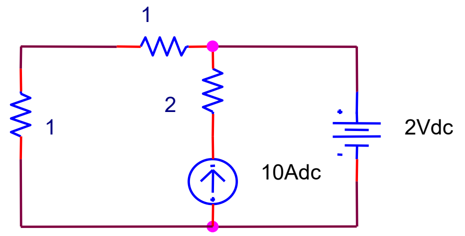
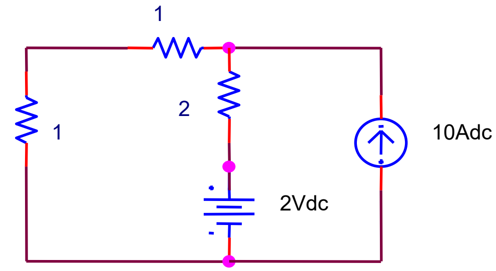
Circuit Analysis

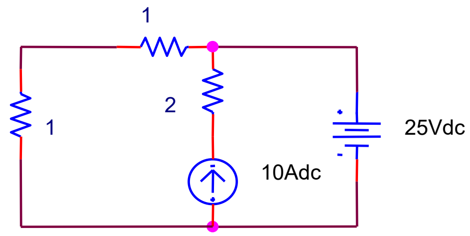
Lesson #2

Homework

- Voltage and Current division
  - How does the voltage divide across two capacitors in series? Show your results.
  - How does the current divide among two capacitors in parallel? Show your results.
- Calculate the Currents and Voltages for the following circuits:







Homework Answers #2

- Voltage and Current division

Voltage divison

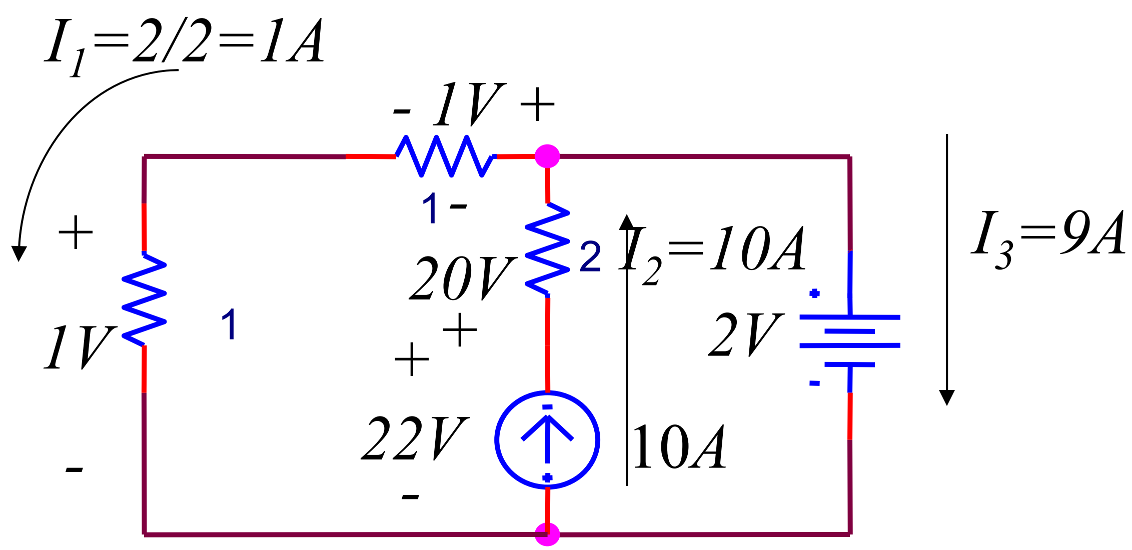
$$Va = \frac{Za}{Za + Zb}Vin; Va = \frac{\frac{1}{j\omega Ca}}{\frac{1}{j\omega Ca} + \frac{1}{j\omega Cb}}Vin = \frac{\frac{1}{Ca}}{\frac{Ca + Cb}{CaCb}}Vin = \frac{Cb}{Ca + Cb}Vin$$

Current divison

$$Ia = \frac{\frac{1}{Za}}{\frac{1}{Za} + \frac{1}{Zb}}Iin; Va = \frac{j\omega Ca}{j\omega Ca + j\omega Cb}Iin = \frac{Ca}{Ca + Cb}Iin$$

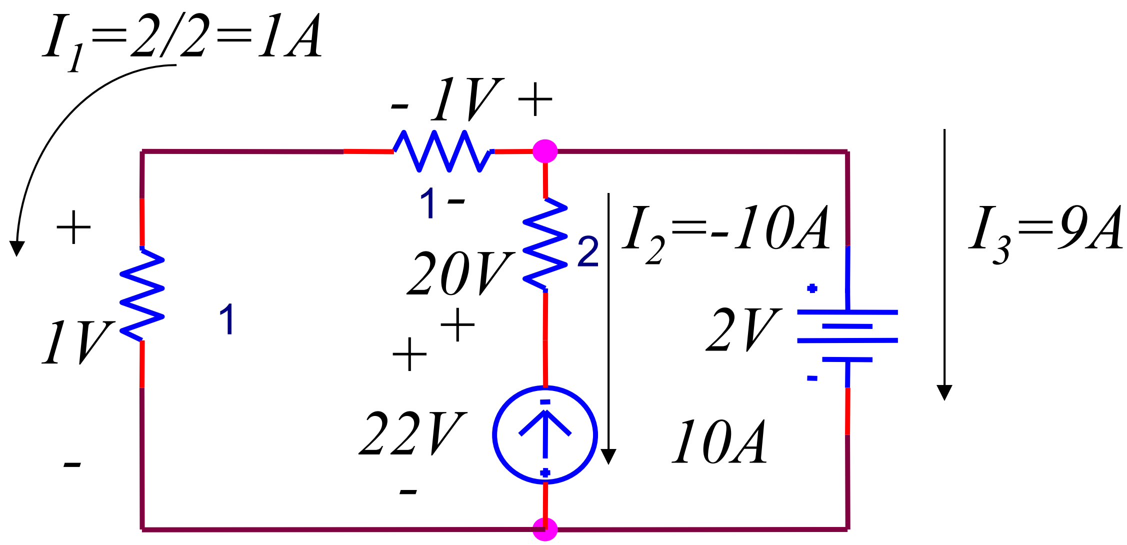
Homework Answers #2

- Calculate the Currents and Voltages for the following circuits:



Homework Answers #2

- Calculate the Currents and Voltages for the following circuits:



Nodal

$$I_1 + I_2 + I_3 = 0$$

Note:

$$I_2 = -10$$

$$\frac{V}{2} - 10 + I_3 = 0$$

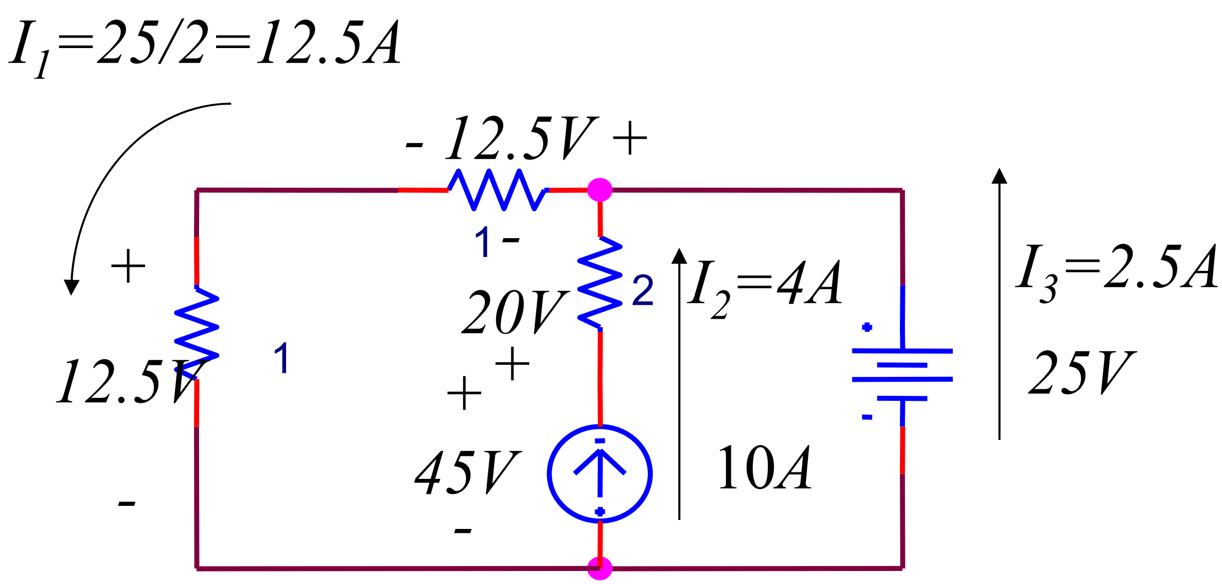
Note:

$$V = 2$$

$$1 - 10 + I_3 = 0 \Rightarrow I_3 = 9$$

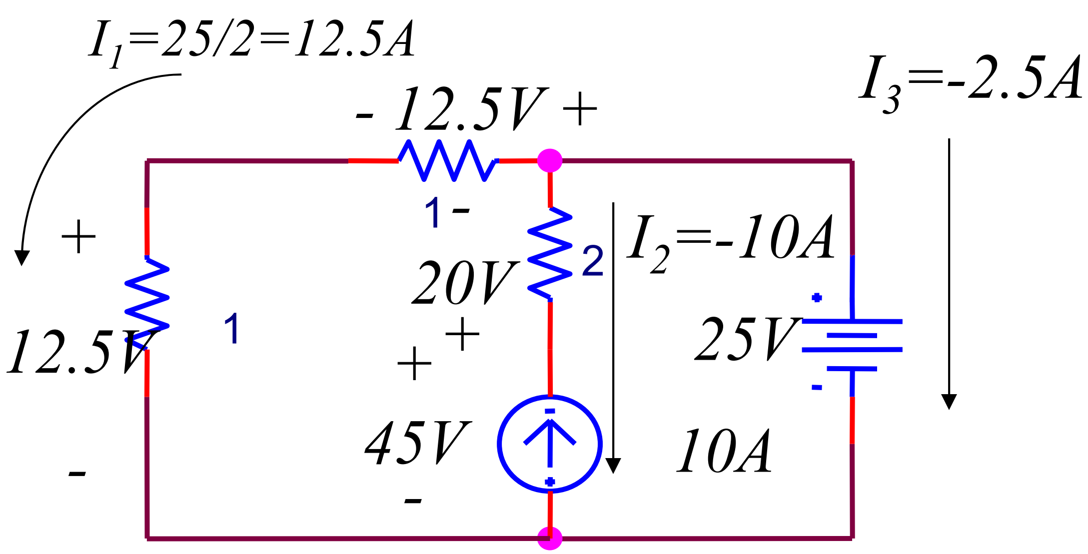
Homework Answers #2

- Calculate the Currents and Voltages for the following circuits:



Homework Answers #2

- Calculate the Currents and Voltages for the following circuits:



Nodal

$I_1 + I_2 + I_3 = 0$

Note:

$I_2 = -10$

$\frac{V}{2} - 10 + I_3 = 0$

Note:

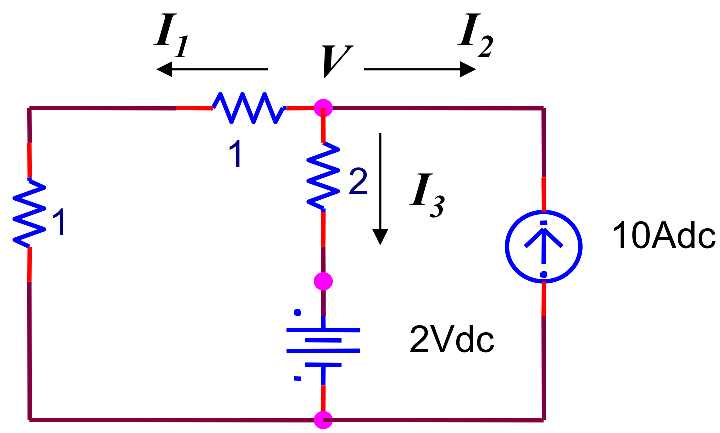
$V = 25$

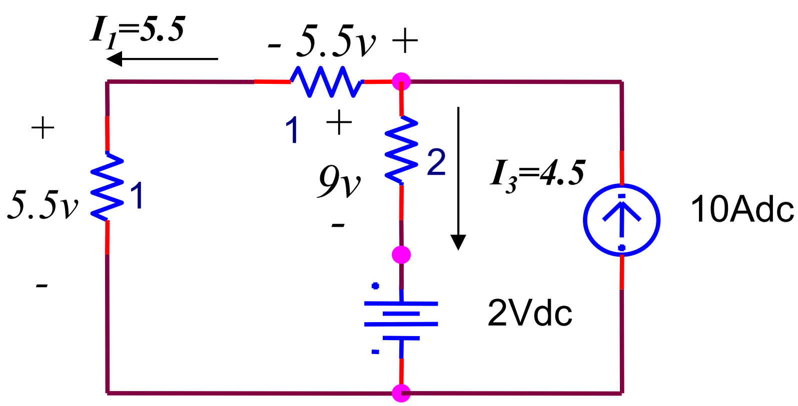
$12.5 - 10 + I_3 = 0 \Rightarrow I_3 = -2.5$

$V_{CS} = 25 - I_2 2 = 25 - (-10) \times 2 = 45$

Homework Answers #3

- Calculate the Currents and Voltages for the following circuits:





Using Nodal Analysis:

$$I_1 + I_2 + I_3 = 0$$

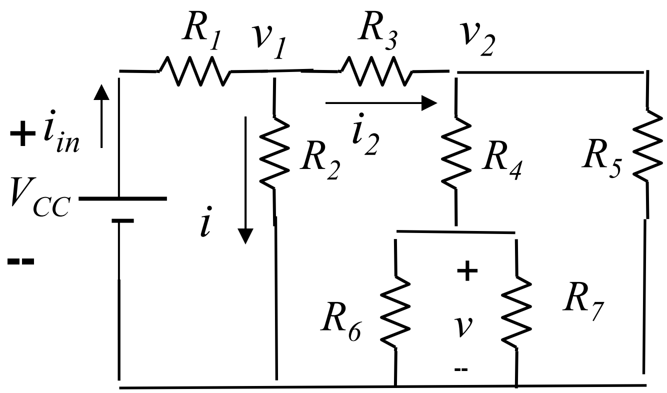
$$\frac{V}{2} + (-10) + \frac{V-2}{2} = 0$$

$$\frac{2V}{2} = 11 \Rightarrow V = 11$$

$$I_1 = \frac{11}{2} = 5.5A;\ I_3 = 10 - 5.5 = 4.5$$

$$Vcs = 11$$

Homework



Calculate the current labeled *i* and the voltage labeled *v* in the following circuit

$R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 1\Omega$,

$R_4 = 1\Omega$, $R_5 = 2\Omega$, $R_6 = 2\Omega$,

$R_7 = 2\Omega$, $V_{cc} = 4v$

$$R'_1 = R_6 \parallel R_7 = \frac{R_6 R_7}{R_6 + R_7}$$

$$R'_2 = R_4 + R'_1 = R_4 + \frac{R_6 R_7}{R_6 + R_7}$$

$$R'_3 = R'_2 \parallel R_5 = (R_4 + \frac{R_6 R_7}{R_6 + R_7}) \parallel R_5 = \frac{(R_4 + \frac{R_6 R_7}{R_6 + R_7})R_5}{(R_4 + \frac{R_6 R_7}{R_6 + R_7}) + R_5} = \frac{R_4 R_5 R_6 + R_4 R_5 R_7 + R_5 R_6 R_7}{R_4 R_6 + R_4 R_7 + R_5 R_6 + R_5 R_7 + R_6 R_7}$$

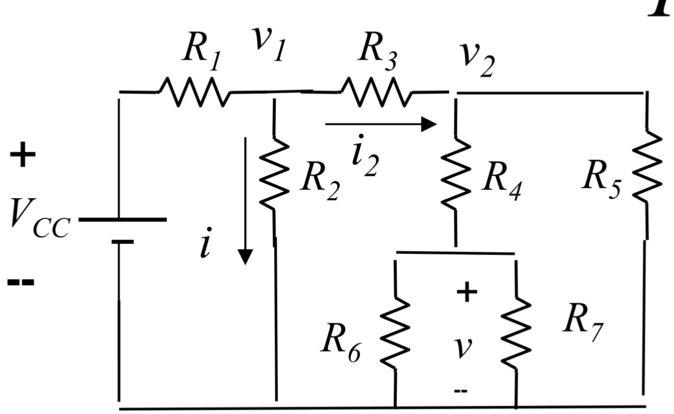
$$R'_4 = R'_3 + R_3 = \frac{R_4 R_5 R_6 + R_4 R_5 R_7 + R_5 R_6 R_7}{R_4 R_6 + R_4 R_7 + R_5 R_6 + R_5 R_7 + R_6 R_7} + R_3$$

$$= \frac{R_3 R_4 R_6 + R_3 R_4 R_7 + R_3 R_5 R_6 + R_3 R_5 R_7 + R_3 R_6 R_7 + R_4 R_5 R_6 + R_4 R_5 R_7 + R_5 R_6 R_7}{R_4 R_6 + R_4 R_7 + R_5 R_6 + R_5 R_7 + R_6 R_7}$$

$$R'_5 = R_2 \parallel R'_4$$

$$R'_6 = R_1 + R'_5$$

Homework



Calculate the current labeled *i* and the voltage labeled *v* in the following circuit

$R_1 = 3\Omega$, $R_2 = 6\Omega$, $R_3 = 12\Omega$,

$R_4 = 4\Omega$, $R_5 = 2\Omega$, $R_6 = 2\Omega$,

$R_7 = 4\Omega$, $V_{cc} = 4v$

$$R'_5 = R_2 \,\|\, R'_4 = R_2 \,\|\, \frac{R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}{R_4R_6 + R_4R_7 + R_5R_6 + R_5R_7 + R_6R_7}$$

$$= \frac{R_2 \times \dfrac{R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}{R_4R_6 + R_4R_7 + R_5R_6 + R_5R_7 + R_6R_7}}{R_2 + \dfrac{R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}{R_4R_6 + R_4R_7 + R_5R_6 + R_5R_7 + R_6R_7}}$$

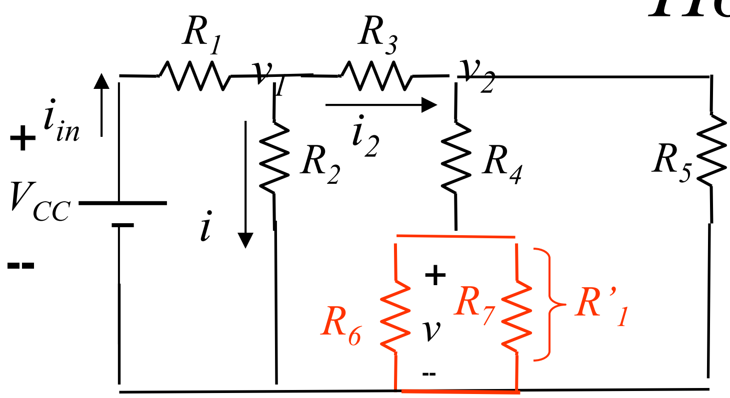
$$= \frac{R_2R_3R_4R_6 + R_2R_3R_4R_7 + R_2R_3R_5R_6 + R_2R_3R_5R_7 + R_2R_3R_6R_7 + R_2R_4R_5R_6 + R_2R_4R_5R_7 + R_2R_5R_6R_7}{R_2R_4R_6 + R_2R_4R_7 + R_2R_5R_6 + R_2R_5R_7 + R_2R_6R_7 + R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}$$

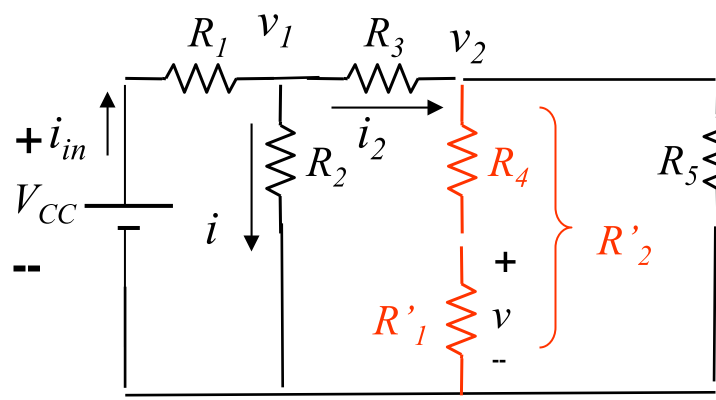
$$R'_6 = R_1 + R'_5 = R_1 + \frac{R_2R_3R_4R_6 + R_2R_3R_4R_7 + R_2R_3R_5R_6 + R_2R_3R_5R_7 + R_2R_3R_6R_7 + R_2R_4R_5R_6 + R_2R_4R_5R_7 + R_2R_5R_6R_7}{R_2R_4R_6 + R_2R_4R_7 + R_2R_5R_6 + R_2R_5R_7 + R_2R_6R_7 + R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}$$

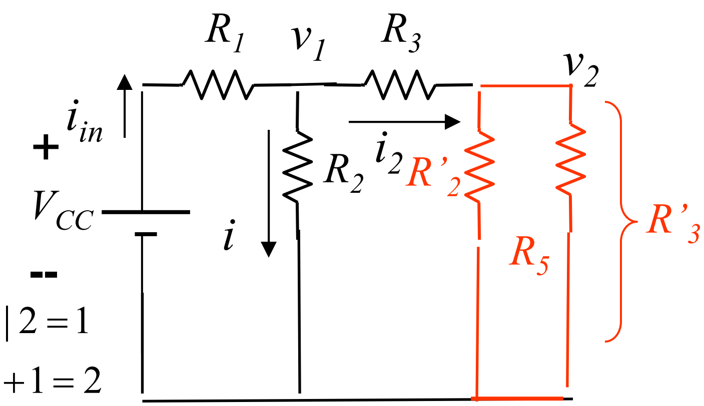
$$= \frac{R_1R_2R_4R_6 + R_1R_2R_4R_7 + R_1R_2R_5R_6 + R_1R_2R_5R_7 + R_1R_2R_6R_7 + R_1R_3R_4R_6 + R_1R_3R_4R_7 + R_1R_3R_5R_6 + R_1R_3R_5R_7 + R_1R_3R_6R_7 + R_1R_4R_5R_6 + R_1R_4R_5R_7 + R_1R_5R_6R_7}{R_2R_4R_6 + R_2R_4R_7 + R_2R_5R_6 + R_2R_5R_7 + R_2R_6R_7 + R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}$$

