Lecture 4: Amplitude Modulation (Double Sideband *Suppressed Carrier*, DSB-SC)

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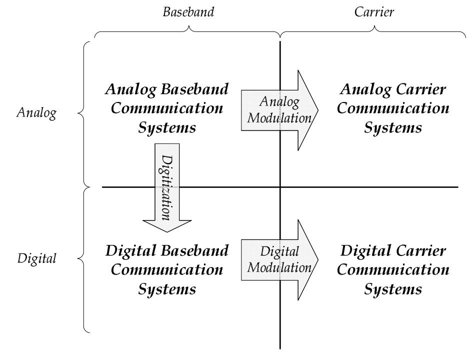
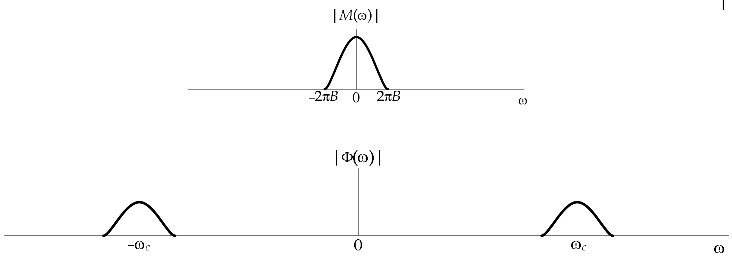
Modulation

- Modulation is a process that causes a shift in the frequency spectrum of a message signal $m(t)$ (from baseband to carrier).
- Modulation has advantages.
- Modulation is achieved by varying one of the basic parameters (amplitude, frequency or phase) of a **high-frequency sinusoidal** signal, called the carrier $c(t)$, in proportion to the baseband message signal $m(t)$.

