# EE310, Electronic Devices and Circuits I

Lecture Slides

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# EE310 – Chapter 1

## Introduction to Electronics

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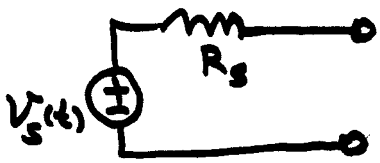
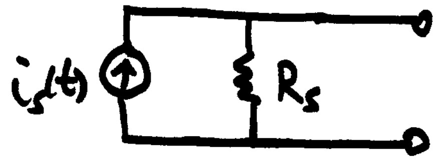
# 1.1 Signal Source

(a) Thévenin Form




(b) Norton form




1.1 For the signal-source representations shown in Figs. 1.1(a) and 1.1(b), what are the open-circuit output voltages that would be observed? If, for each, the output terminals are short-circuited (i.e., wired together), what current would flow? For the representations to be equivalent, what must the relationship be between $v_s$, $i_s$, and $R_s$?

Sol) i) Open Circuit voltage: (a) $V_{oc} = V_s$ (b) $V_{oc} = i_s R_s$

ii) Short circuit current: (a) $i_{sc} = \frac{V_s}{R_s}$ (b) $i_{sc} = i_s$

iii) For Thévenin (a) and Norton (b) to represent the same source: Voc and isc must be the same!

$\therefore V_{oc} = V_s = i_s R_s \qquad i_{sc} = \frac{V_s}{R_s} = i_s$

1.2 A signal source has an open-circuit voltage of 10 mV and a short-circuit current of 10 $\mu$A. What is the source resistance?

Sol) $V_{oc} = 10\,mV \qquad i_{sc} = 10\,\mu A \qquad R_s = ?$

$i_{sc} = \frac{V_s}{R_s} = \frac{10\,mV}{R_s} = 10\,\mu A \qquad \therefore R_s = \frac{10\,mV}{10\,\mu A} = 1\,K\Omega$

# 1.2 Frequency Spectrum

$$V_a(t) = V_a \sin \omega t$$

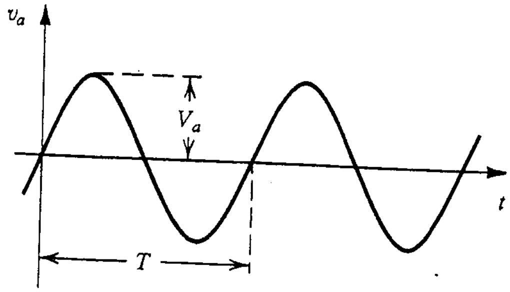



**FIGURE 1.3** Sine-wave voltage signal of amplitude $V_a$ and frequency $f = 1/T$ Hz. The angular frequency $\omega = 2\pi f$ rad/s.

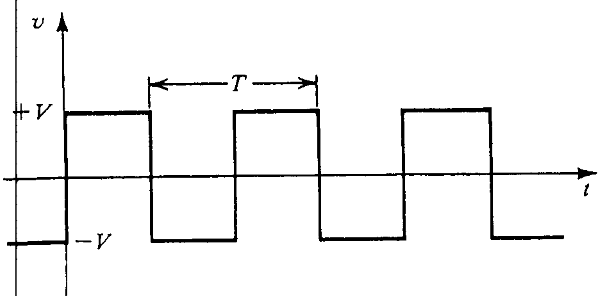



**FIGURE 1.4** A symmetrical square-wave signal of amplitude $V$.

## Fourier Expansion:

$$v(t) = \frac{4V}{\pi}\left(\sin\omega_0 t + \frac{1}{3}\sin 3\omega_0 t + \frac{1}{5}\sin 5\omega_0 t + \cdots\right)$$

