DIRECTED, HIGH FREQUENCY, OPEN-AIR COMMUNICATION

GROUP 29:

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GIVEN PROJECT DESCRIPTION

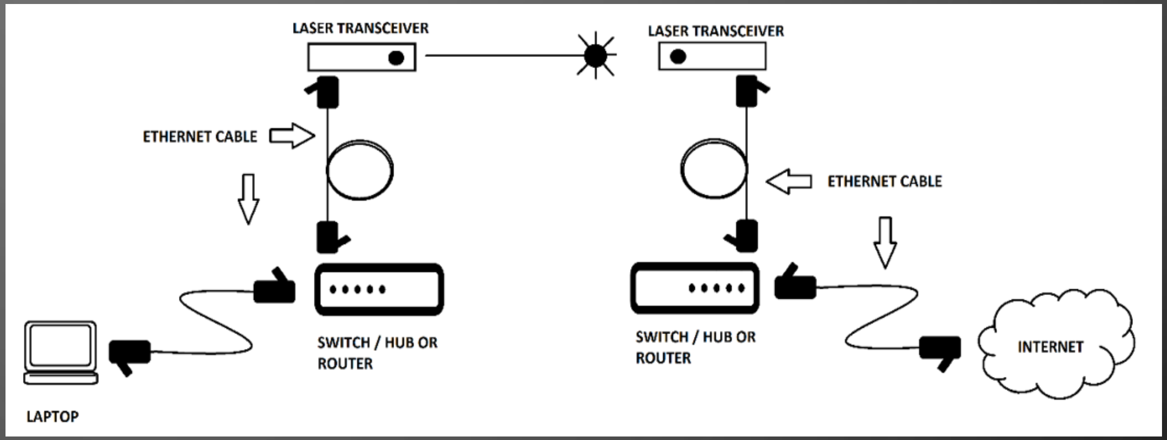
RF communication is the most popular form of data transfer currently for untethered devices. Wi-Fi, Bluetooth, and GSM are all broadcast technologies that allow any slave devices within a spherical range to communicate with the host device. This is wasting energy which could be focused on higher-powered and directed data transfer. This project would contain one primary focus and a secondary focus (given enough available resources):

1. An emitter and receiver pair using lasers to communicate between devices.
2. A modification to the emitter that is able to track the receiver around a room.

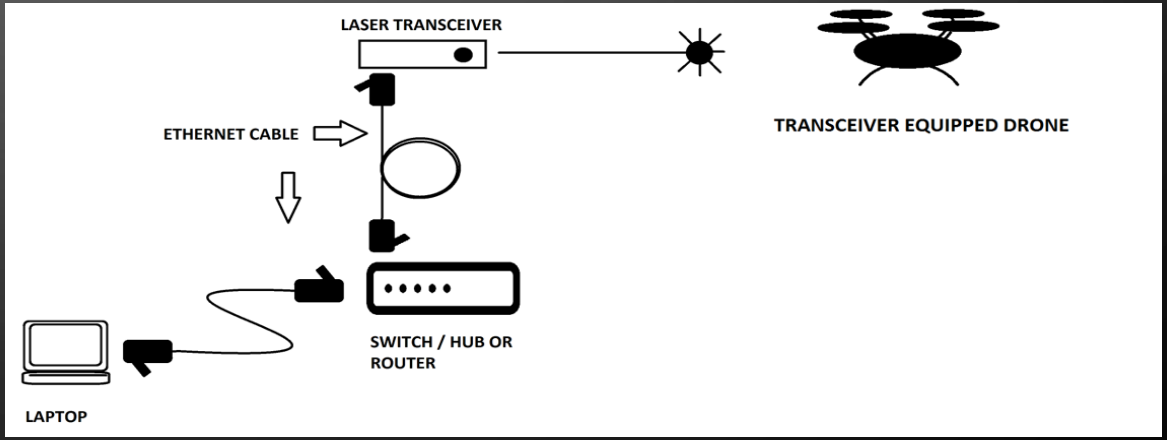
The applications of this product would be, among others, more directed Wi-Fi communications for homes and businesses, long-range communications where Wi-Fi is unable to reach the target receiver, or in low-power scenarios (where other communication mediums would be restricted by power limitations).

IMPLEMENTATION SCENARIOS

- The transceivers should be able to replace long haul Ethernet or optical fiber cables.



- The transceivers should be able to maintain beam alignment on a mobile unit.



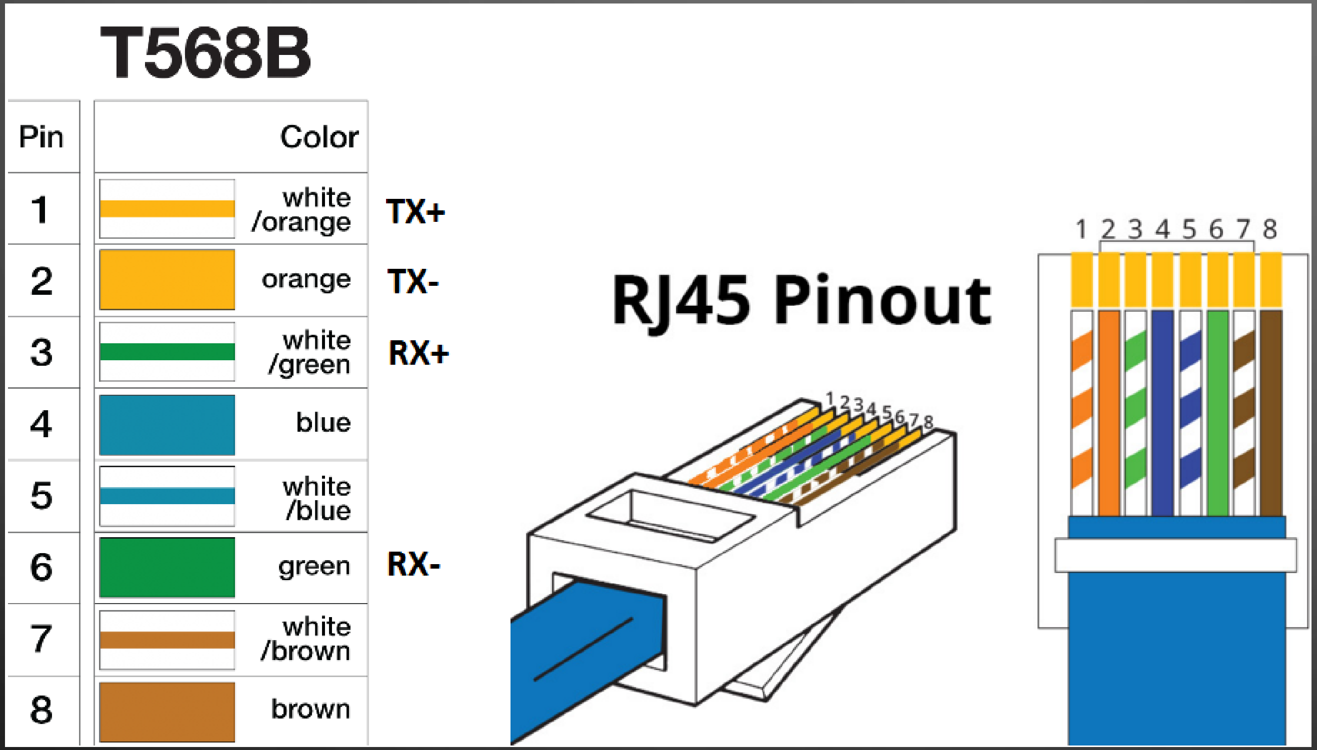
GIVEN PROJECT GOALS

1) Create optical transceiver pair that can transmit data from an Ethernet or USB connection in a serialized fashion.
2) Find a way to integrate object or beam tracking to let a static transceiver track a mobile transceiver.

SPECIFICATIONS & PROJECT REQUIREMENTS

- BANDWIDTH >= 10 MBps
- BATTERY TIME >= 30 mins.
- SIZE < 1 $ft.^3$
- WEIGHT < 10 lbs.
- RANGE : [1, 100] ft.

