Lab 1 – Lab Policies, Procedures and Equipment

Objectives

- To execute the instructions of Lab 1 as provided for ECE 3410 from Canvas (https://usu.instructure.com/).
    - To prepare materials needed for the semesters' lab assignments.
    - To review techniques and procedures required for professional laboratory work.
    - To gain experience using the function generator, power supply, oscilloscope and multimeter located in the ECE Circuits Lab (EL 104).

Preparation

Component and Materials

- 10 kΩ resistor (1)
- 1 kΩ resistor (1)
- 1 nF capacitor (1)
- Solderless Breadboard/Superstrip (1)

Equipment

- Digital Multimeter (1)
- Oscilloscope (2 channels)
- Function generator (1)
- Banana-to-alligator cables (1 pair, red and black)
- BNC-to-BNC cable (2)
- BNC-to-alligator cable (1)
- Oscilloscope probe (2)

Pre-Lab Analysis

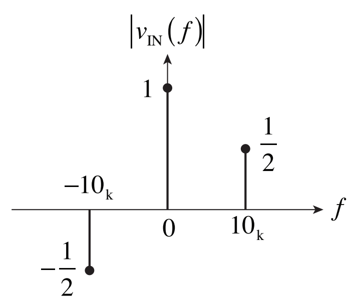
➤Analytical

Exercise 1

$$\Rightarrow_1 \quad v_{\text{IN}}(t) = 1 + 2\sin(2\pi f_0 t) \qquad f_0 = 10\text{ kHz}$$

$$\Rightarrow_2^{\text{FT}} \quad v_{\text{IN}}(f) = \delta(f) + \frac{1}{j2}\left[\delta(f - f_0) - \delta(f + f_0)\right]$$

$$\Rightarrow_3 \quad \left|v_{\text{IN}}(f)\right| = \delta(f) + \frac{1}{j2}\left[\delta(f - 10_{\text{k}}) - \delta(f + 10_{\text{k}})\right]$$



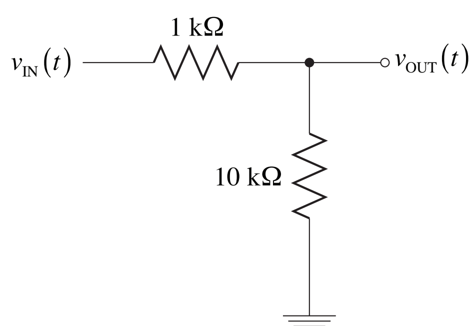
$$\delta(f) = \begin{cases} 1 & f = 0 \\ 0 & f \neq 0 \end{cases}$$

Exercise 2

$$\Rightarrow_1 \quad v_{\text{OUT}}(t) = \left[\frac{10_{\text{k}}}{1_{\text{k}} + 10_{\text{k}}}\right] v_{\text{IN}}(t) = \frac{10}{11} v_{\text{IN}}(t)$$

$$\Rightarrow_2 \quad v_{\text{OUT}}(t) = \frac{10}{11}\left[1 + 2\sin(2\pi f t)\right]$$

$$\boxed{v_{\text{OUT}}(t) = 0.909 + 1.818\sin(2\pi f t)}$$



Exercise 3

Low-Pass Filter (see Appendix for circuit diagram)

$$v_{\mathrm{IN}}(t)\cdots R\cdots\frac{1}{sC}\quad v_{\mathrm{OUT}}(t)=v_C\quad R=10\ \mathrm{k\Omega}\quad C=1\ \mathrm{nF}$$

Number	Frequency, f (kHz)	Frequency, ω (krad/s)	Gain	Gain (dB)	Phase Shift	Output Signal (V)
1	1	6.283	0.998	-0.017	-3.595°	1+1.996sin(6.283$_k$t-3.595°)
2	10	62.832	0.847	-1.445	-32.142°	1+1.693sin(62.832$_k$t-32.142°)
3	50	314.159	0.303	-10.362	-72.343°	1+0.607sin(314.159$_k$t-72.343°)

$\omega=2\pi f$ Frequency

$\left|H(j\omega)\right|=\dfrac{\omega_c}{\sqrt{\omega^2+\omega_c^2}}$ Gain

$A_{\mathrm{dB}}=20\log_{10}\left|H(j\omega)\right|$ Gain (dB)