$$\omega_0 = \frac{2\pi}{T}$$

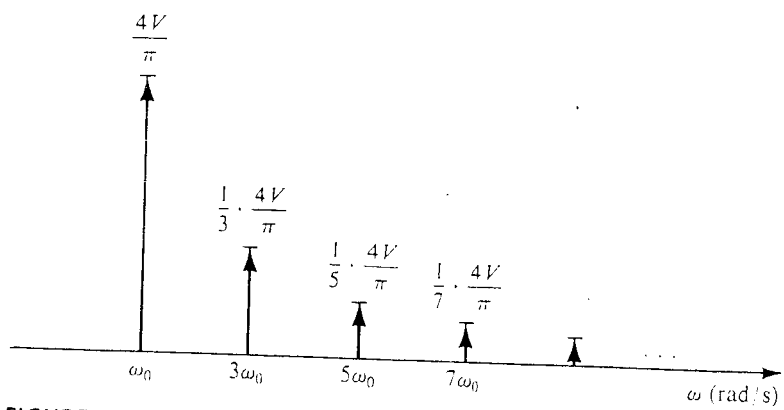



**FIGURE 1.5** The frequency spectrum (also known as the line spectrum) of the periodic square wave of Fig. 1.4.

1.6 When the square-wave signal of Fig. 1.4, whose Fourier series is given in Eq. (1.2), is applied to a resistor, the total power dissipated may be calculated directly using the relationship $P = 1/T \int_0^T (v^2/R)\,dt$ or indirectly by summing the contribution of each of the harmonic components, that is, $P = P_1 + P_3 + P_5 + \cdots$, which may be found directly from rms values. Verify that the two approaches are equivalent. What fraction of the energy of a square wave is in its fundamental? In its first five harmonics? In its first seven? First nine? In what number of harmonics is 90% of the energy? (Note that in counting harmonics, the fundamental at $\omega_0$ is the first, the one at $2\omega_0$ is the second, etc.)

Sol) $\text{Power} = \frac{1}{T}\int_0^T \frac{v^2}{R}\,dt$, $\quad v^2 = \left(\frac{4V}{\pi}\right)^2\left(\sin^2 w_0 t + \frac{1}{9}\sin^2 3w_0 t + \frac{1}{25}\sin^2 5w_0 t + \cdots\right)$

$$= \frac{1}{T}\left(\frac{4V}{\pi}\right)^2 \cdot \frac{T}{2R}\left(1 + \frac{1}{9} + \frac{1}{25} + \frac{1}{49} + \cdots\right)$$

$$= \frac{8}{\pi^2}\frac{V^2}{R}\sum_{m=1}^{\infty}\frac{1}{m^2} \qquad \sum_{m=1}^{\infty}\frac{1}{m^2} = \frac{\pi^2}{8}$$

$$= \frac{V^2}{R}$$

$$P = P_1 + P_3 + P_5 + P_7 + \cdots$$

$$\frac{P_1}{P} = \frac{1}{\Sigma \frac{1}{m^2}} = \frac{1}{\pi^2/8} = 0.81$$

$$\frac{P_1 + P_3 + P_5}{P} = \frac{1 + \frac{1}{9} + \frac{1}{25}}{\Sigma \frac{1}{m^2}} = \frac{1.151}{\pi^2/8} = 0.93$$

$$\frac{P_1 + P_3}{P} = \frac{1 + \frac{1}{9}}{\pi^2/8} = 0.90$$

# 1.4 Amplifier

Gain :

$V_o(t) = A\ V_i(t)$

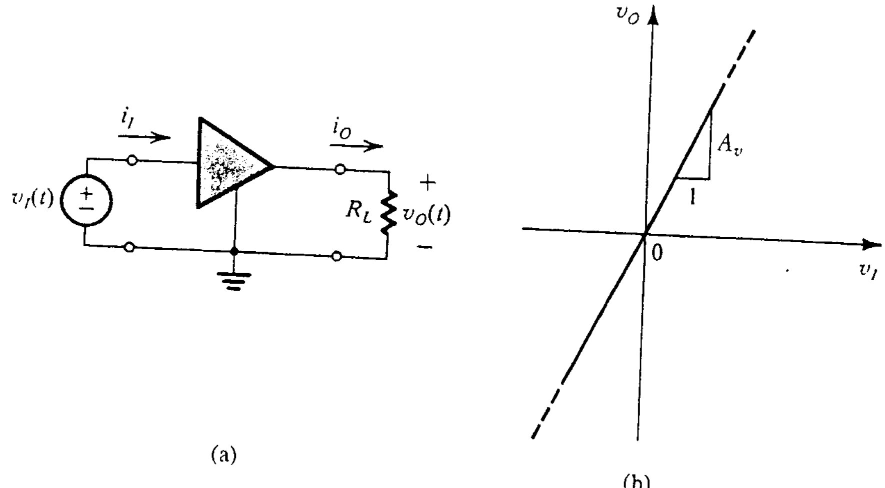



**FIGURE 1.11** (a) A voltage amplifier fed with a signal $v_I(t)$ and connected to a load resistance $R_L$. (b) Transfer characteristic of a linear voltage amplifier with voltage gain $A_v$.

