenuator must be *pre*-transformer as well as *pre*-FET. Extra circuits can help minimize, but not eliminate, the inherent distortion of this topology. What remains is part of the sound of any FET-based device. (Discussed in a future article, more than one output amplifier design was used as the 1176 evolved, affecting yet another facet of its sound.)

For stereo operation, FETs must first be matched and the circuit must include adjustments to "find the threshold" of the device so that it operates within its linear region. The Attack and Release times can be much faster than an optical-based product.

- **PW:** The 525 could match the channels quite closely. They used a 5-kohm, feedback resistor (variable) with the FET connected from the "minus" input of the op-amp (a "virtual" ground) to ground. By adjusting the gain to match the unity level, they were almost always gain matched. The only other problem was distortion matching, which was few and far between, requiring some FETS to be replaced.

VOLTAGE CONTROLLED AMPLIFIERS

Voltage controlled amplifiers, or VCAs, have been around for a while. They are the most common method of gain control, followed by the FET. Early VCA devices did not sound very good, two of the difficulties included matching a half-dozen or so transistors as well as keeping them all at the same temperature. Modern VCAs are much better because they are "monolithic," a.k.a, an "integrated circuit," or IC. Since all of the transistors are grown on the same piece of silicon, they match and stay at the same temperature.

- **PW:** They used to be called "modulators", and the original Blackmer patent was never challenged on this, as no one ever mixed dc with audio. The original VCA was Class-B and had thermal relationships to distortion. That is why everyone in this country got into the habit of leaving everything on! They (THE SILICON) were only grown in the same county, and had to be potted. You first had to match the transistors, then pot them.
- **PW:** The Allison VCA was Class-A and thermal relationships only effected gain. The early Allison (blue) was also comprised of discrete devices, matched and potted.

There are two basic types of VCA, the log / anti log amplifier and the trans-conductance amplifier. For the log / anti-log type to work well requires well-matched transistors with a "perfect" relationship between base-emitter voltage and emitter current. Using this over a large control range can run into problems. Increased gain reduction results in less current flow in the circuit, which means hi-frequency response decreases as gain reduction increases. Mis-matched transistors in the VCA can create a strange character of distortion than may occur at one gain setting and not another.

The trans-conductance amplifier looks like a discrete differential amplifier — the gain is manipulated by changing the emitter current. Like the FET, this type of circuit does not tolerate large signals well — distortion sets in — and with large amounts of gain reduction it can also lose high frequency response. Its well-matched transistors must also have very low noise.

- **PW:** Trans-conductance devices also were noisy, comparable with a noise level of a good cassette deck.

Modern integrated circuit technology has resulted in great improvement over the years, but the VCA can still suffer from control feed through and have different types of distortion at different signal levels. A major advantage of using VCA devices is that they can have a very useable dynamic range, which is particularly useful in building automation systems.

- **PW:** That corporation has pretty much licked the problems with VCAs.

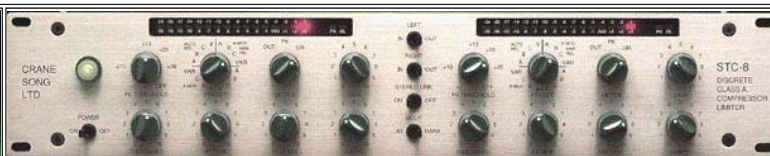
PULSE WIDTH MODULATOR

Using Pulse-Width Modulation (PWM) to control an FET is what Crane Song uses in both the STC-8 and Trakker compressor / limiters. The technology has been around for about 20 years, having been used by several companies, including EMT. With modern technology, a PWM gain-control circuit can be very fast — from 0 to full gain reduction in 500 nS (0.0005 mS or 0.5 uS) and an audio frequency response to 60Khz or more.

PWM works as a gate, quickly switching the FET from "off" to "more-on" by varying the pulse-width. With careful selection of components and PC board layout it is possible to have very low control feed-through, a very low noise floor and an audio-path frequency response that does not vary with gain reduction. This type of circuit requires costly high-speed components and as a result, there is a fair amount of power consumption (it runs hot). Distortion is very low and does not change with gain reduction.



CRANE SONG: Trakker with 12 Classic Settings



CRANE SONG: STC-8 Stereo Compressor with interactive Peak Limiter

- **PW:** Dave is real smart. PWM is the basis of the "Class-D" amplifier. Only a real engineer would be able to think that up. It's from having transmitters and oscillators hammered into our heads at school.

Questions?

If you are unsure about how to set the various parameter options — Attack, Release, Ratio, for example — it's not a bad idea to play it safe. Consider that the optimum range of some gain reduction devices is limited. Rather than over-use a compressor / limiter in one pass, try less-aggressive settings. Process the signal twice, once going to tape (for example) and once coming from tape (or your storage medium of choice).

