Modernized Analog Video Distortion Device

ECE 445 Design Document - Spring 2025

Project #16

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1 Introduction

1.1 Problem

In recent years, the force of nostalgia has made the aesthetic of analog glitches increasingly popular, and they have found wide use in mediums such as music videos, live concert visuals, video editing, and even film. However, authentic analog glitch devices are made only by a small number of artisans who alter (or "bend") the circuitry of vintage video hardware to introduce these visual artifacts, making them inaccessible to general hobbyist visual artists, such as the VJs who make visuals for house shows on campus.

The cost of a unit generally ranges from \$300 to \$700, with resold units sometimes reaching over \$1,000 [1]. This is due both to the increasing rarity of the hardware they're built from and the small number of people who hand-make these devices. Even after placing an order, the turnaround time can be upwards of 6 months. Additionally, controls on these devices are abstruse, typically consisting of unlabeled switches and potentiometers. This makes operating them confusing and requires the user to carefully experiment with the controls in order to figure out how to dial in a visually appealing setting.

The niche nature of this field makes it ripe for innovation, most importantly in the way of making them more accessible to the general artistic community. Live show venues often record performers and audience members live and project the resulting picture in real time against a wall after passing through some sort of video processing algorithm (e.g., edge detection, color quantization, smearing, and/or delay line effects). Sourcing these visual effects requires most venues (such as Gallery Art Bar here in Urbana) to hire a third party for the job, which can become expensive [2]. Additionally, most commercial VJs don't offer natural analog effects, the closest being digital emulations of analog effects, which are not always accurate.

1.2 Solution

The overall goal of this project is to make a robust and easily manufacturable analog glitch device that can be digitally controlled, with an aim towards making them more accessible to hobbyists and people who are interested in analog video. Using a custom PCB design, we aim to replicate the functionality of both a normal and bent video enhancer. Additionally, the analog circuitry will be controlled digitally using a microcontroller to adjust various amplifier gains and reroute signal flow. This way, the device can be interfaced with a user-friendly controller, making it easier and more fun to play with video distortion.

To do this, we will design a video enhancement circuit with carefully designed “bends” built into the PCB. Digital-to-analog converters connected to a microcontroller will serve as the go-between for our analog circuit and an external controller, allowing digital control over parameters of both the enhancement and distortion functionality. The microcontroller and analog circuitry will both be powered by a DC power supply. The enhancement circuit will consist mainly of amplifiers which cleanly boost or attenuate elements of the composite video input, while the distortion circuit will consist of feedback lines which connect into the enhancement circuit to create interference and distortion. The glitches we aim to achieve in our design include “ringing”, “rainbowing”, “ghosting”, and “tearing”.

This technology will open barriers to recreational VJing in the house show scene, and generally for at home hobbyists/enthusiasts.

1.3 Visual Aid

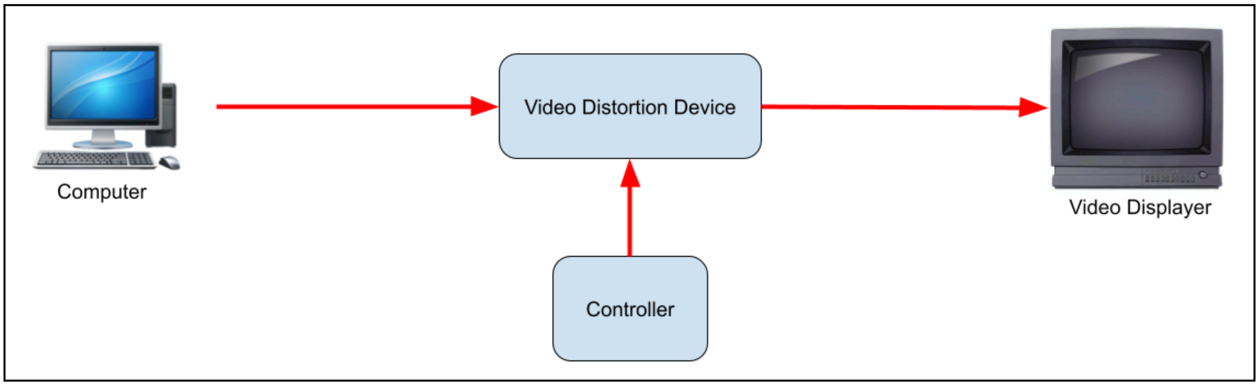


Figure 1: Simplified device integration diagram

The video source will most likely come from some kind of computer. We can control distortion attributes with the controller block shown above. The final processed video signal is sent into a video displayer, which could be an analog device such as a CRT TV, or a digital display that takes HDMI, assuming the user provides the necessary RCA-HDMI converter. If a video effects artist wishes to display their distorted video at a music venue, a projector output would also be acceptable.

1.4 High Level Requirements

To consider our project successful, it must meet the following criteria:

1. The frequency response of our bent enhancer circuit must be at least 10 MHz to accommodate the full bandwidth of the video signal [4].
2. Glitch strength must be able to be varied from suppressed to fully visible using a control voltage between 0V and 1V.
3. Video output must remain within the range of 0V to ~1V in order to ensure the signal is in-spec with the CRT [4].
4. Sync signals must be preserved and appear with an amplitude of -300mV, unless being intentionally subverted [4].

