The Shimmer Effect Box

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Abstract

A shimmer effect box was constructed using two main circuits: a 1/*f*-noise producing circuit, and a phase shifting circuit. The 1/*f* noise is very musical as humans relate well to it, and it can provide a warm sound. The noise falls as 1/*f* with increasing frequency. The phase shifting circuit was built using strategic placing of a voltage controlled resistor and a capacitor on the positive inputs to an op amp. The circuits built did produce 1/*f* noise and a phase shifted signal. Some improvements can be made on the design. While the effect is not extremely obvious, it does have an effect and sounds pretty.

I. Introduction

A circuit was constructed so that a "shimmer" effect would be produced with a guitar. This effect is a stereo effect that requires two guitar amplifiers. The basic principle is that there is a direct output into one amplifier and a phase shifted signal of the same amplitude in the other amplifier. The stereo effect gives the illusion that the notes are quickly passing back and forth from the two amplifiers, giving a spatial quality to the sound. Since it is a quick effect, there is no noticeable amplitude of the tones that goes in and out of the two amplifiers. Instead, there is a "shimmer" effect that nicely enhances the tones heard. Two main components of the effect are the 1/*f* noise that kicks the voltage in the second part, which is the phase-shifting component. I will discuss the two components further in this report.

The 1/*f* Noise

I have spent considerable time researching 1/*f* noise, specifically in carbon composition and thick film resistors, while writing my senior thesis [1]. Notably, 1/*f* noise is a voltage noise that falls as 1/*f* with increasing frequency. That is, for every decade increase in frequency, a decade decrease occurs in the noise. The noise is measured in V_{rms}^2/Hz. On a log-log plot, the noise appears linear with a slope = −1. While many theories behind 1/*f* noise have been proposed, no one theory explains the physics completely. Since frequency and time are inversely proportional, the noise is greatest at long timescales. Specifically, the charge carriers have long term time correlations with each other [2].

Why do we care about 1/*f* noise? Humans respond well to 1/*f* noise. Raindrops fall as 1/*f* patterns as well as blood flowing through veins and electromagnetic brainwaves. Since 1/*f* noise is so innate to people, other things that appear as 1/*f* can be musical.

Motivation

Since spending time with 1/*f* noise, I wanted to pursue some of the musical aspects of it. In my previous research, I studied it but never heard it. Since I am a guitar player, I wanted to see how the effects of 1/*f* noise could be applied to a guitar effect. Being applied to a guitar sound, the 1/*f* noise would be a warmer sound because of the higher-level low frequency noise.

Another part that was potentially interesting was having a stereo effect along with the 1/*f* noise. Since the noise is a voltage, the noise could kick a voltage controlled resistance, which offers a phase shifting effect. More explanations on that will be explored later in this report.

II. Theory

The Varistor

A varistor is a voltage dependent resistor. It acts as a resistor at constant voltage. However, at different voltages, the resistance value changes. This phenomenon can be probed by examining a voltage-current graph as in **Figure 2-1**.

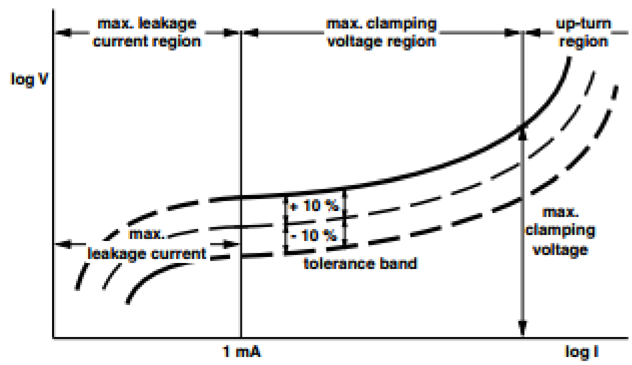

Figure 2-1: *A graph of the voltage as a function of current of a standard varistor. N.B. this varistor is not the same as the one used in the effect box. Image courtesy of [3].*

Looking at Ohm's law, we know that $V = IR$, where *V* is voltage, *I* is current, and *R* is resistance. As a function of current, voltage should be linear, with the slope *R*. However, looking at **Figure 2-1**, voltage is clearly non-linear. Thus, *R* is not a constant, but a voltage dependent resistance. Such is the resistance of the varistor.

