“Dual Peaks”
Analog Guitar Distortion Effects Pedal

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Abstract

The Dual Peaks distortion pedal is an analog effects pedal for electric guitar that distorts and boosts the guitar signal in order to achieve tonal characteristics often heard in music genres such as blues, rock, hard rock, and metal. Dual Peaks aims to remedy the current distortion pedal design, and provide a new spin not often provided in the majority of pedals. Dual Peaks contains two separate distortion channels which provide the player with a vast array of distortion and overdrive tones at the press of a switch. Also, Dual Peaks has a “noise gate” and 3-band equalizer circuits built directly into the pedal; these modifications eliminate the need to purchase additional noise gate or equalizer pedals, saving the player money and floor space. This pedal will require little to no setup time; after dialing in the desired settings, the user will be able to “plug in and play”. This pedal design is intended to be handed off to Cal Poly’s Audio Engineering Society club as a kit for members to recreate. This kit will not only allow members to learn more about analog hardware in audio applications, but also to attract new potential members with project ideas and involvement, as well as raise club funds.
Acknowledgements

This project could not have become reality without the support of quite a few people. I’d like to take this opportunity to share my utmost gratitude to these people, though a simple thank you does not suffice. First and foremost, I’d like to thank Dr. Bridget Benson for the guidance and support throughout this project as my senior project advisor, and for supporting my academic endeavors during these past two quarters. I’d also like to extend my gratitude towards Dr. John Oliver, the head of Cal Poly’s Computer Engineering department for providing me with academic guidance during my senior year. I’d like to extend my utmost gratitude to my friends, family, and loved ones for continuously providing me support throughout my time here at Cal Poly. Finally, I’d also like to thank my parents for instilling the love for music and engineering at a very young age, and for being my unwavering support system during my time at Cal Poly. You both are the reason for this project and I can never thank you enough.
Glossary

- **Guitar pickups**: mounted components on an electric guitar that pick-up and amplify the vibration of the guitar strings. Pickups are usually large magnets wrapped in copper wire, and behave like inductors.
- **“In front of the amp”**: placing a pedal “in front of the amp” refers to the pedal’s placement in the guitar signal chain. If a pedal is “in front of the amp” then it is placed in between the guitar and the guitar amplifier in the signal chain. Furthermore, this placement results in the distortion of the signal before the preamp boost in the guitar amplifier.
- **“In the effects loop”**: the effects loop of a guitar amplifier is a signal path after the preamp boost in the guitar amplifier. This path allows the player to run heavy modulation effects pedals (delay, reverb, chorus, etc.) without being “muddied” by the preamp boost. There is no “right” placement for an effects pedal; pedal placement, whether it be in front of the guitar amplifier or in the effects loop, is entirely up to player preference.

![Image of Pedals in Effects Loop](image)

**Figure 1**: Pedals in front of amplifier and in effects loop

- **Op-amp**: the IC chip used in an analog amplifier circuit
- **Guitar amplifier**: the combination of the preamp and loudspeaker used to power and add volume to the electric guitar signal. The distinction of guitar amplifier and op amp is intended to prevent confusion throughout the course of this report.
- **Pedalboard**: a floor module used by guitarists that is used to linked together certain effects pedals in the signal chain. Most pedalboards are equipped with a power source to power each pedal; usually each supply provides 9V, ~1A DC, however some pedals may require AC power or higher DC voltage.
- **Distortion**: the “dirt” of a signal, often described as “gritty” or “aggressive” or “fuzzy”
- **Overdrive**: similar to distortion but is intended to push the signal into a tonal state emulating “natural overdrive”, whereas distortion aims to dirty the signal as much as possible.
- **Natural Overdrive**: the tonal state where the guitar signal naturally clips due to volume level, speaker/amplifier characteristics, etc.. Prior to the mainstream use of distortion pedals, guitar players would set their amplifiers to maximum volume in order to achieve natural overdrive.
• **Fuzz**: a distortion type similar to regular distortion and overdrive that generates a “fuzzier” tone (hence the name). Whereas distortion and overdrive boost mid and treble frequencies, fuzz boosts bass and mid frequencies, while drastically dampening treble frequencies. This equates to a tone that has less note articulation and sounds thicker and muddier

• **Modulation**: a guitar effect different from distortion that alters the signal characteristics in various different ways, rather than boosting and distorting. Popular modulation effects include reverberation, flanger, and delay

• **Delay**: a modulation effect similar to an echo, where the echoed signal repeats are heard clearly

• **Reverberation**: a modulation effect best described as playing in a large open room, like a hallway or a stadium. Reverberation differs from delay in that it’s a dispersed echo, rather than a clear repeated echo

• **Flanger**: a modulation effect that can be described as “warbly” or “swirly”. A famous use of flanger is in the opening riff of Van Halen’s song “Unchained”
Introduction

Rock and roll has been a staple to the modern music scene for almost a century. It has inspired generations after generations of music fans to pick up the electric guitar, a preferred instrument to playing rock music. From the full-fuzzed sound of Cream's "Sunshine of Your Love", to the slinky growl of Led Zeppelin's "Heartbreaker", to the crushing riffs of Metallica's "Enter Sandman", guitar players have been forever chasing the guitar tone of their heroes. However, despite differing genres and musical preferences, the one audio effect that is common throughout is distortion. In the early days of electric guitars, guitar players would play their amplifiers at maximum volume to push them into natural overdrive, resulting in a natural distortion. As the article "A Brief History of Guitar Distortion" states aptly, "Using equipment incorrectly made one of music's most enduring sounds"[11]. While guitarists may still be "cranking their amps to 11", manufacturers have produced other devices that achieve signal distortion such as tube and valve amplifiers, analog distortion pedals and devices, digital signal processing that emulate distortion, etc.

