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VCA-2162 Dual channel Voltage Controlled Preamplifier module

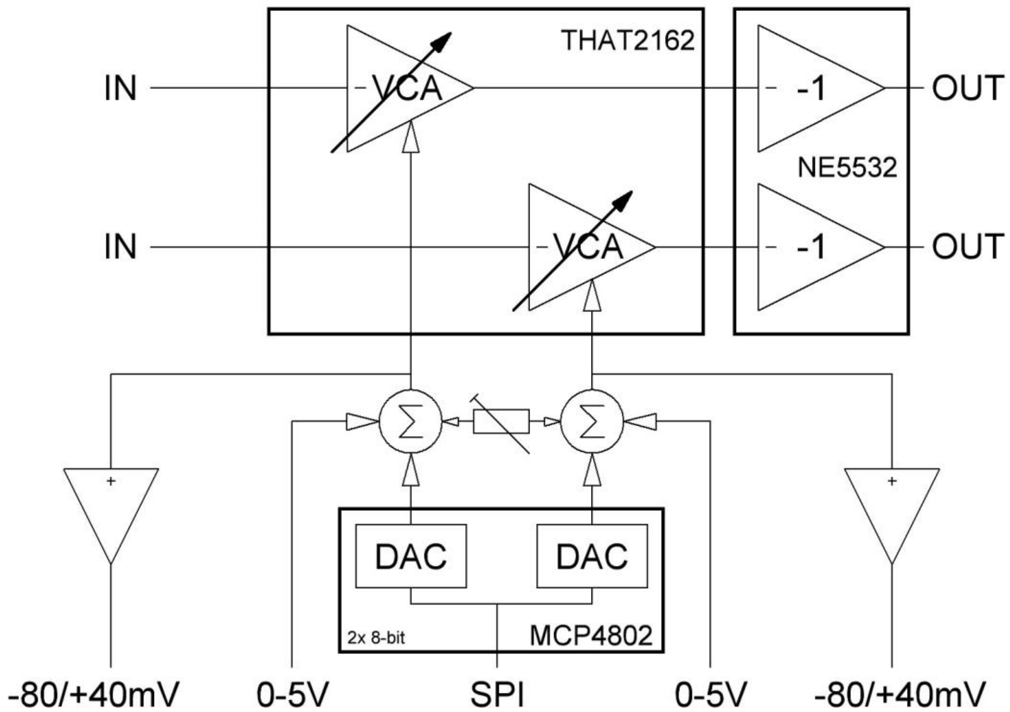
Basically, a preamplifier is nothing more than a collection of connectors, input switch, volume control and maybe tone/balance control components. There are all kinds of ways to control the volume from a potentiometer up to a most complex, DSP based setup.

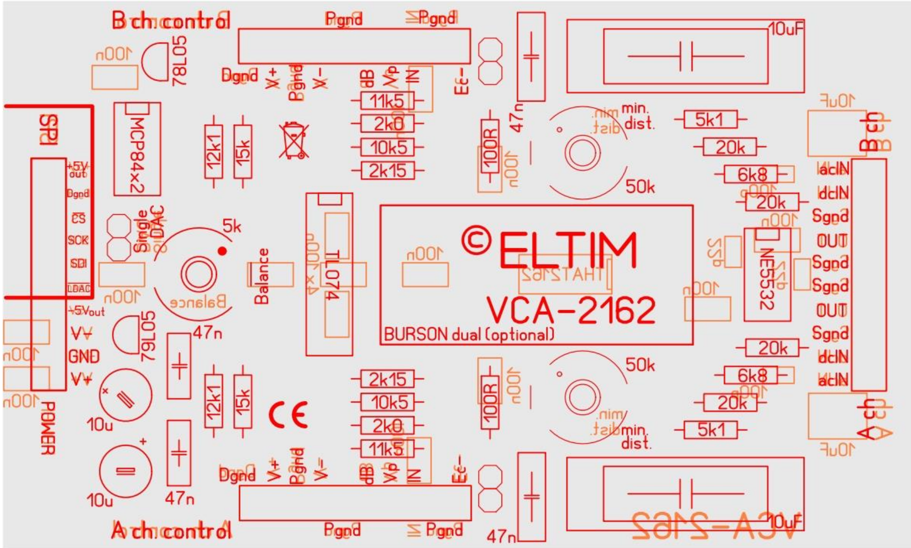
In line with our Power Amplifier modules, we spent a lot of time to find the best available solution to make a volume control / buffer module as base of a High-End Preamplifier.
We believe a DSP is way too complex for many people and we also don't like the digital hocus pocus causing huge phase errors, distortion and loss of musicality. We ended at THAT Corp, providing a logarithmic Voltage Controlled Amplifier (VCA), able to set the attenuation/gain in a wide range of -80/+60dB in two channels. These VCA's truly just give more or less signal.
On the board we added some electronics so that it can be controlled by an SPI D/A converter too.

