

Pro Co Rat Analysis

([/web/20220504054715/https://www.electrosmash.com/proco-rat](https://web/20220504054715/https://www.electrosmash.com/proco-rat))

The Pro Co Rat is a distortion pedal by Pro Co Sound designed by Scott Burnham and Steve Kiraly in Kalamazoo, Michigan 1978. The original circuit and appearance suffered some changes over the different revisions but the tone remained the same.

Due to the pedal success there are several versions designed by Pro Co like the Juggernaut (1979), R2DU (1984), RAT2 (1988), Turbo RAT (1989), Vintage RAT (1991), BRAT (1997), Deucetone RAT (2002), Juggernaut Bass RAT (2003), You Dirty RAT (2004), '85 Whiteface RAT Reissue (2010).



([/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/prc85rat_intro.jpg](https://web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/prc85rat_intro.jpg))

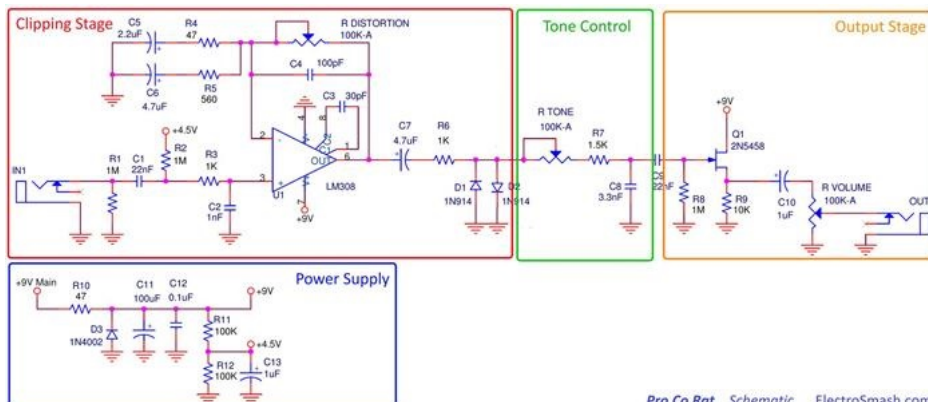
Although the pedal was originally built as custom-order product in 1978, Pro Co began to mass produce it in 1979. In 2008 production moved to China and is now manufactured by Neutrik for Pro Co Sound.

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1. Pro Co Rat Schematic

The Pro Co Rat circuit can be broken down into four simpler blocks: Power Supply, Clipper Amplifier, Tone Control and Output Stage:



([/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-schematic-parts.jpg](https://web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-schematic-parts.jpg))

The design is based on the LM308 single op-amp. The distortion is produced using a variable gain circuit with diodes clipping the waveform. The distortion stage is followed by a tone filter and an output buffer stage that ends up with a tone control.

Pro Co Rat Circuit Layout.

It uses a single layer PCB with standard through-hole components which easily fits in the steel enclosure. The different version/revisions use different substrates.

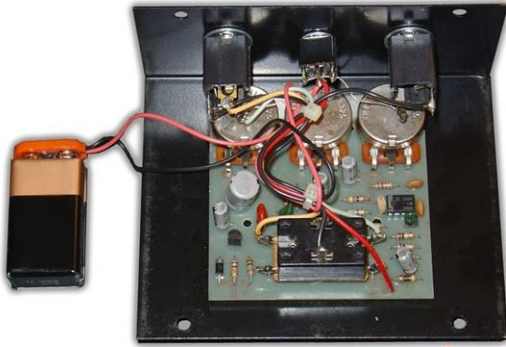


image by Drasp



image by MusicGarage.fi



image by EffectsDataBase.com

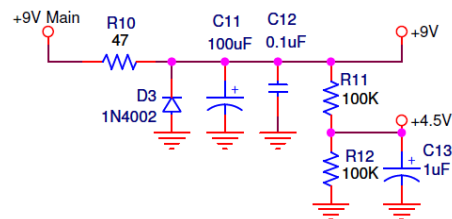
(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/proco-rats-pcb.jpg)

Pro Co Rat Parts List/Bill of Materials.

