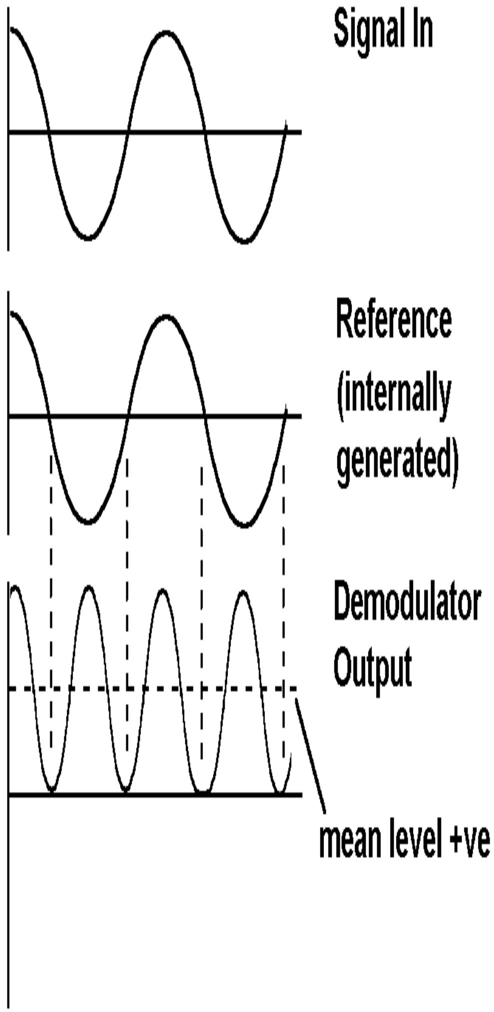
How to make
1)Lock-in Amplifier
2)Current Source

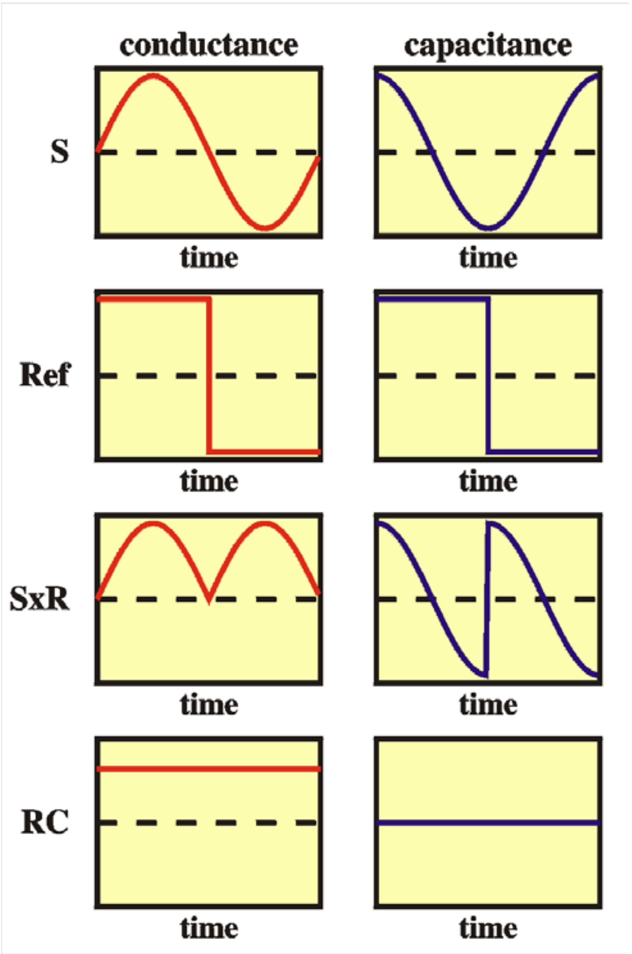
By Sultan Abdul Wadood

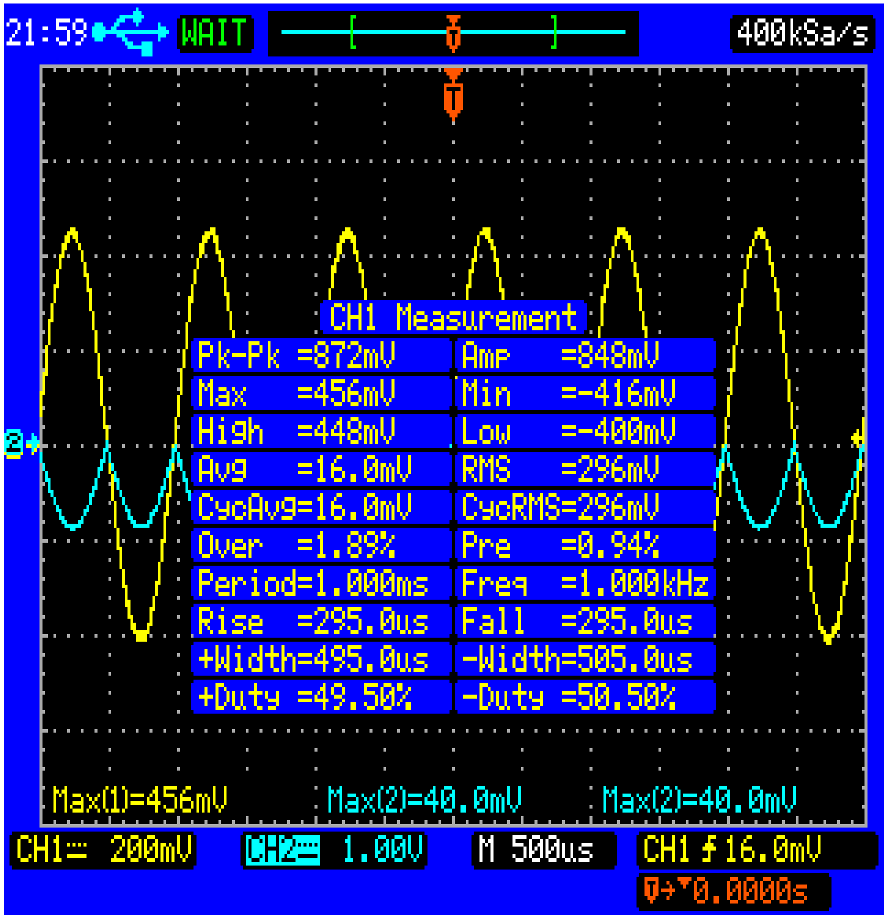
Introduction

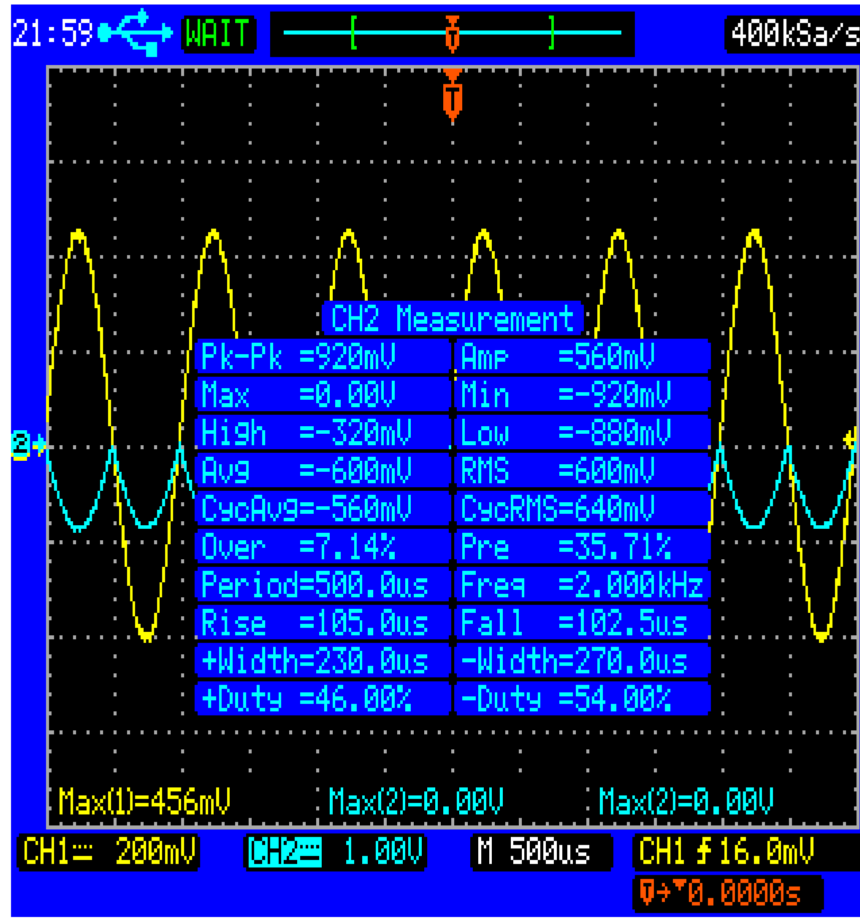
- Used to recover a small signal buried in a large noise
- Essentially a band-pass filter with very narrow bandwidth and very low attenuation
- Accomplishes this by phase sensitive detection, as conventional filtering is not helpful

Phase Sensitive Detection






21:59 WAIT 400kSa/s
CH1 Measurement
Pk-Pk =872mV
Amp =848mV
Max =456mV
Min =-416mV
High =448mV
Low =-400mV
Avg =16.0mV
RMS =296mV
CycAvg=16.0mV
CycRMS=296mV
Over =1.89%
Pre =0.94%
Period=1.000ms
Freq =1.000kHz
Rise =295.0us
Fall =295.0us
+Width=495.0us
-Width=505.0us
+Duty =49.50%
-Duty =50.50%
Max(1)=456mV
Max(2)=40.0mV
Max(2)=40.0mV
CH1 200mV
CH2 1.00V
M 500us
CH1 16.0mV
0.0000s


21:59 WAIT 400kSa/s
CH2 Measurement
Pk-Pk =920mV
Amp =560mV
Max =0.00V
Min =-920mV
High =-320mV
Low =-880mV
Avg =-600mV
RMS =600mV
CycAvg=-560mV
CycRMS=640mV
Over =7.14%
Pre =35.71%
Period=500.0us
Freq =2.000kHz
Rise =105.0us
Fall =102.5us
+Width=230.0us
-Width=270.0us
+Duty =46.00%
-Duty =54.00%
Max(1)=456mV
Max(2)=0.00V
Max(2)=0.00V
CH1 200mV
CH2 1.00V
M 500us
CH1 16.0mV
0.0000s

- Mixer/Multiplier
- Product of two sinusoids(f1 and f2) is a signal containing two parts:

1. Sum of frequencies
2. Differences of frequencies

The mixer operates by multiplying the two signals together so, the output V_o will be,

$$
\begin{aligned}
V_o &= A\sin(\omega t)B\sin(\Omega t+\phi) && (3)\\
&= \frac{AB}{2}(\cos((\omega-\Omega)t+\phi)-\cos((\omega+\Omega)t+\phi)), && (4)
\end{aligned}
$$

showing that the mixer output comprises two AC signals, one at the difference frequency $(\omega-\Omega)$ and other at the sum frequency $(\omega+\Omega)$. If reference frequency is equal to the frequency of input signal i.e. $\omega=\Omega$, a sinusoidal output is obtained with some DC offset Figure (5).

$$
V_o = \frac{AB}{2}(\cos(\phi)-\cos(2\Omega t+\phi)). \tag{5}
$$

So, the output V_o is proportional to the magnitude of input signal A, the cosine of angle between input and reference and it is modulated at twice the reference frequency.

- Our Mixer will multiply the incoming signal with a square wave, which will create some problems, more on this later.

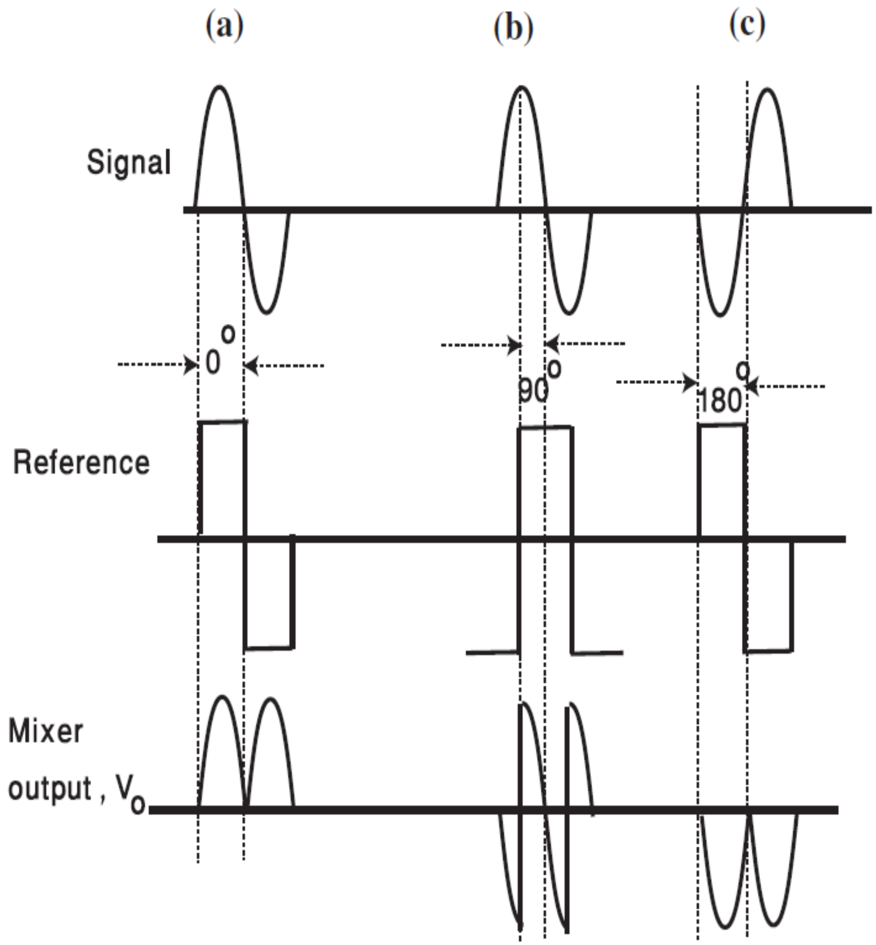


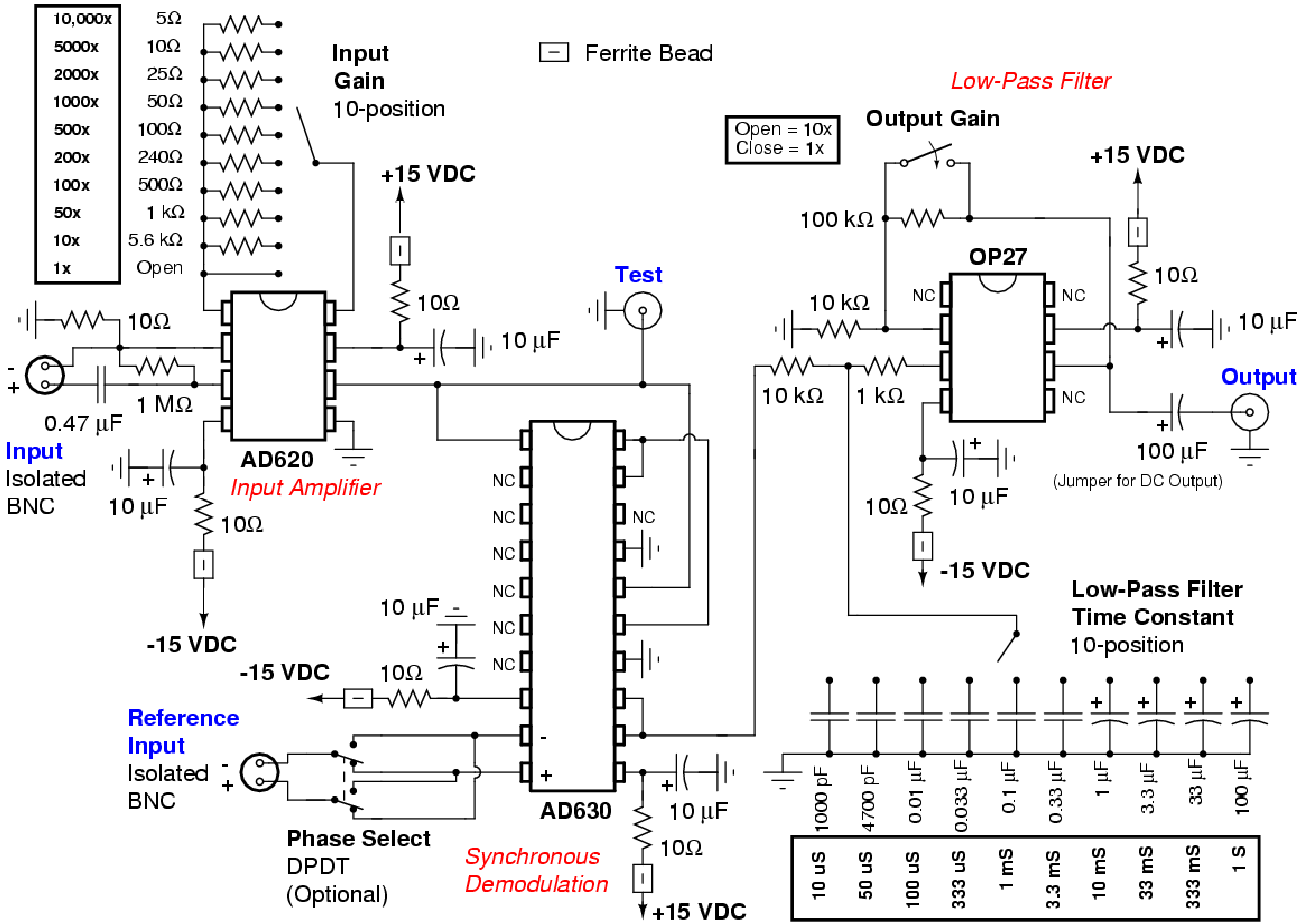
Figure 5: The output V_o is determined by multiplying the signal and the reference wave.

