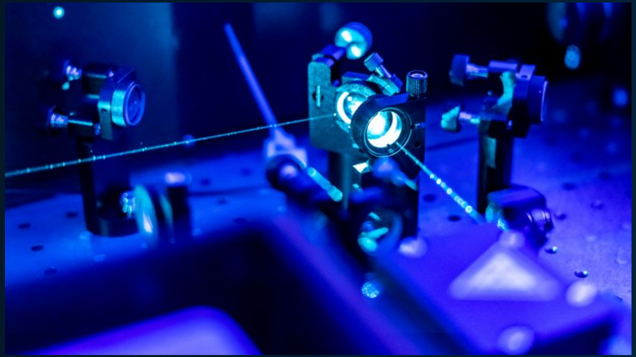
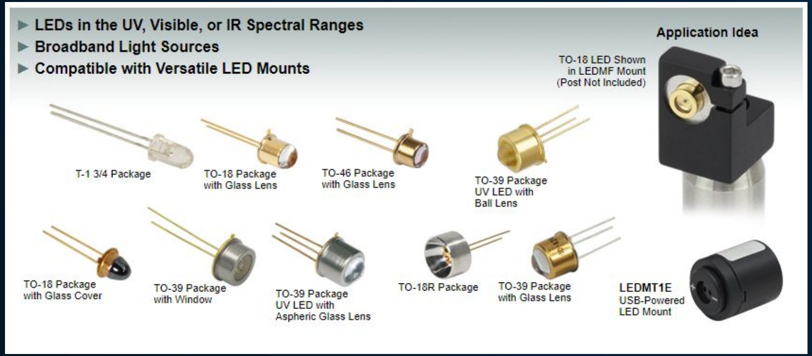


Li-Fi Project

Spring 2023

Devon Gonzales, Enive Bien-Aime, Kevin Harper



Refresher - Project Goals

- Design and implement a digital signal transmitter-receiver (transceiver) module based on LiFi technology
- Design and implement an analog signal transmitter-receiver (transceiver) module based on LiFi technology
- After successful design and implementation of digital and analog LiFi transceivers, find suitable applications to demonstrate LiFi communication technology.

Refresher - Why?

- On a low-level, light waves have a higher frequency and shorter wavelength than radio waves, and so a wireless communication protocol implementing Li-Fi technology has the potential to outpace speeds of traditional wireless communication methods.
- It also provides the added benefit of security as most objects are not penetrable by light. What's more is that Li-Fi technology, implemented on a large scale in complement with traditional wireless communication methods could free up some of the radio band.
    - This is especially beneficial for densely packed areas where the radio spectrum can be congested.
- Lastly, a light-based protocol implemented in areas containing sensitive electronics may make possible wireless communications where previously not feasible.

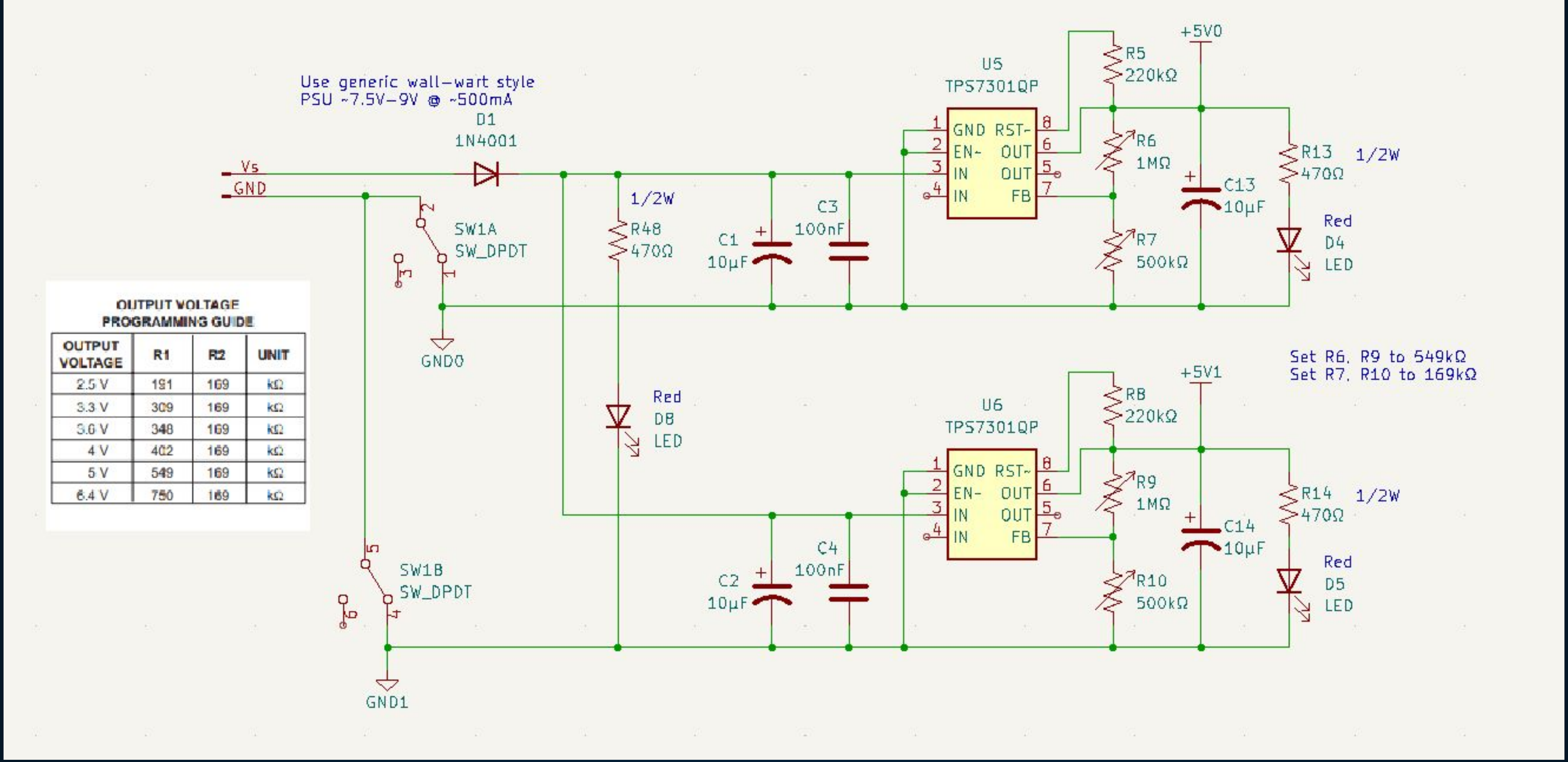
Our Approach

- Implement a UART transceiver in an optical fashion…

- Power supply: LDO with switched ground for on/off and LED indicators
- Transmitter: logic level FET with HF shunt for overshoot/ringing, 5mm LED load @ drain
- Receiver: op amp cascade with transimpedance front-end and comparator output stage
- Control: Arduino Nano with appropriate peripherals for control and operation (OLED, push button, potentiometer, LDR, etc.)

Hardware (Power Supply)

- The power supply circuitry was designed according to the chosen regulator datasheet (TPS7301QP):
  - Hardware programmed with resistors to set output voltage of 5V with 7-9V input
  - 500mA max output per regulator
  - Regulated voltage indicator LEDs to aid in future debugging
  - Input supply voltage indicator LED
  - Grounds are switched with a DPDT switch to turn the test fixture on and off
  - As shown, we used trim pots to accurately set the resistance values necessary to step down the input to 5V

