Varying Optical Frequency Shifter

Group B

Marcus Darby - EE

Kevin Gaj - EE / Photonics

Samuel Nunez - Photonics

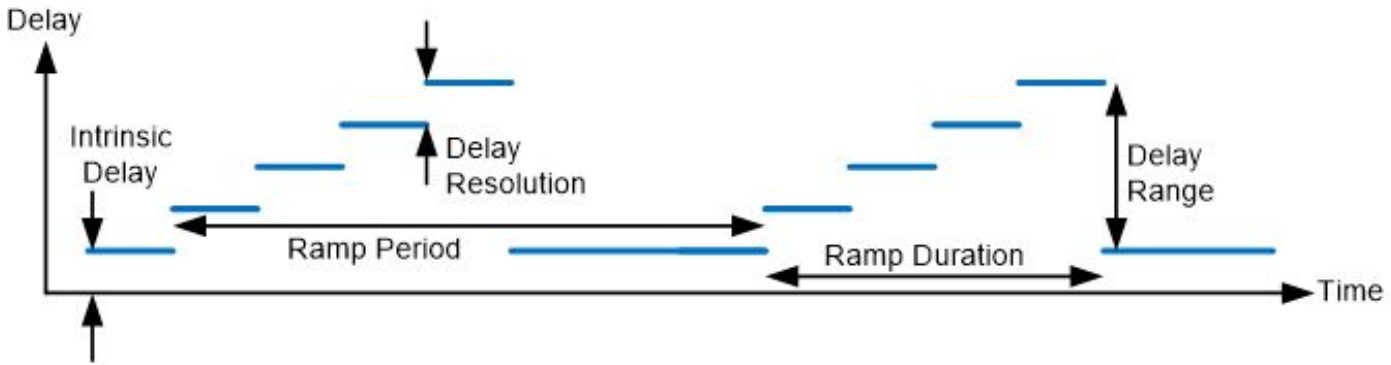
Caleb Stephan - Photonics

Motivation

- Communications systems are moving towards photonic approaches
- Many benefits over traditional electronic solutions
- Larger frequency bandwidth means higher data rates
- Optical components have lower SWaP penalty
- Variable optical delays are an important photonics processing tool

Goals and Objectives

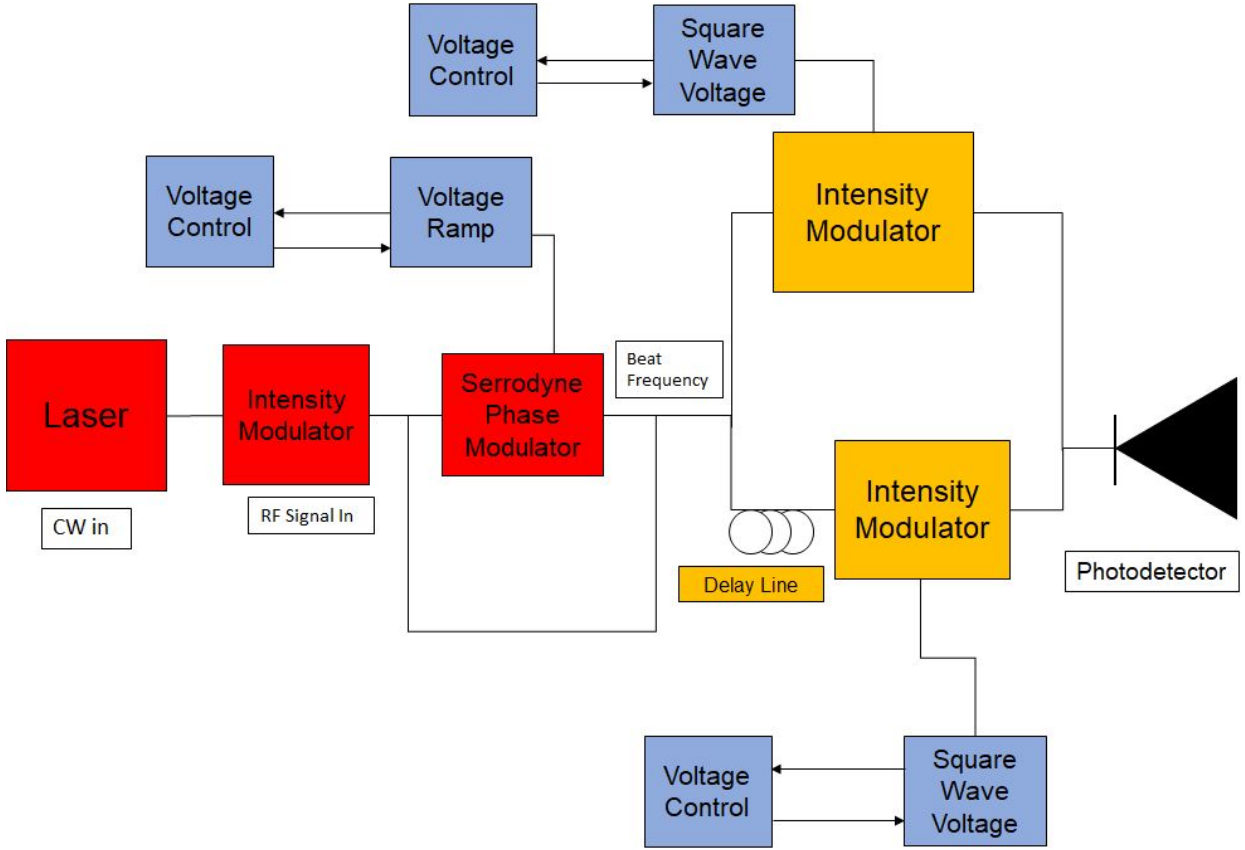
- Rapidly swept and very precise optical delay as required by sponsor
- Achieve frequency shifts that will generate these delays
- Unique electronics design will function alongside photonics components to achieve delays



Specifications

Design Parameter	Target	Description/Notes
Max Delay Range	1-2 ns	This sets the total maximum path length of the system
Intrinsic Delay	1 ns (more if necessary)	Shortest possible delay through the entire system
Delay Step Size/Resolution	<10 ps	Maximum difference in delay time between steps
Delay Step Duration	<50 μs	Maximum allowable time spent at one delay. Derived assuming linear profile.
Max Delay Step Transition Time	Less than 50% of the Delay Step Duration	
Maximum Frequency Shift	Approx. 100 MHz	
Number of Frequency Shifts	186	
Ramp Period	10 ms	
Ramp Duration	≤ Ramp Period	

