Principles of Communications
ECS 332

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4.5 AM

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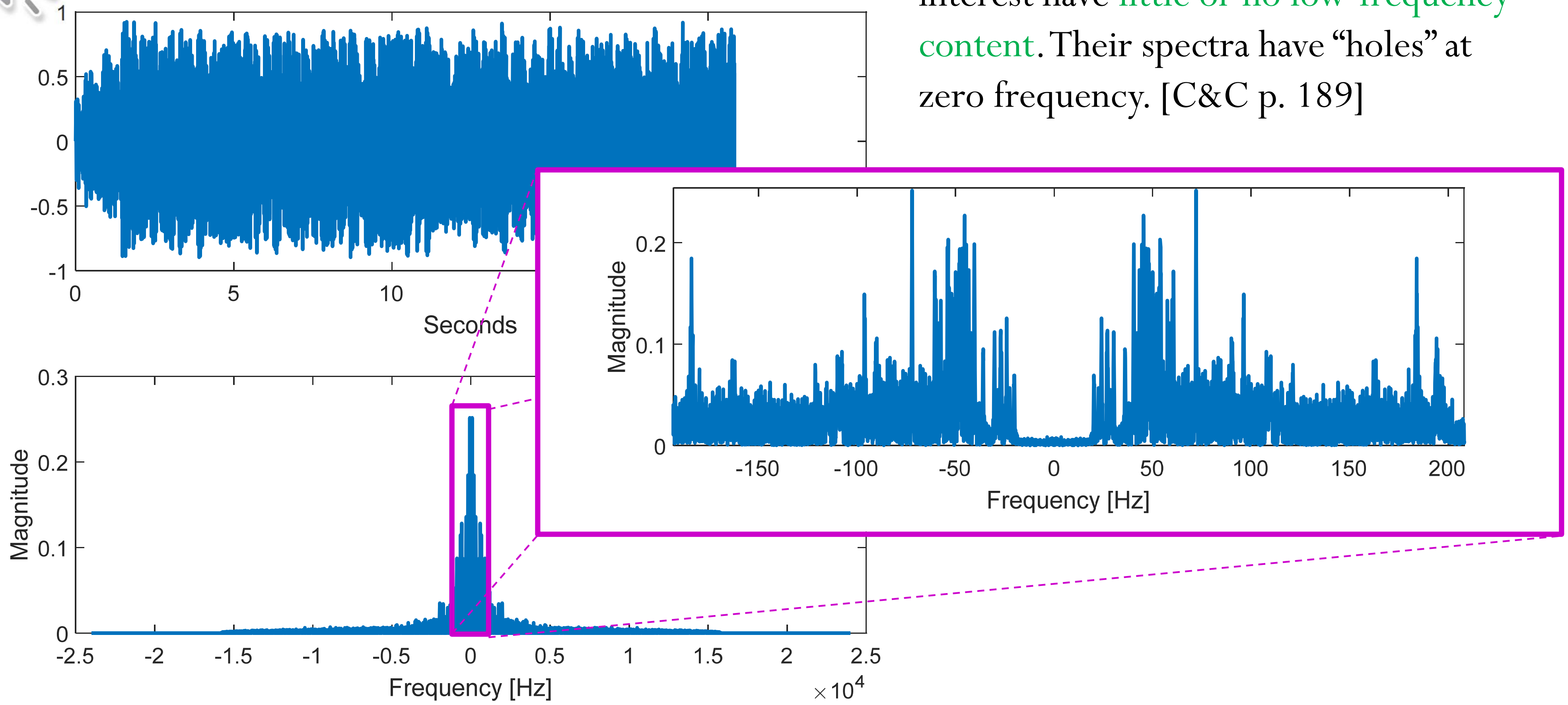
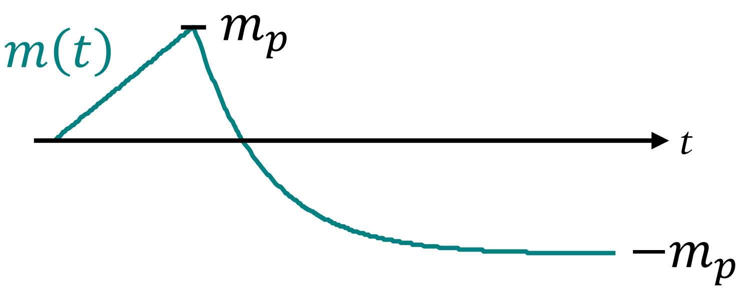
Remark:

Many modulating signals of practical interest have little or no low-frequency content. Their spectra have “holes” at zero frequency. [C&C p. 189]



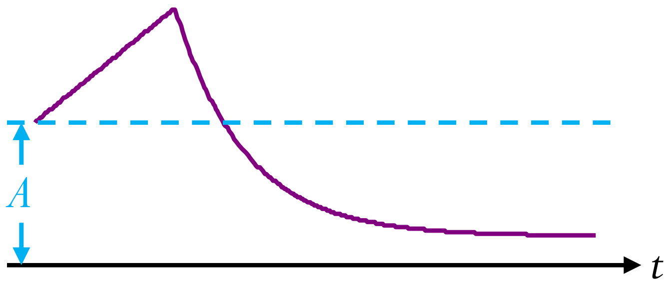
AM Review [Figure 27]



Assumptions

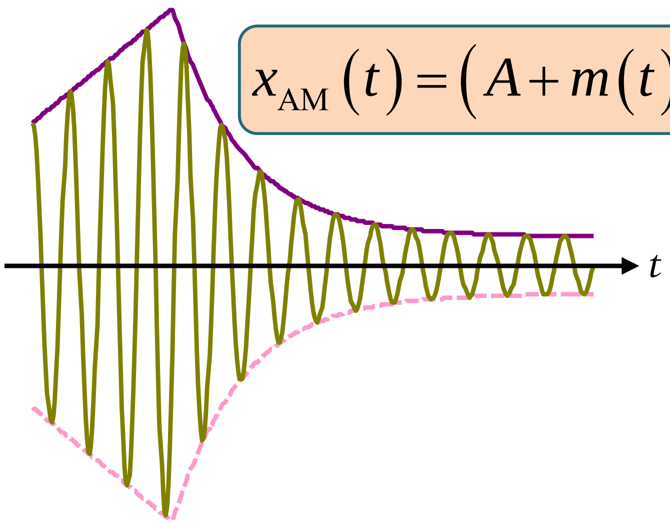
- $|M(f)| = 0$ for $|f| > B$
- $|m(t)| \leq m_p$

Case (a) $A + m(t) > 0$ for all t



Modulation index:

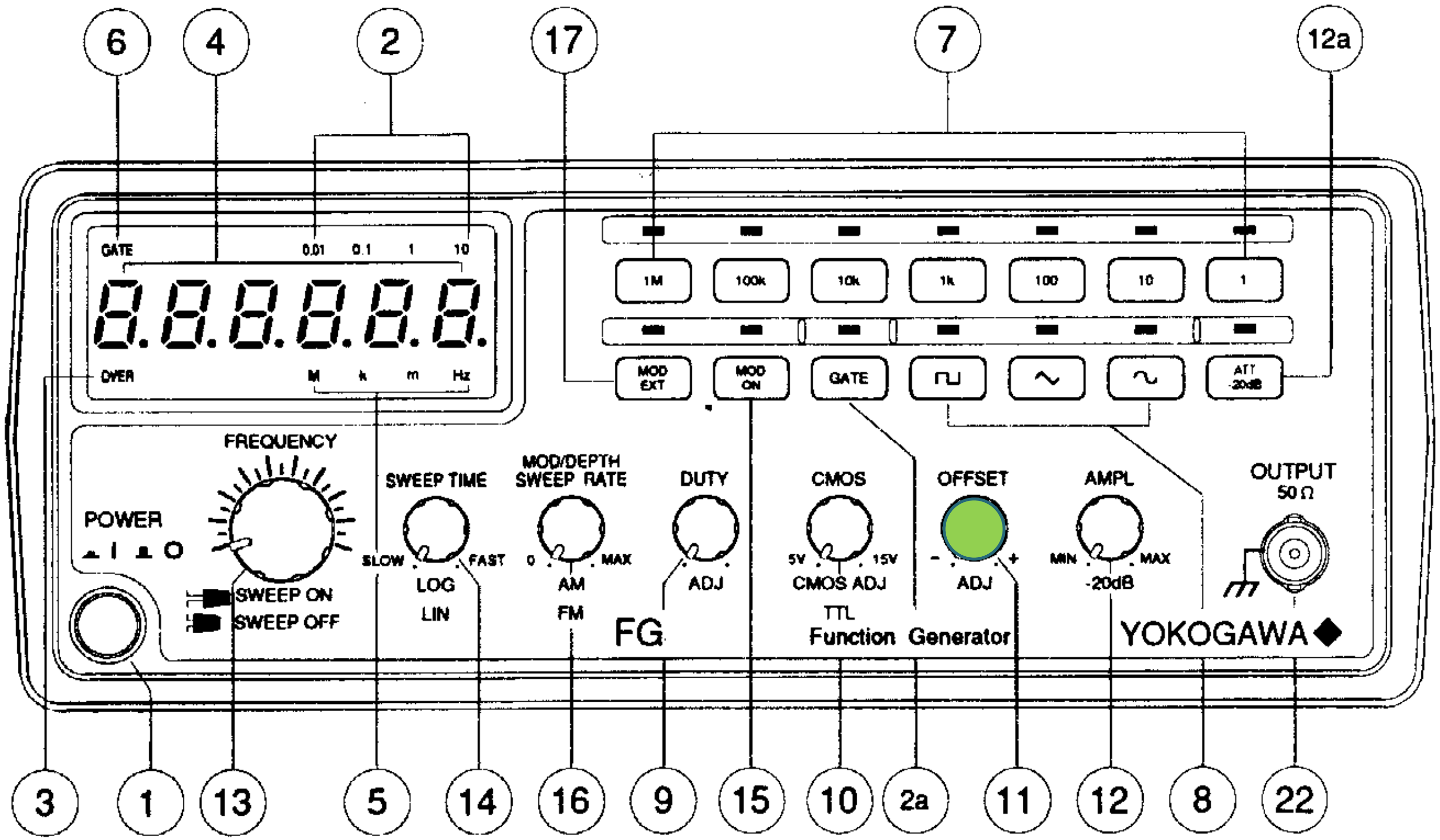
$$\mu = \frac{m_p}{A}$$



$$x_{AM}(t) = \left(A + m(t)\right)\cos\left(2\pi f_c t\right) = \underbrace{A\cos\left(2\pi f_c t\right)}_{\text{carrier}} + \underbrace{m(t)\cos\left(2\pi f_c t\right)}_{\text{sidebands}}$$

[Slides from basic EE lab]

Adjusting the DC Offset

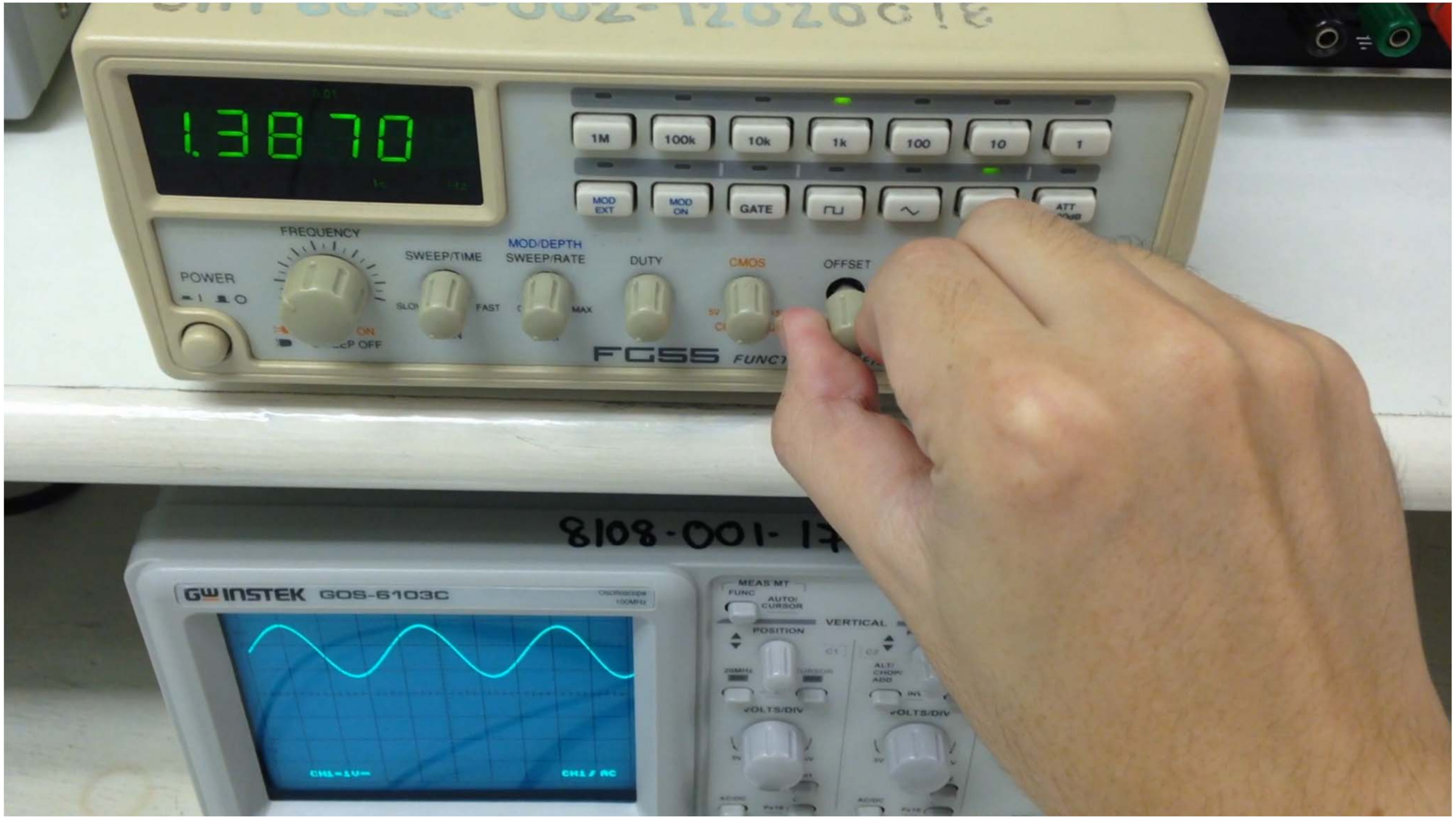


$$v_{out}(t) = v_{\text{no-offset}}(t) + V_{\text{Offset}}$$

Note: the ground level of the oscilloscope stays at the same place on the screen.