DESIGN APPROACH

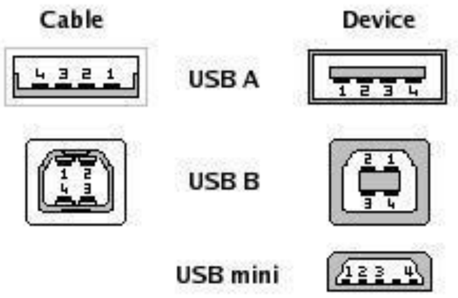


T568B

Pin	Color	
1	white /orange	TX+
2	orange	TX-
3	white /green	RX+
4	blue	
5	white /blue	
6	green	RX-
7	white /brown	
8	brown	

- The majority of wired network hardware employs Ethernet over twisted pair.
- There are two leads responsible for transmitting one signal.
- Line coding methods change depending on Ethernet standard.
- 10BASE-T uses differential Manchester encoding.

DESIGN APPROACH

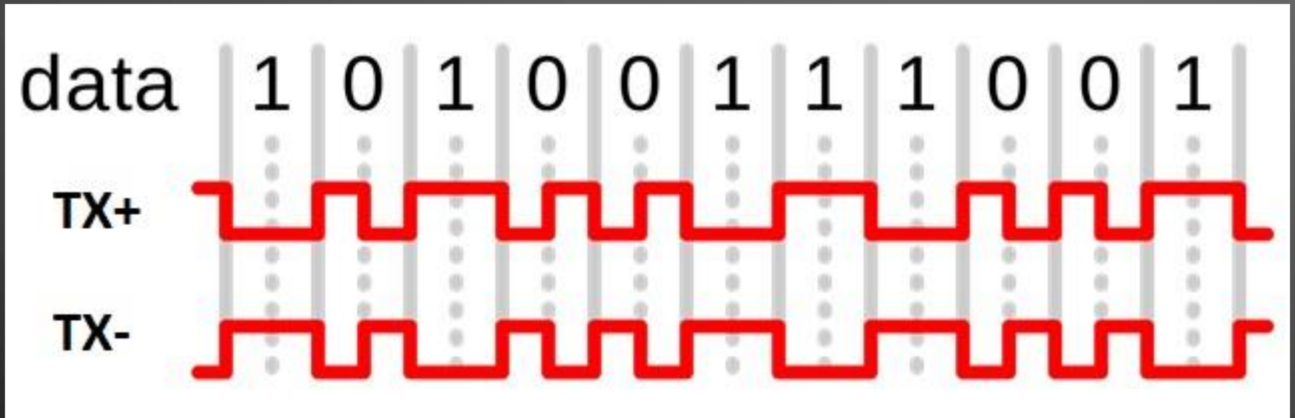


Pin	Signal	Color	Description
1	VCC		+5V
2	D-		Data -
3	D+		Data +
4	GND		Ground

- USB also uses two leads to transmit one signal.
- The line coding employed by the USB 2.0 standard is NRZI

DESIGN APPROACH

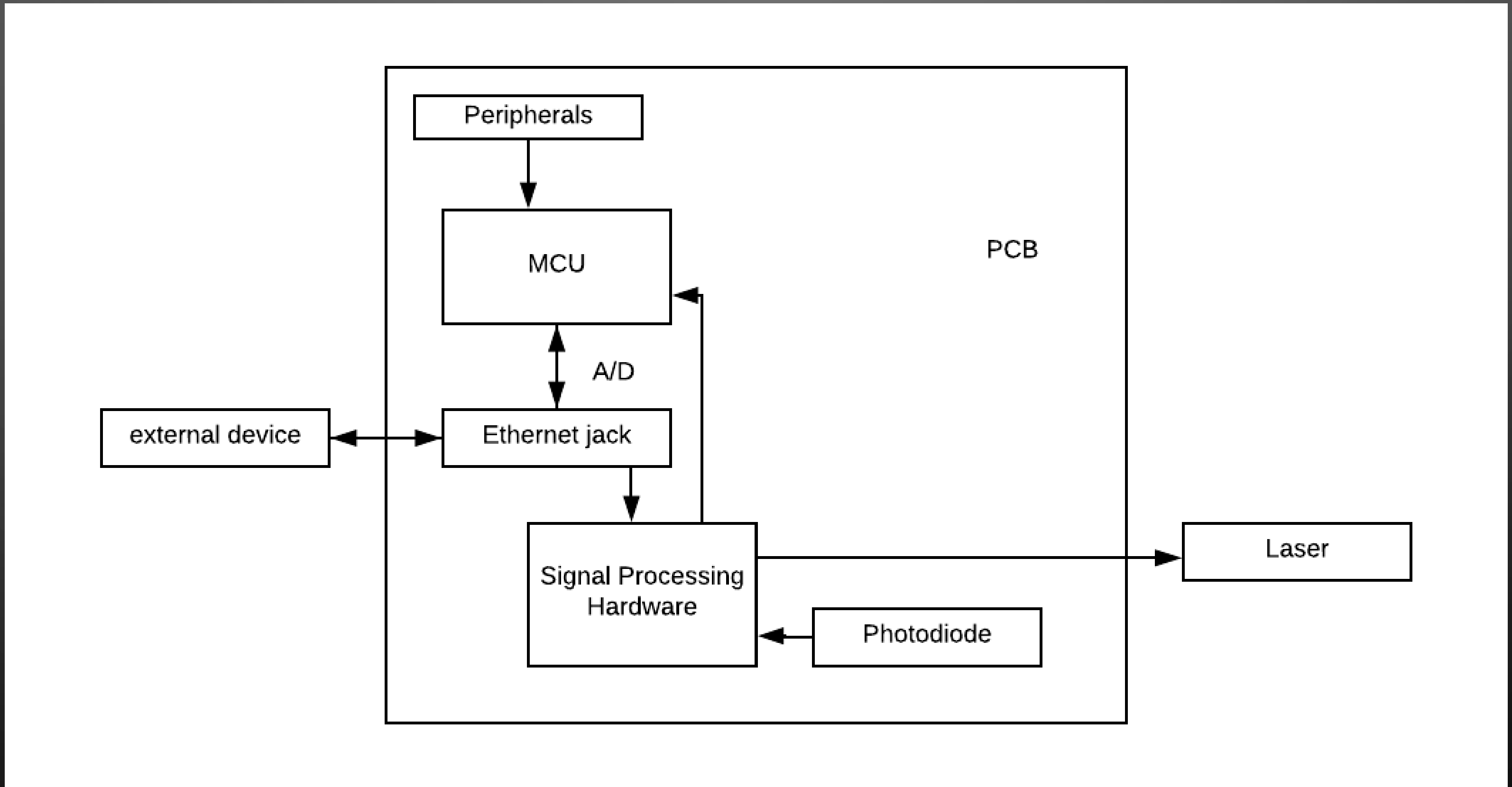
An example of an ideal signal transmitted via USB or 10BASE-T Ethernet with arbitrary amplitude is shown below:



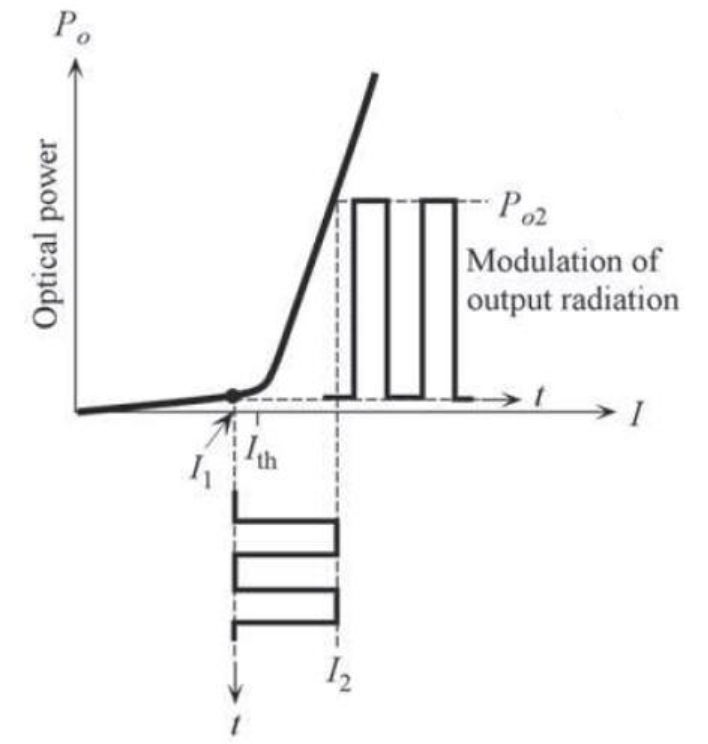
So the question is:

“How do we prepare a differential signal to a waveform that can be sent via laser?”