Overall Block Diagram

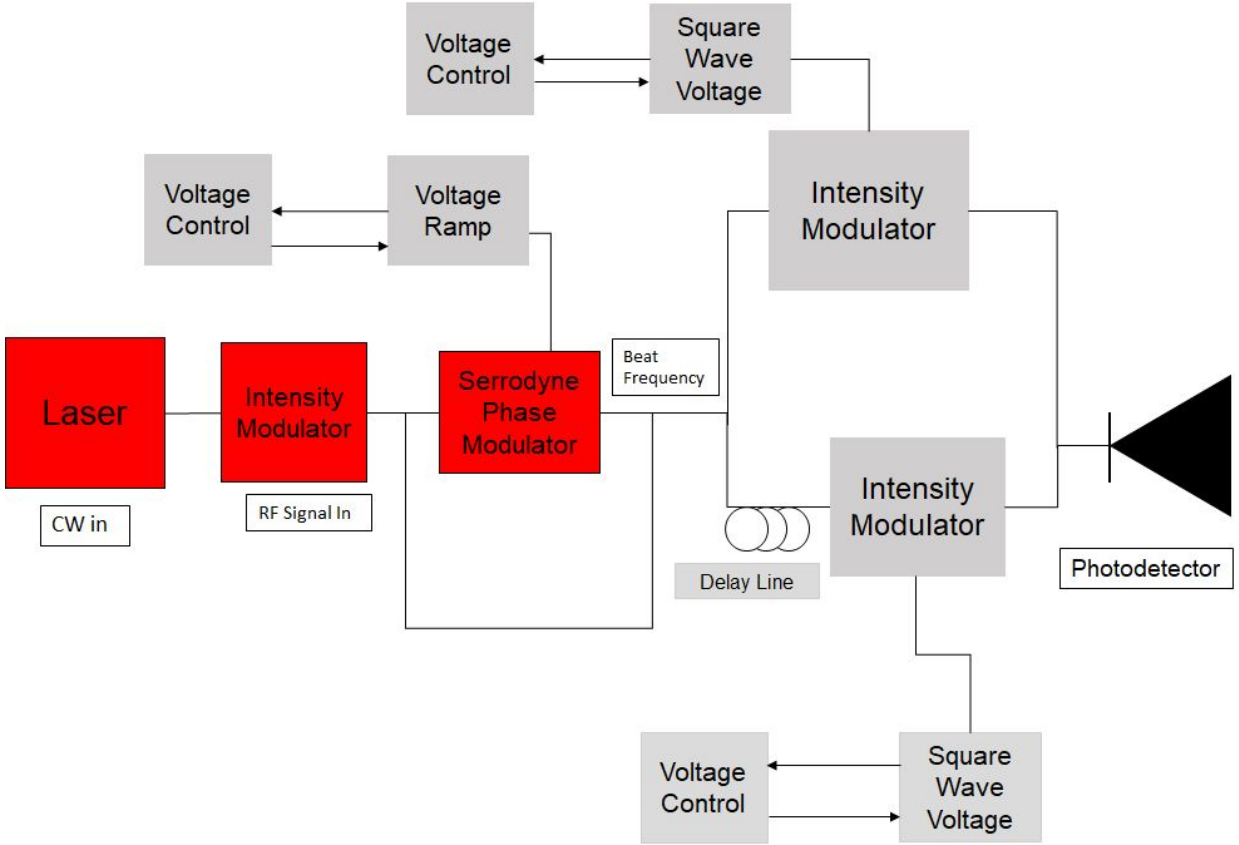


Red: Serrodyne components

Blue: Electronic Components

Gold: Spur Reduction Components

Serrodyne Components



Red: Serrodyne components

Blue: Electronic Components

Gold: Spur Reduction Components

Serrodyne Design Approach

- Frequency shift created from linear phase modulation
  - Frequency is the derivative of the phase with respect to time
- Spurs due to finite fall time of sawtooth phase modulation
  - Use of intensity modulators with delay line to reduce spurs
- Free space vs. fiber optics

LASER

- OEwaves Sub-Hz Linewidth Semiconductor Laser
  - Provided by sponsor
- C-band (1530-1565 nm) laser source
- Popular fiber optic communications wavelength range
  - Low fiber losses

Manufacturer	OEwaves
Wavelength Range	1530-1565nm
Spectral Linewidth	1 Hz
Output Power	10 mW

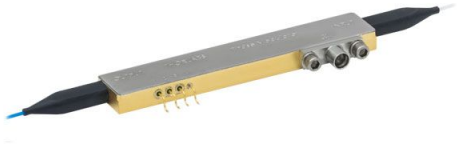
Signal Intensity Modulator

- Eospace intensity modulator will be provided by sponsor
- Lithium Niobate crystal modulates light via voltage bias
  - Refractive index is altered, changing the optical path length
  - Using this effect with a Mach-Zehnder interferometer allows for intensity modulation
- Radio Frequency signal is used to modulate the laser with information

Manufacturer	Eospace
Operating Wavelength	1550 nm
Optical Connectors	FC/PC standard
Insertion Loss	<4-5 dB
Modulation Port Vpi	<4-5 volts

Phase Modulator

- Thorlabs Low Vpi Phase Modulator will be used
- Monolithic crystal adjusts optical phase via electric bias
- Low drive voltage
- Thorlabs recommended by sponsor
    - Relatively low price

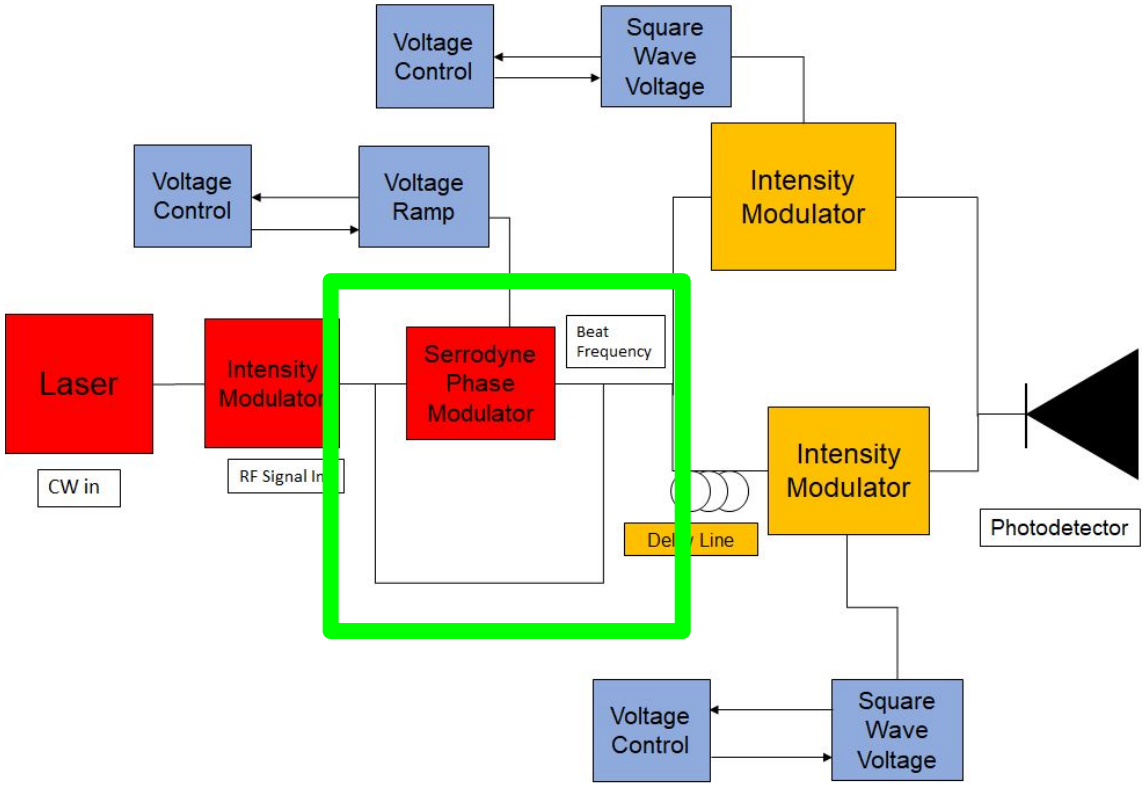


LN53S-FC

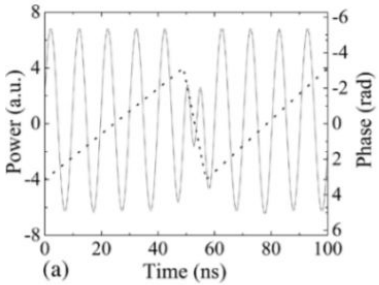
Manufacturer	Thorlabs
Operating Wavelength Range	1525 - 1605 nm
Insertion Loss	~3 dB
Electro-Optic Bandwidth	~10Ghz

