Electronic Sound Generator

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Abstract

The Electronic Sound Generator is a low-cost analog synthesizer that can help music enthusiasts be able to enjoy the wonderful effects that normally come with a very large cost. We designed and built a low frequency oscillator, attack and release envelope generator, voltage-controlled oscillator, voltage-controlled amplifier, and a white noise generator for the effect that this system will generate. In this paper we will discuss our design of each module and how they work to generate the various effects of the electronic synthesizer.

Contents

1. Introduction

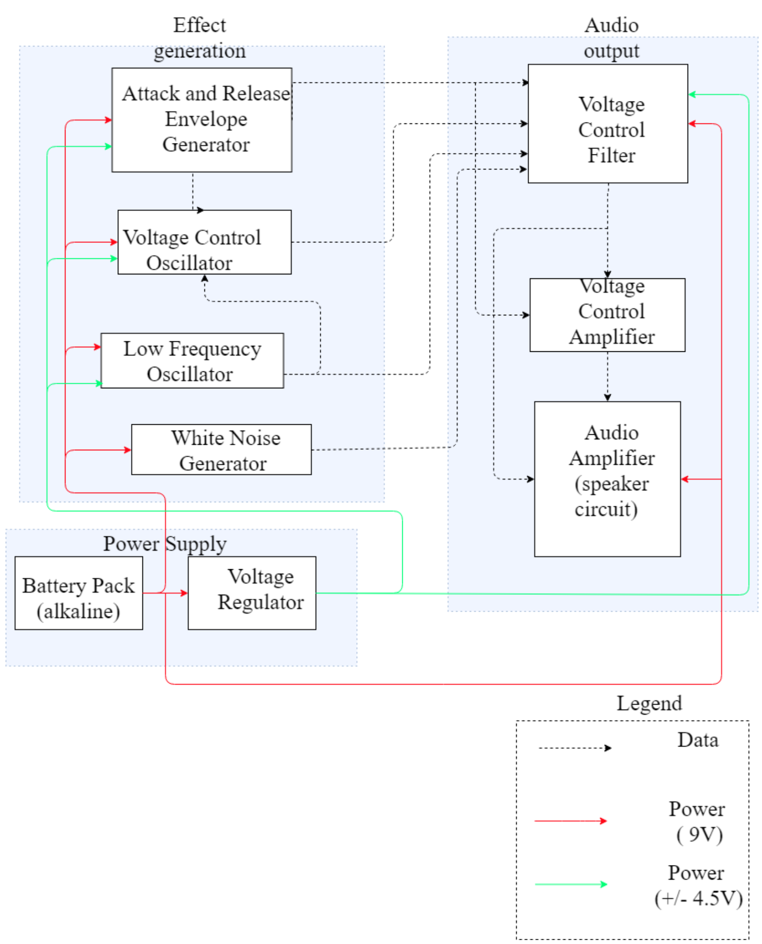
Synthesizers can be very costly and have a complex design [7]. Some studio quality synthesizers can cost as much as $10,000 with the simpler models going for around $200 to $400[5]. This complexity and expense involved blocks many would be musical hobbyists from enjoying the wonderful effects that synthesizing can bring to their musical experience.

Our plan is to design a relatively inexpensive synthesizer with a simple control scheme with the use of manual switches and dial, in such a way that, the musician could pick a different sound effect quickly to add to their musical experience. This plan will need to be inexpensive enough, under $40, to produce if possible as we need to make sure the musician will not have to empty their bank account just to gain access to our synthesizer. To achieve this reduced cost, we are removing the rather large preinstalled input that is seen accompanying the analog synthesizers. This will reduce the overall size of the synthesizer, which will help in making it transportable.

2 Design

The Electric Sound Generator will require three sections to be complete which include the power supply, the effect generation, and the audio output blocks. The power supply will supply 9V (+/- 5%) and +/- 4.5V (+/-5%) to the rest of the device. The effect generation block will take the input voltage from the power supply and use that to generate a signal that will be modulated to create various effects, such as, the ripple effect, a chirping effect, and adjusting the frequency of the output audio signal. From there, the effect generation block will send the signal to the Audio Output block where it will be filtered, amplified, combined with white noise, and then output through the audio amplifier. The system must be able to produce a signal of 32 to 247 hz to achieve the first three octaves, which is the standard set of inputs of a keyboard [18]. The system should also have a simple design that can be run for more than ten hours before battery replacement for ease on the musical hobbyist. The system must also be able to manipulate the voltage of the system to generate the desired sound effects which include, a ripple, chirp, hiss, and reverberation effects.

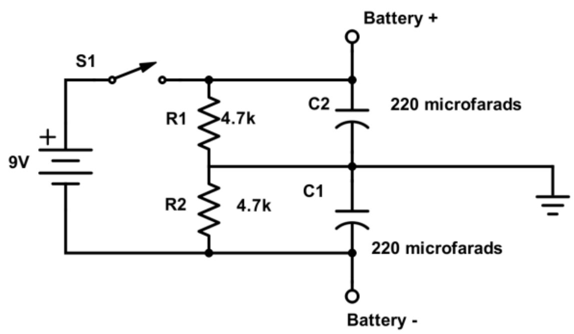
Figure 1. Block Diagram



2.1 Power Supply

The power supply, Figure 2, is made up of two major components. The battery and the voltage regulator. The power supply needed to be able to power the whole device for a reasonable length of time so musical hobbyists could enjoy the sound effects. With that fact in mind, we decided upon a nine-volt battery as the main source of power for the system. We then added a voltage regulation module to the power supply for powering the op amps needed for the oscillator circuits. Another option would have been to use power from the wall with an AC to DC converter, however we felt that a battery powered device would make it easier to transport as well as make the cost of the system cheaper for the user.

Figure 2. Power Supply circuit



2.1.1 Battery

The Battery is a standard alkaline nine-volt battery with a current rating of 550 mAh. We chose this battery due to the common size for convenience to the user as well as it gave ample power to run the device for an extended period.

