ESE 3400: Medical Devices Lab

Lec 3: September 12, 2022

Sensing Principle

Lecture Outline

- System Examples
- Sensing Principle
- Biosensors
- Lab 2 Prompt

Medical Instrument Systems

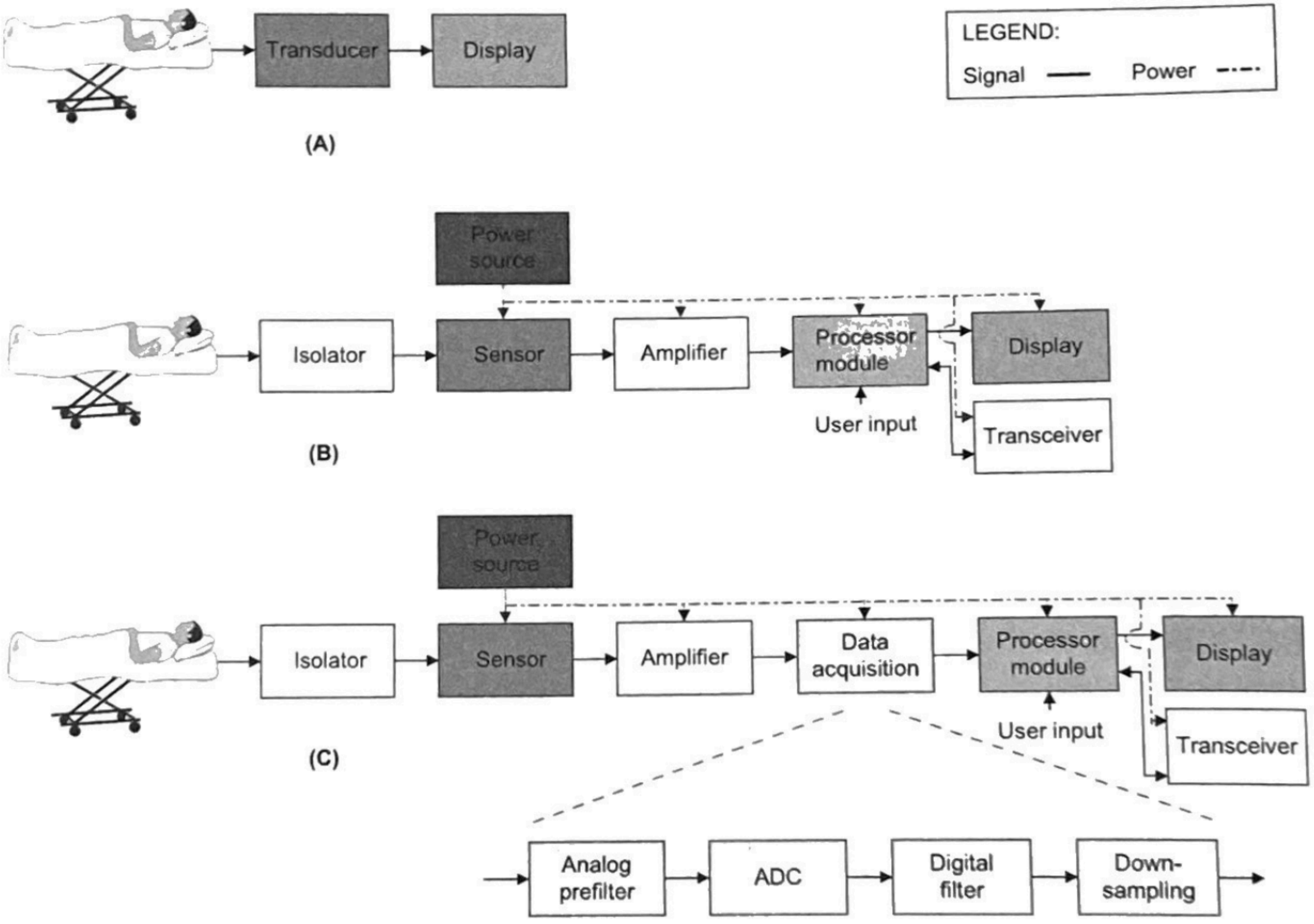


FIGURE 1.1

Three types of medical instruments. **(A)** Simple. (B) Analog. (C) Digital.

Definitions

- Medical instrument
    - Medical device that makes measurements
- Measurand
    - The physiologic quantity, property or condition that the system measures
- Transducer
    - Converts the energy or information from a measurand to another form
- Sensor
    - Device that transform biologic, chemical, electrical, magnetic, mechanical, optical or other stimuli input into an electrical signal output

Pulse Oximeter System Digram

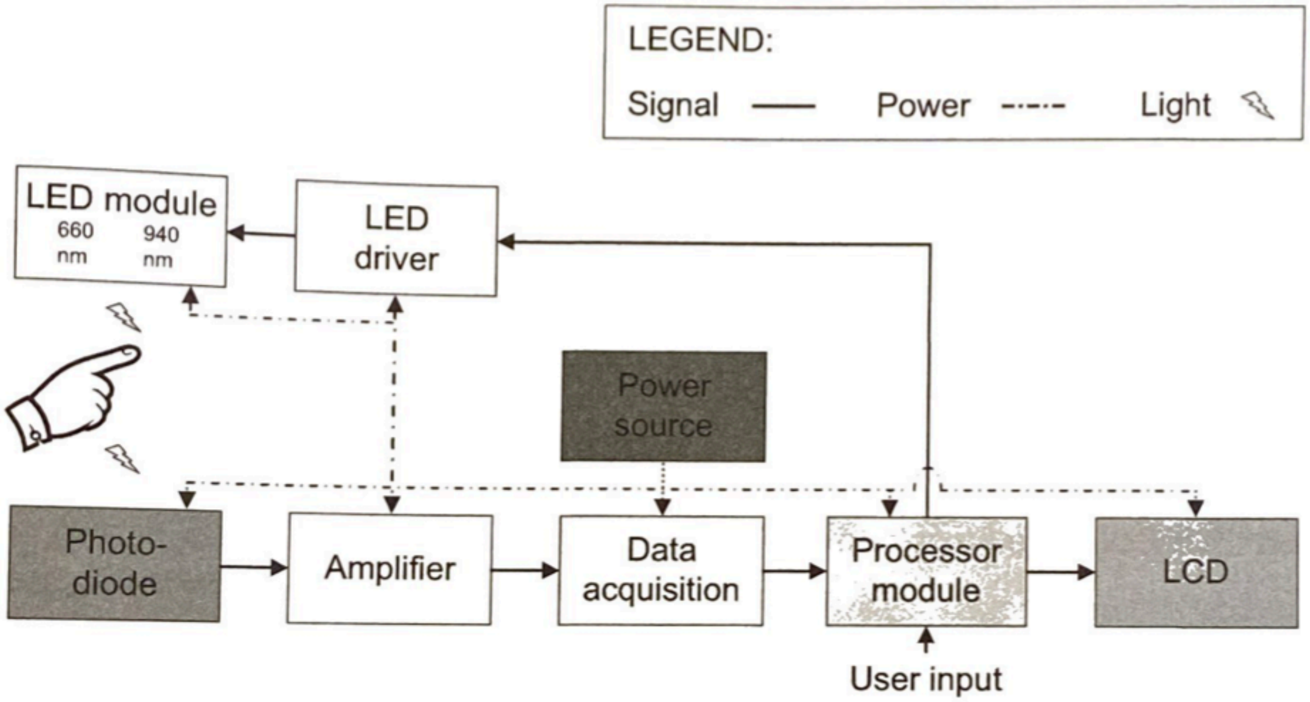
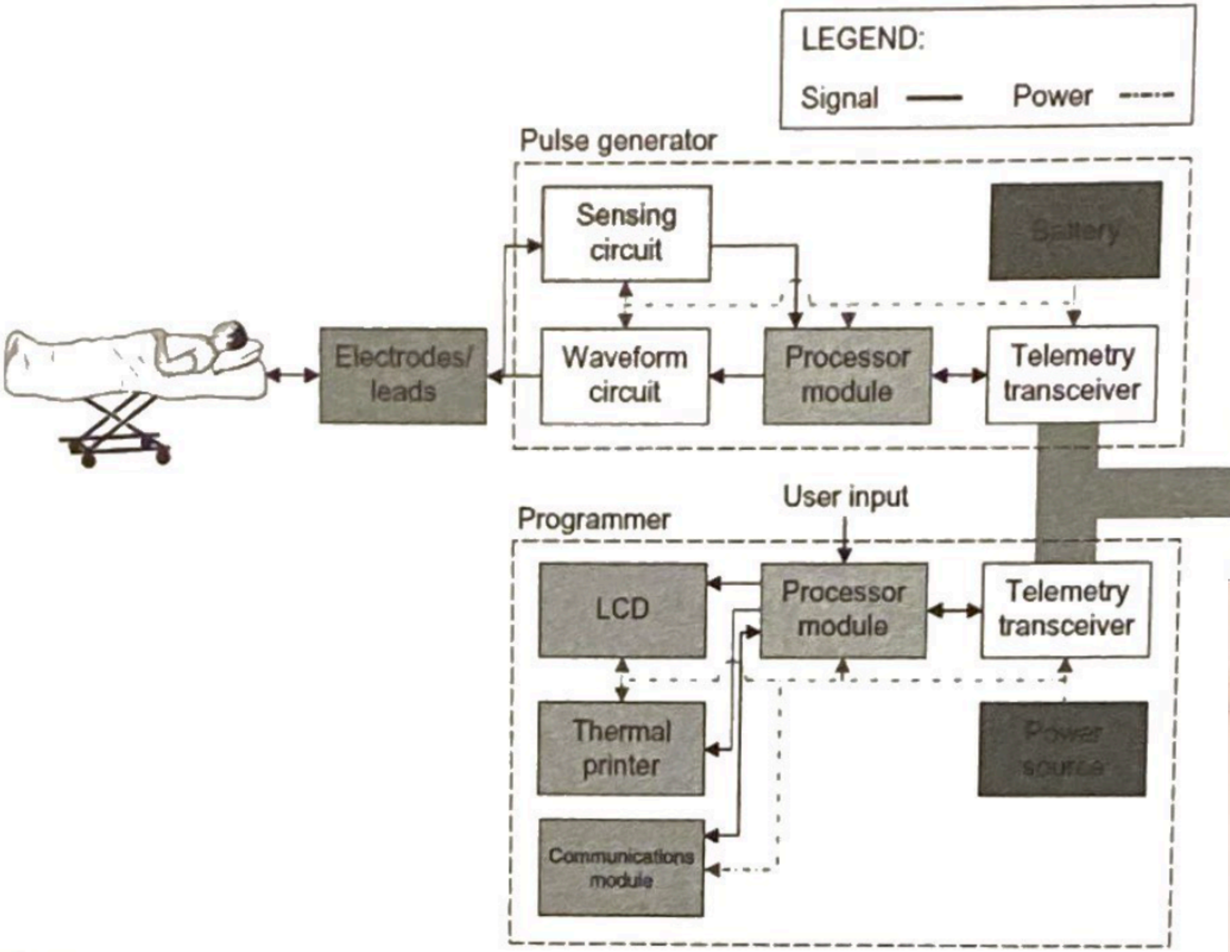
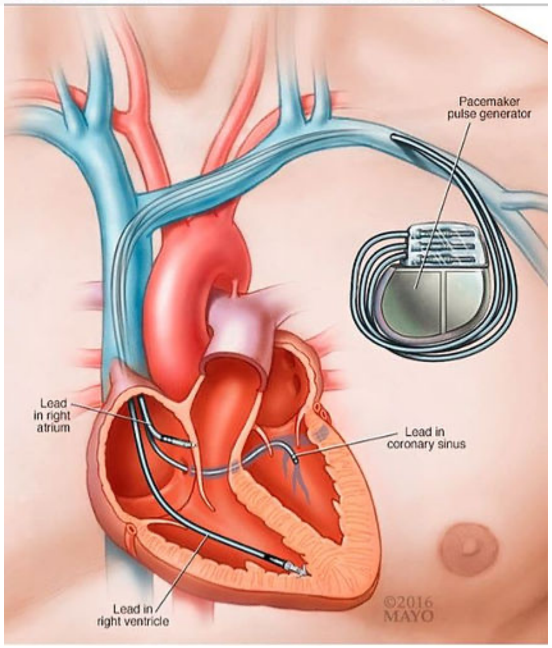