C₁, C₉ 22nF
C₂ 1nF
C₃ 30pF
C₄ 100pF
C₅ 2.2uF
C₆, C₇ 4.7uF
C₈ 3.3nF
C₁₀, C₁₃ 1uF
C₁₁ 100uF
C₁₂ 0.1uF
D₁, D₂ 1N914
D₃ 1N4002
Q₁ 2N5458
R_{VOLUME}, R_{TONE}, R_{DISTORTION} 100K-A
R₁, R₂, R₈ 1M
R₃, R₆ 1K
R₄, R₁₀ 47
R₅ 560
R₇ 1.5K
R₉ 10K
R₁₁, R₁₂ 100K
U₁ LM308

2. Power Supply Stage.

The Power Supply stage provides 9V for the active circuits (op-amp and transistor). Generating 4.5 volts using a simple voltage divider (R₁₁, R₁₂) to be used as virtual ground.



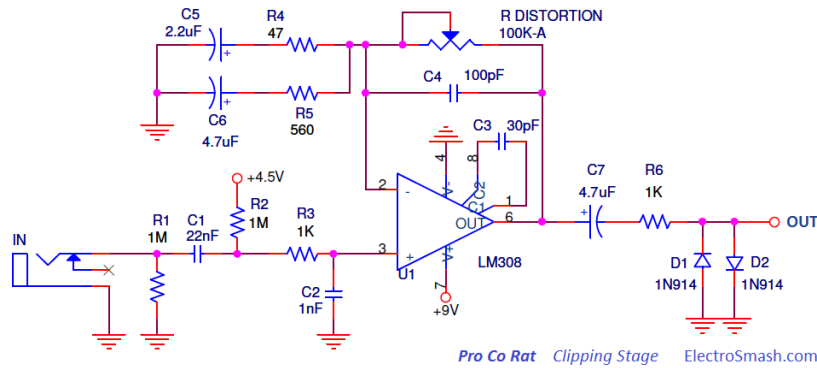
Pro Co Rat Power Supply ElectroSmash.com

(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-power-supply.png)

- Caps C₁₁ and C₁₂ remove ripple from the 9V supply, the C₁₃ does the same in the 4.5V line.
- R₁₀ 47Ω resistor filter noise in power line, this low-value resistor together with the caps C₁₁ and C₁₂ will create a low pass filter which attenuates high-frequency impulse noise.
- Diode D₃ is placed for reverse polarity protection.

3. Clipper Amplifier.

The Clipping Amplifier is the core of the circuit, it is made of a non-inverting op-amp amplifier with variable voltage gain and some filters to shape the distortion response. Two diodes D₁ and D₂ will perform the hard clip action.



(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-clipping-stage.png)

- The 1MΩ input resistor R₁ next to the input jack to ground is a pull-down resistor, which avoids popping sounds when the pedal is switched on. This input pull-down resistor becomes the maximum input impedance of the pedal.
- The 22nF cap C₁ blocks DC and provides simple high pass filtering. All the interesting guitar signal will pass through, only harmonics below 7.2Hz will be attenuated. The cut-off frequency is defined by the formula:

$$f_{c1} = \frac{1}{2\pi \cdot R_2 \cdot C_1} = \frac{1}{2\pi \cdot 1M \cdot 22nF} = 7.2Hz$$

- The 1K resistor R₃ protects the op-amp from input over currents. The 1nF cap C₂ shunts high freqs to ground and out to mellow the signal.
- The big C₇ is just a coupling capacitor which removes DC content and connects the op-amp to the diodes stage. The resistor R₆ will limit the amount of current through the diodes.

Pro Co Rat Input Impedance.