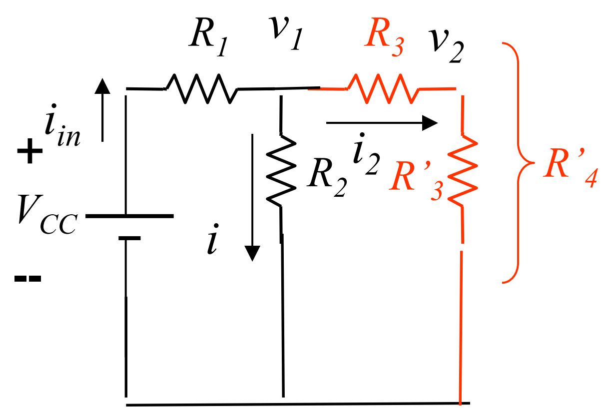
$$+ \frac{R_2R_3R_4R_6 + R_2R_3R_4R_7 + R_2R_3R_5R_6 + R_2R_3R_5R_7 + R_2R_3R_6R_7 + R_2R_4R_5R_6 + R_2R_4R_5R_7 + R_2R_5R_6R_7}{R_2R_4R_6 + R_2R_4R_7 + R_2R_5R_6 + R_2R_5R_7 + R_2R_6R_7 + R_3R_4R_6 + R_3R_4R_7 + R_3R_5R_6 + R_3R_5R_7 + R_3R_6R_7 + R_4R_5R_6 + R_4R_5R_7 + R_5R_6R_7}$$

Homework





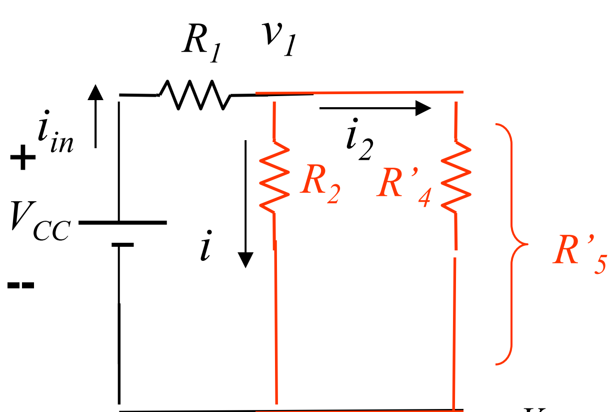


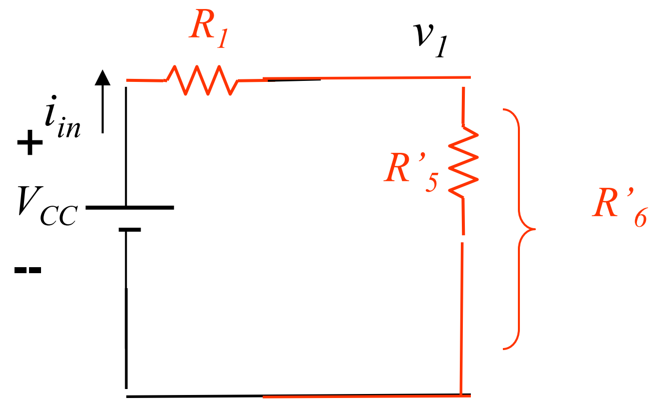


$$R'_1 = R_6 \parallel R_7 = 2 \parallel 2 = 1$$
$$R'_2 = R_4 + R'_1 = 1 + 1 = 2$$
$$R'_3 = R'_2 \parallel R_5 = 2 \parallel 2 = 1$$
$$R'_4 = R'_3 + R_3 = 1 + 1 = 2$$
$$R'_5 = R_2 \parallel R'_4 = 2 \parallel 2 = 1$$
$$R'_6 = R_1 + R'_5 = 1 + 1 = 2$$

$$i_{in} = \frac{Vcc}{R'_6}; i = i_{in}\frac{R'_4}{R'_4 + R_2}; i_2 = i_{in}\frac{R_2}{R'_4 + R_2};$$
$$v_1 = i_2 R'_4; v_2 = v_1 \frac{R'_3}{R'_3 + R_3}; v = v_2 \frac{R'_1}{R'_1 + R_4}$$

Homework





$$i_{in} = \frac{Vcc}{R'_6} = \frac{4}{2} = 2;$$

$$R'_1 = R_6 \,||\, R_7 = 2 \,||\, 2 = 1$$

$$R'_2 = R_4 + R'_1 = 1 + 1 = 2$$

$$R'_3 = R'_2 \,||\, R_5 = 2 \,||\, 2 = 1$$

$$R'_4 = R'_3 + R_3 = 1 + 1 = 2$$

$$R'_5 = R_2 \,||\, R'_4 = 2 \,||\, 2 = 1$$

$$R'_6 = R_1 + R'_5 = 1 + 1 = 2$$

$$i = i_{in} \frac{R'_4}{R'_4 + R_2} = 2 \times \frac{2}{2+2} = 1$$

$$i_2 = i_{in} \frac{R_2}{R'_4 + R_2} = 1 \times \frac{2}{2+2} = 0.5$$

$$v_1 = i_2 R'_4 = 0.5 \times 2 = 1$$

$$v_2 = v_1 \frac{R'_3}{R'_3 + R_3} = 1 \times \frac{1}{1+1} = 0.5$$

$$v = v_2 \frac{R'_1}{R'_1 + R_4} = 0.5 \times \frac{1}{1+1} = 0.25$$

Homework

$$R'_1 = R_6 \parallel R_7 = 2 \parallel 2 = 1$$
$$R'_2 = R_4 + R'_1 = 1 + 1 = 2$$
$$R'_3 = R'_2 \parallel R_5 = 2 \parallel 2 = 1$$
$$R'_4 = R'_3 + R_3 = 1 + 1 = 2$$
$$R'_5 = R_2 \parallel R'_4 = 2 \parallel 2 = 1$$
$$R'_6 = R_1 + R'_5 = 1 + 1 = 2$$

$$i_{in} = \frac{Vcc}{R'_6} = \frac{4}{2} = 2;$$

$$i = i_{in}\frac{R'_4}{R'_4 + R_2} = 2 \times \frac{2}{2+2} = 1$$

$$i_2 = i_{in}\frac{R_2}{R'_4 + R_2} = 2 \times \frac{2}{2+2} = 1$$

$$v_1 = i_2 R'_4 = 1 \times 2 = 2$$

$$v_2 = v_1\frac{R'_3}{R'_3 + R_3} = 2 \times \frac{1}{1+1} = 1$$

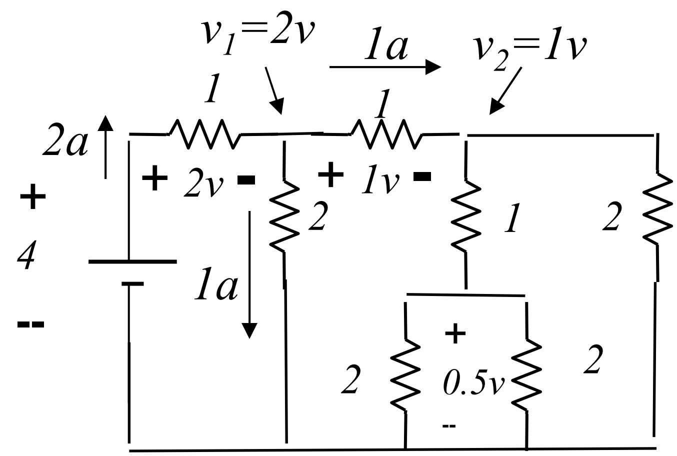
$$v = v_2\frac{R'_1}{R'_1 + R_4} = 1 \times \frac{1}{1+1} = 0.5$$

Calculate the current labeled *i* and the voltage labeled *v* in the following circuit

$R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 1\Omega$,

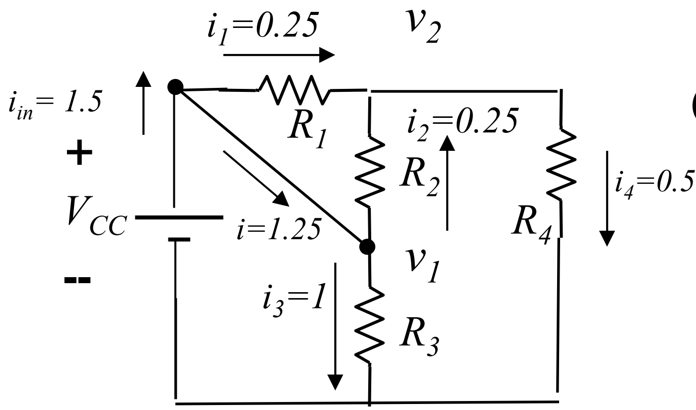
$R_4 = 1\Omega$, $R_5 = 2\Omega$, $R_6 = 2\Omega$,

$R_7 = 2\Omega$, $V_{cc} = 4v$



CHECK YOUR ANSWERS!

Homework



Calculate the current labeled, *i*.

$R_1 = 2\Omega$, $R_2 = 2\Omega$, $R_3 = 2\Omega$, $R_4 = 3\Omega$, $V_{cc} = 2v$

$$R'_1 = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} = 2 \parallel 2 = 1$$

$$R'_2 = R_4 + R'_1 = R_4 + \frac{R_1 R_2}{R_1 + R_2} = 3 + 1 = 4$$

$$R'_3 = R'_2 \parallel R_3 = (R_4 + \frac{R_1 R_2}{R_1 + R_2}) \parallel R_3 = \frac{(R_4 + \frac{R_1 R_2}{R_1 + R_2})R_3}{(R_4 + \frac{R_1 R_2}{R_1 + R_2}) + R_3}$$

$$= \frac{R_1 R_3 R_4 + R_2 R_3 R_4 + R_1 R_2 R_3}{R_1 R_4 + R_2 R_4 + R_1 R_3 + R_2 R_3 + R_1 R_2}$$

$$= 4 \parallel 2 = \frac{8}{6} = \frac{4}{3}$$

$$i_{in} = \frac{Vcc}{R'_3} = \frac{2}{\frac{4}{3}} = \frac{3}{2};$$

$$i_3 = i_{in} \frac{R'_2}{R'_2 + R_3} = \frac{3}{2} \times \frac{4}{4+2} = \frac{3}{2} \times \frac{4}{6} = \frac{2}{2} = 1; v_1 = 2v$$

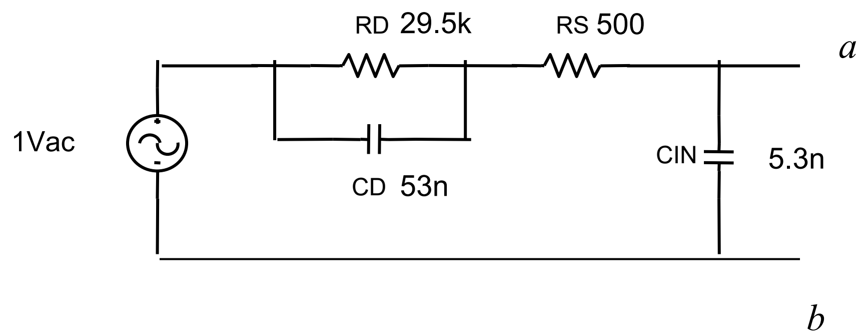
$$i_4 = i_{in} \frac{R_3}{R'_2 + R_3} = \frac{3}{2} \times \frac{2}{6} = \frac{1}{2}; v_1 = \frac{3}{2} v$$

$$i_1 = i_4 \frac{R_2}{R_2 + R_1} = \frac{1}{2} \times \frac{2}{4} = \frac{1}{4}$$

$$i_2 = i_4 \frac{R_1}{R_2 + R_1} = \frac{1}{2} \times \frac{2}{4} = \frac{1}{4}$$

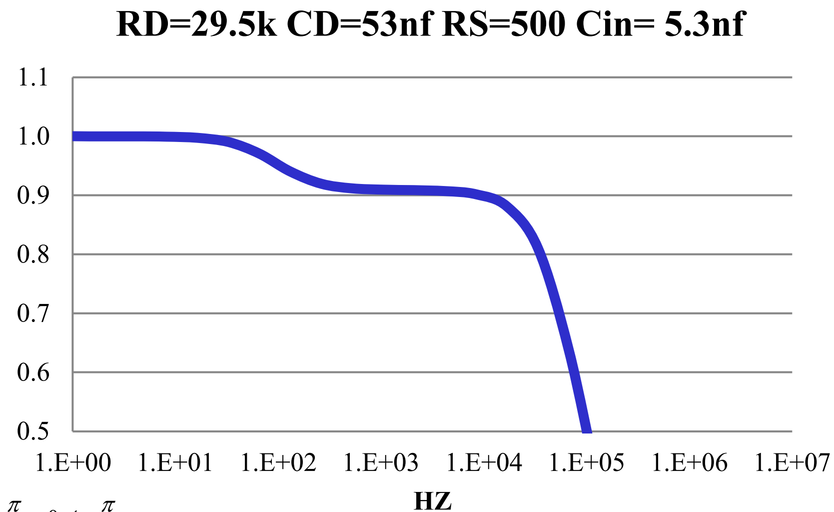
$$i = i_{in} - i_1 = \frac{3}{2} - \frac{1}{4} = \frac{5}{4}$$

Homework



An electrode is connected to an oscilloscope which has a purely capacitance input impedance, CIN. Find and plot the output voltage $V_{ab}(j\omega)$ as function of ω. Use Matlab to perform the plot.