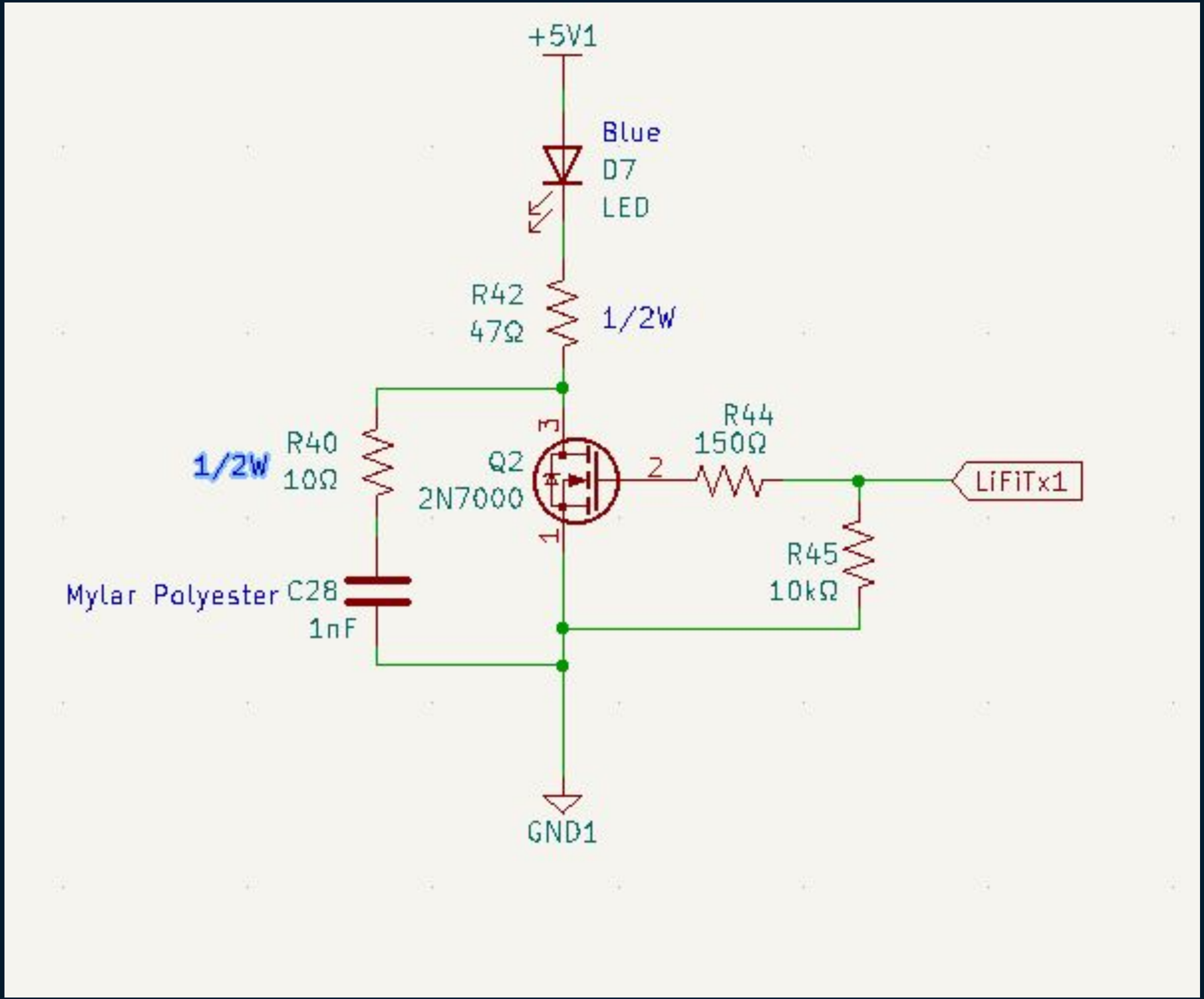


OUTPUT VOLTAGE PROGRAMMING GUIDE

OUTPUT VOLTAGE	R1	R2	UNIT
2.5 V	191	169	kΩ
3.3 V	309	169	kΩ
3.6 V	348	169	kΩ
4 V	402	169	kΩ
5 V	549	169	kΩ
6.4 V	750	169	kΩ

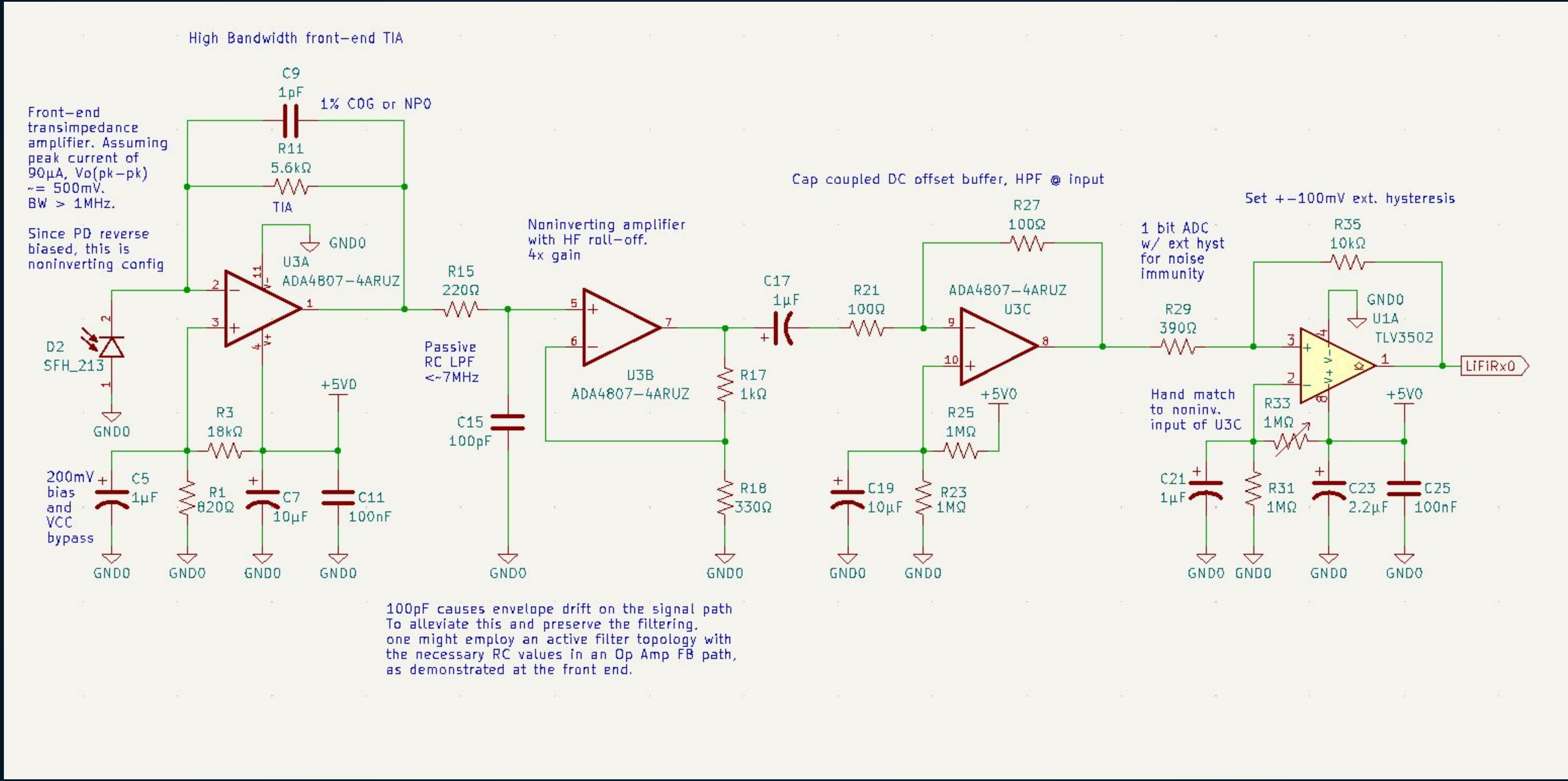
Hardware (Transmitter)

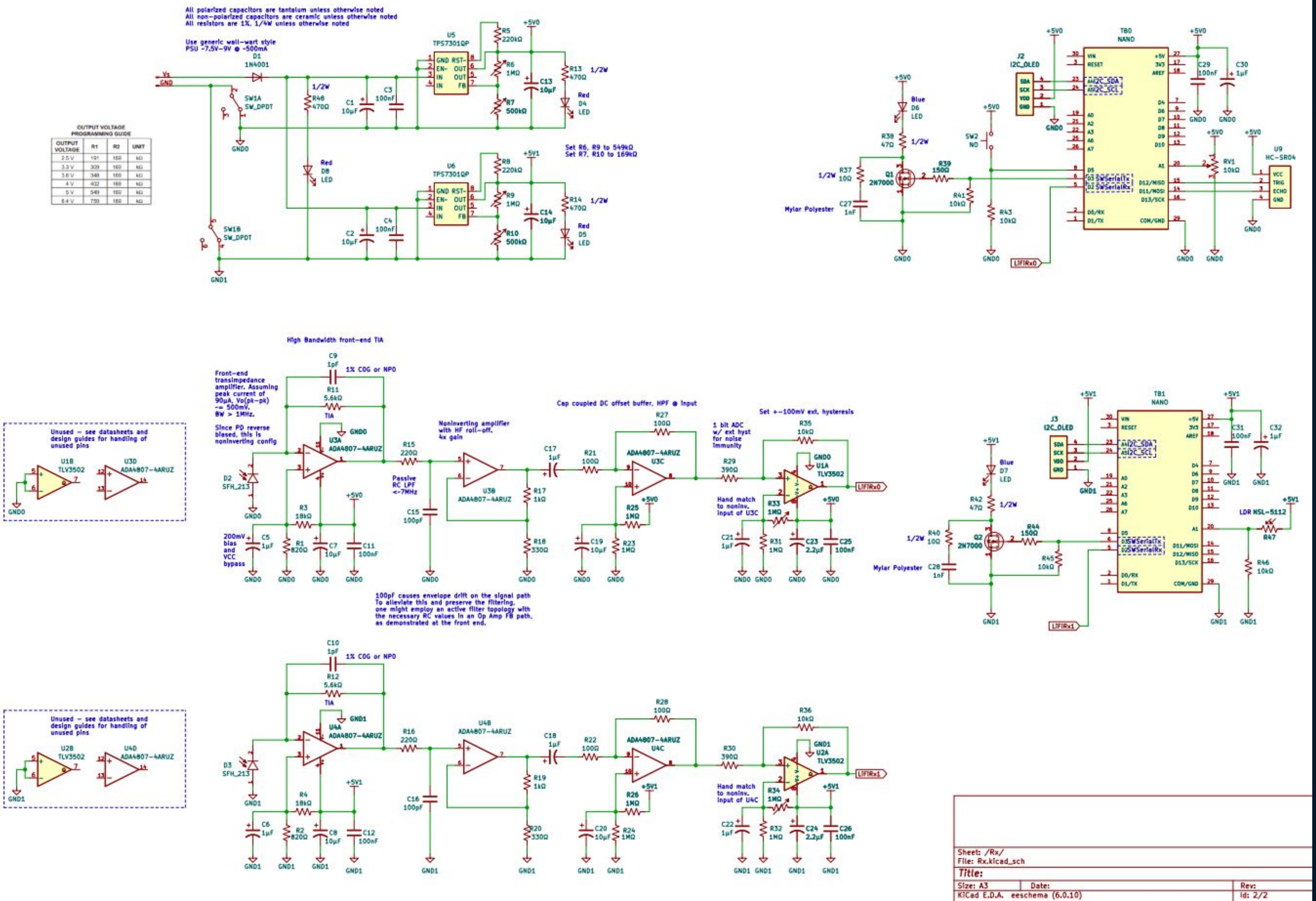
- The transmitter is a simple logic-level FET driven load:
  - Shunted from the drain terminal of the FET to ground is a passive RC filter which dumps high frequency overshoot and ringing to ground
    - If left undealt with, this is coupled into the op amp circuitry and appears as noise which improperly switches the output stage comparator
  - The gate has a 10kΩ pull down resistor to attenuate floating effects and solidify the off state of the load
  - The gate also has a 150Ω resistor in series with the gate to limit the transient current through the capacitive gate of the MOSFET


