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Digital effects unit for an electric guitar

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Resümee/Abstract

Digitaalne efektiplokk elektrikitarrile

Selle bakalaureuseöö eesmärgiks oli luua efektiplokk elektrikitarrile. Erinemaks tavapäraselt kättesaadavatest efektiplokkidest, oli selle töö raames loodud seade mõeldud kitarri sisse paigaldamiseks. Seade oli loodud digitaalseks signaalitöötluseks, selleks et pakkuda lihtsat võimalust erinevate heliefektide lisamiseks. Esialgse prototüübina sai seade disainitud nii, et sellega saaks luua ülevõimenduse (*ingl distortion*) efekti. Antud bakalaureusetöö sisu hõlmab loodud seadme disaini ja selle paigaldust kitarri sisse, teisi sarnaseid lahendusi antud projektiga ning teoreetilist tausta ülevõimenduse efekti kohta.

CERCS: T120 Susteemitehnoloogia, arvutitehnoloogia; T171 Mikroelektroonika;

Märksõnad: manussüsteem, signaalitöötlus, heliefektid

Digital effects unit for an electric guitar

The aim of this thesis was to create an effects unit for an electric guitar. In contrast to many mainstream formats of effects units, the intention for this device was to be installed inside of a guitar. It was designed for digitally processing sound for the possibility to easily change the effects it can create. As a prototype it was initially created to be able to produce the distortion sound effect. The content of this thesis will cover the design of the device and it's installation inside of a guitar, other similar solutions to this project, and the theory behind the distortion effect.

CERCS: T120 Systems engineering, computer technology; T171 Microelectronics;

Keywords: embedded system, signal processing, sound effects

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List of abbreviations, constants etc.

MCU - microcontroller unit

ADC - analog-to-digital converter

DAC - digital-to-analog converter

LDO - low-dropout regulator

SPI - Serial Peripheral Interface

PCB - printed circuit board

PGA - programmable-gain amplifier

PLL - phase-locked loop

I2C - Inter-Integrated Circuit

AGC - automatic gain control

PSU - power supply unit

1 Introduction

It is common for guitarists to use a wide variety of different sound effects when playing on stage or recording in a studio in order to personalize their sound and make it come forth. For that purpose, effects units are used. Effects units are electronic devices which take the input signal from an instrument - in the context of this thesis, an electric guitar - and output a modified signal according to the effect or effects they are intended to create.

One of the most common and available format for an effects unit is a stompbox. A typical stompbox consists of control knobs for the effect and a footswitch to turn the unit on or off. Stompboxes are often connected in series to apply multiple effects and are typically carried around in a case to hold the used units [1].

The topic for this thesis came from the idea to create an effects unit of a different format which could be used instead of such a typical solution. The aim was to create a reprogrammable digital effects unit which could be placed inside of an electric guitar with little modification to the guitar itself. Such an effects unit could reduce the need for a new unit when a new effect is desired, offering reduced cost and increased utility in terms of carrying around a case full of effects pedals.

The concept of an electric guitar with onboard effects is not something new. Several guitars have been designed with built-in effects [2]. Using such a pre-built guitar could be costly and might not offer the possibility to add new effects or customize them.

Although there are some manufacturers who have made compact effects circuitry with the purpose of installing them inside of a guitar, they are mostly analog and would require switching out when adding different effects.

1.1 Thesis goals

The goal of this thesis is to create a prototype of a reprogrammable digital effects unit which will be placed inside of an electric guitar. The aim is to provide some utility when compared to the standard use of stompboxes and pedalboards. Reprogrammability of a digital device will offer the ability to create effects by writing new software instead of buying new effects units. The initial prototype should provide the capability to implement a distortion effect.

The overall goal could be divided into three main parts:

1. Designing the electronics of the circuitboard.
2. Programming the hardware.

3. Modifying a guitar for the unit's installation.

The created device should have compact dimensions for easier installation inside of a guitar. Power consumption should be kept low for prolonged use without changing the power supply. In the presence of digital signals, care should be taken to keep the analog signals noise free.

1.2 Thesis structure

Content of this thesis is divided into three main chapters. Chapter two will focus on effects units in general and how the project for this thesis contrasts with mainstream solutions. Chapter three will give an overview of the effect the created device is intended for. It will cover the concept of a distorted signal and how properties of such a signal create the audible effect. Chapter four will cover the design and configuration of the effects unit created for this thesis. It will also show the installation of the unit inside of an electric guitar.

2 Overview of existing solutions

There are various formats of effects units. They may come as stand-alone stompboxes, relatively small in size and created for a single effect; built-in effects in amplifiers or instruments; larger units intended for mounting on racks or used as tabletop units, incorporating a wide range of effects [1]. Figure **2.1** shows some forms of effects units.

Figure 2.1: A stompbox (top left), rackmounted units (top right), guitar with built-in effects (bottom)

A relatively simple to use and widely available option for a hobbyist guitarist for creating sound effects is the use of stompboxes. This chapter will describe this mainstream solution and what the created device for this thesis might offer in comparison. Additionally, some solutions that resemble this project are introduced.

2.1 Stompboxes

A stompbox can be described as an effects pedal with some manual controls for the effect and an on-off switch operated by the users feet. The complexity and the effects created by a stompbox, aswell as the controls for the effects, will vary depending on the exact unit. Stompboxes are often connected in series for the application of multiple effects. When using multiple pedals, they are commonly carried around in a pedalboard, which is placed on the ground in front of the player. [1]. An example of a chain of stompboxes is illustrated by figure **2.2**.

Figure 2.2: Example of an effects chain of stompboxes

The format of the effects unit created for this thesis aims to be an alternate approach to this. When a digital effects unit can be reprogrammed for the effects applied, it can reduce the need for additional effects units. Small size of the unit and the installment inside a guitar offers utility when a big pedalboard is no longer needed to be carried around. Additionally, when incorporated inside a guitar, the controls of the effects are by the player's hand, rather than at their feet. This would allow, for example, to turn up the gain of a distortion effect without crouching over the pedalboard.

2.2 Produced guitars with onboard effects

Guitars with onboard effects have remained a niche product in the mainstream guitar community, although having been around for a while. Still, some guitar manufacturers, Ibanez and Gibson among them, have designed just such guitar models. This section will mention three of such guitars. They can be seen on figure **2.3**.

Figure 2.3: From left to right: Ibanez RGKP6, Gibson Firebird X, BilT Guitars Relevator

2.2.1 Ibanez RGKP6

Ibanez RGKP6 [3] is a guitar whose signal can be routed through a digital effects processor. It has a dock where a Mini Kaoss Pad S2 can be attached.

Mini Kaoss Pad S2 (MKPS2) [4] is a digital effects processor manufactured by Korg originally intented to be used by DJs. It has a selection of 100 effects which can be adjusted with a touchpad. The effects programs are divided into the following categories: filter, modulation, low-frequency oscillation (LFO), delay, reverb, looper, vocoder, synthesizer. The downside to MKPS2 might be that since it is designed for DJs, not all sounds might be applicable to a guitar.

In addition to the digital effects processor, Ibanez RGKP6 incorporates a distortion circuit (which can be bypassed) with tone and gain controls.

2.2.2 Gibson Firebird X

Gibson Firebird X [5] comes with multiple onboard digital effects. Some included ones for example are distortion, reverb, delay, chorus, tremolo. In addition, the guitar enables the user to fine-tune the effects and save them as presets.

There are 55 factory effect presets. There are two modes to select from - play mode and edit mode. In play mode the user can select a factory preset to use while playing. The amount of distortion and reverb can be adjusted with potentiometers. In edit mode the presets can be fine-tuned by the user with onboard switches, sliders, and potentiometers and then saved for later use. The guitar can also be interfaced with a computer for better editing of the effects.

2.2.3 BiLT Guitars Relevator

BiLT Guitars Relevator [6] has analogue circuitry for two onboard effects: distortion and delay. Each of those effects have controls to adjust the effect in addition to the on and off switches.

The delay circuit offers three potentiometers to control delay, mix and feedback of the effect. There is a button to turn on modulation, which adds a pitch shift to the repeated signal. The speed and width of the pitch shift can also be adjusted.

The distortion circuit has fewer controls. It has a potentiometer to adjust the gain of the effect. There is also an ”oscillate” switch, which adds unpredictable noise to the signal when turned on.

2.3 Compact effects circuits

There are some manufacturers who have created small-sized effects units. They are designed to be installed inside of a guitar so a user could customize their instrument with onboard effects. For example, Lee Jackson has a range of such effects modules, including compressor and distortion effects [7]. Some more solutions can be found from online stores like TNT Custom Guitars [8]. Such units are typically analog and don’t offer easy reconfigurabilty other than control knobs or buttons for the effect. This would mean buying and installing new units for additional effects.

3 Distortion effect

A device created for this thesis offers the capability of implementing a distortion effect. Distortion happens naturally (in the analog domain) when a system tries to amplify an input signal beyond it's physical limits, effectively clipping the signal at the limits. The general effect of clipping a signal is the addition of a wide range of new frequencies. [12]. This chapter will cover some main concepts of a distorted signal and their impact on the frequency content. To illustrate the effect, a recorded guitar note will be distorted by applying a clipping function. The audible aspect associated with the harmonic content of a distorted sound is briefly described later in the chapter.

3.1 Signal clipping

Two different types of clipping are usually distinguished in distortion devices - hard clipping and soft clipping. Hard clipping happens when the amplitude of a signal is abruptly cut off at the distortion threshold. Soft clipping leaves the peaks of the output signal smoother. Both types of clipping add odd-order harmonics to the original signal, but hard clipping tends to add stronger higher order harmonics. [12]. Figures **3.1** and **3.2** show examples of hard clipping and soft clipping respectively in the case of a simple sine wave input. The middle graphs show the transfer characteristics of the clipping methods.

