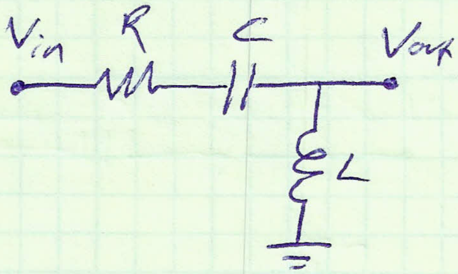
Question #1

a) High-pass filter:



$$\frac{V_{out}}{V_{in}} = \frac{sL}{sL + R + 1/sC}$$

$$\frac{V_{out}}{V_{in}} = \frac{s^2LC}{1 + sCR + s^2LC}$$

b) $\omega_o = \frac{1}{\sqrt{LC}} = 10^8 \rightarrow LC = 10^{-16}$

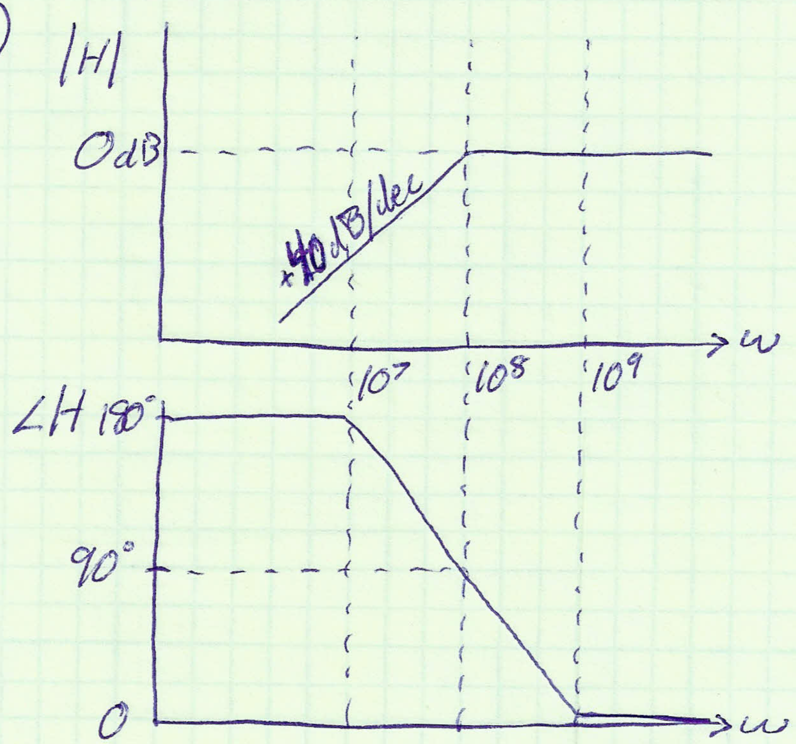
$\zeta = \frac{1}{\sqrt{2}}$ for Butterworth $\quad \frac{2\zeta s}{\omega_o} = sCR \rightarrow \zeta = \frac{1}{2}CR \cdot \frac{1}{\sqrt{LC}} = \frac{R}{2}\sqrt{\frac{C}{L}}$

choose $L = 10^{-7} = 100nH$, and $C = 10^{-9} = 1nF$ to set ω_o

(other values are possible too)

$R = \frac{2}{\sqrt{2}}\sqrt{\frac{10^{-7}}{10^{-9}}} = 14\Omega$

c)



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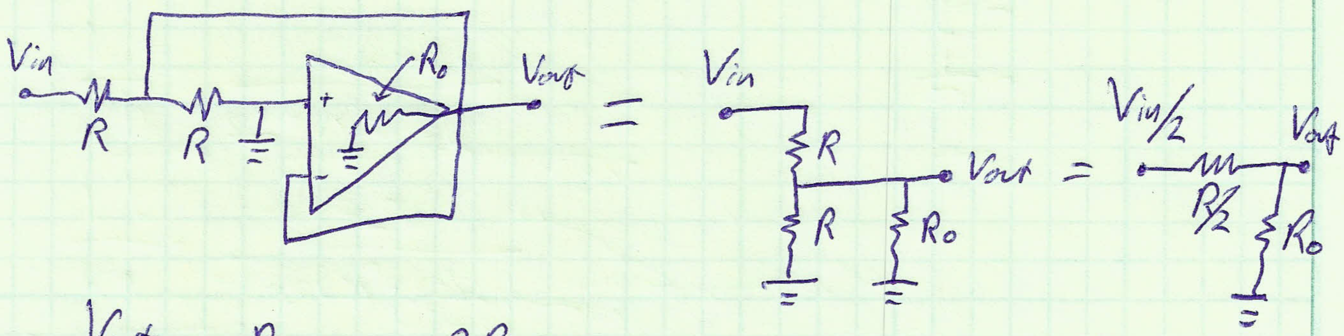
Question #2