FIGURE 11.13

Pulse oximeter system diagram.

Pacemaker System Diagram





Deep Brain Stimulation System Diagram

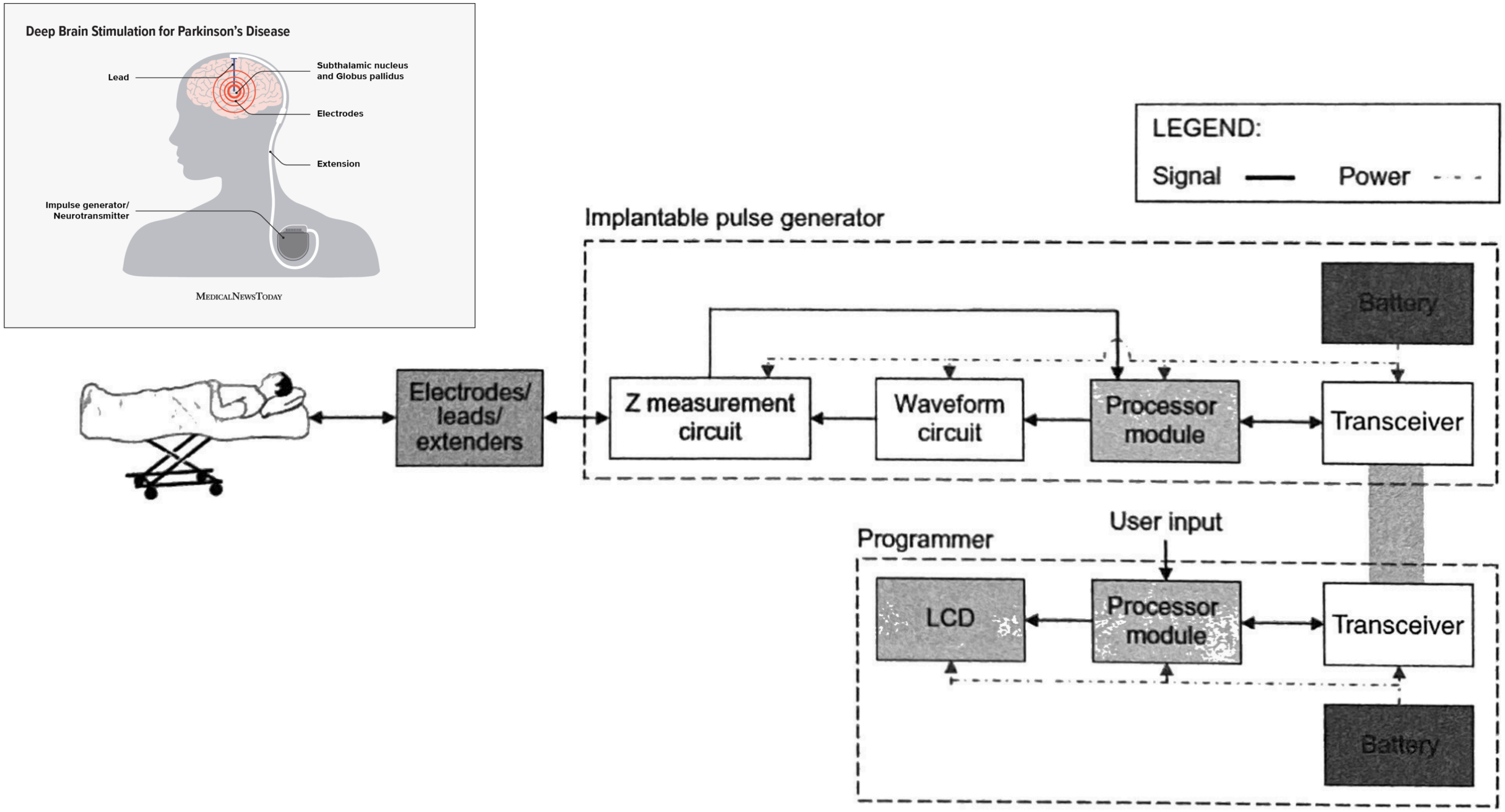


FIGURE 14.9

Deep brain stimulator system diagram.