2 Design

2.1 Block Diagram

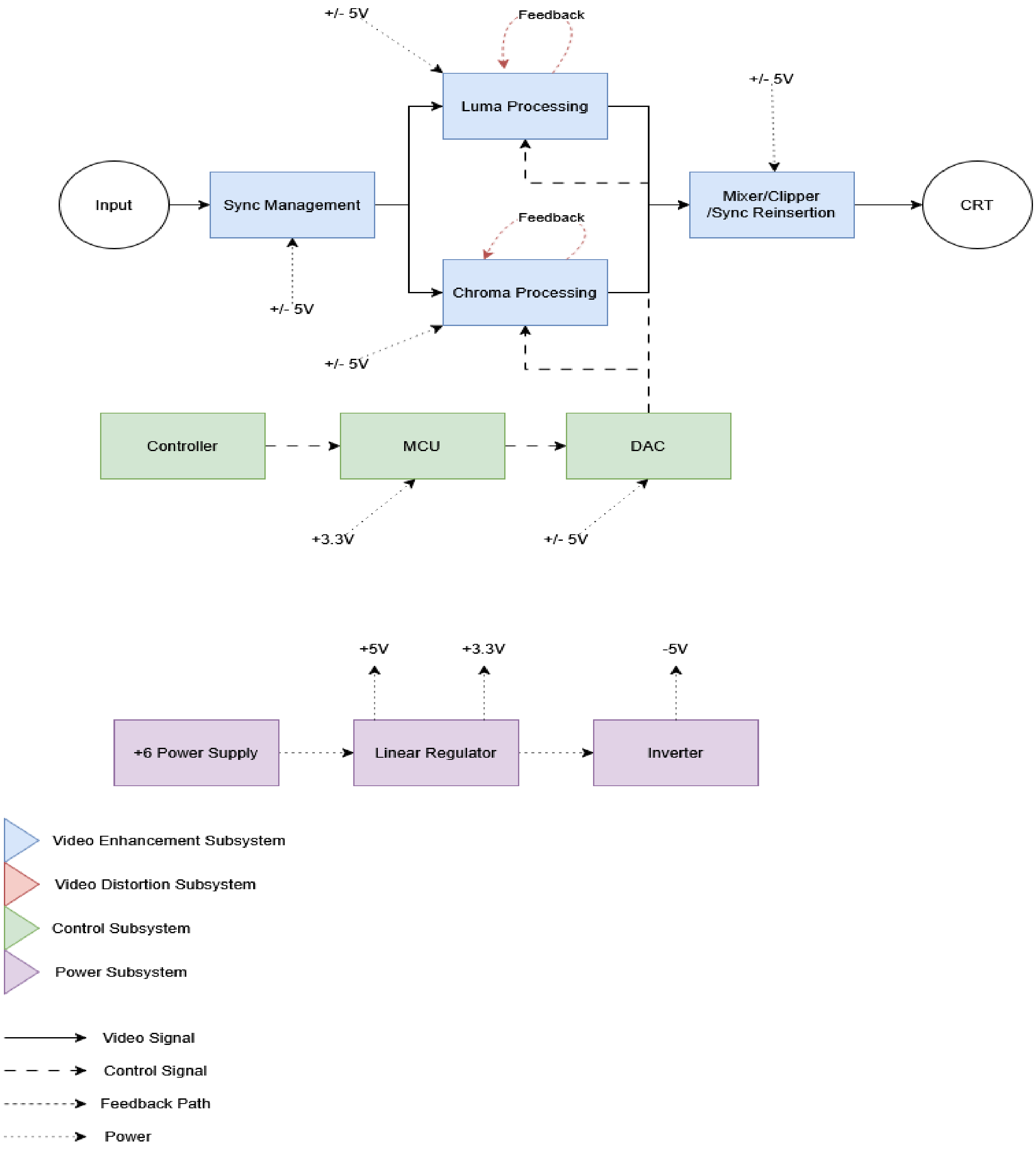


Figure 2: Modernized Analog Video Distortion Device Block Diagram

2.2 Functional Overview & Block Diagram Requirements

2.2.1 Video Enhancement Subsystem

The video enhancement subsystem will be the heart of our design. It will be responsible for amplifying and attenuating parts of the video signal in order to modify qualities of the image such as contrast, brightness, and saturation. These parameters will be digitally controlled via the control subsystem. The video enhancement subsystem will also protect the “housekeeping” parts of the signal (sync pulses, color burst) by periodically bypassing the amplification stage when the row initialization portion of the signal is detected (prevents unintentional sync manipulation, allows for chroma to be phase shifted to a constant reference phase) [3]. The video distortion subsystem will hijack the enhancement circuitry using feedback loops to artfully introduce glitches into the image, see section 2.2.2 for an explanation on glitches that are generally considered artful/interesting. Active circuit components will receive power from the power subsystem.

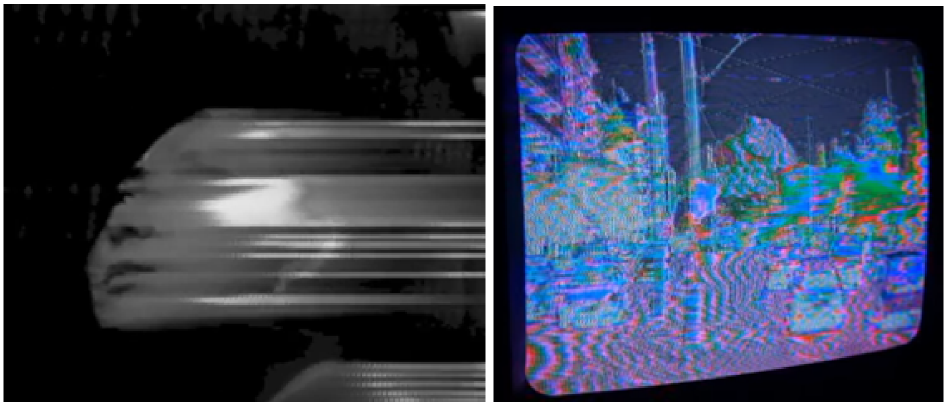
Table 1: Video Enhancement Subsystem - Requirements & Verification