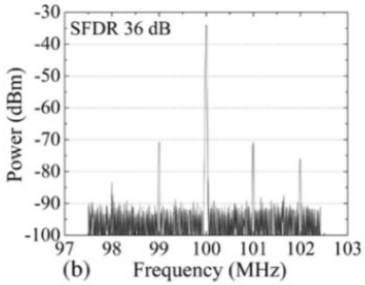
Signal Detection

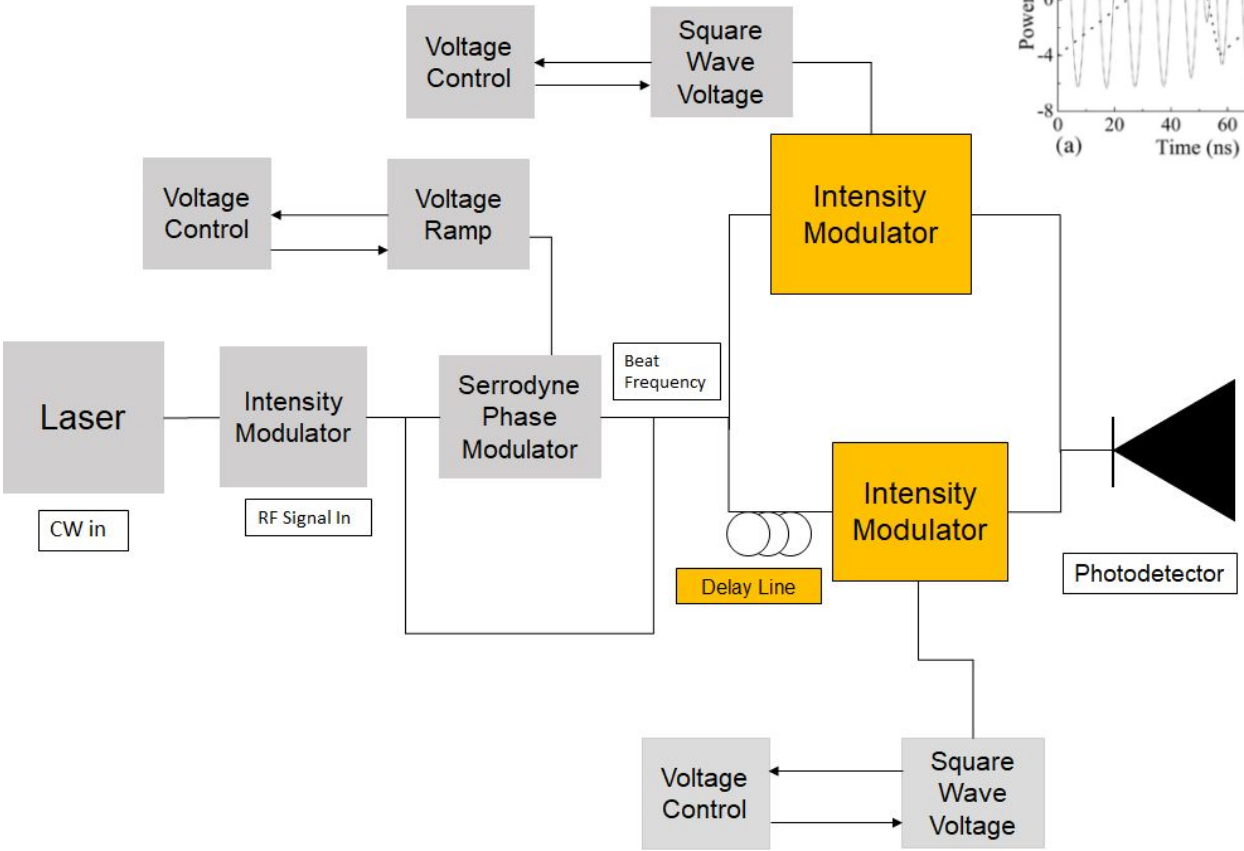
- Optical down-conversion allows for detection of microwave frequency
- Frequency difference (or beat frequency) is observed
- Detected signal viewed using spectrum analyzer



Spur Reduction Components







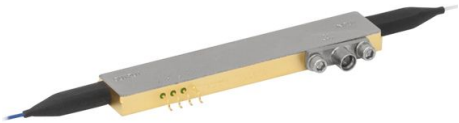
Red: Serrodyne components

Blue: Electronic Components

Gold: Spur Reduction Components

Spur Reduction Intensity Modulators

- Thorlabs intensity modulators will be used
  - Less expensive than high data rate modulators
- Biased using square wave voltage
- Act as accurate interferometric switches
- Blocks signal during “reset” time

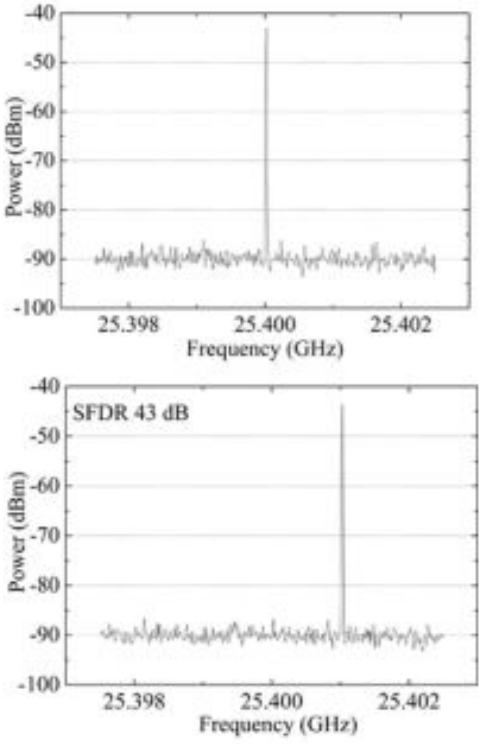


LN82S-FC

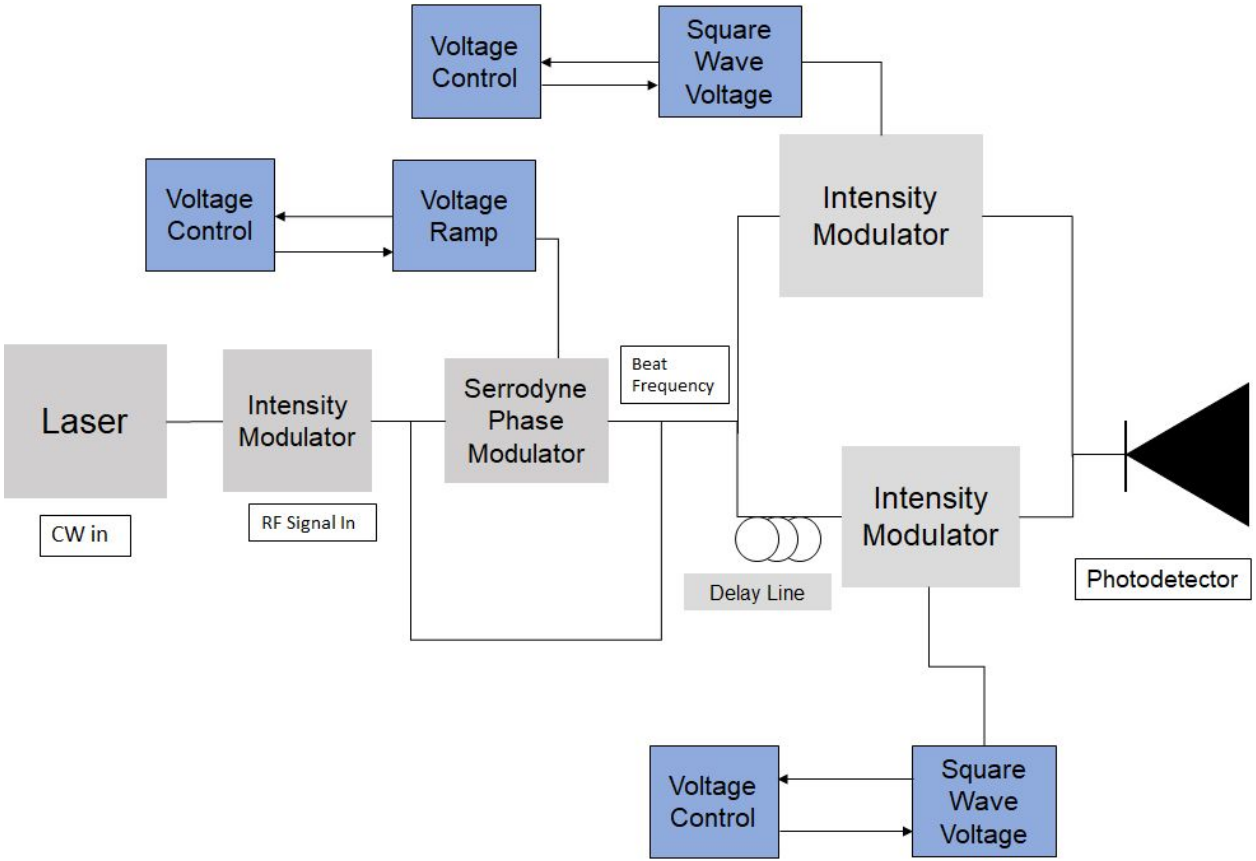
Manufacturer	Thorlabs
Operating Wavelength Range	1525 - 1605 nm
Insertion Loss	~3 dB
Electro-Optic Bandwidth	~10Ghz

