ScopeTV: Decoding and Transmission of NTSC Video and Audio

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Abstract:

This project aims to convert an analog oscilloscope into a monochrome television that can accept NTSC video and audio output signals. The ScopeTV should consist of a sync separator/DC restorer, horizontal and vertical sweep generators, a video amplifier with brightness/contrast controls, and an audio amplifier with a volume control. By breaking down the circuit into functional modules, each module can be designed and tested separately before integration into the final circuit. The result is a low-cost and customizable ScopeTV that can display analog video signals that can be read by the Oscilloscopes CRO, and play audio through a speaker.

Introduction:

In the world of electronics, analog oscilloscopes are a common tool for measuring and visualizing electrical signals. But what if you could repurpose your oscilloscope to do something new? In this project, we explore how to convert an analog oscilloscope into a monochrome television, capable of displaying video signals and playing audio from external devices. By leveraging the existing X/Y/Z mode operation of the oscilloscope, we can construct a low-cost and customizable ScopeTV that can provide a unique viewing experience. The ScopeTV should be able to accept NTSC video and line-level audio output signals from external devices such as DVD players or VCRs. The video output should be displayed on the oscilloscopes CRO screen, while the audio output should played through a speaker. The video portion of the ScopeTV should present a 75-ohm load to the video output of the connected device and assume the video signal to be approximately 1Vpp and may be AC coupled. The video portion must be constructed using discrete components, op-amps, and other components. Using devices that simplify the video portion, such as using an LM1881 video sync separator, is not permitted. The audio amplifier should provide reasonable power in an 8 ohm speaker and present a 1000 ohm load to the audio output of the connected device. It is acceptable to use an IC such as the LM386 to implement the audio amplifier. Component values must be obtained by manual calculations and circuit operation must be verified using LTspice.

In addition to meeting the design specifications for converting an analog oscilloscope into a monochrome television (ScopeTV), the final product must also be mounted in a professional-style enclosure

The enclosure must include front panel-mounted volume and brightness/contrast controls for easy adjustment of the audio and video output. All signals to the scope must be via BNC connectors, while video and line audio input must be via RCA phono jacks. Power must be supplied via banana jacks. To ensure proper usage and prevent confusion, all connectors and controls must be labeled. All circuit boards must be securely fastened inside the enclosure, and all connections to switches, potentiometers, jacks, and other components must be soldered for stability and reliability.

NTSC Video Decoding:

In Figure 1 below, we can what a single "pixel" of NTSC video looks. Each pixel contains a horizontal sync, color bust, and color data which includes details such as wavelength/hue/amplitude. We are only interested in extracting the hsyncs, which occur briefly reaching -0.4v. We do not need the color data because our oscilloscope output CRO is monochrome. We can easily separate the hsyncs by using a comparator with reference voltage around -.35v, thus triggering a hsyncs output. For every 525 pixels/hsyncs, a vsync is transmitted and its pattern is show in Figure 2. We can see that the video color portion between the hsyncs is entirely empty, and the moment a vsync occurs, the signal is mostly a negative 0.4v square wave for a few clock cycles. We can use this information to charge up a capacitor such that when a vsync occurs, it reaches a sufficient voltage to trigger a comparator, thus generating a vsync. We can then generate their individual ramps triggered by the syncs, where hsync triggered ramp will be the X input to the oscilloscope and vsync triggered ramps will be the Y-input signal. The Z-input will be just the inverted waveform of the original NTSC Signal since the oscilloscopes Z axis is inverted. Changing the DC level of the Z input affects the brightness, while changing the peak to peak of the waveform changes the contrast.

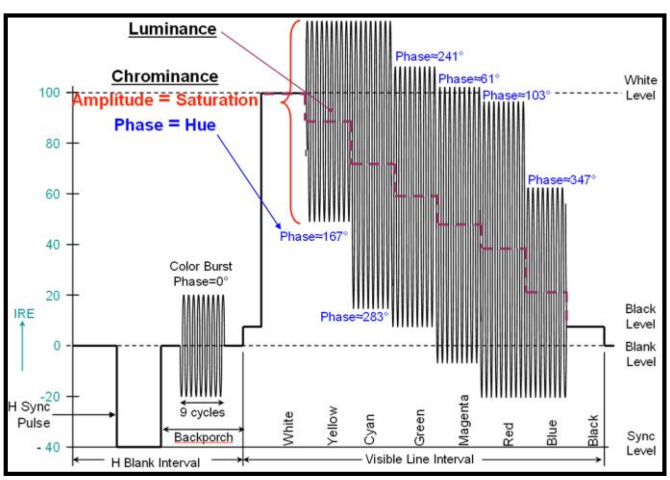

Figure 1: NTSC Video Signal

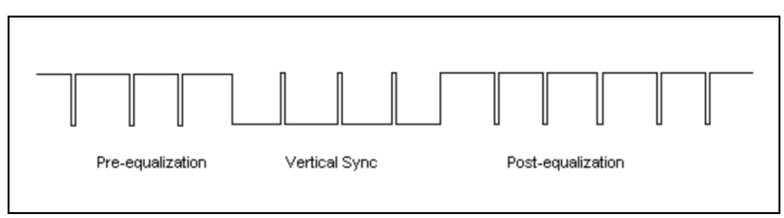

Figure 2: VSYNC Waveform

Block Diagram:

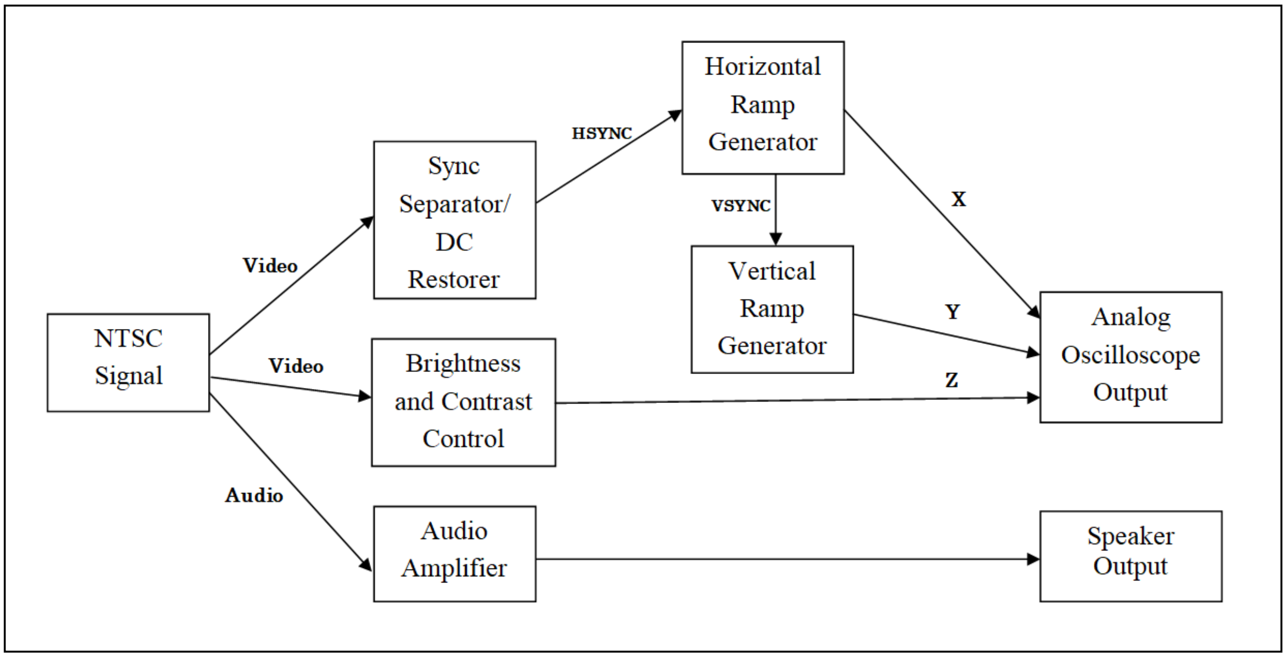

Figure 3: Block Diagram of ScopeTV

Schematic Diagram:

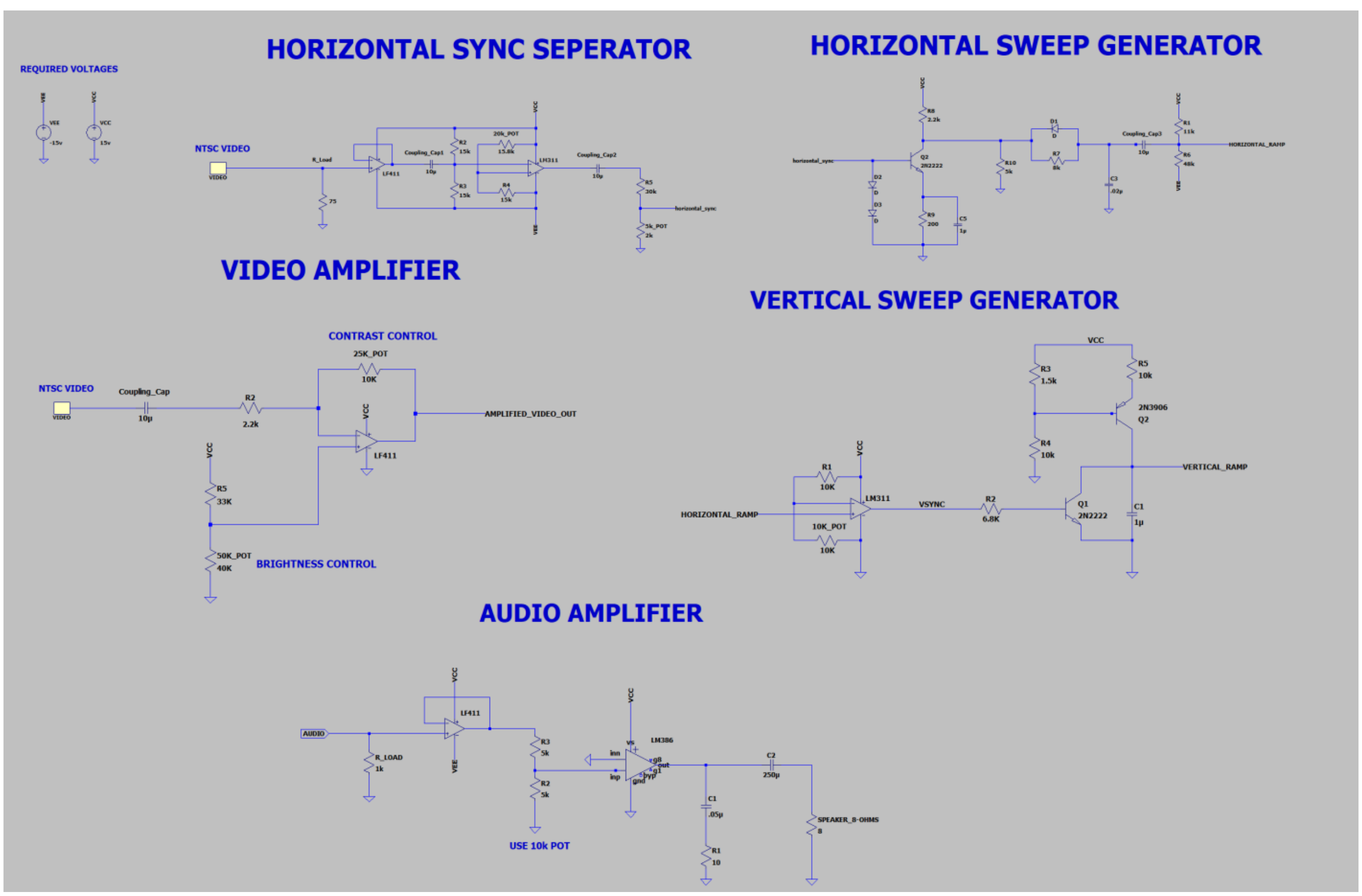

Figure 4: Complete LTspice Schematic of ScopeTV

Horizontal Sync Separator LTspice:

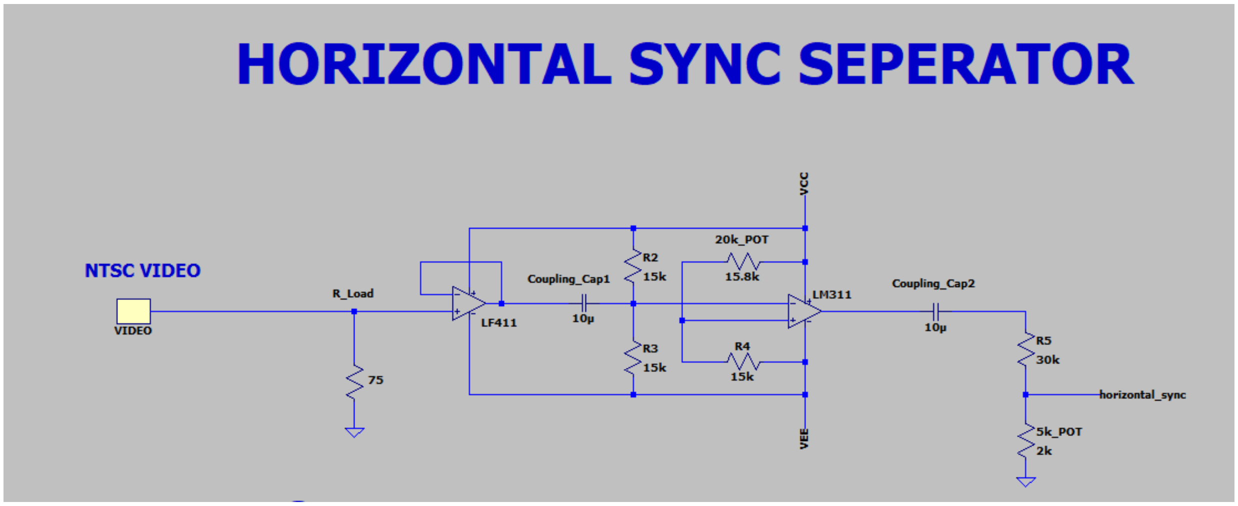

Figure 5: Horizontal Sync Separator LTspice Schematic

To maintain a 75ohm video load, we used an OPAMP as a buffer and tied a 75ohm resistor to ground. This results in an input impedance of 75ohms, meeting spec. A comparator was considered to obtain the horizontal sync by setting the output to VCC or VEE depending on the NTSC signal's polarity. The horizontal sync occurs at negative 0.4V, while the color burst's lowest voltage is at -0.2V. A reference voltage of -0.35V was chosen using a voltage divider. Finally, the resulting hsync peak can be tuned using a voltage divider to get 1v peak-to-peak.