PROJECT BLOCK DIAGRAM

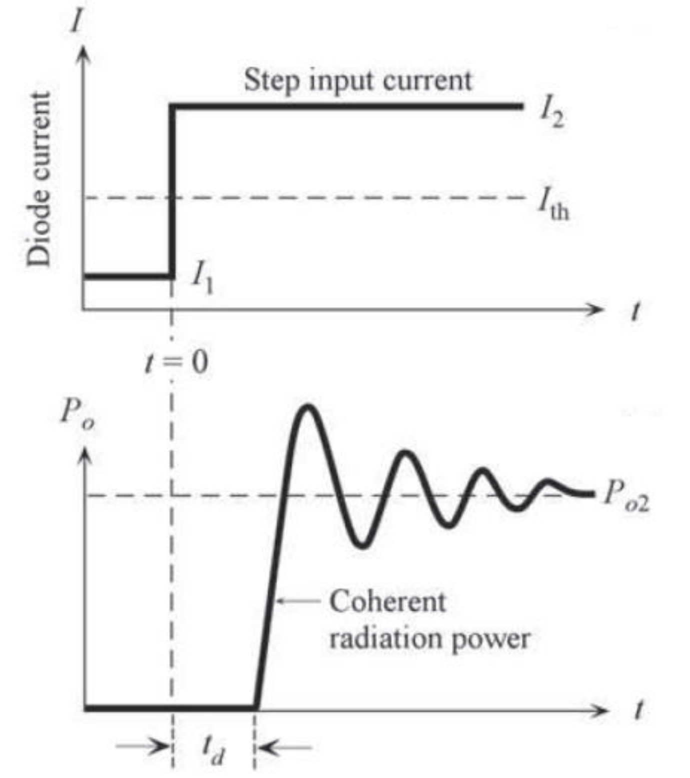


DESIGN APPROACH – LASER TX



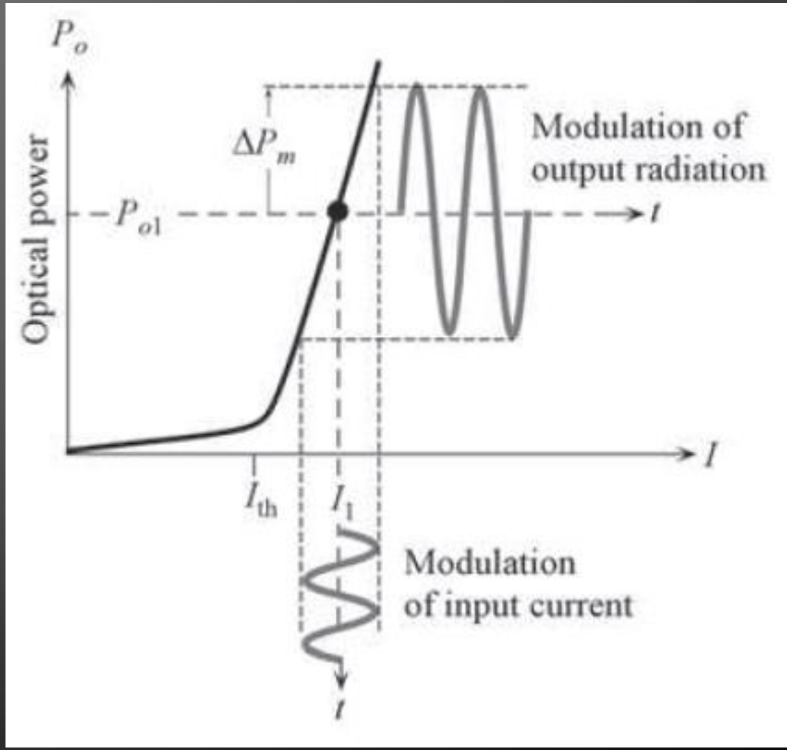
- The TX+ or TX- signal can be used to modulate a laser.
- On/Off keying is the simplest method of modulation.

DESIGN APPROACH – LASER TX



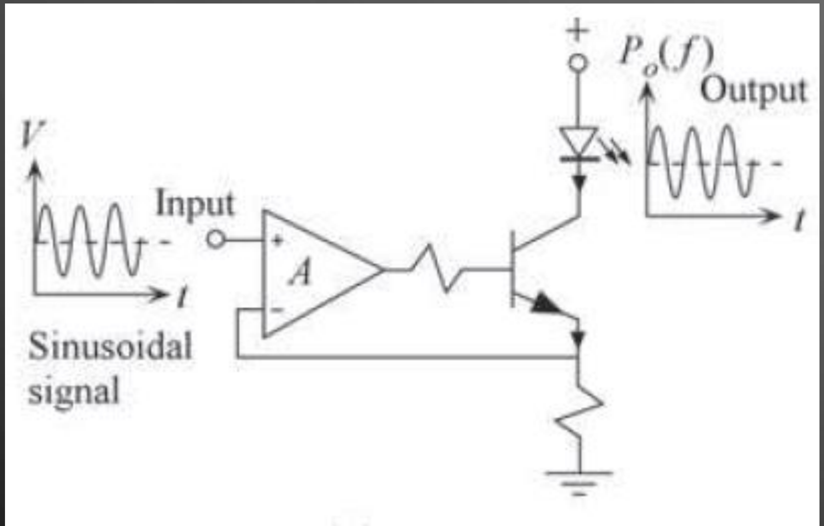
- There is a delay when direct modulation of a laser is employed that is biased around threshold.

- Ideally to avoid this delay, amplitude modulation will be used.



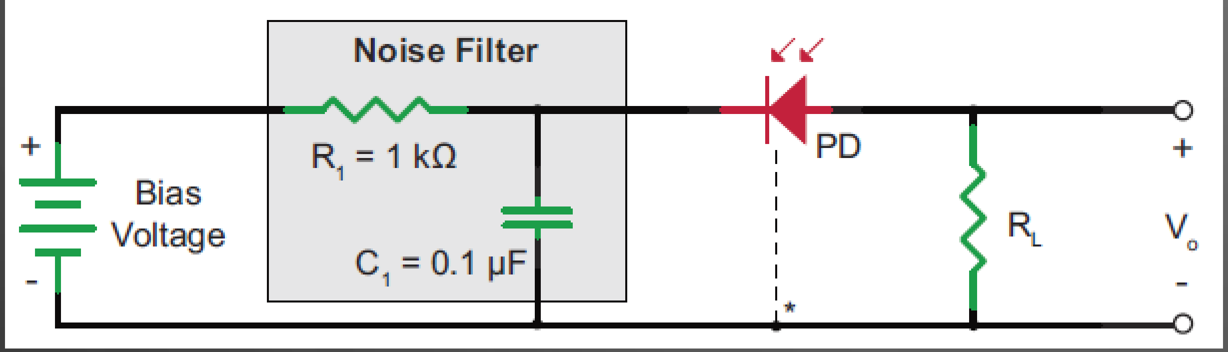
DESIGN APPROACH – LASER TX

Basic laser driver circuit example:



- A constant current source must be provided to bias the laser.
- MAX4390 will be used.

DESIGN APPROACH – PHOTODIODE RX

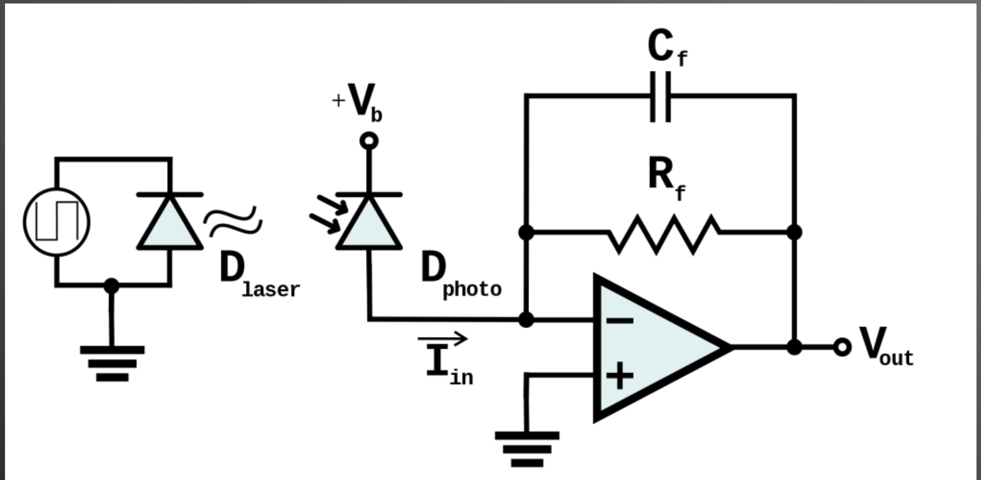


Schematic provided by Thorlabs

- An example schematic for the photodiode FGA01 is shown to the left.
- In order to make the distinction between bits and noise the diode must be properly biased.

