Portable Sensing Field Device

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Project Introduction

- Laser-Based Rangefinder
- IR Contactless Temperature Sensor
- Combine both functions into one light-weight, handheld device activated by a trigger.
- Provide simultaneous range and temperature readings via a 16x2 LCD output.

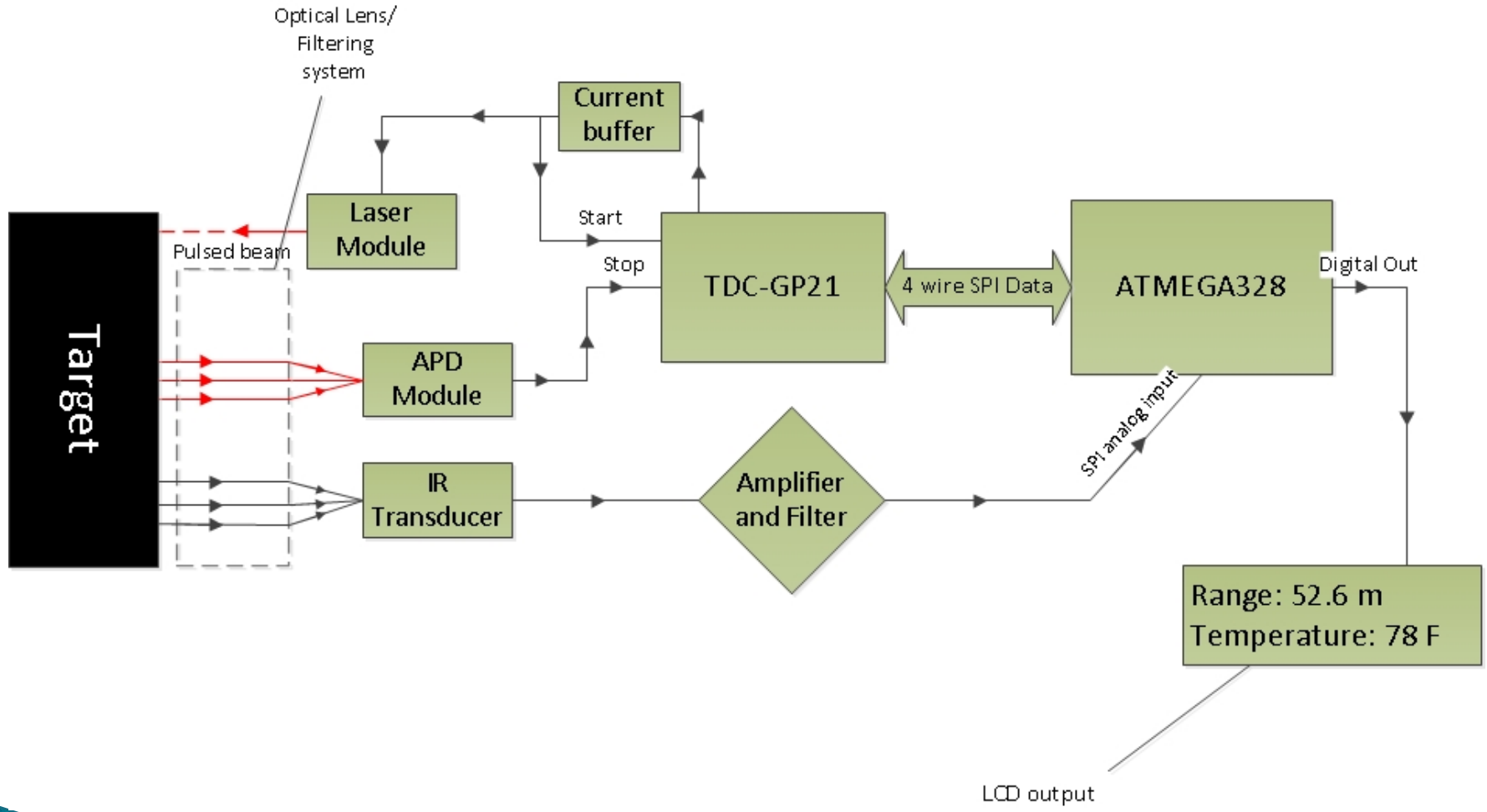
Motivation

- New to optical systems
  - Group interest in laser technology and infrared technology
- Combines 2 tools used every day
  - Lightweight
  - Small form-factor
  - Easy to read
  - Low power consumption
- Time of Flight ranging is a challenge

Specifications

- Ranging from 1-50 meters
- +/- 1 meter accuracy in subsequent measurements
- Temperature readings from 0-5 meters
- +/- 2 degree accuracy in subsequent measurements
- Device should weigh no more than 2.5 pounds for portability.
- LCD display must switch between temperature and range readings on button press.

Block Diagram



Power

- Each individual part of our device operates in a range between 3.3 and 140 VDC.
  - Our high voltage supply needs to supply 140 volts. It supplies 400V at 12V, and through testing we have determined it can run 140V at ~5 volts.
- Our device must remain portable, meaning we must choose a portable power source (i.e. batteries).
- To obtain the different supply voltages to our silicon, our battery sources must be regulated.
  - Linear regulators are the cheapest and easiest to use for our application.

Power

- Our project uses an op-amp that has dual rails, +- 5VDC.
  - Instead of buying an expensive buck-boost converter to obtain the negative voltage from the same source, we opted to use a secondary source and drive a negative voltage regulator from it.

Source Options

Technology	Cell Voltage	Weight	Price
Nickel Cadmium	1.2V	~20g	~$1 USD
Nickel Metal Hydride	1.2V	~28g	~$1.50 USD
Lithium Ion	3.6V	~45g	$5-$10 USD
9V Alkaline	9V	~45g	~$5 USD

Since we must use two batteries, one to supply the positive voltages, and one to supply the negative voltages, we have to consider the price and weight of making a battery pack of individual cells. In the end, two battery packs of any of the first three technologies becomes undesirable. We will use two 9V batteries.

Voltage Regulation

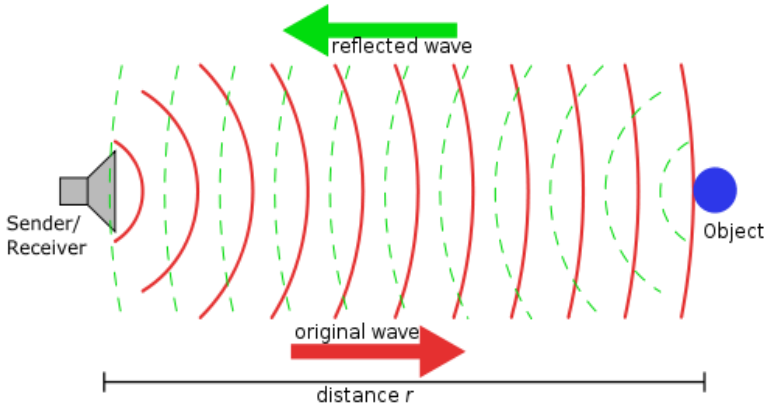
- In order to power the different chips we have employed, we have to regulate our 9V sources to lower voltages in order to operate them.

Regulator	Input Voltage	Output Voltage	Output Current
LM7805	7-35VDC	4.8-5.2VDC	Up to 1.2A
LM7905	-(7-35)VDC	-(4.8-5.2)VDC	Up to 1.2A
LD1117V33	4.3-15VDC	3.267-3.333	Up to 1.3A

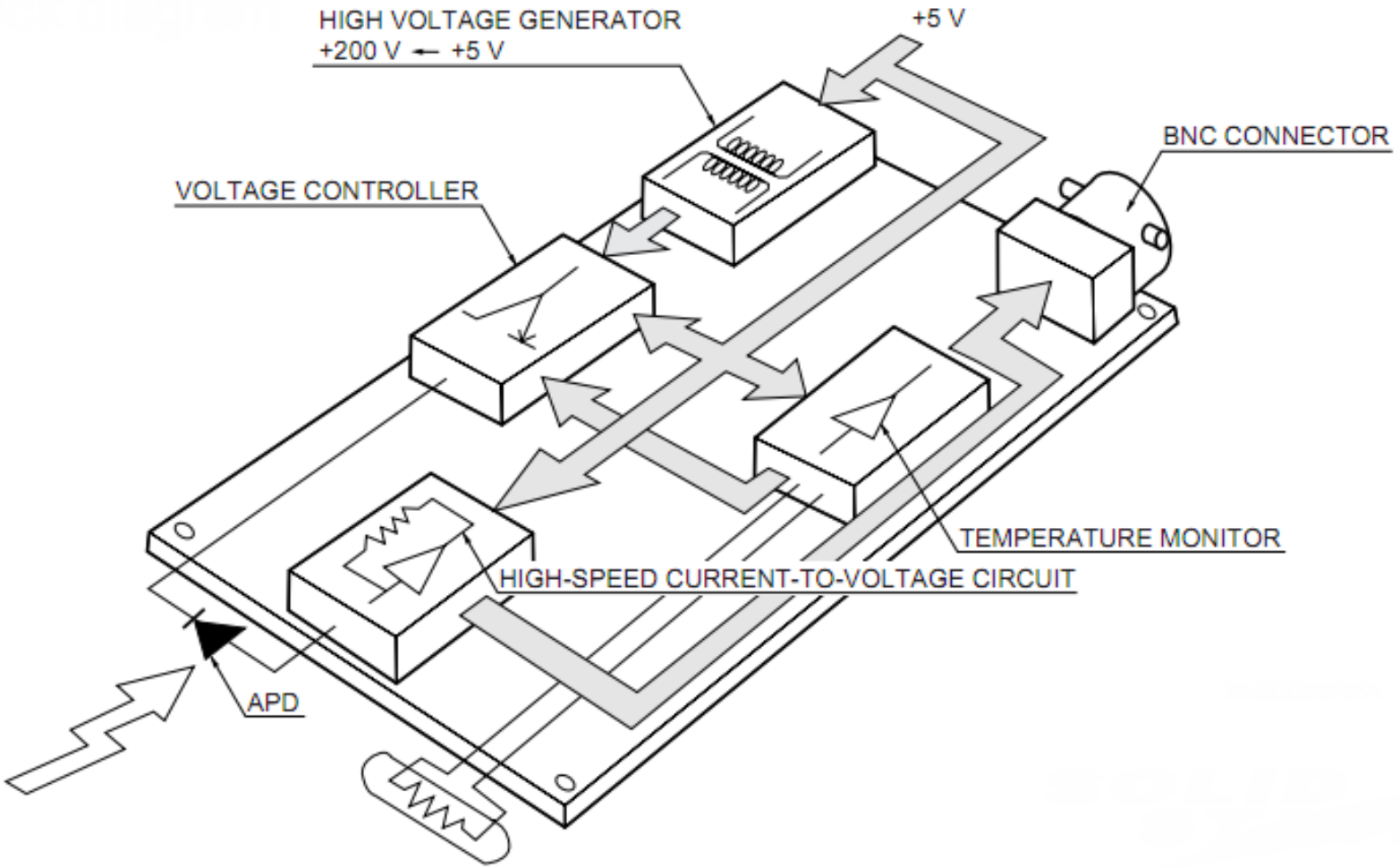
Ranging – Design Considerations

Design Considerations

- Methods of Ranging considered
  - SONAR (ultrasonic)
    - Cheapest to implement
    - Easy to use
    - Distance limited to less than 10m
  - RADAR
    - Can achieve very far distance readings
    - Does not bounce off all objects
  - LIDAR (Laser\infrared)
    - Best choice: Line of sight ranging and will reflect at least some light off almost all surfaces.
    - Our design will use the time of flight method

