Twin-T 60 Hz Notch Filter

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DeVon Gazaway
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01/16/2007 – 2/13/2007

Project Objectives

- Design and build a prototype “Twin-T” design 60 Hz Notch Filter, using common Op-amps.
- Use this prototype to test the operation of the NI ELVIS Prototyping platform, comparing it’s operation to discrete equipment, i.e. an Oscilloscope.

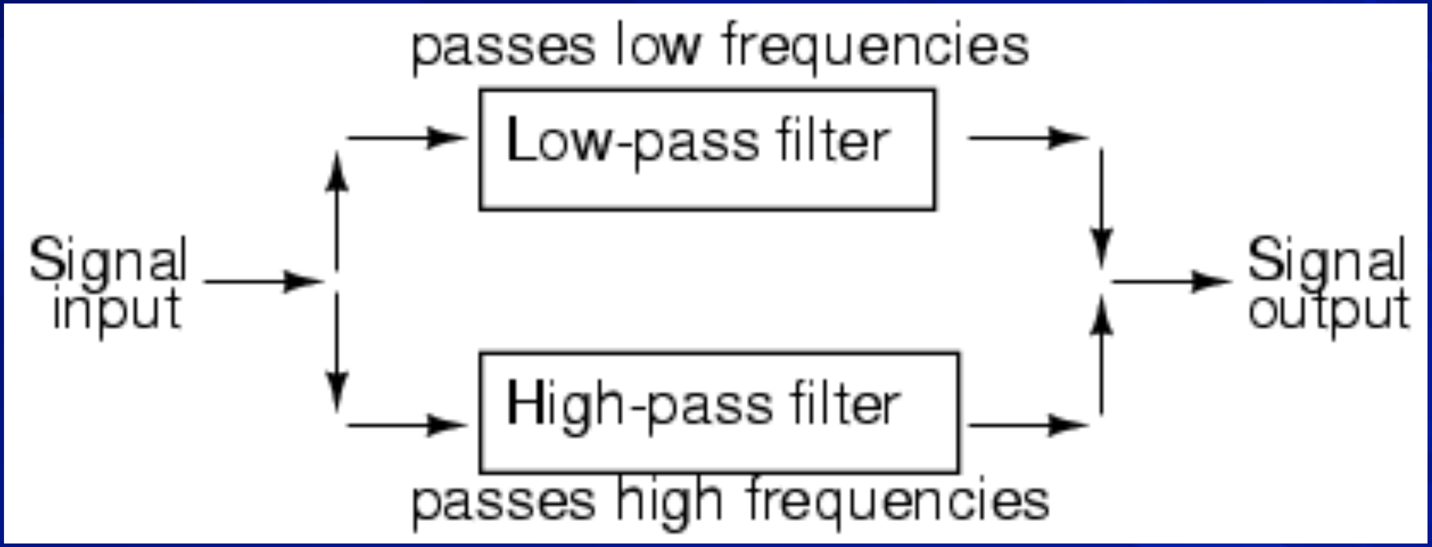
Project Sections

I. Notch Filter Information
II. Prototype Construction
III. Prototype Output and Analysis
IV. NI ELVIS
V. Gantt Chart and Budget

Part I: Notch Filter Information

Operation of a Notch Filter

This kind of filter passes all frequencies above and below a particular range set by the component values.



The low-pass filter section is comprised of R1, R2, and C3 in a "T" configuration. The high-pass filter section is comprised of C2, C1, and R3 in a "T" configuration as well

http://www.ibiblio.org/kuphaldt/electricCircuits/AC/AC_8.html

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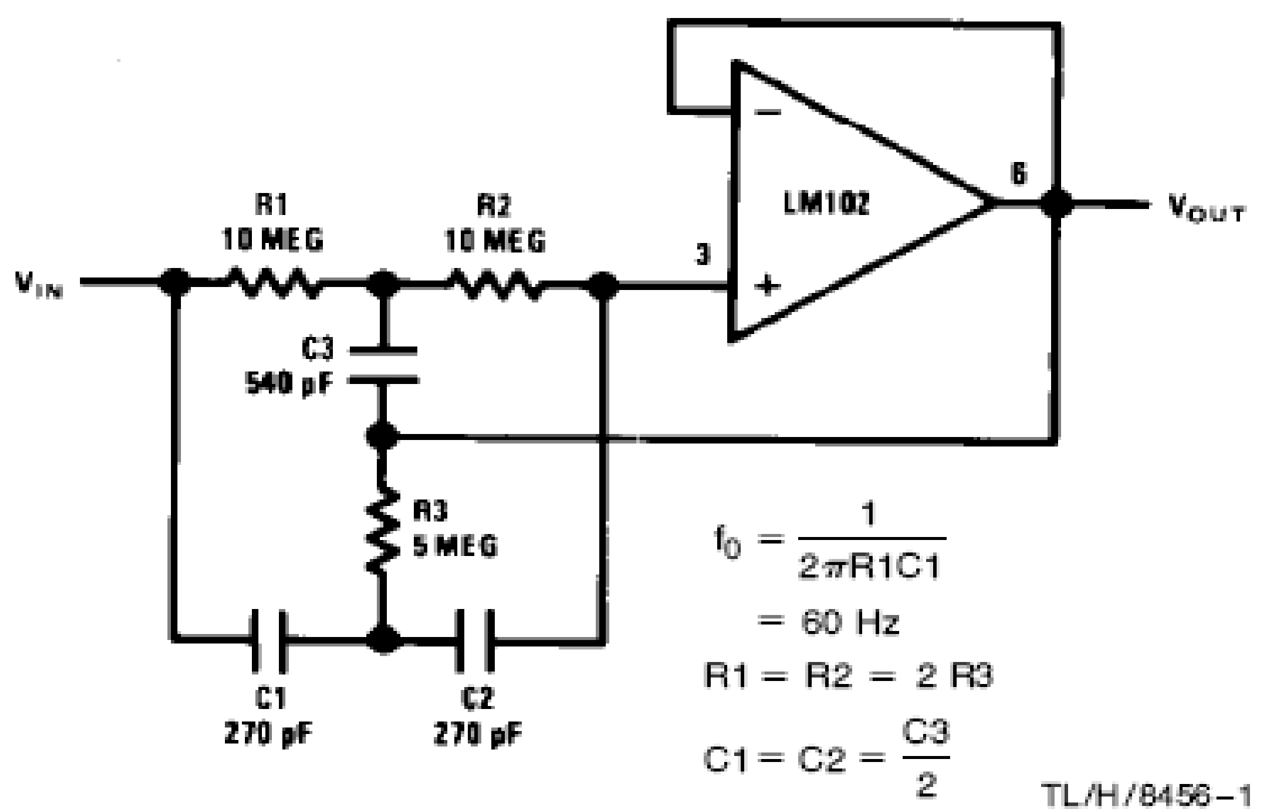
Operation of Notch Filter cont.

- At the notch frequency, each filter has a 90 degree phase shift
- Therefore, they are 180 degrees out of phase, thus cancelling each other out.
- At frequencies outside of Notch, the Phases are in line and allow current to flow.