DESIGN APPROACH – PHOTODIODE RX

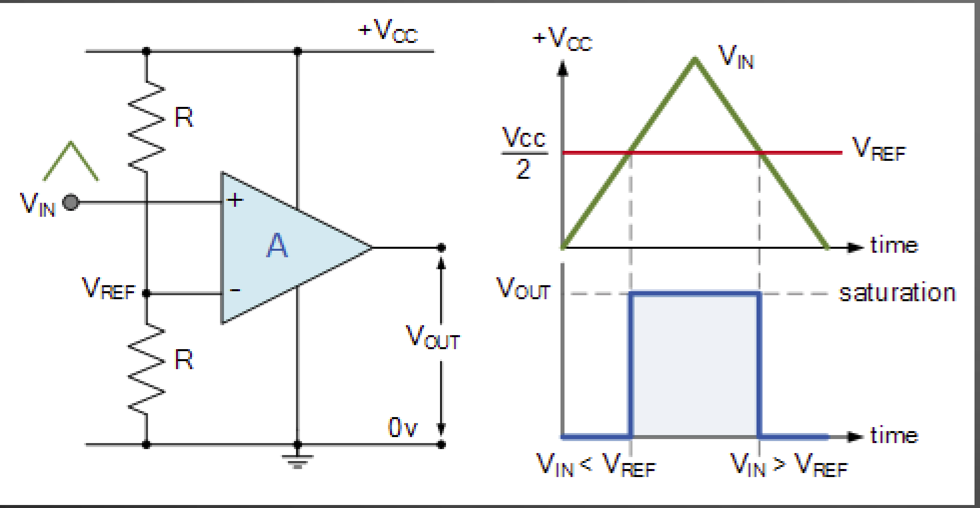
TIA Op-amp example schematic:



- The OPA695 will be used as a trans-impedance amplifier.
- Photogenerated current will be converted to a voltage signal and then fed to a comparator.

DESIGN APPROACH – SIGNAL PROCESSING

Example comparator schematic with waveform output

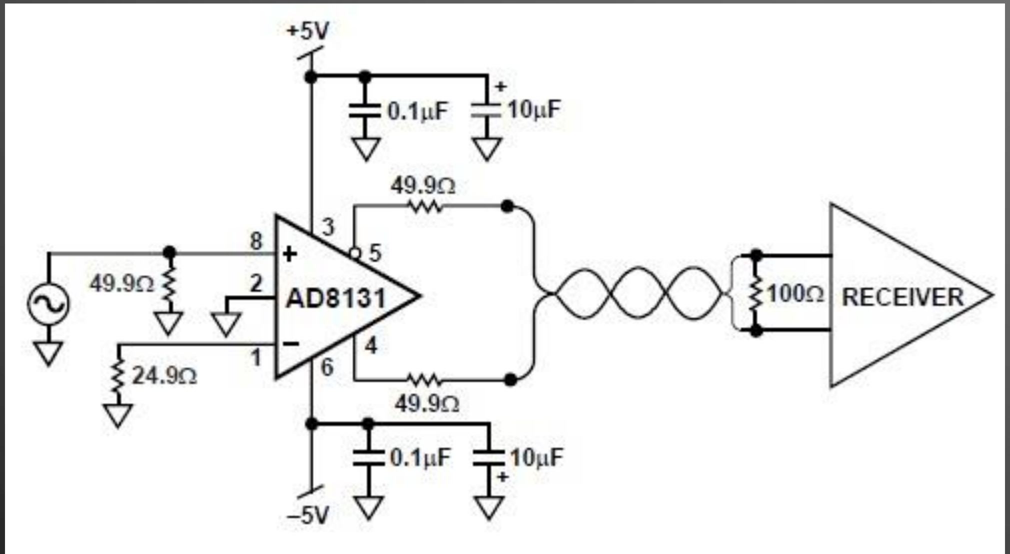


https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html

- The comparator will distinguish between incoming light pulses and noise.
- Output will be a square wave similar to what is seen on a TX+ or TX- line.
- LT1713 will be the comparator of choice.

DESIGN APPROACH – SIGNAL PROCESSING

Differential driver example schematic:

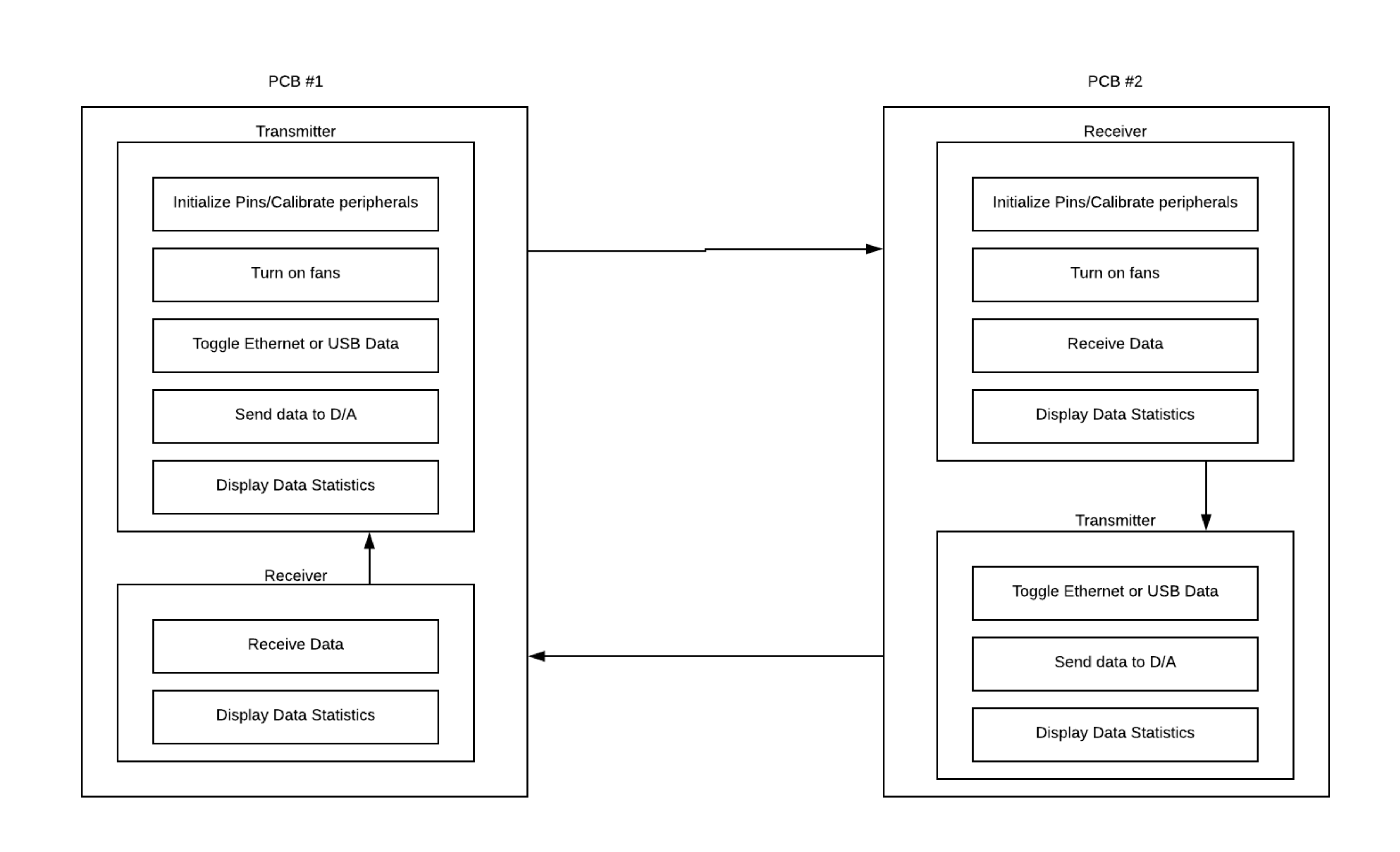


- The square bits are sent to a single-ended to differential op-amp.
- This final amplification stage conditions the waveform to be sent via twisted pair cable.
- AD8130 is the differential driver of choice.

