VE 216 Signals & Systems

Lab Introduction

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Note: lab intro revised from slides by previous TAs

Outline

- Policy
- Lab content
  - Lab one
  - Lab two
  - Lab three
- Q & A

General Policy: TBD

- Online (use Pretuos software) vs. Offline
- Individual vs. Group
- Time Arrangement

Grading Policy

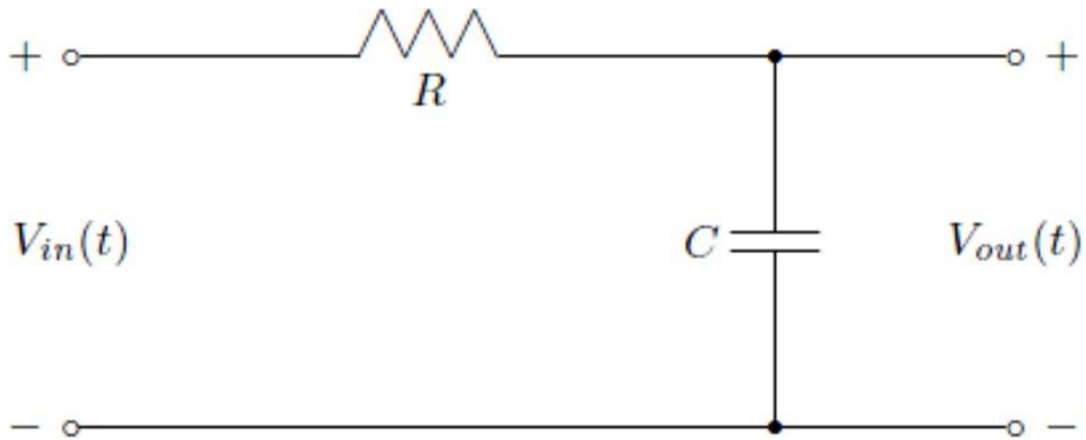
- Labs will take 15% of overall grading
  - 5% for each lab
    - 3% depends on your in-lab performance
      - Attendance
      - Finish the experiment process (follow Lab Manual)
    - 2% depends on your pre/post lab report
- All detailed experiment procedural instructions are to be posted

Grading Policy

- Contents to be included in your pre-lab report
  - Solutions for (possibly) selected pre-lab exercises
- Contents to be included in your post lab report
  - Objectives
  - Theoretical background
  - Experiment procedures
  - Results (Figures)
  - Error analysis (Comparison with theoretical results)
  - Conclusion
  - No need to be so comprehensive as that in VP141/241

Lab 1 Content

- Lab One
- RC circuit
  - Step response
  - Pulse response
  - Ramp response
  - Sine response

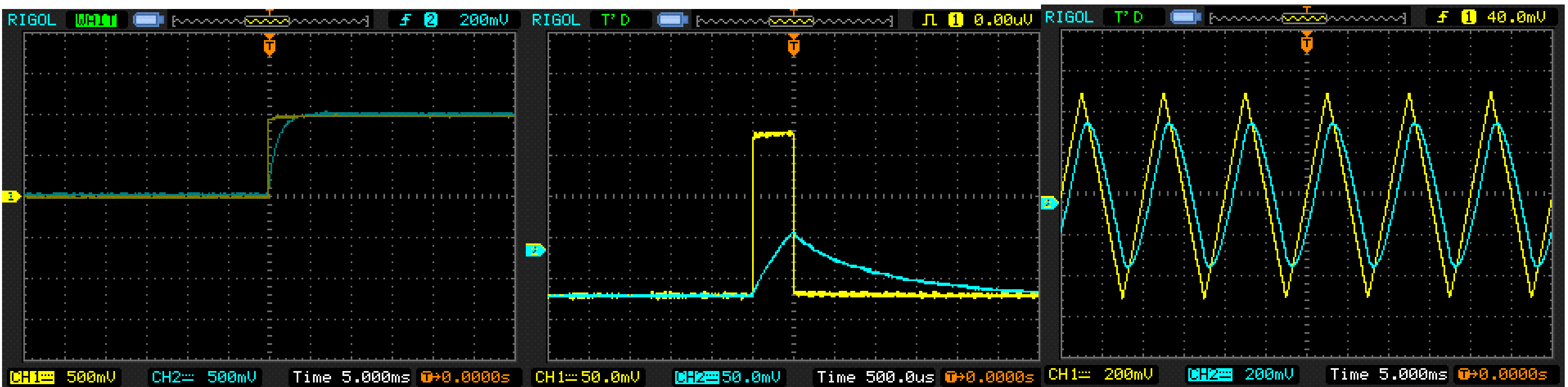


$$RC\frac{dV_{out}(t)}{dt} + V_{out}(t) = V_{in}(t).$$

$$V_{out}(t) = V_0 e^{-t/RC} + \int_0^t \frac{1}{RC} e^{-(t-\tau)/RC} V_{in}(\tau) d\tau, \quad t \geq 0,$$

Lab one

- Step response $$y_{\text{step}}(t) = \left(1 - e^{-t/RC}\right) u(t)$$
- Impulse response $$h(t) = \frac{1}{RC} e^{-t/RC}$$
- Ramp response



Lab 2 Content

- Lab Two: AM Radio
  - Will work on the **receiver part**
  - Overview:

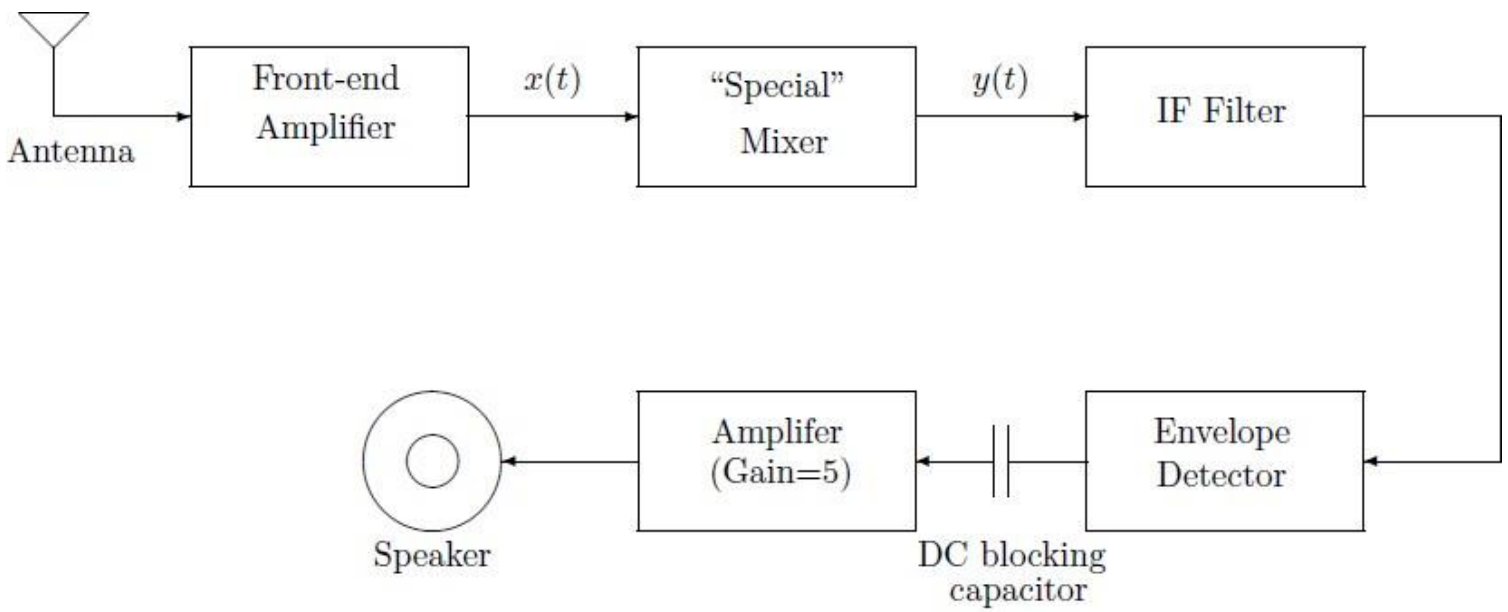


Figure 3.5.1: AM Radio With "Special" Mixer

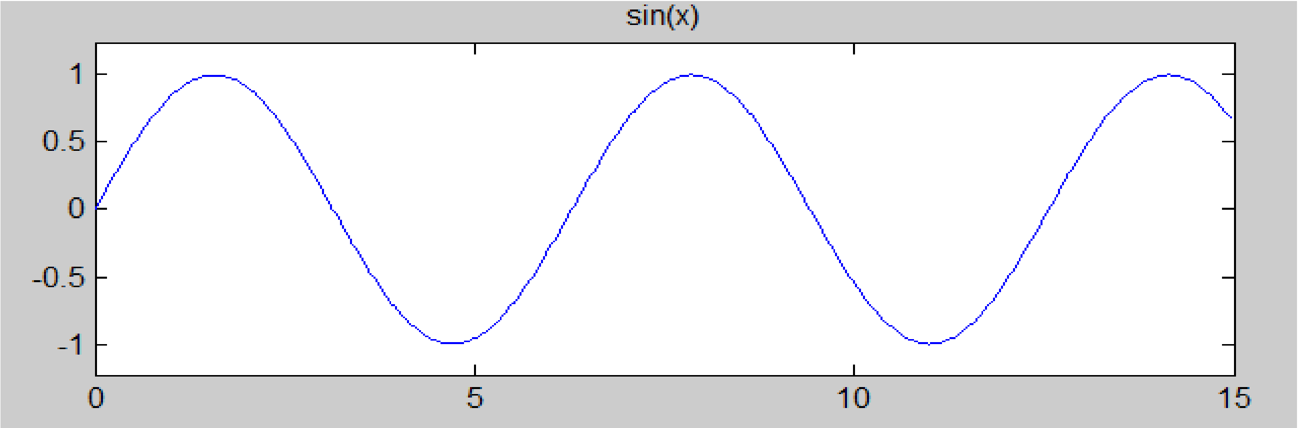
Image from UM PreLab 3

Unfortunately…

- Antenna is not available…
- Thus no use for Front-end Resonator, Mixer and IF Filter (only be discussed in your PreLabs).
- We will realize the **Envelope Detector and** the **Amplifier**.