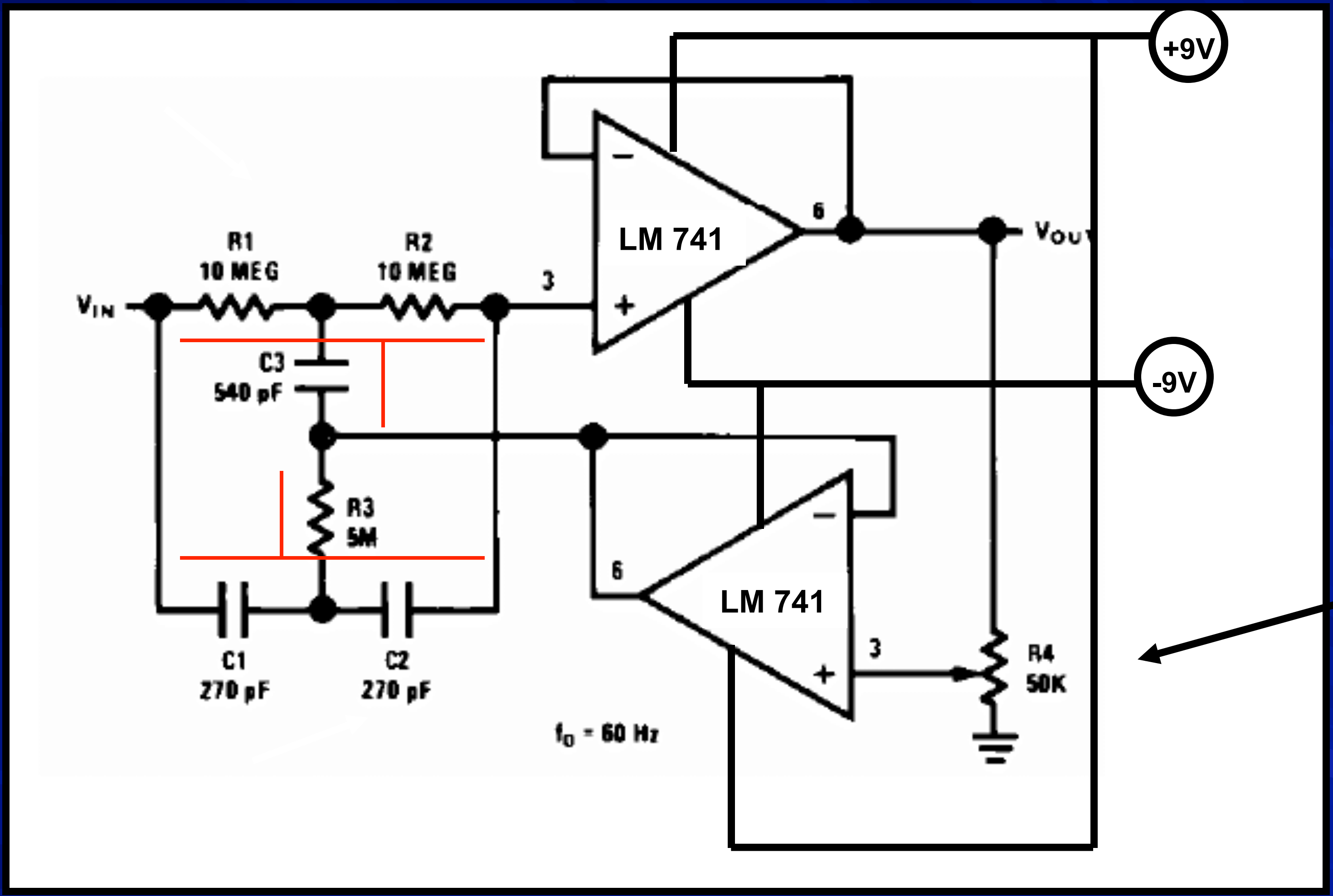
Original Schematic

Figure 1 shows a twin "T" network connected to an LM102 to form a high Q, 60 Hz notch filter.



http://www.national.com/ms/LB/LB-5.pdf

Chosen Notch Filter Schematic



50k Pot.

http://www.national.com/ms/LB/LB-5.pdf

Part II: Prototype Construction

What Equipment must be used?

- Breadboard: NI ELVIS
- Capacitors: 4 x 270pF
- Resistors: 4 x 10 MΩ
- Norton Op-amp : 2 x LM741
- Signal Generator: NI ELVIS and Discrete
- DC Power Supply: NI ELVIS
- Oscilloscope: NI ELVIS and Discrete
- Multi-meter: Discrete