Home Brew Lock-in Amplifier

- Four Parts:

1. Input Amplifier (AD620)
2. Mixer (AD630)
3. Low Pass Filter (Single Pole)
4. Output Amplifier (OP 27)

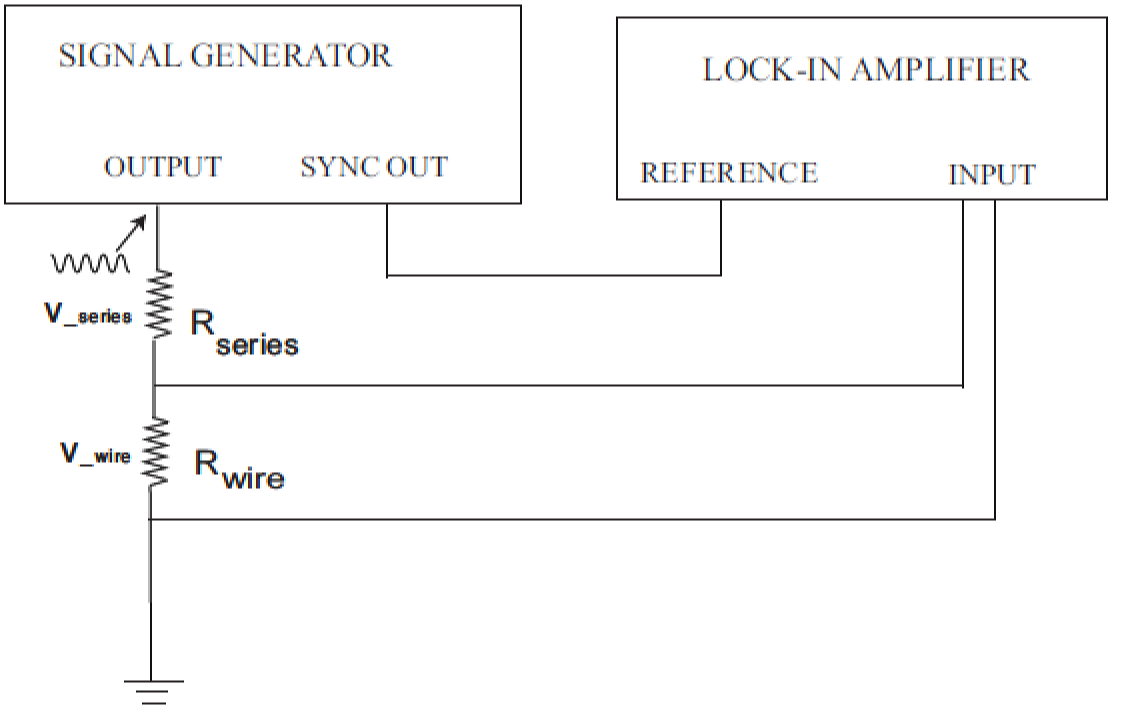
Lock-In Amplifier

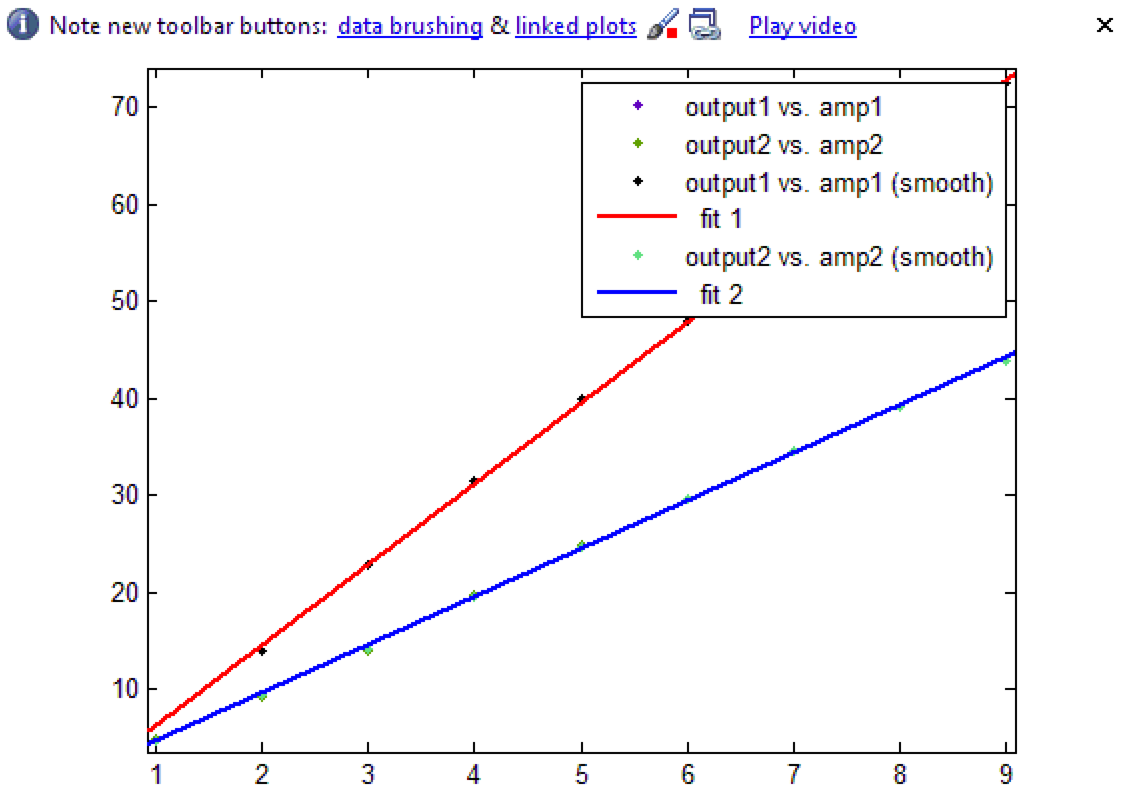


Noise and Other Terms

- Many types of noise but we have restricted ourselves to White Noise and 1/f noise.
- Inherent Worst noise figure of 75.83μV.
- Dynamic Reserve= Ratio of Overload level of noise to full scale input signal
- SNR:Signal to Noise Ratio
- 1MHz unity gain bandwidth of AD620

- Measurement of resistance of a wire





Y-axis: Voltage drop across wire in mV.

X-axis: Amplitude of Source

- Commercial:22.3mOhm
- Homebrew:14m Ohm
- Erroneous Results.

Malus's Law Verification

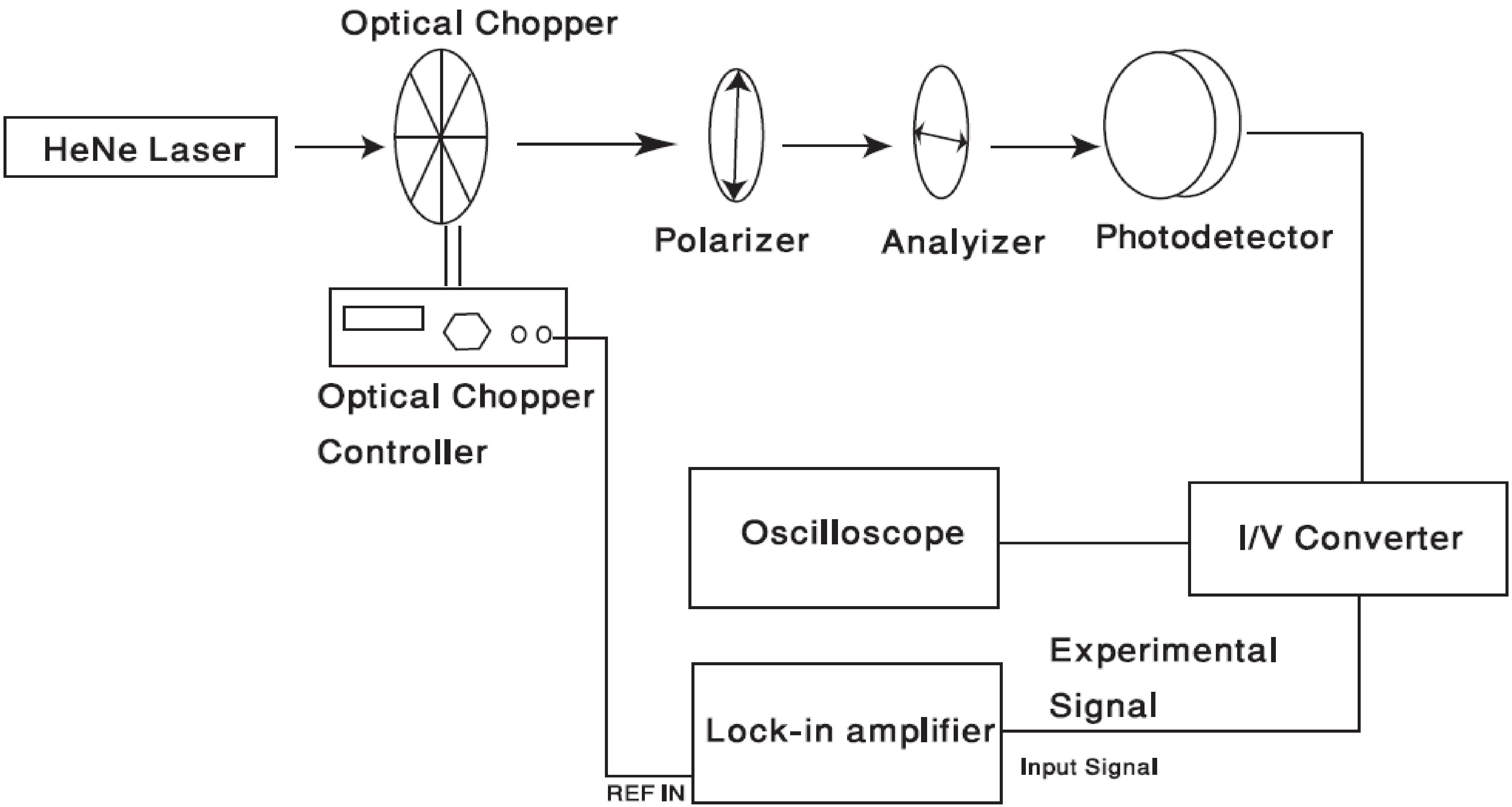


Figure 6: Weak Signal Measurement.

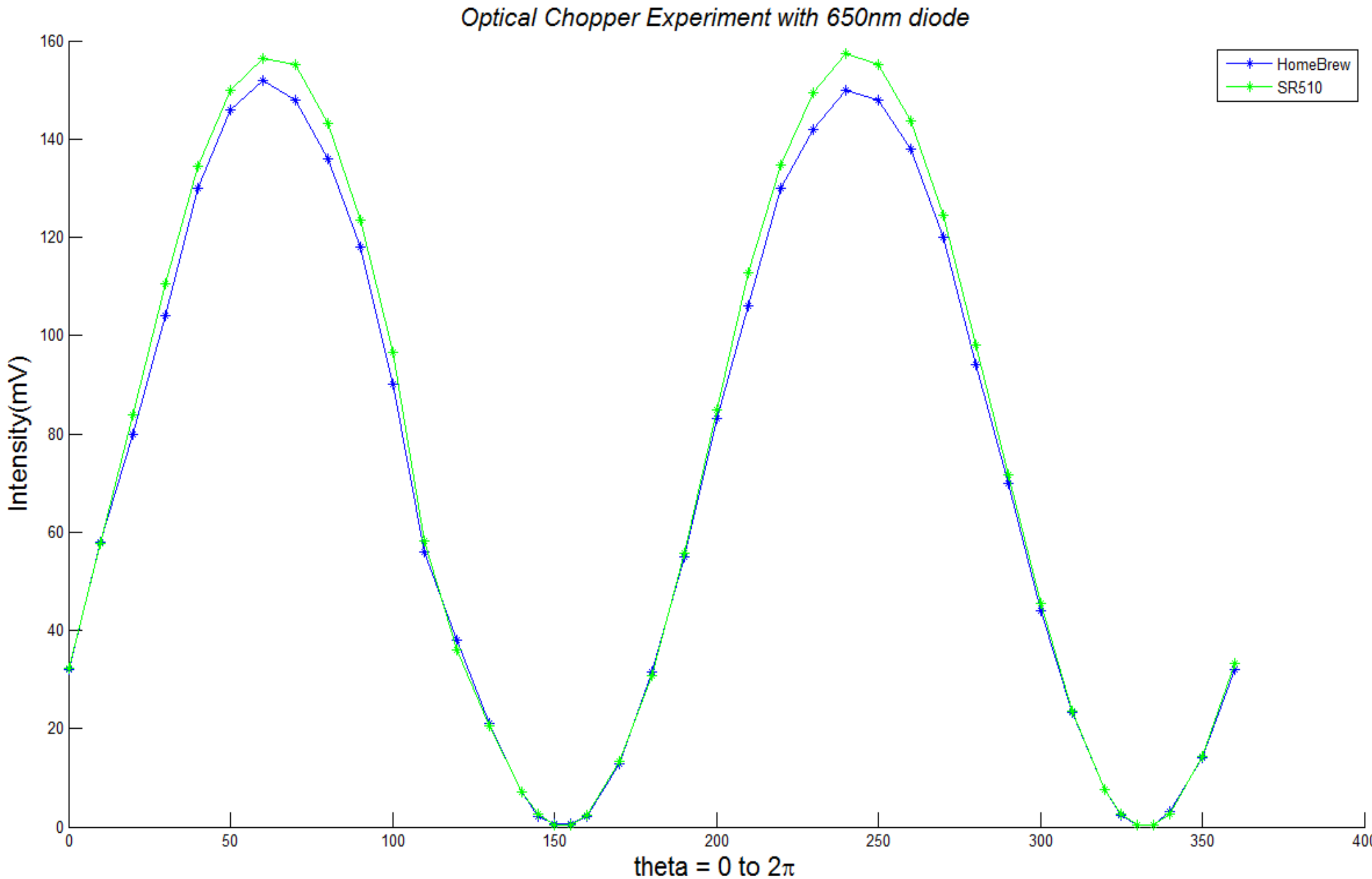
- Main Test was Malus's law which states :
- **According to malus, when completely plane polarized light is incident on the analyzer, the intensity I of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer.** i.e $I \propto \cos^2\theta$

Results

- Large Deviation from the Commercial Lock-ins.
- Cursory measurements to be avoided.
- Further Testing required.
- Improvements like PLL, dual phase,phase shifter etc. can be made.

- This year, with some little tweaks, better results have been obtained.

Verification of Malus's Law



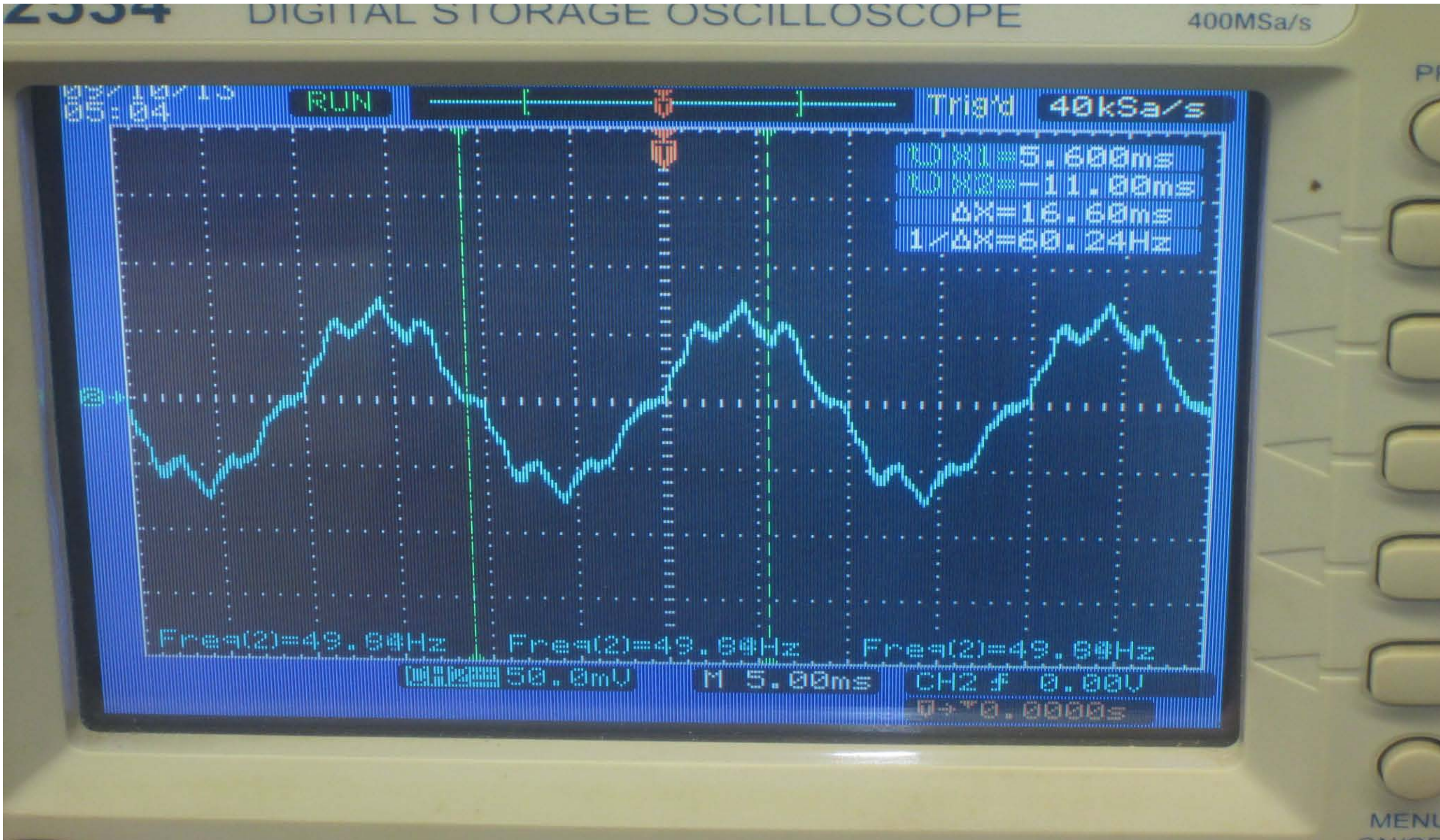
Two Main Problems

- Line Hum reduction
- Proper reading of photodiode output through trans-impedance Amplifier