One of the most commonly used devices is the guitar effects pedal. This is a small device (usually within a 3" x 5" enclosure) that receives the guitar signal as an input, modifies it, and outputs it into the signal chain. These effects can range from distortion, overdrive, fuzz, delay, reverberation, flanger, etc. These guitar pedals are usually powered by 9V DC (though there are exceptions), and are activated through the press of a foot switch. While a guitar amplifier often times will have its own preamp distortion channel, effects pedals are more commonly used. In 2017, Statista.com estimated that around 1.3 million guitar effects pedals were sold[12], while only around 675,000 tube amplifiers were sold [13]. Furthermore, according to Statista.com, not only are effects pedals sold at a higher rate than tube amplifiers, but effects pedal sales have been increasing since 2005, whereas tube amplifier sales have been decreasing [14].

The most plausible explanation for this trend is cost. Pedals are overall much less expensive than tube amplifiers. A metric for average guitar pedal and amplifier cost is difficult to estimate. However, from my 16 years of experience with playing and purchasing guitar equipment, effects pedals appear to cost around $50 - $400, whereas amps tend to range from $300 - $3000. In the majority of circumstances where a guitarist wants another type of distortion, a new pedal costs a lot less than a new amp and is typically the preferred route.

However, despite its popularity and necessity for most guitar players, the analog distortion pedal has some weaknesses by nature. First, most simple analog distortion pedals only offer one distortion circuit, and thus one distortion type. For example, a distortion pedal aimed at a high-gain, scooped mid frequencies-typed distortion will not perform the same as a vintage-style overdrive. Therefore, a player will oftentimes have to purchase multiple effects pedals in order to achieve multiple desired distortion types.

Another one of the major shortcomings of a distortion pedal is the noise generated when the signal is amplified. There are many factors within the guitar signal chain (pickups, cable materials, other pedals) that generate signal noise. This signal noise is also amplified in the guitar signal, and thus generates loud humming and “squealing” that is often unpleasant to the listener. To remedy this, guitar players (myself included) will purchase a noise gate pedal, which contains an adjustable signal attenuator. However, this results in financial, spatial, and power accommodation for another pedal in the signal chain.
The Dual Peaks distortion pedal aims to address these shortcomings. Named after the beautiful mountains Bishop and Cerro San Luis Peak (locally referred to as Madonna Mountain), the Dual Peaks distortion pedal will provide one channel for a smooth overdrive, as well as a heavy-distortion channel. The smooth overdrive (named “Madonna channel” for its flatter rise), will provide the user with an overdrive used for alternative rock and blues tones. The heavy gain channel (named “Bishop channel” due to its rugged features) will provide hard rock and metal tones. Also, the Dual Peaks will have a built-in noise attenuation circuit to help filter out any squeal or hum generated by the op-amps.
Background

There are quite a few different types of signal distortion, whether it be compression, clipping, linear distortion, and harmonic distortion to name a few. Despite there being multiple different types of audio distortion, the type of distortion associated with rock guitar is clipping distortion[2]. Clipping distortion is commonly generated by two diodes configured in opposite polarity placed in parallel to one another, like the circuit[3] in Figure 2 below. Clipping distortion is a compression-type effect in which the peaks of the waveform are leveled at a certain voltage level. This voltage difference, \( V_{\text{max}} - V_1 \), is equal to the forward voltage of the diode. Therefore, a diode with a higher forward voltage will cause heavier clipping, and thus more distortion.

![Combination Clipper Diagram](www.CircuitsToday.com)

**Figure 2:** Combination clipping circuit[3]

This type of combination clipping circuit produces hard clipping; the output waveform is leveled heavily once the signal level passes \( V_1 \) and \( V_2 \). The other type of clipping is soft clipping, which is similar to hard clipping, yet the output waveform is leveled off in a smoother fashion. Hard clipping is often associated with harsher, more aggressive sounding distortion, whereas soft clipping sounds smoother and easier on the player’s hearing. However, hard clipping circuits are rarely a sharp clipping, like the waveform in Figure 2; often times, there’s a small value capacitor placed in parallel with the clipping diodes to filter out harsh high frequencies.

There are two main ways to produce hard and soft clipping within a distortion circuit. The first major factor is diode material type. A germanium diode will produce soft clipping, whereas a silicon diode or an LED will produce hard clipping[2]. The other main factor is the placement of the clipping diodes within the amplifier circuit. Soft clipping is produced when the clipping diodes are placed in the feedback loop of the op-amp[2]; this type of distortion is branded as “overdrive”[1]. Hard clipping is produced when the clipping diode is placed in parallel with the op-amp output and ground[4]. Various combinations of clipping circuits and diode materials will produce different types of distortion, whether they be fuzz, overdrive, and heavy metal distortion. These design choices are purely dependent on user preference, as no choice is the “right” choice for the design.

Another common feature in a guitar pedal is “true bypass”. True bypass is the concept that a guitar signal will only be affected by the effects pedal when the pedal is turned on. Thus, if the pedal is turned off, the signal should bypass the effects circuit. Older guitar pedals manufactured in the 20th century utilized switches that were not true bypass, and thus utilized a JFET switching circuit, similar to this circuit in Figure 3 used in an Ibanez TS808 overdrive pedal[7]:
Figure 3: TS808 JFET switching circuit[7]

However, since then a mechanical latching switch called a 3 pole dual throw switch (3PDT) was developed. The 3PDT switch provides the same true-bypass functionality as the JFET switching circuit, but in mechanical functionality, as opposed to analog. Because of this, 3PDT switches are a lot more reliable. Furthermore, they eliminate the number of components necessary for the circuit, thus greatly simplifying the circuit, and lowering the cost.