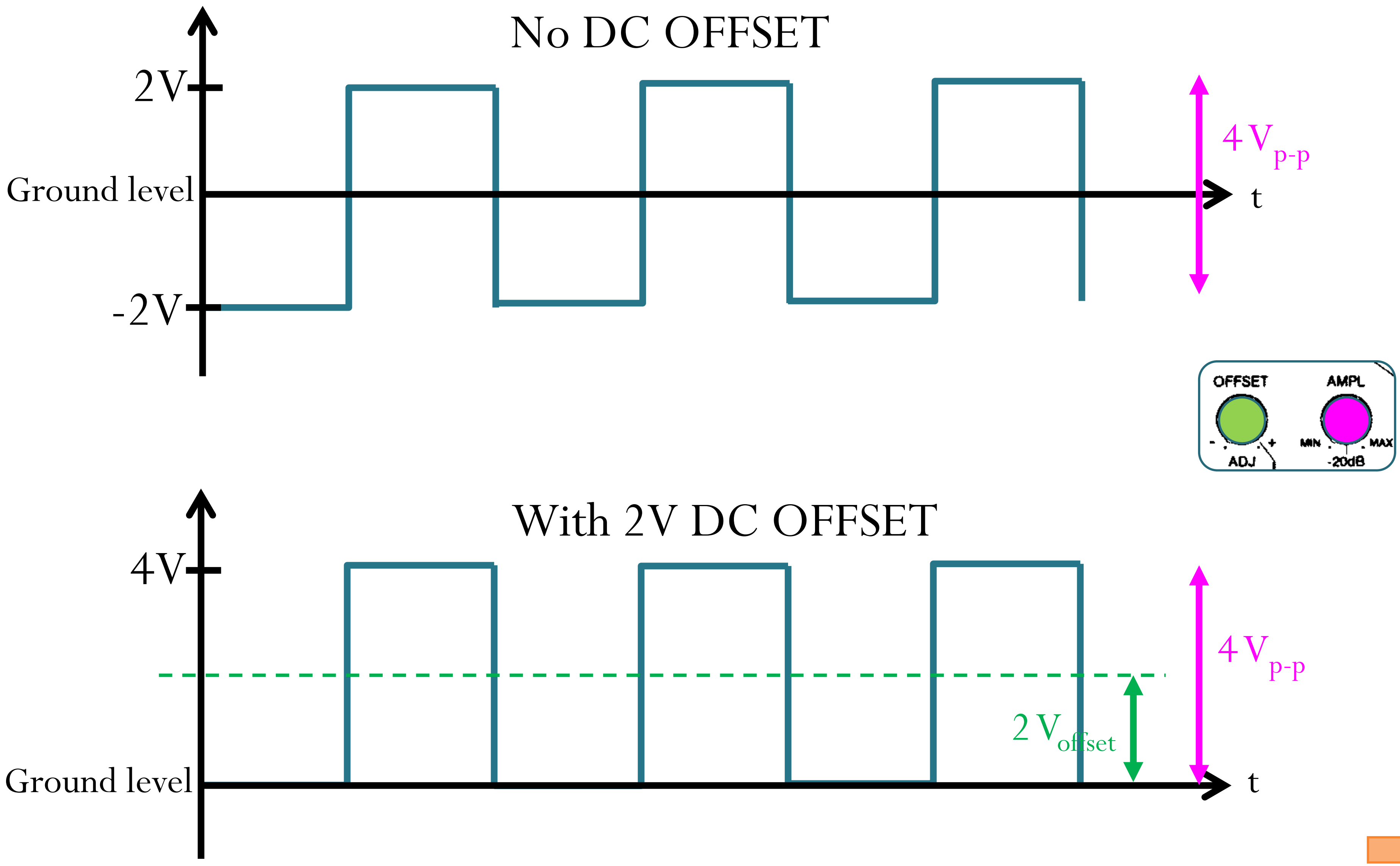
[Slides from basic EE lab]

Adjusting the DC Offset

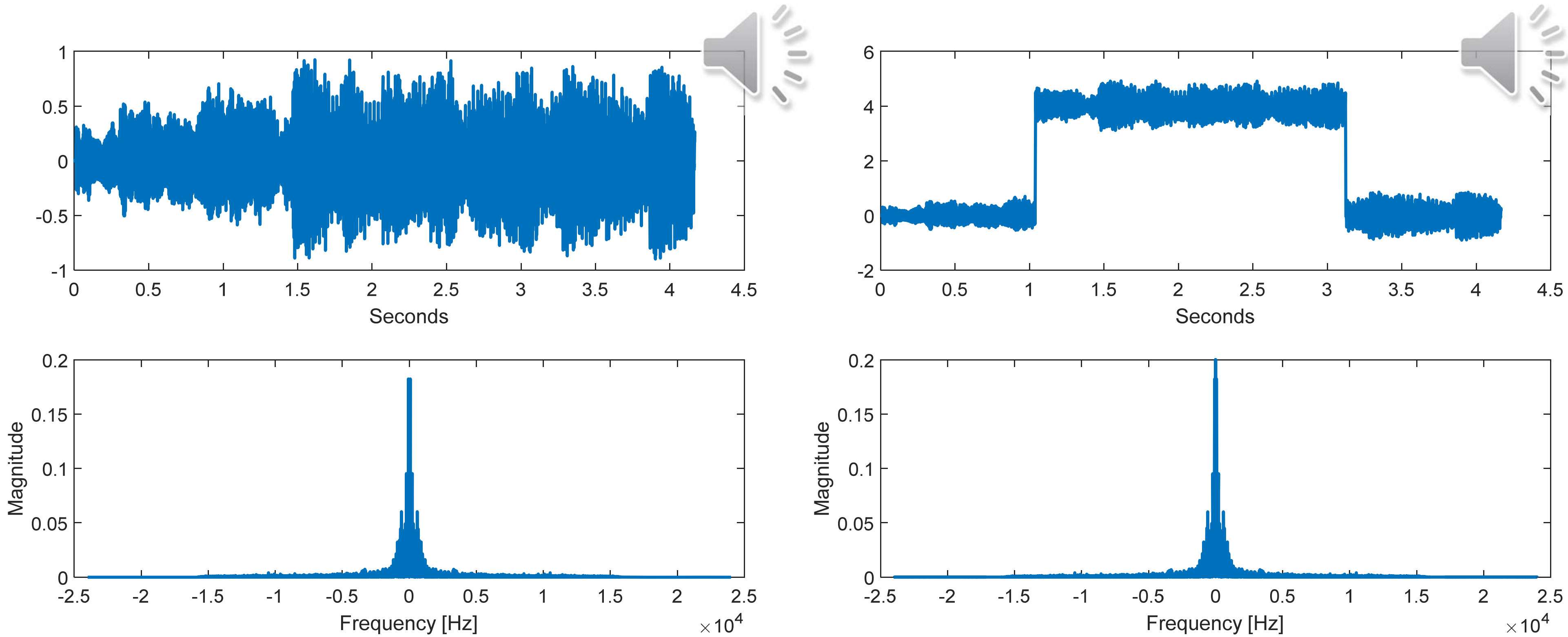


[Slides from basic EE lab]

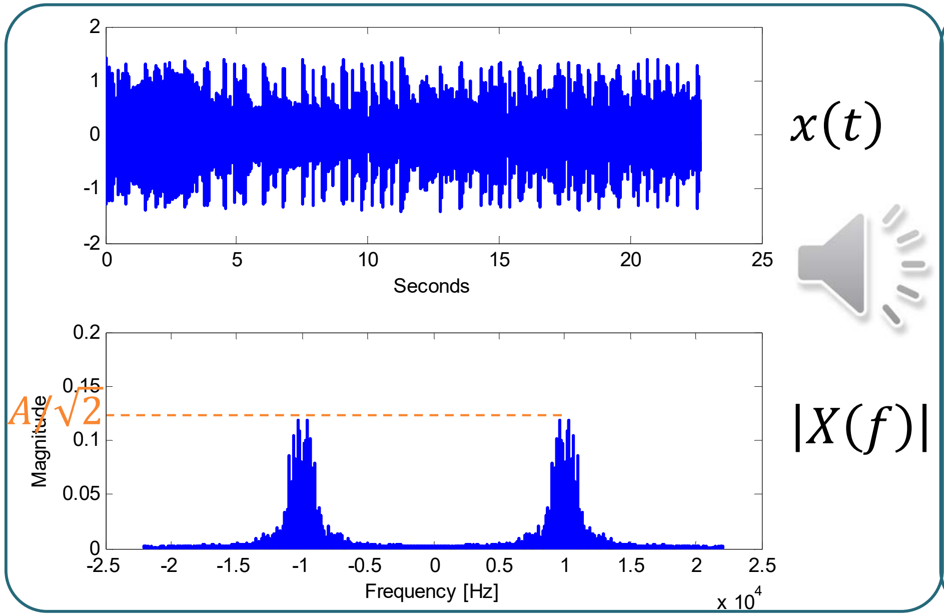
4 $V_{p\text{-}p}$ Square Wave



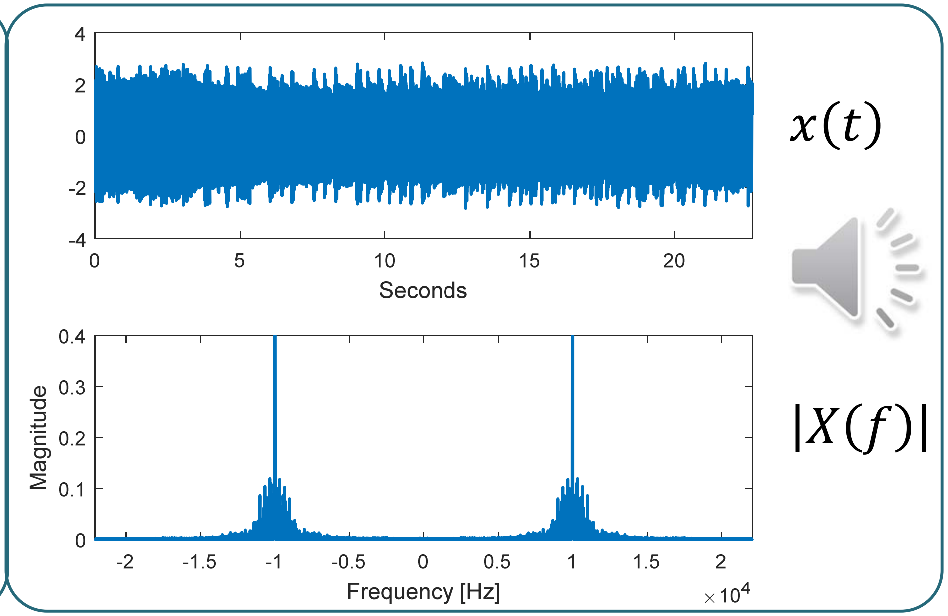
Effect of DC Shift on Audio



DSB-SC vs. AM



Seconds
Frequency [Hz]
Magnitude
x 10^4
$A/\sqrt{2}$
$x(t)$
$|X(f)|$



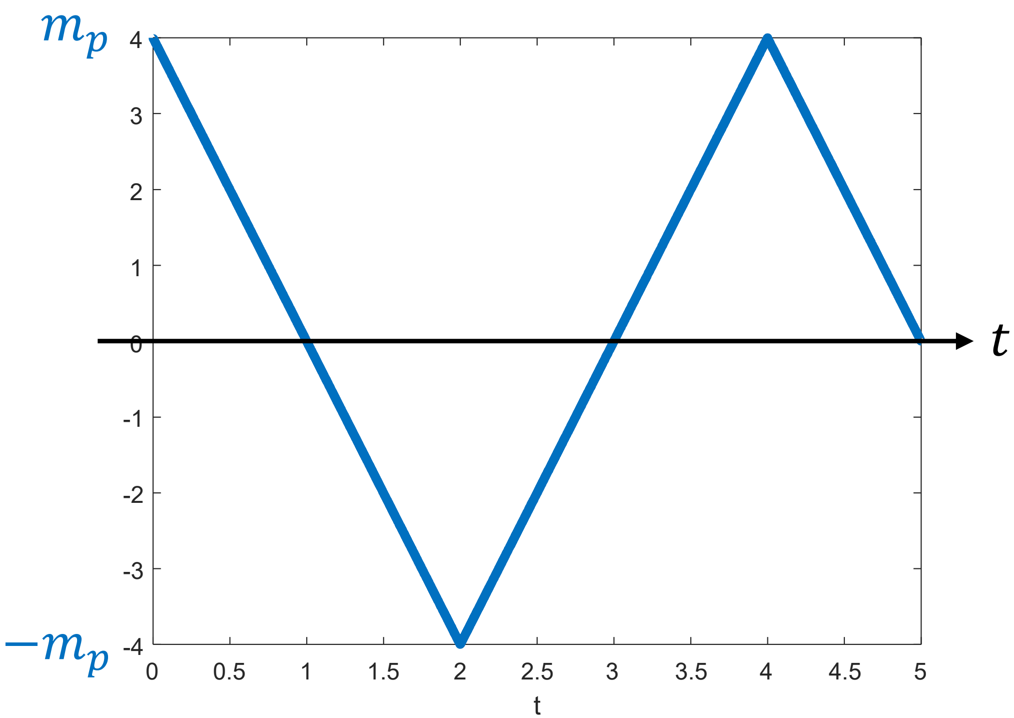
Seconds
Frequency [Hz]
Magnitude
×10^4
$x(t)$
$|X(f)|$