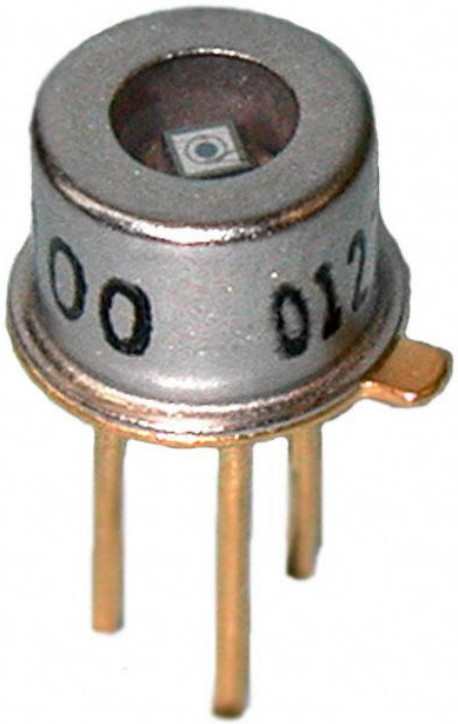


APD Module


HIGH VOLTAGE GENERATOR
+200 V ← +5 V
+5 V
BNC CONNECTOR
VOLTAGE CONTROLLER
TEMPERATURE MONITOR
HIGH-SPEED CURRENT-TO-VOLTAGE CIRCUIT
APD

Avalanche Photodiode

- Must be operated under high voltage (100V+)
- Very sensitive photo-receiver
  - Advantages include:
    - Exploits the avalanche multiplication process for added gain
    - Ideal for a rangefinder
    - High speed operation
    - High quantum efficiency
  - Design considerations:
    - Terminal capacitance
    - Sensitive to ambient temperature changes
    - Exhibit measurable dark current

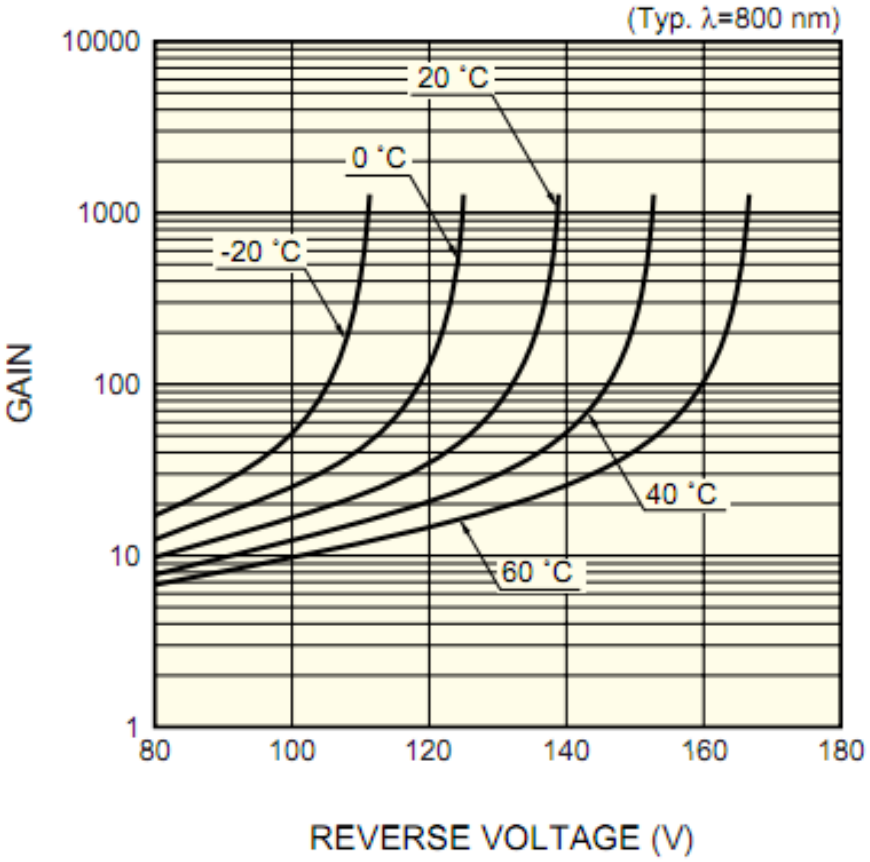


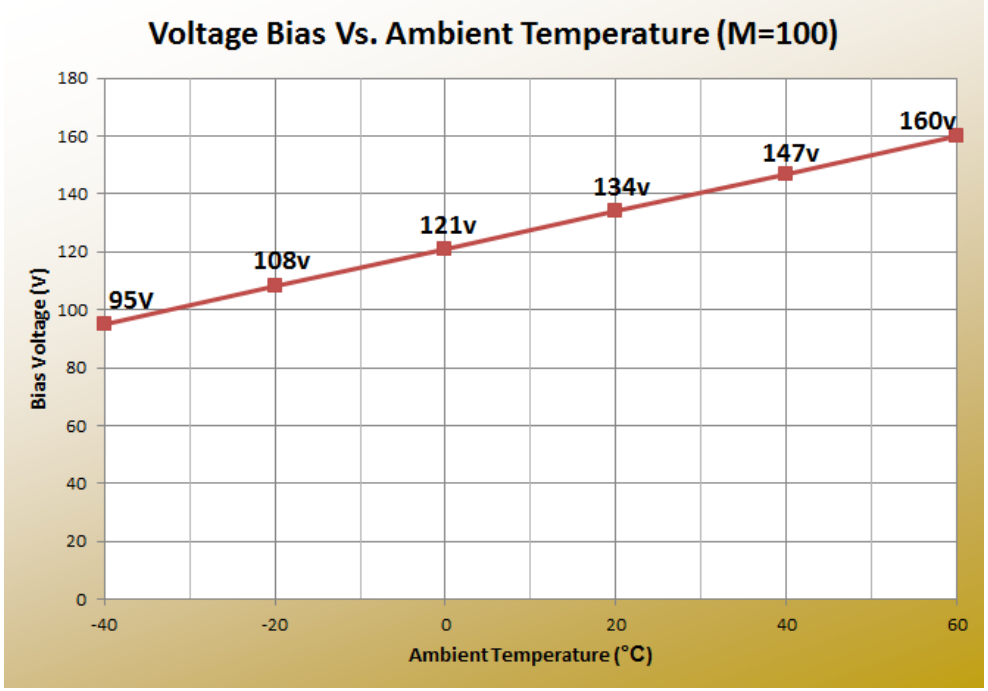
APD Selection

- Main selection aspects included:
  - Low bias operation
  - Peak spectral sensitivity
  - Low price
  - Max dark current
  - Temperature coefficient
- Selected mid-range Hamamtsu S2381

Manufacturer	Part Number	Active area mm	Peak wavelength (λ) nm	Peak sensitivity (A/W)	Max dark current (nA)	Temperate coefficient (V/°C)	Typical breakdown voltage (V)	Unit Price $
Hamamatsu	S9251-05	0.5	860	0.52	2	1.85	250	91.00
Hamamatsu	S9251-02	0.2	860	0.52	1	1.85	250	83.00
Hamamatsu	S6045-02	0.5	800	0.5	1	0.4	200	100.00
Hamamatsu	S6045-01	0.2	800	0.5	0.5	0.4	200	91.00
Hamamatsu	S5139	0.5	800	0.5	1	0.65	150	83.00
Hamamatsu	S2383-10	1.0	800	0.5	2	0.65	150	136.00
Hamamatsu	S2382	0.5	800	0.5	1	0.65	150	83.00
Hamamatsu	S2381	0.2	800	0.5	0.5	0.65	150	76.00
Pacific Silicon	TO52-S1	0.5	900	0.6	1.5	1.55	200	93.10

Temperature effects on S2381

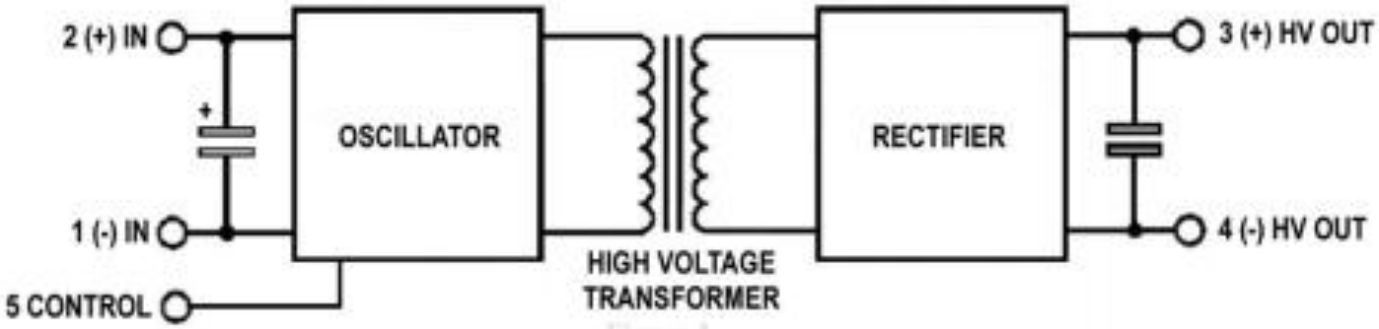




- As the ambient temperature increases, the voltage required to maintain constant gain must increase.
- We are operating with M at 100.

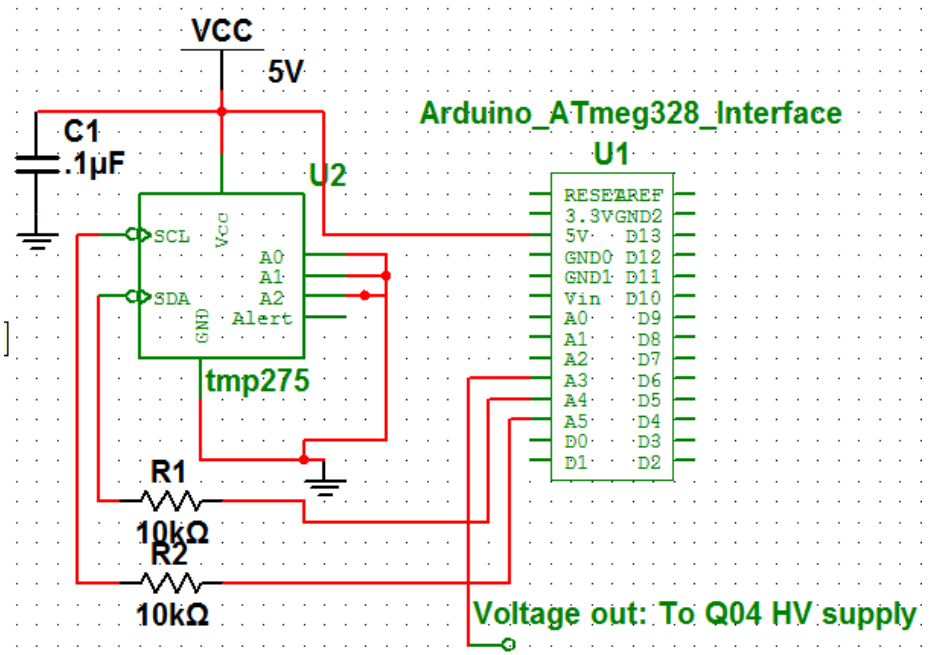
High Voltage DC-DC Converter

- Decided to buy pre-made converter instead of building our own due to size goal.
- Emco Q04 outputs 60-400V
- Maximum output current of 1.25mA
- Peak-peak output ripple less than .1%
- Draws less than 100mA under full load at 12v input voltage.
- As a cube of only 0.5 inches and a weight of just over 4 grams, the Q04 is ideal for portable applications.



