Instrumentation Lab, Physics 111A
Lab 1, Introductory and Linear Circuits I

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Signature Card

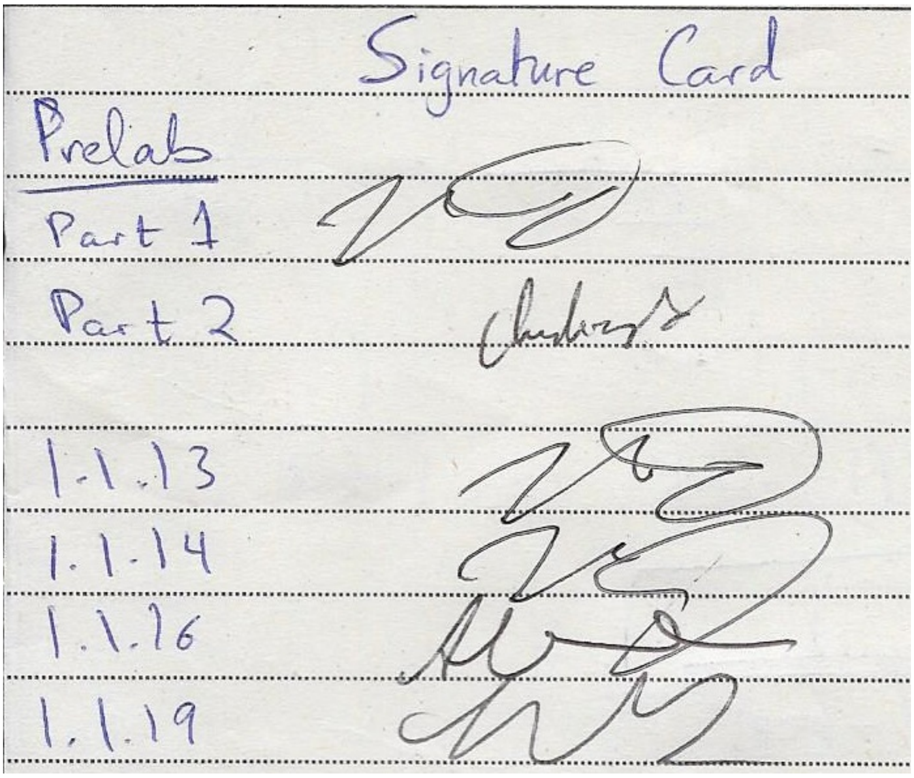


Figure 1: Prelab and Problems 1.13, 1.14, 1.16, 1.19

Part 1

Problem 1.1.1 - Breadboard Layout

The breadboard serves as a base for building prototype circuits that doesn't involve soldering. The rows of terminals are connected horizontally while the large blocks are connected vertically. You will not get a current flowing through your circuit if you do not attach one of the terminals of your circuit elements in the same column. We measured resistances of R = 1.30 Ω

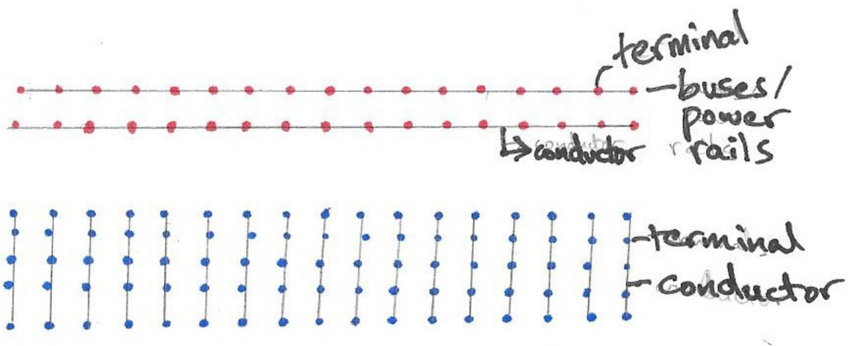


Figure 2: Problem 1.1.1

Problem 1.1.2 - Power Supply Voltages: Conceptual

a) For +24 V connect the ground terminal to the -12 V green terminal, this will make the red +12 V terminal read +24 V with respect to the ground. Figure3a)
b) For -24 V connect the red +12 V terminal to the ground terminal, this will make the green -12 V terminal read -24 V with respect to the ground. Figure3b)
c) For +12 V connect the black 0 V terminal to the ground terminal, this will make the red +12 V terminal read +12 V with respect to the ground. Figure3c)
d) For -12 V connect the black 0 V terminal to the ground terminal, this will make the green -12 V terminal read -12 V with respect to the ground. Figure3d)
e) For +17 V connect the black 0 V terminal to the red +5 V terminal, this will make the red +12 V terminal read +17 V with respect to the ground. Figure3e)

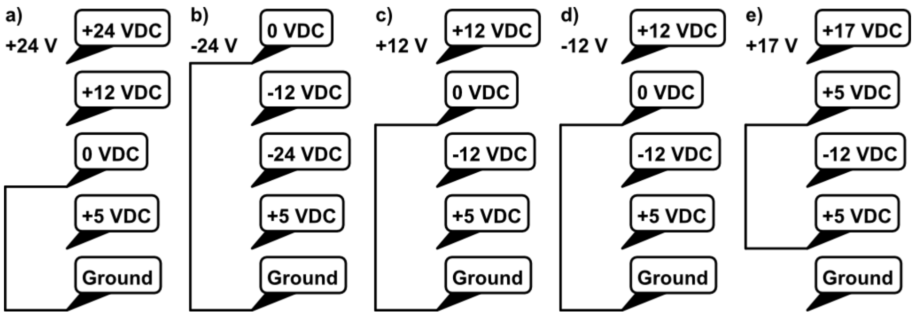


Figure 3: Problem 1.1.2

Problem 1.1.3 - Power Supply Voltages: Measurements

Having the +12 V and the 0 V terminals connected to each other with no other connections, the DMM reads a voltage of roughly 0 V. This is because the top three terminals are "floating" supplies meaning when they are connected to one another, the circuit remains an open circuit because these terminals are not connected to the ground, so even though there is a 12 V potential difference with respect to each other between those two elements, they are not grounded so the actual potential difference with respect to ground is 0 V. The table 1 below contains the actual values recorded by the DMM for the connections made in 1.1.2.

Setup	Nominal Value	Actual Value
a)	+24 V	26.36 V
b)	-24 V	-26.37 V
c)	+12 V	13.17 V
d)	-12 V	-13.17 V
e)	+17 V	18.34 V

Table 1: Problem 1.1.3 - DMM measurements of voltages from 3

Problem 1.1.4 - Voltage Divider: General Calculation

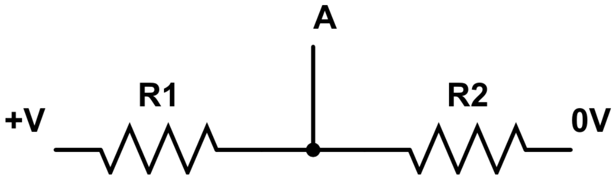


Figure 4: Voltage Divider

Begin with the general voltage divider equation derived in the prelab part 1;

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1 + R_2}$$

Then, for $V_{out} = V_A$ and V_{in}=V;

$$\boxed{V_A = V\frac{R_2}{R_1+R_2}}$$

Problem 1.1.5 - Voltage Divider: Specific Current Calculation

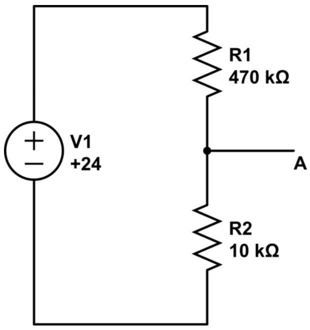


Figure 5: Voltage Divider, 470 kΩ and 10 kΩ

Current in a series circuit is the same through each circuit component so the calculation is as follows;

$$\begin{aligned}
R_{tot} &= R_1 + R_2 \\
R_{tot} &= 470\ \text{k}\Omega + 10\ \text{k}\Omega = 480\ \text{k}\Omega \\
I &= \frac{V}{R} \\
I &= \frac{24V}{480\ \text{k}\Omega} \\
&\boxed{I = 5 * 10^{-5}\ \text{mA} = 50\ \mu A}
\end{aligned}$$

Problem 1.1.6 - Voltage Divider: Specific Voltage Calculation

Simply make use of the following formula;

$$V_A = V \frac{R_2}{R_1 + R_2}$$

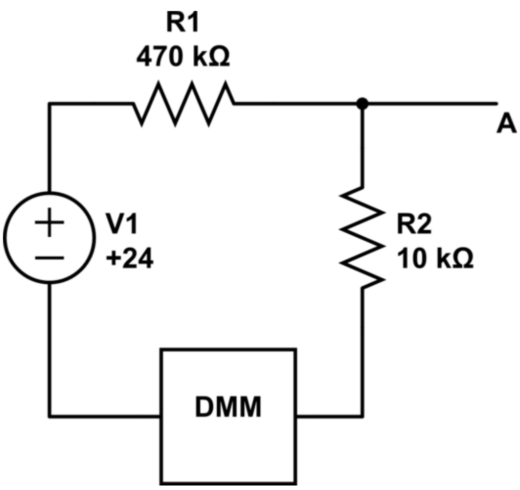
Then we have,

$$V_A = 24\ \mathrm{V} \frac{10\ \mathrm{k\Omega}}{470\ \mathrm{k\Omega} + 10\ \mathrm{k\Omega}}$$
$$V_A = 24\ \mathrm{V} \frac{10\ \mathrm{k\Omega}}{480\ \mathrm{k\Omega}}$$
$$\boxed{V_A = 0.5\ \mathrm{V}}$$

Problem 1.1.7 - Voltage Divider: Measurement Setup

a) To measure the current across the 10 kΩ resistor connect the DMM in series with the resistors and the power supply. The live terminal should be connected to the black terminal on the top right of the DMM and the ground should be connected to the 3 A fuse on the bottom left as shown in the figure 6a, the circuit diagram is shown in figure 6b

(a) DMM Connections



(b) Circuit diagram

Figure 6: Measuring current across 10 kΩ resistor using DMM

b) To measure the voltage drop across the 470 kΩ resistor connect the DMM in parallel with the resistor, the circuit diagram is shown in figure 7

