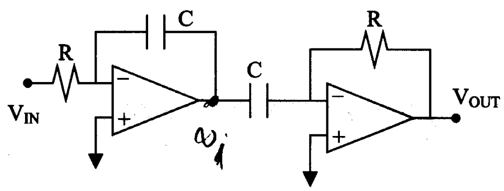
EE323 | **Final Examination** | Date: December 11, 2001
Instructor: A. Dinh | Time: 9:00am – 12:00pm

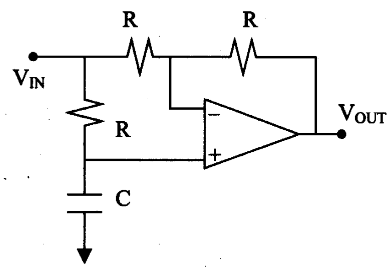
Solution
Open books, open notes.
Good luck and have a Merry Christmas.

1. **Question 1: (20 marks)**

For the circuits (a) and (b) below, derive transfer functions V_{OUT}/V_{IN} as a function of frequency. For R=10K and C=15.9nF, sketch amplitude and phase response of V_{OUT}/V_{IN}.



(a)

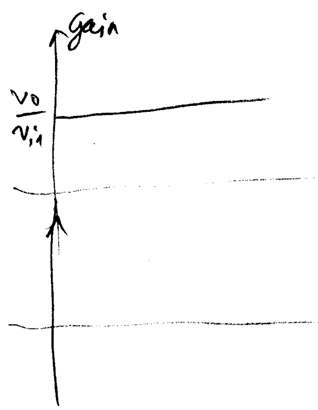


(b)

$v_1 = -\frac{Z_C}{R} v_{in}$, $v_o = -\frac{R}{Z_C} v_1$

$\Rightarrow v_o = \left(-\frac{R}{Z_C}\right)\left(-\frac{Z_C}{R}\right) v_{in}$

$v_o = v_{in} \Rightarrow T(s) = \frac{v_o}{v_i} = 1$



$v_+ = v_- \Rightarrow \frac{Z_C}{Z_C+R} v_{in} = \frac{1}{2} v_o + \frac{1}{2} v_{in} = \frac{1}{2}(v_o + v_{in})$

$\frac{1}{2} v_o = -\frac{1}{2} v_{in} + \frac{\frac{1}{sC}}{\frac{1}{sC}+R} v_{in} = v_{in}\left(\frac{1}{1+j\omega RC} - \frac{1}{2}\right)$

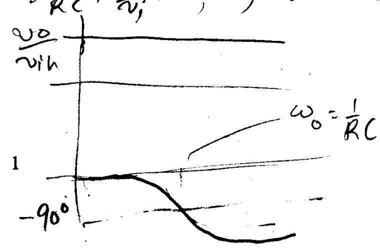
$v_o = 2 v_{in}\left(\frac{1}{1+j\omega RC} - \frac{1}{2}\right) = 2 v_{in}\left(\frac{2-1-j\omega RC}{2(1+j\omega RC)}\right)$

$\boxed{\frac{v_o}{v_{in}} = \frac{1-j\omega RC}{1+j\omega RC}}$ $\quad \measuredangle = -\tan^{-1}\frac{\omega RC}{1} - \tan^{-1}\left(\frac{\omega RC}{1}\right)$

$= -2\tan^{-1}(\omega RC)$

$\omega = 0 \Rightarrow \frac{v_o}{v_{in}} = 1$, $\measuredangle = 0$

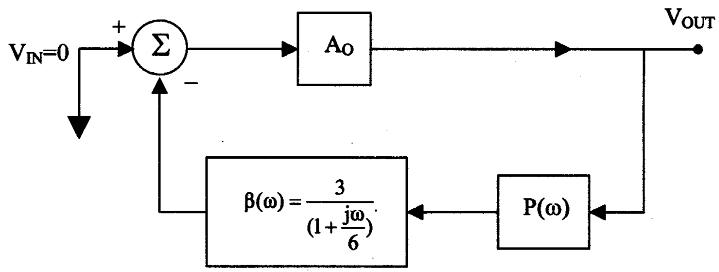
$\omega = \frac{1}{RC}$, $\frac{v_o}{v_i} = 1$, $\measuredangle\ -2\tan^{-1}(1) = -90^\circ$



$\omega_o = 6290$ rad/s or $f = 1$ KHz with R=10K C=15.9nF

2. **Question 2: (20 marks)**

The feedback diagram shown below describes an oscillator circuit. In this case, $|P(\omega)|=0.1$ and $\measuredangle P(\omega) = -135^{\circ}$ for all ω.



a) Find the frequency of oscillation.
b) Find the minimum value of A_O needed to maintain oscillation.