ADMINISTRATIVE TASK LAYOUT

Team Members	PCB Schematics	Embedded Systems	Software Design	Components Selection	Optics
Brian	Primary	Primary		Primary	
Ryan		Secondary	Primary		
Sandy	Secondary				Primary
Shane		Secondary	Primary	Secondary	Secondary

SOFTWARE BLOCK DIAGRAM

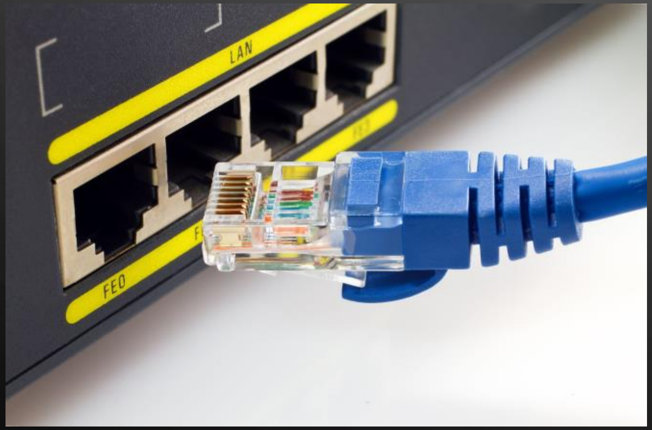


SOFTWARE TASKS

- Implement LWIP (LightWeight Internet Protocol)
- Send and receive data through the Ethernet and USB
- Send and receive data from external data device
- Using an LCD interface to display network statistics
- Generate test patterns
- Data validation

LWIP TCP/IP PROTOCOL SUITE

- Reduced version of a TCP/IP protocol suite to apply to embedded systems.
- When sending data through Ethernet, the microcontroller will implement this protocol.
- Supports several different protocols such as TCP, IP, UDP, ICMP, etc.



COMPONENT SELECTION SUMMARY

- Laser – L1550P5DFB
- Photodiode – FGA01
- MCU - ATSAMEJ19A
- Transimpedance amplifier – OPA695
- Operational amplifier – MAX4390
- Comparator – LT1713
- Differential driver – AD8130
- Voltage regulator – LM7805CT
- Boost converter - TBD

ELECTRICAL CONCERNS

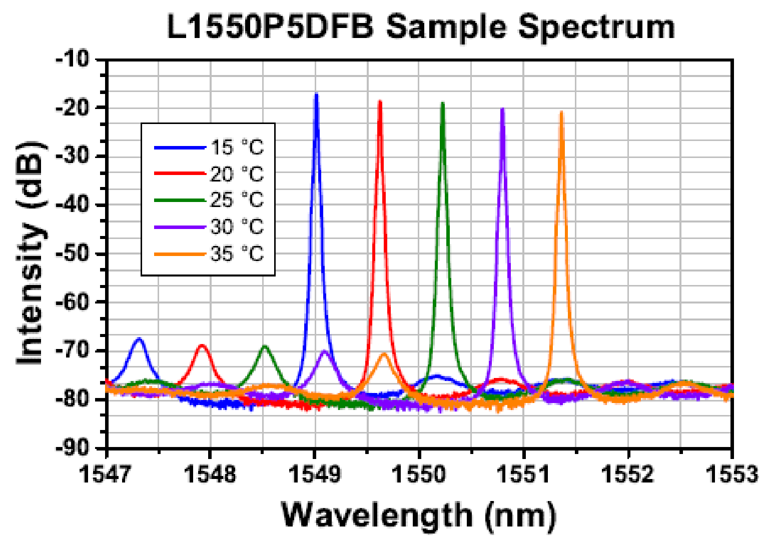
- Want transceiver to operate in adverse conditions.
- Power consumption of all components will dictate necessary battery source.
- Heat dissipation is also a challenge for a well sealed housing.
- Thermal management options in consideration are regular PC fans, peltier modules and small heatsinks for ICs.

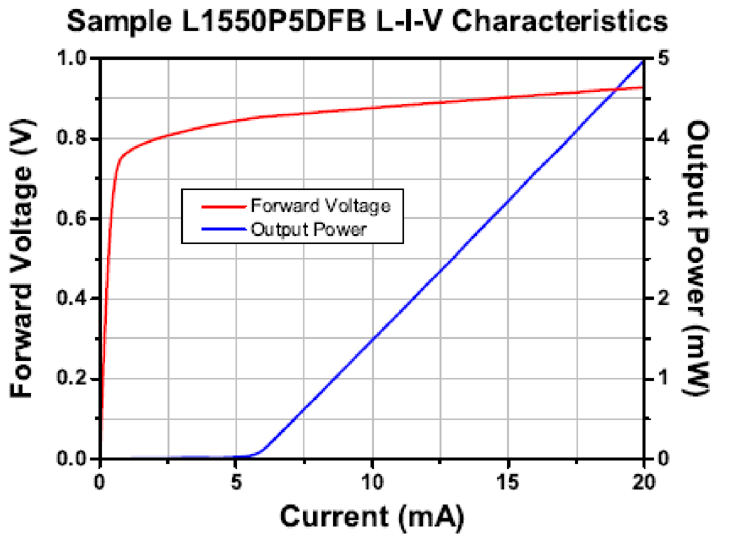
LASER CONSIDERATIONS

Model	Output power (mW)	Operating current (mA)	Operating voltage (V)	rise/fall time(ns)	Cost (USD)
ML925B11F	6	20	1.2	0.2	$16.83
L1550P5DFB	5	30	1.1	0.1	$81.69
ML925B45F	6	30	1.1	0.3	$50.95

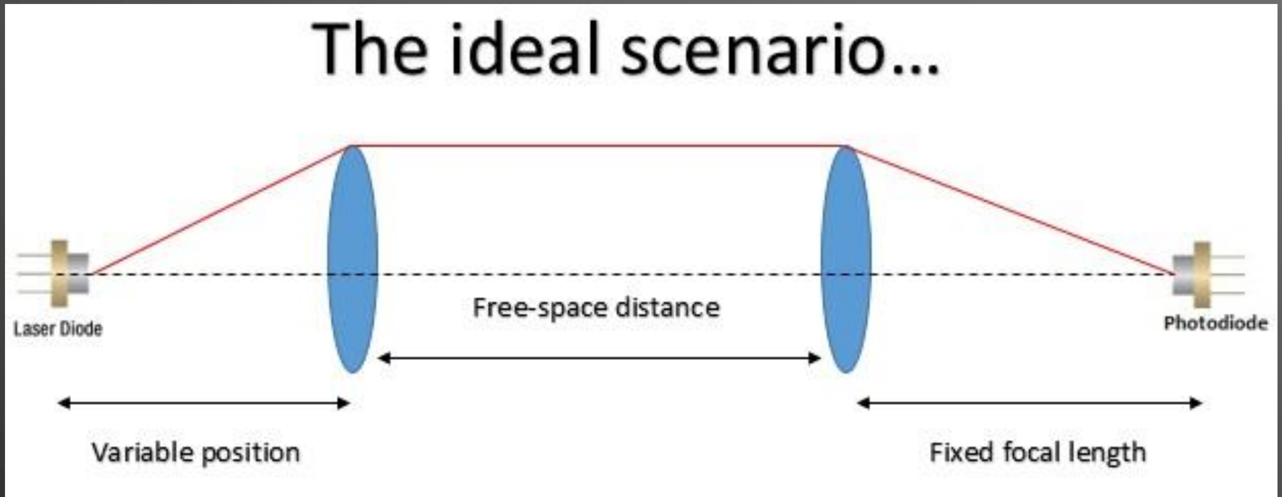
THORLABS 1550 NM DFB LASER DIODE

- 5 mW output
- ball lens to aid in collimation
- single frequency

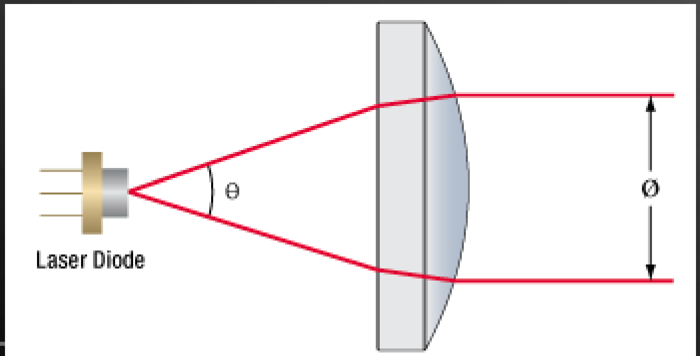




OPTICAL LAYOUT



- Transceivers are symmetrical in design, allowing for full duplex transmission.



- Variable position between laser and collimating lens allows for adjusting beam width.