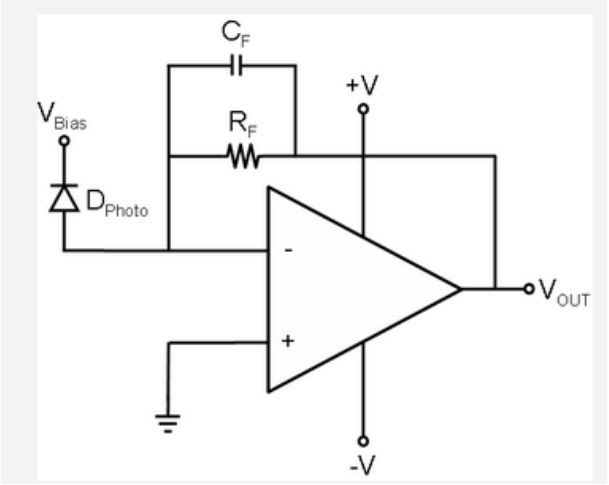
Ambient Temperature Adjust

- Control pin on HV supply must be adjusted to maintain constant gain.
  - Tmp275 – Digital output temperature sensor will be used to detect ambient temperature.
    - Eight addresses
    - Two wire serial interface using I2C
    - Capable of reading temperatures with a resolution of 0.0625°C
    - Temperature range of -40 to +125°C
- As ambient temperature changes, analog output from MCU will change from 0-5V; directly changing the HV output.



Transimpedance Amplifier

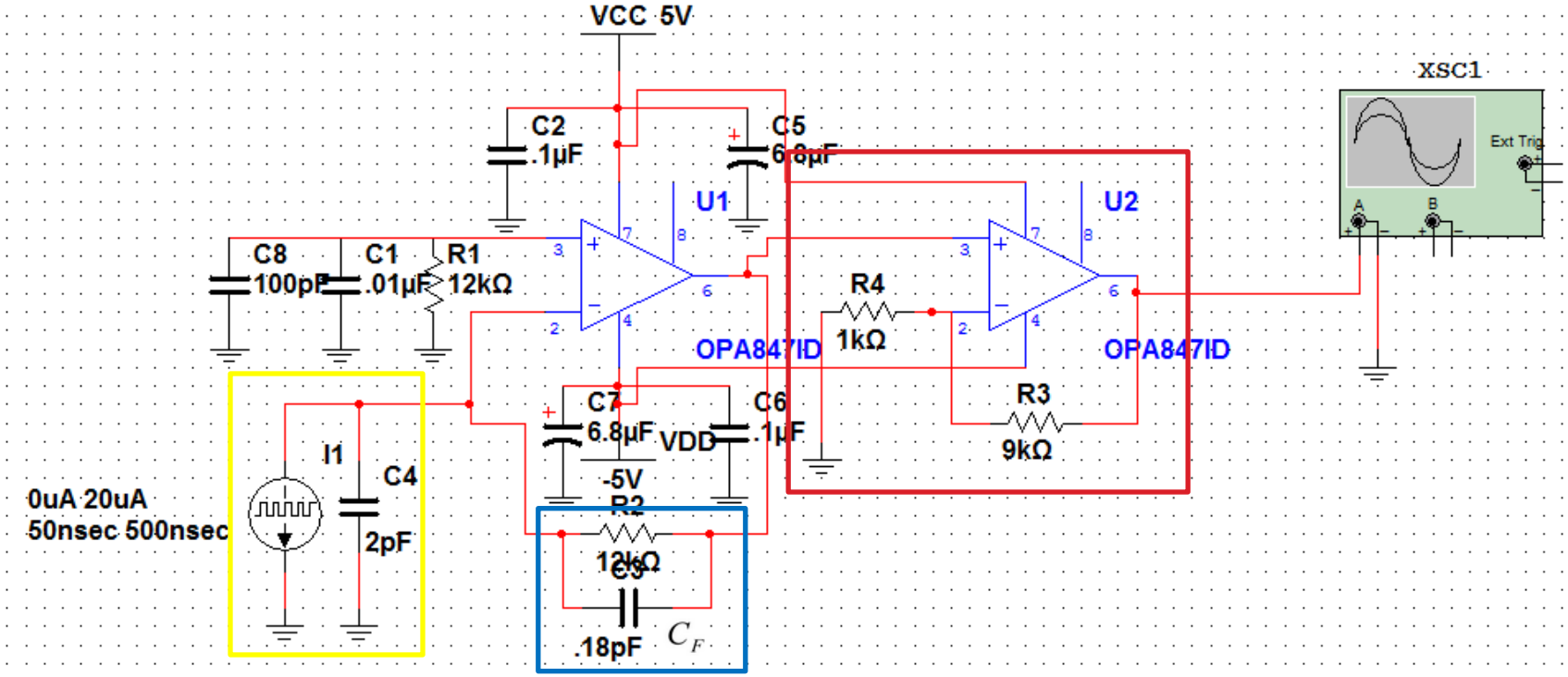
- Requirements
  - Must be very low noise
  - Must provide acceptable gain
    - Vo max 5 volts pk-pk
  - High speed response
- TI OPA847
  - BJT amplifier
  - High GBP: 3.9GHz
  - High slew rate 950V/us
  - Very low voltage noise of 0.85nV/$\sqrt{}$Hz
  - Since feedback capacitor is inversely proportional to resistance, an additional gain stage will be needed.



$$C_F = \sqrt{\frac{C_{IN}}{2\sqrt{2}\pi f_{GBW} R_F}}$$

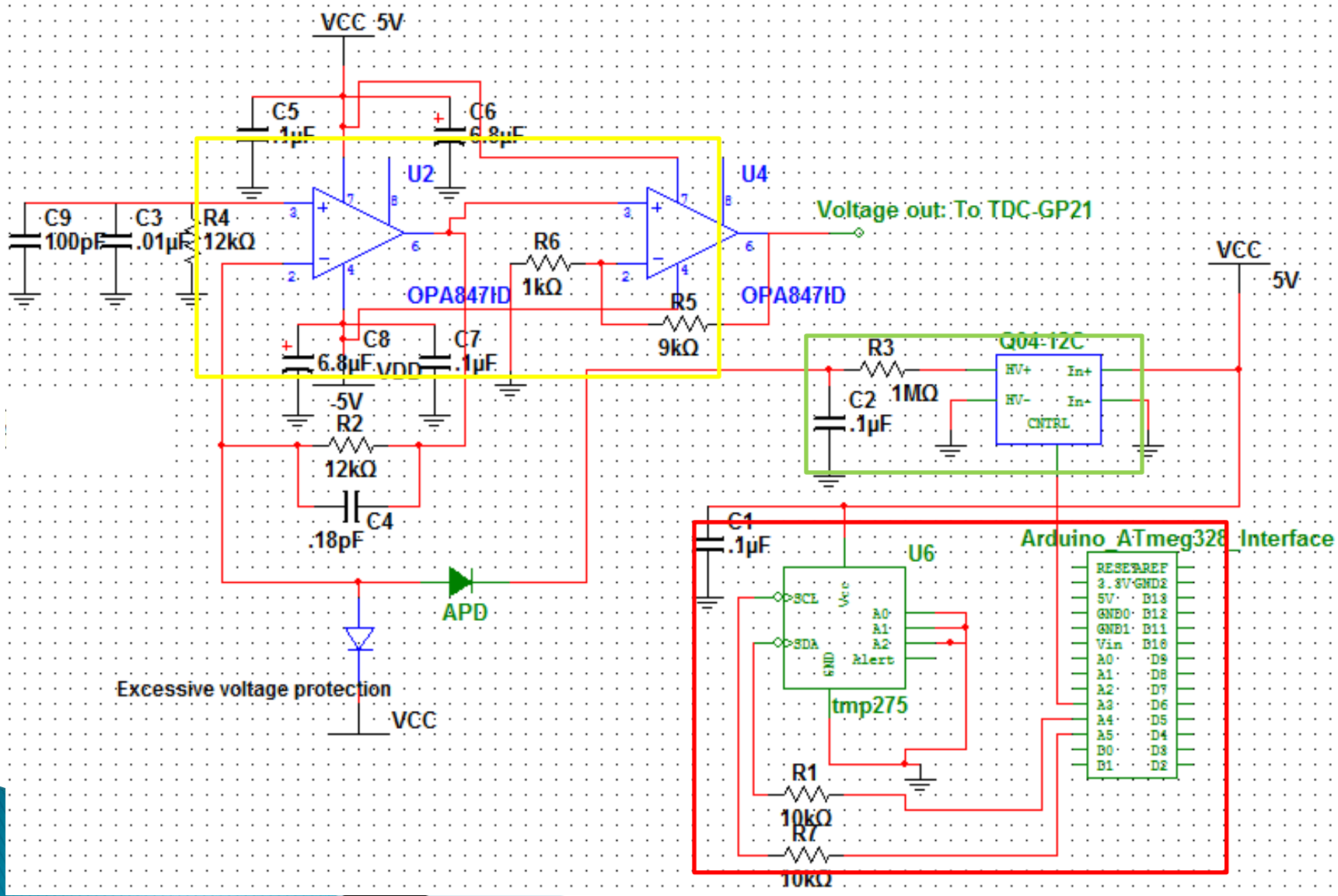
$$V_{OUT} = \frac{-R_F}{1 + sC_F R_F} \times I_{PK}$$