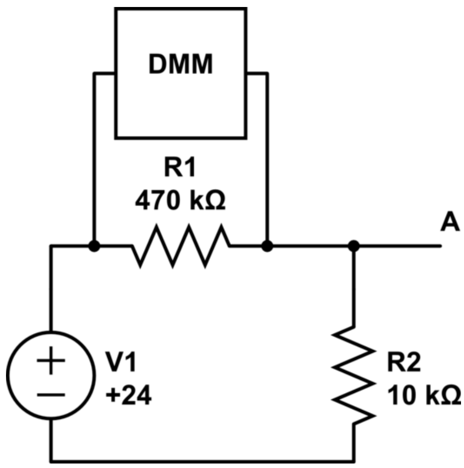


Figure 7: Measuring voltage across 470 kΩ resistor

Problem 1.1.8 - Voltage Divider: Component Measurements

Circuit Element	Nominal Value	Actual Value	Accuracy
Resistor	470 kΩ	465 kΩ	1%
Resistor	10 kΩ	10.2 kΩ	2%
Power Supply	24 V	26.37 V	-

Table 2: Accurate values for circuit elements from circuit in figure 5

Problem 1.1.9 - Voltage Divider: Calculations With Actual Component Values

Current in the series circuit using the actual values;

$$R_{tot} = R_1 + R_2$$
$$R_{tot} = 465\ \text{k}\Omega + 10.2\ \text{k}\Omega = 475.2\ \text{k}\Omega$$
$$I = \frac{V}{R}$$
$$I = \frac{26.37V}{475.2\ \text{k}\Omega}$$
$$\boxed{I = 5.54 * 10^{-5}\ \text{A} = 55.4\ \mu A}$$

The difference between the actual calculated values and nominal calculated values is 5.4 µA or about 10%.

Voltage at point A using the actual values;

$$V_A = 26.37\ \text{V}\frac{10.2\ \text{k}\Omega}{465\ \text{k}\Omega + 10.2\ \text{k}\Omega}$$
$$V_A = 26.37\ \text{V}\frac{10.2\ \text{k}\Omega}{475.2\ \text{k}\Omega}$$
$$\boxed{V_A = 0.566\ \text{V}}$$

The difference between the actual and nominal calculated values is 0.066 V or about 13%.

Problem 1.1.10 - Voltage Divider: Voltage Measurement

The measured voltage value at point a was;

$$\boxed{V_A = 0.56546\ \text{V}}$$
$$Range = 1\ \text{V}$$

Then we use the following formula;

$$Accuracy = 0.012\%\ of\ value + 0.004\%\ of\ range$$
$$Accuracy = \frac{0.012}{100} * 0.56546\ \text{V} + \frac{0.004}{100} * 1\ \text{V}$$
$$\boxed{Accuracy = 1.08 * 10^{-4}\ \text{V}}$$

Voltage calculated in Problem 1.19: V_A=0.566 V. According to this our experimental value was 9.5*10^-4 or 0.095% off from the calculated value which is slightly outside of the measurement uncertainty.

Problem 1.1.11 - Voltage Divider: Current Measurement

The measured current was;

$$\boxed{I = 0.0555\ \text{mA}}$$
$$Range = 1\ \text{mA}$$

Then we use the same formula;

$$Accuracy = 0.012\%\ of\ value + 0.004\%\ of\ range$$
$$Accuracy = \frac{0.012}{100} * 5.55 * 10^{-5}\ \text{A} + \frac{0.004}{100} * 1 * 10{-}3\ \text{A}$$
$$\boxed{Accuracy = 4.666 * 10^{-8}\ \text{A}}$$

The current calculated in Problem 1.19: I=5.54*10^-5 A. According to this our measured value was off by 1.80*10^-3 or about 0.18% off from the calculated value which was outside of the measurement uncertainty.

Problem 1.1.12 - Voltage Divider: Power Calculations

a) Power dissipated by a resistor is given by the following formula;

$$P = I^2 R$$

We use R_1=470 kΩ, R_2=10 kΩ and I=50 µA

$$P_1 = I^2 R_1$$
$$P_1 = 50\ \mu A^2 470\ k\Omega$$
$$P_1 = 0.001175\text{W}$$

$$P_2 = I^2 R_2$$
$$P_2 = 50\ \mu A^2 10\ k\Omega$$
$$P_2 = 2.5 * 10^-5\text{W}$$

Since both P_1 and P_2 are less than 1/4W they are rated for their respective power dissipation.

b) Ohm's Law gives us;

$$P = I^2 R$$
$$P = \frac{V^2}{R}$$

As we can see, holding V constant;

$$P \propto \frac{1}{R}$$

Then we know we would need to decrease the resistance of both resistors to approach the power rating.

c) If we were to set both resistors to their maximum power at 1/4W and multiply each resistance by the same factor 'x';

$$I_1^2 = \frac{0.25\text{W}}{470\ k\Omega * x}$$
$$I_2^2 = \frac{0.25\text{W}}{10\ k\Omega * x}$$

Maxing out R_1 will result in a smaller current than maxing out R_2. When we decrease resistance the current increases and to reach the maximum power rating first, the resistor with the lower current at maximum power output will reach that power output first, this is R_2=470 kΩ.

d) The factor we decrease resistances by is 1/x, in order to find this, we recognize that the potential difference across both resistors remains the same;

$$P_1 = 0.25 \text{ W} = \frac{V_1^2}{R_1}$$
$$0.25 \text{ W} = \frac{23.5 \text{ V}}{470\text{k}\Omega * x}$$
$$x = 4.7 * 10^{-}3$$

So we'd have to decrease both resistors by a factor of ~ 213.

Problem 1.1.13 - Scope Practice

Refer to signature card, figure 1

Problem 1.1.14 - Generating Waveforms

Refer to signature card, figure 1

Problem 1.1.15 - Measurement of DC and AC voltages

a) The DMM measures an output voltage of,

$$\boxed{V_{out} = 5.173 \text{ V}}$$
$$Range = 10 \text{ V}$$

The estimated error is,

$$Accuracy = \frac{0.012}{100} * 5.173 \text{ V} + \frac{0.004}{100} * 10 \text{ V}$$
$$Accuracy = 1.02 * 10^{-3} \text{ V} = \pm 1.03 \text{ mV}$$

b) The scope measures an output voltage of,

$$\boxed{V_{out} = 5.20 \text{ V}}$$

The oscilloscope manual lists an estimated error of 3% in measurements, therefore;

$$Error = \frac{3}{100} * 5.2 \text{ V}$$
$$Error = \pm 0.156\text{V}$$

c) There was no variation in our measurements between channel 1 and channel 2 however the changing the V/div settings resulted in incremental changes for 0.5 V/div.

d) The 0 V level and the 1 V/div settings give the optimal measurement.

Problem 1.1.16 - Supply Noise and the Scope AC Setting

Refer to signature card, figure 1

Problem 1.1.17 - RMS Voltages: Calculations

Amplitude and peak-peak Voltage vary by a factor of 2. In order to find the RMS voltage we use the following formula;

$$V_{RMS} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [V(t)]^2 dt}$$

a) A sine wave is given by the formula V(t)=V_0sin(ωt) therefore the RMS conversion factor is as follows;

$$V_{RMS} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} V_0^2 \sin^2 \omega t \, dt}$$
$$V_{RMS} = \sqrt{V_0^2 \frac{\omega}{2\pi}\frac{\pi}{\omega}}$$
$$\boxed{V_{RMS} = \frac{V_0}{\sqrt{2}}}$$

b) A triangle wave is given by V(t)=$V_0\frac{t}{T}$ therefore we have the following RMS coefficient;

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V_0^2 [\frac{t}{T}]^2 \, dt}$$
$$V_{RMS} = V_0 \sqrt{\frac{1}{T^3}\int_0^T t^2 \, dt}$$
$$V_{RMS} = V_0 \sqrt{\frac{1}{T^3}\frac{T^3}{3}}$$
$$\boxed{V_{RMS} = \frac{V_0}{\sqrt{3}}}$$

c) A square wave is given by V(t)=V_0 when 0<t<T, therefore the RMS factor is as follows;

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V_0^2 \, dt}$$
$$V_{RMS} = V_0 \frac{1}{T} T$$
$$\boxed{V_{RMS} = V_0}$$

Wave	Amplitude	$V_{p\text{-}p}$	RMS Factor
sine	1 V	2 V	$\frac{1}{\sqrt{2}}$
triangular	1 V	2 V	$\frac{1}{\sqrt{3}}$
square	1 V	2 V	1

Table 3: Conversion table for RMS voltages in 1.17 a, b, and c

Wave	Amplitude	Scope $V_{p\text{-}p}$	Scope V_{RMS}	DMM V_{RMS}
sine	1.05 V	2.10 V	0.714 V	713 mV
triangular	1.02 V	2.04 V	0.579 V	578 mV
square	1.03 V	2.06 V	1.0021 V	1 V

Table 4: Measured voltages for 1kHz wave of each type in 1.17 a, b and c

Problem 1.1.18 - RMS Voltages: Measurements

The table 5 below shows the RMS scope and DMM voltages measured. The figure 8 shows the plot of DMM RMS voltage and Scope RMS voltage against frequency between 10 Hz and 10 MHz.

Frequency	Scope RMS	DMM RMS
10 Hz	714 mV	715.9 mV
15 Hz	714 mV	715.9 mV
20 Hz	714 mV	715.9 mV
100 Hz	714 mV	715.7 mV
500 Hz	714 mV	715.0 mV
1 kHz	714 mV	714.6 mV
5 kHz	714 mV	714.5 mV
10 kHz	714 mV	714.6 mV
50 kHz	708 mV	714.4 mV
100 kHz	704 mV	714.0 mV
500 kHz	704 mV	748.74 mV
1 MHz	702 mV	1044.1 mV
2 MHz	684 mV	93.3 mV
3 MHz	660 mV	3.14 mV
4 MHz	636 mV	0.00 V
5 MHz	618 mV	0.00 V
6 MHz	610 mV	0.00 V
7 MHz	612 mV	0.00 V
8 MHz	622 mV	0.00 V
9 MHz	642 mV	0.00 V
10 MHz	666 mV	0.00 V

Table 5: RMS voltage measurements between 10 Hz and 10 MHz

The DMM is most accurate between 10 Hz and up to just under 500 kHz where the scope and DMM agree to 5.8%. According to the DMM specifications it is accurate up to 300 kHz so it certainly performs within its specs. Data should be taken at geometric rather than arithmetic intervals because the DMM accuracy breaks down at high frequencies so in order to see that break down within our number of data points we needed to take data geometrically.