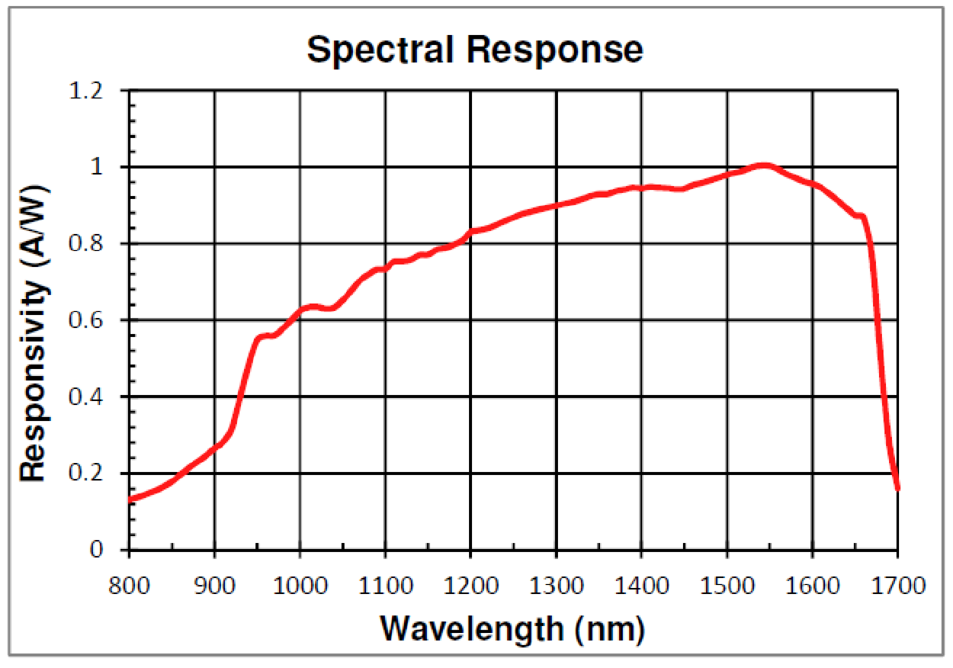
OPTICAL DESIGN CONSIDERATIONS

- Weight and material – plastic or glass?
- Ease of alignment and transmission loss – mounting mechanics, GRIN to fiber coupling?
- Environmental effects on SNR – frequency selective optics or Si window?
- Housing space limitations – Fresnel lenses and linear actuators

PHOTODIODE CONSIDERATIONS

Model	NEP (W/Hz)	Responsivity (A/W)	Rise / fall time (ns)	Active area (mm^2)	Cost (USD)
FGA01	$4.5*10^{-15}$	1.003	.3	.12	$60.93
FGA015	$1.3*10^{-14}$	0.95	.3	.15	$56.65
FDG03	$2.6*10^{-12}$	0.85	600	7.1	$134.48

THORLABS INGAAS HIGH SPEED PHOTODIODE



- ball lens aids in focusing incoming light
- larger area makes optical alignment easier
- fast rise / fall times
- spectral response peaks at 1550 nm

MICROCONTROLLERS CONSIDERATIONS

Microcontrollers	ATSAME70	AT32U3C3	CY8C54LP
Price per unit	$8.74	$9.28	$12.61
Package	64-LQFP	64-LQFP	100-TQFP
Number of I/O	44	45	72
Speed	300 MHz	66 MHz	67 MHz
Operating Voltage	3V ~ 5.5V	1.6V ~ 3.6V	1.71V ~ 5.5V
Resolution	A/D 5x12b, D/A 1x12b	A/D 11x12b, D/A 2x12b	A/D 1x20b, 2x12b D/A 4x8b

MICROCONTROLLER CHOICE: ATSAME70J19A

- Speed: 300 MHz
- On-chip data converters: A/D: 5x12b D/A: 1x12b
- Number of I/O: 44 ports
- Connectivity: Ethernet, USB, UART, SPI, I2C
- Program Memory Size: 512 KB

SOFTWARE DEVELOPMENT TOOLS

- IDE: Atmel Studio 7
- Allows for MCU chip peripheral simulation for Atmel Start Projects
- Language: C
- Bootloader Program: SAM-BA
- Allows code to be loaded to the chips flash memory
- Utilizes USB and UART connectivity.

PROTOTYPING DEVELOPMENT TOOLS

ATMEL-ICE

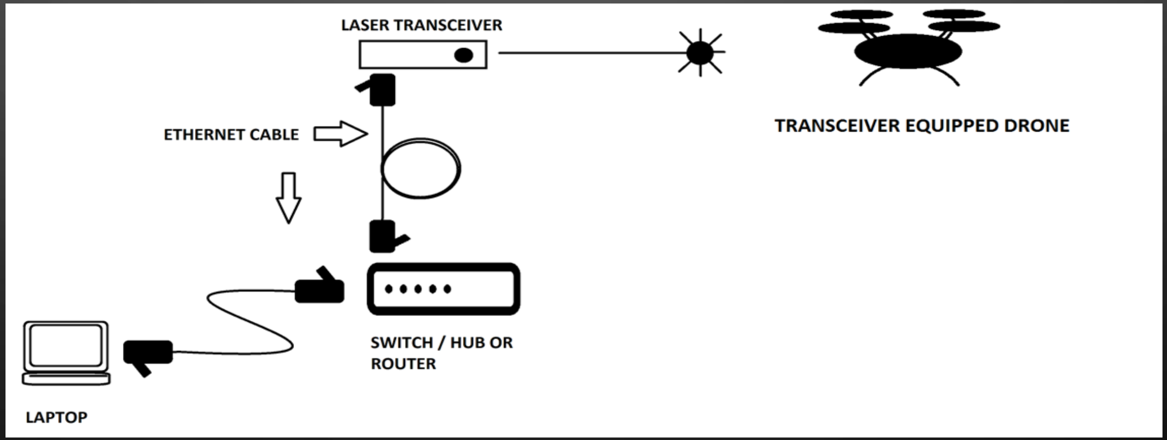
ATSAME70-XPLD

PROJECT DIFFICULTIES & CHALLENGES

- A change in understanding and part availability changes the implementation of design.
- The core function of data transmission and electrical work must preceed the work of optomechanical design and beam alignment automation.
- Exact power requirements can’t be known until final device housing is designed and servo requirements are known.

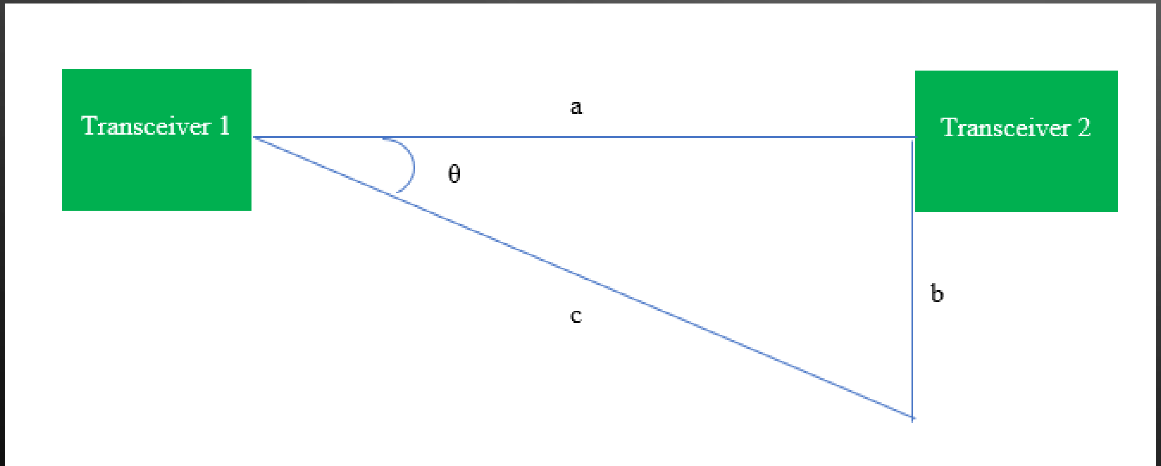
CHALLENGE: ALIGNMENT AND BEAM TRACKING

- Both use cases of our design cannot be done if the beams are not sufficiently aligned to deliver adequate power to the receiver.
- This is difficult since the width of a laser is extremely small, and intensity degrades with propagation distance.