Circuit Schematic



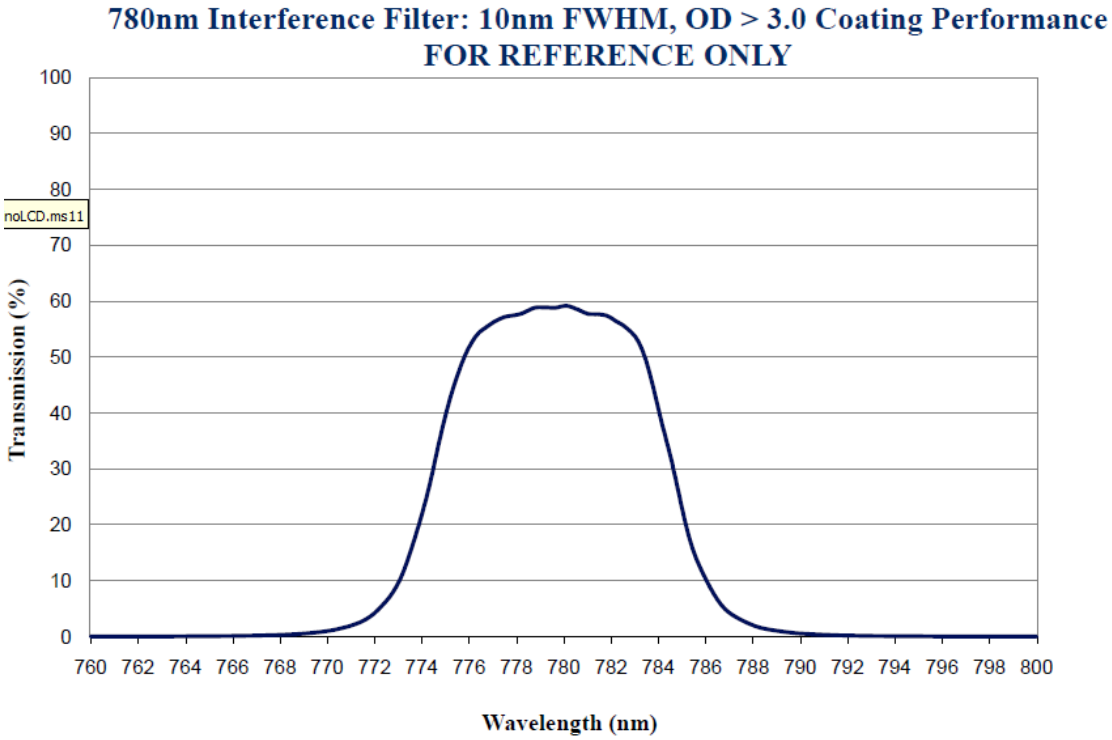
- Shown highlighted in yellow is a current source and input capacitance representing the APD.
- Boxed in blue is the gain resistor of 12k and feedback capacitance used to control the frequency response.
- The red box is the additional op-amp that serves as an extra gain stage to put the output voltage in the range of 1-5V.

APD Module Schematic



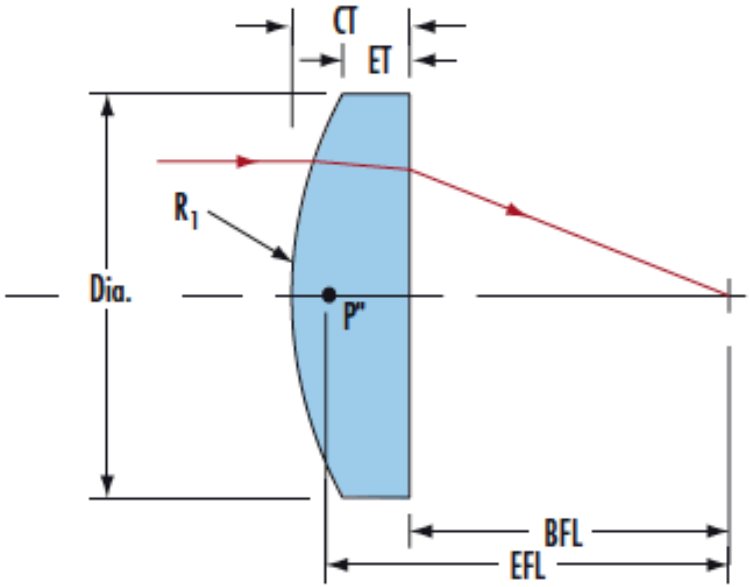
Infrared Optical Filter

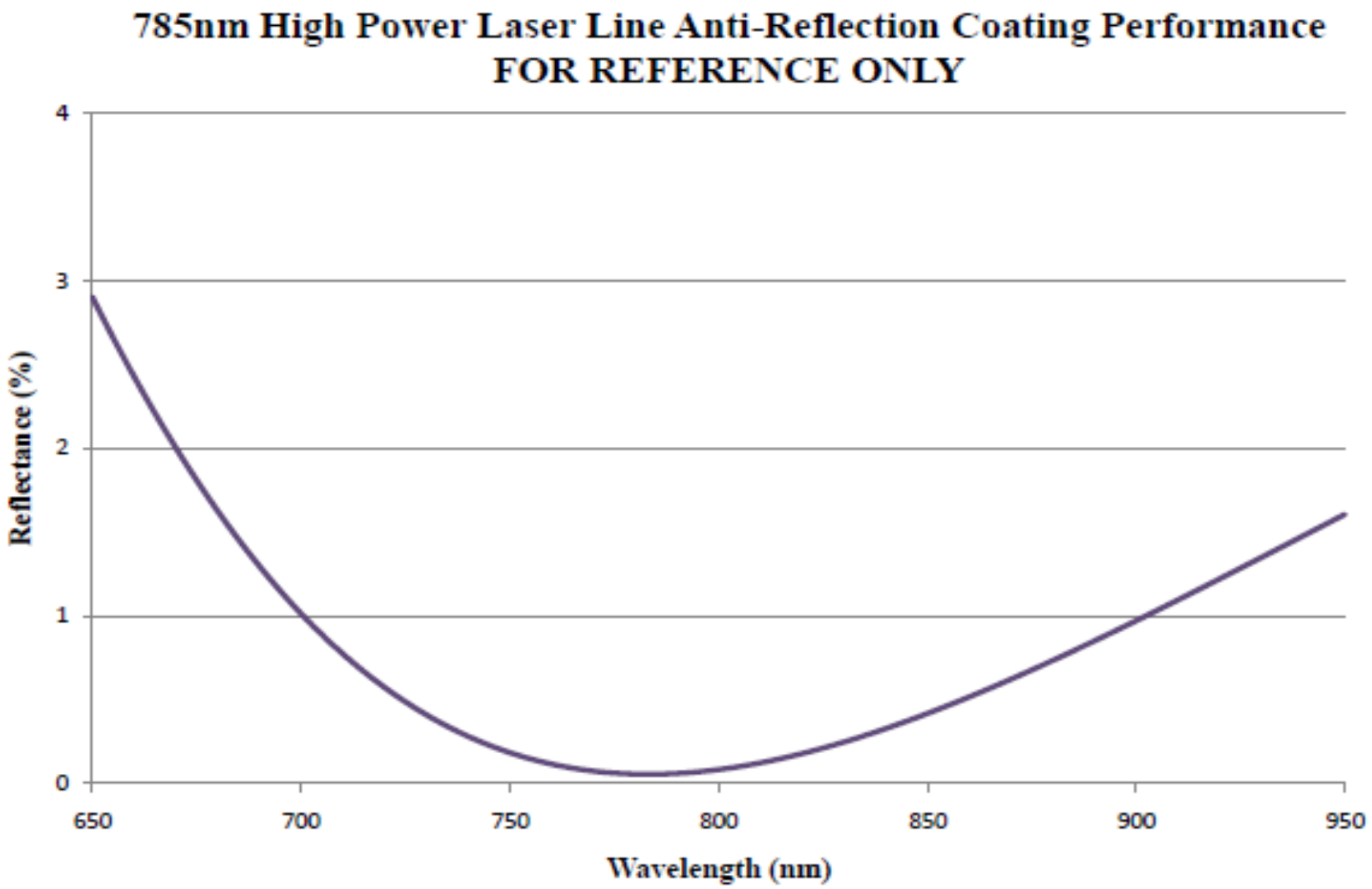
- Required to block out unwanted wavelengths from entering system.
- IR band-pass filter from Edmund optics.
  - Diameter of 25mm
  - CWL of 780nm
    - Same as output laser.
  - With a Pass-band of only 10nm; the filter is very precise



Laser Optics: PCX Lens

- Edmund Optics: V-Coated 785nm
  - Maximum throughput at 785nm
- Glass substrate, N-BK7 (RoHS compliant)
- 125mm Focal Length
  - Longer Focal Length = More intense focal point

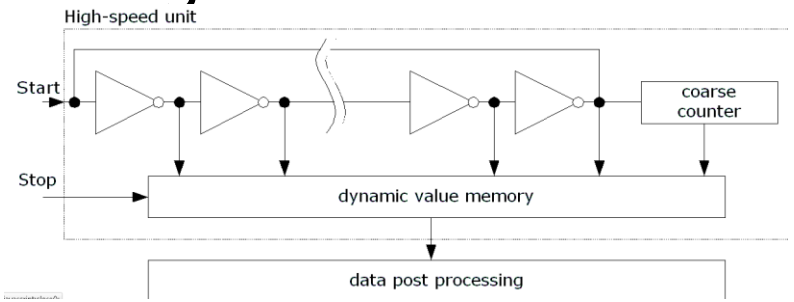



785nm High Power Laser Line Anti-Reflection Coating Performance
FOR REFERENCE ONLY
Reflectance (%)
4
3
2
1
0
650
700
750
800
850
900
950
Wavelength (nm)