Additionally, varistors are known to produce $1/f$ noise as has been shown experimentally many times such as in [4]. The structures of the grains inside the varistor and the quality of the grains produce $1/f$ noise. In fact, the lesser the quality of varistor, the more $1/f$ noise will be produced. Some of the high quality varistors do not produce $1/f$ noise at all [4]! The varistor used in the construction of the effect box came out of an old rotary telephone, which presumably did not have very high quality. Because the varistor produces $1/f$ noise, it is an ideal candidate for the $1/f$ noise producing component of the circuit.

Stereo Modulation

As is discussed in [5], circuits can be constructed to produce a phase shifted signal. Based on the schematic in **Figure 2-2**, the output voltage, v_0 has voltage [5]:

$$v_0 = -\frac{1-i\omega CR}{1+i\omega CR} v_g \qquad \textbf{(Equation 2-1)}$$

In the diagram, $C = 0.1\mu F$ and $R = 10\ k\Omega$, and ω represents the frequency of the incoming AC signal. The actual values used in the construction were different. Here, the coefficient of v_g has a modulus of 1, which means that the amplitudes of v_0 and v_g are the same. This fact is because the gain of the op-amp is 1 since the resistors on the negative input of the op amp are the same.

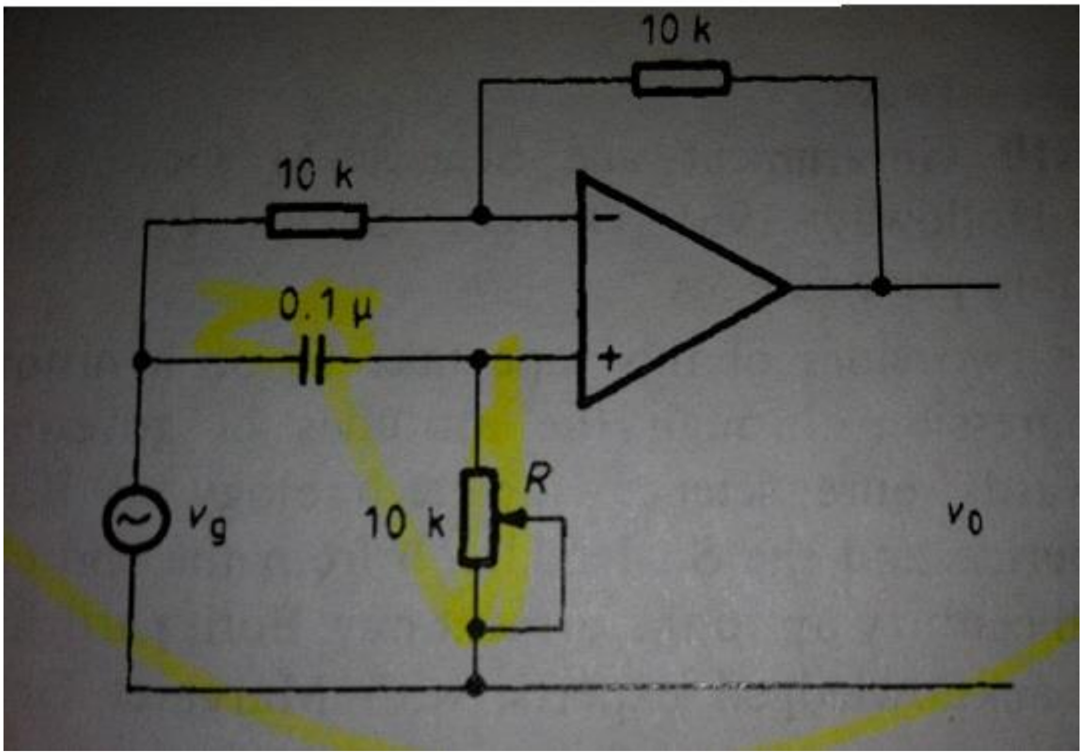

Figure 2-2: *Schematic of the simple phase shifter. Image courtesy of [5]*

Since the output voltage is described by **Equation 2-1**, we can further describe the voltage in convenient ways as follows below [5]:

$$v_o = e^{i\phi} v_g \quad \textbf{(Equation 2-2)}$$

Where φ represents the phase shift given below [5]:

$$\phi = \tan^{-1} \frac{2\omega CR}{(\omega CR)^2 - 1} \quad \textbf{(Equation 2-3)}$$

This is to say that the phase shift of the output signal is dependent on the frequency, the capacitance, and the resistance on the positive input of the op amp. The phase can be controlled by placing certain values for the capacitance and resistance. However, in **Figure 2-2**, the resistor is shown to be a voltage controlled resistor. Thus, by varying the voltage on the resistor, a different phase shift can be attained. This method is precisely the method we used, so that the so-called “sweet spot” of resistance could be found by varying the resistance value.

It is also very important to note that the frequency of the incoming AC signal also affects the phase shift. This means that different notes played by the guitar will have different phase shifts. It is especially interesting when playing chords. The different notes of the chord will have different phase shifts, and will have different spatial quality when listening from two guitar amplifiers.

A similar circuit to that in **Figure 2-2** is shown in **Figure 2-3**. However, the voltage controlled resistor is the junction field effect transistor (JFET). Whatever the resistance of the JFET is corresponds with the *R* in **Equation 2-3**. This is more similar to what was used in the effect box.

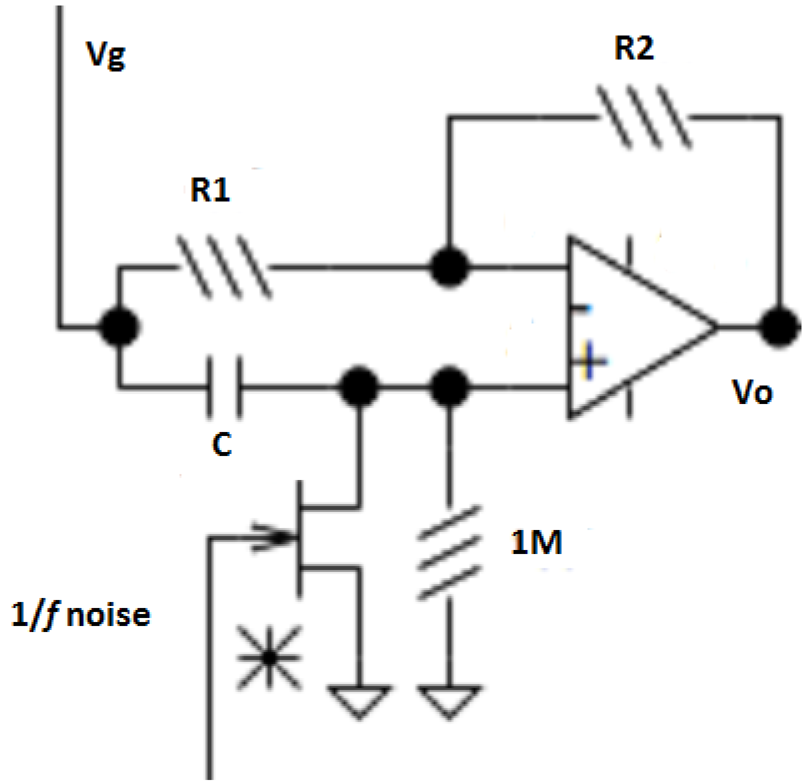

Figure 2-3: *An example of a circuit like in* ***Figure 2-2*** *that uses a JFET as the voltage variable resistor. This schematic came from the Oberheim PS-1 Phase Shifter.*