CHALLENGE: ALIGNMENT AND BEAM TRACKING

- If the deviation angle $\theta = 1^{o}$ a = 15 ft as established in our requirements
- Vertical deviation $b = a*Tan(\theta) = (15ft)*Tan(1^{o}) = 3.14$ inches
  - If $\theta = 5^{o}$, then b = 15.75 inches



Note: This is even in the ideal case where both transceivers are perfectly level with each other both vertically and horizontally. The second case with a moving drone object will be even tougher.

HOW CAN WE SOLVE THIS?

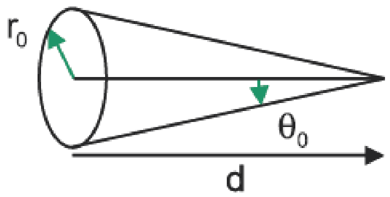
- Servos can be used to physically aim the laser emitters.
- With regards to automatically tracking a moving object…
  - Computer Vision
  - Accelerometer
  - Radiometry calculations

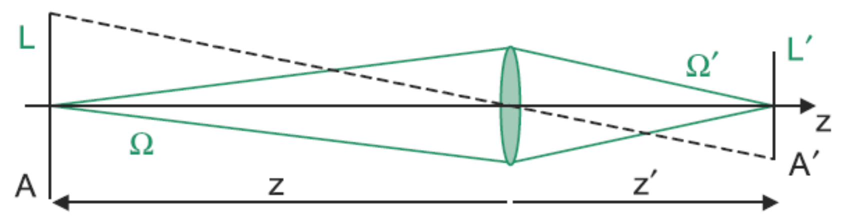
RADIOSITY SOLUTION

- An initial idea to use current feedback from photoresistors at four corners of the housing.
- Unfortunately, the difference in radiometric power over this small distance would prove this solution to likely be unviable.

$$\Omega = 2\pi(1 - \cos\theta_0)$$

$$\Omega \approx \frac{\pi r_0^2}{d^2} \approx \pi\theta_0^2$$





$$L = L' \qquad A\Omega = A'\Omega' \qquad m^2 = \frac{A'}{A} = \left(\frac{z'}{z}\right)^2$$

$$\Phi = LA\Omega = L'A'\Omega'$$

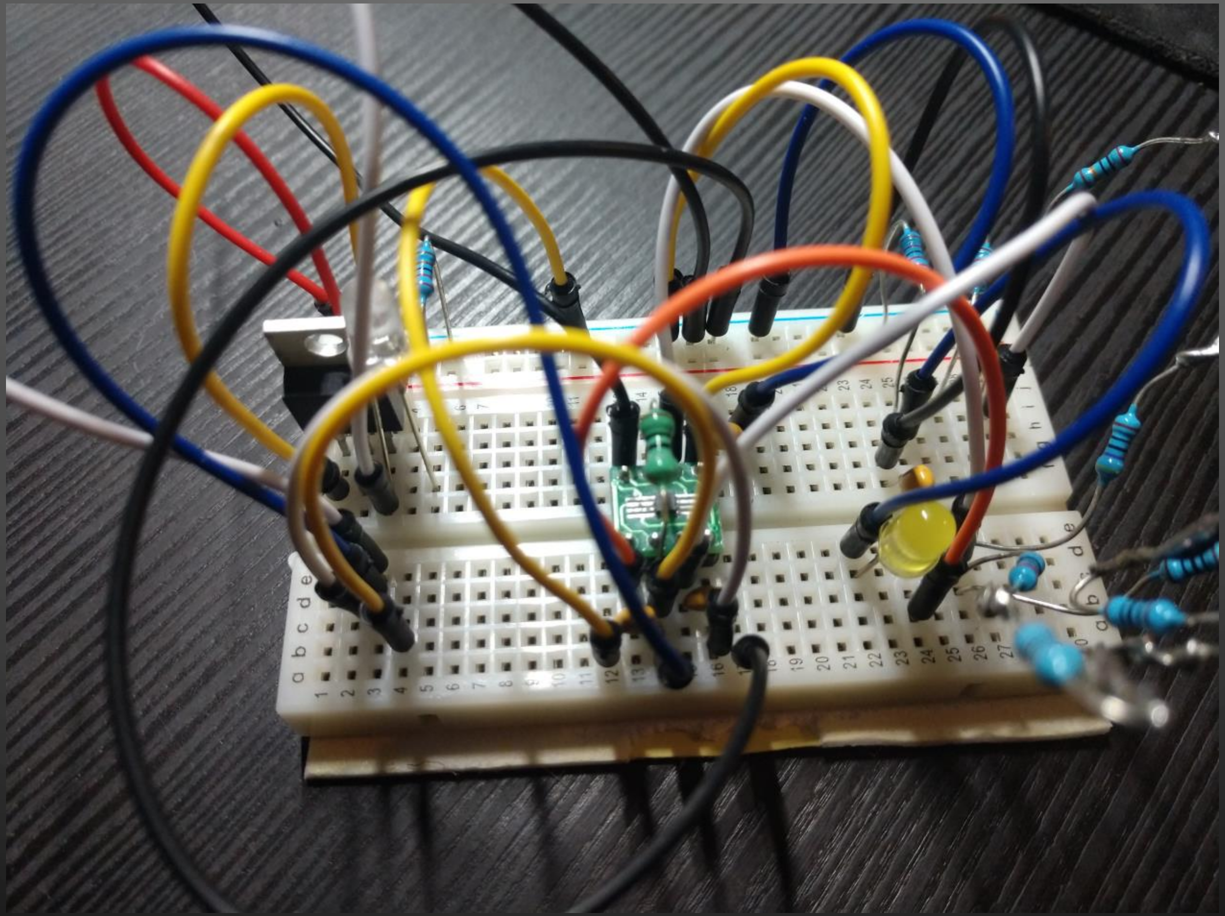
COMPUTER VISION SOLUTION

- Will add to project complexity.
- May require too much power, processing time and development.
- Would require embedded ICs capable of running exported MATLAB code.