Fiber Delay

- Signal is split
  - Routed to intensity modulators
- Optical fiber line introduced to add delay to one wing
- Provides the appropriate delay to allow for spur reduction
  - The delay added is equal to the “reset” time of the serrodyne sawtooth waveform



Electronic Components

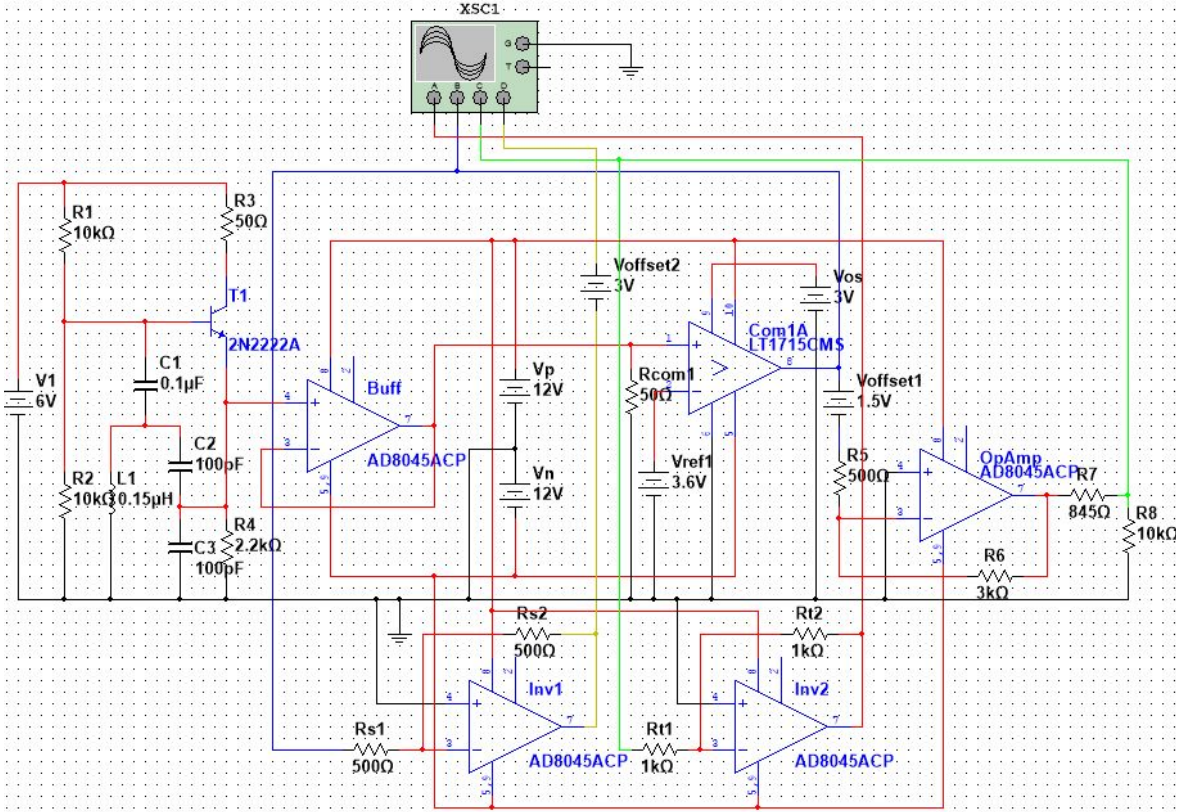


Red: Serrodyne components

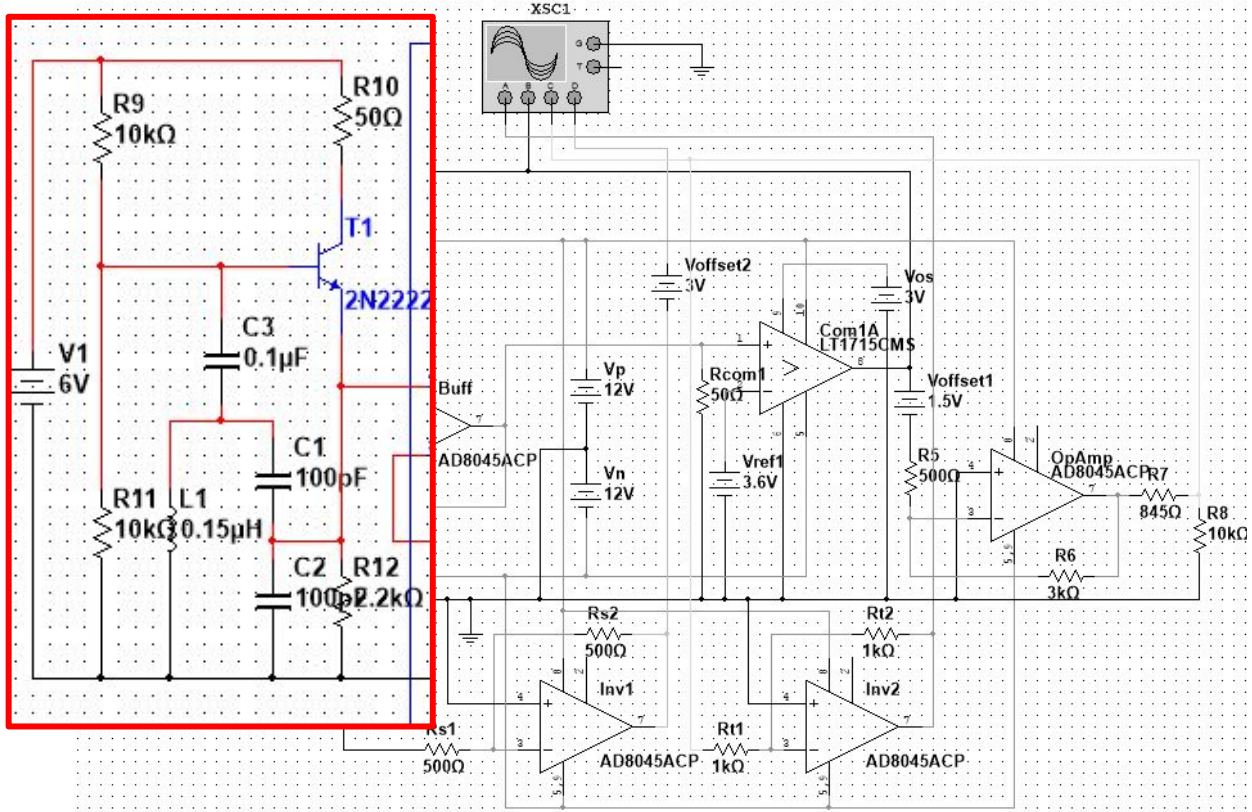
Blue: Electronic Components

Gold: Spur Reduction Components

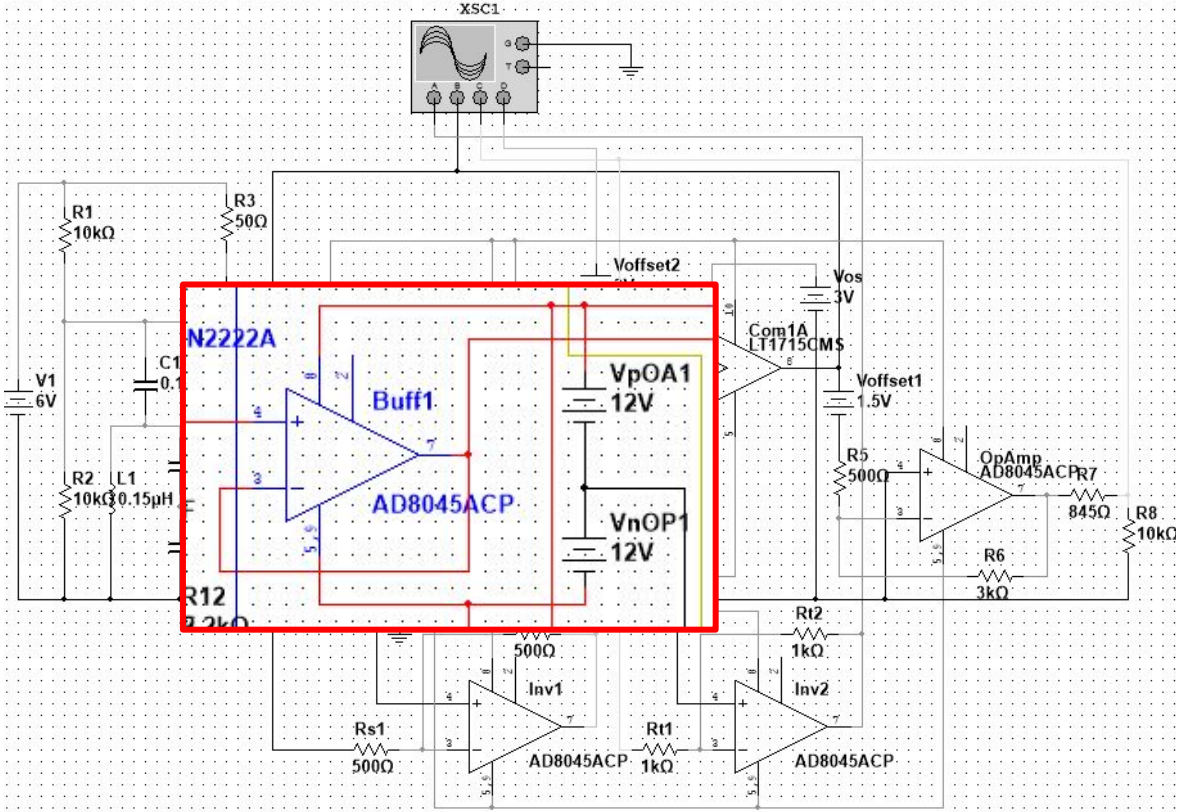
Circuit Design



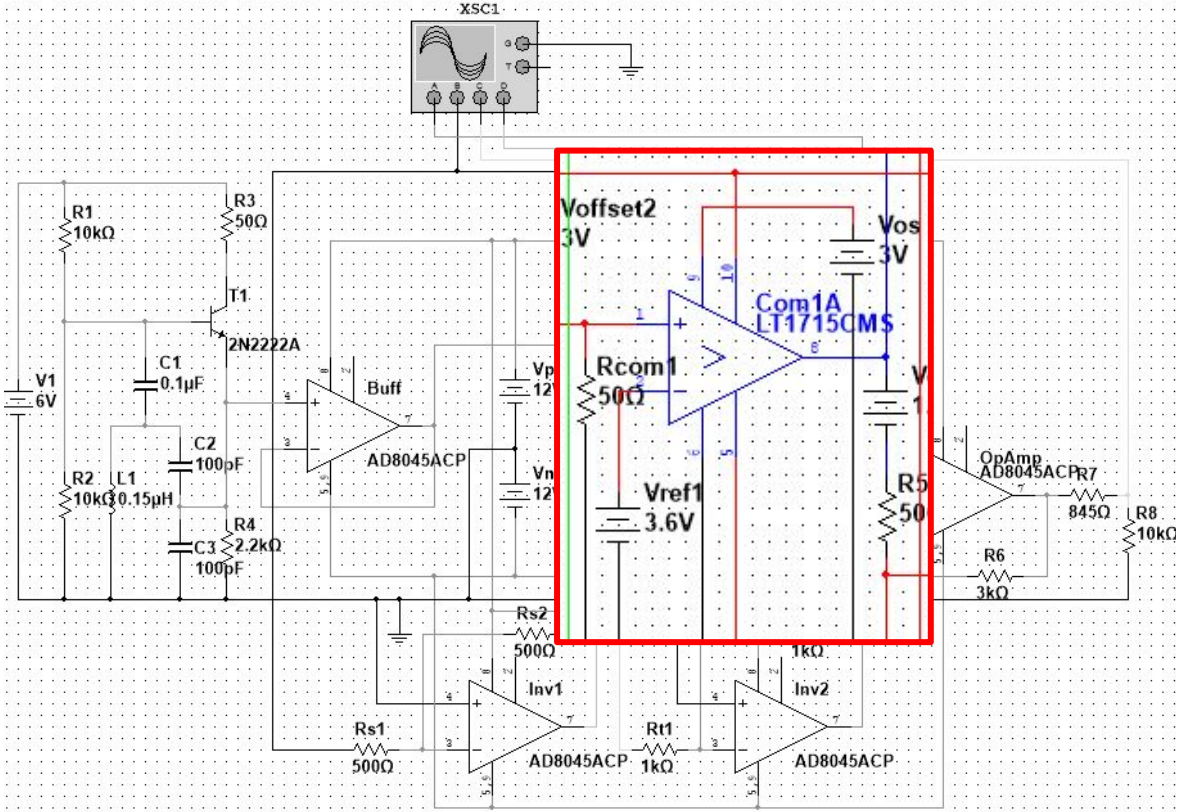
