Mid-term Take-Home Exam

EE 508- Fall 2022 Due Wednesday November 9

Problem 1

A notch filter based upon the Tow-Thomas Biquad is introduced in US Patent 8,436,679.

a) Obtain the transfer function for the filter in the patent.
b) Obtain an expression for the Q of this filter as a function of the Boolean input assuming there are n-bits of control
c) Design this filter for a notch frequency of 60 Hz and a bandwidth of 5 Hz
d) Comment on how this filter can be used to accurately set the notch frequency at 60Hz.

Problem 2

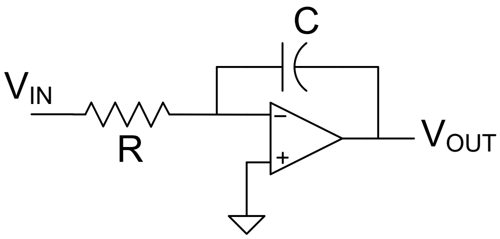
The integrator in US Patent 8,436,679 uses an R-2R ladder instead of a single resistor resulting in a unity gain frequency that is digitally programmable. Compare the performance of this R-2R integrator with that of the basic Miller integrator.

Problem 3

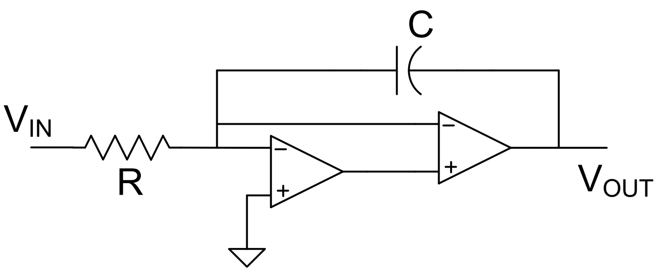
A new method of building filters is proposed in US Patent 8,952,749 by Mediatek. Obtain the transfer function for the basic embodiment in this patent which is included in Fig. 2 and comment on the practicality of this circuit.

Problem 4

Compare the integrator Q factor of the zero sensitivity Miller inverting integrator with that of the standard Miller Integrator. Include derivations needed to make these comparisons.



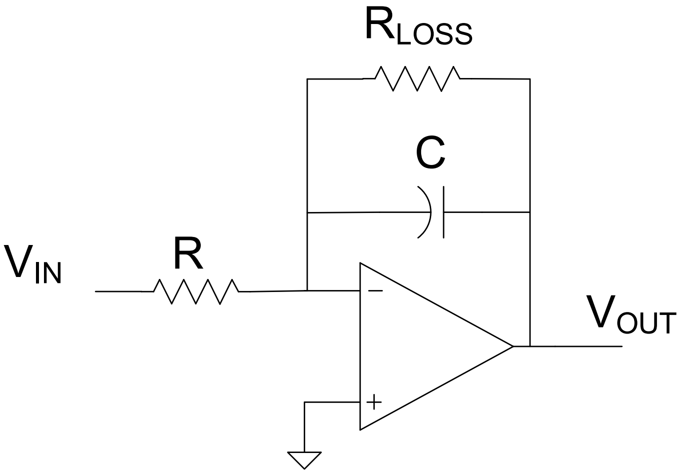
Miller Inverting Integrator



Zero Sensitivity Miller Inverting Integrator

Problem 5

A standard Miller integrator is shown below. One of the major challenges of integrating this circuit for audio frequency applications is the area required for the resistors and the capacitor. In particular, if the loss is small, the resistor R_{LOSS} can be very large. If a standard unit cell is used for the resistor R and if a number of these are placed in series to form R_{LOSS}, then the area for R_{LOSS} can be much larger than the area for R. And, even if there is no loss in the integrator, the area required for the resistor R is often unacceptably large. For example, if in a process the sheet resistance is $R_{\square}=30\Omega/\square$, and the resistance require to achieve a given integrator unity gain frequency is determined to be R=30K, and if $R_{LOSS}=20R$, the number of squares of resistance is given by $n=n_1+n_2$ where n_1 is the number of squares for R and n_2 is the number of squares for R_{LOSS}. In this example, $n_1=1000$ and $n_2=20{,}000$ so the total number of squares is $n=21{,}000$.



