# Upgrading Modular VCAs

The appearance of the first modular VCAs in the 1970s dramatically accelerated the field of fader automation. While the performance of those early VCAs is rather lacking by today's standards, many of the early SSL and Quad-8 consoles built during that era are still in operation, and when a channel fails, most operators opt to repair the channel strip rather than replace the entire desk. This presents the problem of how to replace devices that may not have been in production for over 20 years.

Fortunately (at least until recently), footprint-compatible successors to these early VCAs have been built by dbx Inc., and later THAT Corporation. In most cases, upgrading to one of the newer devices is simply a matter of altering the components surrounding the VCA to those of the recommended schematic for the newer VCA. There are a number of circumstances, however, where the situation is not so straightforward. In order to replace the VCA in these latter implementations, it is beneficial to understand the nuances of the device's operation and the constraints placed on its performance by the technology available at the time the device was designed.

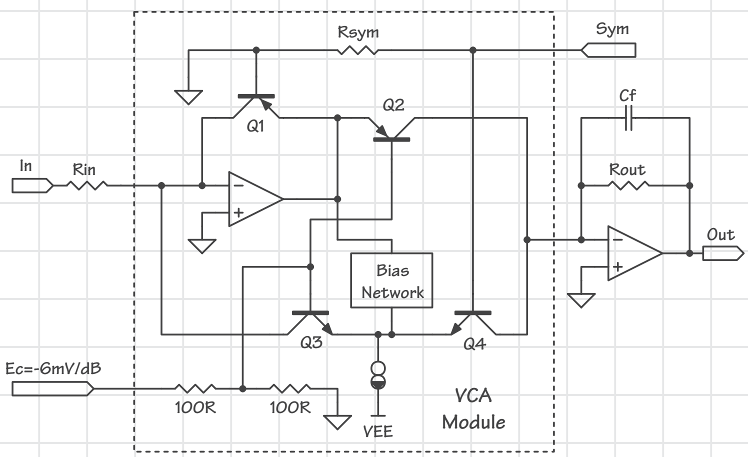

Figure 1. Simplified schematic of a log/anti-log VCA

The earliest log/anti-log VCAs, and all those that followed, use some variation of the Blackmer gain cell shown in Figure 1.

When one considers only negative going input signals, one can see that Q1 and the input amplifier act as a log amplifier, logging the input current. Q2, in conjunction with the external output amplifier, acts as an anti-log amplifier, returning the signal to the linear domain. Positive going signals are handled similarly by Q3 and Q4. A bias network biases the gain cell Class AB, and keeps crossover distortion at a minimum by keeping a small current running through the gain cell at all times. Ultimately, it is the shot noise in this current that limits noise performance at moderate gain. Changes in gain are accomplished by adding a DC gain control signal to the logged input signal and then anti-logging (See the section titled: "<u>How is gain changed in a log anti-log VCA?</u>" for further details).

And this all works fine, until one considers the effects of component mismatch and temperature gradients. In order to make the early discrete VCAs viable, groups of transistors were sorted to match well over temperature, an expensive and time consuming process. Even after matching, a symmetry adjustment was required to minimize THD. Beyond this, a log slope adjustment (not shown) was needed to compensate for the differences between the NPNs and PNPs. After all of this, the performance at zero dB gain was deemed acceptable, but, as the gain of the VCA was changed, transistor parasitics began to affect the log conformity, introducing an additional source of harmonic distortion. As a result, it was necessary to limit

 

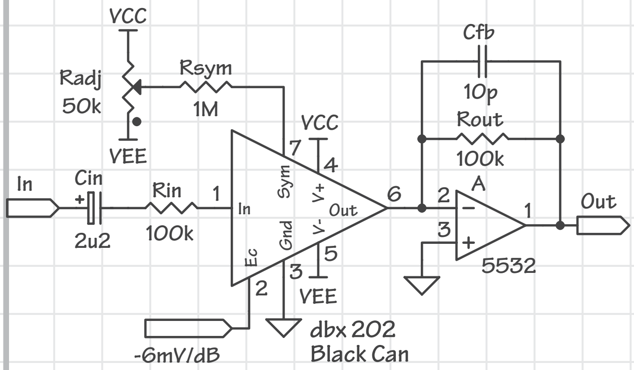


Figure 2. The original "Black Can" 202

input and output currents with large resistors, though this amplified the effect of the shot noise in the gain cell transistors, and thereby, limited the available dynamic range.