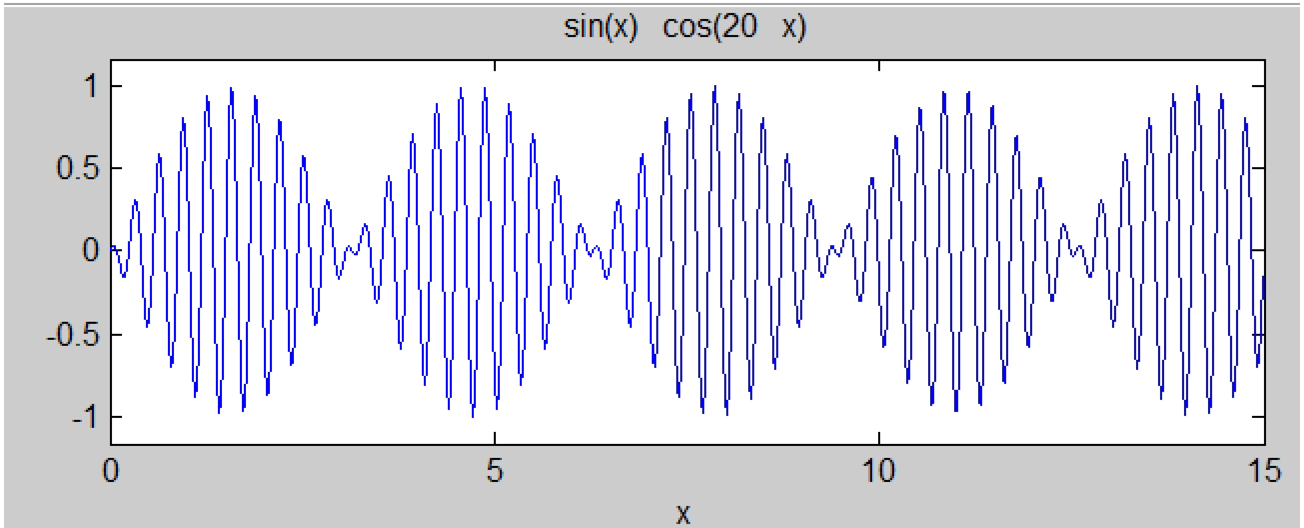
AM: Time-domain Illustration

- $x(t)$:



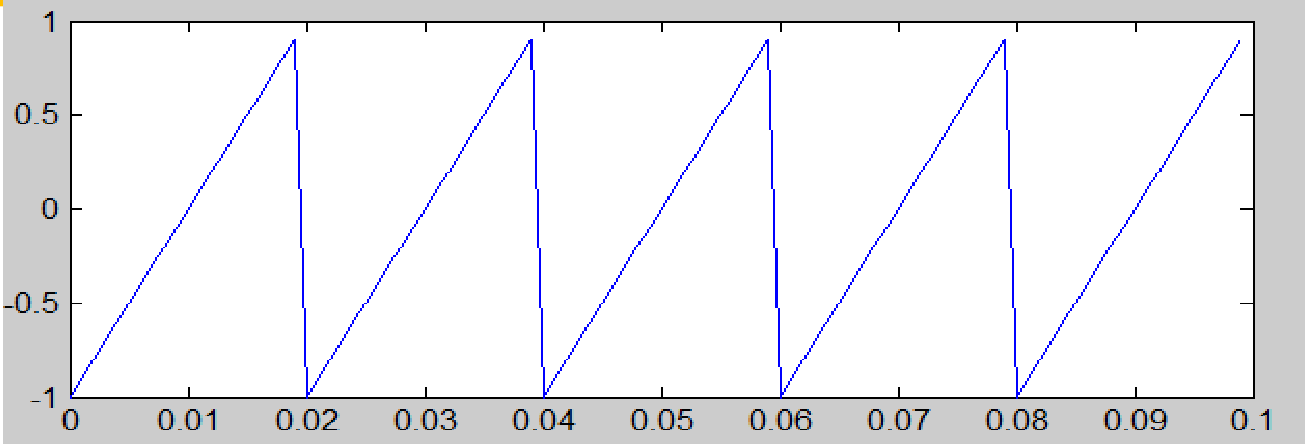
- $x(t)\cos(\omega_c t)$:

Freq. seems higher!



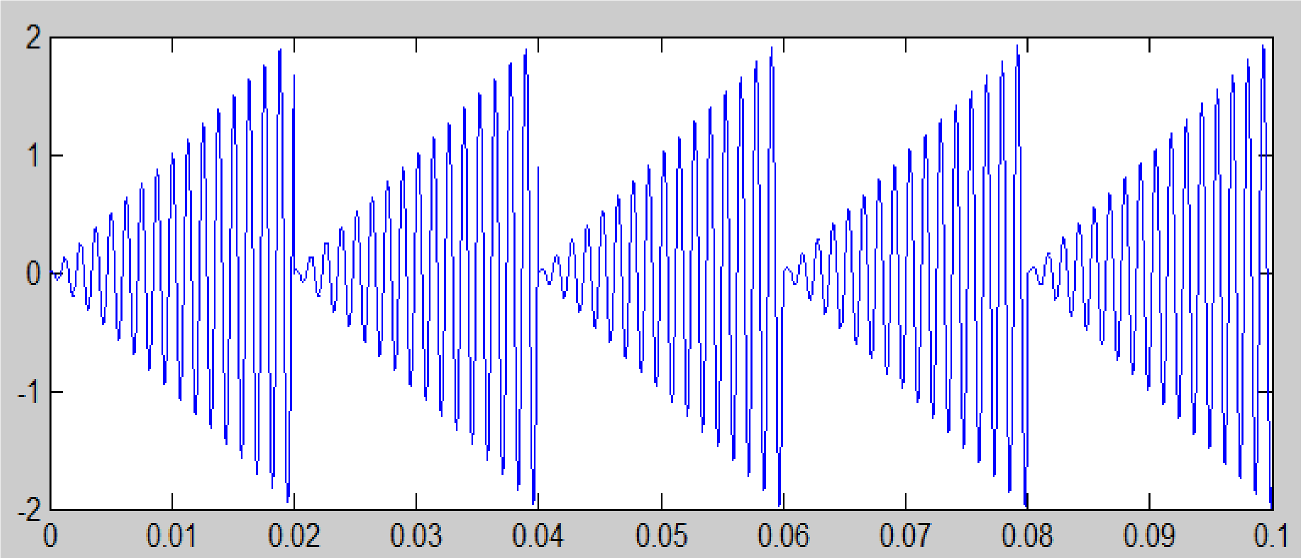
Time-domain Illustration

- $x(t)$:



- $x(t)\cos(\omega_c t)$:

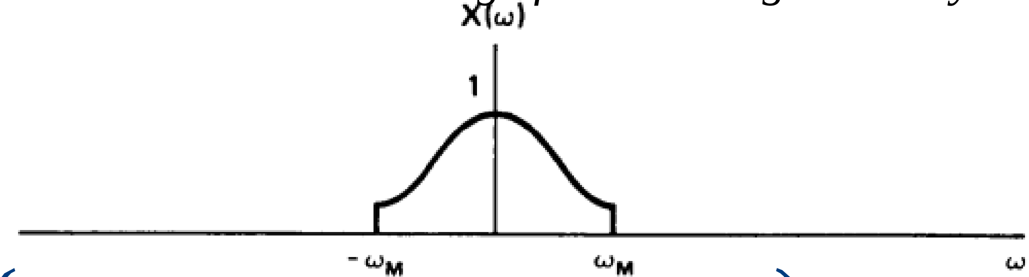
Freq. seems higher!



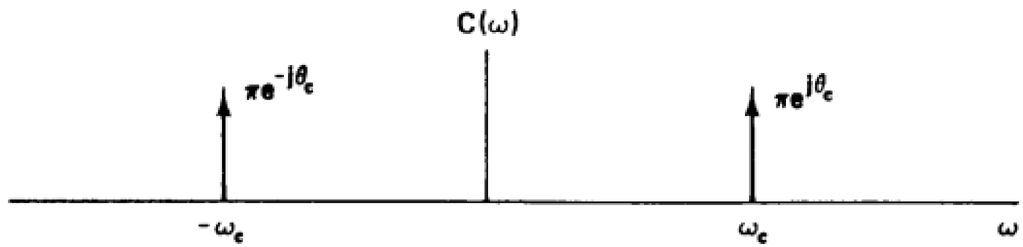
Frequency-domain Illustration

Image from MIT Signals & Systems Lectures

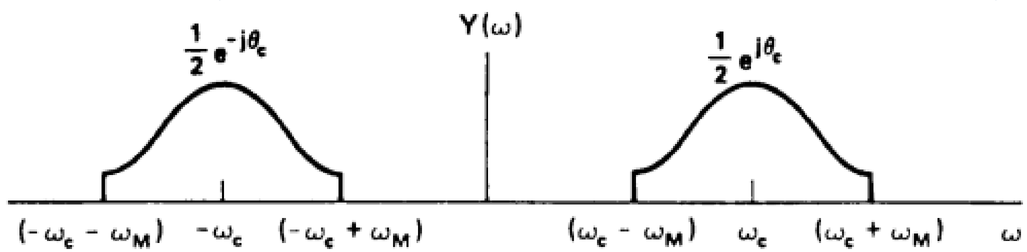
$$x(t) \leftrightarrow X(\omega)$$



$$\cos(\omega_c t) \text{ — } \pi\big(\delta(\omega-\omega_c)+\delta(\omega+\omega_c)\big)$$



$$x(t)\cos(\omega_c t) \text{ — } 0.5\,\big(X(\omega-\omega_c)+X(\omega+\omega_c)\big)$$



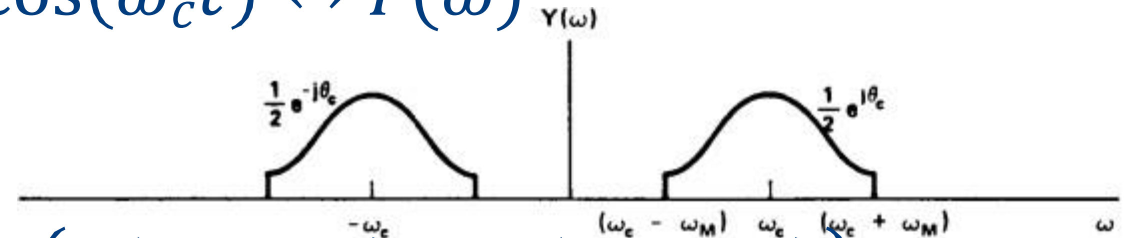
- The frequency band has been shifted!