Week 1

- Observed a 100mV amplitude 50Hz wave at input even though the circuit was powered off

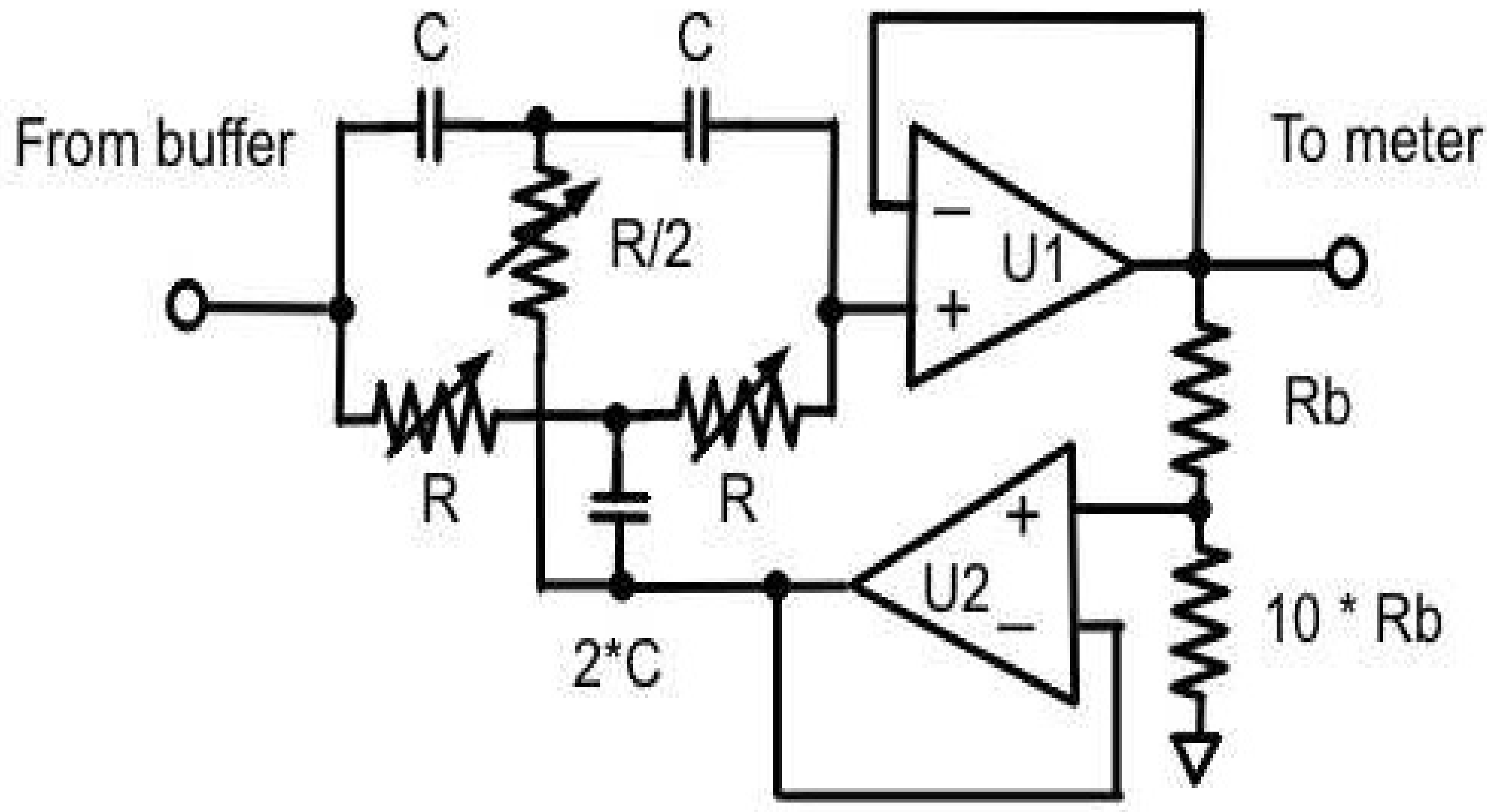
Hum


DIGITAL STORAGE OSCILLOSCOPE
400MSa/s
RUN
Trig'd
40kSa/s
X1=5.600ms
X2=-11.00ms
ΔX=16.60ms
1/ΔX=60.24Hz
Freq(2)=49.84Hz
50.0mV
M 5.00ms
CH2 ƒ 0.00V
0.0000s
MENU

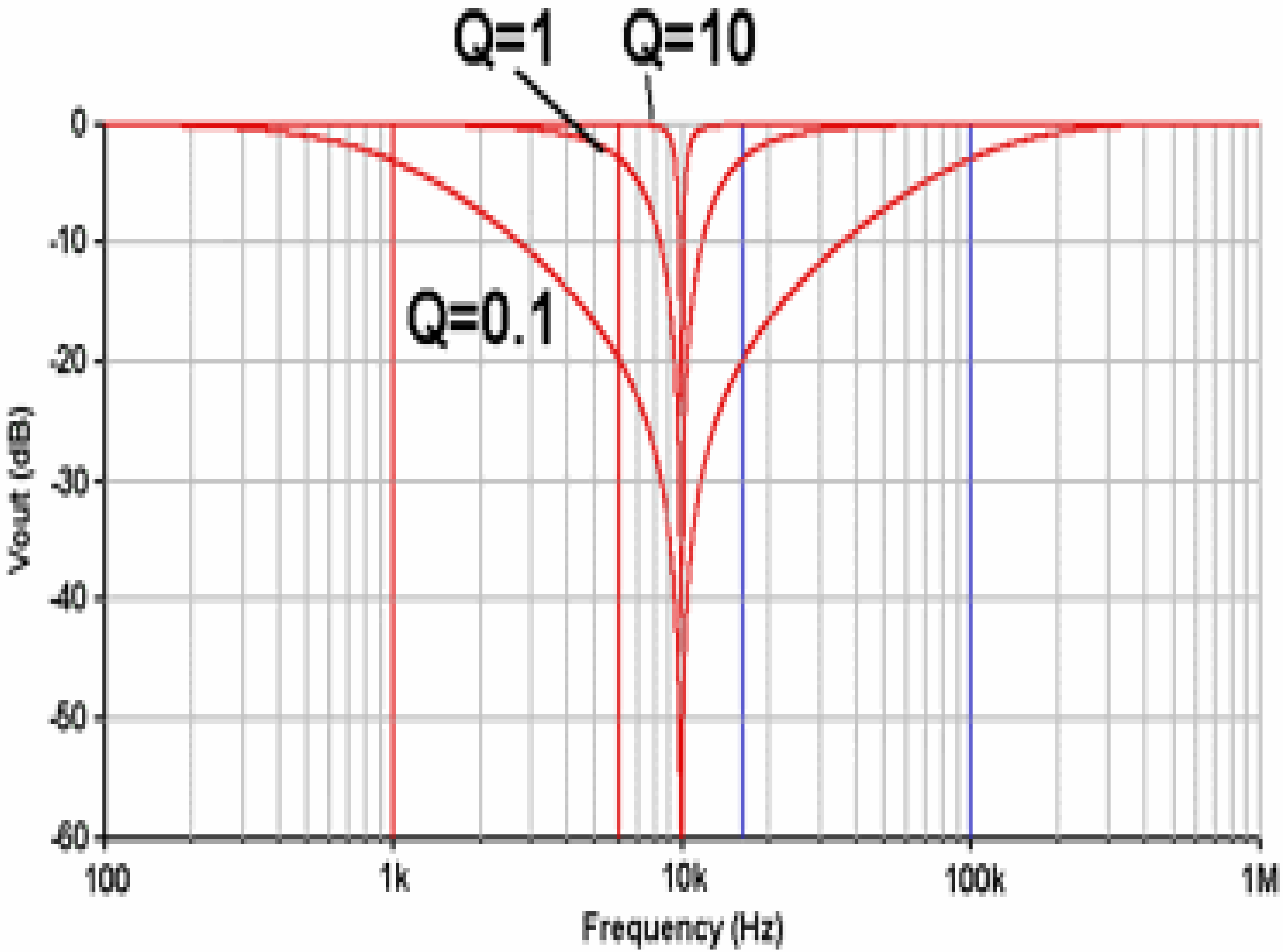
- Natural Option to deal with it was a notch filter
- But Notch are RLC filters, and inductors must be avoided in precision circuits.
- An inductor-less notch is a ‘twin-tee’ notch.

Twin-T active notch filter

$$f = \frac{1}{2\,\mathrm{Pi}\,R\,C}$$



- Recursive Problem: We need a high Q ‘Twin-T’ notch to remove hum for building a lock-in amplifier, which is itself a very-high-Q notch.
- Line-in option in SR510 for hum removal.
- Low Q notches were made.(Max. depth of 28.8dB) and using AD620 as op-amp instead of UA741 for high precision.
- Bandwidth was very high(of the order of 100kHz)
- Q=w/B.W


Q=1
Q=10
Q=0.1
0
-10
-20
-30
-40
-50
-60
Vout (dB)
100
1k
10k
100k
1M
Frequency (Hz)

- The AD630 data sheet mentions recovering 50uV of signal from 100dB of noise(5V).
- So I tried this circuit:

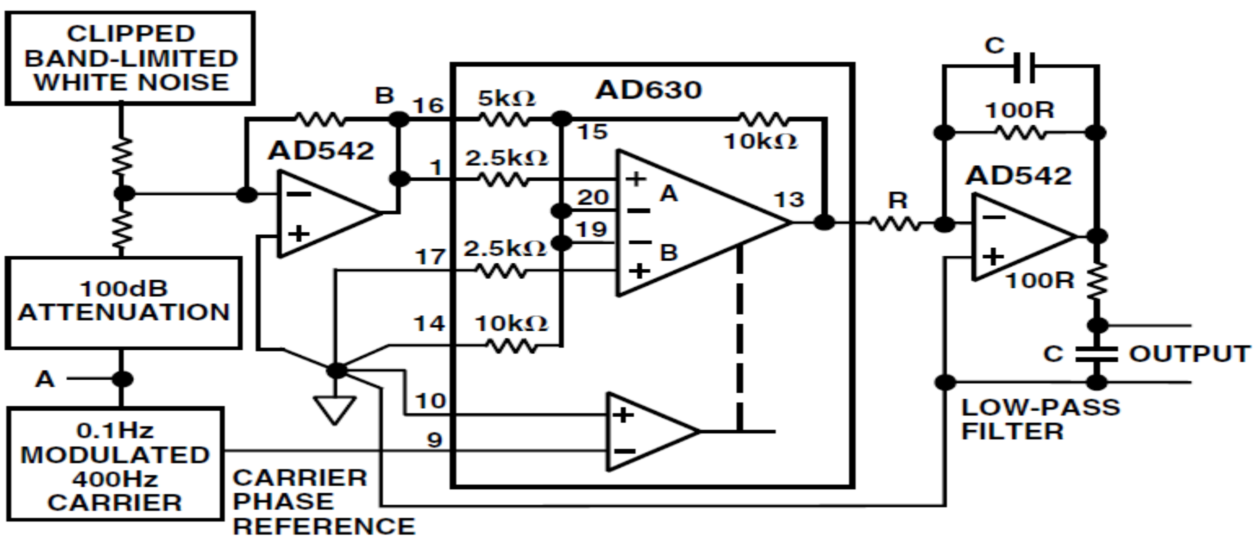


Figure 14. Lock-In Amplifier

- Maybe the AD630 would take care of hum itself and I won't have to AC amplify the signal.
- But there was another problem with my measurement of photodiode output.
- I was also exploring the option of shielding.

Week 2

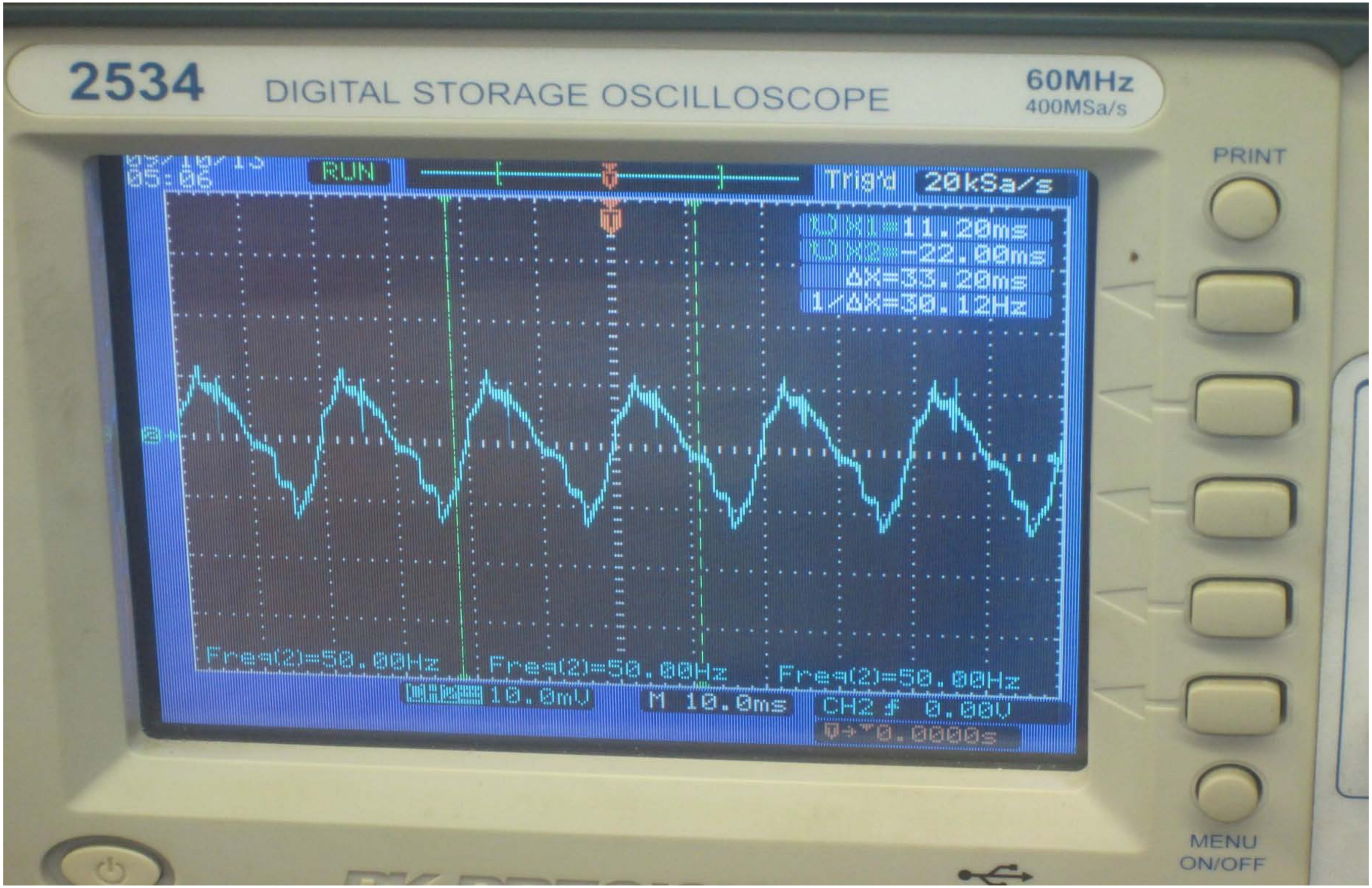
- Stray thoughts on the reasons for wrong results of Optical Chopper experiments, overloading, non-linearity, PLL?
- Put the circuit in an Al-foil enclosed box. Hum was reduced but still observed funny effects. The Al-foil was not grounded.

Al Foil

An Eid spent in the Car

- Jana, Eid par aana, phir ghar jana, phir wapis Lahore Aana.
- Talked to some experts, they told me to ground the foil.

Hum with Al shielding



Ground the Foil at various Points to ensure uniform grounding

Week 3

- Read more upon noise removal and proper grounding.
- Rarely Asked Questions on Bread boarding.
- Basic Principle of Noise Reduction:
- COPPER IS NOT A SUPERCONDUCTOR

CAPACITANCE

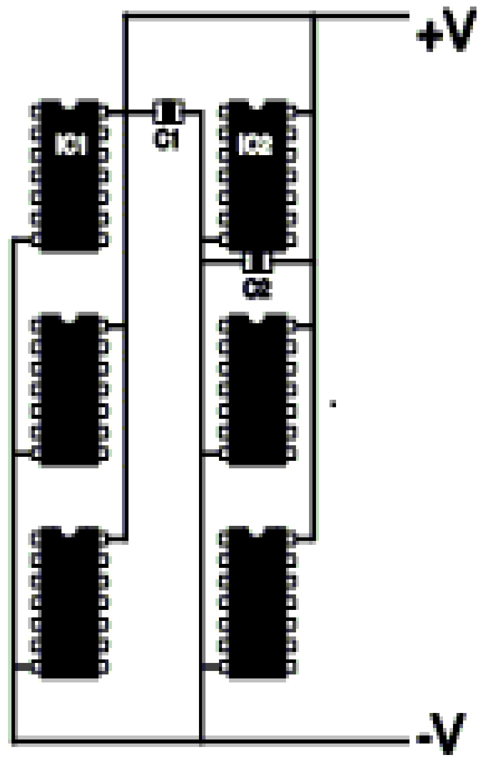
Wherever two conductors are separated by a dielectric (including air or a vacuum) there is capacitance.