Standard Lossy Miller Integrator

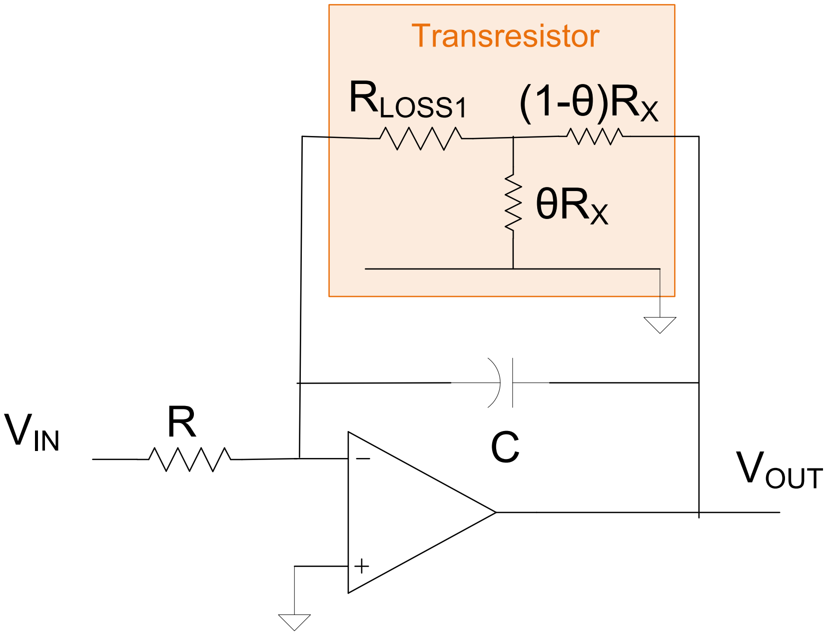
A lossy integrator with a transresistive loss element is shown below. Also shown below is a lossy integrator with two transresistive elements.

a) Derive the transfer function for the circuit with a single transresistor under the assumption $\theta R_X << R_{LOSS1}$ and show that for an appropriate R_{LOSS1} and θ, this lossy integrator can have the same integrator gain characteristics as the Standard Lossy Miller Integrator.

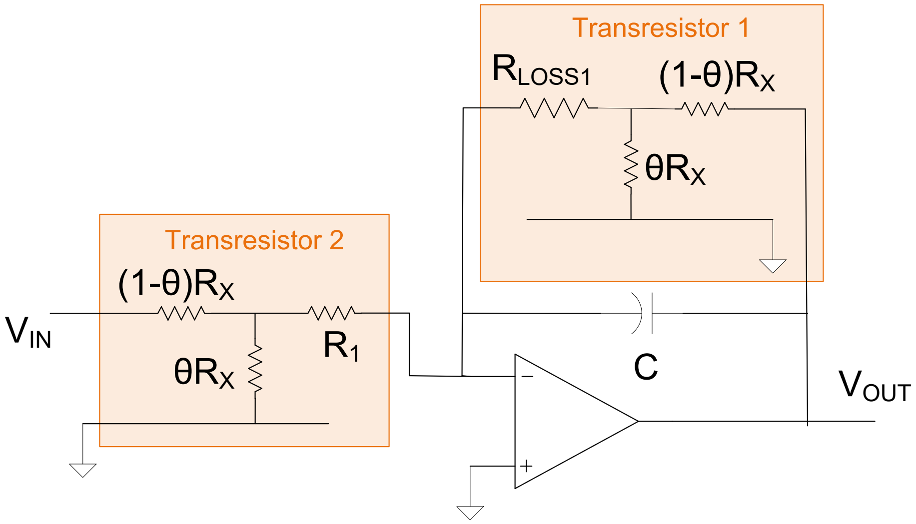
b) If $R_X=R/20$ (where R is the input resistance in the Standard Lossy Miller Integrator)and $\theta=0.1$, compare the total area (specified as the total number of squares)required to realize the same integrator unity gain frequency as was obtained with the Lossy Miller Integrator.