+5V1
Blue
D7
LED
R42
47Ω
1/2W
R40
1/2W
10Ω
Q2
2N7000
3
2
1
R44
150Ω
LiFiTx1
R45
10kΩ
Mylar Polyester
C28
1nF
GND1

Hardware (Receiver)

- The receiver is a 3 op amp cascade with comparator at the output that functions as a 1 bit ADC:
  - The first op amp functions as a transimpedance amplifier with feedback capacitor to cancel out the parasitic effects of the input capacitance seen by the op amp at its' input terminals
    - The reference voltage of the noninverting input terminal is set in accordance with the limits specified in the component datasheet (to ensure max speed, bias such that the op amp saturates 200mV above the negative supply rail)
  - This is fed to the following stage which consists of a LPF input with 4x gain
  - Then, the following stage consists of an AC coupled non inverting amplifier configuration with reference voltage set such that the output signal will ride a DC value of ~½ Vcc
  - The final portion is a comparator that digitizes the signal for a final clean up to be read by a microcontroller GPIO pin initialized as a digital input.
    - The comparator reference voltage is set to match that of the final stage op amp using trim pots. Match with a multimeter and adjust as necessary based on test results


High Bandwidth front-end TIA
C9
1pF
1% C0G or NP0
Front-end transimpedance amplifier. Assuming peak current of 90µA, Vo(pk-pk) ~= 500mV. BW > 1MHz.
Since PD reverse biased, this is noninverting config
R11
5.6kΩ
TIA
GND0
U3A
ADA4807-4ARUZ
D2
SFH_213
GND0
R3
18kΩ
+5V0
200mV bias and VCC bypass
C5
1µF
R1
820Ω
C7
10µF
C11
100nF
GND0
GND0
GND0
GND0
Noninverting amplifier with HF roll-off. 4x gain
R15
220Ω
Passive RC LPF <~7MHz
C15
100pF
GND0
U3B
ADA4807-4ARUZ
R17
1kΩ
R18
330Ω
GND0
C17
1µF
Cap coupled DC offset buffer, HPF @ input
R21
100Ω
R27
100Ω
ADA4807-4ARUZ
U3C
+5V0
R25
1MΩ
C19
10µF
R23
1MΩ
GND0
GND0
1 bit ADC w/ ext hyst for noise immunity
Set +-100mV ext. hysteresis
R35
10kΩ
R29
390Ω
GND0
U1A
TLV3502
LiFiRx0
Hand match to noninv. input of U3C
R33
1MΩ
+5V0
C21
1µF
R31
1MΩ
C23
2.2µF
C25
100nF
GND0
GND0
GND0
GND0
100pF causes envelope drift on the signal path
To alleviate this and preserve the filtering,
one might employ an active filter topology with
the necessary RC values in an Op Amp FB path,
as demonstrated at the front end.



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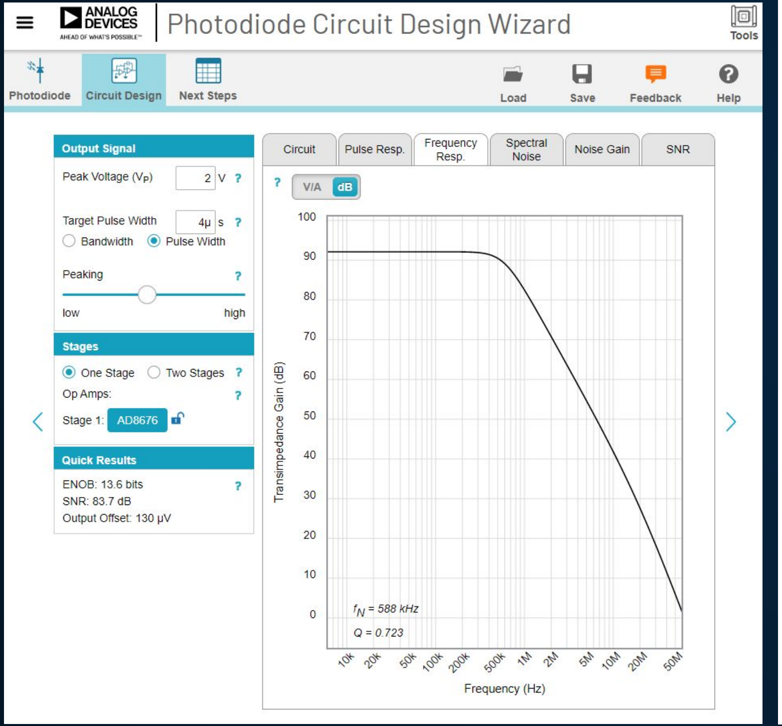
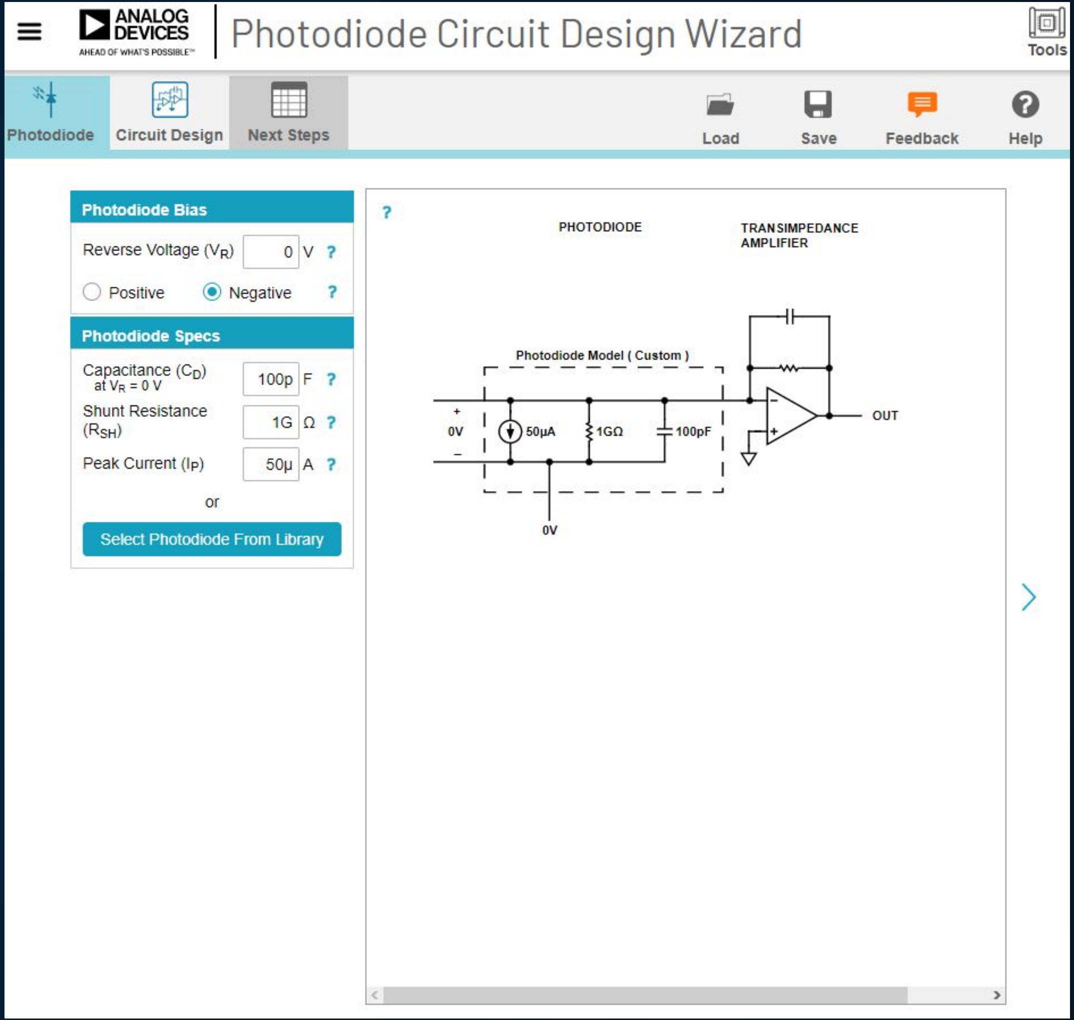
5 V	549	169	kΩ
6.4 V	750	169	kΩ