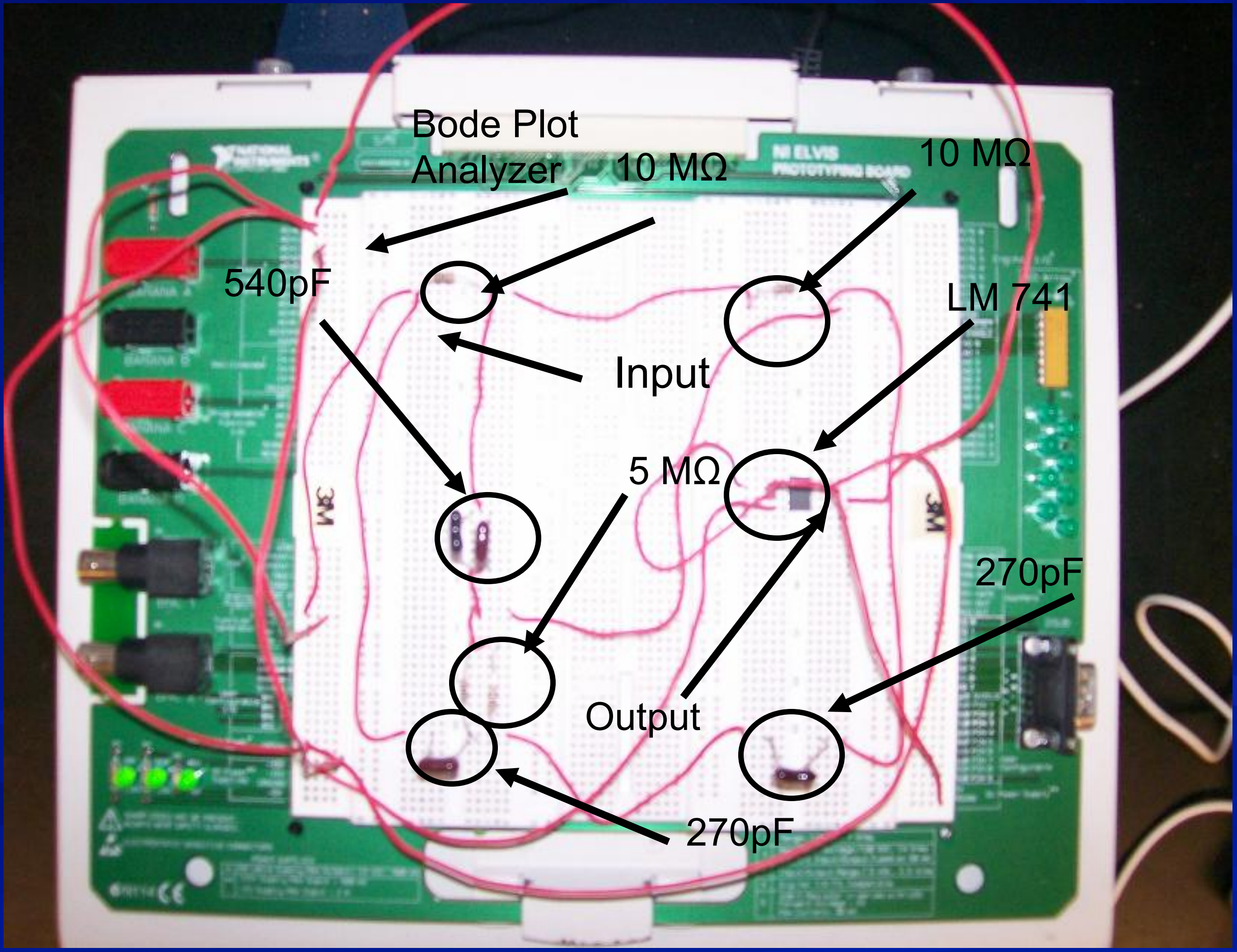
Risk Analysis

- Potential Problems
  - Blown/Defective LM 741 Op-Amp
  - Defective Caps/Resistors
  - Steep Learning curve of NI ELVIS
  - Incorrect build of prototype
  - Prototype not performing as expected

Problems Encountered:

- Incorrect prototype construction initially
- Learning curve for NI ELVIS
- Bode Plot analyzer can't run at same time as Oscilloscope or Function Generator.
- Incorrect Prototype Output:
  - Unexpected spike before Notch, caused by Ringing of Caps.
  - Unexpected Attentuation, required redesign

Prototype: Build 1



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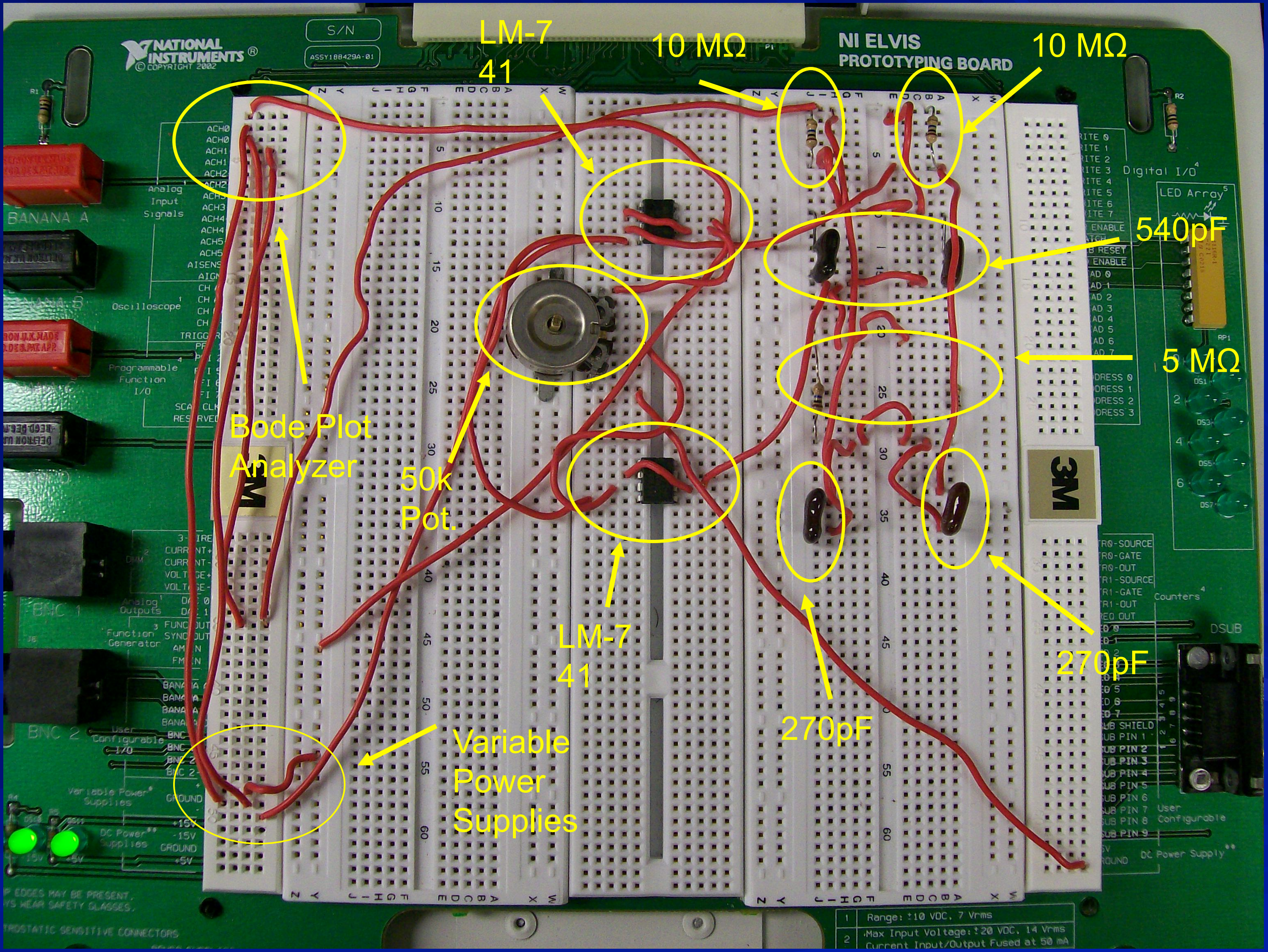
Prototype: Final Build



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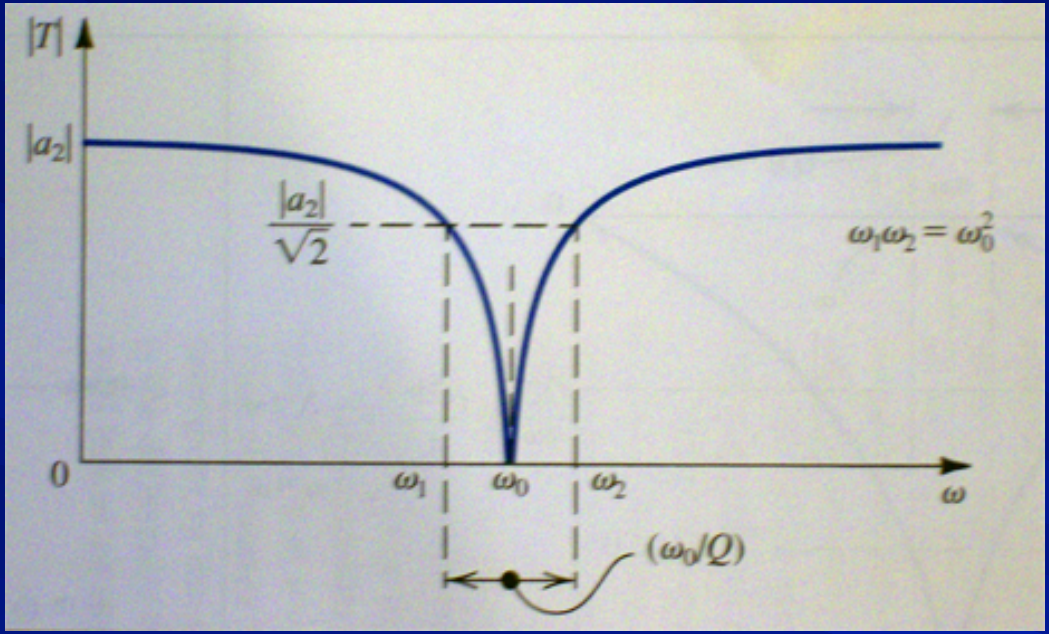
Part III: Prototype Output and Analysis

Predicted Specs



Desired Q: 10

Center Freq: 58.83 Hz

Corner Freqs: ~57Hz + ~63Hz

R1=R2=2R3= 10 MΩ

C1=C2=.5C3=270pF

Q := Center Freq / Bandwidth

Bandwidth := Corner 2 – Corner 1

Center Freq: := 1 / (2* Pi * R1 * C1)

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Data taken from Microelectronic Circuits, Sedra/Smith 5th Ed.