2.1.2 voltage regulator

The voltage regulator is comprised of a resistor and capacitor network that splits the voltage from the battery in half as well as creates a virtual ground for use with powering the op amps. We could have used a voltage regulator chip instead, but again the cost of the chip was more than the resistor capacitor network, so we decided to against the chip as we did not need as robust of a voltage regulation as the chip would provide. Knowing that half the nine volts would be needed and using the voltage divider equation Eq. (2.2), we knew the resistors would need to be the same value. We decided on a resistance value of 4.7k ohms as that gave us one milliamp of current flowing through the resistors. Using Eq. (2.1) we were able to solve for the total impedance of the system using 4.5V and 0.7 mA which was required to power the op amps. From there, we used Eq. (2.3) to calculate the magnitude of the impedance with the resistance we chose and the total impedance we calculated to solve for the required capacitor values needed, 220 microfarad, to power the op amp while giving us a stable ground point.

$$V = IR \tag{2.1}$$

$$\frac{V_{in} * R_1}{R_1 + R_2} = V_1 \tag{2.2}$$

$$C = \frac{1}{\sqrt{(Z_{Total})^2 + (R_1)^2}} \tag{2.3}$$

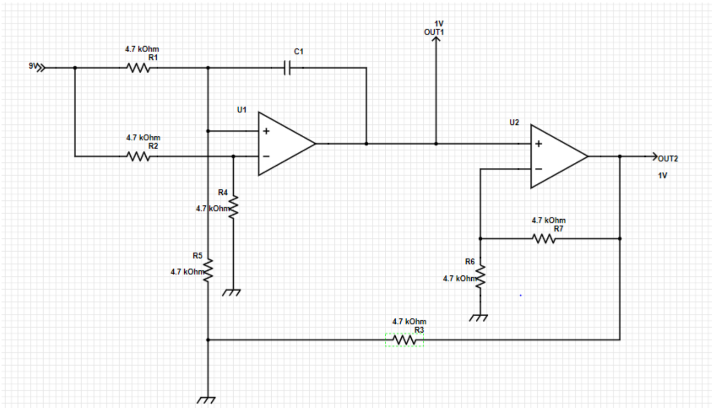
2.2 Effect Generation

The Effect Generation Block is the main source for the effects heard from the output speaker. This block is comprised of the Low Frequency Oscillator, Voltage Control Oscillator, White noise Generation, and the Attack and Release envelope Generator. This block uses input power from the power supply, both 9V and (+/-)4.5V, to generate the base signal that will then be modulated and altered by the modules in the system. The signal produced by this block will then be sent to the Audio Output block for amplification to be output through the speaker.

2.2.1 Voltage Control Oscillator

The voltage-controlled oscillator is the module that will produce a tone as the output after accepting the input of frequency and voltage from the user and will produce any of five given types of tones/waveforms. Those are: rectangular, triangle, ramp (reverse and straight) and sinusoidal. This will be achieved with the operation of the PWM input, which will modulate the frequency to achieve the desired output. The input voltage will have a potential difference of 9 V between it and the ground, or in other words, (+/-4.5V). We will accept 1 V of input, and for every extra 1V of input, the frequency will double exponentially for the exponential input, but increase at a constant rate with a linear CV (controlled voltage) input. Design alternatives for this module are difficult to decide, due to this module being used for industrial purposes other than the project we created, and due to our current design being barely viable for use and functioning outside of this project.

Figure 3. Voltage Control Oscillator



Equations used:

$$V = I*R \tag{2.4}$$

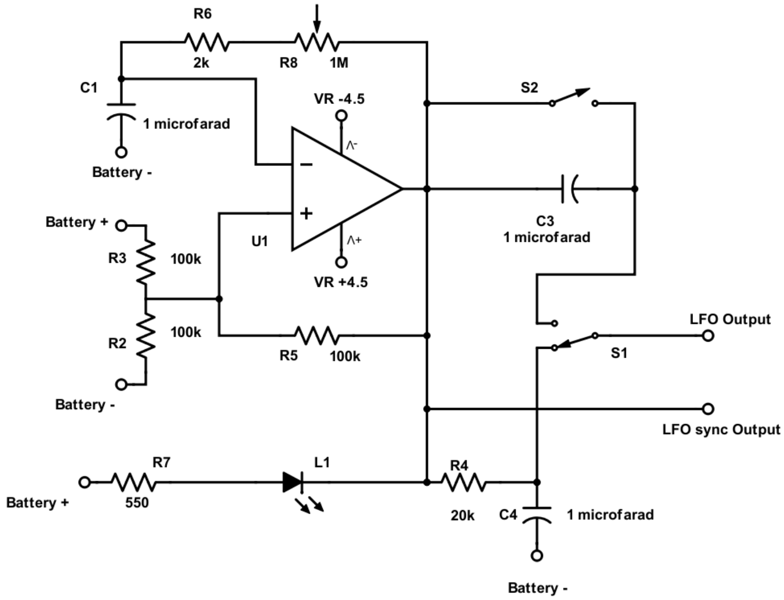
$$F = 1 / (2*Pi*R*C) \tag{2.5}$$

2.2.2 Low Frequency Oscillator

The low frequency oscillator, Figure 4, is made up of a Schmitt-trigger comparator to generate the square wave. We adjust the time the capacitor takes to charge and discharge which in turn changes the rate at which the comparator switched from high to low giving us the square wave. Once we had the square wave, we used a passive integrator and differentiator to get the desired waveforms we needed to create the different sound effects. An alternative design we could have used would have been to use an active integrator and differentiator, however that would have led to more op amps and a larger circuit. So, we decided upon the passive setup as it would be less expensive and still does a decent job for our project.

To begin with designing this module, we started with the basic Schmitt-trigger comparator recommended in the LM324N datasheet for square wave generation [12]. The use of a capacitor and resistor network is used to manipulate the square wave frequency by adjusting the time constant for the capacitor connected to the negative input of the op amp. We picked a frequency range of 0.5 Hz to 230 Hz and decided to have a one Megohm potentiometer for a wide range of frequency adjustment between that range. Using the equations (2.6), (2.7) and (2.8), we were able to calculate the capacitance needed to reach that frequency range given our resistors that were already chosen [10].