Cochlear Implant System Diagram

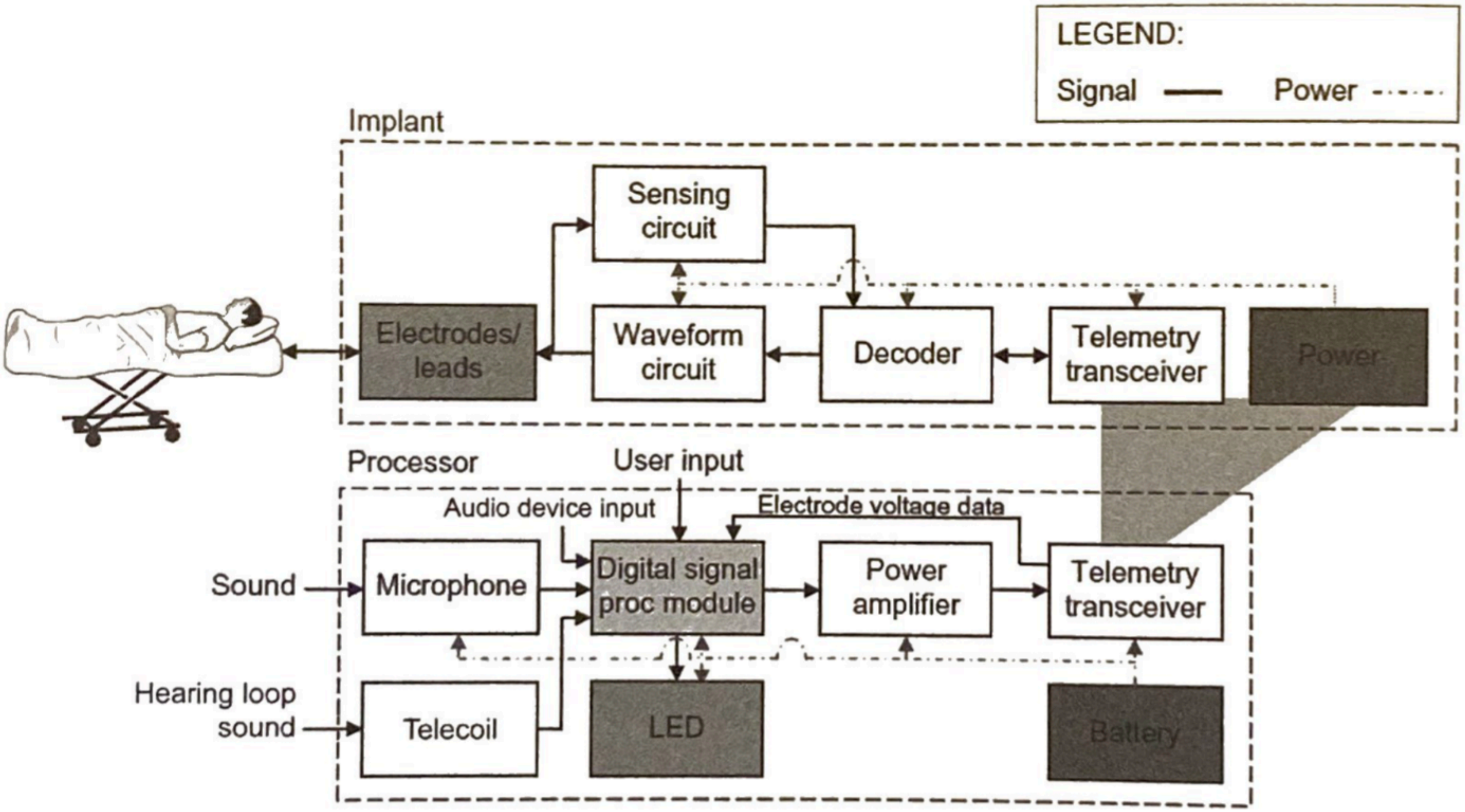


FIGURE 15.15

Cochlear implant system diagram.

Defibrilator System Diagram

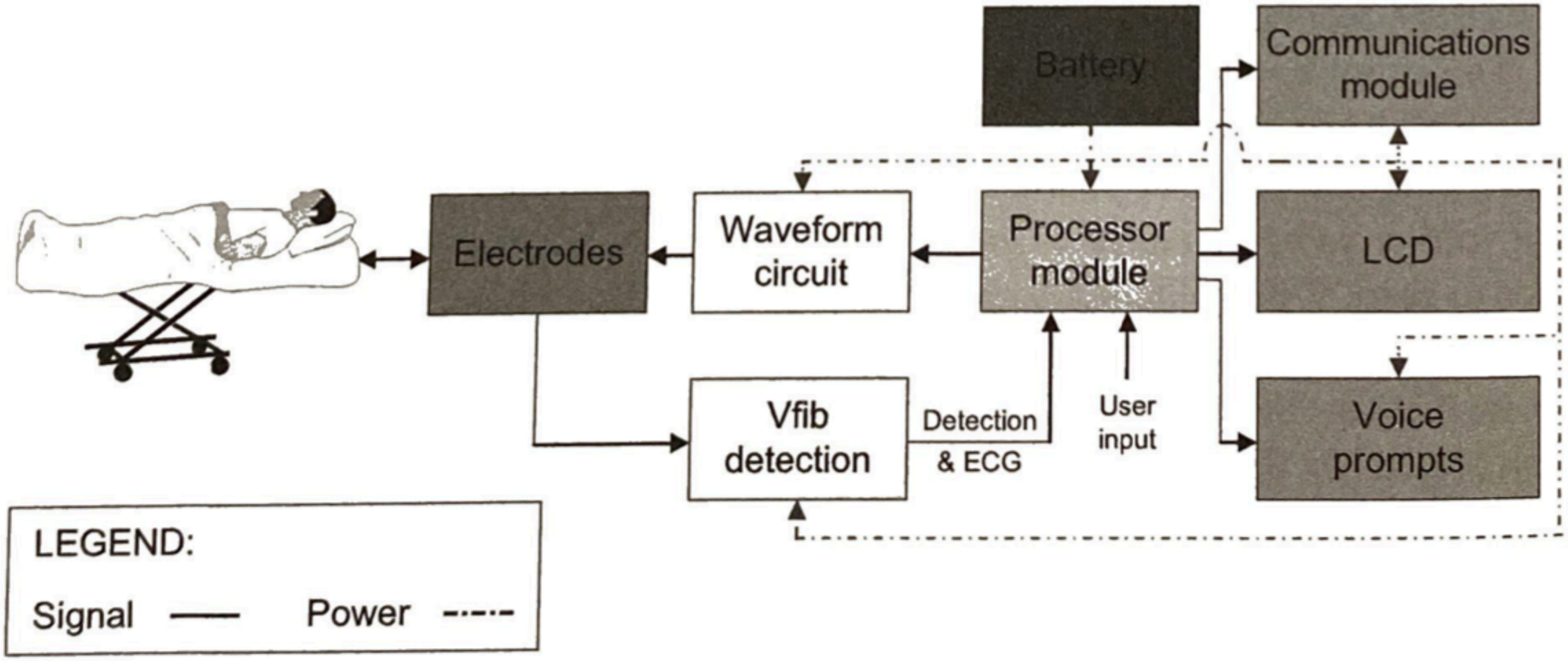


FIGURE 4.11

Automated external defibrillator system diagram.

Sensing Principle

- Sensor is a device that can detect changes or events in its environment as an electrical signal

Accuracy, Bias and Precision

- Accuracy “usually denotes in some sense the closeness of the measurand values to the true value, taking into consideration both precision and bias. Bias, defined as the limiting mean and the true value, is a constant, and does not behave in the same way as the index of precision, the standard deviation” (Ku, 1988)

Accuracy, Bias and Precision

- In practice:
  - Accuracy is usually defined as the percentage difference between the measured and true values, based on a full scale reading.
  - Eg. The Welch Allyn SureTemp Plus digital thermometer is ±0.2ºF, for the patient temperature range of 80-110ºF.

Accuracy, Bias and Precision

- Bland-Altman analysis:

$$\text{bias} = \frac{\sum_{i=1}^{n}(m_i - s_i)}{n}$$

$$\text{precision} = 2\times\sqrt{\frac{\sum_{i=1}^{n}(m_i - \text{bias})^2}{n-1}}$$

- Where m_i is the measured standard and s_i is the reference standard for n samples