Figure 4: 3PDT switch button
The full wiring of the 3PDT switch is available in the Hardware Design section.

When designing distortion-type circuits for the application of guitar electronic, there are quite a few choices of types of capacitors one can use such as electrolytic, ceramic, tantalum, etc. Each capacitor, based on the dielectric materials of which they’re manufactured, serve different purposes within the design of an AC circuit. For the Dual Peaks distortion pedal, the three types of capacitors used are electrolytic, film, and ceramic. The electrolytic capacitors serve the purpose of filtering out any large value DC values[9], and are used as coupling capacitors for the input and output of amplifier stages. These are present whenever a value of 1μF or greater is needed. Ceramic capacitors are used to roll off any high frequencies that may be generated, specifically within clipping stages. Due to their very small capacitance (usually within the range of pF) and low inductance and impedance, ceramic capacitors have excellent frequency response and work well in AC circuits[8]. Within the application of distortion pedals, ceramic capacitors filter harsh clipping and result in a “smoother” distortion sound. Finally, film capacitors are cheaply-produced and low inductance capacitors that are the most common type of capacitor used in this design. They are generally preferred over electrolytic capacitors in this design due to their stability over time[10].
Figure 6: (left to right) film cap., electrolytic cap., ceramic cap.
List of Materials

Op-Amps
- Texas Instruments TL072 x 2

Resistors
- 100kΩ x 4
- 10kΩ x 24
- 1kΩ x 2
- 2.2kΩ x 1
- 20kΩ x 1
- 220Ω x 1
- 4.7kΩ x 1
- 470kΩ x 1

Capacitors

Film
- 1nF x 1
- 22nF x 2
- 470nF x 1

Electrolytic
- 0.02μF x 4
- 0.22μF x 5
- 10μF x 1
- 1μF x 4
- 4.7μF x 1

Ceramic
- 10nF x 1
- 18pF x 1
- 1nF x 3
- 22nF x 1
- 51nF x 1

Diodes
- Red LED x 3
- Green LED x 1
- 1N4148 x 5
Transistors
- 2N4401 x 6
- BS170 (NMOS) x 1

Potentiometers
- 1MΩ x 3
- 500kΩ x 2
- 100kΩ x 2

Switches
- 3PDT switch x 2

Power
- 2.1mm DC Power Jack x 1
- 9V battery cell connector
Requirements/Specifications

Upon beginning the conceptual design of the Dual Peaks distortion pedal, there was an initial list of features to be added, such as the built-in noise gate, 3-band parametric EQ, etc. However, given my involvement with various music groups on campus and online, I wanted to utilize the experience and input of other guitar players. I proposed two questions:

1. What is a feature/modification to the general distortion pedal design that you’d like to see in a new model?
2. What is a specific shortcoming with the traditional analog distortion pedal design that you’d like to see “fixed” in a new model?

After filtering through the responses and identifying overlapping answers, I finalized the list of requirements to go into the Dual Peaks distortion pedal. First, the main desire was two separate and independent distortion channels that provided drastically different tones. One channel would be a soft-clipping overdrive channel that could serve not only as a distortion effect, but also as a signal boost for high-gain applications. The second channel would be a hard-clipping distortion circuit that provided the player with a high-gain, high-saturation, stand-alone distortion for any and all hard rock applications.

To remedy the noise amplification issue mentioned previously, I decided to include a noise gate circuit within the pedal itself. A professional guitar pedal manufacturer, MXR, has included this feature in a couple of their models, and have received positive reviews of this feature[15][16]. This need for a built-in noise gate was a feature frequently requested in the results of my survey. There were other interesting and plausible suggestions, such as a built-in 3-band equalizer circuit, but that would result in 10 potentiometers on-board, as well as additional components and hardware. Thus, this idea was abandoned.

---

1 Based off the customer reviews of two MXR products that contain this feature, the Precision Drive, and the EVH 5150 Overdrive pedal.
<table>
<thead>
<tr>
<th>Spec #</th>
<th>Description</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Engineering Compliance</th>
<th>Spec. Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compatible with 2.1mm 9V DC power jack</td>
<td>Low</td>
<td>High</td>
<td>I, S</td>
<td>Most guitar pedals are powered by 9V DC, and most pedal power supplies are compatible with 2.1mm power connectors</td>
</tr>
<tr>
<td>2</td>
<td>Powered by 9V battery</td>
<td>Low</td>
<td>High</td>
<td>I, S</td>
<td>Accommodates for players not using pedal power supplies. A pedal with both a 9V battery and a 2.1mm DC supply connected will not be powered with 18V</td>
</tr>
<tr>
<td>3</td>
<td>Enclosure no bigger than 6 inches by 6 inches big</td>
<td>Medium</td>
<td>Low</td>
<td>I, A</td>
<td>Pedal enclosure footprint should be as small as possible</td>
</tr>
<tr>
<td>4</td>
<td>Pedal provides LED indication when distortion channels are activated</td>
<td>Low</td>
<td>High</td>
<td>I, T</td>
<td>User should be notified by LED when each channel is activated. Change in guitar tone should not be the only indication</td>
</tr>
<tr>
<td>5</td>
<td>Both channels provide a signal boost of at least 20dB</td>
<td>Medium</td>
<td>Med.</td>
<td>T, A</td>
<td>Most standard guitar overdrive/distortion pedals provide a dB boost of this level range. Dual Peaks will follow this guideline too.</td>
</tr>
<tr>
<td>6</td>
<td>Each distortion channel will have independent volume, distortion level, and tone controls</td>
<td>Low</td>
<td>Low</td>
<td>I, S</td>
<td>This is standard for most distortion pedals, and provides wide variety of tonal options</td>
</tr>
<tr>
<td>7</td>
<td>Noise gate will attenuate all signal levels above adjustable threshold</td>
<td>Medium</td>
<td>Low</td>
<td>T, A</td>
<td>Noise gate will have adjustable knob control</td>
</tr>
<tr>
<td>8</td>
<td>Must be true bypass</td>
<td>Low</td>
<td>High</td>
<td>T, I</td>
<td>“True bypass” refers to the guitar signal being unaffected by the pedal circuit if the switches are not activated. True bypass is a standard for any analog pedal on the market</td>
</tr>
</tbody>
</table>

