The frequency response of the *MXR®* *MICRO AMP* amplifier

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1 Introduction

The quality of a guitar amplifier can sometimes be gauged by how flat its response is, ie. how flat the graph of the ratio of the amplified signal and the input signal is. Being interested in both music and electronics, my decision as to what I'd do for my internal assessment was clear - I'd measure the frequency response of a small amplifier. Electrical engineers often ask themselves the question of how well an amplifier performs. The frequency response of the amplifier plays a big part in how good an amplifier is.

Frequency response is a measure of how much a certain circuit alters the amplitude of an input sine signal with respect to the frequency of the signal (Horowitz, and Hill). A flat frequency response is one where the output signal is amplified by a constant value, independent of the frequency of the input signal. Usually, alteration of the frequency response is done with passive filters. Even amplifiers that advertise themselves as flat use some sort of filter to reduce noise or potential harmonic effects. The derivation for the *cut-off frequency*[1] is given in the following paragraph.

Suppose a capacitor is driven by a voltage source with a sinewave frequency $V(t) = V_0 sin(\omega t)$. The current of the capacitor is given by:

$$I(t) = C\frac{dV}{dt} = C\omega V_0 cos(\omega t) = C\omega V_0 sin(wt + \frac{\pi}{2})$$

This means that the current amplitude is $C\omega V_0$ and that it is offset by 90° with respect to the driving voltage. The amplitude (disregarding phases) of the current is:

$$I = C\omega V = \frac{V}{1/(\omega C)}$$

Given that $\omega = 2\pi f$ it follows that:

$$I = \frac{V}{1/(2\pi f C)}$$

$$\frac{I}{V} = 2\pi f C$$

[1] Defined as the frequency at which the amplitude of a signal is reduced by 3dB, ie. the frequency at which the power of the signal is approximately halved of a passive first stage filter.

$$R = \frac{1}{2\pi f C}$$

Finally:

$$f = \frac{1}{2\pi RC} \tag{1}$$

Whether an *RC* circuit is going to be a low-pass one or a high-pass one depends on the layout of the circuit. If the capacitor is connected to ground it passes the low frequencies (under the cutoff frequency), otherwise, if the resistor is connected to ground, the filter passes through higher frequencies.

The *MXR® MICRO AMP* (Jim Dunlop) is a small, simple +26dB guitar amplifier pedal, based on the *TL061* (Texas Instruments) operational amplifier. It is designed specifically not to change the tone of the guitar, but instead to provide a clean, boosted signal. Its main application is to have louder guitar solos, or to use it when using two guitars of unequal output signal power (Jim Dunlop).

The schematic of the *MXR® MICRO AMP* is given in figure 1.