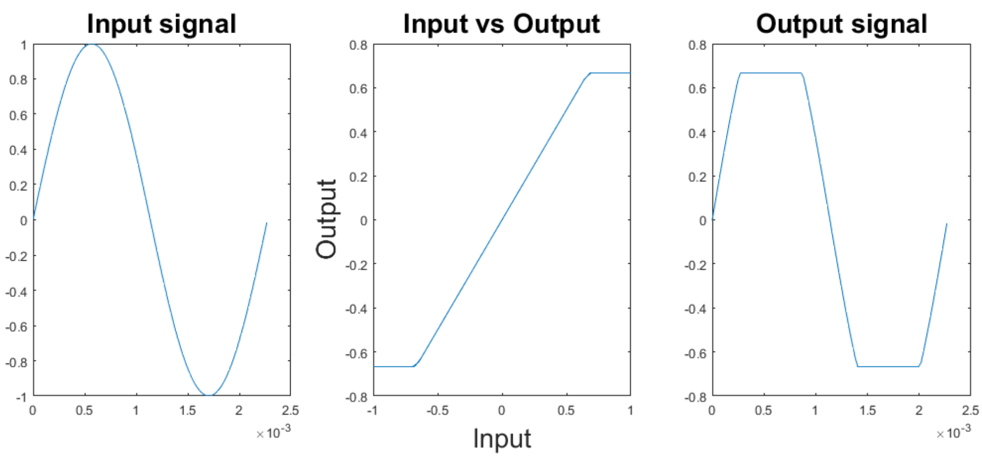

Figure 3.1: Hard clipping

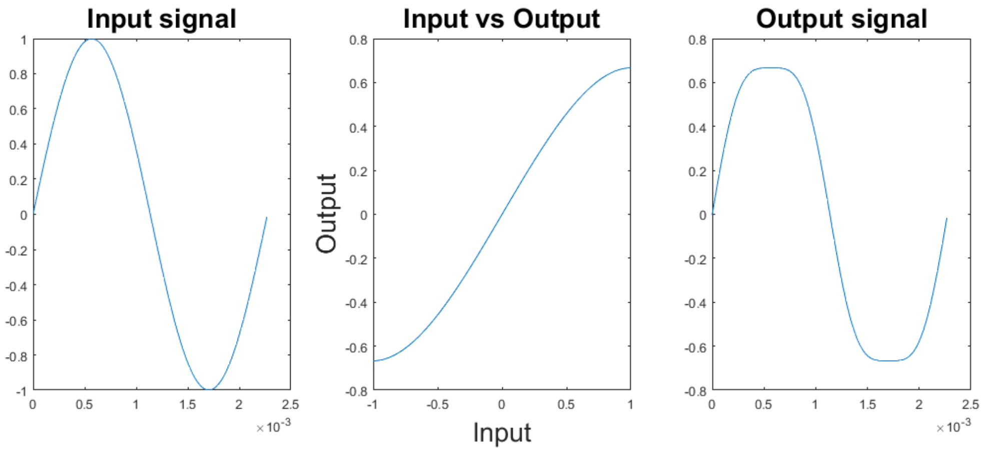

Figure 3.2: Soft clipping

3.2 Asymmetric distortion

The transfer characteristics of hard and soft clipping are symmetrical. If there is asymmetry in the transfer characteristic, even-order harmonics will be added to the original signal [12]. Figure **3.3** shows an example of asymmetric distortion.

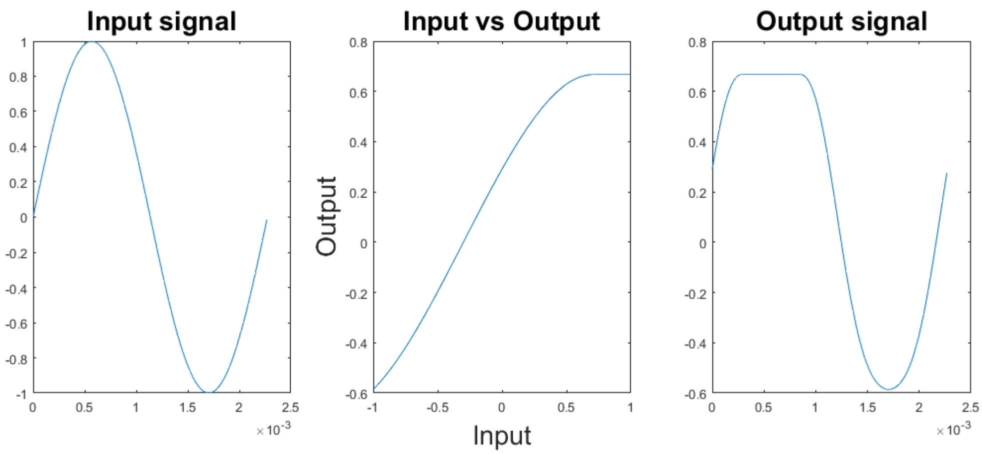

Figure 3.3: Asymmetric distortion

3.3 Intermodulation distortion

When the input signal contains more frequency components than just the principle frequency (as is the case with a note played by a guitar), more frequencies are generated by distorting the signal than just the even and odd harmonics of each initial frequency. Sum and difference frequencies of the original components will be introduced. For example, if frequencies f_1 and f_2 are present in the input signal, then the output would have frequencies at $f_1 + f_2$ and $f_1 - f_2$.

Depending on the specific distortion device, sum and difference frequencies of the harmonics might also be present in the output signal, such as $2f_1$ - f_2, $3f_2$ - $2f_1$, etc [12].

3.4 Distorted guitar note

In order to illustrate a realistic frequency content of a distorted signal, a recorded guitar note was distorted by applying a clipping function on it using MATLAB. In the normalized form, the following equation **3.1** shows the function used for this distortion simulation.

$$f(x) = \begin{cases} \frac{-2}{3}, & \text{if } x \leq -1 \\ x - \frac{x^3}{3}, & \text{if } -1 \leq x \leq 1 \\ \frac{2}{3}, & \text{if } x \geq 1 \end{cases} \tag{3.1}$$

Gain can be added to the input signal to increase the amount of distortion. [13]. Equation **3.2** shows the final distortion function, where y(n) is the output sample, f is the clipping function, g is gain applied to the input sample, and x(n) is the input sample.

$$y(n) = f[gx(n)] \tag{3.2}$$

To show how frequencies are added when the input signal nears the clipping limits, this function was applied at two gain levels: 20 - distortion resembles asymmetric soft clipping; 100 - distortion resembles asymmetric hard clipping. Also the original signal without distortion is displayed. The modified signal is a recorded A440 note (fundamental frequency of 440Hz) played by an electric guitar with a duration of four seconds.

Figure **3.5** depicts the original signal. It can be seen that the ”clean” note of a guitar already contains multiple harmonics of the fundamental frequency. The transfer characteristics of the distortions (shown on figure **3.4**) are asymmetric due to the presence of even-order harmonics in the original signal. Figures **3.6** and **3.7** display the distorted signal at a gain of 20 and 100, respectively. They represent how increasing gain and thus clipping the signal transfers energy over to higher harmonics of the signal, changing the balance of the frequency content. The sharper the clipping, the more energy is transferred to higher harmonics. The effect of intermodulation distortion can be seen, as frequencies between the harmonics are introduced. It can also be noticed how the increase in gain adds sustain to the effect, as the power of the higher harmonics decays over a longer period of time.

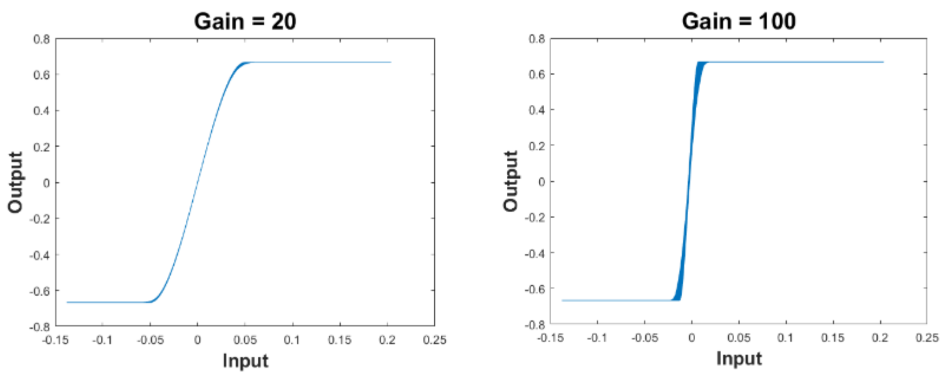

Figure 3.4: Transfer characteristics of the distortion function at different gain levels