Demodulation

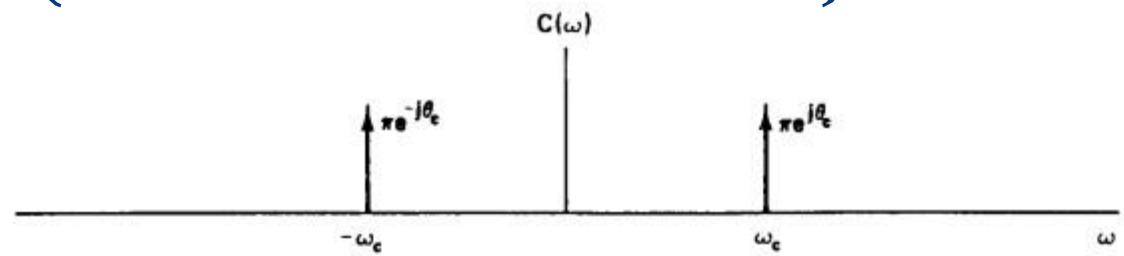
- Obviously, we need to recover (shift back) our signal to "baseband" so that they can be "heard" by us
- How?
  - Interestingly, the easiest way is to again multiply our "modulated" signal with $\cos(\omega_c t)$!

Demodulation: Illustration

$$y(t) = x(t)\cos(\omega_c t) \leftrightarrow Y(\omega)$$



$$\cos(\omega_c t) \text{ — } \pi\big(\delta(\omega - \omega_c) + \delta(\omega + \omega_c)\big)$$



$$y(t)\cos(\omega_c t) \text{ — } W(\omega)$$

Note the "Mirror Image" band

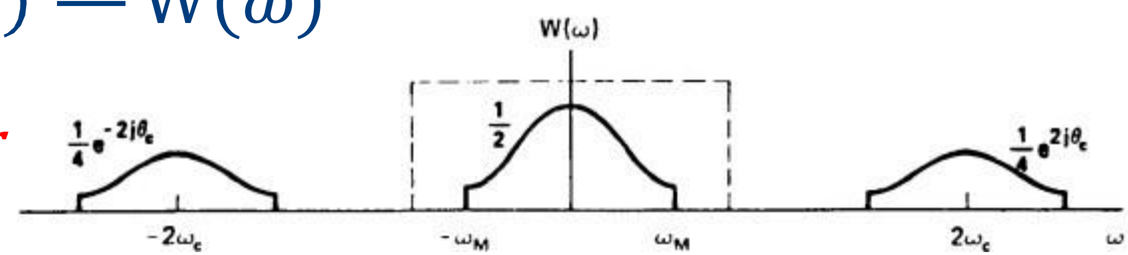


Image from MIT Signals & Systems Lectures

- Then we just need to low-pass filtering $W(\omega)$!

Demodulation in Real Life

- There are some practical problems if we directly shift our modulated signal back to baseband (centered at $\omega = 0$). (skip)
- In practice we first shift the signal to a lower frequency band (say, centered at $\omega_{IF} = 100kHz$). Then instead of low-pass filtering, we use a IF (bandpass) filter to get rid of the "image" bands.

IF Bandpass Filter: Illustration

- Two Possible Ways:

$\pm f_c$: Center Freq. for modulated signal

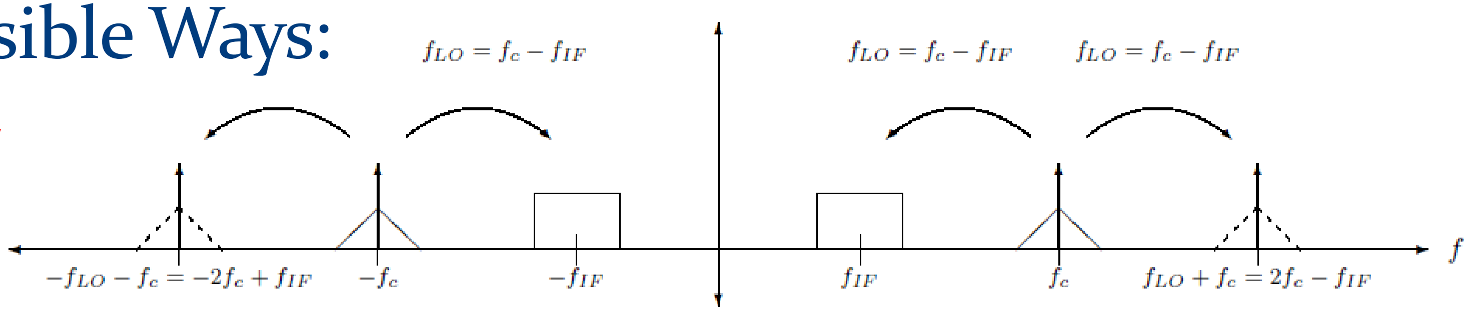


Figure 2.4.2: Using LO to Mix into IF Band when $f_{LO} = f_c - f_{IF}$

$\pm f_{IF}$: Target band to shift

$\pm f_{LO}$: Center Freq. for Mirror Image band

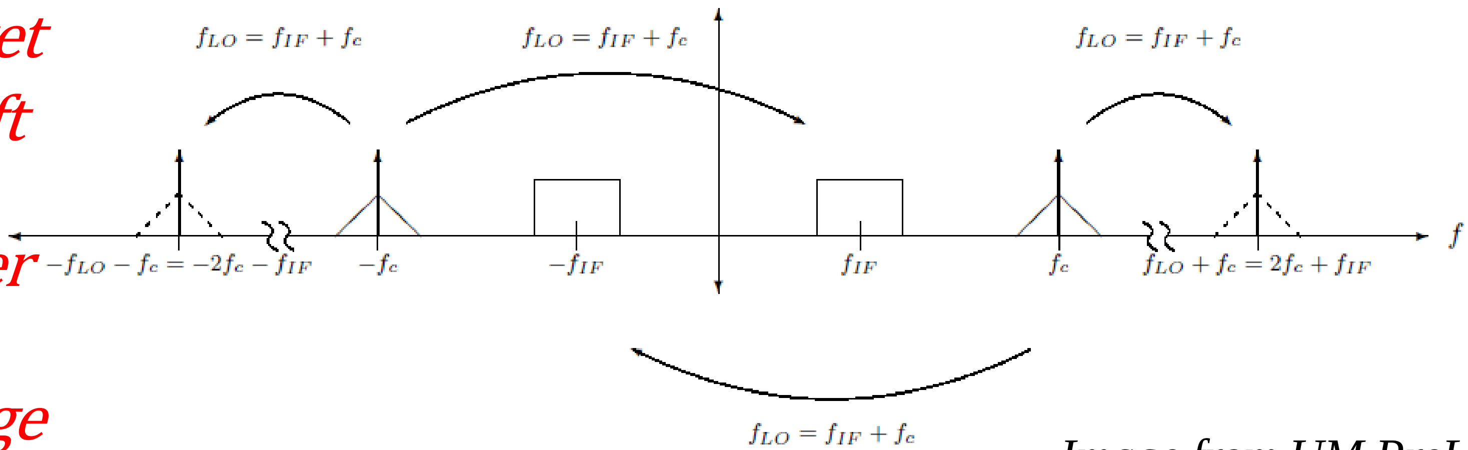
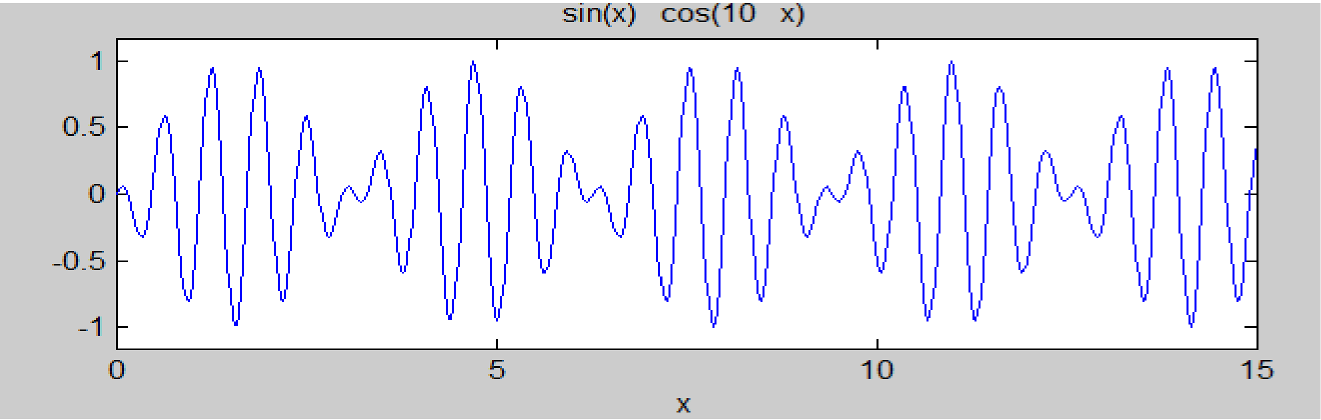


Image from UM PreLab 3

Figure 2.4.3: Using LO to Mix into IF Band when $f_{LO} = f_{IF} + f_c$

Envelope Detector

- You may notice that instead of directly obtaining our original signal in the first case, the output of the IF filter is still in the form $x(t)\cos(w_{IF}t)$: (in a high freq. band)



- We need to further "demodulate" it!

Envelope Detector

- The "brutal but smart" way: envelope detector.
- Based on the observation that the"envelope" of our modulated signal is (almost) what we want.