The end result was a device dubbed the dbx 202 "Black Can" VCA, so called because of the shiny, black, drawn steel can that encased the electronics. The recommended schematic for this device is shown in Figure 2. Note the 100 kΩ input and output resistors and the symmetry adjustment.

Designers were glad to have this new, versatile building block, but almost immediately began asking for more dynamic range (some things will never change!). Dynamic range was limited by two factors: 1) At high signal levels, and particularly with gain or cut, transistor parasitics result in distortion which limits the maximum signal current. 2) At low signal levels, the limiting factor was shot noise in the gain cell transistors and their quiescent current. The level of bias current was chosen as the best compromise between noise and crossover distortion.

Since the level of bias current was now fixed, dbx began developing a device which had electronic compensation for the parasitics in the transistors. The result was a VCA housed in a gold can -- the dbx 202C "Gold Can". The recommended schematic for this device is shown in Figure 3. This version still required a symmetry trim, but the input and output impedances were cut in half. Also note that the control voltage constant was changed to -50 mV/dB, which became the standard for subsequent models. While this device was a substantial improvement over the original 202, the change barely kept pace with the development of VCAs elsewhere.

Meanwhile, others outside of dbx were designing their own VCAs, publishing papers, and discussing the merits of different VCA topologies. Allison Research and Valley People were also manufacturing an 8-transistor, Class A gain cell. During this time, dbx chose to develop its own Class A VCA, the dbx 2001, housed in a silver can. Class A operation resulted in a substantially higher noise floor, resulting from higher current through the gain cell and the correspondingly higher shot noise. However, some users claimed to prefer the sound of this device because of its lower THD. Using 8 transistors, one could construct 4 "composite" transistors by connecting one device as a transistor and a complementary device an a series diode. Since the logging elements in the lower and upper halves of the gain cell both contained NPNs and PNPs, the requirement for a log slope correction was eliminated.

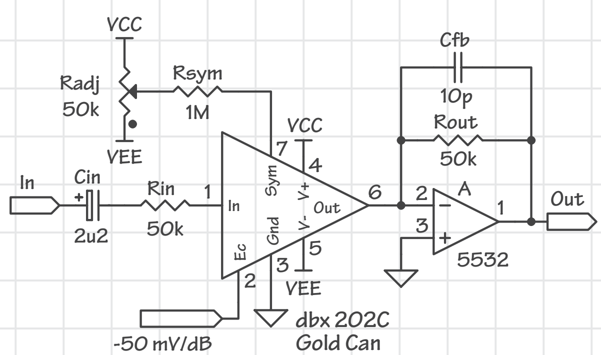


Figure 3. dbx 202C with internal current correction circuitry


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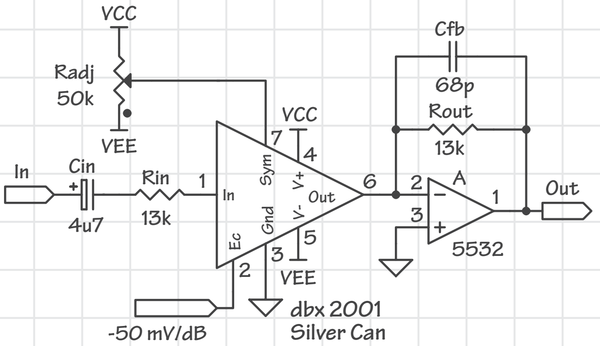


Figure 4. The dbx 2001 -- dbx's only Class A VCA

The dbx 2001 is primarily of interest because, in spite of the fact that it works somewhat differently from the 202s that came before it, the more recent THAT 2002 can be used to retrofit a console built with dbx 2001s. Its predecessor the THAT 202 is not as compatible, since the recommended schematic, which is shown in Figure 4, does not have a divider resistor for the symmetry adjustment.

