# Principles of Communications System

## Chapter 1 (Part 2): Gain, Loss And Noise

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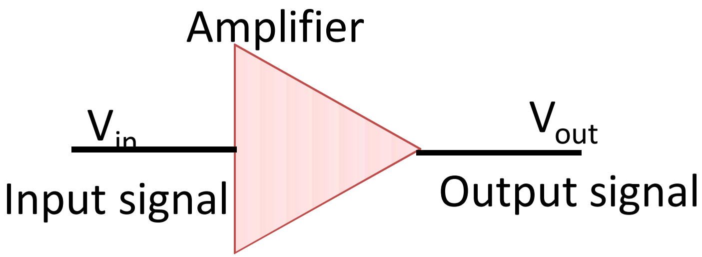
# Gain, Attenuation, and Decibels

- **Amplifier** is an electronic device that increase the power of a signal fed into it.
- **Gain** represent this amplification process. It gives the ratio of output of a circuit to its input.




$$A_V = gain = \frac{\text{output}}{\text{input}} = \frac{V_{out}}{V_{in}}$$

- Power gain $(A_p) = P_{out} / P_{in}$

  where $P_{in}$ is the power input and $P_{out}$ is the power output.

# Example 1

The power output of an amplifier is 10 watts (W). The power gain is 80. What is the input power?

**SOLUTION:**

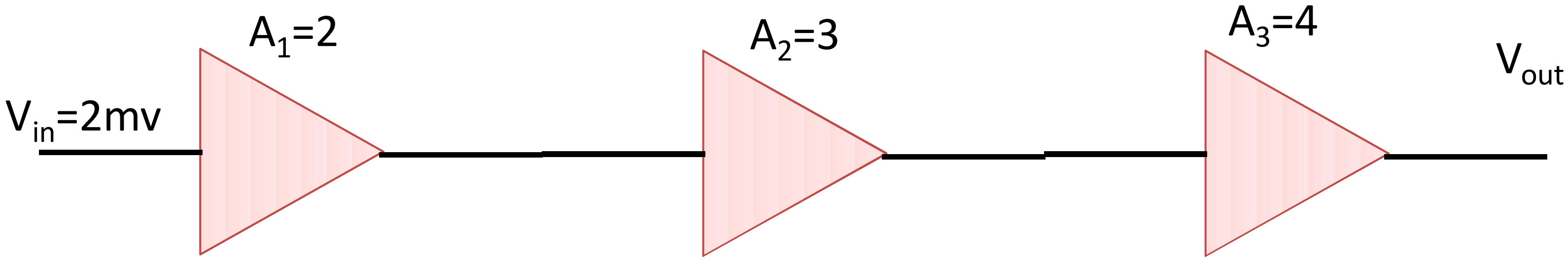
$A_p = P_{out} / P_{in}$

therefore $\quad P_{in} = P_{out} / A_p$

$P_{in} = 10 / 80 = 0.125\ \text{W} = 125\ \text{mW}$

# Gain, Attenuation, and Decibels

- When two or more amplifiers are connected together (cascaded), total gain is the product of each individual gain at every stage




Total gain, $A_T = A_1 \times A_2 \times A_3 = 2 \times 3 \times 4 = 24 = V_{out}/V_{in}$

Thus $V_{out} = A_T \times V_{in} = 2 \times 24 = 48mV$

# Example 2

A circuit has three cascaded amplifiers, with power gains of 3, 2, and 7 respectively. If the input power is given as 50 mW, find the total gain and output power

$$A_p = A_1 \times A_2 \times A_3 = 3 \times 2 \times 7 = 42$$

$$A_p = P_{out} / P_{in}$$

therefore $P_{out} = A_p P_{in}$ $P_{out} = 42\ (50 \times 10^{-3}) = 2.1\ \text{W}$