(a) to get -180°, $\measuredangle\beta$ must be -45° since $\measuredangle P(\omega) = -135^{\circ}$

$-45^{\circ} = -\tan^{-1}\left(\frac{\omega}{6}\right)$ or $\frac{\omega}{6} = 1$ $\boxed{\omega = 6 \text{ rad/s}}$

$f = \frac{6}{2\pi} = 0.95\,Hz$

(b) Magnitude $= 1$

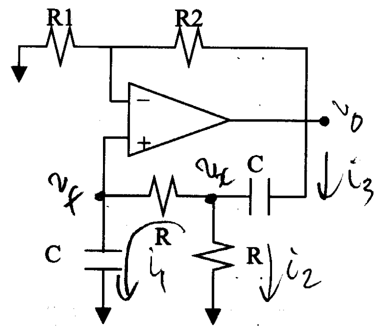
$A\beta P = 1 \Rightarrow A = \frac{1}{\beta P} = \frac{1}{|\beta_{(\omega)}|\ 0.1}$

$|\beta(\omega)| = \frac{3}{1+j1} = \frac{3}{\sqrt{2}}$

$A = \frac{1}{\frac{3}{\sqrt{2}}(0.1)} = \frac{\sqrt{2}}{0.3} = 4.7$

3. Question 3: (20 marks)

For the circuit below, find the loop gain L(s), L(jω), the frequency for zero loop-phase. Find R2/R1 for oscillation.



Many way to solve:

use KCL at nodes, find v_f vs v_o

$$\frac{v_f}{v_o} = \frac{1}{sRC + 3 + \frac{1}{sRC}} = \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

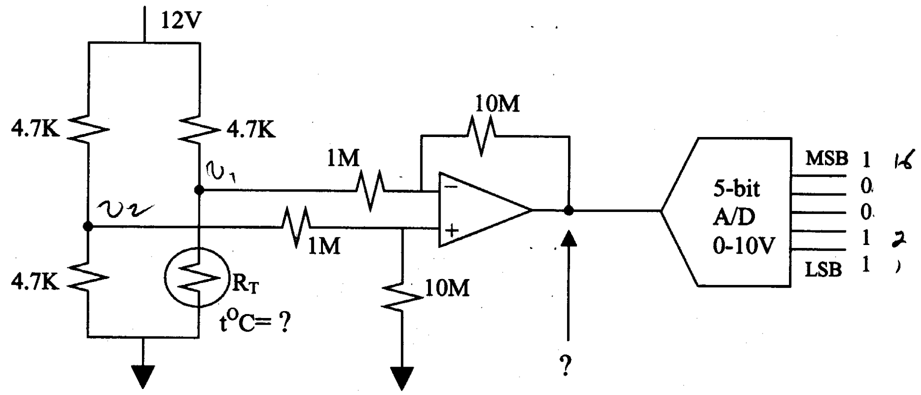
phase $= 0 \Rightarrow \omega RC = \frac{1}{\omega RC}$ or $\boxed{\omega = \frac{1}{RC}}$

then at $\omega = \frac{1}{RC}$, $\frac{v_f}{v_o} = \frac{1}{3}$

or $\frac{v_o}{v_f} = 3 = 1 + \frac{R_2}{R_1}$ or $\boxed{\frac{R_2}{R_1} = 2}$

4. Question 4: (20 marks)

Consider the circuit in a temperature measurement below. The A/D is a 5-bit successive-approximation A/D converter type with an analog span of 0 to 10V, find the input voltage of the A/D converter. The thermistor, R_T, has a resistance of 2K at 20^oC and the coefficient β is assumed to be constant at 3650, find temperature of the thermistor.



A/D 5bit $\Rightarrow 2^5 = 32$ steps or $\frac{10}{2^5} = 0.3125V$ each step.