$$A_v = \frac{V_o}{V_i}\ [V/V] \leftrightarrow 20\log|A_v|\ [dB]$$

$$A_i = \frac{i_o}{i_i}\ [A/A] \leftrightarrow 20\log|A_i|\ [dB]$$

$$A_p = \frac{P_o}{P_i}\ [W/W] = \frac{V_o i_o}{V_i i_i} \leftrightarrow 10\log|A_p|\ [dB]$$

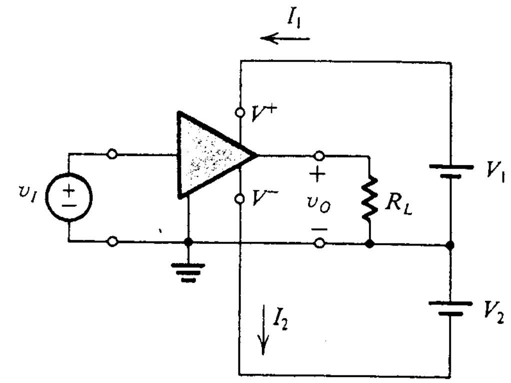
1.8 An amplifier has a voltage gain of 100 V/V and a current gain of 1000 A/A. Express the voltage and current gains in decibels and find the power gain.

sol) $A_v = 100\ V/V \leftrightarrow 20\log 100 = 40\,dB$

$A_i = 1000\ A/A \leftrightarrow 20\log 1000 = 60\,dB$

$A_p = A_v \cdot A_i = 10^2 \cdot 10^3\ W/W \leftrightarrow 10\log 10^5 = 50\,dB$

# Amplifier Power Supplies




$$P_{dc} = V_1 I_1 + V_2 I_2$$

$$P_{dc} + P_I = P_L + P_{dissipated}$$

1.9 An amplifier operating from a single 15-V supply provides a 12-V peak-to-peak sine-wave signal to a 1-kΩ load and draws negligible input current from the signal source. The dc current drawn from the 15-V supply is 8 mA. What is the power dissipated in the amplifier, and what is the amplifier efficiency?

sol) DC supply: $V_{DC} = 15\text{-V}$ $\quad I_{DC} = 8\,mA$

input: $i_i \simeq 0$

output: $V_o = 6V \sin\omega t$ $\quad R_L = 1\text{-}K\Omega$

$$P_{diss} = P_{dc} + P_I - P_L$$

$$P_{dc} = V_{DC} I_{DC} = 15V \cdot 8mA = 120\,mW$$

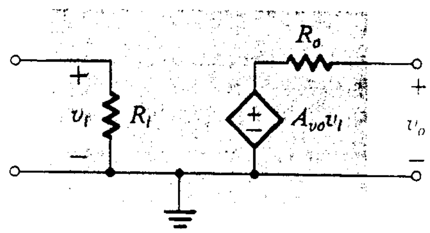
$$P_I \simeq 0$$

$$P_L = \frac{V_{o,rms}^2}{R_L} = \frac{(6/\sqrt{2})^2}{1\text{-}K\Omega} = 18\,mW$$

$$\therefore P_{diss} = 120 + 0 - 18 = 102\,mW$$

$$\text{Efficiency } \eta = \frac{P_L}{P_{dc}} \times 100 = \frac{18}{120} \times 100 = 15\%$$

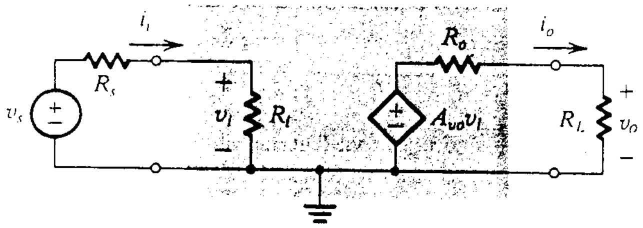
# 1.5 Amplifier Circuit Models
## – Voltage Amp