**Engineering Compliance Categories**

- **A (Analysis):** Spec indicates some mathematical, modelling, etc.
- **T (Test):**
- **S (Similar to Existing Design):**
- **I (Inspection):** Spec can be confirmed/disapproved with simple user inspection

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*Figure 7: Engineering Requirements List*

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*Engineering Compliance categories taken from CPE350 Capstone | engineering requirements guideline*
<table>
<thead>
<tr>
<th>Milestone</th>
<th>Milestone Description</th>
<th>Delivery Date</th>
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<tr>
<td>CPE461: Milestone 1</td>
<td>Project Introduction/Design Concept Presentation</td>
<td>January 26th, 2018</td>
</tr>
<tr>
<td>CPE461: Milestone 2</td>
<td>Parts Demo/Alpha Demo Prototype Preparation</td>
<td>February 20th, 2018</td>
</tr>
<tr>
<td>CPE461: Milestone 3</td>
<td>Alpha Prototype Demo</td>
<td>March 23rd, 2018</td>
</tr>
<tr>
<td>CPE462: Milestone 1</td>
<td>Beta Prototype Video Demo/Project Report Rough Draft</td>
<td>May 7th, 2018</td>
</tr>
<tr>
<td>CPE462: Milestone 2</td>
<td>Final Project Demo at CENG Senior Project Expo</td>
<td>TBD</td>
</tr>
<tr>
<td>CPE462: Milestone 3</td>
<td>Final Report and Final Video Demo</td>
<td>June 8th, 2018</td>
</tr>
</tbody>
</table>

**Figure 8:** CPE461/462 Deadlines and Milestones
Design

DISCLAIMER: Despite the amplifier design and engineering that went into the Dual Peaks distortion pedal, musical and tonal preferences are subjective and no amount of engineering can satisfy every guitar players’ preference. The Dual Peaks distortion pedal, while it seeks to provide the player with more distortion options, is not intended to be the “end all” to distortion pedals. Other users may find their preference in a different manufacturer or pedal model, and that is completely fair. Furthermore, this design is intended to be a DIY kit, and thus capacitor types, resistor values, and capacitor values can be tuned to the user’s preferences.

System Design

From a high-level view, the Block 0 design (as shown below in Figure x) is fairly simple. The guitar pedal receives the signal from the guitar, distorts the signal, and then outputs the signal to the guitar amplifier. Also, the pedal is powered by 9VDC, whether through the 2.1mm power adapter or a 9V battery cell.

![Figure 9: Block 0 Diagram](image.png)

Granted, this diagram is predicated on the user running the Dual Peaks in front of their amplifier. As stated previously, a player could place the Dual Peaks in the effects loop of their amplifier as the design does not limit the player to only run it in front of the amplifier. However, the Dual Peaks was designed to be run in front of the amplifier, and was tested in the same fashion.

The Block 1 diagram (as shown below in Figure 10) the Bishop and Madonna channels are run in series, each with their own separate 3PDT switch. This allows the user to run each channel completely independently from one another, or run both channels at the same time to blend the two different types of distortion. There is no particular reason as to why the Madonna channel lies after the Bishop channel; theoretically, if one were to recreate this project, they could place the distortion channels in any order they choose. Each distortion channel has an input buffer before the distortion stage, and an output buffer after the distortion stages. These buffers filter out any DC voltage in the signal, and set the necessary input and output
impedances of the amplifier. Finally, the noise gate lies at the end of the guitar signal chain in order to filter out any excess noise generated by the distortion stages.

Figure 10: Block 1 Diagram
Hardware

The op-amp chosen for the Dual Peaks design were the Texas Instruments TL072B for the distortion channels, and for transistors 2N2219 NPN BJTs for the built-in noise gate channel. When researching popular op-amps for guitar circuit applications, the recurring favorite for a low-noise, low-power, and inexpensive amplifier was the TL072 series. The decision for this op-amp was for a multitude of different reasons. First, the TL072B is a dual-channel IC chip, thus allowing both the clipping stage and the volume/tone stage of a distortion channel to be built using only one chip. Second, the TL072 offers a variety or highly-desirable features: low-power (around 18 nV/√Hz), high input impedance (a must for AC amplifiers), and low total harmonic distortion, to name a few.[19]

Single-turn, 3-pin potentiometers are used in the design of the Dual Peaks distortion pedal. Larger impedance values for potentiometers will naturally allow for more player control over the gain, tone, and volume stages of the distortion channel. For gain control, 1MΩ potentiometers are placed in the feedback of the clipping stages in the distortion and overdrive channels. These high-impedance potentiometers will produce a larger signal amplification, as the higher gain will result in a more aggressive sounding distortion. Also, for volume control, 500kΩ potentiometers will be placed at the output of the volume stage of each distortion channel. This high impedance value allows for a more precise volume adjustment due to a large voltage swing. Another 1MΩ potentiometer is used for the filtering control for the noise gate.

