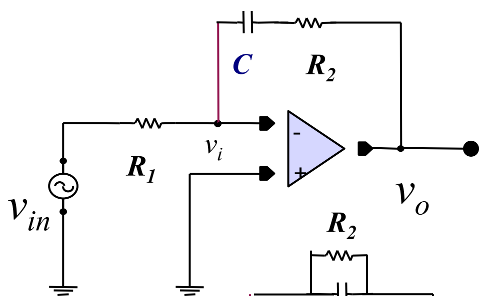
Electronic Systems

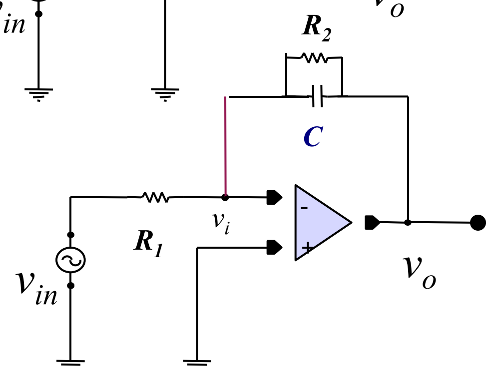
Lesson #4

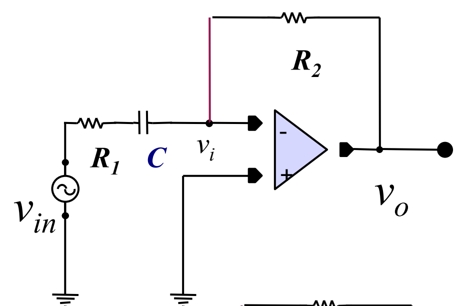
Chapter 1

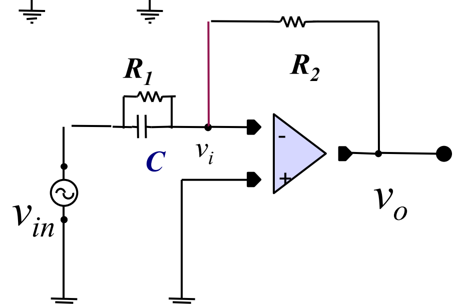
Homework

- Probs 2.2, 2.5, 2.6, 2.10, 2.22, 2.24, 2.25, 2.28
- Calculate and plot the output vs frequency for these circuits. R_1=1k, R_2=3k, C=1mf









Homework Answers #10

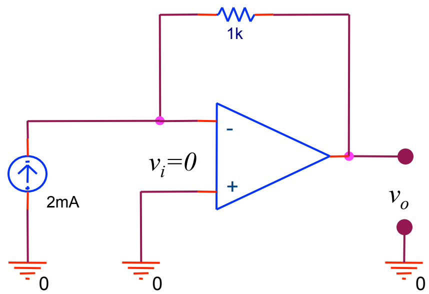
- Probs 2.2

$$v_1(t) = 0.1\cos(20\pi t) + 20\sin(120\pi t)$$
$$v_2(t) = -0.1\cos(20\pi t) + 20\sin(120\pi t)$$
$$v_{cm}(t) = \frac{v_1(t) + v_2(t)}{2} = 20\sin(120\pi t)$$
$$v_d(t) = v_1(t) - v_2(t) = 0.2\cos(20\pi t)$$

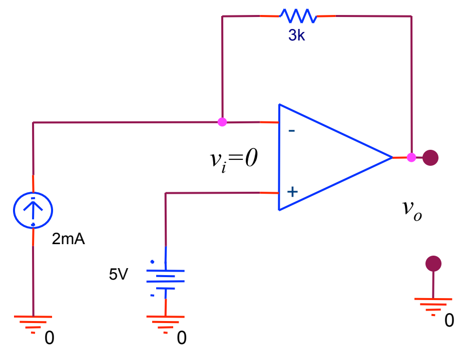
- Probs 2.5
  - The summing point constraint only applies to negative feedback
- Probs 2.6
  - Verify that negative feedback is present
  - Assume that the differential input voltage and input current of the op amp forced to zero
  - Apply standard circuit analysis principles such as Kirchhoff's laws and Ohn's law to solve the for quantities of interest.