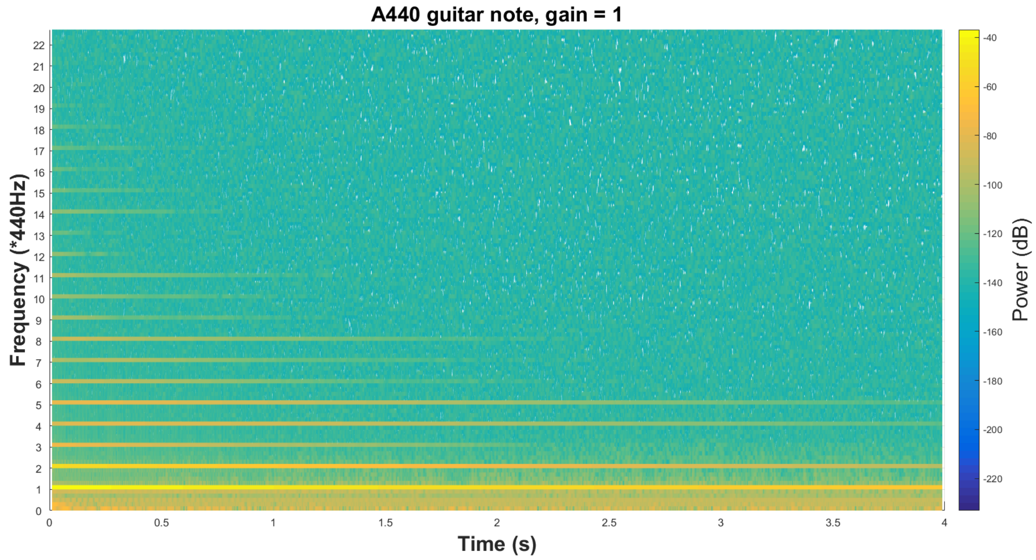

Figure 3.5: Undistorted A440

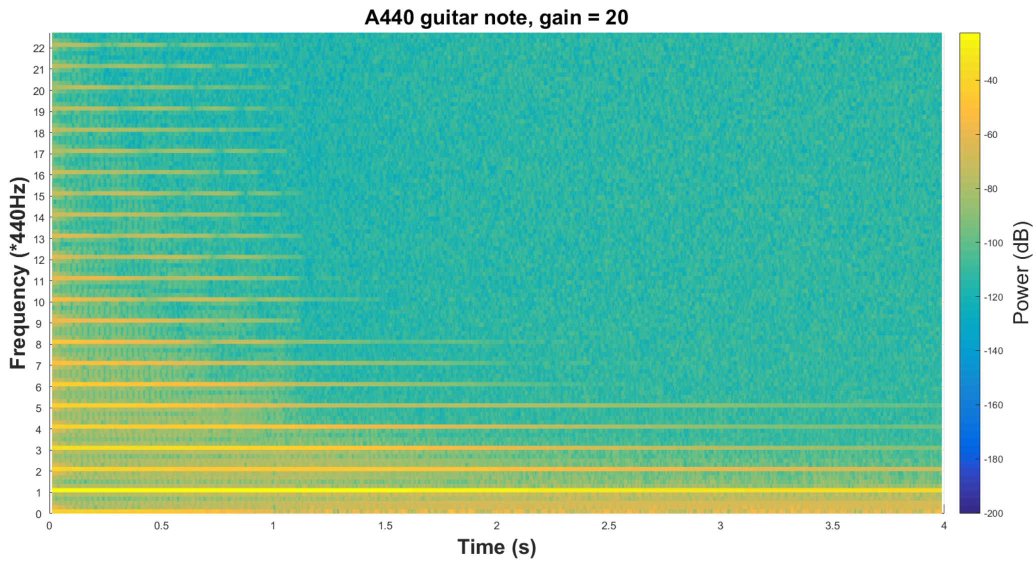

Figure 3.6: Distorted A440, gain = 20

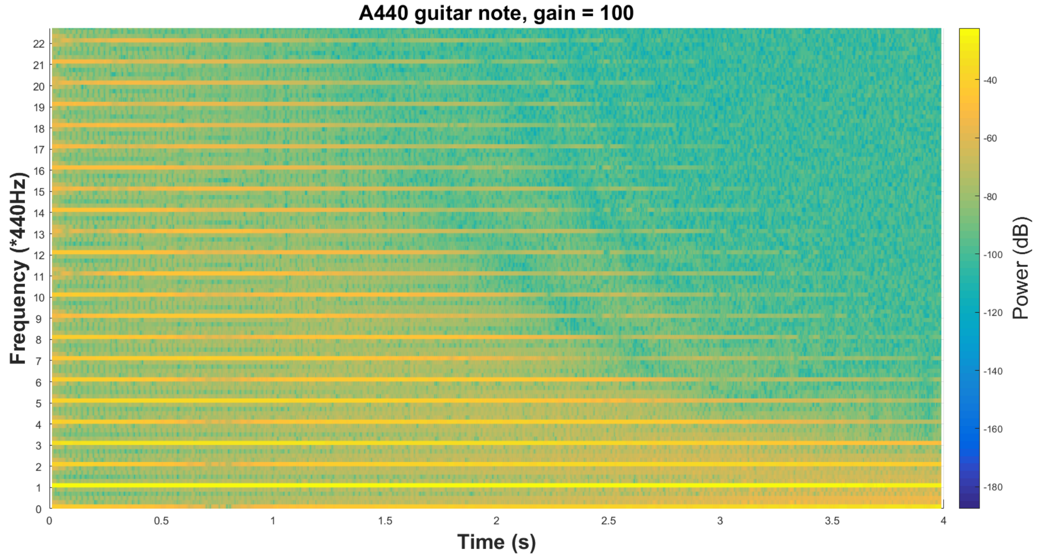

Figure 3.7: Distorted A440, gain = 100

3.5 Distortion's perceptual effect

Due to having a wide frequency content, distortion is a harmonic sound. Timbre is the aspect that is mostly changed by the balance of odd and even harmonics present in a distorted signal. Although timbre is a quality that is difficult to describe precisely, one way of verbalizing it is in terms of roughness of the sound [14].

A distorted tone is often described as ”fuzzy”, ”growling” or ”gritty” [16]. The harshness of the sound can be associated with the way the frequencies create musical intervals and how many of the harmonics are out of tune with the actual notes of a western chromatic scale (especially the 7th, 11th and 13th harmonic) [17]. The exact theory behind musical intervals and the psychoacoustic phenomena associated with their perception is a more complicated subject and will not be discussed in this thesis.

4 Created effects unit

This chapter will describe the device created for this thesis. Main parts of the electronics design will be discussed, as well as the software configuration for creating the distortion effect. It will be shown how the unit can be installed inside of a guitar and the modifications done to a guitar for that purpose. A possible option for future developments of the device is also briefly discussed.

4.1 Digital vs. analogue

The signal processing for creating a sound effect can be done using either analogue or digital processing techniques. The device for this thesis is created for digital processing. The main consideration for this choice is the simple reconfigurability of a digital system for the addition or modification of sound effects. In addition, choosing digital over analogue does not really limit the effects that can be created and often simplifies the design process [9].

4.2 General hardware description

Figure **4.1** shows a simplified block diagram of the created circuitry for the effects unit. Keep-

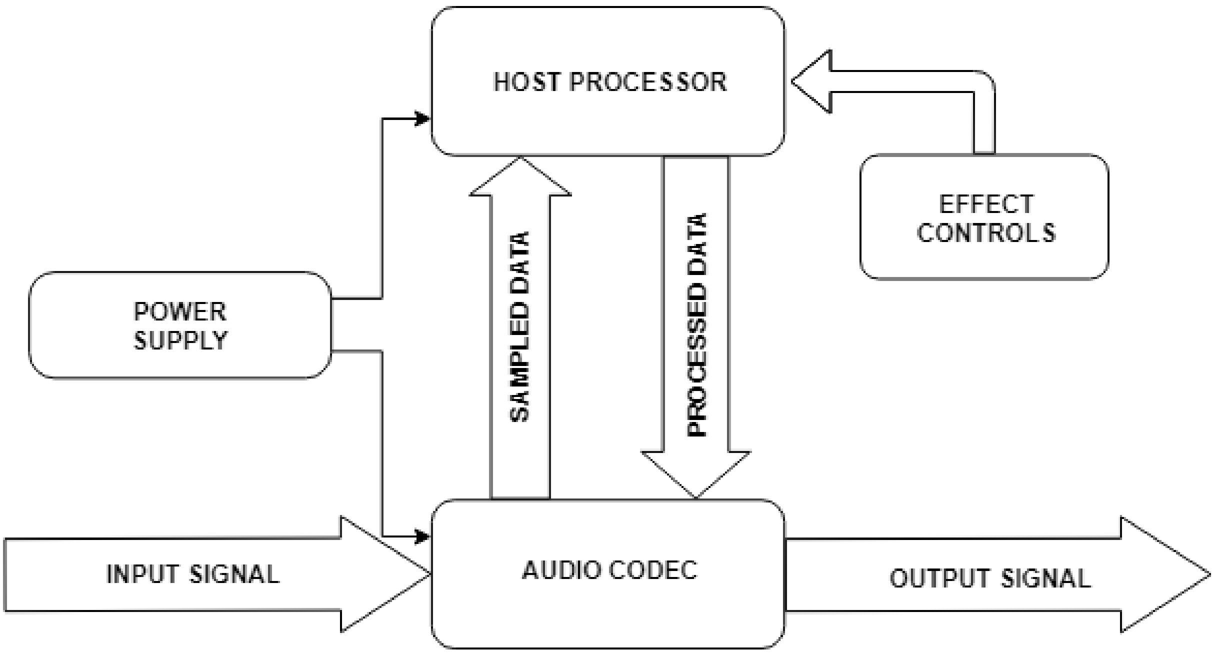

Figure 4.1: Block diagram of the effects unit

ing the hardware design simple helps to keep the board dimensions small. The circuitry has two main components: the audio codec and the host processor (MCU). Additionally, there are analog controls which can be used to modify the effect in real time.

The audio codec is used for digitizing the input signal for the MCU and creating an analog output signal from processed samples. It's audio interface can be used for streaming data sampled by it's analog-to-digital converter (ADC) to the MCU. The codec's digital-to-analog converter (DAC) can receive a stream of processed data from the MCU over the same interface. In addition to processing streamed data for creating effects, the MCU is used for programming the codec.