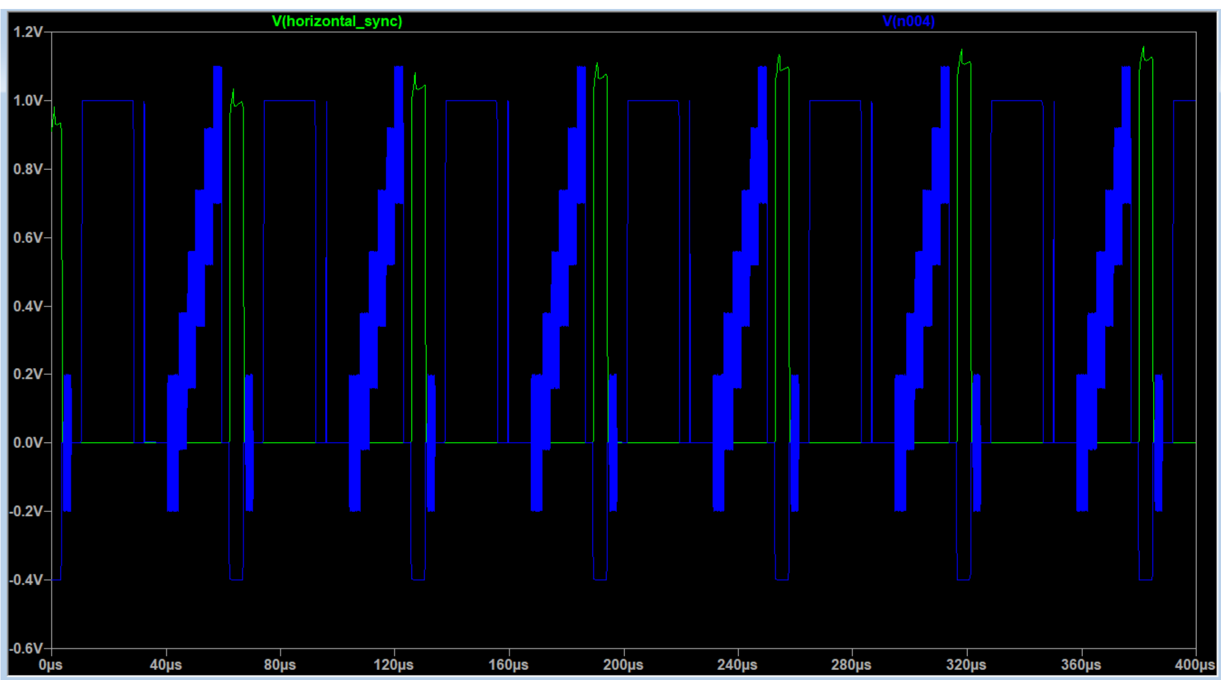

Figure 6: Horizontal Sync Separator LTspice Transient Simulation

Horizontal Sweep Generator LTspice:

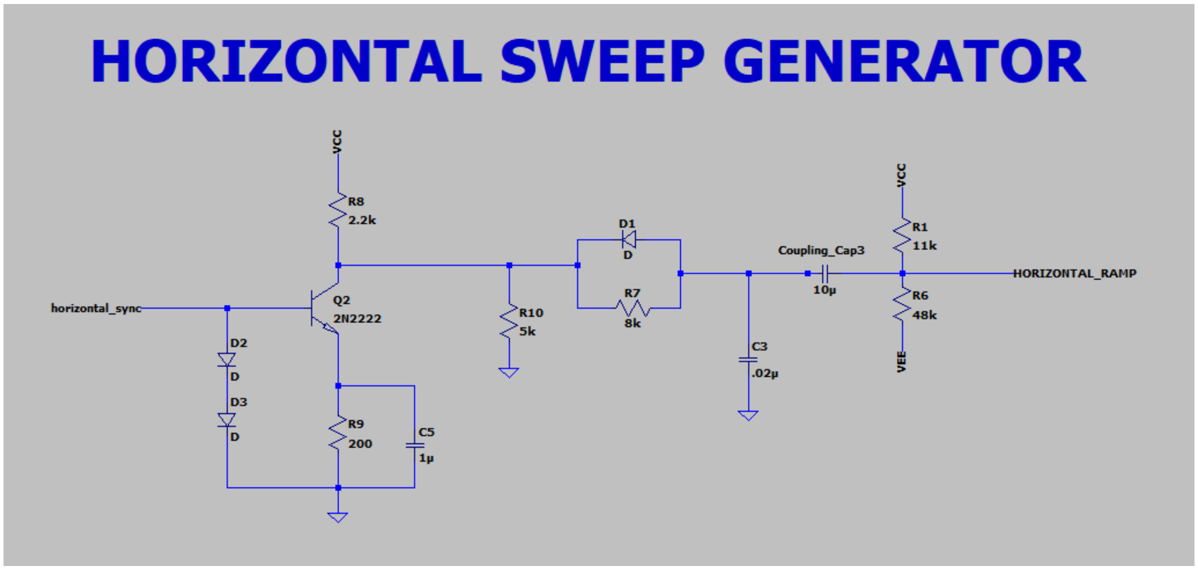

Figure 7: Horizontal Sweep Generator Schematic

The development of a horizontal ramp generator using a sync separator is can be achieved by creating a circuit that behaves like an integrator up until the start of the sync pulse, after which it sharply drops down and repeats. The initial design for the horizontal ramp generator focuses on how the circuit functions when the hsync signal switches between negative 15 V and 15 V. The time constant formed by the resistor and capacitor is large in comparison to the frequency of the hsync, allowing the capacitor to be approximated as linear despite charging at an exponential rate. The circuit performs well in simulations, with the capacitor being depleted in roughly 2 us, which is satisfactory for a horizontal sync lasting around 60 us.

