ECE 445
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Project #3: CCD Image Sensor Board for Film Camera Retrofit

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1. Introduction

1.1 Problem

The sudden explosion of demand for old CCD sensor equipped cameras amidst the digicam trend [1][2] is mismatched against a supply of 10-20 year old cameras that are increasingly unreliable and outdated. Between strong consumer demand for these out-of-production cameras, a rise in age-induced failures, and a shortage of outdated, scarce accessories such as proprietary batteries and obsolete storage cards, functioning examples of these CCD cameras are now very difficult to obtain and more fragile than ever.

1.2 Solution

Our proposal is to create a new source of reliable CCD sensor cameras. We will create a PCB that accepts commonly available salvaged CCD sensors and drops them into an advanced film camera. We can minimize our PCB's BOM cost and maximize reliability and compatibility by pairing these salvaged CCD sensors with modern microcontrollers and components, and the plentiful supply of advanced film cameras will ensure that this conversion is practical. The rising price of film [3] has created a glut of technologically advanced film cameras that are cheap to purchase in working condition but too expensive to operate (akin to an inkjet printer).

In practice, our PCB and resulting conversion will emulate the Kodak DCS460 from 1995, but much smaller and modernized to 2025. The PCB will contain the Sony ICX-453 CCD sensor, accompanying power supply, driving, and A->D conversion circuitry, an STM32 microcontroller with SDRAM buffer, an SD card slot, Li-Ion BMS for replaceable 2S 18650 cylinder cells, and buttons and 7-segment displays for user interface. The PCB will be installed into a 3D printed enclosure ("Module") that also holds the batteries and interfaces with the Nikon N90s camera ("Host Camera"), and the Module will synchronize with the Host Camera through its Nikon 10-pin serial interface.

1.3 Visual Aid

Fig. 1: High level implementation of solution depicting old camera to be harvested and the final product that our solution would resemble. Please note that our solution would be a lot more compact than the depicted model

1.4 High-level requirements list

- The completed module will connect to the Nikon N90s camera, and it will save 6 Megapixel color images in uncompressed RAW format.
- The UI will consist of, at minimum, 3 buttons (Delete, Navigate, Select) and a dot-matrix display for status readout.
- The module will accept and save images to SDHC/SDXC cards of at least 32GB capacity.
- The module can be charged over USB-C.
- The N90s camera and module will shoot at a rate of 1 picture per second, with no loss of data.