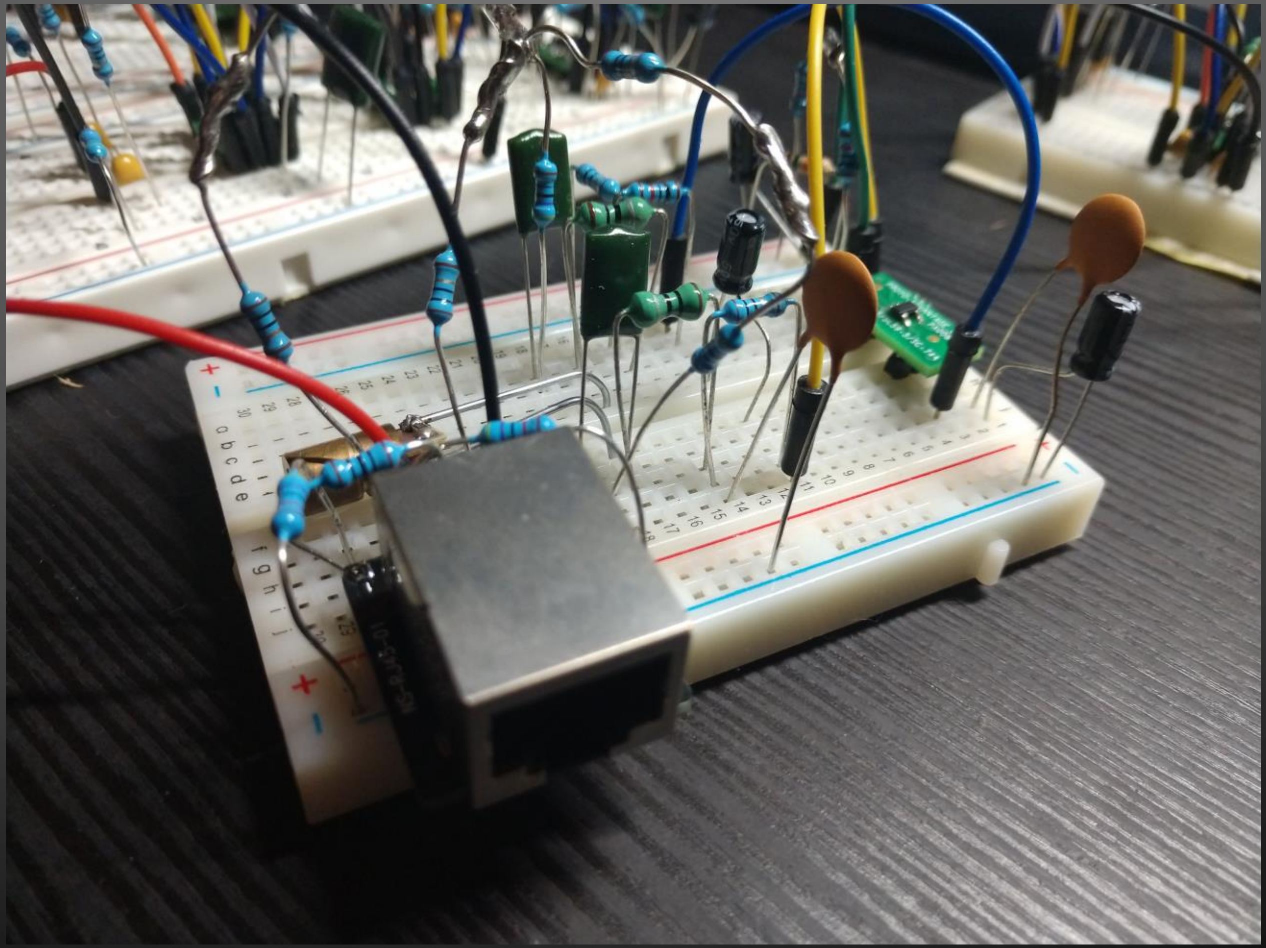
ACCELEROMETER SOLUTION

- Could provide a simple way to inform the stationary transceiver how much the mobile transceiver has been displaced.
- However, this trigonometric solution needs distance information to accurately align the laser beams.
- If received signal amplitude can be used to approximate for distance, a reasonable accuracy can be expected.
- This solution requires that transceivers already have an optical link established.

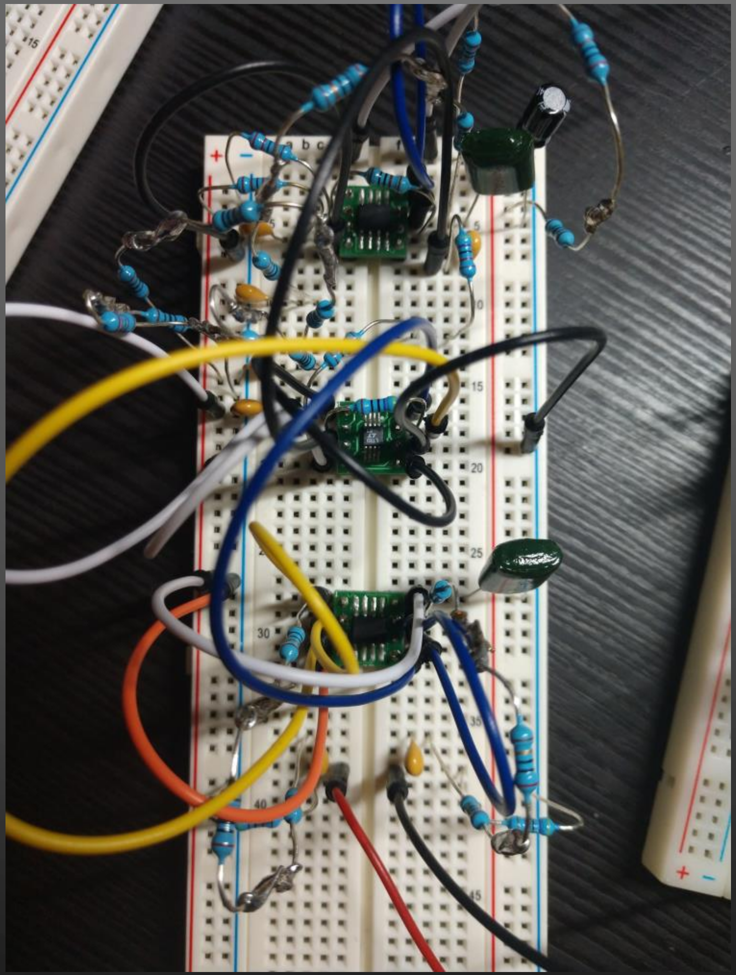
CURRENT PROTOTYPE – PSU



CURRENT PROTOTYPE – TX CIRCUIT



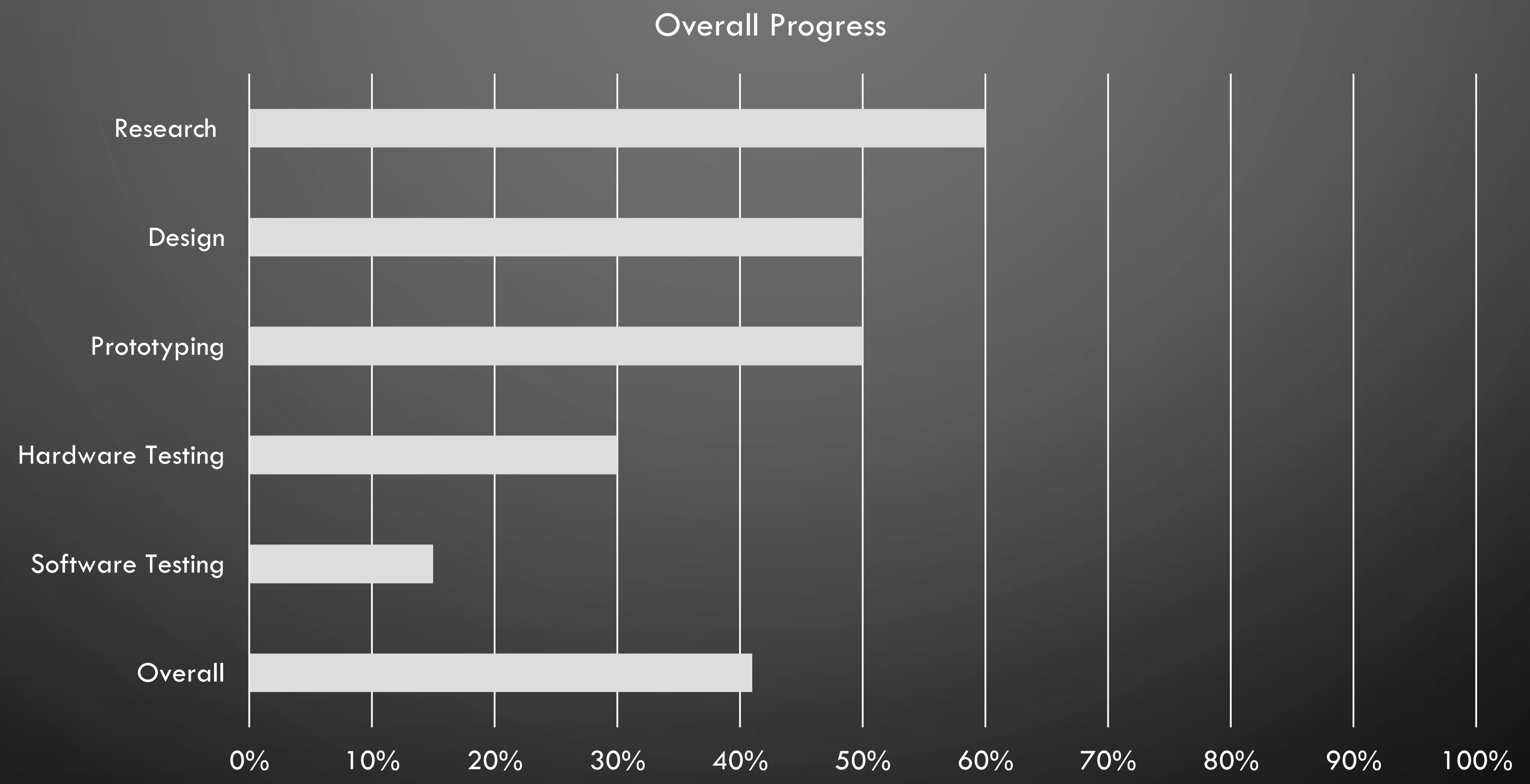
CURRENT PROTOTYPE – RX CIRCUIT



PROJECT EXPENSES

Part	Quantity	Cost ($ USD)
ATMEL ICE	1	150.00
L1550P5DFB	2	163.38
FGA01	2	121.86
LT1713	2	8.28
LM78M05CT	2	3.02
AD8131ARZ	2	9.92
OPA695	2	8.64
ATSAME70J19A	2	8.74

CURRENT PROGRESS



IMMEDIATE DEVELOPMENT TASKS

- Laser and photodiode biasing
- Optomechanical design / beam tracking
- Integrating required sensors with the MCU
- Integrating MCU with existing signal processing hardware
- Programming the sensor data to be sent for feedback to servos

QUESTIONS