EECS 16B Designing Information Systems and Devices II UC Berkeley Spring 2022

Review Worksheet 1

1. Logic Gates

In digital design, we often use 'synchronous' circuits, i.e. circuits which evaluate when a clock signal transitions from 0 to V_{DD}. One such implementation, called domino CMOS logic, is shown in Figure 1. Initially $V_{\text{clk}} = 0$ ('reset phase') for a long time, so the output node is high, i.e. $V_{\text{out}} = V_{DD}$ and the capacitor is fully charged, regardless of the values of V_A and V_B. We want to complete the Truth Table 1 during the 'evaluation phase'.

For cases (ii) and (iv), when V_{clk} transitions from 0 to V_{DD} and V_A and V_B are equal to the values specified in the table, what is V_{out}? Justify your answer.

Note that if all transistors connected to the output node are switched off, then the capacitor C at the output node 'holds' the voltage since there is no charging / discharging path in that case.

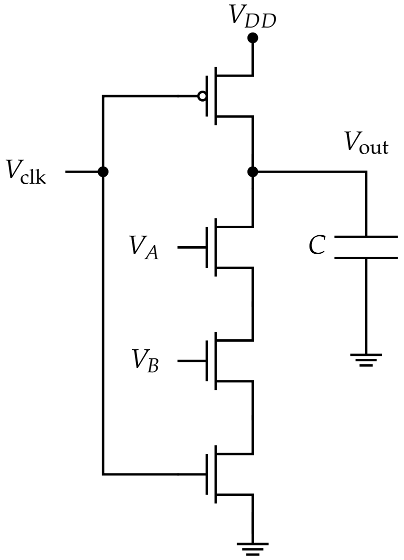


Figure 1: Domino Logic Gate

Case	V_{clk}	V_A	V_B	V_{out}
(i)	$0 \rightarrow V_{DD}$	0	0	$V_{DD} \rightarrow V_{DD}$
(ii)	$0 \rightarrow V_{DD}$	0	V_{DD}	$V_{DD} \rightarrow \underline{\textbf{?}}$
(iii)	$0 \rightarrow V_{DD}$	V_{DD}	0	$V_{DD} \rightarrow V_{DD}$
(iv)	$0 \rightarrow V_{DD}$	V_{DD}	V_{DD}	$V_{DD} \rightarrow \underline{\textbf{?}}$

Table 1: Truth Table

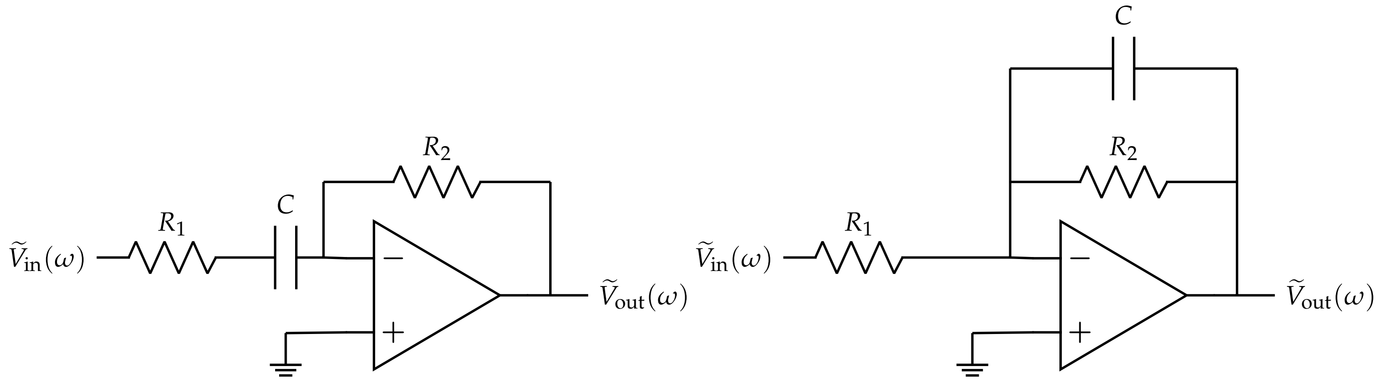
2. **Analog Signal Processing**

In this problem, we will study an example of one of the most common applications in signal processing: removing noise and amplifying the desired signal in a receiver.

In 16B we have learned about filters, so we can selectively remove specific noise frequency bands. Assume that we have a low frequency desired signal $s(t) = \cos(\omega_{\text{sig}} t)$, where $\omega_{\text{sig}} = 10 \frac{\text{rad}}{\text{s}}$, and a high frequency noise $n(t) = 2\cos(\omega_{\text{noise}} t)$, where $\omega_{\text{noise}} = 1000 \frac{\text{rad}}{\text{s}}$, at the receiver input. We wish to amplify the desired signal and also reject the noise.