Electrode Impedance



$$Z_E = \frac{R_D + R_S + j\omega R_D R_S C_D}{1 + j\omega R_D C_D}$$

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{j\omega C_{in}}}{\frac{1}{j\omega C_{in}} + Z_E} = \frac{1}{1 + j\omega C_{in} Z_E} = \frac{1}{1 + j\omega C_{in}\frac{R_D + R_S + j\omega R_D R_S C_D}{1 + j\omega R_D C_D}}$$

$$= \frac{1 + j\omega R_D C_D}{1 + j\omega R_D C_D + j\omega C_{in}(R_D + R_S + j\omega R_D R_S C_D)}$$

$$= \frac{1 + j\omega R_D C_D}{1 - \omega^2 R_D R_S C_D C_{in} + j\omega(R_D C_D + C_{in}(R_D + R_S))}$$

$$\left.\frac{V_{out}}{V_{in}}\right|_{\omega=0} = \left.\frac{1 + j\omega R_D C_D}{1 - \omega^2 R_D R_S C_D C_{in} + j\omega(R_D C_D + C_{in}(R_D + R_S))}\right|_{\omega=0} = 1$$

$$\left.\frac{V_{out}}{V_{in}}\right|_{\omega\to\infty} = \left.\frac{1 + j\omega R_D C_D}{1 - \omega^2 R_D R_S C_D C_{in} + j\omega(R_D C_D + C_{in}(R_D + R_S))}\right|_{\omega\to\infty} \to \frac{j\omega R_D C_D}{-\omega^2 R_D R_S C_D C_{in}} = \frac{1}{\omega R_S C_{in}}\angle -\frac{\pi}{2} = 0\angle -\frac{\pi}{2}$$

$$\left.\frac{V_{out}}{V_{in}}\right|_{\omega=\frac{1}{\sqrt{R_D R_S C_D C_{in}}}} = \left.\frac{1 + j\omega R_D C_D}{1 - \omega^2 R_D R_S C_D C_{in} + j\omega(R_D C_D + C_{in}(R_D + R_S))}\right|_{\omega=\frac{1}{\sqrt{R_D R_S C_D C_{in}}}} = \frac{1 + j\frac{1}{\sqrt{R_D R_S C_D C_{in}}} R_D C_D}{j\frac{1}{\sqrt{R_D R_S C_D C_{in}}}(R_D C_D + C_{in}(R_D + R_S))}$$

$$= \frac{\sqrt{R_D R_S C_D C_{in}} + jR_D C_D}{j(R_D C_D + C_{in}(R_D + R_S))} = \frac{\sqrt{R_D R_S C_D C_{in} + (R_D C_D)^2}}{(R_D C_D + C_{in}(R_D + R_S))}\angle \tan^{-1}\left(\frac{R_D C_D}{\sqrt{R_D R_S C_D C_{in}}}\right) - \frac{\pi}{2}$$

$$\frac{V_{out}}{V_{in}} = \frac{1 + j\frac{f}{f_p}}{1 - (\frac{f}{f_R})^2 + jf(\frac{1}{f_p} + \frac{1}{f_{in}})} = \frac{\sqrt{1 + (\frac{f}{f_p})^2}}{\sqrt{(1 - (\frac{f}{f_R})^2)^2 + (f(\frac{1}{f_p} + \frac{1}{f_{in}}))^2}}\angle \tan^{-1}\left(\frac{f}{f_p}\right) - \tan^{-1}\left(\frac{f(\frac{1}{f_p} + \frac{1}{f_{in}})}{1 - (\frac{f}{f_R})^2}\right)$$

$$f = \frac{\omega}{2\pi}, f_p = \frac{1}{2\pi R_D C_D}, f_R = \frac{1}{2\pi\sqrt{R_D R_S C_D C_{in}}}, f_{in} = \frac{1}{2\pi C_{in}(R_D + R_S)}$$

Electrode Impedance

$$\frac{V_{out}}{V_{in}}(j\omega) = \frac{1 + j\omega R_D C_D}{1 - \omega^2 R_D R_S C_D C_{in} + j\omega(R_D C_D + C_{in}(R_D + R_S))}$$

$$\frac{V_{out}}{V_{in}}(s) = \frac{1 + sR_D C_D}{1 + s^2 R_D R_S C_D C_{in} + s(R_D C_D + C_{in}(R_D + R_S))} = \frac{sR_D C_D + 1}{s^2 R_D R_S C_D C_{in} + s(R_D C_D + C_{in}(R_D + R_S)) + 1} = \frac{R_D C_D}{R_D R_S C_D C_{in}} \frac{s + \frac{1}{R_D C_D}}{s^2 + s(\frac{R_D C_D + C_{in}(R_D + R_S)}{R_D R_S C_D C_{in}}) + \frac{1}{R_D R_S C_D C_{in}}}$$

$$= \frac{1}{R_S C_{in}} \frac{s + \frac{1}{R_D C_D}}{s^2 + s(\frac{R_D C_D + C_{in}(R_D + R_S)}{R_D R_S C_D C_{in}}) + \frac{1}{R_D R_S C_D C_{in}}} = \frac{1}{R_S C_{in}} \frac{s + s_z}{(s + s_{p_1})(s + s_{p_2})}$$

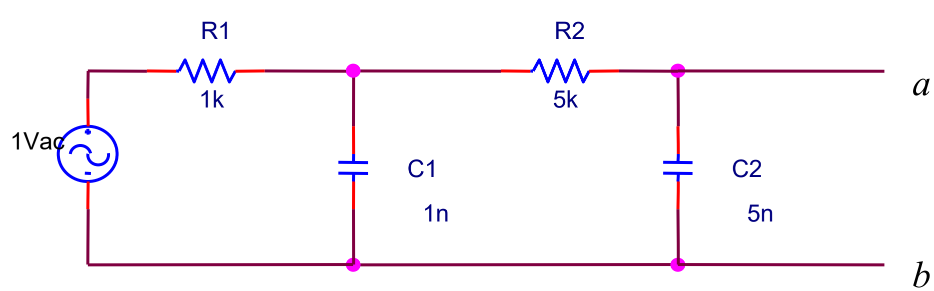
$$s_z = -\frac{1}{R_D C_D}; s_{p_1,p_2} = \frac{-\frac{R_D C_D + C_{in}(R_D + R_S)}{R_D R_S C_D C_{in}} \pm \sqrt{(\frac{R_D C_D + C_{in}(R_D + R_S)}{R_D R_S C_D C_{in}})^2 - 4\frac{1}{R_D R_S C_D C_{in}}}}{2} = \frac{-R_D C_D + C_{in}(R_D + R_S) \pm \sqrt{(R_D C_D + C_{in}(R_D + R_S))^2 - 4R_D R_S C_D C_{in}}}{2R_D R_S C_D C_{in}}$$

$$s_z = -640; s_{p_1,p_2} = -581, 4.2 \times 10^5$$

$$fz = 102Hz; f_{p_1,p_2} = 92.5Hz, 6.6 \times 10^4 Hz$$

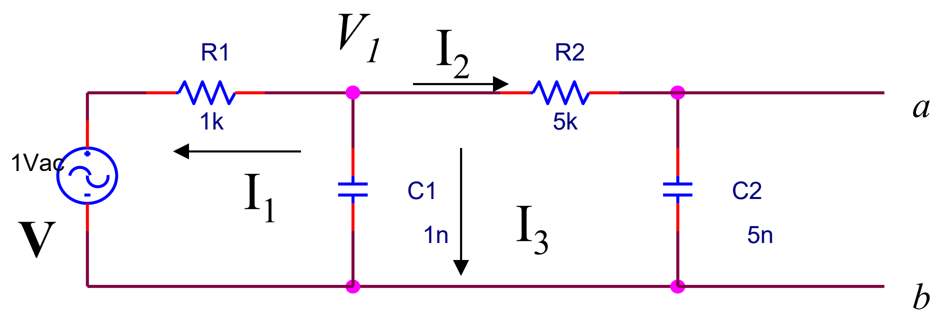
Homework

- Repeat the analysis of this circuit using Mesh and Nodal Analysis. That is find V_{ab} as a function of frequency



Homework Answers #7

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



$$I_1 + I_2 + I_3 = 0$$

$$\frac{V_1 - V}{Z_{R_1}} + \frac{V_1}{Z_{R_2} + Z_{C_2}} + \frac{V_1}{Z_{C_1}} = 0$$

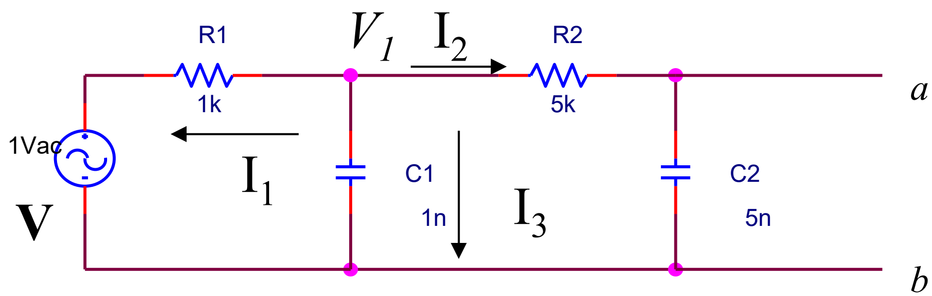
$$\frac{V_1}{Z_{R_1}} + \frac{V_1}{Z_{R_2} + Z_{C_2}} + \frac{V_1}{Z_{C_1}} = \frac{V}{Z_{R_1}}$$

$$\left(\frac{1}{Z_{R_1}} + \frac{1}{Z_{R_2} + Z_{C_2}} + \frac{1}{Z_{C_1}}\right)V_1 = \frac{V}{Z_{R_1}}$$

$$\left(\frac{(Z_{R_2} + Z_{C_2})Z_{C_1} + Z_{R_1}Z_{C_1} + (Z_{R_2} + Z_{C_2})Z_{R_1}}{Z_{R_1}(Z_{R_2} + Z_{C_2})Z_{C_1}}\right)V_1 = \frac{V}{Z_{R_1}}$$