Figure 4. Low Frequency Oscillator



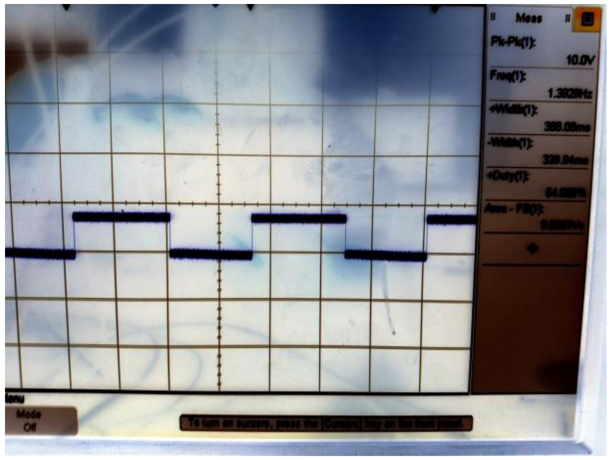
$$T = 2RC[ln(\frac{1+\beta}{1-\beta})] \quad (2.6)$$

$$f = \frac{1}{T} \quad (2.7)$$

$$\beta = \frac{R_2}{R_3+R_2} \quad (2.8)$$

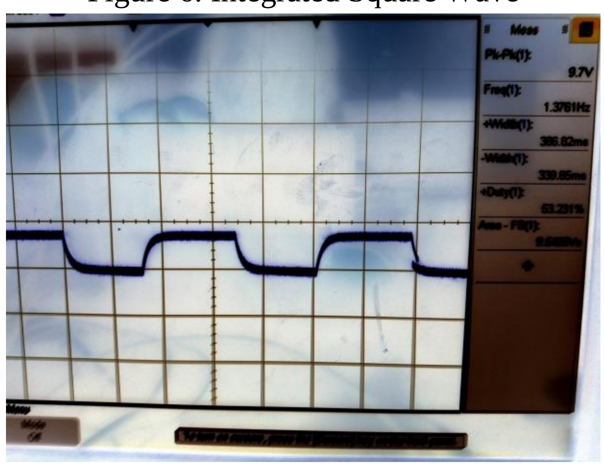
Since R_2 and R_3 in the Figure 4 are the same we have a $\beta$of one half. Using the one Megohm as the R in Equation (2.6) and setting the f in Equation (2.7) to be 0.5 Hz we were able to get a capacitance of 0.91 microFarad. Rounding up, this gives us a capacitance for C1, seen in Figure 4, of one microFarad.We then used C1 as the C in Equation (2.6) and used 230 Hz as the frequency to solve Equations (2.7) and (2.6) to find the lower resistance needed for when the potentiometer was at zero ohms. This gave us a resistance of 1978.78 ohms which we rounded up to 2000 ohms for sizing. This gave us the basic square wave generator for the Low Frequency Oscillator with an output seen in Figure 5.

Figure 5. Square Wave Output from LFO



The passive integrator, output seen in Figure 6, is comprised of a resistor in series with the output of the square wave generator with a capacitor attached to the end of the resistor and the other end attached to ground which is essentially a low pass filter [9]. Using Equation (2.9) we were able to calculate the resistance we need using a one microfarad capacitor for the capacitor there as well and the frequency of 230 Hz, changing frequency to time using Equation (2.7). This gave us a resistance of 21,739 ohms Which we picked a 20 kiloohm resistor for sizing.

Figure 6. Integrated Square Wave

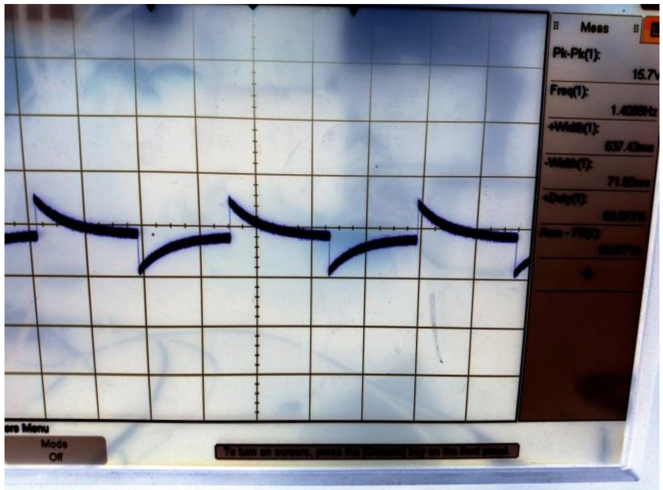


$$RC \geq 5T \tag{2.9}$$

The passive differentiator has a capacitor in series with the output, which is essentially a high pass filter [8]. We used the same size capacitor as the first one, one microfarad, for ease of sizing here as well with an output seen in Figure 7. Finally, we worked on the LED to blink at the frequency of the LFO output. Looking at the data sheet for a red LED, the voltage drop across the standard LED is between about two volts and we needed 20 mA of current for the device to work [13]. From there we used Equation (2.10) to figure out the resistor we would need to limit the current for the LED to have a maximum of 20 mA.

$$V_{\square} - V_f - V_{squarepeak} = V_R \qquad (2.10)$$

Figure 7. Differentiated Square wave

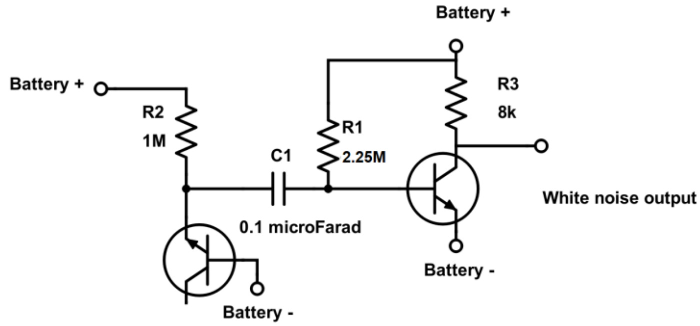


When the Square wave was high, this gave us a V_R of 2.7V and 11.7V when the square wave was low. Using the Ohm's Law, Equation (2.1), and the current of 20mA we got a resistance of 585 ohms which we rounded to 550 for sizing.