a) High-frequency limit: as $\omega \to \infty$, $A \to 0$, caps $\to$ shorts



$$\frac{V_{out}}{V_{in}/2} = \frac{R_o}{R_o + R/2} \simeq \frac{2R_o}{R}$$

$$\frac{V_{out}}{V_{in}} \simeq \frac{R_o}{R}$$

b)

$$\left|\frac{V_{out}}{V_{in}}\right|^2 = -60\text{dB} = 10^{-6}$$

$$\frac{R_o^2}{R^2} = 10^{-6} \longrightarrow R = 10^3 R_o \quad , R_o = 100\Omega$$

$$R_{min} = 100k\Omega$$

c)

$$sC_1(R_1 + R_2) = \frac{2\zeta s}{\omega_o}$$

$$2\times10^5 C_1 = \frac{2}{10^5} \rightarrow C_1 = 10^{-10} = 100pF$$

$$\frac{1}{\sqrt{10^5\times10^5\times10^{-10}\times C_2}} = 10^5 \longrightarrow C_2 = 10^{-10} = 100pF$$

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Question #3

a) Transfer function:

$$B = \frac{R_2}{R_1 + R_2}, \quad A(V_{in} - BV_{out}) \cdot \frac{1/sC}{R_o + 1/sC} = V_{out}$$

$$\frac{G}{s} V_{in} - \frac{BG}{s} V_{out} = (1 + sR_oC) V_{out}$$

$$\frac{G}{s} V_{in} = \left(1 + sR_oC + \frac{BG}{s}\right) V_{out}$$

$$\frac{V_{out}}{V_{in}} = \frac{G/s}{1 + sR_oC + BG/s} = \frac{1}{B} \cdot \frac{1}{1 + \frac{s}{GB} + \frac{s^2 R_o C}{GB}}$$

b) no ringing if $\zeta \simeq 1$ or greater

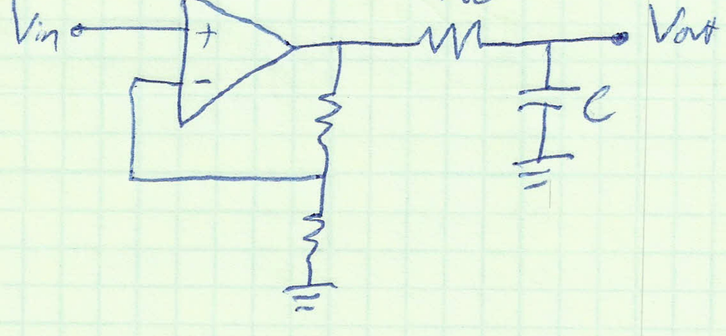
$$\frac{2\zeta s}{\omega_o} = \frac{s}{GB}, \quad \omega_o = \sqrt{\frac{GB}{R_oC}}$$

$$\zeta = \frac{1}{2GB} \cdot \sqrt{\frac{GB}{R_oC}} = \frac{1}{\sqrt{4GBR_oC}}$$

$$\zeta = \frac{1}{\sqrt{4 \cdot 10^7 \cdot 0.1 \cdot 100 \cdot 2.5 \times 10^{-7}}} = \frac{1}{\sqrt{100}} = \frac{1}{10} < 1$$

There will be overshoot and ringing

c) This can be reduced with a compensation resistor:



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Question #4

a) Transfer function:

$$\frac{V_- - V_{in}}{sL} + \frac{V_- - V_{out}}{R} = 0 \quad , \quad V_- = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{-R}{sL}$$