Requirements	**Verification**
• The contrast will be controlled by amplifying the luma component of the composite video signal and must be able to amplify between a factor of -2 and 2.	• Apply the appropriate 2:1 feedback resistor ratio such that a voltage control domain of [-1V, 1V] provides an amplification range (in V/V) of [-2, 2]. • Confirm our design using a waveform generator to send a sine wave into the amplifier, then looking at the output signal with an oscilloscope, correcting our design as necessary.
• The brightness will be controlled by applying a DC offset to the luma signal, which must range from pure black (0V) to pure white (715mV).	• Attenuate chroma subcarrier with a properly tuned notch filter and provide DC offset from a voltage source and voltage divider circuit if needed. • Apply a diode clipping circuit to ensure the signal does not pass 715mV in amplitude. • Analyze results through an oscilloscope and verify both the DC offset and the clipping.
• The saturation will be controlled by amplifying the sinusoidal chroma subcarrier component, which encodes color, and must be able to amplify between a factor of -5 and 5.	• Apply a bandpass filter to isolate the chroma subcarrier • Setup the amplifier circuit making sure to apply a 5:1 feedback resistor ratio. • Use a 2V peak-to-peak sine wave with zero DC offset. The oscilloscope should display (approximately) a 10V peak-to-peak sine wave at the output of the amplifier.
• The hue will be shifted by applying a phase shift, and the phase shift circuit must be able to apply a shift from 0 degrees to 360 degrees.	• Observe an input sine wave as one channel on an oscilloscope, and the output sine wave on another channel of the oscilloscope.

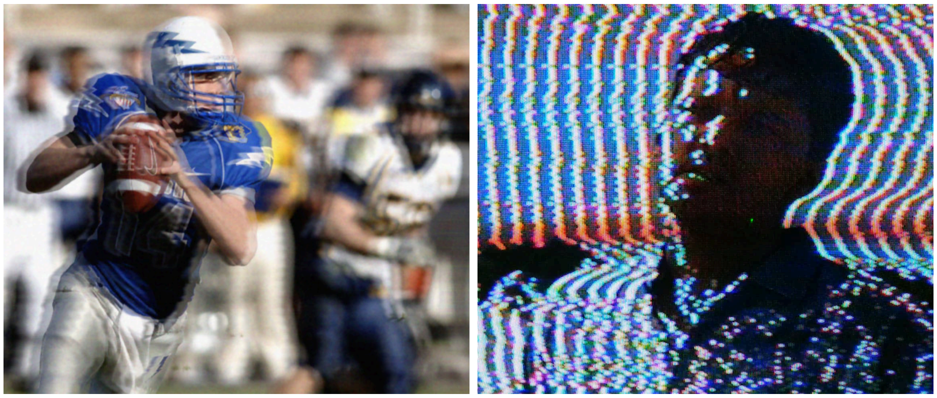
Requirements	Verification
	- Run the sine wave through the phase shift circuit and compare the phase shift shown on the oscilloscope with the expected phase shift (computed mathematically).
- To control these effects, control voltage will be delivered to the amplifier ICs from a DAC to control their gain. Control over the full range of effects must be achieved using a control voltage between -1V and 1V.	- Send a digital test signal via our MCU and observe the output from our DAC to verify correct operation. - Write code in STM32 Cube IDE to convert output of infinite encoder to a value between -1V and 1V, clipping the encoder value if necessary.
- Sync pulses must be protected using a sync extraction IC. When reinserted at the end of the processing chain, its voltage must be at -300mV in order to remain in spec with the video signal.	- Verify the separation of sync from the video signal via an oscilloscope - Utilize an op amp summer to add sync back into the base signal after the base signal passes completely through the processing circuit. - Make note of any temporal deviation between the restored sync signal and the base signal post processing.
- In order to ensure the distorted image can be displayed on a CRT, the luma signal must be clipped at 0mV and 715mV.	- Generate a 1V zero-to-peak sine wave and run it through our clipper circuit. - Analyze the output on an oscilloscope. There should be a clear, abrupt cutoff at 715mV.

2.2.2 Video Distortion Subsystem

This subsystem will be responsible for generating the glitches we aim to achieve from this device. It will function by interfering with the enhancement subsystem, introducing resonant feedback loops which cause oscillating interference in the image signal. The feedback gain and the subsystem activation will be controlled from the control subsystem using control voltage and digital switches, respectively. Active circuit components will receive power from the power subsystem. The figure below shows the four examples of interesting glitches we aim to replicate on our device:



Tearing *Rainbowing*



Ghosting *Ringing*

Figure 3: Video Distortion Effects

Table 2: Video Distortion Subsystem - Requirements & Verification

Requirements	**Verification**
● To control the quality of these glitches, the fed-back signal will pass through RC highpass and lowpass filters to achieve the ringing and ghosting effects, respectively. We will experiment with various feedback configurations to find visually appealing setups. Our feedback configurations should be unity gain.	● Make sure that applied effects are the result of added circuitry and not loose wires or capacitive effects from outer forces. ● Analyze changes in overall signal gain from feedback loop with an oscilloscope.
● To control the strength of our distortion effects, we will vary the amplitude of the fed-back signal, via a control voltage ranging either -1V to 1V or 0V to 1V. This can be done with a specialized voltage-controlled amplifier IC.	● Ensure through visual inspection on both a CRT TV and oscilloscope a smooth transitioning from no distortion to a full distortion effect when adjusting the feedback gain.

2.2.3 Control Subsystem

This subsystem will form the user interface of the device. The user will input digital control signals using a controller featuring knobs, buttons, and an LCD screen providing user feedback. This screen will display the parameter being controlled and the control voltage being outputted. These signals will be transmitted to a STM32 microcontroller which will decode these signals into voltage levels or switching signals to be delivered to elements of the video enhancement and distortion subsystem. The MCU will communicate over SPI to several DAC ICs which will generate and deliver the specified voltages, and use GPIO to drive binary switches.