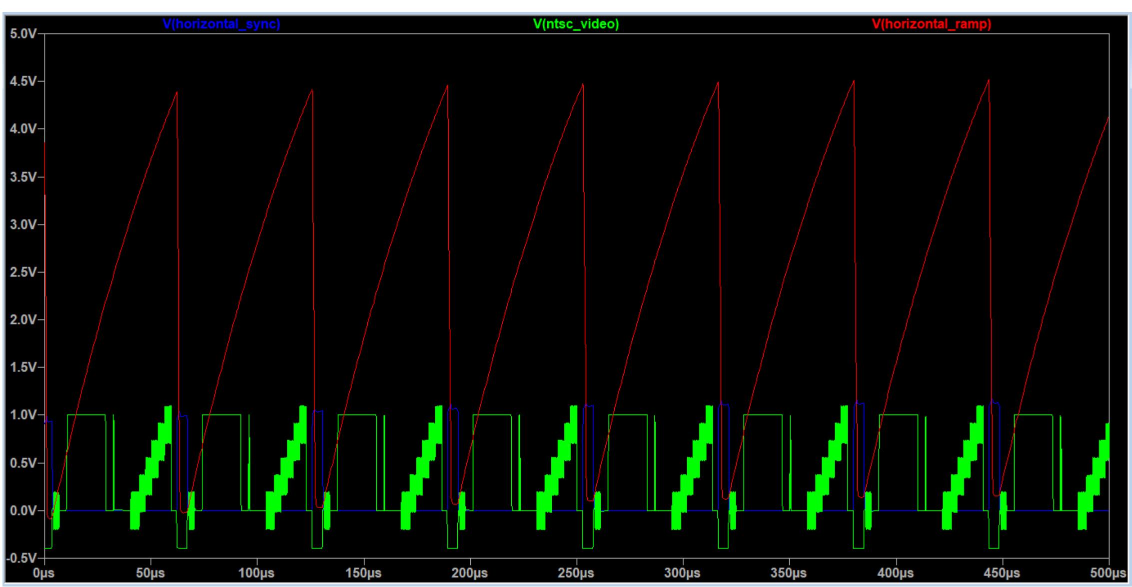

Figure 8: *Horizontal Sync Separator LTspice Transient Simulation*

Vertical Sweep Generator LTspice:

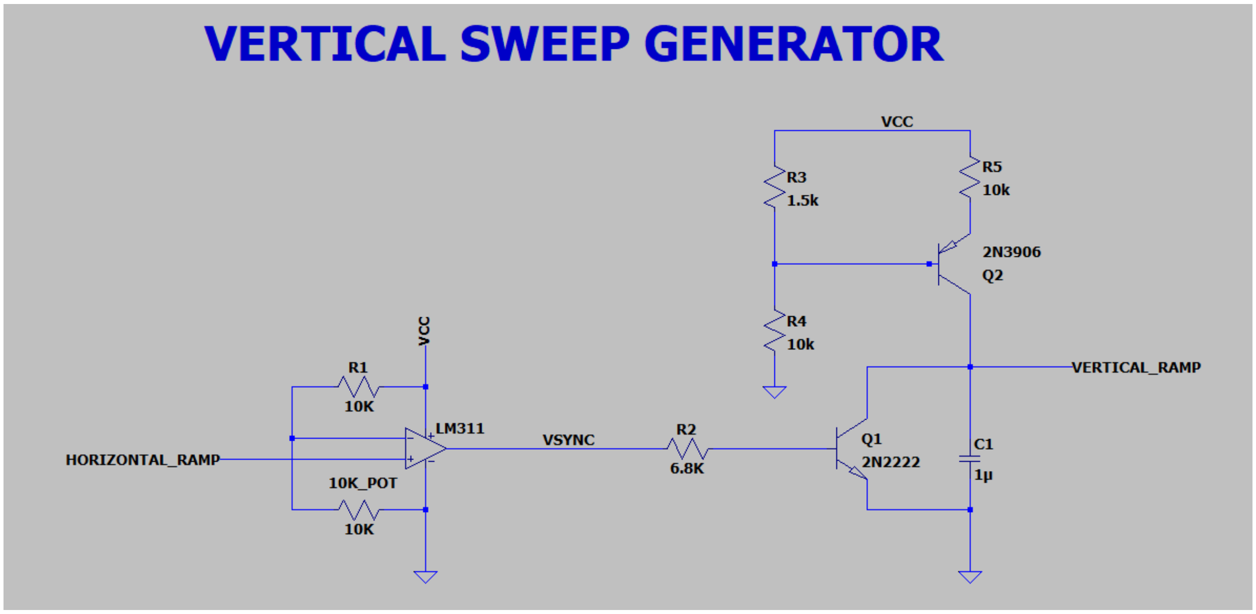

Figure 9: Vertical Sweep Generator Schematic

Using the Horizontal Ramp, we can detect when a vsync occurs because we know that there will be a relatively large interval where the signal will be at negative 0.4 volts, which is the hsync voltage. A consequence is that the previous horizontal ramp circuit will have a climbing voltage value twice as large as the normal peaks of the horizontal ramp. Using a comparator and voltage refrence using a voltage divider, we can extract this particular moment and characterize it as the "vsync". Next we feed this to an NPN which triggers, creating a short between the cap, discharging it whenever a vsync occurs. During the down time, the cap is charged through a biased PNP acting as a current source. The 10kΩ resistor and 1uF provide a sufficient time constant that allows for a linear ramp.

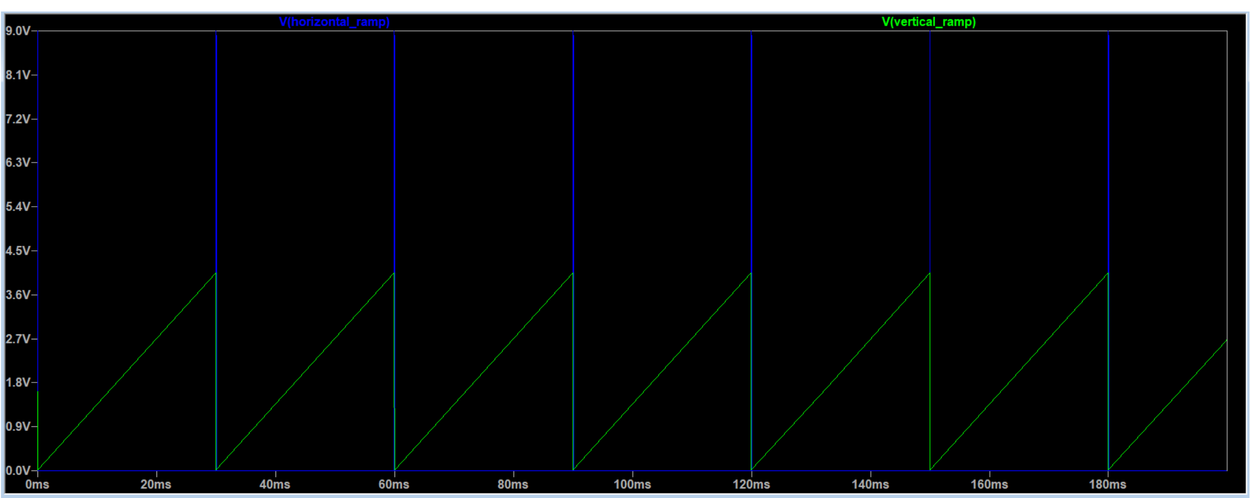

Figure 11: Vertical Sweep Generator Transient Simulation

Video Amplifier LTspice:

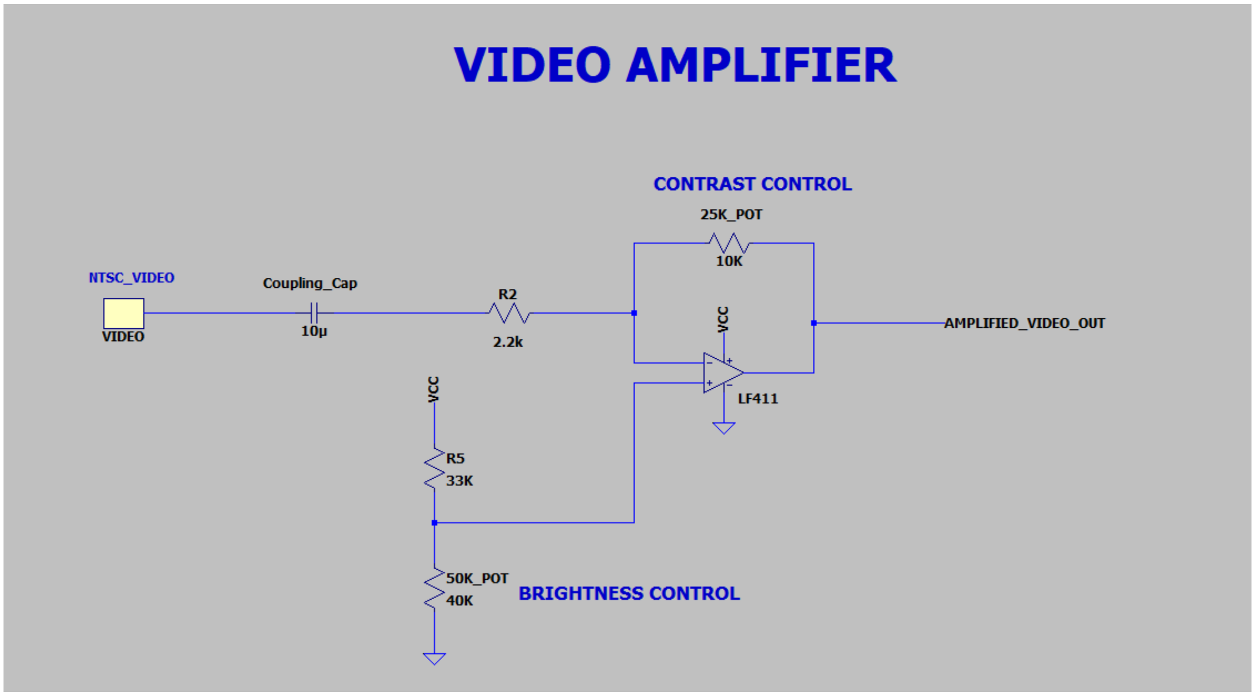

Figure 12: Video Amplifier Schematic

This is a simple circuit involving a single OPAMP to amplify the NTSC video signal. Since the Z-axis of the oscilloscope is inverted, we need to use an inverting amplifier to compensate. Using a voltage divider at the positive input of the OPAMP, we can shift the DC of the signal, hence the brightness control, where lowering the DC should make image brighter. Using the feedback resistor, we can tune the gain or the peak to peak of the signal which represents the contrast. Greater the gain, greater the contrast.

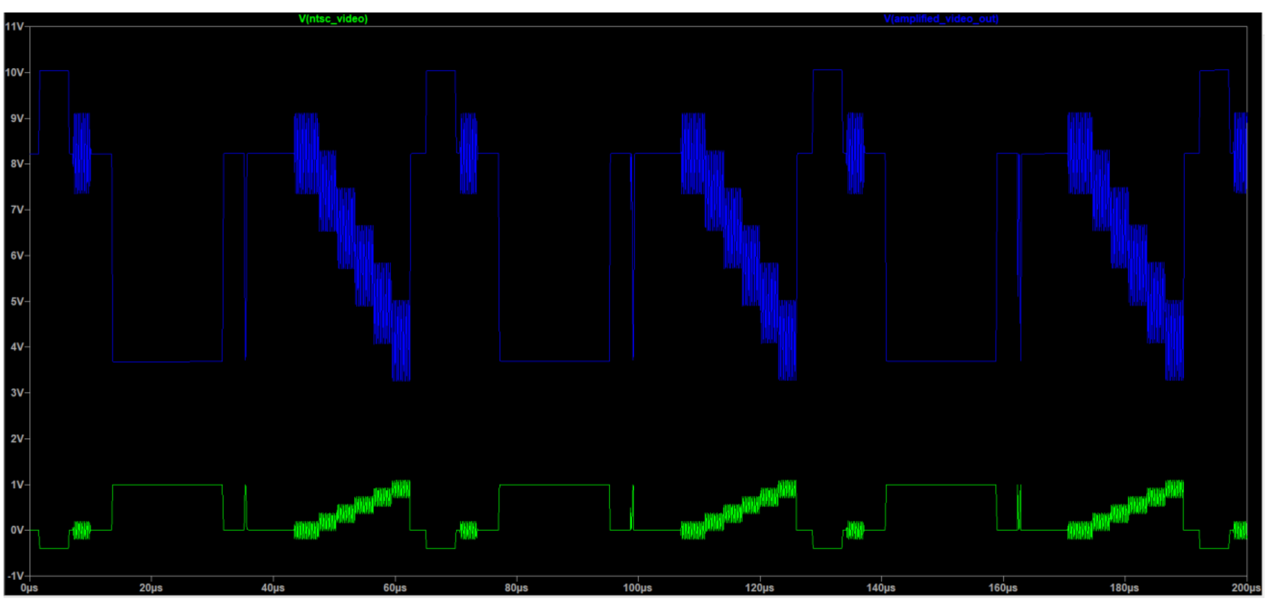

Figure 10Video Amplifier Transient Simulation

Audio Amplifier LTspice:

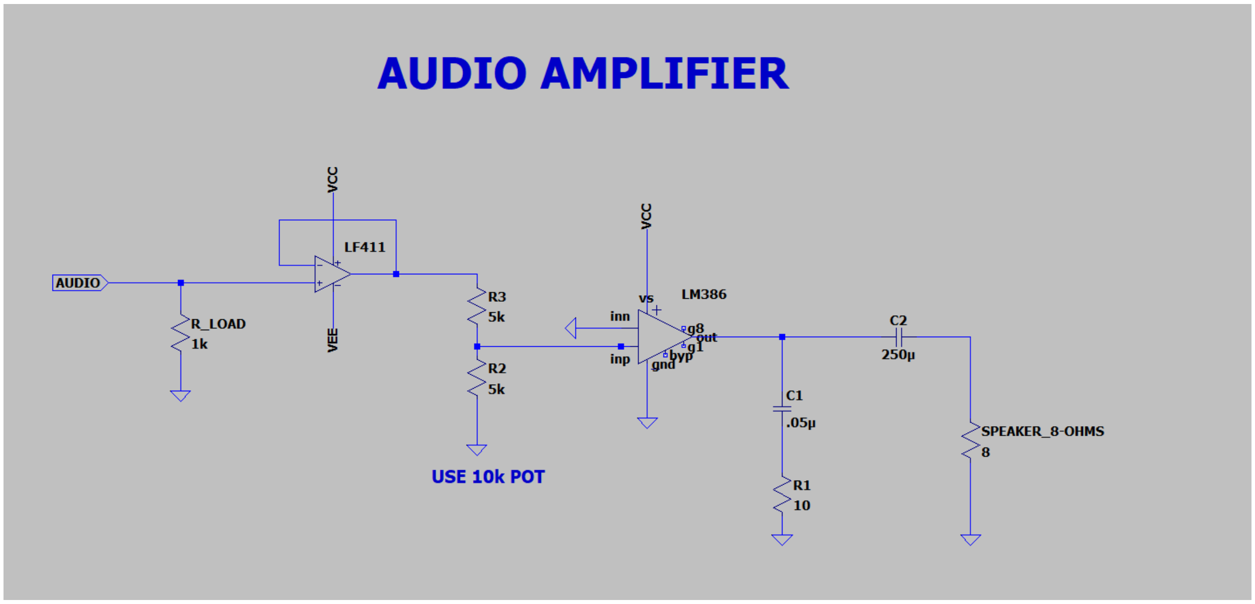

Figure 14: Audio Amplifier LTspice Schematic

The figure above shows the typical wiring necessary to create the audio amplifier with 20dB gain and 8Ω speaker using an LM386. The schematic was retrieved from the LM386 data sheet. The one modification we made was adding a buffer and a load resistor to ground to create an input impedance of 1kΩ, meeting the audio input specification. The figure below shows the circuit retrieved from the data sheet. There is no simulation for this schematic as the LM386 symbol is not readily available in the LTspice software.

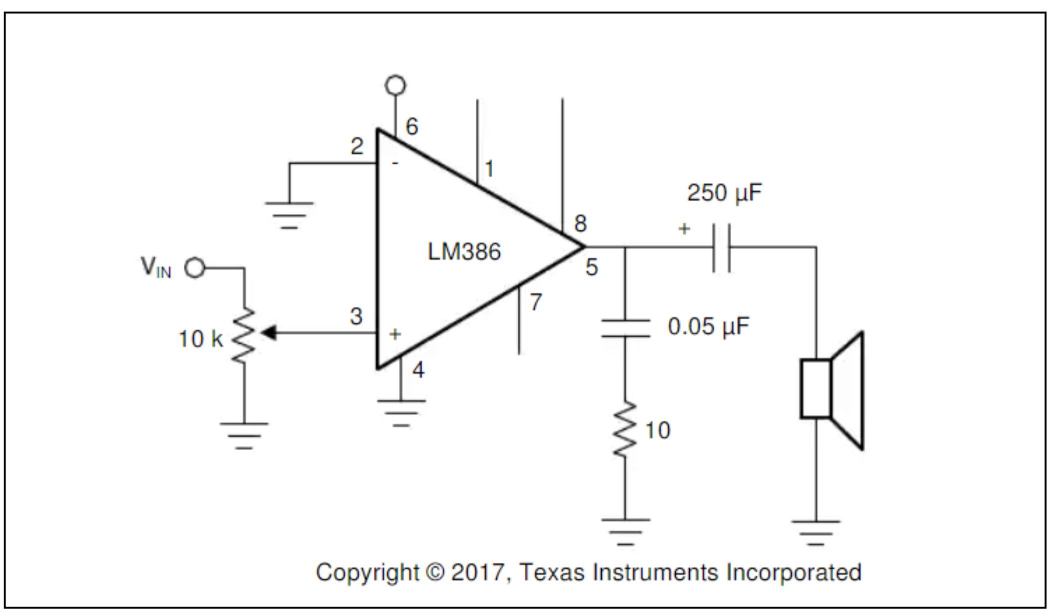

Figure 15: Schematic from LM386 Datasheet

Finished Construction:

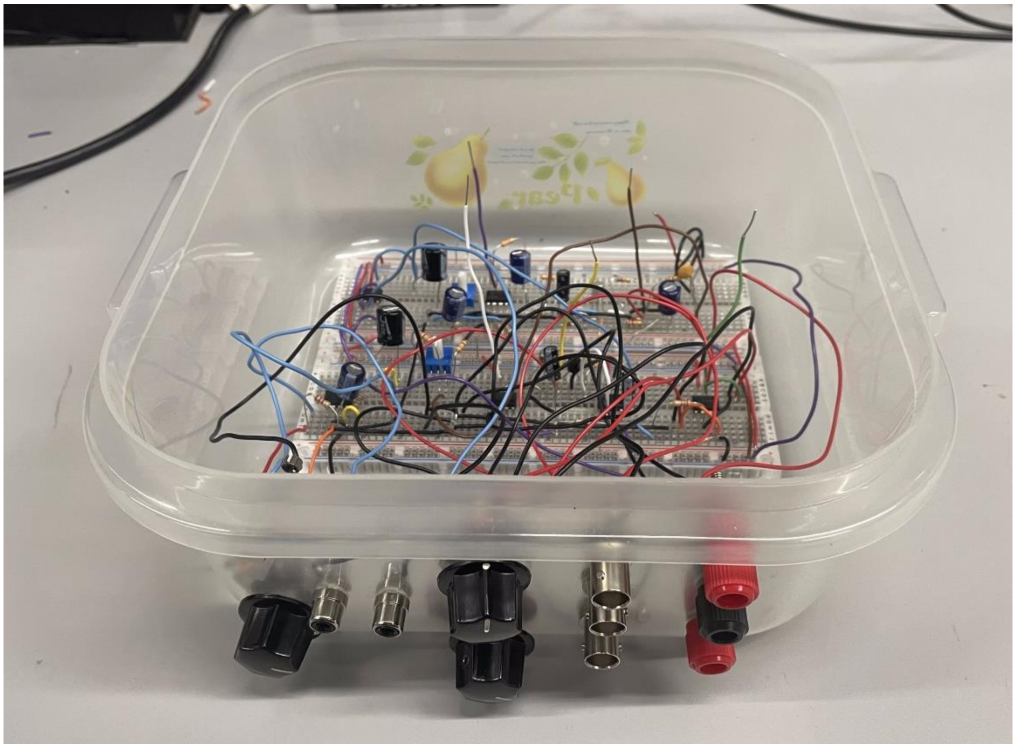

Figure 16: Finished Circuit on breadboard and mounted inside enclosure

Figure 17: Labeled Input/output Instrument Panel

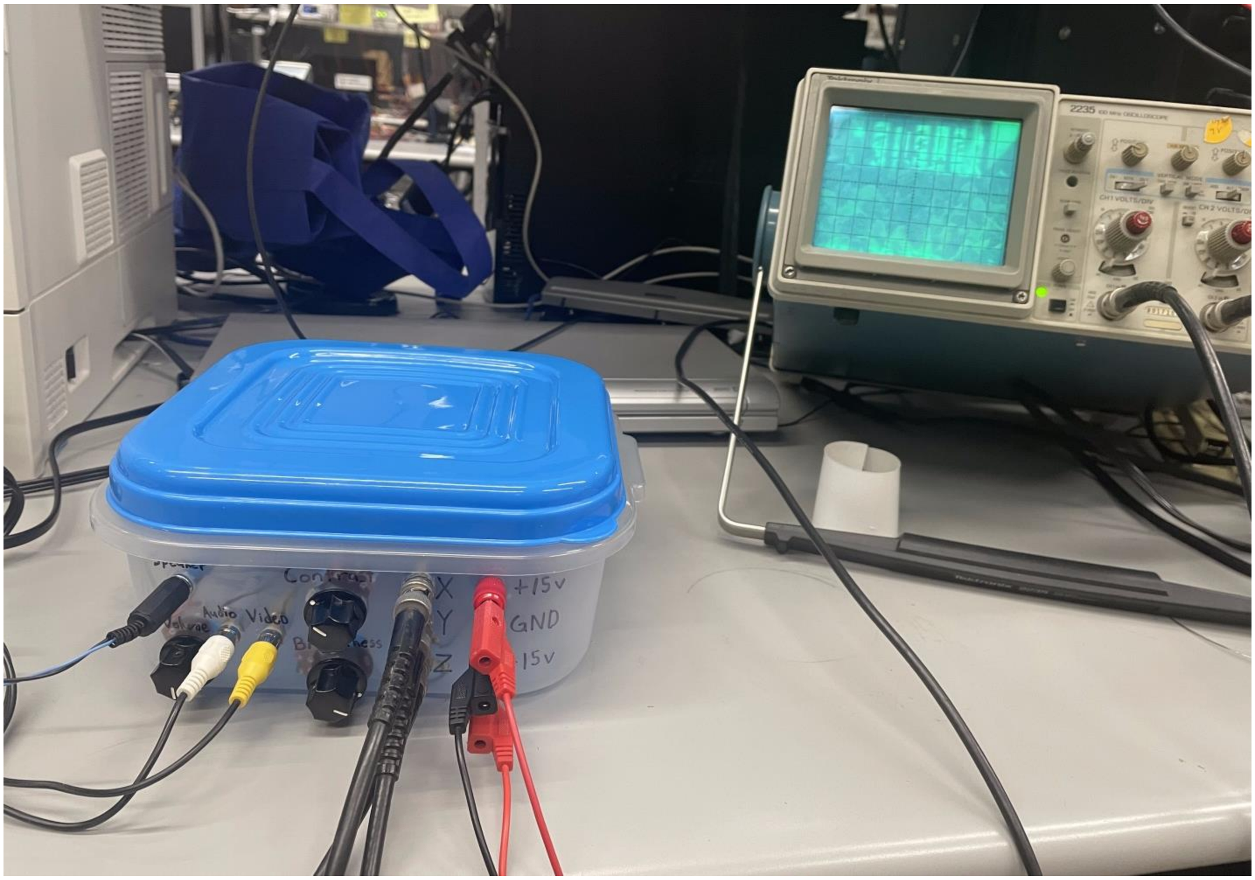

Figure 18: ScopeTV is full wired and output an image on the Oscilloscopes CRO

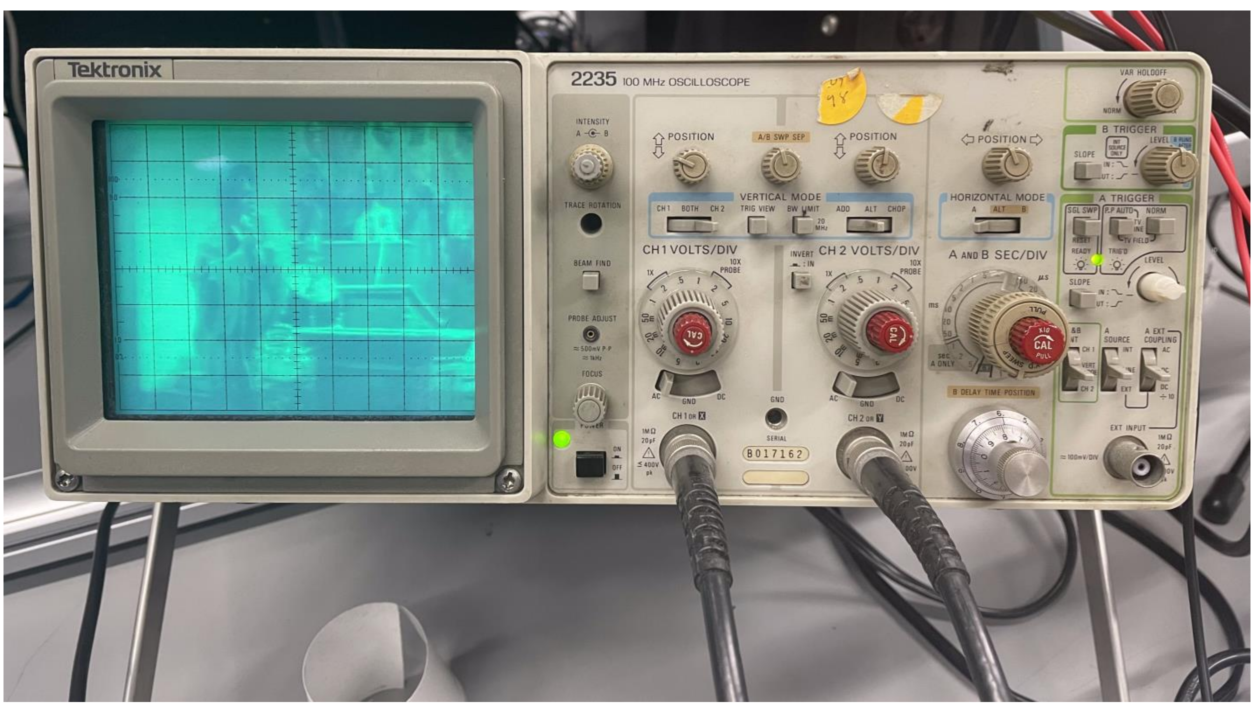

Figure 19: Close-up on CRO Oscilloscope Image Quality from ScopeTV

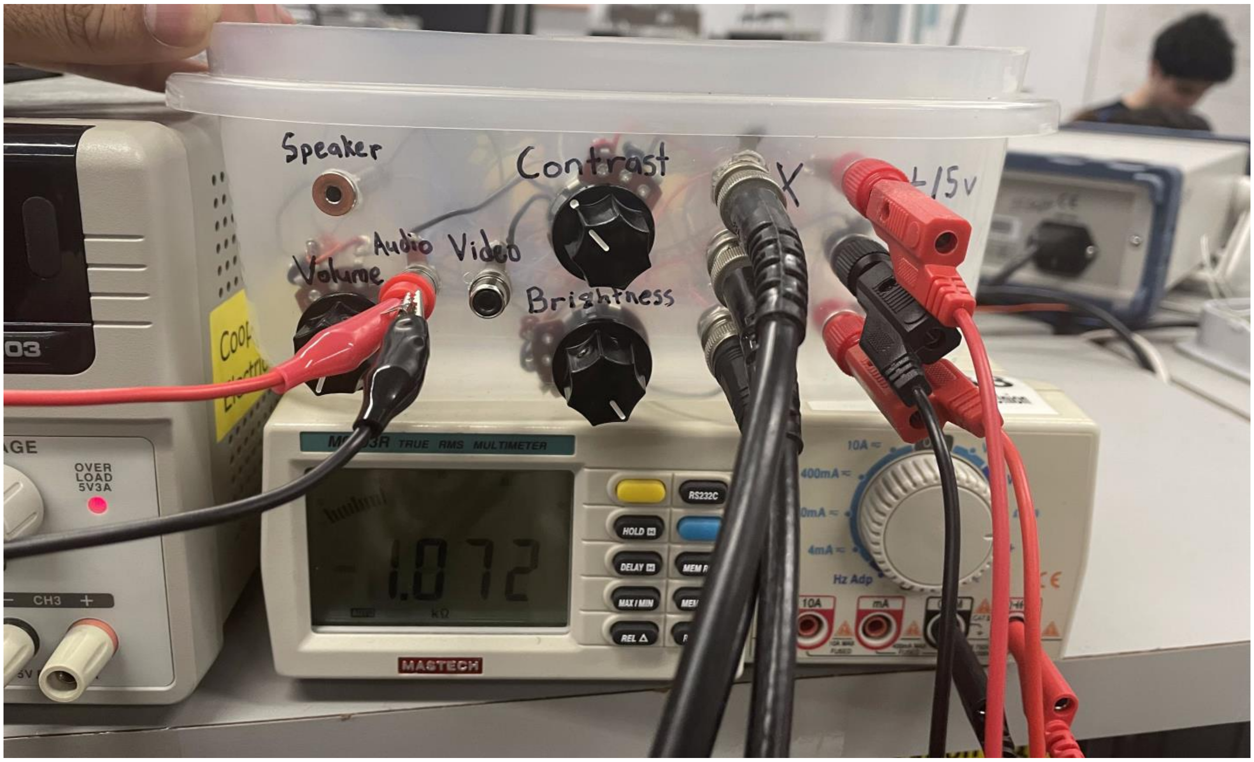

Figure 20: ScopeTV Input Impedance of Audio is around 1k Ω

Figure 21: ScopeTV Input Impedance of Video is around 75Ω

Lab Results:

Figure 22: Oscilloscope shows hsync (yellow) and NTSC video (green)

Figure 23: Oscilloscope shows Horizontal Ramp (yellow) and NTSC video (green)

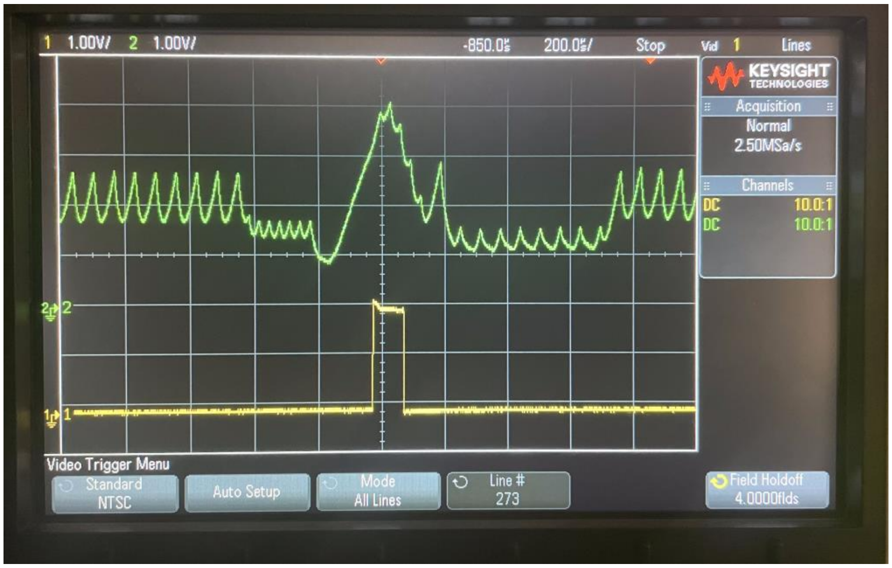

Figure 24: Oscilloscope shows vsync (yellow) generated by horizontal ramp (green) during vertical sync interval.

Figure 25: Oscilloscope shows vsync (yellow) and NTSC video (green)

Figure 26: Oscilloscope shows Vertical Ramp (green) and NTSC video signal (yellow)

Figure 27: Oscilloscope shows NTSC Video Signal (yellow) and Video Amplifier Z-axis output. Wave form is clearly inverted, with variable DC and Amplitude.

Discussion:

The circuit was built on a breadboard using available components from the lab. A different comparator was used instead of the desired one because an LTspice model for it was not available, but it did not significantly affect the performance. The composite cables were modified for better contact and soldered securely to ensure a connection to the NTSC and audio signals. The brightness and contrast of the video signal were adjusted using a non-inverting amplifier with a potentiometer and a voltage divider with