Example 4.67: Modulation Index μ

$\mu = 50\%$

$m(t)$

$x(t) = \left(A + m(t)\right)\cos(2\pi f_c t)$

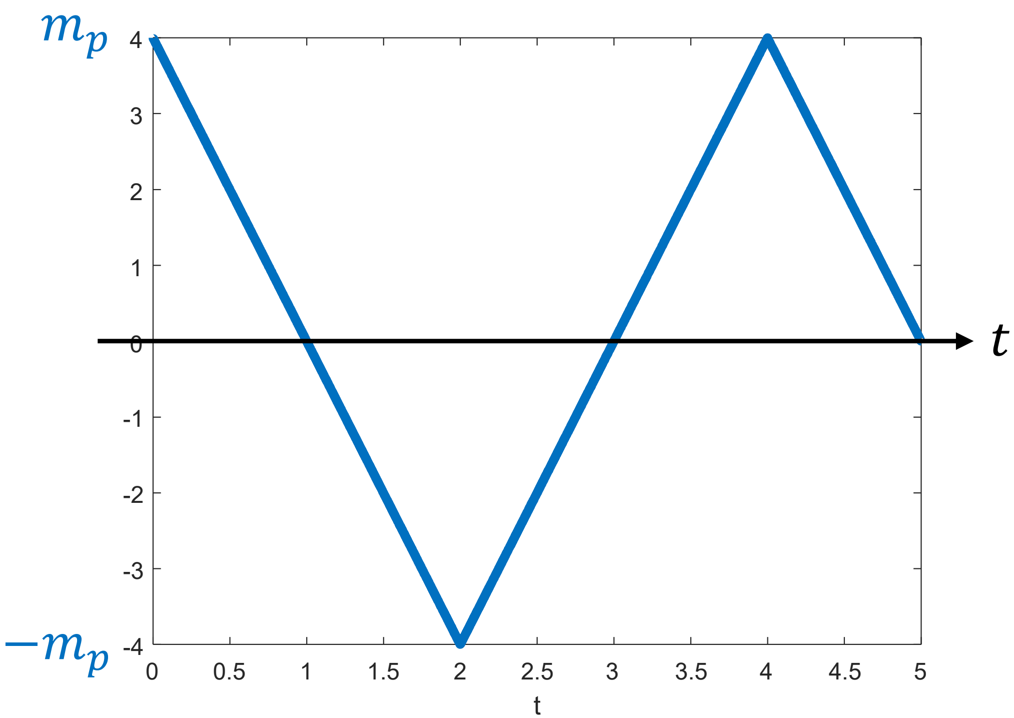


$m_p = 4$

$\mu = \frac{m_p}{A}$ ⇒ $A = \frac{m_p}{\mu} = \frac{4}{0.5} = 8$

Example: Modulation Index μ

$m(t)$



$\mu = 50\%$

$$x(t) = \underbrace{\left(A + m(t)\right)}_{g(t)} \cos(2\pi f_c t)$$

Recall that, to plot $g(t)\cos(2\pi f_c t)$, we first plot $g(t)$ and $-g(t)$, and then draw the oscillation between these two graphs.

$m_p = 4$

$$\mu = \frac{m_p}{A} \Rightarrow A = \frac{m_p}{\mu} = \frac{4}{0.5} = 8$$

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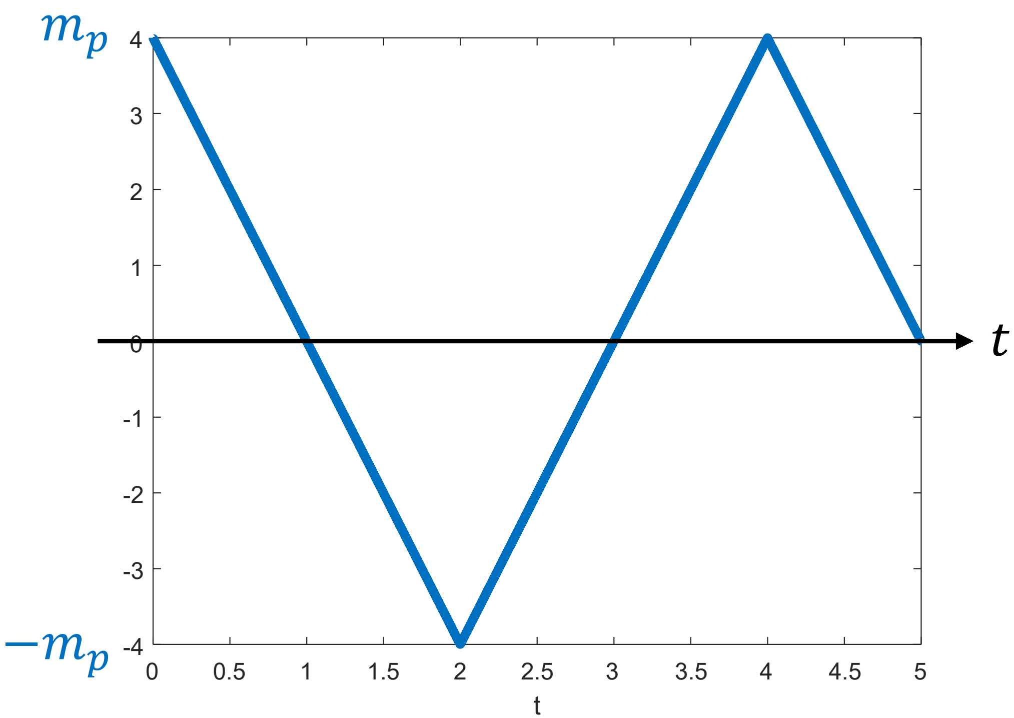

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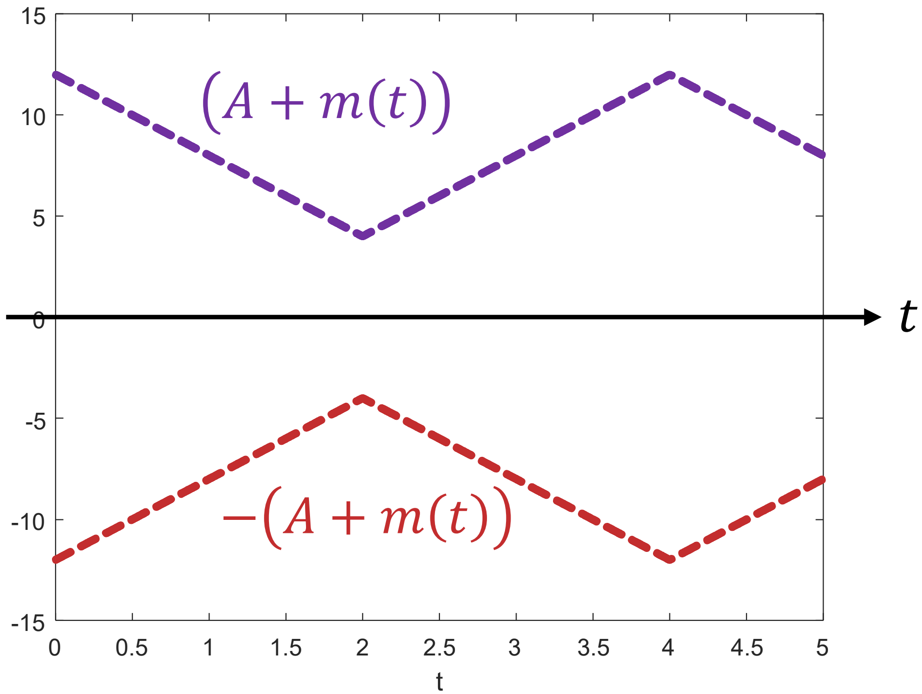

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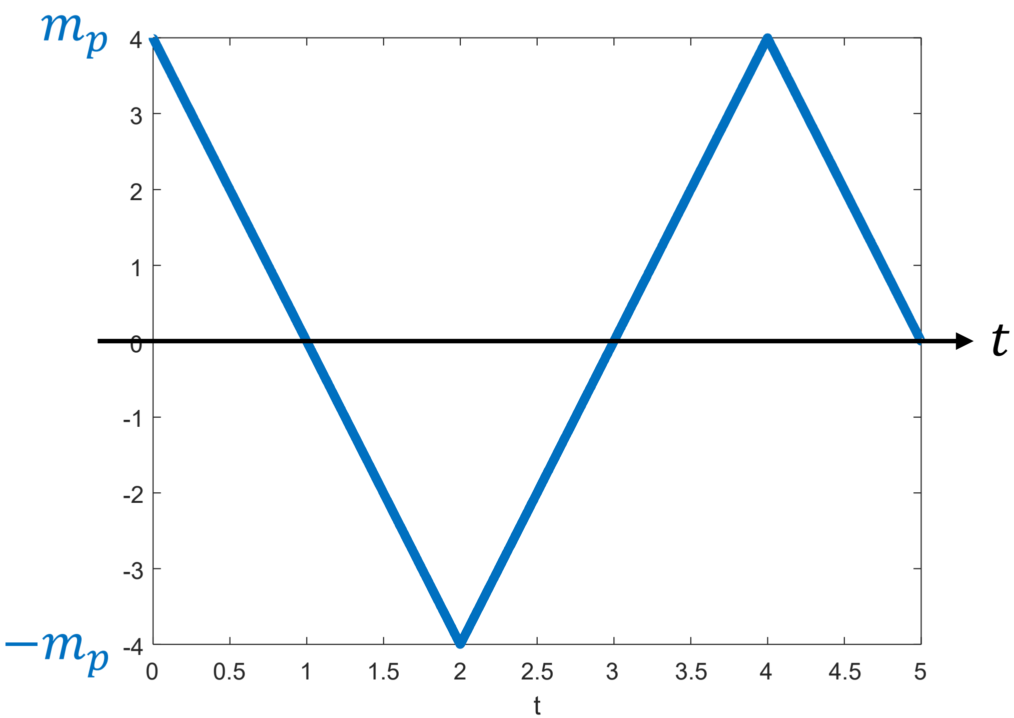

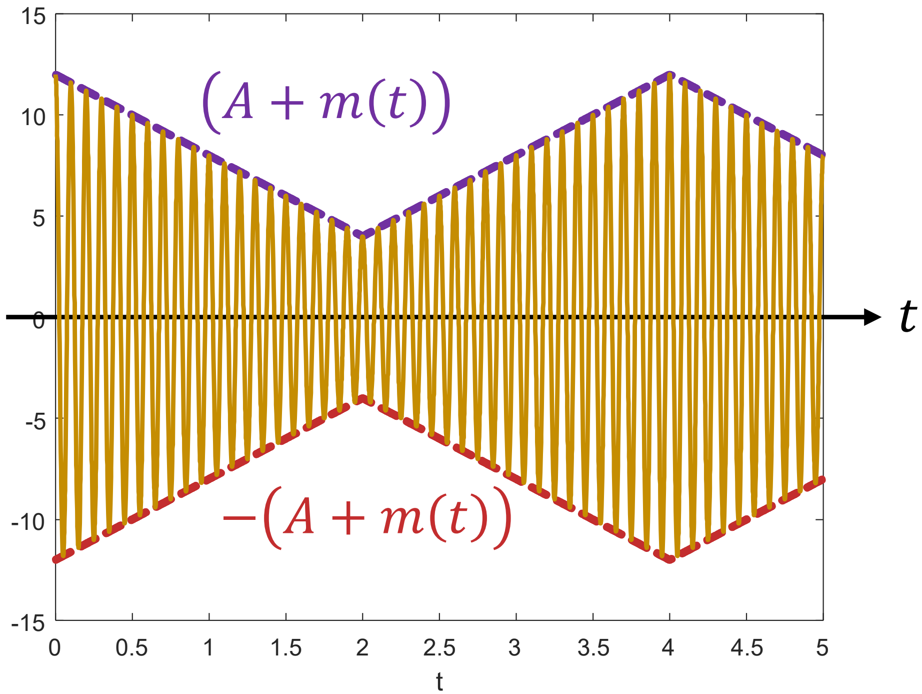

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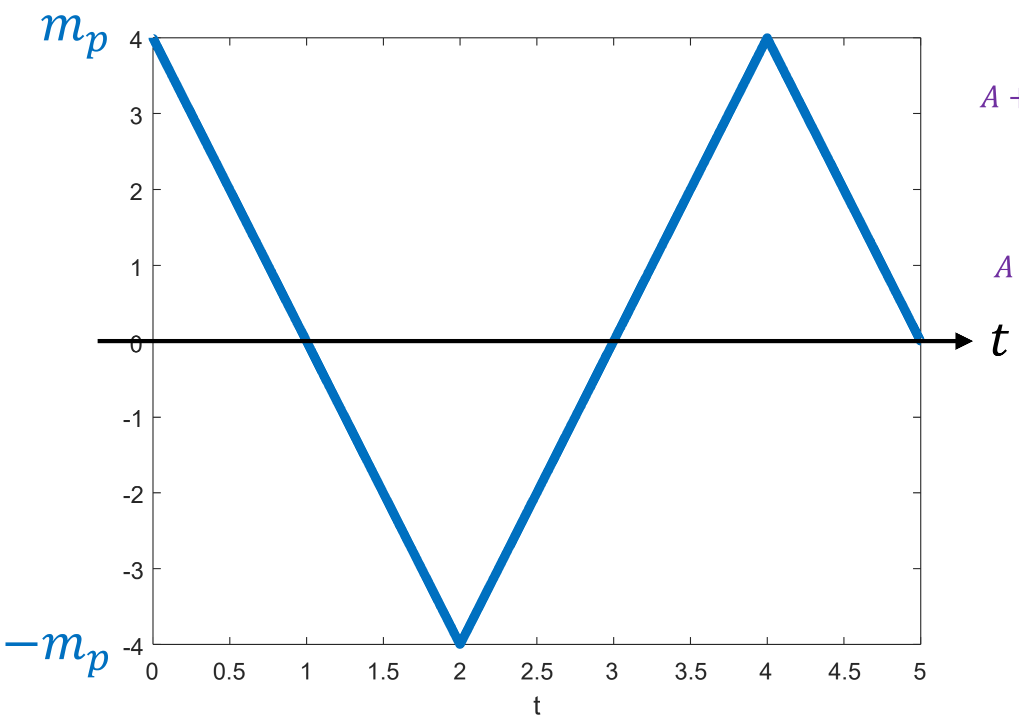