Table 3: Control Subsystem - Requirements & Verification

Requirements	**Verification**
● To interface with a controller, we must either connect a pre-built controller to the MCU over USB, or build a custom controller which can communicate over a simpler protocol, such as SPI.	● Determine the controller's expected protocol to transfer data to the MCU. ● Verify that the controller is communicating with MCU via a basic pin readout program on the STM32Cube IDE.
● The MCU must interpret the signals indicating changes in the positions of joysticks, knobs, or the press of a button and send signals to a DAC using SPI to tell it to change voltage levels in the analog circuitry.	● Read the value of pins attached to switches to make sure they toggle between two discrete values appropriately.

2.2.4 Power Subsystem

The power subsystem will be responsible for powering all parts of the design. It will consist of a DC power supply which feeds into a linear voltage regulator. This regulator will provide a stable power supply to the MCU, controller, and analog circuitry. We will invert the 5V output of our voltage regulator in order to apply a negative bias for our op amps. The figure below shows how we will achieve 3.3V, 5V, and -5V DC sources from a wall outlet.

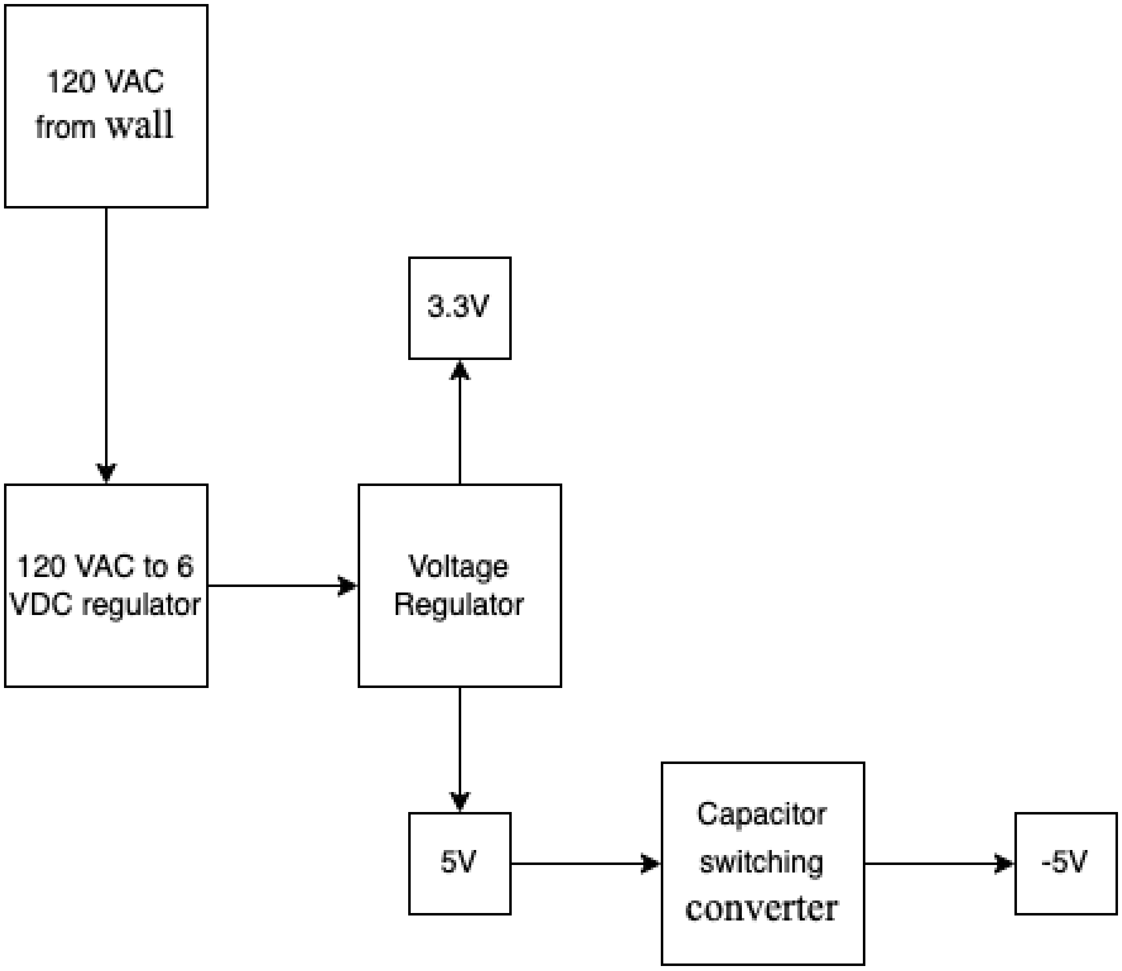


Figure 8: Power subsystem block diagram.

Table 4: Power Subsystem - Requirements & Verification

Requirements	**Verification**
● We will use a 6V DC power supply to deliver power to all components, and use a linear regulator to step the voltage down to 5V for the active circuit components, and 3.3V for the MCU.	● Determine the controller’s expected protocol to transfer data to the MCU. ● Verify that the controller is communicating with MCU via a basic pin readout program on the STM32Cube IDE.
● We will use a buck converter to additionally convert the positive 5V DC voltage to a -5V DC voltage.	● Input 5V into the buck converter and use a multimeter to read the DC voltage output of the buck converter. Ensure the output is -5V.

2.3 Physical Design

We will control our feedback and enhancer gains with infinite encoders, which when rotated clockwise will cause a counter programmed on our IDE to count upward, and when rotated counterclockwise it will count downward. The integer value read at the input will be converted to a control voltage level, clipping beyond a certain threshold [5]. Our program will be able to tell counterclockwise rotation from clockwise rotation by looking at the phase offset of the clock and data pins of the encoder, as shown in the figure below.