4.3 Input signal origin

The input signal for the system is produced by an electric guitar's electromagnetic pickup. The principle that makes the pickups work is electromagnetic induction. A typical single coil pickup consists of stationary magnets and a coil of wire wrapped around them. The purpose of the magnets is to magnetize ferromagnetic guitar strings. When the magnetized strings vibrate in the presence of the coil, alternating current is induced in the coil, which is the signal to be processed [10]. Figure **4.2** shows the main components of a magnetic pickup.

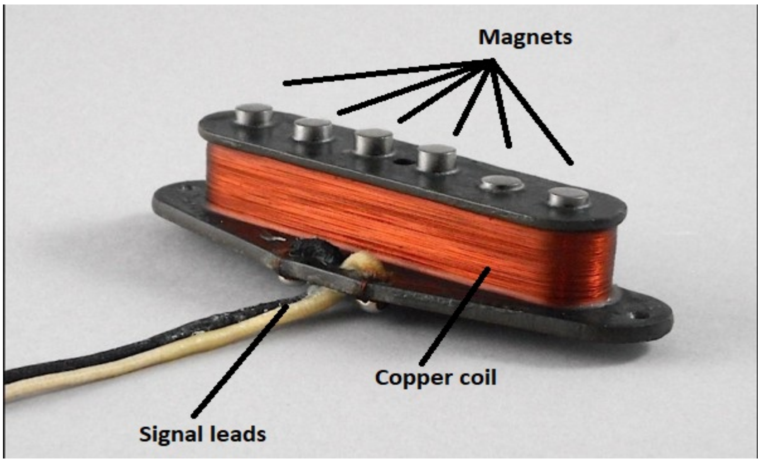

Figure 4.2: Single coil pickup

Due to the nature of vibrating strings, the signal contains multiple frequency components, with the principal frequency of the played note (for example, 440Hz in the case of A440 note) and it's harmonics [11].

4.4 Component selection

This section will bring out the main components used in the circuitry and the considerations for choosing them. Other more common components, such as voltage regulators, potentiometers and switches used on the device will not be mentioned here. A common reason for the selection of the components was that for the required features they provided, they had relatively low cost, low power consumption, and good availability. When considering the power supply (discussed in section **4.5**), a worst-case power consumption of 100mA was assumed and the combined consumption of the selected components should stay well below that threshold.

4.4.1 Audio codec

Audio codecs are components that are intended for encoding analog audio signals into digital signals and decoding digital signals back into analog signals. They include adequate ADCs and DACs required for that process and often provide a variety of additional features. Although most available audio codecs could have been used for the purpose of converting an audio signal between analog and digital domains, one was selected which provided just enough necessary features and had low cost compared to other codecs. The selected audio codec is TLV320AIC3109-Q1 by Texas Instruments. The information about this component is taken from it's datasheet [15].

It features one ADC and one DAC and single-ended line inputs and outputs. It has a full-duplex audio interface for streaming data to and from the MCU. The ADC and DAC are mono-channel, as opposed to stereo, which is not required since the input signal does not feature channel-side information. To help keep the hardware design simple, no external components are needed for amplifying the input signal to match the ADC's dynamic range. This is due to the integrated programmable-gain amplifier (PGA) of the codec. Additionally, no external anti-aliasing filter is required due to the oversampling nature of the ADC and integrated analog anti-aliasing and digital decimation filters.

4.4.2 MCU

The MCU for the created effects unit was chosen due to previous experience with the processor. The selected MCU is STM32F413RG by STMicroelectronics. The information about this component is taken from it's datasheet [18]. Prior to creating the effects unit, a development board (32F412GDISCOVERY) was used to determine whether this processor could be used for the intended purpose. The development board included an audio codec (although not the same one used for the created effects unit) and audio inputs and outputs which could be used to test the digital processing of an audio signal.

It was assumed that an operating frequency of 100MHz would be sufficient to create various digital sound effects in real time. Other reasons for the initial consideration of the MCU were the inclusion of a floating-point unit, audio interfaces for streaming data to and from an audio codec, and a separate audio phase-locked loop (PLL) for accurate clock generation for the audio interfaces. The familiarization with the processor using the development board included doing simple sample by sample processing (such as clipping the samples at some values) of data streamed from the codec. No comprehensive tests were run, but judging by empirical information, the MCU was able to create the expected results.

4.5 Main power supply

The device created for this thesis is portable by nature and thus a prolonged use without changing the supply is desired. Additionally, size of the power supply unit (PSU) is concerned, as the device is meant to be installed inside a guitar. In order to offer a good compromise between size and battery life, a 3xAA battery pack was chosen as the PSU.

When considering battery life, a worst-case scenario of 100mA power consumption was assumed. The input voltage is brought down for the components by a 3.3V LDO [19], whose dropout voltage at 100mA output current is stated as 50mV. As a reference, the battery life of a Duracell AA battery is shown on figure **4.3** [20]. If it is said that the LDO stops regulating

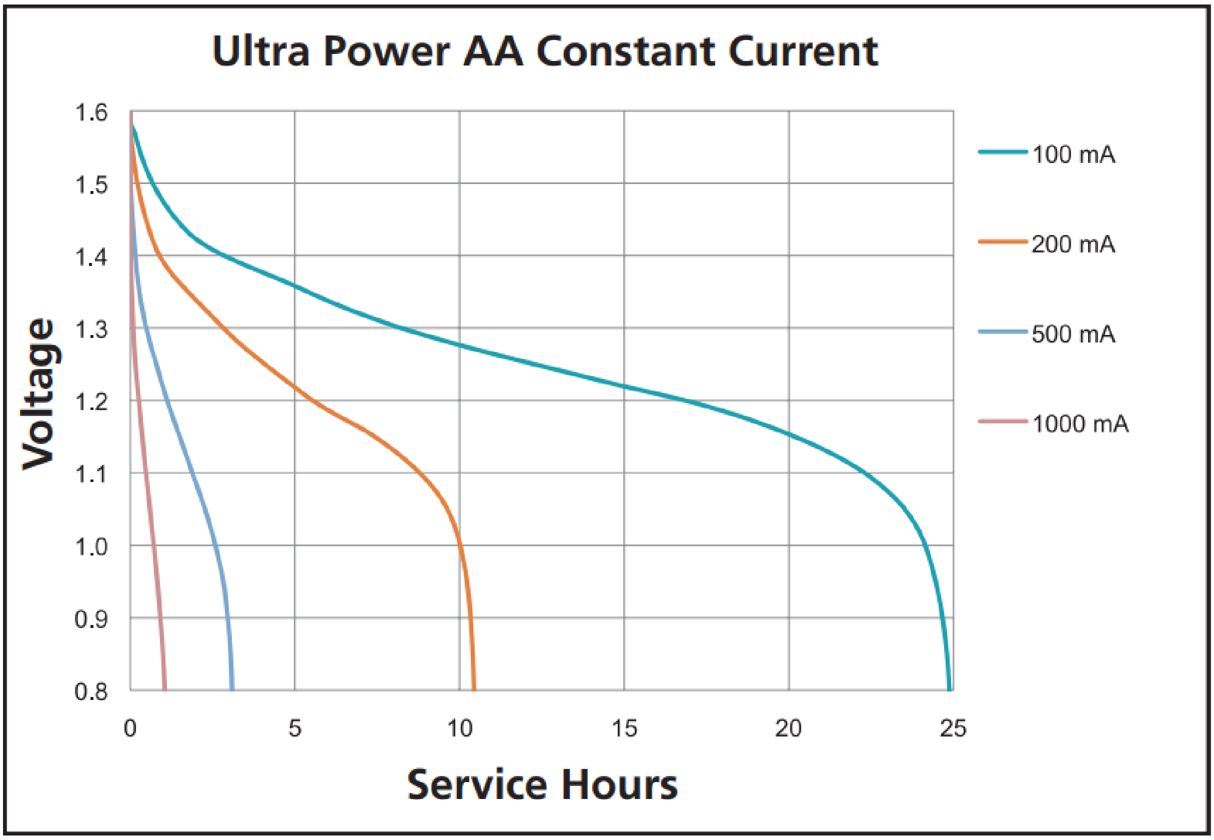

Figure 4.3: AA battery discharge rate at 100mA

at $3.3V + 50mV = 3.35V$ (roughly 1.1V per battery) and that is the point where the device stops working, then according to the 100mA discharge rate tests graph, the battery life would be approximately 22h, which is a sufficient result.

The downside of such a battery pack is it's dimensions. The used case in this project has dimensions of 4.7cm by 6.81cm by 7cm. This requires creating extra space inside the body of the guitar. Using a 9V battery was considered for reduced size, but it would have poor battery life [21].

4.6 Electronics design

The electronics for the circuitboard (PCB) were designed using Altium CircuitMaker. The full circuit schematics are provided in **Appendix 1**. The PCB itself has four layers and 5x5cm dimensions. Figure **4.4** shows the top side of the PCB with the components mounted on.