c) Determine the total area (specified as the total number of squares) required for the lossy integrator with the two transresistance elements if $R_X=R/20$ and $\theta=0.1$ if this structure has the same loss and the same integrator unity gain frequency as the Lossy Miller Integrator.

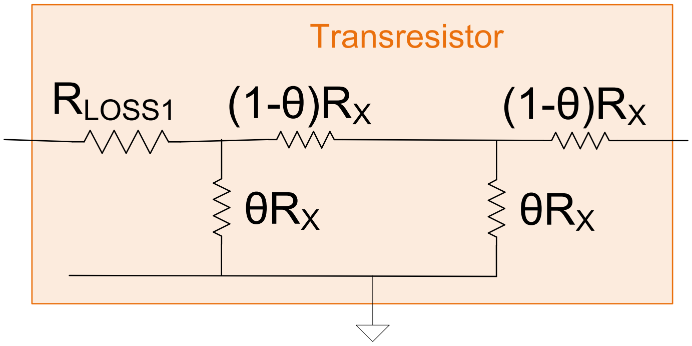
d) This process can be repeated again to further reduce the resistor area by using a two-stage transresistor ladder shown below. Is this use of transresistor elements (with one, two, or even more stages) an effective method for reducing the area requirements for building integrated audio frequency or even sub-audio frequency active filters? Discuss the benefits and/or limitations of this approach.



Lossy Miller Integrator with Transresistor Loss Element



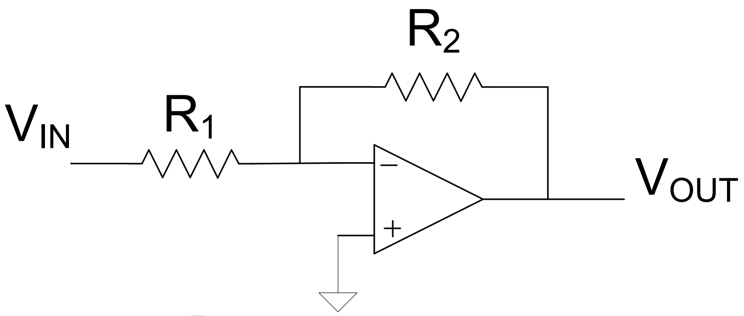
Lossy Miller Integrator with Two Transresistor Elements



Transresisor with Two-Stage Ladder

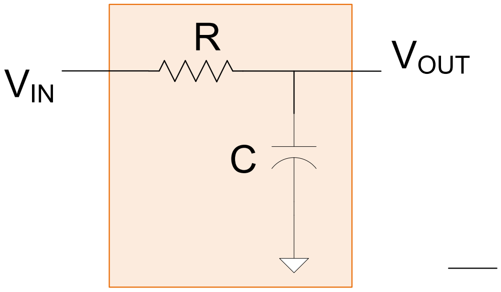
Problem 6 Consider the following amplifier where the op amp is assumed to be ideal. Assume the amplifier is to be designed to have a gain of $16 \pm 0.5\%$ and the layout of the resistors uses a common-centroid geometry to cancel gradient effects. Assume the resistors are created by using a series connection of a unit resistors of 50 ohms and area 5um^2. Assume the matching characteristics for closely-placed interdigitized resistors is characterized by the Pelgrom parameter X_R=.01μ^{-1}.

a) Determine the area for the resistors and the yield if the nominal value of R_2 is 3.2K.
b) How does the area and yield change if the nominal value of R_2 is increased to 32K



Problem 7 Consider the first-order RC filter shown below. Assume the resistor is comprised of a series connection of resistors with resistance density D_R and the capacitor has a capacitance density of D_C. Assume also that ω_0 is the 3B frequency.

a) The area required to realize this filter is given by $A=A_R+A_C$ where A_R is the area for the resistor and A_C is the area for the capacitor. Give an expression for the area required to realize this filter in terms ω_0, D_R, and D_C.
b) If the value of R and C are selected to minimize the total area for a given ω_0, how does A_R compare to A_C?



