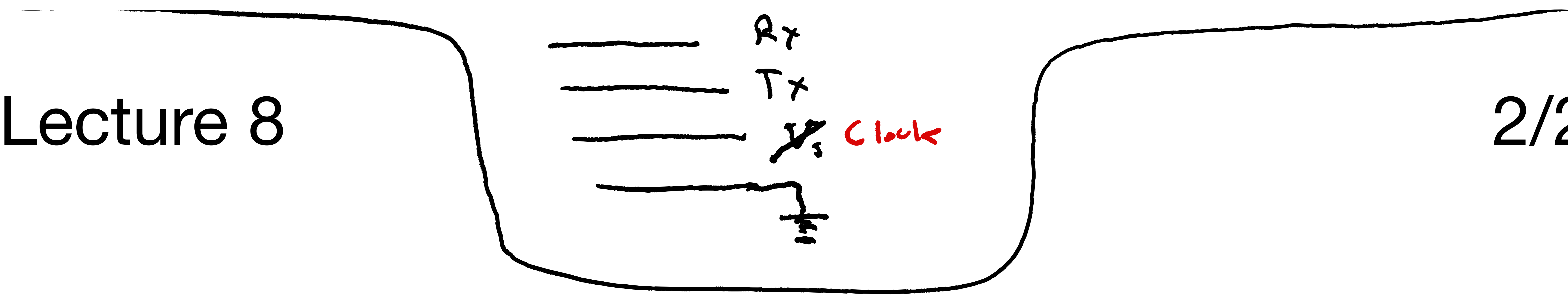
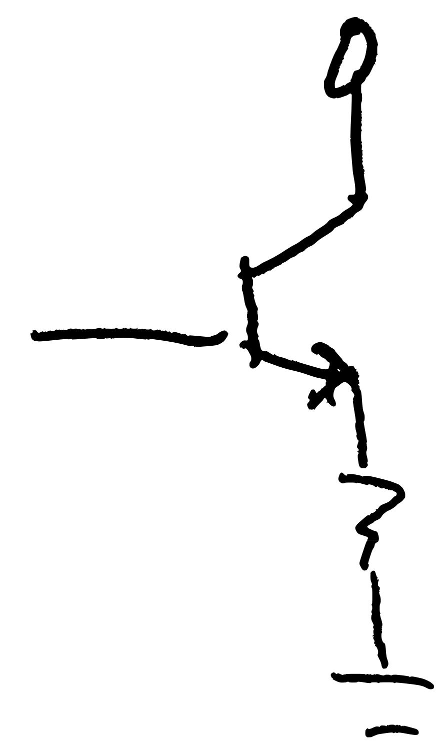
ME133 Lecture 8

2/2/23



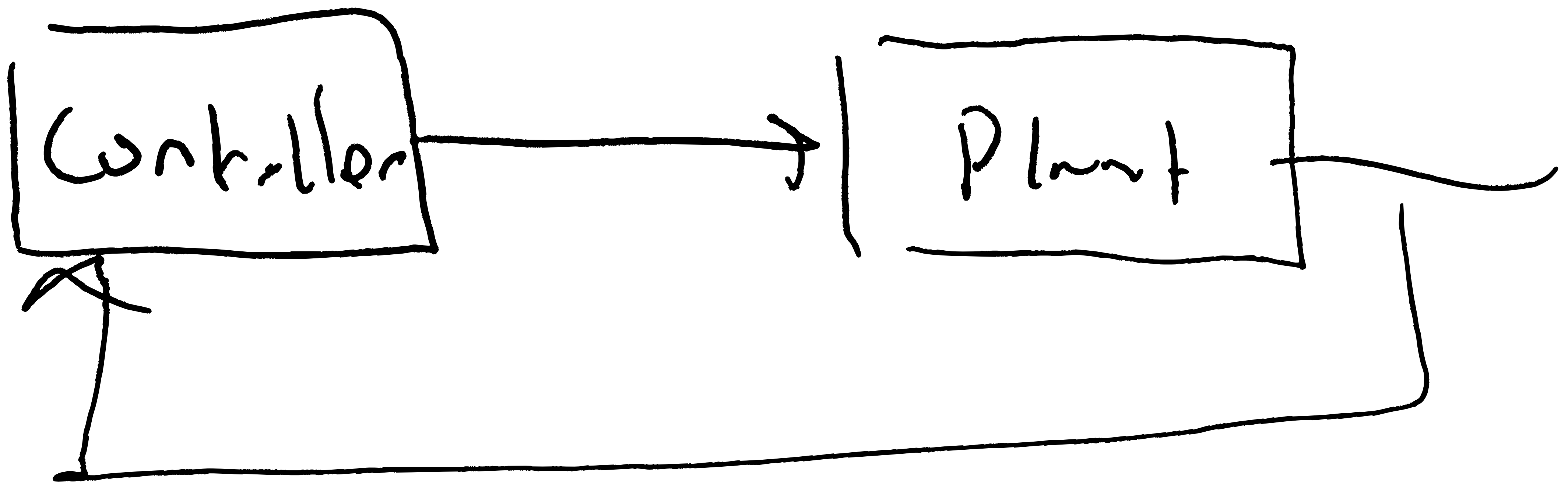
Last time:

- Emitter Degeneration



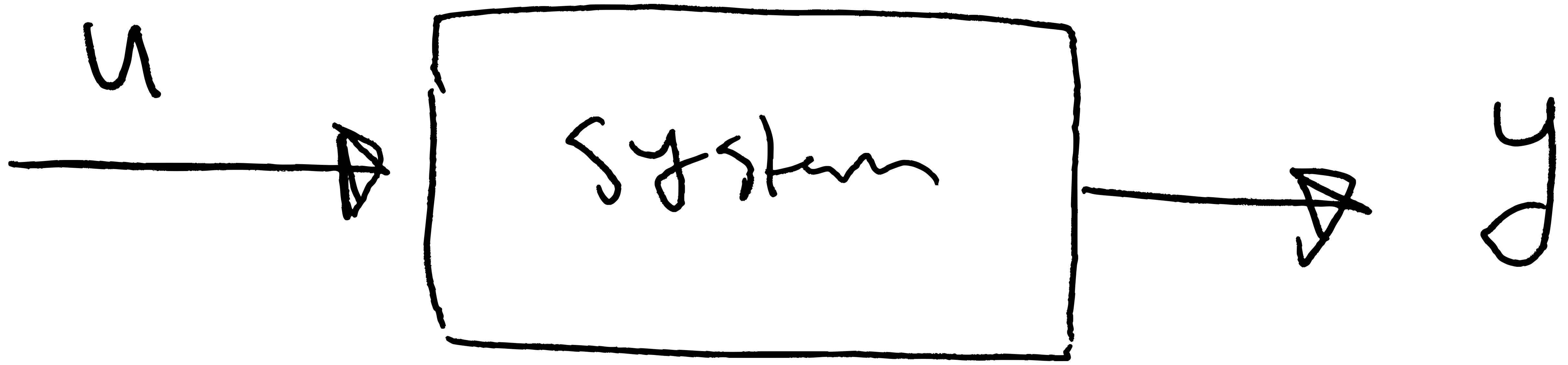
no good

- FET

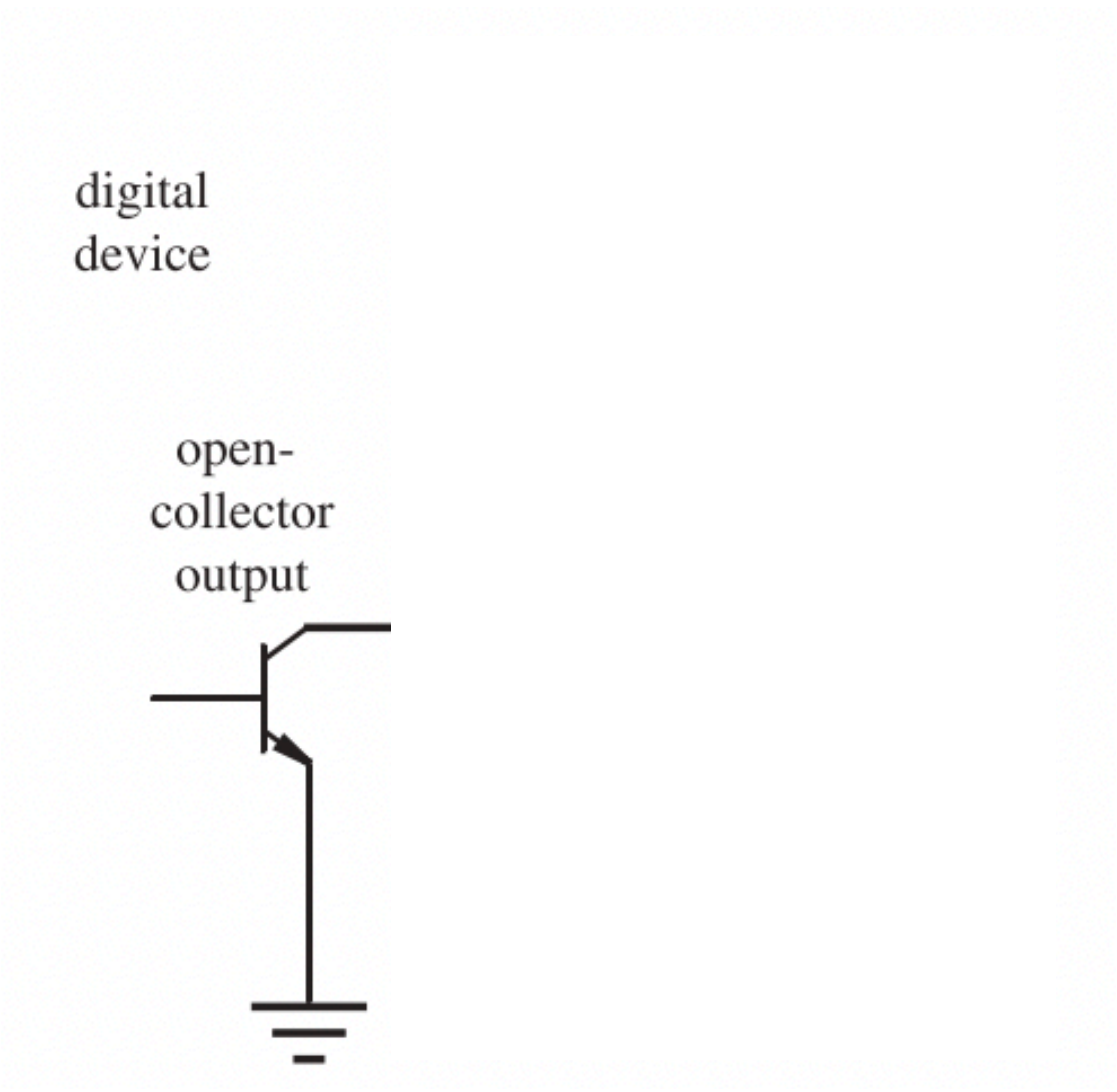


Today:

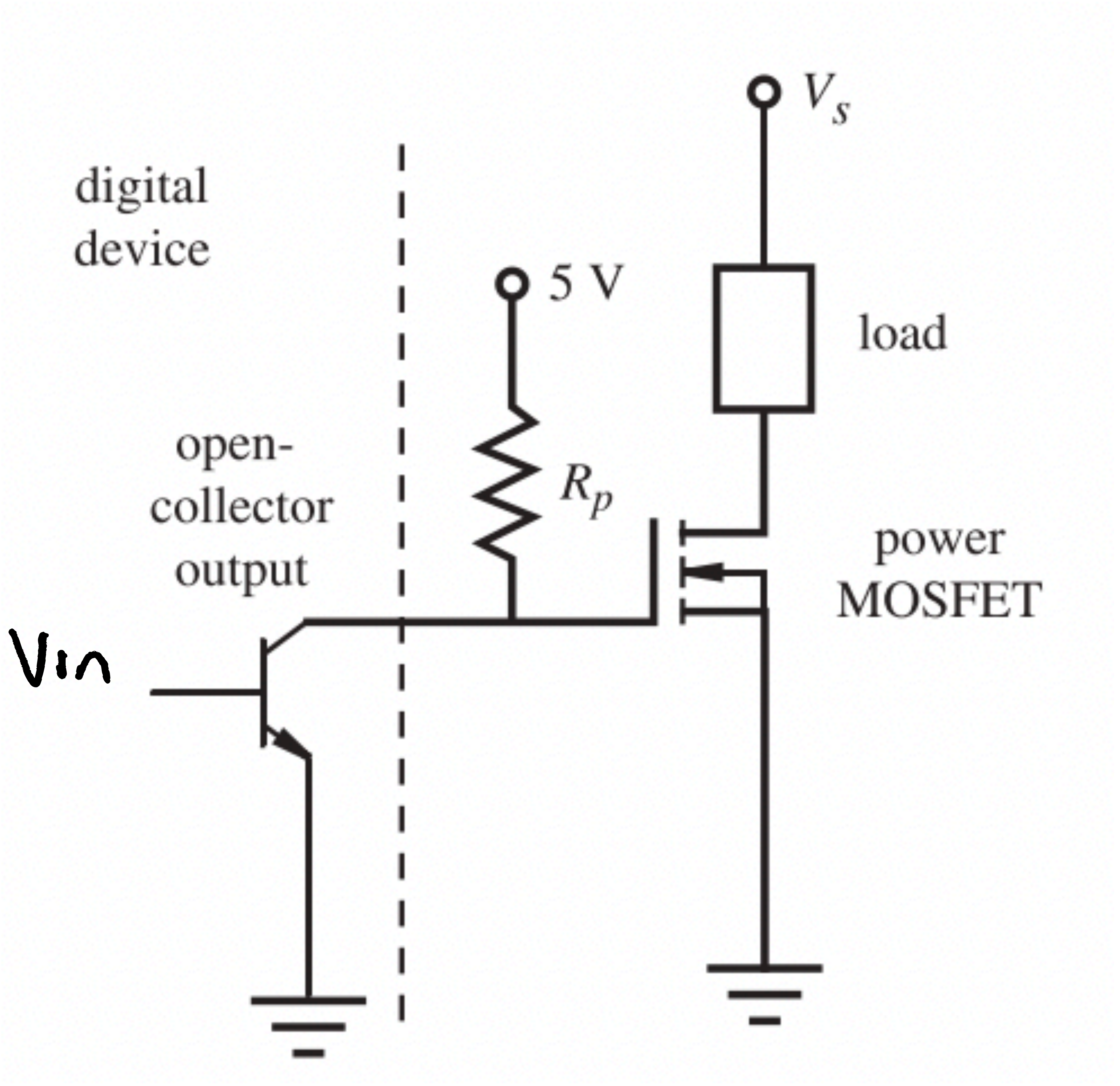
> System Response



Design Example 3.4: pull-up resistors



Design Example 3.4: pull-up resistors



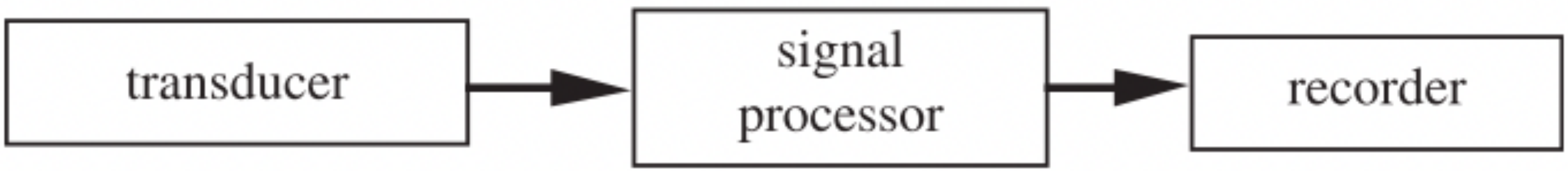
open collector output: npn transistor must be in cutoff or saturation

R_p : pull-up resistor

$V_{in} = 0 \rightarrow$ Mosfet <u>on</u>

$V_{in} = 5 \rightarrow$ Mosfet <u>off</u>

What is a measurement system?



transducer: converts energy from one form to another.

for a measurement system transducer → sensor

convert physical energy to V & current (electrical power)

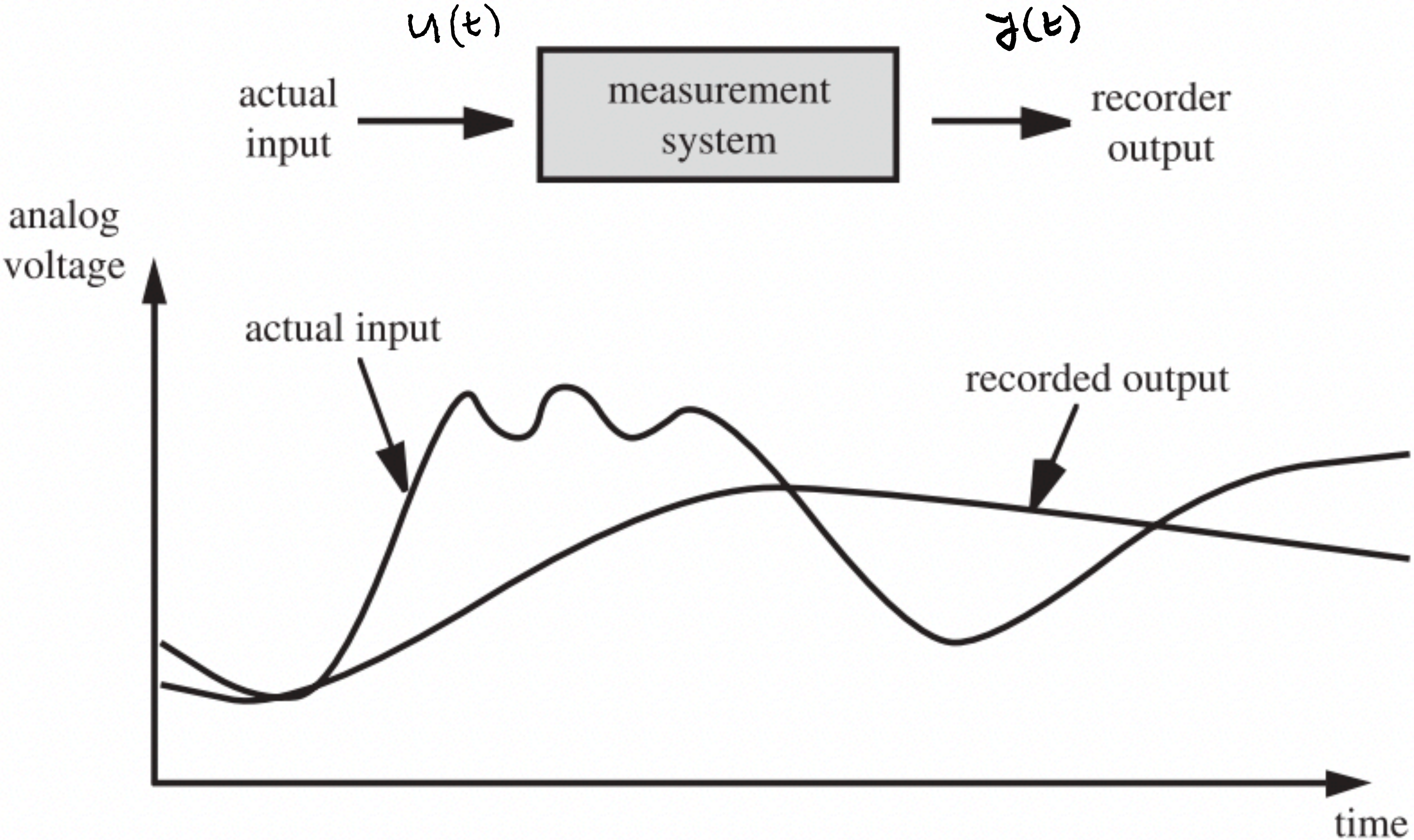
signal processor: "conditions" the signal:

- remove noise (filtering)
- amplify
⋮

recorder: "digitize" data & saves it

measurement system as a canonical example.

