Question 1  Short Takes – 2 points each.

1. What is the 3-dB bandwidth of the circuit below?

   (a) \( \approx 8 \text{ kHz} \)
   (b) 31.83 kHz
   (c) 15.92 kHz
   (d) 100 kHz

2. What frequency is 2.2 decades higher than 500 Hz?

   (a) 1.01 kHz     (b) 644 Hz    (c) 522 Hz     (d) 79.24 kHz

3. What frequency is 3 decades down from 220 Hz?

   (a) 22 mHz     (b) 220 mHz   (c) 6.4 mHz     (d) 190 Hz

4. A signal with amplitude \( v = 4 \text{ V} \) at 4 kHz decreases at 2 dB/octave as frequency increases. What is the amplitude in V at 13 kHz?

5. An engineer measures the (step response) rise time of an amplifier as \( t_r = 0.7 \mu \text{s} \). Estimate the 3 dB bandwidth of the amplifier.
6. What is the time constant of the circuit?

\[ R_{TH} = 10 \text{K} | 10 \text{K} = 5 \text{K}, \text{ so the time constant is} \]
\[ \tau = R_{TH} C = \left(5 \times 10^3\right) \left(1 \times 10^{-6}\right) = 5 \text{ms}. \]

7. Assume the input voltage is a 1-V step function \( u(t) \). What is the long-term value of \( v_o(t) \)? That is, what is \( v_o(t) \) for \( t \to \infty \)?

\[ v_o(\infty) = v_s \left( \frac{R_L}{R_L + R_S} \right) = 0.5 \text{V}. \]

8. Classify the filter circuit below.

(a) Low-pass filter  
(b) High-pass filter  
(c) Band-pass filter  
(d) Notch filter

9. True or false: the following is a two-pole active filter:
10. Briefly (2–3 sentences) describe the purpose of the 100K resistor in the op-amp integrator circuit below.

![Op-amp integrator circuit](image)

11. True or false: the following is a low-pass active filter

![Low-pass active filter](image)

12. True or false: the following is a high-pass active filter:

![High-pass active filter](image)

13. True or false: the following is a high-pass active filter.

![High-pass active filter](image)

14. A single-pole op-amp has an open-loop low-frequency gain of $A = 10^5$ and an open loop, 3-dB frequency of 4 Hz. If an inverting amplifier with closed-loop low-frequency gain of $|A_f| = 50$ uses this op-amp, determine the closed-loop bandwidth. (2 points)

Answer:

The gain-bandwidth product is $4 \times 10^5$ Hz. The bandwidth of the closed-loop amplifier is then $4 \times 10^5 / 50 = 8 \text{ kHz}$.

15. A single-pole op-amp has an open-loop gain of 100 dB and a unity-gain bandwidth frequency of 2 MHz. What is the open-loop bandwidth of the op-amp? (2 points)

Answer:

A gain of 100 dB corresponds to $10^5$ and the gain-bandwidth product is 2 MHz. Thus, the open-loop bandwidth is $(2 \text{ MHz}) / 10^5 = 20 \text{ Hz}$. 
16. A single-pole op-amp has an open-loop gain of 100 dB and a unity-gain bandwidth frequency 5 MHz. What is the open-loop bandwidth of the amplifier? The amplifier is used as a voltage follower. What is the bandwidth of the follower?

17. Consider a frequency $f_1 = 2.4$ Hz. How many octaves higher is the frequency $f_2 = 10$ Hz? (2 points)

18. Consider a frequency $f_1 = 2.4$ Hz. How many decades higher is the frequency $f_2 = 10$ Hz? (2 points)

19. Consider a first-order RC low-pass filter with 3-dB frequency $f = 25$ Hz. What is the phase shift in degrees at 75 Hz? (3 points)

20. Consider a first-order RC low-pass filter with corner frequency $f = 1$ kHz. What is the phase shift in degrees at 15 kHz? (3 points)
21. The following circuit has a time-constant of $\tau = 1$ ms. What is the attenuation (in dB) at a frequency of 1.6 kHz? (4 points)

\[ R \quad C \quad + \quad - \quad v_i \quad v_o \]

22. Consider the Bode plot of a 1st order RC network. What is the attenuation of the network at $f = 60$ Hz? Provide your answer in dB. (4 points)

23. Consider a first-order RC low-pass filter with 3-dB frequency $f = 60$ Hz. What is the phase shift in degrees at 50 Hz? (3 points)
24. Consider a first-order RC low-pass filter with 3-dB frequency \( f = 60 \) Hz. By how much does it delay a 50 Hz sine wave? Express your answer in ms. \((3 \text{ points})\)

\[ f_{\text{3dB}} = 100 \times 2\pi \frac{1}{\tau} = 60 \] Hz

\[ \tau = 0.53 \text{ ms} \]

\[ \text{Delay} = \frac{\Delta \phi}{2\pi} \times 4.06 = 2.3 \text{ ms} \]

25. A constant gain-bandwidth amplifier has a 3-dB bandwidth of 1 MHz. By how much (\( \mu s \)) does it delay a 250-kHz sinusoidal signal?

\[ f_{\text{3dB}} = 100 \times 2\pi \frac{1}{\tau} = 1 \text{ MHz} \]

\[ \tau = 0.53 \text{ ms} \]

\[ \text{Delay} = \frac{\Delta \phi}{2\pi} \times 4.06 \]

26. The following circuit has a time-constant of \( \tau = 0.53 \text{ ms} \). What is the attenuation (in dB) at 30 kHz? \((4 \text{ points})\)

\[ H(s) = \frac{1,000}{s^2 + 16s + 1,000} \]

\[ H(j2\pi \times 300) = 20 \log_{10} \left( \frac{1000}{\sqrt{1 + (2\pi \times 300)^2}} \right) = 40 \text{ dB} \]

**Question 2** A filter has the transfer function below. Determine the output \( y(t) \) if the input is \( x(t) = 3 \cos(100\pi t + 45^\circ) \). \((6 \text{ points})\)

\[ H(s) = \frac{1,000}{s^2 + 16s + 1,000} \]

\[ y(t) = x(t) \cdot H(j2\pi f) \]

\[ y(t) = 3 \cos(100\pi t + 45^\circ) \times 20 \log_{10} \left( \frac{1000}{\sqrt{1 + (2\pi \times 300)^2}} \right) \]
Question 3  Consider the active filter below. (a) What type of filter is this (LP, BP, Notch, etc.)? To get credit, you must motivate your answer with a short explanation. (3 points) (b) What is the order of the filter? To get credit, you must motivate your answer with a short explanation. (3 points)
**Question 4** (Filters) A filter has the transfer function below. At what frequency (in Hz) will it “ring” in response to a step function? *(4 points)*

\[
H(s) = \frac{s + 20}{s^2 + 8s + 100}
\]