For a parallel plate capacitor $C = {}^{.0885 E_r A}/_{d}$ pF

where A is the plate area in sq.cm
d is the plate separation in cm
& E_r is the dielectric constant

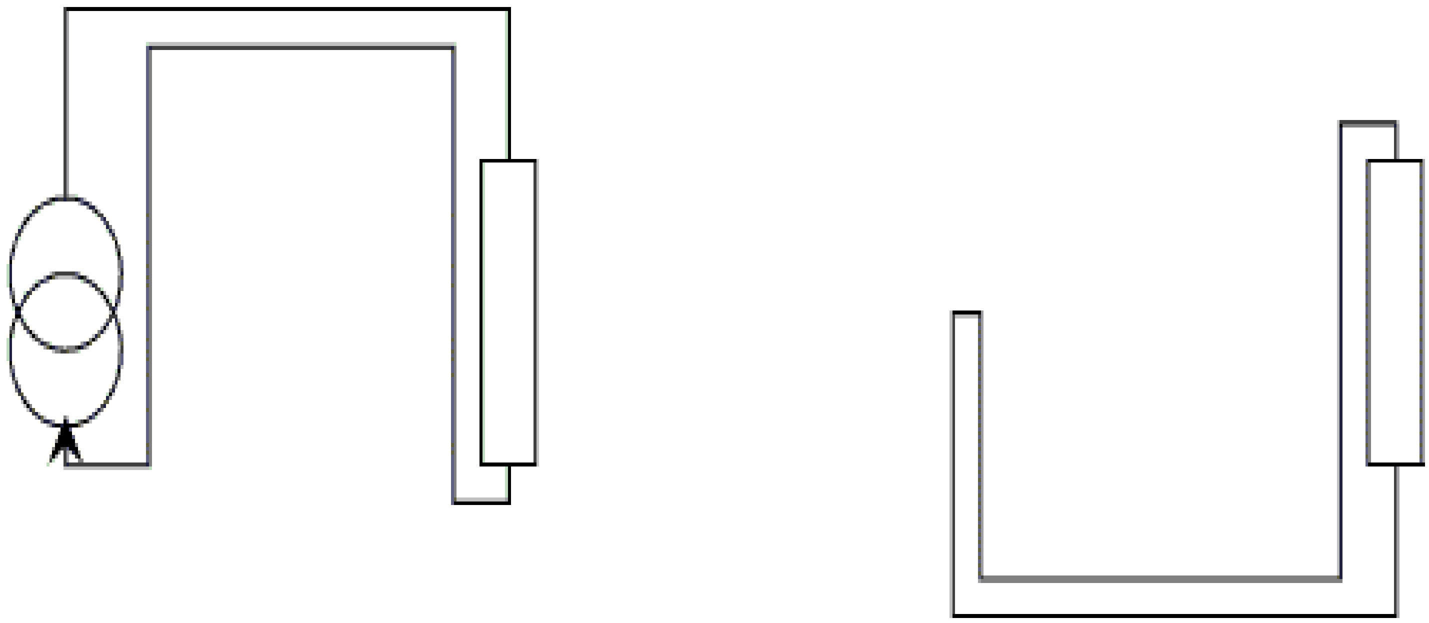
Epoxy PCB material is often 1.5 mm thick and E_r =4.7
Capacity is therefore approximately 2.8 pf/sq.cm

CAPACITOR LEADS MUST BE SHORT



Although the leads of C1 are short the HF decoupling path of IC1 is far too long.
The decoupling path of IC2 is ideal.

INDUCTANCE



Inductance is reduced by reducing loop area - mutual inductance is reduced by reducing loop area and increasing separation.

Since the magnetic fields around coils are dipole fields they attenuate with the *cube* of the distance - so increasing separation is a very effective way of reducing mutual inductance.

OBEY THE LAW

Unexpected behaviour of analog circuitry is almost always due to the designer overlooking one of the basic laws of electronics. Remember and obey Ohm, Faraday, Lenz, Maxwell, Kirchoff

and MURPHY.

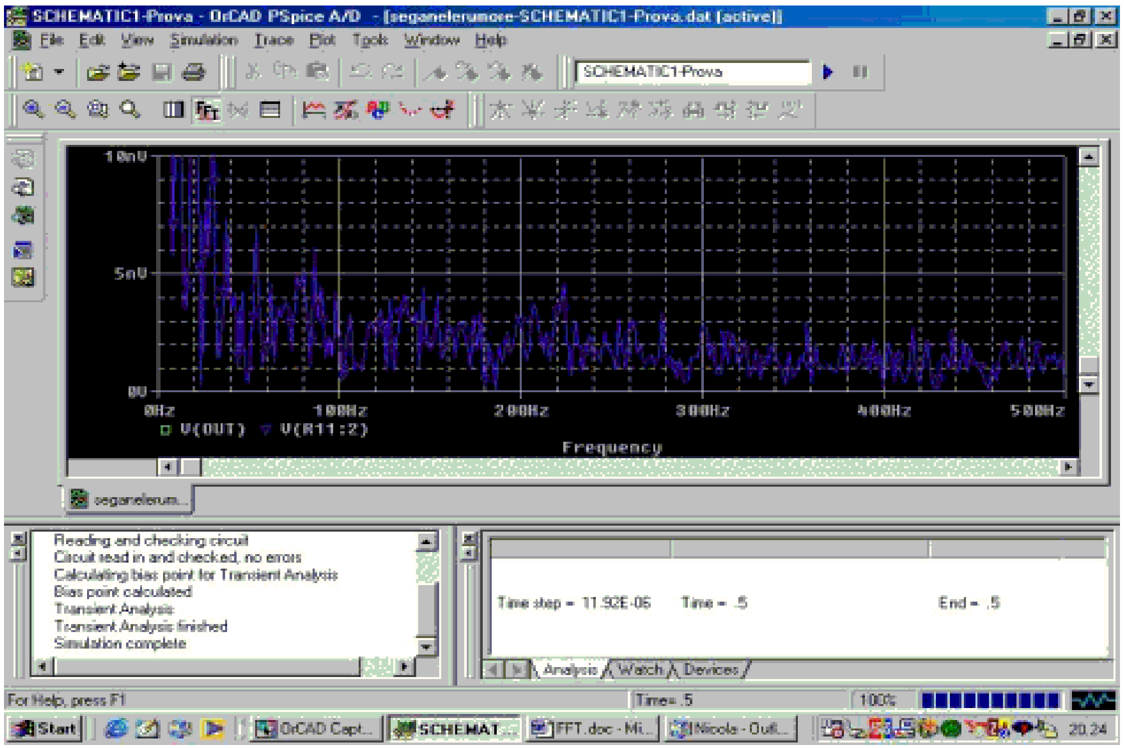
- Grounding the foil reduced Hum to 2-3mV from 50mV.
- Twisting cables are better than straight ones.
- Differential Input: Required or not.

Weekend

- Met Prof. Shameeem: Says that life is a tragedy, we will never know the truth and will die hunting for it.(So is the case of Noise with precision circuits).

Week 4

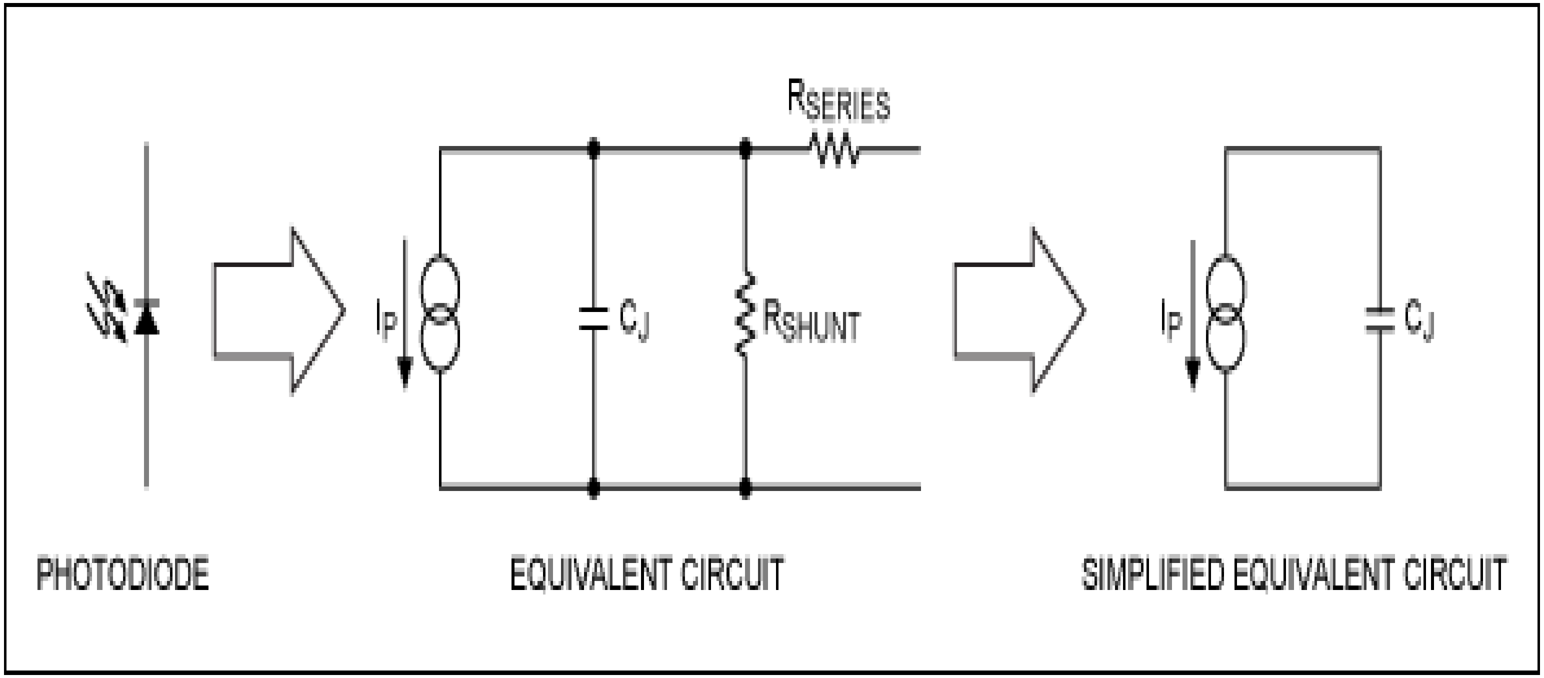
- Studied AD630 in more detail, resistors reducing input bias current, frequency compensation.
- Saw other works using Ad630 as a lock-in.
- Realised all of them were working on mV scale, not uV.
- Accurate voltage readings till 1mV with simple voltage dividers.
- In one project, PSPICE simulation could provide maximum SNR of 45dB, instead of the data sheet’s 100dB.
- Zeroing the phase of SR510.

Vin Vpp	Vnoise $\frac{Veff^2}{Hz}(1Khz)$	Sign/Noise $\frac{S}{N}(dB)$	GAmp $20Log\left(1+\left(\frac{R_2}{R_1}\right)\right)$	Demod.	Simulazione: Red=Input 100 Hz Green=Out Demodulated
0.01V	1.90 $\frac{Veff^2}{Hz}(1Khz)$	-45 dB	46 dB	No	
					

The Pspice© simulation given some important result, we can't confirm the Analog Device result obtained at 1 Khz but we could be satisfy for our -45 dB ($\frac{S}{N}(dB)$) a 100 Hz.

Week 5

- Trans-Impedance Amplifier
- Photo Diode Model:



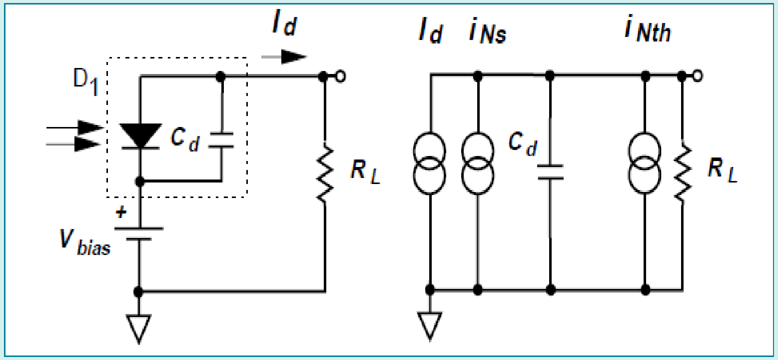


Figure 1. The world's simplest front end: a load resistor.

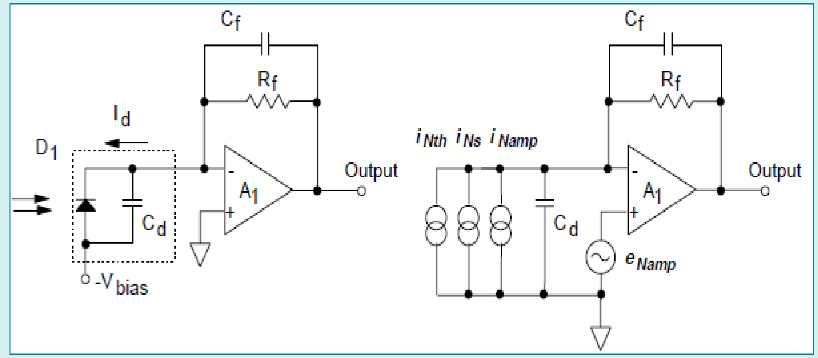


Figure 3. Transimpedance amplifier schematic and noise model.

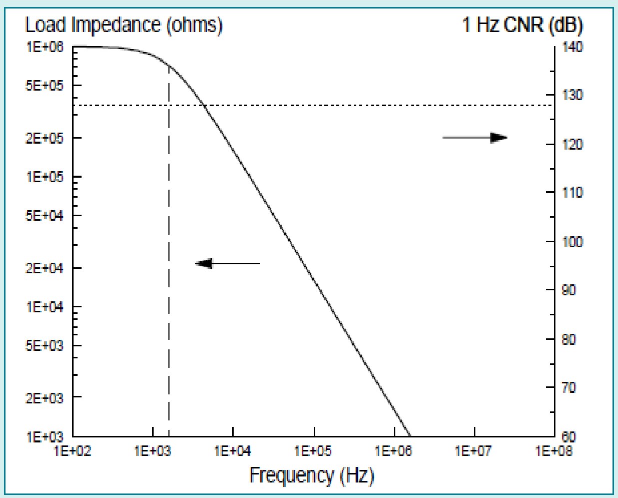


Figure 2. Photodiode/load resistor circuit: frequency response and 1 Hz SNR.

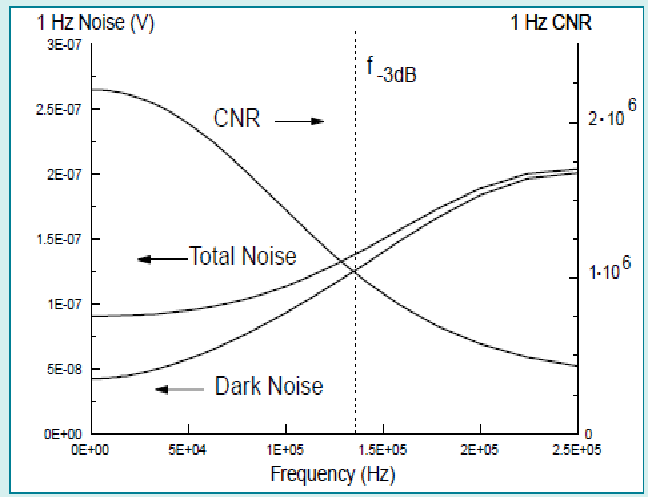
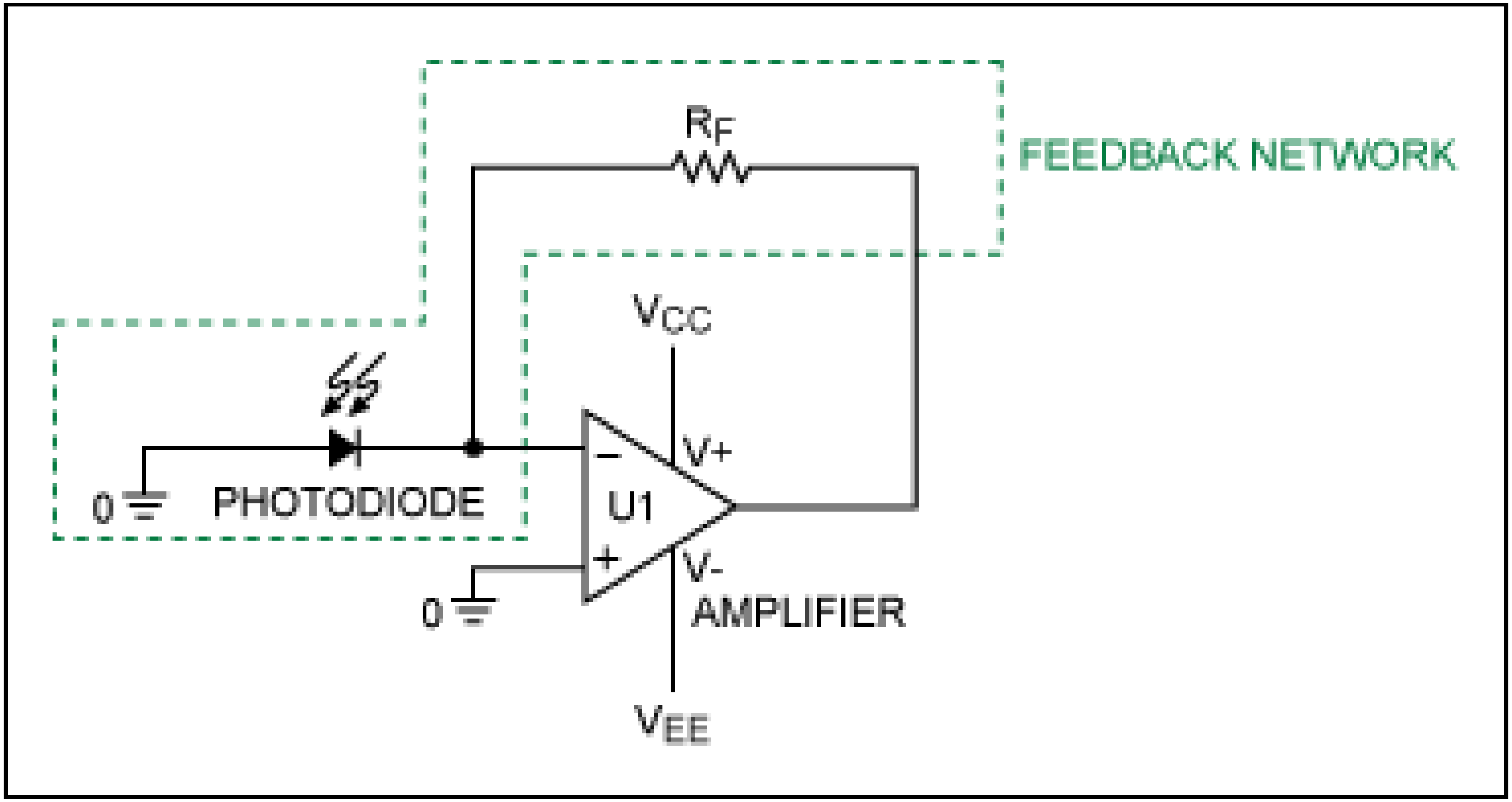