In the late 1970's dbx began development on what eventually became the dbx 2150 integrated VCA. Unlike their competitors, dbx used the "extra" diode-connected transistors of the 8-transistor gain cell in an elegant configuration that corrected for transistor parasitics at gains other than zero dB, much as had been done in the 202C.

These events could have signaled the end of modular VCAs, but one young engineer noted that, since these new IC VCAs were current in/ current out devices, paralleling them would be relatively easy. When paralleled, the signal currents rise linearly with the VCA count, but noise current rises only as the square root of the number of devices. Thus, for four paralleled devices, the maximum signal current goes up by four, but the noise current only goes up by two, resulting in a 6 dB improvement in SNR.

There are, of course, practical limitations, not the least of which is cost. Another is the input offset of each VCA. If the VCA inputs were directly shorted together with no impedance in between, significant currents would flow as each IC tried to force the VCA's composite input to its own input offset. This current would, in turn, be modulated by gain changes, resulting in undesirable "thumps". To remedy this situation, each IC in a module had a 10kΩ resistor in series with its input to limit this effect.

Consequently, subsequent modular VCAs no longer utilized equal input and output resistors. The first of these hybrid modules was the dbx 202X. Since there were 8 IC VCAs in this module, and each had a 10 kΩ resistor in series, the net internal input resistance was

$$R_{int} = \frac{1}{\frac{8}{10\,k\Omega}} = 1.25\ k\Omega$$

As a result, the input resistance is 1.25 kΩ less that the output resistor. This situation is reflected in the recommended circuit, shown in Figure 5. Note that the can was eliminated from this and all subsequent 202s.

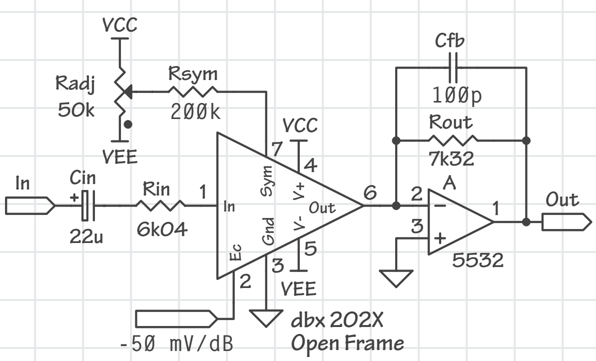


Figure 5. The dbx 202X used eight IC VCAs in parallel

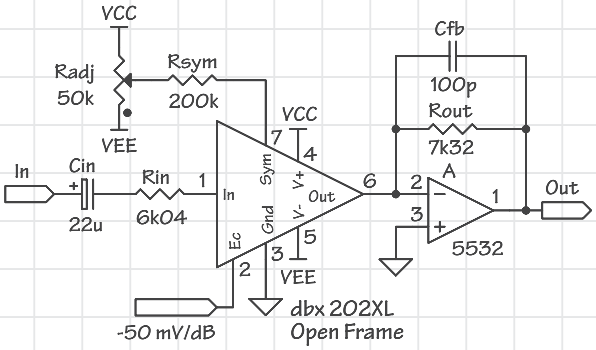


Figure 6. The dbx 202XL used complementary control port drive, but suffered from excessive noise modulation

IC fabrication offers some distinct advantages over the use of discrete components, particularly with regards to parametric and thermal matching. The downside is that the designer is typically required to allow for lower performance in certain parameters, particularly minimum transistor β and maximum device current. In particular, comparatively large parasitic resistance in the transistor collectors affected the way these devices saturated, which in turn resulted in the dbx 202 X having a noticeable "thump" coming out of mute.

Figure 6 shows the recommended schematic for the dbx 202XL, the next model in this series of devices. This model used complementary control port drive to mitigate the "thump" problem. Unfortunately, this particular implementation exacerbated another problem which was noise modulation. This effect is the result of the fact that all log/anti-log VCAs are multipliers, and noise on the control port is exponentiated and then multiplied by the output signal. Note that this effect can only be observed in the presence of signal.

After THAT Corporation acquired dbx's OEM product line, which included modular VCAs, the control port drive was modified to minimize this problem. This new model was THAT's first modular VCA, the THAT 202XT. The recommended schematic is shown in Figure 7.