![3PDT switch pin configuration with wires](image)

Figure 11: 3PDT switch pin configuration with wires

The wiring above is used to mechanically redirect the input guitar signal into the distortion circuit which the switch controls. The red lead connects directly to 9VDC, and the black lead connects to the LED indicator to notify the player when the pedal is turned on. The white lead is connected to the input of the guitar signal, which is outputted from the blue lead. The yellow lead connects to the input of the distortion circuit, and the green lead receives the output of the distortion circuit. When the switch is engaged, the white lead internally shorts to the yellow lead, and the green lead internally shorts to the blue.
Madonna Channel

The “Madonna” channel is a distortion channel that provides a softer, less aggressive sounding distortion suitable for a light “crunch” guitar tone. This channel provides two main functionalities. First, the channel can be run as a stand-alone distortion to provide softer, classic-rock type guitar tones. Second, the channel can be run with an already distorted signal to provide not only more signal boost, but also to push the signal into high-gain distortion stages suitable for metal guitar tones. To achieve this, the Madonna channel offers a two-stage distortion channel with silicon diode soft-clipping, as well as gain, volume, and “tone” controls. This channel also has input and output buffers on the beginning and end of the signal (view the Input/Out Buffers Design section for more details).

![Figure 12: Clipping Stage for Madonna Channel](image)

The first stage of this channel performs all of the clipping of the signal. As stated in the background, soft clipping is achieved by placing the clipping diodes in the feedback of the amplifier. The silicon diodes used are three 1N4148 diodes, which have a forward voltage of 1V. Initially, these diodes were germanium diodes, but these were replaced due to the lack of audible clipping. Germanium diodes have a forward voltage of only 0.3V. Therefore, the 1N4148s were used instead, as the higher forward voltage provides more distortion (As mentioned in Background). Two diodes in series, and then parallel with another causes uneven clipping, and ultimately provided a more unique and pleasant sounding distortion than just two diodes. The 22pF ceramic capacitor in parallel is used to filter out a high-pitched squeal generated by the distortion channel. The 1MΩ potentiometer provides a large voltage swing for a fine-tuned gain setting. This stage is a non-inverting amplifier because a non-inverting
amplifier will always be greater than or equal to unity gain. The ground 10kΩ resistor, R20, sets the gain of the amplifier. Even with the 1MΩ set to 0, the gain of the stage is still at 6dB. At full gain, this stage provides 20dB of signal gain. The grounded 10kΩ resistor, R35, sets to bias the amplifier at around 4V, preventing the op-amp from entering saturation. C15 and C14 both provide more filtering of signal hum.

![Diagram of the amplifier circuit](image)

**Figure 13:** “Tone” stage for Madonna Channel

The second stage of the Madonna channel provides the tone functionality, as well as a small amount more gain. Once again, this stage is a non-inverting amplifier. The 100kΩ potentiometer adjusts the placement of the high-pass filter created by R24 and C18. On one extreme, the filter is shorted to the positive input of the op-amp. On the other extreme, the filter is shorted to the feedback. This filter attenuates frequencies below 3.3kHz. The 10kΩ resistor, R23, serves to bias the op-amp at around 4V, preventing the op-amp from entering saturation.
Bishop Channel

The “Bishop” channel provides a more aggressive distortion suitable for rock, hard rock, and metal tones. This gain stage is intended to act as a stand-alone distortion, as running this channel with an already distorted signal may cause too much distortion, and thus signal clarity loss. However, the level of distortion can be adjusted in this stage so as to allow this functionality if preferred. To achieve this, the Bishop channel offers a single stage hard-clipping distortion through the use of red LEDs as diodes, as well as providing volume, gain, and tone controls. This channel also has input and output buffers on the beginning and end of the signal (view the Input/Out Buffers Design section for more details).

![Figure 14: Clipping stage for Bishop channel](image)

This channel is a non-inverting amplifier, similar to the Madonna channel stages. However, as previously stated in the Background section, hard clipping is produced through the clipping circuit being placed in the output of the amplifier. The two red LEDs were initially a pair of 1N4148 silicon diodes, similar to the Madonna channel. However, the red LEDs have a higher forward voltage of 1.8V, and thus provided more distortion. The 1MΩ Gain potentiometer produces a gain of around 20dB at its highest setting. The 10kΩ resistor, R7, biases the op-amp at around 4V, thus preventing the op-amp from entering saturation mode. The various capacitors, C4, C5, and C6, help filter out various noise in the signal. The 51pF capacitor, C8, in parallel with the clipping LEDs was crucial in attenuating a high-pitched frequency in the signal. This unpleasant, high-pitched sound was very apparent in the Alpha prototype demo. Also, a tone stage was designed for the Bishop channel that was identical to the Madonna channel. However, this stage unfortunately was killing the signal and did not work for the Bishop channel for reasons unbeknownst to me. Because of this, this tone stage was replaced with the 100kΩ Tone potentiometer in parallel with a 22nF film capacitor. This adjustable high-pass filter grounds any signal on a range from 72.3Hz to 7.23MHz.
Input/Output Buffers

Each distortion channel contains an input buffer before the distortion stage and an output buffer after the distortion stage. These buffers are common-collector (CC) BJT amplifier circuits, which both have a voltage gain of 1 (a characteristic of CC amplifiers). They are essentially the same design, aside from the output buffer containing the grounded 10kΩ on the output.