Accuracy, Bias and Precision

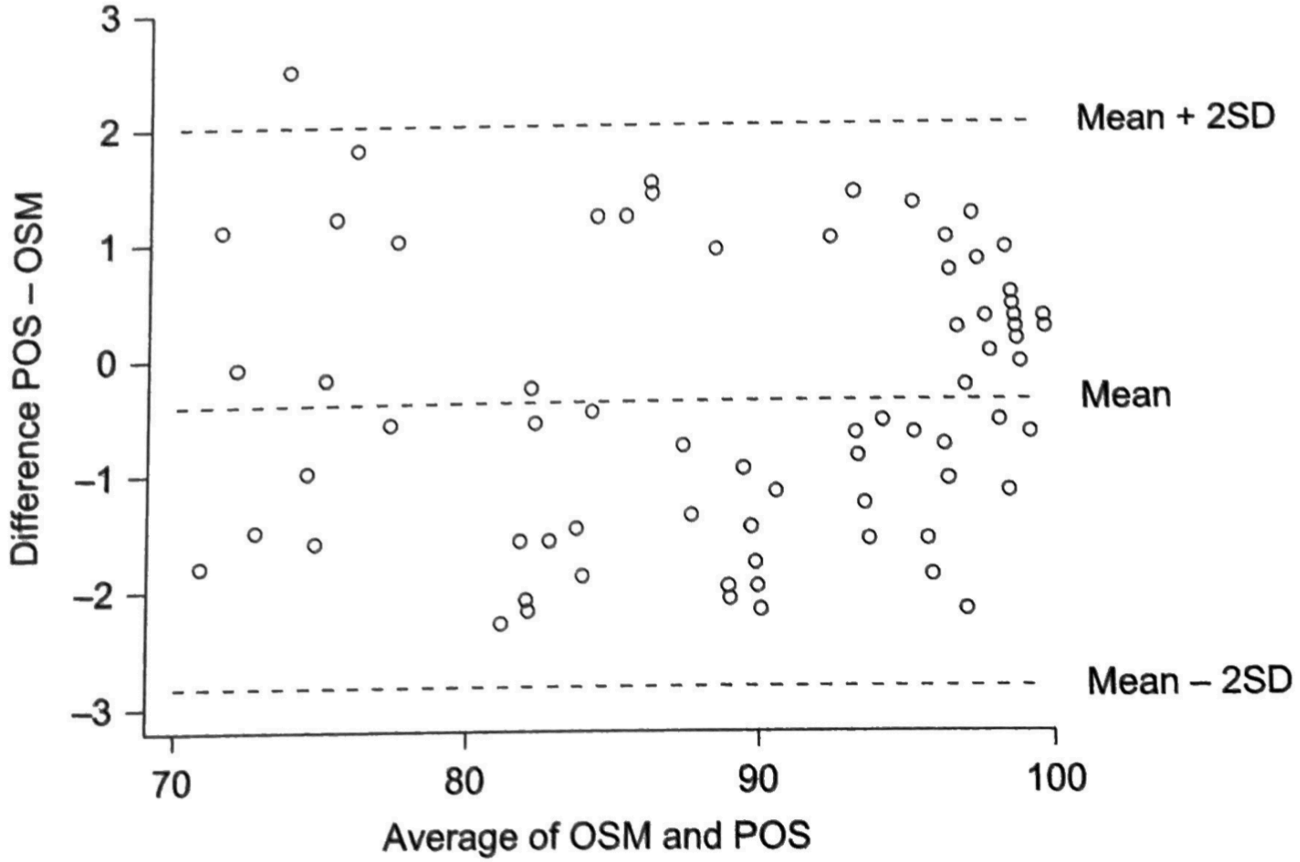
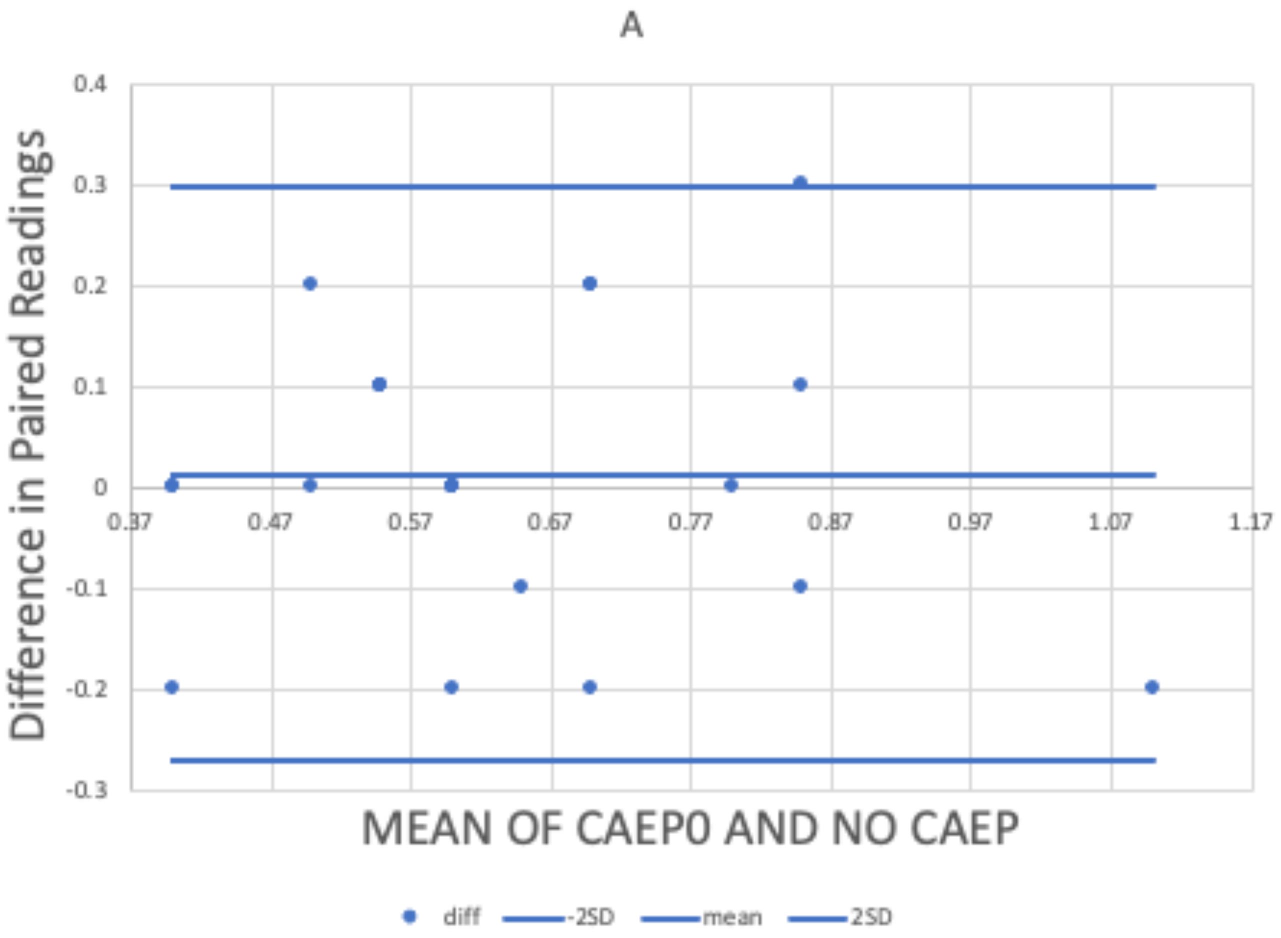


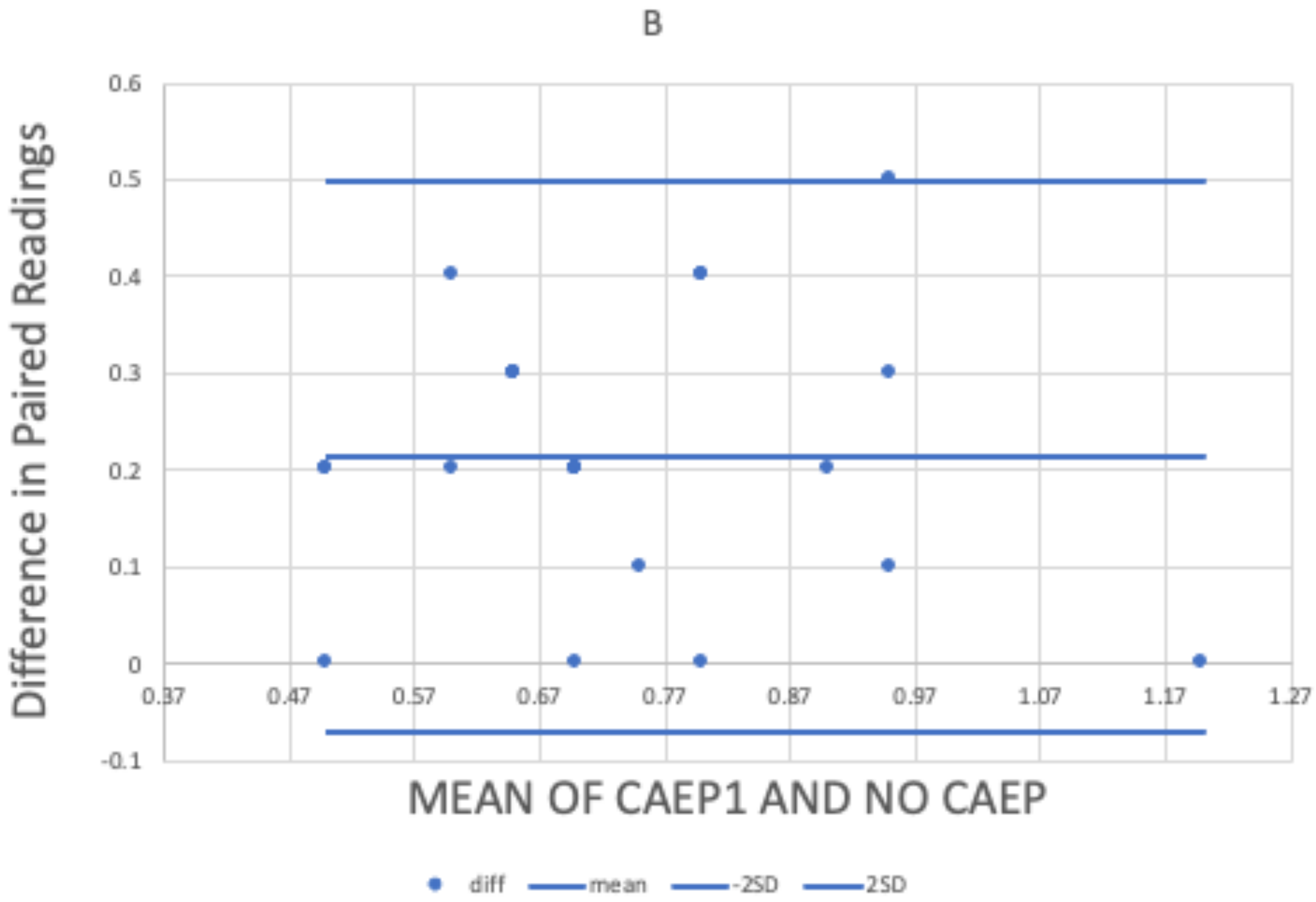
FIGURE 1.6

Bland-Altman plot of oxygen saturation measured by oxygen saturation monitor (OSM) and pulsed oxygen oximeter (POS). After publication of this graph, a pulsed oxygen oximeter became commonly known as a pulse oximeter.