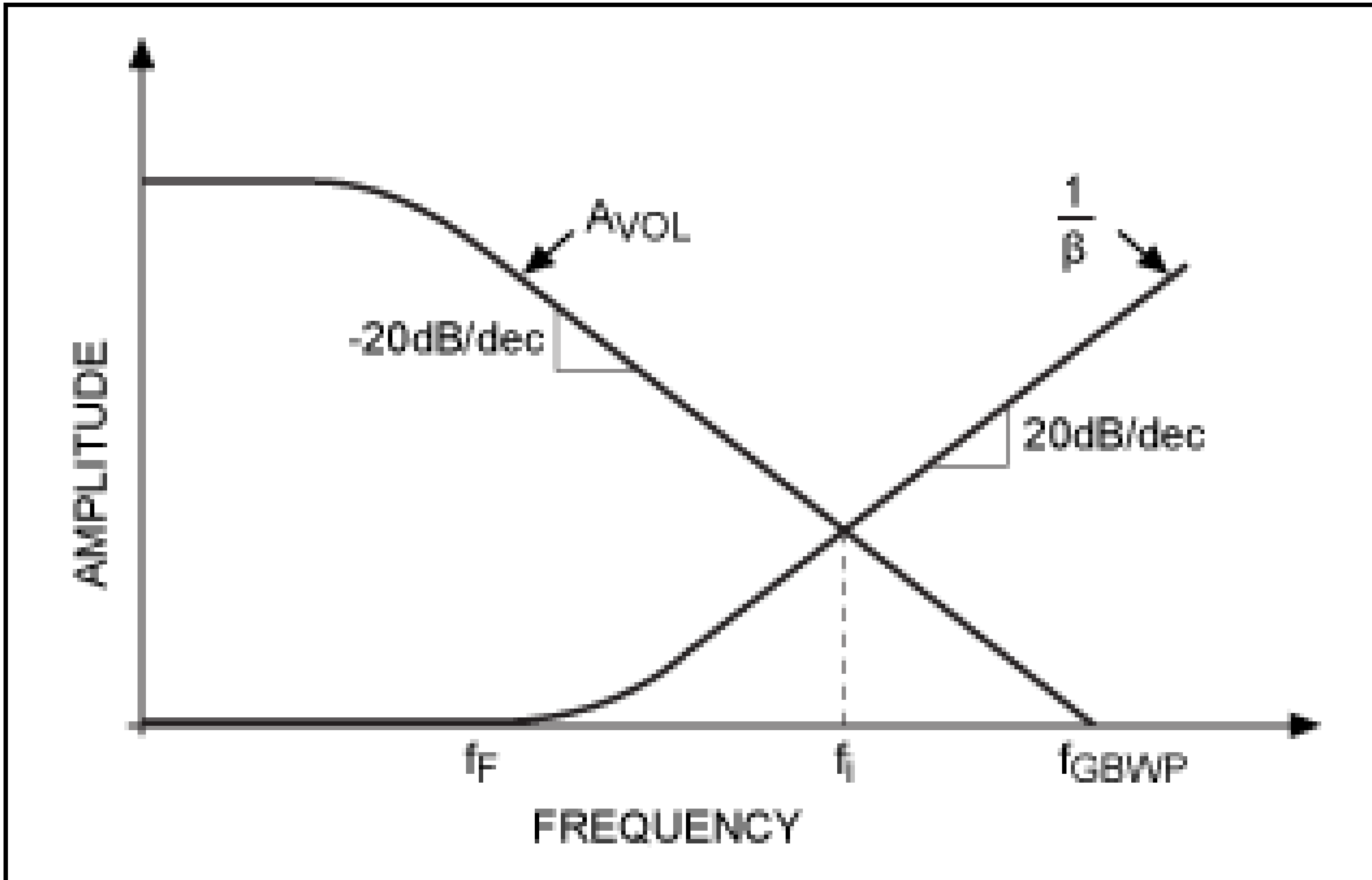
Figure 4. Noise performance of the transimpedance amplifier of Fig. 3, showing the dominance of e_{NAmp} at high frequency. A_1 is an LF356, R_f=100kΩ, C_f=0.5 pF.

Basic Trans-Impedance Amplifier

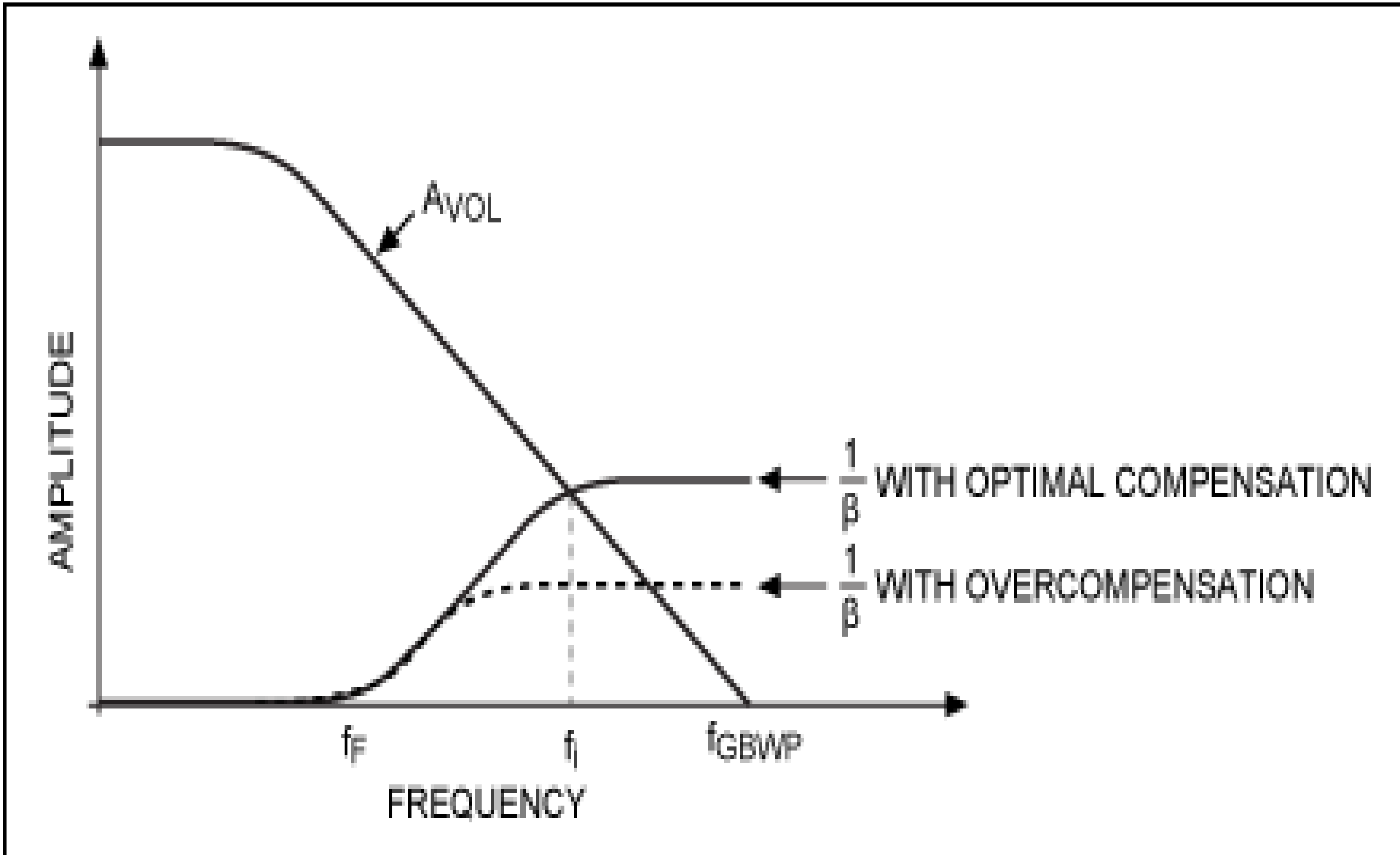
- Gain is equal to Rf (V/A or Ohm)