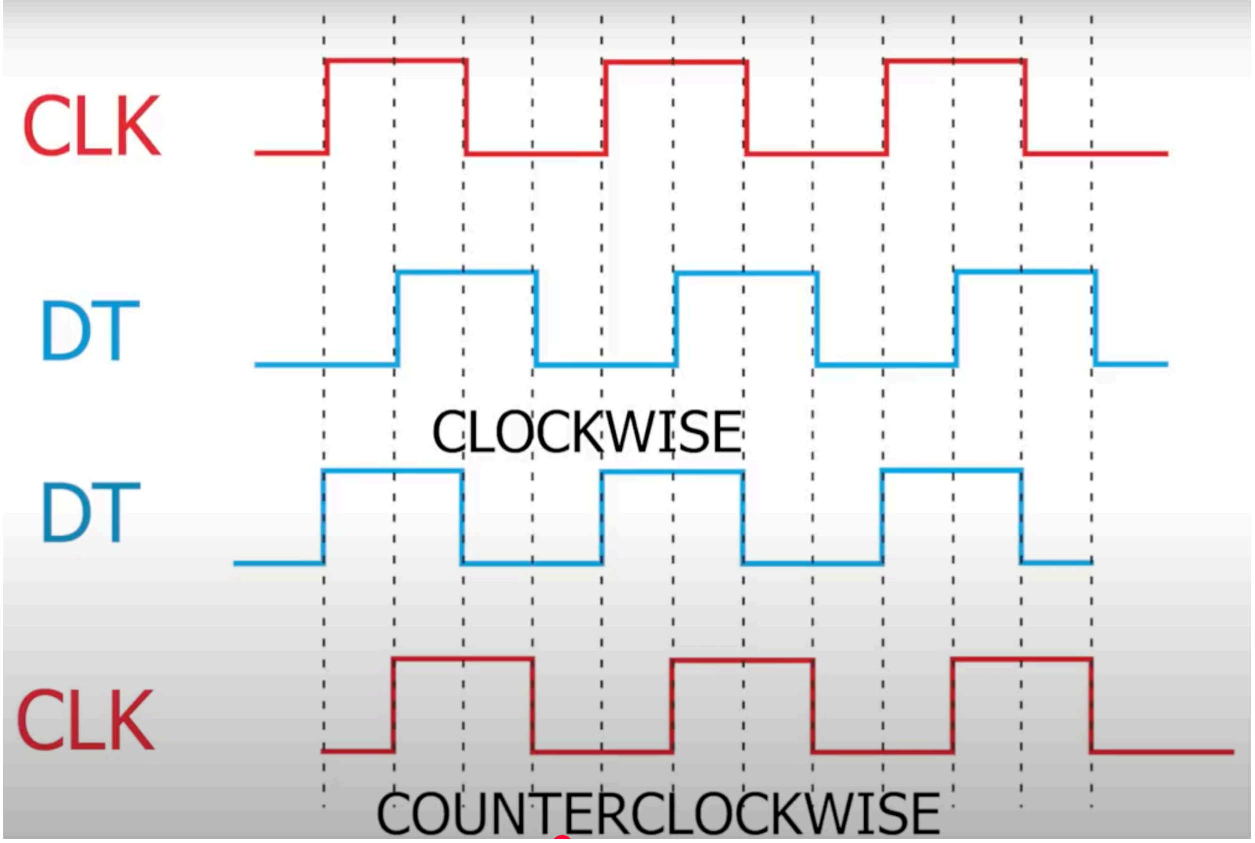


Figure 8: Power subsystem block diagram.

The basic design of our controller will be a panel with 6 of these encoders. Two for the luma amplifier (enhancement and feedback) and two for the chroma amplifier (enhancement and feedback). The other two will control the mastering stage, where processing affects the entire summed together signal. We will use GPIO to read the input from the encoders. A diagram of our control is shown in the figure below.

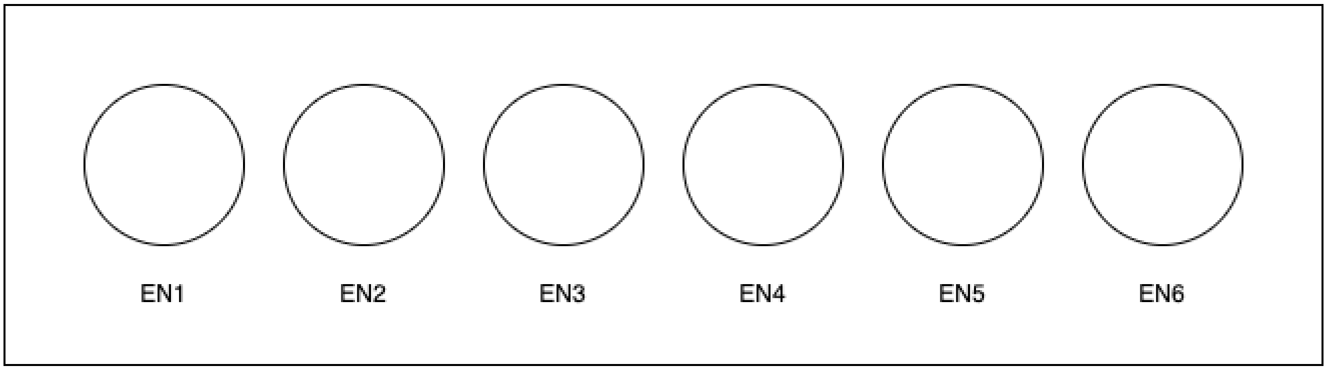


Figure 9: High level controller diagram.