The FET as a Voltage Controlled Resistor

Here, we are using a 2N5485 FET as a voltage controlled resistor. The FET has two operating regions: the linear region and the saturation region. Here, we are using it in the linear region to be a controlled resistor. The equation that satisfies that is given below [6]:

$$\text{For } V_{DS} < V_{GS} - V_P: I_D = k[2(V_{GS} - V_P)V_{DS} - V_{DS}^2] \quad \textbf{(Equation 2-4)}$$

Where V_{DS} is the voltage difference from the drain and the source, V_{GS} is the voltage difference between the gate and the source, V_P is the minimum gate voltage, and *k* is a constant. The source is grounded. If we know the current on the drain and the voltage applied to the gate, we can figure out the resistance. This will vary with the voltage applied to the gate.

III. Procedure

The 1/*f*-Noise Producing Circuit

This circuit, which is featured in **Figure 3-1,** is similar to the data acquisition system in [1].

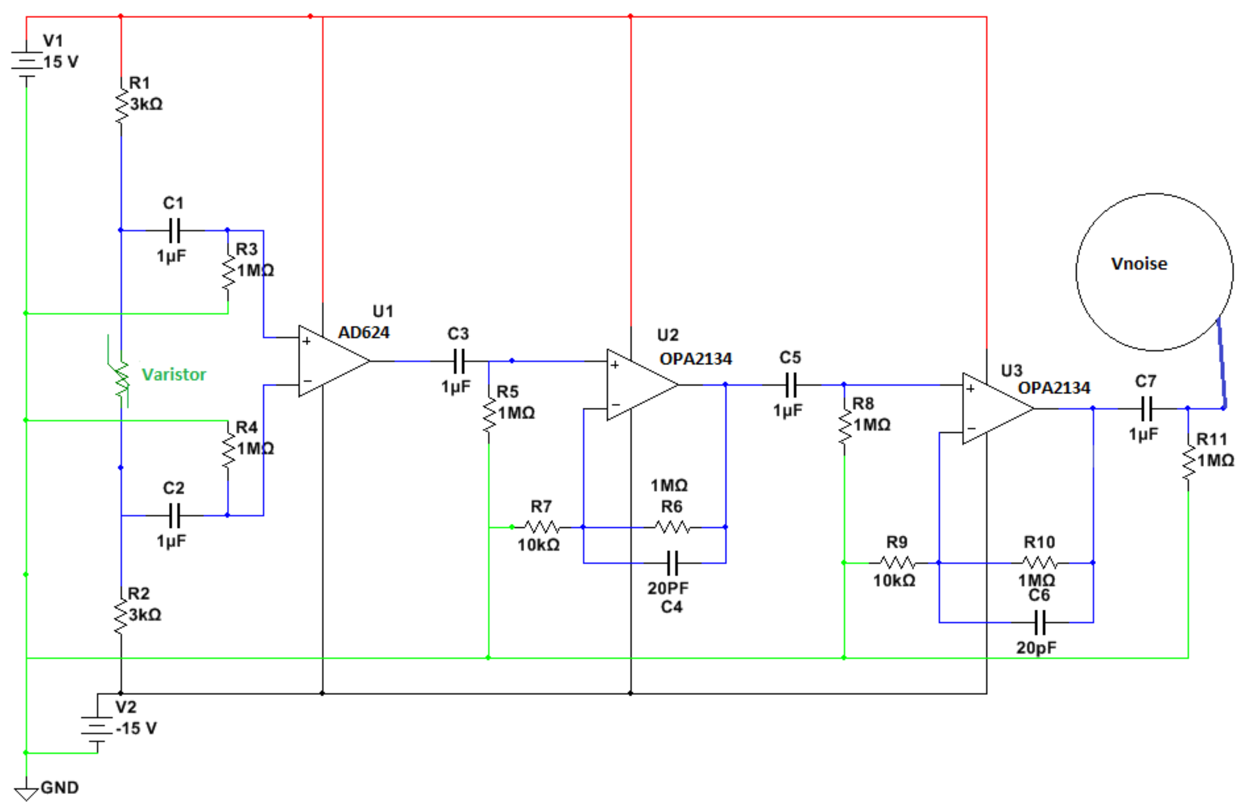

Figure 3-1: *The 1/f-noise producing circuit.*

Here, the varistor is producing the noise voltage, which goes into the AD624 [7]. Originally, the INA212 was used, but AD624 was placed instead. The AD624 has a gain of 100x through a connection on the chip. The signal then goes into two op-amps, the OPA2134 [8]. Each of these op amps has a gain of 100x because of the 10 kΩ and 1 MΩ resistors on the negative input to the op amp. The amplified noise then goes into the phase shifting circuit, which drives the FET.

The Phase Shifting Circuit

As explained above in **Figure 2-3**, the phase shifting component has the capacitor and voltage controlled resistors placed strategically. Here, it is highlighted in **Figure 3-2** below.