2.2.3 White Noise Generator

We began working on the white noise generator, Figure 8, by researching how to generate a white noise signal. We discovered that if you connect an NPN transistor up like a Zener diode, with the emitter to base breakdown voltage exceeded, the transistor would activate randomly and produce the white noise signal we required [16]. While searching we did see alternative designs for this circuit, however they involved using a low pass filter as well as an op amp with added capacitors and inductors. We chose our design as it fulfilled our effect generation requirements and was much cheaper and more compact. We chose an NPN transistor that we used in previous classes as a starting point, the 2N3904 transistor that has a breakdown voltage of about six volts and a max emitter to base current of 10 microamps [14]. Using Equation (2.1) we calculated a resistance needed to limit the current into the transistor of 0.9megohms. For sizing we rounded up to one Megohm. It was common to see a small capacitor of 0.1 microfarad as a high pass filter on the

Figure 8. White Noise Generator

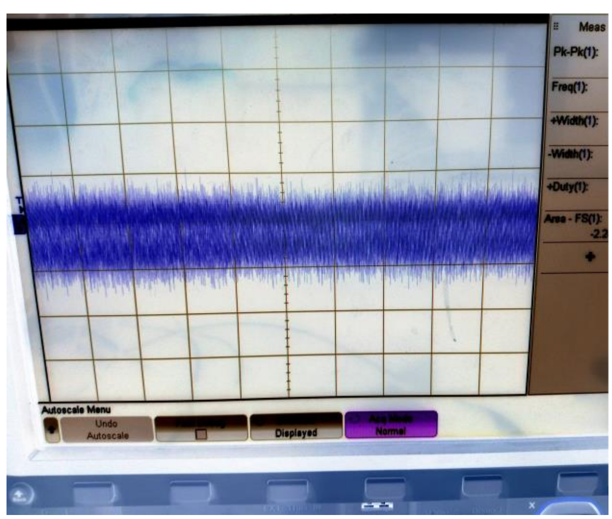


output of the transistor that was generating the white noise [16]. Once we had the signal generation, we then needed to amplify the signal to about one to three volts for the signal to be noticeable, seen in Figure 9, in the waveforms it will be added to [16]. To amplify the signal, we chose a second transistor and then biased it to have a gain of 250. Using the Equation (2.1), the nine volts from the battery, and the collector current of one mA we calculated the resistance needed to set I_{ce}, eight kiloohm. Then, using Equation (2.11), we calculated the current needed for I_B given the gain was 250 [15].

$$I_{B} = \frac{I_{C}}{\beta} \qquad (2.11)$$

Then, Using Equation (2.1) and (2.11) we calculated a resistance of 2.25 Megohms needed to bias the transistor to have 250 gains.

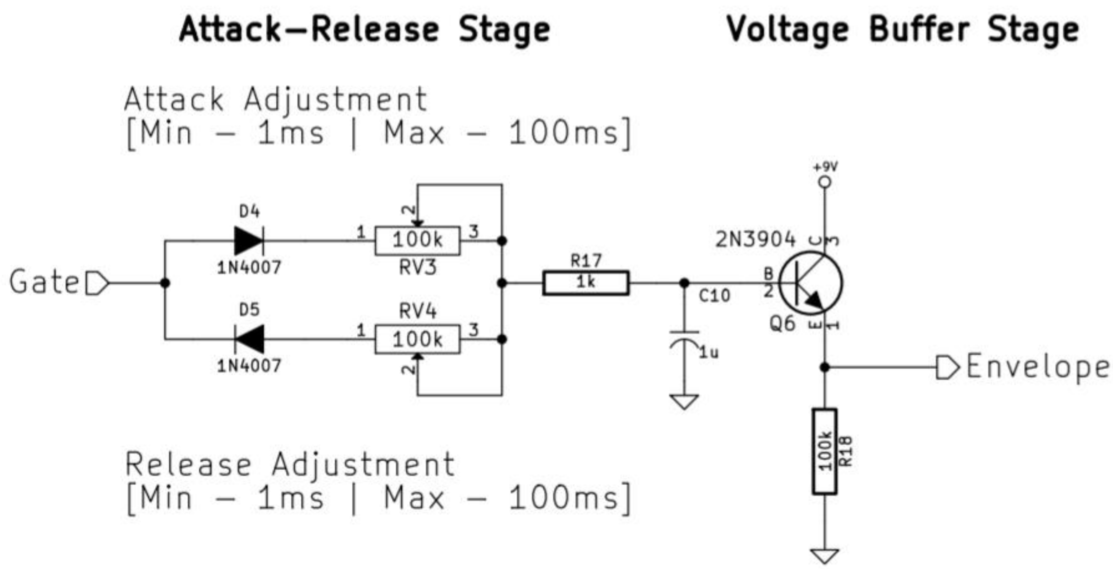
Figure 9. White Noise Output Signal



2.2.4 Attack and Release Envelope Generator

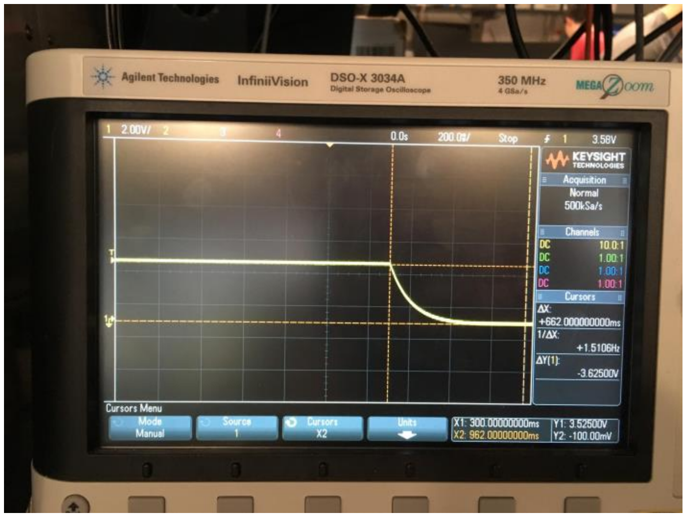
The goal for Attack and Release Envelope Generator is to generate a gradually increasing voltage during Attack State and generate a gradually decreasing voltage during Release State, and therefore reaching the goal of generate sound with changing amplitude, after several weeks of research, I finally made the circuit like this