2.4 Tolerance Analysis

It is important that we provide a component that prevents the scaling down of our video signal, via unwarranted voltage division, after any amplification stages. We will use a voltage buffer to protect our signal from this. It will provide a large input impedance with a very small output impedance, driving the voltage division equation between output buffer impedance and input impedance to the next module close to 1, leaving the signal unaltered. This will help maintain expected brightness and saturation levels as the signal propagates through the circuit. The visuals below show the composite video signal post-amplification with and without a buffer stage. The traces below will compare the signal at ‘Vin’ (leftmost node on Figure 1) with the signal at ‘Vout’ (rightmost node on Figure 1). The y-axis increments of each trace graph are identical.

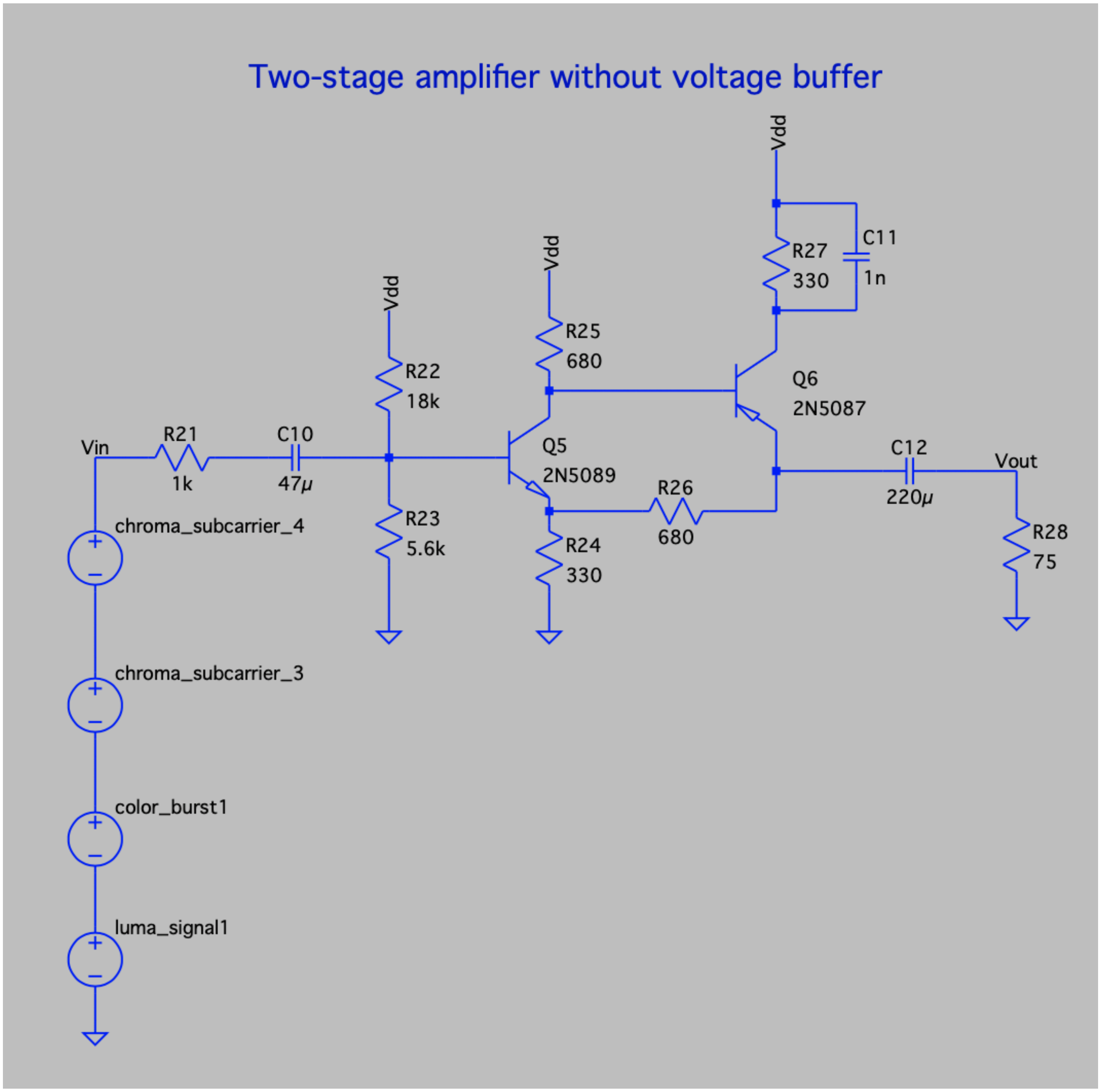


Figure 4: Amplification circuit without a voltage buffer

The figure above shows the two stage amplifier without any voltage buffer. The two trace graphs below demonstrate how the amplifier fails to properly amplify the signal at the 'Vout' node. This is due to an unwanted, significant voltage division between the output impedance of the two stage amplifier and the 75 Ω impedance of the output RCA cable.