![Input and output buffer circuits](image)

**Figure 15:** Input buffer (left) and output buffer (right)

These buffers serve to "condition" the signal flowing into/from each distortion stage in multiple ways. First, the large value capacitors (the 0.2μF on the input and 0.02μF on the output) filter out any DC voltage within the signal. This provides protection to the guitar and amplifier; the guitar pickups and speakers in the amplifier act like large inductors, and these inductors can be damaged by DC voltage. Also, these input/output buffers set the necessary input/output impedances of the distortion stages. For the input buffer, the input impedance can be calculated as:

\[
Z_{\text{ip}} = (100k \parallel (r_s + (\beta + 1)10k)) + 10k \approx 100k
\]

(Where \(\beta\) is 200, from the 2N2219 transistors)

The output impedance of the output buffer is:

\[
Z_{\text{out}} = Z_{\text{in(output buffer)}} \parallel 10k \approx 9k
\]

Since high input impedance in comparison to output impedance is favorable for this type of amplifier, these impedances suffice for the circuit. While these values can serve to be larger, the TL072B op-amps have a very high input impedance (though the datasheet does not specify the value) and thus accommodate for this fact.
Noise Gate

Admittedly, the noise gate design was quite puzzling. While the concept for the circuit was clear, my technical knowledge was limited for such a filtering circuit. The goal of the circuit was to filter out any underlying hum of the circuit that the distortion channels produced. With the approval of my advisor, it was decided to use a circuit found online and find areas for improvement within the original design. The decided circuit[20] was used from H&G Amplifiers:

![Guitar Noise Gate](image)

**Figure 16:** H&G Amplifiers Noise Gate[20]

The above circuit is two cascading common-emitter amplifiers being gated by an NMOS transistor. The 1MΩ potentiometer at the signal input controls the amount of the attenuation effect on the signal. Upon testing with a clean signal, the initial design would attenuate too much of the signal, resulting in a pinched-off sounding guitar tone. Even with the 1MΩ potentiometer at its highest impedance, the signal was being over-attenuated. In LTSpice, I simulated both the output waveform (using a 250mVpp sine wave at 10kHz) and the AC frequency analysis on a range from 20Hz to 20kHz (the range of human hearing) on the original design.
As evident, at the highest setting the H&G design attenuates the signal by a factor of 10. The frequency response is quite favorable, as frequencies below 100Hz are filtered out. Frequencies less than 100Hz are in the range of a typical guitar amplifier hum. To remedy the over-attenuation while maintaining the frequency response, I decided to convert the first common-emitter stage into a common collector. As stated in the input/output buffer design section, common collector amplifiers have unity gain, meaning the waveform is unaltered. This lowers the amount of attenuation in the signal, while still preserving the frequency response. I also changed the second transistor’s base capacitor of 220nF to 470nF, purely on the basis of sounding more pleasant. I also changed the 2.2MΩ resistor to 1MΩ, and the 2.2kΩ to 220Ω to increase the disparity between itself at the 1MΩ potentiometer.
Figure 19: Updated Noise Gate Design

Figure 20: Vin (n007) vs. Vout (n001) (Updated Design)

Figure 21: 20Hz-20kHz Frequency Analysis (Updated Design)
As was intended by my changes, the updated design at its highest attenuation setting only attenuates the input waveform by a factor of around 2, while still rolling off the 20-100Hz frequency range.
Testing

When first testing the pedal, I connected a waveform generator to the input of the pedal, and outputted a 250mVpp, 1kHz sine wave. When measuring the AC voltage of my guitar signal, the values would fluctuate from 250mVpp to 500mVpp, depending on the force on which I struck the strings. To be conservative, I decided to set the test waveform to 250mVpp. I tested each channel independently with the drive potentiometer set to the fullest potential on each channel. Using the voltage output voltage, I calculated the signal gain in dB with the following equation:

\[
A_v(dB) = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)
\]

**Equation 1: Voltage Gain in Decibels**

Captures Without Noise Gate

![Figure 22: Bishop Channel, Output Waveform](image)
Figure 23: Madonna Channel, Output Waveform

Figure 24: Both Channels On, Output Waveform
Captures With Noise Gate

**Figure 25:** Test Input Waveform (250mVpp Sine @ 10kHz), Gated Output Waveform

**Figure 26:** Bishop Channel, Gated Output Waveform
Non-Gated Output Waveforms Gain
Madonna channel: 6.69dB
Bishop channel: 9.19dB
Both channels: 8.43dB
Gated Output Waveforms Gain
Neither channel: -20dB
Madonna channel: -3.198dB
Bishop channel: 2dB
Both channels: 0.7dB

Using these test results, and the final design, the project requirements were revisited and assessed.