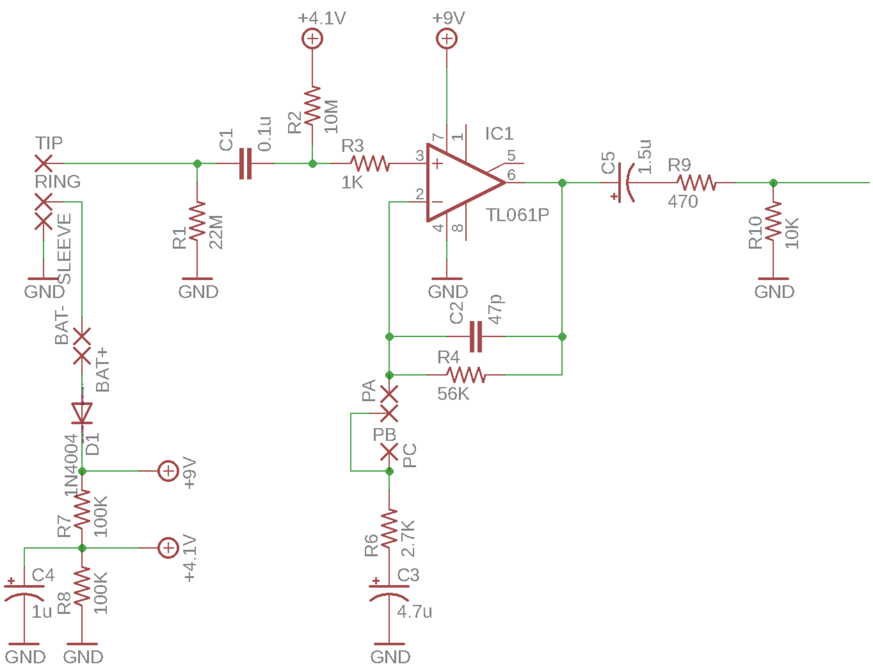

Figure 1: The schematic of the *MXR® MICRO AMP*

The circuit is composed out of two major sections - the power regulation section and the actual amplifier circuit, both given in figures 2 and 3, respectively.

The power regulation section is quite simple. It consists out of a rectifier diode to protect the circuit from reverse polarity, a low current voltage divider (R_8 and R_7) for stepping down the +9V DC voltage into +4.5V for use in the amplifier section and a small ceramic capacitor (C_4) for absorbing potential voltage spikes or drops.

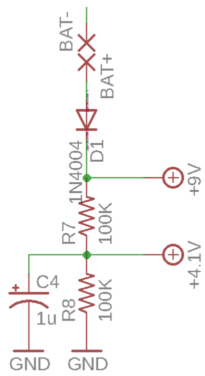

Figure 2: The power regulation section of the *MXR*® *MICRO AMP*

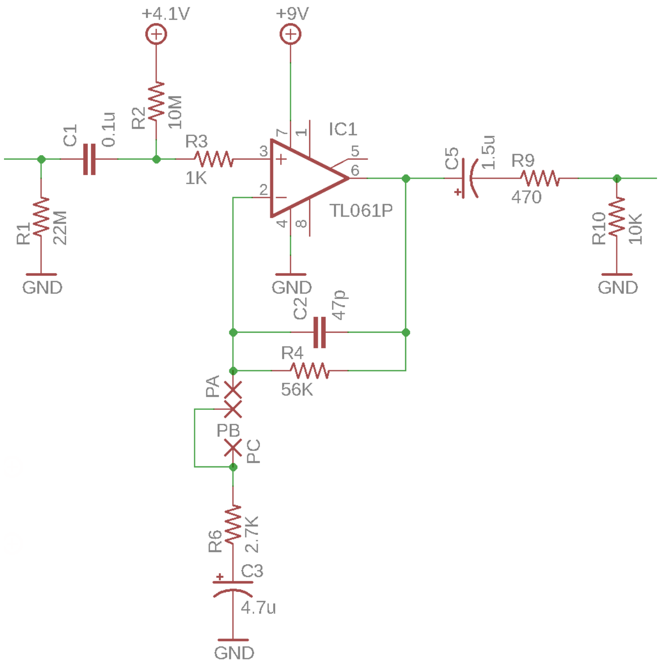

Figure 3: The amplifier section of the *MXR*® *MICRO AMP*

The amplification section is centered around the $TL061$ operational amplifier. R_1 is a pull-down resistor which serves as as a method of discharging any residual charge that may have built up in C_1. C_1 is a coupling capacitor which removes any DC bias. Through R_2, the signal is offset by +4.5V because the $TL061$ in this configuration only allows for positive amplification. Offsetting the signal by +4.5V allows for bipolar amplification. C_5 couples the signal at the output.