Actual Specs

Pot. = **10.5 Ω**
ω0 = 57.54 Hz
ω1 = ~55.5 Hz
ω2 = ~60Hz
Q= ~12.8
Max Atten.: -3.8dB

High Q, Shallow Notch

Pot. = **2.5 kΩ**
ω0 = ~57.54 Hz
ω1 = ~54 Hz
ω2 = ~64 Hz
Q= ~5.7
Max Atten.: -7dB

Desired Specs

Pot. = **50 kΩ**
ω0 = 57.54 Hz
ω1 = ~14 Hz
ω2 = ~263 Hz
Q= ~.23
Max Atten.: -27.6dB

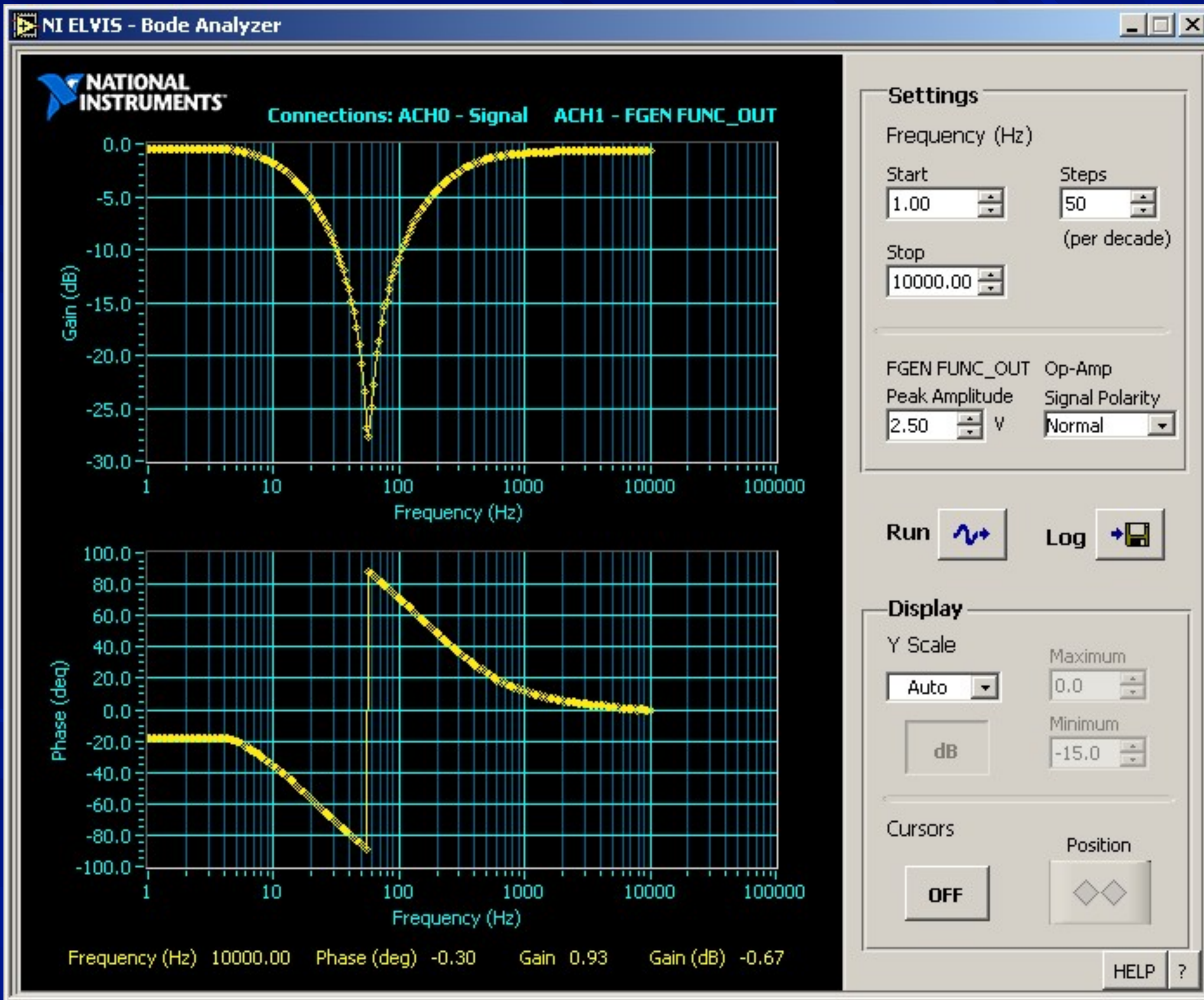
Low Q, Deep Notch

Comparison

Required Specs	Actual Specs
- Center Frequency: 60 Hz - Q: Not defined - Design: Twin-T w/ Op-amp	- Center Frequency: 57.75 Hz – Off due to 5% uncertainty of Components. - Q: Variable, Achieved ". 23" – "12.8" - Design: Twin-T w/ Two Op-amps + Potentiometer

Conclusion: Prototype Meets Specs. Slight Increase in cost = Better Product.