Circuit Design - 50MHz Oscillator



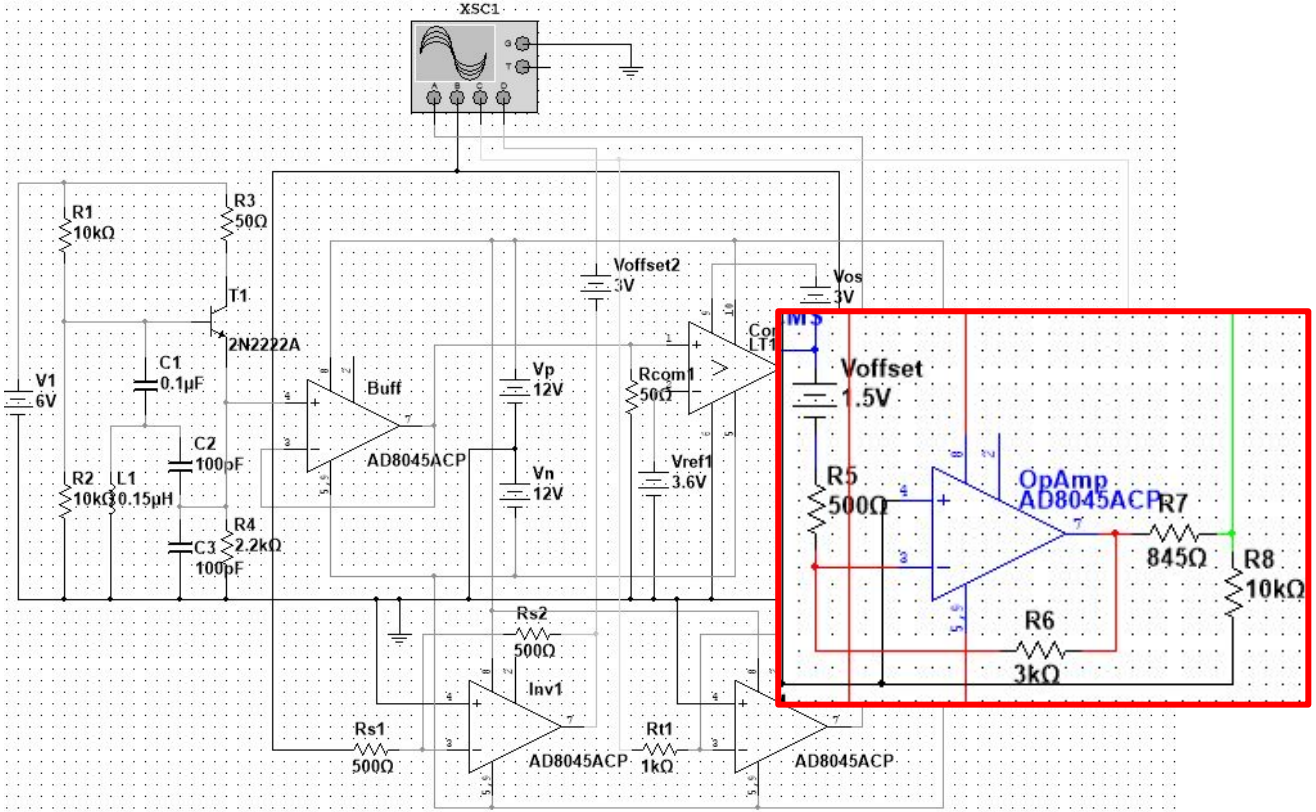
Circuit Design - Buffer



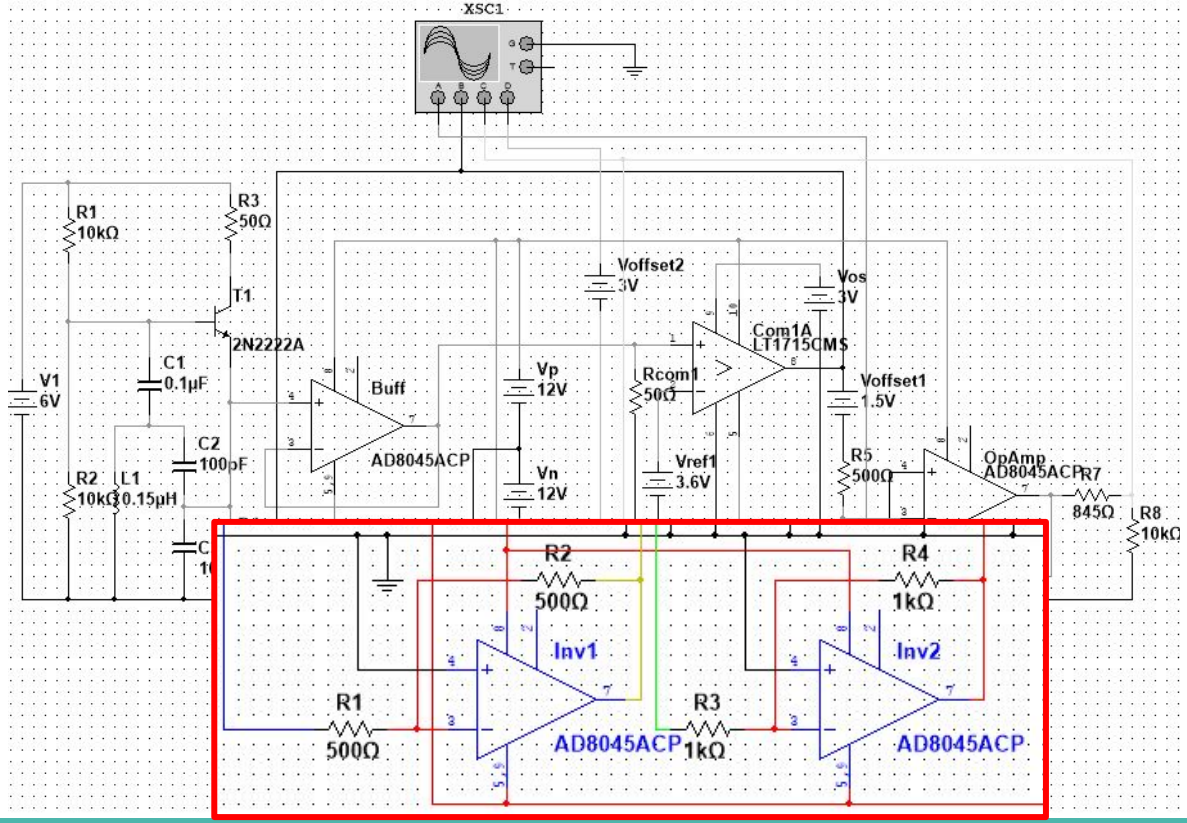
Circuit Design - 50MHz Square Waveform



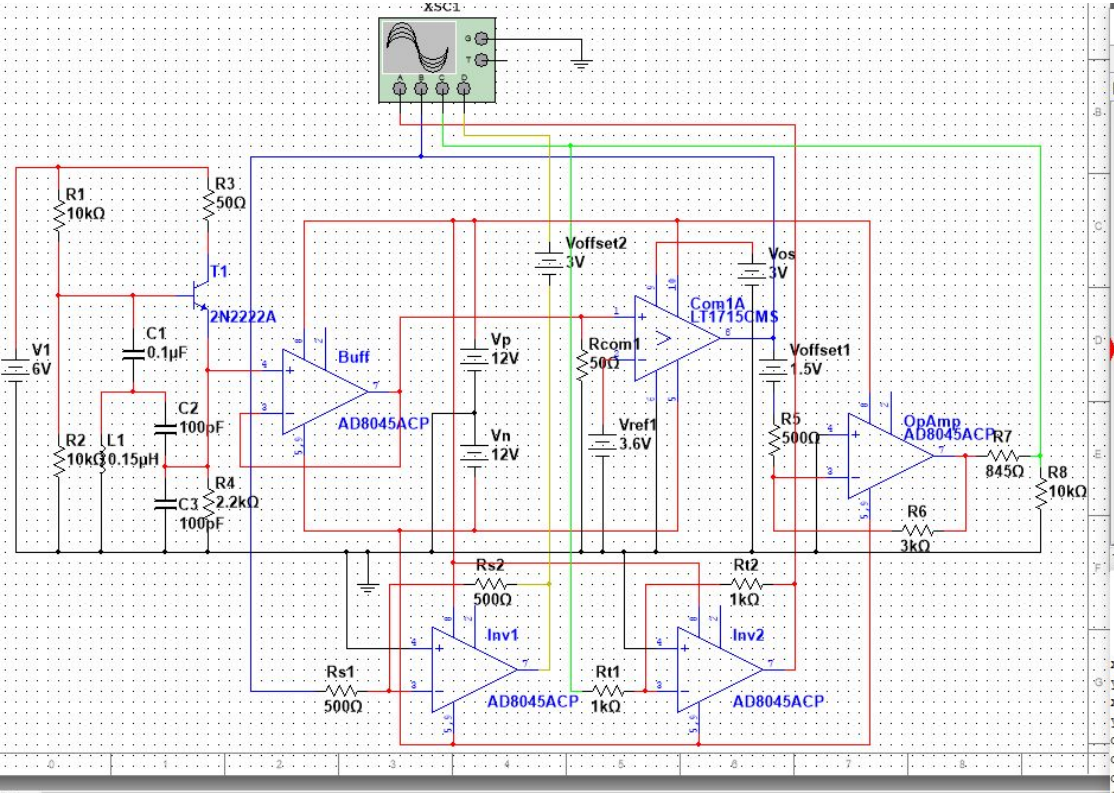
Circuit Design - 50MHz Triangle Waveform