Figure 10. Attack and Release Envelope Generator



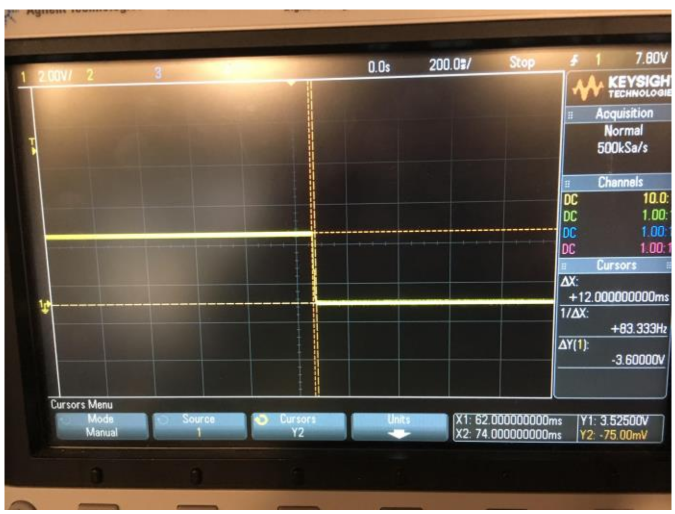
So, my idea is this, by setting the Gate to 4.5V, voltage across capacitor gradually increases, thus, before the voltage across capacitor hits the maximum, there is an increasing voltage across envelope, after the voltage across capacitor hits the maximum, the voltage output from envelope will stay the same. By setting the Gate to 0V, voltage across capacitor decreases, and some of the power in capacitor will be used to be outputted, but as voltage across capacitor decreases, the output voltage from envelope gradually decreases, and when there is no current in capacitor, no current will go through the envelope and thus the voltage from envelope will decrease. Furthermore, the amount of time that voltage increases in output envelope or decreases in output envelope depends on the resistance of two potentiometers, RV3 and RV4, the higher the resistance of RV3, the longer time for output voltage to rise from 0 to maximum value, and the lower the resistance of RV3, the shorter time for output voltage to rise from 0 to maximum value. Same as Release State, the lower the resistance of RV4, the longer time for output voltage from envelope to decrease from maximum voltage to 0, and the higher the resistance of RV4, the shorter time for output voltage from envelope to decrease from maximum voltage to 0.

Figure 11. AREG Output



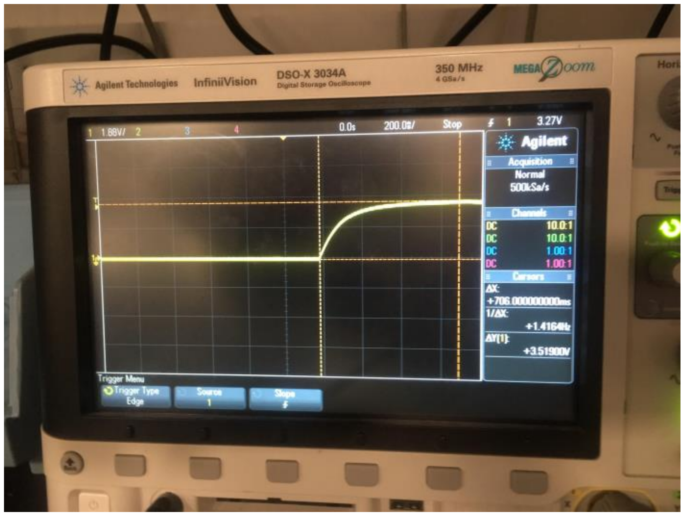
In Release state, voltage decrease from maximum value (3.52V) to 0V with 5% fluctuation within 700ms with 5% fluctuation if RV4 is set to position with lowest resistance, and 700ms is the longest time for voltage to drop from maximum to 0V.

Figure 12. AREG Output Low Resistance



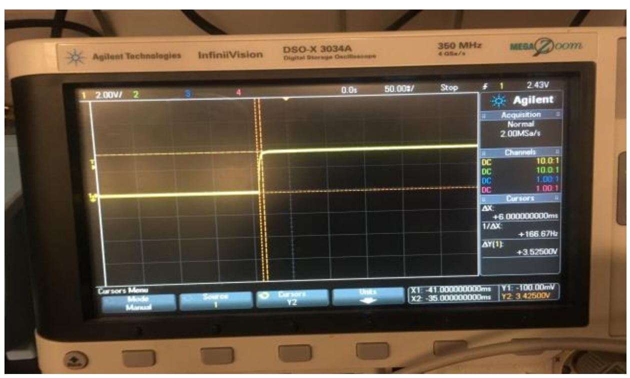
If RV4 is set to position with maximum resistance, the voltage drop from envelope will decrease from 3.52V to 0V with 5% fluctuation within 10 ms with 5% fluctuation, and that is the shortest time for voltage to decrease.

Figure 13. AREG Output High Resistance, Rise



In the Attack State, the voltage increases from 0 to 3.52V with 5% fluctuation within almost 700ms with 5% fluctuation if RV3 is set to position with highest resistance.

Figure 14. AREG Output, Rise



In the Attack State, the voltage increases from 0 to 3.52V with 5% fluctuation within approximately 10ms with 5% fluctuation if RV3 is set to position with lowest resistance.

2.3 Audio Output

The Audio Amplification Block is where the final processing of the Effect Generation waveform will be amplified for the user to be able to hear the effects they generate. The Audio Output block is comprised of The Voltage Controlled Filter, The Voltage Controlled Amplifier, and The

Audio Amplifier modules. The waveform produced by the AREG will be used to control the VCA 2N3904 transistor to add the reverberation effect if desired, or the VCA will be bypassed and the output of the VCF will be sent directly to the Audio Amplifier where it will be output from the speaker.

2.3.1 Voltage Control Filter

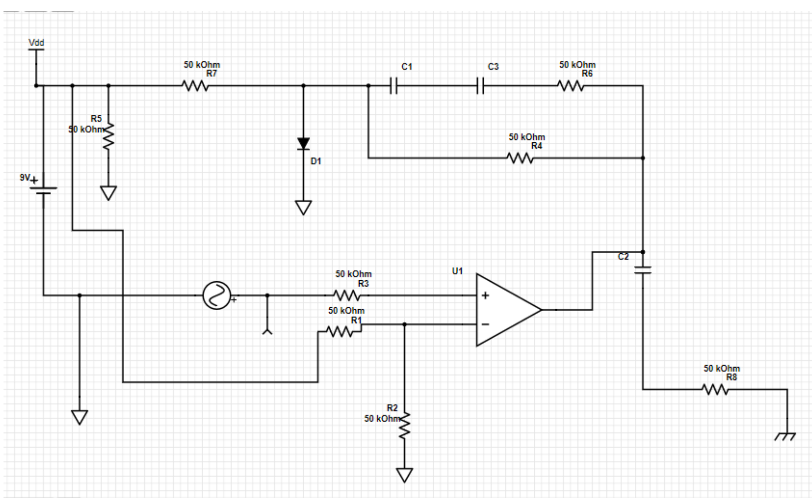
The voltage-controlled filter is the module that will smoothen the input of frequency and voltage from the user and will make use of any of the three filters - bandpass, high pass and lowpass. The input voltage will have a potential difference of 9 V between it and the ground, or in other words, (+/-4.5V). Like the VCO, we will accept 1 V of input, and for every extra 1V of input, the frequency will double exponentially for the exponential input, but increase at a constant rate with a linear CV input. Design alternatives for this module are difficult to decide, due to this module being used for industrial purposes other than the project we created, and due to our current design being barely viable for use and functioning outside of this project.

