ARDUINO BASED GUITAR SOUND PEDAL

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I.ABSTRACT:

This paper describes about Design, Construction of GUITAR PEDAL USING ARDUINO and the various effects that can be implemented to improve the quality of the sound produced by the amplifier. Guitar Pedal is used for tone shaping. They are foot-pedal boxes that provide sound effects for guitar. The main purpose of effects is to enhance the guitar pedal uses an ARDUINO UNO (microcontroller) paired with digital potentiometers. Piezoelectric transducer is used to convert sound generated from guitar into voltage signal. This voltage signal is further amplified using op-amp. One op-amp will prepare the signal to be digitized and the other op-amp will recover the signal from the Arduino UNO microcontroller.

The various effects which have been embedded are:

1. Bit crusher
2. Booster
3. Fuzz
4. Distortion
5. Delay
6. Clean

This guitar pedal has the added advantage of being compact, light and practically inexpensive. The complex circuitry of a guitar pedal with analog potentiometers was replaced by a digital potentiometer using a microcontroller (ARDUINO UNO).

II.KEYWORDS:

Distortion, Potentiometers, Music, Audio systems, acoustic distortion, acoustic signal processing, acoustic waves, audio signal processing, microcontrollers, musical instruments, potentiometers, distortion circuit, analog potentiometer, Arduino microcontroller, digital potentiometer, Arduino UNO circuit board, musical instrument, sound waves, electric guitar, distortion effects, Amplifier, Arduino, Digital potentiometer, Distortion, Microcontroller.

III.INTRODUCTION:

In the **distortion** effect the peaks of the sound waves are compressed which results in adding more overtones to the audio output. Over-driving of the tube amplifiers result in the production of the distorted guitar sounds and hence the name gain is also given to the distortion effect. Distortion effects are most commonly produced by effects pedal, also known as the distortion pedal which usually uses an analog circuitry to modify the electric guitar signals such as clipping and harmonic multiplication to result in a wide range of sounds. Modifying the sound waves are generally termed as distortion which is usually associated with having a negative consequence. But in the context of music, distortion would refer to addition of newer frequencies by clipping of the amplifier circuits.

A **bit crusher** is an audio effect that produces distortion by reducing of the resolution or bandwidth of the digital audio data. This resulting quantization noise may produce a "warmer" sound impression or a harsh one, depending on the amount of reduction. A typical bit crusher uses two methods to reduce audio fidelity.

The **clean boost effect** can be used to preserve the high-end tones of the guitar solos. A decent clean boost will have a high input impedance value. This means that the pedal's input will impede signal current and shove your pickups magnetic field right back where it should be. This also helps in improving the high-gain tones. It can also be used in a series effect loop.

Fuzz is a special type of distortion where harmonic overtones dominate the overall sound. A fuzz tone tends to emphasize upper frequencies and can sometimes cut away the middle frequencies. This makes a fuzz tone harder to hear in a dense band mix—but the saturation is undeniable.

The stereo speakers are technically designed differently due to their mode of application as compared to the guitar speakers. The stereo speaker, including the public address speaker systems are required to produce the sound as clearly as possible, or in other words, with as little distortion as possible. On the other hand, the guitar speakers would want to only highlight some of the frequencies to bring in the effects and the tone of the distortion of the electric guitar, by enhancing those frequencies while the other unwanted frequencies are attenuated.

III.A. Amplifier Modelling

The digital emulation of a physical amplifier is referred to as amplifier modelling. An amplifier is often used to recreate the sound of a specific model of vacuum tube amplifiers. This process of recreation of sound can add the effect of distortion to the recording in the otherwise undistorted recording. The dynamic behaviour of the amplifier modelling, renders it useful, as the amplifier setting can be modified instantaneously without undergoing the trouble of re-recording the audio. Digital Signal Processing (DSP) is generally used in the process of amplifier modelling to recreate the sound of plugging into analog pedals and overdriving the valve amplifiers

III.B. Solid State Distortion

Solid-state amplifiers incorporate transistors and operational amplifiers (op-amps) to produce hard clipped and distorted waves. There are two methods to achieve this distortion using hard clipping. One is by either amplifying the signal to such an extent that the signals get flattened by clipping due to crossing the threshold value, or by clipping the signal across diodes, which is a simpler method.