(a) Let's first attempt to use a low-pass filter to achieve this goal. Since we wish to amplify the desired signal, we need to use a low-pass filter with gain > 1 (i.e. use an amplifier combined with a filter). Assume that the op-amps are ideal and follow the golden rules.

  i. **Derive a transfer function for the filter configuration in Figure 2a.** Show your work.
  ii. **Derive a transfer function for the filter configuration in Figure 2b.** Show your work.
  iii. Out of the two filter configurations in Figure 2, **which one is the low-pass filter? Justify your answer.**



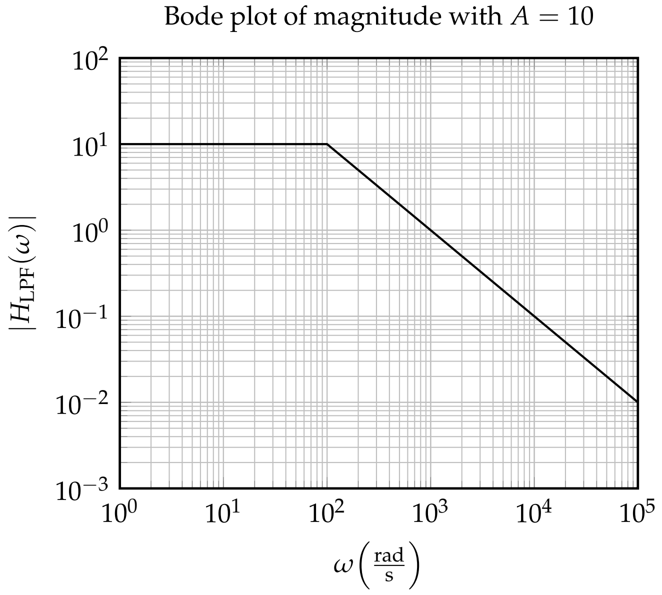
(a) Config 1 **(b)** Config 2

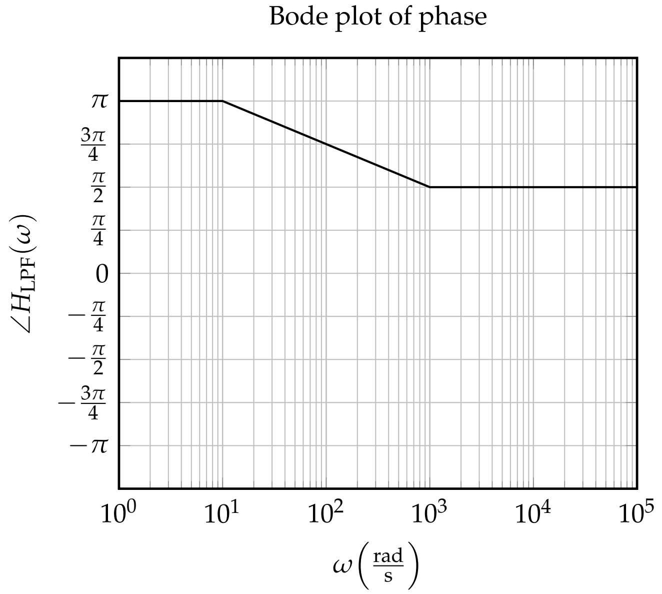
Figure 2: Active filter receiver configurations

(b) Suppose that the transfer function of the low-pass filter with gain from part (a) was $H_{\text{LPF}}(\omega) = -\frac{A}{1+\mathrm{j}\frac{\omega}{\omega_c}}$, where the cutoff frequency frequency is $\omega_c = 100\,\frac{\text{rad}}{\text{s}}$ and the gain is $A = 10$. The Bode plots for the low-pass filter with gain are shown below. Read-off the numerical values corresponding to the appropriate points on the Bode plots.

  i. What are the magnitude and phase of the filter output signal when the input into the filter is $s(t) = \cos(\omega_{\text{sig}} t)$, where $\omega_{\text{sig}} = 10\,\frac{\text{rad}}{\text{s}}$? **Derive the time domain expression for the filter output signal.**

  ii. What are the magnitude and phase of the filter output signal when the input into the filter is $n(t) = 2\cos(\omega_{\text{noise}} t)$, where $\omega_{\text{noise}} = 1000\,\frac{\text{rad}}{\text{s}}$? **Derive the time domain expression for the filter output signal.**