<table>
<thead>
<tr>
<th>Spec #</th>
<th>Description</th>
<th>Pass/Fail</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Engineering Compliance</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compatible with 2.1mm 9V DC power jack</td>
<td>Pass</td>
<td>Low</td>
<td>High</td>
<td>I, S</td>
<td>Verified with multimeter, simultaneously connection a 2.1mm DC adapter provides 9V of power</td>
</tr>
<tr>
<td>2</td>
<td>Powered by 9V battery</td>
<td>Pass</td>
<td>Low</td>
<td>High</td>
<td>I, S</td>
<td>Verified with multimeter, simultaneously connection a 2.1mm DC adapter and 9V battery cell provides 9V of power</td>
</tr>
<tr>
<td>3</td>
<td>Enclosure no bigger than 6 inches by 6 inches big</td>
<td>Fail</td>
<td>Medium</td>
<td>Low</td>
<td>I, A</td>
<td>Pedal enclosure design not met; for future iteration</td>
</tr>
<tr>
<td>4</td>
<td>Pedal provides LED indication when distortion channels are activated</td>
<td>Pass</td>
<td>Low</td>
<td>High</td>
<td>I, T</td>
<td>LED connected in series with resistor to pin 4 of each 3PDT switch, and turns on/off when switch is pressed</td>
</tr>
<tr>
<td>5</td>
<td>Both distortion channels provide a signal boost of at least 20dB</td>
<td>Fail</td>
<td>Medium</td>
<td>Med.</td>
<td>T, A</td>
<td>A sine wave at 250mVpp and 10kHz was inputted into the circuit, and the output waveform was captured. Both channels fail to meet initial 20dB gain</td>
</tr>
<tr>
<td>6</td>
<td>Each distortion channel will have independent volume, distortion level, and tone controls</td>
<td>Pass</td>
<td>Low</td>
<td>Low</td>
<td>I, S</td>
<td>Both channels provide independent gain, volume, and tone controls</td>
</tr>
<tr>
<td>7</td>
<td>Noise gate will attenuate all signal levels above adjustable threshold</td>
<td>Fail</td>
<td>Medium</td>
<td>Low</td>
<td>T, A</td>
<td>Noise gate does not provide adjustable threshold control. Rather, the one potentiometer control how much of the signal</td>
</tr>
<tr>
<td></td>
<td>Must be true bypass</td>
<td>Pass</td>
<td>Low</td>
<td>High</td>
<td>T, I</td>
<td>is gated</td>
</tr>
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</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of 3PDT switches ensures true bypass</td>
</tr>
</tbody>
</table>

**Figure 29:** Specification Test Results
Conclusion and Future Work

In its current state, the Dual Peaks distortion pedal requires more work. Currently, the decibel gain of neither channel reaches the requirement goal of 20dB increase. This could be due to the lack of amplifier stages in each channel. I initially attempted to provide the Bishop channel with a volume/tone stage similar in design to the Madonna channel. However, the clipped output signal did not respond to this second amplifier stage. I tried to connect the output of the Bishop channel tone stage to the input of the Madonna channel (a stage I verified was working properly), and the same behavior persisted. This unusual behavior will be investigated in future iterations.

A custom enclosure and a PCB printout would have also been an improvement on the overall project, as it would’ve achieved my goal of a usable guitar pedal. The silver lining to this result is the ability to improve upon the current design by both fine tuning the distortion channels and noise gate circuit.

Furthermore, the toggle feature would be interesting to implement in a later design. With implementing the toggle feature, the 3PDT switches would be unusable, and thus the pedal would not be true bypass without having to pass through the microcontroller. This could possibly result in latency issues with the tonal characteristics of the guitar signal. As it stands, the current design offers the player to toggle the channels fairly easily, as well as run them at the same time.

The noise gate also requires more adjusting and further development. As it stands, the noise gate attenuates too much of the signal (as apparent by the -20dB gain). While the current common collector-common emitter amplifier suffices for proof of concept, it seems a usable noise gate requires a more sophisticated design. I would like to improve my understanding of envelope filtering before attempting to design another noise gate circuit.

Regarding lack of voltage gain in the amplifiers, this is not a purely negative factor. The op-amp signals are still fully distorting the guitar signal, and each provide a unique guitar distortion that fulfill the distortion goals set out at the beginning of the project. Also, most guitar players aren’t relying on the main signal boost from. Therefore, so long as distortion occurs, a somewhat small dB gain is not a terrible flaw. This pedal in its current state is not as professionally designed as current pedals in the market. However, it serves as a solid foundation for a professional quality to be built upon.
References


Appendix A Analysis of Senior Project Design

1. **Summary of Functional Requirements**
   The Dual Peaks analog distortion pedal is a two-channel analog used to distort the input guitar signal and provide more aggressive guitar tonal characteristics. Utilizing low-power op-amp design, the Dual Peaks distortion pedal is able to offer more tonal options to the player than a traditional single-channel distortion pedal. Using an easy and intuitive knob and switch interface, the guitar player is able to dial in their preferred distortion settings, as well as clean up the signal with the built-in noise gate circuit. Furthermore, the player is able to use the publicly available schematic to update the distortion channel designs to create a distortion pedal that is truly their own.

2. **Primary Constraints**
   First and foremost, the Dual Peaks distortion pedal must be compatible with any ¼ inch standard guitar cable. Second, the Dual Peaks must fit the power constraint of a 9V DC power supply, and must provide the option to be powered by either a standard 2.1mm DC power input or a 9V battery. The Dual Peaks distortion pedal must not exceed a 5 inch by 3 inch enclosure size so as to minimize overall footprint. Please refer to the Requirements/Specifications section for a full list of project requirements.

3. **Economic**
   Current cost of building the Dual Peaks distortion pedal implausible to estimate, as PCB printout and enclosure machining costs have not been fully planned. This pedal is not intended to be manufactured on a commercial basis.