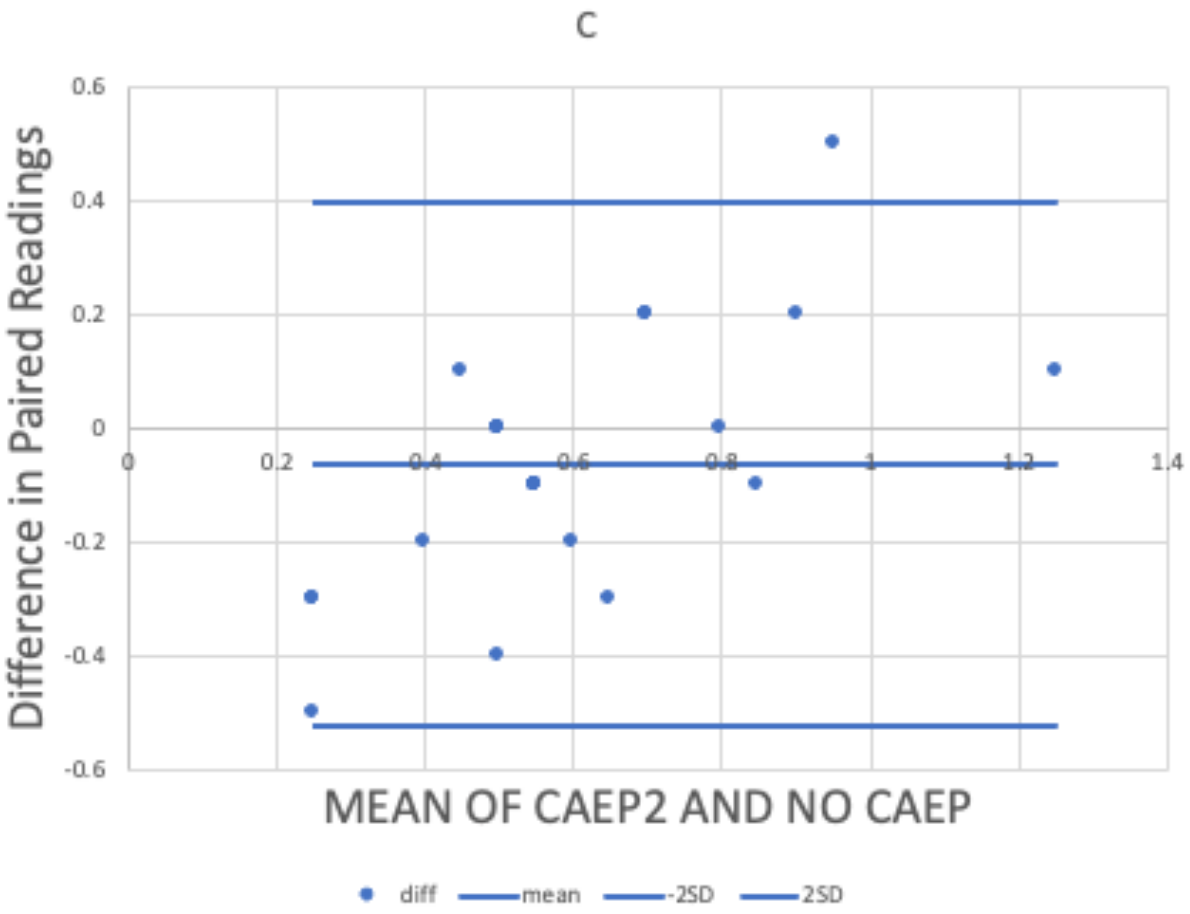
a)


A
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0.37
0.47
0.57
0.67
0.77
0.87
0.97
1.07
1.17
Difference in Paired Readings
MEAN OF CAEP0 AND NO CAEP
● diff
-2SD
mean
2SD

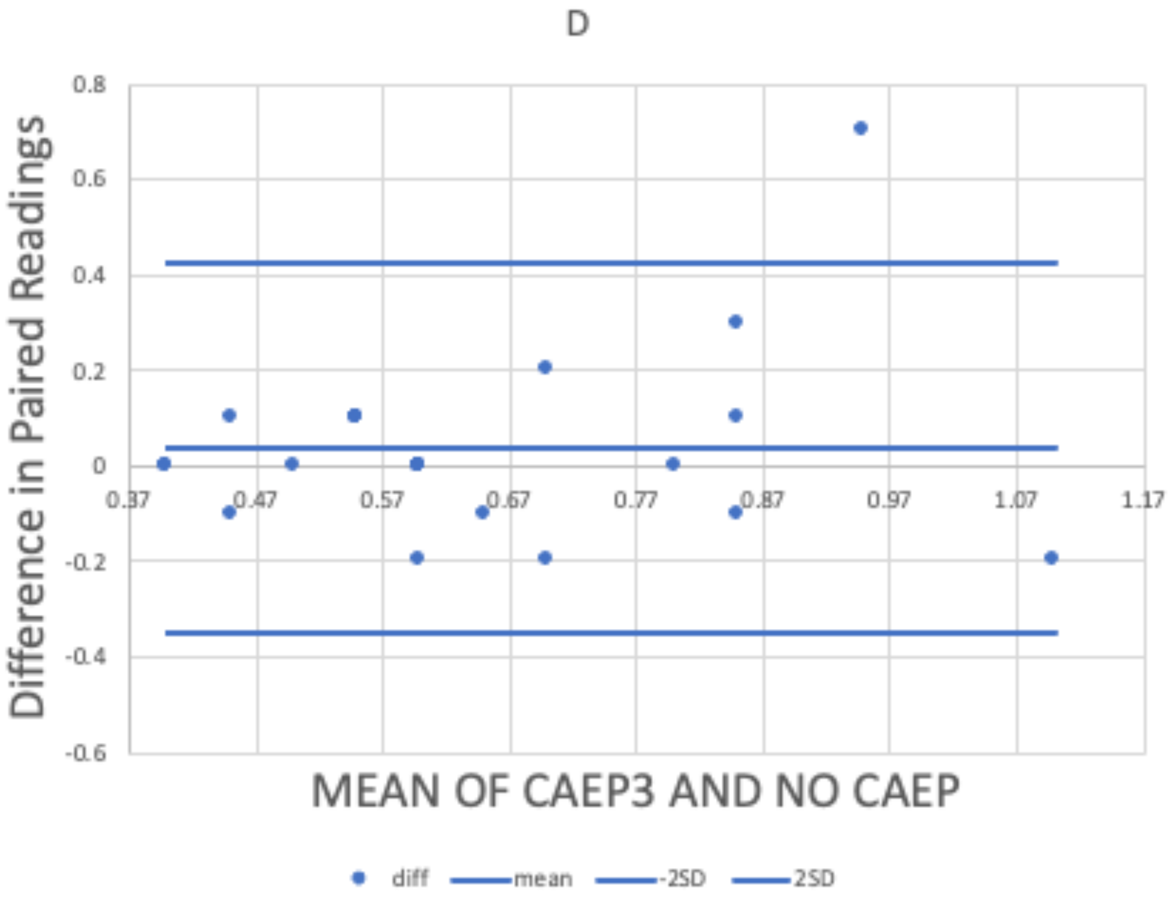
b)


B
Difference in Paired Readings
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0.37
0.47
0.57
0.67
0.77
0.87
0.97
1.07
1.17
1.27
MEAN OF CAEP1 AND NO CAEP
diff
mean
-2SD
2SD

