EE230 Analog Circuits Lab

Experiment 1

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Contents

1 RC Integrator

1.1 Circuit

Given: $R = 10\ \mathrm{k}\,\Omega$, $C = 0.1\mu\,\mathrm{F}$ $\quad\Rightarrow\quad$ $\tau = RC = (10 \cdot 10^3\Omega)\cdot(0.1 \cdot 10^{-6}\,\mathrm{F})\,\mathrm{s} = 1\mathrm{ms}$

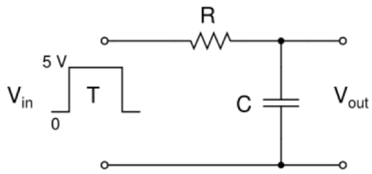
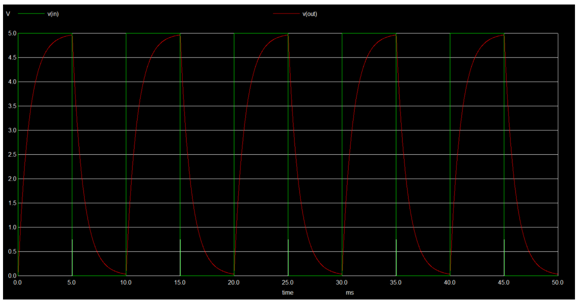
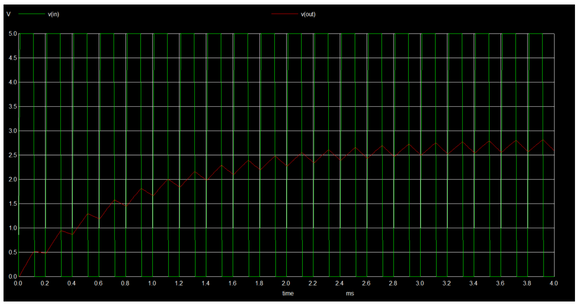


Figure 1.1: RC Integrator

1.2 Plots



(a) Time response, RC Integrator for $T = 5\tau$



(b) Time response, RC Integrator for $T = 0.1\tau$

1.3 Codes

```
Param Rathour (190070049), RC Integrator

* Elements
* For Pulse Width = 0.1ms and Simulation Time = 4ms
Vin in gnd pulse(0 5 0 0 0 0.1m 0.2m)
R1 in out 10k
C1 out gnd 0.1u

* I have chosen TSTEP = 0.01ms, TSTOP = 4ms
.tran 0.01m 4m

* Analysis
.control
run

* Display
plot V(in) V(out)
.endc
.end
```

2 RC Differentiator

2.1 Circuit

Given: $R = 10\ \mathrm{k}\,\Omega$, $C = 0.1\mu\,\mathrm{F}$ $\quad\Rightarrow\quad$ $\tau = RC = (10 \cdot 10^3 \Omega) \cdot (0.1 \cdot 10^{-6}\,\mathrm{F})\,\mathrm{s} = 1\mathrm{ms}$

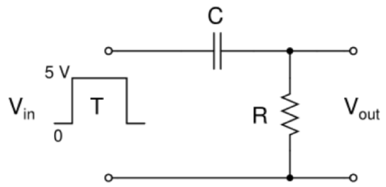
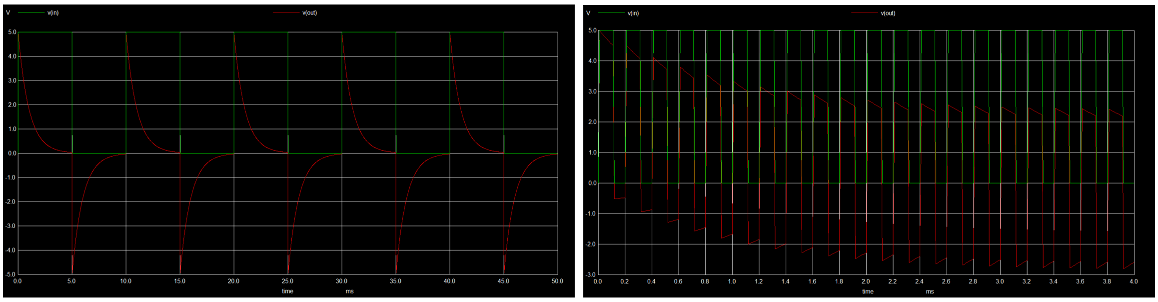