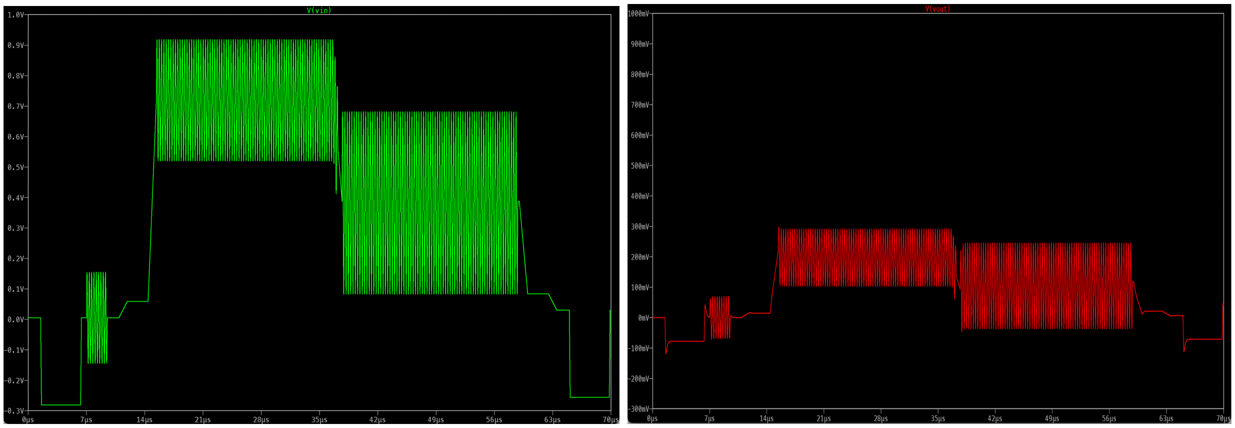


Figure 5: Input (left) compared with output (right) of Figure 1 circuit. Notice how the signal was scaled down.

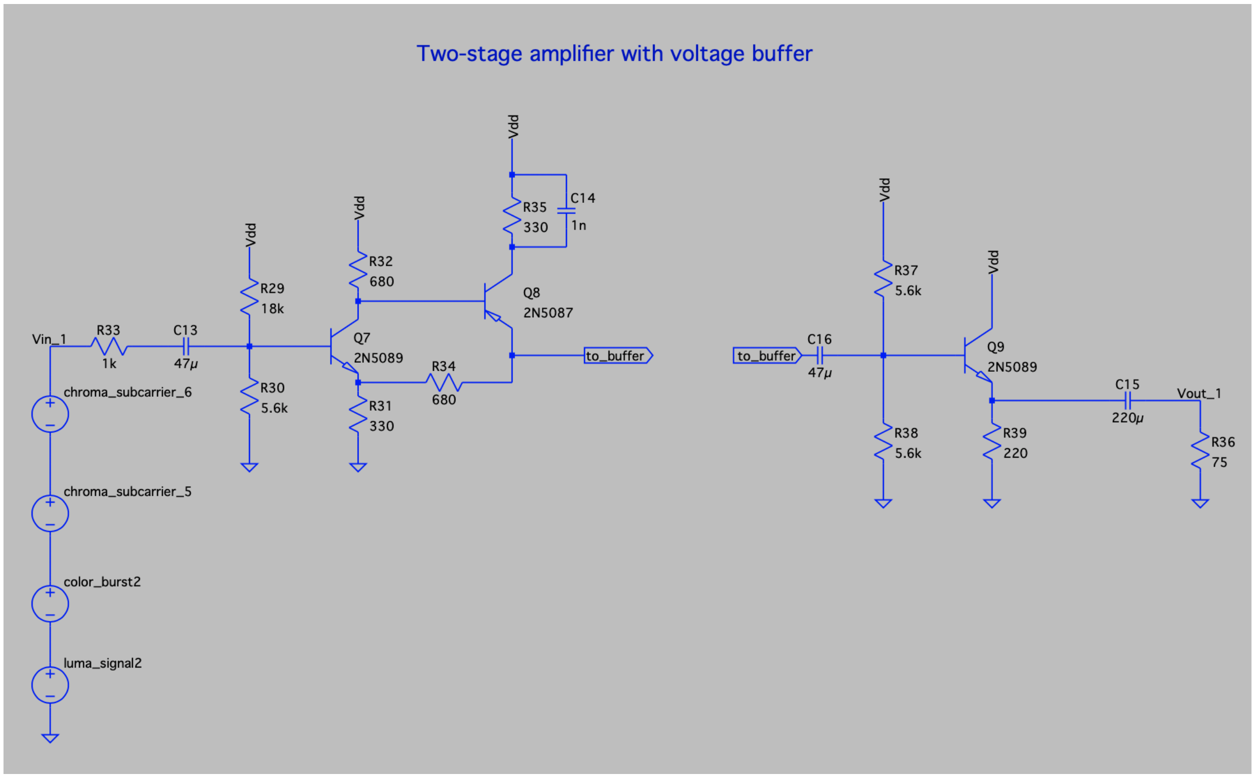


Figure 6: Amplification circuit with a voltage buffer

The circuit above shows the same two-stage amplifier configuration with an additional buffer added between the output 75 Ω cable and the output impedance of the two-stage amplifier. The output impedance of the buffer is so low, that it becomes negligible in the voltage division of the signal, meaning nearly all of the signal's energy is put into the 75 Ω output cable. The results are shown in the traces below, and it is clear that the output is properly amplified [3].

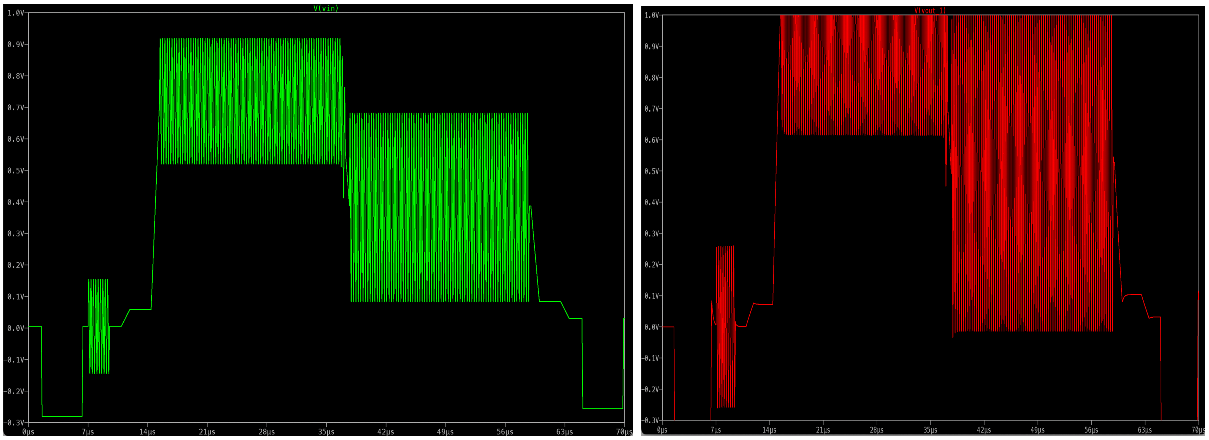


Figure 7: Input (left) compared with output (right) of Figure 1 circuit. Notice how the signal was properly amplified and scaled up with the presence of the voltage buffer. The output signal reaches a maximum value of 1.4 volts, but is clipped in order to maintain equal voltage increments across all trace graphs.