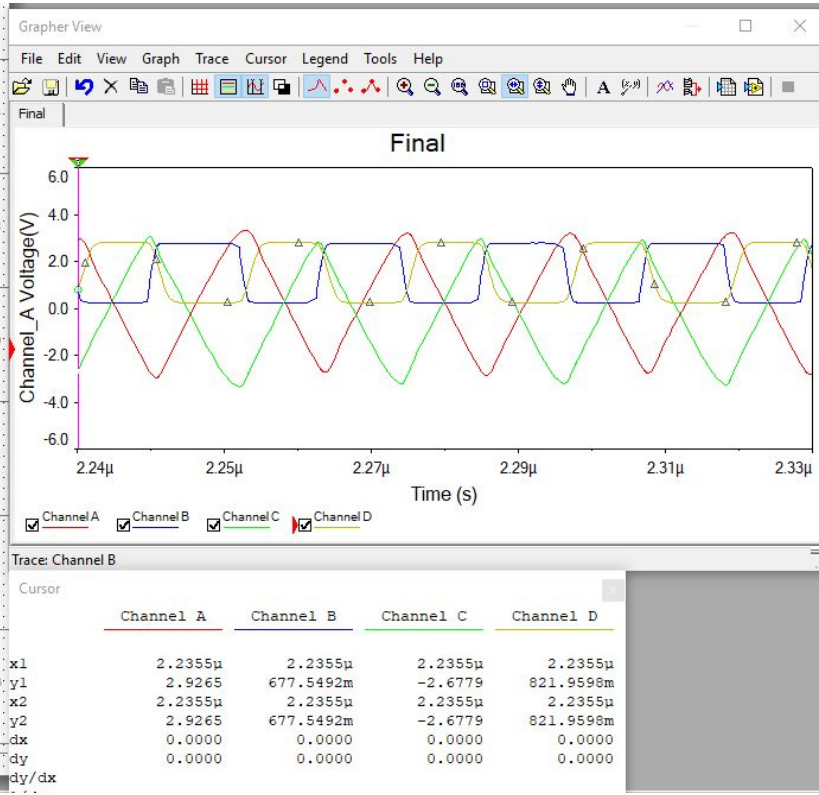


Circuit Design - Triangle and Square Inversion



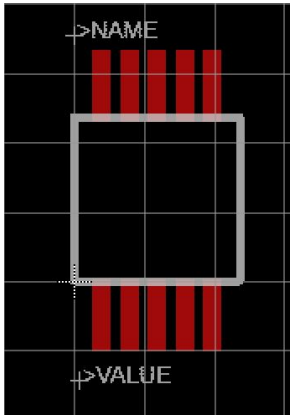
Expected Outputs





PCB Layout

- In the process
- Footprints are created
- Trace width of 10 mil
- Trace spacing > 2 mil
- Two layer PCB with ground plane
- SMT parts

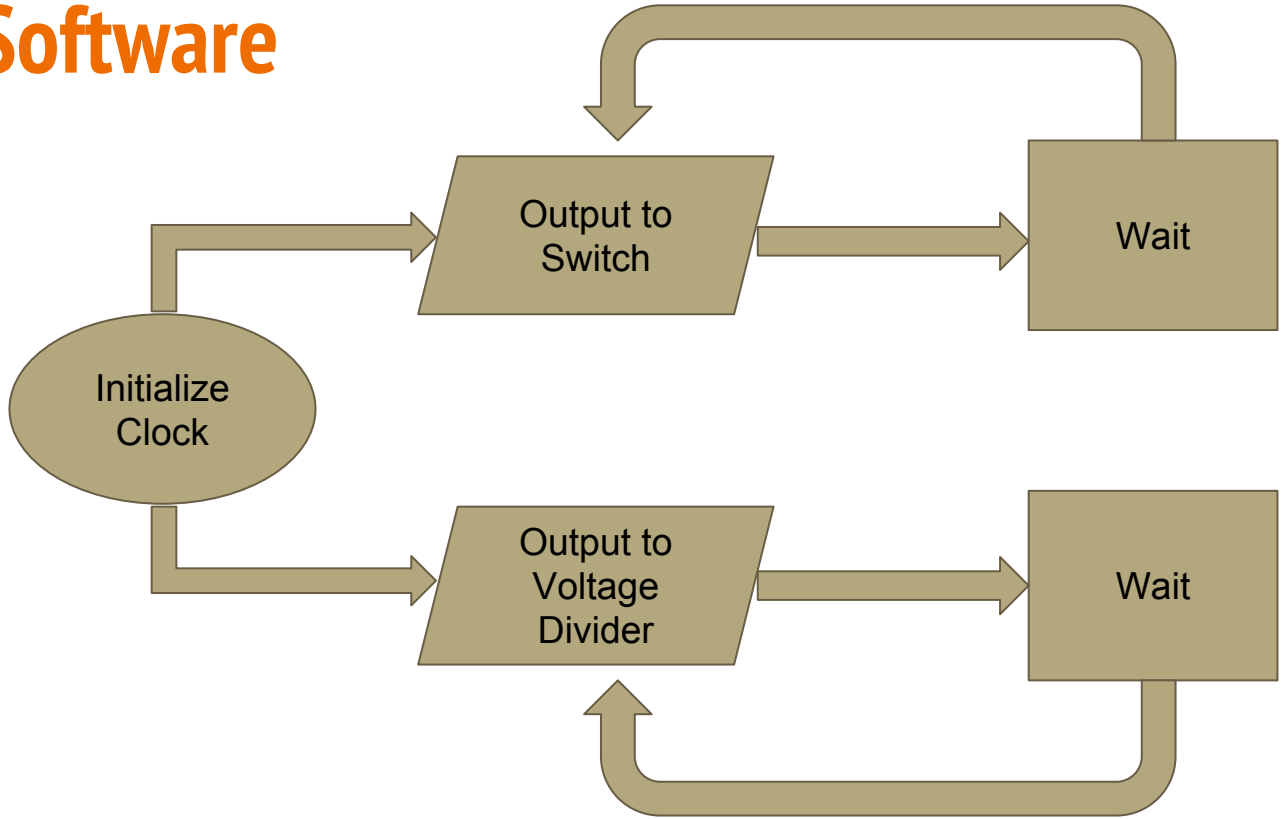


Microcontroller

- MSP-EXP430G2
- Controls output switches for selecting inversion stage and voltage dividers
- Familiar with this model

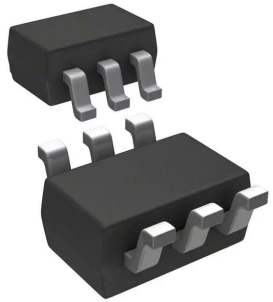
Manufacturer	Texas Instruments
Manufacturer Part #	MSP-EXP430G2
Unit Price	$10.37
GPIO	10
CLK SPEED (Max as packaged)	16 MHz
Dimensions	67 x 50 (mm)

Software


Initialize Clock
Output to Switch
Wait
Output to Voltage Divider
Wait

Digital Potentiometer (Digipot)

- Resistor ladder used to scale voltage ramp
- Programmable by MSP430
- Two needed to create voltage divider



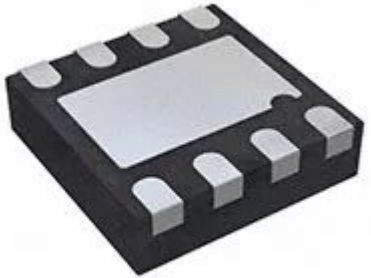
Manufacturer	Microchip Technology
Manufacturer Part #	MCP4018T-503E/LT
Unit Price	$0.53
Number of Resistors	128
Total Resistance	50 k-Ohm
Bandwidth	260 kHz
Dimensions	2.1 x 2.0 (mm)

Operational Amplifier

Used for:
Buffer
Amplifier/Triangle wave generator
Inversion

Main requirements:
High Frequency

Choice:
AD8045



Manufacturer	Analog Devices Inc.
Manufacturer Part #	AD8045ACPZ-REEL7
Unit Price	$3.85
Bandwidth	1 GHz

Comparator

Used for:
Square waveforms generation from sinusoid

Main requirements:
High Frequency

Part:
LT1715

Manufacturer	Linear Technology / Analog Devices
Manufacturer Part #	LT1715CMS#TRPBF
Unit Price	$8.04
Toggle Frequency	150 MHz

Power

Not a primary concern

Laser only requires a wall plug

Electronics use relatively low power and low current

Battery Selection

Electronics only use DC Batteries (Non-rechargeable):

- 50 MHz Oscillator (6V)
- Two (2) for Power Rails for OpAmps and Comparator (12V)
- Comparator Reference Voltage (3.6V)
- Comparator Supply Voltage (3V)
- Offset (1.5V, 3V)

Work Distribution

	Marcus	Kevin	Sam	Caleb
Serrodyne Frequency Shift			S	P
Frequency Spur Reduction			P	S
Circuit Design	P	S		
PCB Layout	S	P		
Software Design	S	P		