Homework Answers #11

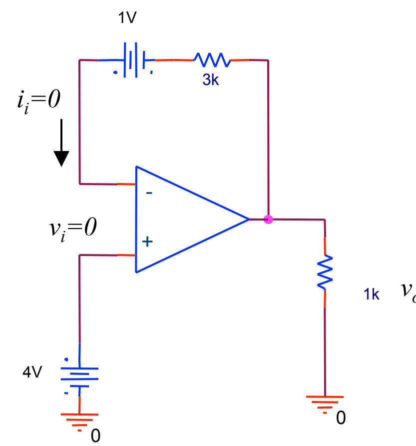
- Probs 2.10



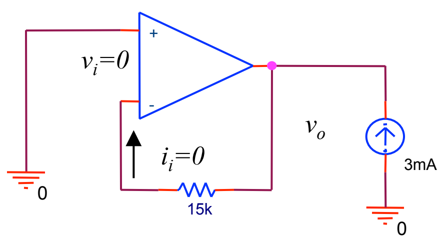
$v_o = -2mA \times 1k + v_i = -2V$



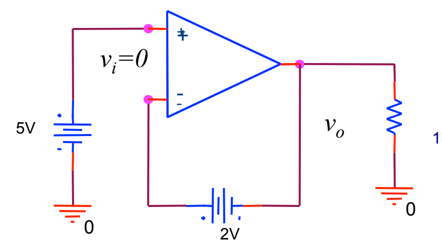
$v_o = -2mA \times 3k + v_i + 5V = -1V$



$v_o = 4V + v_i - 1V + 0 = 3V$



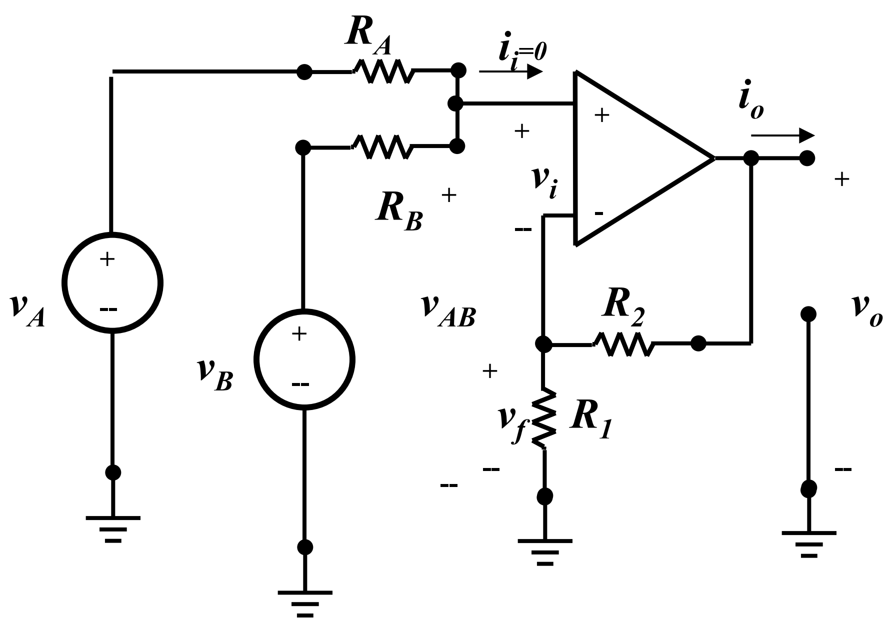
$v_o = 0 + v_i = 0V$



$v_o = -2V + v_i + 5V = 3V$

Homework Answers #12

- Probs 2.22



$$v_{AB} = v_i + v_f = v_f$$

$$v_f = \frac{R_1}{R_1 + R_2} v_o$$

$$i_i = i_A + i_B = 0$$

$$0 = \frac{v_A - v_{AB}}{R_A} + \frac{v_B - v_{AB}}{R_B}$$

$$\frac{v_A}{R_A} + \frac{v_B}{R_B} = (\frac{1}{R_A} + \frac{1}{R_B}) v_{AB}$$

$$v_{AB} = \frac{v_A R_B + v_B R_A}{R_A R_B} (\frac{R_A R_B}{R_B + R_A})$$

$$= \frac{v_A R_B + v_B R_A}{R_B + R_A}$$

$$v_o = \frac{v_A R_B + v_B R_A}{R_B + R_A} \times \frac{R_1 + R_2}{R_1}$$

Homework Answers #13

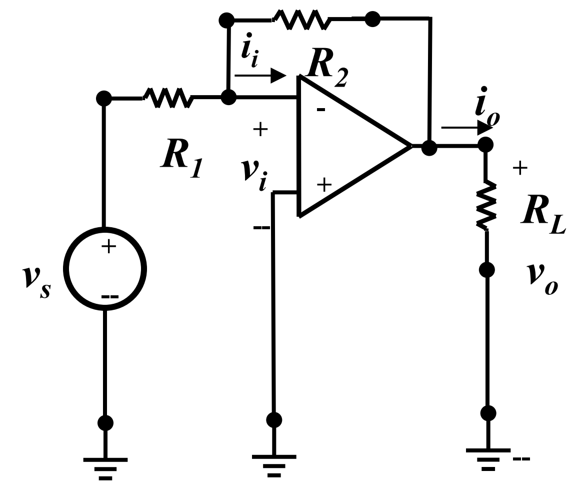
- Probs 2.24

INVERTING AMP

$$v_o = -i_f R_2; i_f = \frac{v_s}{R_1}; \frac{v_o}{v_s} = -\frac{R_2}{R_1}$$

$$P_{in} = \frac{v_s^2}{R_1}; P_{out} = \frac{v_o^2}{R_L} = \frac{v_s^2}{R_L}(\frac{R_2}{R_1})^2$$