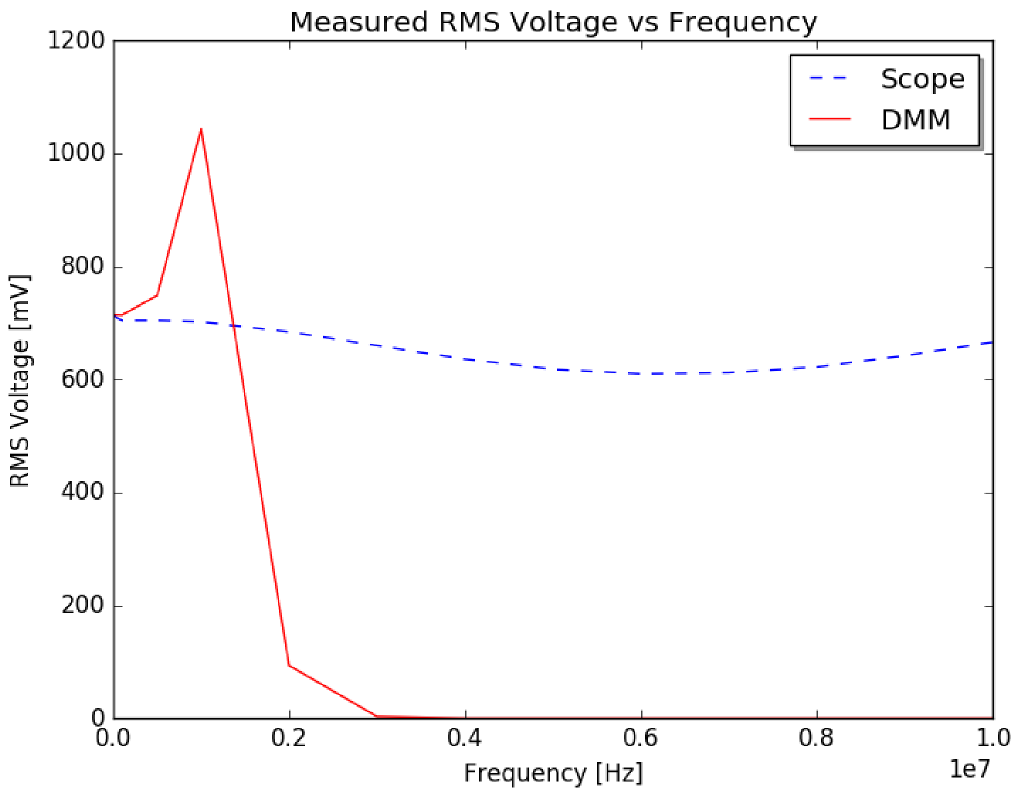


Figure 8: Measured RMS Voltage for Problem 1.1.18

Problem 1.1.19 - Scope AC Settings Distortions

Refer to signature card, figure 1.

Part 2

Problem 1.2.1 - Thévenin Analysis

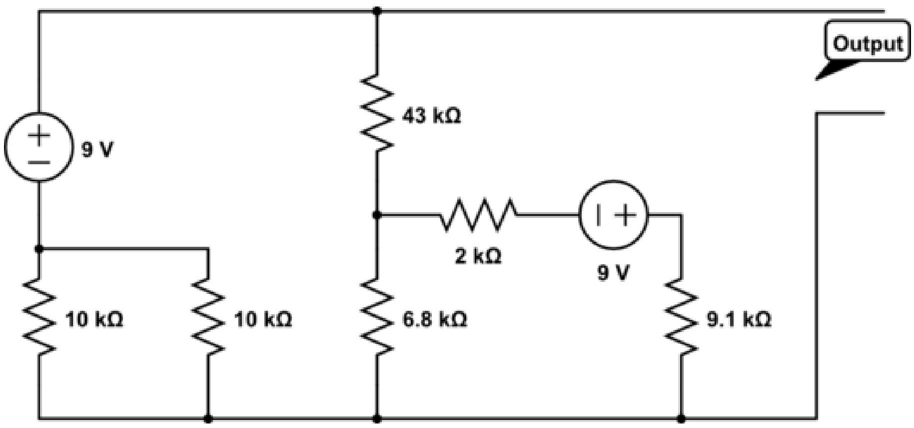


Figure 9: Blackbox circuit with equivalent resistances

We measured;

$$V_{open} = 4.37 \text{ V}$$
$$I_{short} = 1.49 \text{ mA}$$
$$R_{thévenin} = \frac{V_{open}}{I_{short}}$$
$$\boxed{R_{thévenin} = 3.17 \text{ k}\Omega}$$

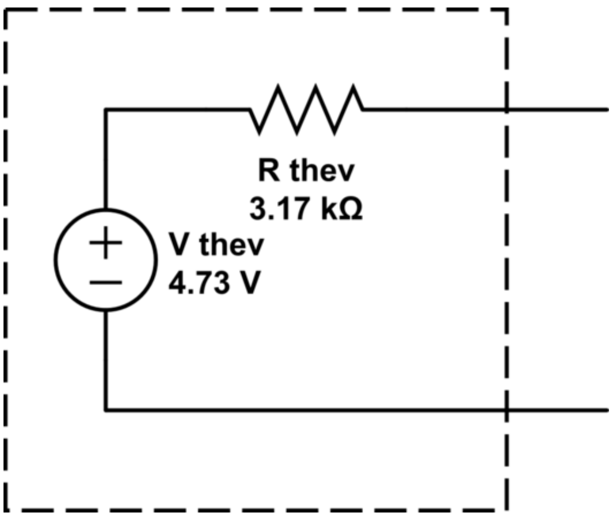


Figure 10: Blackbox circuit with Thévenin equivalent resistance

Resistance / Ω	Voltage / V	Current / mA
100	0.1435	1.447
330	0.4433	1.353
1k	1.122	1.139
3.3	2.431	0.7260
10k	3.610	0.3530
33k	4.316	0.1296
100K	4.421	0.0445

Table 6: Blackbox circuit measurements

The following plot figure 11 shows the real measured current against voltage and the predicted Thévenin circuit current against voltage given by;

$$I_{thev} = 1.49 \text{ mA} - \frac{V}{3.17\text{k}\Omega}$$

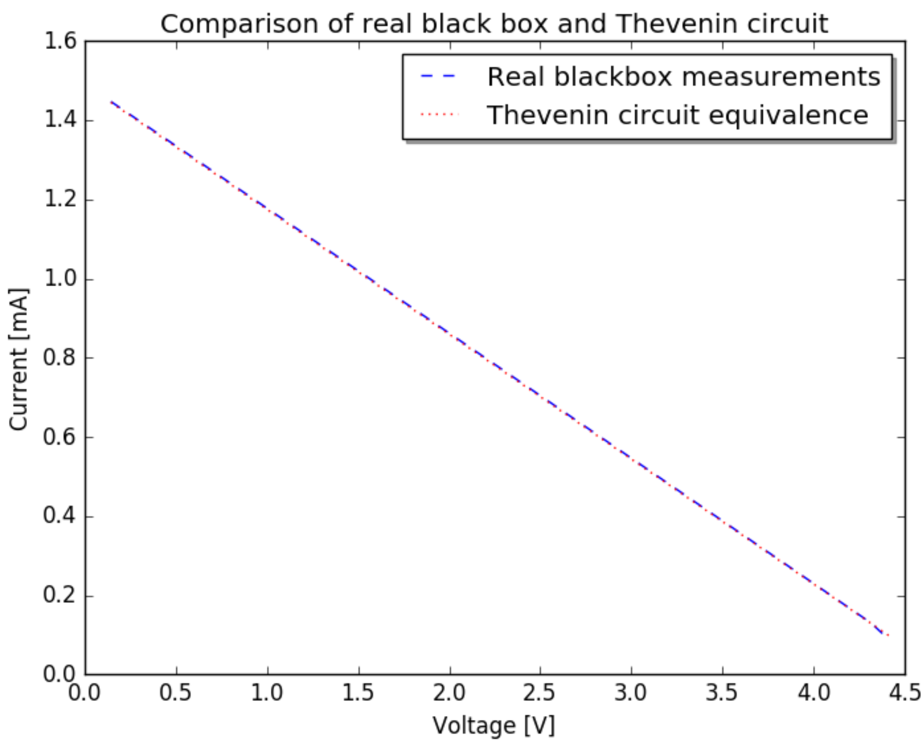


Figure 11: Measured RMS Voltage for Problem 1.1.18

We can see from the plot that the Thévenin equivalent circuit provides a very accurate prediction of the actual current and voltage from the real blackbox circuit.
Shorting the terminals of the battery holders produces a resistance of 11.61 kΩ, this is not the same as R_{thev} = 3.17 kΩ likely due to improper connections.

Problem 1.2.2 - Pickup Noise

a) Touching the end of the red lead yields a peak to peak voltage of between 300 mV and 400 mV. It appears to be a sine wave, this is a result of small oscillating signals meeting high resistance in our finger when we touch it and being bounced back.

b) Pinching the insulation of the minigrabber yields some very low amplitude noise but no clear signal.

c) After creating the "loop antenna" and playing about with the scope settings for a bit we found what looked like a rough sinusoidal interface in a low amplitude, high frequency envelope.

d) The loop antenna picks up very high frequency (radio and microwave) signals and displays them on the scope, what we saw could be a result of radio signals such as from cell phones, possible CMB although the loop is probably too weak to pick that up and small leaked voltages from our circuit elements.

Problem 1.2.3 - Scope Input Impedance

We used a driving voltage of 1 V peak to peak, the input voltage against resistance is given in the table 7 below.