# Attenuation (Loss)

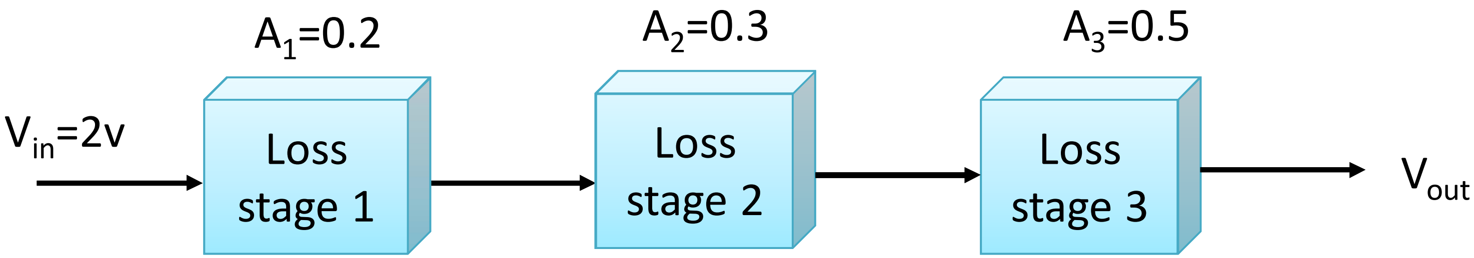
- The opposite of gain is **Attenuation**
- It refers to refers to reduction (loss ) of output power at the of a circuit or component.
- As with gain previously, attenuation can be found by:

$$A = \text{output/input} = V_{out}/V_{in}$$

- If A is less than 1, then the circuit causes attenuation

# Gain, Attenuation, and Decibels

As with gain, for circuit with several loss stages, total attenuation is the product of individual attenuations of each cascaded circuit.

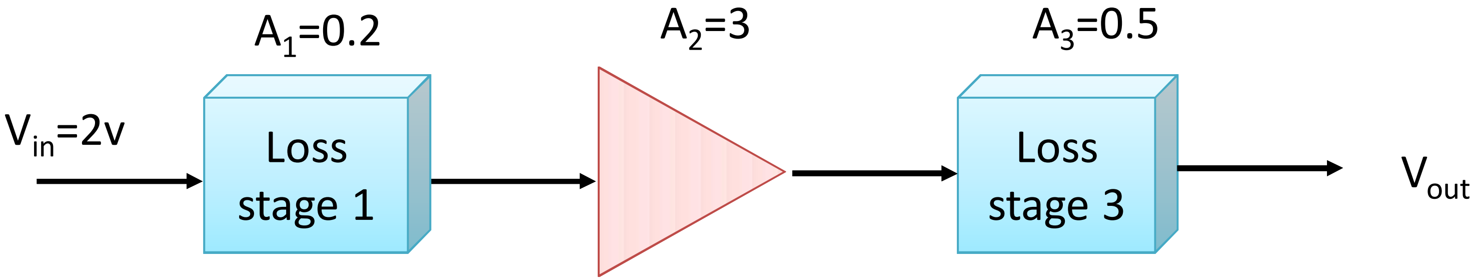



Total loss, $A_T = A_1 \times A_2 \times A_3 = 0.2 \times 0.3 \times 0.4 = 0.024 = V_{out}/V_{in}$

Thus $V_{out} = A_T \times V_{in} = 2 \times 0.024 = 0.048 = 48mV$

# Total gain & attenuation

- A circuit can also consists of combination of amplifiers and attenuators.
- Thus, total gain is the product of all stages of gains and attenuations




Total gain, $A_T = A_1 \times A_2 \times A_3 = 0.2 \times 3 \times 0.4 = 0.24 = V_{out}/V_{in}$

Thus $V_{out} = A_T \times V_{in} = 2 \times 0.24 = 0.48V$

# Decibel (dB) – ration of two powers

- If 2 powers are expressed in the same units (e.g. watt, miliwatt), their ratio is a dimensionless quantity that can be expressed in decibel form as follow

$$dB = 10\log_{10}\left(\frac{P_1}{P_2}\right) \qquad (1)$$

Where $P_1$ : power level 1 (watts)