$\phi(j\omega)=-\tan^{-1}\left(\dfrac{\omega}{\omega_c}\right)$ Phase Shift

$v_{\mathrm{OUT}}(t)=V_{\mathrm{OUT}}+\left|H(j\omega)\right|v_{\mathrm{in}}(t)$ Output Signal (V)

$\omega_c=2\pi f_c=\dfrac{1}{RC}$ Cutoff Frequency

$\boxed{f_c=15.912\ \mathrm{kHz}}$ $\boxed{\omega_c=100\ \mathrm{krad/s}}$

$\boxed{\phi(j\omega_c)=-45°}$

$H(j\omega)=\dfrac{V_{\mathrm{OUT}}}{V_{\mathrm{IN}}}=\dfrac{\omega_c}{j\omega+\omega_c}$ Transfer Function

$V_{\mathrm{OUT}}=\dfrac{1}{j\omega RC+1}V_{\mathrm{IN}}$ Output Signal, DC (V)

$V_{\mathrm{IN}}=1\ \mathrm{V}\quad \omega=0\quad V_{\mathrm{OUT}}=V_{\mathrm{IN}}=1\ \mathrm{V}$

Exercise 4

High-Pass Filter (see Appendix for circuit diagram)

$$v_{\mathrm{IN}}(t)\cdots\frac{1}{sC}\cdots R\quad v_{\mathrm{OUT}}(t)=v_R\quad R=10\ \mathrm{k\Omega}\quad C=1\ \mathrm{nF}$$

Number	Frequency, f (kHz)	Frequency, ω (krad/s)	Gain	Gain (dB)	Phase Shift	Output Signal (V)
1	1	6.283	0.063	-24.054	-86.405°	0.125sin(6.283$_k$t-86.405°)
2	10	62.832	0.532	-5.481	-57.858°	1.064sin(62.832$_k$t-57.858°)
3	50	314.159	0.953	-0.419	-17.657°	1.906sin(314.159$_k$t-17.657°)

$\omega=2\pi f$ Frequency

$\left|H(j\omega)\right|=\dfrac{\omega}{\sqrt{\omega^2+\omega_c^2}}$ Gain

$A_{\mathrm{dB}}=20\log_{10}\left|H(j\omega)\right|$ Gain (dB)

$\phi(j\omega)=90°-\tan^{-1}\left(\dfrac{\omega}{\omega_c}\right)$ Phase Shift

$v_{\mathrm{OUT}}(t)=V_{\mathrm{OUT}}+\left|H(j\omega)\right|v_{\mathrm{in}}(t)$ Output Signal (V)

$\omega_c=2\pi f_c=\dfrac{1}{RC}$ Cutoff Frequency

$\boxed{f_c=15.912\ \mathrm{kHz}}$ $\boxed{\omega_c=100\ \mathrm{krad/s}}$

$\boxed{\phi(j\omega_c)=45°}$

$H(j\omega)=\dfrac{V_{\mathrm{OUT}}}{V_{\mathrm{IN}}}=\dfrac{j\omega}{j\omega+\omega_c}$ Transfer Function

$V_{\mathrm{OUT}}=\dfrac{j\omega RC}{j\omega RC+1}V_{\mathrm{IN}}$ Output Signal, DC (V)

$V_{\mathrm{IN}}=1\ \mathrm{V}\quad \omega=0\quad V_{\mathrm{OUT}}=0\ \mathrm{V}$

➤Calculated

circuit1.sp (Exercise 2) >>

```
Lab 1 , Circuit 1
******************************
** Created by Chris Winstead
******************************

Vin n1 0 DC 5V

R1 n1 n2 1k
R2 n2 0 10k

.control
dc Vin 0V 5V 0.1V
plot v(n2)
hardcopy circuit1_dc.ps v(n2)
meas dc y FIND v(n2) AT=1
echo Solution: vout = vin*$&y
.endc

.end
```

log.txt (results) >>

```
*** RESULTS FOR CIRCUIT 1:
y  =  9.090909e-01
Transfer Characteristic:
vout = vin*0.909091
```

