Department of Electronic and Telecommunication

University of Moratuwa

EN2090 : LABORATORY PRACTICE-II

# The Analog-Piano

**Team : Dream Epic**



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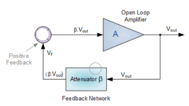
# Contents

# 1 Theory

## 1.1 Oscillator

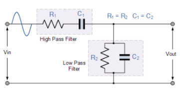


An oscillator is an amplifier that uses positive feedback that generates an output frequency without the use of an externally applied input signal. Once the oscillation is started, the parameters A and $\beta$ are aligned to maintain a unity gain at the required frequency in order to keep the oscillation indefinitely stable.

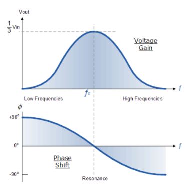
### Wein-Bridge Oscillator

The Wien Bridge Oscillator uses a feedback circuit consisting of a series RC node cascaded with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency. Effectively they act as a second-order frequency dependant Band-Pass-Filter with a high Q factor at the selected frequency $f_r = \frac{1}{2\pi RC}$. This RC network is connected in the positive feed-back path of the amplifier and has zero phase shift at just one frequency.

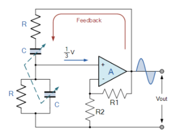
Other part of the feedback signal is connected to the inverting input terminal(negative feed-back) via resistor divider network of $R_1 \& R_2$. Then at the selected resonant frequency($f_r$), the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase". So the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.



RC-Network



Response



Oscillator

### Starting and Damping Oscillation

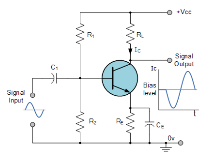
By controlling the negative feedback ratio($\frac{R_2}{R_1+R_2}$) of the oscillator we can start and damp the oscillation as required. To start oscillation, we need to slightly reduce the negative feedback($< \frac{1}{3}$). This will give rise to a resultant signal on the amplifier input side which is get amplified and fed back recursively turns out to drive oscillation.

Keeping the feedback ratio slightly more ($> \frac{1}{3}$) will give rise to a resultant negative input which is get added adversely with output resulting in damping of the oscillation. By fine-tuning the ratio in a very elegant manner, it is possible to control the damping time constant.

## 1.2 Amplifier

Driving a high-power (3W) speaker draws a high amount of current from the circuit. These current ranges are very much higher than the maximum supply available from op-amps and other low power components used in generating the wave patterns. So it is crucial to maintain an amplifier boundary between low power noisy signal to high power driving signal free of noise. In the following context, we will discuss the theories behind our amplifier design in detail.

### Class-A



These are the simplest configuration among other families. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches "ON" it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability.

The current handling capability of such an amplifier family can be increased drastically by replacing the output transistor with the structure of **Darlington pair**. These devices provide high input impedance.

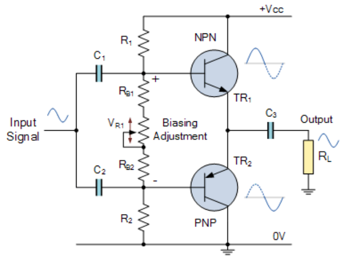
### Class-B

Class B Amplifiers are biased to only conduct half of the input signal. Using 2 such amplifiers arranged in a "Push-Pull" configuration, and combining the output signal, the full waveform can be obtained.

As the quiescent current for this amplifier is 0, there is little or no DC, therefore much less power dissipation. However, there is a slight waveform distortion due to the bias voltage requirement of the transistor known as cross-over distortion.

### Class-AB

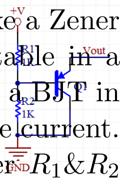
Class AB amplifiers overcome the distortion issue of class B amplifiers by permanently bringing the two transistors just into the active region. This




reduces the efficiency, but results in an undistorted the waveform in the output.

As the power dissipation due to the DC component is much less than class A amplifiers, these circuits allow the use of compact heat sinks during the operation.

### Variable Zerner Diode



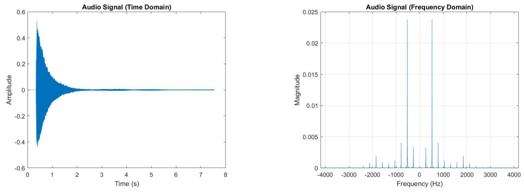

This variable Zener diode circuit acts like a Zener diode with a breakdown voltage adjustable in a vast domain. This is achieved by driving a BJT in the active region and controlling the base current. The current through the voltage divider $R_1 \& R_2$ must be higher compared to the base current.

# 2 Methodology

## 2.1 Preliminary Analysis

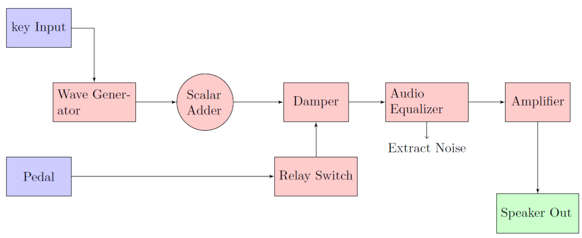
At an earlier stage of the project, we plan to build an octave piano with twelve notes including minor keys. At that stage, we analyzed the frequency spectrum of each note and found out it is possible to produce a majority feeling of sound with only four harmonics to a given note.