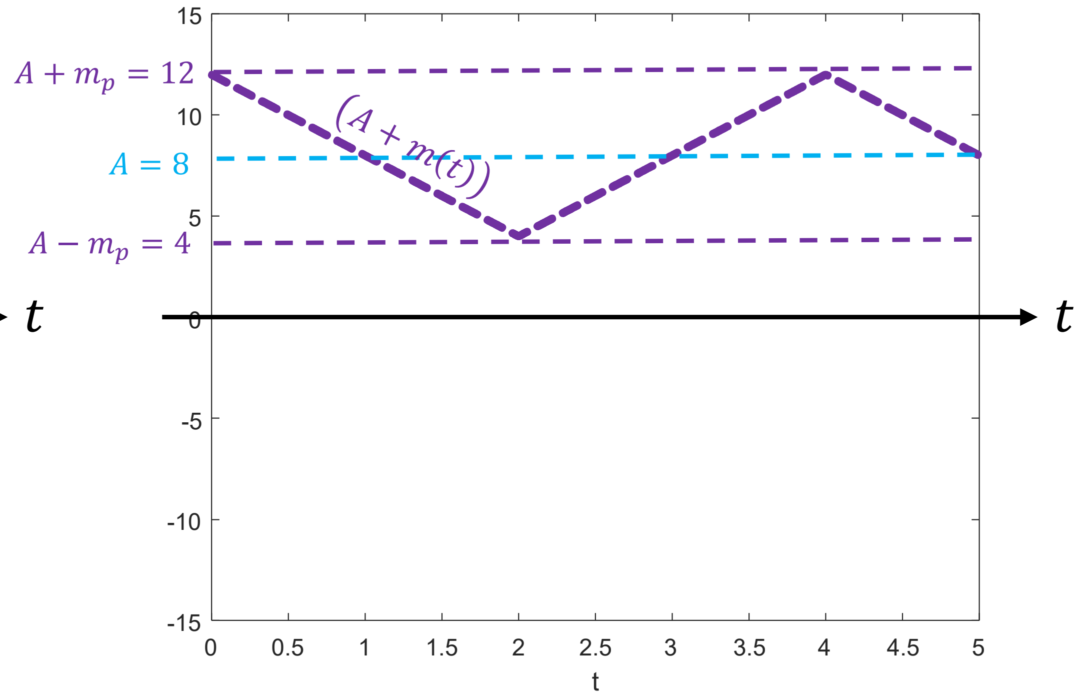

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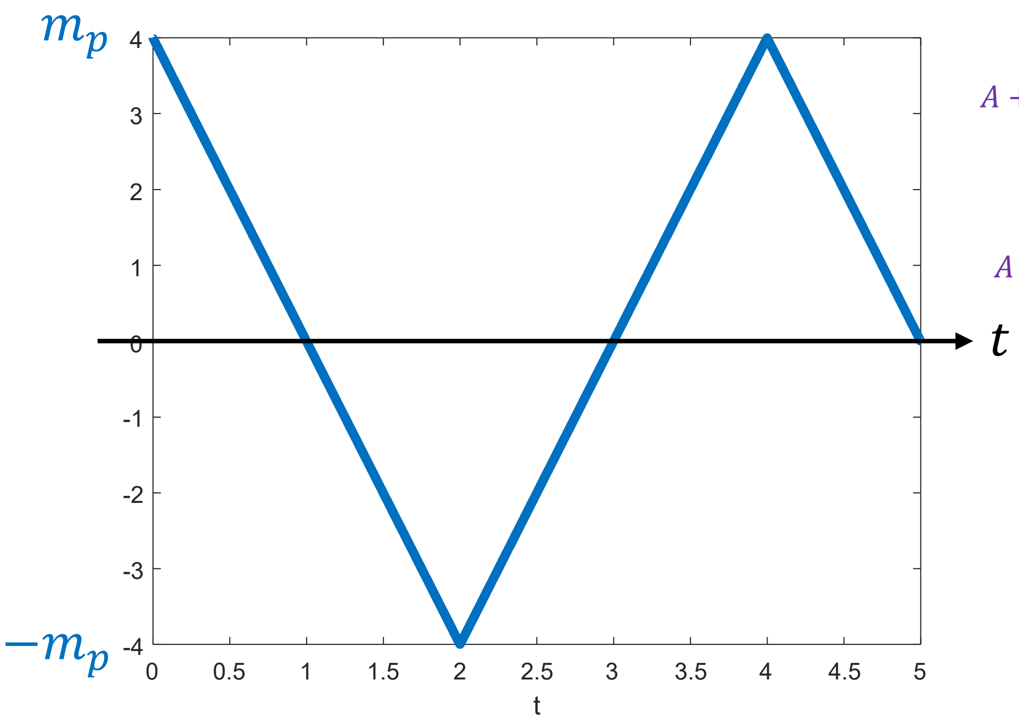

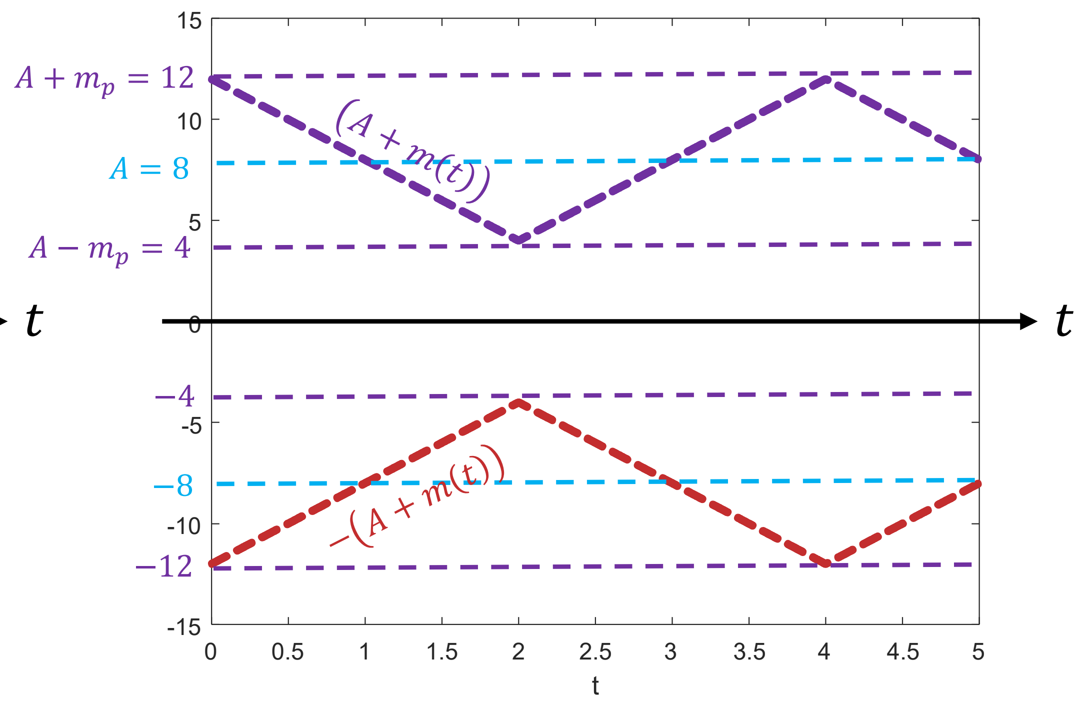

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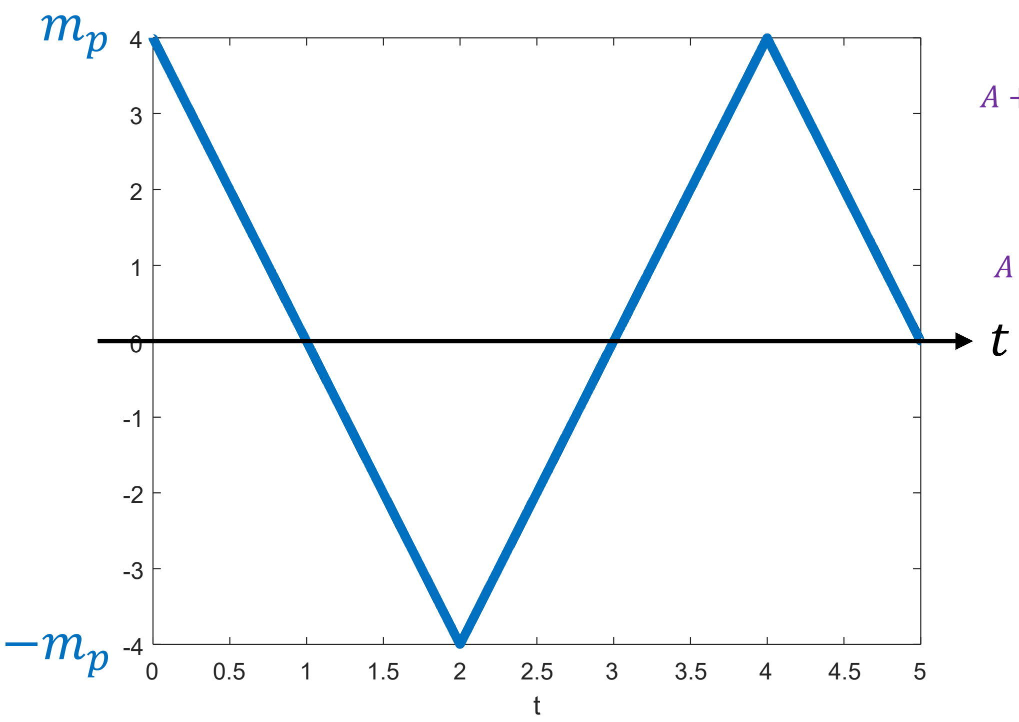
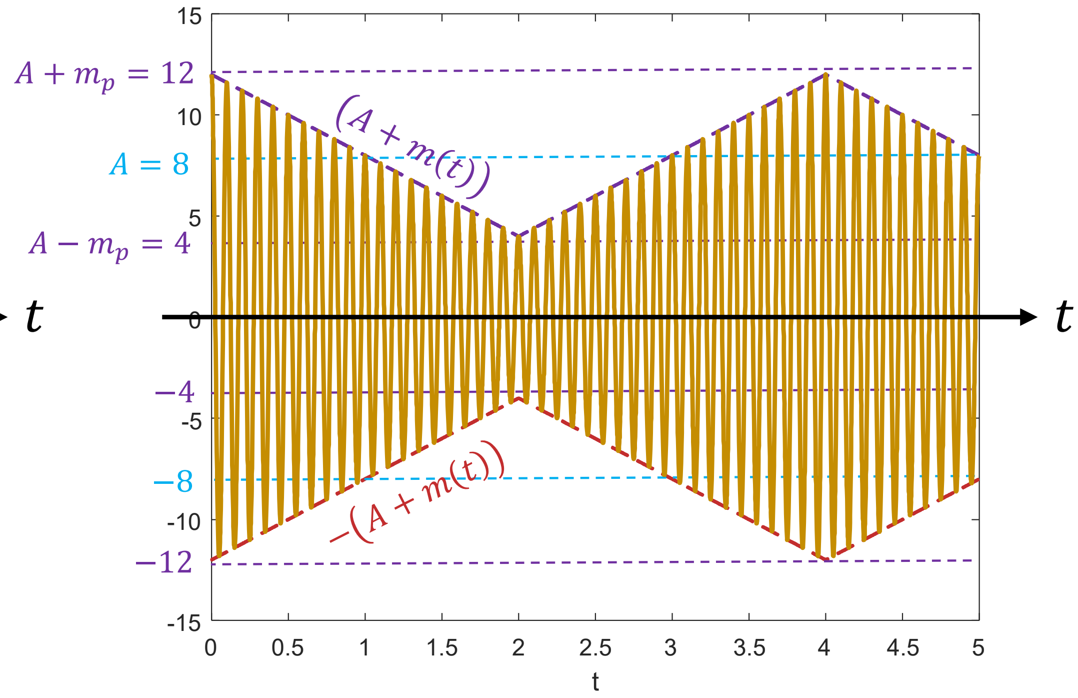