Resistance / Ω	V_{in} / mV
0 Ω	1030
200 kΩ	872
470 kΩ	720
820 kΩ	588
1 MΩ	530
2.2 MΩ	350
4.7 MΩ	200
10 MΩ	124
20 MΩ	76

Table 7: Blackbox with external resistor

From Ohm's law, we get the following equation;

$$I_{in} = \frac{V_{ext}}{R} - \frac{V_{in}}{R}$$

We exclude the first data point because that would give us infinite current, and the input voltage against current plot using the above equation and data is shown below in figure 12

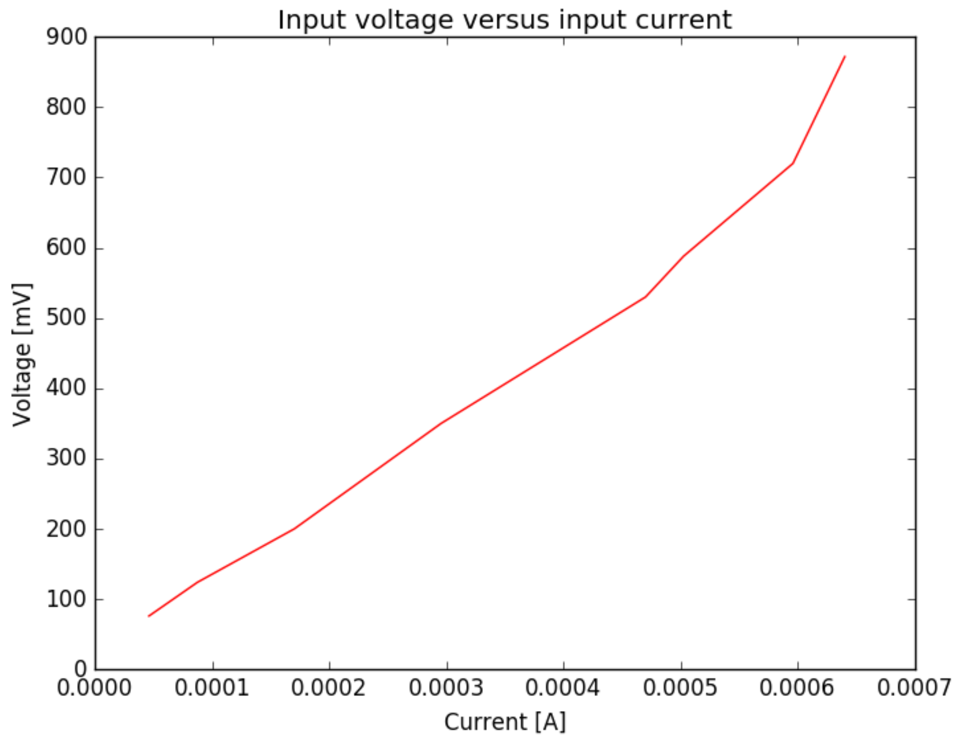


Figure 12: Input voltage versus input current for varied resistances

The simple formula for input impedance is as follows;

$$Z_{in} = \frac{V_{in}}{I_{in}}$$

The data fits the theory close to the center of plot because the above equation does not hold for very low or very high resistances.

Taking two data points close to the middle we get;

$$\boxed{Z_{in} = 1.37 \text{ M}\Omega}$$

We note that these resistors have a 5% accuracy and the accuracy of the voltages does not factor since it cancels out so our measured input impedance is accurate to about 5%.

Problem 1.2.4 - Scope Probe Input Impedance

Resistance / Ω	V_{in} / mV
0 Ω	1030
200 kΩ	856
470 kΩ	696
820 kΩ	544
1 MΩ	484
2.2 MΩ	302
4.7 MΩ	161
10 MΩ	88.8
20 MΩ	47.4

Table 8: Blackbox with external resistor measurements with scope probe

Since the scope probe functions by attenuating signals by a factor of 10 we multiply our measured voltages by a factor of 10 and plot them using the same equation from Problem 1.2.3 as in figure 13 below.

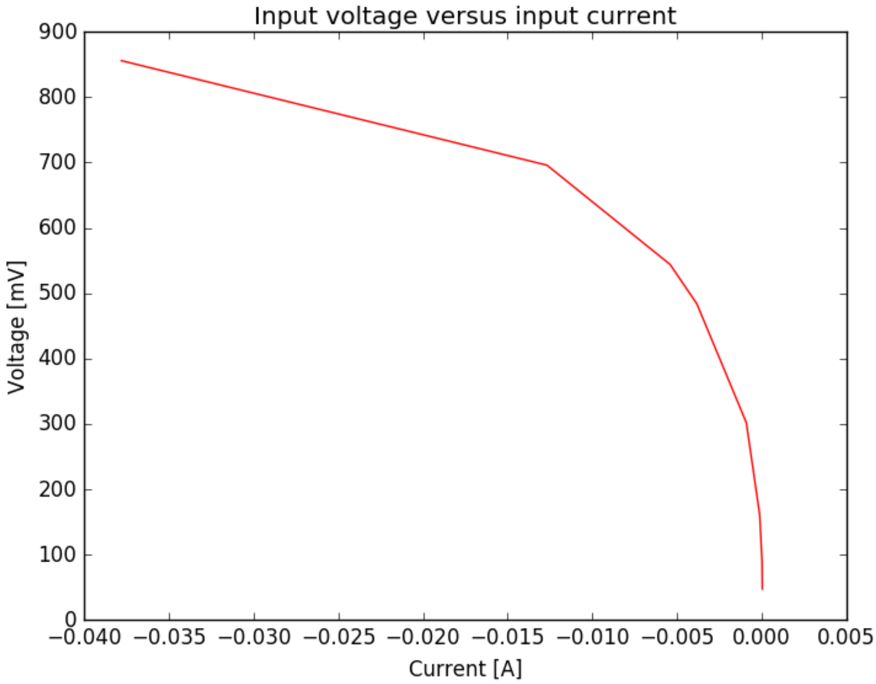


Figure 13: Input voltage versus input current for varied resistances and using a scope probe

Once again we see that this method does not work well for very low resistances so we take the slope of the graph for high resistance values and we get the following input impedance;

$$Z_{in} = 0.95 \text{ M}\Omega$$

This is much smaller than the input impedance using just the scope alone.

Problem 1.2.5 - Output Impedance

There was likely something wrong with our setup with this problem since the High Z and 50 Ω settings gave identical output voltages.

Resistance / Ω	High Z V_{out} / V	50 Ω V_{out} / V
0	2.08	2.08
10	0.354	0.354
50	1.08	1.08
200	1.62	1.62
500	1.88	1.88
680	1.94	1.94
1000	1.94	1.94
1200	2.00	2.00
1500	2.00	2.00
1800	2.04	2.04
2000	2.04	2.04

Table 9: High Z and 50 Ω setting output voltages for varied resistors

The figure 14 below shows the output voltage using the same methods as in Problems 1.2.3 and 1.2.4.

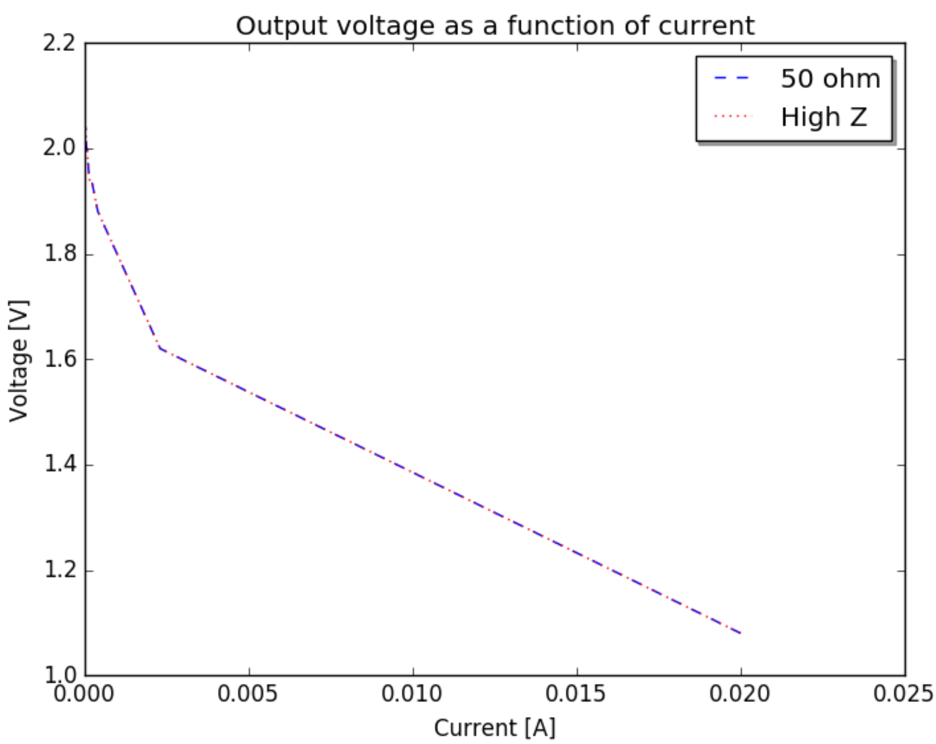


Figure 14: Output voltage versus current for High Z and 50 Ω settings

Our plot is linear across all ranges except at high resistances so we can once again use the slope method and take the negative value to find output impedance and it is the same for both High Z and 50 Ω;

$$Z_{out} = 30.5\ \Omega$$

Problem 1.2.6 - RC Circuits: Measurement Techniques

We set up the high pass filter shown in figure 15 and the scope output after auxiliary triggering and setting up averaging is shown in figure 16.

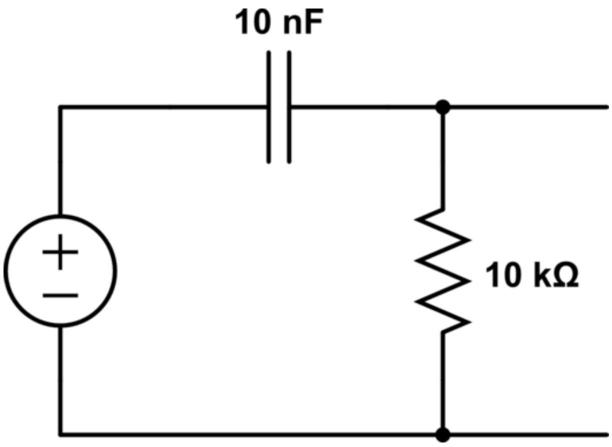


Figure 15: High pass filter

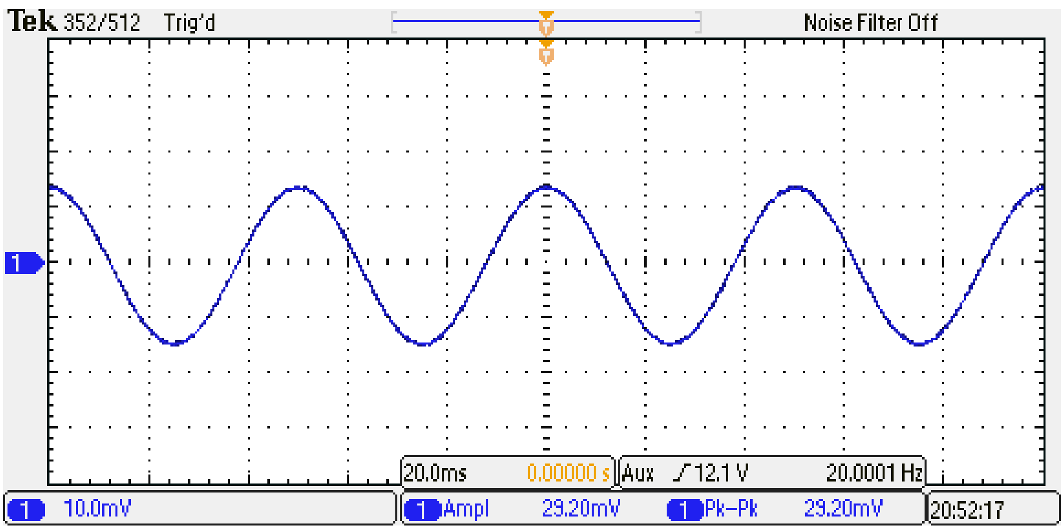


Figure 16: Scope output

Problem 1.2.7 - RC Circuits: Amplitude Measurements

We use a driving amplitude of 1 V peak to peak and measure V_{out} for frequencies between 10 Hz and 20 kHz