Low Q, Deep Notch



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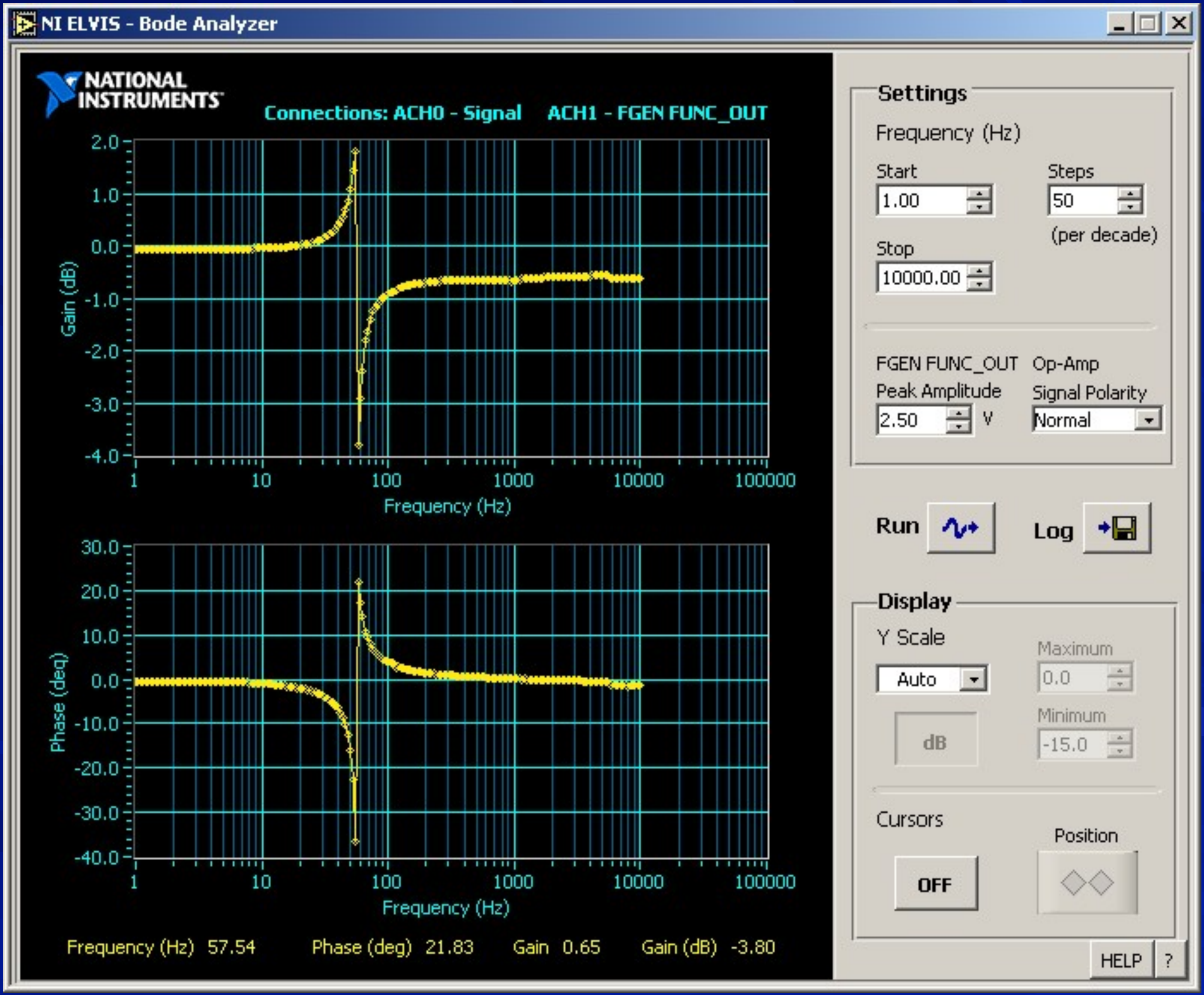
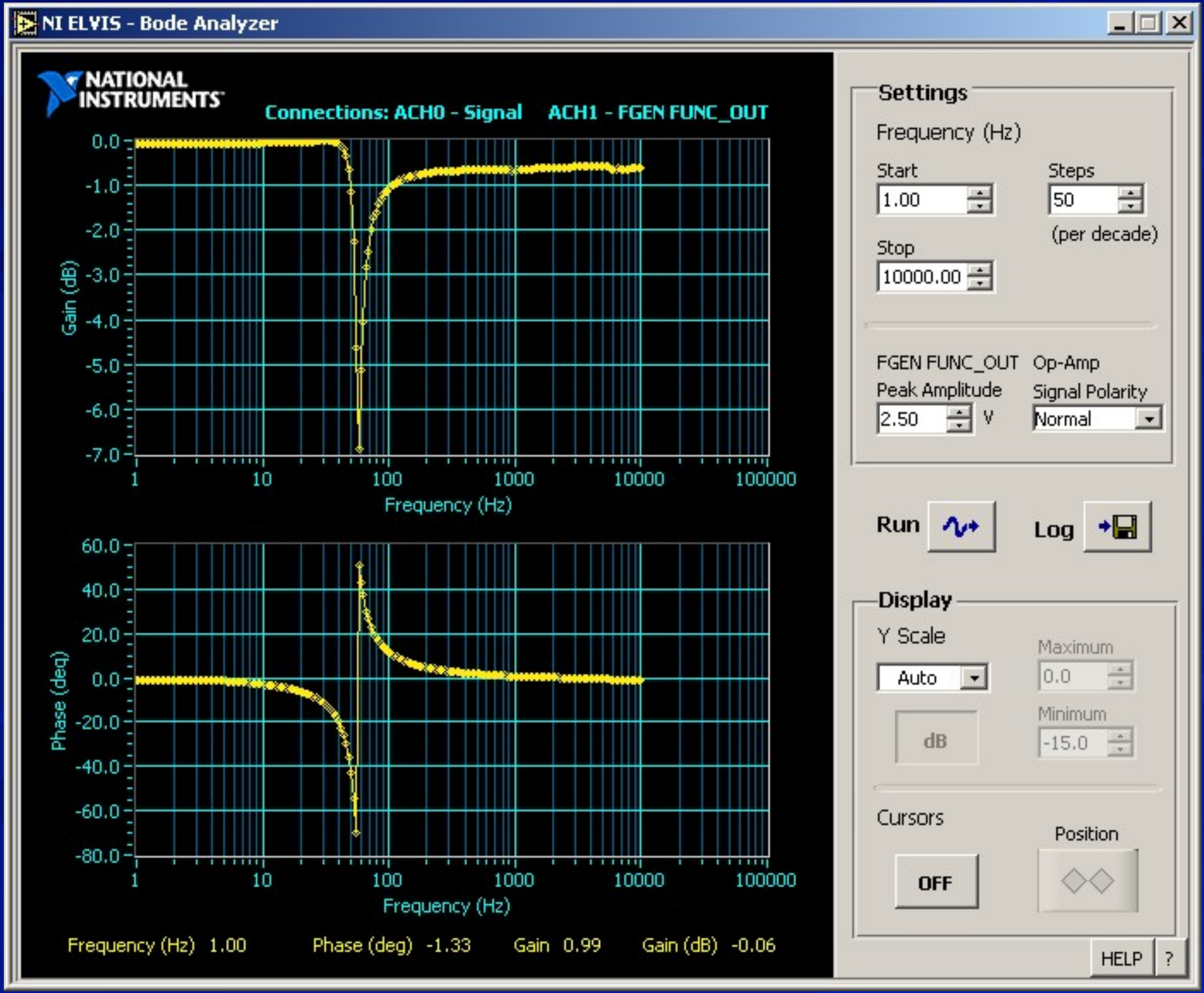
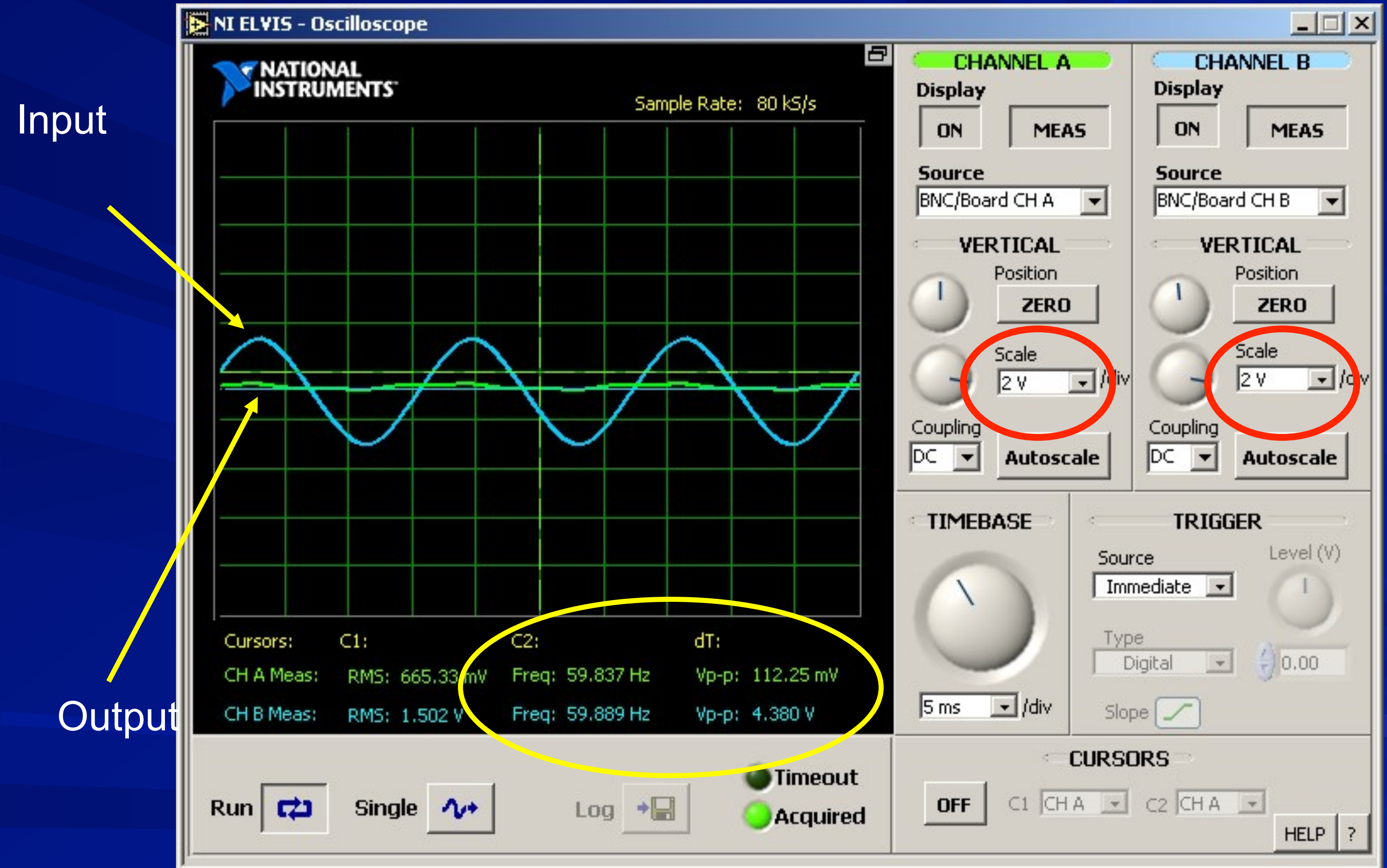
High Q, Shallow Notch