R_4, P[2] and R_6 control the gain of the $TL061$. Since the $TL061$, like any other operational amplifier, tends to make the voltage difference between the inputs equal to 0, and draws negligible current (Horowitz, and Hill). Its theoretical gain can be calculated as

[2] P is actually supposed to be a $500K\Omega$ potentiometer, but inside the actual pedal the printed circuit board is connected via cables to the potentiometer, so in this schematic pad symbols (P_A, P_B and P_C) were used.

follows. The op-amp[3] tends to make:

$$V_{TL061-3} = V_{TL061-2} \tag{2}$$

R_4, P and R_6 are setup in a manner such that they constitute a voltage divider, therefore:

$$V_{TL061-2} = V_{TL061-6} \cdot \frac{P + R_6}{P + R_4 + R_6}$$

Let us define $V_{TL061-6}$ as V_{out1} and $V_{TL061-3}$ as V_{in}. Given this and from equation 2, it follows that:

$$V_{in1} = V_{out} \cdot \frac{P + R_6}{P + R_4 + R_6}$$

The gain G_1 is then:

$$G_1 = 1 + \frac{R_4}{P + R_6}$$

However, the resistors $R9$ and $R10$ behave as another voltage divider, making the final gain G between the input and the output of the pedal:

$$G = (1 + \frac{R_4}{P + R_6}) \cdot \frac{R_{10}}{R_9 + R_{10}}$$

For the values of the resistors used in the pedal, these calculate to:

$$G_{min}|_{P=500k\Omega} = 1.06 \approx 1$$

$$G_{max}|_{P=0k\Omega} = 20.8$$

$C1$, $R3$ and the $TLP061$ input impedance together build a high-pass filter, whose cutoff frequency is calculated using equation 1:

$$f_{C1} = \frac{1}{2\pi C1(R2/(R3 + Z_{TL061-3})} = 1.59\text{Hz}$$

It is obvious that this filtering has no effect on the audio, since the frequency is inaudible.

C_2, together with R_4, serves to filter out high harmonics that are unnecessary, but do introduce noise to the op-amp:

$$f_{C_2} = \frac{1}{2\pi C_2 R_4} = 60.4\text{kHz}$$

C_3 is a very common capacitor used in similar guitar pedals. It is used to filter out deep sounds that may saturate the operational amplifier, but are inaudible.

$$f_{C_3} = \frac{1}{2\pi C_3(P + R_6)}$$

$$f_{C3min}|_{P=500\text{k}\Omega} = 6.74 \cdot 10^{-2}\text{Hz}$$

$$f_{C3max}|_{P=0\text{k}\Omega} = 12.5\text{Hz}$$

C_5 is the last capacitor which constitutes a filter. R_{10} and C_5 create a high-pass filter, whose cutoff frequency is:

$$f_{C_5} = \frac{1}{2\pi C_5 R_{10}} = 10.6\text{Hz}$$

[3] Operational amplifier

This amplifier pedal advertises itself as having a flat frequency response. The research goal of this paper is to determine the frequency response of the pedal. Other studies have determined that the frequency response is, indeed, flat ("MXR Microamp Analysis")

2 Hypothesis

It was expected of this pedal to have a flat frequency response and no effects on the input signal.

3 Method

A copy of the *MXR® MICRO AMP* was assembled on a breadboard[4]. Due to a lack of components, some were substituded. A schematic with the used components is given in 4. The original R_1 is replaced with two resistors that add up to 20MΩ, making a small difference between the original 22MΩ. C_5 was replaced with two 1μF capacitors in parallel, bringing the cutoff frequency to:

$$f_{C_5} = 7.95\text{Hz}$$

This should not influence the frequency response in any significant manner.