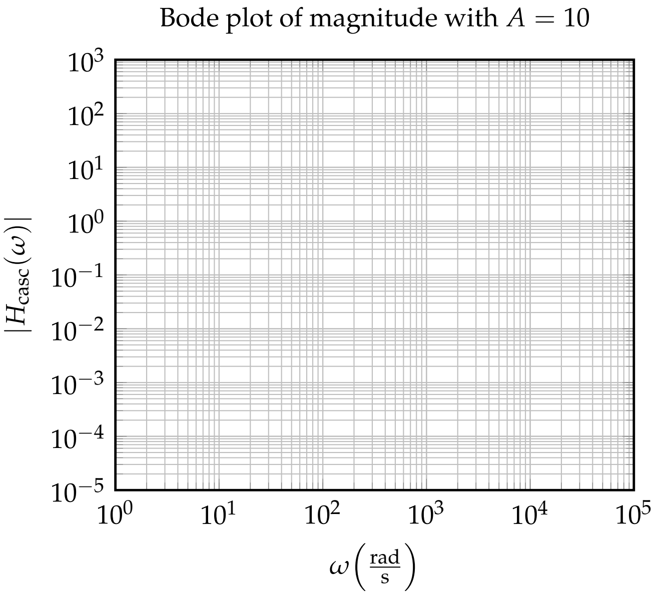


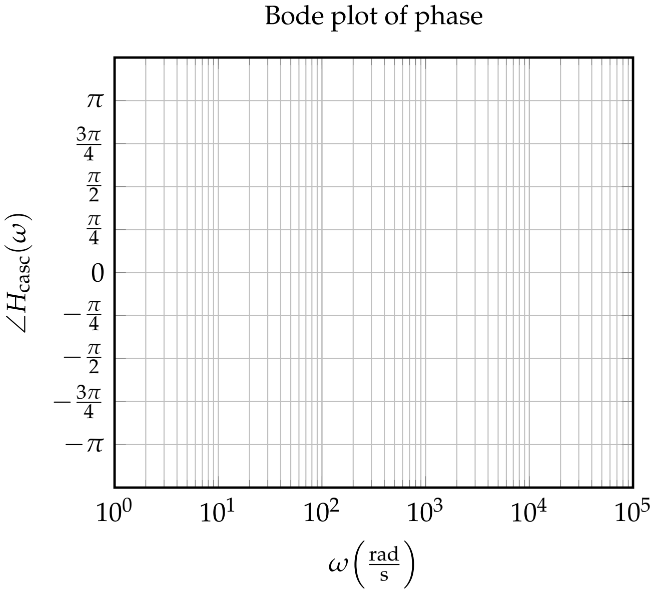


(c) We wish to have the signal be more amplified with respect to the noise. One approach is to cascade two copies of the filter $H_{\text{LPF}}(\omega)$ to make a second-order low-pass filter with gain. Note that it is not necessary to put a unity gain buffer between the two filters, because the V_{out} loading **does not affect** the behavior of this specific filter configuration.

   i. **Derive the transfer function** $H_{\text{casc}}(\omega)$ **of the second-order low-pass filter** by cascading 2 of the first order transfer function $H_{\text{LPF}}(\omega) = -\frac{A}{1+\mathrm{j}\frac{\omega}{\omega_c}}$ from part (b) with $\omega_c = 100\frac{\text{rad}}{\text{s}}$ and $A = 10$. **Show your work.**

   ii. **Sketch the Bode magnitude and phase plots of** $H_{\text{casc}}(\omega)$ **on the charts in your answer template.**





(HINT: Pay attention to the direction of the slopes.)

(d) Our implementation of the cascaded second-order filter from part (c) uses 2 op-amps. Can we get even more noise attenuation by using a single op-amp? One approach is to use a Notch filter that ideally completely rejects the noise.

Let's consider the cascade of an LC Notch filter with a non-inverting amplifier in Figure 3. We wish to have a notch at the noise frequency so that the noise $n(t) = 2\cos(\omega_{\text{noise}} t)$, where $\omega_{\text{noise}} = 1000\frac{\text{rad}}{\text{s}}$, is completely rejected, while the the signal $s(t) = \cos\big(\omega_{\text{sig}} t\big)$, where $\omega_{\text{sig}} = 10\frac{\text{rad}}{\text{s}}$, is amplified.

i. **Derive the transfer function** $H_{\text{notch}}(\omega) = \frac{\widetilde{V}_{\text{out}}(\omega)}{\widetilde{V}_{\text{in}}(\omega)}$ **of the filter in Figure 3.** Assume that the op-amp is ideal and follows the golden rules. Show your work.

ii. Using $C = 0.5\,\text{mF}$, **find the inductance value** L **so that the notch (i.e. the frequency at which the magnitude of the transfer function is** 0**) is at the noise frequency** $\omega_{\text{noise}} = 1000\frac{\text{rad}}{\text{s}}$**.** Show your work.