Total 19 steps $\Rightarrow$ input $= (19)(0.3125V) = 5.937V$

The amplifier has a gain of:

$$v_o = -10v_1 + \frac{10}{11}v_2(1+10) = 10(v_2 - v_1)$$

$$\therefore v_2 - v_1 = \frac{5.937V}{10} = 0.59375V$$

$$v_1 = v_2 - 0.59375V = 6V - 0.5937V = 5.40625V$$

$$v_1 = V_{RT} = 5.4065V = \frac{R_T}{R_T + 4K} \cdot 12V \Rightarrow R_T = 3.85k\Omega$$

$$R_T = R_o e^{\beta(\frac{1}{T} - \frac{1}{T_o})}$$

$$e^{\beta(\frac{1}{T} - \frac{1}{T_o})} = \frac{R_T}{R_o} = 1.9267 \Rightarrow \beta\left(\frac{1}{T} - \frac{1}{T_o}\right) = \ln(1.9267)$$

$$\frac{1}{T} = \frac{\ln(1.9267)}{\beta} + \frac{1}{T_o}$$

4

T = 19.9°C

5. Question 5: (20 marks)

In a digital instrumentation system to measure velocity of a fluid pipe, the A/D converter has a sampling rate of 20Ksample/second. Find the Nyquyst frequency of the analog signal from the transducer. Design an <u>active filter</u> for anti-aliasing purpose in front of the A/D converter. The filter should have a cut off frequency at Nyquist frequency with a selection of F_{50}/F_3 is at least 3. Since the output signal of the transducer has a wide range of frequency, no ripple is allowed in the filter passband and only 10K resistors are available to realize the filter.

Table 12-1. Design Data for Chebyshev Filters

Ripple = 0 dB (Butterworth) Cutoff frequency = section frequency = 1.0

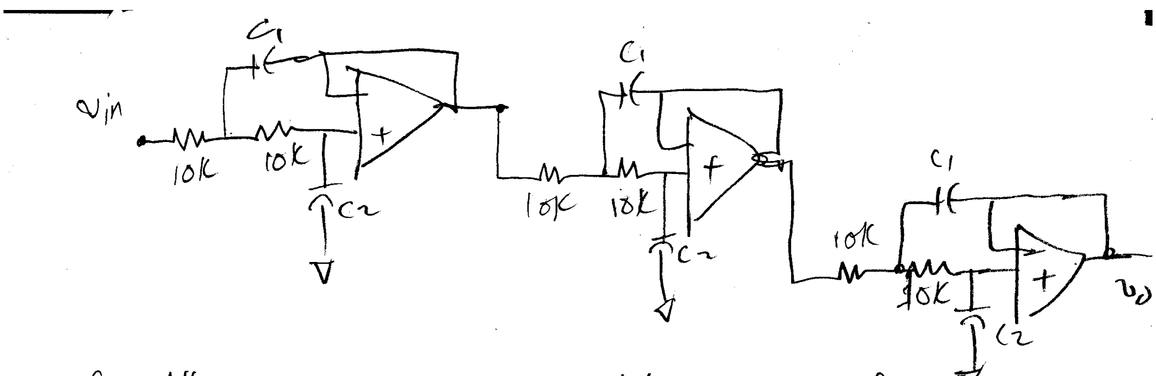
Number of sections	F_{50}/F_3	Q Sct 1	Q Sct 2	Q Sct 3	Q Sct 4	Q Sct 5	Q Sct 6	Q Sct 7	Q Sct 8
1	17.79	0.7071							
2	4.22	0.5411	1.306						
3	2.61	0.5176	0.7071	1.932					
4	2.05	0.5098	0.6014	0.8999	2.563				
5	1.78	0.5062	0.5612	0.7071	1.101	3.196			
6	1.61	0.5043	0.5412	0.6302	0.8213	1.307	3.831		
7	1.51	0.5032	0.5297	0.5905	0.7071	0.9401	1.514	4.466	
8	1.43	0.5024	0.5225	0.5669	0.6468	0.7882	1.061	1.722	5.101

Ripple = 0.1 dB Cutoff frequency = 1.0

Number of sections	F_{50}/F_3	F Sct 1 Q Sct 1	F Sct 2 Q Sct 2	F Sct 3 Q Sct 3	F Sct 4 Q Sct 4	F Sct 5 Q Sct 5	F Sct 6 Q Sct 6	F Sct 7 Q Sct 7	F Sct 8 Q Sct 8
1	16.59	0.9321 0.7674							
2	3.36	0.6491 0.6190	0.9491 2.185						
3	1.96	0.4688 0.5997	0.7628 1.333	0.9717 4.639					
4	1.52	0.3623 0.5934	0.6129 1.184	0.8493 2.456	0.9828 8.092				
5	1.32	0.2940 0.5906	0.5065 1.128	0.7292 2.046	0.8984 3.926	0.9887 12.54			
6	1.22	0.2469 0.5890	0.4296 1.100	0.6314 1.863	0.8038 3.123	0.9275 5.733	0.9920 17.98		
7	1.16	0.2126 0.5881	0.3723 1.084	0.5539 1.798	0.7187 2.794	0.8523 4.403	0.9459 7.871	0.9941 24.40	
8	1.12	0.1866 0.5875	0.3280 1.074	0.4920 1.748	0.6463 2.619	0.7796 3.860	0.8852 5.883	0.9582 10.34	0.9955 34.82