THAT Corporation also released two other versions of the 202. One, the THAT 202R, had the same -6 mV/ dB control voltage constant as the original "Black Can" 202. The other, the THAT 202XTC, was a version of the THAT 202XT with a temperature compensated control port. The recommended circuit for the THAT 202R is shown in Figure 8 and the recommended circuit for the THAT 202XTC is shown in Figure 9. While none of these devices will be available from THAT Corporation in the future, replacement parts should be available from various console manufacturers for some time.

The different versions of the THAT 202 had no marks to distinguish between them. The only way to ascertain a particular model is by looking at either R3 or R5, which are nestled in between the VCAs. These will be 210 Ω for the THAT 202R. They'll be 100 Ω for both the THAT 202XT and the THAT 202XTC, but on the THAT 202XTC, these resistors will have two orange bands on the end, signifying their +3300 ppm/C° temperature coefficient.

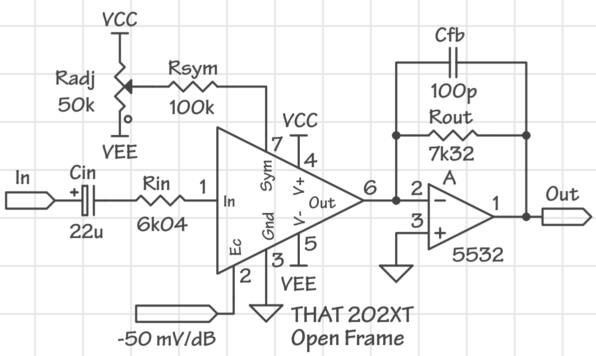


Figure 7. THAT Corporation's 202XT addressed some of the flaws of the dbx 202XL

Up to this point, users had two main complaints about VCAs; that they required a symmetry trim,


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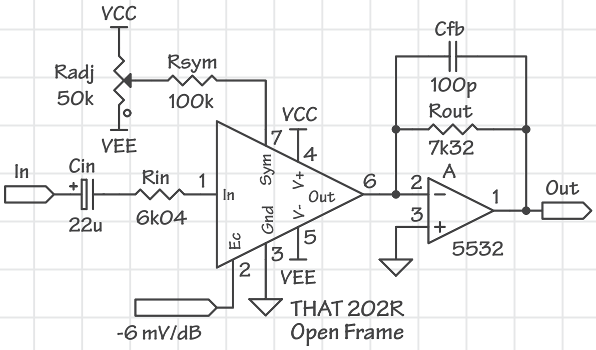


Figure 8. The THAT 202R with it's 6 mV/dB control voltage constant, was intended to retrofit consoles outfitted with the original "Black Can" dbx 202

*and that they had a certain "sound". THAT Corporation has addressed both of these issues with their upgraded line of IC VCAs composed of various grades of the THAT 2180 and 2181. These new VCAs, fabricated in a bipolar, dielectrically isolated semiconductor process, have provision for wafer level symmetry adjustment, and can be purchased in pre-trimmed grades. Dielectric isolation yields gain cell transistors whose small signal parameters nearly match those of the original, discrete VCAs, but have the matching characteristics of an integrated circuit. Lower parasitics result in a substantial improvement in performance, particularly at high frequencies. For a more in-depth, technical discussion of these devices, see Gary Hebert's paper titled An Improved Monolithic Voltage-Controlled Amplifier, presented at the 99th AES Convention in New York, New York in 1995.*

*The performance of these new devices rivals that of the THAT 202, and the company decided to use these new ICs to produce an improved modular VCA, the THAT 2002. The dramatically improved performance of the THAT 2181s allowed the designer to use only 4 IC VCAs in this module, and each had a 5.6 kΩ resistor in series with its input, resulting in an equivalent internal input resistance of*

$$R_{int} = \frac{1}{\frac{4}{5.6\,k\Omega}} = 1.4\ k\Omega$$

*Thus, for the THAT 2002, the input resistor was 1.4 kΩ less that the output resistor. This situation is reflected in the recommended circuit, shown in Figure 10.*

*Early versions of this modular VCA came with two internal trims, and the device was potted in a blue can. The final version, the THAT 2002T1 came in an open, un-potted frame, and required external symmetry trim.*