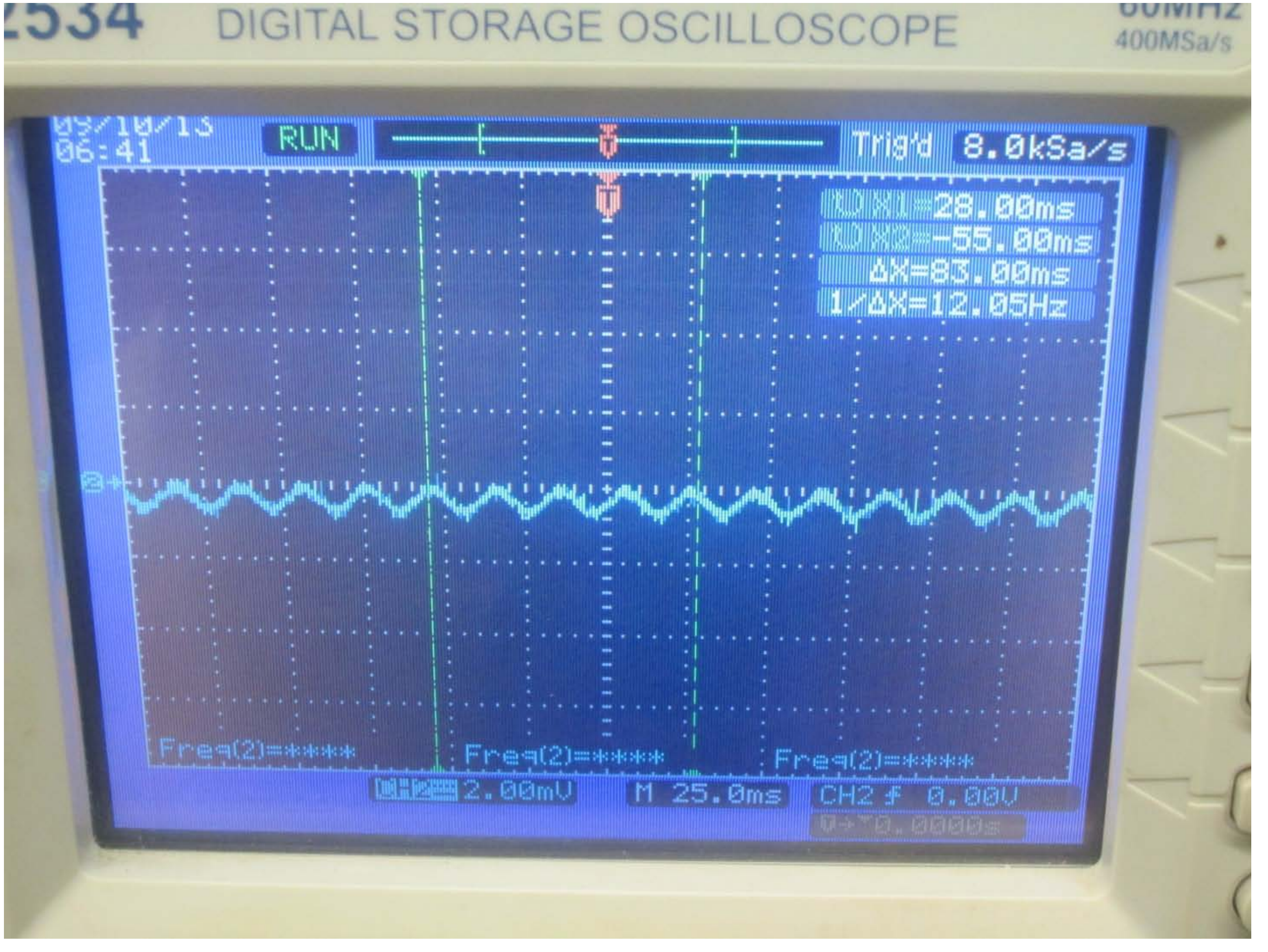
Barkhausen stability criterion



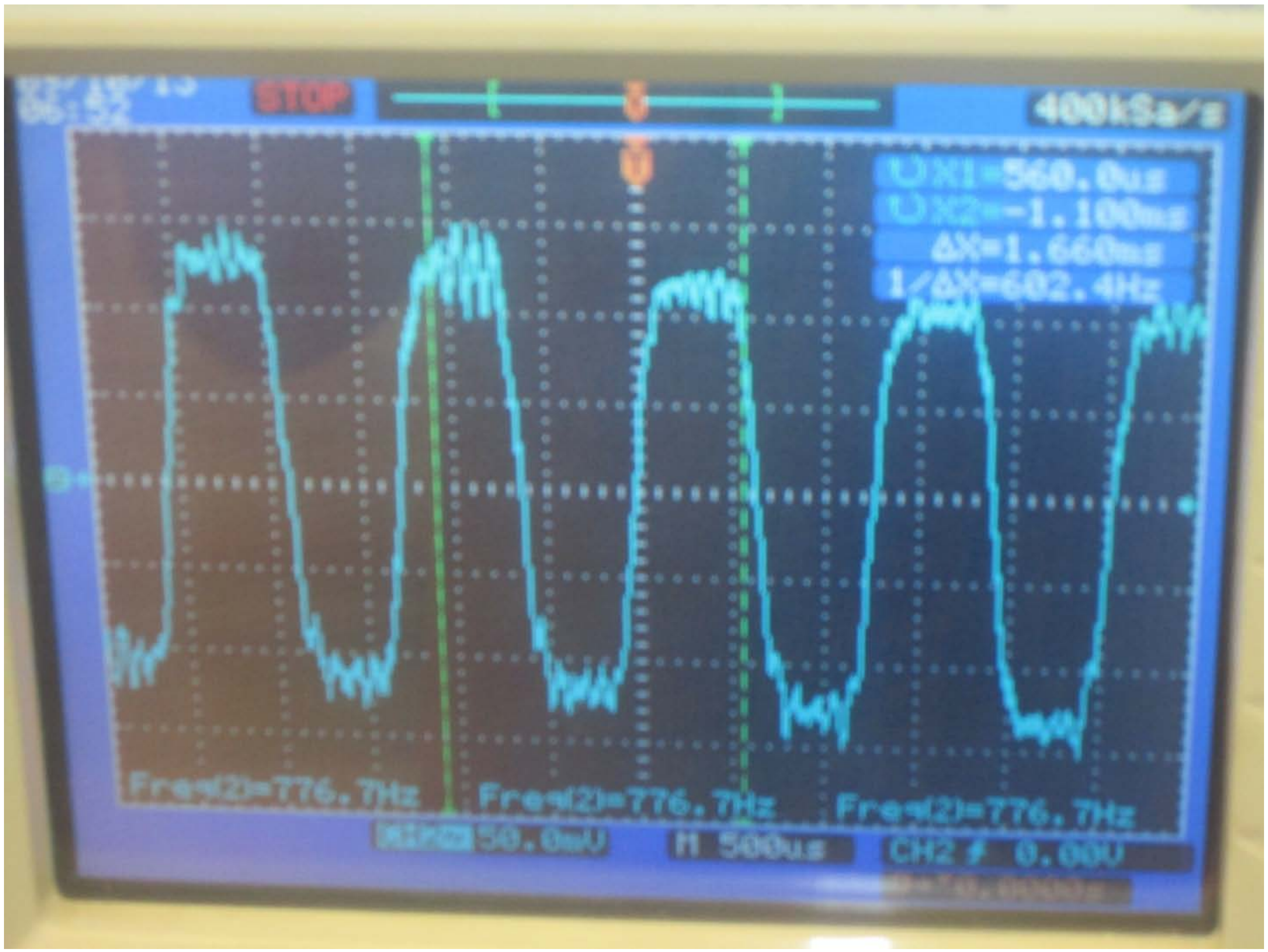
Compensation Feedback Capacitor



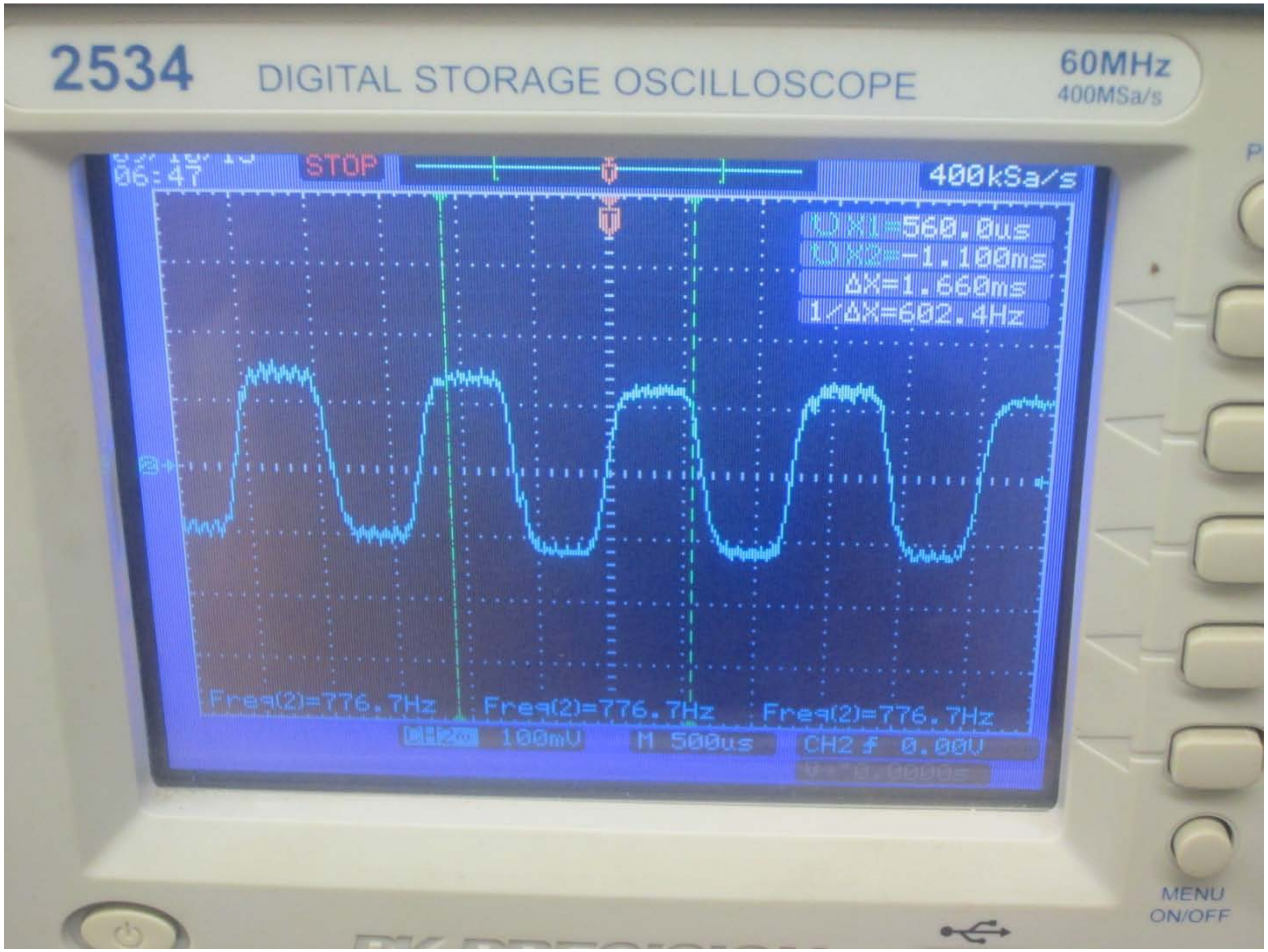
Directly Connecting Photodiode output to Oscilloscope



Ringing and Oscillation

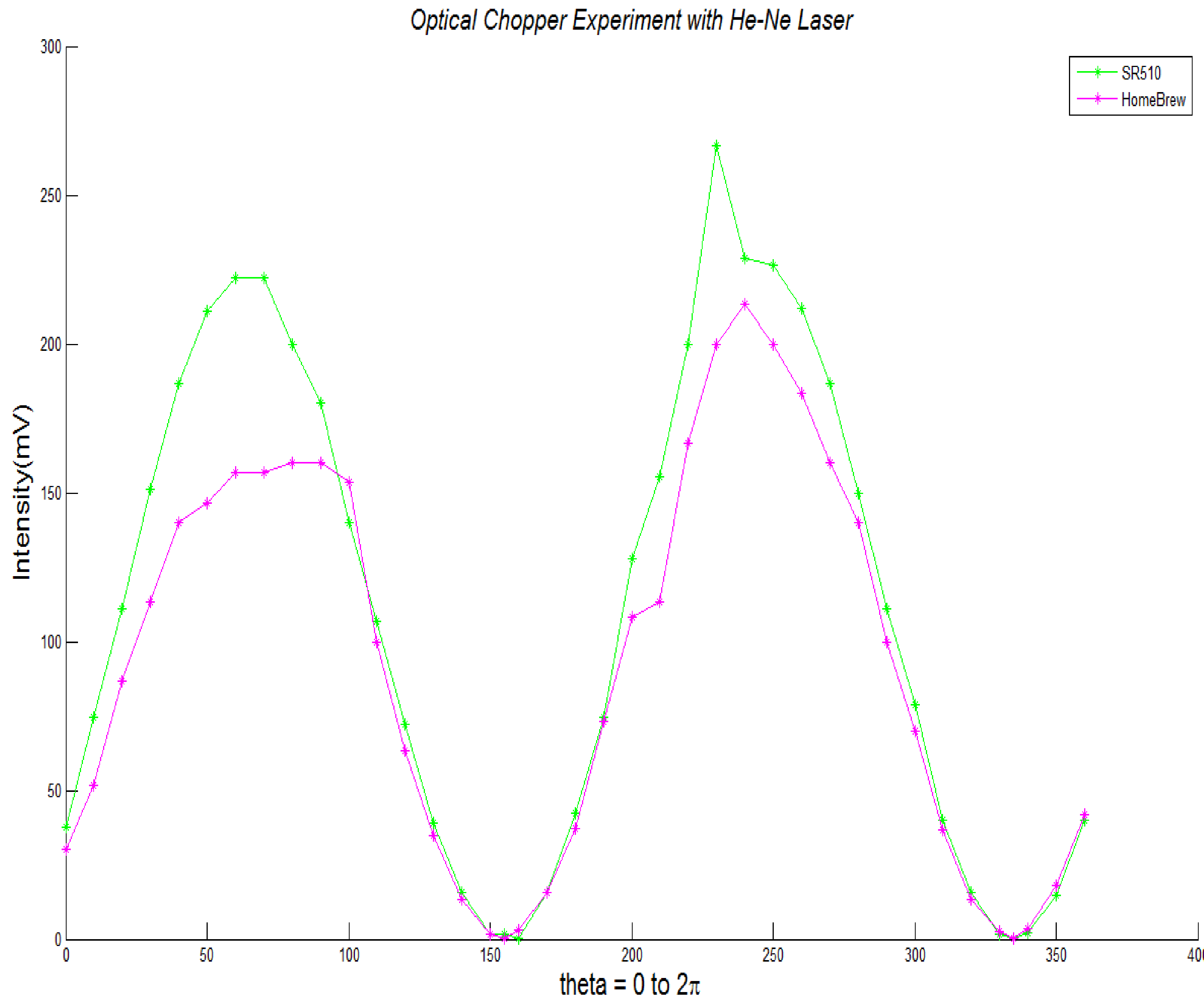


After adding feedback capacitor



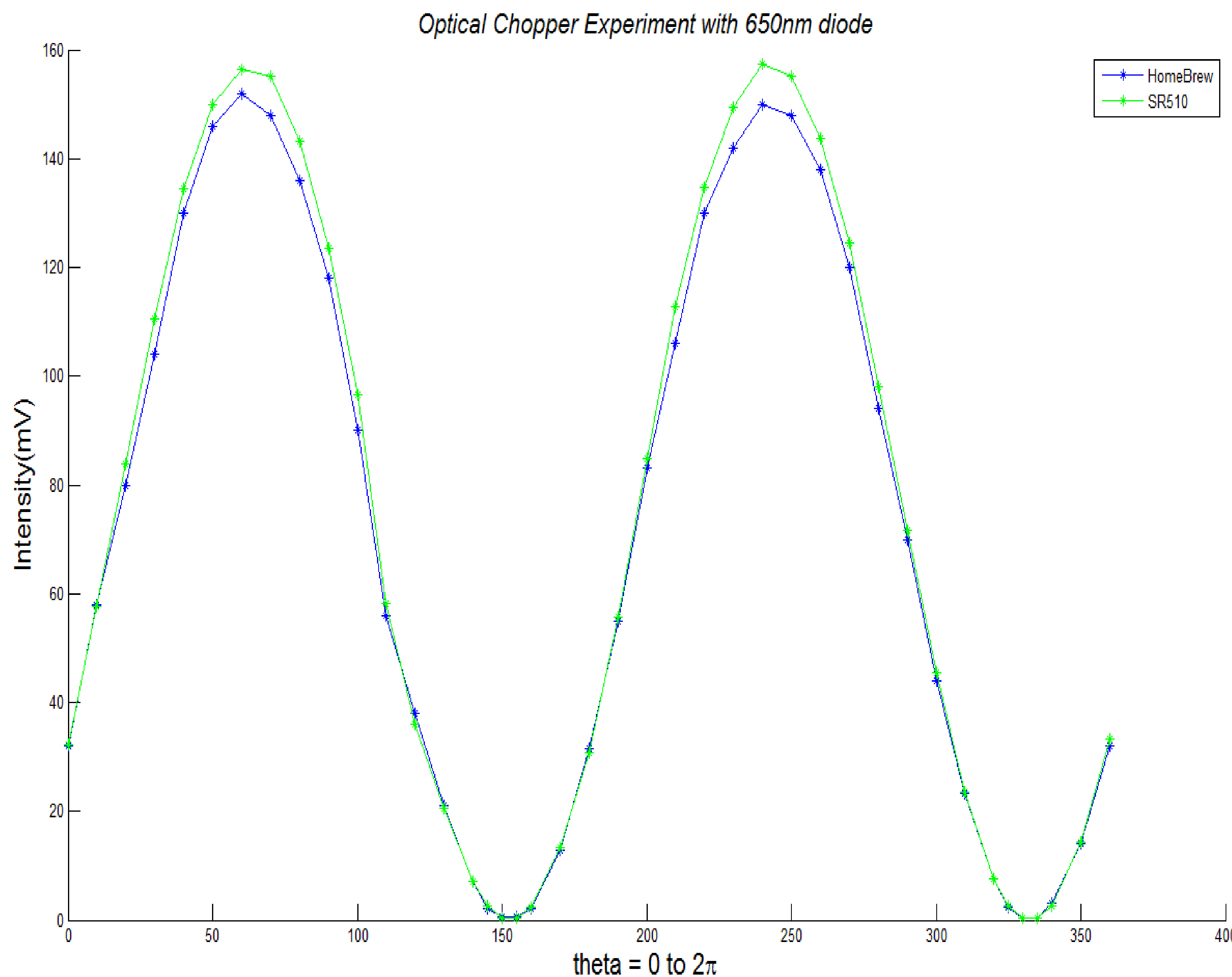
Results

- The 4mW He-Ne Laser was used first. The results were a bit eerie owing to the unstable output of the Laser.

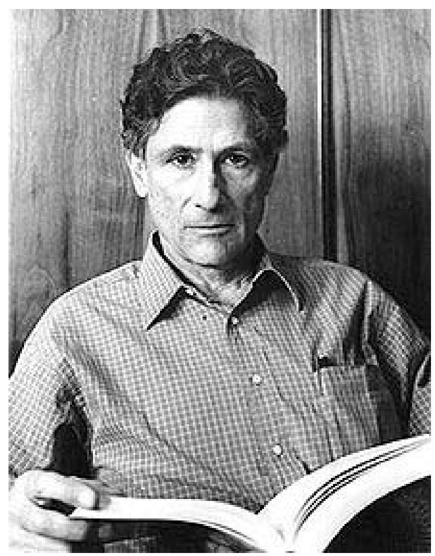


Optical Chopper Experiment with He-Ne Laser
SR510
HomeBrew
Intensity(mV)
theta = 0 to 2π
0
50
100
150
200
250
300
350
400

- Then tested with 650nm laser diode which has more stable output.
- Results are pretty good and the readings match with a maximum difference of 5mV at the peak of the curve.


Optical Chopper Experiment with 650nm diode
Intensity(mV)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
theta = 0 to 2π
HomeBrew
SR510

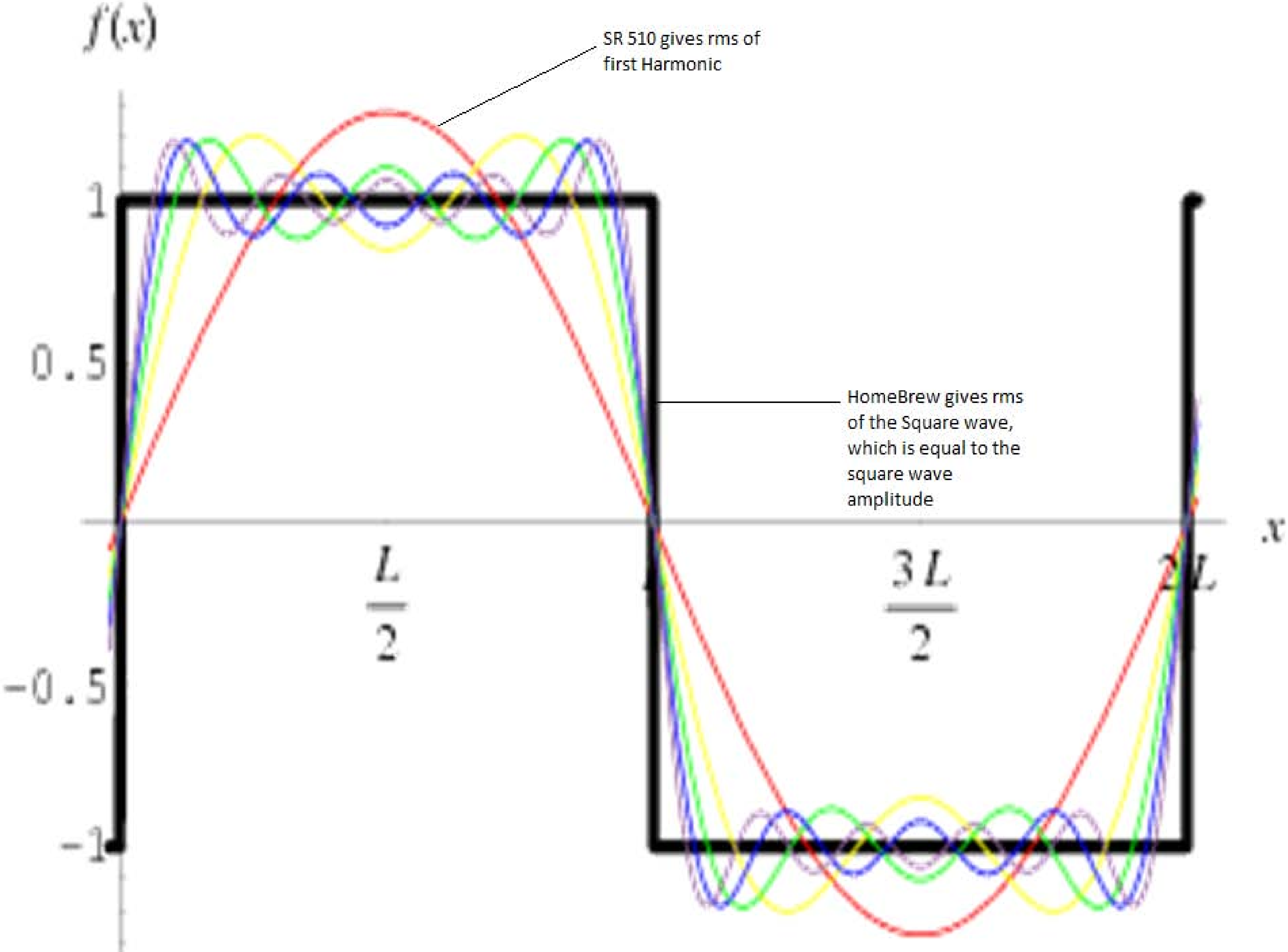
- Started Afsana course: Convinced my mom I wasn't in bad company.
- Too much noisy post-colonialism and Saidian secularism. I can't hear myself!