2. Design

2.1 Block Diagram

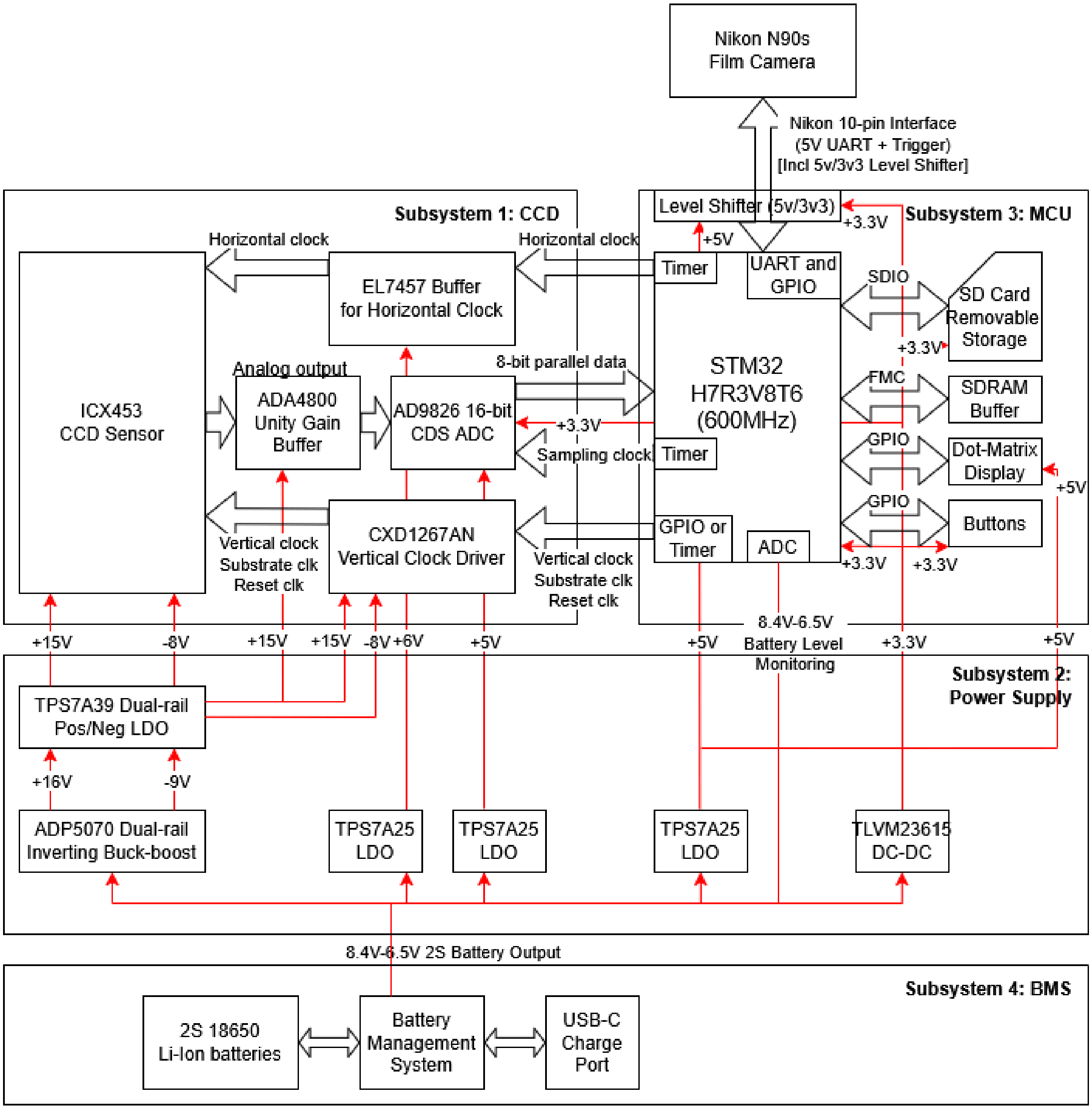


Fig 2. Block diagram representing subsystems connected throughout the PCB and module.

2.2 Subsystem Overview

2.2.1 Subsystem 1: CCD sensor, driving circuitry, and A-D

Subsystem 1 is responsible for properly driving the CCD sensor, and it sends digitized pixel data to Subsystem 3. We recognize that driving the CCD sensor is not only the most critical and irreplaceable part of our project but also the most error-prone part of our project. Thus, we borrowed many aspects of the parts selection, operation, and schematic of Subsystem 1 from the well-proven open-source CAM86 [4][5][6][7][8] astrophotography camera project. This subsystem includes the Sony ICX-453 CCD sensor as salvaged from old cameras, CXD1267 CCD vertical clock driver, EL7457 horizontal clock driver, ADA4800 low-noise buffer, and AD9826 16-bit CDS ADC.

2.2.2 Subsystem 2: Power supply system

The ICX453 CCD sensor requires +15V, -8V, and +6V and may draw moderate current at times due to its large capacitances. Additionally, the supporting circuitry in Subsystem 1 and Subsystem 3 (Microcontroller, SDcard, and UI) will require 5V and 3.3V rails to support their components. This totals to 5 discrete voltages used in our project, powered by 2s Lithium Ion battery cells (a source that varies between 6.5-8.4V)

The power supply architecture for our project primarily targets low noise and secondarily targets a small footprint and good power efficiency. Low noise is necessary since Subsystem 1 is partially analog and generates digital picture data, so best picture quality requires careful power rail noise suppression. Footprint and power efficiency considerations are driven by the desire to minimize Size, Weight, and Power (SWAP) on a hand-held, battery-powered device.

Correspondingly, we are implementing a power supply architecture that uses DC-DC boost conversion followed by low-noise LDO regulators for the +15V and -8V rails used in Subsystem 1, low-noise LDOs for +6V and +5V used in Subsystem 1, a second LDO for +5V in Subsystem 3, and DC-DC for +3.3V digital components in Subsystem 3. The +5V rails of Subsystem 1 and Subsystem 3 are deliberately separated to reduce analog noise, and the +3.3V rail uses more efficient DC-DC since the digital components are less sensitive to noise. Where possible, we will use compact, efficient, and highly integrated DC-DC converters such as TI ‘Micro-SIP’. We also plan to selectively power these rails by toggling the “Enable” pins on the converters, enabling the MCU to control power-saving functionality.