$$G = \frac{P_{out}}{P_{in}} = \frac{R_2^2}{R_L R_1}$$



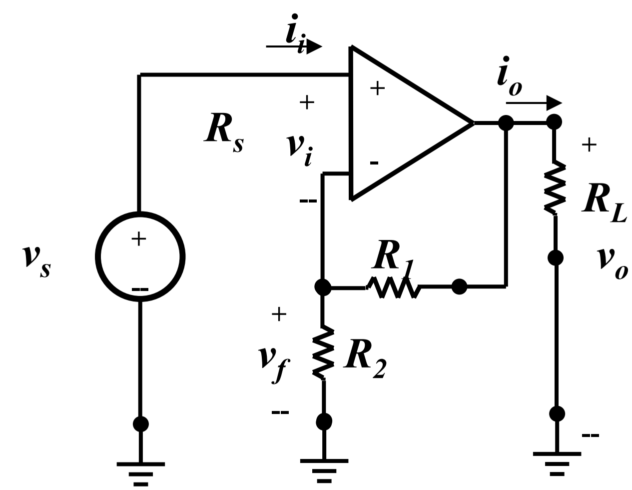
NON INVERTING AMP

$$v_s = \frac{R_2}{R_1 + R_2} v_o; \frac{v_o}{v_s} = \frac{R_1 + R_2}{R_1}$$

$$P_{in} = 0; i_i = 0$$

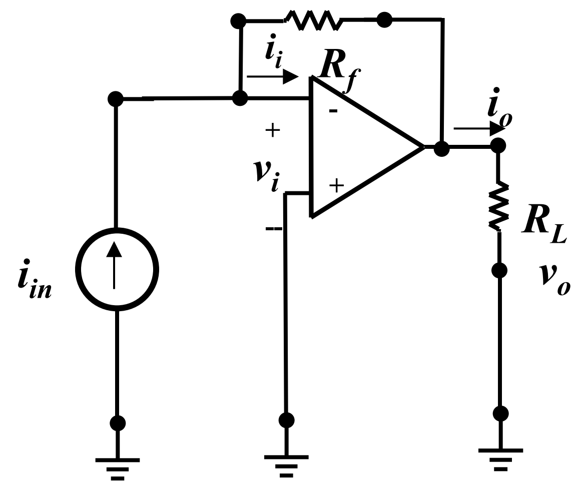
$$P_{out} = \frac{v_o^2}{R_L}$$

$$G = \frac{P_{out}}{P_{in}} = \infty$$



Homework Answers #14

- Probs 2.25



a) $v_o = -i_{in} R_f$

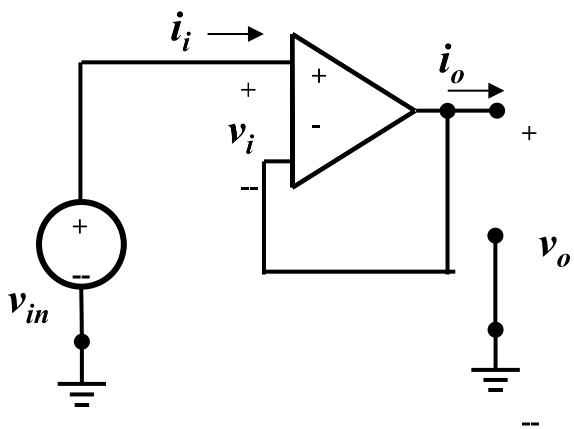
b) Since v_o is independent of R_L, then we have an ideal voltage source and $R_{out} = 0$

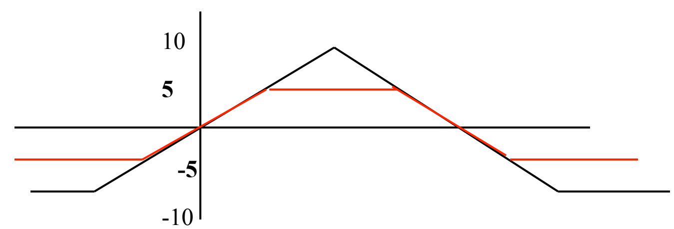
c) $R_{in} = \frac{v_i}{i_{in}} = \frac{0}{i_{in}} = 0$

d) Since the output voltage is proportional to the input current, it is an ideal transresistance amplifier