After synthesizing all the keynotes from its harmonics using Matlab, we moved to circuit development. At this stage, we decided to stimulate only one note from the piano because the generation of notes is modularizable. For this purpose, we have chosen the C-wave which is in the middle of the spectrum.




## 2.2 Circuit Design

The key components of the circuit are illustrated below in the block diagram. Before moving to the prototype all the circuits are simulated using NI Multism.Working simulation models of all the circuits can be found in the git-repository.




Block Diagram of the Circuit

### 2.2.1 Wave Generator

Square wave generation of half the frequency together with a bandpass active filter is considered in the first stage of the circuit development. Need for achieving a larger Q factor for the filter as the number of harmonics increases, lift the choice to not-feasible.

Moving towards a stable solution brought the Wien bridge oscillator into play. These oscillators have the flexibility over frequency choice ($\frac{1}{2\pi RC}$) making them the most suitable option to be used with modularizable piano.

### 2.2.2 Key and Pedal

After a clear analysis of the waveform using Matlab, it is expected to achieve an exponential decay in the waveform once the oscillation is triggered. Looking at the discharging behavior of the capacitor initially it decided to engage a capacitor together with an analog multiplier to form an envelope around wave output.

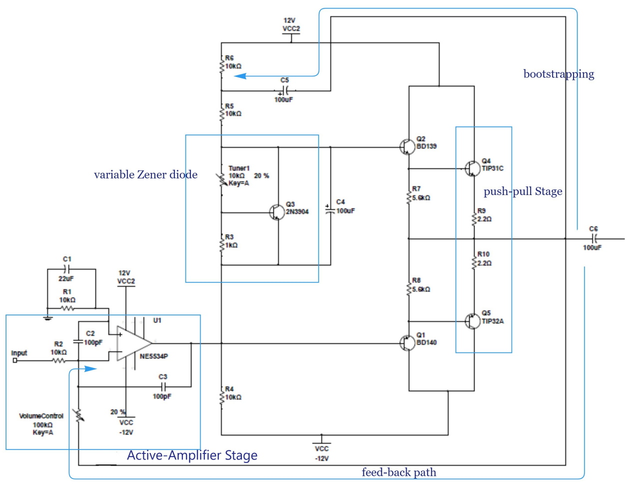
Due to the power inefficiency of the design and difficulty in finding good quality multipliers, the design moved to engage tuning of negative feedback of oscillator to achieve necessary output. This is further utilized to mimic the damping pedal of the piano by controlling the elongation of the signal-out of each oscillator.

### 2.2.3 Scalar Adder

Direct connection between outputs of oscillators even after scaling leads to interference in the signal generation stage of the oscillator. In contrast, using a scaling adder we can provide a low impedance output path while scaling the inputs as specified.

### 2.2.4 Amplifier

At earlier stages, the amplifier was implemented in class-A configuration. The requirement for lower output resistance of the bias path leads to high power dissipation in the signal-free state. This made such a model not practical without huge heatsinks at the cost of low power efficiency. **Active Amplifier Stage**: In the first part of the



amplifier design an op-amp is used in the inverting configuration. The feedback path is connected to the end of the overall circuit to ensure enough current supply available in the output.
The op-amp NE5534 was chosen for the purpose according to its key characteristics such as high unity-gain bandwidth(10MHz), very low harmonic distortion,high common mode rejection ratio (100dB). The capacitance values of C2 and C3 are chosen to allow only higher frequencies ($> 20kHz$) to pass through. These are utilized in a manner to remove high-frequency noises from the wave-form.

**Push-Pull Stage**: Considering the requirement of high power gain it is decided to engage Darlington pairs for this purpose. These components failed in the long run due to the inability of compensating for high power dissipation. Considering this, the design moved to engage two coupled BJTs to allow the choices for transistors to be used in the high current path. The similar pairs TIP31C and TIP32C were chosen after considering their high power compensation capability(around 40W).

**Bias**: Due to the requirement for a sudden supply of high current on the keypress, the signal gets noisy when we drive the speaker without any bias. In earlier stages, a few diodes are used to bias the circuit which failed to get rid of the noise. As the next step, we used Zener diodes that provide the capability to choose higher bias voltage. This results in the low efficiency of the circuit. After considering all the methods it is decided to implement the variable Zener diode which has the flexibility over varying bias voltage in a wider range. This provides control over two extremities, effecieny and quality of the output.

**Bootstrapping**: The capacitor C5 gets charged to the pre-decided bias voltage. By maintaining the circuit time constant very large ($t = R5 \parallel R6 \star C5 > 0.5S$) the overall bias voltage of the circuit is maintained as a constant value to compensate for the effect of thermal runaway.