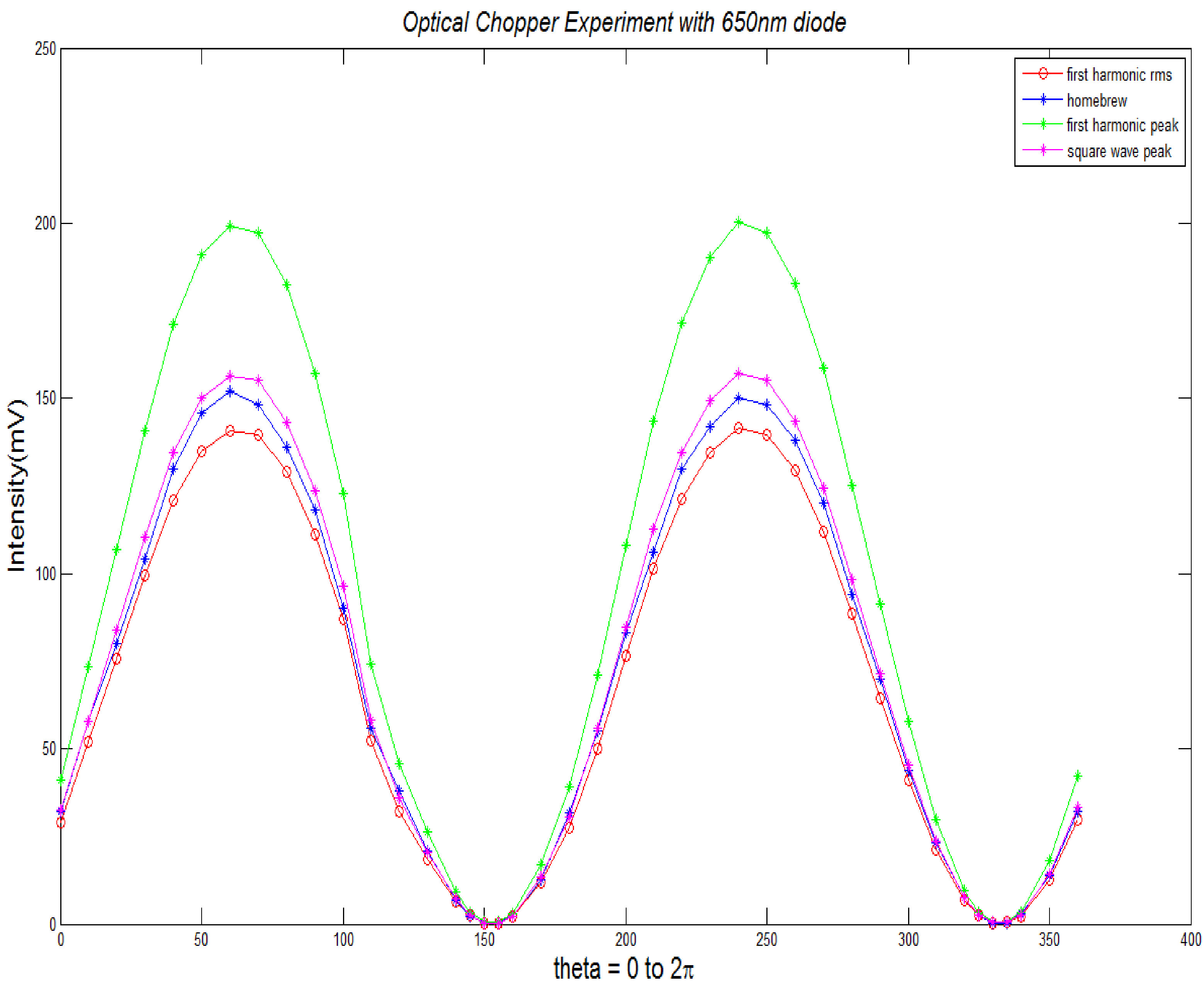


What do the measurements mean?

- Lock-In measures rms value of that component of input signal whose frequency is equal to the reference frequency.
- If input is a square wave of 1KHz, for example, the SR510 would measure the rms value of the first harmonic of the square wave.
- This is accomplished by to sine wave multipliers.
- Walsh demodulator circuits approximate sine-wave multiplication

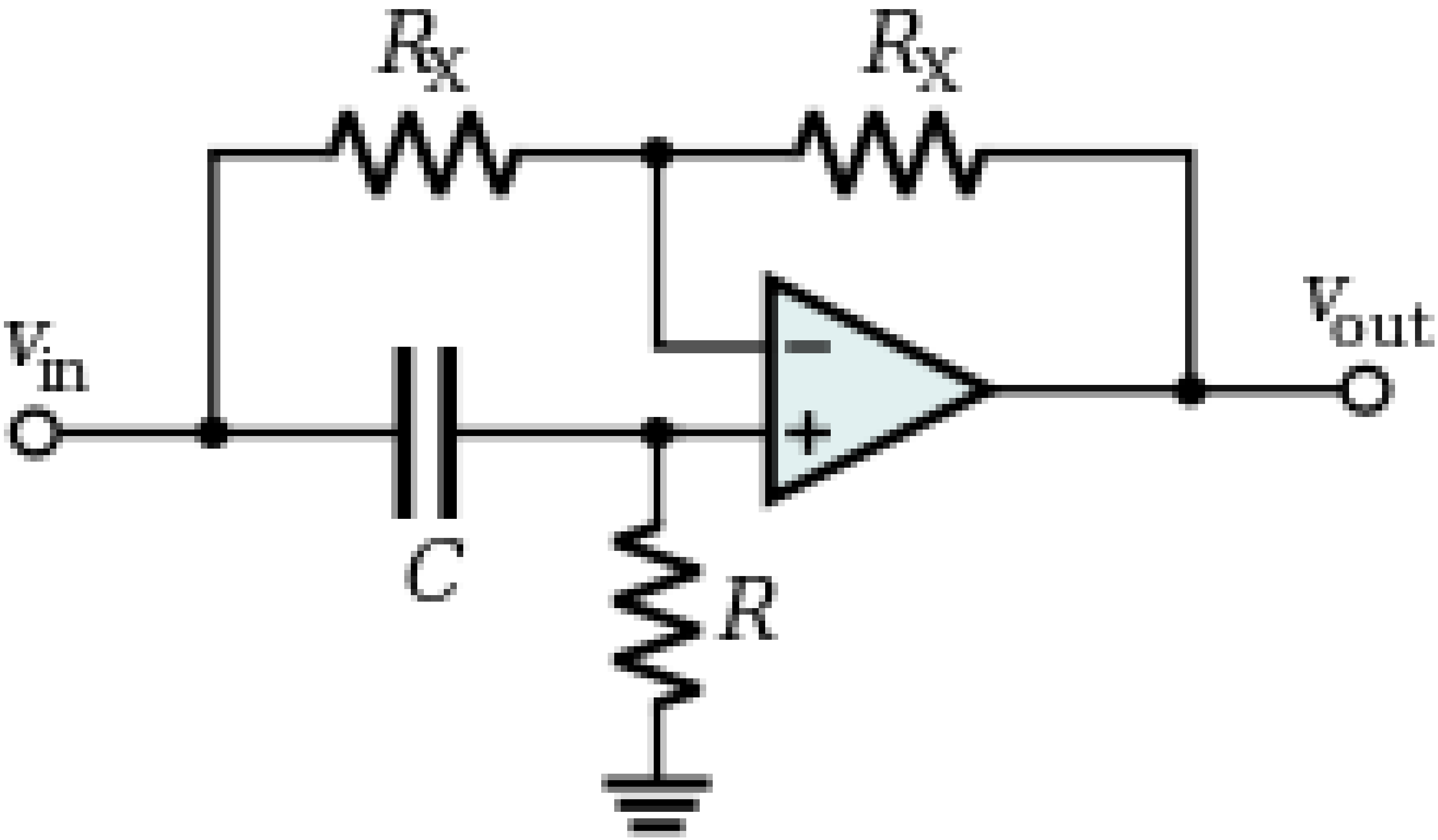
- The home-brew lock-in is a bit old-fashioned.
- It multiplies the input signal with a square wave.
- Thus it multiplies the input signal with all of its harmonics.
- This could generate spurious outputs if a heavy noise component resides at one of the harmonics.


f(x)
SR 510 gives rms of
first Harmonic
1
0.5
HomeBrew gives rms
of the Square wave,
which is equal to the
square wave
amplitude
x
L/2
3L/2
2L
-0.5
-1



Optical Chopper Experiment with 650nm diode
first harmonic rms
homebrew
first harmonic peak
square wave peak
Intensity(mV)
theta = 0 to 2π
0
50
100
150
200
250
0
50
100
150
200
250
300
350
400

Phase Shifter

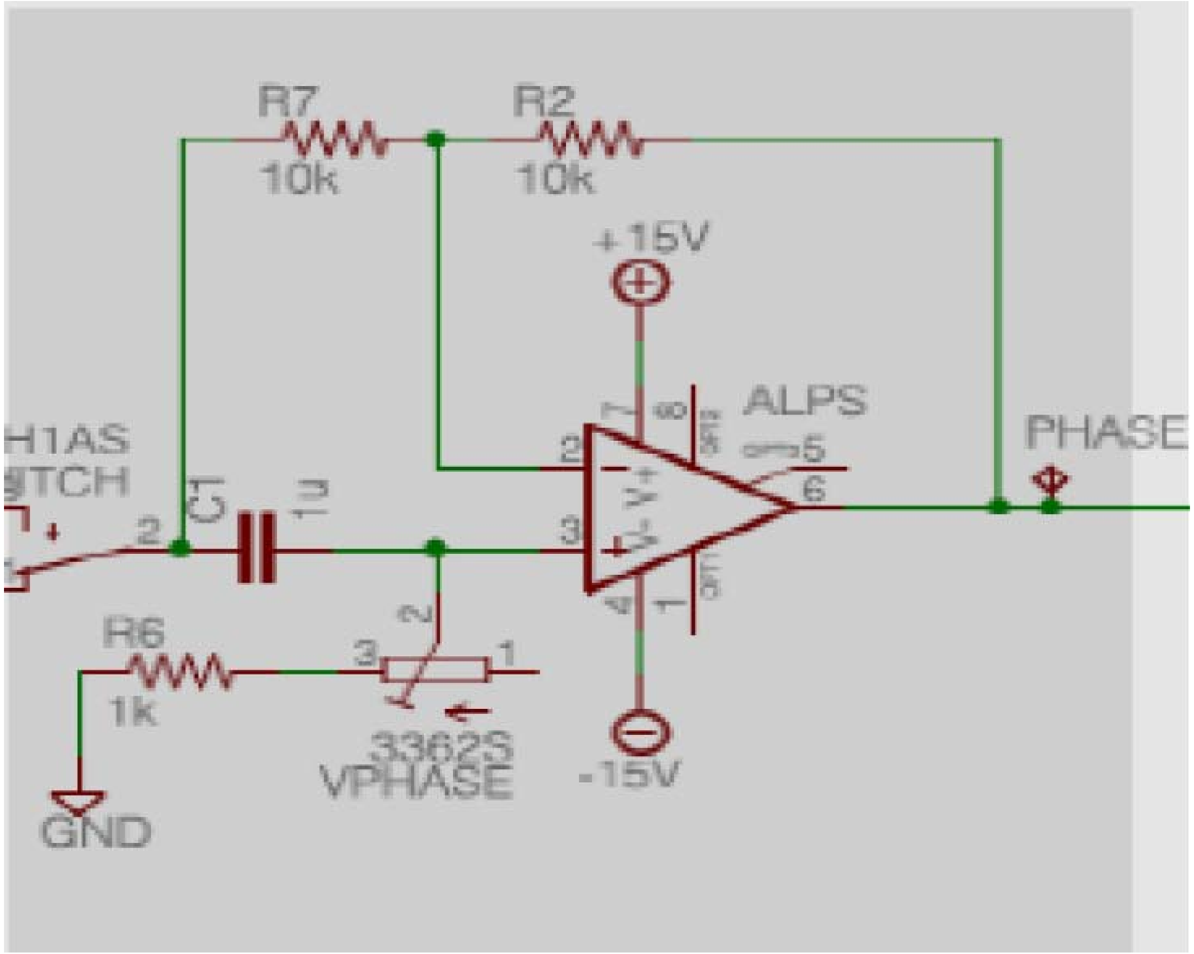


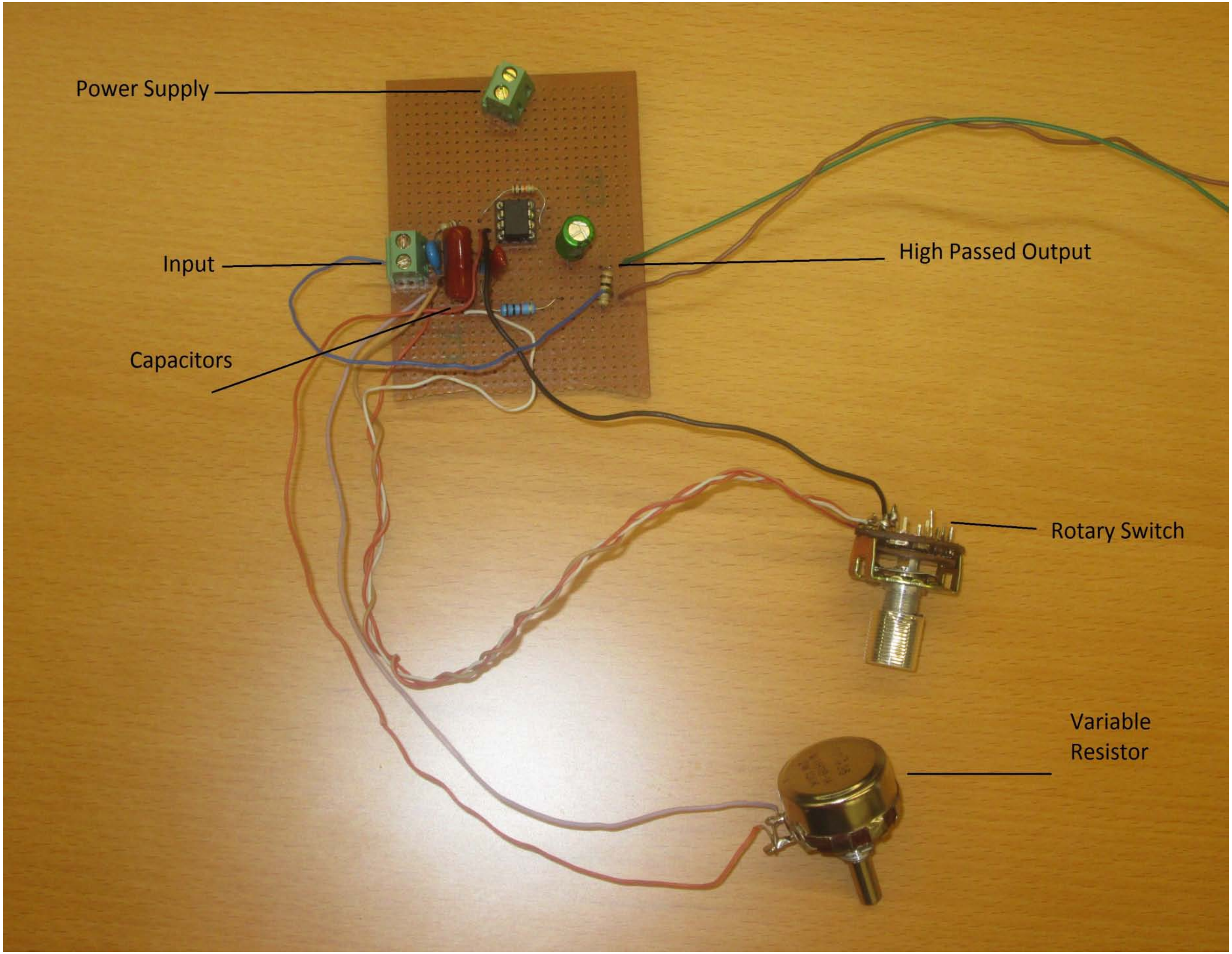
Phase Shifter

- Unity Gain for all frequqncies
- Phase shift= pi-2*arctan(wRC) where w is signal ferquency
- It’s unlike a PLL which keeps a constant phase difference between input and output.
- Can be used in two ways:

1. Vary the phase until DC output goes to maximum
2. Measure the value at one particular phase, and then add a 90 degree shift and then measure the value at that phase. The root of the sum of squares of these values should be equal to maximum value measured by method 1.