Homework Answers #8

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



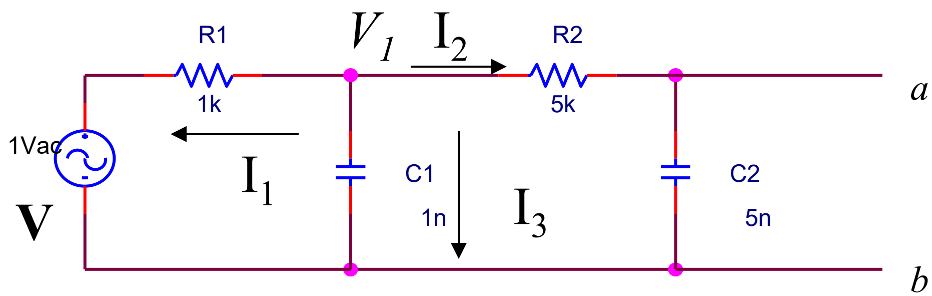
$$V_1 = \frac{(Z_{R_2} + Z_{C_2})Z_{C_1}}{Z_{R_2}Z_{C_1} + Z_{C_2}Z_{C_1} + Z_{R_1}Z_{C_1} + Z_{R_2}Z_{R_1} + Z_{C_2}Z_{R_1}} V$$

$$V_{ab} = \frac{Z_{C_2}}{(Z_{R_2} + Z_{C_2})} V_1 = \frac{Z_{C_2}}{(Z_{R_2} + Z_{C_2})} \frac{(Z_{R_2} + Z_{C_2})Z_{C_1}}{Z_{R_2}Z_{C_1} + Z_{C_2}Z_{C_1} + Z_{R_1}Z_{C_1} + Z_{R_2}Z_{R_1} + Z_{C_2}Z_{R_1}} V$$

$$= \frac{Z_{C_1}Z_{C_2}}{Z_{R_2}Z_{C_1} + Z_{C_2}Z_{C_1} + Z_{R_1}Z_{C_1} + Z_{R_2}Z_{R_1} + Z_{C_2}Z_{R_1}} V$$

Homework Answers #8

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



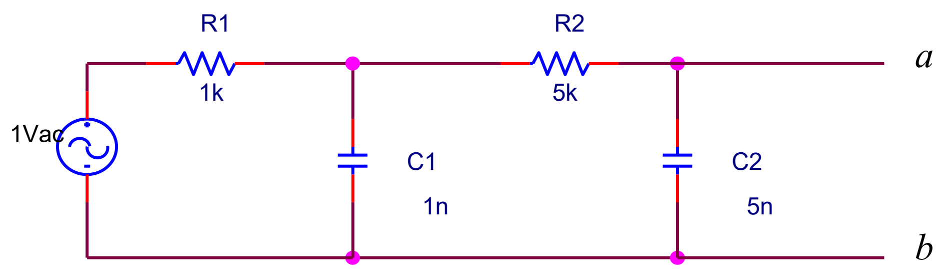
$$V_{ab} = \frac{Z_{C_1} Z_{C_2}}{Z_{R_2} Z_{C_1} + Z_{C_2} Z_{C_1} + Z_{R_1} Z_{C_1} + Z_{R_2} Z_{R_1} + Z_{C_2} Z_{R_1}} V$$

$$= \frac{\frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}{R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_2} + R_1 \frac{1}{j\omega C_1} + R_2 R_1 + \frac{1}{j\omega C_2} R_1}$$

$$= \frac{1}{j\omega C_2 R_2 + 1 + j\omega C_2 R_1 - \omega^2 C_1 C_2 R_2 R_1 + j\omega C_2 R_1}$$

$$= \frac{1}{1 - \omega^2 C_1 C_2 R_2 R_1 + j\omega (C_2 R_2 + C_2 R_1 + C_2 R_1)}$$

Homework Answers #6



$$\frac{V_{ab}}{V} = \frac{1}{(1-\omega^2 C_2 C_1 R_1 R_2) + j\omega[C_2(R_1+R_2) + C_1 R_1]}$$

$$= \frac{1}{1-(\omega 5\times10^{-6})^2 + j\omega 31\times10^{-6}}$$

$$= \frac{1}{\sqrt{[1-(\omega 5\times10^{-6})^2]^2 + \omega^2 961\times10^{-12}}} \angle -\tan^{-1}[\frac{\omega 31\times10^{-6}}{1-(\omega 5\times10^{-6})^2}]$$

$$\frac{V_{ab}}{V}|_{\omega=0} = \frac{1}{\sqrt{[1-(0\times 5\times10^{-6})^2]^2 + 0\times961\times10^{-12}}} \angle -\tan^{-1}[\frac{0\times31\times10^{-6}}{1-(0\times5\times10^{-6})^2}]$$

$$= \frac{1}{\sqrt{1}} \angle -\tan^{-1}[\frac{0}{1}] = 1\angle 0$$

$$\frac{V_{ab}}{V}|_{\omega=\frac{1}{5\times10^{-6}}} = \frac{1}{\sqrt{[1-(\frac{1}{5\times10^{-6}}\times5\times10^{-6})^2]^2 + \frac{1}{5\times10^{-6}}^2\times961\times10^{-12}}} \angle -\tan^{-1}[\frac{\frac{1}{5\times10^{-6}}\times31\times10^{-6}}{1-(\frac{1}{5\times10^{-6}}\times5\times10^{-6})^2}] = \frac{1}{\sqrt{[0]^2 + \frac{1}{5\times10^{-6}}^2\times961\times10^{-12}}} \angle -\tan^{-1}[\frac{\frac{1}{5\times10^{-6}}\times31\times10^{-6}}{0}] = \frac{1}{\sqrt{38.44}} \angle -\tan^{-1}[\frac{6.2}{0}]$$

$$= \frac{1}{6.2} \angle -\frac{\pi}{2}$$

$$\frac{V_{ab}}{V}|_{\omega\to\infty} = \frac{1}{1-(\omega5\times10^{-6})^2 + j\omega31\times10^{-6}}|_{\omega\to\infty} \to \frac{1}{-(\omega5\times10^{-6})^2} \to 0\angle -\pi$$

Homework Answers #6

$$\frac{V_{ab}}{V_{a'b}}=\frac{\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_2}+R_2}=\frac{1}{1+j\omega R_2C_2}$$

$$\frac{V_{a'b}}{V}=\frac{Z_{a'b}}{Z_{a'b}+R_1}$$

$$Z_{a'b}=\frac{(\frac{1}{j\omega C_2}+R_2)\frac{1}{j\omega C_1}}{\frac{1}{j\omega C_2}+R_2+\frac{1}{j\omega C_1}}=\frac{(\frac{1+j\omega C_2R_2}{j\omega C_2})\frac{1}{j\omega C_1}}{(\frac{1+j\omega C_2R_2}{j\omega C_2})+\frac{1}{j\omega C_1}}$$

$$=\frac{1+j\omega C_2R_2}{j\omega C_1(1+j\omega C_2R_2)+j\omega C_2}=\frac{1+j\omega C_2R_2}{-\omega^2C_2R_2C_1+j\omega(C_1+C_2)}$$

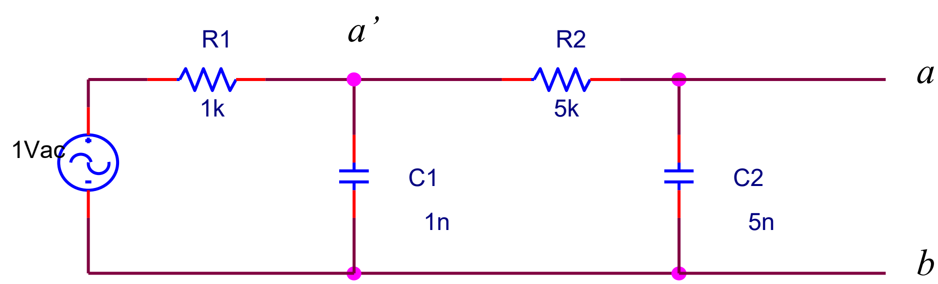
$$\frac{V_{a'b}}{V}=\frac{Z_{a'b}}{Z_{a'b}+R_1}=\frac{\frac{1+j\omega C_2R_2}{-\omega^2C_2R_2C_1+j\omega(C_1+C_2)}}{\frac{1+j\omega C_2R_2}{-\omega^2C_2R_2C_1+j\omega(C_1+C_2)}+R_1}$$

$$=\frac{1+j\omega C_2R_2}{1+j\omega C_2R_2+R_1(-\omega^2C_2R_2C_1+j\omega(C_1+C_2))}$$

$$=\frac{1+j\omega C_2R_2}{1-\omega^2C_2R_2C_1R_1+j\omega(R_1C_1+R_1C_2+C_2R_2)}$$

$$\frac{V_{ab}}{V}=\frac{V_{ab}}{V_{a'b}}\frac{V_{a'b}}{V}=\frac{1}{1+j\omega R_2C_2}\frac{1+j\omega C_2R_2}{1-\omega^2C_2R_2C_1R_1+j\omega(R_1C_1+R_1C_2+C_2R_2)}$$

$$=\frac{1}{1-\omega^2C_2R_2C_1R_1+j\omega(R_1C_1+R_1C_2+C_2R_2)}$$

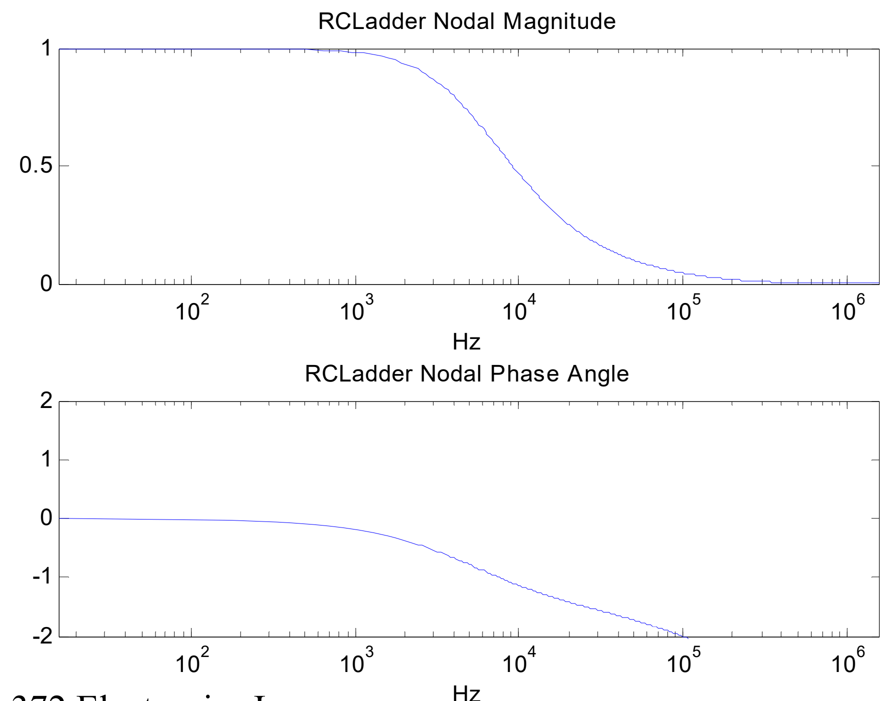


$$\frac{V_{ab}}{V}=\frac{1}{1-\omega^2C_2R_2C_1R_1+j\omega(R_1C_1+R_1C_2+C_2R_2)}$$

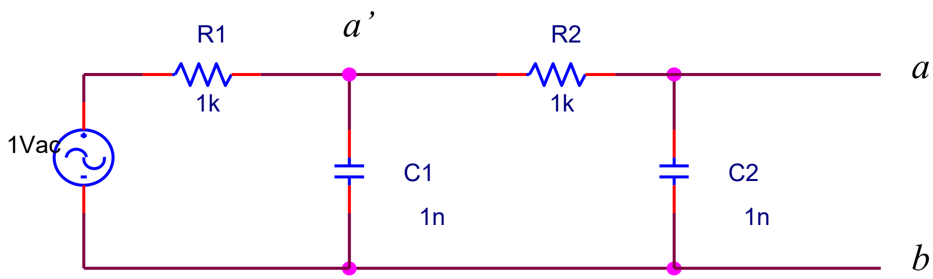
$$=\frac{1}{\sqrt{(1-\omega^2C_2R_2C_1R_1)^2+(\omega(R_1C_1+R_1C_2+C_2R_2))^2}}\angle\tan^{-1}(\frac{\omega(R_1C_1+R_1C_2+C_2R_2)}{1-\omega^2C_2R_2C_1R_1})$$