*There were three models of the encapsulated version of the THAT 2002, which corresponded to the three varieties of THAT 202. The standard, uncompensated module was the THAT 2002N, whose schematic is shown in Figure 10. The schematic for the THAT 2002R, intended to replace the "Black Can" 202 and the THAT 202R, is shown in Figure 11. The schematic for the THAT 2002T, a retrofit for the THAT 202XTC and used in some newer SSL consoles, is shown in Figure 12. Note that these*

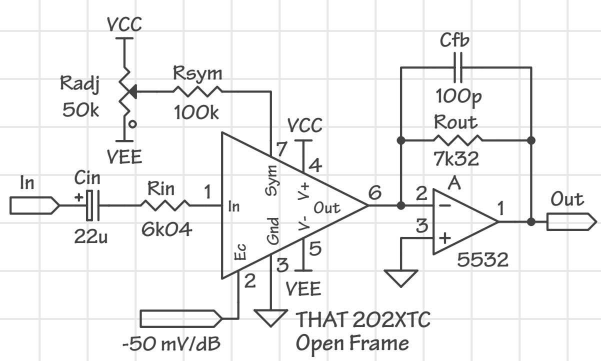


Figure 9. The THAT 202XTC was a temperature compensated version of the THAT 202XT

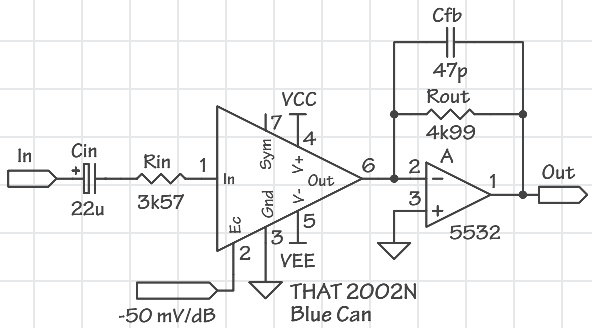


Figure 10. The basic 2002N with 50 mV/dB and no temperature compensation

*schematics are all identical except for the model of the VCA and the VCAs control voltage constant.*

*The last modular VCA built by THAT Corporation was the THAT 2002T1. For various reasons, this device was sold in an un-potted, open frame, and did not have factory trimmed symmetry. The recommended schematic is shown in Figure 13. Note the potentiometer for trimming symmetry. While this device was produced with an open frame like later dbx and THAT 202s, it is distinct in that it only has 4 IC VCAs in parallel.*

## *Replacement considerations*

*Once you've found the correct replacement part, retrofitting one of these older consoles is usually a simple matter of updating the circuitry around the VCA to the values appropriate for that particular model. Acquiring the correct module may be more difficult. Contacting a console manufacturer is a good place to start, but one may wish to look into used or reconditioned parts. There are, however, some circumstances where it takes more effort to replace the VCA.*

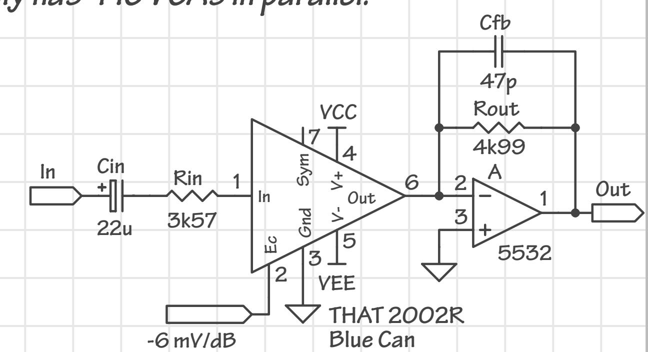


Figure 11. The THAT 2002R with 6 mV/dB. An upgrade for the "Black Can" 202 and the THAT 202R.