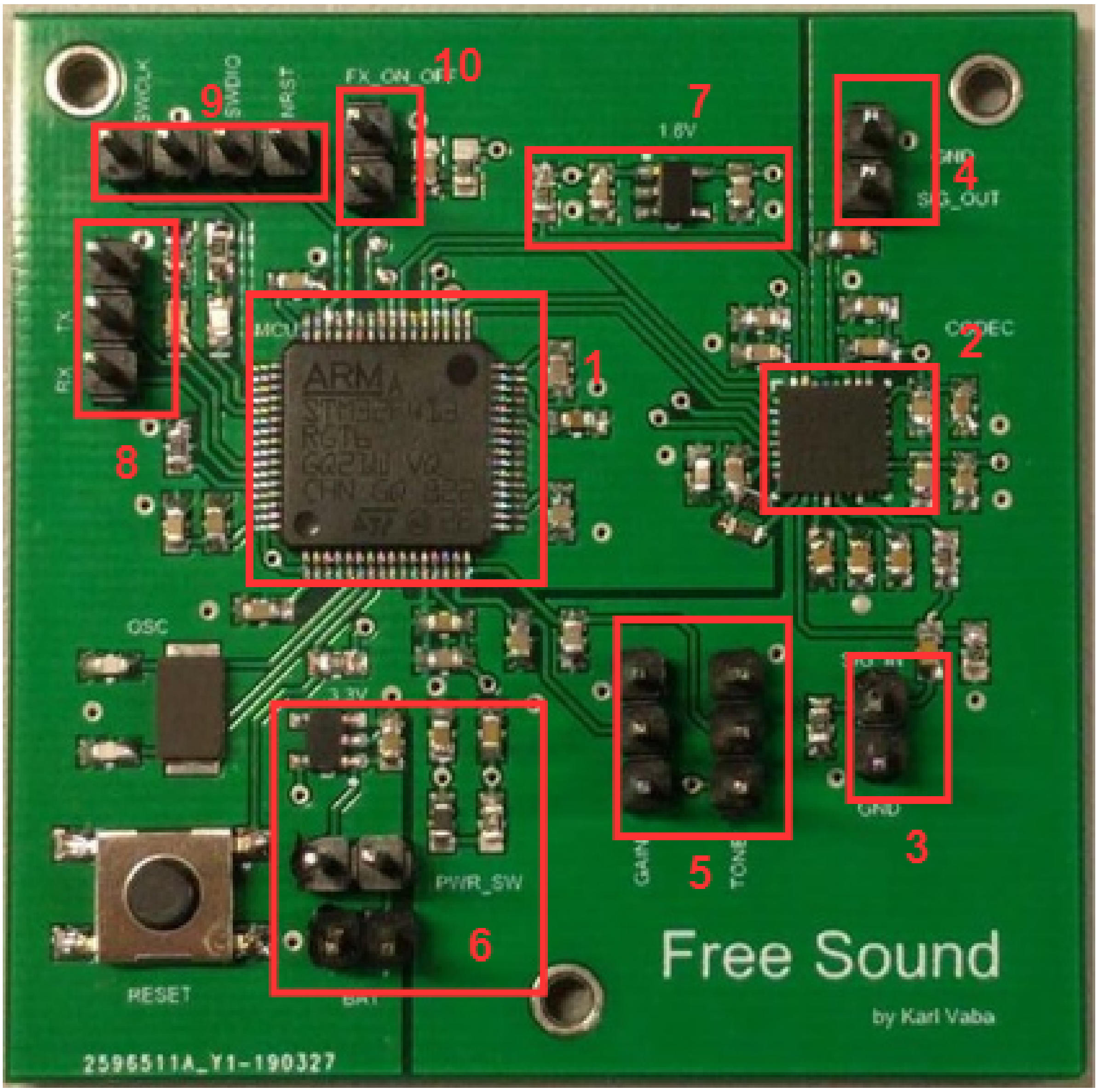

Figure 4.4: Top side of effects unit PCB

The number markings for the figure are as follows: 1) MCU; 2) Audio codec; 3) Input signal connector; 4) Output signal connector; 5) Connectors for gain and tone control potentiometers; 6) Battery connector and main 3.3V power; 7) 1.8V power; 8) UART pins for debugging; 9) SWD pins for MCU programming and debugging; 10) On-off switch for effects.

4.6.1 User controls

There are three user controls connectors on the PCB: gain and tone control and an effects on-off switch. The gain and tone controls are intended to be potentiometers used as voltage dividers, whose outputs are connected to ADC inputs of the MCU. The effects on-off switch is connected to a GPIO pin of the MCU. The purpose for this switch was when multiple effects are implemented by the device, then one of those could be turned on or off. For example, if the effects unit adds distortion and sustain to the signal, then the user could turn the distortion on or off. Future work relating to more versatile user controls is discussed in section **4.9**.

4.6.2 Digital and analog separation

In order to keep analog signals in a mixed-signal system clean, care was taken in designing the board to keep analog and digital parts of the circuitry separated. To reduce the interference of digital signals with analog signals in their return paths, the ground plane was split and analog and digital components were placed accordingly. Figure **4.5** illustrates this.

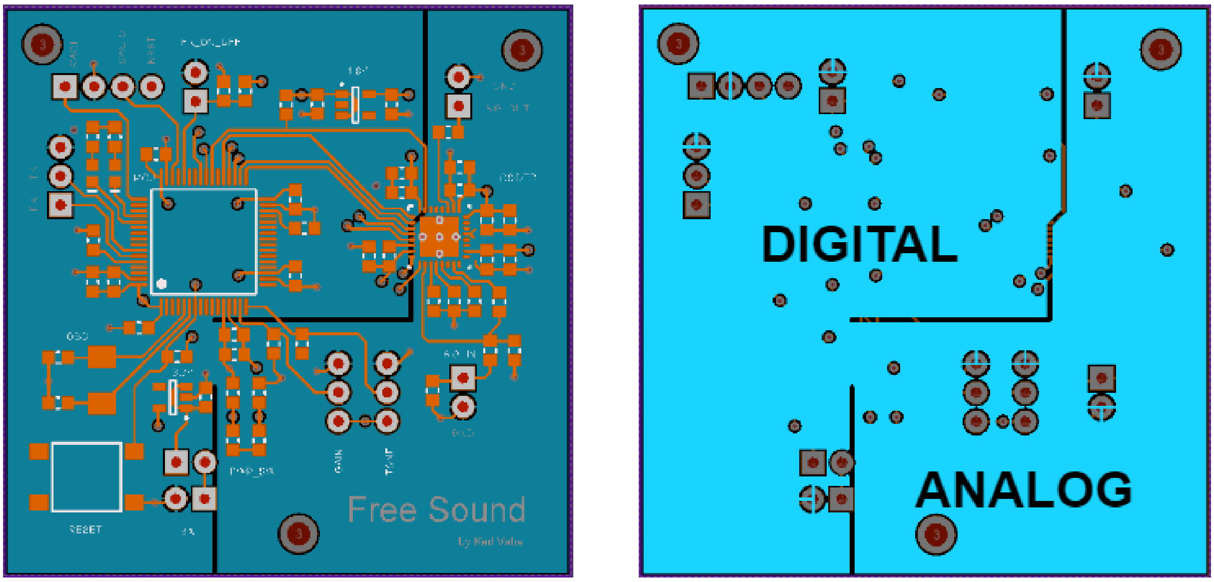

Figure 4.5: Component placement (left) over the ground layer (right)

The components using analog signals (signal connectors, codec's analog pins, gain and tone control) are placed on the right and lower section of the PCB over the analog ground sections. The rest of the signals run through the digital section of the ground plane (MCU, codec's pins). The ground planes connect near the power supply.

Additionally, the power supply for the analog components was separated by a filter in order to reduce high frequency noise generated by digital circuitry. This was mainly for allowing the PLLs of the MCU and codec to generate more stable clock signals. The circuit of the filter is shown in figure **4.6**. Figure **4.7** shows the magnitude response of the filter, as simulated by LTspice software.

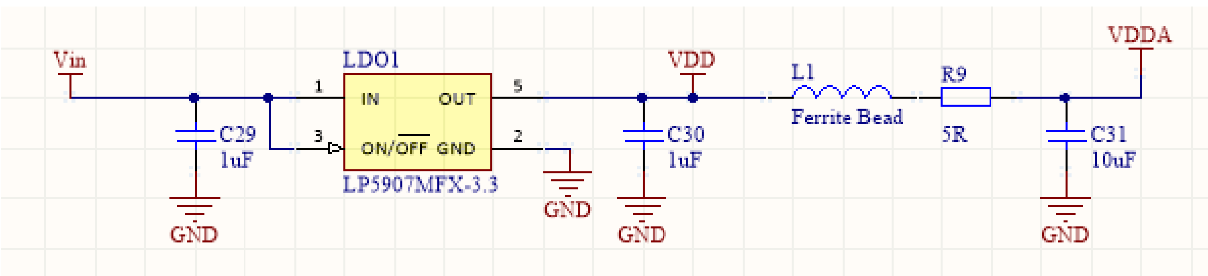

Figure 4.6: Filter separating 3.3V analog and digital power planes.

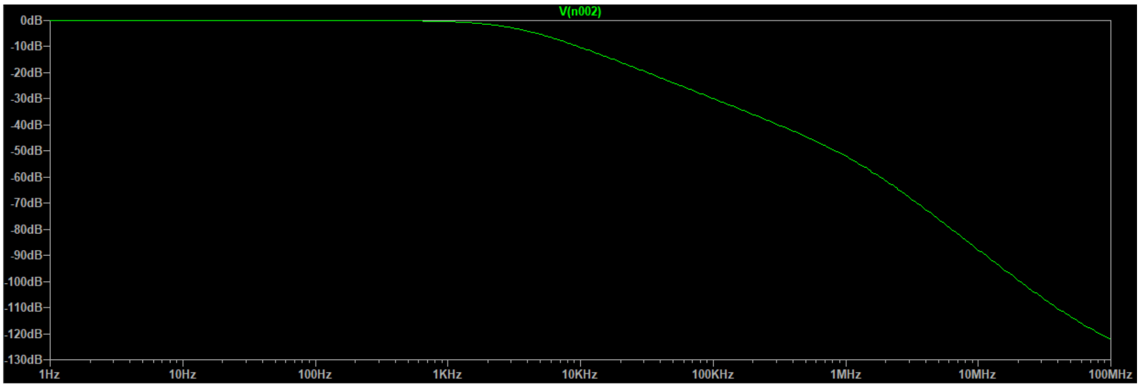

Figure 4.7: Magnitude response of the filter separating digital and analog power planes.