Phase Shifter Used in Homebrew Lock-in

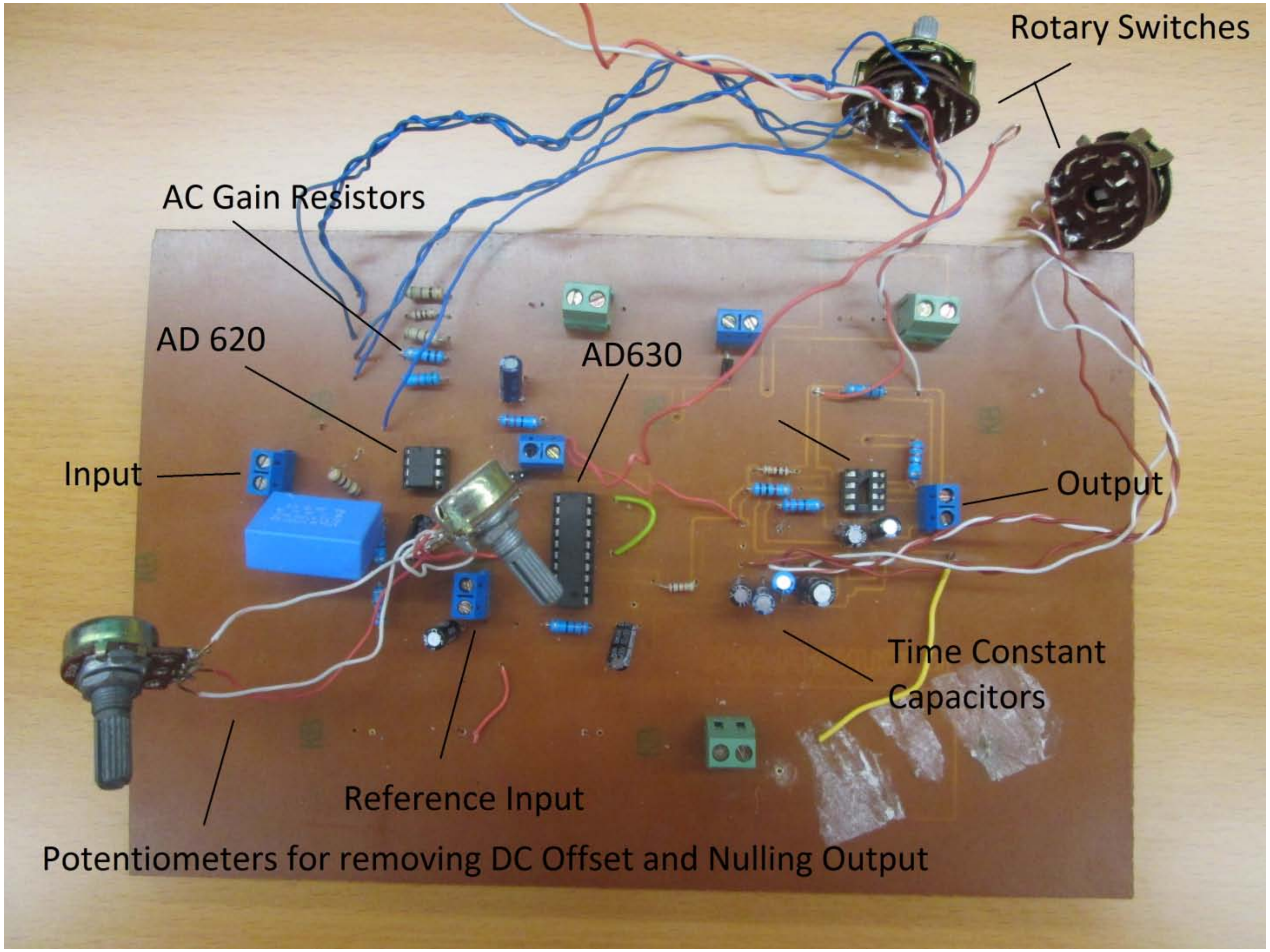



Power Supply
Input
Capacitors
High Passed Output
Rotary Switch
Variable
Resistor

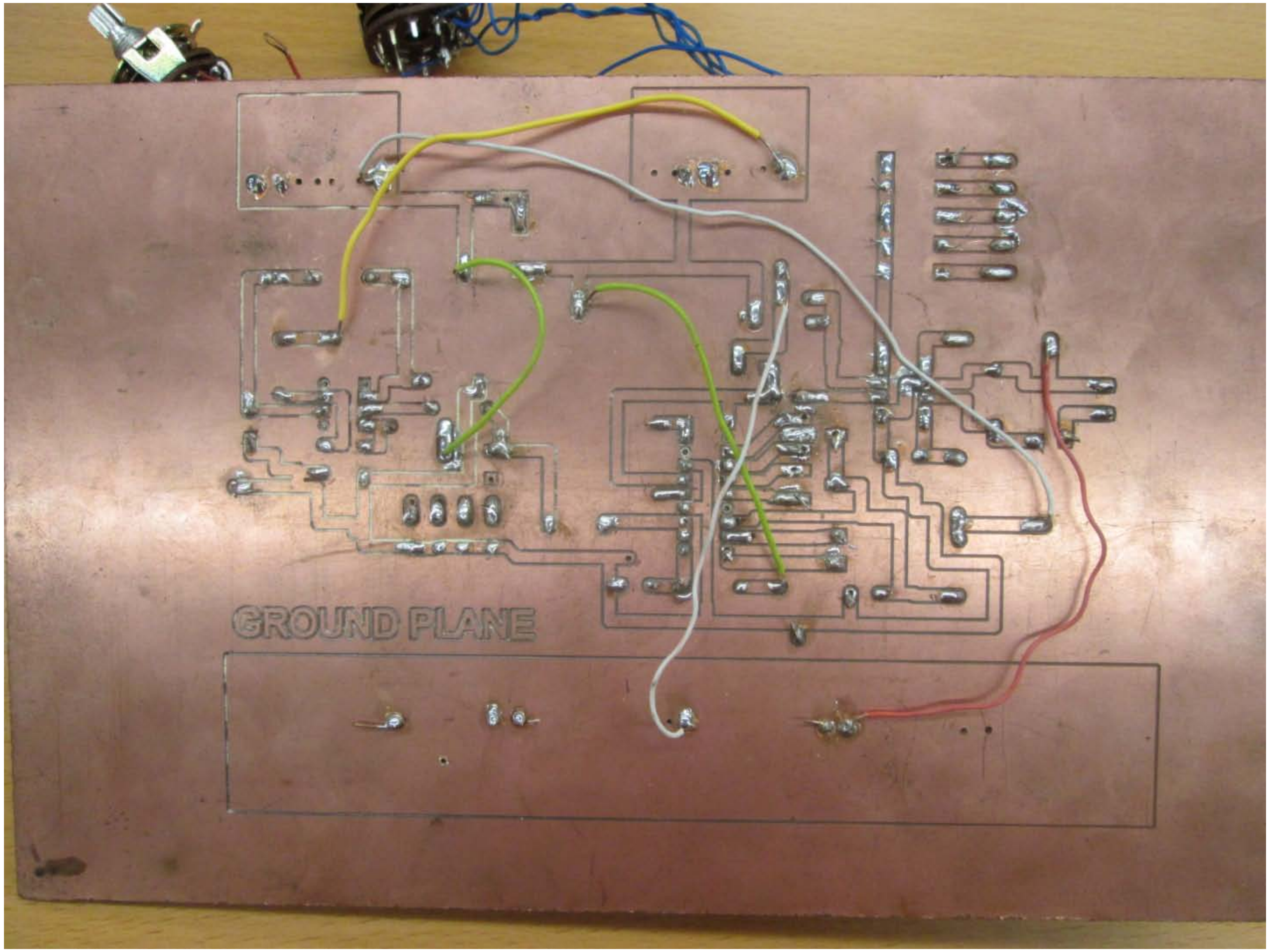
PCB

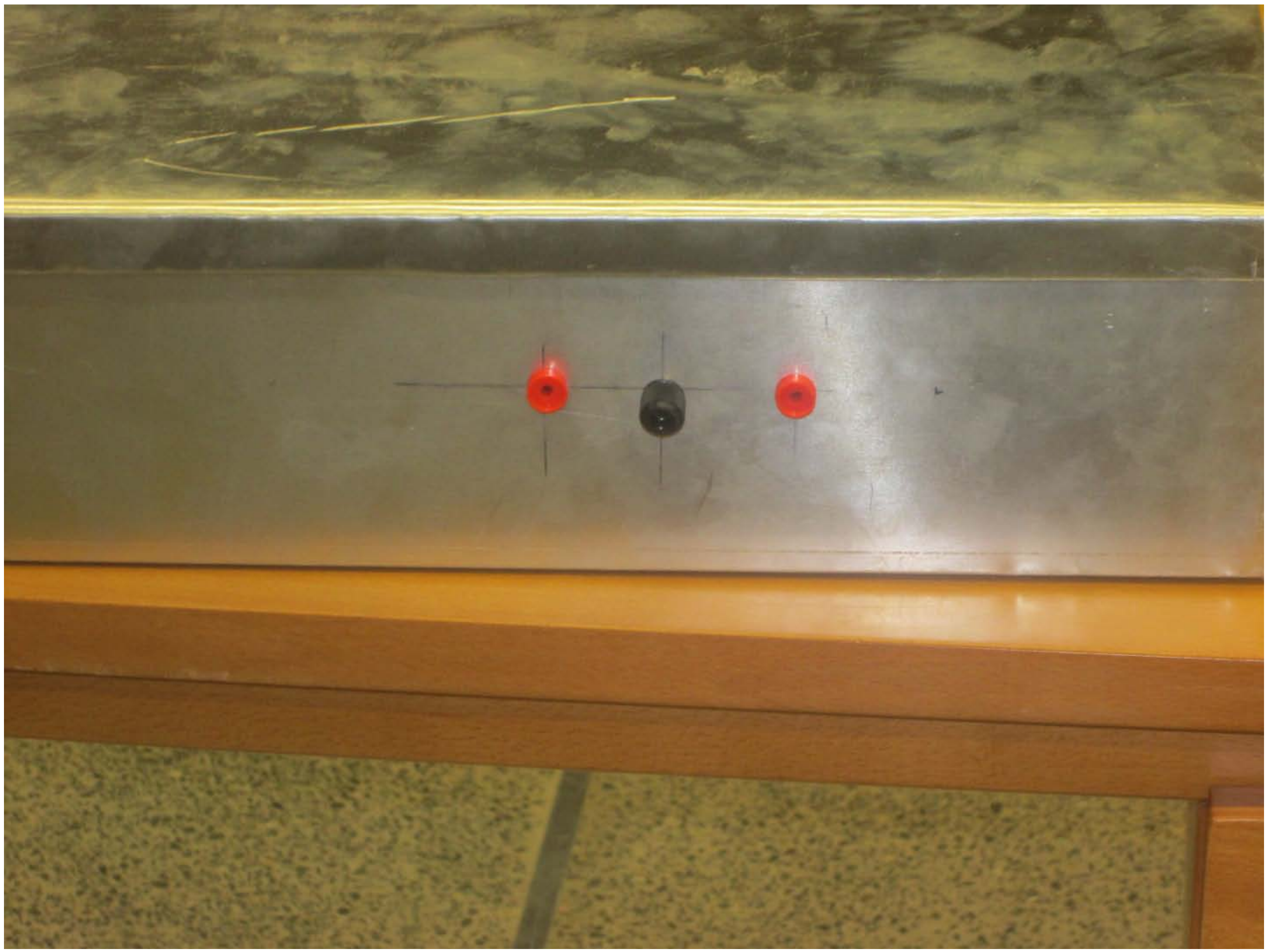
- Tried to follow the Noise-reduction techniques in routing.
- 0.76 mm thick Al box for shielding.

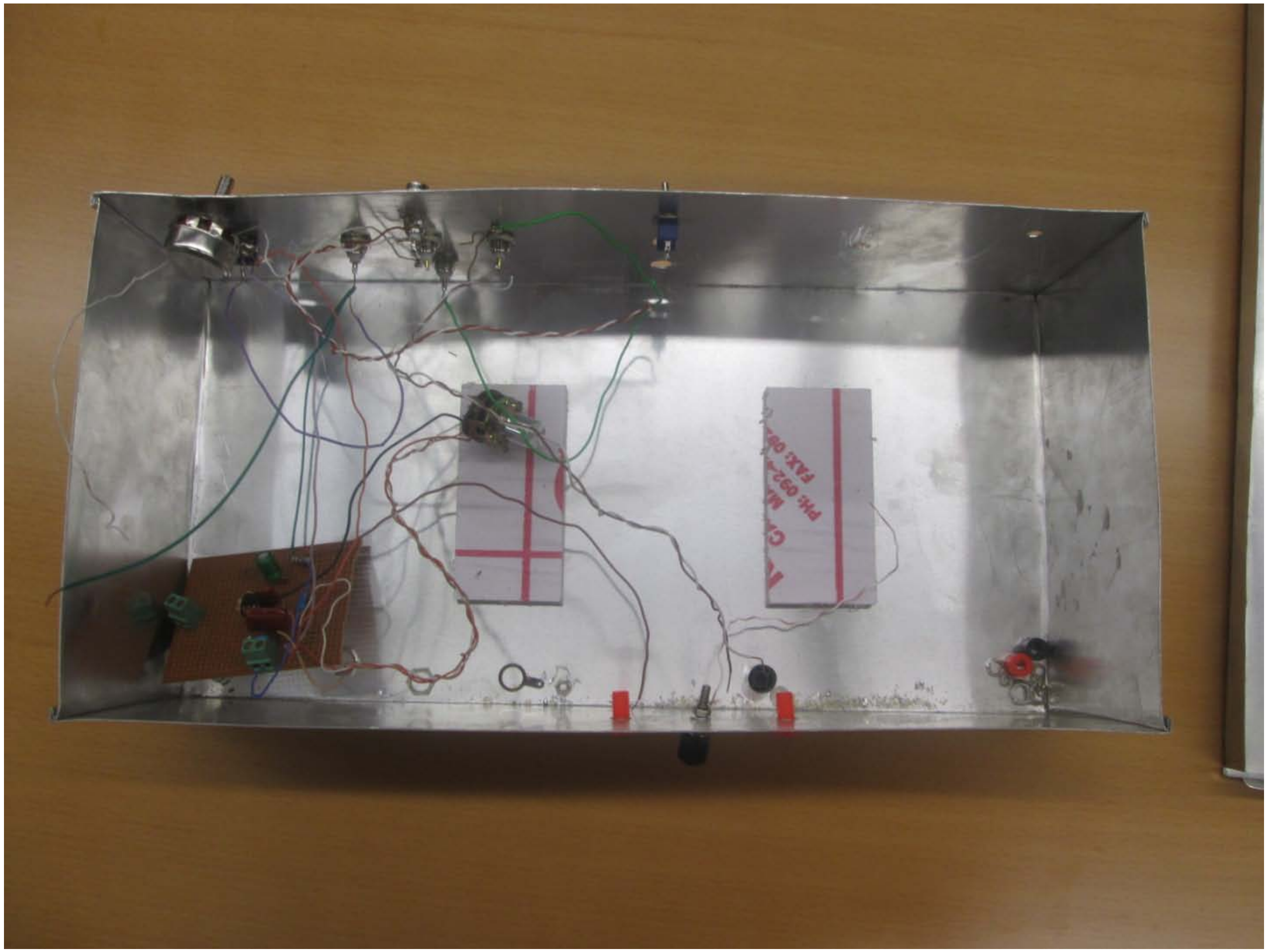
PCB Pics



Rotary Switches
AC Gain Resistors
AD 620
AD630
Input
Output
Time Constant
Capacitors
Reference Input
Potentiometers for removing DC Offset and Nulling Output


GROUND PLANE

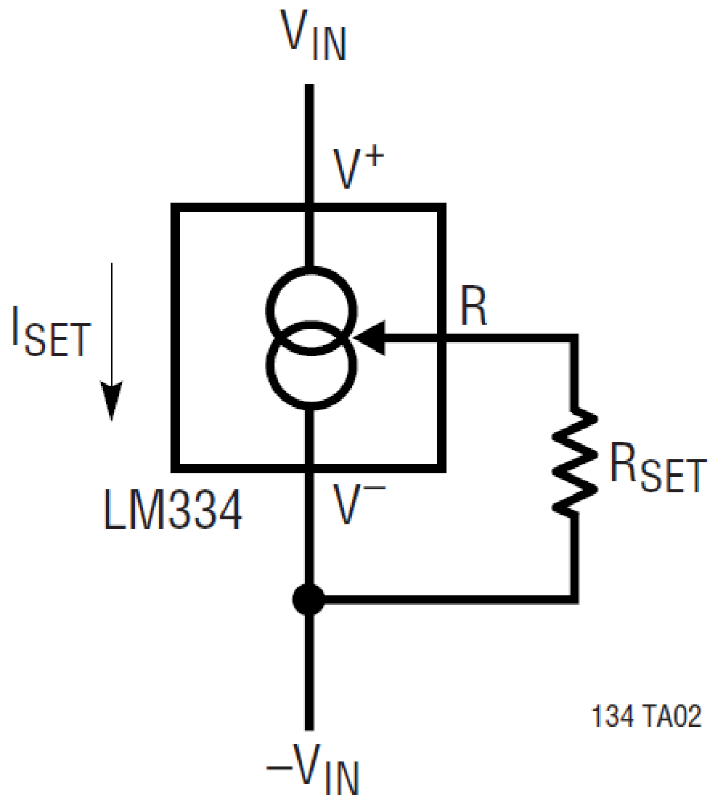




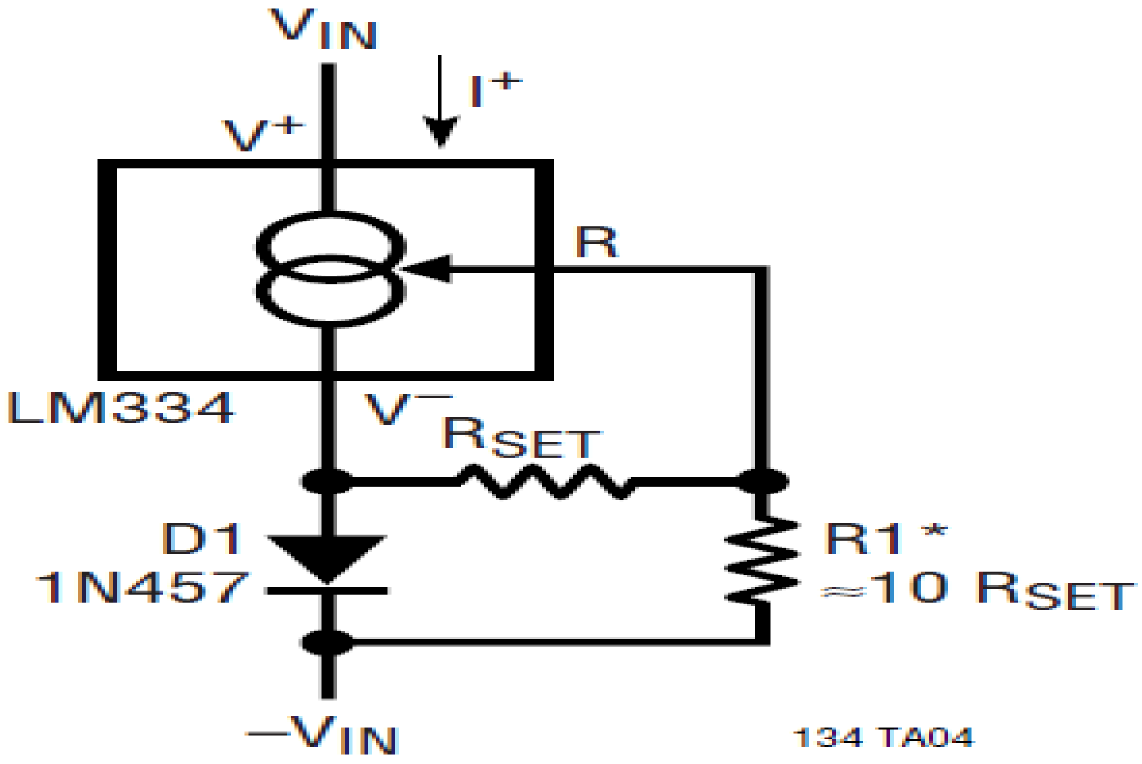
Constant Current Source

- Maintains constant current by varying the voltage across a load, or by varying the load across which there is a constant potential drop.
- Maximum Current allowed 10mA.
- Temperature Co-efficient of (227/R)uAmp per degree centigrade.
- Can also be used in temperature measurement applications.

Basic 2-Terminal Current Source



Zero Temperature Coefficient Current Source



*SELECT RATIO OF R1 TO R_{SET} TO OBTAIN ZERO DRIFT. $I^+ \approx 2\ I_{SET}$.

Thank You Physlab People!

- For providing me the opportunity to work on such a fascinating project.
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