Equations used:

$$V = I*R \tag{2.12}$$

$$F = 1 / (2*Pi*R*C) \tag{2.13}$$

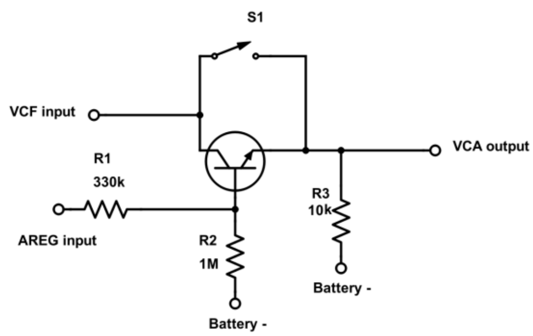
Figure 15. VCF Circuit



2.3.2 Voltage Controlled Amplifier

The voltage-controlled amplifier, Figure 16, chops up an input signal to the emitter of the transistor at the frequency of the control signal, the attack and release envelope detector in our case, which causes the signal to have a reverberation effect [11]. The forum we looked at recommended a one Megohm resistor in series with the base and ground to limit the current to the base as well as a 330 kiloohm resistor in series with the voltage control signal and the base of the transistor [11]. For ease, we started with those values for the resistors and simulated the circuit with the control voltage of a square with a peak to peak voltage of nine volts. we used a sinusoidal wave as the input of the circuit for simulation just to verify that the circuit would work for oscillating signals. Using a ten kiloohm resistor as the load the simulation, seen in figure 16, worked out nicely, thus we decided to stay with those resistor values as they worked for our overall circuit Figure x. we added in a switch to bypass the transistor to allow this effect to be optional. Some other designs we saw used a multitude of op amps and transistors for a much robust and a less noise signal, however, for our purposes, the design we came up with was more than adequate to generate our effect as well as being smaller and much cheaper to build.

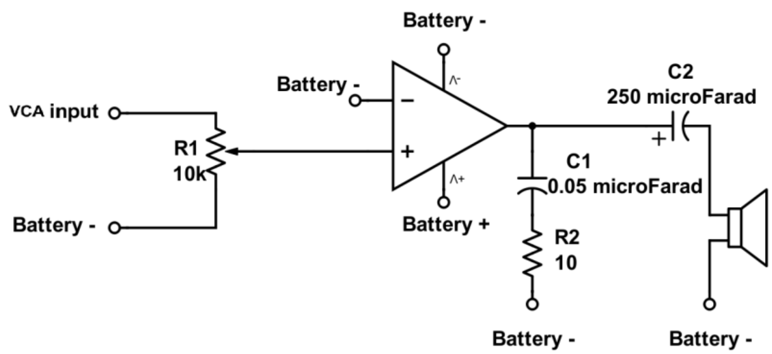
Figure 16. Voltage Controlled Amplifier



2.3.3 Audio Amplifier Circuit

The Audio Amplifier circuit, Figure 17, design was recommended in the Texas Instrument LM386 datasheet [13]. The required load impedance of for the circuit must be within a range of 4 to 32 ohms, which we decided on a speaker with 8 ohms impedance to fulfill that requirement. The general setup has a basic gain of 20 dB in this configuration. We could have increased the gain further by adding a 10-microfarad capacitor across pins 1 and 8 of the chip to increase the gain to 200 dB [13]. However, that was unnecessary as it was loud enough to hear the sound. Now, there are many Audio Amplification chips out there, but we chose this due to it being a low power chip, which is perfect for battery operations, and it fit the basic needs for this project cheaply.

Figure 17. Audio Amplifier Circuit



3. Design Verification

3.1 Power Supply

The power supply consists of a 9-volt battery and voltage regulator circuit needed to create our virtual ground. The battery can be checked with a digital multimeter to confirm that it is nine volts.

3.1.1 Voltage Regulator

The voltage regulator has a virtual ground which allows our circuit to have the required voltage to power the op amps, see Table 2, needed in our circuit. To test the voltage regulator, we just used a digital multimeter to see if we had the (+/-)4.5 volt that we required. This system worked and was straightforward in design.

3.2 Effect Generation

The effect generation block is comprised of our voltage-controlled oscillator, low frequency oscillator, attack and release envelope generator, and the white noise generator.

3.2.1 Voltage Control Oscillator

The VCF will modulate an input voltage to get a waveform corresponding to a desired frequency and a shape corresponding to a desired sound type. It will accept a voltage of 1 V, with a corresponding waveform frequency of 100 Hz, and it will make the waveform have an even shape. We can measure this on the oscilloscope, where we probe a selected input and output point on the module and compare the input and output waves to check if they are really removing the harmonics, i.e., the wave is evenly shaped.

3.2.2 Low Frequency Oscillator

The low frequency oscillator, see Table 3 for RV table, needed to be able to generate three types of waveforms, square wave, differential square wave, and integrated square wave. To test the circuit, we used an oscilloscope to measure the output of this module to see the waveforms being produced. Now, this circuit worked on the breadboard before we built the PCB. Unfortunately, it did not work once on the PCB. Unsure of what was wrong, we rebuilt the circuit on the breadboard, using the PCB schematic, and retested the circuit to verify that we did not make a mistake. The circuit did work on the breadboard, so we figured we burnt up the chip when soldering it on the board. We soldered on our second chip and retested the circuit; however, it still did not work. This leads us to believe that there is an issue with the PCB itself, as every point we checked had the voltages we were looking for, except that the op amp did not oscillate.