*One of these situations is when one needs to maintain an atypical gain structure. All of the recommended schematics assume zero dB of standby gain. Standby gain is the net gain of the VCA when the control port is at zero volts. Let's assume you're replacing a dbx 202C with a THAT 2002N, and while the output resistor of the 202C (see Figure 3) is 50 kΩ, the input resistor in this specific situation is actually 100 kΩ. In this case, the standby gain is one half, or -6 dB.*

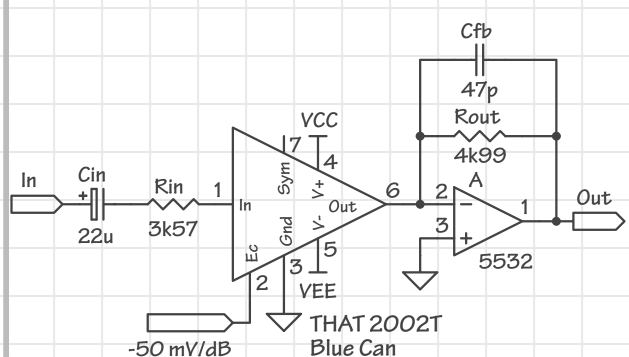


Figure 12. The recommended schematic for the THAT 2002T

*To achieve the same result with the THAT 2002N, one must take into account the built-in 1.4 kΩ input resistor. In order to achieve a net standby gain of -6 dB, one needs a total input resistance of 10 kΩ. Thus, the external input resistance should be*

$$R_{in} = 10\ k\Omega - 1.4\ k\Omega \cong 8.66\ k\Omega$$

*Sometimes a user must accommodate a different control voltage because a 202R or 2002R is unavailable. If this is the case, then one can alter the control port drive in a manner similar to that shown in Figure 14.*

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*The circuit on the left in Figure 14 is designed to drive a "Black Can" 202 with a -6 mV/dB control voltage constant. We can increase the gain of the control port drive by a factor of*

$$G = \frac{50\ mV/dB}{6.1\ mV/dB} \cong 8.2$$

*Thus, if the control port buffer's feedback resistor was 619 Ω, then the new value would be*

$$R_{FB} = 619\,\Omega \times \frac{50\ mV/dB}{6.1\ mV/dB} \cong 4.99\ k\Omega$$

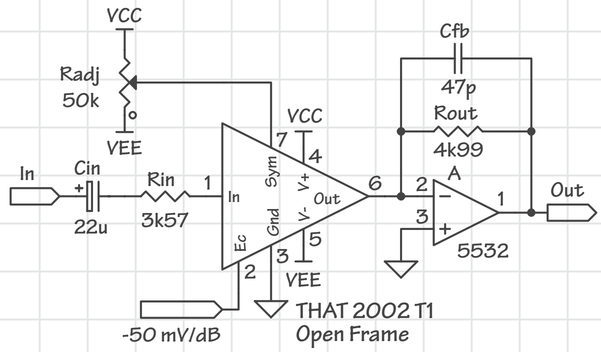


Figure 13. The "open frame" THAT 2002 T1

*This new value is reflected in the circuit on the right in Figure 14. Changing the gain immediately ahead of the VCA's control port not only scales the control voltage constant appropriately, it also correctly scales any offsets that might have been added earlier in the drive chain circuitry.*

*Log/anti-log VCAs have an inherent +3300 ppm/C° temperature coefficient of gain, though some models came with onboard compensation. Early SSL consoles used uncompensated dbx and THAT 202s, though later models used the temperature compensated THAT 2002T and T-1. If forced to replace a non-compensated VCA with a compensated version, one should attempt to disable the console's compensation scheme, which is usually implemented with a PTC resistor. Commonly used TC's are +3300 ppm/C°, +3900 ppm/C°, +7500 ppm/C°. Ultimately, +3300 ppm/C° was achieved by putting the second two TC's in some series/ parallel combination with more stable resistors. It's best to consult the console's documentation when making this kind of change.*

*If retrofitting any of the 2002 VCA into a console designed for standard 202s, one must consider adding excursion limits on the control port drive to avoid thump. This is because, when THAT Corporation designed the 2002, they went away from complementary control port drive to keep modulation noise low. As a result, the thump ascribed to the dbx 202X returned, though to a lesser degree, since the THAT 2181s used in the 2002 are much less susceptible to this effect. Fortunately, the VCA cards found in many consoles (particularly those from SSL) still contain the component locations around the control port buffer for limiting the excursions that cause these thumps. Adding zener diodes that limit the swing at the output of the control buffer to ±3.5 $V_{DC}$ will preclude these sonic artifacts when coming out of mute.*