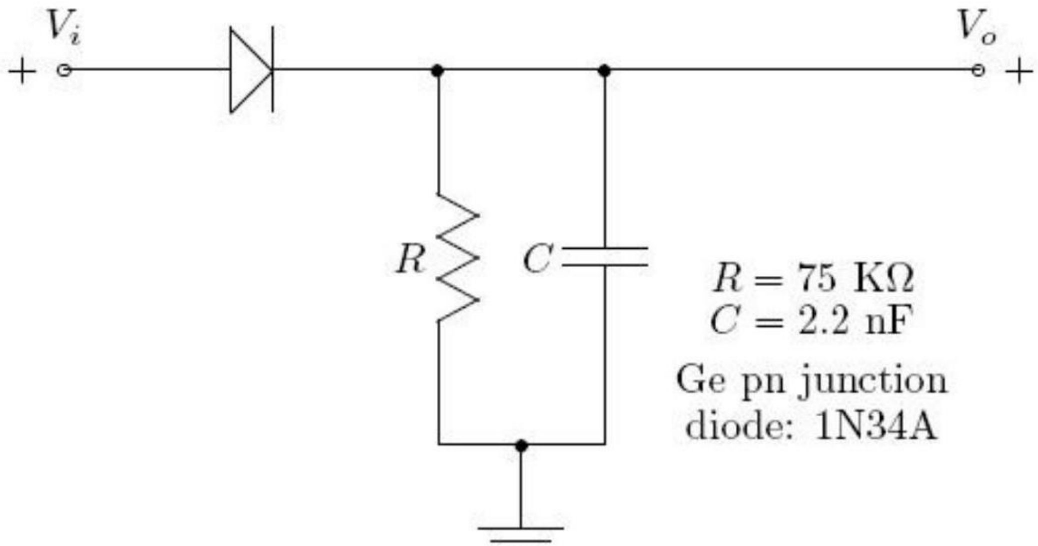


Image from UM PreLab 3

Envelope Detector: Principles

- Diode: conduct (like a wire) when voltage higher at the anode side. / No current at all when voltage higher at the cathode side.
- Capacitor: always *prevent* voltage changing abruptly (slowly discharge if C large)

- *In one cycle, The diode conducts only during ΔT (Capacitor charging).*
- *Otherwise, Capacitor discharging.*
  (See blackboard.)

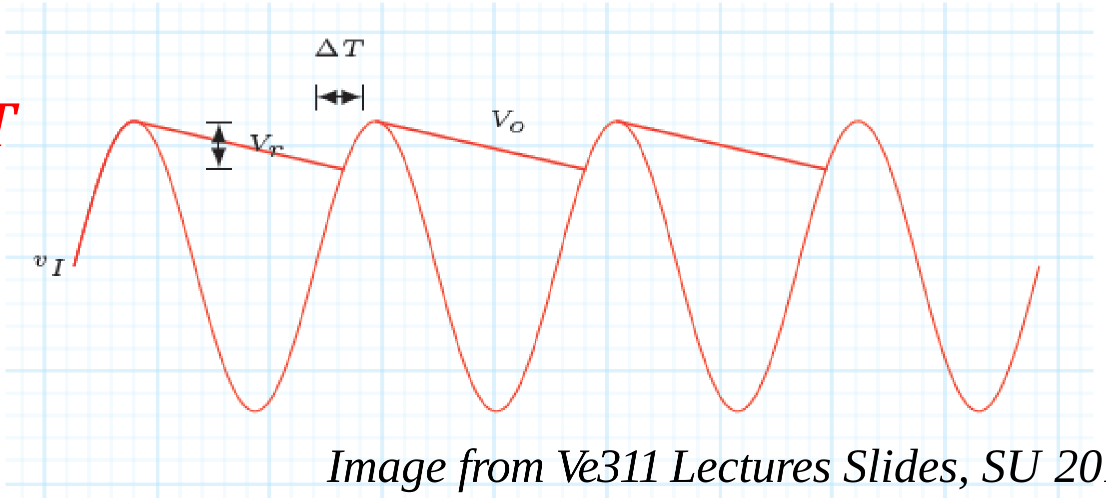


Image from Ve311 Lectures Slides, SU 2015

Envelope Detector: Principles

- If the time constant (discharging period) of the RC combination is much longer than signal period, the output willapproximately become the envelope and we obtain the "demodulated signal".

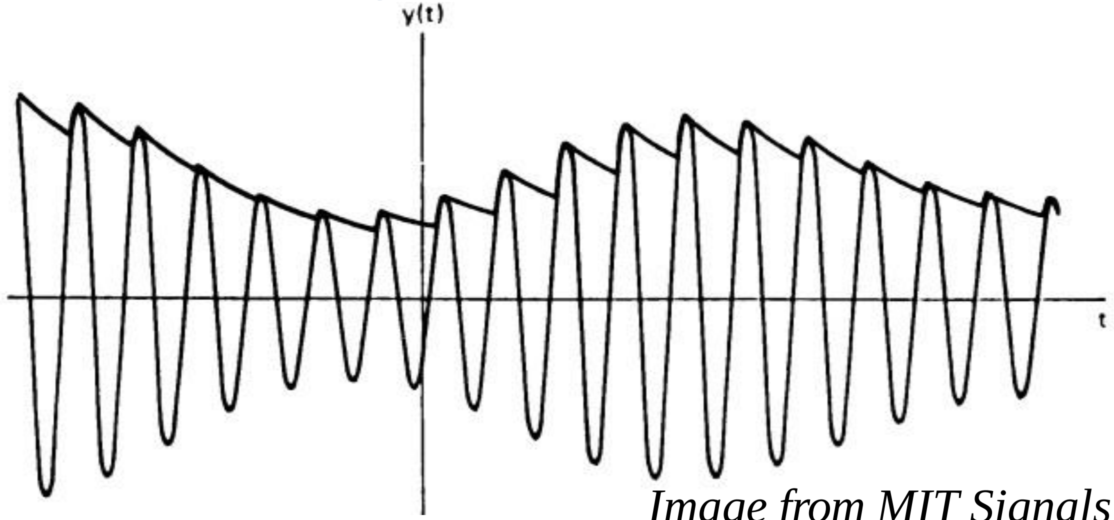
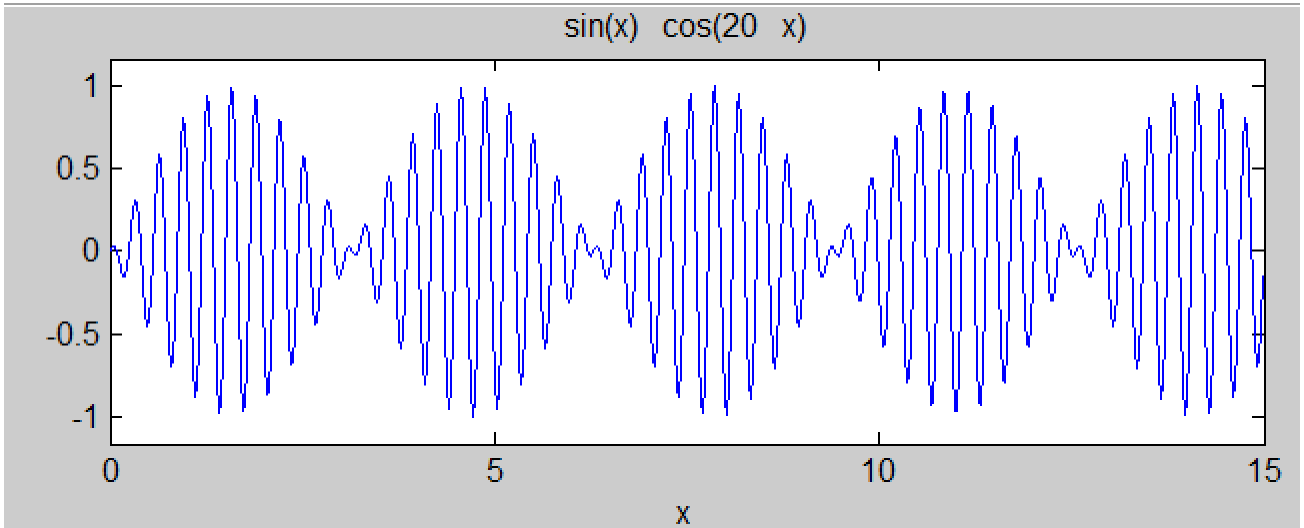


Image from MIT Signals & Systems Lectures

Problem with Envelope detectors

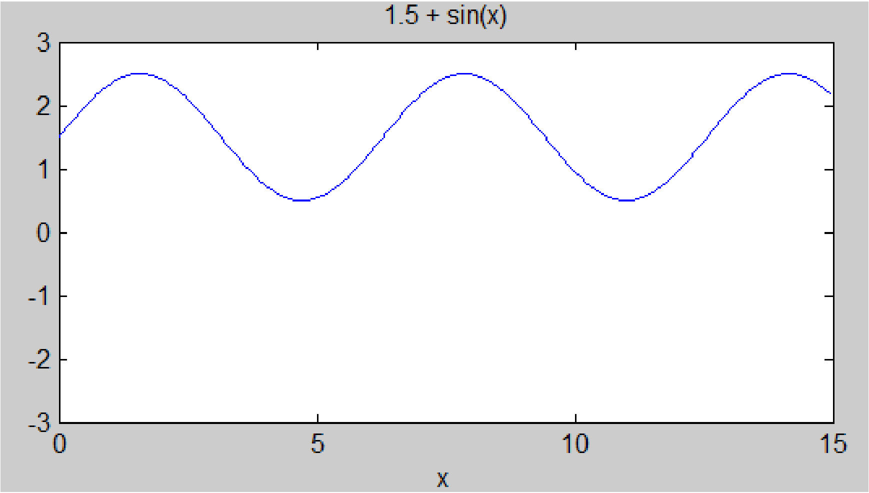
- What will the output of the envelope detector be?