Baseband vs. Carrier

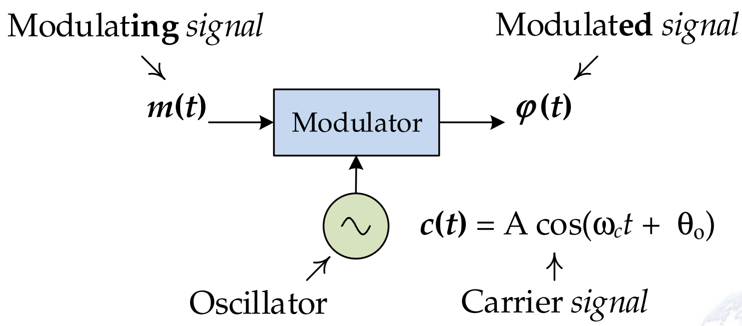




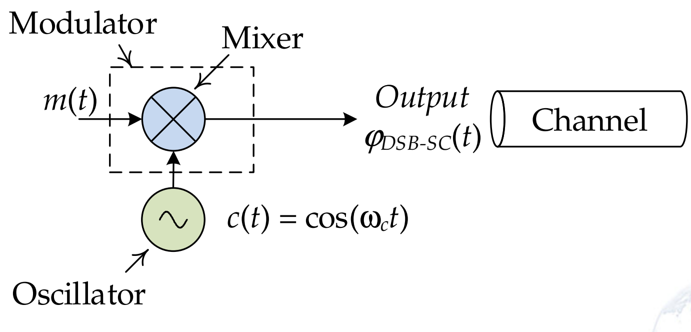
Three Modulation Types

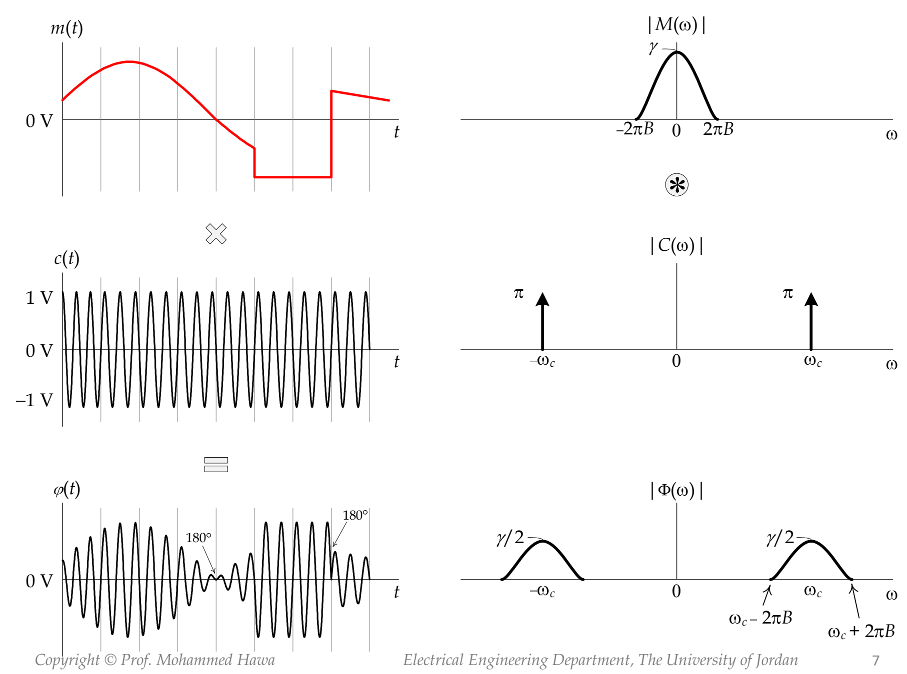
- $\boldsymbol{A \propto m(t)}$; $\omega_c = constant$; $\theta_o = constant$
  - Amplitude Modulation (AM)
  - Amplitude Shift Keying (ASK)
- $A = constant$; $\boldsymbol{\omega_c \propto m(t)}$; $\theta_o = constant$
  - Frequency Modulation (FM)
  - Frequency Shift Keying (FSK)
- $A = constant$; $\omega_c = constant$; $\boldsymbol{\theta_o \propto m(t)}$
  - Phase Modulation (PM)
  - Phase Shift Keying (PSK)

Notation



DSB-SC Modulator: Mixer





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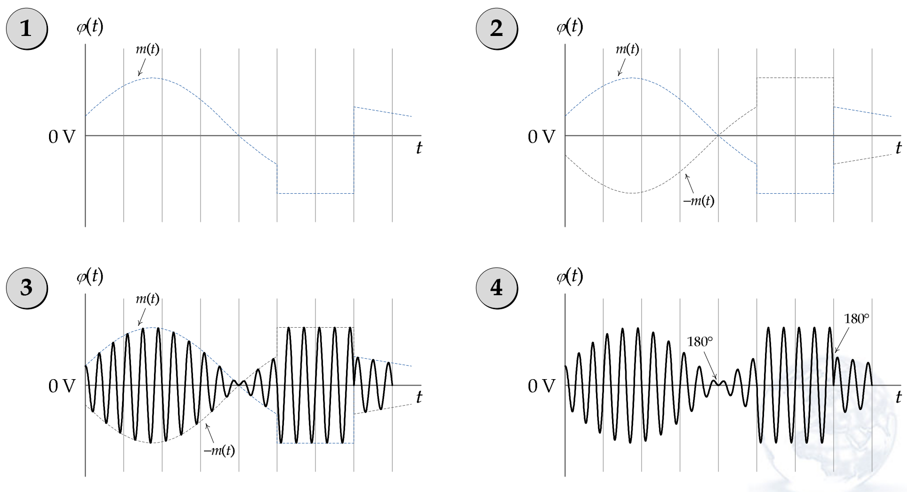
Drawing a DSB-SC modulated signal



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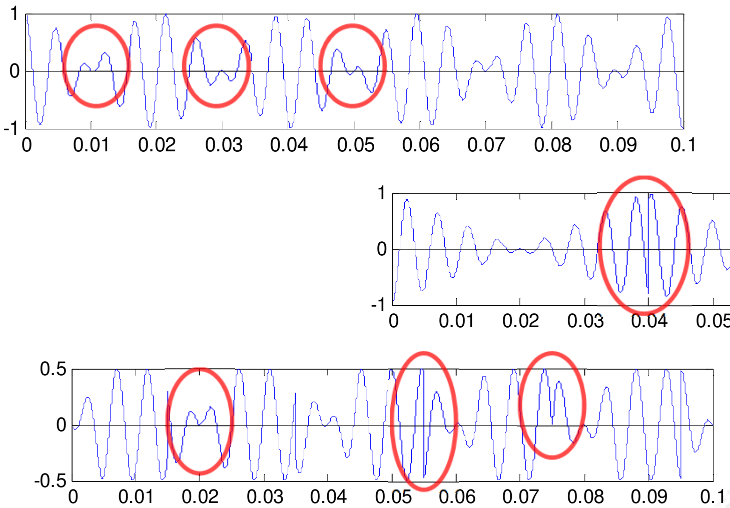
180° *Phase Shift*