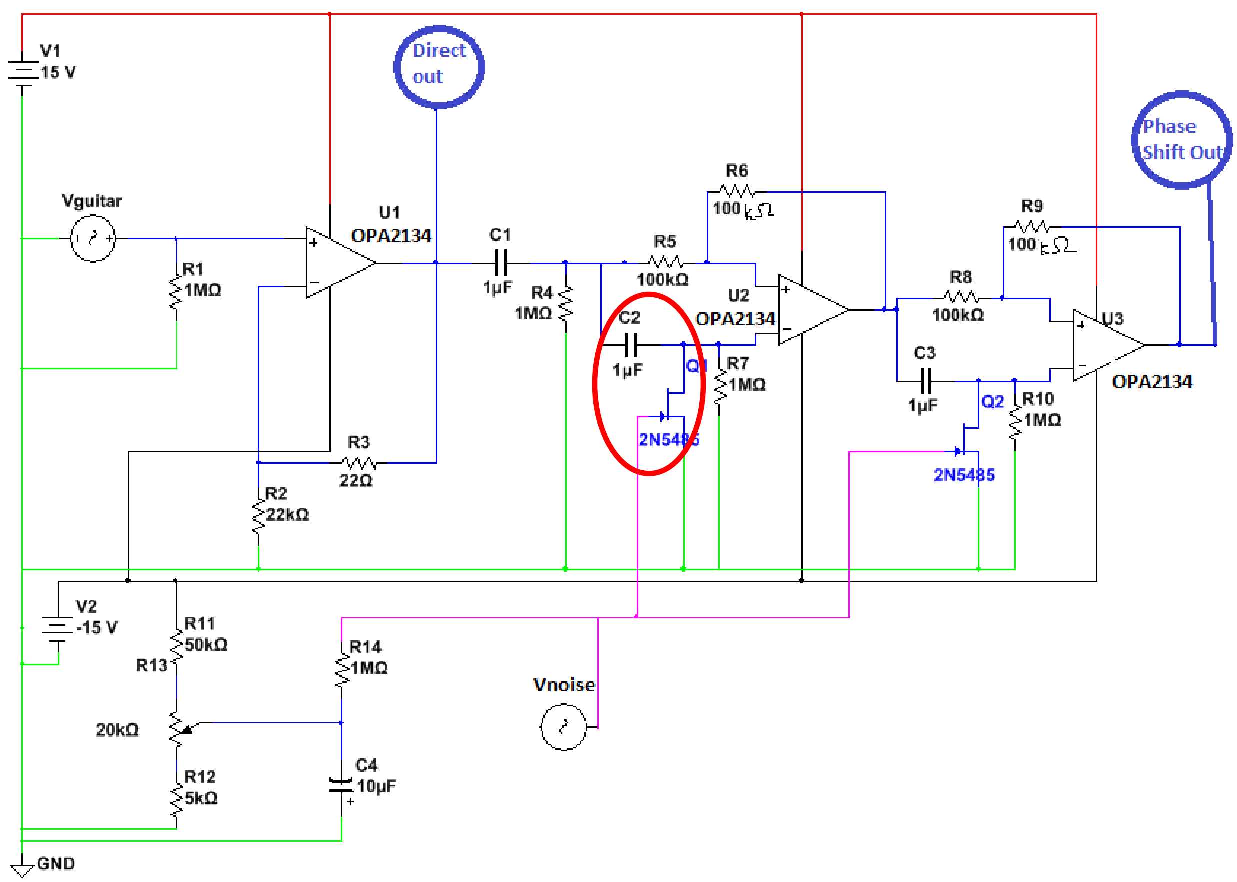

Figure 3-2: *The phase shifting circuit. In the red circle is the strategically placed capacitor and resistance value from the FET.*

Here we have a guitar signal being amplified by the OPA2134 labeled by U1 in the figure. This has a gain of two on there, but the resistor R3 would likely be an audio grade potentiometer so that we can control the volume of the guitar. The signal then goes into the phase shifting stages. Here, we have two stages, which have no gain. We have the 1 MΩ resistor to ground in front of the negative input of the op amps so that if the FET turns off, there is still some resistance driving the op amp. The pink line represents what drives the FET. We used a 2N5485 FET [9]. The potentiometer has a middle point of 20 kΩ, but can be changed. Changing this resistance changes the voltage applied to the FET, which changes the resistance of the FET. In turn, it changes the phase shift of the circuit. Each FET was carefully chosen so that they are likely to behave in the same manner when they are driven at the same voltage. The noise also drives the FET and the long term time correlations jumps the phase shifted signal around, creating a warm sound.

IV. Results

The 1/*f* Noise

The 1/*f* noise was measured in a similar way to that in [1]. The circuit that produced 1/*f* noise was built and tested separately from the phase shifter circuit. The Agilent 35670A dynamic signal analyzer was used to measure the noise. The following diagram shows the noise for the circuit.