The input impedance can be calculated as:

$$Z_{in} = (R_1 // R_2) // (R_3 + Z_{inLM308})$$

$$Z_{in} = (1M // 1M) // (1K + 40M) = 494K$$

note: 494KΩ is a high input impedance and can be considered fairly good for a distortion pedal. Anyway, the best practice is to keep the input impedance at least in 1 MΩ, avoiding tone sucking. By increasing R₁ and R₂ values to 2MΩ for instance, the pedal input impedance will rise to 1MΩ and the pedal will keep better all the guitar original sonic features.

3.1 Voltage Gain

The voltage gain is trimmed with the distortion knob, in the non inverting topology can be calculated as:

$$G_v = 1 + \frac{R_{DISTORTION}}{R_4 // R_5}$$

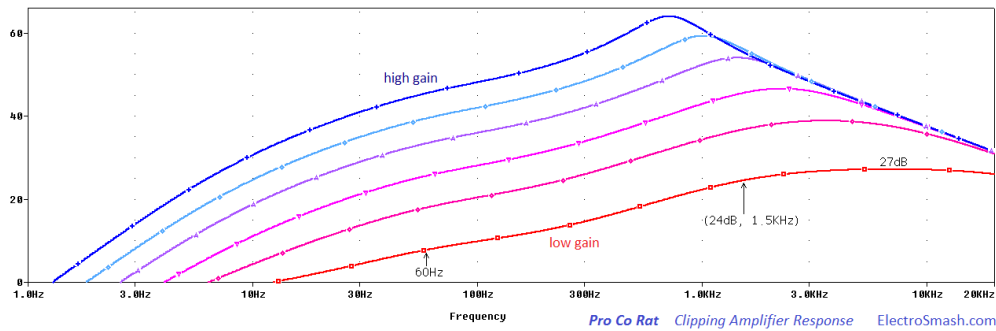
$$G_{vmin} = 1 + \frac{0}{47 // 560} = 1 (0dB)$$

$$G_{vmax} = 1 + \frac{100K}{47 // 560} = 2305 (67dB)$$

note: this voltage gain can be considered slightly high for a distortion pedal and similar to other distortion pedals like Big Muff Pi (G_{vmax}=60dB), MXR Distortion + (G_{vmax}=46dB) or Tube Screamer (G_{vmax}=41dB). However, the voltage gain of this stage will not reach such a values as 67dB. The gain will be limited by op-amp characteristics and also by the clipping diodes action, as it will be studied in the Diode Clipping Section.

3.2 Low/High Pass Filtering.

It is usual to find a combination of low pass and high pass filters before or within the clipping stage in distortion pedals. The distortion makes the original guitar signal more harmonically complex, this means that more amounts of distortion are being added, it can be more difficult to give each sound its own space in the band mix. Artificially band-limiting a distorted signal, using both high and low-pass filters, can help it sit more comfortably in a mix, by preventing its spectrum from spreading over too wide an area.



(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-clipping-response.png)

In the image above, the response of the Clipping Amplifier is shown. The signal is band limited in high and low frequencies. This mid hump around 1KHz helps to keep the guitar sound from getting lost in the overall mix of the band.

Harmonics below 1.5 KHz and 60Hz are attenuated due to the high-pass filters. In high frequencies there is also a roll-off because of the low pass filter and the op-amp gain-bandwidth product, both effects more noticeable at high-gain (blue lines).

Low pass Filter.

The small 100pF capacitor C_4 across the feedback resistor works as a low pass filter, softening the corners of the guitar waveform and mellowing out the high end before the clipping.

The cut-off frequency of the filter is defined by the formula:

$$f_{c1} = \frac{1}{2\pi \cdot R_{DIST} \cdot C_4}$$

$$f_{c1min} = \frac{1}{2\pi \cdot 100K \cdot 100pF} = 16KHz$$

The $R_{DISTORTION}$ potentiometer will shift the f_{c1} frequency, making the action of the 100pF is more dramatic when the distortion control is maxed out at 100K, bringing the cut-off minimum frequency to the audible frequencies (16 KHz) and then softening the distortion. When the distortion knob is not maxed out, the f_c goes higher being less noticeable.