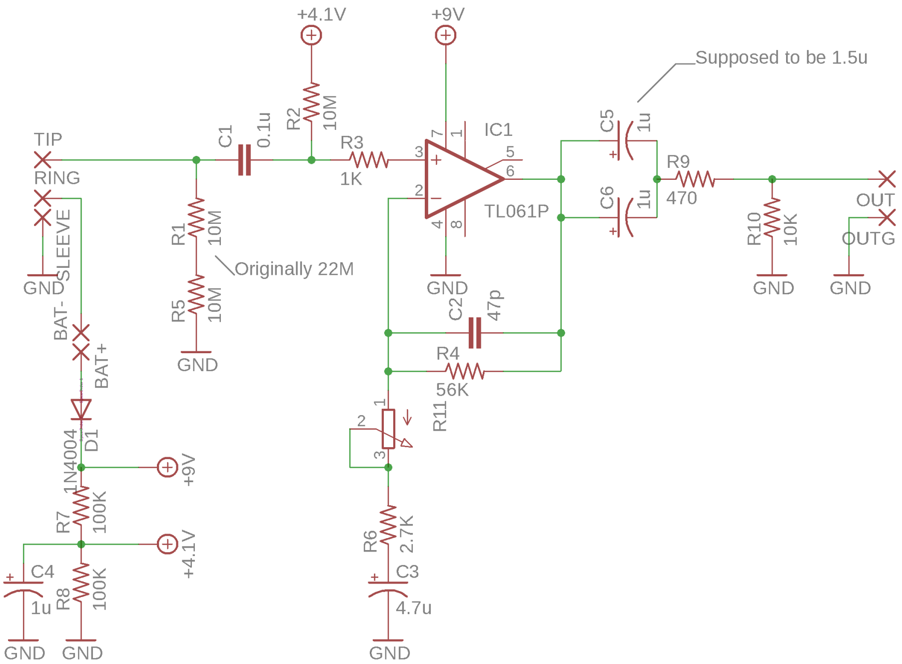

Figure 4: The schematic of the assembled *MXR® MICRO AMP*

The assembled circuit was connected to a computer with sine-wave generating capabilities. At the output it was connected to an oscilloscope, which was set to automatically measure the data every two seconds. The recorded data was then copied to a computer which did the data processing. A program on the computer enabled the sine-wave frequency to be automatically increased by a fixed value of $25Hz$.

[4] A board which allows for making prototypes of electronic circuits easily

4 Data

4.1 Raw data

The oscilloscope recorded a total of 23376000 different voltage points for varying frequencies. Due to the sheer amount of raw data, it was only possible to publish it online and it is available at the following link:

The uncertainty is not given online, however the oscilloscope specification states that the voltage uncertainty is

4.2 Data processing

For every frequency, the oscilloscope generated 4000 individual voltage points. Using a custom *python*, *matplotlib* and *numpy* program[5], a sinusoidal fit was achieved. An example of this is given in figure 5. From this fit the amplitude was calculated.

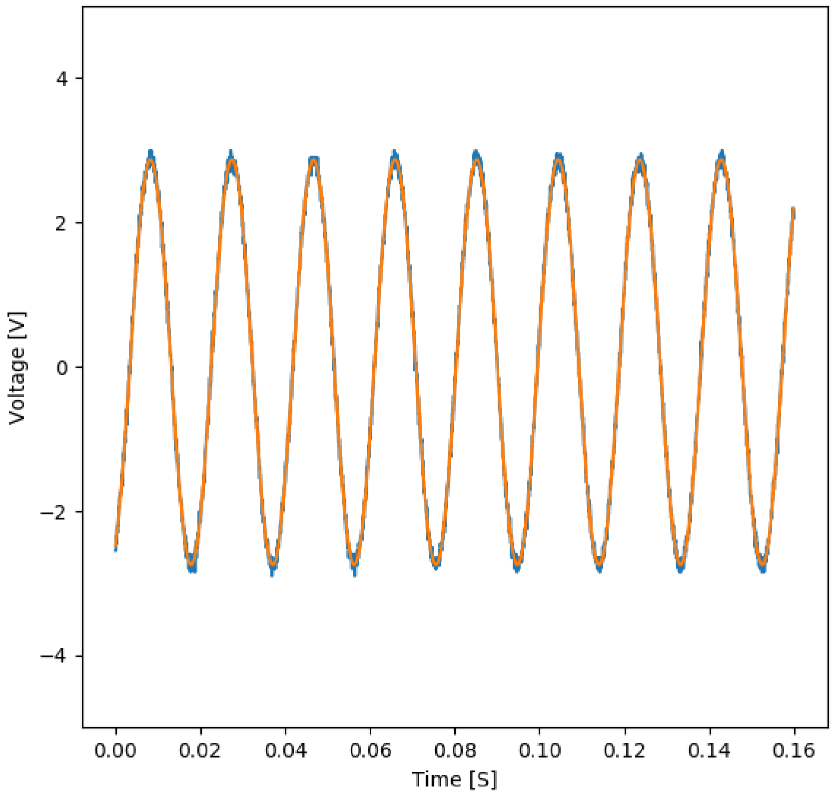

Figure 5: An example of plotted raw data and a sinusoidal fit with the original data given in blue and the fit in orange