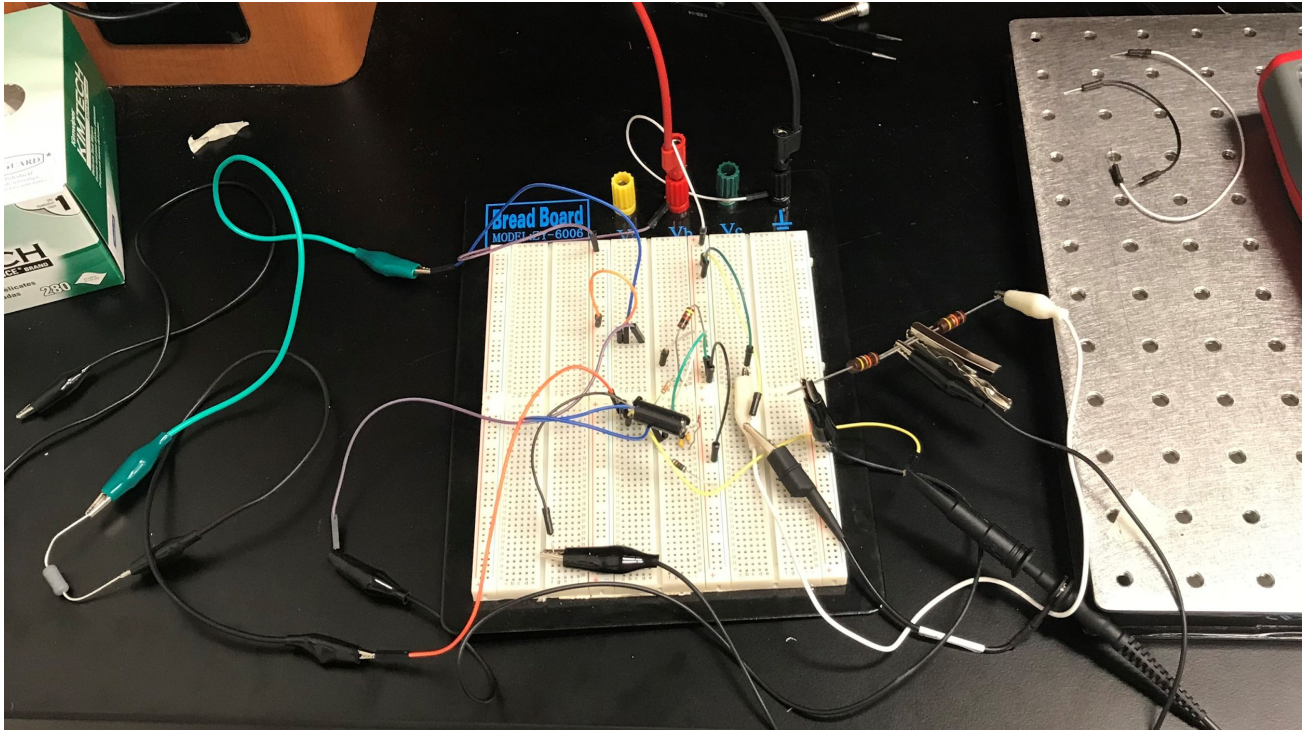
P: Primary

S: Secondary

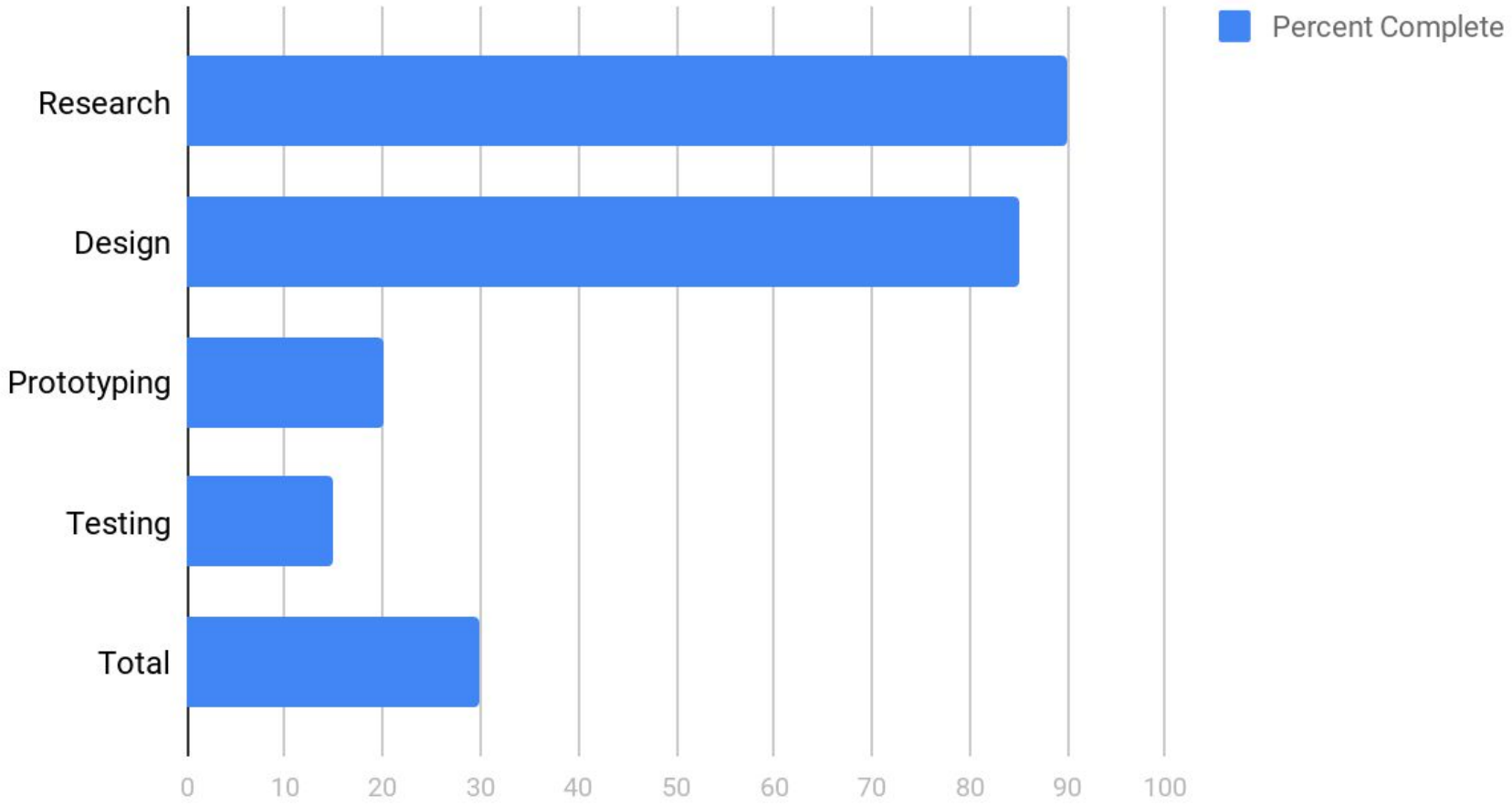
Budget & Financing

- Necessary parts require a budget of $9000
- The sponsor has agreed to supply these funds and more if the need arises
- Some equipment, such as the LASER, will be provided by the sponsor
- Additional test components will be paid for by the team (~$200)

Initial Oscillator Testing



Progress


Percent Complete
Research
Design
Prototyping
Testing
Total
0
10
20
30
40
50
60
70
80
90
100

Issues

High Frequency Electronics

Precision and Accuracy of components

Obtaining parts through Sponsor

Questions?

Citations

1. http://www.oewaves.com/narrow-linewidth-laser/subhertz
2. http://www.eospace.com/
3. https://www.thorlabs.com/thorproduct.cfm?partnumber=LN53S-FC
4. S. Ozharar, F. Quinlan, S. Gee, and P. Delfyett, “Demonstration of endless phase modulation for arbitrary waveform generation,” IEEE Photonics Technology Letters, vol. 17, no. 12, pp. 2739–2741, 2005.
5. https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=3918
6.