3.2.3 White Noise Generator

The white noise generator, Table 4 in the appendix, needed to produce a signal of one to three volts peak to peak of a random signal. To verify this, we used an oscilloscope to look at the output waveform from this module which showed us the randomly generated signal from the transistor.

3.2.4 attack and release envelope generator

We can verify the output by setting input gate to 4.5V, then if we can see a gradually increasing voltage curve on oscilloscope, then we get what we expect in Attack State, and if output is set to 0V, then if we can see a gradually decreasing voltage curve on oscilloscope, then we get what we expect in Release State.

3.3 Audio Output

The audio output circuit is comprised of our voltage-controlled filter, voltage-controlled amplifier, and the audio amplifier circuit.

3.3.1 Voltage Control Filter

The VCF will remove unwanted harmonics from the input signal, which makes it a subtractive synthesis element [11]. It will accept a voltage of 1 V, with a corresponding waveform frequency of 100 Hz, and it will make the waveform have an even shape. We can measure this on the oscilloscope, where we probe a selected input and output point on the module and compare the input and output waves to check if they are really removing the harmonics, i.e., the wave is evenly shaped.

3.3.2 Voltage Controlled Amplifier

The voltage-controlled amplifier, Table 7, needed to be able to split up the input waveform from the voltage-controlled filter at the frequency of the attack and release envelope generator. To verify this, we used an oscilloscope to measure the output wave from and the attack and release waveform to see if the signal was being split up as desired for the reverberation effect.

3.3.3 Audio Amplifier Circuit

The audio amplifier circuit, Table 8, takes the given waveform from the voltage-controlled amplifier and then amplifies the sign to be audible to the user of the device. To verify that this circuit is performing within specifications, we use an oscilloscope to measure the output waveform and the input waveform. We then look at the frequency of the waveform output to the speaker as well as checking the input-output voltage ratio. If the voltage ratio is between one to ten, then we have the proper range, zero to 20 dB, for the volume.

4. Costs

4.1 Parts

Table 1. Cost of Device

Part	Description	Amount	Cost each ($)	Total cost ($)
Resistors	¼ watt (5%)	32	free	0.00
LED	Red, 5mm	1	0.35	0.35
LM324N	Quad low power op amp	2	0.52	1.04
LM386	Low power audio amp	1	0.35	0.35
Potentiometers	¼ W 1M to 100K	4	0.75	3.00
Capacitors, Ceramic	16V, (+/-10%)	9	free	0.00
Capacitors, Electro	16V, (+/-10%)	4	free	0.00
Switches	SPST, SPDT	3	2.00	6.00
Speaker	8 Ohm 1 Watt	1	3.00	3.00
Battery	9V	1	3.35	3.35
Battery Snap	Connector	1	4.07	4.07
2N3904	NPN transistor	4	0.06	0.24
Total	-	-	-	21.40

4.2 Labor

Assuming an average salary of $60,000 a year working a 40-hour work week,

$$\frac{60{,}000}{52*40} = \$28.8\ per\ hr \qquad (4.1)$$

Gives us $28.8 an hour. Rounding that up to $30 an hour, with the 16 weeks to work on it at around 10 hours a week,

$$30*10*16 = \$4800 \qquad (4.2)$$

Next, we multiply by the 2.5 scaling factor given to us and by 3 for each member,

$$4800 * 2.5 * 3 = \$36000 \qquad (4.3)$$

Gives us $36,000 for labor costs alone. Adding together the Table 1 total and the total for labor costs,

$$36{,}000 + 21.40 = \$36{,}021.40 \qquad (4.4)$$

5. Conclusion

5.1 Accomplishments

If we can speak of any accomplishments that we made during this project, we would say that those were all made only during the intermediate stages of its design and production. One example could be when we tested individual modules on the breadboard. Because we previously had an existing knowledge of circuit analysis and breadboarding, we were easily able to wire our circuits on the breadboard and verify that they worked with very few errors, and if they existed, we were easily able to identify them and fix them in time. Our PCBs also passed the audit from PCBway, which produced our PCBs, which were delivered to us, which also could be considered an accomplishment, although later, soldering them turned out to be a challenge, which we will explain in the next paragraph.

5.2 Uncertainties

If we would say anything about the number of uncertainties/errors involved in the production and design of this project, we would say that were many, which resulted in our project not working in the end. During the final integration of our project, we noticed that our circuits were too large and were being soldered on boards that were too small to hold them, and we made many systematic errors in wiring them together and soldering the PCBs. Over time, our PCBs, especially the ones that were soldered long before the others, suffered from wear and tear and the effects of natural external disturbances such as wind and heat, which electricity and electronics are vulnerable to, and thus this caused our circuit connections and functioning to become so faulty that they ended up not functioning on the day of the final demo.

5.3 Ethical considerations

There were many ethical considerations that we had to obey, as stated in the IEEE Code of Ethics. The production, design and development of this product required us to do so. We worked in a team consisting of members hailing from different races, ethnicities, religions, disabilities, economic backgrounds and other distinguishable personality features, whether immutable or not. We had to pay attention to the level of safety standards required when designing our product, so that when shipped to the public, individuals who had purchased the product and used it would not be at an avoidable risk of being physically harmed. Our product design also had to maintain a significant amount of originality, so that it did not put itself at risk of being subject to lawsuits by other companies that may have coincidentally created the same product before we did.

5.4 Future work

As of now, since our project was not industrially spectacular, both in our design and in our final demonstration results, we would say that this project would serve as a learning experience for us when we join the industry or possibly, academia. Perhaps, since we were not creative or knowledgeable enough to create a more advanced and meaningful product this time, we will certainly be required to design more sophisticated products that this project may have been a rudimentary unit of, such as a 500-tone synthesizer or a pair of noise-canceling headphones. We will implement this later if we are able to join design teams at companies such as Bose, Sony, Yamaha, or other globally reputed electronic design firms. Thus, all we can say is that our future work consists of designing more sophisticated products conceived by top-level employees at multinational electronic firms that we may later end up working for after graduation.