2.2.3 Subsystem 3: MCU, camera I/O, SDcard, User Interface

Subsystem 3 will consist of an STM32H7 MCU, SDRAM buffer, MCU programmer circuit, SDcard slot, user-accessible buttons, and dot-matrix display. The MCU will be responsible for the following:

- Controlling Subsystem 1 and receiving its image data. Clocks will be generated with onboard timers or GPIO pins, and image data will be received with the DCMIPP/PSSI interface or GPIO pins.
- Controlling Subsystem 2 to implement power saving functionality. This will be accomplished with GPIO pins.
- Monitoring battery voltage from Subsystem 4. This will be accomplished with the onboard ADC.
- Synchronizing with the Host Camera through the camera's Nikon 10-pin interface (including a triggering signal and a serial interface for querying the camera's state and configuration)
- Buffering images to SDRAM to enable rapid shooting
- Processing and saving images to the SDcard over SDIO, maximizing readout speed to flush the buffer as quickly and possible
- Accepting user inputs via button press and reacting accordingly, including configuration changes and a delete button that erases the most recently saved file. This will include the user-accessible power button, so that a power-off does not cause data loss.
- Driving the dot matrix display to display the module's state to the user

Since these tasks require high-speed I/O and significant processing power, the MCU must have a native SDIO capability, an SDRAM interface, and a JPEG engine to enable real-time JPEG compression at minimum cost. For these reasons, the STM32H7R3V8T6 MCU was selected. While the JPEG compression and preceding Bayer conversion are not part of the success criteria, we will target this functionality since it would significantly enhance the camera's practical usability.

As Subsystem 1 is largely based on the CAM86 [4][5][6][7][8] project, some of the code from CAM86 [4][5][6][7][8] may also be referenced or borrowed to form the interface between Subsystem 3 and Subsystem 1. Any borrowed code will require substantial revision due to the integration of substantially more functionality in this project, and the use of an STM32 MCU as opposed to CAM86's [4][5][6][7][8] AVR MCU.

2.2.4 Subsystem 4: Battery Management System

Subsystem 4 will consist of an integrated BMS system and a USB-C charging port for the 2S 18650 Li-Ion power source, as well as a power kill switch for use during debug and assembly. This subsystem will integrate primarily with Subsystem 2 (Power regulation), but will also integrate with Subsystem 3 (MCU) to enable a user-visible battery level readout.

The BMS will provide short circuit and overcurrent protection, as well as overcharge and over-discharge protections to the sensitive and dangerous Li-Ion battery cells. The BMS system should be able to charge the battery cells from a USB-C port that is exclusively used for charging. We may incorporate USB-C fast-charging capability, but it will not be part of this project's success criteria.

2.3 Subsystem Requirements

2.3.1 Subsystem 1 Requirements:

- The CCD must return a usable 3000x2000 pixel image at a clock rate of 12.5MHz.
- The clock drivers, ADC, and other analog circuitry must function correctly at 12.5MHz.

2.3.2 Subsystem 2 Requirements:

- When taking an image, the +15V power rail for Subsystem 1 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- When taking an image, the -8V power rail for Subsystem 1 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- When taking an image, the +6V power rail for Subsystem 1 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- When taking an image, the +5V power rail for Subsystem 1 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- When taking an image, the +5V power rail for Subsystem 3 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- When taking an image, the +3.3V power rail for Subsystem 3 must operate continuously at +/-5% regulation, given a battery voltage of 8.4V or 7V.
- Rails equipped with MCU toggle control must turn on and off according to the MCU’s instructions.

2.3.3 Subsystem 3 Requirements:

- The MCU must generate a 12.5MHz Horizontal clock for Subsystem 1.
- The MCU must be capable of buffering 12.5MB/sec image data from Subsystem 1.
- The MCU must sense the battery voltage to within 5%.
- The MCU must successfully save individual images to the SDcard without corruption or data loss, when images are taken at a rate of 1 image per second.
- The MCU must react to the Host Camera shutter.

2.3.4 Subsystem 4 Requirements:

- The BMS must cut off the battery output at or above 6.5V.
- The BMS must be able to charge the battery to above 8.0V and not above 8.6V.

2.4 Tolerance Analysis

The most critical component of this project is the CCD, as its absence or malfunction would negate the entire purpose of the project. It is not reasonable to simulate the complete functionality of the CCD, since it is a very complex analog device with minimal documentation that warrants too many unknown variables to simulate. However, we can use simulations to confirm that its supporting circuits are capable of supplying signals that meet the CCD's input specifications. The CCD has significant parasitic capacitances and requires certain rise and fall times on its clocks. We can accurately calculate if our driving circuitry is capable of meeting these timings and transient current requirements using the equivalent circuit capacitances labelled on the CCD's datasheet and the known current carrying capabilities of the supporting circuits.