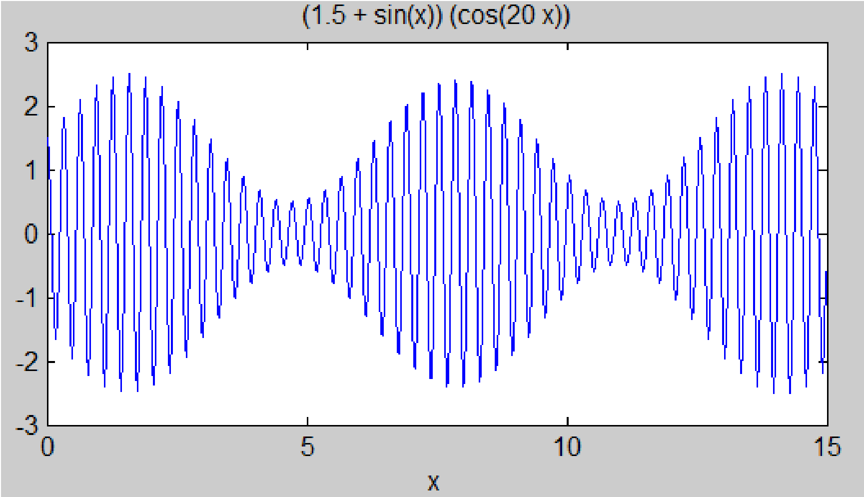


Unfortunately, The absolute value of our initial signal!

- However, we could solve the problem by adding a DC bias to our original signal $(x(t) + A)$ before modulation, so that $x(t) + A$ is always kept greater than zero.

Adding a DC Bias





- By keeping our signal before modulation positive, we could therefore fully recoverthis signal from an envelopedetector.
- Then we just use a capacitor to get rid of the additional DC bias!

Sample Results: Envelope Detector

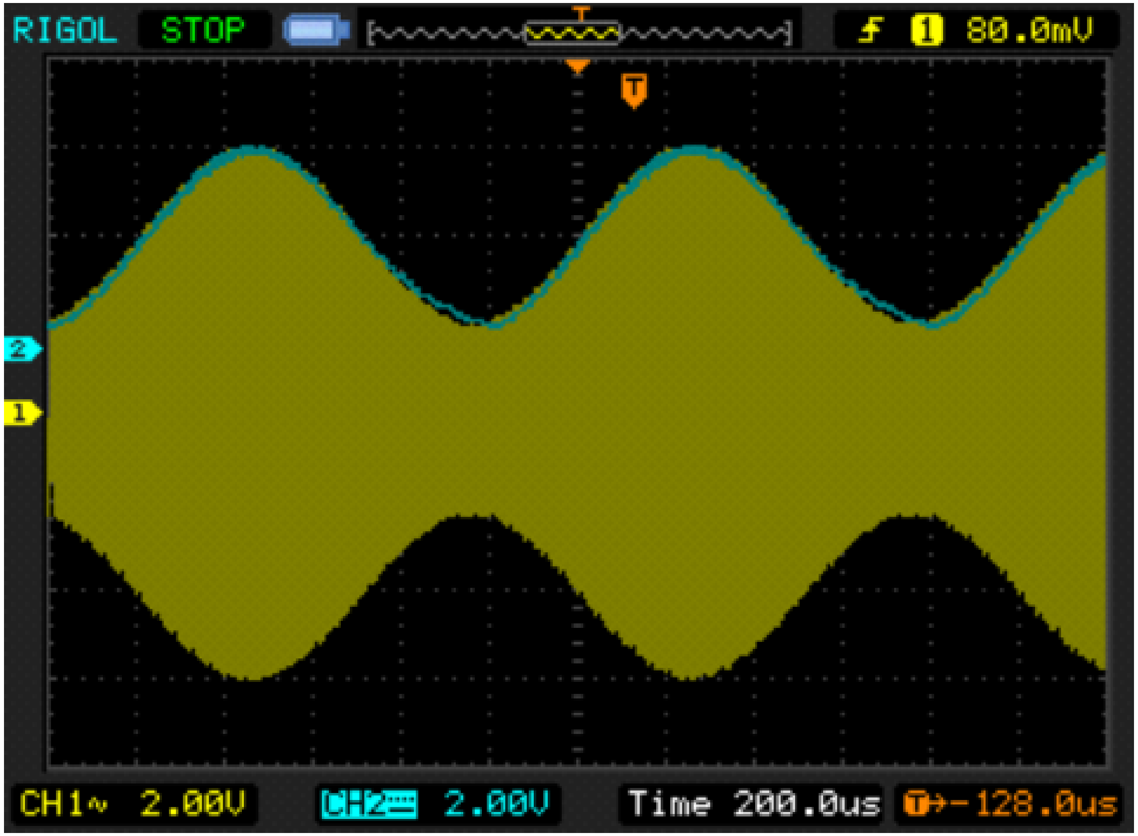


Image from Ve216 Lab Introduction SU 2014

Sample Results: Amplifier

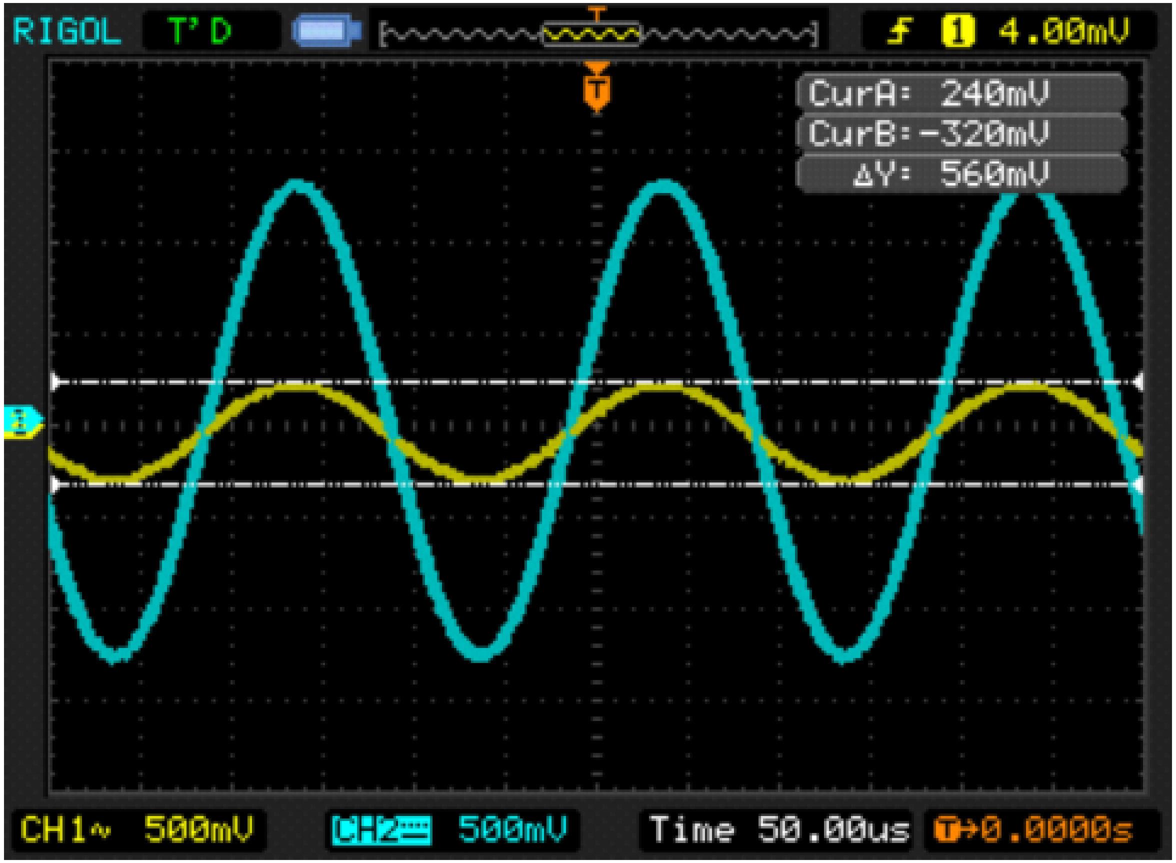


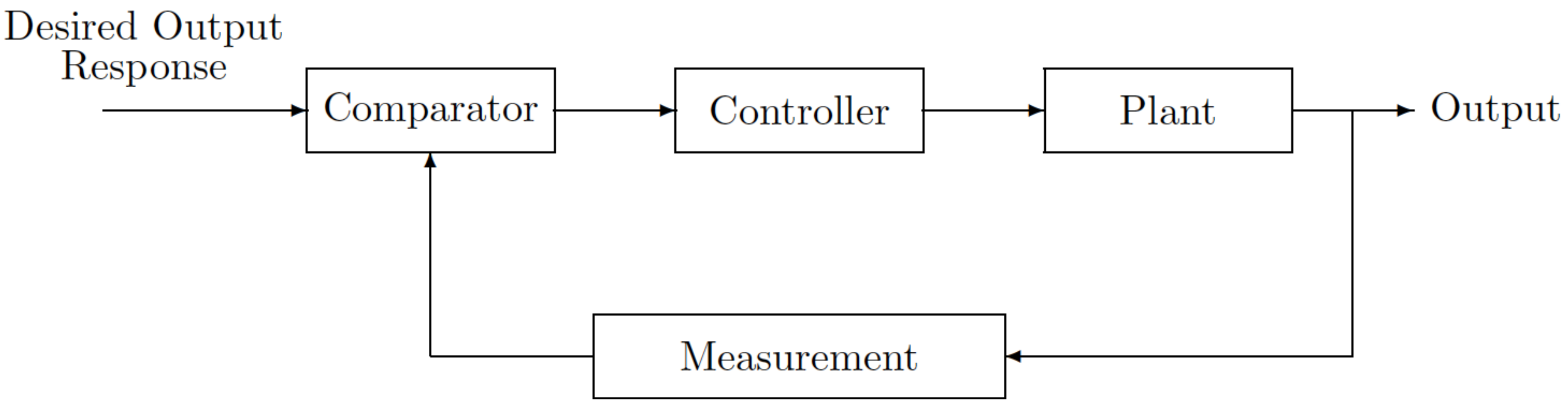
Image from Ve216 Lab Introduction SU 2014

Lab 2 Summary

- Prelab:
  - Lots of analysis on hardware, don't be too anxious about it
  - Contents on demodulation are very useful (actually I understood demodulation only after I have completed Prelab2)
- Lab process
  - I expect to build a "radio" to receive from radio station, e.g.: AM792 (kHz)
    - But no antenna available, so let's see a video!
      - MIT Video Lecture 14 (30:10 – 33:00 min)
  - Only need to build Envelop Detector, Amplifier

Lab 3 Content

- Lab Three： Feedback Control
- Overview:



- Plant: the system to be controlled

Feedback Control

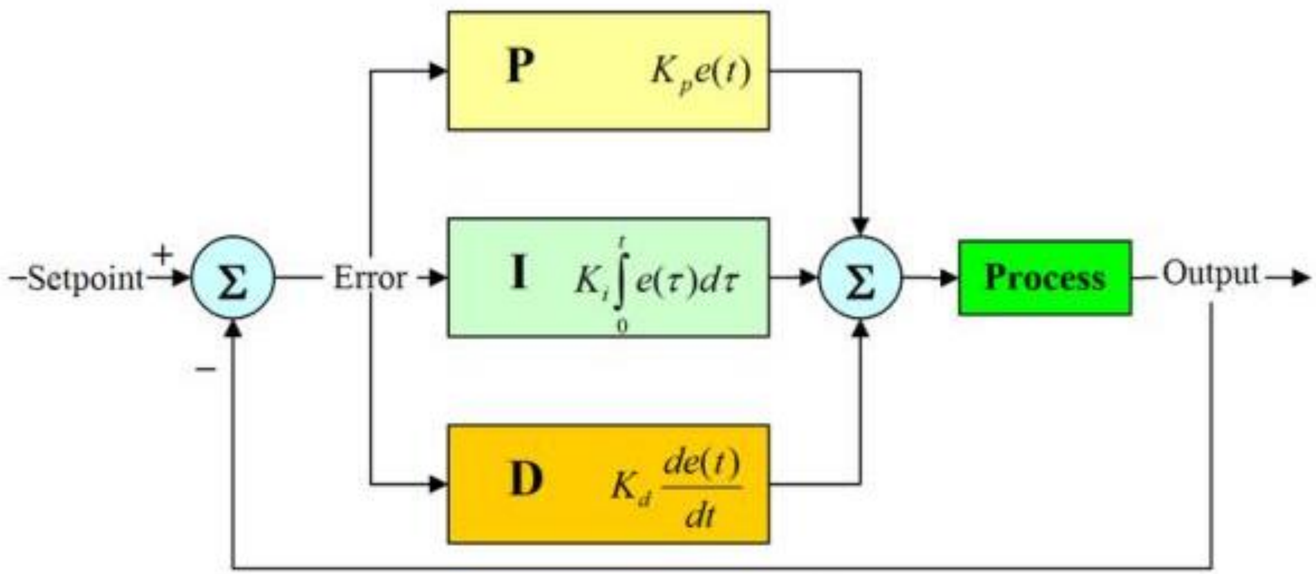
Key Elements:

- A measured Quantity that is to be regulated to a desired value—output
- An input—Can be varied so as to drive the output to desired value
- Controller—Determine how to adjust the input
- Plant—Whose output we want to control

Example: The Inverted Pendulum

https://ocw.mit.edu/resources/res-6-007-signals-and-systems-spring-2011/video-lectures/lecture-26-feedback-example-the-inverted-pendulum/

PID Feedback Control



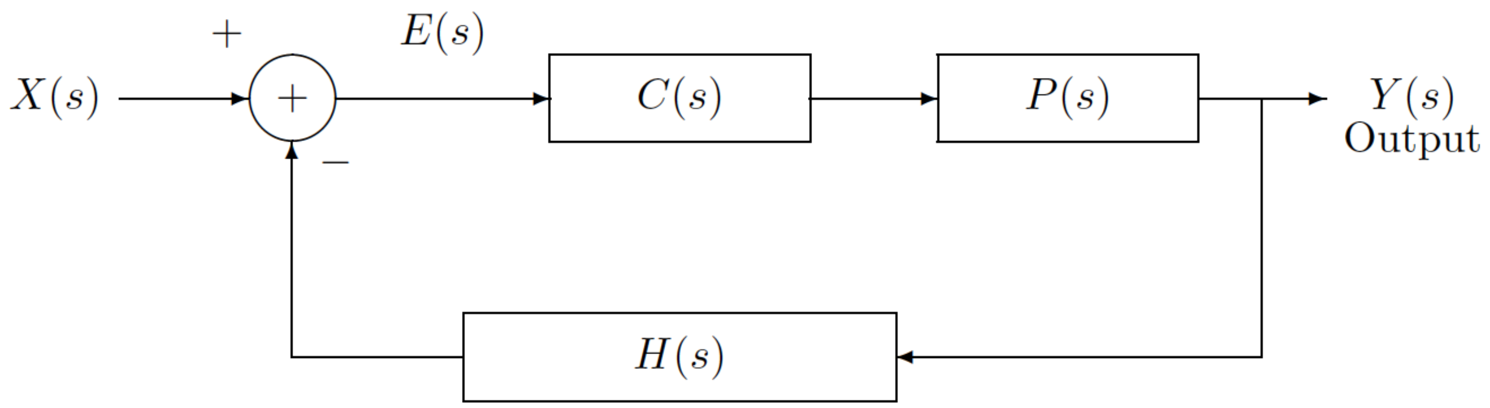
PID Feedback Control

- P—Proportional
- I—Integral
- D—Differential

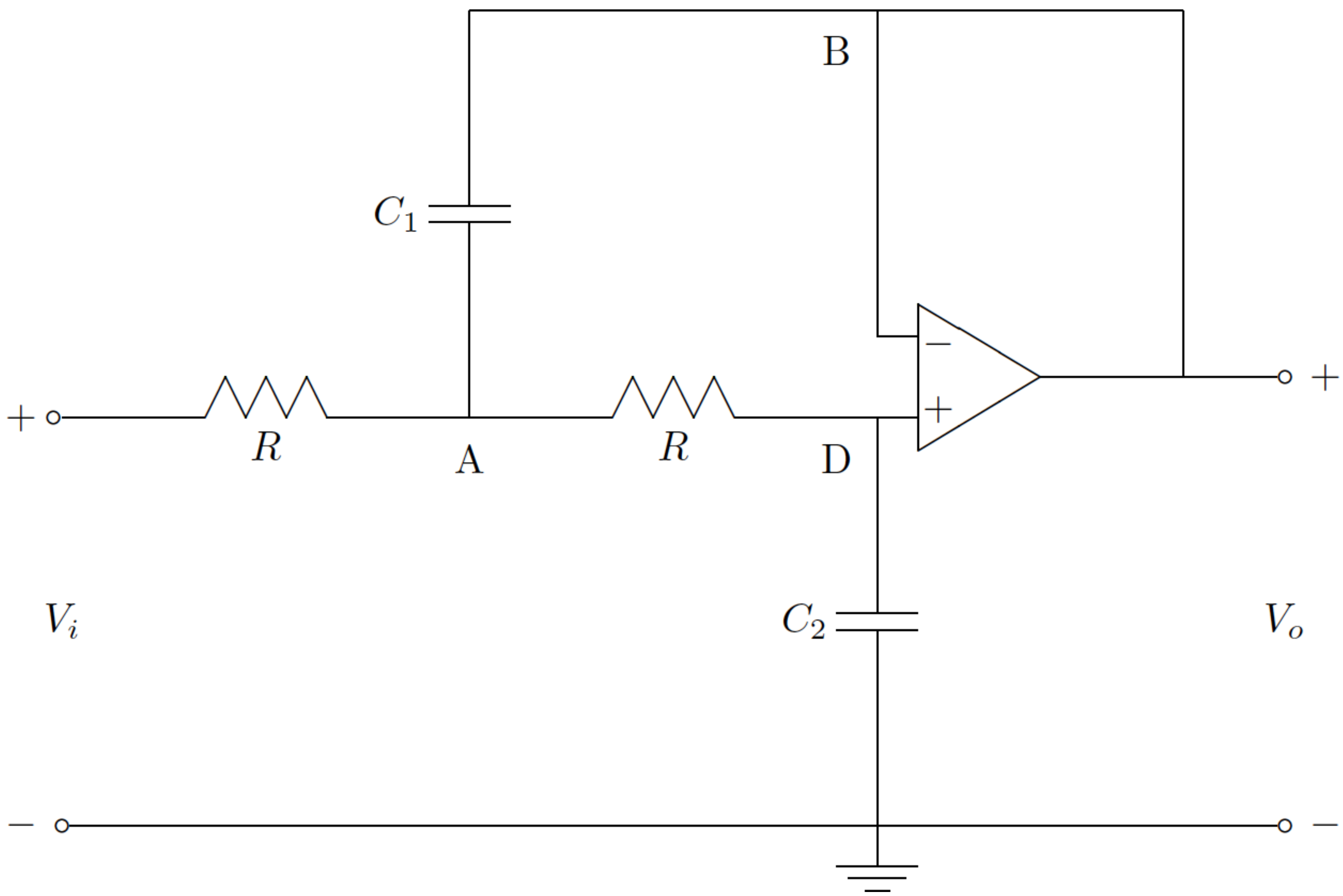
- Adjust the coefficient term to get a desired performance.