Design Tools…





JavaScience

Transimpedance Photodiode Amplifier

May 06, 2012

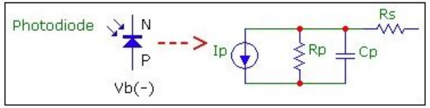
Introduction:

This article discusses basic modeling theory and results for the photodiode transimpedance op-amp circuit. The exact predicted circuit response, optimum feedback capacitance and phase margin are compared with commonly used approximate analytical expressions. Calculators are included which (a) accurately calculate the feedback capacitance required for a stable optimally flat transimpedance response and (b) calculate detailed transimpedance amplifier properties for arbitrary GBW, Rf, Cf, Ri and Ci parameters. A specific worked example is included that can be used as a reliable modeling benchmark.
More advanced discussion and design information including noise calculation is available in these articles:

- 1.6 MHz Bandwidth Transimpedance Photodiode Amplifier (ADA4627-1)
- 45 kHz High Gain Transimpedance Photodiode Amplifier (OPA606)
- Transimpedance Noise Calculator   Bare Bones Calculator
- Transimpedance Cumulative Noise Calculation
- Transimpedance Full Noise Calculation
- Bias Offset Noise
- Transimpedance Reference Data
- Transimpedance f3db and Cf Design Curves for Maximally Flat Response
- Feedback Amplifier Stability
- Feedback Amplifier Stability Calculator
- Op-amp Output Capacitance Isolation

Photodiodes:

The PN junction photodiode is essentially an optical power to electrical current converter. The wavelength sensitivity of the photodiode depends on the photodiode material (Si, GaAs, Ge etc) with Si photodiodes being used for visible and near infrared detection. The materials, fabrication design (layer thicknesses etc.) and wavelength λ largely determine the photodiode **Responsivity** in units of A/W. At the most fundamental level, the electronic processes in a semiconductor junction photodiode involve electron and hole carrier drift and diffusion transport processes. The degree of complexity required in a lumped-circuit element description of a photodiode depends largely on the intended usage, with speed or bandwidth usually being the key parameter. Indeed, for speeds in the GHz range or higher, an accurate model requires proper treatment of the internal junction transit-times and the complexity of the lumped-circuit model increases. For bandwidths below roughly 100 MHz, the photodiode can be usefully approximated with an electrical equivalent circuit consisting of an ideal fixed magnitude current source **Ip** with a shunting junction capacitance **Cp**, a shunting junction resistance **Rp** and an internal series resistance **Rs** as shown below. Cp and Rp will be dependent on the reverse bias, if any, applied to the photodiode. Since the photocurrent generated by a photodiode is a reverse current, the direction of the current source in the equivalent circuit below corresponds to the orientation of the PN junction in the diagram:



References used in design…

- 1. BB (SBOA059) - Single-Supply Operation of Op Amps
- 2. LT (AN13) - High Speed Comparator Techniques
- 3. REN (R13AN0003EU0100) - Biasing Op Amps
- 4. TI (DU535) -1MHz, Single-Supply, Photodiode Amplifier Reference Design
- 5. TI (DU871) - AC-Coupled Single Supply Op Amp Reference Designs
- 6. TI (SBOA263A) - Non-Inverting Op Amp with Non-Inv. Pos. Reference Voltage
- 7. TI (SBOA313A) - Non-Inverting Comparator with Hysteresis Circuit
- 8. Y. Sanghvi, "Cyclic redundancy check (CRC) in Arduino," Tutorials Point, 24-Jul-2021. [Online]. Available: https://www.tutorialspoint.com/cyclic-redundancy-check-crc-in-arduino
- https://www.jensign.com/transimpedanceamp/
- https://tools.analog.com/en/photodiode/

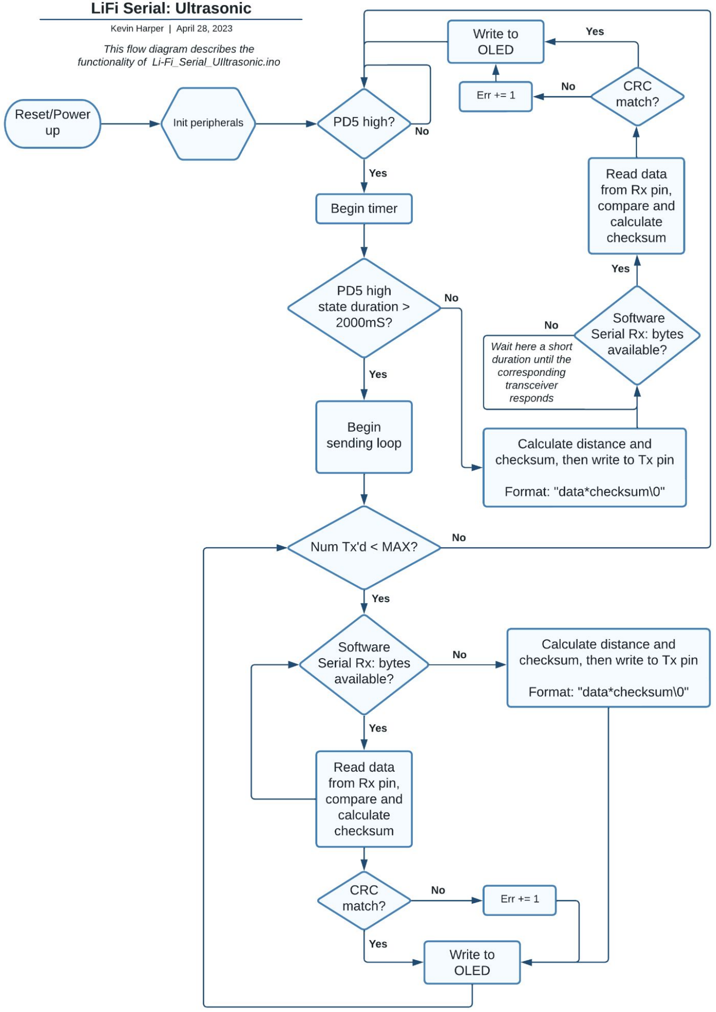
Software (Li-Fi_Serial_Distance.ino)

- Arbitrarily decided to control the flow of communication between the two transceiver modules in the test fixture
- Upon release, a press of the push button input is used to step messages out over the serial link
- In the event that the button is held for longer than two seconds, an alternative mode of operation is entered in which the Arduino will continuously send
    - The delay between messages can be adjusted via the potentiometer
- When data is received, it is accepted as a string and chopped up into substrings according to delimiter bytes.
- The trailing half of the message string, which contains a checksum, is compared with a local call of the same checksum algorithm passed the received data value.
    - If a mismatch in the two checksums occurs, then we know that an error occurred during transmission, and we must take action to adjust some physical features of the system to ensure a more ideal optical link.
- Efforts were taken to assign the distance measurement from the ultrasonic sensor to a persistent, globally available variable for use in between measurements where possible

LiFi Serial: Ultrasonic

Kevin Harper | April 28, 2023

This flow diagram describes the functionality of Li-Fi_Serial_UIltrasonic.ino



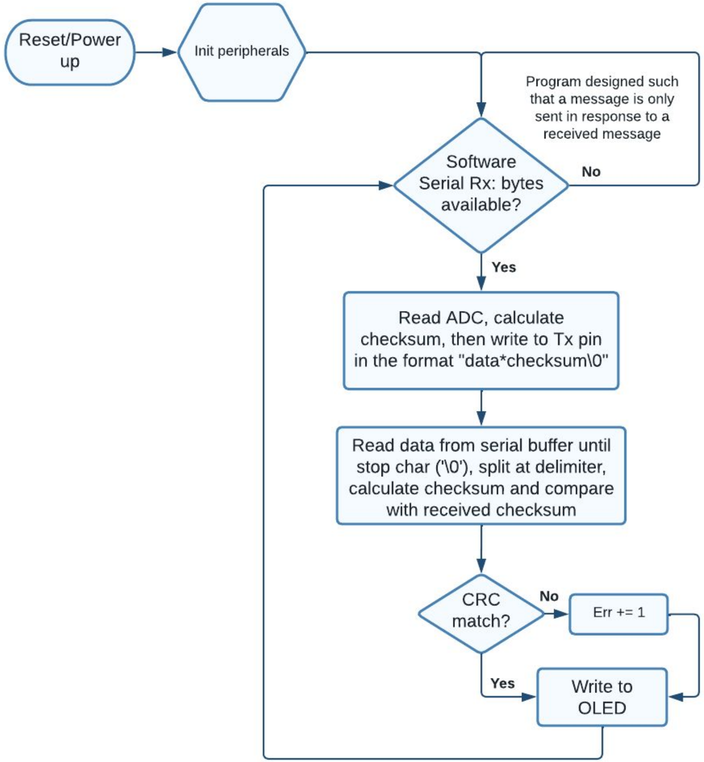
Software (Li-Fi_Serial_ADC.ino)