circuit2.sp (Exercise 3) >>

```
Lab 1 , Circuit 2
******************************
** Created by Chris Winstead
******************************

Vin n1 0 DC 0V AC 1 SIN(1V 2V 10k)

R1 n1 n2 10k
C1 n2 0 1n

.control
**********************
* TRANSIENT SIMULATION
**********************
tran 1u 1m
plot v(n2)
hardcopy tran_circuit2.ps v(n2)

**********************
* AC SIMULATION
**********************
ac dec 10 100 10e6

set units=degrees
plot vdb(n2)
plot vp(n2)
hardcopy magnitude_circuit2.ps vdb(n2)
hardcopy phase_circuit2.ps vp(n2)
meas ac y1 FIND vdb(n2) AT=1k
meas ac y2 FIND vdb(n2) AT=10k
meas ac y3 FIND vdb(n2) AT=50k
meas ac f3dB WHEN vdb(n2)=-3
meas ac p3dB FIND vp(n2) AT=$&f3dB
echo The -3dB frequency is $&f3dB Hz
echo with Phase phi=$&p3dB degrees
.endc

.end
```

log.txt (results) >>

```
*** RESULTS FOR CIRCUIT 2:
y1  =  -1.711150e-02
y2  =  -1.445070e+00
y3  =  -1.036042e+01
f3db  =  1.587800e+04
p3db  =  -4.492628e+01
The -3dB frequency is 15878 Hz
with Phase phi=-44.9263 degrees
```

circuit3.sp (Exercise 4) >>

```
Lab 1 , Circuit 3
******************************
** Created by Chris Winstead
** Modified by Joel Meine
******************************

Vin n1 0 DC 0V AC 1 SIN(1V 2V 10k)

C1 n1 n2 1n
R1 n2 0 10k

.control
**********************
* TRANSIENT SIMULATION
**********************
tran 1u 1m
plot v(n2)
hardcopy circuit3_tran.ps v(n2)

**********************
* AC SIMULATION
**********************
ac dec 10 100 10e6

set units=degrees
plot vdb(n2)
plot vp(n2)
hardcopy circuit3_magnitude.ps
vdb(n2)
hardcopy circuit3_phase.ps vp(n2)
meas ac y1 FIND vdb(n2) AT=1k
meas ac y2 FIND vdb(n2) AT=10k
meas ac y3 FIND vdb(n2) AT=50k
meas ac f3dB WHEN vdb(n2)=-3
meas ac p3dB FIND vp(n2) AT=$&f3dB
echo The -3dB frequency is $&f3dB Hz
echo with Phase phi=$&p3dB degrees
.endc

.end
```

results.txt (results) >>

```
*** RESULTS FOR CIRCUIT 3:
y1                  =  -2.405351e+01
y2                  =  -5.481473e+00
y3                  =  -4.198595e-01
f3db                =  1.598052e+04
p3db                =  4.491032e+01
The -3dB frequency is 15980.5 Hz
with Phase phi=44.9103 degrees
```

Lab Experiments

Procedure 1

Resistance, Measured (10 kΩ) =	9.91 kΩ (0.9% err.)
Resistance, Measured (1 kΩ) =	0.98 kΩ (2.0% err.)

Procedure 2

Frequency (10 kHz) =	10.05 kHz (0.5% err.)
Peak-to-Peak (4 V) =	4.04 V (1.0% err.)
Offset Voltage (1 V) =	1.06 V (5.7% err.)

Procedure 3 (see Appendix for oscilloscope plots)

Procedure 4

	v_{IN}	v_{OUT}
Peak-to-Peak = (4 V, 3.6 V)	4.04 V (1.0% err.)	3.72 V (2.3% err.)
Offset Voltage = (1 V, 0.9 V)	1.06 V (5.7% err.)	0.99 V (8.2% err.)

Procedure 5

Cutoff Frequency = (15.9 kHz)	14.7 kHz (7.5% err.)

Procedure 6

Cutoff Frequency = (15.9 kHz)	13.1 kHz (17.6% err.)

Procedure 7

- The effect of aliasing was observed and documented in the lab notebook. When SEC/DIV was set to 100 kS/s, the first range of the aliasing effect begins at 50 kHz, the second at 100 kHz, and so on in 50 kHz increments.