4.7 Functional configuration

The codec can be configured in a variety of ways by programming it over it's Inter-Integrated Circuit (I2C) control interface. Different features of the codec can be enabled or disabled and they include programmable paramateres relating to the feature (for example filter coefficients for digital filters). The input signal can be routed through the codec according to the features used. The signal path and features used for the created effects unit can be see on figure **4.8**.

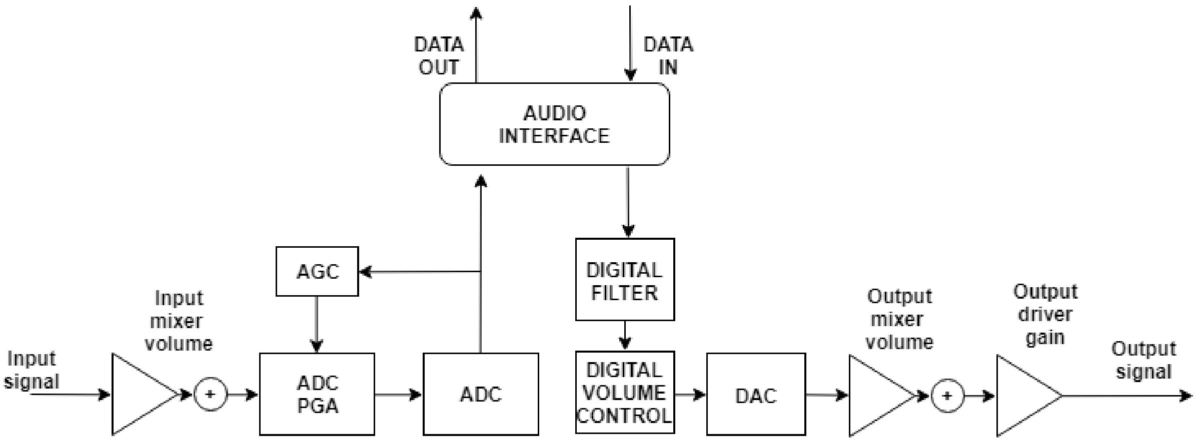

Figure 4.8: Configured signal path

Inputs and outputs of the codec include mixers and mixer volume controls for each signal line in case multiple signals are routed through the system. As there is only one signal present, both of the input and output mixer volumes for the used signal line was set to 0dB. The input signal is routed to the ADC through a programmable gain amplifier (PGA), whose gain is controlled by the automatic gain control (AGC) feature of the codec. The audio interface is used for streaming data to and from the MCU. Data received from the MCU are routed to the DAC through a digital filter, which was configured to reduce some of the high frequencies of the signal. The features used and the processing of the signal are further discussed in this section. Programming of the codec was done using an I2C (I2C3) interface of the MCU.

4.7.1 Sustain using AGC

In order to add sustain to the input signal, the AGC feature of the codec was enabled. Figure **4.9** (taken from the datasheet) shows the effect of AGC on the input signal.

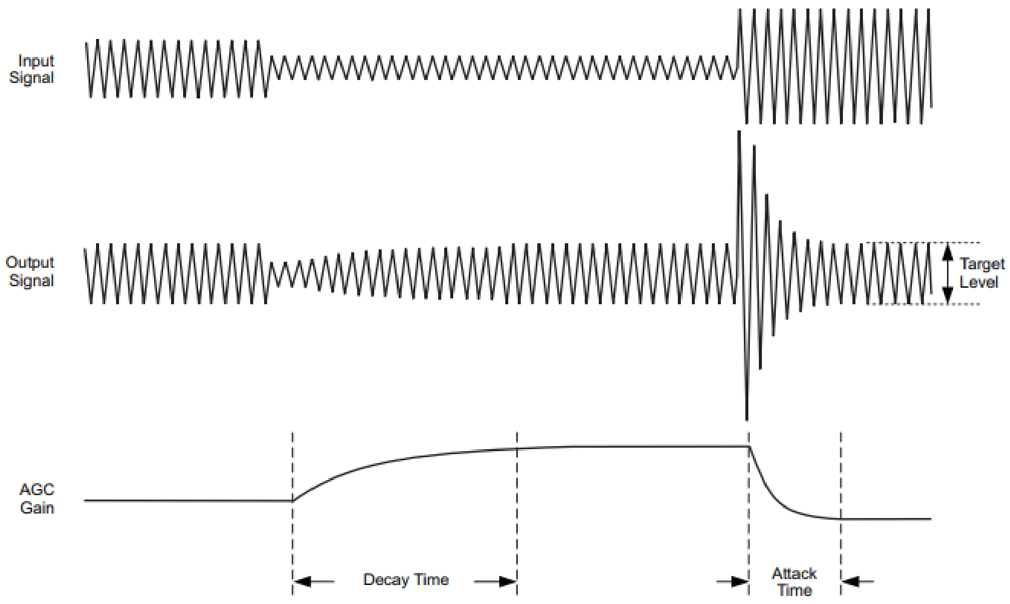

Figure 4.9: Automatic gain control

AGC tries to hold the signal at a set target level. It amplifies weaker and attenuates stronger signals. The main configurable parameters for AGC were target level, decay time, and attack time. The exact values of the parameters were modified according to the audible output signal. The decay and attack times (1600ms and 7ms, respectively) were set so there would not be any signal clipping by the AGC. As the decay time is rather long, the target level (-24dB of the full scale range) was set so the signal would not grow gradually too loud over this period of time.

4.7.2 Cutting high frequencies

To remove some audible noise from the output signal, the digital de-emphasis filter of the codec was enabled and configured as a low-pass filter. The filter's transfer function, seen on figure **4.1**, has three programmable coefficients, with the possible range of integer values being -32768 to 32767. The range of values allows the filter to be used for different responses, ranging from high-pass to low-pass filtering. To achieve a low-pass filter, the coefficients were set to N0 = -32767, N1 = 8850 and D1 = 19410. Figure **4.10** shows the magnitude response of the filter with these coefficients.

$$H(z) = \frac{N0 + N1 * z^-1}{32767 - D1 * z^-1} \tag{4.1}$$

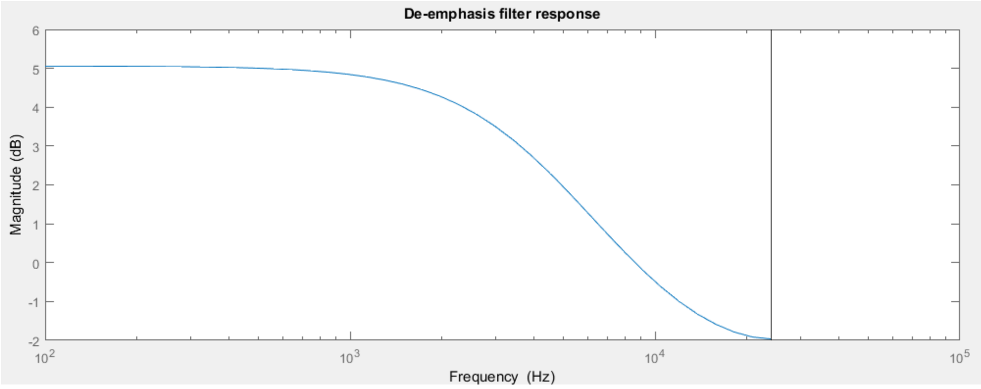

Figure 4.10: Magnitude response of the de-emphasis filter

4.7.3 Data streaming

In order to stream data to and from the codec, an SPI interface of the MCU (SPI2) was configured as an audio interface. The communication protocol used by the interfaces of the two components is the left-justified standard, whose timing diagram can be seen on figure **4.11**. This protocol was chosen as one possible option available on both the MCU and the codec. The sampling rate was set to 48kHz and word length to 16 bits. These two values and the number of channels determine the clock rates for the communication. All the clocks are provided by the MCU, which is configured as the master device. The protocol uses channel side information but as the ADC and DAC are mono channel, right channel information needs to be disregarded. Although the timing diagram shows a single data line, the audio interfaces communicate in full-duplex mode. In addition to the clock signals shown in the timing diagram, the MCU's interface outputs a master clock (MCK) as a reference clock for the codec.

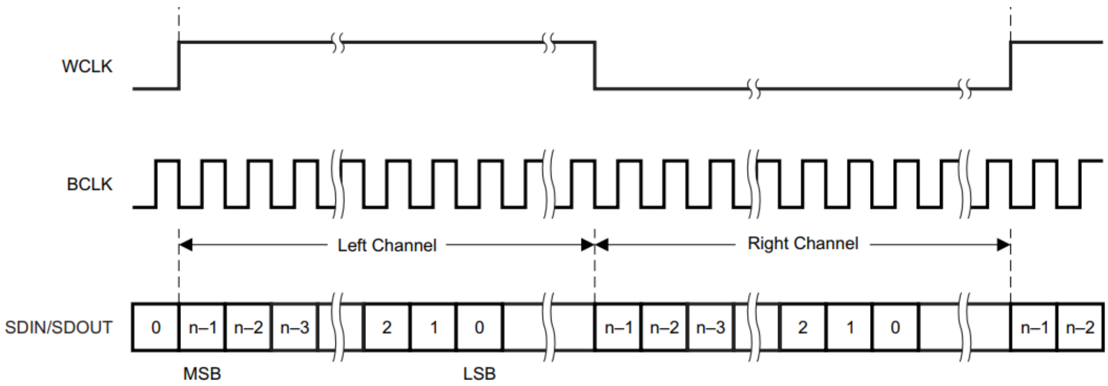

Figure 4.11: Left-justified timing diagram

4.7.4 Creating distortion by sample processing

The distortion effect can be implemented as a memoryless system, as no information about previous or future samples is needed in order to clip a sample. Samples received by the MCU are clipped by the function shown in equation **3.1** (described in section **3.4**) and are immediately sent to the codec. The gain of the input samples can be changed between the values 1 and 50. The output of a potentiometer is read every 10ms by the ADC of the MCU and is mapped to the specified range. Additionally, the effects on-off switch can be used to turn the distortion on or off. Figure **4.12** shows the output signal of the created effects unit with distortion off and on.