- In consequence of choosing the other transceiver module as the main controller, was arbitrarily decided to have no manual control of its' transmission
- This code was written to demonstrate the capability of bidirectional communication for the Li-FI transceivers using the Arduino in a simple manner requiring no additional control inputs.
- The message contents are a mapped reading of an ADC voltage divider. This is intended to give an indication of the amount of incident light on the system
- Uses the same checksum algorithm and data formatting (data*checksum/0)

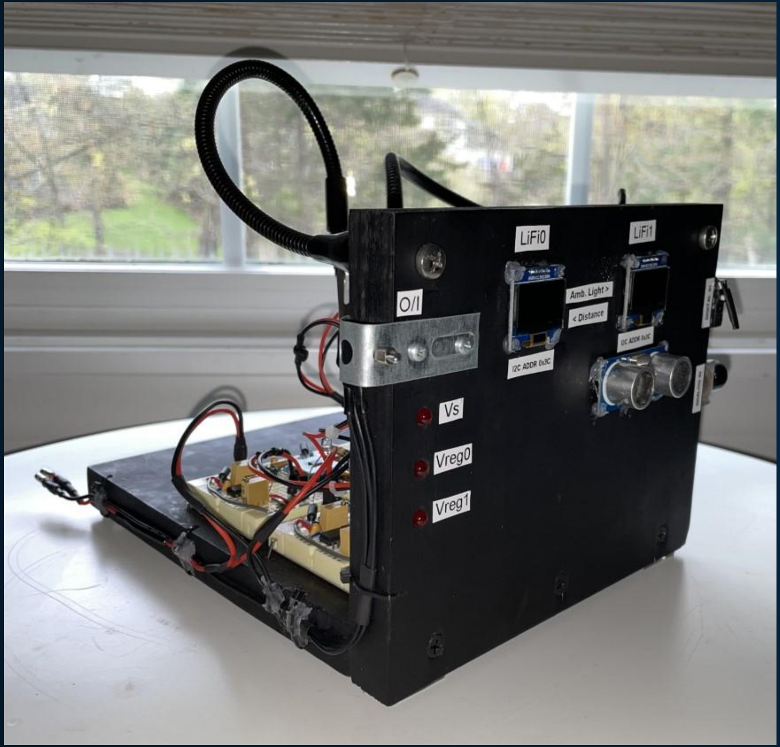
LiFi Serial: ADC

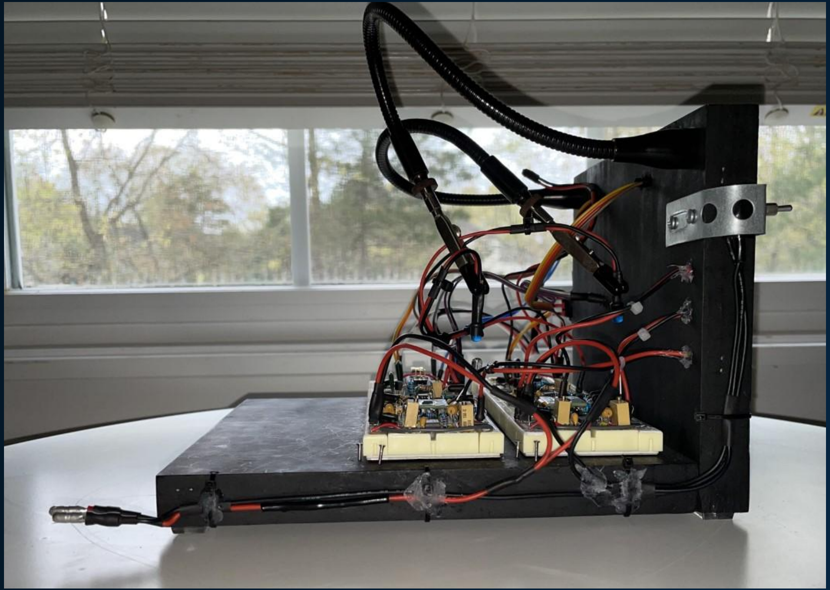
Kevin Harper | April 30, 2023

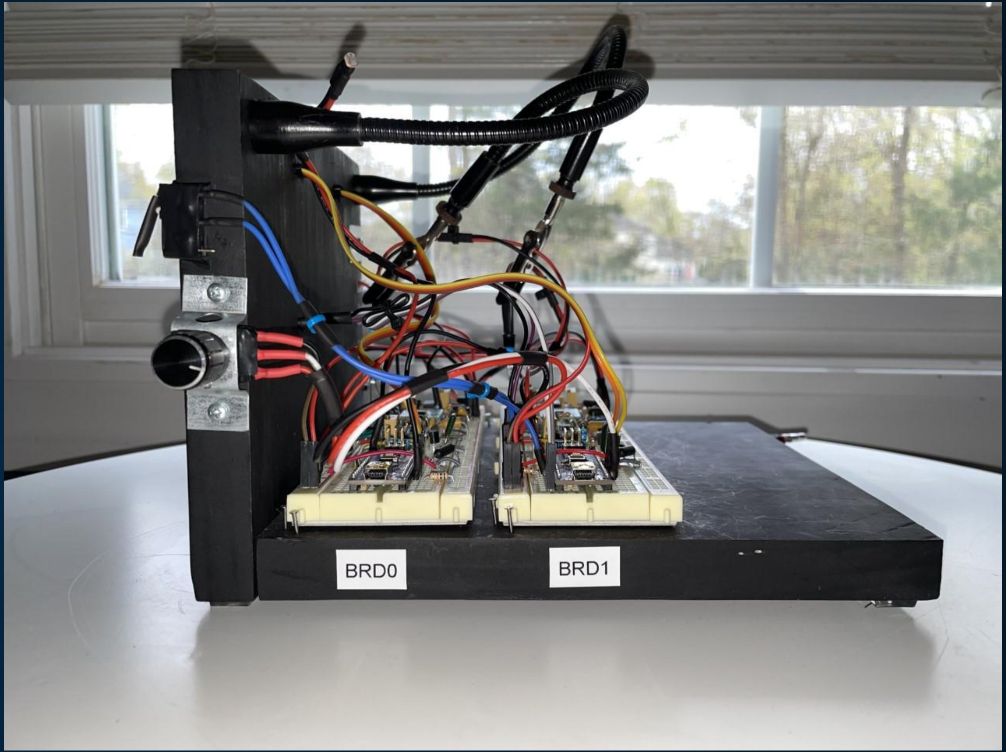
This flow diagram describes the functionality of Li-Fi_Serial_ADC.ino