High Pass Filter.

There are two parallel RC networks formed by R_4C_5 and R_5C_6 from the (-) input to ground. They are an active high pass filter, placing two poles and attenuating frequencies below the cut-off frequencies:

$$f_{c2} = \frac{1}{2\pi \cdot R_4 \cdot C_5} = \frac{1}{2\pi \cdot 47 \cdot 2.2uF} = 1539Hz$$

$$f_{c3} = \frac{1}{2\pi \cdot R_5 \cdot C_6} = \frac{1}{2\pi \cdot 560 \cdot 4.7uF} = 60Hz$$

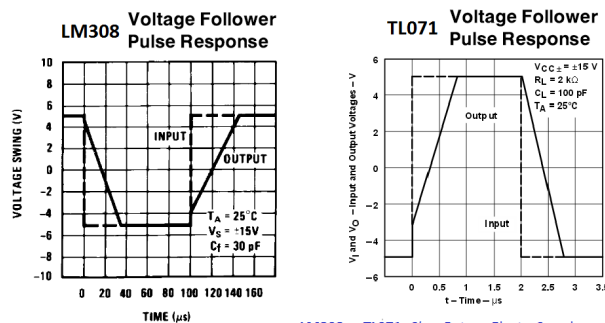
Harmonics below 1.5KHz will have an attenuation 20dB/dec and lower harmonics below 60Hz will be severely muted at 40dB/dec. This filtering provoke that bass notes will be attenuated before the clipping action, making the low end less clipped and creating a frequency selective distortion.

3.3 The Op Amp Selection.

The original Rat pedal uses the LM308N Motorola op-amp, the Texas Instruments OP07DP was a replacement op-amp used in the new models. Part of the Rat's tone remains on the choice of the chip as a function of the Slew Rate, the Gain-Bandwidth Product, and the Compensation Capacitor:

The Slew Rate.

It refers to how fast the op-amp can swing its output. If the signal to be amplified is *too fast* (high frequencies), the op-amp will not be able to perform properly, only amplifying signals below the slew rate limit.



(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/lm308-slew-rate.png)

In the image above, the slew rate of the LM308 is shown together with the TL071 (standard op-amp used in stomptboxes) for comparison purposes. The TL071 slew rate is 13V/us, the LM308 is 0.3V/us around 40 times slower, it indicates how slow is the Rat op-amp is.

- The slew rate is inversely proportional the compensator capacitor, the smaller the cap the faster the slew rate.

For a guitar signal (approximated to a sinusoidal) the Slew Rate of the op-amp will limit the rise speed of the signal following the equation:

$$\text{Slew Rate} \geq 2\pi f \cdot V_p$$

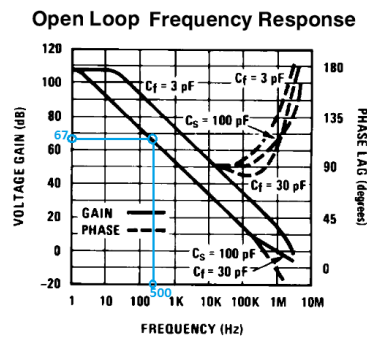
$$f_{\max} = \frac{\text{Slew Rate}}{2\pi \cdot V_p} = \frac{300000}{2\pi \cdot 9V} = 5.3 \text{ KHz}$$

Where V_{peak} is 9V, and the Slew Rate taken from the datasheet image is 300000 V/s.

That means that the op-amp output will not be able of following harmonics higher than 5.3KHz, so high frequencies will not pass through the amplifier, limiting or muting high harmonics.

The Gain-Bandwidth Product

It is relative to the gain setting; the *Open Loop Frequency Response* (gain-bandwidth product) graph below extracted from the datasheet, shows that not all frequencies can be amplified the same quantity.



