Switched-Capacitor Filter Summary 3

97.477 Official Course Summary
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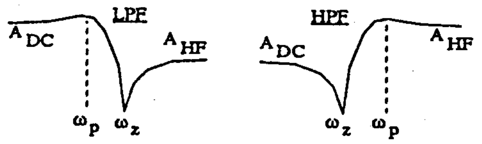
General Filtering

FIR (Finite Impulse Response) no feedback, zeros only in the transfer function.

IIR (Infinite Impulse Response), has feedback, realizes poles and zeros, also called recursive filter.

Early filters used Delay Lines using S&H, BBD or CCD (sample and holds, Bucket Brigade devices or charge coupled devices). S.C. filters instead store charge in opamp feedback capacitors.

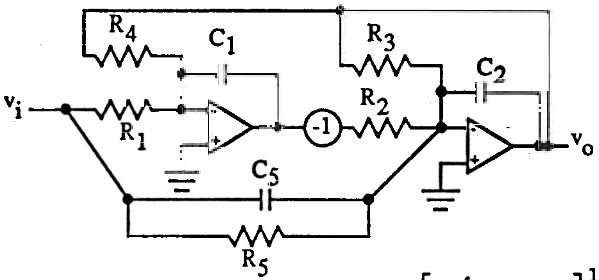
General Second Order Equation



$$\frac{v_o}{v_i} = A_{HF}\frac{s^2 + s\frac{\omega_z}{Q_z} + \omega_z^2}{s^2 + s\frac{\omega_p}{Q_p} + \omega_p^2} \quad \begin{matrix}\leftarrow \text{zeros} \\ \leftarrow \text{poles}\end{matrix} \qquad \frac{A_{DC}}{A_{HF}} = \frac{\omega_z^2}{\omega_p^2}$$

if the s term in the numerator is missing, then we have a notch filter since $Q_z \to \infty$

Biquad Filters



$$\frac{v_o}{v_i} = -\frac{C_5}{C_2}\frac{s^2 + \frac{s}{C_5R_5} + \frac{1}{C_1C_5R_1R_2}}{s^2 + \frac{s}{C_2R_3} + \frac{1}{C_1C_2R_2R_4}}$$

$$A_{DC} = -\frac{R_4}{R_1} \qquad A_{HF} = -\frac{C_5}{C_2}$$

RMS Calculations

$$v_{rms} = \left[\frac{1}{T}\int_0^T v(t)^2 dt\right]^{1/2}$$

v_{rms} for one waveform

$$v_{rms} = \left[v_{1,rms}^2 + v_{2,rms}^2 + \ldots\right]^{1/2}$$

total v_{rms} for uncorrelated signals, v_1, v_2, etc

$$v_{rms} = \left[\int_{f_1}^{f_2} S(f)df\right]^{1/2}$$

total v_{rms} for continuous spectrum f_1 to f_2

power spectral density (psd) is $S_i(f)$ in $\frac{V^2}{Hz}$ and voltage spectrum is $\frac{volts}{\sqrt{Hz}} = \sqrt{psd}$

for voltage, if total rms voltage v has been measured over $\Delta f = f_2 - f_1$ then to convert to a density, divide v by $\sqrt{\Delta f}$ which is equivalent to normalizing it to $\sqrt{1\text{ Hz}}$.

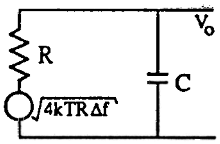
Resistor Noise The single-sided spectrum for white noise or thermal noise in a resistor is given by $S = 4kTR$ volts^2/Hz where k is Boltzmann's constant, T is in Kelvin; $4kT = 1.66 \times 10^{-20}$ joules at room temperature.

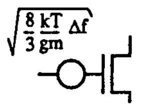
Noise Through System

$$v_{no}^2 = \int_0^\infty S_o(f)df = \int_0^\infty S_i(f)\,|H(f)|^2\,df \quad \text{where} \quad H(f) = \frac{V_o(f)}{V_i(f)} \quad \text{and} \quad S_o(f) = S_i(f)\,|H(f)|^2$$

R-C circuit

$$\sqrt{\overline{V_{no}}^2} = \left[\int_0^\infty 4kTR\left|\frac{1}{1+j\omega RC}\right|^2 df\right]^{1/2} = \sqrt{\frac{kT}{C}}$$





Noise in MOSFETS

For thermal noise - insert a thermal noise source in series with the gate with psd of $S_{it} = \frac{8}{3}\frac{kT}{g_m}\Delta f$

For flicker or 1/f noise, the gate psd is $S_{if} = \frac{K_f}{C_{ox}WL}\frac{\Delta f}{f}$.

-for opamp calculate the output referred noise due to each transistor, divide by the open-loop gain to refer to the input. Note: noise close to the input is more important as it experiences more gain to the output. The result for the input referred thermal noise of a current mirror opamp is:

$$S_i = \frac{16}{3}\frac{kT}{g_m}\left(1 + \frac{g_{m4}}{g_{m1}}\right) \quad \frac{V^2}{\text{Hz}}$$

where g_{m1} and g_{m4} are the transconductances of the input and the current mirror transistors respectively.

To minimize noise: for thermal noise, need input pair with large g_m or W/L, for 1/f noise, input pair needs large product of W and L.

-To find signal-to-noise ratio (SNR) find ratio of maximum signal at the output to RMS noise at the output.