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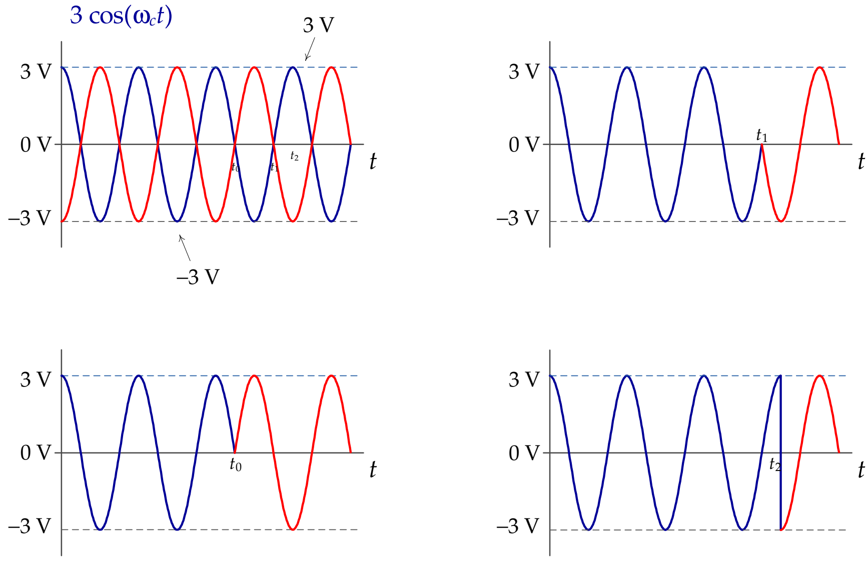
$-3\cos(\omega_c t) = 3\cos(\omega_c t - 180°)$

$3\cos(\omega_c t)$



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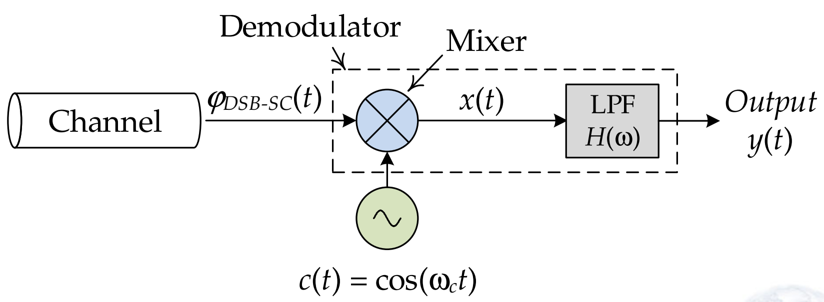
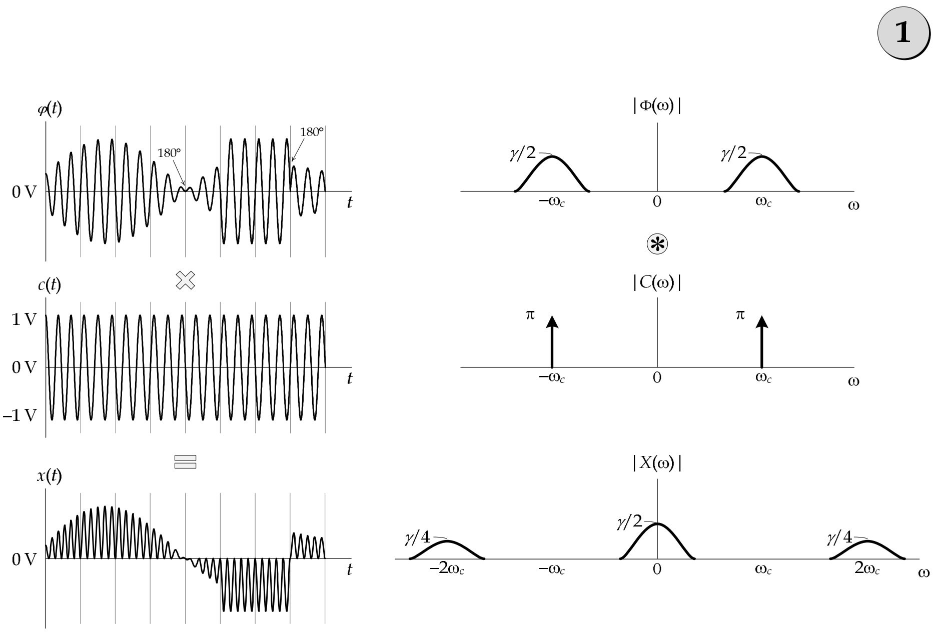
DSB-SC Demodulator: Mixer again!