Introduction

For proper functioning of a preamplifier, we need at least some kind of amplification/buffer circuits in order to avoid impedance changes at the output while changing the gain/attenuation (volume).
So, why not use these amp circuits to control the gain/attenuation of the whole?
In this design we go for the cheapest and simplest way. We decided to use the cost effective VCA chip from the THAT stable. Despite its price, this Blackmer® THAT2162 provides high quality audio and is supplied in a two-channel setup with a gain setting linearity of 1,0% in the range of -80/+40dB. They are not only setting attenuation (-80dB min.), but also providing gain up to an amazing 40dB. Besides an 2-channel analogue control voltage, we use an SPI controlled, 8-bit, dual DAC IC, resulting in 256 (231 effective) steps of 0,4dB for each channel. You can use both at random.

Functional diagram





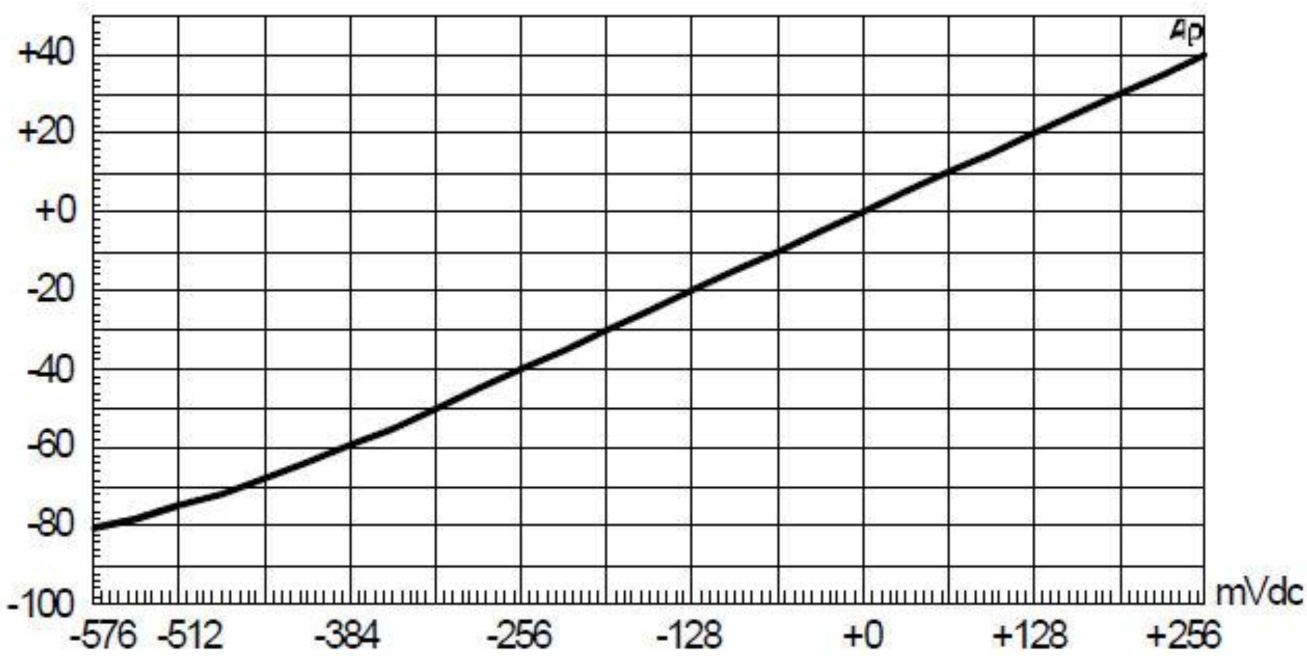
True dimensions: 100x60mm

Some features:

- Extremely wide attenuation/gain control range:
    - Analog controlled 0-4,8V: -80/+40dB, 40mV/dB, linear curve.
    - SPI controlled 8-bit DAC : -80/+12dB, in 256 (231 effective) steps of 0,4dB
- Total circuit is processing currents, not voltages.
- Output level can be driven up to the power rail levels, or ±11,7Vrms.
- There is NO output capacitor required if input signal is DC-free.
- Ceramic (no elco…) 10uF input capacitor mounted. Can be exchanged by a larger or external one.
- Input capacitor can be bypassed by use of dcIN.
- Extra (DC) control port for specific functions like expander/compander/limiter, etc.
- Very low output impedance (0,3ohms) by the audiophile NE5532 dual Opamp IC.
- This Opamp IC can be exchanged by many other types, even the BURSON dual channel hybrids.
- Logarithmic performance (see graph below) generated by the VCA's with linear control signal, so unlike with digital potmeters you can use ALL steps for a logarithmic scaled output signal.
- No mechanical and/or nonlinear, inductive or capacitive components in the circuit.
- While controlling with 20MHz max. clocked, double SPI DAC, gain is limited to +12dB, using maximum number of steps in logic 0,4dB step rates. Lowest 25 steps are inactive (-80/-90db).
- While adding an extra analogue signal, gain of 60dB can still be reached, 40mV/dB rise.
- Locations for trimmers to optimise VCA THD levels (not mounted).
- Location for balance trimmer (not mounted).
- By changing just one control bit, range halves to -80/-20dB, with half sized steps (0,2dB).
- By changing just one control bit, the DAC goes in sleep mode and so simulating Mute mode.
- The same software can be used for all three types of DAC without any extra precautions.
- +5 V regulator on board for DAC and analogue (potmeter) signal.
- Dual channel layout for space and cost saving operation.
- Multiple DAC's can read the same data at the same time (f.e. in balanced stereo circuits!)
- VCA-2162 is pin compatible with other ELTIM VCA modules like VCA-2180x and VCA2181x.
- Header connectors are provided, but not mounted, so you can decide at which side they are mounted.

Analog control

As the name already tells, the attenuation/gain of a VCA is adjustable by a voltage. So, without difficult extra electronics we simply can feed a DC voltage and set the attenuation/amplification that way.
Since our ears react in a logarithmic way to increasing sound level, a conversion from linear to a logarithmic function has to be implemented in any volume control. In most cases this is done by the use of a logarithmic potentiometer. Here it is performed by the THAT2162 VCA's from -80 up to +40dB (1,0%):



Vertical: LOGARITHMIC Attenuation/gain scale. **Horizontal: LINEAR VCA control voltage**

On this VCA-2162 module, volumes (or better: attenuation/gain) of both channels are set separately by 0-4,8Vdc LINEAR control signals, f.e. coming from a regular, mechanical LINEAR potentiometer(s). Use a single potentiometer and tie both control inputs to this if there is no balance function required.

Also, a digital circuit giving SPI data can control the volume. A two-channel 8-bit (256 steps) A/D converter is added to this. So, you can even control the volume/balance by microprocessor based systems.
At the next page we go into details about this SPI data.

Two Opamps convert the 0-4,8Vdc control signals into the -576 <> +256mV required for the VCA's.

Trimming

The THAT 2162 VCA shows an acceptable low THD already. While trimming the VCA's, distortion can be set at an amazing low level. There is space to mount a 240º trimmer (not mounted) per channel on board.

Balance/ Input level correction

With a precision system like this, due to slight tolerances of components used, there will always be a small error in linearity between both channels. We mounted a 240º trim potmeter, feeding more or less balance voltage to both VCA circuits. This way, you can trim/balance both VCA's exactly at 0dB level.

Similar, you can change one or both bit words in the DAC's in order to provide a balance control.

Digital, SPI control

With the popularity of Arduino and many other small and cheap uP-systems, we believed we needed to provide a digital control input as well. Doing so, new applications open for your Arduino, etc. like use in an amplifier system to control and display the volume, etc.

With adding an SPI controlled DAC, volume can be set in 256 (0,4dB) steps. Due to matching with the other modules we produce and the limited attenuation of this module, lowest 25 steps will hardly bring extra attenuation below -80dB. The *half rate mode* of the DAC could be used as an attenuation function, resulting in the same number of steps, but limited attenuation range from -80 / -20dB in 256x 0,25dB steps. Present the dB value on your Arduino screen.