4. **Environmental**
   While it does not pose any immediately dangerous environmental threats, the Dual Peaks requires the expense of various materials such as silicon, copper, and metals to produce the various components that build the device. However, due to its relatively small amount of components this environmental impact is fairly small. There is a risk of the pedal becoming bio-waste, as the components are not biodegradable, but the Dual Peaks distortion pedal will be marketed as a device that must be properly recycled.

5. **Manufacturability**
   In its current form, the Dual Peaks pedal must be manufactured and soldered by hand. While the components can be soldered through the use of a solder bath, they must be placed and configured by hand. This not only diminishes manufacturing speed and rate, but also increases production cost through manual labor. Furthermore, there is an implication when beginning this project that the user understands and is knowledgeable about basic soldering techniques for through-hole mount devices. Also, the pedal is built using a custom-built enclosure that must be machined properly and professional. This will most likely incur more manufacturing costs, as a third-party manufacturer will most likely need to be used.
6. **Sustainability**
   The Dual Peaks design somewhat limits the ability to update the current design. While the various component values and materials can be updated and altered to fit the user’s needs, the design of a dual channel, dual switch, seven knob interface cannot be altered. If the user wishes to alter this design, they must alter the actual PCB layout and remanufacture. The Dual Peaks design is intended to allow the user to alter the design to what they deem sounds “good”, regardless of technical ability; by enforcing a constraint of PCB design software knowledge, this diminishes the usability and sustainability of the Dual Peaks pedal.

7. **Ethical**
   The Dual Peaks aims to adhere to the IEEE Code of Ethics[20]. The Dual Peaks distortion pedal was developed using only ethical and sustainable practices, and uses minimal amounts of resources to achieve the design goals. Any safety hazards directly correlated with the project stem from safe soldering habits as well as understanding of proper use of power and measurement equipment.

   There are no conflicts of interest regarding any third parties. The project was intended to combine a love for music and extensive technical education over the past four years. The ultimate goals of this project are to broaden my understanding of designing AC amplifier circuits for the application of guitar equipment, and to provide Cal Poly’s Audio Engineering Society with a kit to engage club members. All profits gained from that kit are put directly back into club funds to further financially support the education of Cal Poly students in the realm of audio engineering.

   I did not accept any forms of bribery during the course of this project. Any technical claims made by the requirements specification were either proven true with test data, or disclaimed as false. The Dual Peaks distortion pedal in every demo received honest feedback and critique from colleagues, whether they were faculty or fellow students. Any constructive criticism regarding design was accommodated and utilized to further improve the design. The Dual Peaks distortion pedal design does not exclude or discriminate against persons of any sex, gender, race, ethnicity, and nationality. As previously mentioned, the Dual Peaks distortion pedal design does not cause harmful environmental effects; however improper use or disposal can lead to negative environmental impacts and thus do justify concern. Lastly, the Dual Peaks distortion pedal seeks to apply AC amplifier design to the dynamic world of guitar playing and music.

8. **Health and Safety**
   The main primary health and safety concerns with the Dual Peaks distortion pedal are power and hearing safety. Regarding power, the user should not power the Dual Peaks with any power cables, outlets, or batteries that are damaged or are exhibiting faulty behavior. A lack of awareness regarding faulty powering equipment could result in damage to the Dual Peaks or any other device, whether it be pedal, guitar, or amplifier, in the signal chain. Also, the Dual Peaks boosts and distorts the guitar signal to a higher volume than the input signal. If under any circumstance the user becomes uncomfortable with the volume level of the guitar amplifier, they should lower the output level of the Dual Peaks, guitar, or amplifier. If any discomfort persists, they should cease playing guitar for the temporary future.
9. Social and Political
The project creator (myself) is the sole benefactor of this project in the immediate future. A successful project will result in a good grade in CPE 461 and 462. Furthermore, this design can be profited on by anyone willing to pay for the components and effort that goes into producing a unit. In the long term, Cal Poly’s Audio Engineering Society will also become a financial and social benefactor as well. This design is intended to be handed off to current members following my graduation, and can be used as a DIY kit for club members. The motive for this kit is to not only provide the club with more funds and the members with an engaging project, but also to attract outside students to the club with the promise of a tangible product from an educational experience in audio engineering.

While the goal of this project is to improve upon current design shortcomings, the Dual Peaks distortion pedal and its creator (myself) does not intend on undermining any current pedal manufacturer or design. My design is not “better” than any other distortion pedal out on the market currently, and it’s ultimately the consumer’s needs and desires that will result in the purchase of a Dual Peaks distortion pedal.

10. Development
I learned many technical and professional skills as a result of this project. Technically, I gained more experience in small-signal amplifier design in the context of electrical engineering. I also gained more experience with rapid prototyping and breadboard modelling with analog components. Furthermore, I gained more experience troubleshooting hardware designs and fine-tuning amplifier designs to best suit the project goals. Professionally, I gained first-hand experience with meeting the deadlines set by my project advisor Dr. Benson, as well as writing technical documentation through this report. This project required not only extensive research as to the basic designs of an analog distortion signal, but also extensive surveying of online forums and on-campus music-related clubs as to fit customer needs. Lastly, this project forced me to update and reconcile my project with design choices and considerations during development, thus strengthen my adaptability as an engineer.
Appendix B: Hardware Schematics

Figure 30: Audio In / 9VDC Power Supply / Biasing Voltage Divider

Figure 31: Madonna Channel Schematic

Figure 32: Bishop Channel Schematic
Figure 33: “Noise Gate” Attenuation Circuit / Audio Out