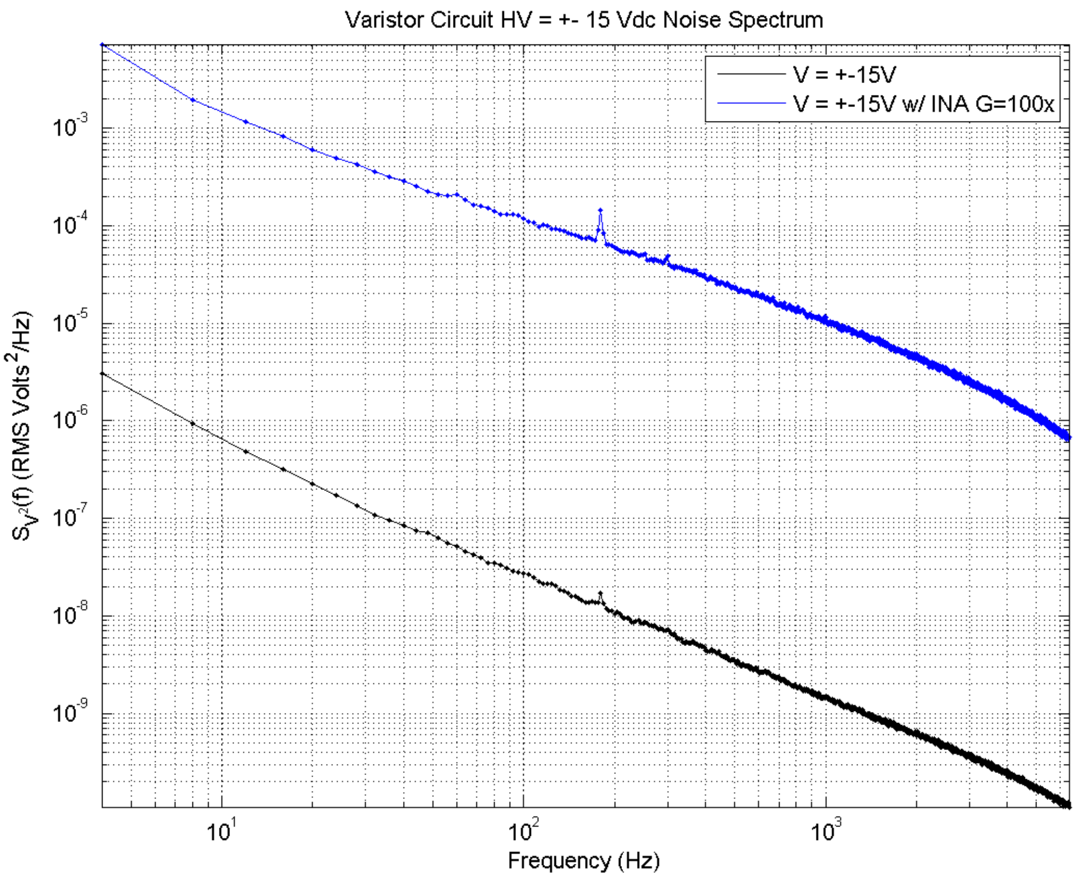

Figure 4-1: *The spectrum of 1/f-noise producing circuit. The black curve is without the gain on the first op amp, and the second curve is with a gain of 100x.*

In **Figure 4-1**, we see that the circuit generally produces 1/*f* noise. The black curve shows the noise with no gain on the first op amp stage, and the blue curve shows the noise with it. As was previously mentioned, the INA212 had been previously used. These data were taken with the INA212 op amp instead of the AD624. The noise should however, be the same as the AD624 had a gain of 100x as well. As can be seen particularly in the range of 100 Hz to 1 kHz, the blue curve's noise decreases in one decade, showing 1/*f* noise. At higher frequencies, there is a stronger fall off than 1/*f* noise, but generally speaking, the curve is 1/*f*.

The Final Product

The 1/*f*-noise producing circuit was then placed into the phase shifter circuit. The results from using a function generator can be seen in **Figure 4-2**.