Figure 2.1: RC Differentiator

2.2 Plots



(a) Time response, RC Differentiator for $T = 5\tau$ (b) Time response, RC Differentiator for $T = 0.1\tau$

2.3 Codes

```
Param Rathour (190070049), RC Differentiator

* Elements
* For Pulse Width = 5ms and Simulation Time = 50ms
Vin in gnd pulse(0 5 0 0 0 5m 10m)
C1 in out 0.1u
R1 out gnd 10k

* I have chosen TSTEP = 0.01ms, TSTOP = 50ms
.tran 0.01m 50m

* Analysis
.control
run

* Display
plot V(in) V(out)
.endc
.end
```

3 RC Lowpass Filter

3.1 Circuit

Given: $R = 10\ \mathrm{k}\,\Omega$, $C = 0.1\mu\,\mathrm{F}$ $\quad\Rightarrow\quad$ $\tau = RC = (10 \cdot 10^3\Omega) \cdot (0.1 \cdot 10^{-6}\,\mathrm{F})\,\mathrm{s} = 1\mathrm{ms}$

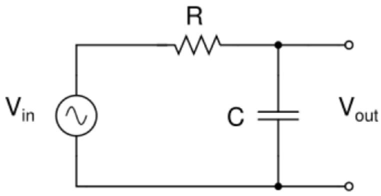


Figure 3.1: RC Lowpass Filter

3.2 Plots

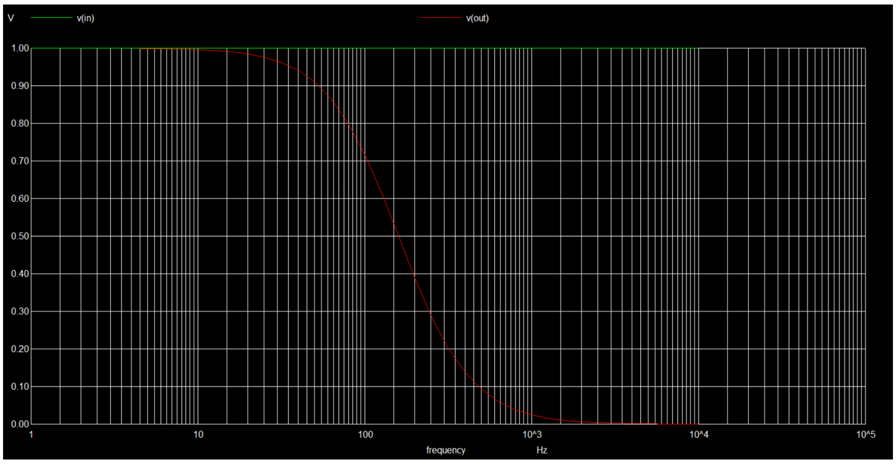


Figure 3.2: Time response, RC Lowpass Filter

3.3 Codes

```
Param Rathour (190070049), RC Lowpass Filter

* Elements
* For Input Voltage as sinwave with amplitude = 1V and Frequency Range 1Hz - 10kHz
Vin in gnd dc 0 ac 1
R1 in out 10k
C1 out gnd 0.1u

* I have chosen ND = 10, FSTART = 1Hz, FSTOP = 10kHz
.ac DEC 10 1 10k

* Analysis
.control
run

* Display
plot V(in) V(out)
.endc
.end
```

4 RC Highpass Filter

4.1 Circuit

Given: $R = 10\ \mathrm{k}\,\Omega$, $C = 0.1\mu\,\mathrm{F} \quad \Rightarrow \quad \tau = RC = (10 \cdot 10^3\Omega) \cdot (0.1 \cdot 10^{-6}\,\mathrm{F})\,\mathrm{s} = 1\mathrm{ms}$