$y = Cx$

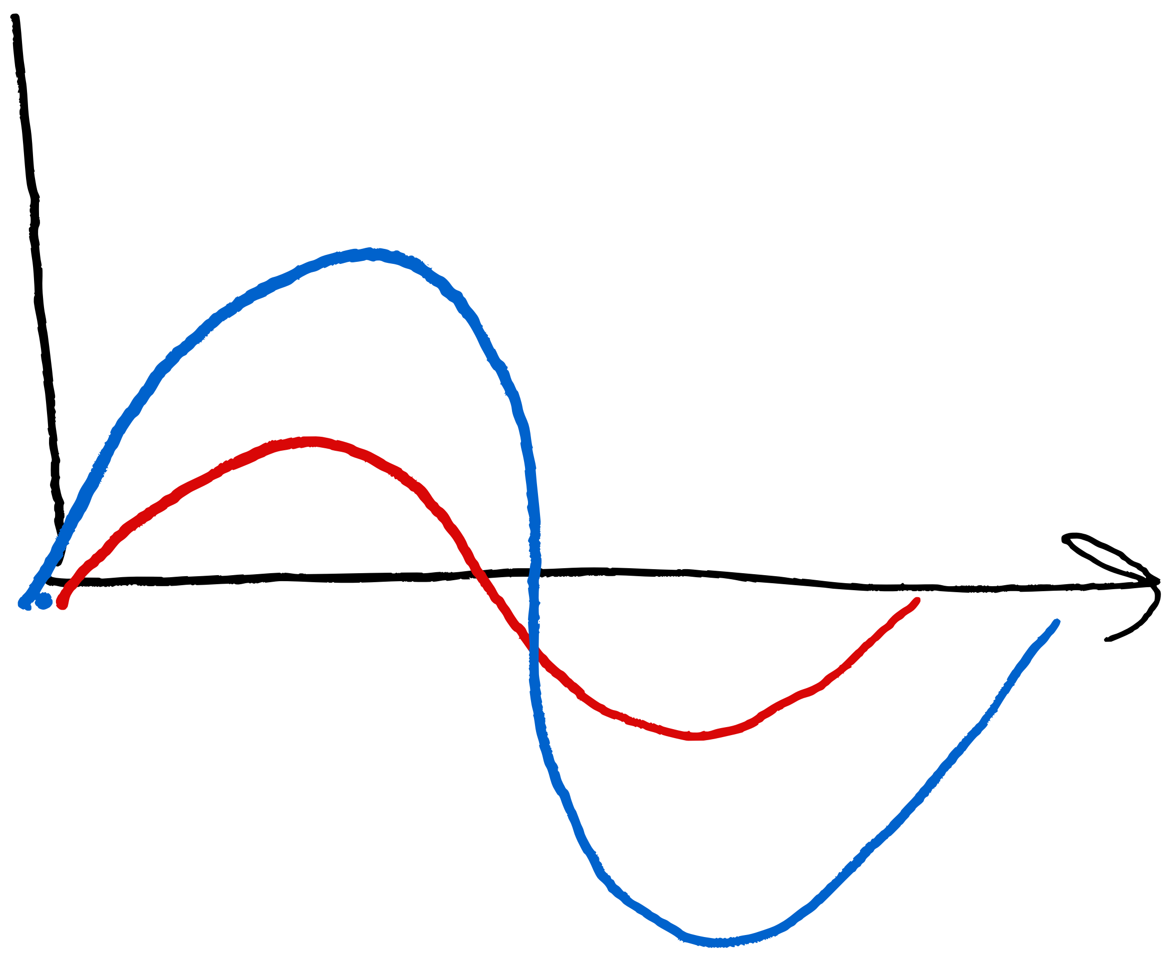

u(t)
y(t)
actual
input
measurement
system
recorder
output
analog
voltage
actual input
recorded output
time

What is a good measurement system?

1. Amplitude linearity
2. Adequate bandwidth

today.

3. Phase linearity



Amplitude linearity

$$f(x) \longrightarrow \begin{cases} f(\alpha \cdot a) = \alpha \cdot f(a) \\ f(a) + f(b) = f(a+b) \end{cases}$$

$$V_{out}(t) - V_{out}(0) = \alpha \left[V_{in}(t) - V_{in}(0) \right]$$

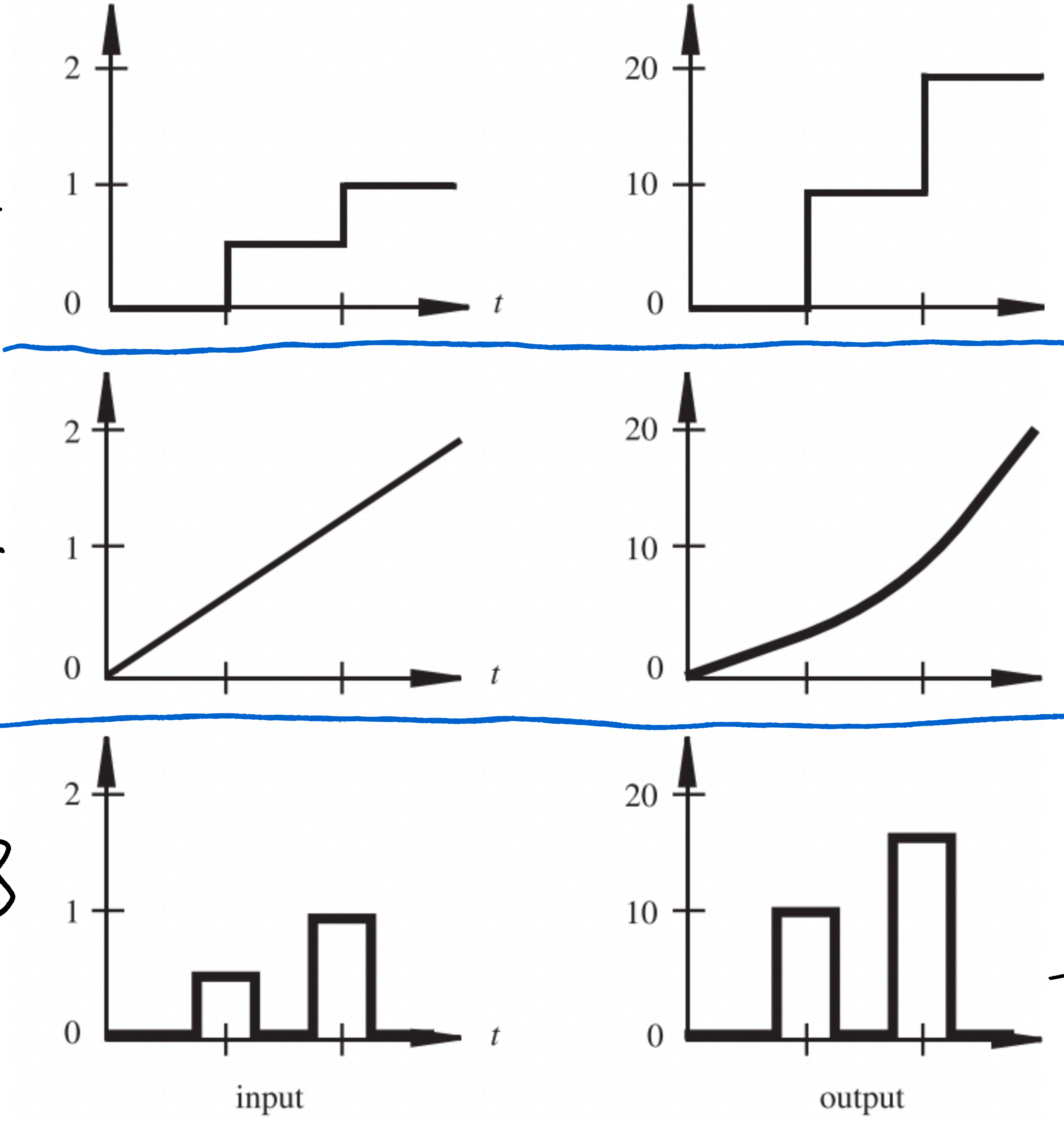
IN OUT

$\alpha = 20$

1

2

3



linear

Which have amplitude linearity?

How to prove?

nonlinear

nonlinear

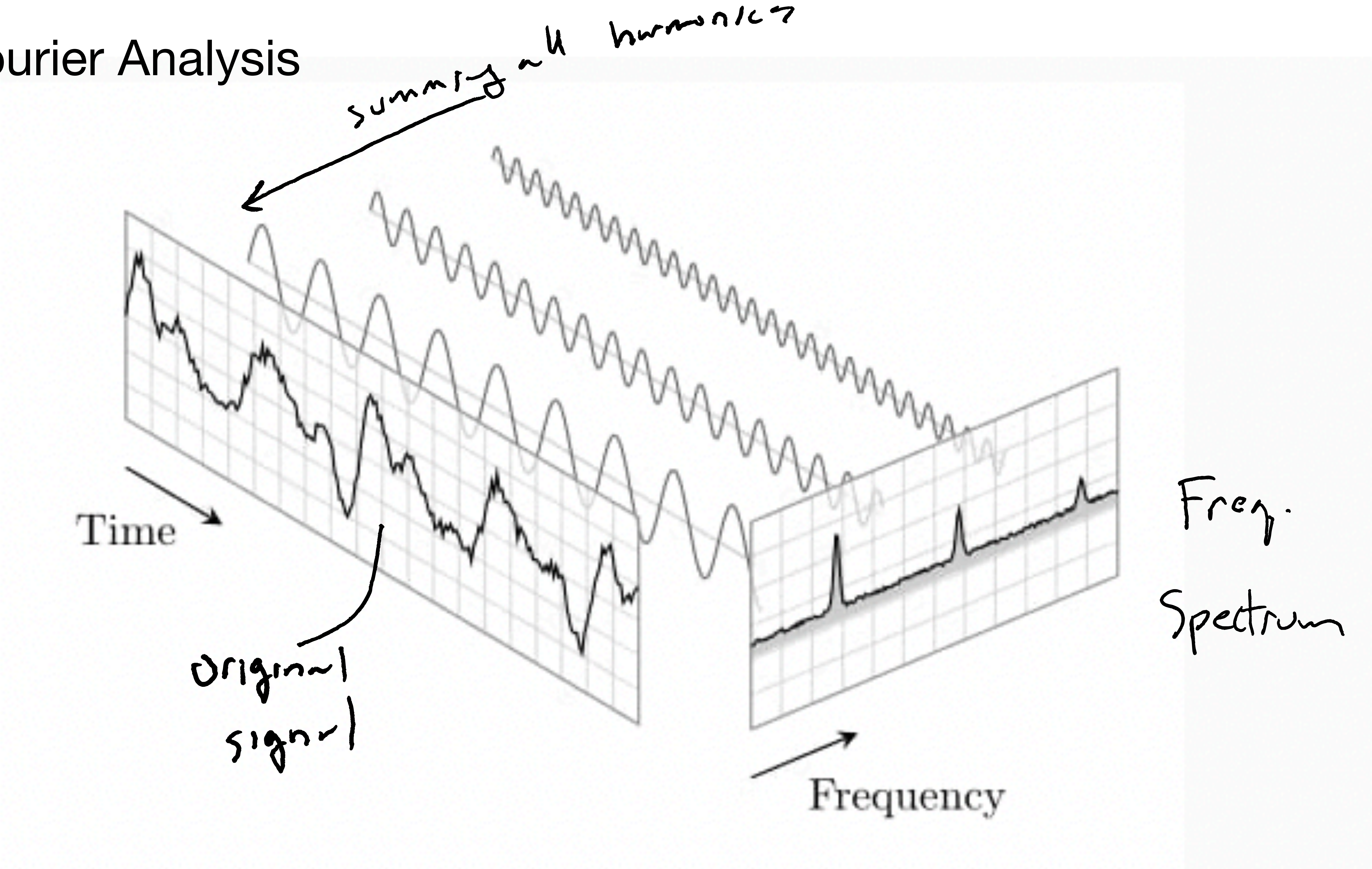
Fourier Analysis

Main idea: Any periodic signal can be represented as an infinite sum of sine & cosine waveforms of different amplitude & freq.