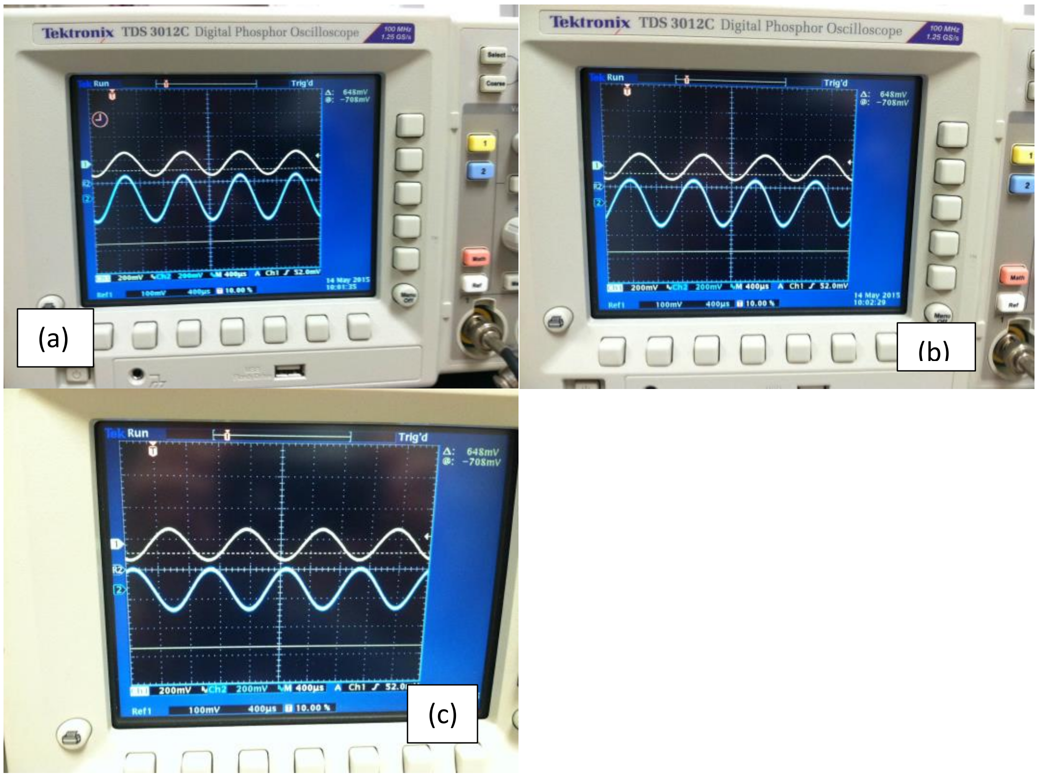

Figure 4-2: *Screen shots of the output of the circuits on an oscilloscope. Yellow indicates direct output and the blue indicates the phase-shifted output. (a) The curves are in phase, (b) The curves are slightly out of phase, (c) The curves are 180° out of phase.*

The function generator used produced an output sine wave at 1 kHz with a peak-to-peak voltage of 100 mV. The potentiometer was adjusted to get these different images. In **Figure 4-2.a**, the curves are in phase. In **Figure 4-2.b**, the curves are slightly out of phase, and in **Figure 4-2.c**, the curves are 180° out of phase. The potentiometer's resistance is different for all three. The 1/*f* noise is not well represented here as the main effect of the noise was that it made the output jump around. So instead of sitting nicely at each image, the noise made it so the blue curve was shaking around. This does have an effect on the output sound.

V. Potential Improvements

Many improvements could have been made to better the sound of the effect box. The gain of the 1/*f* noise producing circuit could have been higher to increase the effect of the 1/*f* noise. The signal was a little weak compared to what would have been ideal. In this design, only two gain stages on the phase shifting circuit were built. Adding more stages would have more effect on the output phase shifted. A voltage follower right before R13 in **Figure 3-2** also would have improved the circuit. The output impedance of what was input to the voltage follower would be high, and the voltage follower could produce a low input impedance to the FET. The voltage follower is just a unity gain buffer driver that the construction just includes an op amp. In addition, a new FET was found that could replace the 2N5845. The