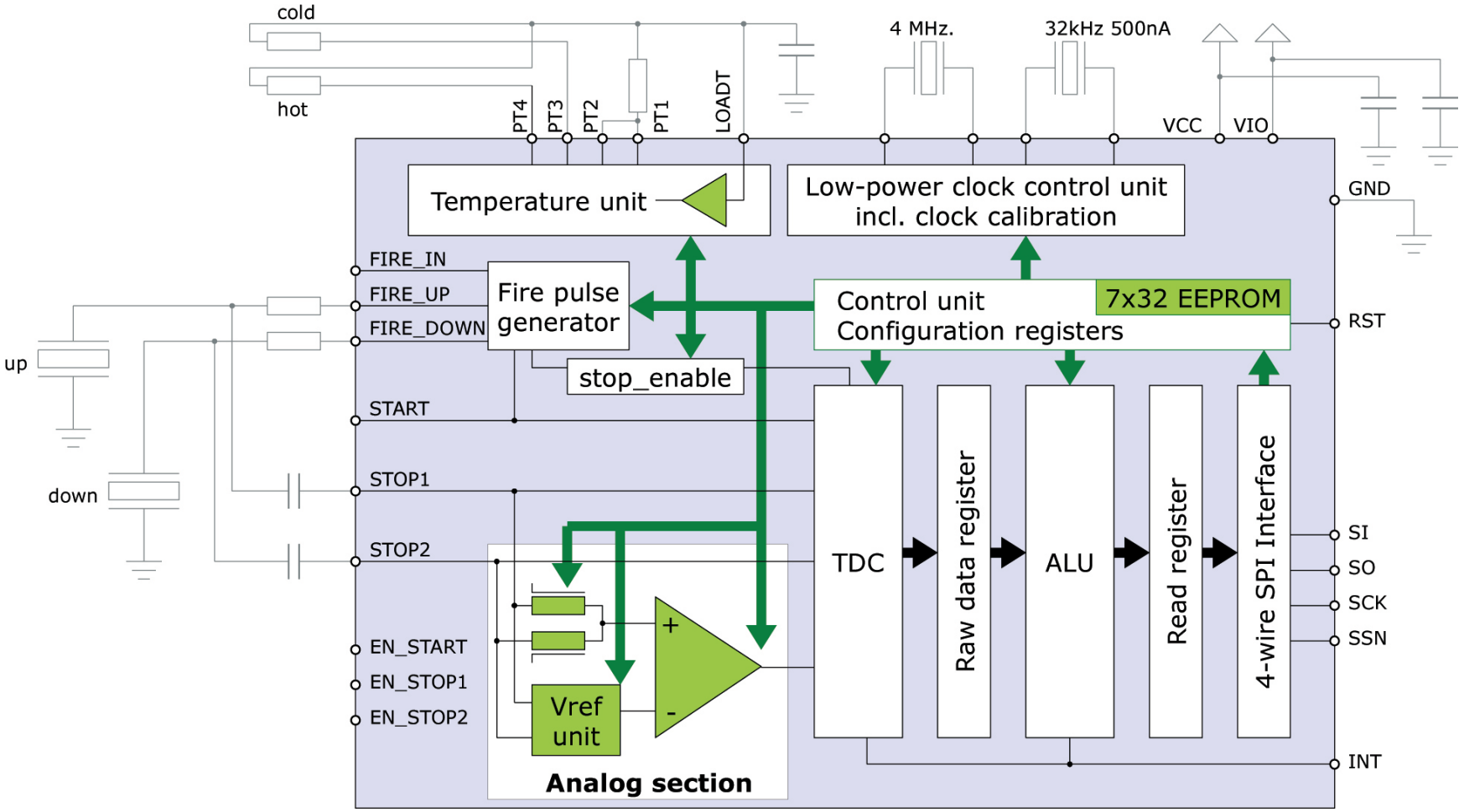
Range Measurement Hardware

ACAM TDC-GP21

- Time to Digital Converter
  - Measures the time difference between 2 signals
  - Capable of implementing TOF laser ranging due to redundant circuitry and propagation delays.
  - Multiple clock signals capable of measuring 3ps intervals (3 mm)
- QFN 32 package
- SPI communication
- Fire Pulse Generator
  - Output tied to laser module and START channel
- Cost effective: $40.00 for a large increase in range



ACAM TDC-GP21



ATmega328 & Arduino Uno Board

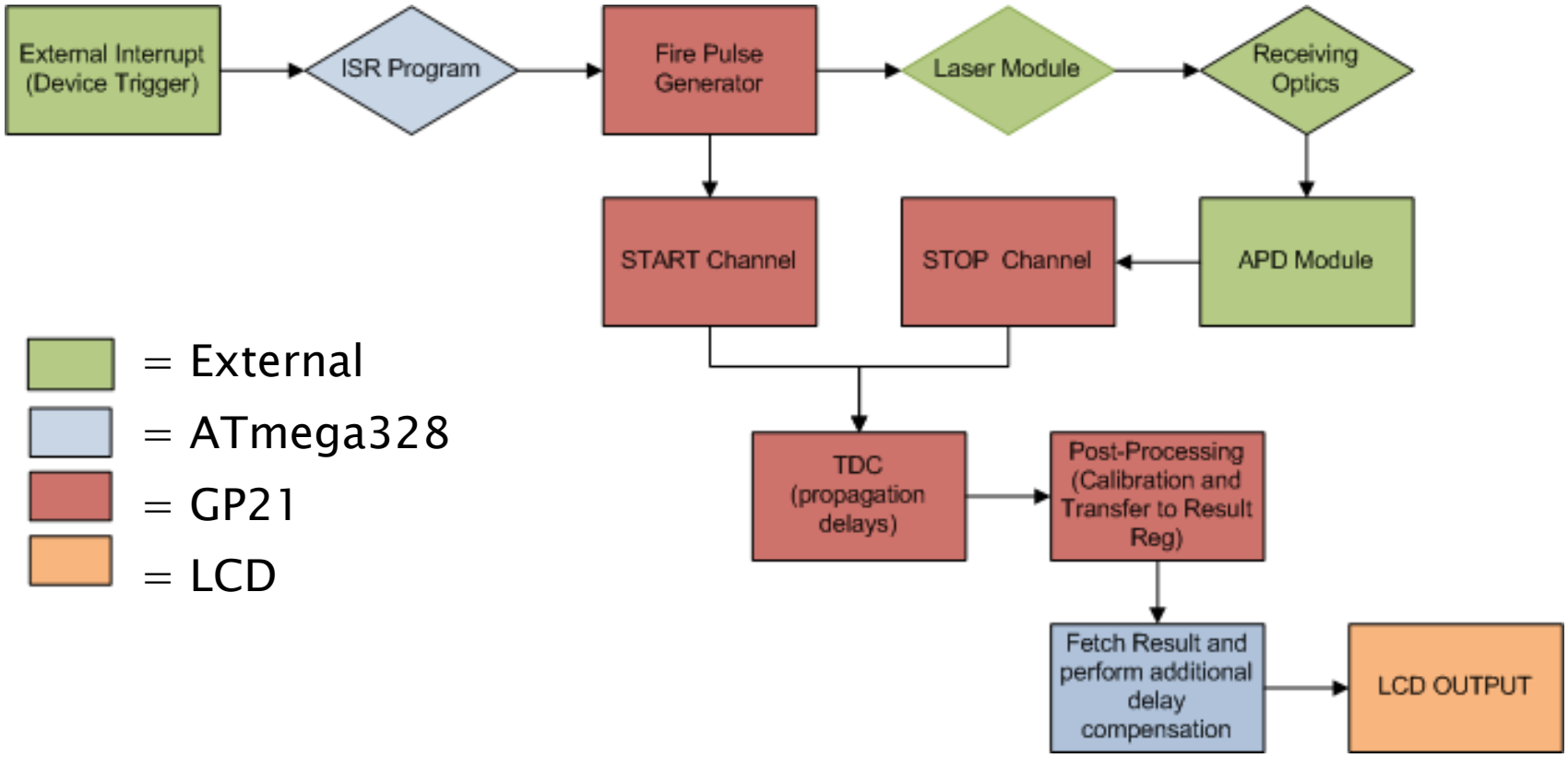
- 13 digital GPIO pins
- 6 analog input pins
  - Can serve as digital GPIO
- 16 MHz Crystal Oscillator
- 5V and 3.3V output perfect for prototyping
- Price: $35.00
- SPI and I2C compatible

Arduino Uno Environment

- C-based programming
- SPI Library (GP21 Communication)
- I2C Library (TMP 275 Ambient Temp Sensor)
- LCD Library (Hitachi HD 44780)
- Extensive Support Community
- Online Tutorials

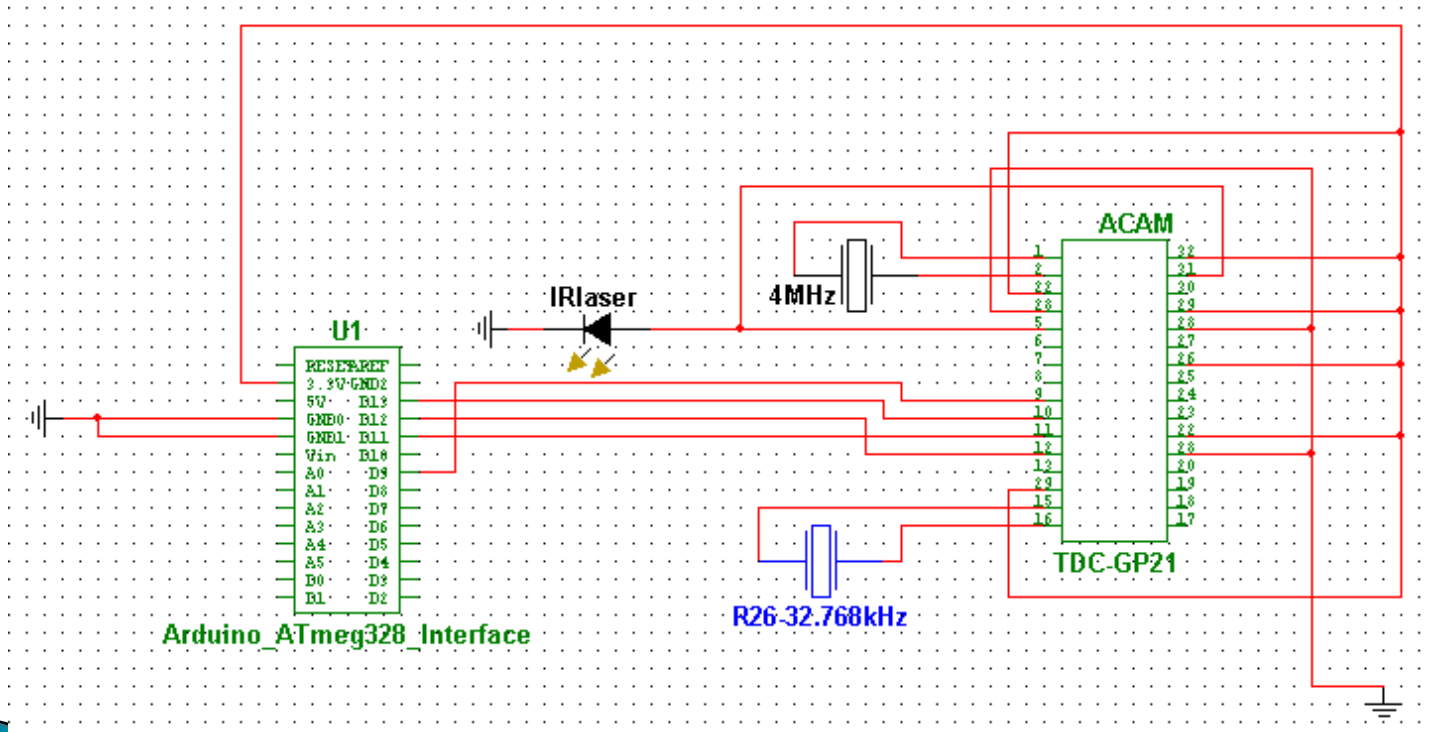
- Limitations with SPI communication require new functions to be written

Ranging Process Flow



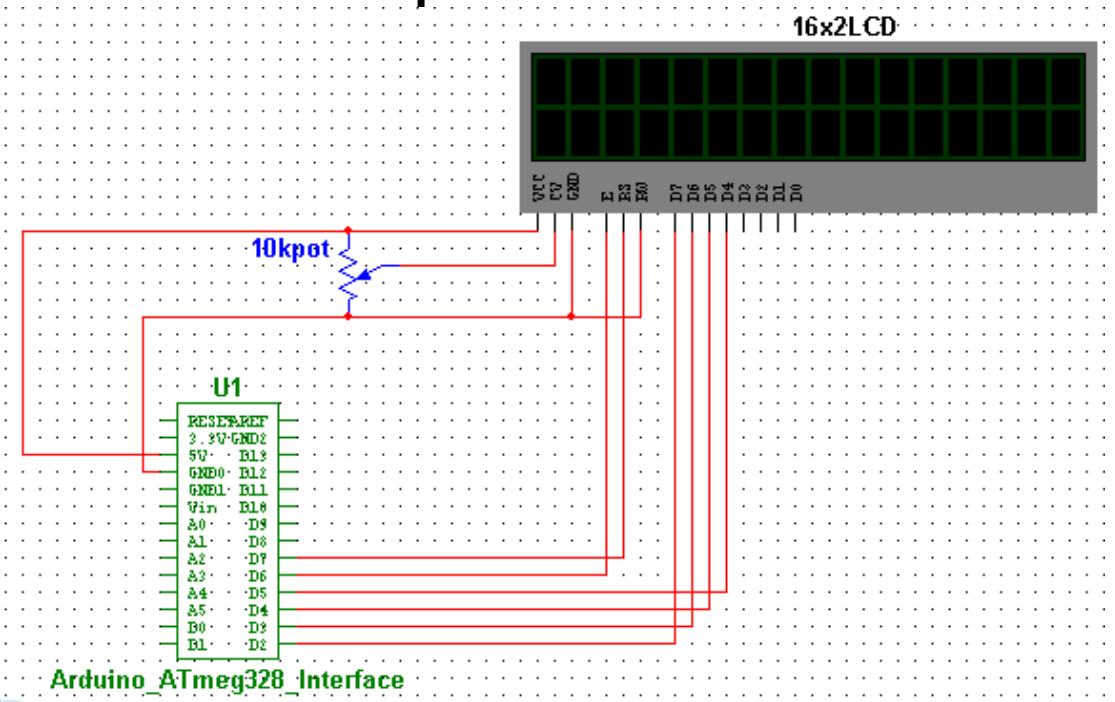
Arduino-GP21 Prototyping

- 4 Wire SPI connection
  - Declare new Slave Select Line for GP21
- 3.3V Supply from Arduino to TDC