Combining the fastest Attack with the fastest Release settings can create undesirable distortion. Most Compressor / Limiters feature a range of Attack times that are

faster than the range of Release times making it easy to smash transients. (These same transients are also responsible for "image localization.") To keep the sound "alive" without destroying it, do the reverse of what is more-often the default.

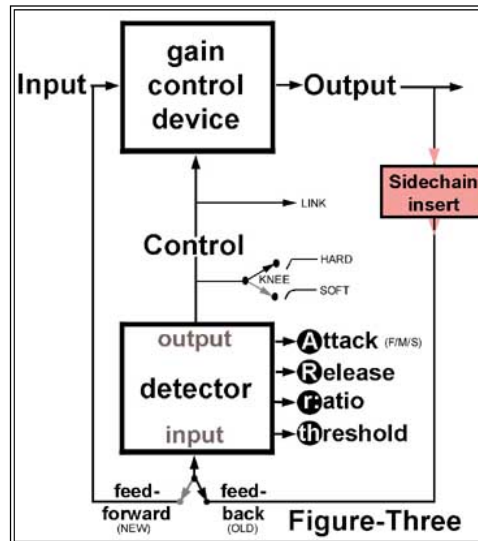
On the first pass, go for the fastest Release time and start the Attack time at its slowest setting using a ratio not higher than 2:1. It's ok to increase the Attack speed until it just starts to have a dramatic effect, then back off. This will even out the dynamics so that, on the second pass, conservative but more traditional settings — Fast Attack, Slow Release — will have a more dramatic and consistent effect.

Being "musical" is not necessarily the most desirable end-result. Sometimes what might be considered undesirable artifacts could end up being a cool effect. The best example of this is the vocal effect (of the pitch corrector) on Cher's big summer hit "Do You Believe."

[e-mail eddie](#)

Sidebar-1: Detector and Side Chain

The function of the Detector circuit is to convert (rectify) the audio signal (AC) into a DC Control Voltage (CV) that corresponds with the signal's changing amplitude. The CV is then used to manipulate the gain of the control device. If this sounds like the workings of an old analog synthesizer, you are correct. Integrated around the rectifier (Peak or RMS detection) is a time-constant circuit to manipulate attack and release speed, some type of threshold circuit (soft-knee, hard knee plus ratio) and perhaps an analog computer circuit. The side-chain control-voltage should correspond as closely as possible with the useable range of the gain control element.



Sidebar-2: Feed Me!

There are two basic compressor / limiter topologies: feed-back and forward-feed, each with their own characteristics, each appropriate for specific types of signals. The block diagram, Figure-Three, is the easiest way to understand the difference. I was lucky enough to witness a demonstration by API designer, Paul Wolff, who included both options on the API 225L compressor / limiter. The difference is so obvious.



API 225L from the Legacy Series

Forward-feed processors can have attack, release, and slope controls that are labeled with fixed numbers — so that dialing up and achieving, a slope of 4 to 1 and an Attack time of 50-mS yields consistent and repeatable results. Two examples of Forward-feed processors are the dbx 160 and the Gain Brain 2.

Flipping the switch at the input of the Detector from forward-feed to feed-back now selects the audio signal, *post-processing*, that is, after the gain control device has done its job. Now the compressor limiter can "see" what it has done and literally tailor the processing to the signal, now more than ever, a moving target. The feed-back topology makes the front panel settings — Attack and Release times as well as the Ratio and Knee — more arbitrary, which to some users can be slightly disconcerting.

- **PW:** That's why the controls don't work the same in both positions.

With the 2500, we have added a patented circuit of ATI's. It is a inverse pink noise response curve filter (3 dB/oct hi-pass) to tip the detector response to equalize the energy/oct of the signal. We call it THRUST, and it is quite cool. I have also applied for a patent on using a filter in the linking circuit to reduce highs or lows or both from the link, eliminating the cross-coupling pumping, which sounds pretty cool.

The Fairchild 660 and 670, API 525 plus the Teletronix LA-2A and LA-3A and UREI 1176 are all examples of the "Feed-back" approach to dynamics manipulation.

Side Chain

Up until this point, we have only considered that the Detector's "job" is to create a DC voltage that corresponds to the signal to be processed and assumed that there will be various tweak-able parameters such as Attack, Release and Ratio. Most detector circuits are designed to treat all frequencies equally, but sometimes it is desirable to insert EQ into the side-chain so that the processor responds, for example, to high frequencies only as would be the case for a de-esser, a hi-frequency limiter.

Other possibilities include inserting a high-pass filter so that the processor would ignore low frequencies. Or, a routing a kick drum to the side chain input to make the processor "duck" a bass guitar with each beat. Taking advantage of the side-chain can be very useful when trying to either create more sonic space or control problem sounds.

End of sidebars.

LINKS

API	Manley Labs	
		UNIVERSAL AUDIO
CRANE SONG	Mercenary Audio (Sales)	
		REVIEWS
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