So, unlike with digital Potmeter IC's and some relay attenuators, <u>every bit step is a true logarithmic step</u>! Programming becomes most simple this way, since you don't need to make a logarithmic response table. Just step up/down by one, or more for fast jumping:

DAC programming

REGISTER 5-1: WRITE COMMAND REGISTER FOR MCP4822 (12-BIT DAC)

W-x	W-x	W-x	W-0	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x
$\overline{A}$/B	—	$\overline{GA}$	$\overline{SHDN}$	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
bit 15															bit 0

REGISTER 5-2: WRITE COMMAND REGISTER FOR MCP4812 (10-BIT DAC)

W-x	W-x	W-x	W-0	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x
$\overline{A}$/B	—	$\overline{GA}$	$\overline{SHDN}$	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	x	x
bit 15															bit 0

REGISTER 5-3: WRITE COMMAND REGISTER FOR MCP4802 (8-BIT DAC)

W-x	W-x	W-x	W-0	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x	W-x
$\overline{A}$/B	—	$\overline{GA}$	$\overline{SHDN}$	D7	D6	D5	D4	D3	D2	D1	D0	x	x	x	x
bit 15															bit 0

Where:

bit 15 **$\overline{A}$/B:** DAC_A or DAC_B Selection bit
1 = Write to DAC_B
0 = Write to DAC_A

bit 14 — Don't Care

bit 13 **$\overline{GA}$:** Output Gain Selection bit
1 = 1x ($V_{OUT} = V_{REF}$ * D/4096)
0 = 2x ($V_{OUT} = 2 * V_{REF}$ * D/4096), where internal V_{REF} = 2.048V.

bit 12 **$\overline{SHDN}$:** Output Shutdown Control bit
1 = Active mode operation. V_{OUT} is available.
0 = Shutdown the selected DAC channel. Analog output is not available at the channel that was shut down. V_{OUT} pin is connected to 500 kΩ (typical).

bit 11-0 **D11:D0:** DAC Input Data bits. Bit x is ignored.

The MCP4802, 2-channel, 8-bit DAC as we use here, is controlling both VCA channels separately and need to be programmed separately as well. Data will only be accepted while the CS pin is low. Only after data is latched, the DAC and the output amplifier will come alive. Till that time the output pin is grounded by a 500kohm resistor. Note that redundant data bits, used for higher resolution DAC's will be ignored.

Check out bit 13; by setting it to "1", the output voltage is reduced by 50%, useful as gain attenuator switch, reducing the gain of the module between -80db and -20dB in half of the original step size (0,25dB).

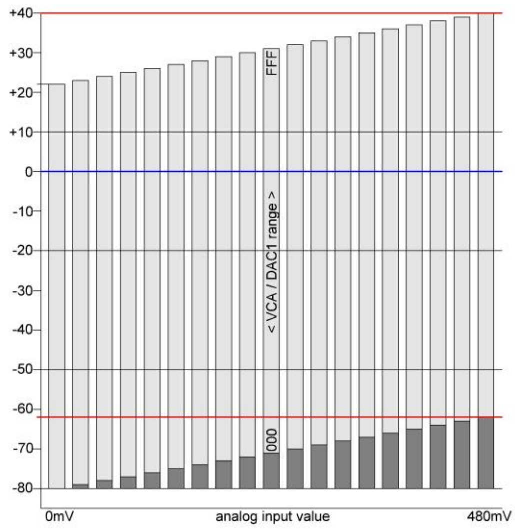
With bit 12 you could mute the system, leaving the latched data untouched. It's meant to power down the DAC and output amplifier in order to save some energy though. No voltage to the VCA's causes -80dB attn.

A hardwired pin at the DAC-chip enables you to load data first in multiple DAC's (taking time) and then ground the LDAC pin. Then all the internally latched data of all DAC's in your system are activated at exactly the same time. This possibility is recommended in this VCA-4 module in order to let both channels step exactly at the same time. We also advise to use this feature while using our VCA-4 modules in multi DAC systems.

As long as there is no data received, both DAC's stay in energy saving mode: it's outputs open and the output pin itself grounded with 500k. So, while just using the analogue control inputs, the DAC stays asleep.

This VCA-2162 has an 8-bit (MCP4802) DAC, so needs all 4 command bits and at least 8 databits for proper functioning. Again: more databits will be ignored without failure readings.

In order to be able to use the same software as with our other VCA modules, the lowest 25 bits (-90/-80dB) will hardly change anything on this module, since the THAT2162 is not able to go that deep.
So, there are 231 active steps available.