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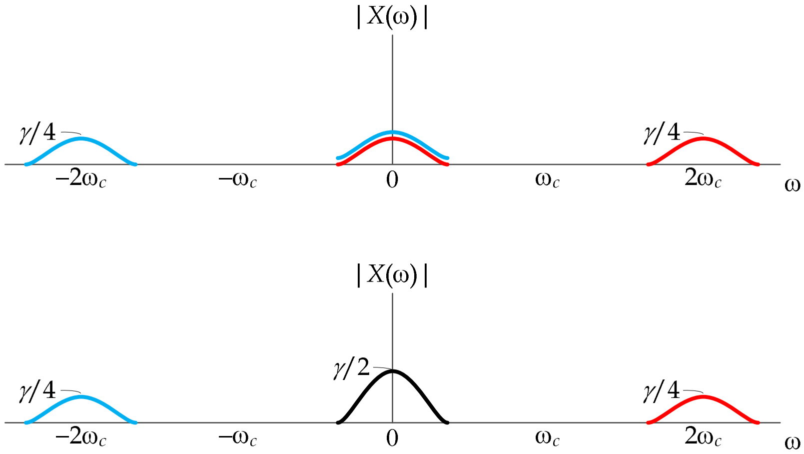

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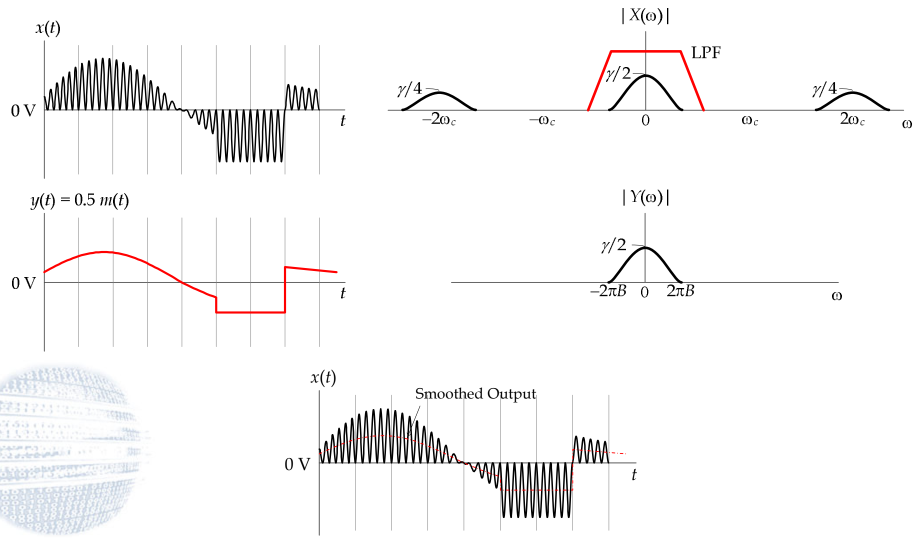
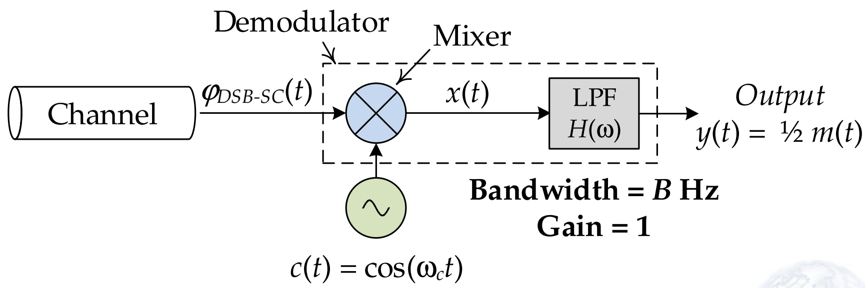
The LPF is *the missing piece!*