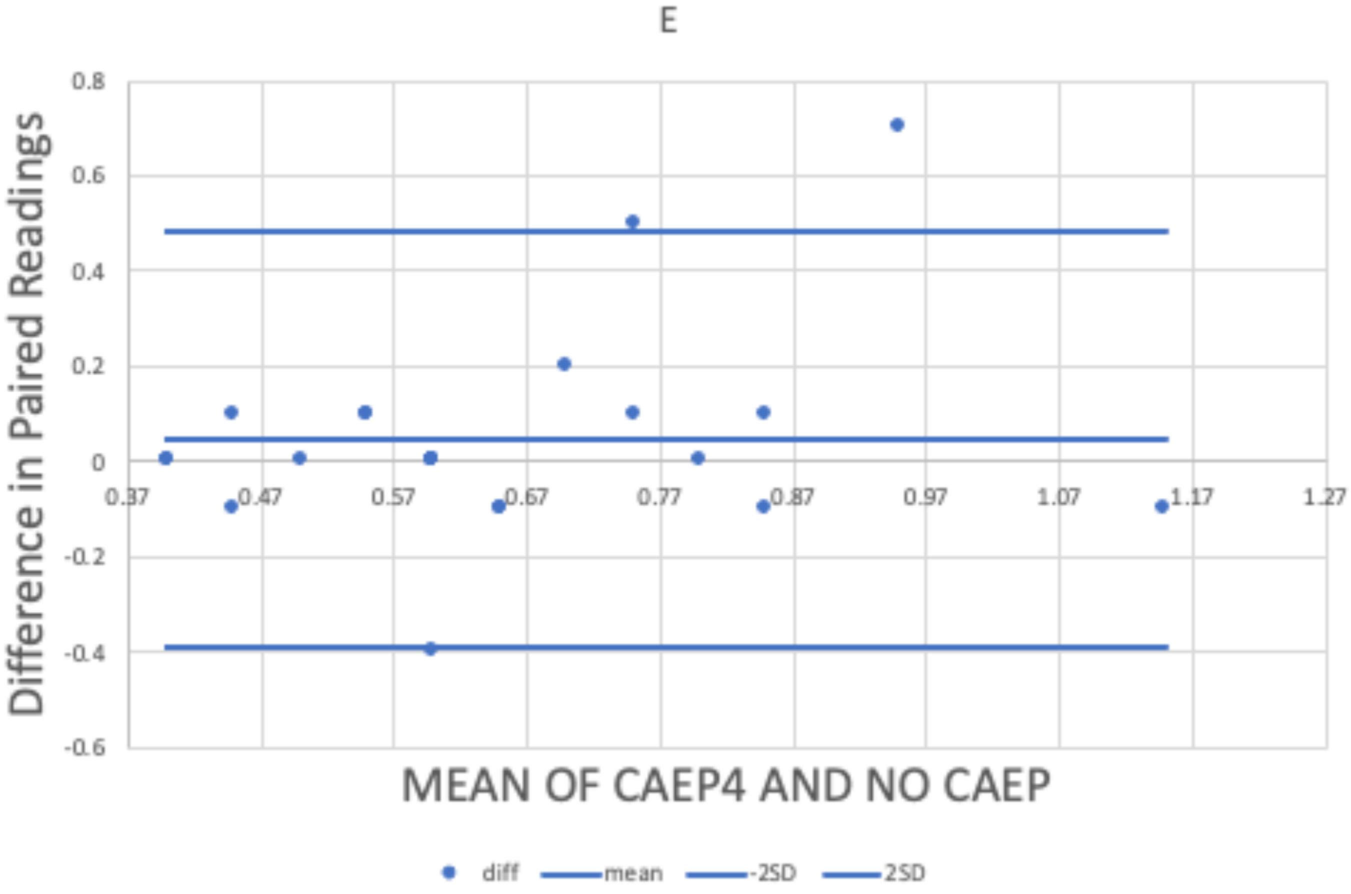
c)


C
Difference in Paired Readings
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
MEAN OF CAEP2 AND NO CAEP
diff
mean
-2SD
2SD

d)


D
Difference in Paired Readings
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.37
0.47
0.57
0.67
0.77
0.87
0.97
1.07
1.17
MEAN OF CAEP3 AND NO CAEP
diff
mean
-2SD
2SD

e)


E
Difference in Paired Readings
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.37
0.47
0.57
0.67
0.77
0.87
0.97
1.07
1.17
1.27
MEAN OF CAEP4 AND NO CAEP
diff
mean
-2SD
2SD

Input Dynamic Range and Frequency Response

- Input dynamic range requirement specifies the mean signal level (if not 0), the range of differential signal, and the fastest acceptable amplitude rate of change (aka slew rate)
- Frequency response requirement typically specifies the frequency bandwidth in terms of the cutoff frequency at which the magnitude of the harmonics has fallen to a significant fraction of the fundamental frequency magnitude
  - The specific fraction is a medical device design choice

Noise Sources

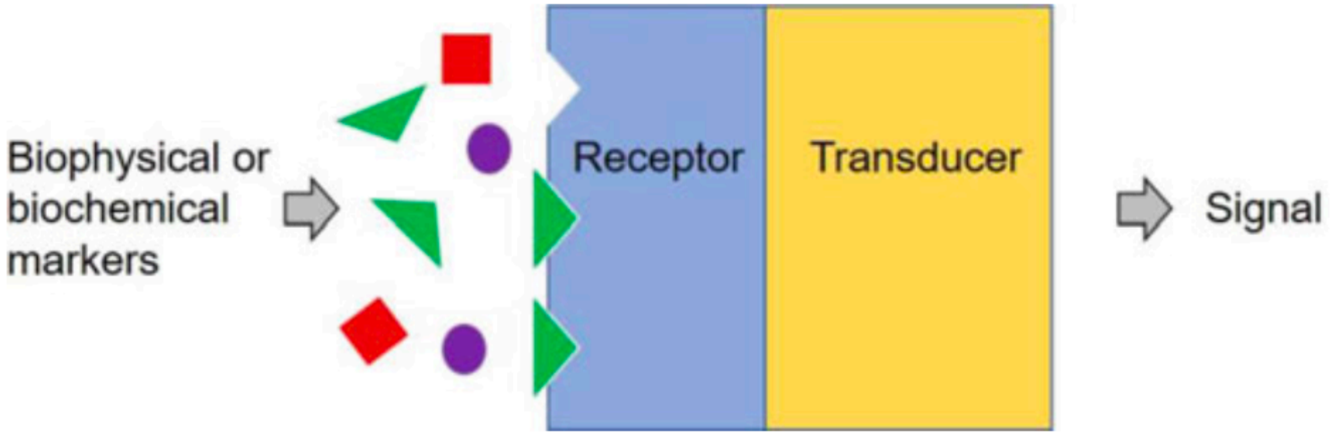
- System noise refers to any artifact we would like to minimize
  - Older monitors have 60-Hz noise from power lines
  - EM interference from surgical cautery equipment
  - Patient motion
  - Respiration and blood pressure

- Can model system noise:

$$\boldsymbol{y}(k) = \boldsymbol{u}(k) + \boldsymbol{n}(k)$$

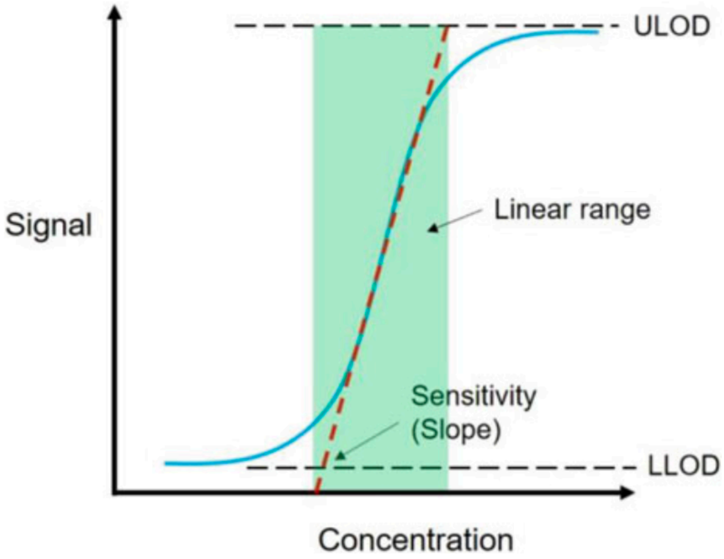
Biosenser

- The basic units of a biosensor are receptor and transducer. The receptor comes in close contact with the analyte and the chemical/physical interactions between the two are translated into a measurable signal by the transducer (Fig. 2.1).



