1. a) \( H(s) = \frac{2000s}{s + 100} = \frac{20s}{1 + \frac{s}{100}} \)

\( H(jw) = \frac{20jw}{1 + \frac{jw}{100}} \)

\[ A_{dB} = 20 \log_{10} |H(jw)| = 20 \log_{10} 20 + 20 \log_{10} |jw| - 20 \log_{10} |1 + \frac{jw}{100}| \]

Phase

- Phase from constant term = 0°
- Phase from zero at origin = +90°
- Phase from pole at 100 = up
  - \( \omega = \frac{10}{\omega} = 0° \), at \( \omega > \omega^{10} = -90° \)
  - \( \omega = \omega_{up} = -95° \)

This is a high-pass filter with gain.
b) $H(s) = \frac{2500}{s^2 + 265s + 2500}$ This transfer function has a pair of complex poles

$(s+\alpha-j\beta)(s+\alpha+j\beta) = s^2 + 2\alpha s + \omega_n^2$

$\Rightarrow \omega_n^2 = 2500 \Rightarrow \omega_n = 50$

$k_a = \frac{k}{\omega_n^2} = \frac{2500}{2500} = 1 = k_a$

$\bar{\beta} = \frac{2\alpha}{2\omega_n} = 0.2$

![Graph showing dB plot and angular response](image)
(C) \[ H(s) = \frac{110s}{s^2 + 110s + 1000} = \frac{110s}{(s + 10)(s + 100)} \]

\[ H(j\omega) = \frac{-11j\omega}{(1 + j\omega/10)(1 + j\omega/100)} \]

\[ A_{dB} = 20 \log_{10} |H(j\omega)| = 20 \log_{10} 11 + 20 \log_{10} |1 + j\omega/10| - 20 \log_{10} |1 + j\omega/100| \]

This is a bandpass filter.

### Diagram Details:
- **Zeros:** \( \omega = 0 \Rightarrow 90^\circ \) phase shift, constant
- **Poles:** \( \omega = 10, \omega = 100 \Rightarrow -90^\circ \) linear phase shift, starts at \( \frac{\pi}{10} \), ends at \( 10 \pi \)
\[ H(s) = \frac{V_o}{V_i} = -\frac{Z_2}{Z_1} \]

\[ Z_2 = \frac{1}{sC_2 + \frac{1}{R_2}} = \frac{R_2}{1 + R_2 s} \]

\[ Z_1 = \frac{1}{sC_1 + \frac{1}{R_1}} = \frac{R_1}{1 + R_1 C_1 s} \]

\[ H(s) = \frac{-R_2}{R_1} \frac{1 + R_1 C_1 s}{1 + R_2 C_2 s} \]

(a) \( C_2 = 1 \), \( C_1 = 1 \mu F \)
\( R_2 = 10R_1 = 10^5 \Omega \)

\[ H(s) = -10 \left( \frac{1 + 10^5 \times 10^5 s}{1 + 10^5 s} \right) = -10 \left[ \frac{1 + 10^2 s}{1 + 10^2 s} \right] \]

Notice: independent of frequency

(b) \( R_2 = 1 \) M\( \Omega \)

\[ H(s) = -10 \times 10^4 \left[ \frac{1 + 10^2 s}{1 + 10^4 s} \right] = -100 \left[ \frac{1 + 5 s}{1 + 10^4 s} \right] \]

(c) \( R_2 = 10 \) k\( \Omega \)

\[ H(s) = -1 \left[ \frac{1 + 5 s}{1 + 5 s} \right] \]
We know that $V$ is $0V$ because of the virtual short between the input terminals of the opamp. Therefore, when $a_3 = 0$ (i.e., $S3$ attached to ground) there is no current flowing through the $10k \Omega$ resistor and if $a_3 = 1$ then the current is $\frac{5V}{10k\Omega} = \frac{1}{2} mA$. So we can express the current as $\frac{1}{2} a_3 mA$.

Similarly, the current through the $20k \Omega$ resistor is $\frac{1}{4} a_2 mA$, through the $40k \Omega$ resistor is $\frac{1}{8} a_1 mA$, and through the $80k \Omega$ resistor is $\frac{1}{16} a_0 mA$.

Since no current flows into the opamp, $I = \text{sum of the above currents}$.

\[ I = \frac{1}{16} a_0 + \frac{1}{8} a_1 + \frac{1}{4} a_2 + \frac{1}{2} a_3 \text{ mA} \]

\[ V_o = -IR_F = -\frac{R_F}{16} \left( 2^0 a_0 + 2^1 a_1 + 2^2 a_2 + 2^3 a_3 \right) \]

Minimum value of $V_o$ is zero.

Max value of $V_o$ is $-\frac{15}{16} R_F$ (when $a_0 : a_1 : a_2 : a_3 = 1$)

\[ -12V = -\frac{15}{16} R_F \Rightarrow R_F = \frac{12 \times 16}{15} = 12.8 \text{ k}\Omega \]
41 Open loop gain at very low frequencies is $4.2 \times 10^5 \text{ V/V}$
at 100 kHz, gain is 70 V/V

$$A_0 = 4.2 \times 10^5 \text{ V/V}$$

$$A = \frac{A_0}{1 + j \frac{f}{f_b}}$$

$$|A| = \frac{A_0}{\sqrt{1 + (\frac{f}{f_b})^2}}$$

$$f_b = \frac{4.2 \times 10^6}{\sqrt{1 + (\frac{100}{f_b})^2}} = 181 \text{ Hz}$$

$$f_t = A_0 f_b = 4.2 \times 10^4 \times 181 = 7.6 \text{ MHz} = f_t$$

51 $V_0 = V_1 + 2v_2 - 3v_3$

To create $V_0$ we will need to use more than one op amp.
There are several ways to decompose $V_0$ so we can build the circuit with existing amplifiers.
For example:

$$V_0 = -2 - v_1 - 2v_2 + 3v_3 \text{ } @$$
$$V_0 = -2 - (v_1 + v_2) + 3v_3 \text{ } @$$
$$V_0 = -2 - (v_1 + 2v_2 - 3v_3) \text{ } @$$

We conclude that (b) is the best design as it is the simplest, using fewer op amps and it has the lowest overall resistance.