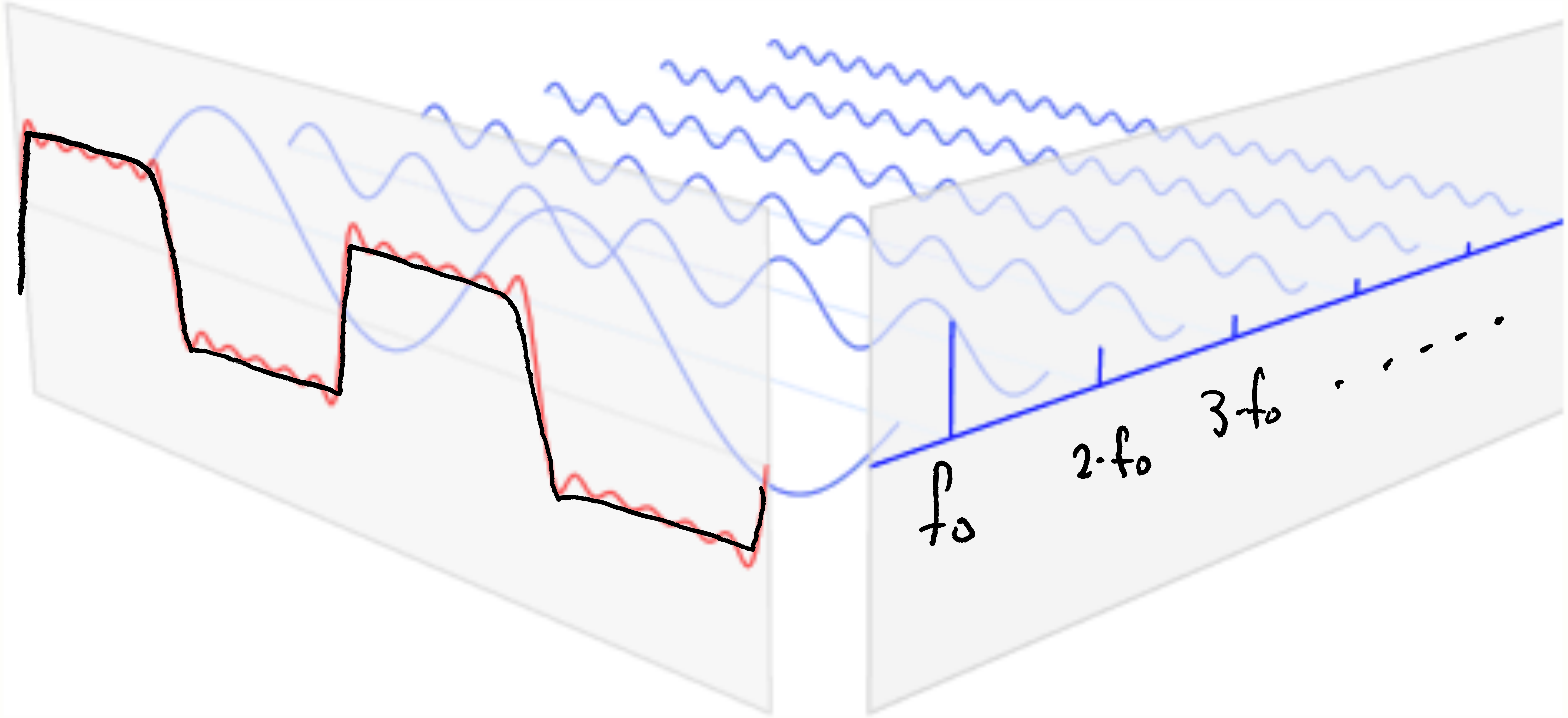
Fundamental Harmonic: $\underbrace{\omega_0}_{rad/s} = \frac{2\pi}{T} = 2\pi \underbrace{f_0}_{Hz}$

all other frequencies in the Fourier representation are integer multiples of ω_0.

Fourier Analysis



Fourier Analysis



Fourier Series Mathematical Representations

$$F(t) = C_0 + \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t) + \sum_{n=1}^{\infty} B_n \sin(n\omega_0 t)$$

$$A_n = \frac{2}{T}\int_0^T f(t)\cos(n\omega_0 t)\,dt$$

$$B_n = \frac{2}{T}\int_0^T f(t)\sin(n\omega_0 t)\,dt$$

$$C_0 = \frac{1}{T}\int_0^T f(t)\,dt = \frac{A_0}{2}$$

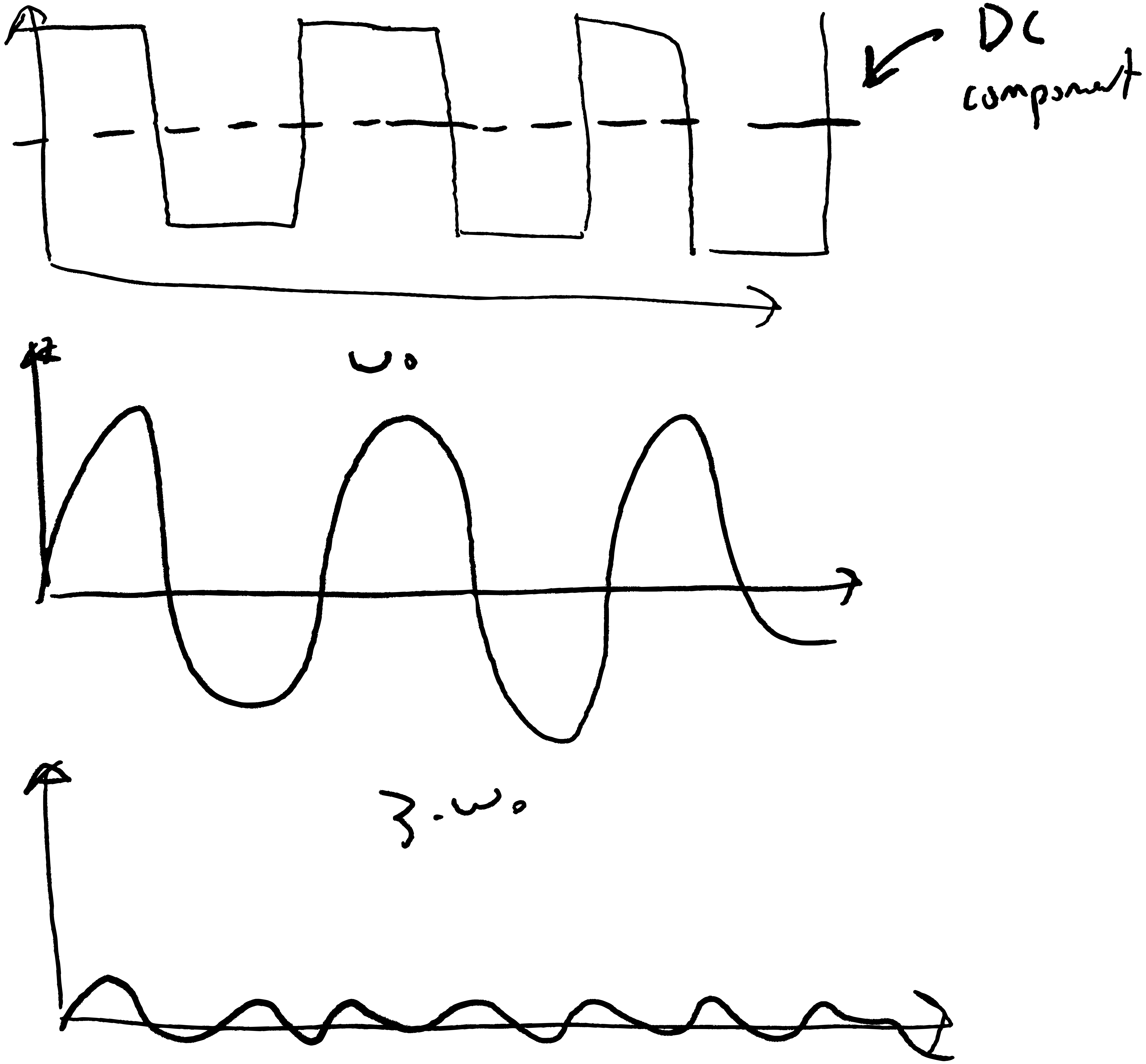
$$F(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t + \phi_n)$$