LCD Prototyping

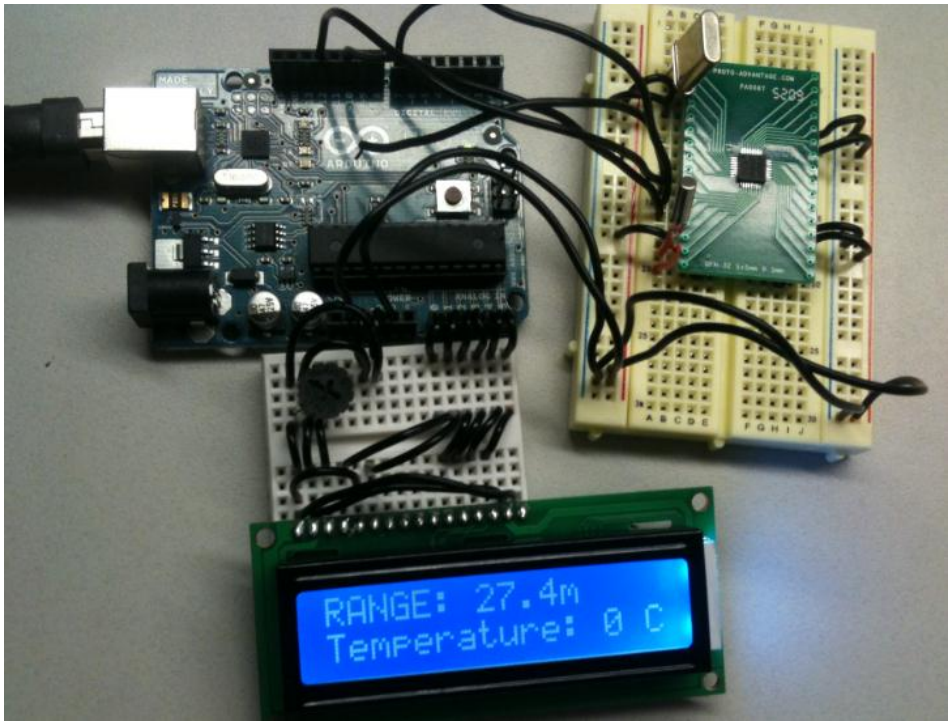
- 4 Wire interface for data transfer (D2-D5)
- 2 Wire interface for Enable and R/W configuration (D6-D7)
- 5V supplied by Arduino to power LCD and backlight



Prototyping GP21, Arduino, LCD

- LCD: Fully Functioning
- GP21: Re-writing the functions needed to communicate with the registers including:

readReg()
writeReg()
TOeeprom()
FROMeeprom()
readResult()
fetchStatus()



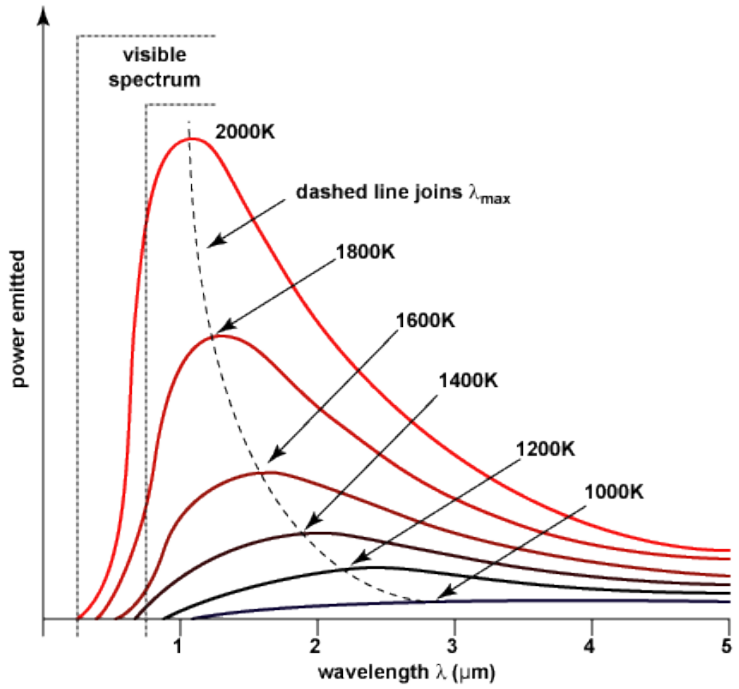
Contactless IR Temperature Sensor

IR Temperature Function

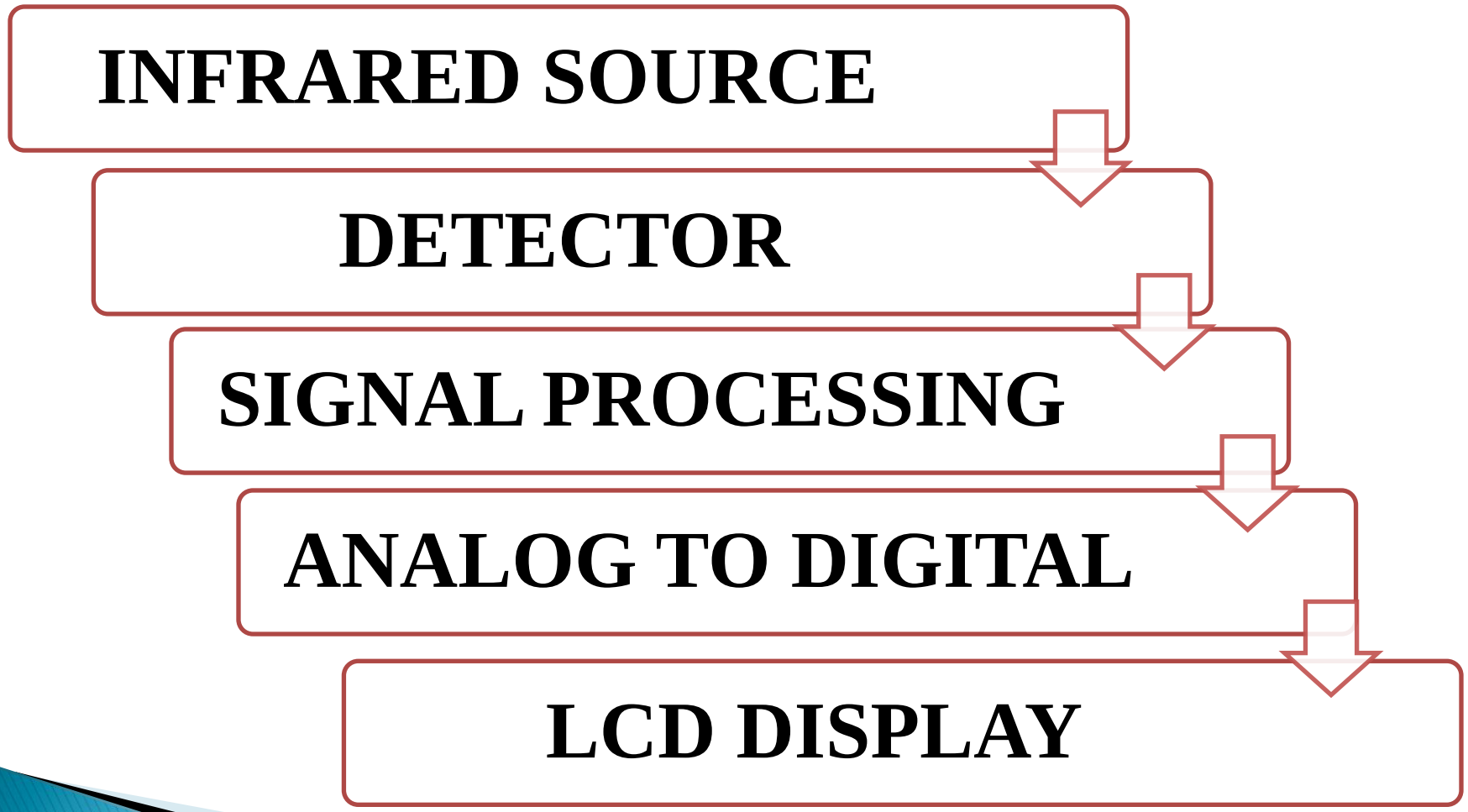
- Temperature need to be control and monitor engineering application like cooling, heating, drying, and storage.
- Increase ability portable sensing field device by giving temperature measuring function.
- Considered methods:
  - * Mechanical
  - * Thermo-junctive
  - * Thermo-resistive
  - * Infrared radiation
- Infrared radiation

Infrared Radiation – Reasons

- Noncontact measurement
- Require small energy
- Long wavelength –transmitted better through various medium.
- It could emit to all kinds of bodies.