The effects alter the instrument sound by clipping the signal (pushing it past its maximum, which shears off the peaks and troughs of the signal waves), adding sustain and harmonic and inharmonic overtones and

leading to a compressed sound that is often described as "warm" and "dirty", depending on the type and intensity of distortion used. The terms distortion and overdrive are often used interchangeably; where a distinction is made, distortion is a more extreme version of the effect than overdrive.

Fig1. A typical distortion pedal

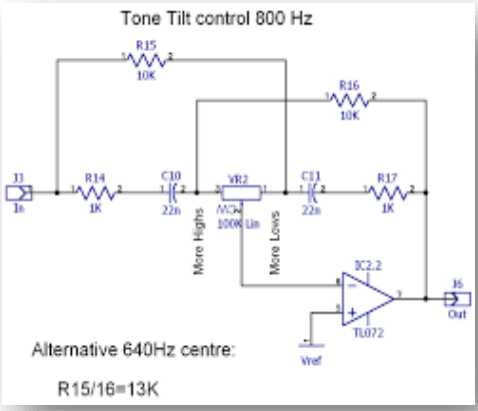


Fig2. A basic distortion pedal schematic

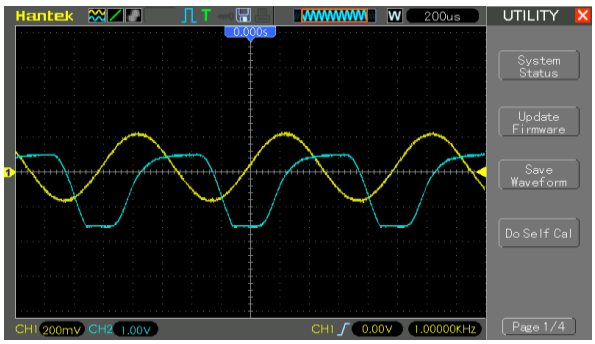


Fig3. THE OUTPUT WAVEFORM OF THE SCOPE OF A DISTORTION PEDAL

III.C. PIEZOELECTRIC EFFECT: The piezoelectric effect refers to a change in electric polarization that is produced in certain materials when they are subjected to mechanical stresses. The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The piezoelectric effect results from the linear electromechanical interaction between the mechanical and electrical states in crystalline materials with no inversion symmetry.

III.C.1. TYPES OF PIEZOELECTRIC MATERIALS AND THEIR PROPERTIES:

Naturally Available Ones: Quartz, Rochelle salt, Topaz, Tourmaline-group minerals, and some organic substances as silk, wood, enamel, bone, hair, rubber, dentin.

Artificially manufactures **piezoelectric materials** are Polyvinylidene difluoride, PVDF or PVF2, Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Potassium niobate, Lithium niobate, Lithium tantalate, and other lead-free piezoelectric ceramics.

Not all piezoelectric materials can be used in **piezoelectric transducers.**

III.D. PIEZOELECTRIC TRANSDUCER:

Fig4. Piezoelectric transducer.

Piezoelectric Transducer is an electrical transducer which can convert any form of physical quantity into an electrical signal, which can be used for measurement. It has very high DC output impedance and can be modelled as a proportional voltage source and filter network. The voltage *V* at the source is directly proportional to the applied force, pressure, or strain. The output signal is then related to this mechanical force as if it had passed through the equivalent circuit. It works with the principle of piezoelectricity. The faces of piezoelectric material, usual quartz, is coated with a thin layer of conducting material such as silver. When stress has applied the ions in the material move towards one of the conducting surfaces while moving away from the other. This results in the generation of charge. This charge is used for calibration of stress. The polarity of the produced charge depends upon the direction of the applied stress. Stress can be applied in two forms as Compressive stress and Tensile stress. The way a piezoelectric material is cut defines one of its three main operational modes:

- Transverse
- Longitudinal
- Shear

The piezoelectric sensor mounted of the instrument, preferably at a spot where the maximum vibration can be picked up by the sensor. Since we are focusing on a guitar amplifier, we mount it on the front of the guitar just below the resonating sound box maybe with double sided tape or a bit of putty. The terminals of the piezoelectric sensor are drawn into an aux output and is later fed into the guitar pedal as the input where the further processing of the sound signal takes place.

OPERATIONAL AMPLIFIER:

Fig5. Rail-to-rail operational amplifiers.