Characteristics of Biosensors

- Limit of Detection (LOD)
  - minimum amount or concentration of the analyte that can be detected
- Detection Range
  - reflection of how much change caused by the external stimuli can be measured



Characteristics of Biosensors

- Sensitivity
  - ratio between the output signal and the input measured property
- Selectivity
  - indicates the sensor's ability to differentiate one analyte from another

Characteristics of Biosensors

- Reproducability
  - ability of the sensor to generate identical results when it is measuring the same level of external stimuli
- Stability
  - ability to maintain the same level of output signal under various environmental disturbances
- Biocompatibility
  - level of compatibility of the material/device with living tissue
    - Toxicity of materials, ractivity with living tissue, mechanical compatibility, biodegradability

Big Ideas

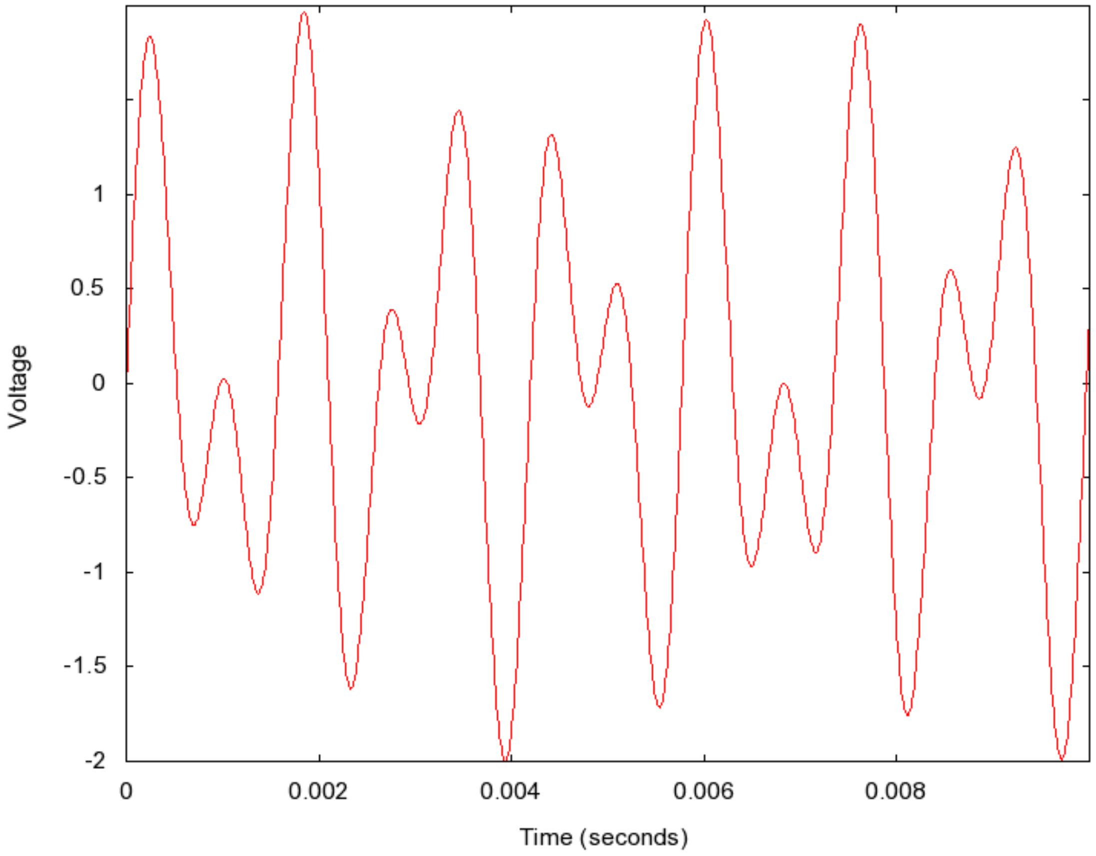
- System block diagrams help break down system into subsystems and individual components
- Sensors convert measurand into electrical signal
  - Accuracy, bias and precision
  - Bland-Altman analysis
  - Dynamic range, frequency response, and noise
- Biosensors
  - Receptor and transducer
  - Characteristics for robustness

ESE 3400 Lab 2

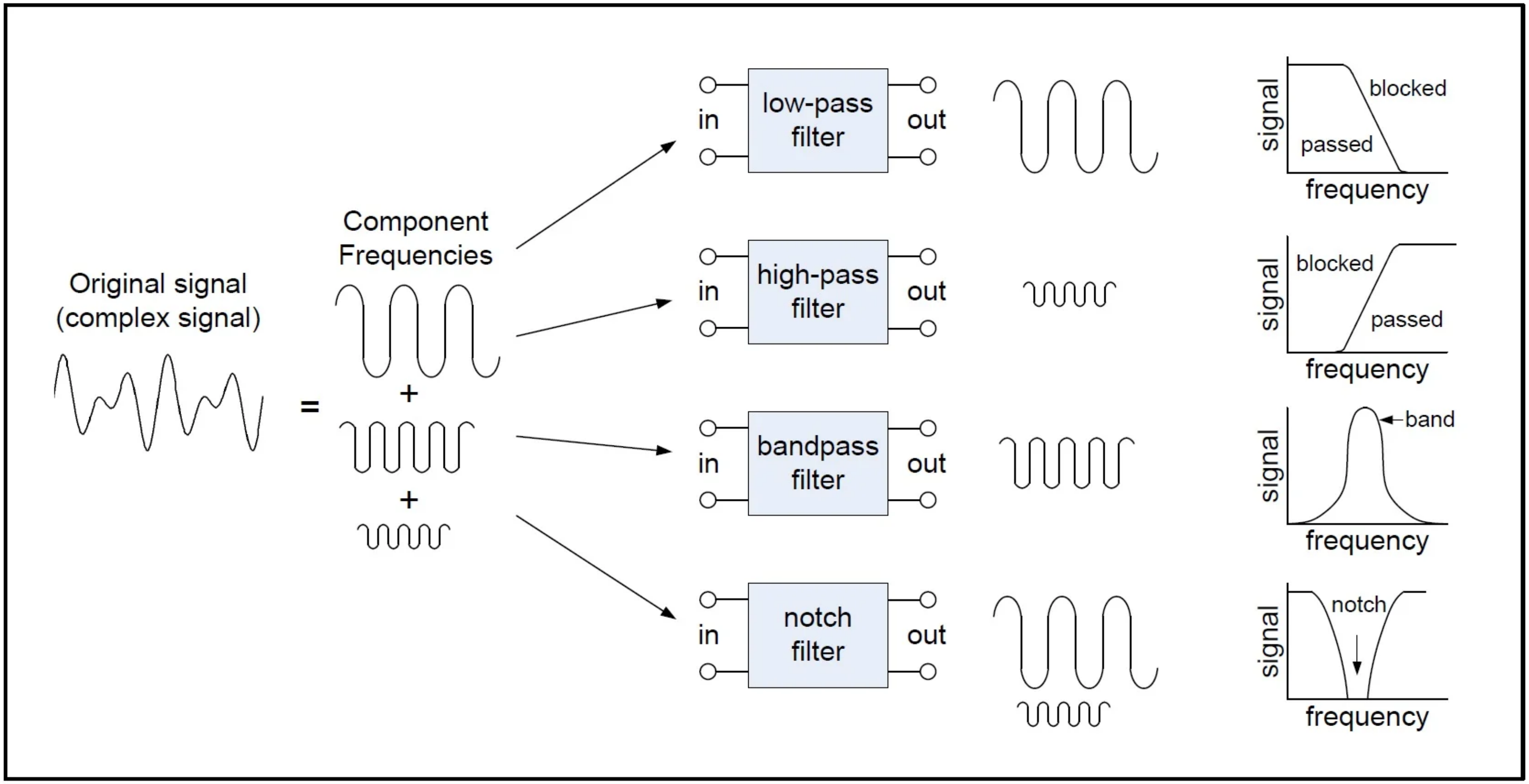
Filters

Time vs. Frequency domains

- Signals like this one are the combination of many sine waves at different frequencies
- Using the time domain is limiting for this reason

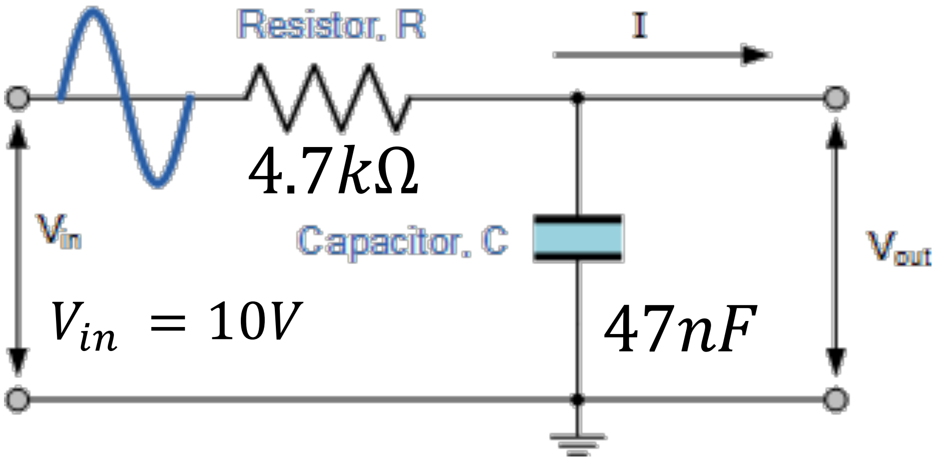


Four Basic Filters



allaboutcircuits.com

What is the frequency response of this circuit?