LM308 Gain-Bandwidth Product ElectroSmash.com

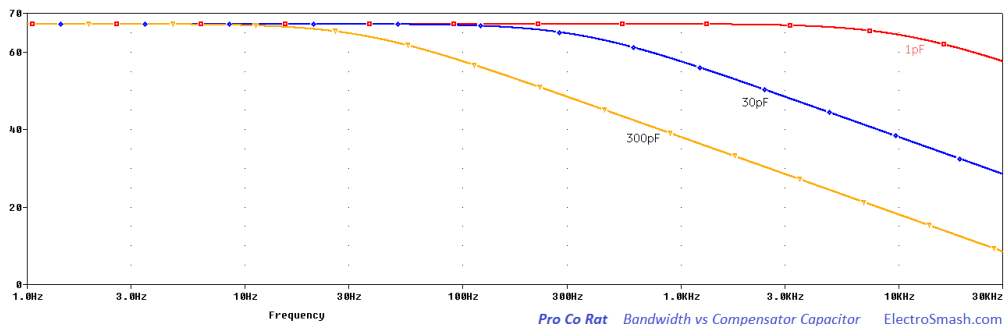
(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/lm308-gain-bandwidth-product.png)

For the Rat maximum voltage gain, which is 67dB, the frequencies below 500Hz will be amplified without problems, but higher frequencies will have less and less amplification as the graph shows. At 10KHz, for instance, the max. voltage gain will be no more than 30dB.

In this way, the amplification of the guitar signal is frequency dependent, bass harmonics will take maximum gain while higher freqs will suffer less gain.

The Compensation Capacitor.

Bandwidth and Slew Rate are proportional to $1/C_{\text{compensation}}$, the smaller the cap the bigger the Bandwidth and Slew Rate. The typical and suggested value by the datasheet is 30pF (same as used in the Rat design).



Pro Co Rat Bandwidth vs Compensator Capacitor ElectroSmash.com

(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-bandwidth.png)

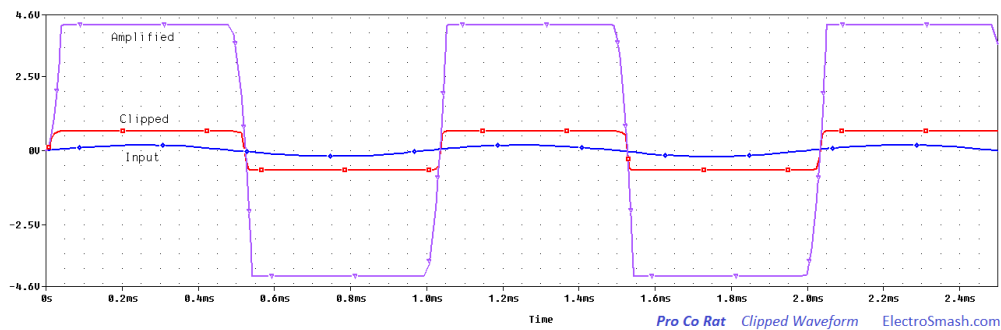
The above image shows again how the high freqs are attenuated, using a 30pF cap. Using bigger/smaller caps the Bandwidth and Slew Rate will be reduced/improved.

Summarizing these 3 effects, part of the signature sound of a Rat is essentially the op-amp collapsing under pressure and how the high-freqs are attenuated and not treated in a linear way. The result of all this will be clipped by the diodes.

3.4 Diode Clipping.

The silicon diodes D_1 and D_2 do hard-clipping on the pre-amplified signal creating symmetric distortion in a similar way as the MXR Distortion+ or Boss DS-1 do. When the voltage difference (positive or negative) between the op-amp output and ground is bigger than the diodes forward voltage V_F , the diode will turn on. As the diode turns on forward biased, the signal will be clipped to the V_F value. The diode D_1 will clip the positive semi-cycle signal to $+V_F$ and D_2 will clip the negative signal semi-cycle to $-V_F$.