Matlab Code

```
clear all;
R1=1e3;C1=1e-9;R2=5e3;C2=5e-9;
omega=(100:1000:10^7);maxomega=length(omega);
z1=R1;GIN=[1/R1];
for i=1:maxomega
   zC1=1/complex(0,omega(i)*C1);
   zC2=1/complex(0,omega(i)*C2);
   z3=R2+zC2;
   G=1/R1+1/zC1+1/z3;
   V1=G\GIN;
   VOUT(i)=V1*(zC2/z3);
end
f=omega/(2*pi);
subplot(2,1,1);
semilogx(f,abs(VOUT));
title('RCLadder Nodal Magnitude');
xlabel('Hz');
axis([f(1) f(maxomega) 0 1]);
subplot(2,1,2);
semilogx(f,atan2(imag(VOUT),real(VOUT)));
title('RCLadder Nodal Phase Angle');
xlabel('Hz');
axis([f(1) f(maxomega) -2 2]);
```



Homework Answers #6



$$\frac{V_{ab}}{V_{a'b}} = \frac{\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_2} + R_2} = \frac{1}{1 + j\omega R_2 C_2}$$

$$\frac{V_{a'b}}{V} = \frac{Z_{a'b}}{Z_{a'b} + R_1}$$

$$Z_{a'b} = \frac{(\frac{1}{j\omega C_2} + R_2)\frac{1}{j\omega C_1}}{\frac{1}{j\omega C_2} + R_2 + \frac{1}{j\omega C_1}} = \frac{(\frac{1 + j\omega C_2 R_2}{j\omega C_2})\frac{1}{j\omega C_1}}{(\frac{1 + j\omega C_2 R_2}{j\omega C_2}) + \frac{1}{j\omega C_1}}$$

$$= \frac{1 + j\omega C_2 R_2}{j\omega C_1(1 + j\omega C_2 R_2) + j\omega C_2} = \frac{1 + j\omega C_2 R_2}{-\omega^2 C_2 R_2 C_1 + j\omega(C_1 + C_2)}$$

$$\frac{V_{a'b}}{V} = \frac{Z_{a'b}}{Z_{a'b} + R_1} = \frac{\frac{1 + j\omega C_2 R_2}{-\omega^2 C_2 R_2 C_1 + j\omega(C_1 + C_2)}}{\frac{1 + j\omega C_2 R_2}{-\omega^2 C_2 R_2 C_1 + j\omega(C_1 + C_2)} + R_1}$$

$$= \frac{1 + j\omega C_2 R_2}{1 + j\omega C_2 R_2 + R_1(-\omega^2 C_2 R_2 C_1 + j\omega(C_1 + C_2))}$$

$$= \frac{1 + j\omega C_2 R_2}{1 - \omega^2 C_2 R_2 C_1 R_1 + j\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}$$

$$\frac{V_{ab}}{V} = \frac{V_{ab}}{V_{a'b}}\frac{V_{a'b}}{V} = \frac{1}{1 + j\omega R_2 C_2}\frac{1 + j\omega C_2 R_2}{1 - \omega^2 C_2 R_2 C_1 R_1 + j\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}$$

$$= \frac{1}{1 - \omega^2 C_2 R_2 C_1 R_1 + j\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}$$

$$\frac{V_{ab}}{V} = \frac{1}{1 - \omega^2 C_2 R_2 C_1 R_1 + j\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}$$

$$= \frac{1}{\sqrt{(1 - \omega^2 C_2 R_2 C_1 R_1)^2 + (\omega(R_1 C_1 + R_1 C_2 + C_2 R_2))^2}} \angle -\tan^{-1}(\frac{\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}{1 - \omega^2 C_2 R_2 C_1 R_1})$$

Homework Answers #6

$$\frac{V_{ab}}{V} = \frac{1}{1-\omega^2 C_2 R_2 C_1 R_1 + j\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}$$

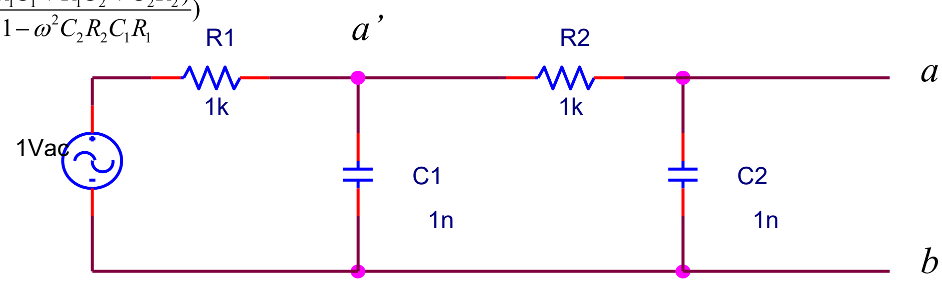
$$= \frac{1}{\sqrt{(1-\omega^2 C_2 R_2 C_1 R_1)^2 + (\omega(R_1 C_1 + R_1 C_2 + C_2 R_2))^2}} \angle -\tan^{-1}\left(\frac{\omega(R_1 C_1 + R_1 C_2 + C_2 R_2)}{1-\omega^2 C_2 R_2 C_1 R_1}\right)$$

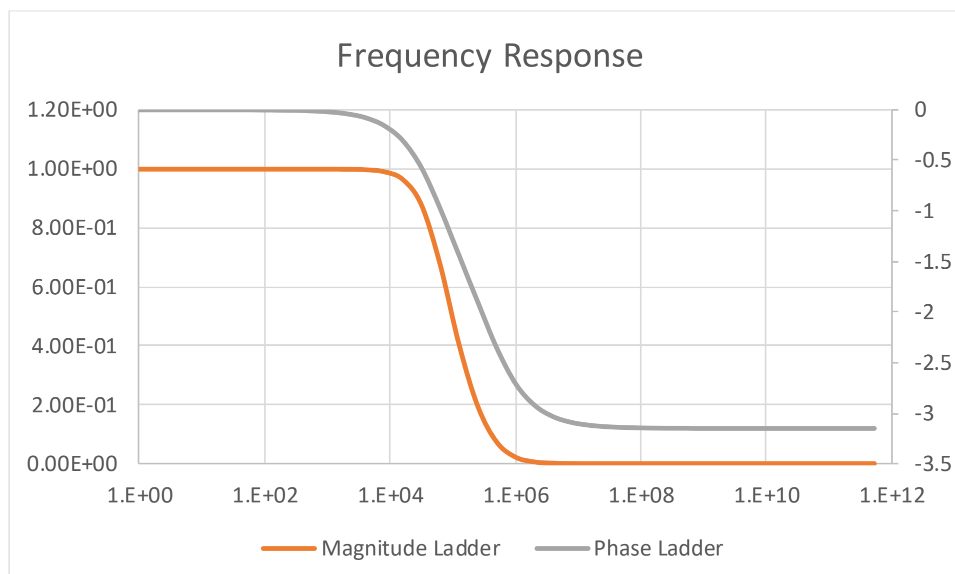
$$\frac{V_{ab}}{V}\Big|_{\omega=0} = \frac{1}{(1-0)+j0} = 1\angle 0$$

$$\frac{V_{ab}}{V}\Big|_{\omega\to\infty} \to \frac{1}{-\omega^2 C_2 C_1 R_1 R_2}\Big|_{\omega\to\infty} = 0\angle \pm\pi = 0\angle -\pi$$

$$\frac{V_{ab}}{V}\Big|_{\omega=\frac{1}{\sqrt{C_2 C_1 R_1 R_2}}} = \frac{1}{(0) + j\frac{1}{\sqrt{C_2 C_1 R_1 R_2}}[C_2(R_1+R_2)+C_1 R_1]}$$

$$= \frac{\sqrt{C_2 C_1 R_1 R_2}}{C_2(R_1+R_2)+C_1 R_1} \angle -\frac{\pi}{2}$$





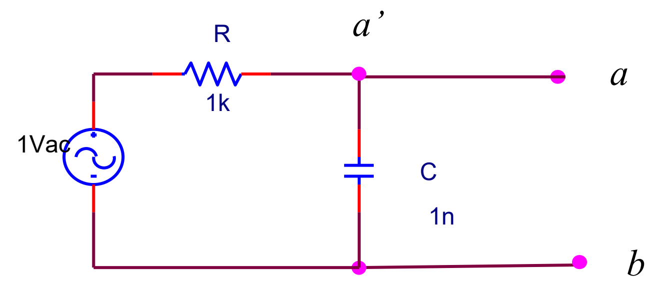
Homework Answers #6

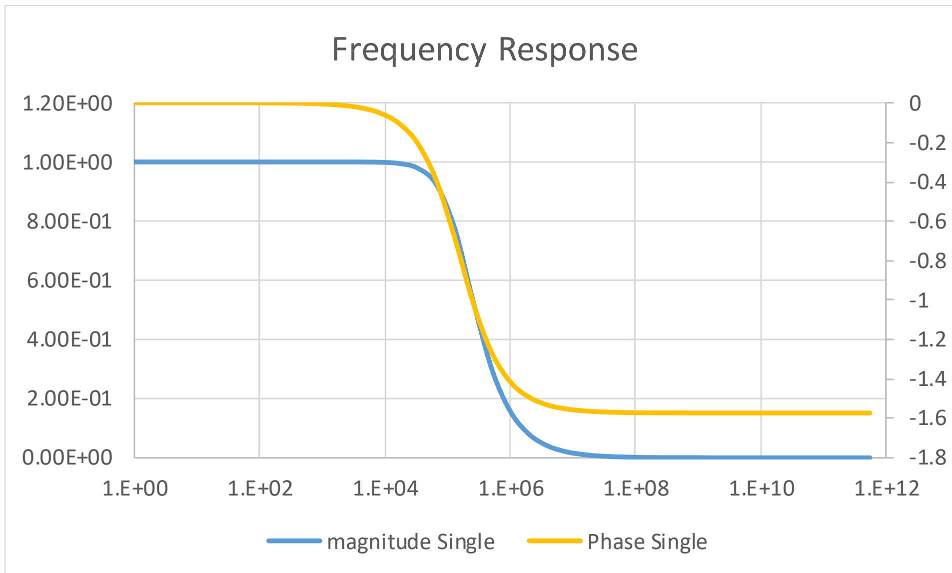
$$\frac{V_{ab}}{V} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C}+R} = \frac{1}{1+j\omega RC} = \frac{1}{\sqrt{1+(\omega RC)^2}}\angle -\tan^{-1}(\omega RC)$$

$$\frac{V_{ab}}{V}\Big|_{\omega=0} = \frac{1}{1+j0} = 1\angle 0$$

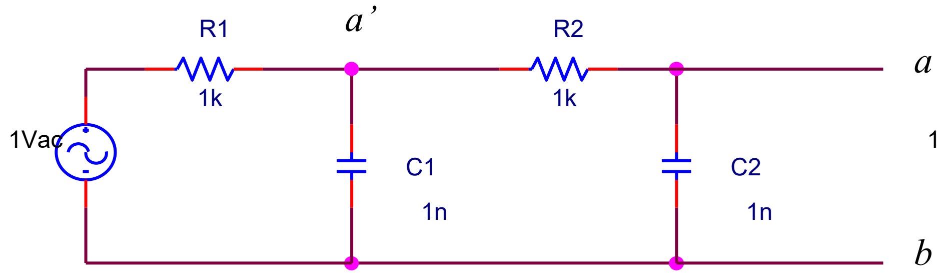
$$\frac{V_{ab}}{V}\Big|_{\omega\to\infty} \to \frac{1}{j\omega RC} = 0\angle -\frac{\pi}{2}$$