2.5 Cost Analysis

The total cost of the items seen in the figure below is \$126.00. With a 5% shipping cost and 10% sales tax, our total becomes \$144.90. We expect a salary per team member of \$40/hr * 2.5 * 80 hrs. This comes out to \$8,000 per team member, yielding a total between three team members of \$24,000. Our total labor cost is \$24,000 + \$144.90 = \$24,144.90.

Description	**Manufacturer**	**Quantity**	**Extended Price**	**Catalog Number**
Sync Separator	Texas Instruments	1	$2.97	926-LM1881MX
VGA Variable Amplifier	Texas Instruments	2	$12.18	926-LMH6505MM
Wideband Variable Gain Amplifier	Texas Instruments	2	$17.90	595-VCA822ID
High Speed Op Amp	Texas Instruments	10	$19.70	926-LMH6646MAX
1.8 Nanofarad Capacitor	TDK Corporation	10	$1.77	445-180714-1-ND
10 Microhenry Inductor	Bourns Inc.	10	$1.56	118-77F100K-TR-RCCT-ND
100 Picofarad Capacitor	Vishay Intertechnology	10	$1.07	BC2657CT-ND
STM32F303RET6 Microcontroller	STMicroelectronics	1	$9.84	497-15163-ND
RCA Through-hole Connector	Kypon, Inc	5	$3.95	2092-KLPX-0848A-2-B-ND
75 Ohm Resistor	Stackpole Electronics Inc	10	$0.43	RNF18FTD75R0CT
100 Nanohenry Inductor	Bourns Inc.	5	$0.95	M10147-ND
1 Microhenry Inductor	Bourns Inc.	5	$0.95	118-78F1R0K-TR-RCCT-ND
40 MHz Feedback Amplifier	Analog Devices Inc.	1	$17.90	505-LT1256CS#PBF-ND
Power Supply (120 VAC to 6 VDC)	Triad Magnetics	1	$11.72	237-2324-ND
Monostable Multivibrator	Analog Devices Inc.	1	$5.70	LTC6993IS6-3#TRMPBFCT-ND
Dual Output Voltage Regulator	Texas Instruments	2	$0.82	296-TLV75101PDSQRCT-ND
Barrel to Through-hole Connector	Kycon, Inc.	10	$4.32	2092-KLDX-0202-AC-ND
Switched Capacitor Voltage Converter	Analog Devices Inc.	1	$6.18	505-LTC1044CN8#PBF-ND
8-bit DACs	Texas Instruments	1	$6.09	296-1862-5-ND

Figure 8: Itemized list of components and costs.

2.6 Schedule

Week	Tasks
Feb 23 - Mar 1	- Order parts to begin prototyping on a breadboard - View NTSC composite video signal from laptop on an oscilloscope - Begin LTSpice simulations for signal separation and filtering
Mar 2 - Mar 9	- Run LTSpice simulations for the luma feedback amplifier - Complete breadboard prototype - Investigate MCU feedback and amplifier control implementation
Mar 10 - Mar 17	- Create PCB design, pass the PCB way audit - Look into MCU programming implementation - Optional: Submit PCB for second round by **March 13th**
Mar 18 - Mar 25	- Begin prototyping monostable multivibrator - Order any parts not already ordered for PCB design - Investigate final signal summation stage and synchronization with extracted color burst and porch - Complete program for MCU
Mar 26 - Apr 1	- Revise PCB as needed, order revised PCB during third round by **March 31st**
Apr 2 - Apr 9	- Run circuit through physical testing - Identify any minor errors - Send a third pcb design by **April 7th** during fourth round if necessary
April 10 - April 17	- Final tweaks
April 18 - End	- Final demo

3 Ethics and Safety

In accordance with the IEEE Code of Ethics, we will disclose all personal knowledge gaps and uncertainties with the team in order to fully understand all issues collectively during the development process. Likewise, we will only undertake tasks with a sufficient knowledge basis, ensuring team safety with testing with lab instrumentation (e.g. power supply) [5]. We will take measures to ensure the width of the copper etchings on our PCB (especially copper traces connected to power sources) are wide enough to prevent excessive heat and thereby potential damages, as in accordance with the IPC 2221 standard [6]. In addition, in regulating voltages and currents throughout our device, we will abide by OSHA 1910.303(b)(5), preventing faults correctly with all electrical components. For example, we will provide voltage buffering when necessary between modules to lower input current. This will also be achieved with current dividers when appropriate [7].

While using the power supplies in the ECEB 2070 lab, we will make sure to set a current limit on our constant voltage power output settings to protect our chips, and prevent burns from ICs becoming overheated.

References

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[4] Analog Devices, *Basics of Analog Video*, Analog Devices. [Online]. Available: https://www.analog.com/en/resources/technical-articles/basics-of-analog-video.html. [Accessed: Mar. 6, 2025].

[5] https://www.instructables.com/How-to-Use-an-Rotary-Encoder-With-Arduino/

[6] IEEE, *IEEE Code of Ethics (P7.8)*, IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: Mar. 6, 2025].

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