Extra gain control port

With our November 2016 update, we managed to feed the extra (ec-) control ports of both VCA's to the side connectors. Normally, a jumper connects them to ground, where this board is functioning as described.
While using this ec- port, a lot of extra functions become possible, like limiter- and expander functions, but also new to develop filtering designs where not the signal itself is changed (causing phase errors due to filtering the audio signal), but by use of a rectifier/filtering circuit providing a correcting DC signal.
We can also imagine a circuit taking action if the output signal of a power amplifier comes close to the voltage rail limits and starts "clipping". Just before that point you amp could take back some volume automatically.
If our VCA modules become a hit, we will do some experiments with these kind of circuits.
In the meantime you can find a lot of extra circuits in the THAT design notes.

Extra Gain

In order to get "rounded" steps from the DAC's, the VCA's are "only" used for a gain up to +12dB, way enough for regular HiFi use. However, these VCA's still have an amazing 28dB headroom to spare.
While, beside some DAC setting, adding a DC-voltage, you can rise the workspace of the VCA's from -80/+12dB to -62/+40dB in a rate of 40mV/dB. You also can use this way for balance control or other correcting functions.

Output Amplifier

Since the VCA's we use invert the audio signal by 180º, inverting circuits are necessary in order to convert the CURRENT output signals of the VCA's into voltages again. The output impedance of the OpAmps used is fantastic low and capable to drive any Power Amplifier. For this, we use an 8-pin NE5534, containing a pair of current driven, Fet input opamps, and known as audiophile opamps. It's used in most affordable High-End.

Since we mount it in a milled 8-pin IC-socket, you can exchange this Opamp. Many other Opamp types will also fit, even the famous BURSON dual Opamps (horizontal or vertical) as we have in our program.

Besides the I/U conversion, we also follow the custom and unwritten rule that any audio circuit should not invert the signal. By using these inverting Opamps, we comply to this rule, since the inverted VCA outputs are inverted again by the buffer opamp. 2x180º=360º=0º. Since in our VCA-2162 module we control gain without any digital "hocus-pocus", total phase error is about flat and near 0º or in other words: staging stays intact.

Other options

Since the attenuation/gain can be controlled, you could connect other electronics to control this gain, either by an analogue signal or in a digital way.
For example, beside functioning as explained above, you could also build in a limiter function, where only a handful of electronic parts can take care that the maximum output level does not exceed a certain level.
The opposite (or even both) will work too, small signals can be amplified automatically till a certain minimum level. For details, check the VCA datasheet and THAT application notes.

Digital dB readout

While controlling this VCA module by a uP, this uP knows what setting is given and can display that values.

For analogue controlled setups you could use cheap and general available voltmeter 200mV readouts. For displaying the value with 199,9mV display modules, we also provided an output per channel, giving the dB level in mV, so from -80,0/+60,0mV, sorry dB -). Just connect a (pair) of universal display module(s) and get a reading. Due a slight non-linearity in the lowest control range of the VCA's (see graph above), the reading will have some larger tolerance than 1% below -50dB, which level is hardly used in practise.

This analogue output signal is coming from the VCA control line, so also working while controlling the module by SPI data. It is also a help feature for you to control if you programmed correct and /or balance both channels, just connect a voltmeter. The VCA's have a tolerance of 1,0% in scaling, way better than any (digital) potentiometer.
You could even add a balance meter. Connect Vin+ of it to one channel and Vin- to the other. Then it will display the difference between both channels -) It can be an analogue meter, LED scale or digital readout.

You also could use this analogue output signal as feedback to your uP or some other device.

Other parts

As always, we use the best parts we can find, double sided FR4 boards, solder masked, silkscreen, etc.

Software

Unfortunately, we don't have time nor knowledge (any more) for programming suitable software.
We believe this makes no sense either, since there are so many different systems and program languages in the market you can use and perhaps already use.
However, for any private initiatives we will make a page on our website.

Model:	**VCA-2162**
VCA-type:	THAT2162
THD@1kHz@0dB:	0,05%
Output buffer:	NE5532
DAC-type (SPI):	MCP4802
DAC-bitrate:	2x 8 bits
DAC-steps:	256
dB steps:	0,4dB

Preliminary technical data:

Max. attenuation:	-80dB
Max. gain:	+40dB
Channel separation:	>100dB
Frequency range:	DC – 40kHz
THD (typ):	0,05%
Slew rate:	6,5V/uS
Crosstalk:	110dB
Output swing:	±14V max.
Output noise:	-97,5dBV@0dB gain
Gain linearity:	1% typical (-60/+40dB)
Power supply:	±15V, 10mA

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NOTE: the audio leading electronics and wiring act as a regular stereo logarithmic potentiometer.
Sgnd is potential free from the board as well, so you need to ground it separately !