$f_N = \frac{f_S}{2} = \frac{20KHz}{2} = 10KHz$

$\frac{f_{50}}{f_3} = 3 \Rightarrow$ 3 section Using Sallen Key (Ripple = 0dB)



$f_1 = 10kHz$

$Q_1 = 0.5176$

$f_2 = 10kHz$

$Q_2 = 0.7071$

$f_3 = 10kHz$

$Q_3 = 1.932$

$$C_1 = \frac{Q}{\pi f R}$$

$$C_2 = \frac{C_1}{4Q^2}$$

$C_1 = 1.647nF$

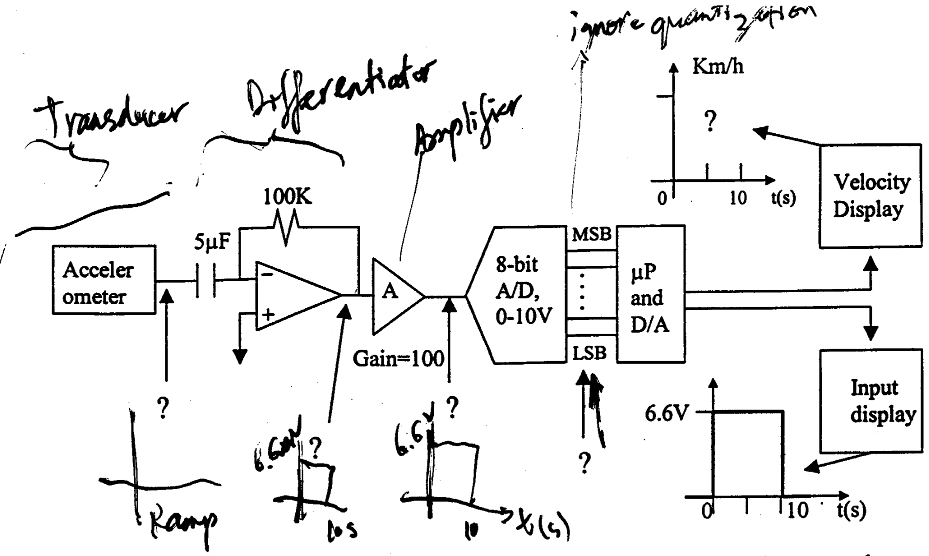
$C_2 = 1.537nF$

$C_1 = 2.251nF$

$C_2 = 1.125nF$

$C_1 = 6.1497nF$

$C_2 = 0.419nF$



The above arrangement is used to measure velocity of a vehicle (not a good design). The waveform shown at the input display is the output of the D/A converter (data from A/D connects directly to D/A). Ignore quantization error, find the A/D output word. Sketch analog input voltage waveform at the A/D converter, the amplifier A input and the accelerometer output. The accelerometer has an inversion factor of 0.25V/m/s^2 (i.e., 250mV corresponds to 1m/s^2), find final velocity of the vehicle if its initial velocity is 100Km/h and sketch the vehicle velocity.

$\frac{10}{2^8} = \frac{10}{256 \text{ steps}} = 0.0391 \text{ V/step}$

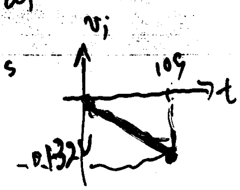
$v_o = -\frac{1}{RC}\frac{dv_i}{dt}$ or $v_i = -\frac{1}{RC}\int v_o(dt)$

$\frac{6.6V}{0.0391 \text{ V/step}} = 169 \text{ steps}$

$v_i = -\frac{1}{(100K)(5\mu F)}\int_0^{10s}(6.6mV)\,dt$

$= -2\,(0.066t)\Big|_0^{10s}$

MSB							LSB
1	0	1	0	1	0	0	1



$v = at + v_0$

$= (-0.132)(10s) + \frac{100k}{hr}$

→ convert into m/s^2 $= 0.528\frac{m}{s^2}$