Chosen Setting



ELVIS O-Scope @ 60 Hz



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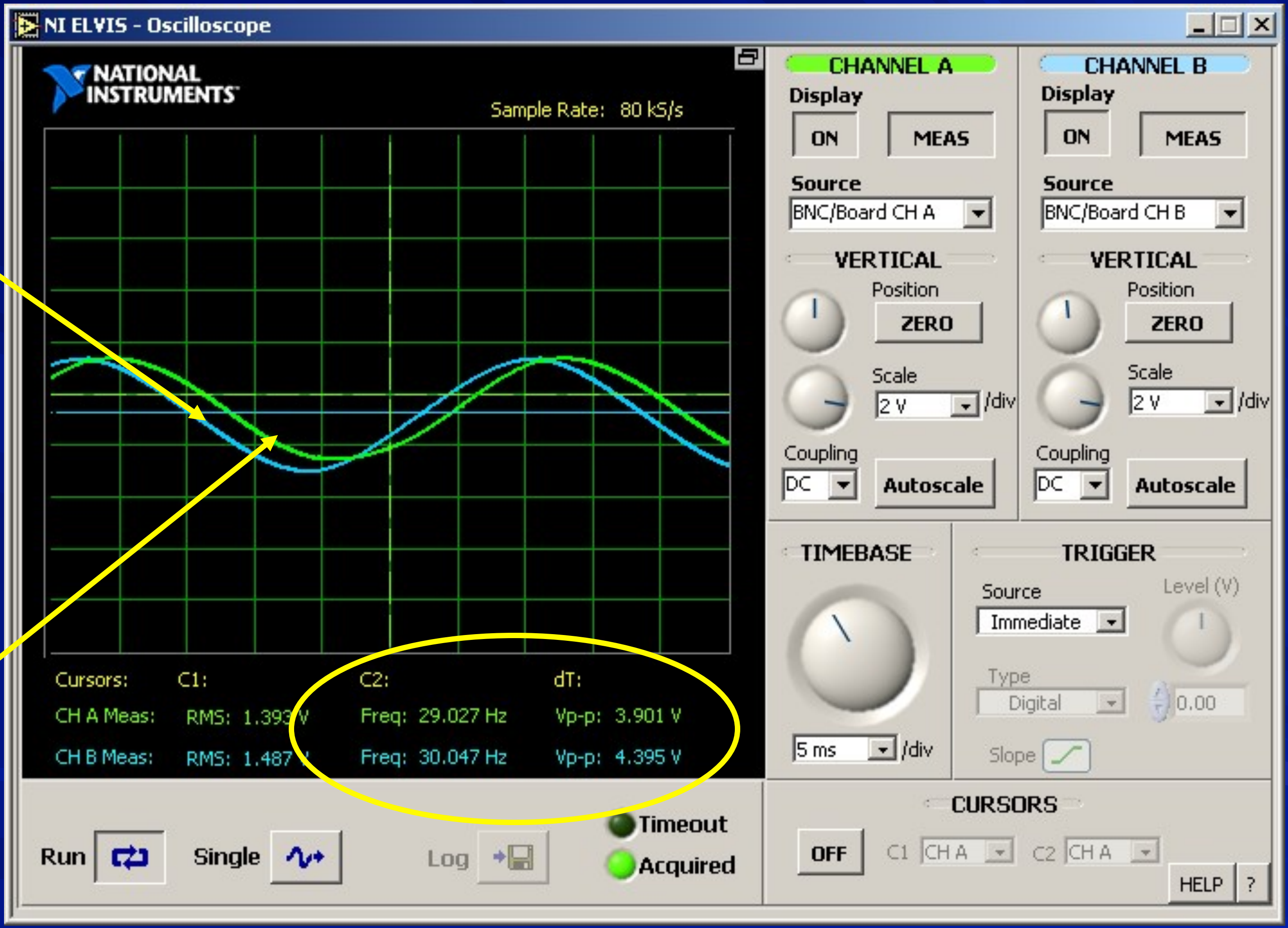
ELVIS O-Scope @ 30 Hz