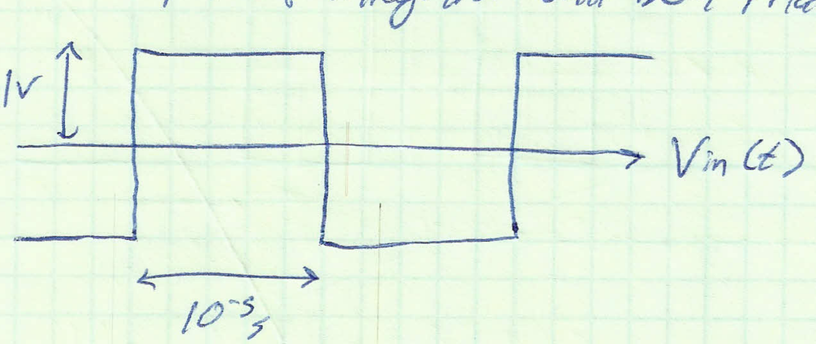
b) This circuit is an <u>integrator</u>

$$V_{out}(t) = \frac{-R}{L}\int_{-\infty}^{t} V_{in}(\tau)\,d\tau$$

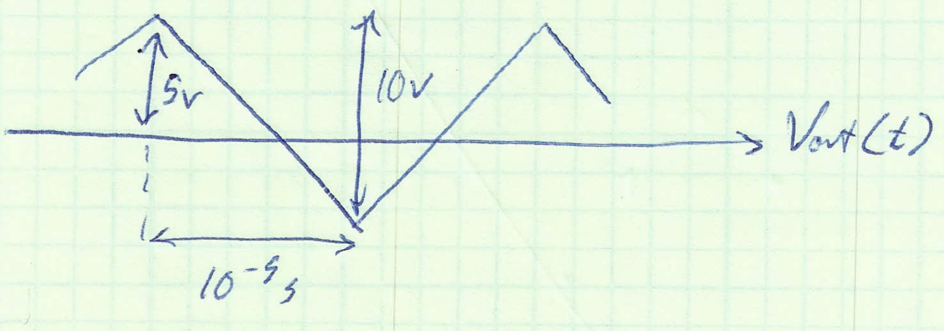
c) 50 kHz square wave with 1v magnitude

period $= \frac{1}{5\times10^4} = 2\times10^{-5}\,s$

output of integrator will be a triangle wave



change in voltage each half cycle $= \frac{-100}{100\times10^{-6}} \times 1\times10^{-5} = 10v$



Output is 50kHz triangle wave with 5v magnitude

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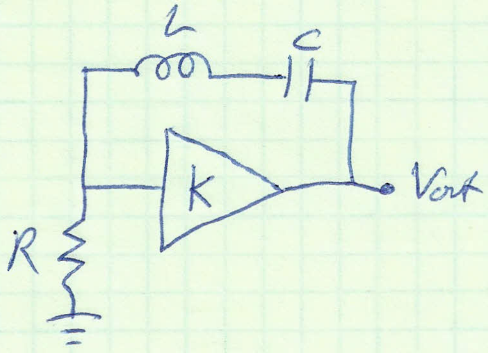
Question #5

a) Op-amp behaves as amplifier with gain of $K = \frac{R_1+R_2}{R_2} = 2$

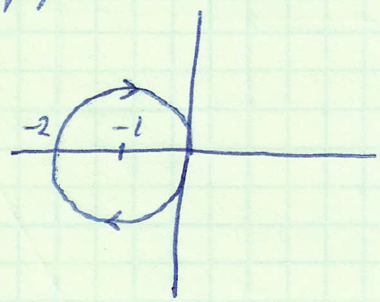


Loop gain AB: $A = K$

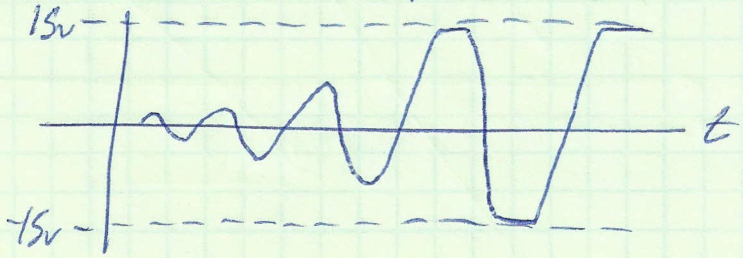
$$B = \frac{-R}{R+sL+\frac{1}{sC}} = \frac{-sRC}{1+sRC+s^2LC}$$

at $\omega = \frac{1}{\sqrt{LC}}$, $AB = \frac{-KsRC}{\cancel{1}+sRC\cancel{+s^2LC}} = -K = -2$

Nyquist plot:



b) Turn on ± 15v supply at $t=0$



c) This is not a useful local oscillator for radio circuits because clipping will generate unwanted harmonics