Frequency	V_{out} / mV
10 Hz	7.54
50 Hz	33.42
100 Hz	66.02
500 Hz	305.5
1 kHz	539.1
5 kHz	947.5
10 kHz	980.5
15 kHz	985.5
20 kHz	988.0

Table 10: Output voltages from high pass filter over a range of frequencies

We use V_{in}= 1 V and we get the following plot where the roll off point is marked in green at a frequency of about 2500 Hz;

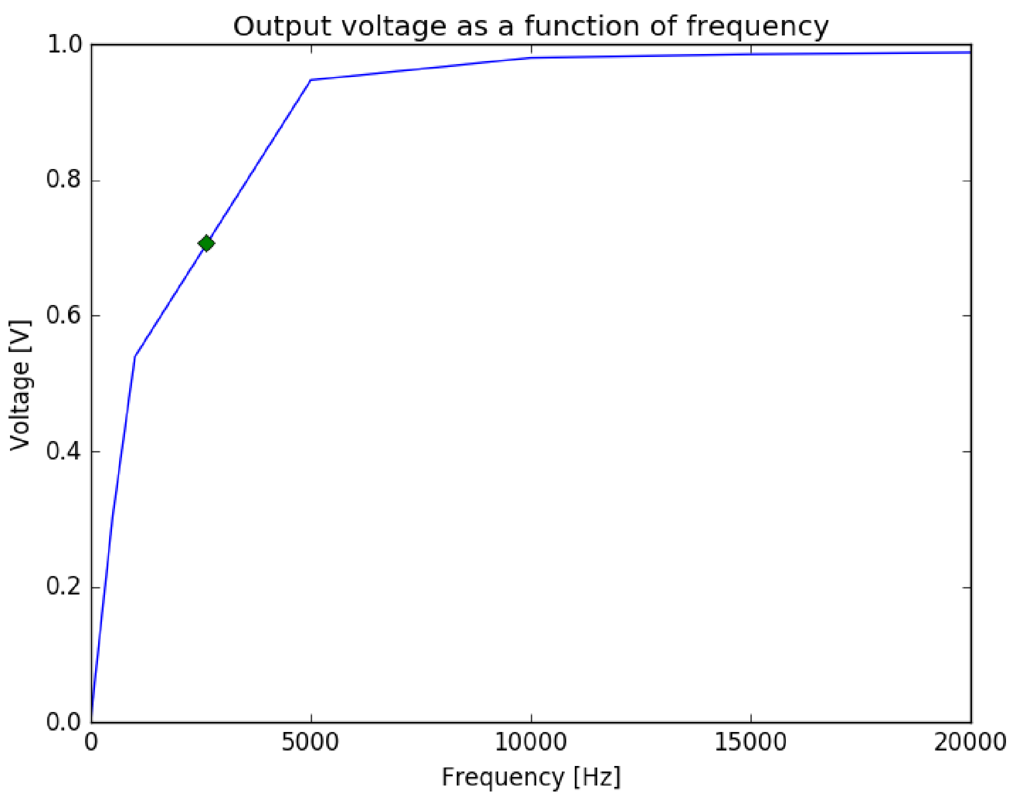


Figure 17: RC circuit output voltage and cut off frequency

Problem 1.2.8 - RC Circuits: Phase Measurements

Frequency	Phase Difference / °
10 Hz	90
50 Hz	74.4
100 Hz	58.1
500 Hz	17.01
1 kHz	6.621
5 kHz	-0.049
10 kHz	-0.065
15 kHz	-1.59
20 kHz	-3.60

Table 11: Phase differences over a range of frequencies

In order to be able to plot both sets of data on the same plot we need to normalize the phase differences to 1 by dividing through by 90 °

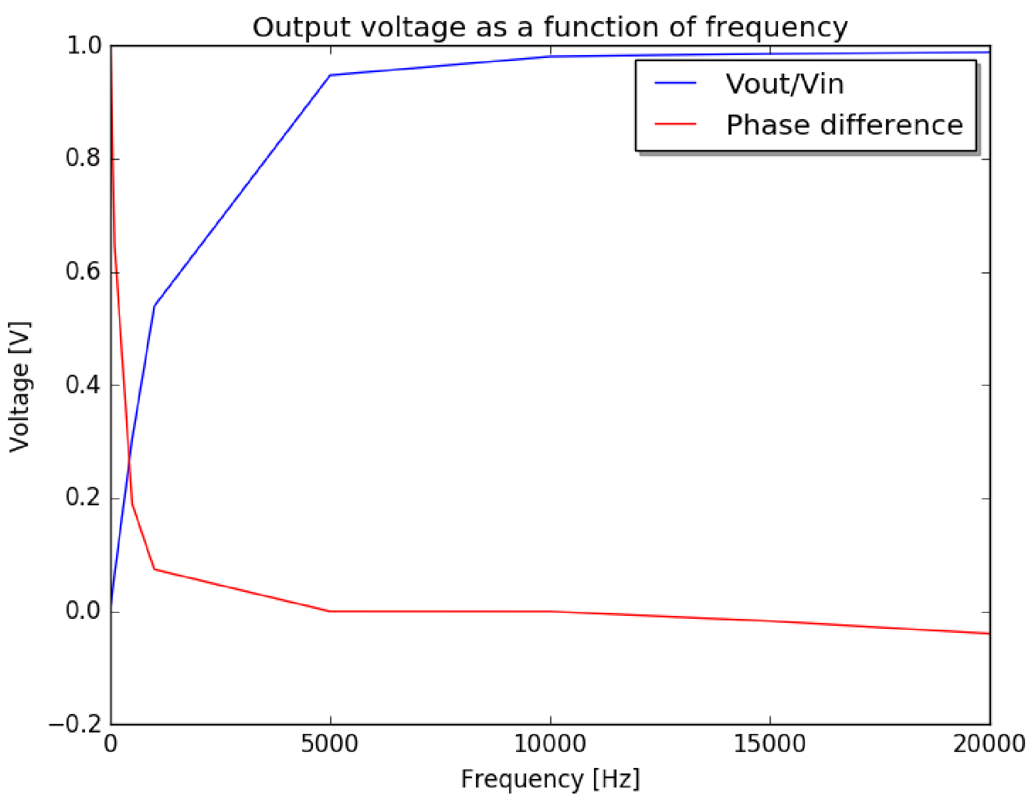


Figure 18: Phase differences and V_{out}/V_{in} for a range of frequencies

Problem 1.2.9 - Analysis

We use the following formula to get the table 14 of measured gain and frequency below;

$$G = 20\ log_{10}\left|\frac{V_{out}}{V_{in}}\right|$$

Frequency	Gain / dB
10 Hz	-42.45
50 Hz	-29.52
100 Hz	-23.61
500 Hz	-10.30
1 kHz	-5.367
5 kHz	-0.4684
10 kHz	-0.1710
15 kHz	-0.1269
20 kHz	-0.1049