Homework Answers #15

- Probs 2.28



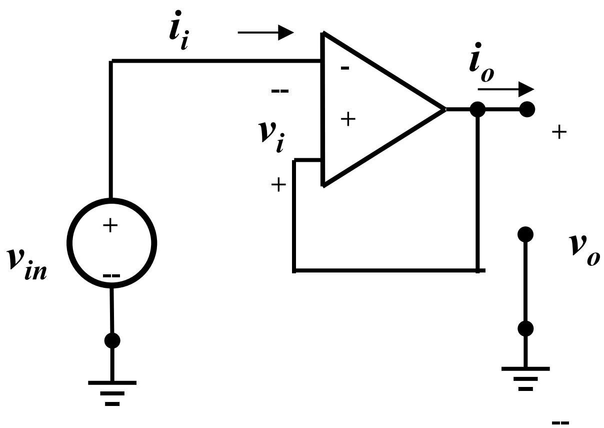


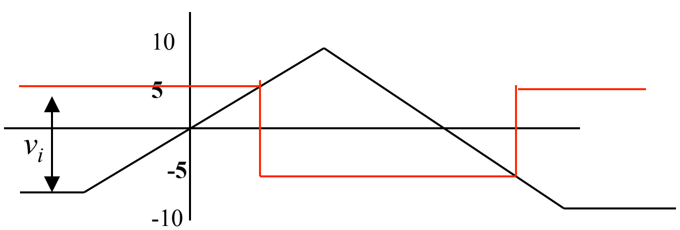
Negative Feedback

$$v_{in} = v_i + v_o = v_o$$

Homework Answers #16

- Probs 2.28





Positive Feedback and $v_i \neq 0$

1) When $v_i > 0$, v_o is $+5$, then:

$v_i = v_o - v_{in} = +5 - v_{in} > 0$; or when $5 > v_{in}$

So v_o switches to -5 when $v_{in} >= 5$ since

$v_i = +5 - v_{in} =< 0$ for $v_{in} > 5$

(e.g., if $v_{in} = 5.001$, then $v_i = +5 - 5.001 = -.001$)

2) When $v_i < 0$, v_o is -5, then:

$v_i = v_o - v_{in} = -5 - v_{in} < 0$; or when $-5 < v_{in}$

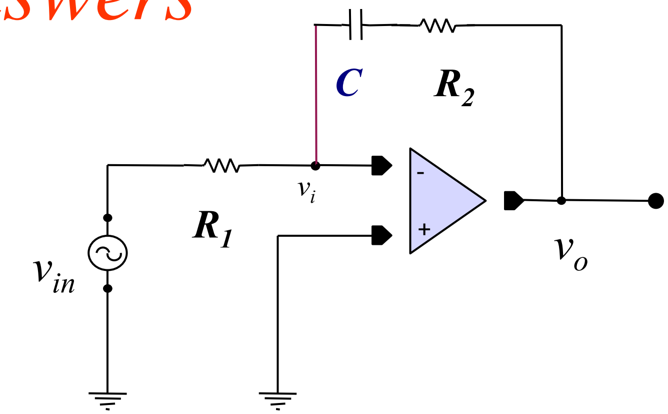
So v_o switches to $+5$ when $v_{in} <= -5$ since

$v_i = -5 - v_{in} => 0$ for $v_{in} < -5$

(e.g., if $v_{in} = -5.001$, then $v_i = -5 - (-5.001) = .001$)

Homework Answers

- Calculate and plot the output vs frequency for these circuits.



$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1}$$

$$Z_2 = R_2 + \frac{1}{j\omega C} = \frac{1 + j\omega CR_2}{j\omega C}$$

$$Z_1 = R_1$$

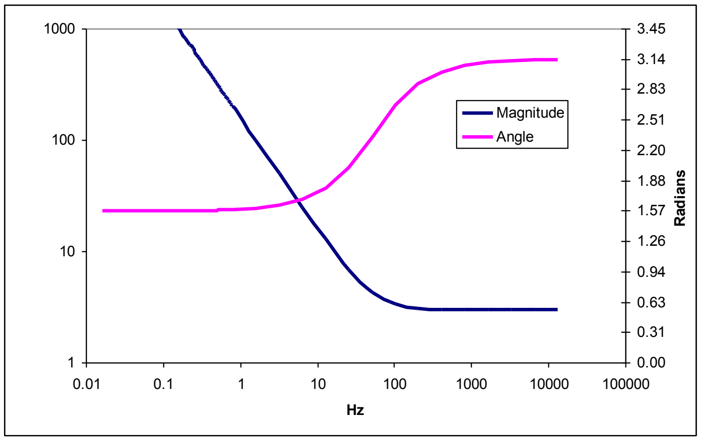
$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1} = -\frac{\frac{1+j\omega CR_2}{j\omega C}}{R_1} = -\frac{1+j\omega CR_2}{j\omega CR_1} = \frac{\sqrt{1+(\omega CR_2)^2}}{\omega CR_1}\angle(\pi + \tan^{-1}(\omega CR_2) - \frac{\pi}{2})$$

$$= \frac{\sqrt{1+(\omega CR_2)^2}}{\omega CR_1}\angle(\frac{\pi}{2} + \tan^{-1}(\omega CR_2))$$

$$\frac{v_o}{v_{in}}|_{\omega\to 0} = -\frac{1+j\omega CR_2}{j\omega CR_1}|_{\omega\to 0} \to -\frac{1}{j\omega CR_1}|_{\omega\to 0} \to \infty\angle\frac{\pi}{2}$$