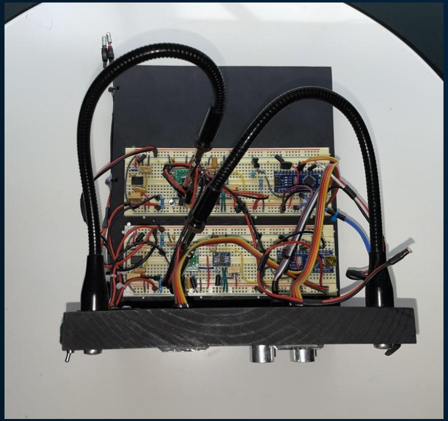


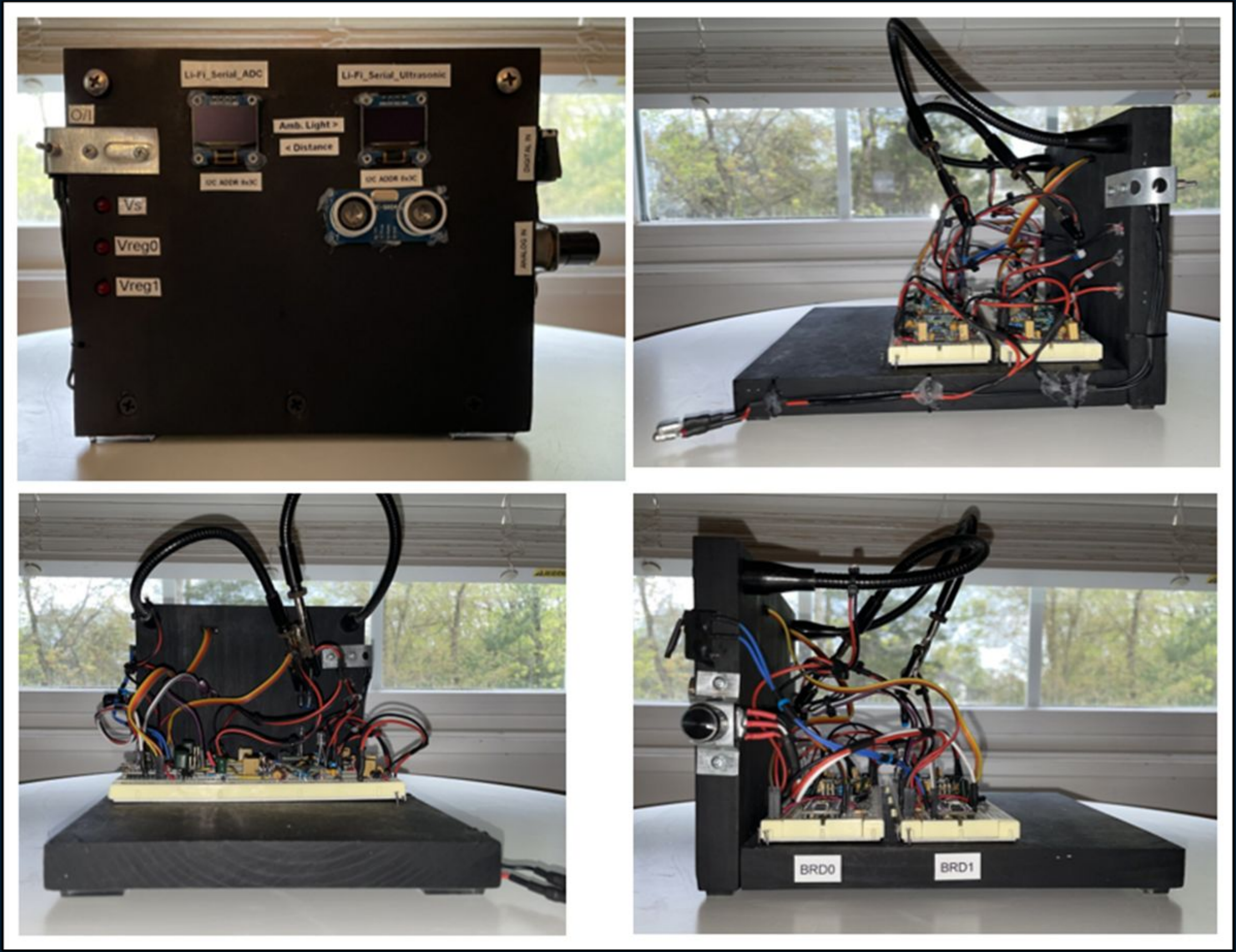
Test fixture, realized…





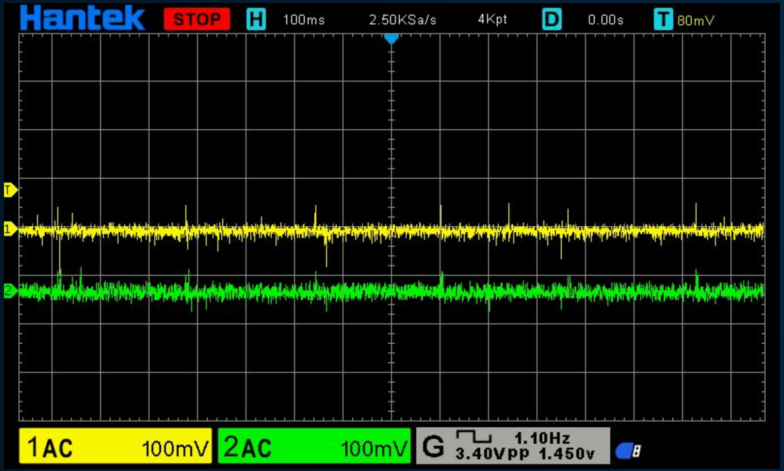

BRD0
BRD1



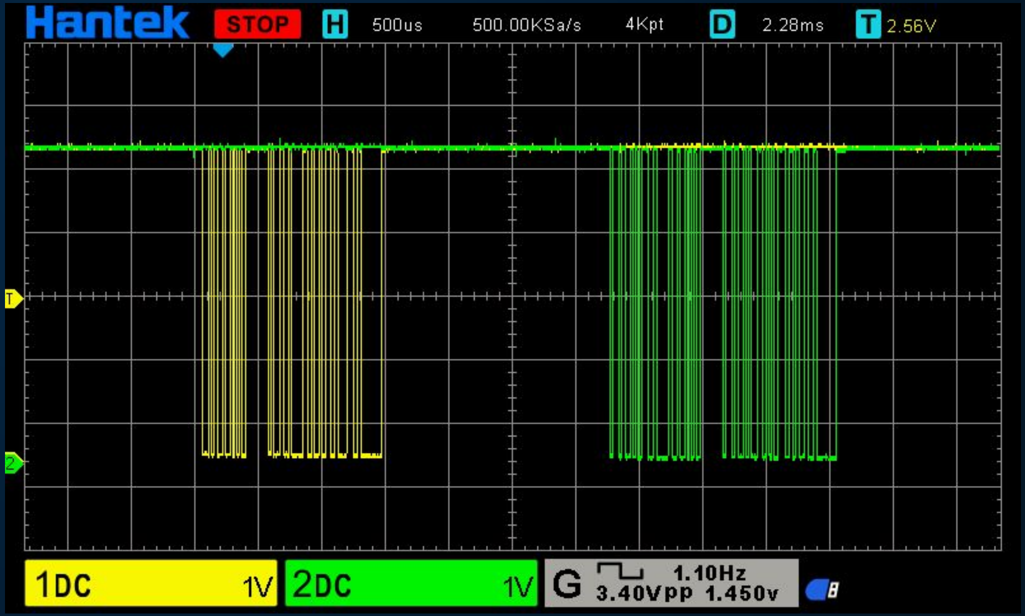

Li-Fi_Serial_ADC
Li-Fi_Serial_Ultrasonic
O/I
Amb. Light >
< Distance
Vs
Vreg0
Vreg1
DIGITAL IN
ANALOG IN
BRD0
BRD1

Some scope captures...