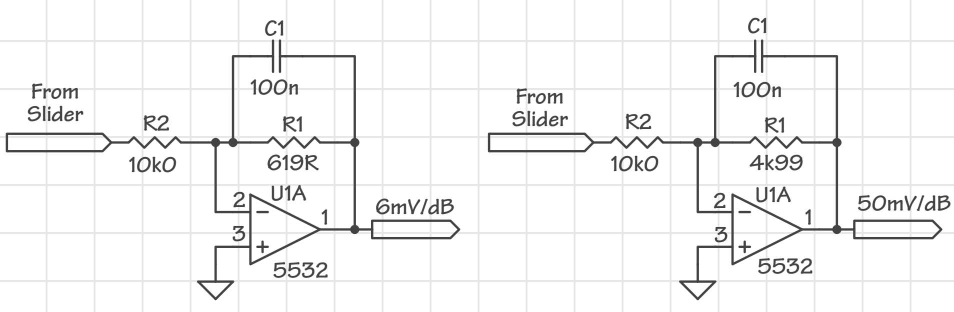


Figure 14. Accounting for a change in control voltage constant

## How is gain changed in a log anti-log VCA?

Referring to Figure 1, consider the positive going portion of an input. If the bases of Q2 and Q3 are grounded, then the voltage at the emitters of Q3 and Q4 will be

$V_E = -V_T \ln\left(\frac{V_{in}}{R_{in} \times I_S}\right)$ (where $I_S$ is the transistor scale factor; usually between $1E^{-12}$ and $1E^{-15}$)

Q4, in conjunction with the output amplifier, anti-logs this signal. Thus, we can calculate the resulting output voltage to be

$$V_{out} = R \times I_S \times e^{\left(\frac{-V_E}{V_T}\right)}$$

If $R_{out}$ is equal to $R_{in}$, then anti-logging of this voltage will result in $V_{out}$ equaling $V_{in}$

$$V_{out} = R \times I_S \times e^{\left(\frac{-(-V_T \ln(\frac{V_{in}}{R \times I_S}))}{V_T}\right)} = R \times I_S \times \frac{V_{in}}{R \times I_S} = V_{in}$$

Assume, instead, that the bases are not grounded, and that there is a voltage, CV, on the bases of Q2 and Q3.

$$V_E = CV - V_T \ln\left(\frac{V_{in}}{R_{in} \times I_S}\right)$$

In this case, our output voltage is

$$V_{out} = R \times I_S \times e^{\left(\frac{-(CV - V_T \ln(\frac{V_{in}}{R \times I_S}))}{V_T}\right)} = R \times I_S \times e^{\left(-\frac{CV}{-V_T} + 1n\left(\frac{V_{in}}{R \times I_S}\right)\right)}$$ yielding

$$V_{out} = R \times I_S \times e^{\frac{CV}{V_T}} \times \frac{V_{in}}{R \times I_S} = V_{in}\ e^{\frac{CV}{V_T}}$$

Note that since we are adding logged values, this is the equivalent of multiplication. Let the input voltage be one volt, $R_{in} = R_{out} = 100\ k\Omega$, let the voltage on the VCA's control port be 60 mV, and let $I_S = 1E^{-12}$. Then

Let $1\ dB = 20 \log \frac{V_{out}}{V_{in}}$ which implies

$$\frac{V_{out}}{V_{in}} = 10^{\frac{1}{20}} = 1.122$$

$$\frac{V_{out}}{V_{in}} = e^{\frac{CV}{V_T}} = 1.122$$

Using $V_T = 26$ mV at room temperature, this equation can be rearranged to be

$$V_T \ln 1.122 = CV = 2.993 \text{ mV per dB}$$

Q1 and Q4 comprise what could be (and in the case of later IC VCAs, is) another control port, though it would be of the opposite polarity. The symmetry port is, in fact, a means of changing the gain of only one half of the gain cell, thus providing a means to correct for slight gain differences between the top and bottom half of the gain cell which arise from small differences in the areas of the 4 transistors.


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