Input

Output



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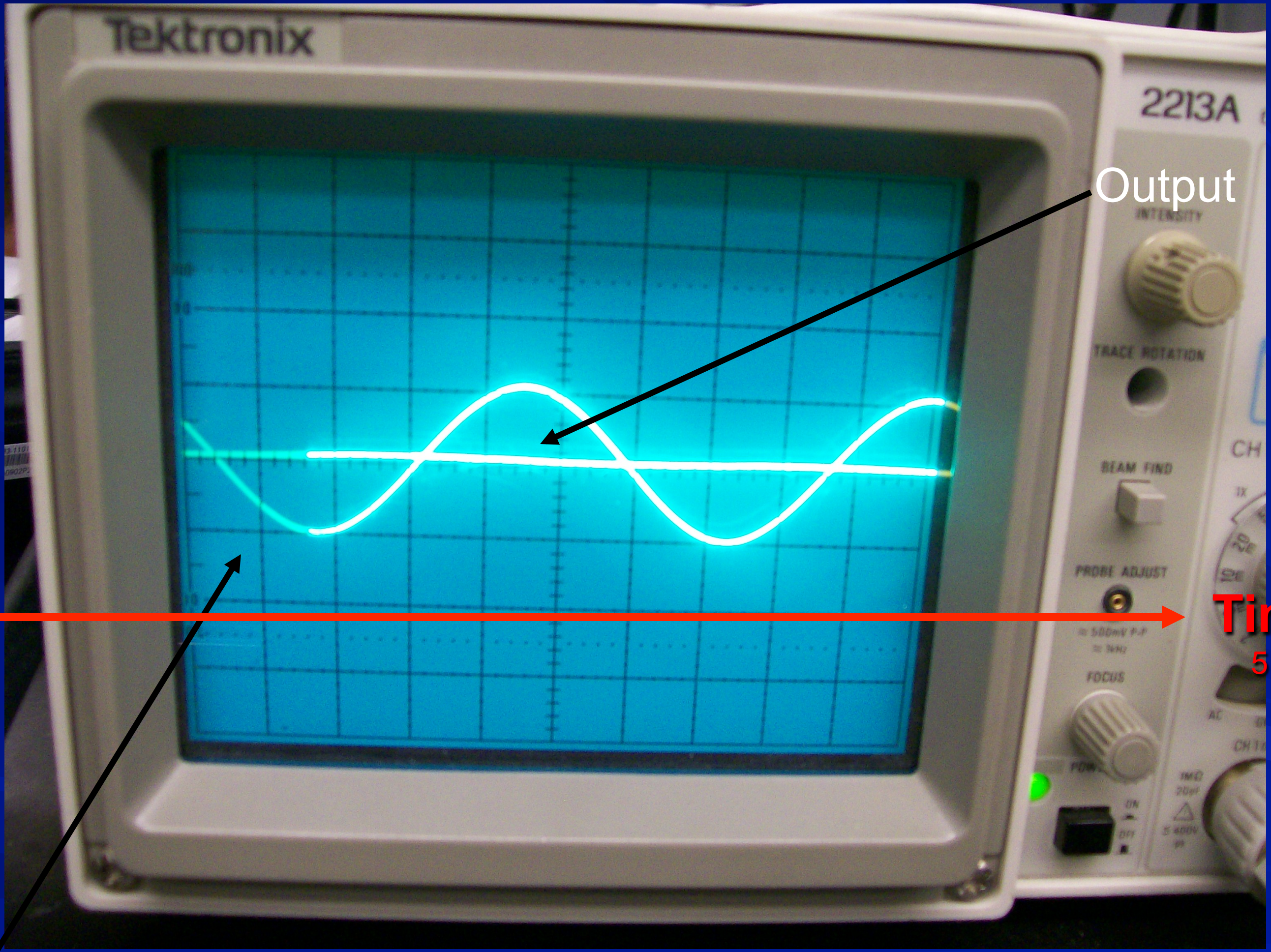
O-scope Output @ 60 Hz



Voltage

2V / Div.

Output

Time

5 ms/Div

Input

Part IV: NI ELVIS

Virtual Instruments

- Made using Visual Programming Style
- Hierarchy of Instruments
  – High Level Instruments Interact with User
  – SubVIs manipulated by higher instruments.
- Instruments Interface directly with ELVIS board.

V.I. Specs

Oscilloscope

Refer to the *Analog Input* section of the DAQ device specifications documentation.

Accuracy	12 bits or 16 bits, DAQ device dependent
Input impedance	DAQ device dependent
Maximum horizontal resolution	DAQ device dependent
Range	±10 V
Sampling rate per channel	100 kHz–500 kHz, DAQ device dependent
Maximum input bandwidth	10 kHz–50 kHz, DAQ device dependent
Vertical resolution	12 bits or 16 bits, DAQ device dependent

Function Generator

Frequency range	5 Hz–250 kHz in five ranges
Software-controlled frequency resolution	0.8%
Frequency set point accuracy	3% of range, max
Frequency read back accuracy	±0.01%
Output amplitude	±2.5 V
Software amplitude resolution	8 bits
Offset range	±5 V
AM voltage	10 V, max
Amplitude modulation	Up to 100%
FM voltage	10 V, max
Amplitude flatness	
To 50 kHz	0.5 dB
To 250 kHz	3 dB
Frequency modulation	±5% of full-scale, max
Output impedance	50 Ω guaranteed. Refer to Appendix C, *Theory of Operation*, for more information on the output impedance configuration options.

Variable Power Supplies

0 to +12 and -12 V

Ripple and noise	0.25%
Software resolution	7 bits
Current limiting	0.5 V at 130 mA, 5 V at 275 mA, 12 V at 450 mA

Bode Analyzer

Amplitude accuracy	12 or 16 bits, DAQ device dependent
Phase accuracy	1 degree
Frequency range	5 Hz–35 kHz

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Discrete Oscilloscope

MAKE: Tektronix

MODEL: 2213

CHANNELS: 2

BANDWIDTH: > 60 mHz

SENSITIVITY: 10 V to 2mV/division (with 1X probes), panel marked for both 1X and 10X probes.

SWEEP RATE: 50 ns/div to .5 sec/div, plus 10X magnifier.

- High Impedance to draw low current from the source
- Deflection Plates Modify Electron Flow from CRT
- The vertical amplifier takes input voltage and causes electron flow to be deflected.
- The timebase is an electronic circuit that generates a ramp voltage
- The Horizontal Amplifier sweeps the electron beam at constant speed from left to right across the screen, and then back to left.
- A positive input voltage bends the electron beam upwards, and a negative voltage bends it downwards, so that the vertical deflection of the dot shows the value of the input.

V.I. Oscilloscope

Oscilloscope

Refer to the *Analog Input* section of the DAQ device specifications documentation.

Accuracy	12 bits or 16 bits, DAQ device dependent
Input impedance	DAQ device dependent
Maximum horizontal resolution	DAQ device dependent
Range	±10 V
Sampling rate per channel	100 kHz–500 kHz, DAQ device dependent
Maximum input bandwidth	10 kHz–50 kHz, DAQ device dependent
Vertical resolution	12 bits or 16 bits, DAQ device dependent

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- High Impedance to draw low current from the source
- VI uses a high sampling rate to capture Input Voltage
- Input Voltage Captured from Data Acquisition Board
- Input voltage is then graphed to the Vertical Axis
- Time is graphed to the Horizontal Axis
- A VI oscilloscope does not have as high of a range of measurement as a discrete piece of equipment
- The Oscilloscope is a high level VI and therefore uses SubVIs to make it’s individual measurements.