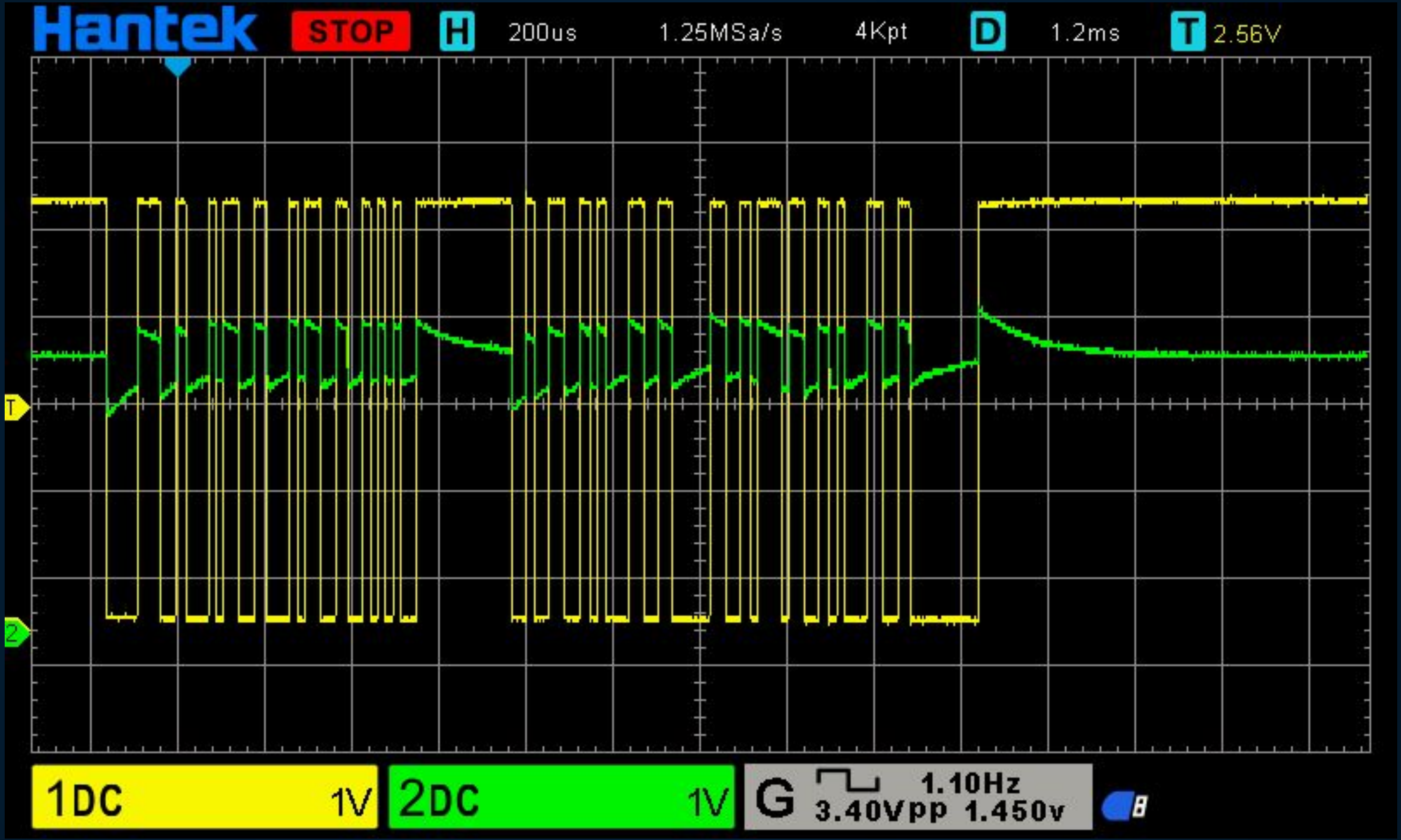
Power supply noise during operation



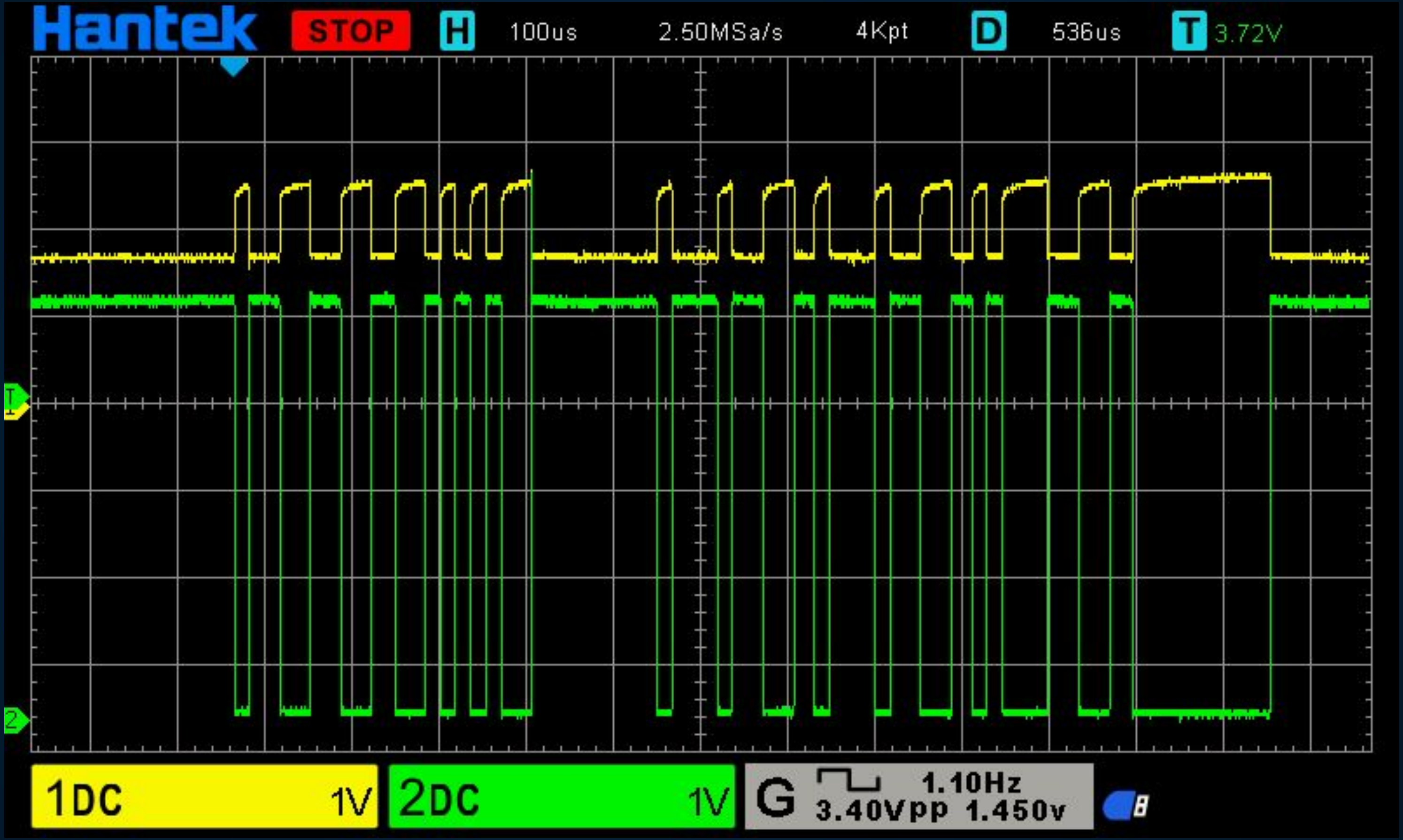
Half duplex proof....

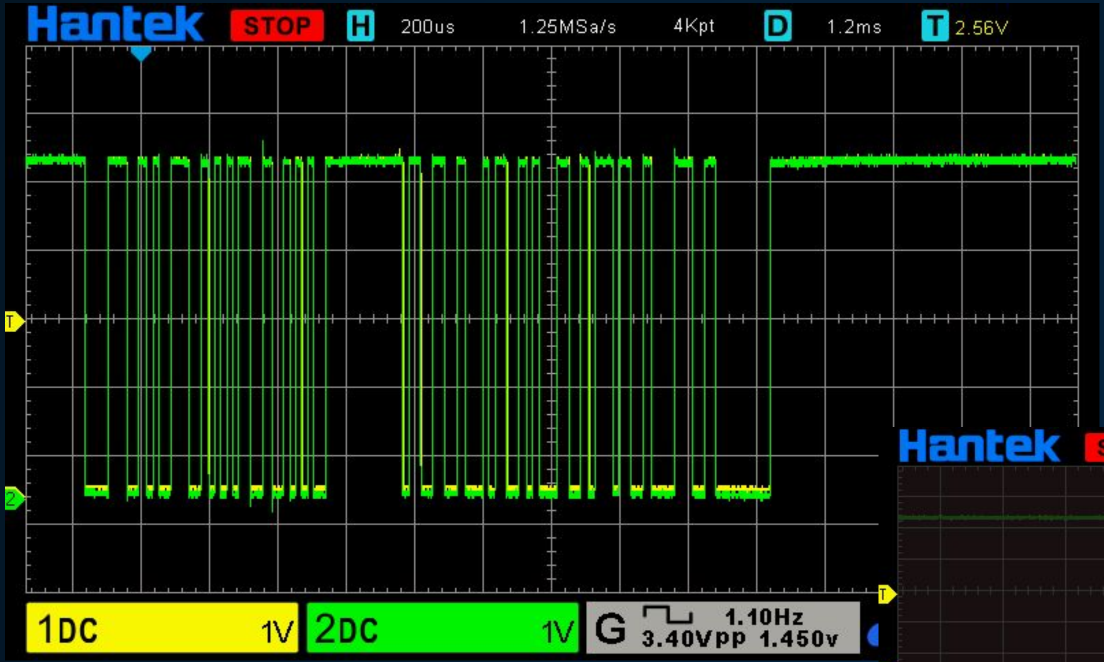


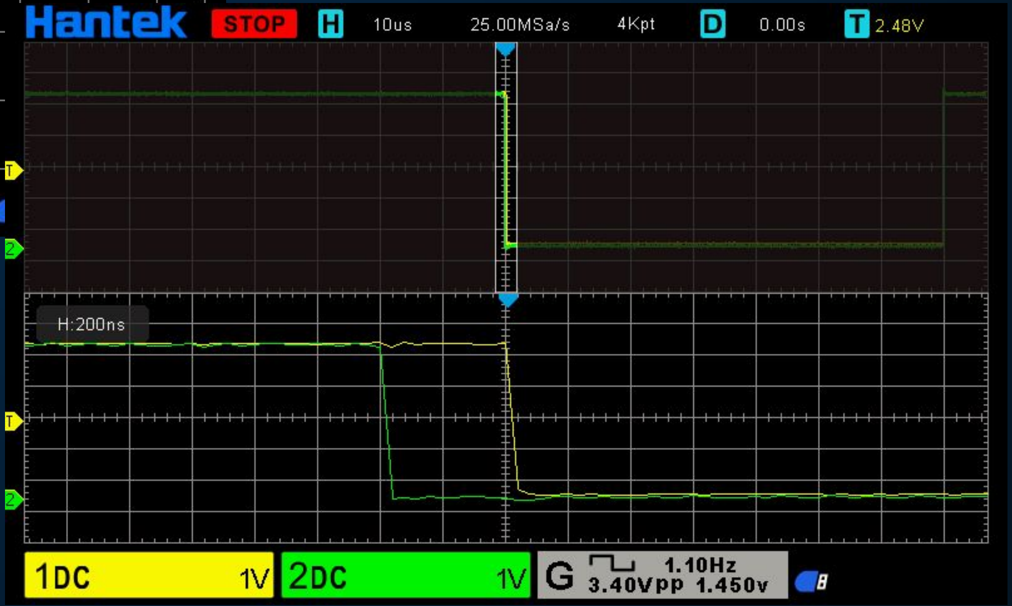
Receiver op amp output and comparator output