Flow Chart


INFRARED SOURCE
DETECTOR
SIGNAL PROCESSING
ANALOG TO DIGITAL
LCD DISPLAY

Detectors

- Consider types:
  + Quantum: Expensive
  + Thermal:
    - Thermocouple
    - Thermopile
    - Bolometer
    - Micro Bolometer

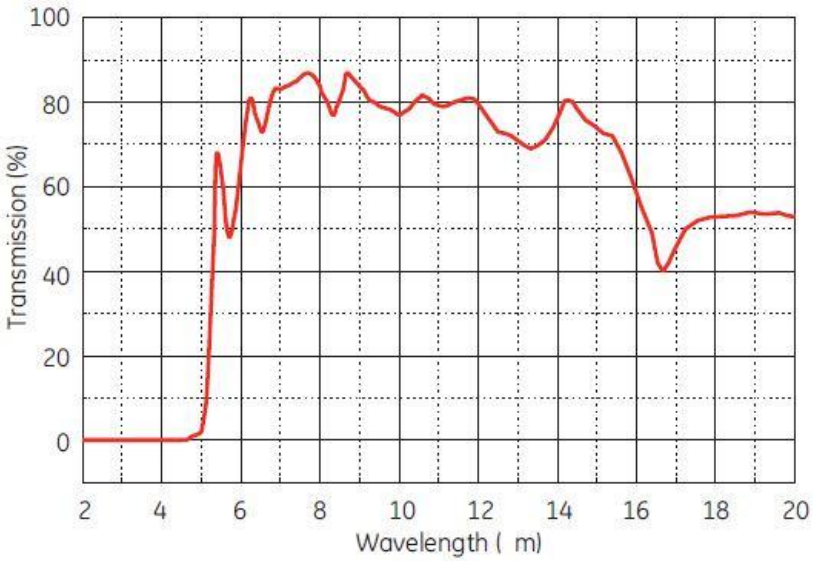
* Thermopile: affordable, small, and accurate

Digital detector : MLX90614

Analog detector: MLX90247 , ZTP – 135SR

ZTP-135SR

Parameter	Unit	Value	Condition
Chip Size	mm^2	1.8 x 1.8	–
Diaphragm Size	mm^2	1.4 x 1.4	–
Number of Couples	–	60	–
Active Area	mm^2	0.7 x 0.7	–
Internal Resistance	kΩ	60 ±30%	@ 77°F (25°C)
Resistance T.C.	% °F (°C)	< 0.12	–
Responsitivity	V/W	62 ±30%	500K, 1 Hz
Responsitivity T.C.	% °F (°C)	0.10	Typical
Noise Voltage	nV rms	32	R.M.S, Typical
NEP	nW/ √Hz	0.51	500K, 1 Hz, Typical
Detectivity	cn √Hz/W	1.35E + 08	500K, 1 Hz, Typical
Time Constant	ms	25	500K, 1 Hz, Typical
Operating Temperature	°F (°C)	-4°F to 212°F (-20°C to 100°C)	–
Storage Temperature	°F (°C)	-40°F to 248°F (-40°C to 120°C)	–
Thermistor Resistance Beta	kΩ K	100 ±3% 3960 ±1%	@ 77°F (25°C)
Package Type	–	TO-41	–



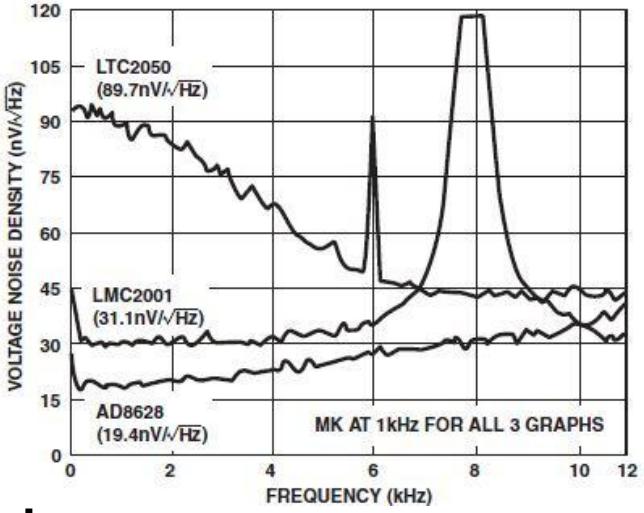
Infrared wavelength: 5 μm to 15 μm

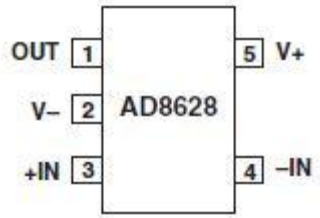
FEATURES

- Small-size sensor (TO-46 package)
- Included ambient temperature (thermistor) sensor for compensation
- High sensitivity
- Fast response time
- Low cost
- Consists of thermo-elements, flat l
- Thermistor of temperature compensation in a hermetically-sealed package.
- Variety of filters available to help maximize performance in specific applications

Op-amp Chopper – AD8628

- Lowest Auto-zero Amplifier Noise
- Low Offset Voltage: 1 µV
- Input Offset Drift: 0.02 µV/C
- Very Low Input Bias Current:
- Low Supply Current: 1.0 mA
- Overload Recovery Time: 10 µs
- No External Components Required
- Rail to Rail Input and Output Swing
- 5V Single-Supply Operation

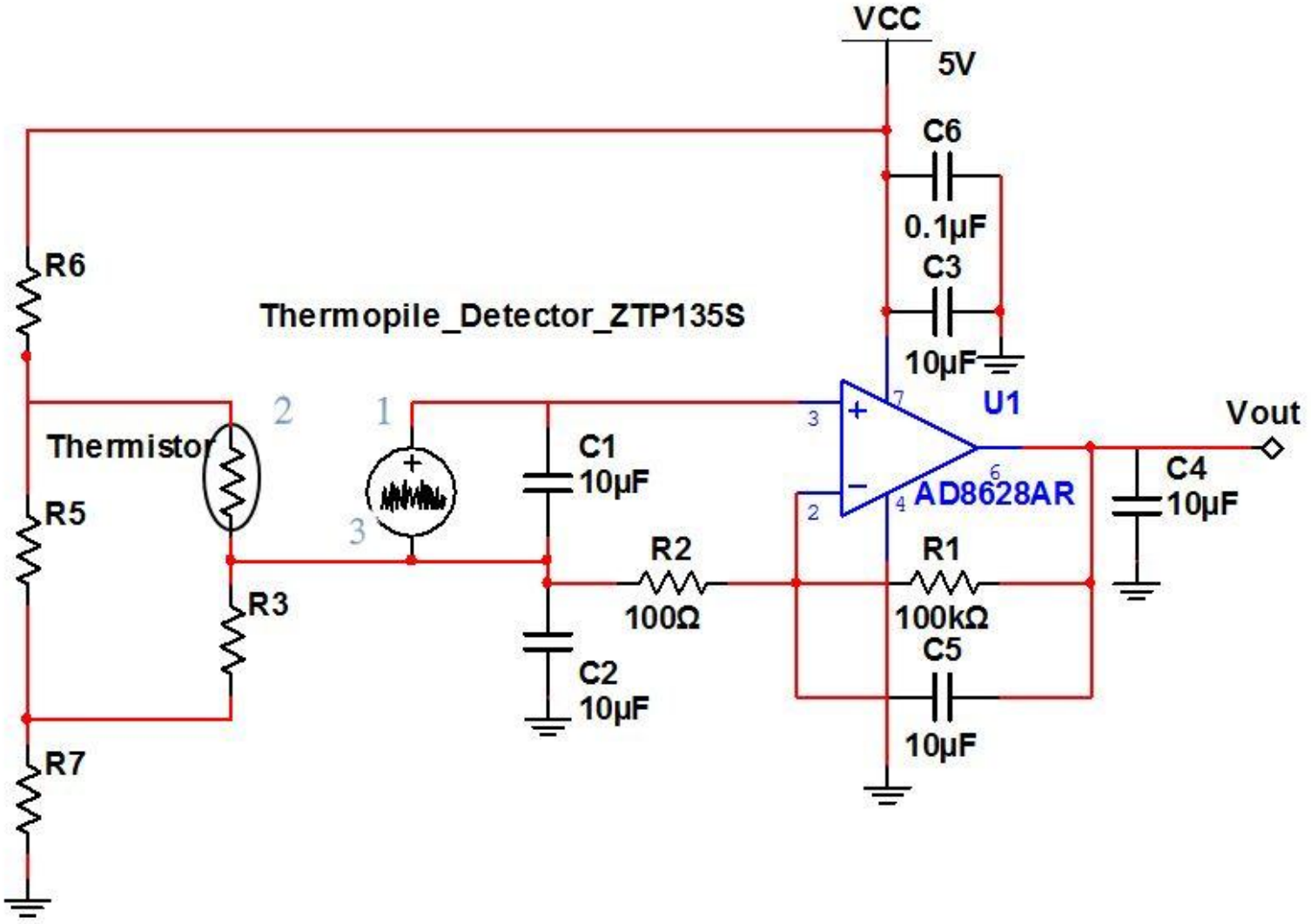




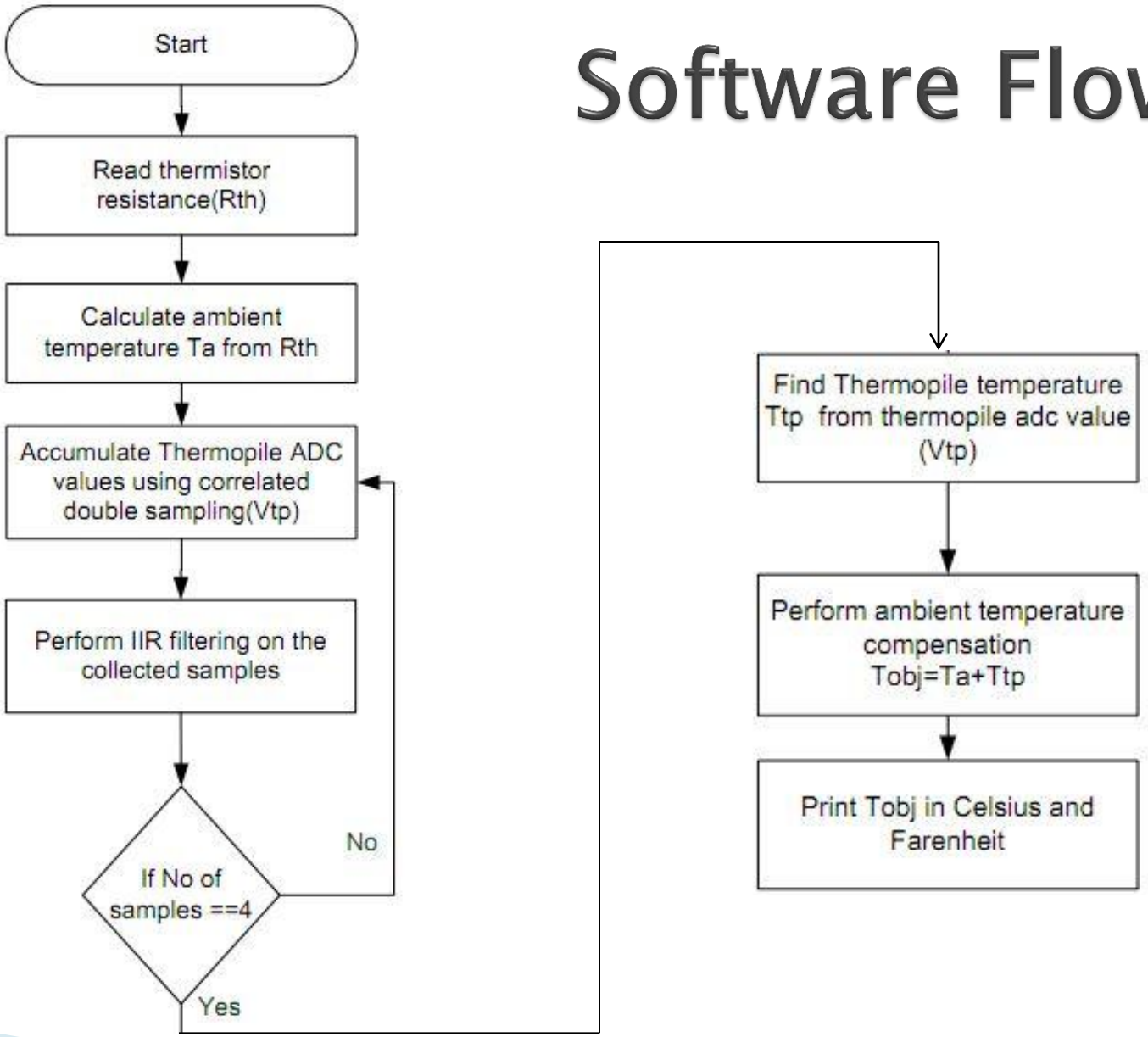
IR Thermometer Optics

- Single Fresnel Lens made of HDPE
- Salvaged from porch-light lens
- Cost-Effective Vs. Germanium or Silicon
- Commonly used in low-cost PIR sensors and IR temperature guns