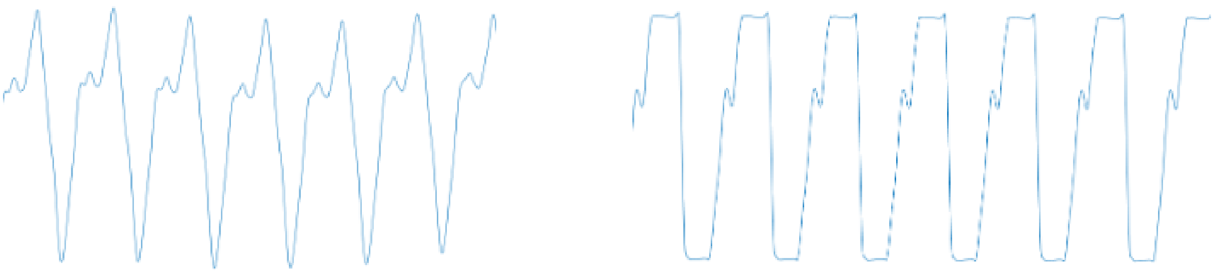

Figure 4.12: Distortion off (left), distortion on(right)

4.8 Installation inside a guitar

This section will cover what modifications were done to the original electric guitar used in this project for the installation of the effects unit. Figure **4.13** shows the body of the guitar with all the hardware and electronic components removed.

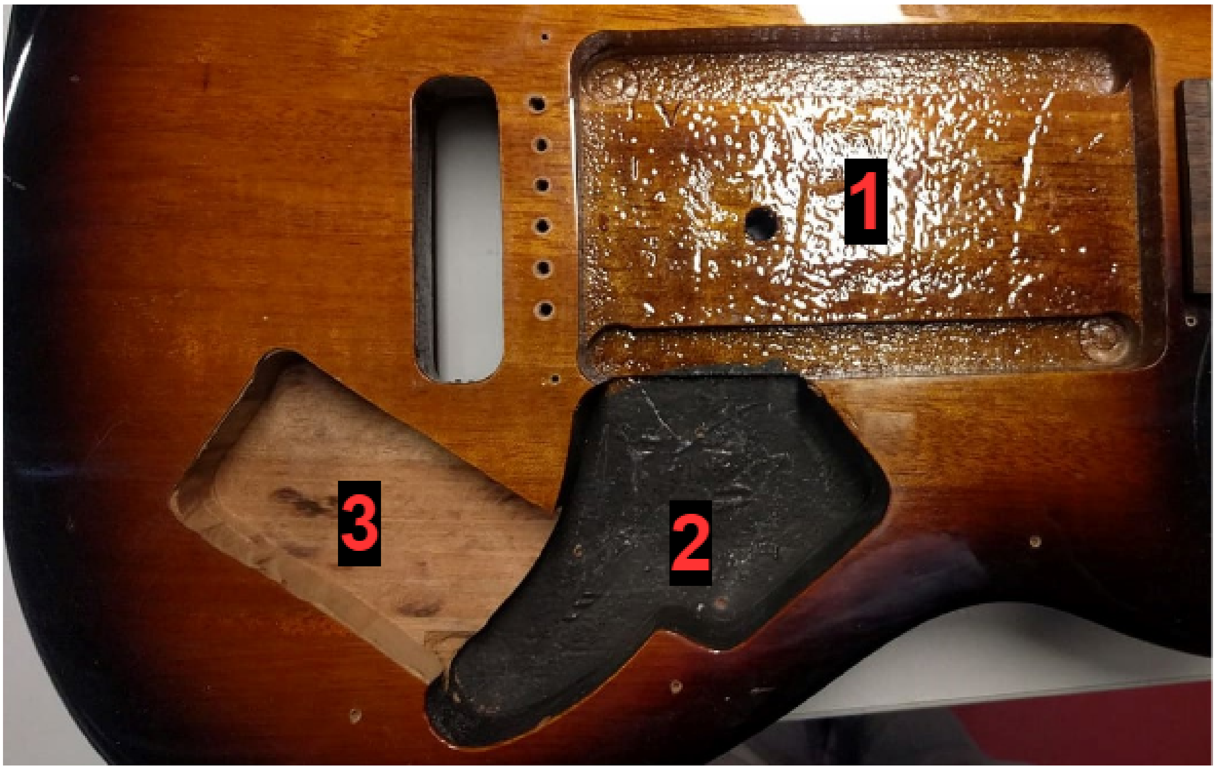

Figure 4.13: Guitar body with components removed

Number one in the picture is the area for the pickups. Originally there were three pickups whose configuration was selectable by a five-way switch. Two of the pickups were removed, which allowed simpler wiring and the removal of the five-way switch for extra space. Number two depicts the area where originally the five-way switch, two tone control and one volume control potentiometers were. Tone controls and the switch were removed, which made space for the PCB. Number three shows the extra space carved out for the battery pack. Figure **4.14** shows how the created space is used for the device with and without the plastic cover. The remaining user controls are the original volume control, the gain control (the plastic knob marked "tone"), power switch of the effects unit, and the distortion on-off switch.

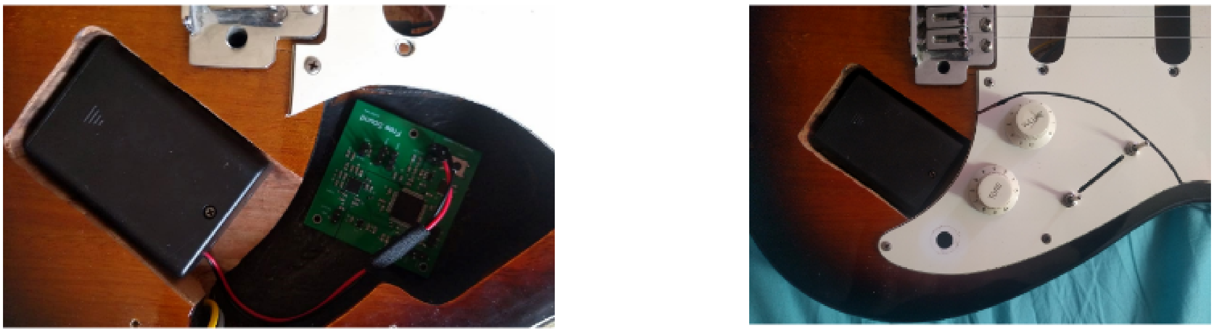

Figure 4.14: Guitar with effects unit placed

4.9 Future work

The created effects unit included some analog controls for the effect that was intended for the initial prototype. However, when implementing multiple effects on a single device, using analog controls can limit the number of effects whose parameters can be changed in real time. Two possible ideas arose for more versatile user controls.

One option is to design the PCB to include a touchscreen as an input device for controlling effects. This could result in a wider range of controls, but would come at a cost to power consumption, hardware design, and an easy installation inside a guitar. Another option would be to add wireless communication (Bluetooth for example) to the effects unit and control the effects from a separate device (smartphone, tablet). This would simplify the hardware design of the unit itself when compared to adding a touchscreen, but would require the use of a separate device to operate the effects unit.

Summary

The main goal of this thesis was to create a digital effects unit for an electric guitar. The reason for a digital device (as opposed to analog) was to provide easy reconfigurability of the device for the addition or modification of effects. The device was intended to be placed inside an electric guitar. The idea was to offer some utility when compared to the mainstream use of a chain of stompboxes.

Although there are plenty of different sound effects that could be created, the distortion effect was selected to be implemented for the first prototype. The theory behind the effect was also introduced. It was shown how clipping a signal adds a wide range of new frequencies to the original signal. The balance of those frequencies is what gives the sound that harsh timbre.

The overall creation of the device was successful. The circuitboard was designed considering the following aspects:

- Compact dimensions for an easier installation inside a guitar
- Low power consumption for a prolonged use without changing the battery
- Keeping analog signals noise free

The hardware design was kept simple in terms of components, which allowed the PCB to be small enough to be placed in an existing space inside a guitar. Two main components were used - a processor and an audio codec. The use of a battery pack as the power supply allowed for a comparatively long battery life (a rough approximation of 22 hours). This resulted in a compromise in terms of size of the entire device. The battery pack required extra space to be created in the body of the guitar.

Care was taken to keep analog signals clean from noise generated by digital circuitry. Power supply for analog components was filtered and ground planes were split in order to keep signal return paths separated.

To create the distortion effect, data sampled by the codec were streamed to the processor. The samples were processed by applying a non-linear clipping function and the processed data were streamed back to the codec for signal reconstruction. Additional functions of the codec were used to do pre- and post-processing of the signal, such as adding sustain to the input signal and filtering out higher frequencies of the output signal. As an end result, the fully configured effects unit was placed inside a modified guitar. The modifications included removing some existing components and carving out space for the battery pack.