Operational Amplifiers, also known as Op-amps, are basically a voltage amplifying device designed to be used with components like capacitors and resistors, between its in/out terminals. Op-amps are linear devices that are ideal for DC amplification and are used often in signal conditioning and filtering. It is made to perform variety of analog signal processing tasks. An *operational amplifier* is basically a three-terminal device which consists of two high impedance inputs. One of the inputs is called the Inverting Input, marked with a negative or “minus” sign, (–). The other input is called the Non-inverting Input, marked with a positive or “plus” sign (+). A third terminal represents the operational amplifiers output port which can both sink and source either a voltage or a current.

In an op amp limited bandwidth also results in lower amounts of feedback at higher frequencies, producing higher distortion, and output impedance as the frequency increases. Typical low-cost, general-purpose op amps exhibit a GBWP of a few megahertz. Specialty and high-speed op amps exist that can achieve

a GBWP of hundreds of megahertz. For very high-frequency circuits, a current feedback amplifier is often used.

IV. METHODOLOGY:

The guitar pedal consists of two operational amplifiers, the first op amp is present in the input stage. Its function is to prepare the analog signal to be digitalized. The second op amp which is present at the output stage is used to recover the signal from the Arduino UNO microcontroller. The input guitar signal is amplified for better acquisition by the first op-amp. The trimmer adjusts the gain of this amplifier from 1 to 21, so the guitar level can be optimized. The signal pass through 3 low pass filters that will remove the excess of high harmonics that can create aliasing during the ADC signal acquisition (fc=5KHz).

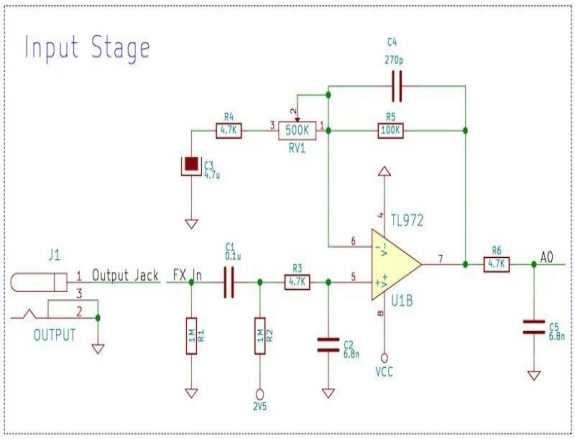


Fig6. Non-inverting operational amplifier.

IV.A. Bit crusher

A Bitcrusher is an audio effect that produces distortion by reducing of the resolution or bandwidth of digital audio data. The resulting quantization noise may produce a “warmer” sound impression, or a harsh one, depending on the amount of reduction.

Digital audio is composed of a rapid series of numeric samples that encode the changing amplitude of an audio waveform. To accurately represent a wideband waveform of substantial duration, digital audio requires a large number of samples at a high sample rate. The higher the rate, the more accurate the waveform; a lower rate requires the source analog signal to be low-pass filtered to limit the maximum frequency component in the signal, or else high-frequency components of the signal will be *aliased*. Specifically, the frequency of sampling (a.k.a. the sample rate) must be at least twice the maximum frequency component in the signal; this maximum signal frequency of one half the sampling frequency is called the Nyquist limit.

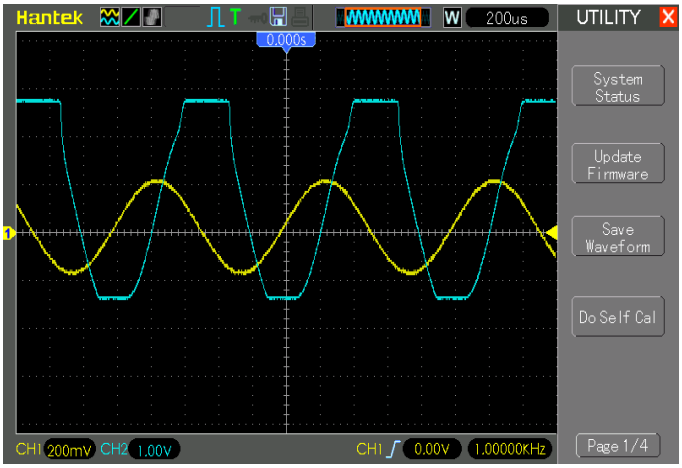


Fig7. A scope view of the bit-crusher effect

IV.B. Fuzz

Distortion and overdrive are forms of audio signal processing used to alter the sound of amplified electric musical instruments, usually by increasing their gain, producing a "fuzzy", "growling", or "gritty" tone. Distortion is most commonly used with the electric guitar, but may also be used with other electric instruments such as bass guitar, electric piano, and Hammond organ.