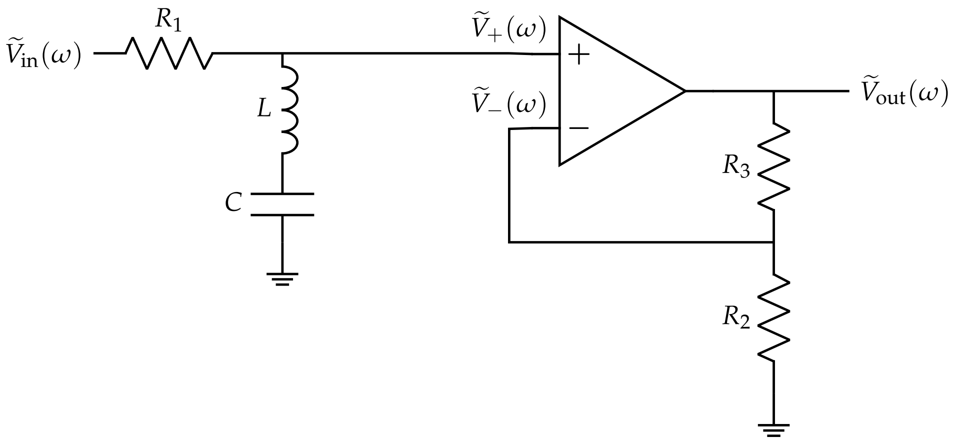
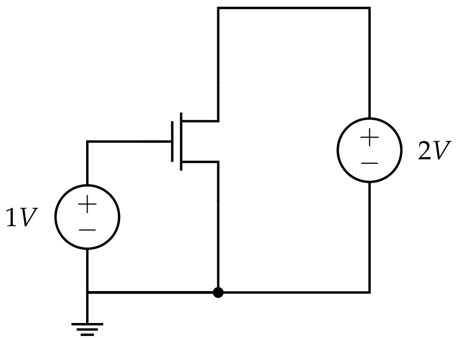


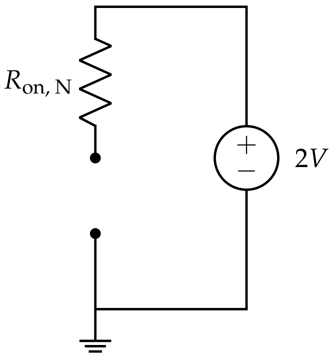
Figure 3: LC Notch filter and non-inverting amplifier

3. Transistor Behavior

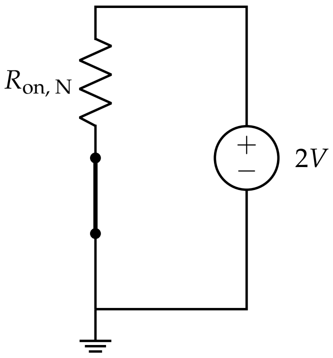
For all NMOS devices in this problem, $V_{tn} = 0.5\text{V}$. For all PMOS devices in this problem, $|V_{tp}| = 0.6\text{V}$.

(a) Which is the equivalent circuit for the right-hand side of the circuit? **Fill in the correct bubble.**





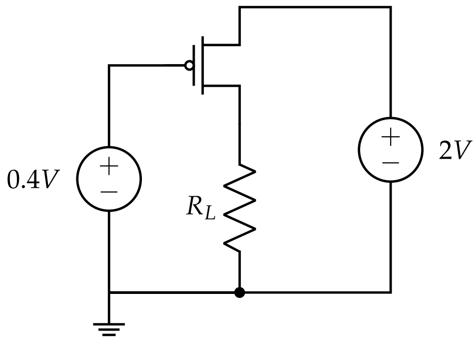
Circuit A

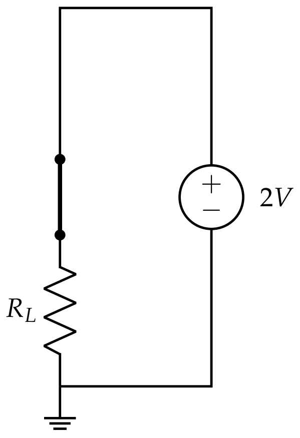


Circuit B

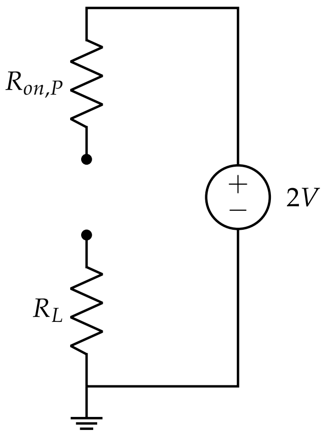
	A	B
Equivalent Circuit	○	○

(b) Which is the equivalent circuit for the right-hand side of the circuit? **Fill in the correct bubble.**