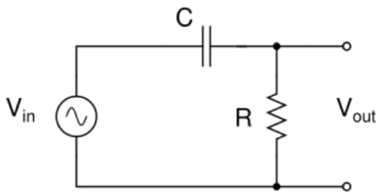


Figure 4.1: RC Highpass Filter

4.2 Plots

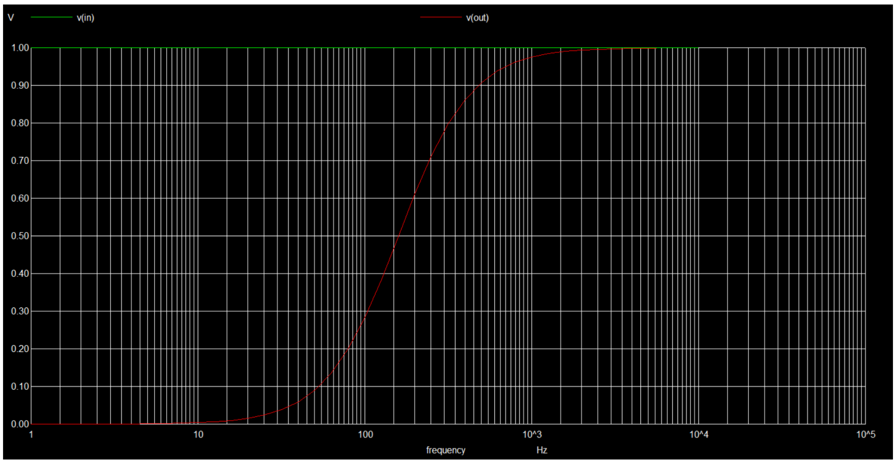


Figure 4.2: Time response, RC Highpass Filter

4.3 Codes

```
Param Rathour (190070049), RC Highpass Filter

* Elements
* For Input Voltage as sinwave with amplitude = 1V and Frequency Range 1Hz - 10kHz
Vin in gnd dc 0 ac 1
C1 in out 0.1u
R1 out gnd 10k

* I have chosen ND = 10, FSTART = 1Hz, FSTOP = 10kHz
.ac DEC 10 1 10k

* Analysis
.control
run

* Display
plot V(in) V(out)
.endc
.end
```