The word distortion refers to any modification of wave form of a signal, but in music it is used to refer to nonlinear distortion (excluding filters) and particularly to the introduction of new frequencies by memoryless

nonlinearities. In music the different forms of linear distortion have specific names describing them. The simplest of these is a distortion process known as "volume adjustment", which involves distorting the amplitude of a sound wave in a proportional (or 'linear') way in order to increase or decrease the volume of the sound without affecting the tone quality.

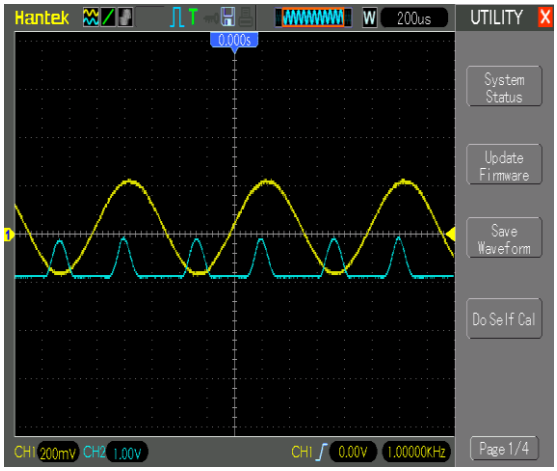


Fig8. Scope view of the output waveform of fuzz effect

IV.C. GUITAR PRE-AMPLIFIER DISTORTION

The pre-amplifier section of a guitar amplifier serves to amplify a weak instrument signal to a level that can drive the power amplifier. It often also contains circuitry to shape the tone of the instrument, including equalization and gain controls. Often multiple cascading gain/clipping stages are employed to generate distortion. Because the first component in a valve amplifier is a valve gain stage, the output level of the preceding elements of the signal chain has a strong influence on the distortion created by that stage. The output level of the guitar's pickups, the setting of the guitar's volume knob, how hard the strings are plucked, and the use of volume-boosting effects pedals can drive this stage harder and create more distortion.

V. WORKING OF THE SYSTEM:

The functionality is simple; 1 op-amp will prepare the signal to be digitized and also 1 opamp will recover the signal from the Arduino UNO microcontroller. One ADCs is used to read the guitar signal and two PWM signals are used to generate the output signal.

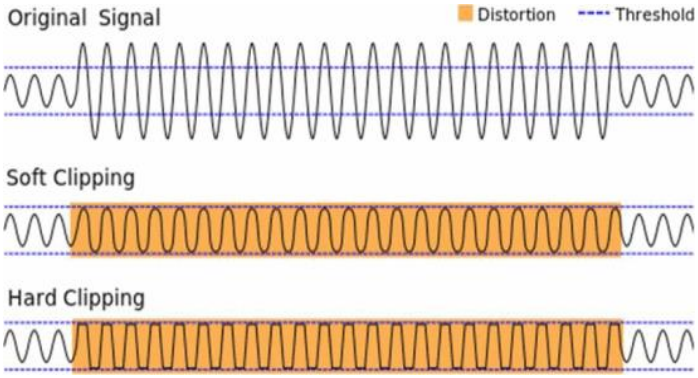


Fig9. Soft and hard clipping of a sine wave input.

Input Stage: The guitar signal is amplified for better acquisition by the first op-amp which follows the Microamp guitar pedal design. The trimmer VR1 adjusts the gain of this amplifier from 1 to 21, so the guitar level can be optimized. The signal pass through 3 low pass filters (formed by R3&C2, R5&C4, R6&C5) that will remove the excess of high harmonics that can create aliasing during the ADC signal acquisition (fc=5KHz).

Output State: Uses a Sallen & Key 3rd order low pass filter which removes harmonics above 5KHz. Two PWM signals are used in parallel improving the bit resolution (2x8bits). If you want to read more about the PWM audio generation read the forum topic dedicated to the PWM configuration options.

Power Supply: The pedal uses the +5V from Arduino Uno to feed the rail-to-rail operational amplifier and achieve design simplicity and maximum signal swing without clipping. A resistor divider R7&R8 generates 2.5V for

virtual ground and the cap C6 remove ripple on the power line.