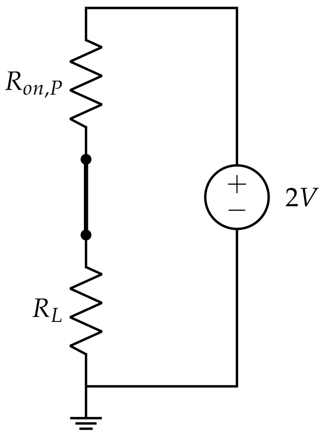




Circuit A



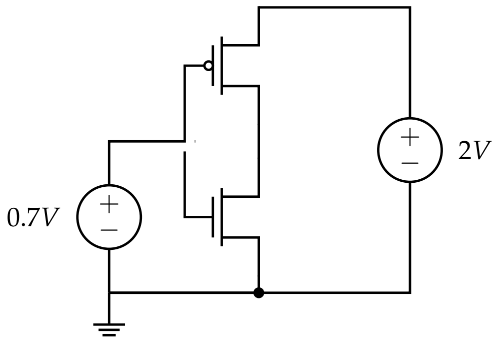
Circuit B

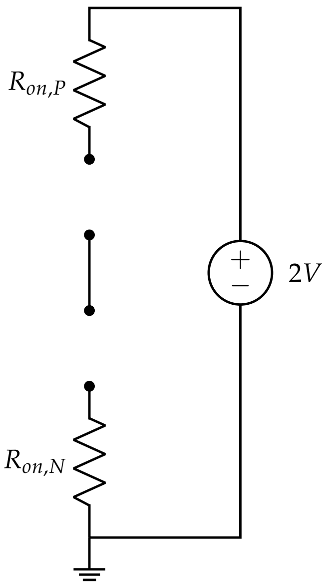


Circuit C

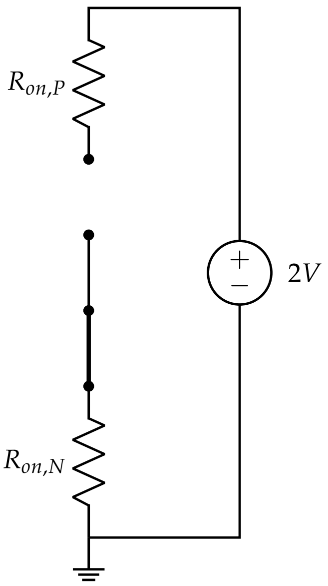
	A	B	C
Equivalent Circuit	○	○	○

(c) Which is the equivalent circuit for the right-hand side of the circuit? **Fill in the correct bubble.**

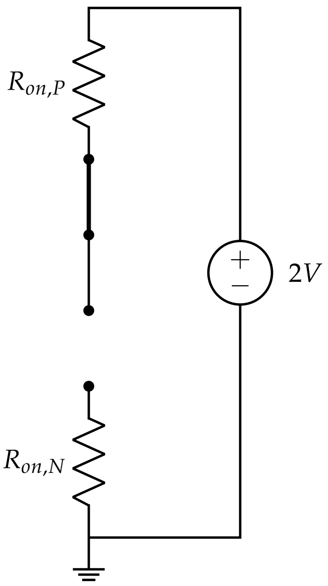




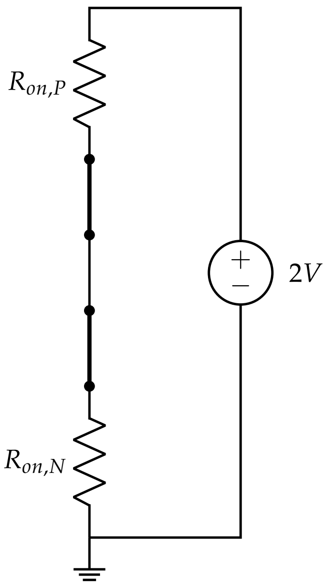
Circuit A



Circuit B



Circuit C



Circuit D

	A	**B**	**C**	**D**
Equivalent Circuit	○	○	○	○