This has been achieved for all calculated frequencies. With the amplitudes for different frequencies present, a final graph was plotted - the relationship between the frequency

[5]Available at

and the amplitude of the signal, given in figure 6.

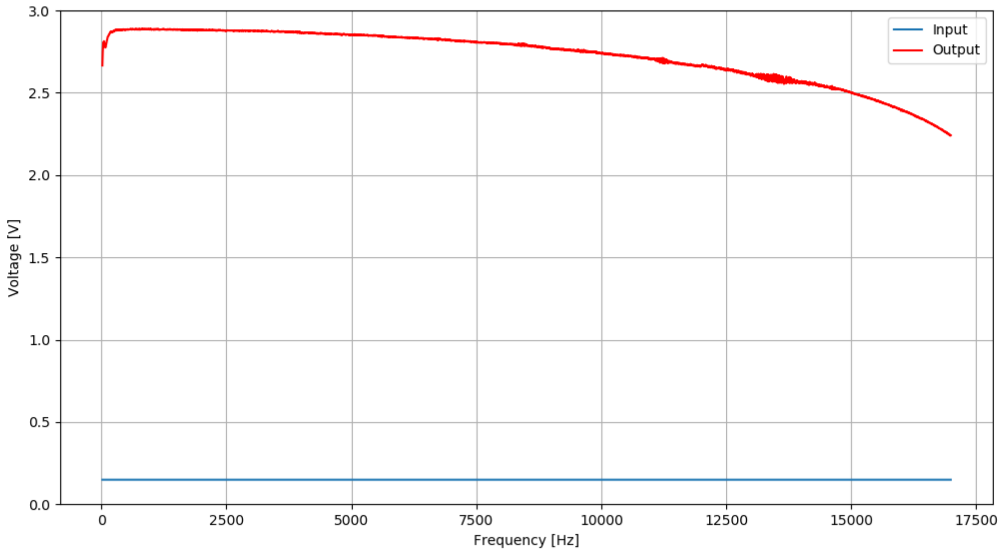

Figure 6: The relationship between the amplitude of the output voltage and the frequency of an *MXR® MICRO AMP*

Due to human ears hearing sound in a logarithmic fashion, the logarithmic plot is given in figure 7. Notice that conversion has been done from absolute voltage to relative gain using the formula:

$$L = 20log_{10}\frac{V_o}{V_i}\text{dB}$$

5 Analysis

5.1 Comparing to other research

Electrosmash.com conducted similar research in the field, measuring the frequency response of the *MXR® MICRO AMP*. Their results are given verbatim in figure 8. The data they acquired differs somewhat than the one acquired in this study in the range of 25Hz-80Hz. It is somewhat difficult to pinpoint the exact cause of the filtering present around 80Hz, however, it can be attributed to the fact that the circuit in this research was physically assembled on a breadboard, which does possess some innate capacitance and resistance in the connections between jumper cables and the breadboard holes.

5.2 Frequency response

The data indicates a non-flat frequency response. Graph 7 shows that the pedal has some oscillations in gain between the 25Hz and 80Hz range. There is a valley at 80Hz, after which the gain increases steadily, flattening out around 250Hz. The amplifier's guitar response remains flat until around 4000Hz. These all indicate that the pedal is