5 RC Bandpass Filter

5.1 Circuit

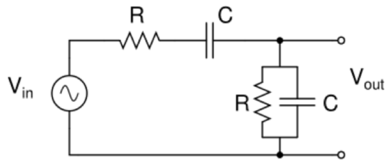


Figure 5.1: RC Bandpass Filter

5.2 Plots

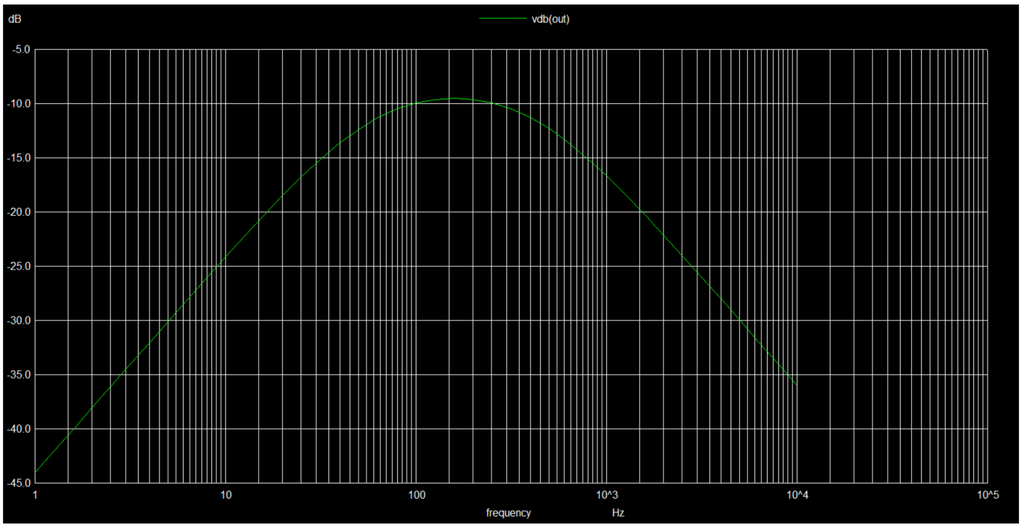


Figure 5.2: Time response, RC Bandpass Filter

5.3 Codes

```
Param Rathour (190070049), RC Bandpass Filter

* Elements
* For Input Voltage as sinwave with amplitude = 1V and Frequency Range 1Hz - 10kHz
Vin in gnd dc 0 ac 1
R1 in mid 10k
C1 mid out 0.1u
R2 out gnd 10k
C2 out gnd 0.1u

* I have chosen ND = 10, FSTART = 1Hz, FSTOP = 10kHz
.ac DEC 10 1 10k

* Analysis
.control

run
meas ac Vdbmax max vdb(out)
let Vdbreq = Vdbmax-3
meas ac fc when vdb(out) = Vdbmax
meas ac fL when vdb(out) = Vdbreq rise = 1
```

```
meas ac fH when vdb(out) = Vdbreq fall = 1

* Display
print fc
print fL
print fH
plot vdb(out) xlog
.endc
.end
```

5.4 Simulation Results

- Peak Amplitude = -9.542459dB
- Centre Frequency = $1.584893 \cdot 10^2$Hz
- Lower Frequency = $4.857104 \cdot 10^1$Hz
- Upper Frequency = $5.251130 \cdot 10^2$Hz

5.5 Theoretical Values

In the circuit,

$$i = \frac{V_{\text{in}}(s)}{\underbrace{R + \frac{1}{sC}}_{\text{series}} + \underbrace{\frac{R \cdot \frac{1}{sC}}{R + \frac{1}{sC}}}_{\text{parallel}}}$$

$$V_{\text{out}} = \underbrace{\frac{V_{\text{in}}(s)}{R + \frac{1}{sC} + \frac{R \cdot \frac{1}{sC}}{R + \frac{1}{sC}}}}_{i} \cdot \underbrace{\frac{R \cdot \frac{1}{sC}}{R + \frac{1}{sC}}}_{\text{resistance}}$$

This gives the transfer function as,

$$H(s) = \frac{sRC}{1 + 3sRC + (sRC)^2}$$

Substitue $s = j\omega$ and simplify to get,

$$H(s) = \frac{j\omega RC}{1 + 3j\omega RC + (j\omega RC)^2}$$

$$|H(s)| = \frac{\omega RC}{\sqrt{(3\omega RC)^2 + (1 - (\omega RC)^2)^2}} \tag{5.1}$$

Now, central frequency is $f = \frac{1}{2\pi} \cdot \frac{1}{RC} = \frac{1}{2\pi} \cdot \frac{1}{(10 \cdot 10^3) \cdot (0.1 \cdot 10^{-6})} = 159.155$Hz

At this frequency $|H(s)| = \frac{1}{3}$,

So, lower frequency (f_L) and higher frequency (f_H) are when $|H(s)| = \frac{1}{\sqrt{2}} \cdot \frac{1}{3} = \frac{1}{3\sqrt{2}}$

$$\frac{\omega RC}{\sqrt{(1 - (\omega RC)^2)^2 + (3j\omega RC)^2}} = \frac{1}{3\sqrt{2}}$$

Squaring both sides,

$$18(\omega RC)^2 = 9(\omega RC)^2 + (1 - (\omega RC)^2)^2$$
$$(\omega RC)^4 - 11(\omega RC)^2 + 1 = 0$$

$$(\omega RC)^2 = \frac{11 \pm 3\sqrt{13}}{2}$$
$$(\omega RC) = \frac{\sqrt{13} \pm 3}{2}$$
$$f = \frac{1}{2\pi} \cdot \frac{\sqrt{13} \pm 3}{2}$$

therefore, $f_L = 48.188\text{Hz}$, $f_H = 525.653\text{Hz}$

5.6 Comparison between Simulated and Theoretical Values

Simulated values then Theoretical values,

- Centre Frequency $= 1.584893 \cdot 10^2\text{Hz}$ and 159.155Hz
- Lower Frequency $= 4.857104 \cdot 10^1\text{Hz}$ and 48.188Hz
- Upper Frequency $= 5.251130 \cdot 10^2\text{Hz}$ and 525.653Hz

As it is evident from the frequencies all Simulated values are close to Theoretical values.