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Appendixes

Appendix 1: Circuit schematics

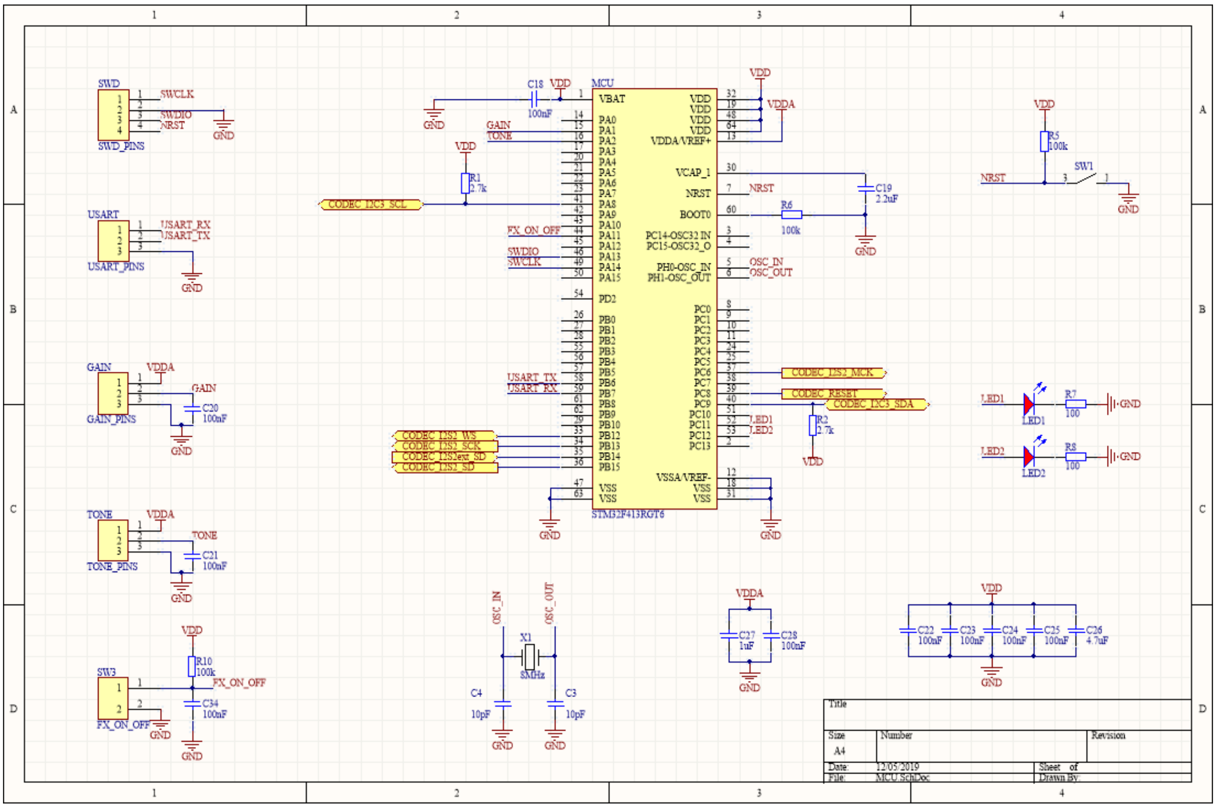

Figure 4.15: MCU schematic scheet

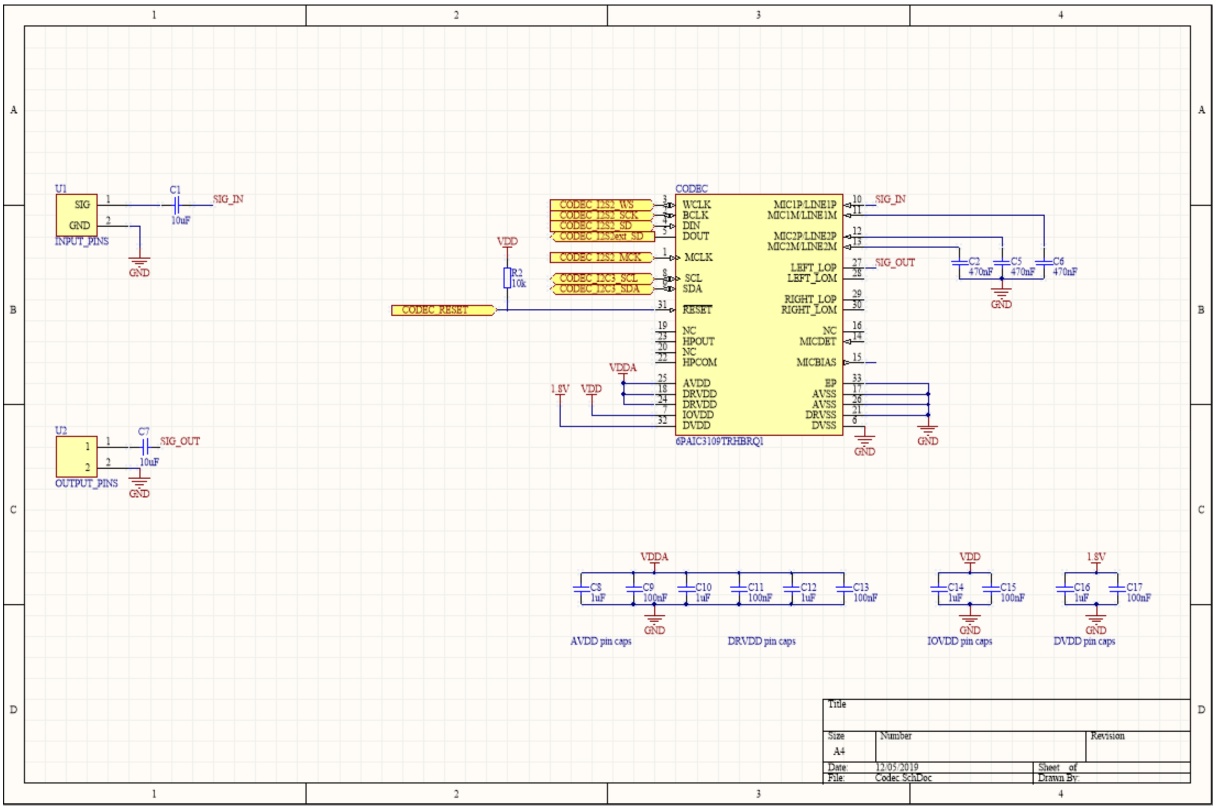

Figure 4.16: Codec schematic scheet

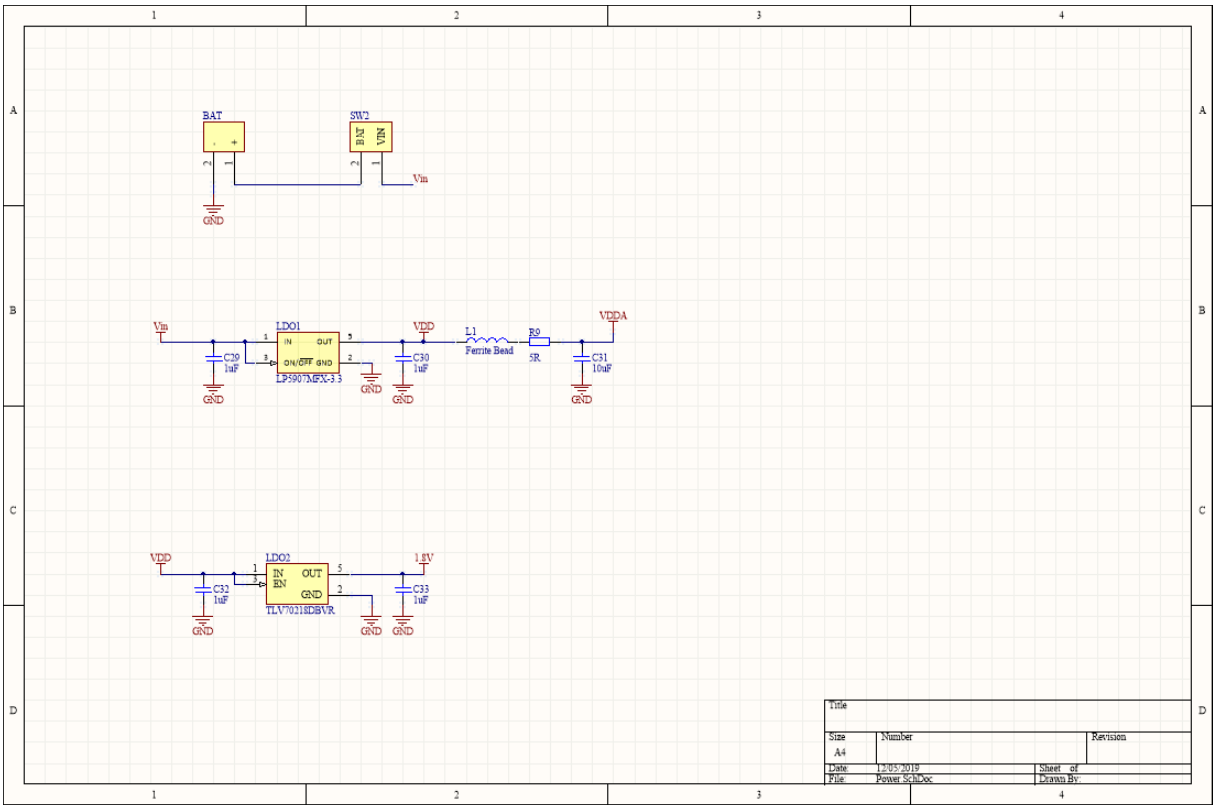

Figure 4.17: Power supply schematic scheet

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