Schematics


VCC
5V
C6
0.1µF
C3
10µF
R6
Thermopile_Detector_ZTP135S
U1
Vout
Thermistor
C1
10µF
AD8628AR
C4
10µF
R5
R2
R1
100Ω
100kΩ
R3
C5
C2
10µF
10µF
R7

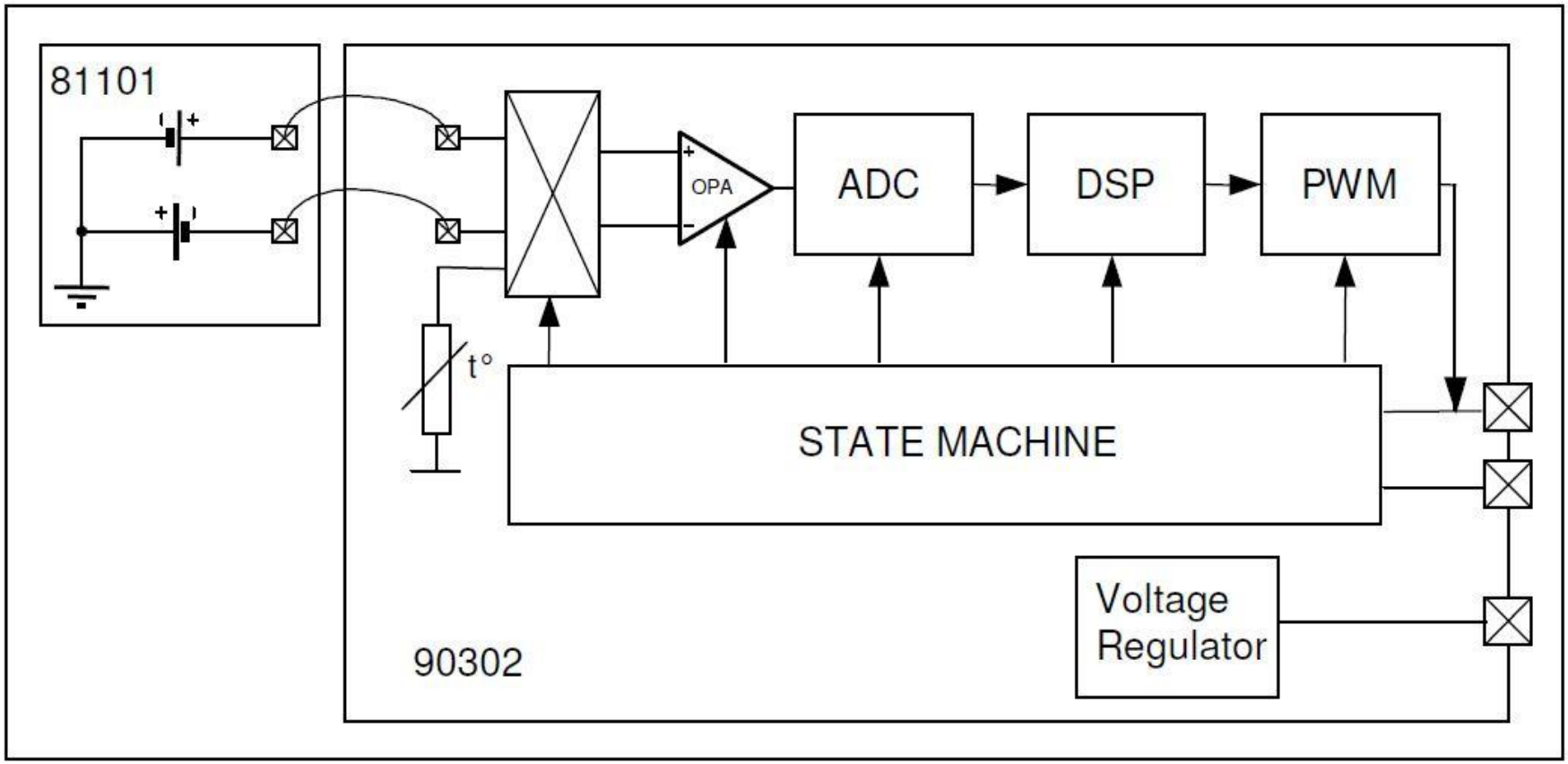
Software Flow



MLX90614

- Small size, low cost
- High accuracy of 0.5°C
- Range -40°C to 125°C ambient temperature 70°C to 382.19°C object temperature.
- SMBus compatible digital interface
- Customizable PWM output for continuous reading
- Sleep mode for reduced power consumption

Schematics


81101
OPA
ADC
DSP
PWM
t°
STATE MACHINE
Voltage
Regulator
90302

Calibration

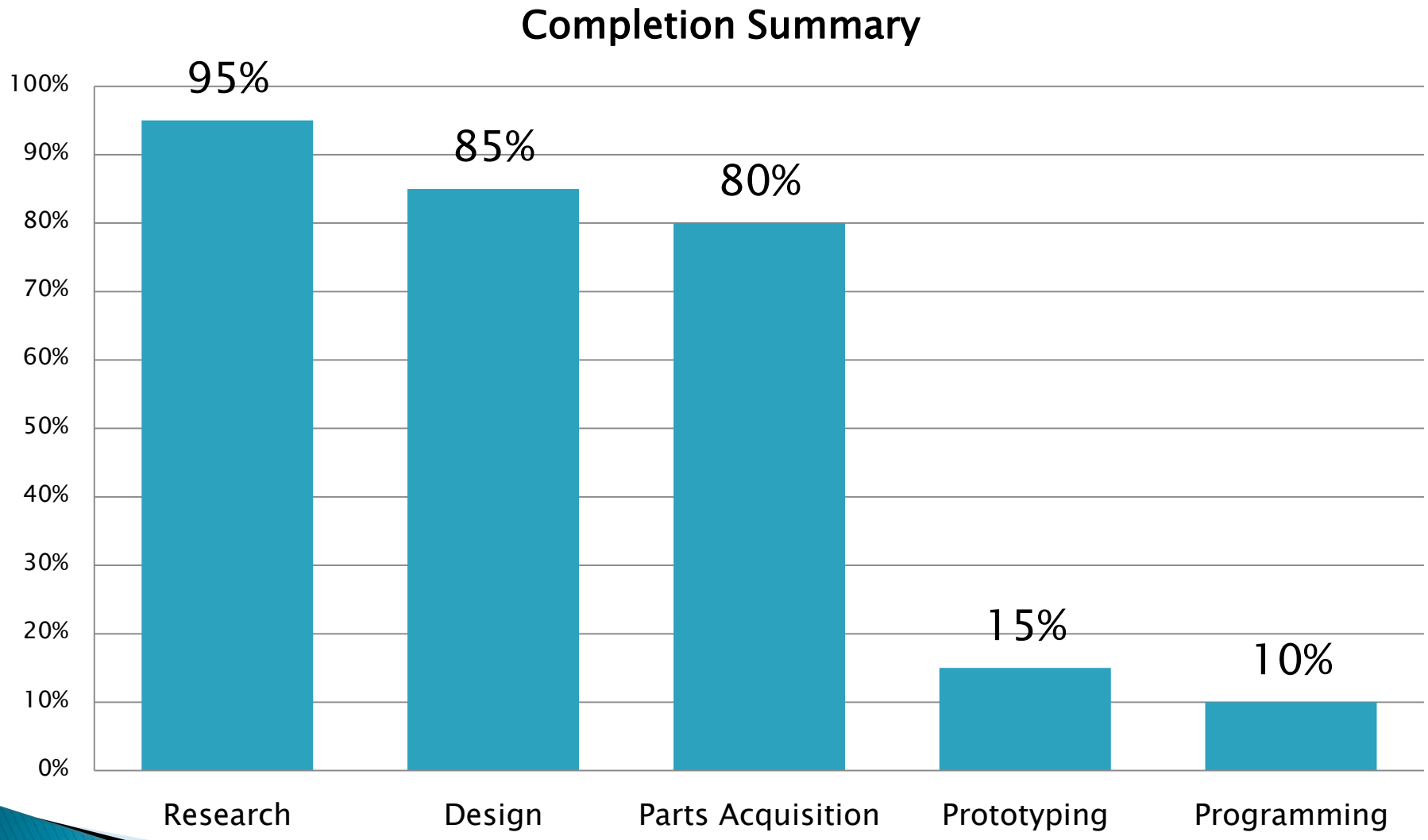
- Range detect
- Fresnel lens
- Emissivity
- EEPROM
- Emissivity 0x04
- Base 0x0F
- Filter 0x25

$$E = \frac{T_{O\_NEW}^4 - T_{A\_NEW}^4}{T_{O\_REAL}^4 - T_{A\_REAL}^4}$$

$$0x0F_{NEW} = DEC2HEX\left(\frac{HEX2DEC(0x04_{OLD})}{E_{NEW}} \middle| HEX2DEC(0x0F_{OLD})\right)$$

Challenges

- Frequency stability with of the transimpedance amplifier
- Interfacing TDC to APD module
- Quantifying the delay of the laser module startup
- Properly mounting the lens and filter so that its focal point is on the APD
- Possibly using a different LCD for increased user experience
- Enclosure issues


Completion Summary
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
95%
85%
80%
15%
10%
Research
Design
Parts Acquisition
Prototyping
Programming

Budget to Date

Name	Source	Cost	Purchased?
TDC-GP21 (QFN)	Transducers Direct	$35.00	yes
Arduino Dev Board: ATMEGA328	Element 14	$30.00	yes
QFN32 Breakout Board	Proto-advantage	$13.99	yes
780nm Laser Module	Aixiz	$13.00	yse
16x2 LCD	Spark Fun	$13.95	yes
Various Resistors	Anywhere	*$5.00	yes
Various Capacitors	Anywhere	*$5.00	yes
PCXOptical Lens - NT65-524	Edmund Optics	$40.00	yes
780nm Optical Filter - NT65-723	Edmund Optics	$99.00	yes
Li-ion 7.4V	Battery Junction	$25.00	no
LM7805 +5V Regulator	Spark Fun	$1.25	yes
LM7905 -5V Regulator	Fairchild Semiconductor	$0.60	yes
LD1117 3.3V Regulator	Spark Fun	$1.95	yes
MLX90614	Melexis	$19.95	yes
Fresnel Lens	N/A	Salvaged	yes
S2381 APD	Hamamatsu	$76.00	yes
Emco Q04 DC - HV DC	Emco	$59.00	yes
OPA847 Op-amp x4	TI	*$10.00 (sampled)	yes
Total		**$428.69**	