6 RLC Bandpass Filter

6.1 Circuit

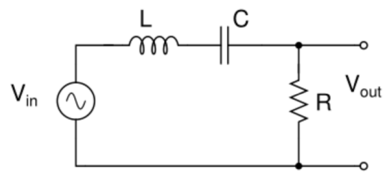


Figure 6.1: RLC Bandpass Filter

6.2 Plots

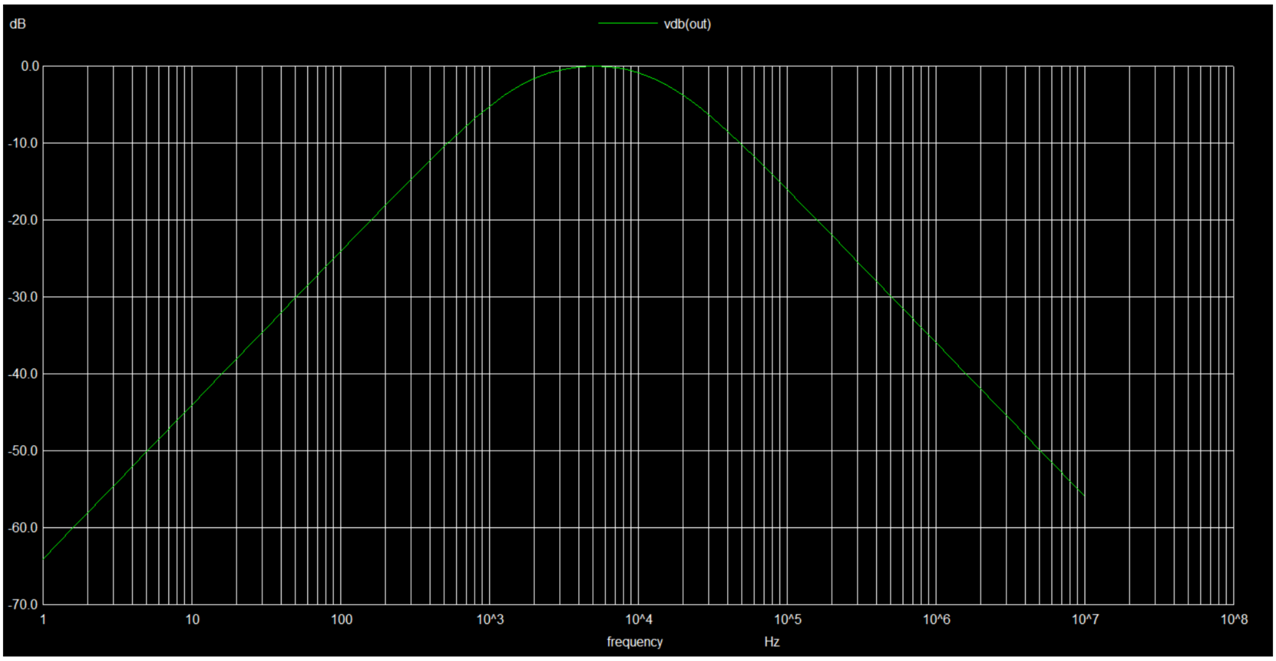


Figure 6.2: Time response, RLC Bandpass Filter

6.3 Codes

```
Param Rathour (190070049), RLC Bandpass Filter

* Elements
* For Input Voltage as sin Wave with amplitude = 1V and Frequency Range 1Hz - 10MHz
Vin in gnd dc 0 ac 1
L1 in mid 10m
C1 mid out 0.1u
R1 out gnd 1k


* I have chosen ND = 10, FSTART = 1Hz, FSTOP = 10000kHz
.ac DEC 10 1 10000k

* Analysis
.control

run
meas ac Vdbmax max vdb(out)
let Vdbreq = Vdbmax-3
meas ac fc when vdb(out) = Vdbmax
meas ac fL when vdb(out) = Vdbreq rise = 1
meas ac fH when vdb(out) = Vdbreq fall = 1

* Display
print fc
print fL
print fH
plot vdb(out) xlog
.endc
.end
```