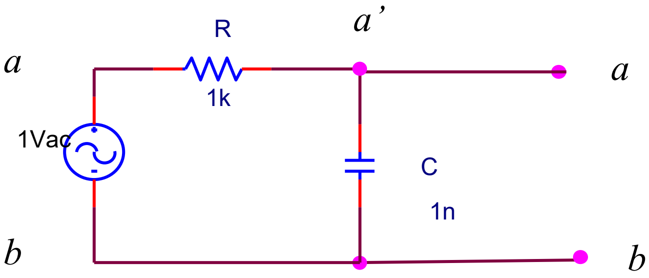
$$\frac{V_{ab}}{V}\Big|_{\omega=\frac{1}{RC}} = \frac{1}{1+j1} = \frac{1}{\sqrt{2}}\angle -\frac{\pi}{4}$$

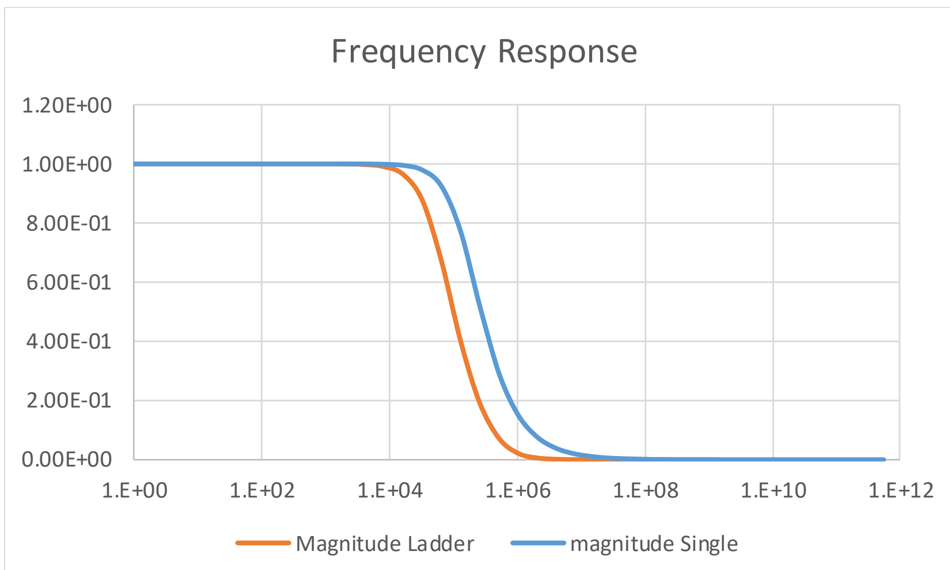




Homework Answers #6

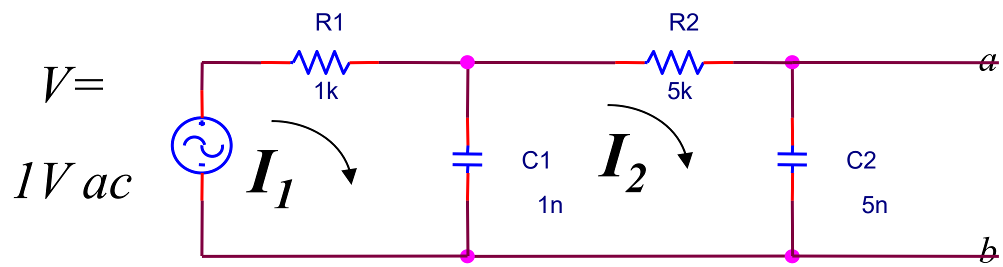






Homework Answers #4

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



Mesh 1

$$V = I_1 Z_{R_1} + Z_{C_1}(I_1 - I_2) = I_1(Z_{R_1} + Z_{C_1}) - I_2 Z_{C_1}$$

Mesh 2

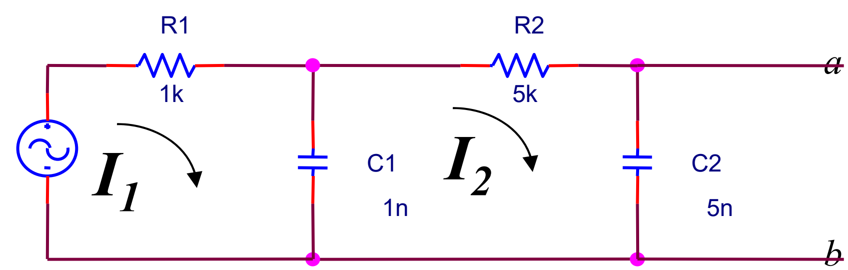
$$0 = I_2(Z_{R_2} + Z_{C_2}) + Z_{C_1}(I_2 - I_1) = -Z_{C_1} I_1 + I_2(Z_{R_2} + Z_{C_2} + Z_{C_1})$$

Homework Answers #5

- Repeat the analysis of this circuit using Mesh and Nodal Analysis

$$I_1 = \frac{Z_{R_2} + Z_{C_2} + Z_{C_1}}{Z_{C_1}} I_2 \text{; from Mesh 2}$$

V=
1V ac



$$V = \{\frac{Z_{R_2} + Z_{C_2} + Z_{C_1}}{Z_{C_1}} I_2\}(Z_{R_1} + Z_{C_1}) - I_2 Z_{C_1}\text{; Substituting this into Mesh 1}$$

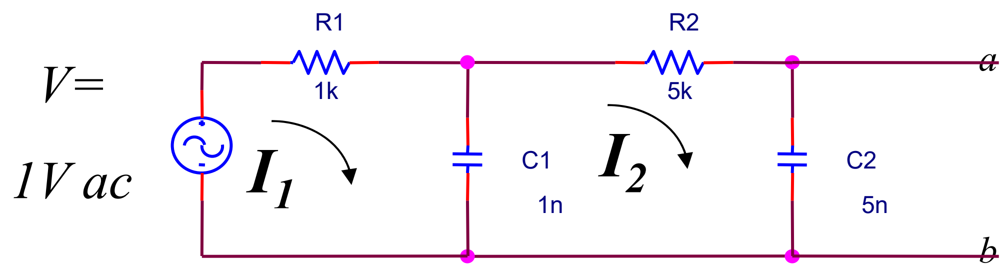
$$= \frac{(Z_{R_2} + Z_{C_2} + Z_{C_1})(Z_{R_1} + Z_{C_1}) - Z_{C_1}^2}{Z_{C_1}} I_2$$

$$= \frac{Z_{R_2} Z_{R_1} + Z_{C_2} Z_{R_1} + Z_{C_1} Z_{R_1} + Z_{R_2} Z_{C_1} + Z_{C_2} Z_{C_1} + Z_{C_1} Z_{C_1} - Z_{C_1}^2}{Z_{C_1}} I_2$$

$$= \frac{Z_{R_2} Z_{R_1} + Z_{C_2} Z_{R_1} + Z_{C_1} Z_{R_1} + Z_{R_2} Z_{C_1} + Z_{C_2} Z_{C_1}}{Z_{C_1}} I_2$$

Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



$$I_2 = \frac{Z_{C_1}}{Z_{R_2}Z_{R_1} + Z_{C_2}Z_{R_1} + Z_{C_1}Z_{R_1} + Z_{R_2}Z_{C_1} + Z_{C_2}Z_{C_1}} V$$

$$V_{ab} = I_2 Z_{C_2} = \frac{Z_{C_1}Z_{C_2}}{Z_{R_2}Z_{R_1} + Z_{C_2}Z_{R_1} + Z_{C_1}Z_{R_1} + Z_{R_2}Z_{C_1} + Z_{C_2}Z_{C_1}} V$$

Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis

$$I_2 = \frac{\frac{1}{j\omega C_1}}{R_1R_2 + \frac{1}{j\omega C_2}R_1 + \frac{1}{j\omega C_1}R_1 + R_2\frac{1}{j\omega C_1} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}V$$

$$= \frac{1}{j\omega C_1R_1R_2 + \frac{C_1}{C_2}R_1 + R_1 + R_2 + \frac{1}{j\omega C_2}}V$$

$$= \frac{j\omega C_2}{(1-\omega^2C_2C_1R_1R_2) + j\omega C_2\frac{C_1}{C_2}R_1 + j\omega[C_2(R_1+R_2)+C_1R_1]}V$$

$$V_{ab} = I_2Z_{C_2} = \frac{j\omega C_2}{(1-\omega^2C_2C_1R_1R_2) + j\omega[C_2(R_1+R_2)+C_1R_1]}VZ_{C_2}$$

$$= \frac{j\omega C_2\frac{1}{j\omega C_1}}{(1-\omega^2C_2C_1R_1R_2) + j\omega[C_2(R_1+R_2)+C_1R_1]}V$$

$$= \frac{1}{(1-\omega^2C_2C_1R_1R_2) + j\omega[C_2(R_1+R_2)+C_1R_1]}$$

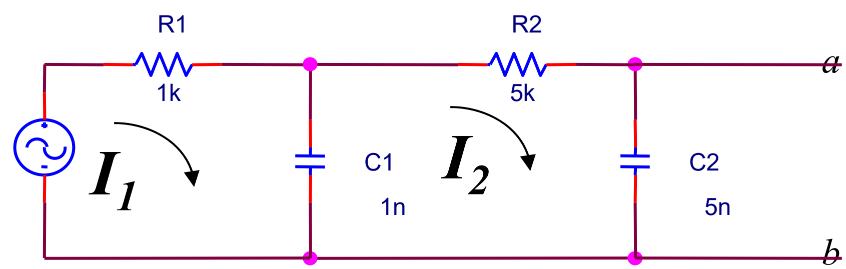
$$V_{ab} = \frac{1}{(1-\omega^2C_2C_1R_1R_2) + j\omega[C_2(R_1+R_2)+C_1R_1]}$$

$$= \frac{1}{1-(\omega 5\times10^{-6})^2 + j\omega 31\times10^{-6}}$$

$$= \frac{1}{\sqrt{[1-(\omega 5\times10^{-6})^2]^2 + \omega^2 961\times10^{-12}}}\angle -\tan^{-1}[\frac{\omega 31\times10^{-6}}{1-(\omega 5\times10^{-6})^2}]\}$$

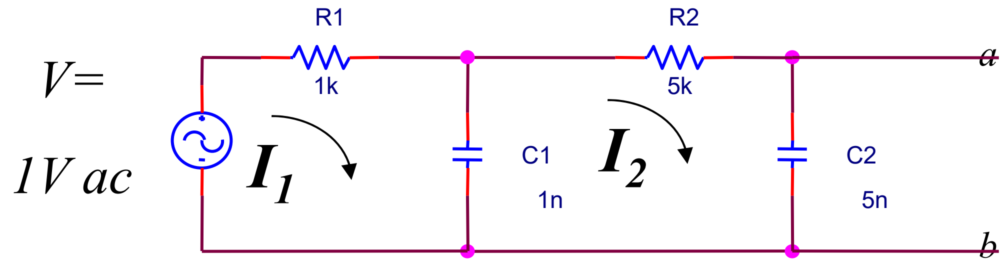
V=

1V ac



Homework Answers #4

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



Mesh 1

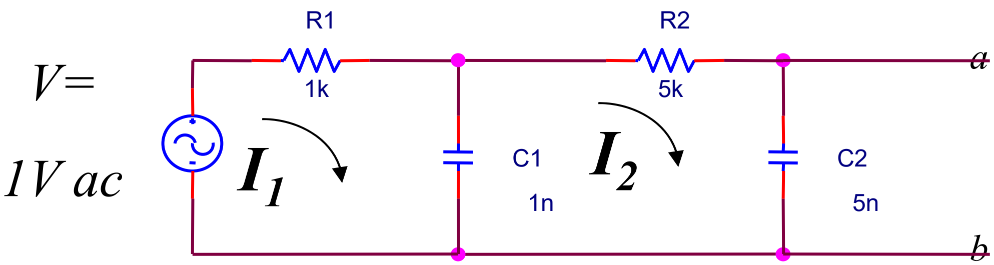
$$V = I_1 R_1 + \frac{1}{j\omega C_1}(I_1 - I_2) = I_1(R_1 + \frac{1}{j\omega C_1}) - I_2 \frac{1}{j\omega C_1}$$