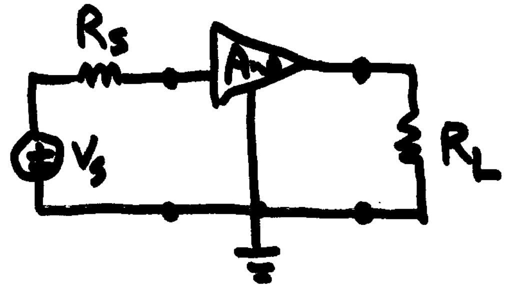

(a)

Open Circuit: $V_o = A_{vo} V_i$

$\therefore$ Gain $= \frac{V_o}{V_i} \equiv A_{vo}$




(b)




Now, with $R_L$: $V_o = A_{vo} V_i \frac{R_L}{R_L + R_o}$

$$\therefore \text{Gain} = \frac{V_o}{V_i} = A_{vo} \frac{R_L}{R_L + R_o} \equiv A_v$$

For a Large $A_v$, make $R_L \gg R_o$

1.12 The output voltage of a voltage amplifier has been found to decrease by 20% when a load resistance of 1 kΩ is connected. What is the value of the amplifier output resistance?

Sol) After $R_L = 1\,k\Omega$ is connected,

$$A_v = A_{vo} \frac{1k}{1k + R_o} = 0.8 A_{vo} \qquad \therefore R_o = 0.25k$$

1.13 An amplifier with a voltage gain of +40 dB, an input resistance of 10 kΩ, and an output resistance of 1 kΩ is used to drive a 1-kΩ load. What is the value of $A_{vo}$? Find the value of power gain in dB.

Amp: 40 dB, $R_i = 10\,k\Omega$ $R_o = 1\,k\Omega$

Load: $R_L = 1\,k\Omega$

Sol) $40\text{ dB} = 20 \log |A_{vo}|$ $\therefore A_{vo} = 100\ V/V$

$$\text{Power Gain} = \frac{P_L}{P_i} \quad \text{where} \begin{cases} P_L = \dfrac{V_o^2}{R_L} \\ P_i = \dfrac{V_i^2}{R_i} \end{cases}$$

$$\therefore A_p = \frac{P_L}{P_i} = \left(\frac{V_o}{V_i}\right)^2 \frac{R_i}{R_L}$$

$$\frac{V_o}{V_i} = A_{vo} \frac{R_L}{R_L + R_o} = 100 \frac{1K}{1K + 1K} = 50$$

$$A_p = \left(50 \frac{V}{V}\right)^2 \frac{10K}{1K} = 25{,}000 \frac{W}{W} = 10 \log(25{,}000)\ \text{dB}$$

$$= 43.98\ \text{dB}$$

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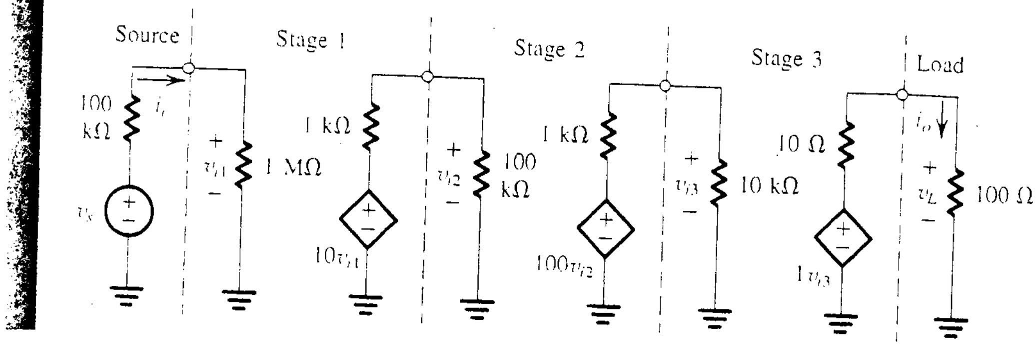
Overall Voltage Gain $\equiv \dfrac{V_o}{V_s} = V_s - \text{to} - V_o$

$$V_i = V_s \frac{R_i}{R_i + R_s}$$

$$\frac{V_o}{V_s} = \frac{V_o}{V_i} \frac{V_i}{V_s} = A_v \frac{R_i}{R_i + R_s} = A_{vo} \frac{R_L}{R_L + R_o} \frac{R_i}{R_i + R_s}$$