Table 12: Output voltages from high pass filter over a range of frequencies

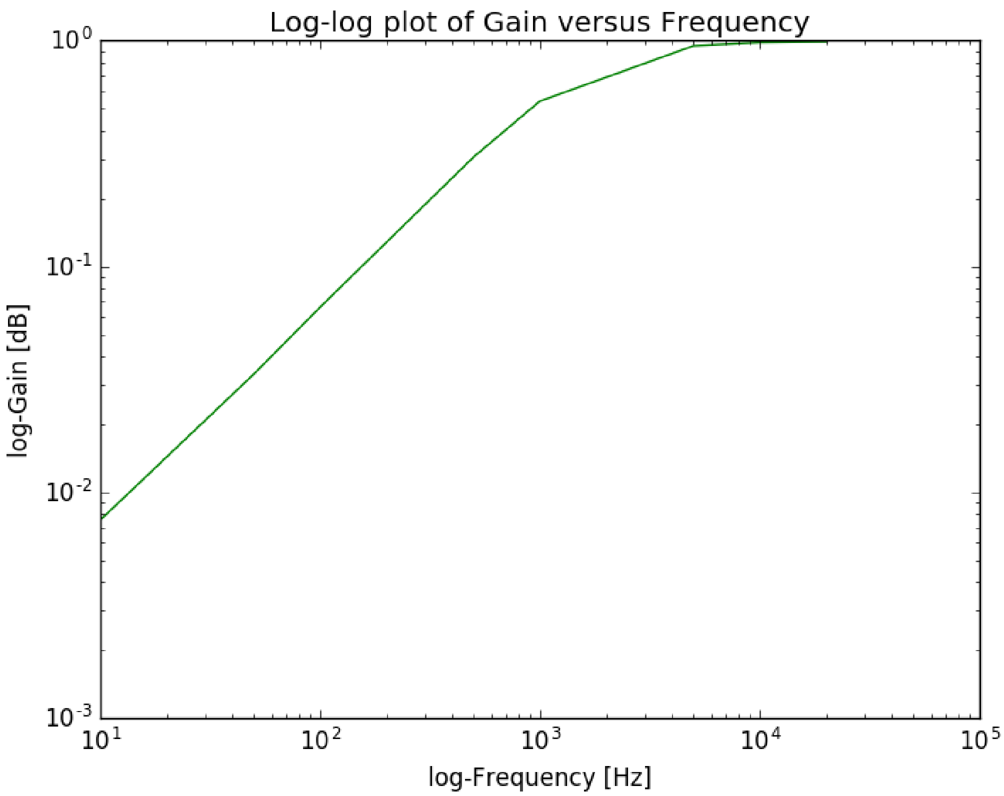


Figure 19: Bode Plot

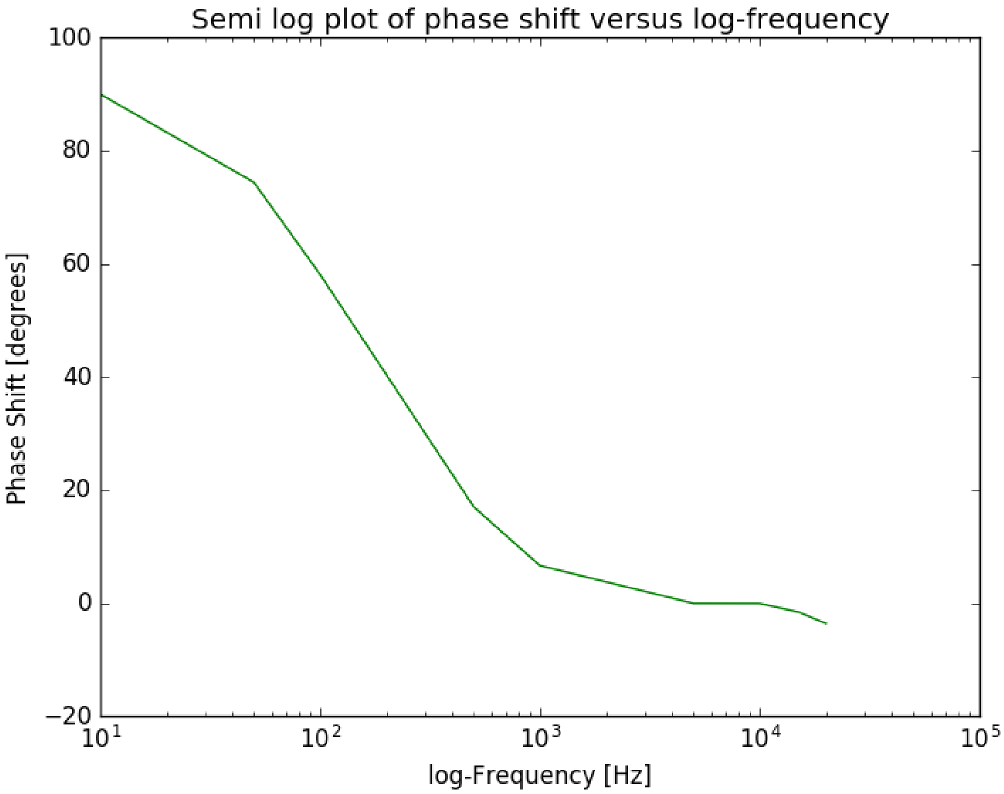


Figure 20: Phase shifts against log-Frequency Plot

The calculated transfer function for a highpass filter is given by the following equation;

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{2\pi fRC}{\sqrt{1+(2\pi fRC)}}$$

Then using our frequencies from Problem 1.2.7;

Frequency	$\lvert V_{\text{out}}/V_{\text{in}}\rvert$
10 Hz	0.0005
50 Hz	0.0025
100 Hz	0.005
500 Hz	0.025
1 kHz	0.05
5 kHz	0.25
10 kHz	0.5
15 kHz	0.75
20 kHz	1.00

Table 13: Output voltages from high pass filter over a range of frequencies

Then we get the following plot of calculated and measured transfer functions. We note that the measured role off point occurs at a lower frequency of the calculated roll off.

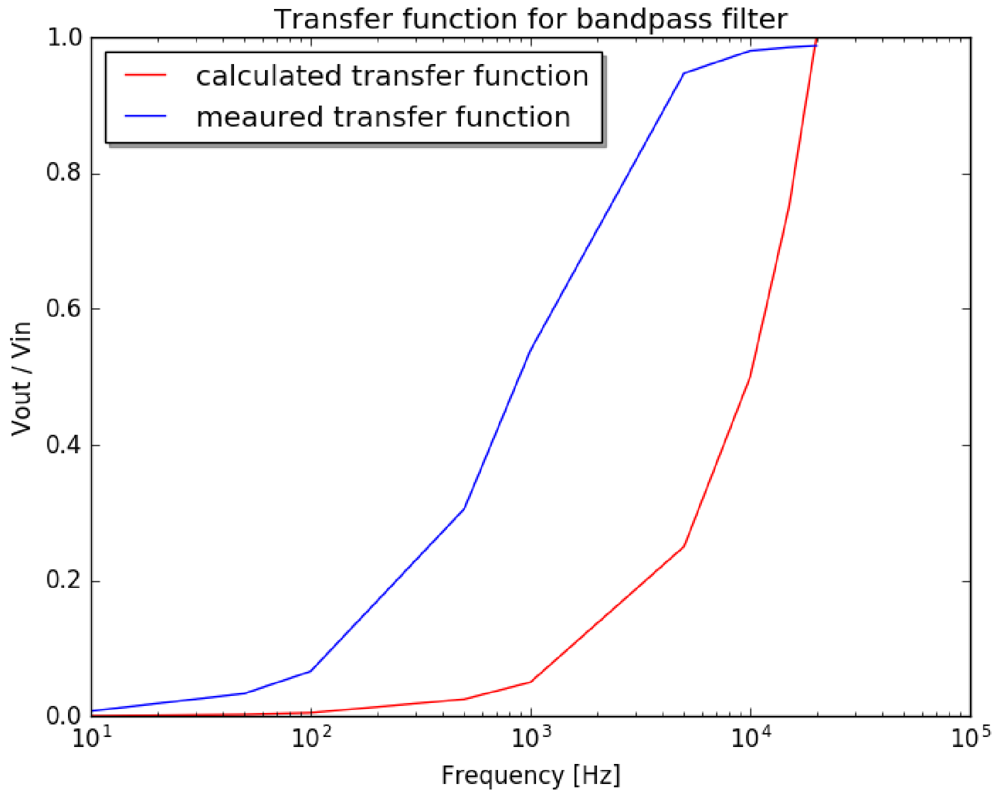


Figure 21: Calculated and measured transfer function for high pass filter

Problem 1.2.9 - Bandpass Filter

The figure 22 below shows the band pass we constructed with appropriate resistances and capacitances to give rolloff points of 500 Hz and 10 kHz. It is a low pass filter with a cutoff frequency of 10 kHz in series with a high pass filter with a cutoff frequency of 500 Hz. We chose R_1 to be less than R_2 and in order to find the appropriate capacitances we used to following equation;

$$C = \frac{1}{2\pi R f}$$

Where R is our selected resistance and f is the required cutoff frequency.

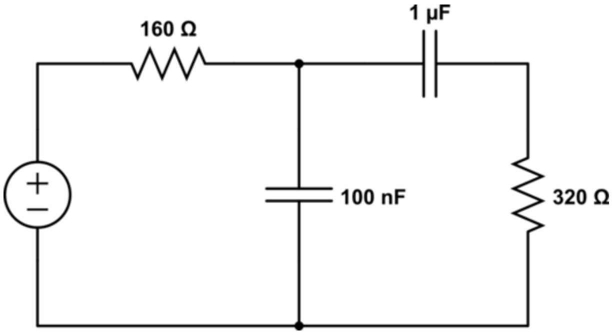


Figure 22: Bandpass filter

Frequency / Hz	V / V
10	0.240
100	0.570
500	1.17
1k	1.26
2k	1.22
5k	0.990
7k	0.840
10k	0.670
20k	0.440
50k	0.260
500k	0.200

Table 14: Output voltages from high pass filter over a range of frequencies

The following figure 23 is the transfer function for the range of frequencies we scanned using our bandpass filter.

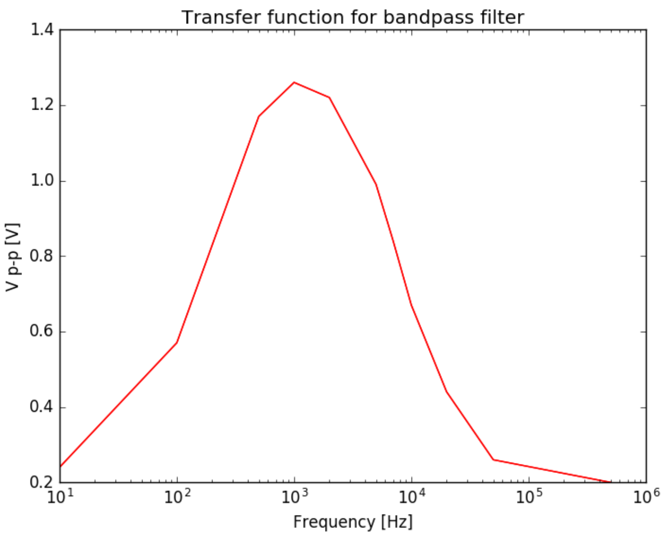


Figure 23: Bandpass filter transfer function

Problem 1.2.10 - Cable Propagation Measurements

a)

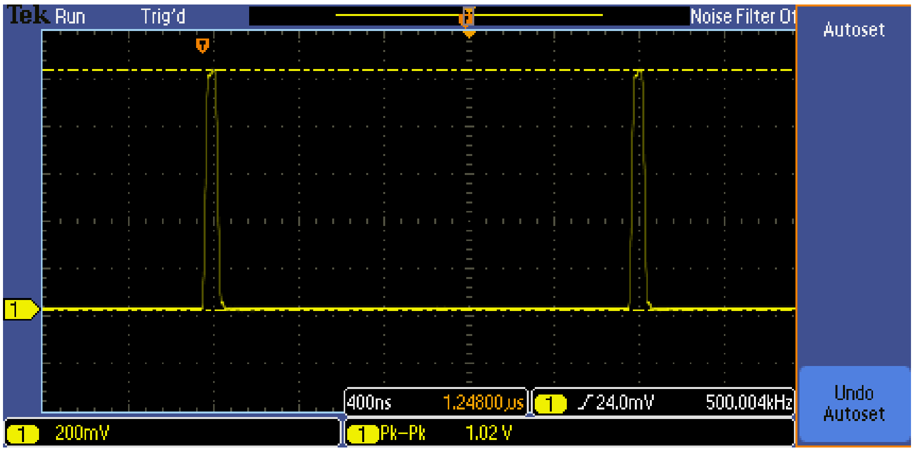


Figure 24: 1 V pulses

b) Attaching the BNC terminator makes the signal amplitude decrease by about half.