To test this, we constructed a simulation of the horizontal driving circuitry according to the CCD sensor's equivalent circuit. The EL7457 horizontal clock driver is specified to 2A current with an RDSon of 3Ohm, and the rise/fall times must be 5ns for 90% change. The LTSpice simulation below shows both these criterias are met; the transient current is around 1.2A and the rise/fall time for 90% change is around 3.3ns. With sufficient bulk capacitance, the +6V power supply should be capable of handling these momentary transients.

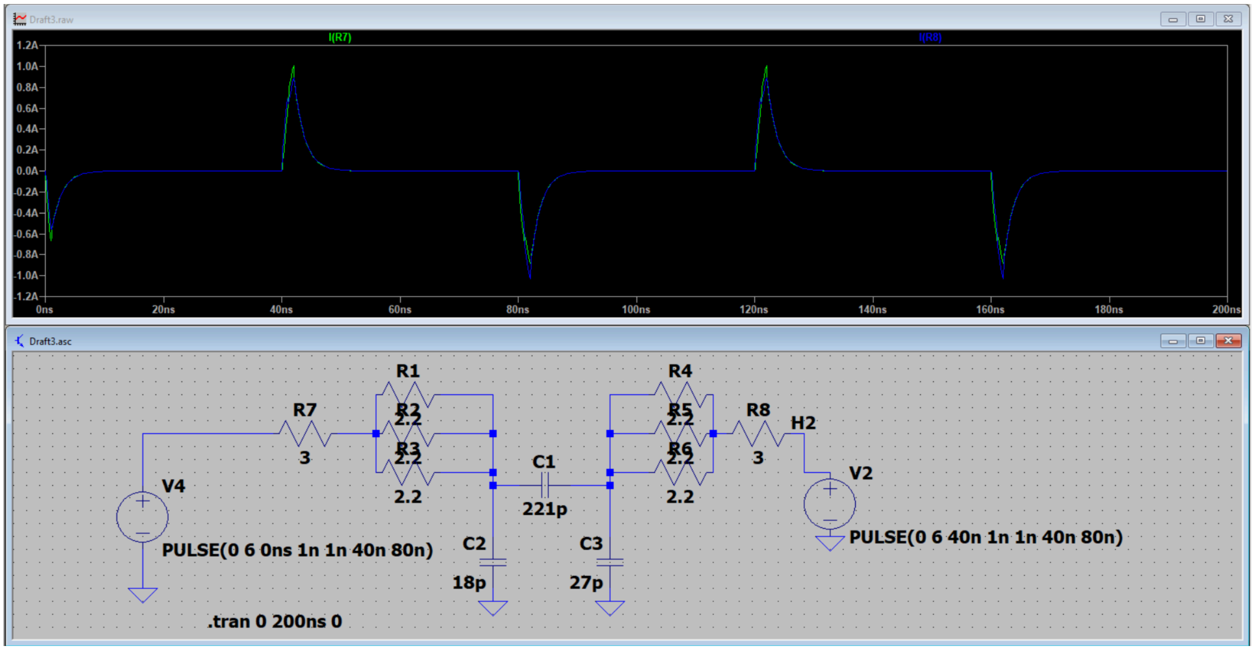
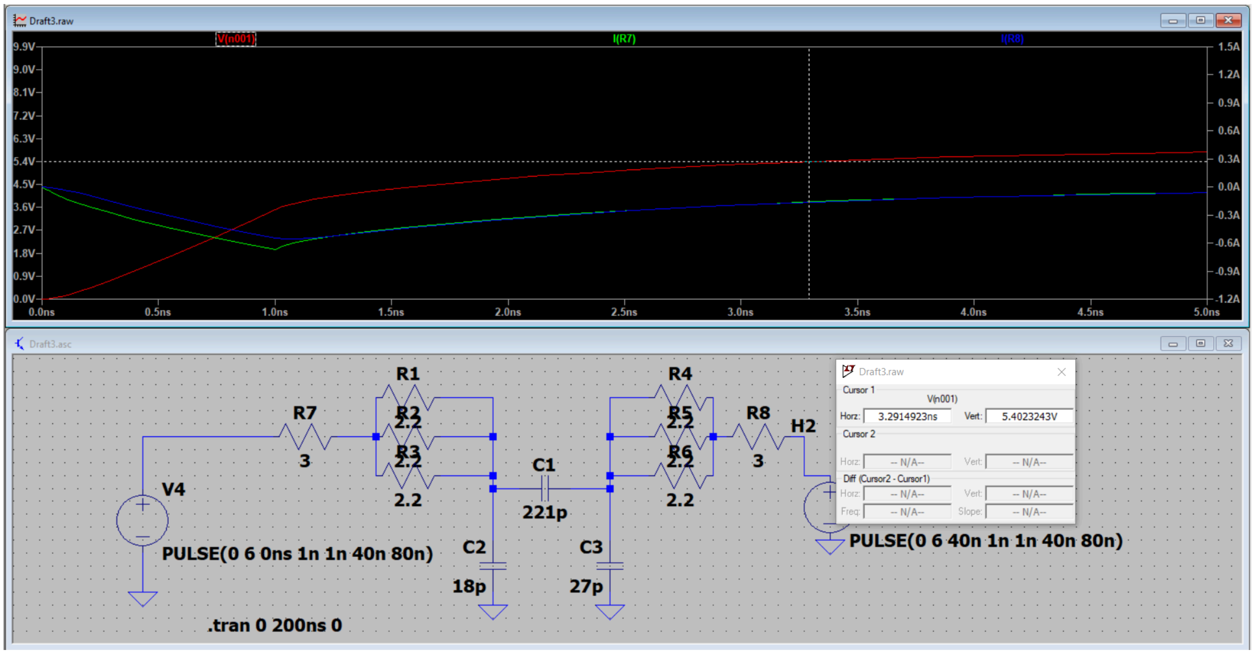