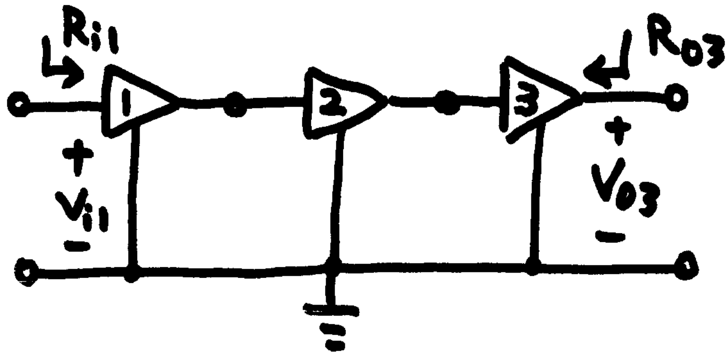
**EXAMPLE 1.3**

### 1.5.2 Cascaded Amplifiers




1.16 (a). Model the three-stage amplifier of Example 1.3 (without the source and load) using the voltage amplifier model. What are the values of $R_i$, $A_{vo}$, and $R_o$?

Sol )

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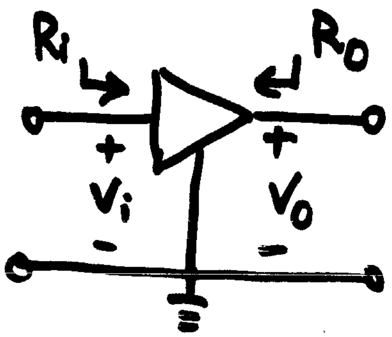



$R_i = R_{i1} = 1M\Omega$ $\qquad$ $R_o = R_{o3} = 10\Omega$

$$A_{vo} = \frac{V_o}{V_i} = \frac{V_{o3}}{V_{i1}}$$
$$= \frac{V_{o3}}{V_{i3}} \cdot \frac{V_{i3}}{V_{i2}} \cdot \frac{V_{i2}}{V_{i1}}$$
$$= 1 \times 909 \times 9.9$$
$$= 900.1 \text{ V/V}$$

From Exa 1.3

$$\frac{V_{o3}}{V_{i3}} = 1 \text{ V/V}$$

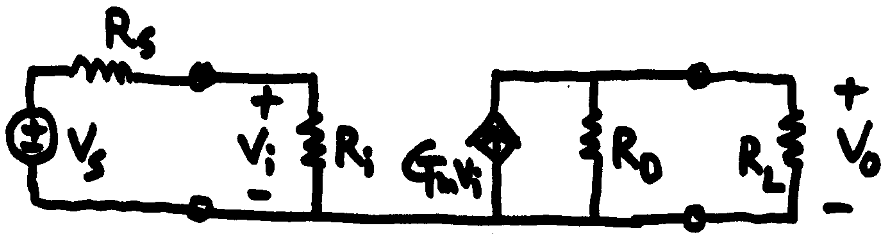
$$\frac{V_{i3}}{V_{i2}} = 100 \cdot \frac{10K}{10K+1K} = 90.9 \text{ V/V}$$

$$\frac{V_{i2}}{V_{i1}} = 10 \cdot \frac{100K}{100K+1K} = 9.9 \text{ V/V}$$

**1.18** Consider the transconductance amplifier whose model is shown in the third row of Table 1.1. Let a voltage signal-source $v_s$ with a source resistance $R_s$ be connected to the input and a load resistance $R_L$ be connected to the output. Show that the overall voltage-gain is given by

$$\frac{v_o}{v_s} = G_m \frac{R_i}{R_i + R_s}(R_o \parallel R_L)$$

Sol) Transconductance Amplifier With Load, Source



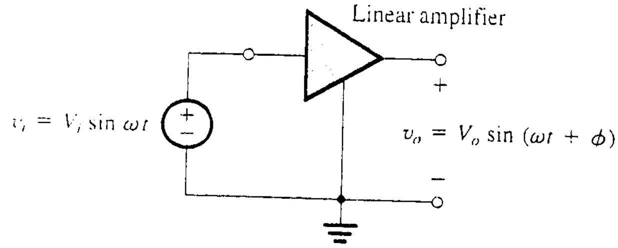

$$V_i = V_s \frac{R_i}{R_i + R_s} \qquad V_o = G_m V_i \cdot (R_o \parallel R_L)$$