User Interface: The player can use 2 configurable push-buttons, 1 configurable toggle switch, 3PDT true-bypass footswitch, and a programmable LED.

Arduino Uno Connectors: Pin headers will link the shield with Arduino Uno transferring the signals and power supply.

- Based on Arduino (16MHz, 2KB RAM).
- Analog stages using TL972 rail-to-rail operational amplifier.
- ADC: 10bits.
- Output Stage: 16 bits (2x8bits PWMs running in parallel)

Interface:

2 Configurable push buttons.

1 Configurable switch

1 programmable blue led.

True Bypass Foot-switch

- Connectors:

Input Jack, 1/4 inch unbalanced, Zin=0.5MΩ.

Output Jack, 1/4 inch unbalanced, Zout=0.1Ω.

Power supply: power taken from the Arduino UNO board.

V.A. Working of a piezoelectric transducer:

The working of a basic piezoelectric transducer can be explained by the below figure.

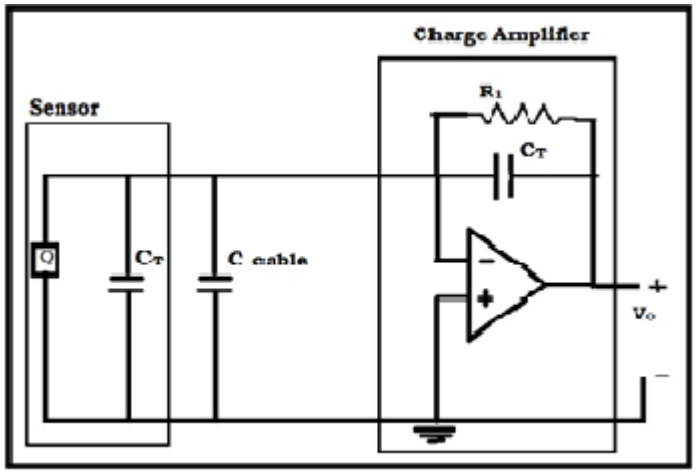


Fig10. Piezoelectric Transducer Circuit

Here quartz crystal coated with silver is used as a sensor to generate a voltage when stress is applied on it. A charge amplifier is used to measure the produced charge without dissipation. To draw very low current the resistance R1 is very high. The capacitance of the lead wire that connects the transducer and piezoelectric sensor also affects the calibration. So the charge amplifier is usually placed very near to the sensor. So in a piezoelectric transducer when mechanical stress is applied a proportional electric voltage is generated which is amplified using charge amplifier and used for calibration of applied stress.

APPLICATIONS:

- As piezoelectric materials cannot measure static values these are primarily used for measuring surface roughness, in accelerometers and as a vibration pickup.
- They are used in seismographs to measure vibrations in rockets.
- In strain gauges to measure force, stress, vibrations etc…
- Used by automotive industries to measure detonations in engines.
- These are used in ultrasonic imaging in medical applications.

V.B. Working of an operational amplifier:

The signal booster is a non-inverting op-amp stage which provides high input impedance, voltage gain, and signal filtering. The op-amp is configured in a classic non inverting topology, the resistors R4, R5, and R6 set the voltage gain. Several capacitors C_1, C_2, C_3, and C_5 will filter the guitar signal, always keeping a flat response.

- The 22MΩ input resistor R_1 next to the input jack to ground is a pull-down resistor which avoids popping sounds when the pedal is switched on. The input pull-down resistor becomes the maximum input impedance of the pedal.
- The (+) input is biased to 4.5V through the R_2 resistor (10MΩ), keeping the virtual ground at 4.5V and being able to amplify bipolar guitar input signals.