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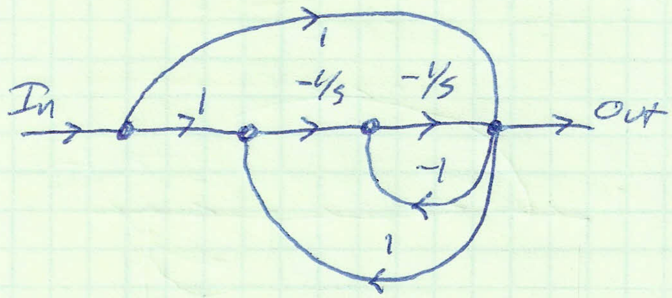
Question #6

a) Signal flow graph:

band reject = 1 − band pass

$$1 - \frac{s}{1+s+s^2} = \frac{1+s^2}{1+s+s^2}$$



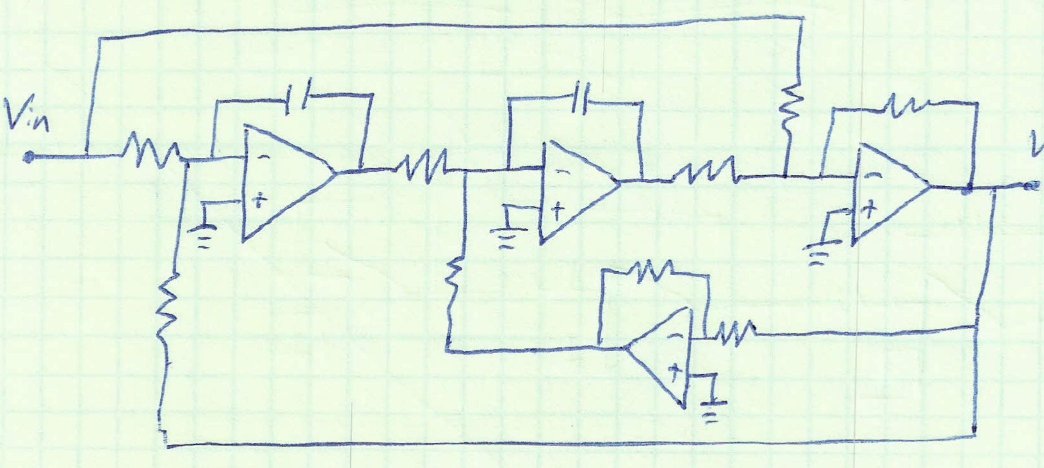
b) Mason's gain formula:

$$\Delta = 1 + 1/s + 1/s^2$$

forward paths: 1 and $1/s^2$

$$H = \frac{1 + 1/s^2}{1 + 1/s + 1/s^2} = \frac{1+s^2}{1+s+s^2} \rightarrow \text{band reject filter}$$

c) circuit implementation:

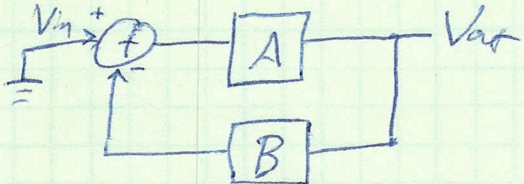


Question #7

a) loop gain:

each stage is $\frac{-A_i}{1+s\tau}$ $\quad \tau = RC$

loop gain is AB $\longrightarrow$



$\Sigma = -1$ cancel negative sign

$$AB = (-1)\cdot\left(\frac{-A_i}{1+s\tau}\right)^3$$

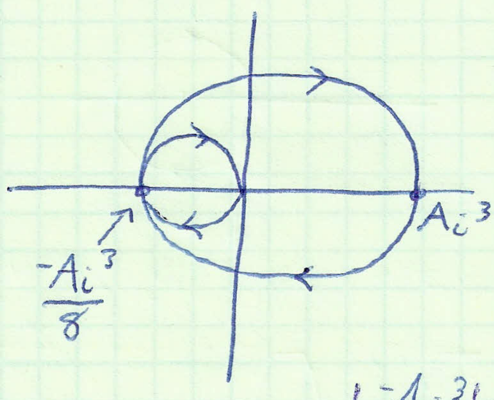
$$AB = \frac{A_i^{\,3}}{(1+s\tau)^3} = \frac{A_i^{\,3}}{1+3s\tau+3s^2\tau^2+s^3\tau^3}$$

b) Nyquist plot:

Imaginary part $=0 \rightarrow 3s\tau + s^3\tau^3 = 0$

$$\omega^2\tau^2 = 3 \rightarrow \omega = \frac{\sqrt{3}}{\tau}$$

$$AB = \frac{A_i^{\,3}}{1-3\left(\frac{\sqrt{3}}{\tau}\right)^2\tau^2} = \frac{-A_i^{\,3}}{8}$$



c) Circuit will oscillate if $\left|\frac{-A_i^{\,3}}{8}\right| > |-1|$

or $A_i > 2$