$$C_n = \sqrt{A_n^2 + B_n^2}$$

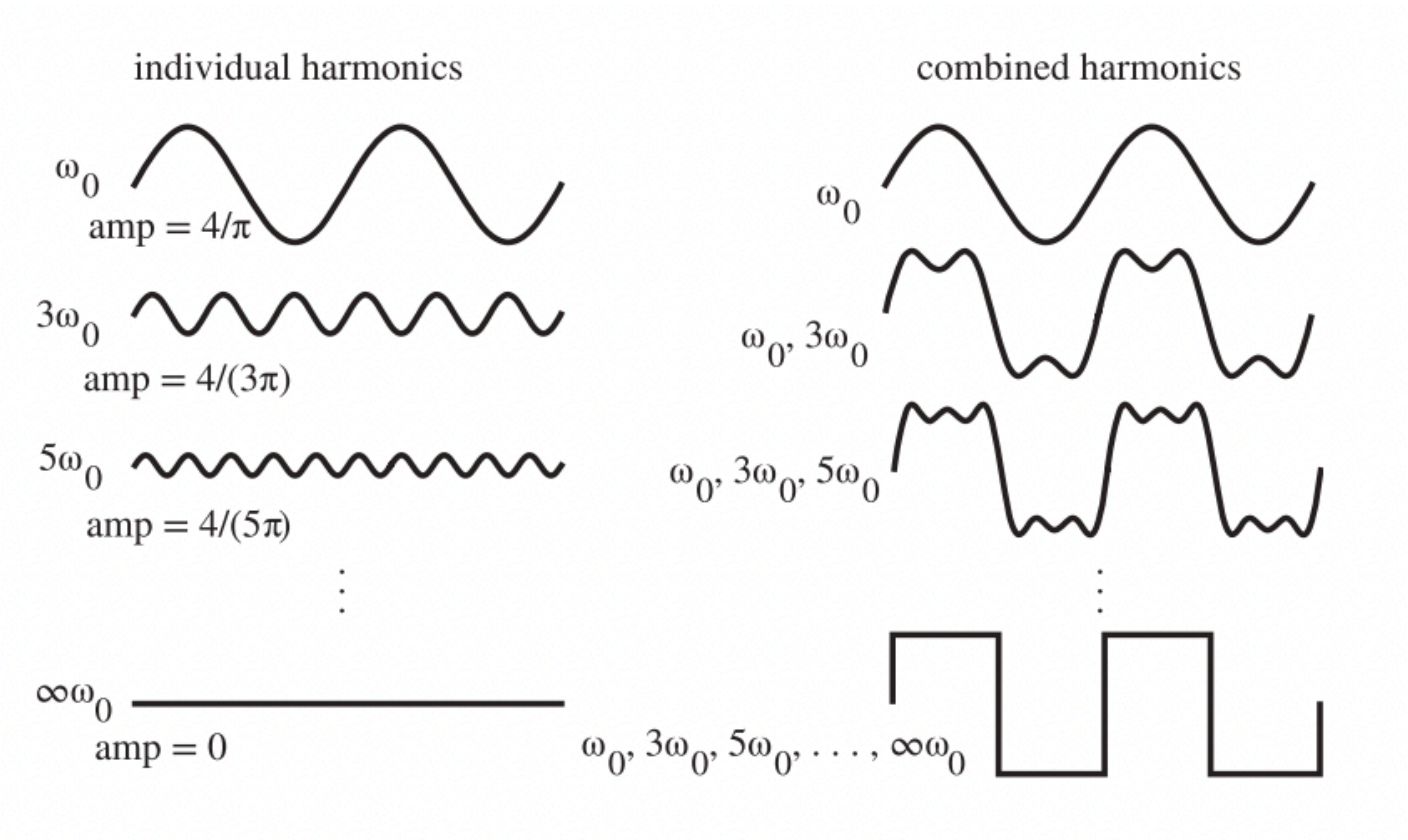
$$\phi_n = -\tan^{-1}\left(\frac{B_n}{A_n}\right)$$

Single amplitude version

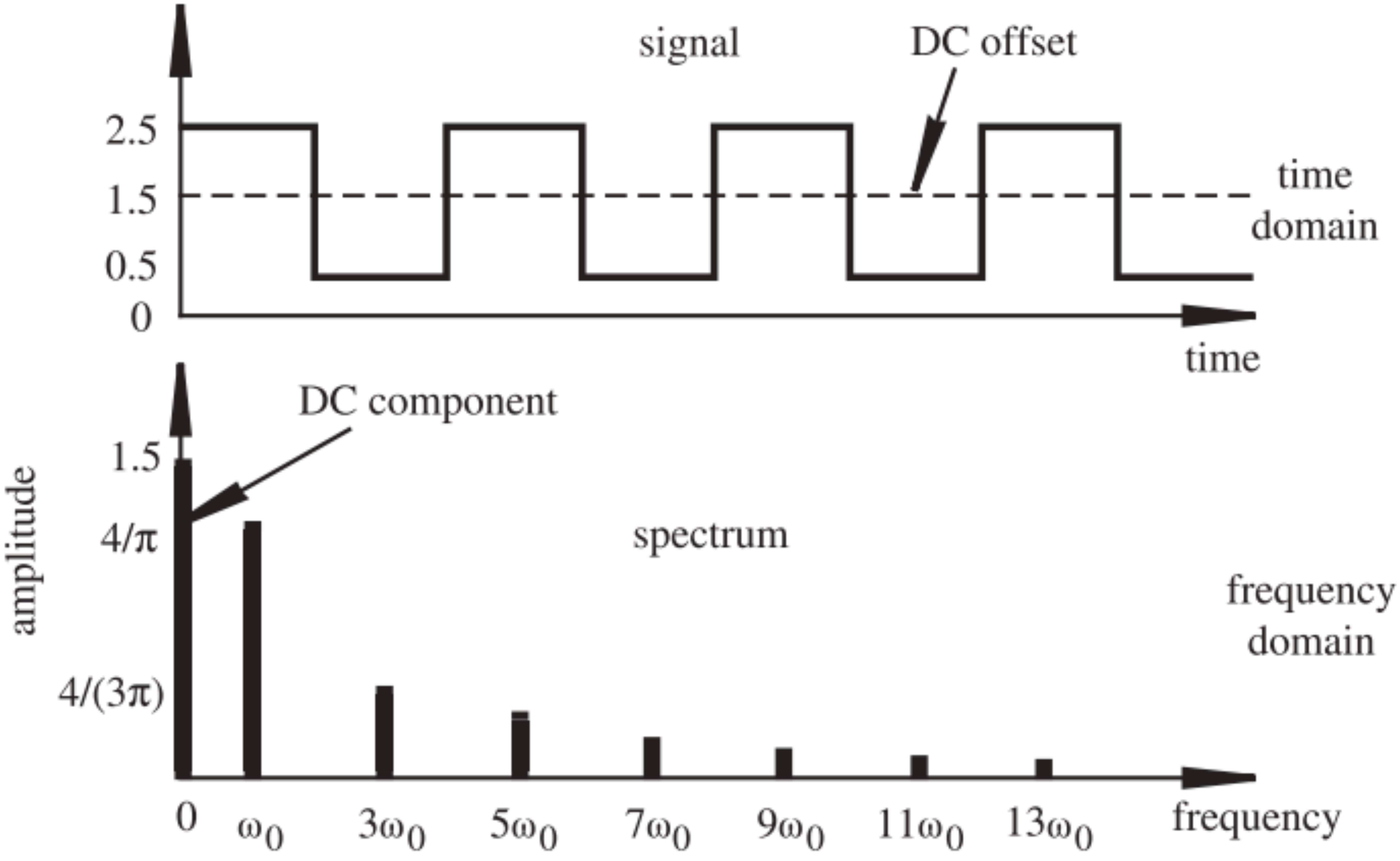
Fourier Series of Square Wave



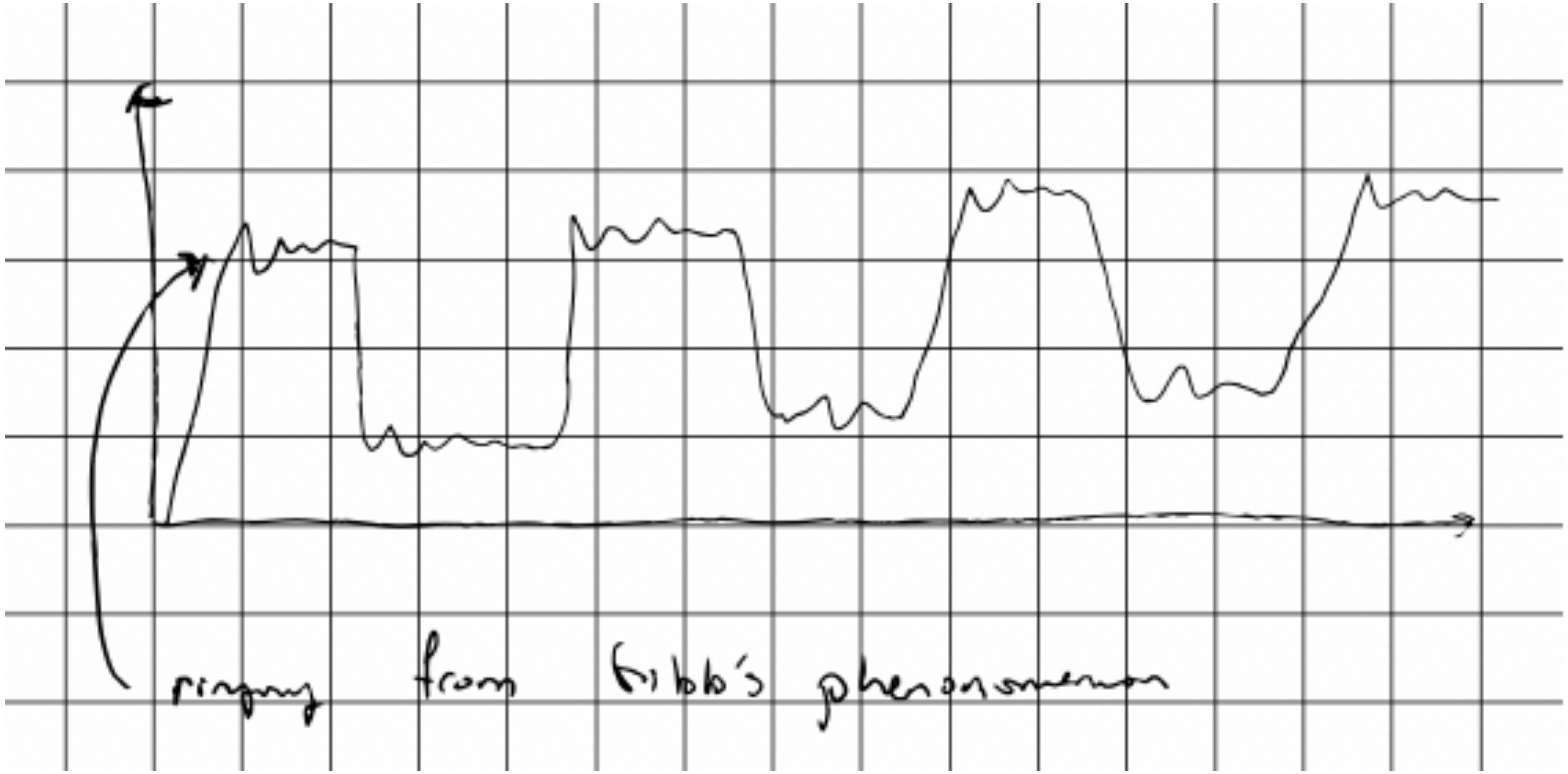
Fourier Series of Square Wave



Fourier Series of Square Wave



Gibbs phenomenon



Square wave is discontinuous — derivative is infinity

video

Bandwidth and Frequency Response

- ideally a measurement system should replicate <u>all</u> frequency components of the input.

how to know?