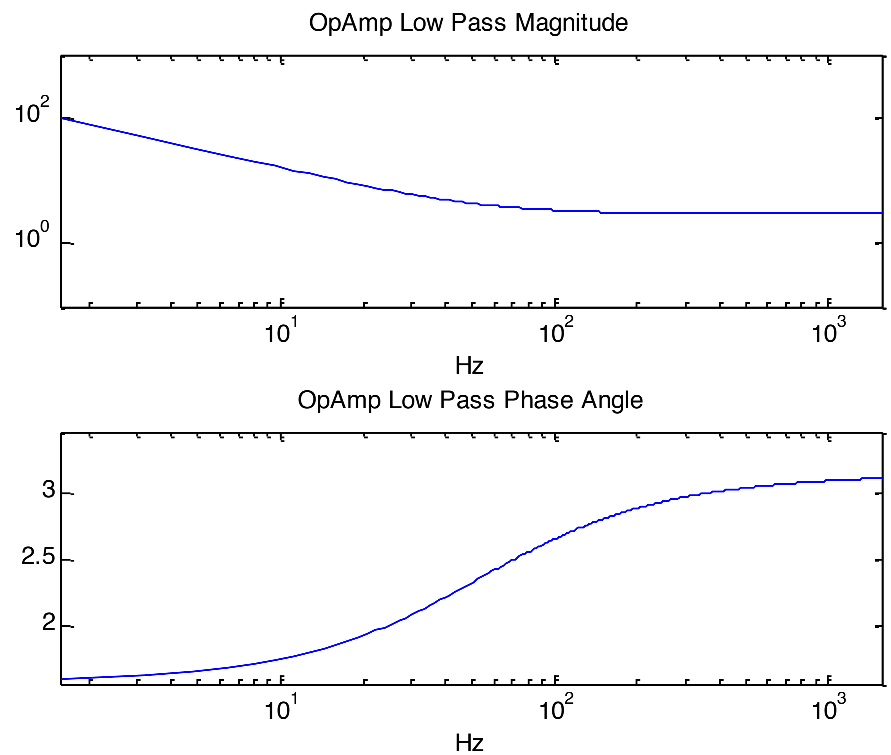
$$\frac{v_o}{v_{in}}|_{\omega=\frac{1}{CR_2}} = \frac{\sqrt{2}R_2}{R_1}\angle(\frac{\pi}{2}+\frac{\pi}{4}) = \sqrt{2}\frac{R_2}{R_1}\angle\frac{3\pi}{4}$$

$$\frac{v_o}{v_{in}}|_{\omega\to\infty} = -\frac{1+j\omega CR_2}{j\omega CR_1}|_{\omega\to\infty} \to -\frac{\omega CR_2}{\omega CR_1}\angle\pi = \frac{R_2}{R_1}\angle\pi = -\frac{R_2}{R_1}$$



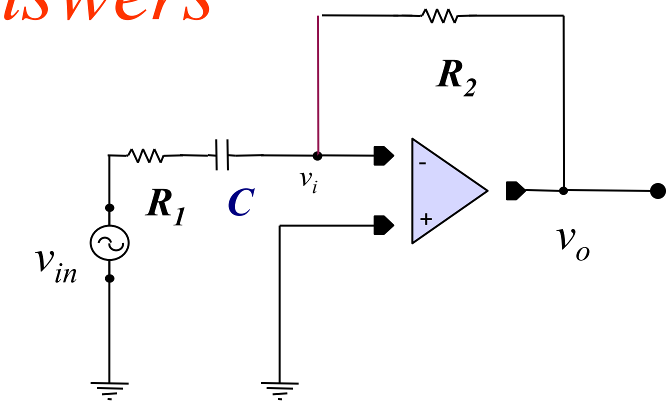
Matlab Code

```
clear all;
R1=1e3;R2=3e3;C=1e-6;
omega=(10:10:10000);maxomega=length(omega);
for i=1:maxomega
  ZC=1/complex(0,(omega(i)*C));
  z1=R1;
  z2=R2+ZC;
  VOUT(i)=-z2/z1;
end
f=omega/(2*pi);
subplot(2,1,1);
loglog(f,abs(VOUT));
title('OpAmp Low Pass Magnitude');
xlabel('Hz');
axis([f(1) f(maxomega) .1 1000]);
subplot(2,1,2);
semilogx(f,atan2(imag(VOUT),real(VOUT)));
title('OpAmp Low Pass Phase Angle');
xlabel('Hz');
axis([f(1) f(maxomega) pi/2 1.1*pi]);
```



Homework Answers

- Calculate and plot the output vs frequency for these circuits.