Fairchild photo-FET optocouplers could be used instead that would eliminate the audible noise of the circuit. This noise is thought to be caused by the gate capacitance of the JFET. We could also have placed the phase shifting circuit on a PC board and put both boards inside of an actual box. We could have used pots on some of the gain to make them adjustable according to your ear.

VI. Conclusions

In all, I was happy with the outcome of the shimmer effect box. When playing a chord on a guitar, there was a definite effect that could be heard that produced a “shimmer”-like sound. While the effect is not extremely obvious and in-your-face, the effect does sound pretty. The use of the 1/*f* noise added warmth to the sound, and the phase shifting was evident. More work could be done to make it even better, but in all I was happy.

VII. References

[1] Barry, Patrick and Errede, Steven *Measurement of 1/*f *Noise in Carbon Composition and Thick Film Resistors*. Unpublished senior thesis. University of Illinois at Urbana-Champaign. 2014.

[2] Edoardo Milotti, 1/f noise: a pedagogical review. Dipartimento di Fisica, Universitá di Udine and I.N.F.N. – Sezione di Trieste. Via delle Scienze, 208—I-33100 Udine, Italy.

[3] Vishay, “Varistors Introduction,” Revised 9/4/2013.

[4] Hasse, Lech Z. et al. Quality assessment of ZnO-based varistors by 1/*f* noise. *Microelectronics Reliability* **54**: 192-199 (2014).

[5] Lopes, J. S. and Melo, A. A. A Simple Phase Shifting Circuit. *Phys Educ* **17**. 1982.

[6] Chapter 8: Field Effect Transistors, Part 3.

[7] Analog Devices, “Precision Instrumentation Amplifier,” AD624 datasheet, 1999.

[8] Burr-Brown, “High Performance Audio Operational Amplifiers,” OPA2134 datasheet, 1997.

[9] Fairchild Semiconductor, “N-Channel RF Amplifier,” 2N5485 datasheet, 1997.