Op-amp output impedance:

The output impedance is defined by the formula-

Zout=R10//(R9+Zoutopamp)

Op-amp voltage gain: The voltage gain is defined by the non-inverting operational amplifier and the output voltage divider formed by R_9 and R_{10}:

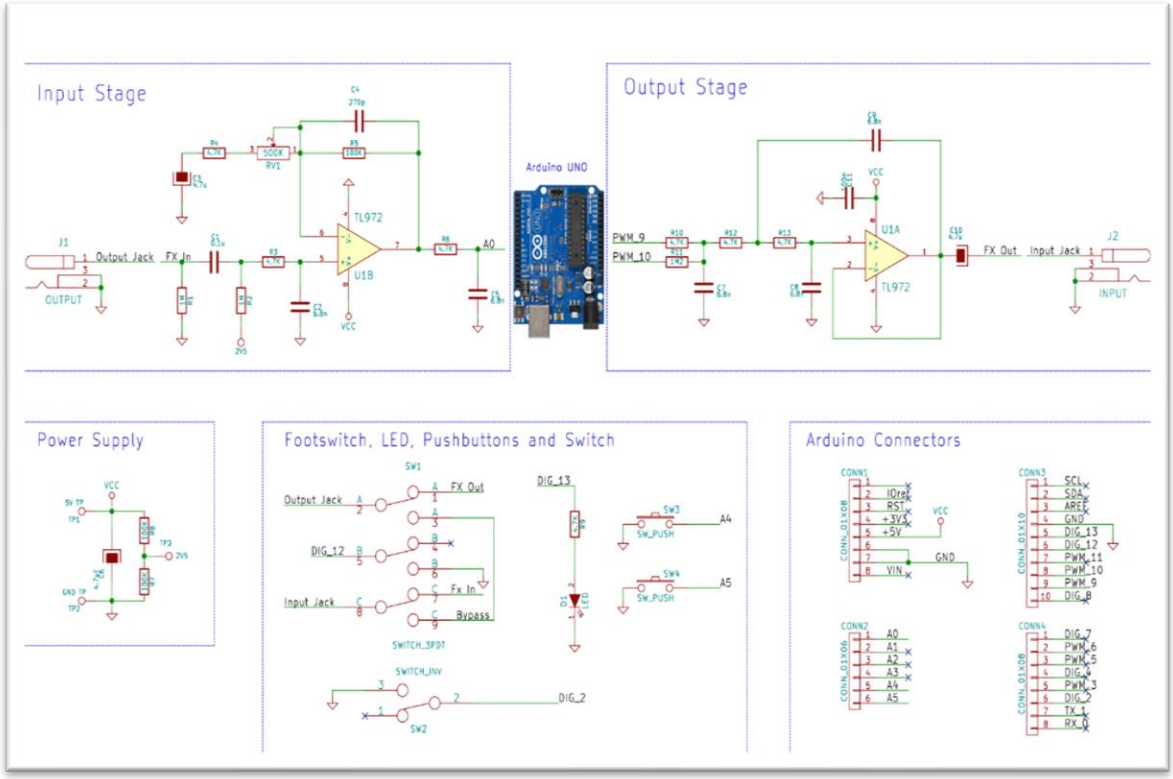
G=[1+(R4//(R5+R6)). (R10//(R9+R10))]

Applications:

- Operations can be applied as inverting amplifiers. The inverting circuits, implemented with an Op-Amp, are more constant, distortion is comparatively lower.
- Application of op-amp as a phase shifter (to reduce voltage swings in a circuit)
- Op-amp as a scale changer. Op-Amp acts as a negative scaler when it multiplies the input by a negative constant factor.
- Op-amp application as an adder or a summing amplifier. Op-amp can be used to sum the input voltage of two or more sources into a single output voltage.
- Differential amplifier, differentiator, integrator.
- Voltage to current convertor.
- Half wave rectifier, a peak detector and so on

VI. Conclusions:

In this paper, a distortion pedal with a variable gating effect and the working of Piezoelectric transducer and op-amp in the distortion pedal has been described in detail. A variable gating distortion pedal has the distinct advantage of being able to completely replace a full effects pedal board with a compact device. A full effects pedal board is expensive and heavy, whereas a variable gating distortion pedal is compact and light, because of the use of modern and better components like the digital potentiometer, controlled by Arduino UNO (Microcontroller).



Schematic diagram of Arduino based guitar pedal

VII. Future Scope:

The guitar pedal has been an integral part of the music industry for a very long time. Music genres such as rock, jazz, blues and so on use the different effects in making their music stunning when they showcase it. Although the guitar pedal has had great strides towards miniaturising and building a more compact system, it has scope for the development of wireless systems to reduce the amount of cables and therefore tangles and loose connections. Huge conferences are held mainly in the US where inventions with can be mounted on a guitar are showcased which have effects and intonations which have a easier user interface. The MIDI controller is a far more efficient system as of now.

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