$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1}$$

$$Z_2 = R_2$$

$$Z_1 = R_1 + \frac{1}{j\omega C} = \frac{1 + j\omega CR_1}{j\omega C}$$

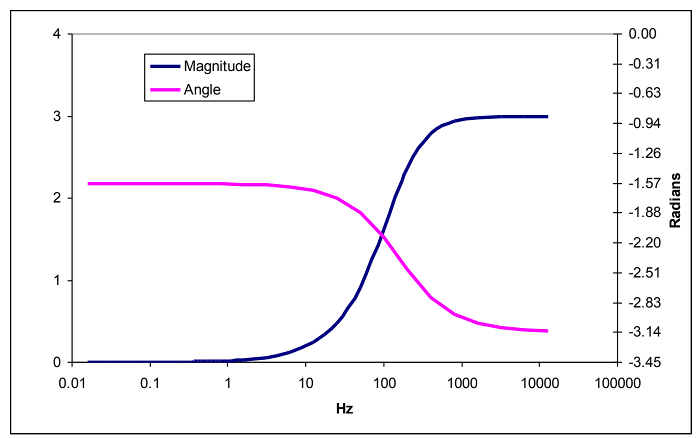
$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1} = -\frac{R_2}{\frac{1+j\omega CR_1}{j\omega C}} = -\frac{j\omega CR_2}{1+j\omega CR_1} = \frac{\omega CR_2}{\sqrt{1+(\omega CR_1)^2}}\angle(\pi + \frac{\pi}{2} - \tan^{-1}(\omega CR_1))$$

$$= \frac{\omega CR_2}{\sqrt{1+(\omega CR_1)^2}}\angle(\frac{3\pi}{2} - \tan^{-1}(\omega CR_1)) = \frac{\omega CR_2}{\sqrt{1+(\omega CR_1)^2}}\angle(-\frac{\pi}{2} - \tan^{-1}(\omega CR_1))$$

$$\frac{v_o}{v_{in}}\Big|_{\omega=0} = -\frac{j\omega CR_2}{1+j\omega CR_1} = 0\angle -\frac{\pi}{2}$$

$$\frac{v_o}{v_{in}}\Big|_{\omega=\frac{1}{CR_1}} = -\frac{j\frac{R_2}{R_2}}{1+j} = \frac{1}{\sqrt{2}}\frac{R_2}{R_2}\angle -\frac{3\pi}{4}$$

$$\frac{v_o}{v_{in}}\Big|_{\omega\to\infty} = -\frac{j\omega CR_2}{1+j\omega CR_1}\Big|_{\omega\to\infty} \to -\frac{j\omega CR_2}{j\omega CR_1} = \frac{R_2}{R_1}\angle -\pi = -\frac{R_2}{R_1}$$



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  z2=R2;
  z1=R1+ZC;
  VOUT(i)=-z2/z1;
end
f=omega/(2*pi);
subplot(2,1,1);
loglog(f,abs(VOUT));
title('OpAmp High Pass Magnitude');
xlabel('Hz');
axis([f(1) f(maxomega) .01 10]);
subplot(2,1,2);
semilogx(f,atan2(imag(VOUT),real(VOUT)));
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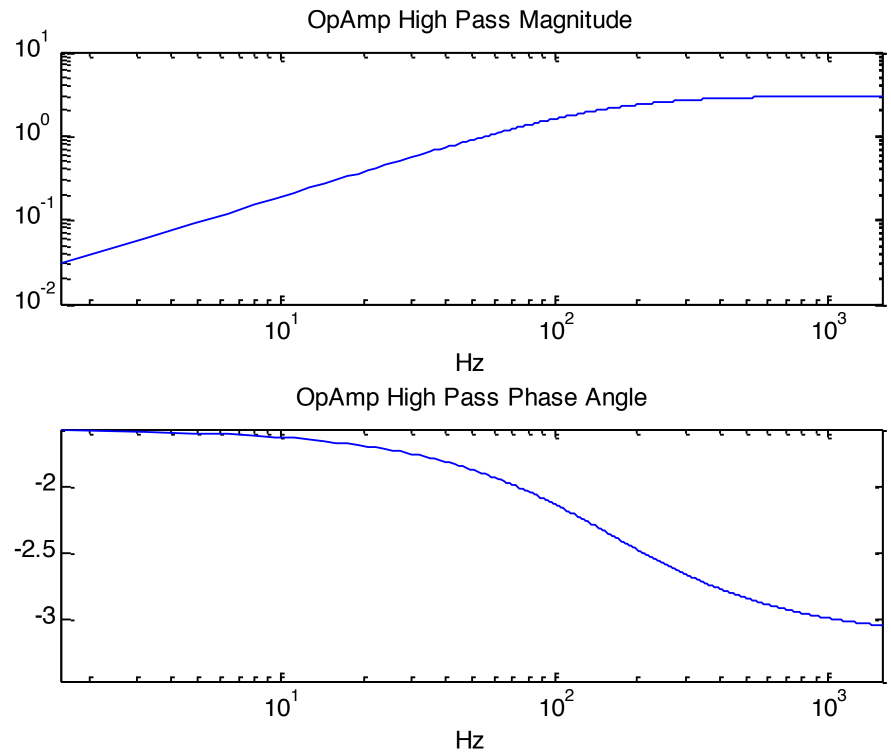
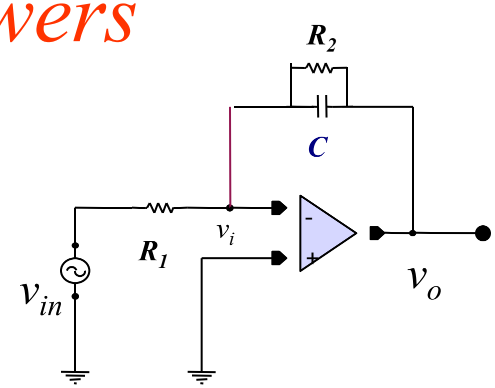