Commentary

- Improved familiarization and increased experience with lab equipment use was accomplished.
- After careful comparison of the analytical and calculated results in the pre-lab analysis, both sets of results perfectly agrees with each other.
- After conducting the lab experiments, the measured values and calculated values for the following metrics did agree each other with marginal error: resistance, frequency, peak-to-peak, and offset voltage. The cutoff frequency, however, did barely yield a significant percentage of error that suggests the error in question is due to a known capacitor component within the frequency probe device. There is no readily known solution at this time to mitigate the margin of error for the measured cutoff frequency. A solution does likely exist, but researching for the solution was not addressed in this lab.
- A comparison of different, standard signal forms was observed within the frequency spectrum. On the oscilloscope when observing the first signal form (i.e. the sine wave), it was apparent that the observed magnitude was only half of the calculated magnitude. Provided external insight explains that the oscilloscope calculates the magnitude to the left-hand side of the frequency plot. The appearance of the spectrum between the sine and square waves yielded no apparent difference. The triangle wave, however, did change considerably as harmonics were observed.
- The effect of frequency aliasing was observed at SEC/DIV set to 100 KS/s and over the range from 0 to 200 kHz. Thus yielding a nyquist frequency of 50 kHz; i.e. the SEC/DIV value divided by two. As the frequency was increased from 0 kHz to 50 kHz, the peak in the spectrum would move from left-to-right, but would reverse direction after reaching 50 kHz. This pattern of change in direction would continue each time that peak in the spectrum reached multiples of 50 kHz. Provided external insight explains that increasing the sampling rate will eliminate of significantly reduce the possibility of aliasing.

Appendix

Low-Pass Filter

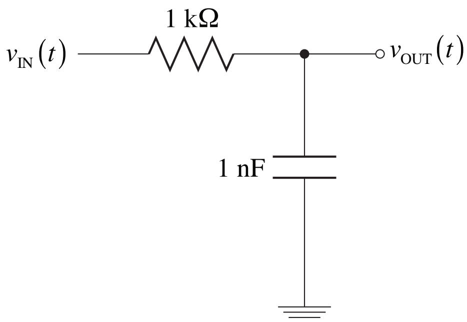


Figure 2: Circuit for Exercise 3.

High-Pass Filter

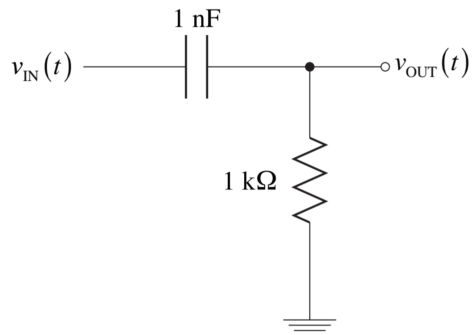
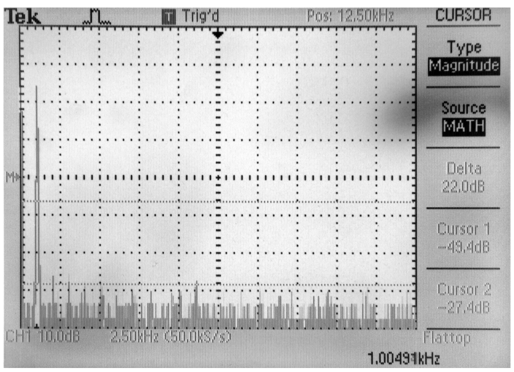
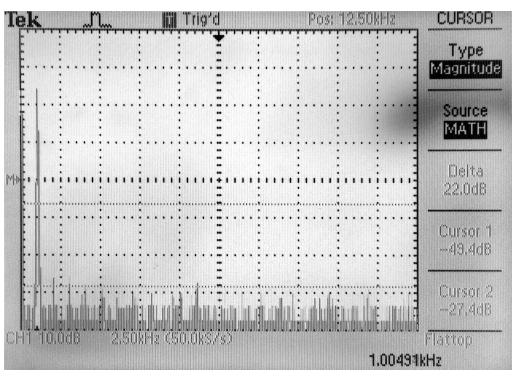


Figure 3: Circuit for Exercise 4.

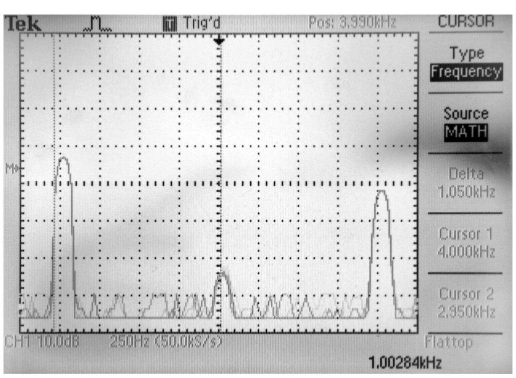
Procedure 3



Sine



Square



Triangle