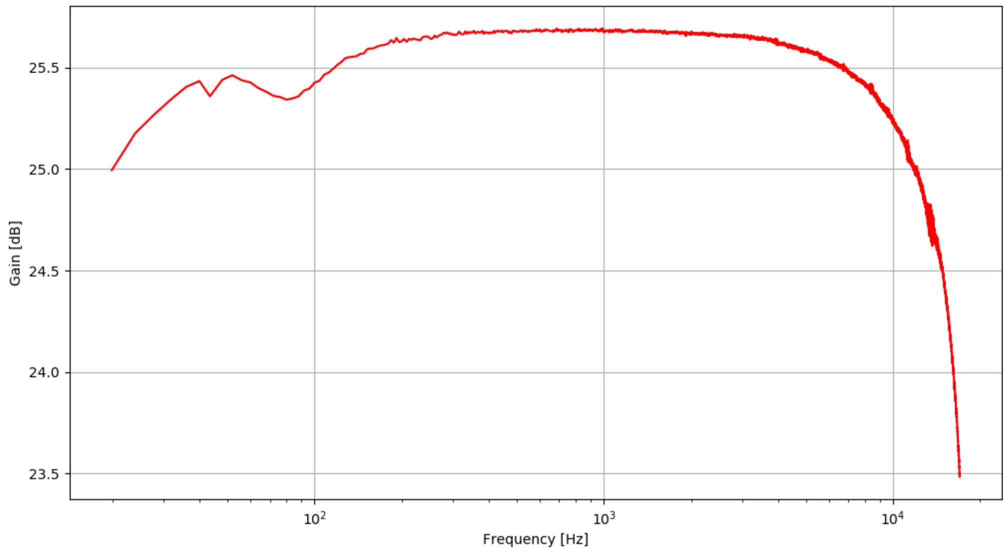

Figure 7: The relationship between the frequency and the gain of the *MXR® MICRO AMP*

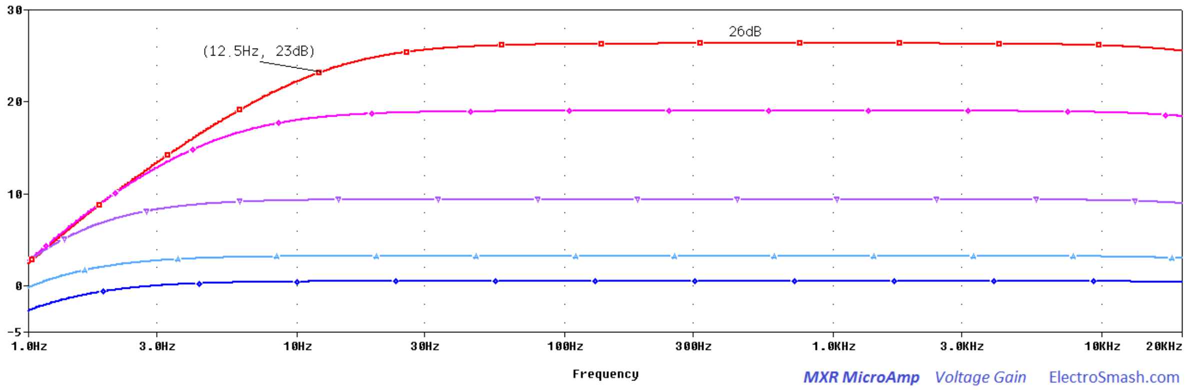

Figure 8: The relationship between the frequency and gain of the *MXR® MICRO AMP* as measured by *Electrosmash.com*

designed to operate in the 80Hz-4000Hz frequency range. Given that a typical guitar's frequency range is between 80Hz and 1200Hz (Case) the pedal performs quite well and is sufficiently flat in the operating range.

5.3 Other phenomena

While gathering the data, it was noticed that distortion occurred at frequencies higher than 15kHz. Since the goal of this research was not investigating distortion, it was ignored, however, given that this pedal is not supposed to have any distortion to it, it is most likely worthwhile to investigate the total harmonic distortion of the pedal.

6 Conclusion

Although the measurements acquired in this study are not equal to those of other parties, even this data indicates that the frequency response of the *MXR®* *MICRO AMP* guitar pedal is sufficiently flat in the frequency band in which it operates.

Works cited

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