$m_p = 4$

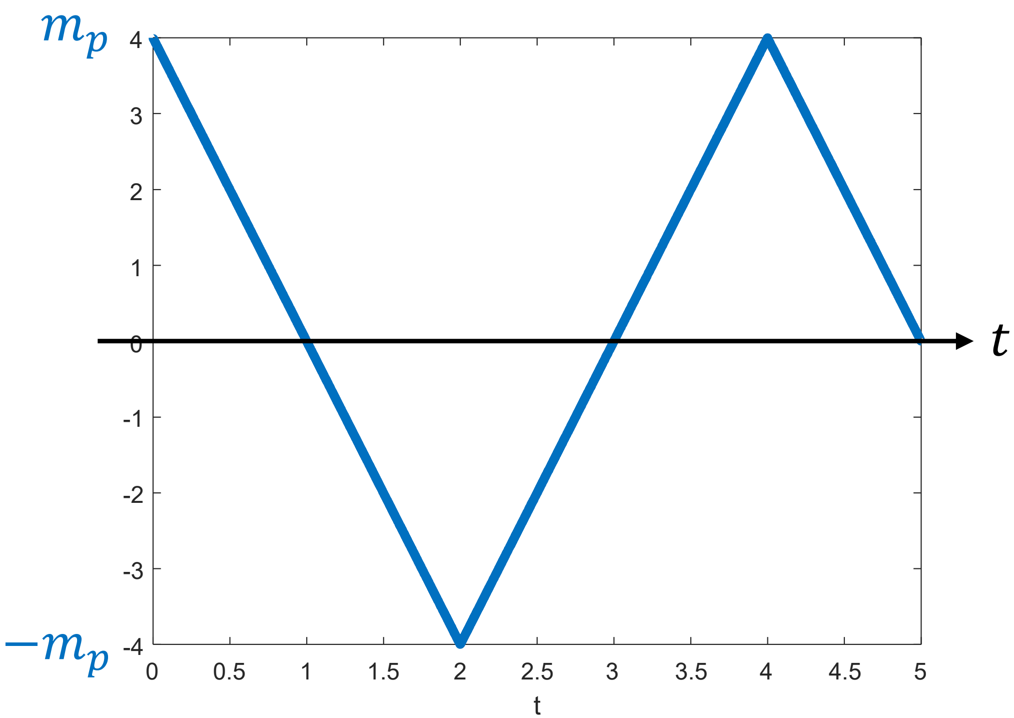
$\mu = \frac{m_p}{A}$ ⇒ $A = \frac{m_p}{\mu} = \frac{4}{0.5} = 8$

Example: Modulation Index μ

$\mu = 100\%$

$x(t) = \left(A + m(t)\right)\cos(2\pi f_c t)$

$m(t)$

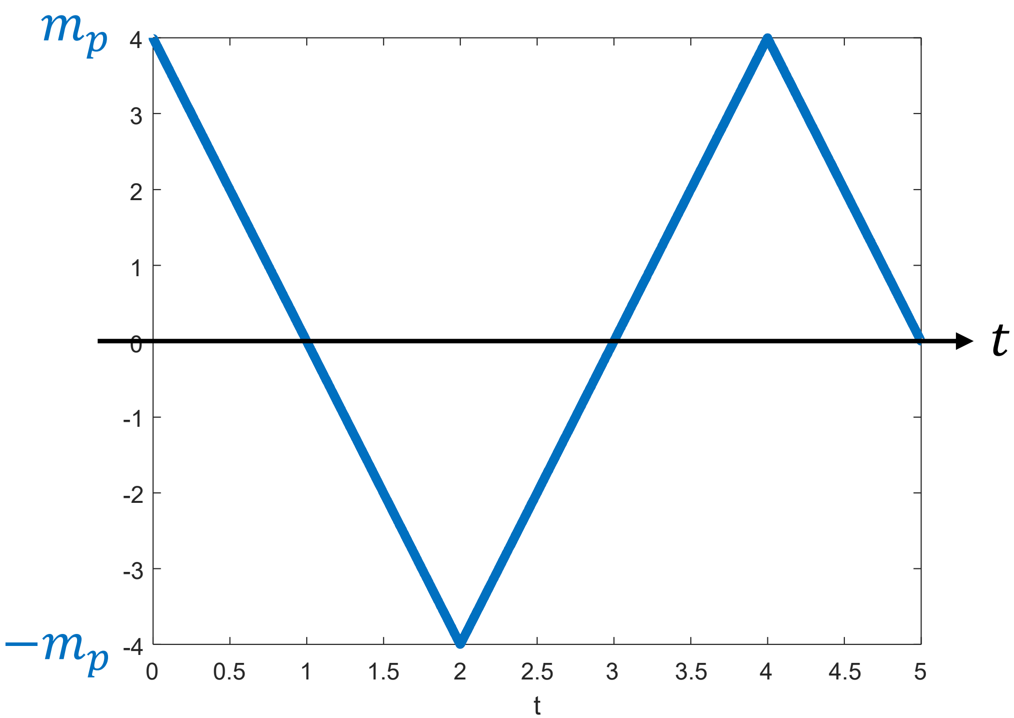


$m_p = 4$

$\mu = \frac{m_p}{A}$ ⇒ $A = \frac{m_p}{\mu} = \frac{4}{1} = 4$

Example: Modulation Index μ

$m(t)$



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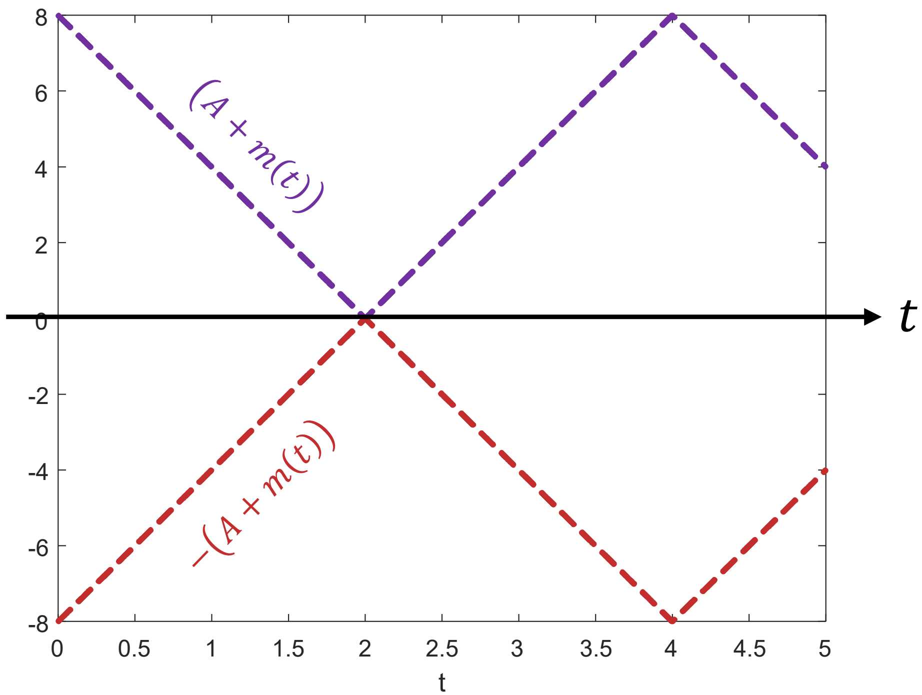


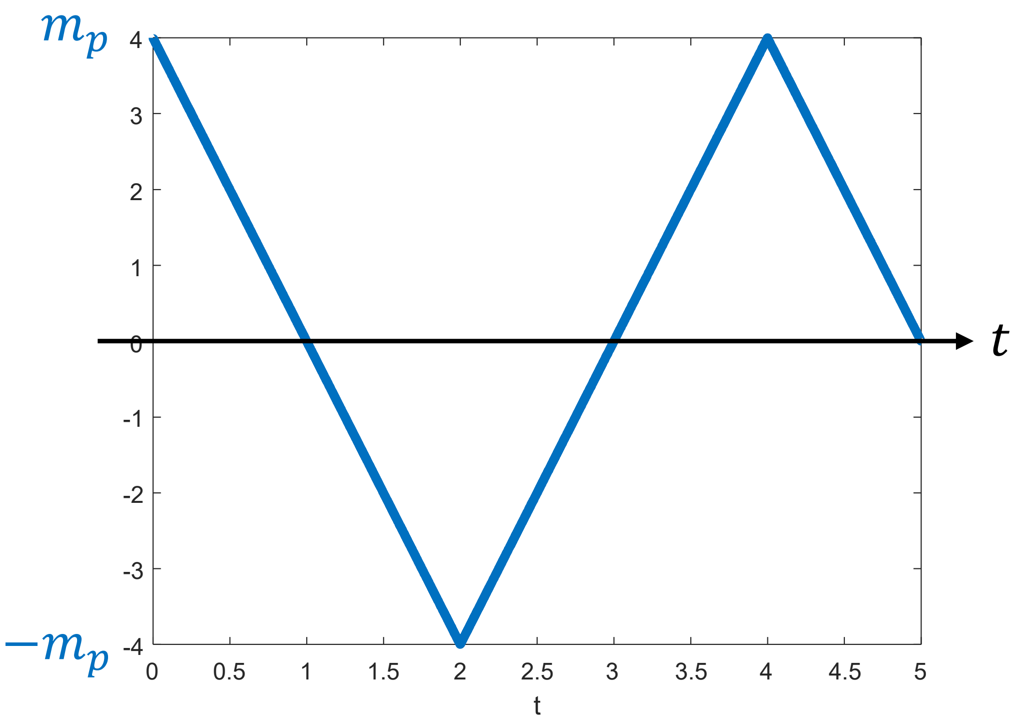
$\mu = \frac{m_p}{A}$ → $A = \frac{m_p}{\mu} = \frac{4}{1} = 4$

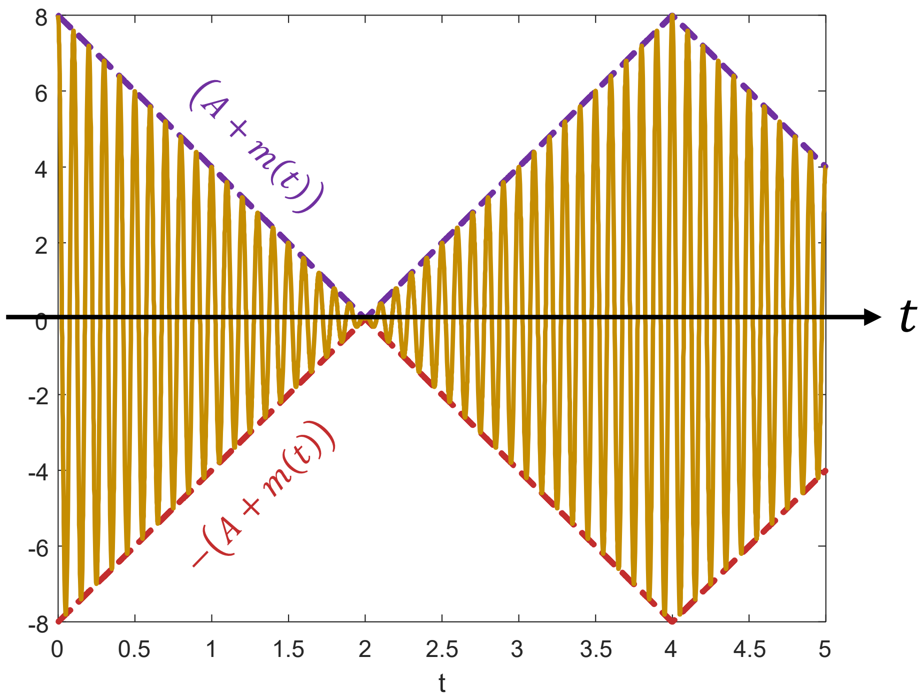
Example: Modulation Index μ

$\mu = 100\%$

$m(t)$

$x(t) = \left(A + m(t)\right)\cos(2\pi f_c t)$





$m_p = 4$

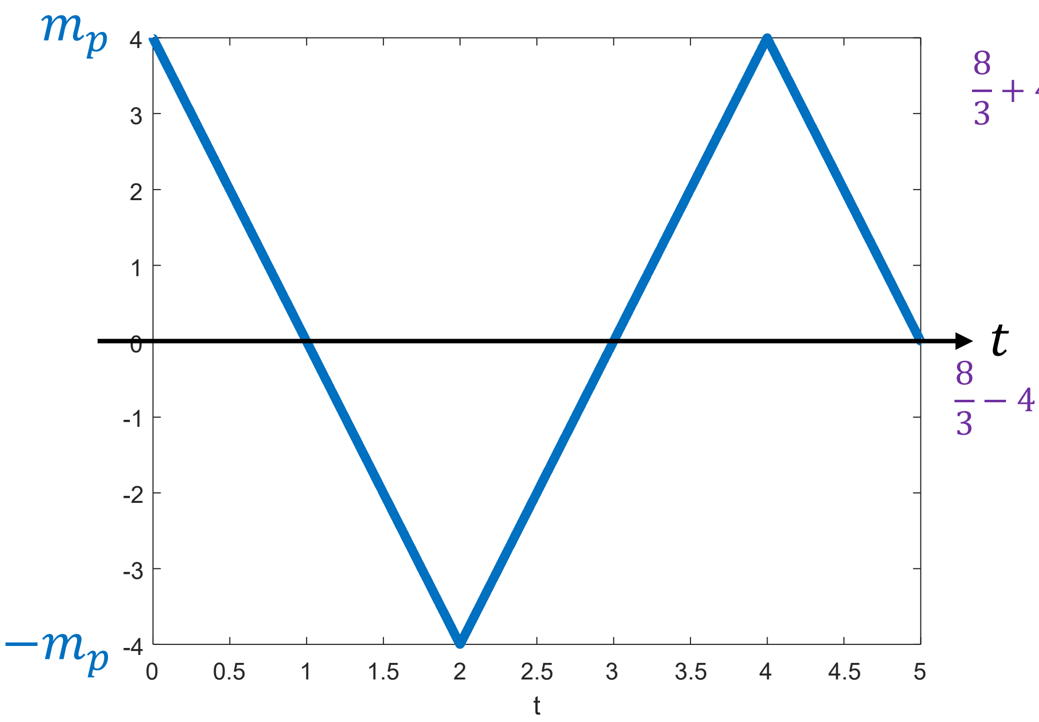
$\mu = \frac{m_p}{A}$ ➡ $A = \frac{m_p}{\mu} = \frac{4}{1} = 4$