Mesh 2

$$0 = I_2(R_2 + \frac{1}{j\omega C_2}) + \frac{1}{j\omega C_1}(I_2 - I_1) = -\frac{1}{j\omega C_1} I_1 + I_2(R_2 + \frac{1}{j\omega C_2} + \frac{1}{j\omega C_1})$$

Homework Answers #5

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



$$I_1 = \frac{R_2 + \frac{1}{j\omega C_2} + \frac{1}{j\omega C_1}}{\frac{1}{j\omega C_1}} I_2 ;\text{from Mesh 2}$$

$$V = \{\frac{R_2 + \frac{1}{j\omega C_2} + \frac{1}{j\omega C_1}}{\frac{1}{j\omega C_1}} I_2\}(R_1 + \frac{1}{j\omega C_1}) - I_2 \frac{1}{j\omega C_1};\ \text{Substituting this into Mesh 1}$$

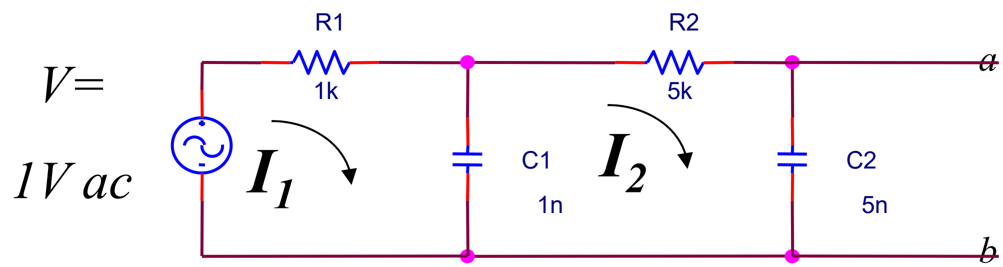
$$= \frac{(R_2 + \frac{1}{j\omega C_2} + \frac{1}{j\omega C_1})(R_1 + \frac{1}{j\omega C_1}) - (\frac{1}{j\omega C_1})^2}{\frac{1}{j\omega C_1}} I_2$$

$$= \frac{R_2 R_1 + \frac{1}{j\omega C_2} R_1 + \frac{1}{j\omega C_1} R_1 + R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_2} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_1} - (\frac{1}{j\omega C_1})^2}{\frac{1}{j\omega C_1}} I_2$$

$$= \frac{R_2 R_1 + \frac{1}{j\omega C_2} R_1 + \frac{1}{j\omega C_1} R_1 + R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_1}} I_2$$

Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis

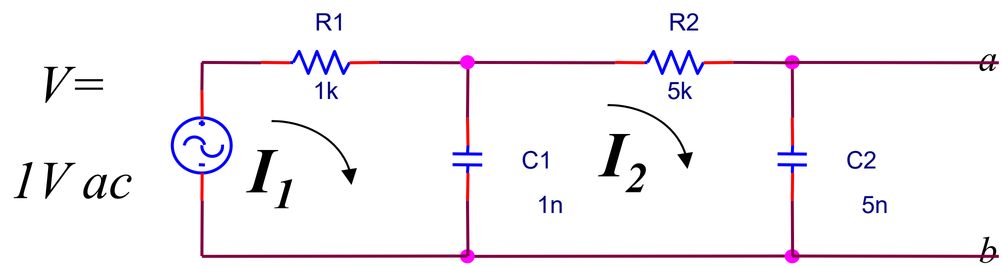


$$I_2 = \frac{\frac{1}{j\omega C_1}}{R_2 R_1 + \frac{1}{j\omega C_2} R_1 + \frac{1}{j\omega C_1} R_1 + R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1} \frac{1}{j\omega C_2}} V$$

$$V_{ab} = I_2 \frac{1}{j\omega C_2} = \frac{\frac{1}{j\omega C_1} \frac{1}{j\omega C_2}}{R_2 R_1 + \frac{1}{j\omega C_2} R_1 + \frac{1}{j\omega C_1} R_1 + R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1} \frac{1}{j\omega C_2}} V$$

Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



$$\frac{V_{ab}}{V} = \frac{\frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}{R_2 R_1 + \frac{1}{j\omega C_2} R_1 + \frac{1}{j\omega C_1} R_1 + R_2 \frac{1}{j\omega C_1} + \frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}$$

$$= \frac{1}{(j\omega C_1)(j\omega C_2) R_2 R_1 + (j\omega C_1)(j\omega C_2)\frac{1}{j\omega C_2} R_1 + (j\omega C_1)(j\omega C_2)\frac{1}{j\omega C_1} R_1 + (j\omega C_1)(j\omega C_2) R_2 \frac{1}{j\omega C_1} + (j\omega C_1)(j\omega C_2)\frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}$$

$$= \frac{1}{(-\omega^2 C_1 C_2 R_2 R_1) + j\omega C_1 R_1 + j\omega C_2 R_1 + j\omega C_2 R_2 + 1}$$

$$= \frac{1}{1 - \omega^2 C_1 C_2 R_2 R_1) + j\omega(C_1 R_1 + C_2 R_1 + C_2 R_2)}$$

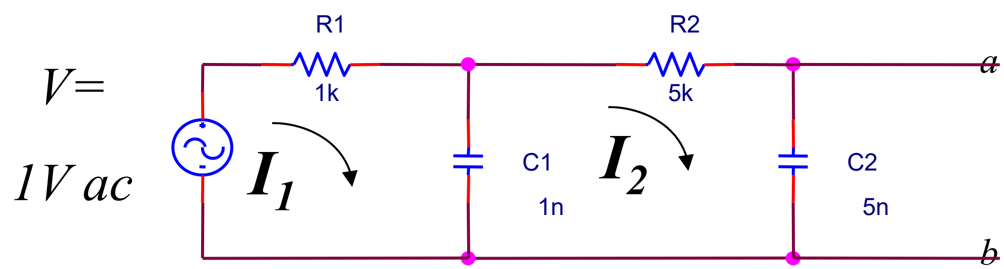
Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis

$$V_{ab} = \frac{1}{(1-\omega^2 C_2 C_1 R_1 R_2) + j\omega[C_2(R_1 + R_2) + C_1 R_1]}$$

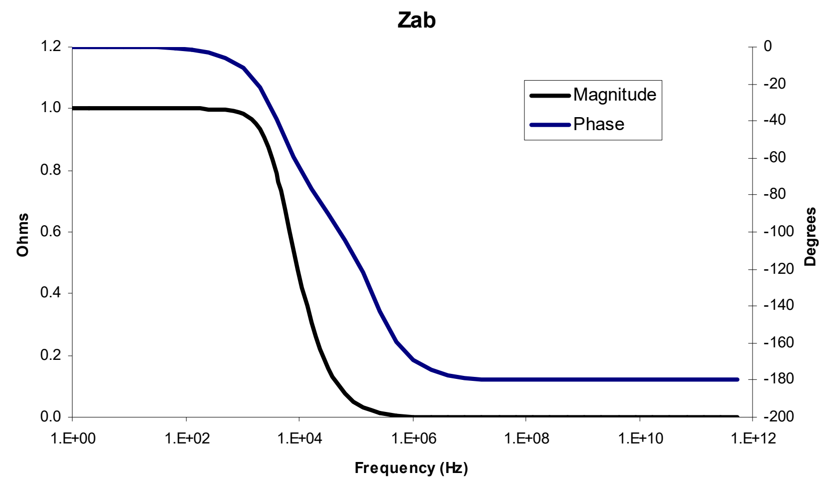
$$= \frac{1}{1-(\omega 5\times 10^{-6})^2 + j\omega 31\times 10^{-6}}$$

$$= \frac{1}{\sqrt{[1-(\omega 5\times 10^{-6})^2]^2 + \omega^2 961\times 10^{-12}}} \angle -\tan^{-1}[\frac{\omega 31\times 10^{-6}}{1-(\omega 5\times 10^{-6})^2}]\}$$



Homework Answers #6

- Repeat the analysis of this circuit using Mesh and Nodal Analysis



$$V_{ab} = \frac{1}{(1-\omega^2 C_2 C_1 R_1 R_2) + j\omega[C_2(R_1+R_2)+C_1R_1]}$$

$$= \frac{1}{1-(\omega 5\times10^{-6})^2 + j\omega 31\times10^{-6}}$$

$$= \frac{1}{\sqrt{[1-(\omega 5\times10^{-6})^2]^2 + \omega^2 961\times10^{-12}}} \angle -\tan^{-1}[\frac{\omega 31\times10^{-6}}{1-(\omega 5\times10^{-6})^2}]$$

$$V_{ab}|_{\omega=0} = \frac{1}{\sqrt{[1-(0\times5\times10^{-6})^2]^2 + 0\times961\times10^{-12}}} \angle -\tan^{-1}[\frac{0\times31\times10^{-6}}{1-(0\times5\times10^{-6})^2}]$$

$$= \frac{1}{\sqrt{1}} \angle -\tan^{-1}[\frac{0}{1}] = 1\angle 0$$

$$V_{ab}|_{\omega=\frac{1}{5\times10^{-6}}} = \frac{1}{\sqrt{[1-(\frac{1}{5\times10^{-6}}\times5\times10^{-6})^2]^2 + \frac{1}{5\times10^{-6}}^2 \times961\times10^{-12}}} \angle -\tan^{-1}[\frac{\frac{1}{5\times10^{-6}}\times31\times10^{-6}}{1-(\frac{1}{5\times10^{-6}}\times5\times10^{-6})^2}] = \frac{1}{\sqrt{[0]^2 + \frac{1}{5\times10^{-6}}^2 \times961\times10^{-12}}} \angle -\tan^{-1}[\frac{\frac{1}{5\times10^{-6}}\times31\times10^{-6}}{0}] = \frac{1}{\sqrt{38.44}} \angle -\tan^{-1}[\frac{6.2}{0}]$$

$$= \frac{1}{6.2}\angle -\frac{\pi}{2}$$

$$V_{ab}|_{\omega\to\infty} = \frac{1}{1-(\omega 5\times10^{-6})^2 + j\omega 31\times10^{-6}}|_{\omega\to\infty} \to \frac{1}{-(\omega 5\times10^{-6})^2} \to 0\angle -\pi$$

Matlab Code

```
clear all;
R1=1e3;C1=1e-9;R2=5e3;C2=5e-9;
omega=(100:1000:10^7);maxomega=length(omega);
VIN=[1; 0];
for i=1:maxomega
   zC1=1/complex(0,omega(i)*C1);
   zC2=1/complex(0,omega(i)*C2);
   Z=[R1+zC1 -zC1;-zC1 R2+zC1+zC2];
   IC=Z\VIN;
   VOUT(i)=IC(2)*zC2;
end
f=omega/(2*pi);
subplot(2,1,1);
semilogx(f,abs(VOUT));
title('RCLadder Mesh Magnitude');
xlabel('Hz');
axis([f(1) f(maxomega) 0 1]);
subplot(2,1,2);
semilogx(f,atan2(imag(VOUT),real(VOUT)));
title('RCLadder Mesh Phase Angle');
xlabel('Hz');
axis([f(1) f(maxomega) -2 2]);
```