$4.7k\Omega$

$V_{in} = 10V$

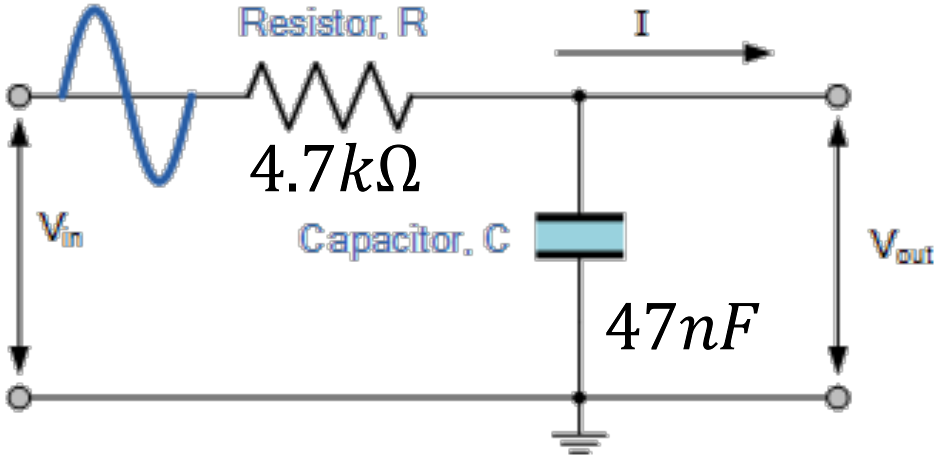
$47nF$

$$X_C = \frac{1}{2\pi f C}$$

$$Z = \sqrt{R^2 + {X_C}^2}$$

$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + {X_C}^2}} = V_{in}\,\frac{X_C}{Z}$$

What is the frequency response of this circuit?



$V_{in} = 10V\ at\ 100Hz$

$$X_C = \frac{1}{2\pi f C}$$

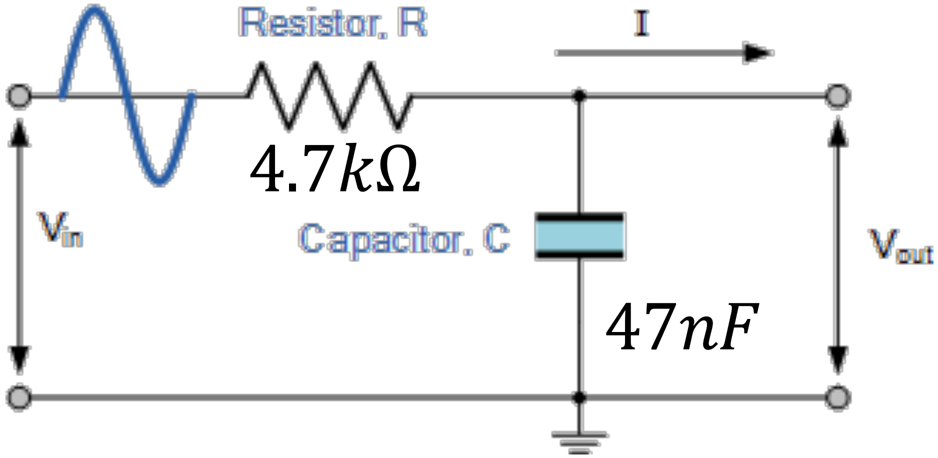
$$Z = \sqrt{R^2 + {X_C}^2}$$

$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + {X_C}^2}} = V_{in}\,\frac{X_C}{Z}$$

$$V_{out} = 10\times \frac{33{,}863}{\sqrt{(4700)^2 + (33{,}863)^2}}$$

$$= 9.9V$$

What is the frequency response of this circuit?



$V_{in} = 10V \; at \; 10kHz$

$$X_C = \frac{1}{2\pi f C}$$

$$Z = \sqrt{R^2 + {X_C}^2}$$

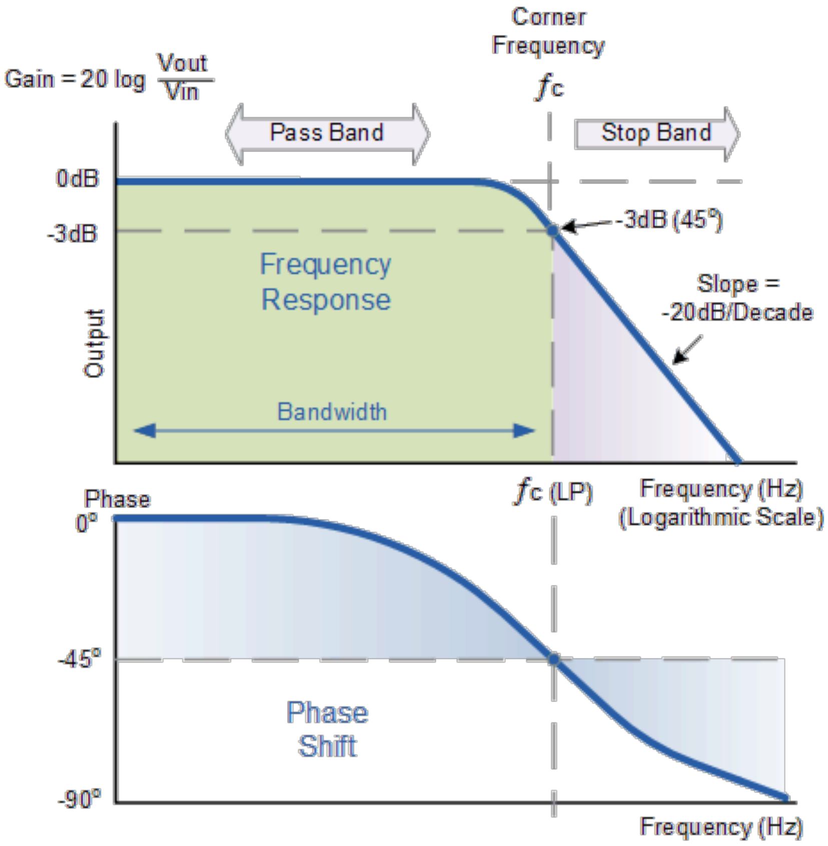
$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + {X_C}^2}} = V_{in}\,\frac{X_C}{Z}$$

$$V_{out} = 10 \times \frac{338.6}{\sqrt{(4700)^2 + (338.6)^2}}$$

$$= .72V$$

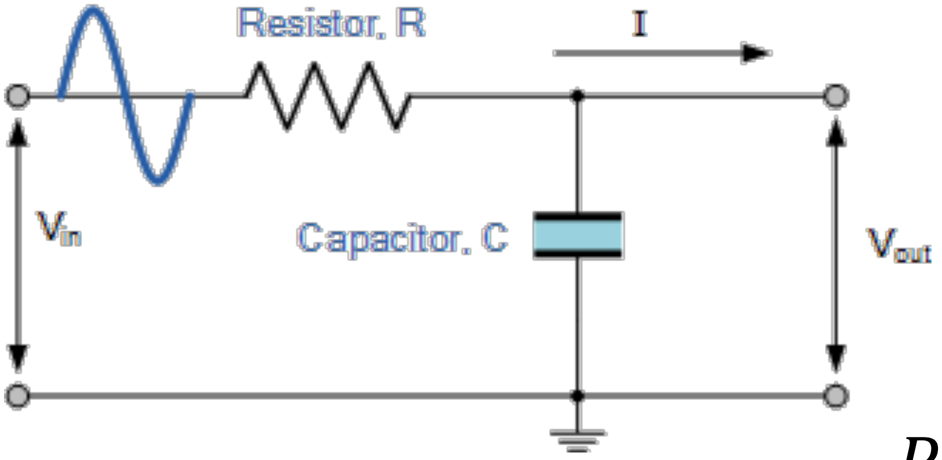
Frequency response of a low pass filter

- ❑ Gain
- ❑ Bandwidth
- ❑ Pass band vs stop band
- ❑ Corner frequency
- ❑ 3dB point
- ❑ Roll off



https://www.electronics-tutorials.ws/filter/filter_2.html

Back to the previous example



$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 4.7k\Omega \times 47nF}$$

$$f_c = 720Hz$$

$$Phase\ shift\ \varphi = -\tan^{-1}(2\pi fRC)$$

$$\varphi = -45° \ at\ 720Hz$$

At f_c, $20\log({}^{V_{in}}/_{V_{out}}) = 70.7\%$ of the input

Admin

- Submit Lab 1 deliverables in Canvas by next lab day at midnight
- Filters lab tomorrow