Adam Linker

O-Scope Comparison

MAKE: Tektronix

MODEL: 2213

CHANNELS: 2

BANDWIDTH: > 60 MHz

SENSITIVITY: 10 V to 2mV/ division (with 1X probes), panel marked for both 1X and 10X probes.

SWEEP RATE: 50 ns/div to .5 sec/div, plus 10X magnifier.

Oscilloscope

Refer to the *Analog Input* section of the DAQ device specifications documentation.

Accuracy .... 12 bits or 16 bits, DAQ device dependent

Input impedance .... DAQ device dependent

Maximum horizontal resolution .... DAQ device dependent

Range .... ±10 V

Sampling rate per channel .... 100 kHz–500 kHz, DAQ device dependent

Maximum input bandwidth .... 10 kHz–50 kHz, DAQ device dependent

Vertical resolution .... 12 bits or 16 bits, DAQ device dependent

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Part V: Gantt Chart and Budget

Project Summary

- Two iterations of Prototype construction:
  - Redesign after first build
    - Changed Schematic, Added extra Op-amp + 50k Pot.
  - Prototype Completed ahead of schedule
- Testing of Prototype Completed on schedule
  - Prototype works according to Project specifications.
- Testing of NI ELVIS completed
  - Comparison of Discrete vs. V.I. operation completed
- All project requirements completed satisfactorily and on schedule.

Gantt Chart – Week 1

ID	ℹ	Task Name	Duration	Start	Finish	Resource
1		Project Lab 1 - Project 1	25 days	Thu 1/18/07	Tue 2/13/07	
2	✓	Week 1	3 days	Thu 1/18/07	Sat 1/20/07	
3	✓	Data Acquisition Phase	3 days	Thu 1/18/07	Sat 1/20/07	
4	✓	Obtain Data about and Understand Notch Filters - 2hr	3 days	Thu 1/18/07	Sat 1/20/07	Kyle
5	✓	Learn How to Use ELVIS System - 2hr	3 days	Thu 1/18/07	Sat 1/20/07	Kyle
6	✓	Determine what discrete testing equipment will be required - 2hr	3 days	Thu 1/18/07	Sat 1/20/07	Adam
7	✓	Design Budget for this project - 2hr	1 day	Sat 1/20/07	Sat 1/20/07	Kyle
8	✓	Obtain Scematics for various Notch Filter Designs -2hrs	2 days	Fri 1/19/07	Sat 1/20/07	Kyle

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Gantt Chart – Week 2

ID	ℹ	Task Name	Duration	Start	Finish	Resource
9	✓	Week 2	4 days	Thu 1/25/07	Sun 1/28/07	
10	✓	Setup and Collection of Parts	4 days	Thu 1/25/07	Sun 1/28/07	
11	✓	Aquire Lab Bench from Department - 1hr	1 day	Thu 1/25/07	Thu 1/25/07	Kyle
12	✓	Aquire Supplies and Data Sheets Necessary for Construction - 1hr	1 day	Fri 1/26/07	Fri 1/26/07	Adam
13	✓	Select Filter design that will be used to build the circuit - 1hr	1 day	Fri 1/26/07	Fri 1/26/07	Kyle
14	✓	Building and Testing of Initial Circuit	3 days	Fri 1/26/07	Sun 1/28/07	
15	✓	Perform a risk analysis of circuit - 1hr	3 days	Fri 1/26/07	Sun 1/28/07	Adam
16	✓	Begin construction of Notch Filter Circuit - 12hr	1 day	Sun 1/28/07	Sun 1/28/07	Adam
17	✓	Test Circuit to determine operational status - 12hr	1 day	Sun 1/28/07	Sun 1/28/07	Devon

Kyle Romero

Gantt Chart – Week 3

ID		Task Name	Duration	Start	Finish	Resource
18	✓	Week 3	5 days	Wed 1/31/07	Sun 2/4/07	
19	✓	Debug Phase	4 days	Wed 1/31/07	Sat 2/3/07	
20	✓	Debug Initial Notch Circuit Build - 5hrs	1 day	Wed 1/31/07	Wed 1/31/07	Kyle
21	✓	After Debug, Risk Analysis, and Redesign, Rebuild -3hrs	3 days	Thu 2/1/07	Sat 2/3/07	Adam
22	✓	Final Build	**2 days**	**Sat 2/3/07**	**Sun 2/4/07**	
23	✓	Final Construction of Notch Filter Circuit - 5hrs	1 day	Sat 2/3/07	Sat 2/3/07	Kyle
24	✓	Perform Final Debug and Analysis of circuit - 5hrs	1 day	Sun 2/4/07	Sun 2/4/07	Devon
25	✓	Analyze, Pinpoint problems, and Rebuild - 2hrs	1 day	Sun 2/4/07	Sun 2/4/07	Devon
26	✓	Retest Circuit to determine new operational status - 1hr	1 day	Sun 2/4/07	Sun 2/4/07	Adam

Gantt Chart – Week 4

ID		Task Name	Duration	Start	Finish	Resource
27		Week 4	5 days	Wed 2/7/07	Tue 2/13/07	
28	✓	Data Colletion and Comparison	3 days	Wed 2/7/07	Fri 2/9/07	
29	✓	Final Theoretical Analysis of Circuit - 5hrs	1 day	Wed 2/7/07	Wed 2/7/07	Kyle
30	✓	Final Analysis of Circuit using NI ELVIS - 5hrs	1 day	Thu 2/8/07	Thu 2/8/07	Adam
31	✓	Data Comparision and Organization -6hrs	1 day	Fri 2/9/07	Fri 2/9/07	Devon
32		Final Presentation	1 day	Tue 2/13/07	Tue 2/13/07	

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Budget

Project 1 - Group 8

Labor Costs

Employee Name	Hourly Rate	Number of Hours Worked	Total Project Salary
Kyle Romero	$10.00	25	$250.00
Devon Gazaway	$10.00	25	$250.00
Adam Linker	$10.00	25	$250.00
		Total Labor Cost	$750.00

Parts Cost

Part	Cost/Unit	Number of Units	Total Cost
270 pF Capacitor	$2.50	4	$10.00
Norton LM 741	$0.22	2	$0.44
10 Meg Resistors	$0.12	4	$0.48
		Total Parts Cost	$10.92

Equipment Rental Cost

Equipment	Purchase Cost	Rental Fee per Day	Number of Days Rented	Total Cost
ELVIS	$2,660.00	$5.32	20	$106.00
DAQ Board	$150.00	$0.80	20	$6.00
Function Generator	$800.00	$1.60	14	$22.40
O-Scope Leads	$24.00	$0.05	14	$0.70
Oscilloscope	$956.00	$1.91	14	$26.74
			Total Cost	$161.84

Project Cost Summery

Labor Cost	$750.00
Parts Cost	$10.92
Equipment Rental Cost	$161.84
Subtotal	$922.92
75% Overhead	$692.12
Grand Total	**$1,615.04**

References

http://www.ibiblio.org/kuphaldt/electricCircuits/AC/AC_8.html

http://www.national.com/ms/LB/LB-5.pdf

Microelectronic Circuits, Sedra/Smith 5th Ed.

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Questions?