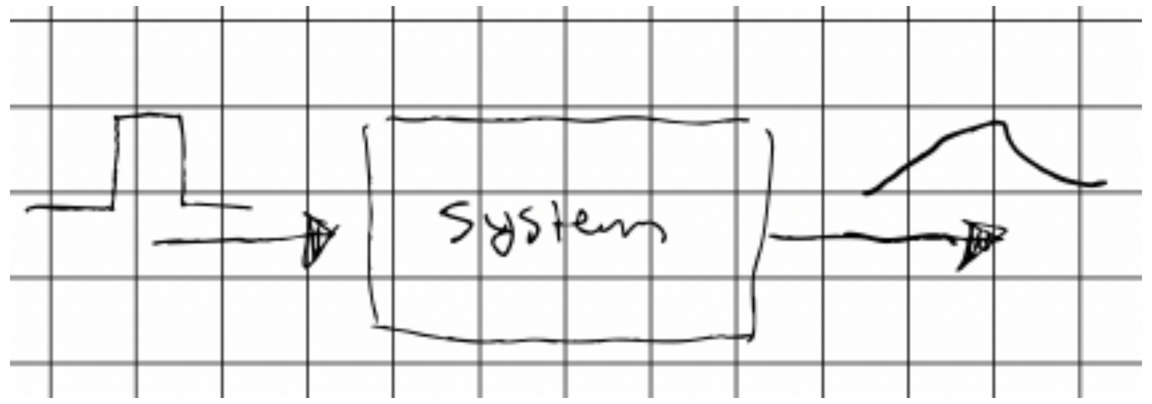
→ Decibels:

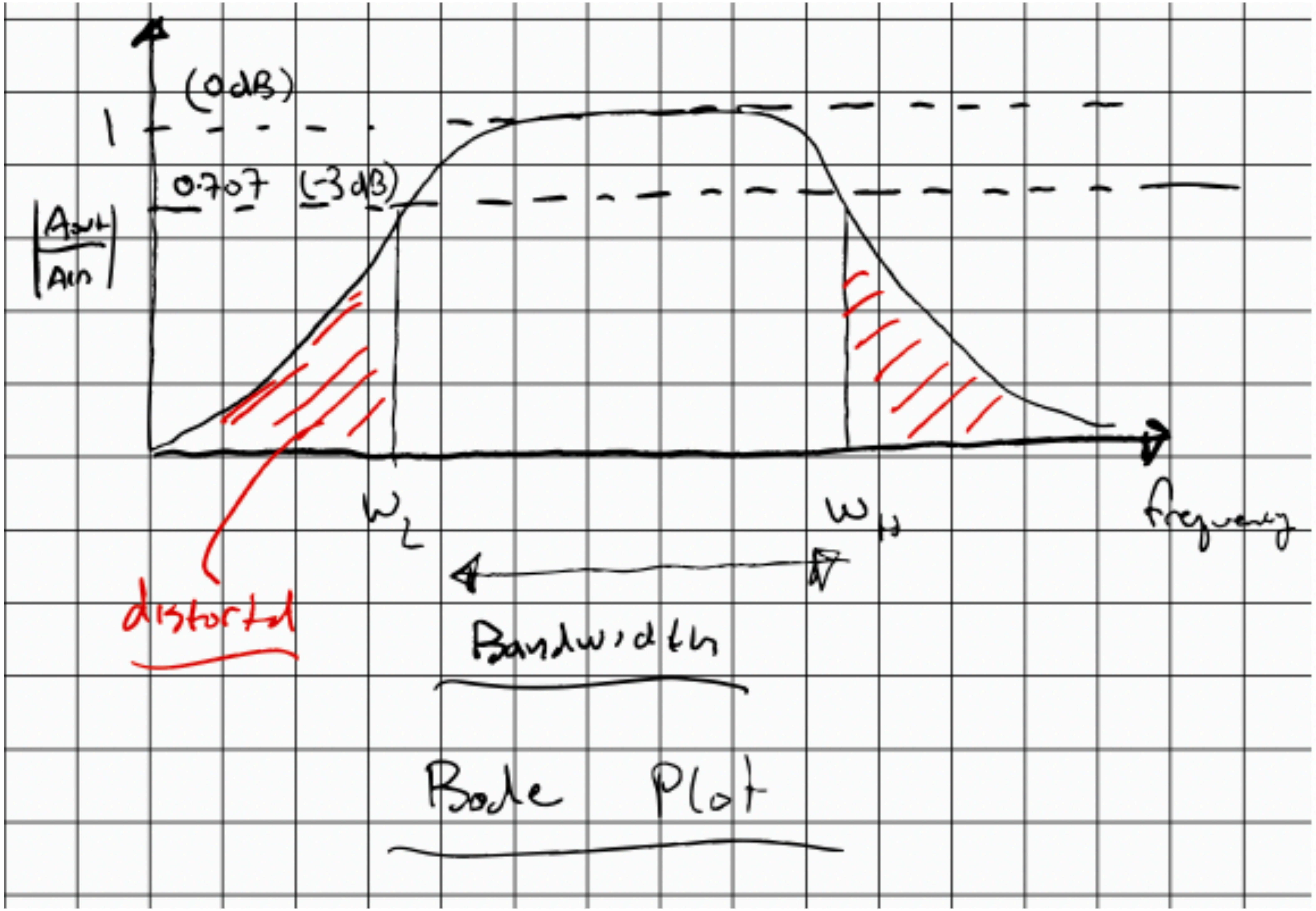
$$dB = 20 \log_{10}\left(\frac{A_{out}}{A_{in}}\right)$$

computed at each frequency!

0	dB	→	$A_{out} = A_{in}$
20	dB	→	$A_{out} = 10 \cdot A_{in}$
40	dB	→	$A_{out} = 100 \cdot A_{in}$
60	dB	→	$A_{out} = 1000 \cdot A_{in}$

Frequency Response Curve





Bandwidth is the range $\omega_L \rightarrow \omega_H$

- Why -3 dB?

"half-power points"

Half power points

$$\frac{P_{out}}{P_{in}} = \frac{1}{2} \rightarrow P = V^2 \cdot R$$

$$\therefore P \sim V^2$$

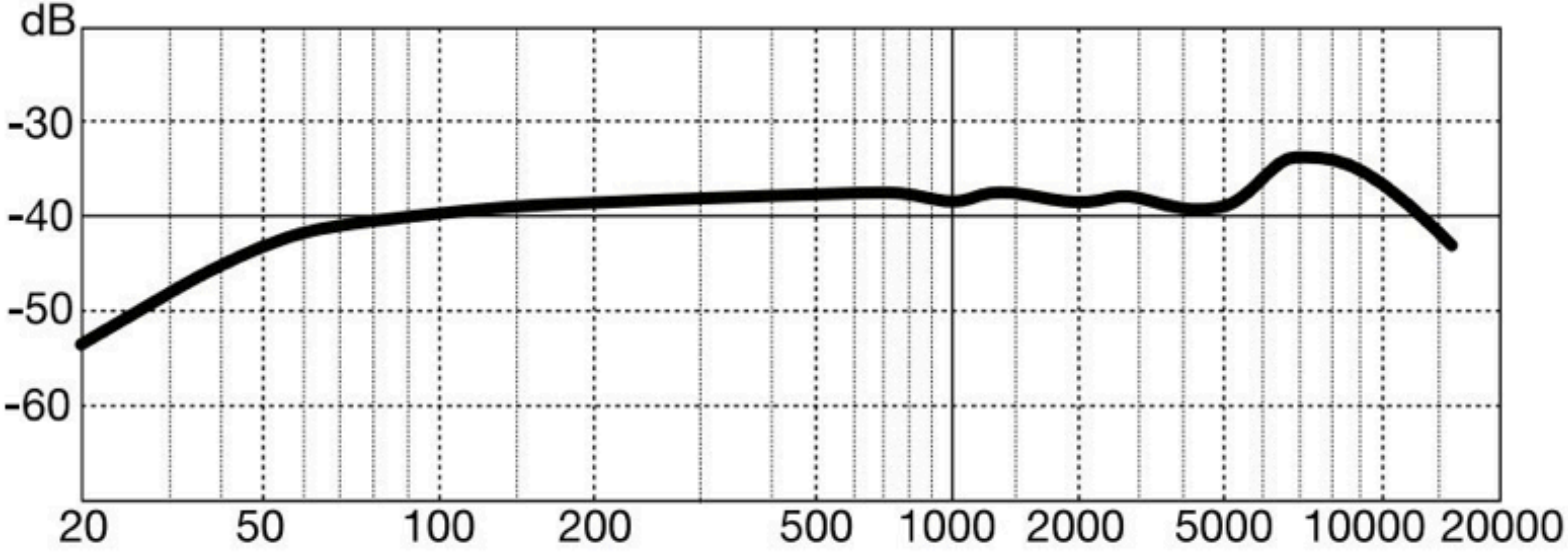
$$\frac{A_{out}}{A_{in}} = \sqrt{\frac{P_{out}}{P_{in}}} = \frac{1}{\sqrt{2}} \approx 0.707$$

$$dB = 20 \log_{10}\left(\frac{1}{\sqrt{2}}\right) \approx -3\,dB$$

ω_L & ω_H → cutoff freq. or corner freq.