Problem 8 Consider now a requirement where two of the filters considered in the previous problem are to be designed and that the poles of these two filters are to be closely matched and are to be nominally equal to ω_0. Assume that a common-centroid layout is used for the resistors and a common centroid layout is used for the capacitors to eliminate gradient effects. Assume the standard deviation of a resistor and of a capacitor are given respectively by the equations

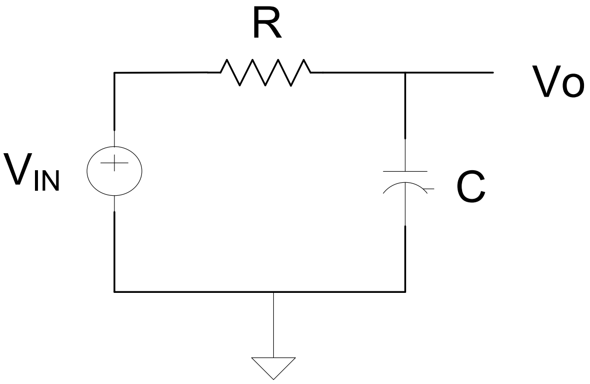
$$\sigma_R = \frac{X_R}{\sqrt{A_R}} \qquad \sigma_C = \frac{X_C}{\sqrt{A_C}}$$

where the parameters X_R and X_C are constants characteristic of the process and where A_R and A_C are the areas of the resistor and capacitor respectively. Following the notation of the previous problem, the resistance density and the capacitance density are respectively D_R and D_C.

a) Determine the relative area of the resistor and the capacitor, A_R and A_C to satisfy the nominal ω_0 requirement that will minimize the variance of the difference between the two band edges, ω_{01} and ω_{02}.

b) How does the area required for minimizing variance compare to that required for minimizing area if X_R=.01u^{-1} and X_C=.005u^{-1}?

c) How much would the variance increase if the sizing strategy to achieve minimum area were used instead of the sizing strategy to minimize variance? Assume the same values for X_R and X_C used in part b).

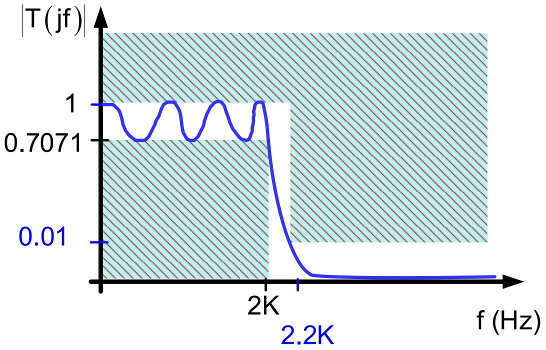


Problem 9

Design a lossy stray-insensitive noninverting switched capacitor integrator that has a nominal integrator unity gain frequency of 100KHz , a clock frequency of 1MHz, and a loss pole at 1KHz where the unity gain frequency and the loss pole are specified in the z-domain. You may assume ideal switches and an ideal operational amplifier. Give the z-domain transfer function for your filter and the approximate s-domain transfer function as well.

Problem 10

Obtain the lowest-order approximating function for a Chebyschev filter that meets the filter mask requirements given below. Verify your solution with a plot of the transfer function magnitude.



Problem 11

Design a 6th-order Chebyschev bandpass filter with 3dB band edges of 1KHz and 4KHz and 3dB of passband ripple. Include an expression for the transfer function of your filter and plot the filter response showing that it meets the performance requirements.