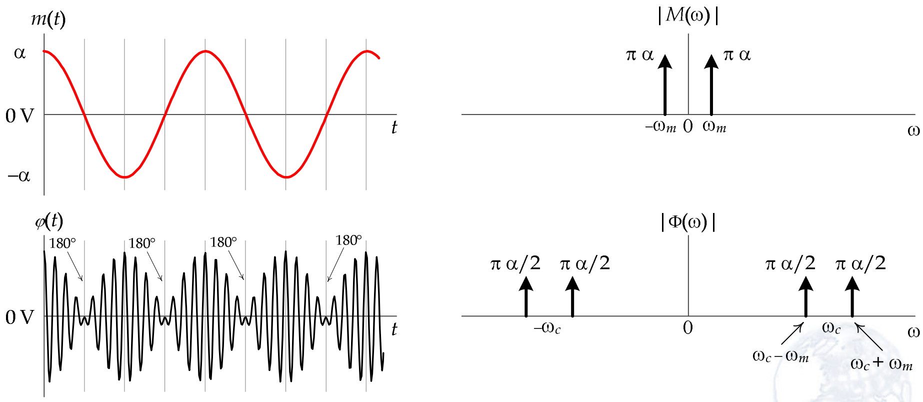
Filter Specifications!



Example

- Assume we perform DSB-SC modulation for the baseband signal $m(t) = \alpha \cos(\omega_m t)$ [the case of tone modulation], where $\omega_c >> \omega_m$:
  - Sketch the **time-domain** modulated signal $\varphi(t)$.
  - Sketch the **Fourier transform** of the modulated signal $\Phi(\omega)$ [frequency domain].
  - Find the **bandwidth** of $m(t)$ and $\varphi(t)$.
  - Find the **average power** in both $m(t)$ and $\varphi(t)$.
  - Find the **average value** in both $m(t)$ and $\varphi(t)$.
  - Show the demodulator hardware.
  - Sketch $x(t)$ and $y(t)$ in the demodulator.

Solution

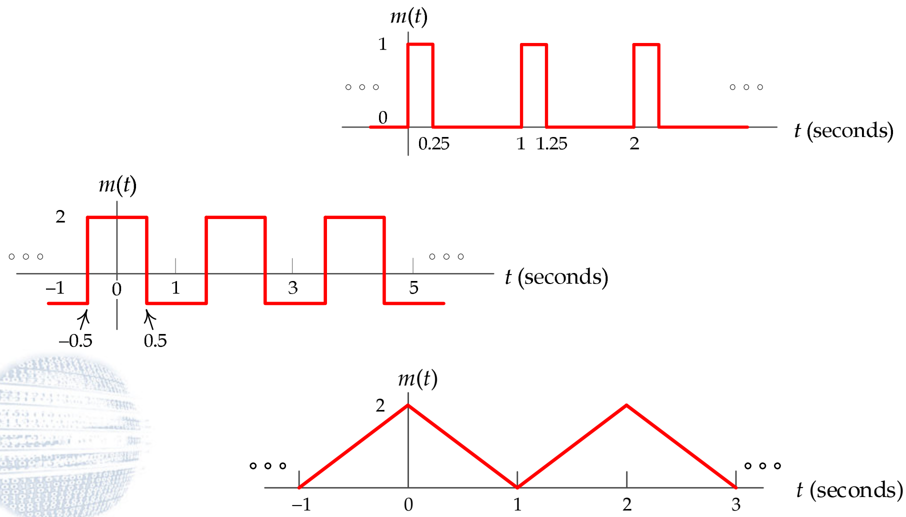


Homework

For the following signals $m(t)$:

- Sketch the modulated signal $\varphi(t)$ at the modulator.
- Are there any sudden 180° phase shifts in $\varphi(t)$?
  If so, where?
- Sketch the Fourier transform $\Phi(\omega)$.
- Sketch the signals $x(t)$ and $y(t)$ at the demodulator.
- Sketch the Fourier transform for $X(\omega)$ and $Y(\omega)$.
- Find the bandwidth for the signals $\varphi(t)$ and $y(t)$.
- Determine the DC value in $m(t)$, $\varphi(t)$ and $y(t)$.
- Calculate the average power in $m(t)$, $\varphi(t)$ and $y(t)$.