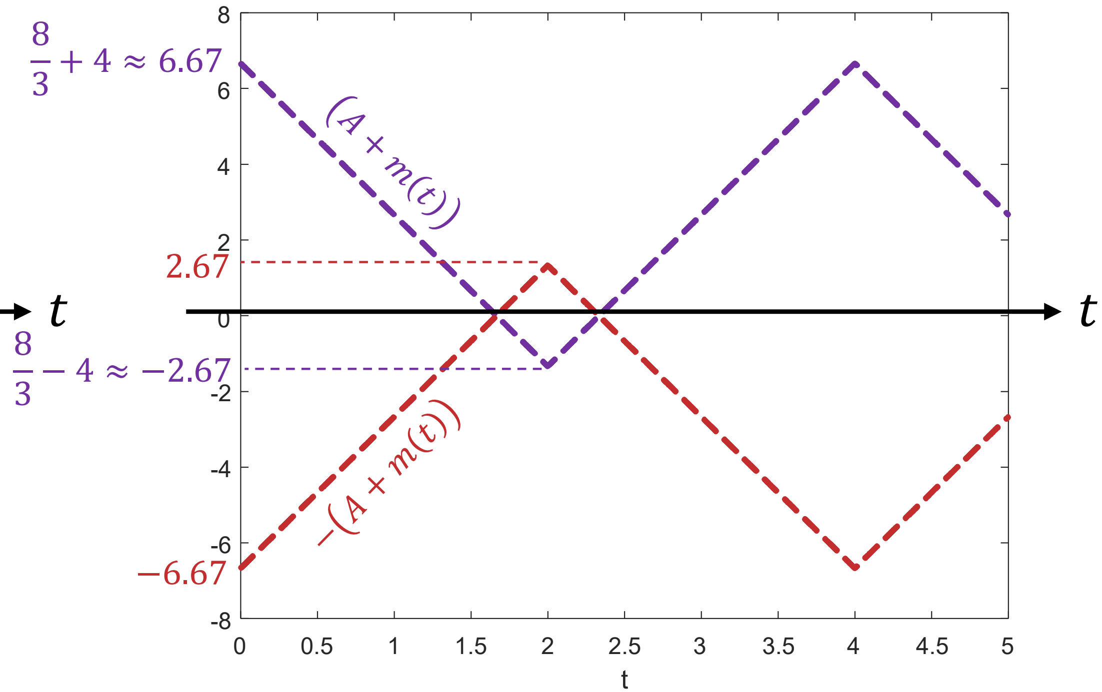
Example: Modulation Index μ

$\mu = 150\%$

$m(t)$

$x(t) = \big(A + m(t)\big)\cos(2\pi f_c t)$





$m_p = 4$

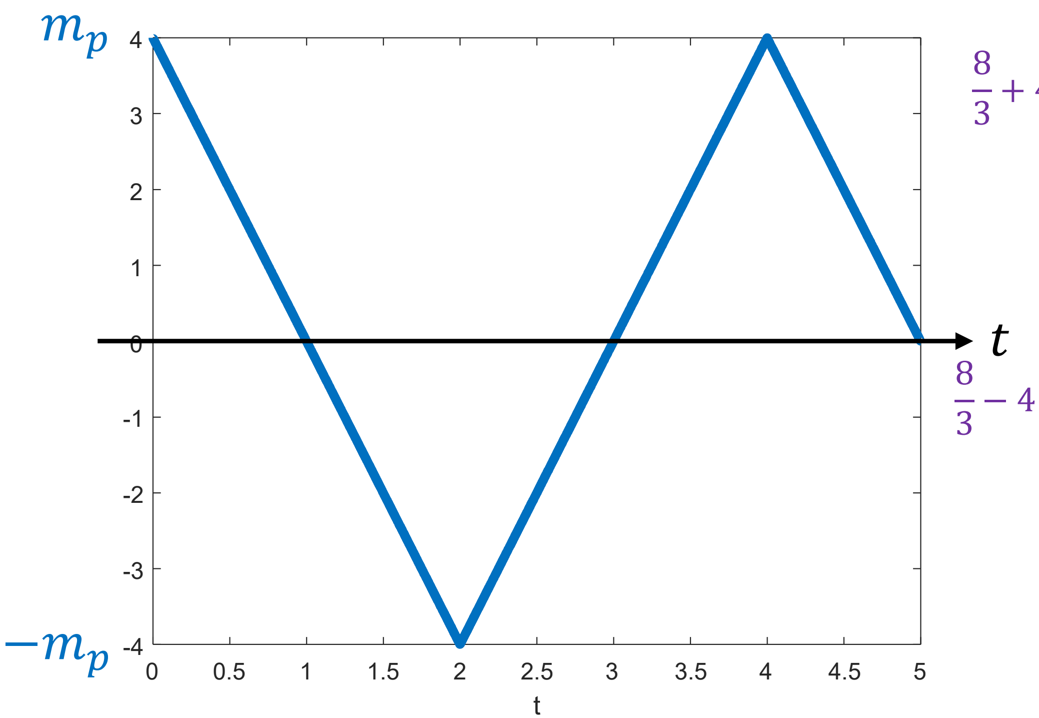
$\mu = \frac{m_p}{A}$ ⇒ $A = \frac{m_p}{\mu} = \frac{4}{1.5} = \frac{8}{3}$

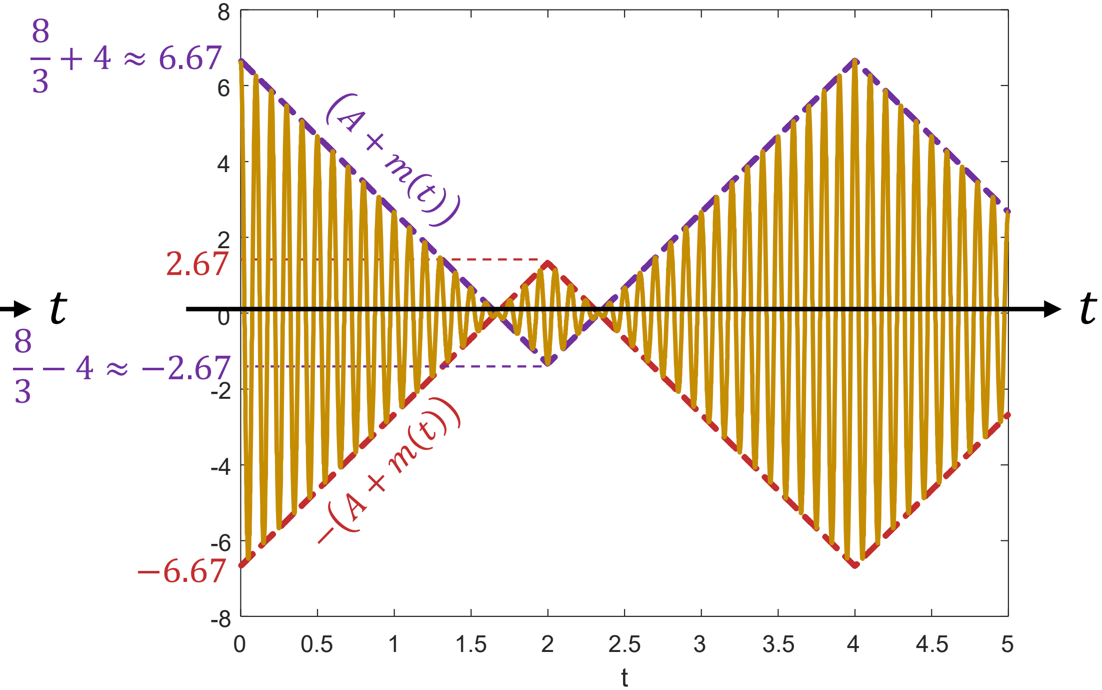
Example: Modulation Index μ

$\mu = 150\%$

$m(t)$

$x(t) = \big(A + m(t)\big)\cos(2\pi f_c t)$

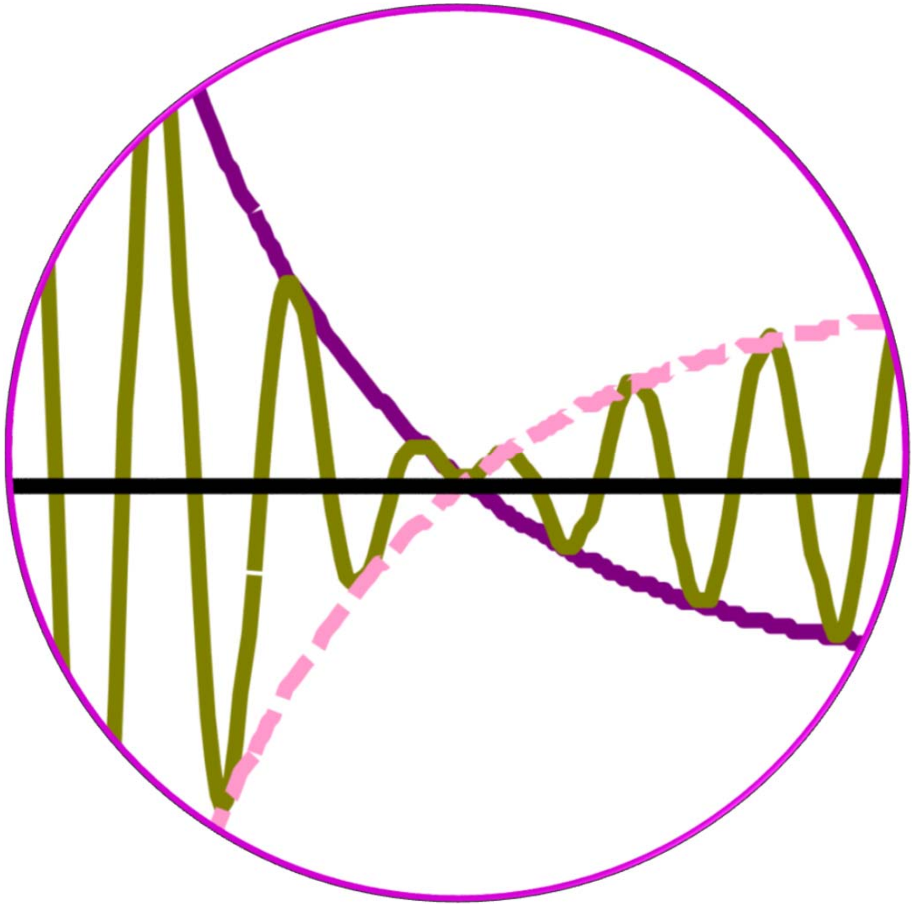




$m_p = 4$

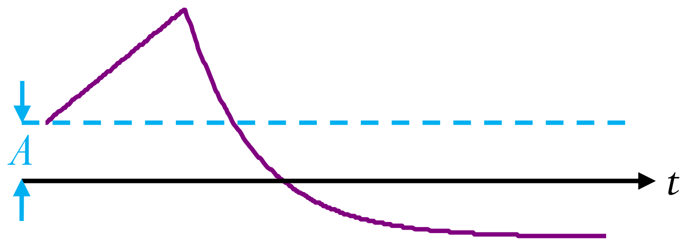
$\mu = \dfrac{m_p}{A} \Rightarrow A = \dfrac{m_p}{\mu} = \dfrac{4}{1.5} = \dfrac{8}{3}$

Phase Reversal [Figure 27]



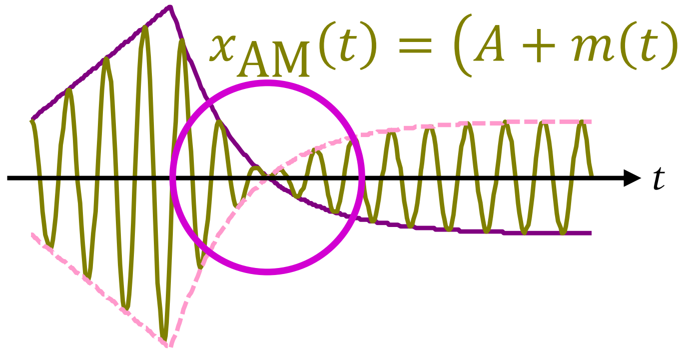
Case (b)

$A + m(t) < 0 \quad \text{for some } t$

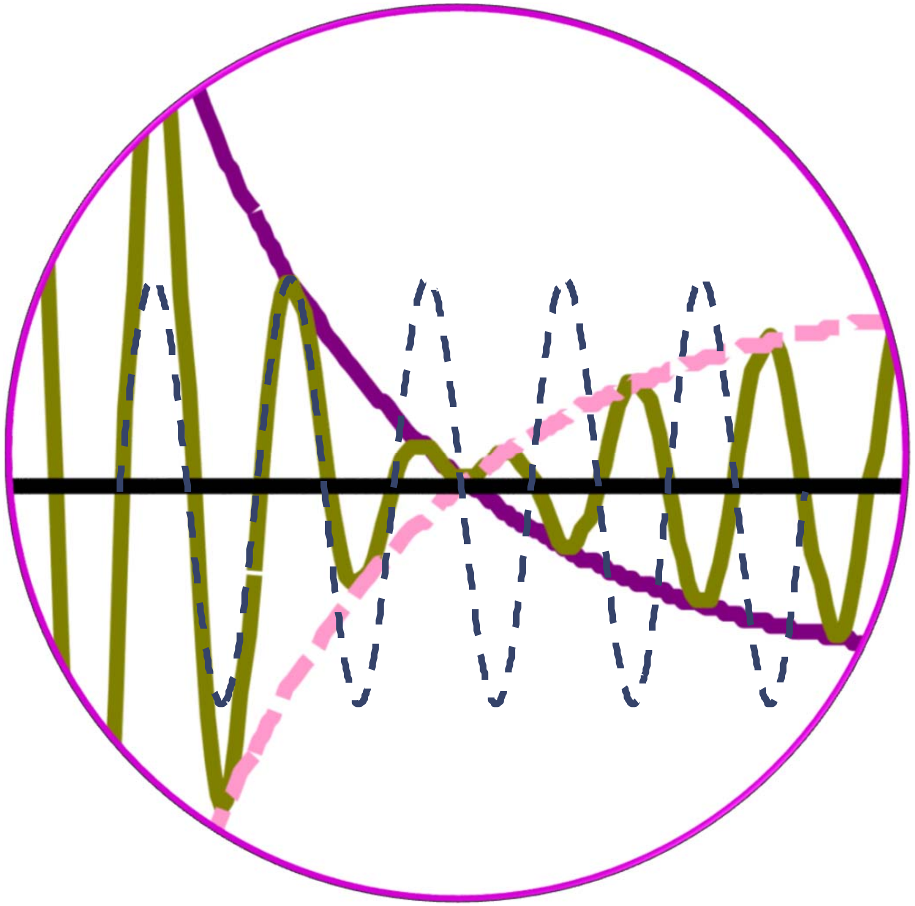


$$\mu = \frac{m_p}{A} > 1$$

$x_{\text{AM}}(t) = \big(A + m(t)\big)\cos(2\pi f_c t)$



Phase Reversal [Figure 26]