Homework Answers

- Calculate and plot the output vs frequency for these circuits.



$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1}$$

$$Z_2 = R_2 \parallel \frac{1}{j\omega C} = \frac{R_2 \times \frac{1}{j\omega C}}{R_2 + \frac{1}{j\omega C}} = \frac{R_2}{1 + j\omega C R_2}$$

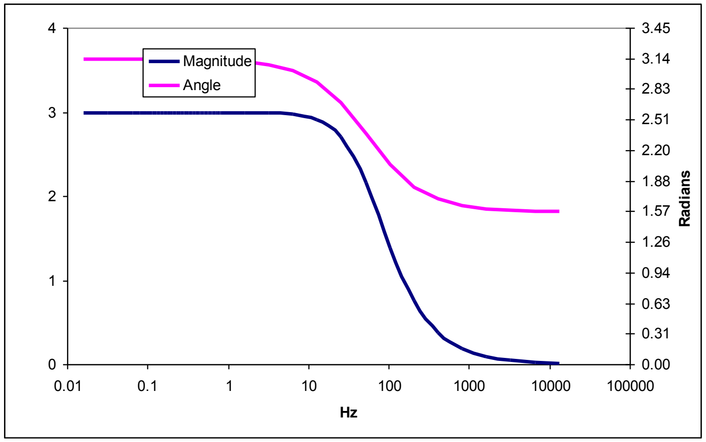
$$Z_1 = R_1$$

$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1} = -\frac{\frac{R_2}{1 + j\omega C R_2}}{R_1} = -\frac{R_2}{R_1} \times \frac{1}{1 + j\omega C R_2} = \frac{R_2}{R_1} \times \frac{1}{\sqrt{1 + (\omega C R_2)^2}} \angle(\pi - \tan^{-1}(\omega C R_2))$$

$$\frac{v_o}{v_{in}}\Big|_{\omega \to 0} = \frac{R_2}{R_1} \times \frac{1}{1} \angle \pi = -\frac{R_2}{R_1}$$

$$\frac{v_o}{v_{in}}\Big|_{\omega = \frac{1}{CR_2}} = \frac{1}{\sqrt{2}} \frac{R_2}{R_1} \angle(\pi - \frac{\pi}{4}) = \frac{1}{\sqrt{2}} \frac{R_2}{R_1} \angle \frac{3\pi}{4}$$

$$\frac{v_o}{v_{in}}\Big|_{\omega \to \infty} = -\frac{R_2}{R_1} \times \frac{1}{1 + j\omega C R_2}\Big|_{\omega \to \infty} \to -\frac{R_2}{R_1} \times \frac{1}{j\omega C R_2} \to 0 \angle \frac{\pi}{2}$$