a variable resistor. The composite video, horizontal ramp, and vertical ramp were fed into the z, x, and y axis ports of the oscilloscope using probes, respectively. The audio amplifier output was connected to an 8 ohm speaker. In the simulation results, the circuit successfully extracted the vertical sync and the horizontal ramp and sync worked well. There was a slight distortion in the vertical sync output, which may have been caused by a small time constant, but reducing the capacitance did not fix the issue. The physical implementation of the vertical ramp looks fine, unlike the simulation which had a distortion. However, there is a slight distortion in the horizontal ramp, likely due to non-idealities of the comparator causing the signal to occasionally go past VCC at the bottom. Despite this, no changes were needed from the simulated design, and the performance was even better than expected.

Conclusion and Further Improvements:

The project involved creating a circuit to convert the NTSC signal from a VCR into vertical and horizontal ramps for display on a CRO, with the physical implementation performing as well as or better than the simulated design. The circuit also allowed for audio playback with adjustable volume. Future work could focus on understanding the distortion in the simulated vertical ramp, reducing power consumption, exploring the use of smaller rail voltages, and examining the impact of using MOSFETs instead of BJTs in the ramp generating circuit. Furthermore, It may be in our interest t add an amplifier directly at the input of the NTSC signal so that the Hsync is easier catch. Sometimes, the signal wanders and we get artifacts of the color bust on the hsync.