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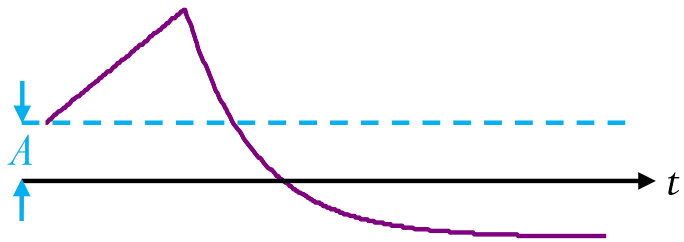

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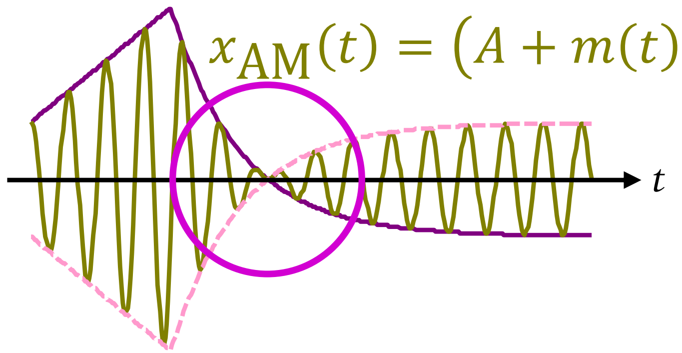
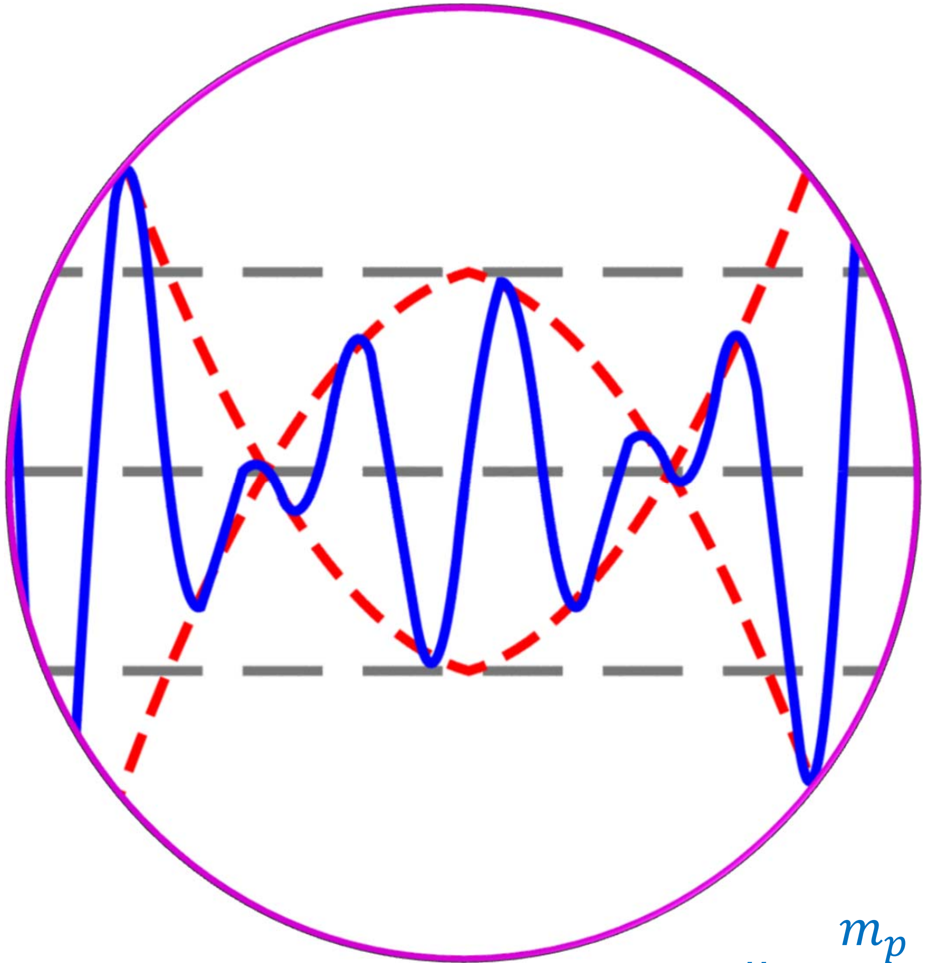
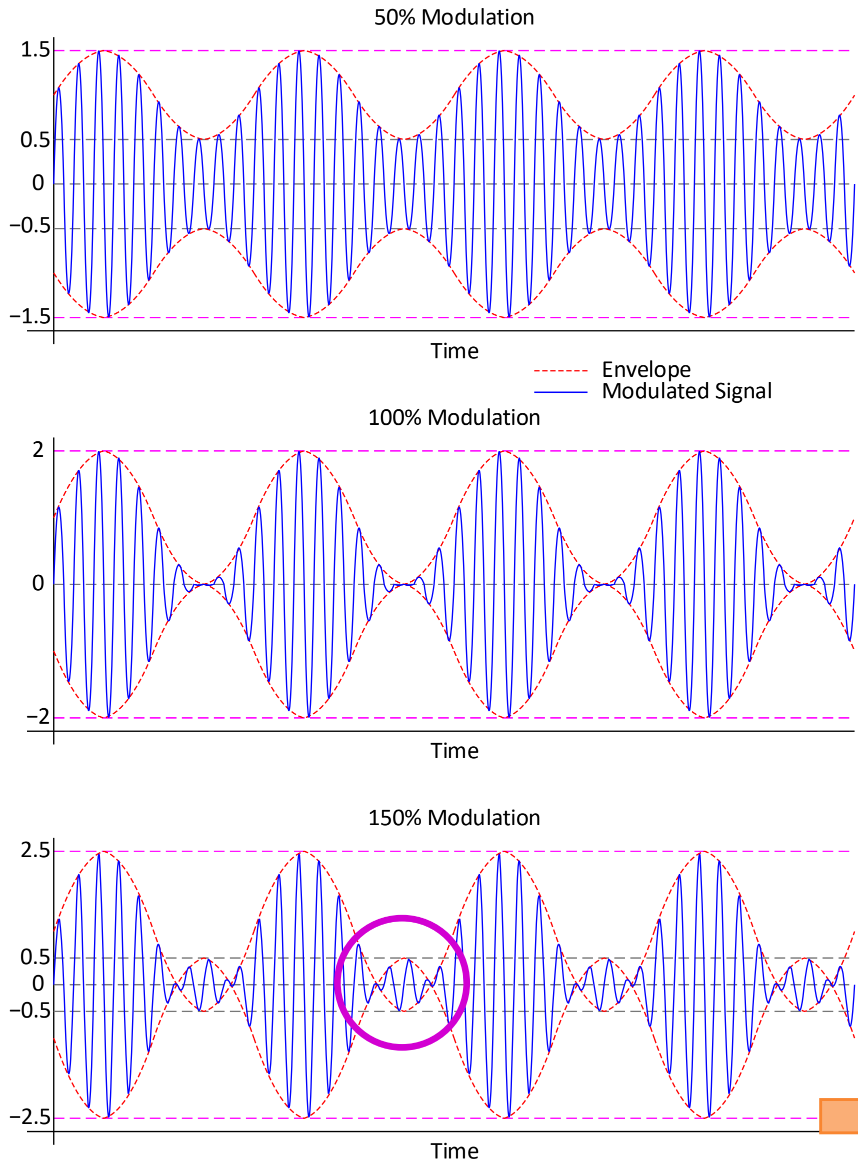


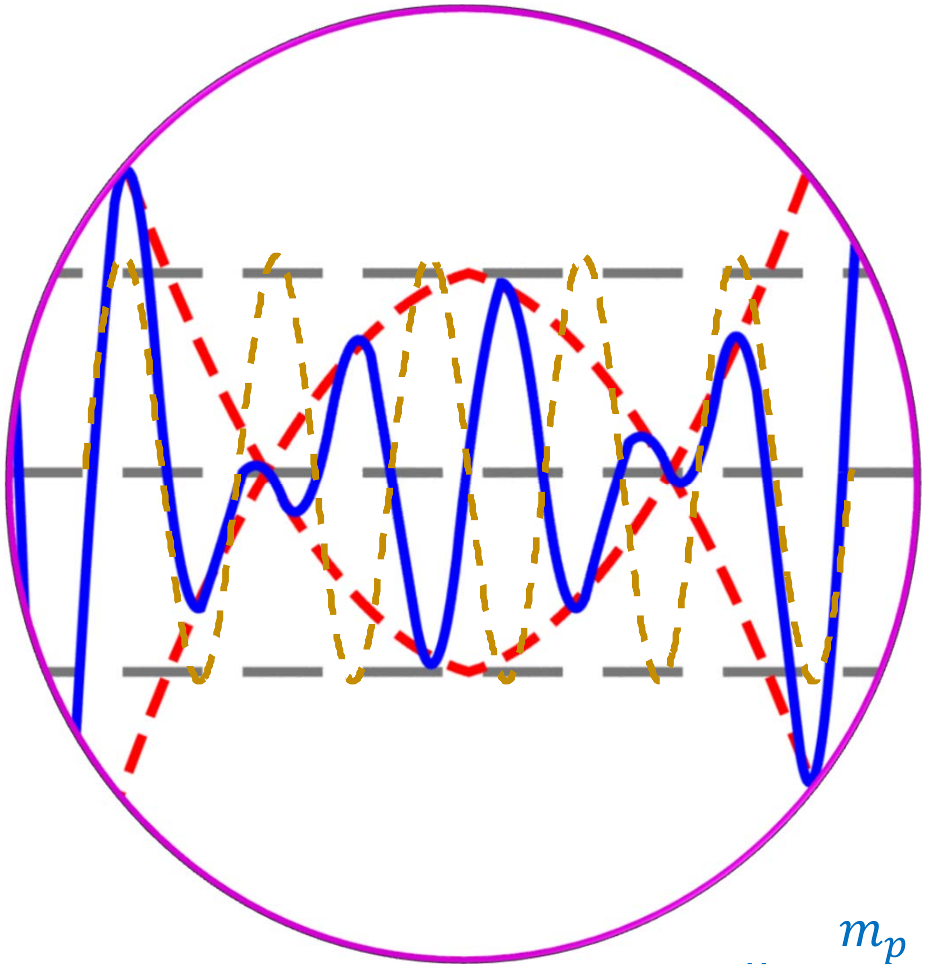
Phase Reversal [Figure 28]



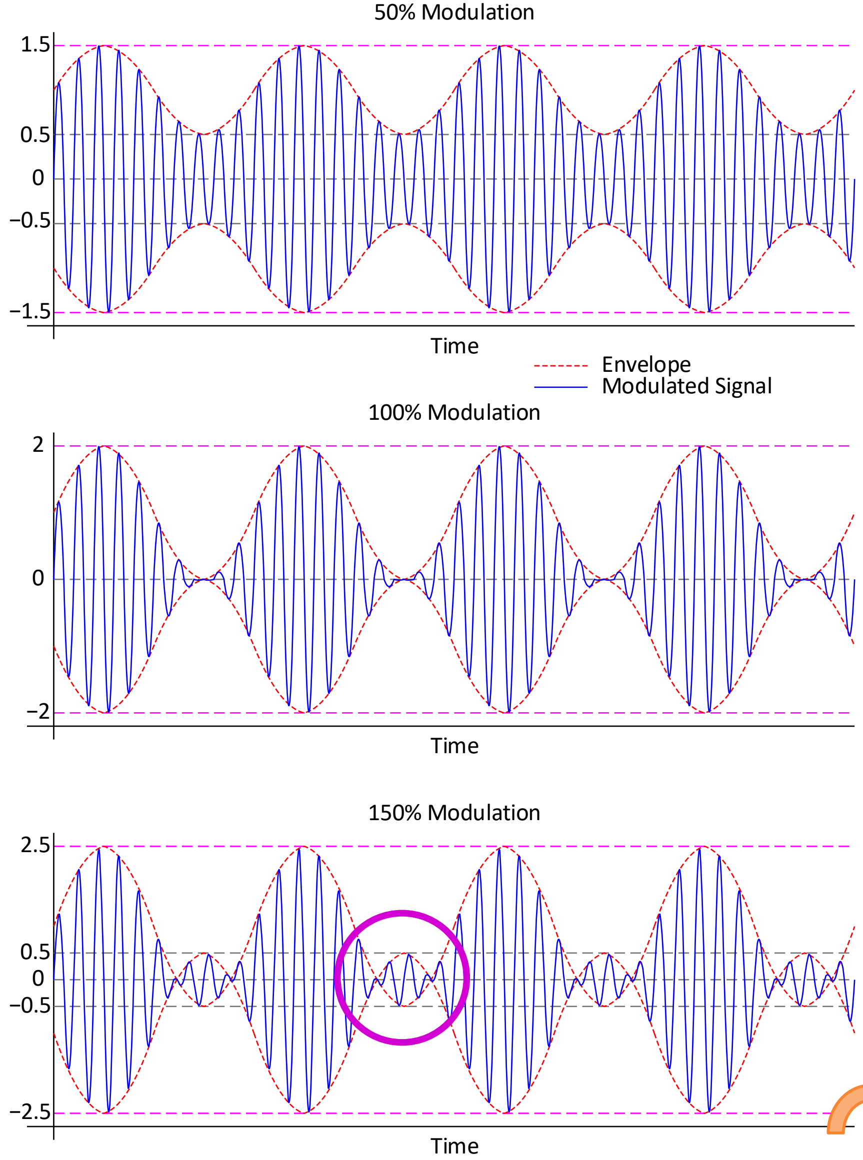


$$\mu = \frac{m_p}{A} > 1$$

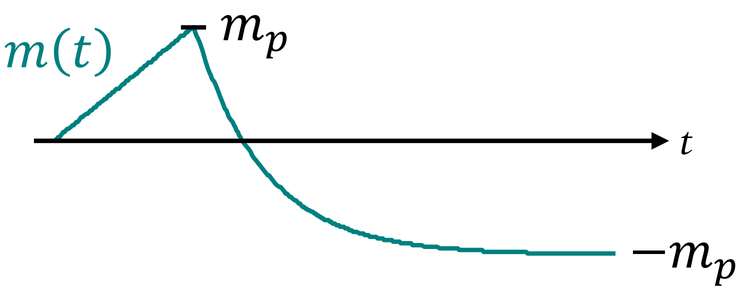
Phase Reversal [Figure 28]



$$\mu = \frac{m_p}{A} > 1$$



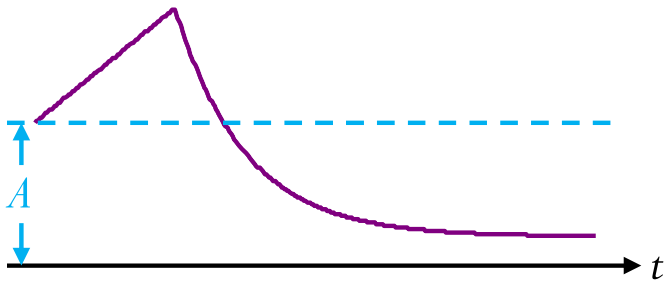
AM Review [Figure 27]