6.4 Simulation Results

- Peak Amplitude $= -3.051282 \cdot 10^{-5}$dB
- Centre Frequency $= 5.011872 \cdot 10^{3}$Hz
- Lower Frequency $= 1.476560 \cdot 10^{3}$Hz
- Upper Frequency $= 1.735767 \cdot 10^{4}$Hz

6.5 Theoretical Values

In the circuit,

$$i = \frac{V_{\text{in}}(s)}{\underbrace{sL + \frac{1}{sC} + R}_{\text{series}}}$$

$$V_{\text{out}} = \underbrace{\frac{V_{\text{in}}(s)}{sL + \frac{1}{sC} + R}}_{i} \cdot \underbrace{R}_{\text{resistance}}$$

This gives the transfer function as,

$$H(s) = \frac{sRC}{1 + sRC + s^2LC}$$

Substitue $s = j\omega$ and simplify to get,

$$H(s) = \frac{j\omega RC}{1 + j\omega RC + (j\omega)^2 LC}$$

$$|H(s)| = \frac{(\omega RC)}{\sqrt{(\omega RC)^2 + (1 - \omega^2 LC)^2}} \tag{6.1}$$

Now, central frequency is $f = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LC}} = \frac{1}{2\pi} \cdot \frac{1}{(10 \cdot 10^3) \cdot (0.1 \cdot 10^{-6})} = 5032.921\text{Hz}$

At this frequency $|H(s)| = 1$,

So, lower frequency (f_L) and higher frequency (f_H) are when $|H(s)| = \frac{1}{\sqrt{2}} \cdot 1 = \frac{1}{\sqrt{2}}$

$$\frac{(\omega RC)}{\sqrt{(\omega RC)^2 + (1 - \omega^2 LC)^2}} = \frac{1}{\sqrt{2}}$$

Squaring both sides,

$$2(\omega RC)^2 = (\omega RC)^2 + (1 - \omega^2 LC)^2$$
$$(\omega RC)^2 = (1 - \omega^2 LC)^2$$

Take square root,

$$\pm(\omega RC) = (1 - \omega^2 LC)$$
$$\omega^2 LC \pm (\omega RC) - 1 = 0$$
$$\omega = \frac{\pm RC + \sqrt{(RC)^2 + 4LC}}{2LC}$$
$$f = \frac{1}{2\pi} \cdot \frac{\pm(10^{-4}) + \sqrt{(10^{-4})^2 + 4 \cdot 10^{-9}}}{2 \cdot 10^{-9}}$$

therefore, $f_L = 1457.986\text{Hz}$, $f_H = 17373.480\text{Hz}$

6.6 Comparison between Simulated and Theoretical Values

Simulated values then Theoretical values,

- Centre Frequency = $5.011872 \cdot 10^3$Hz and 5032.921Hz
- Lower Frequency = $1.476560 \cdot 10^3$Hz and 1457.986Hz
- Upper Frequency = $1.735767 \cdot 10^4$Hz and 17373.480Hz

As it is evident from the frequencies all Simulated values are close to Theoretical values.

7 Conclusions

7.1 Major Learnings from this Experiment

- Learning to simulated NGSPICE
- Documentation reading through SPICE manual and Debugging
- For RC integrators $T << \tau$ and for RC differentiators $T >> \tau$
- Finding Lower and Upper frequencies using Transfer Functions and NGSPICE

7.2 Challenges Faced

- Calculating Lower and Upper frequencies using NGSPICE commands
- Preparing this Large and Comprehensive Report in LaTeX

7.3 Questions or Clarifications (if any)

None