$P_2$ : power level 2 (watts)

- the dB value is for the power of $P_1$ with respect to the reference power $P_2$
- the dB value shows the difference in dB between power $P_1$ and $P_2$

# Gain & Loss (dB)

Å We can measure the ratio between the power at the output and input of any electronic circuit or device by using eq (1) as below: (2)

$$A_{p(dB)} = 10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

where $A_{p(dB)}$ : power gain (unit in dB) of $P_{out}$ with respect to $P_{in}$

$P_{out}$ : output power level (watts)

$P_{in}$ : input power level (watts)

$P_{out}/P_{in}$ : absolute power gain (unitless)

# Gain & Loss (dB)

- Positive (+) dB value: output power is greater than the input power → **power gain** or **amplification**

- Negative (-) dB value : output power is less that the input power →**power loss** or **attenuation**

- If $P_{out} = P_{in}$, (power gain is 1), dB power gain is 0 (unity power gain)

# Gain, Loss, and Decibels

## Decibels: Decibel Calculations

- Voltage Gain or Attenuation

$$dB = 20 \log V_{out} / V_{in}$$

- Current Gain or Attenuation

$$dB = 20 \log I_{out} / I_{in}$$

- Power Gain or Attenuation

$$dB = 10 \log P_{out} / P_{in}$$

# dBm and dBc

dBM is a decibel value when the base value is referenced to 1 mW:

$$P_{(\text{dBm})} = 10 \cdot \log_{10}( P_{(\text{mW})} / 1\text{mW})$$

**dBc** is a decibel gain attenuation value where the reference is the carrier.

# Example

Å To calculate the ratio of 1 kW (one kilowatt, or 1000 watts) to 1 W in decibels, use the formula

$$G_{\mathrm{dB}} = 10\log_{10}\left(\frac{1000\mathrm{W}}{1\mathrm{W}}\right) = 30\mathrm{dB}$$

Å To calculate the ratio of 1 mW (one milliwatt) to 10 W in decibels, use the formula

$$G_{\mathrm{dB}} = 10\log_{10}\left(\frac{.001\mathrm{W}}{10\mathrm{W}}\right) = -40\mathrm{dB}$$

Å To find the power ratio corresponding to a 3 dB change in level, use the formula

$$G = 10^{\frac{3}{10}} \times 1 \ = 1.99526... \approx 2$$

# Example 3

If an amplifier has input of 3 mW and an output of 6 W. What is the gain in decibels?

$G_{dB}$ = 10 log 6/0.003

= 10 log 2000

= 10 (3.301)

= 33.01

# Example 4

Let's say a power amplifier with a 30 dB gain has output power 100 W. Calculate the input power.

Solution:

dB = 10 log (Pout/ Pin )

$30 = 10 \log (P_{out} / P_{in})$

$3 \quad = \log (P_{out} / P_{in})$

antilog = log^(-1)

Antilog 3 = antilog (log (Pout/ Pin ) )

(Pout/ Pin ) =10^3= 1000

Pin =Pout/1000
= 100/1000
= 0.1 W
= 100 mW

# NOISE, INTERFERENCE AND DISTORTION

# Noise, interference and distortion

- Noise
  - unwanted signals that coincide with the desired signals.
  - Two type of noise: internal and external noise.

- Internal noise
  - Caused by internal devices/components in the circuits.

- External noise
  - noise that is generated outside the circuit.
  - E.g. atmospheric noise, solar noise, cosmic noise, man made noise.

# Noise, interference and distortion (Contôd)

- Interference
  - Contamination by extraneous signals from human sources.
  - E.g. from other transmitters, power lines and machineries.
  - Occurs most often in radio systems whose receiving antennas usually intercept several signals at the same time
  - One type of noise.

- Distortion
  - Signals or waves perturbation caused by imperfect response of the system to the desired signal itself.
  - May be corrected or reduced with the help of equalizers.