Homework



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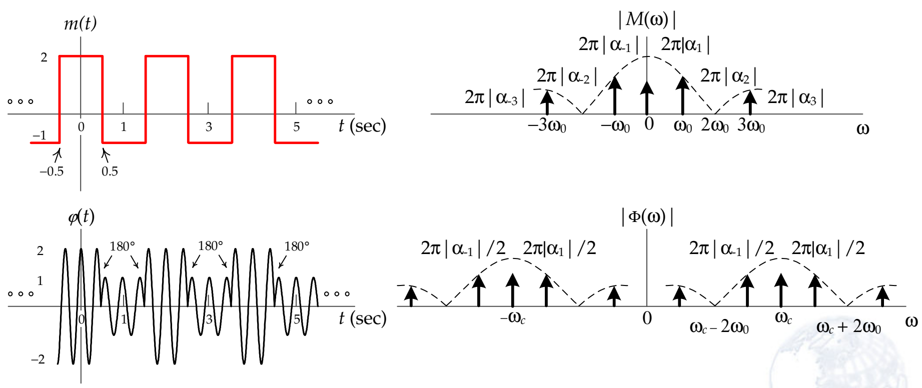
Solution: Part(b)



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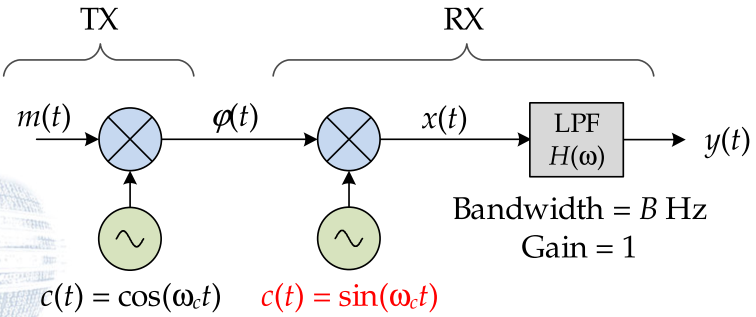
Homework

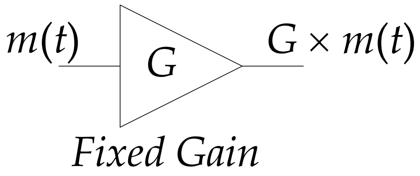
- For the following circuit, sketch $x(t)$ and $y(t)$, along with the Fourier transform $X(\omega)$ and $Y(\omega)$.
- Try both graphical and mathematical solutions.

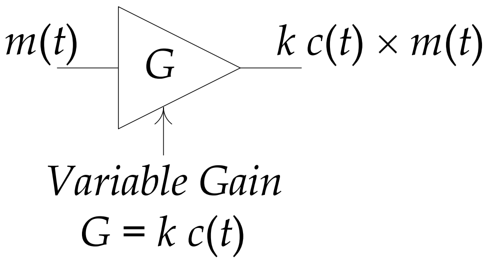


How to build a *Mixer*?

- Variable Gain Amplifier or Switch
  – The basic design.
- Gilbert Cell (e.g., MC 1496)
  – Popular (used in Integrated Circuits).
  – Built using 8 transistors in a configuration of three variable-gain differential amplifiers.
- Switching Modulator
  – Uses diodes or transistors as switches.
  – Diodes represented cheaper option before ICs, but transistors can be used as well.

Variable Gain Amplifier





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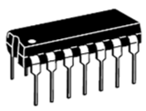
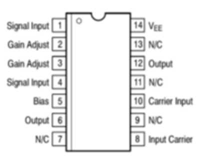
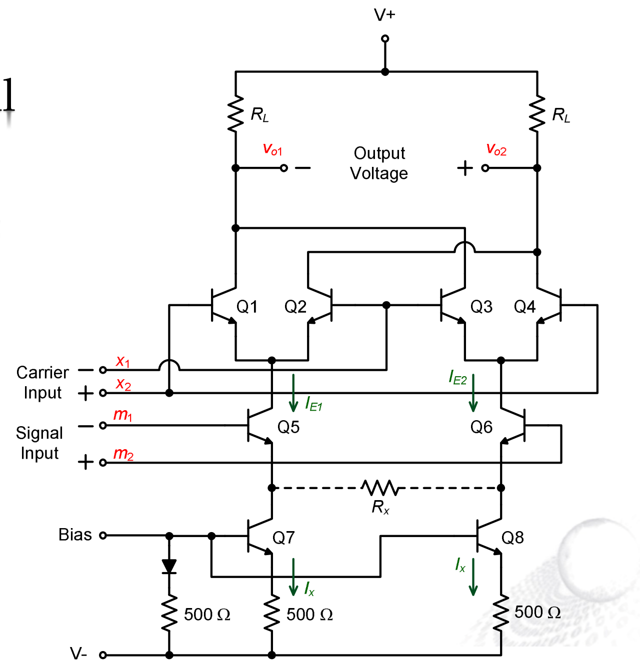
Gilbert Cell (MC1496) Schematic