Fig. 3: LTSpice simulation depicting transient currents do not surpass the driver's specified limit.



Draft3.raw

Cursor 1

V(n001)

Horz: 3.2914923ns Vert: 5.4023243V

Cursor 2

Horz: -- N/A-- Vert: -- N/A--

Diff (Cursor2 - Cursor1)

Horz: -- N/A-- Vert: -- N/A--

Freq: -- N/A-- Slope: -- N/A--

Fig. 4: LTSpice simulation depicting rise and fall times are within stipulated bounds.

3. Ethics and Safety

3.1 Use of Open-Source Work

Our work builds upon a combination of open source projects ported to our specific needs, as such we recognize the ethical responsibility of properly attributing and adhering to licensing terms when reusing such work. In alignment with the ACM Code of Ethics (1.5), which promotes giving appropriate credit and respecting intellectual property rights, we will ensure that all borrowed concepts or code are properly cited and comply with the original licenses.

3.2 Reverse Engineering of Sensor Inputs

Due to the limited documentation available for CCD sensors, we may need to reverse-engineer some sensor inputs. We will ensure that this process does not violate proprietary rights or confidentiality agreements. The IEEE Code of Ethics (7.8.I.4) urges engineers to avoid engaging in practices that could be considered unlawful. As such, we will only use legally obtained resources and publicly available data for reverse engineering.

3.3 Battery Management and Power Safety

Since our device will utilize Li-ion batteries, we will integrate a Battery Management System (BMS) to mitigate risks such as overcharging, overheating, or short-circuiting.

This aligns with industry standards, such as IEEE 1725 for rechargeable battery safety. Furthermore, we will follow proper disposal and recycling guidelines as outlined in environmental regulations, ensuring compliance with both federal and state policies on battery waste management.

3.4 Laboratory Safety Compliance

Our development and testing will take place in University of Illinois laboratories, requiring strict adherence to campus safety policies. This includes compliance with electrical safety protocols, proper handling of PCB components, and adherence to lab-specific regulations to minimize hazards.

4. References

[1]]M. Farrell, “Digital cameras back in fashion after online revival,” *BBC News*, Feb. 06, 2023. Available: https://www.bbc.com/news/technology-64512059

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[3]B. Tridimas, “Why There’s A Colour Film Shortage Right Now,” *VICE*, Jan. 24, 2023. https://www.vice.com/en/article/why-theres-a-colour-film-shortage-right-now/ (accessed Feb. 08, 2025).

[4] “Самодельная охлаждаемая ПЗС камера от grim - стр. 1 - Hand Made,” *Kiev.ua*, 2025. https://www.astroclub.kiev.ua/forum/index.php?topic=28929.0 (accessed Feb. 08, 2025).

[5]smr547, “GitHub - smr547/cam86: Build an CCD camera for astrophotography,” *GitHub*, 2020. https://github.com/smr547/cam86 (accessed Feb. 08, 2025).

[6]axsdenied, “GitHub - axsdenied/cam86_fw: Custom firmware for cam86 astro camera,” *GitHub*, 2017. https://github.com/axsdenied/cam86_fw (accessed Feb. 08, 2025).

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[8]“Cam86,” *Astroccd.org*, 2016. http://astroccd.org/2016/10/cam86/ (accessed Feb. 08, 2025).