\( V_- = \frac{5}{150} (15) = 5 \)

\[ \frac{V_t - V_o}{1M} + \frac{V_t - V_{in}}{100k} = 0 \]

There are 2 states, i.e., \( V_o = +14.6 \text{V} \)
and \( V_o = -14.6 \text{V} \). As a result, there
are 2 thresholds.
Threshold for \( V_o \) switching from \(-14.6 \text{V} \) to \(+14.6 \text{V}\)
and threshold for \( V_o \) switching from \(+14.6 \text{V} \) to \(-14.6 \text{V}\).

\[ V_{in} = V_{t1} \quad (V_o \text{ switching from } +14.6 \text{V} \text{ to } -14.6 \text{V}) \]

\[ \frac{5 - 14.6}{1M} + \frac{5 - V_{t1}}{100k} = 0 \]
\[ V_{t1} = 100k \left( \frac{5}{100k} + \frac{5 - 14.6}{1M} \right) = 4.04 \text{V} \]

\[ V_{in} = V_{t2} \quad (V_o \text{ switching from } -14.6 \text{V} \text{ to } +14.6 \text{V}) \]

\[ V_{t2} = 100k \left( \frac{5}{100k} + \frac{5 + 14.6}{1M} \right) = 6.96 \text{V} \]
\[ f_{3\text{dB}} = 500\text{Hz} \]
\[ f_{40\text{dB}} = 100\text{Hz} \implies \text{steepness factor} = 5 \]

According to the Butterworth filter curves for steepness factor = 5 and 40 dB attenuation, \( n = 3 \) will suffice.

Poles are \( -0.5 \pm j\times0.866 \)

-1

Constant C sections are used in this solution. The general form for highpass is obtained by transforming

\[ H(s) = \frac{s^2}{s^2 + \frac{2\alpha s}{\alpha^2 + \beta^2} + 1} \]

Comparing with \( \frac{V_o}{V_i} = \frac{s^2}{s^2 + \frac{2\alpha s}{\alpha^2 + \beta^2} + 1} \)

we find \( R_2 = \frac{1}{\alpha} \) (for Butterworth) and \( R_1 = \alpha \). So, the \( n = 2 \) stage is:

\[ C' = \frac{(ESR)(Z)}{Z} = 3.18 \times 10^3 \]

Complete filter after frequency scaling + impedance scaling:
\[ f_{3\text{dB}} = 1 \text{kHz} \Rightarrow \text{Steepness factor} = 3.33 \]
\[ f_{20\text{dB}} = 300 \text{Hz} \]

According the Butterworth curves for steepness factor = 3.33 and 20 dB attenuation, \( n = 2 \) will suffice.

Poles are \(-0.7071 \pm j\cdot0.7071\)

A constant C section is used in this solution. The general form for \( n = 2 \) highpass is obtained by transforming

\[
T_{HP}(s) = \frac{s^2}{s^2 + \frac{2\alpha s}{\alpha^2 + \beta^2} + 1} 
\Rightarrow \]

Comparing with \( \frac{V_o}{V_i} = \frac{s^2}{s^2 + \frac{2s}{R_2} + \frac{1}{R_1R_2}} \), we find \( R_2 = \frac{1}{\alpha} \) (for Butterworth) and \( R_1 = \alpha \). So, the \( n = 2 \) stage is:

\[
\begin{array}{c}
\frac{C'}{R_1(=C)} = \frac{C}{(=C)(2)} \Rightarrow \\
\therefore \quad Z = \frac{1}{2\pi(10^3)(1.1 \times 10^{-6})} = 1.59 \times 10^3
\end{array}
\]

Complete filter after frequency and impedance scaling:

\[
\frac{1.73k\Omega}{\Omega} \quad \frac{1\mu F}{\mu F} \quad \frac{2.25k\Omega}{\Omega}
\]
It is clear from the schematic that \(-\frac{V_0}{3} \leq V_{cap} \leq \frac{V_0}{3}\).

Consider the charging through the 10kΩ resistor, resulting in:
\[ R = 10kΩ, \quad C = 10μF \]
\[ V_{cap}(t) = K_1 + K_2 e^{\frac{-t}{RC}} \]
\[ V_{cap}(0) = \frac{-V_0}{3} \Rightarrow K_1 + K_2 = \frac{-V_0}{3} \]
\[ V_{cap}(\infty) = V_0 \Rightarrow K_1 = V_0 \text{ and } K_2 = -\frac{4}{3} V_0 \]
So, \[ V_{cap}(t) = V_0 \left(1 - \frac{4}{3} e^{\frac{-t}{RC}}\right) \]

Find when \( V_{cap}(t = \tau) = \frac{V_0}{3} \Rightarrow \frac{V_0}{3} = V_0 \left(1 - \frac{4}{3} e^{\frac{-\tau}{RC}}\right) \)

Or, \( \frac{2}{3} = \frac{4}{3} e^{\frac{-\tau}{RC}} \Rightarrow \tau_1 = RC \ln(2) \)

A similar analysis for charging through the 50kΩ resistor leads to:
\[ V_{cap2}(t) = -V_0 \left(1 + \frac{4}{3} e^{\frac{-t}{5RC}}\right) \]

Find when \( V_{cap2}(t = \tau_2) = -\frac{V_0}{3} = -V_0 \left(1 + \frac{4}{3} e^{\frac{-\tau_2}{5RC}}\right) \)

Or, \( \frac{2}{3} = -\frac{4}{3} e^{\frac{-\tau_2}{5RC}} \Rightarrow \tau_2 = 5RC \ln(2) \)

So, Duty Cycle is \( \frac{\tau_1}{\tau_1 + \tau_2} = \frac{1}{6} \)

Frequency of oscillation is:
\[ f = \frac{1}{\tau_1 + \tau_2} = \frac{1}{6(10kΩ)(10×10^{-6})\ln(2)} \]
\[ = 2.4 \text{ Hz} \]
5 (Inverting
(Schmitt Trigger))

\[
\frac{V_t - 15}{20.55k} + \frac{V_t - V_o}{1M} + \frac{V_t}{10.38k} = 0
\]

There are 2 states, i.e., \( V_o = +14.6V \)
and \( V_o = -14.6V \). As a result there
are 2 thresholds.
Threshold for \( V_o \) switching from \(-14.6V \)
to \(+14.6V \) and threshold for switching
from \(+14.6V \) to \(-14.6V \).

\[ V_t = V_{t1} \quad (V_o \text{ switching from } -14.6V \text{ to } +14.6V) \]

\[
V_{t1} \left( \frac{1}{20.55k} + \frac{1}{1M} + \frac{1}{10.38k} \right) = \frac{15}{20.55k} + \frac{(-14.6)}{1M}
\]

\[ V_{t1} = 4.9V \]

\[ V_t = V_{t2} \quad (V_o \text{ switching from } +14.6V \text{ to } -14.6V) \]

\[
V_{t2} \left( \frac{1}{20.55k} + \frac{1}{1M} + \frac{1}{10.38k} \right) = \frac{15}{20.55k} + \frac{(-14.6)}{1M}
\]

\[ V_{t2} = 5.1V \]

\[ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \]

\[ V_o = 14.6V \]

\[ V_o = -14.6V \]
Be able to sketch in block-diagram form 5 major functions of an op amp:
- Differential input stage
- Gain stage
- Power output stage
- Bias circuitry
- D.C. level translation

Understand operation as described in section 12.9 of text.

Understand operation as described in section 12.10 of text.