# Noise Temperature

Å Thermal noise, $P_n$ can be found using:

Where

$P_n$ @ N = noise power ($Watt$)

$k$ = Boltzman constant (1.38 x $10^{-23}$ $J/K$)

$T$ = $T(K) = T(°C) + 273$

environmental temperature ($K$)

$B$ = Bandwidth of system ($Hz$)

# Example 5

In a circuit, a resistor with 25 °C temperature is connected in across the input of an amplifier. The bandwidth of the system is 50 kHz. Calculate the amount of noise caused by the resistor to the input of the amplifier.

**SOLUTION**

$T(K) = T(°C) + 273$

$= 25 + 273$

$= 298$ K

$P_N = kTB$

$= 1.38 \times 10^{-23} \times 298 \times 50 \times 103$

$= 2.06 \times 10^{-16}$ W

$= 0.206$ fW

# Signal-to-Noise Ratio

- **Signal-to-noise** ratio is one of the most important characteristics of a communication system
- It represents the ratio of a signal strength to interference.
- Generally it is expressed in decibels.
- Signal-to-noise ratio is found by:

$$S/N = \frac{P_S}{P_N}$$

- In dB:

$$S/N(\mathrm{dB}) = 10\log\frac{P_S}{P_N}$$

# Example 6

For an amplifier with output signal of 10 W and an output noise power of 0.01 W, determine the signal-to-noise power ratio in dB:

$$S/N(\mathrm{dB}) = 10\log\frac{P_S}{P_N} = 10\log\frac{10}{0.01} = 30dB$$

# Noise Figure

- Since thermal noise is produced by all conductors and active devices, it follows that any stage in a communication system will add noise

- **Noise Factor (in ratio) and Noise Figure (in dB)** shows how much SNR degrades as a signal pass through a circuit

- Ratio of SNR at the input to SNR at the output of a circuit

# Signal to Noise Ratio

- SNR is ratio of signal power, *S* to noise power, *N*.

$$SNR = 10 \log \frac{S}{N} \; dB$$

- Noise Factor, *F*

$$F = \frac{S_i / N_i}{S_o / N_o}$$

- Noise Figure, *NF*

$$NF = 10 \log F$$
$$= 10 \log \frac{S_i / N_i}{S_o / N_o} (dB)$$

# Equivalent noise Temperature

Å Equivalent noise temperature, ($T_e$) is a hypothetical value, used to indicate thermal noise

$$T_e = T(F\text{-}1)$$

Where T = environmental temperature = 290 (kelvin)

F = Noise factor

Å $T_e$ is often used in low noise, sophisticated radio receivers rather than noise figure.

# Example 3

The signal power at a receiver is 100 µW and the noise power is 1 µW. The components in the receiver has an additional 80 µW of noise, $N_d$, and has a power gain of 100 W. Find the receiver's:

(i) input SNR

(ii) output SNR

(iii) noise figure.

# Solution

(i) Input SNR in dB

$$S/N_i = \frac{P_S}{P_N} = \frac{100\times10^{-6}}{1\times10^{-6}} = 100$$

$$S/N_i(\mathrm{dB}) = 10\log 100 = 20dB$$

(ii) Output SNR in dB

$$N_o = A_p N_i + N_d = (100)(1\times10^{-6}) + 80 = 1.8\times10^{-4}W$$

$$S_o = A_p \times S_i = (100)(100\times10^{-6}) = 1\times10^{-2}W$$

# Solution (cont.)

$$S/N_i = \frac{P_S}{P_N} = \frac{1\times10^{-2}}{1.8\times10^{-4}} = 55.56$$

$$S/N_O(\text{dB}) = 10\log 55.56 = 17.45\,dB$$

(iii) The receiver's noise figure in dB

$$F_{db} = 10\log\frac{S_i/N_i}{S_o/N_o}(dB) = 10\log\frac{100}{55.56}(dB) = 2.55$$

OR: $F_{db} = 20 - 17.45 = 2.55dB$

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