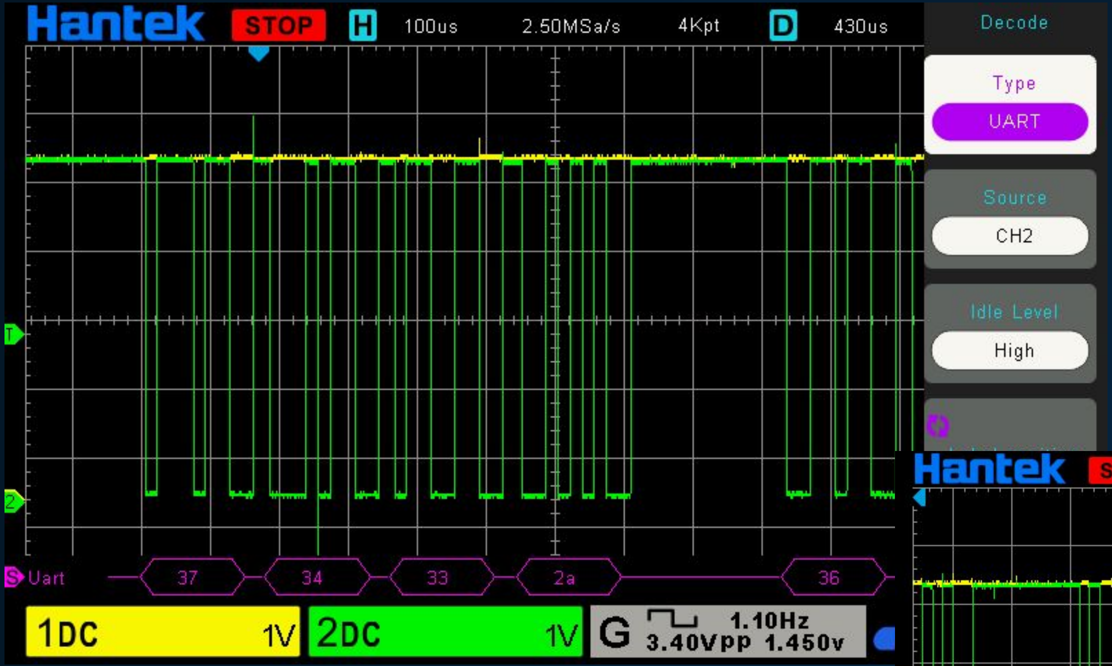
Transmitter gate and drain





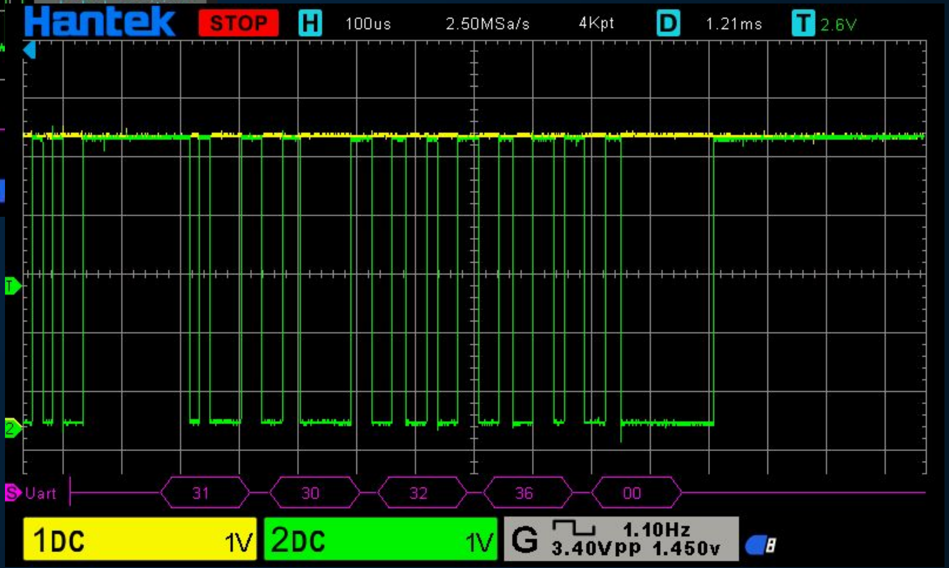


Time delay from end to end (how long does the transmission take?)



ADC checksum:
Bytes 0x31, 0x30, 0x32, 0x36, 0x00

== “1026/0”



ADC message:
Bytes 0x37, 0x34, 0x33, 0x2a

== “743*”

The Project: Demo Video 1 (Live Signal Watch)

https://youtu.be/1GJ8T9eoe20

The Project: Demo Video 2 (Final Working Demo)

https://youtu.be/hCBdTFn2qZ4

https://youtu.be/JKYV6c7ScP0

The Project: Demo Video 3 (I2S, Li-Fi audio)

https://youtube.com/shorts/jnBFJcJJ6aU?feature=share

Project Evaluation

- Envelope drift issue (evident in scope captures)
    - The issue seems to be a result of some capacitive effects present in the signal path. Issues did not arise in the serial processing for the test fixture despite the presence of the envelope drift. See C15 and passive LPF in received signal path
- Software, polling approach
    - On average, per 10,000 sent messages, about 30 are missed entirely, presumably because of the polling approach. This number is made more threatening knowing that the ATMega was programmed to only worry about the serial messages. In other words, in an application requiring more of the processor other than demonstrating the ability of the Li-Fi transceivers, more messages would be missed.
- Software emulated serial is less efficient than a dedicated hardware implementation
- Arduino Software Serial limitations
    - Disables interrupts for the entire time that a character is being sent **or** received, and cannot do both at the same time. Restricted with Software Serial to baud rates no higher than 57600. Usefulness of Software Serial ends at 115200 baud for capable Arduino boards
- Expensive BOM
    - Can be reduced by removing an op amp stage and combining functionality into one stage.
    - Less hysteresis for tighter performance

Project Evaluation

We did not find an analog application for the transceiver, although the receiver portion was designed such that the signal prior to the comparator has its linearity relatively preserved for frequencies up to 500kHz. The transmitter end of such an analog optical transceiver could be adapted from the current design by biasing the transistor so that the pattern of light emitted by the LED is analogous to an alternating gate voltage.

Professional hardware/software

Hardware:

- TPS7301 voltage regulator IC’s, Texas Instruments, DIPs
- AD4807 quad op amp from Analog Devices, TSSOP14
- TLV3502 from Texas instruments, SOIC8
- SFH213 photodiode from Osram, 5mm through hole clear
- HCSR04 Ultrasonic distance sensor module from Adafruit
- 2N7000 logic level FETs from Fairchild (many other manufacturers)
- Many jelly bean parts, but mostly 1% (not strictly necessary) 1/4W resistors and tantalum capacitors

Software:

- Arduino Software Serial lib for software UART on GPIO
- Third-party NewPing lib for interfacing the ultrasonic distance sensor
- Timer lib for shifting mode of test fixture operation
- Adafruit SSD1306 OLED display lib and Wire lib for I2C on GPIO

Safety/Legal

All solder connections and pin-header jumper wires are shrink wrapped and secured to the fixture with zip ties where sensible. The test fixture supply wires have an integrated input polarity protection diode. A wall-wart style power supply with output short circuit protection should be used if a lab benchtop supply is not available. Caution should be taken to ensure that no metal objects short together the thin exposed portion of the butt splices when the power supply is plugged into the test fixture. When programming the Arduino's in the breadboard, turn off the board power via the test fixture power switch and remove the red 5V supply jumper. Ensure not to redeclare the GPIO direction for any of the initialized GPIO pins in the source code as this could result in internal shorts occurring in the microcontroller on reset, which is unresolvable.

There are no legal issues with the Li-Fi transceiver design, as they simply make use of common op amp and transistor topologies.

Societal and Economic Context

Using visible light, LiFi is secure and there is less interference from external sources which ensure data privacy and security.

Using LED ,LiFi is energy efficient and can use existing lighting infrastructure which lead to cost saving .The high speed of data transmission ensure a growth for the global economy

Societal and Economic Context

- While an optically implemented serial protocol may be less practical, the idea of sending information over light, as per reasons discussed, could prove beneficial to society in terms of data security and affordability.
- In its’ current form, a single transceiver is fully capable of being used to benchmark optical drivers and transducers. A further application of the transceiver might be in the shipping industry, where shipping vessels and ports could use the transceiver with a long-distance, high-powered laser as the transmission means to communicate back and forth without relying on any form of conventional internet connection. This implementation of the transceiver would understandably require line of sight (LOS).
- Even then, since the transceiver hardware was designed with the goal of having a high bandwidth, it has the potential to provide an optical solution for faster, more modern, and more capable communication protocols with little additional changes necessary.

How might the transceiver be used?

- In its’ current form, a single transceiver is fully capable of being used to benchmark optical drivers and transducers.
  - Fancy way of saying “able to test flashlight PWM”
- A further application of the transceiver might be in the shipping industry, where shipping vessels and ports could use the transceiver with a long-distance, high-powered laser as the transmission means to communicate back and forth without relying on any form of conventional internet connection. This implementation of the transceiver would understandably require line of sight (LOS).

Reflection/Team Evaluation

As for the team evaluation, the team was unified and very transparent in our communication skills, very efficient on time management and we all did a outstanding and a collaborative effort job to prepare this magnificent LI-FI Communication Technology project. We proud of what we accomplished.

Suggested Improvements

- Adopt an interrupt-based approach
  - Ensures that the source code is portable to a larger system where there are I/O devices operating at many different speeds or the processor is otherwise often busy
- Phase out the reliance on so many global variables
  - May otherwise cause issues with portability in the presence of additional compile modules
- Use hardware serial if serial is the chosen application
  - Hardware serial would allow for the test fixture to demonstrate the higher speeds that the system is capable of in a serial application and would otherwise free up processing power for the microcontrollers in the Li-Fi test fixture
- Reduce BOM cost by removing amplifier stages and swapping capacitor types
  - Browse alternative manufacturer/distributor offered solutions
- Implement on a PCB
  - Make the highest possible bandwidth stable system
- Nice to haves for the test fixture

Conclusion

In sum, Lifi is a wireless communication technology that use visible light to transmit data using light waves.The LED lights used, transmit data in binary form by turned on and off quickly. As advantages,LiFi provide a higher data transfer compare to Wifi because of the large bandwidth of the visible light spectrum.As of security,Lifi is very secure as the light does not pass through walls like radio waves do, which can prevent hackers from intercepting communications.In term of economy, the LED used by Lifi are energy efficient which consume less power and are environmental friendly.In term of heath ,Lifi does not transmit any radio wave which make it an option for the environment.However LiFi require a visible line between the transmitter and receiver