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Appendix A Requirement and Verification Table

Table 2. Voltage Regulator RV Table

Requirements	Verification	Verification Status (Y or N)
1. The voltage regulator will have an output voltage of +/- 4.5V (+/-5%).	1. We will use a voltage meter to test the output points, Battery - and Battery + (Figure 2) with reference to the virtual ground.	Y
2. The output from the voltage regulator to ground will be able to support the needed 0.7 mA required to power the LM324N op amp [12].	2. We will measure the current output to the LM324N op amp with an ammeter to test if the current draw is near 0.7mA required to power the LM324N op amp.	Y

Table 3. Low Frequency Oscillator

Requirements	Verification	Verification Status (Y or N)
1. The LFO must provide modulation waveforms of Square, Differentiated Square, and Integrated Square as the output signal within an amplitude of +/-4.5V at a frequency range of 0.5 Hz to 230(+/-10%).	**1.** A. With the use of an oscilloscope, you can probe across a resistive load of 100k Ohms to see a square wave with +/-4.5V (+/-5%) with S1(Figure 4) closed(Square) and a frequency of 1.4Hz, setting potentiometer to 470k Ohms. B. Using the same load and potentiometer resistance, probe across the load to see a differentiated square waveform +/-9V (+/-5%) when S2(Figure 4) is set to open and S1 is set to the upper pole(Differentiator). C. With the same load potentiometer resistance, probe across the load when the S1 set to lower pole (integrator).	**A. Y** **B. Y** **C. Y**

2. The module must be able to provide the modulation waveform to the VCO as well as the VCF when wanted.	**2**. see the same waveform at LFO sync (Figure 4), using a separate 100k ohms load, as the resistive test load.	**Y**
3. The LFO must have a LED that will blink at the of the frequency the LFO output.	**3.** Using an oscilloscope to probe L1 (Figure 4) and confirm the current pulses match the output frequency across the test load of 100k ohms.	**Y**

Table 4. White noise generator

Requirements	Verification	Verification Status (Y or N)
1. The white Noise Generator will be able to produce a random static signal of 1.5V (+/-10%)	**1.** With the use of an oscilloscope, we will probe the node labeled white noise output (Figure 7) with reference to the Battery - terminal (Figure 7).	**Y**
2. The Gain of the second 2N3904 transistor will be 250(+/-10%).	**2.** To measure the gain of the 2N3904 transistor, we will measure, using an ammeter, the collector current through R3(Figure 7) and the base current through R1(Figure 7). We then divide the collector current by the base current for the gain value.	**Y**

Table 5. Voltage Controlled Filter

Requirement	Verification	Verification status (Y or N)
1. Removal of unwanted harmonics from the input signal a. Subtractive synthesis element should be the identity of the module b. We want an even output shape of the waveform after inputting 1 V and getting a 100 Hz waveform	1. Use lab test bench equipment a. Probe the appropriate corresponding input and output points on the module circuit to check if the right input and output waveform shapes are being generated	Y

Table 6 System Requirements and Verifications for VCO

Requirement	Verification	Verification status (Y or N)
1. Input a voltage and output a corresponding frequency wave of a certain shape a. Accept four types of inputs: exponential, linear, PWM and sync b. If we input 1V, we will get a 100 Hz output wave c. Frequency should be	1. Make use of lab test bench equipment a. Probe the appropriate points on the circuit which correspond to the output and input of the module b. Check on the oscilloscope if the right shape and frequency of	Y

modulated using a potentiometer	the output is being produced c. Adjust the potentiometer and check if the input voltage and output frequency is increasing	

Table 7. Voltage Controlled Amplifier

Requirements	Verification	Verification status (Y or N)
1. The VCF current cannot exceed 200mA	**1.** To verify this, we will use an ammeter to measure the current into VCF input (Figure 16).	**Y**
2. The output waveform must be modulated to the frequency of the AREG if the effect is desired.	**2.** To verify the output waveform is being properly modulated, being turned on and off at the frequency of the AREG, we will use an oscilloscope to see the AREG input (Figure 16) with reference to Battery -(Figure 16), and VCA output (Figure 16) with reference to Battery -(Figure 16). We will then vary the AREG output frequency to see the effect.	**Y**

Table 8. Audio Amplifier Circuit

Requirements	Verification	Verification status

		(Y or N)
1. The speaker must have an impedance in the range of 4 to 32 ohms [13]. **2.** The sound produced will be loud enough, 20 Db, to hear the waveform produced by the system.	**1.** To verify this, we will use a multimeter to measure the impedance across the terminals of the speaker (Figure 17). **2.** To verify the sound is loud enough to hear, we will turn the device on and generate a fixed square wave signal at a frequency of 200Hz (+/-15%) which we will use an oscilloscope to measure the VCA input (Figure 17) with reference to Battery -(Figure 4) and then measure the voltage across the load to calculate the Db output.	**Y** **Y**

Table 9: Attack and Release Envelope Generator

Requirements	Verification	Verification status (Y or N)
	1. 9V DC battery will be	Y

1. For the attack state, when (A) RV3 and RV4 are set to positions with maximum resistance, we should see a voltage rise from 0V to 3.52V with variance of 5% within 700ms with variance of 10% (B) RV3 and RV4 are set to positions with minimum resistance, we should see a voltage rise from 0 to 3.52V with variance of 5% within 10ms with variance of 10%. 2. For the release state, when (A) RV3 and RV4 are set to positions with maximum resistance, we should see a voltage drop from 3.52V to 0V with variance of 5% within 700ms with variance of 10%. (B) RV3 and RV4 are set to positions with minimum resistance, we should see a	used as power input to my circuit. There are two power inputs: 9V to power up the transistor and 4.5V to be connected to input gate controlled by a button. 2. Output is connected to oscilloscope. 3. When RV3 and RV4 are set to positions with maximum resistance, and input gate is connected to 4.5V, we should see a voltage rise from 0 to 3.52V with variance of 5% within 700ms with variance of 10% and when RV3 and RV4 are set to positions with minimum resistance, we should see a voltage rise from 0 to 3.52V with variance of 5% within 10ms with variance of 10%. 4. When RV3 and RV4 are set to positions with maximum resistance and input gate is connected to the ground, we should see a voltage drop from 3.52V to 0V with variance of 5% within 700ms with variance of 10% and when RV3 and RV4 are set to positions with minimum	Y Y Y

voltage drop from 3.52V to 0V with variance of 5% within 10ms with variance of 10%.	resistance and input gate is connected to the ground, we should see a voltage drop from 3.52V to 0V with variance of 5% within 10ms with variance of 10%.	