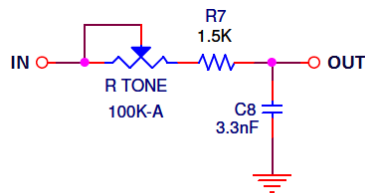
The Rat uses 1N914 standard diodes, any other silicon compatible like 1N4148, 1N4448, or 1N916 can be replaced without troubles.



(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-clipped-waveform.png) In the above graph, the input signal is represented in blue color. This original signal will be amplified by the op-amp until the power supply limits (line represented in purple). After the voltage gain, the diodes will clip the signal to $\pm V_F$.

4. Tone Control.

The passive Tone Control is a simple low pass filter.



Pro Co Rat Tone Control ElectroSmash.com

(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-tone-control.png)

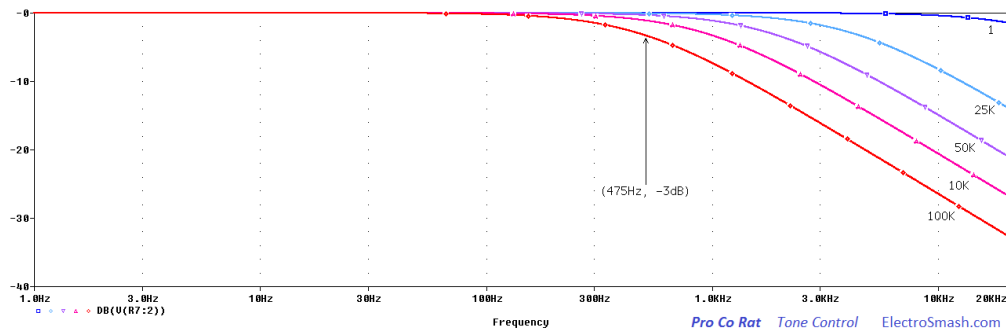
The cut-off frequency can be calculated as:

$$f_c = \frac{1}{2\pi \cdot (R_{TONE} + R_7) \cdot C_8}$$

$$f_{cmin} = \frac{1}{2\pi \cdot (100K + 1.5K) \cdot 3.3n} = 475Hz$$

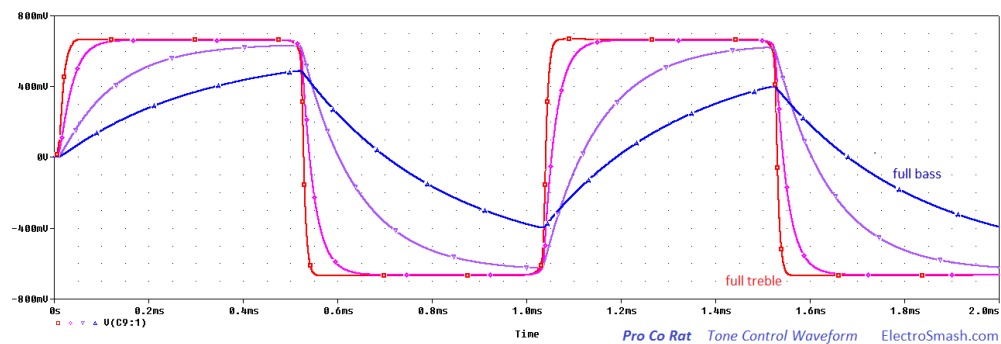
$$f_{cmax} = \frac{1}{2\pi \cdot (0 + 1.5K) \cdot 3.3n} = 32KHz$$

So the high harmonics above the f_c selected by R_{TONE} are attenuated like the graph below:



(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-tone-control-response.png)

The range of the filter is pretty wide, being able to sweep almost all the audio spectrum from 475Hz to 32KHz. The Tone Control combined with all the other filters placed in the pedal will create a mid-hump, to be analyzed in the Frequency Response Section.