large bandwidth → high fidelity

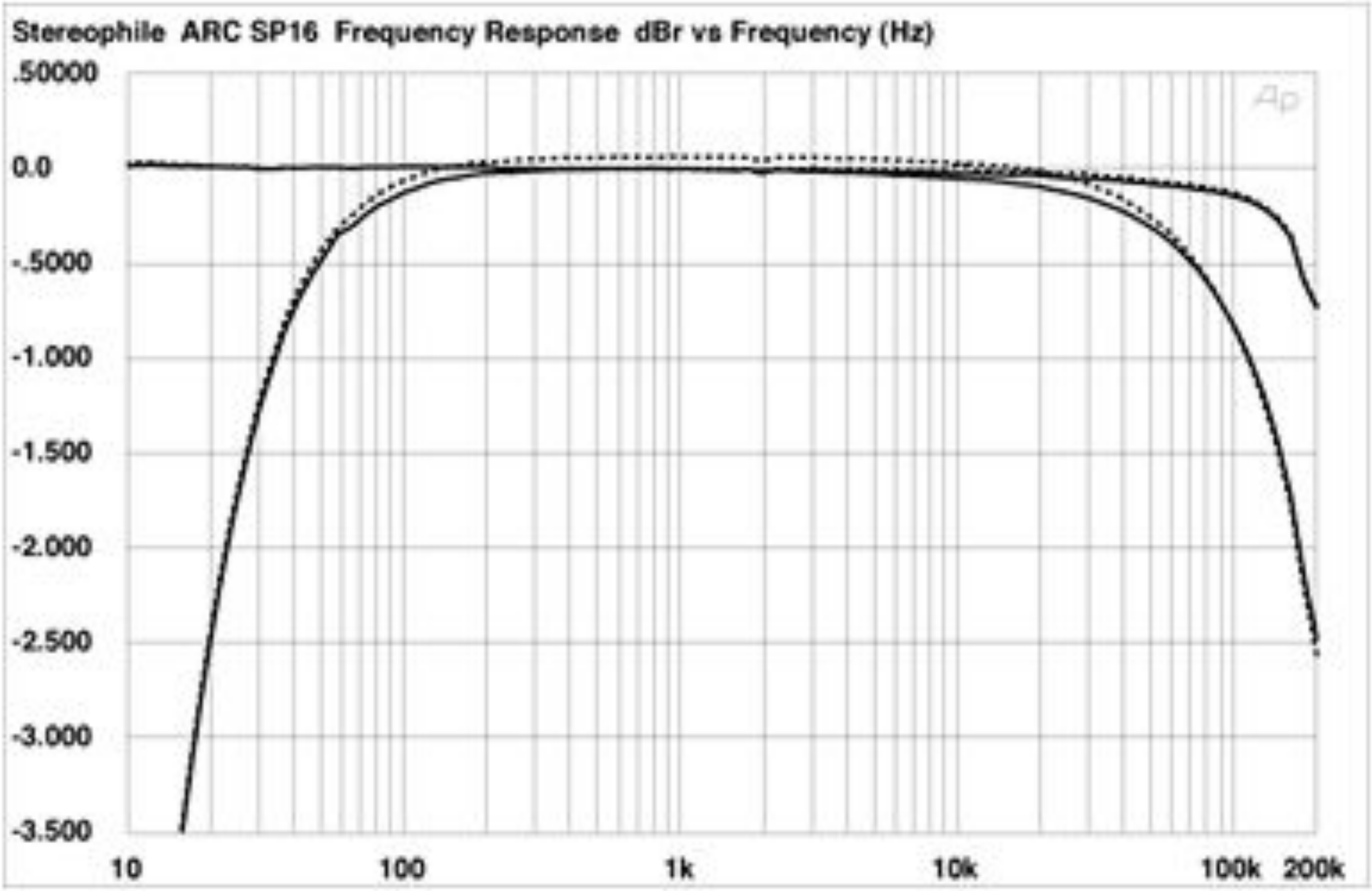
Frequency Response of a microphone



freq.

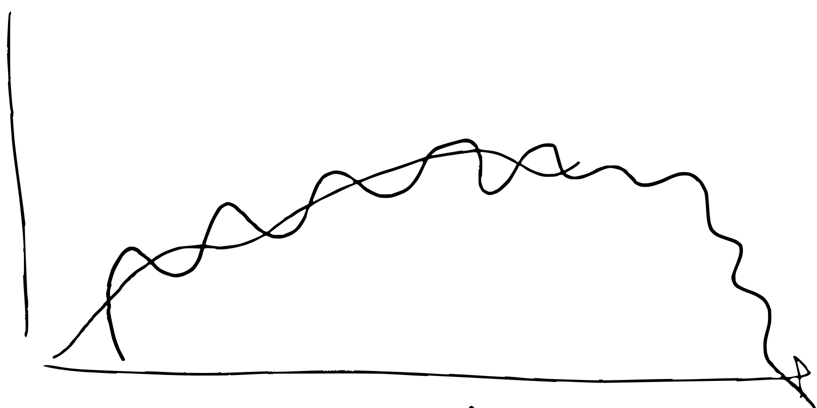
the pressure waves!

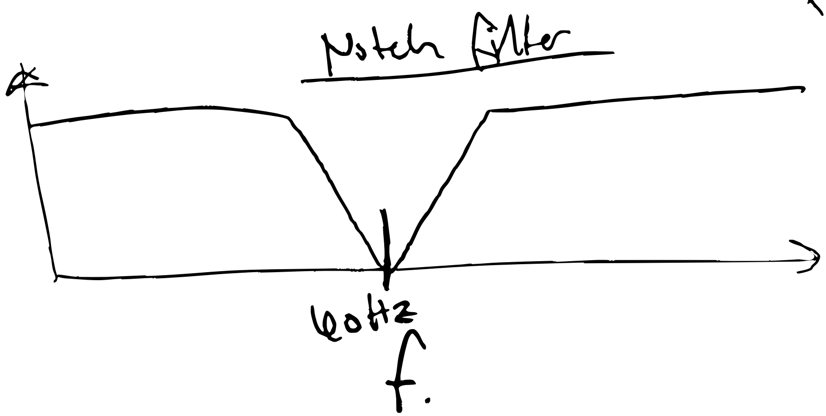
Same Idea Applies to Output devices! High Fidelity Amplifiers