Therefore,

the Overall Voltage Gain $= \frac{V_o}{V_s}$

$$\frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = G_m (R_o \parallel R_s) \cdot \frac{R_i}{R_i + R_s}$$

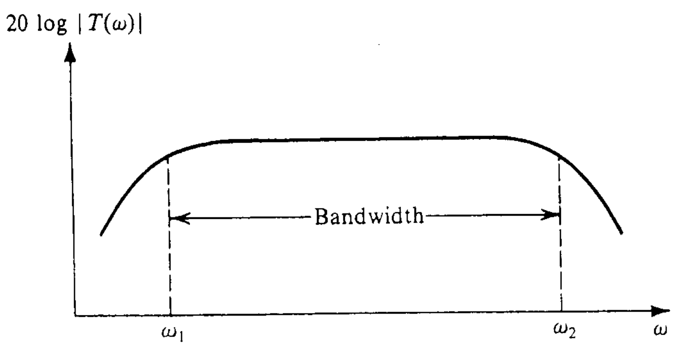
## 1.6 FREQUENCY RESPONSE OF AMPLIFIERS




**Transfer Function T(w)**

$$|T(\omega)| = \frac{V_o}{V_i}$$
$$\angle T(\omega) = \phi$$

### 1.6.2 Amplifier Bandwidth



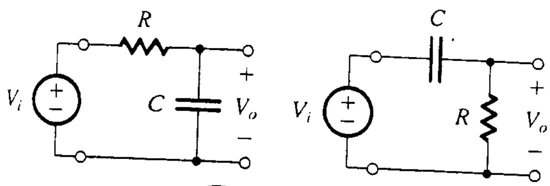

$$T(w) = \frac{V_o(w)}{V_i(w)}$$

OR,

$$T(s) = \frac{V_o(s)}{V_i(s)}$$ , where

$S \equiv jw$ = Complex Freq.

1.6.4 Single-Time-Constant Networks




(a) LP (b) HP

(a) Low-Pass : $\frac{V_o}{V_i} = \frac{1/sC}{1/sC + R} = \frac{1}{1+sCR} \equiv \frac{1}{1+\frac{s}{\omega_o}}$

where, $\omega_o \equiv \frac{1}{CR}$

To account for DC gain, use K :

$$\boxed{T(s) = \frac{K}{1+\frac{s}{\omega_0}}}$$

ex) $T(\omega=0) = K$ $T(\omega=\infty) = 0$ $\therefore$ LP

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(b) High-Pass : $T(s) = \frac{V_o}{V_i} = \frac{K}{1+\frac{\omega_o}{s}}$

ex) $T(\omega=0) = 0$ $T(\omega=\infty) = K$ $\therefore$ HP

1.21 Consider a voltage amplifier having a frequency response of the low-pass STC type with a dc gain of 60 dB and a 3-dB frequency of 1000 Hz. Find the gain in dB at $f = 10$ Hz, 10 kHz, 100 kHz, and 1 MHz.

Sol) $K = 60\,dB = 1000\,V/V$, $f_{3dB} = 1\,KHz$ LP

Gain at $f = 10$, $10K$, $100K$, and $1MHz$ ?

LP: $T(s) = \dfrac{K}{1 + \frac{s}{w_0}}$

At $w = w_0$,

$|T| = \dfrac{K}{\sqrt{2}}$, and

$20\log|T| = 20\log K - 3dB$

$\therefore\ w_0 = 2\pi f_{3dB}$

For $|s| = w \gg w_0$,

$$|T(s)| \approx \frac{K}{|s/w_0|} = K\frac{w_0}{w}$$

$$\text{Gain} = 20\log|T| \approx 20\log K - 20\log\frac{w}{w_0}$$

ex) $w \rightarrow$ 10x 100x 1000x

Gain $\rightarrow$ -20dB -40dB -60dB

For $|s| = w \ll w_0$, $T(s) = K$

$\therefore\ f = 10Hz \ll \underset{f_{3dB}}{1K} \ll 10K$ 100K 1MHz

Gain = 60dB 57dB 40dB 20dB 0dB

Note: Unity Gain Frequency $w_T$: Gain = 0dB at $w_T$

$$\text{Gain} = K\frac{w_0}{w_T} = 1 \quad \therefore\ w_T = K w_0$$

check $f_T = K f_{3dB} = 1000\,\frac{V}{V} \cdot 1KHz = 1000\,KHz$