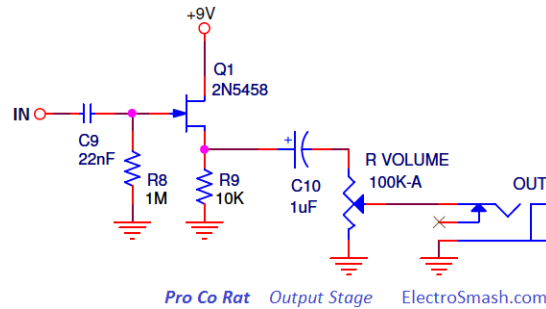
(/web/20220504054715/https://www.electrosmash.com/images/tech/pro-co-rat/pro-co-rat-tone-waveform.png)

The clipped waveform will be affected by the low pass filter, as shown above, creating a *shark fin* shape as the tone control is maxed.

5. Output Stage.

The Output Stage is a JFET unitary gain amplifier in common drain (source follower) configuration

(https://web.archive.org/web/20220504054715/http://en.wikipedia.org/wiki/Common_drain). It is placed to create a low output impedance, that is good to keep tone integrity in the signal chain. It also isolates the volume stage from the Tone Control in order to make both controls independent, otherwise changing the volume will alter the tone:



(<https://web.archive.org/web/20220504054715/https://www.electrosplash.com/images/tech/pro-co-rat/pro-co-rat-output-stage.png>)

The JFET common drain is useful because it uses a very reduced amount of components, it has a high input impedance (approx $R_8=1M\Omega$) and a medium-low output impedance (few hundred of ohms).

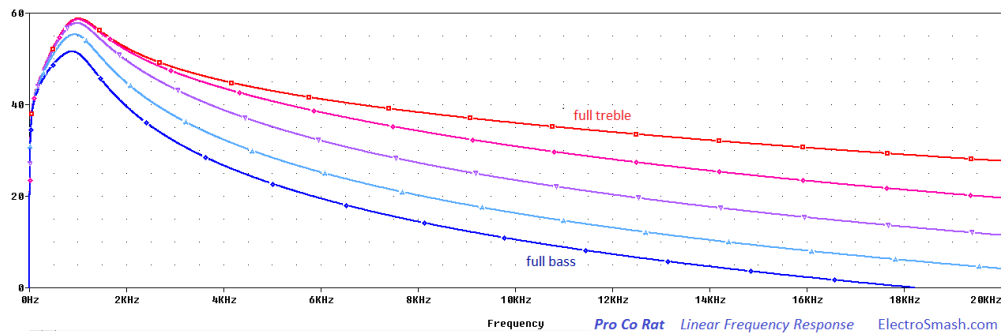
- **Volume Control:** The passive volume control is a standard 100K audio potentiometer which bleeds part of the input signal to ground.

6. Frequency Response.

The frequency response of the Pro Co Rat is designed to empathize the mid frequencies. In order to do it, the waveform is filtered through the different stages, removing the harsh high-freq harmonics and the overloading bass presence.

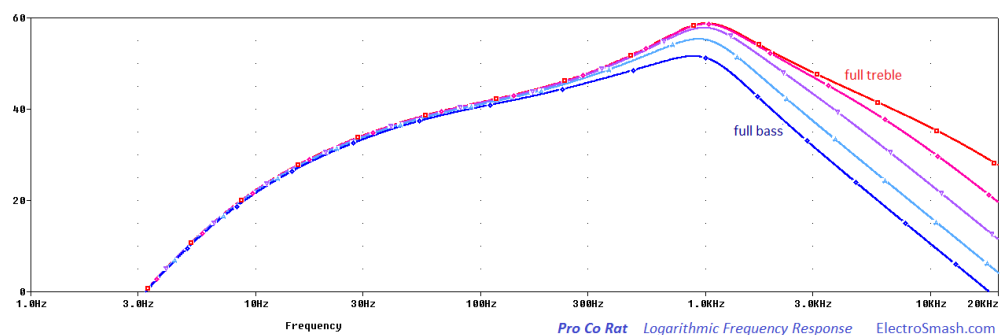
- In the Clipping Amplifier Stage, there is a double RC network which places two poles and attenuates harmonics below 1.5KHz.
- There are several high pass filters, but the Tone circuit and the op-amp bandwidth limit will roll off harmonics higher than 1KHz.