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  z1=R1;
  z2=1/(1/R2+1/ZC);
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f=omega/(2*pi);
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xlabel('Hz');
axis([f(1) f(maxomega) .01 10]);
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semilogx(f,atan2(imag(VOUT),real(VOUT)));
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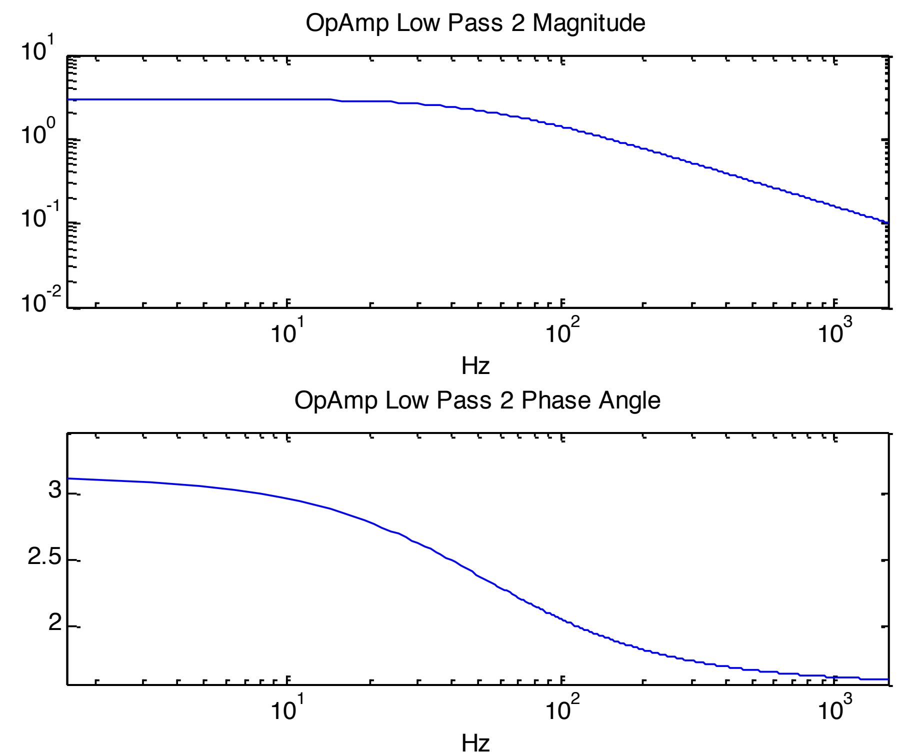
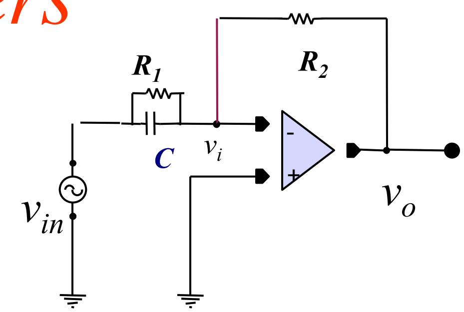


Homework Answers



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$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1}$$

$$Z_2 = R_2$$

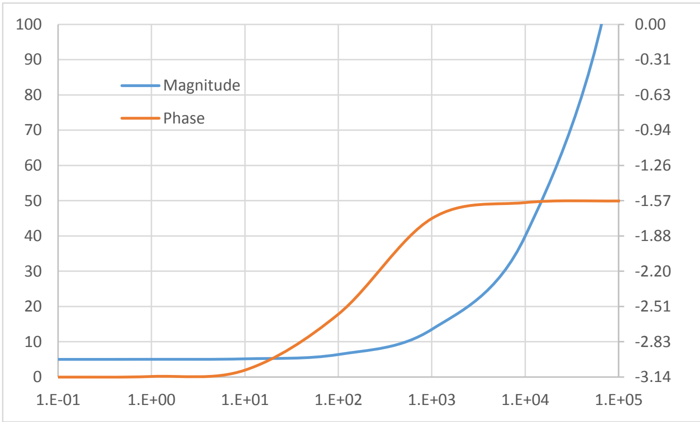
$$Z_1 = R_1 \,||\, \frac{1}{j\omega C} = \frac{R_1 \times \frac{1}{j\omega C}}{R_1 + \frac{1}{j\omega C}} = \frac{R_1}{1 + j\omega C R_1}$$

$$\frac{v_o}{v_{in}} = -\frac{Z_2}{Z_1} = -\frac{R_2}{\frac{R_1}{1 + j\omega C R_1}} = -\frac{R_2}{R_1} \times (1 + j\omega C R) = \frac{R_2}{R_1} \times \sqrt{1 + (\omega C R_1)^2} \angle(-\pi + \tan^{-1}(\omega C R_1))$$

$$\frac{v_o}{v_{in}} \Big|_{\omega=0} = -\frac{R_2}{R_1} \times (1 + j\omega C R) = -\frac{R_2}{R_1} = \frac{R_2}{R_1} \angle -\pi$$

$$\frac{v_o}{v_{in}} \Big|_{\omega=\frac{1}{CR_1}} = \frac{R_2}{R_1} \times \sqrt{2} \angle(-\pi + \frac{\pi}{4}) = \sqrt{2}\frac{R_2}{R_1} \angle -\frac{3\pi}{4}$$

$$\frac{v_o}{v_{in}} \Big|_{\omega\to\infty} = -\frac{R_2}{R_1} \times (1 + j\omega C R) \Big|_{\omega\to\infty} = -\frac{R_2}{R_1} \times \sqrt{1 + (\omega C R_1)^2} \angle(-\pi + \tan^{-1}(\omega C R_1)) \Big|_{\omega\to\infty} \to \infty \angle -\frac{\pi}{2}$$



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xlabel('Hz');
axis([f(1) f(maxomega) 1 1000]);
subplot(2,1,2);
semilogx(f,atan2(imag(VOUT),real(VOUT)));
title('OpAmp High Pass 2 Phase Angle');
xlabel('Hz');
axis([f(1) f(maxomega)  -1.1*pi -pi/2]);
```