- More Details will be covered in VE460

Come Back to This Lab



Plant



Proportional Controller

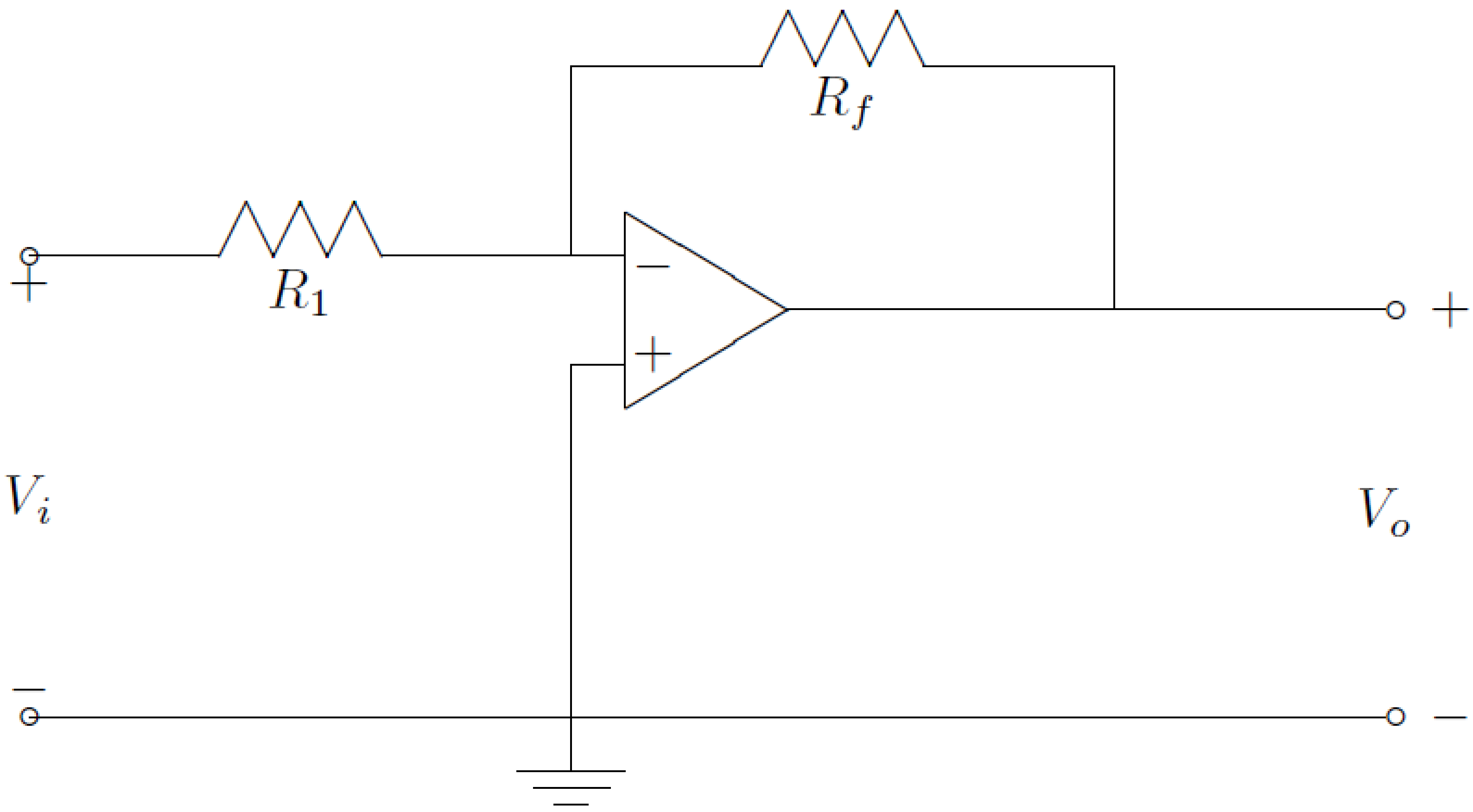


Figure 3.2.1: Proportional Controller

Differential Controller

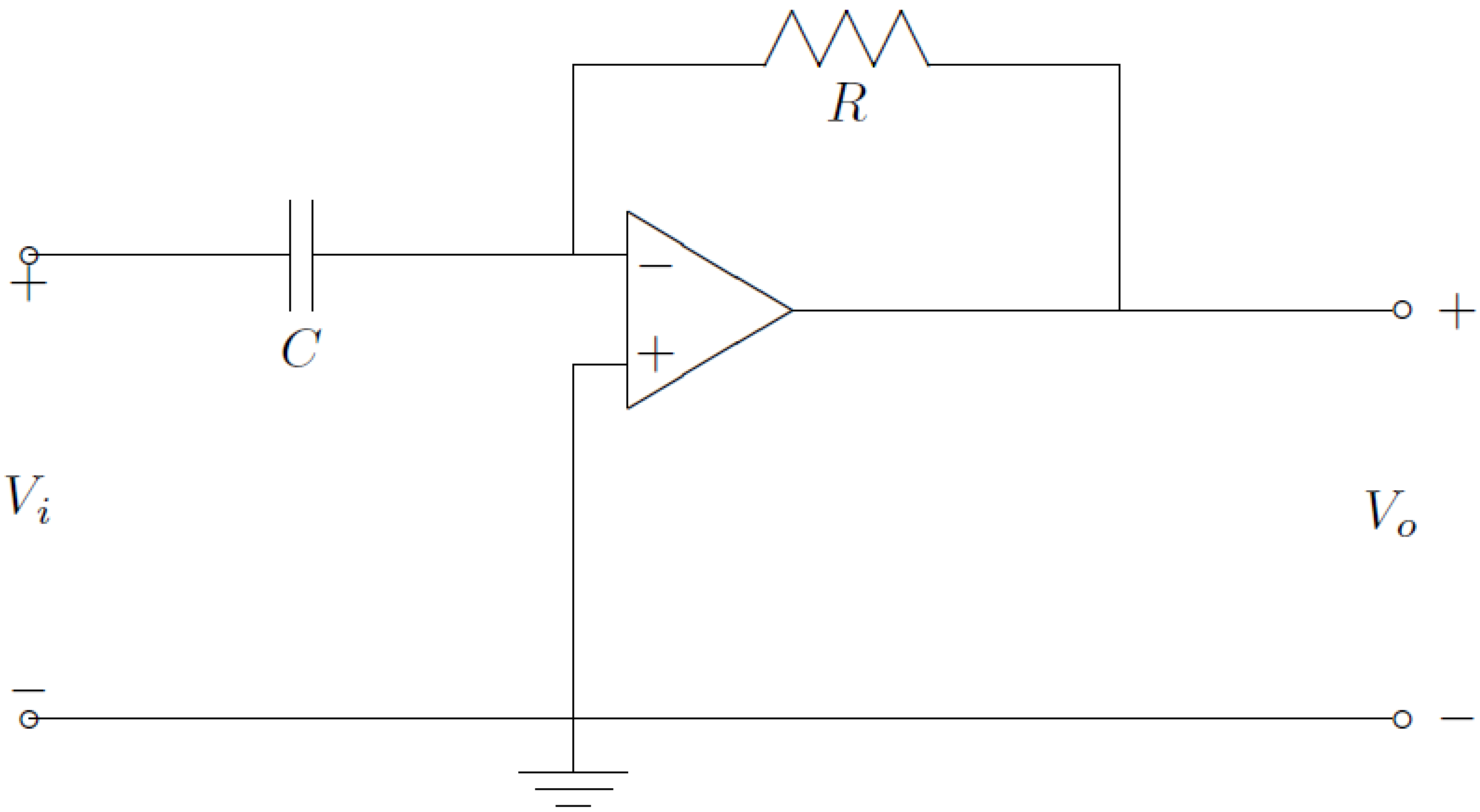


Figure 3.2.2: Differential Controller

Integral Controller

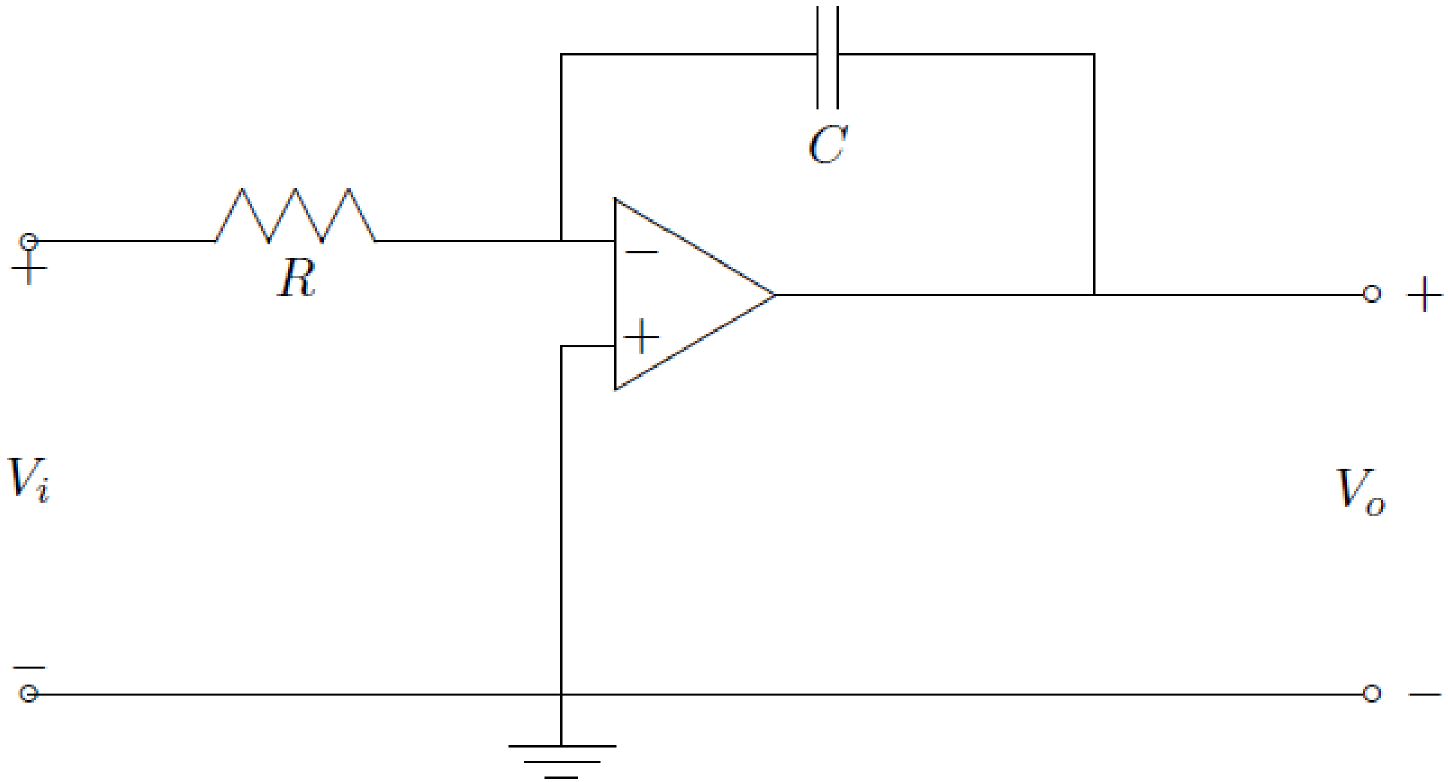


Figure 3.2.3: Integral Controller

PID Controllers

- Proportional controller (Fig. 3.2.1):

$$\frac{V_o(s)}{V_i(s)} = K_p \text{ where } K_p = -\frac{R_f}{R_1}$$

- Differentiator controller (Fig. 3.2.2):

$$\frac{V_o(s)}{V_i(s)} = K_D s \text{ where } K_D = -RC$$

- Integral controller (Fig. 3.2.3):