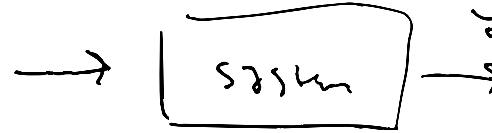
EMG: electromyography

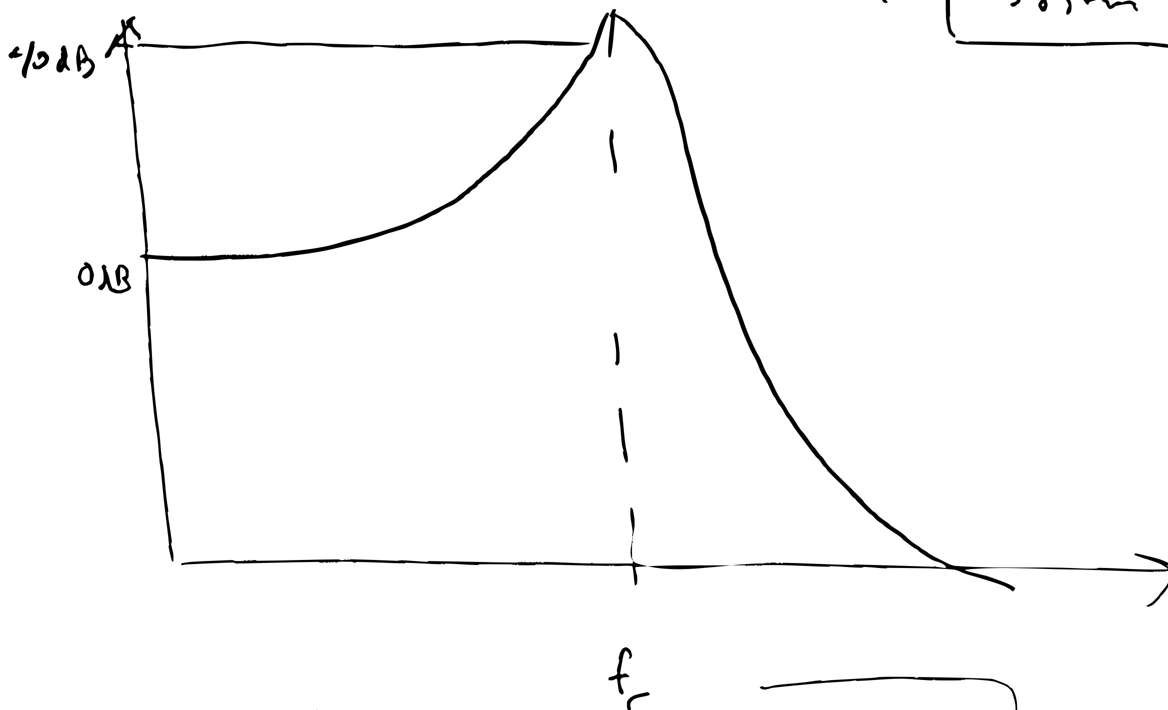
senses muscle voltage μV

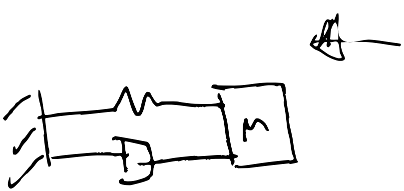


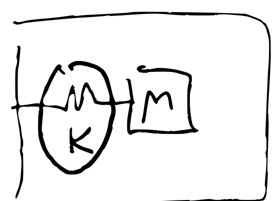


u @ f_r

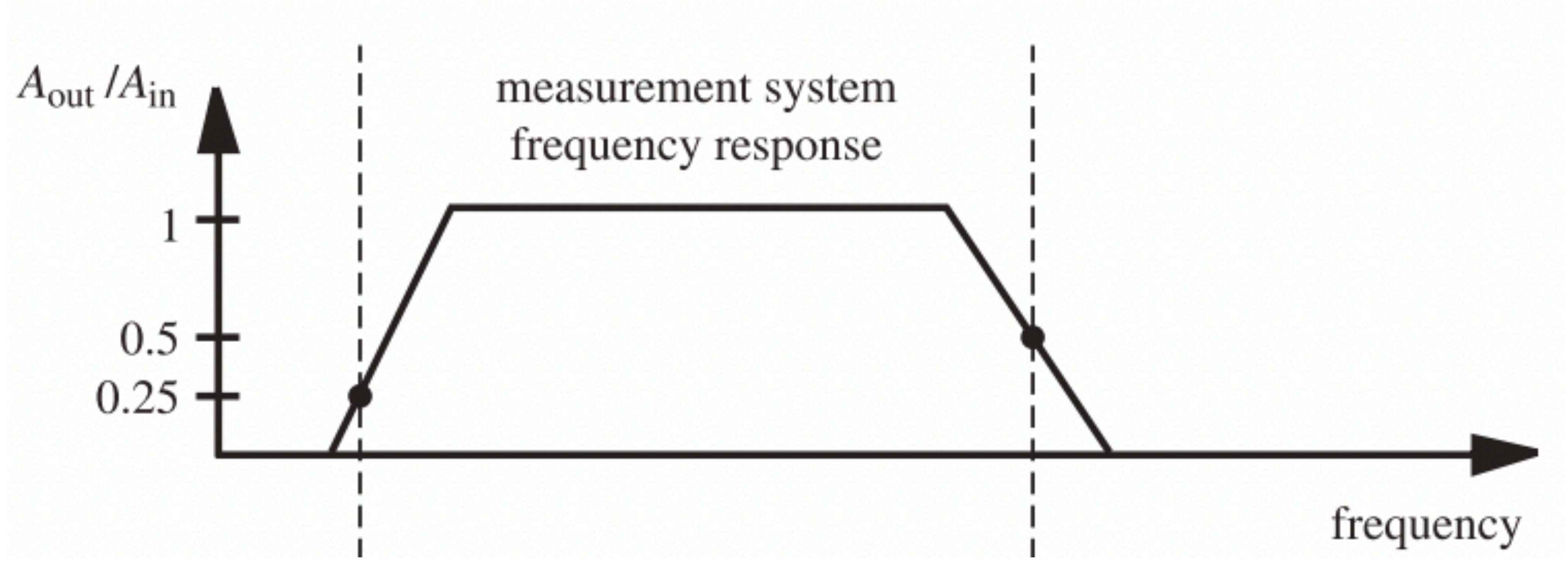






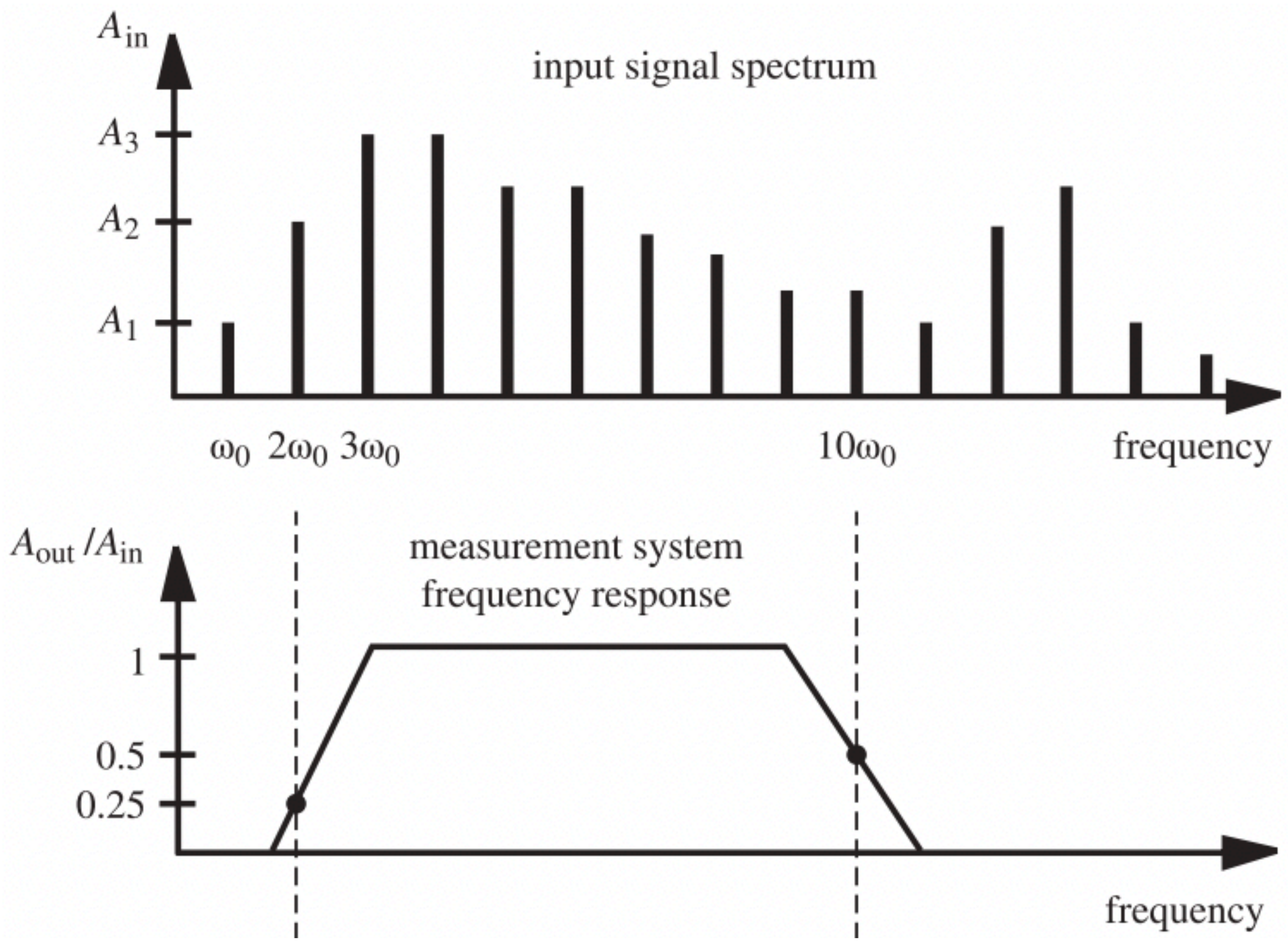


If you know the FR of your device & you know the Frequency content of your input signal, you can predict the output:



Known

If you know the FR of your device & you know the Frequency content of your input signal, you can predict the output:



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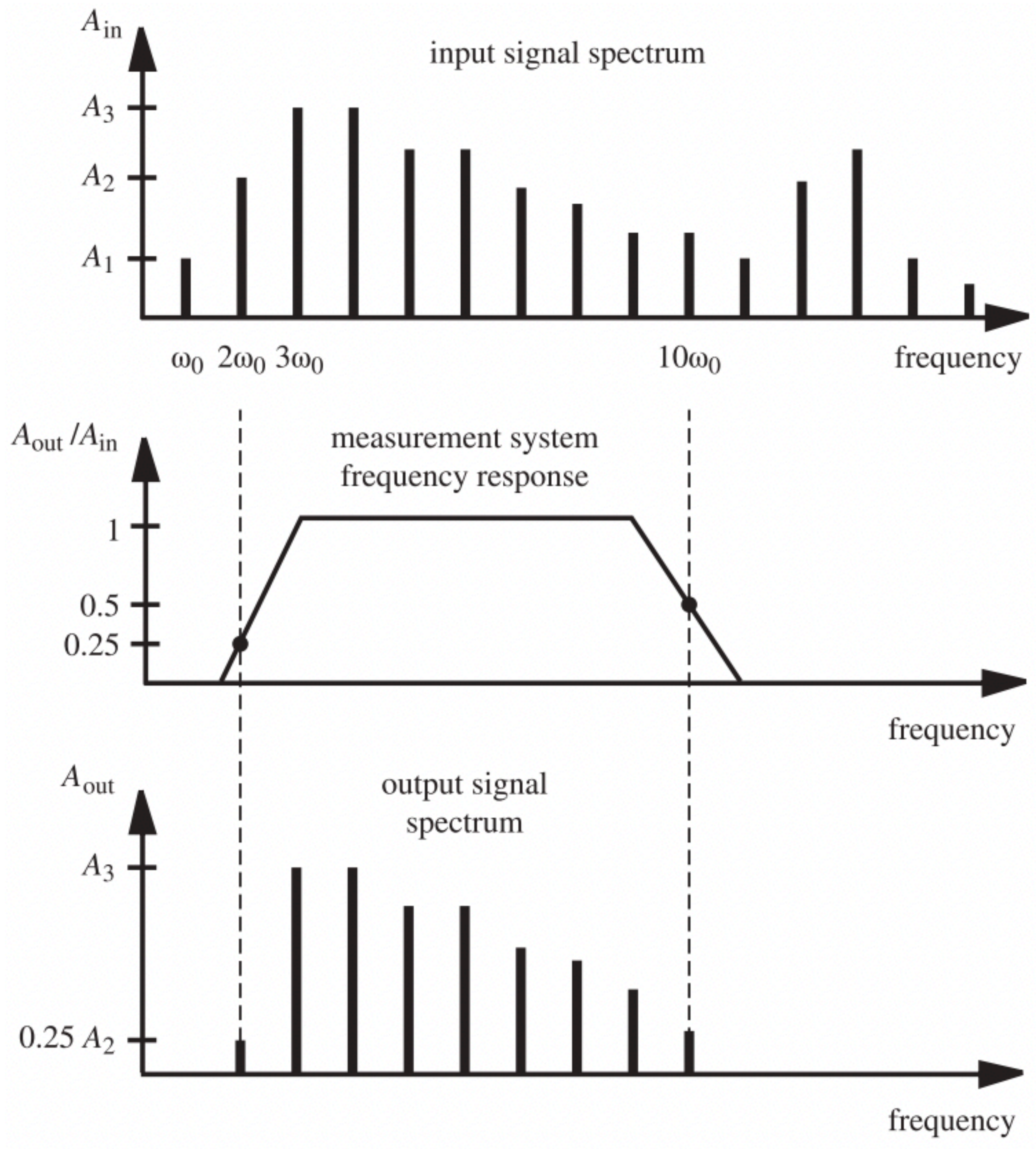

How to find?

How to find bandwidth?

Field: System Identification

> send pure sine waves in
measure output

ω	A_{in}	A_{out}	A_{out}/A_{in}

> Gaussian noise
$\longrightarrow$ full spectrum

Example: Bandwidth of a lowpass filter

Example: Bandwidth of a lowpass filter

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