Assumptions

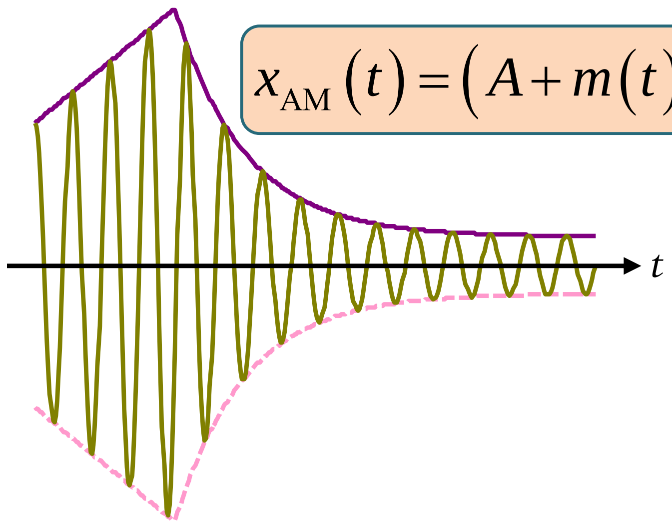
- $|M(f)| = 0$ for $|f| > B$
- $|m(t)| \le m_p$

Case (a) $A + m(t) > 0$ for all t



Modulation index:

$$\mu = \frac{m_p}{A}$$



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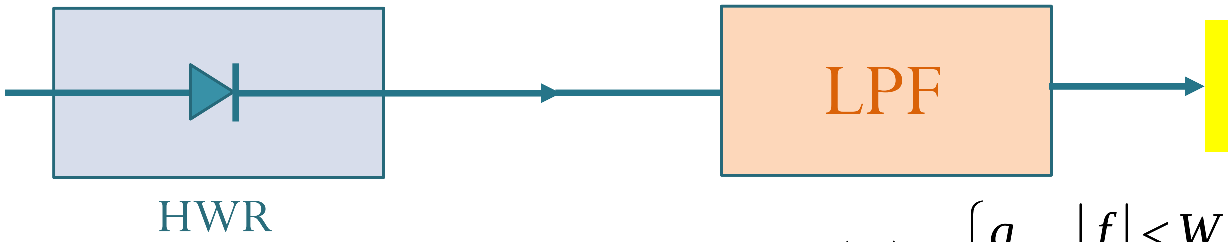
Rectifier Demod.

$A(t)\cos(2\pi f_c t)$

$A(t)$ is bandlimited to B.

$\boldsymbol{A(t) \geq 0}$

$f_c > 2B$



$\frac{g}{\pi}A(t)$

$$H_{\text{LPF}}(f) = \begin{cases} g, & |f| < W, \\ 0, & \text{otherwise.} \end{cases}$$

$B \leq W < f_c - B$

- In particular, when $A(t) = A + m(t)$,
  - A must be large enough to make $A + m(t) \geq 0$ at all time
  - if $m(t)$ is band-limited to B, then so is $A(t)$.
    - This is because $A(f) = A\delta(f) + M(f)$.
      - The $\delta(f)$ part is at $f = 0$; so it is still inside the $\pm B$ interval.

[Slides from basic EE lab]

DMM: DC vs. AC Modes

- V_{DC} = Measured value of the voltage using **DMM in DC mode**
  - Theoretically,
    - V_{DC} = Average value = DC offset voltage = DC component

$$V_{DC} = \langle v(t) \rangle = \frac{1}{T}\int_{t_0}^{t_0+T} v(t)\,dt$$

- V_{AC} = Measured value of the voltage using **DMM in AC mode**
  - Theoretically, for "True RMS" DMM,

$$V_{AC} = \sqrt{\left\langle \left(v(t) - V_{DC}\right)^2 \right\rangle}$$

  - For non-true-rms DMM, the measurement is calibrated so that the above property hold for sinusoids.
- Theoretically,

$$V_{RMS} = \sqrt{\langle v^2(t) \rangle} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} v^2(t)\,dt} = \sqrt{V_{AC}^2 + V_{DC}^2}$$

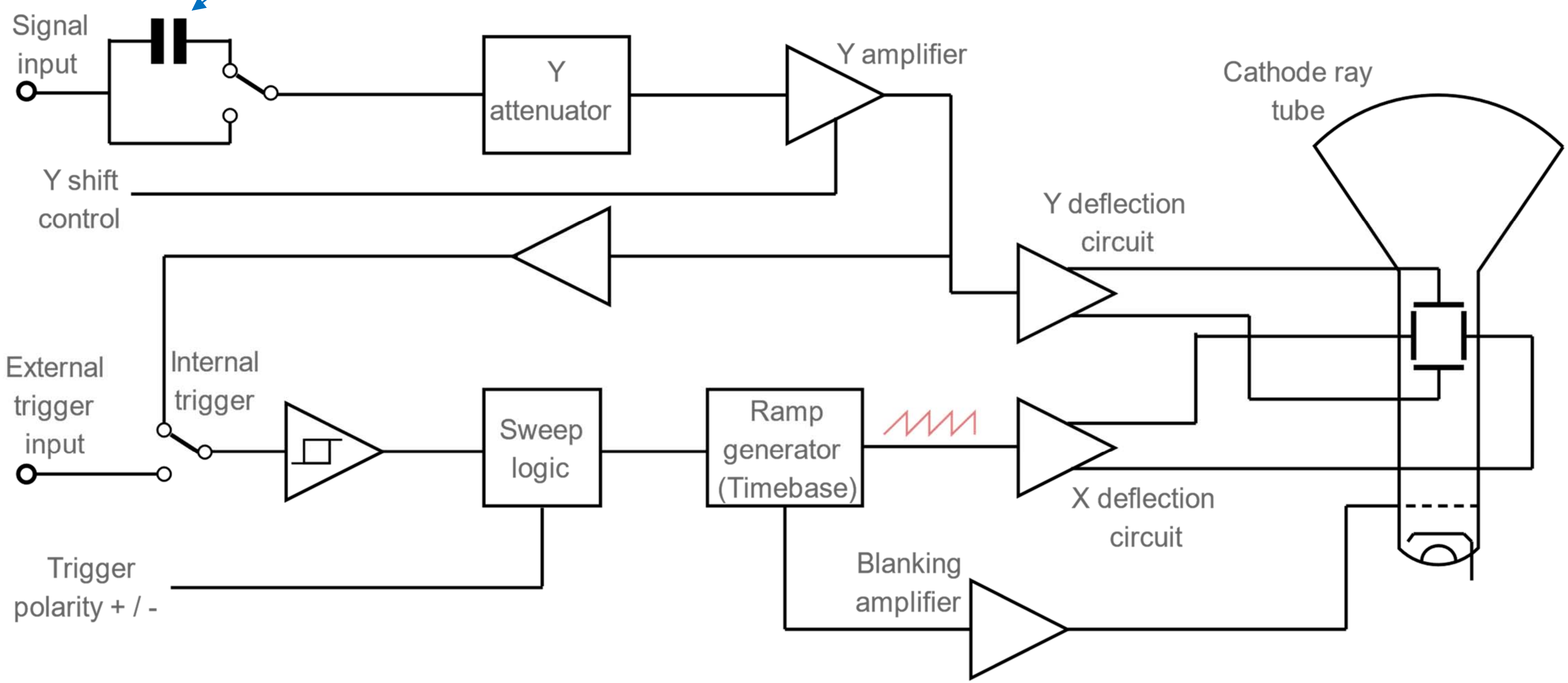
[Slides from basic EE lab]

Oscilloscope: DC vs. AC Modes

- Input signal: $v(t)$
- DC mode: Show $v_{DC}(t) = v(t)$
- AC mode: Show $v_{AC}(t) = v(t) - \mathrm{V}_{\mathrm{DC}}$
  - $v_{AC}(t)$ always have 0 average (theoretically)
- $v_{AC}(t) = v_{DC}(t)$ when $\mathrm{V}_{\mathrm{DC}} = 0$.

Analog Oscilloscope: Block Diagram

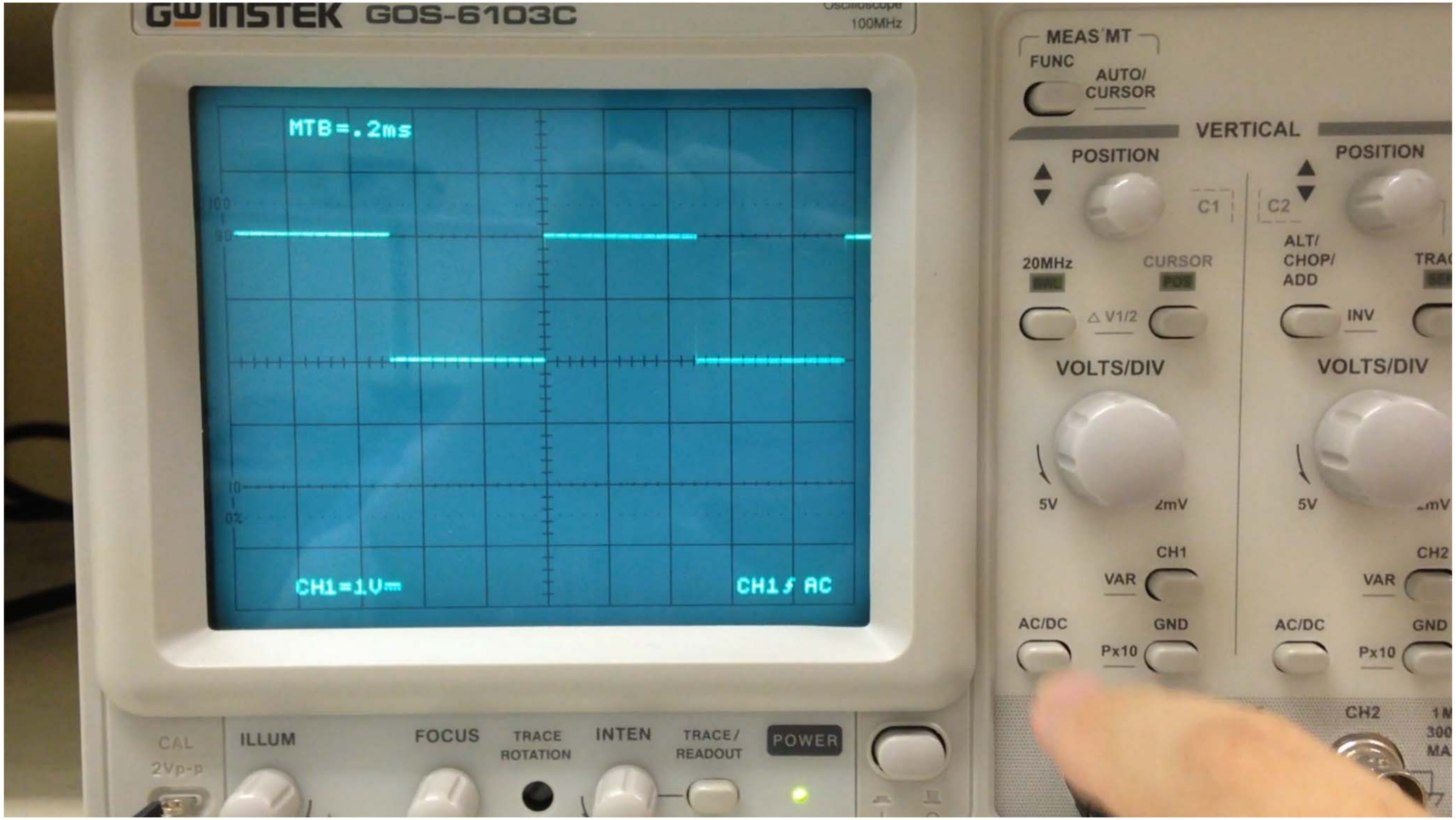
a capacitor is placed in series with the input to block DC



https://www.electronics-notes.com/articles/test-methods/oscilloscope/analogue-oscilloscope.php

[Slides from basic EE lab]

Oscilloscope: DC vs. AC Modes



Oscilloscope: DC vs. AC Modes

- Here, we see that when the scope is in AC mode, the offset voltage is eliminated.
- As we adjust the value of the offset, the oscilloscope still brings the whole plot down to 0 average.