$$\frac{V_o(s)}{V_i(s)} = \frac{K_I}{s} \text{ where } K_I = -\frac{1}{RC}$$

2-Degrees of Freedom PD Controller

$$C_1(s) = K_p \ and \ C_2(s) = KDs$$

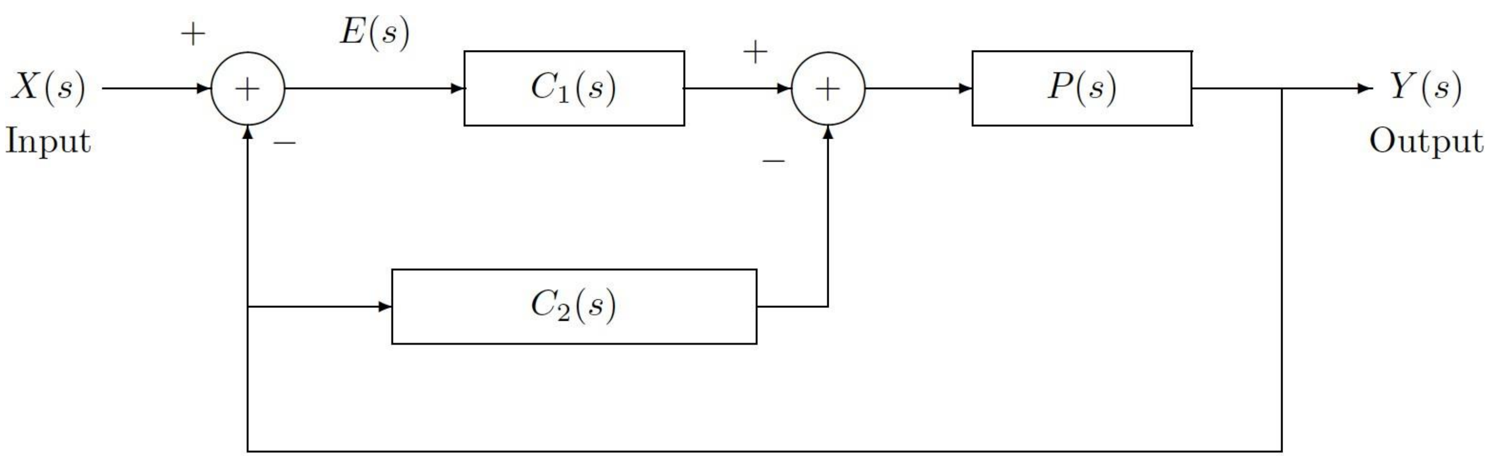


Figure 3.3.1: Two-Degree of Freedom Controller

Lab Circuitry

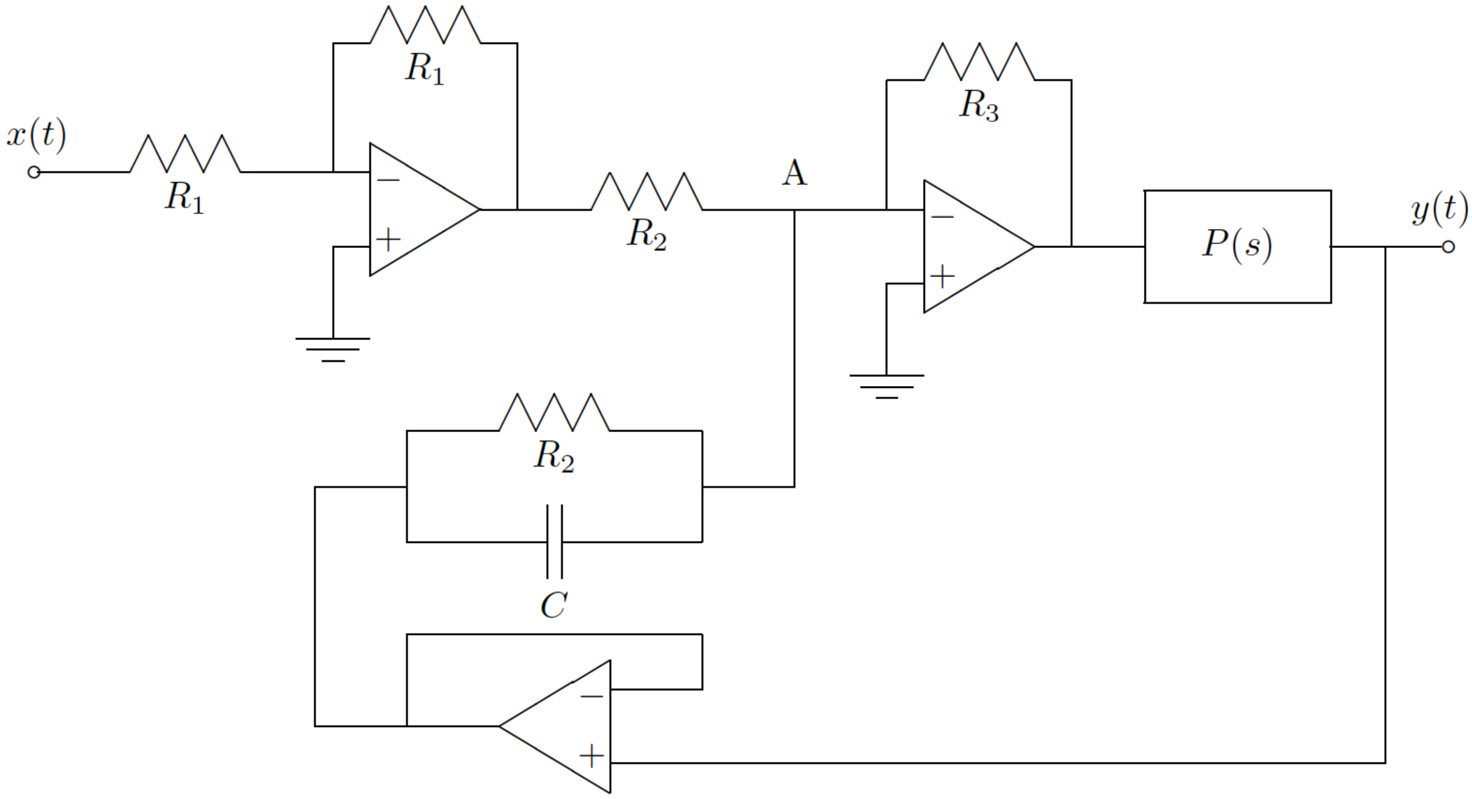


Figure 3.5.1: Op-Amp Realization of PD Controller with 2-Degrees of Freedom

Analysis

$$Y_B(s) = -X(s)$$

$$Y_C(s) = Y(s)$$

So at node A, we can get

$$\frac{-X(s)}{R_2} + \frac{Y(s)}{R_2} + Y(s)sC = \frac{-W(s)}{R_3}$$

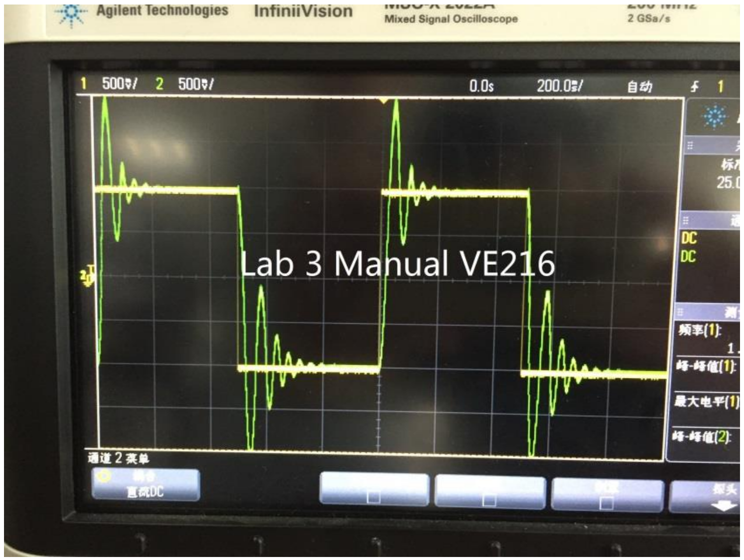
$$W(s) = \frac{R_3}{R_2}(X(s) - Y(s)) - sCR_3Y(s)$$

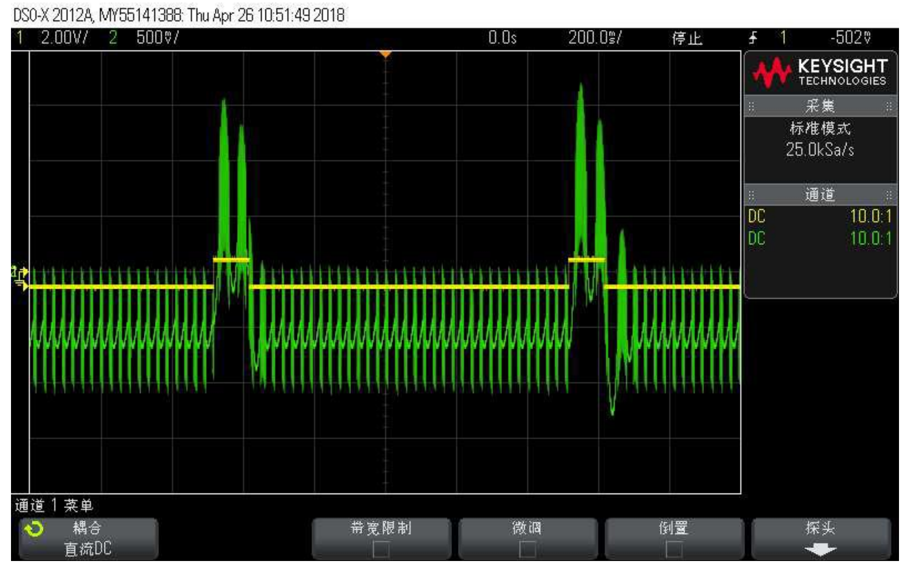
So

$$K_P = \frac{R_3}{R_2}$$

$$K_D = CR_3$$

What You Wish vs. What You Get





- Need to add a capacitor to circuit
- Hope everything works fine in software

Example: The Inverted Pendulum

- MIT Video Lecture 26 (29:30 – 33:30 min)