Frequency Response with Linear time base:



(<https://web.archive.org/web/20220504054715/https://www.electrosplash.com/images/tech/pro-co-rat/pro-co-rat-frequency-response-linear.png>)

Frequency Response with Logarithmic time base:



(<https://web.archive.org/web/20220504054715/https://www.electrosplash.com/images/tech/pro-co-rat/pro-co-rat-frequency-response.png>)

The frequency response of the Pro Co Rat is similar to the Tube Screamer response (<https://web.archive.org/web/20220504054715/https://www.electrosplash.com/tube-screamer-analysis#frequency>) showing a mid-hump around 1KHz.

7. Resources.

LM308 Datasheet. (<https://web.archive.org/web/20220504054715/http://www.linear.com/docs/1704>)

DIYStompboxes thread (<https://web.archive.org/web/20220504054715/http://www.diystompboxes.com/smf/forum/index.php?action=printpage;topic=96351.0>) about the Rat op-amp.

Great article about Distortion (<https://web.archive.org/web/20220504054715/http://www.soundonsound.com/sos/apr10/articles/distortion.htm>) in

SoundonSound.com

Pro Co RAT models (<https://web.archive.org/web/20220504054715/http://webpages.charter.net/daosmun/>) by Dosum.

Pro Co RAT in (<https://web.archive.org/web/20220504054715/http://www.effectsdatabase.com/model/proco/rat>) by Effects Data Base.

Pro Co RAT (<https://web.archive.org/web/20220504054715/http://www.musicgarage.fi/2011/07/01/flea-market-find/>) in Jaska's Music Garage.

Pro Co RAT info (<https://web.archive.org/web/20220504054715/http://filters.muziq.be/model/proco/rat>) by Muziq.be

Thanks for reading, all feedback is appreciated.

Our sincere appreciation to M. Chiampi for helping us with the article.

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Instagram photos



New Updates

- [Arduino Audio Meter \(/web/20220504054715/https://www.electrosmash.com/arduino-audio-meter\)](https://www.electrosmash.com/arduino-audio-meter)
- [Dallas Rangemaster Treble Booster Analysis \(/web/20220504054715/https://www.electrosmash.com/dallas-rangemaster\)](https://www.electrosmash.com/dallas-rangemaster)
- [Time Manipulator - Arduino Delay/Echo/Reverb \(/web/20220504054715/https://www.electrosmash.com/time-manipulator\)](https://www.electrosmash.com/time-manipulator)
- [Marshall The Guvnor Analysis \(/web/20220504054715/https://www.electrosmash.com/marshall-guvnor-analysis\)](https://www.electrosmash.com/marshall-guvnor-analysis)
- [You Can Build the Perfect Germanium Fuzz \(/web/20220504054715/https://www.electrosmash.com/germanium-fuzz\)](https://www.electrosmash.com/germanium-fuzz)
- [MXR Distortion + Analysis \(/web/20220504054715/https://www.electrosmash.com/mxr-distortion-plus-analysis\)](https://www.electrosmash.com/mxr-distortion-plus-analysis)

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- [Boss DS-1 Distortion Analysis \(/web/20220504054715/https://www.electrosmash.com/boss-ds1-analysis\)](https://www.electrosmash.com/boss-ds1-analysis)
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- [Dunlop CryBaby GCB-95 Cicuit Analysis \(/web/20220504054715/https://www.electrosmash.com/crybaby-gcb-95\)](https://www.electrosmash.com/crybaby-gcb-95)

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(<https://web.archive.org/web/20220504054715/https://www.pinterest.com/electrosmash/>)



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(https://web.archive.org/web/20220504054715/https://twitter.com/electro_smash)

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