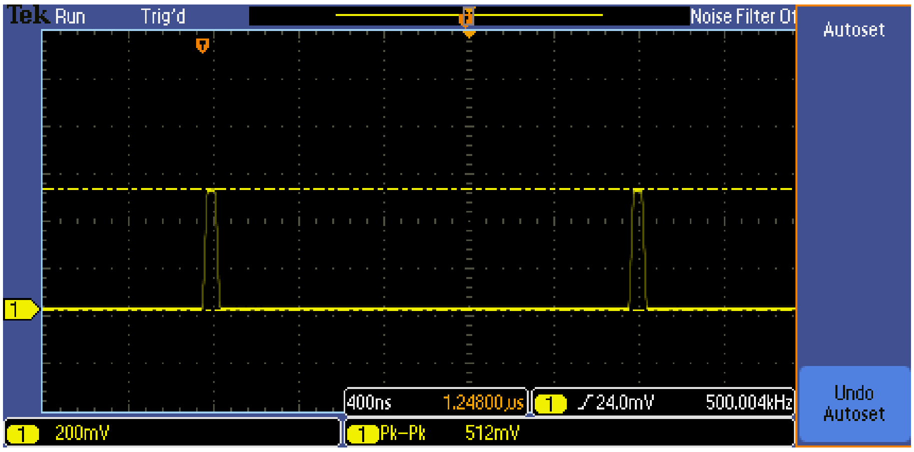


Figure 25: Signal with 50 Ω terminator

Shorting the scope input signal makes the signal almost disappear.

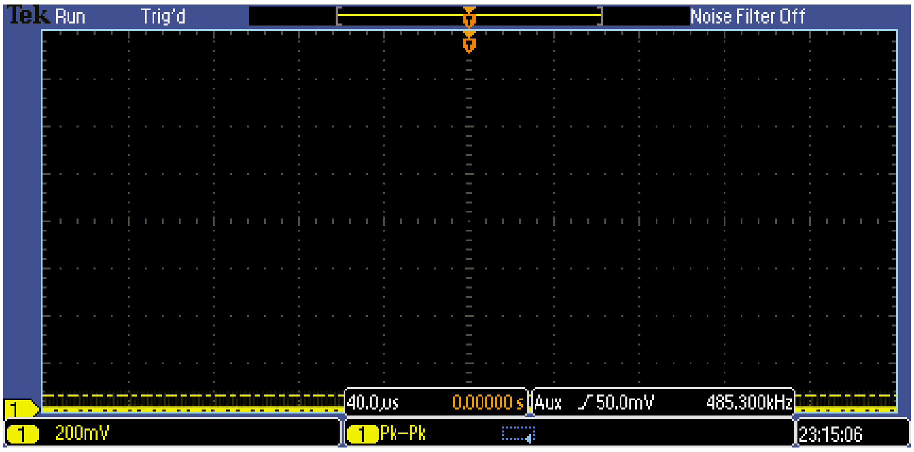


Figure 26: Signal with shorted input

c)

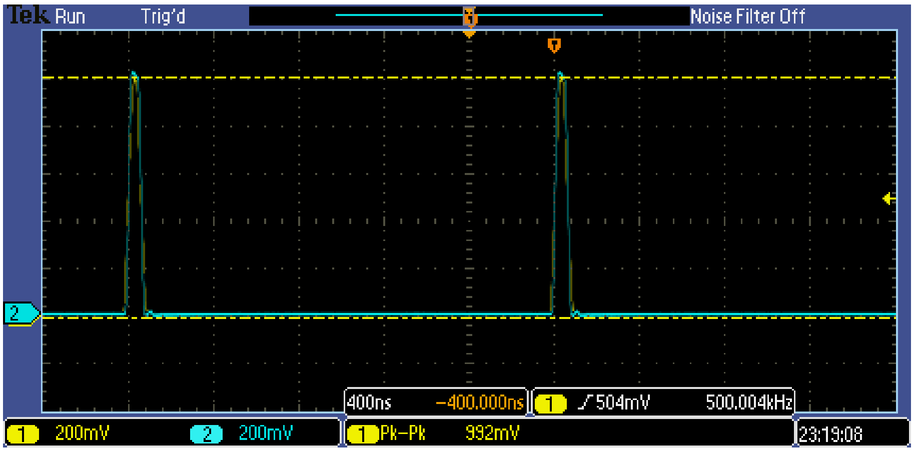


Figure 27: Signal with BNC connecting channel 1 and 2

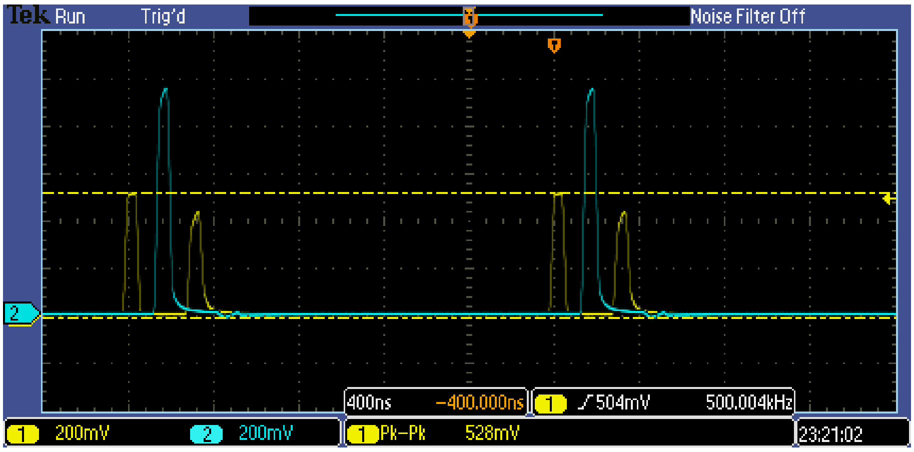


Figure 28: Signal with 100ft BNC connecting channel 1 and 2

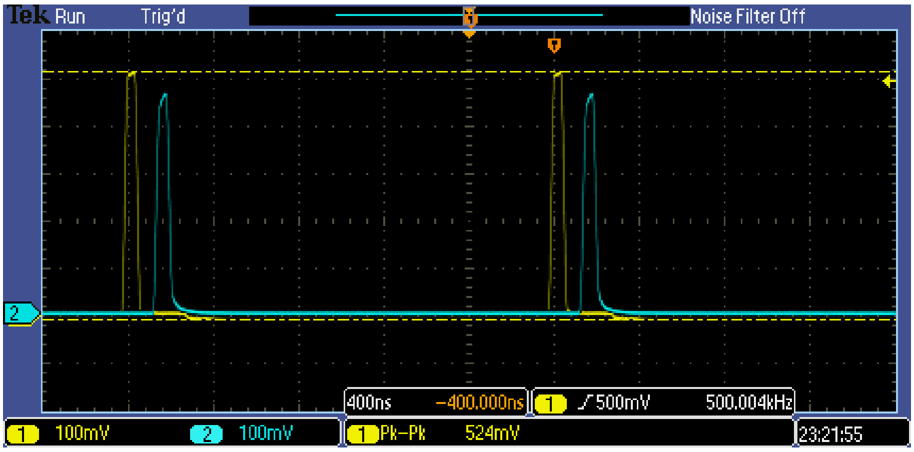


Figure 29: Signal with 100ft BNC connecting channel 1 and 2 and 50 Ω terminator on far end

With the 50 Ω terminator connected to the T on the far end we see both signals being cleaned up and extraneous signals are not seen.

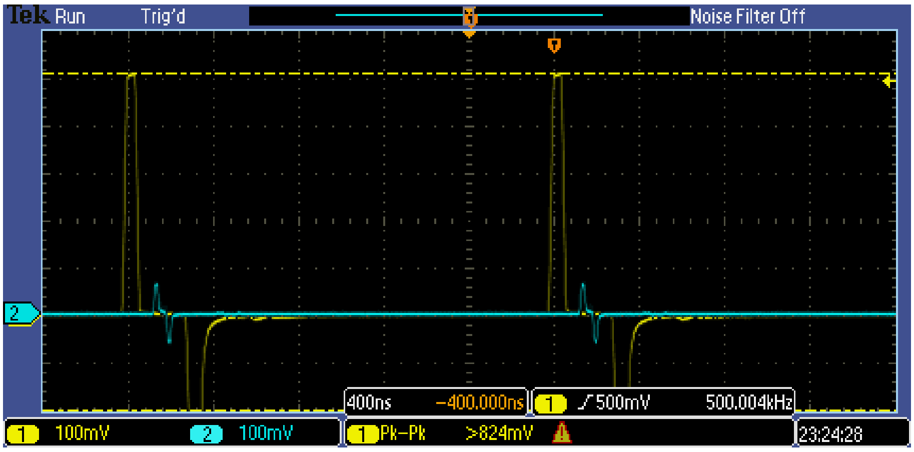


Figure 30: Signal with 100ft BNC connecting channel 1 and 2 and short on far end

Even when shorted at the far end, the signal has a relatively longer distance to travel through the 100ft BNC which is why we see the delayed pulse.

The signals at the near are upright when there is resistance at the far end, this causes the signal to be reflected and it bounces back but is not inverted. The signals are upside down when the far end is shorted, this is because the signal flips it's orientation and is bounced back when it is shorted.
d)

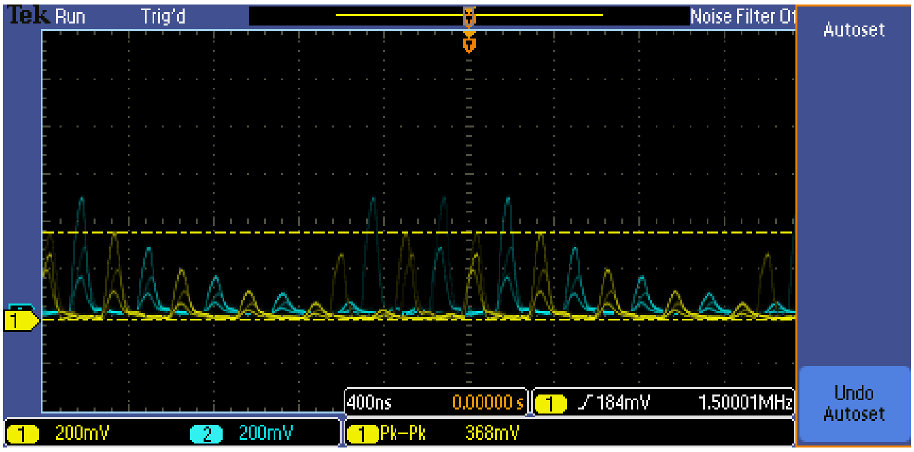


Figure 31: Signal with far end connected normally and a 200 Ω series resistor on signal generator end

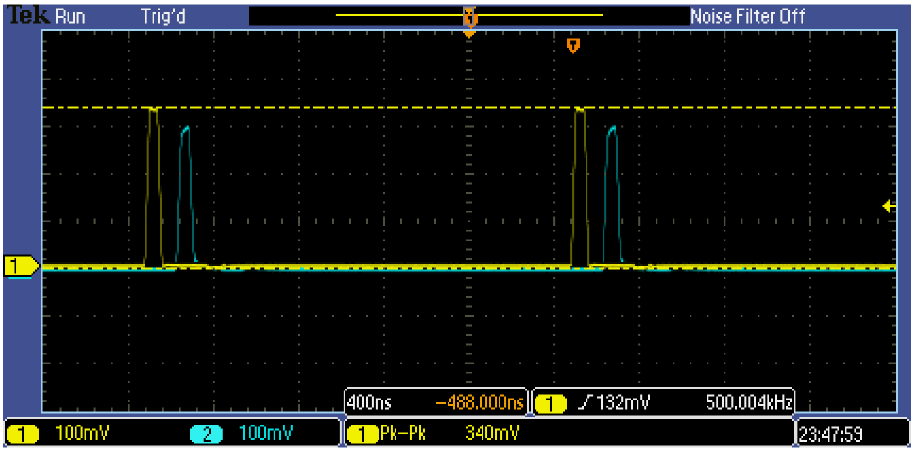


Figure 32: Signal with far end with 50 Ω terminator and a 200 Ω series resistor on signal generator end

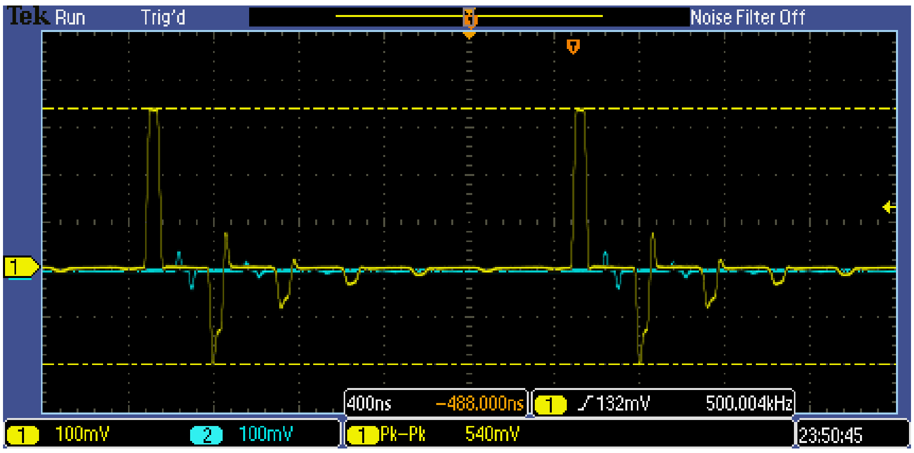


Figure 33: Signal with far end with shorted and a 200 Ω series resistor on signal generator end

e)

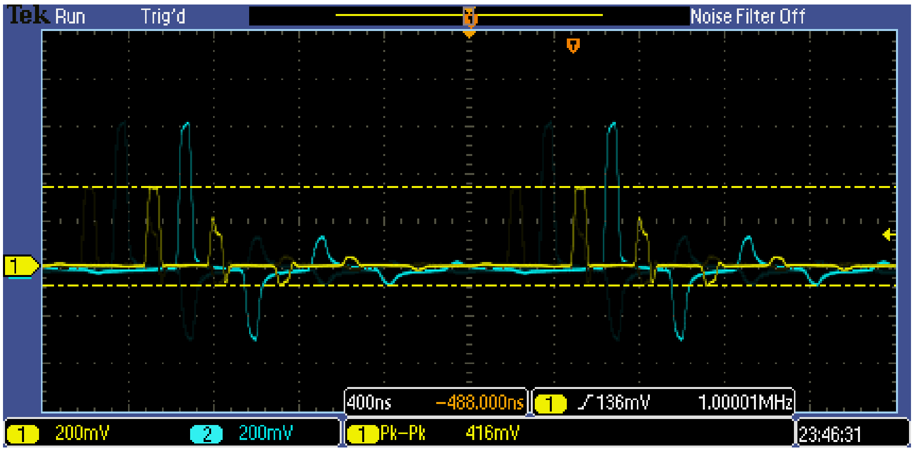


Figure 34: Signal with far end connected normally and a 20 Ω resistor in parallel on signal generator end

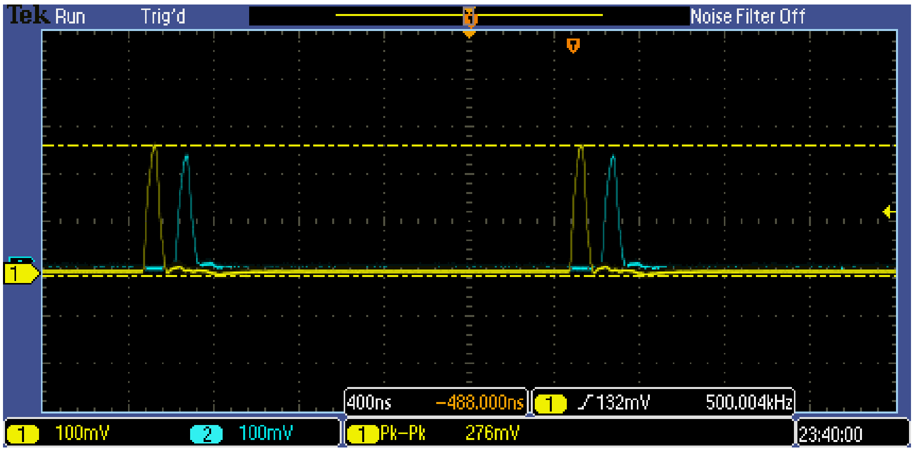


Figure 35: Signal with far end with 50 Ω terminator and a 20 Ω resistor in parallel on signal generator end

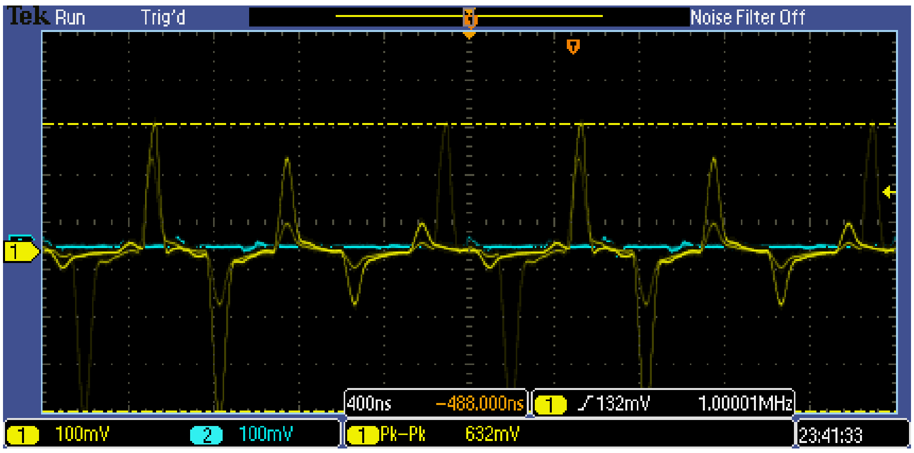


Figure 36: Signal with far end with shorted and a 20 Ω resistor in parallel on signal generator end

f) To approach this problem we tried to match impedances on both ends of the cable. We attached a 300 Ω resistor on the end of the twin cable and a 200 Ω resistor in series on the signal generator end. This set up gave the cleanest signal.

Problem 1.2.11 - Cable Propagation Calculations

We know that signals propagate at 2/3 the speed of light, and the BNC cable we used was 100ft long. To find the time it takes the signal to travel the cable;

$$t = \frac{d}{v}$$
$$t = \frac{30.48 \text{ m}}{\frac{2}{3}c}$$
$$\boxed{t = 1.524 * 10^{-7}\ s = 152\ ns}$$

This is roughly the timescale of the frequency of the signal we were outputting this accounts for the delay we were seeing between channel 1 and channel 2.

We see extra pulses on the near end because the signal is reflected at the far end by the resistance it encounters. The pulses are upright when they meet resistance and flipped when the far end is shorted. This depends on the kind of boundary the signal hits, it is similar to how light behaves when it is being refracted. Resistors serve like a medium with a lower index of refraction and do not flip the wave while a short behaves like a medium with a higher index of refraction which will flip the wave when it hits it. The signal disappears when there is no resistance at all and the signal does not reflect back.

Problem 1.2.12 - Black Box Output Impendace Calculations

We have the following equation where V_{thev} is the "no load" output;

$$V_{thev} = V_{out} + Z_{out}I_{out}$$
$$Z_{out} = \frac{V_{thev} - V_{out}}{\frac{V_{out}}{R}}$$
$$Z_{out} = R\ [\frac{V_{thev}}{V_{out}} - 1]$$
$$Z_{out} = 1\ \text{k}\Omega\ [\frac{1\ V}{0.8\ V} - 1]$$
$$\boxed{Z_{out} = 250\ \Omega}$$

Problem 1.2.13 - Light Bulb Resistance

We know from Ohm's law;

$$
\begin{aligned}
P &= I^2 R \\
P &= \frac{V^2}{R} \\
P &= \frac{110^2 \text{ V}^2}{9 \ \Omega} \\
&\boxed{P = 1344 \text{ W}}
\end{aligned}
$$

A light bulb is not a linear circuit component because it's resistance varies with input voltage. Therefore the 100 W power rating is adequate for the bulb because its resistance will increase largely when 110 V are applied across it.