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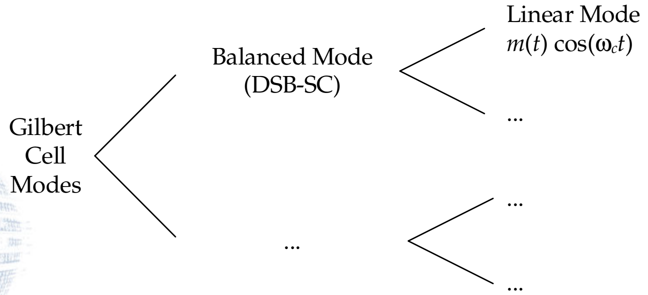
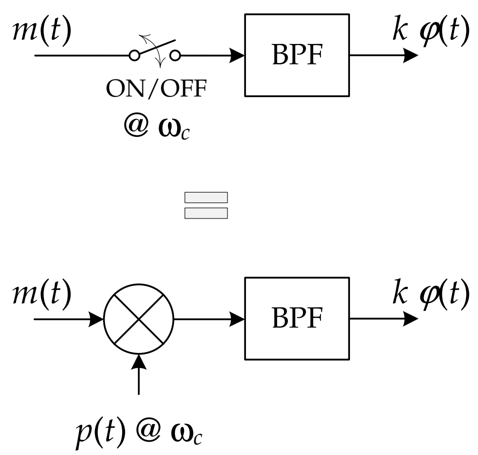
Gilbert Cell Four Modes

- Gilbert Cell (MC1496) can operate in one of four possible modes based on balancing and/or saturating the upper differential amplifiers.

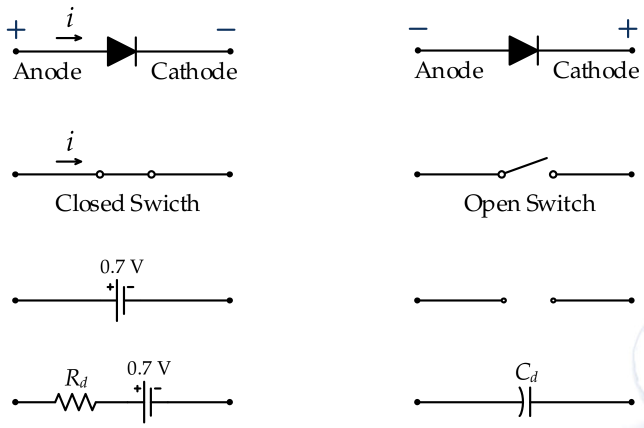


Switching Modulator



Diode *is a* Fast Switch

Forward Biased | Reverse Biased



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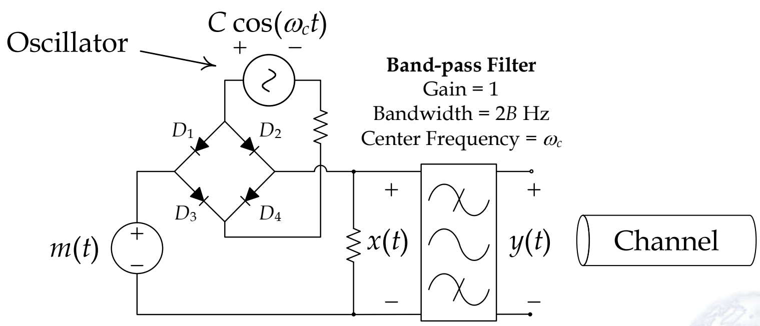
DSB-SC Switching Modulator
(*Series-bridge diode modulator*)



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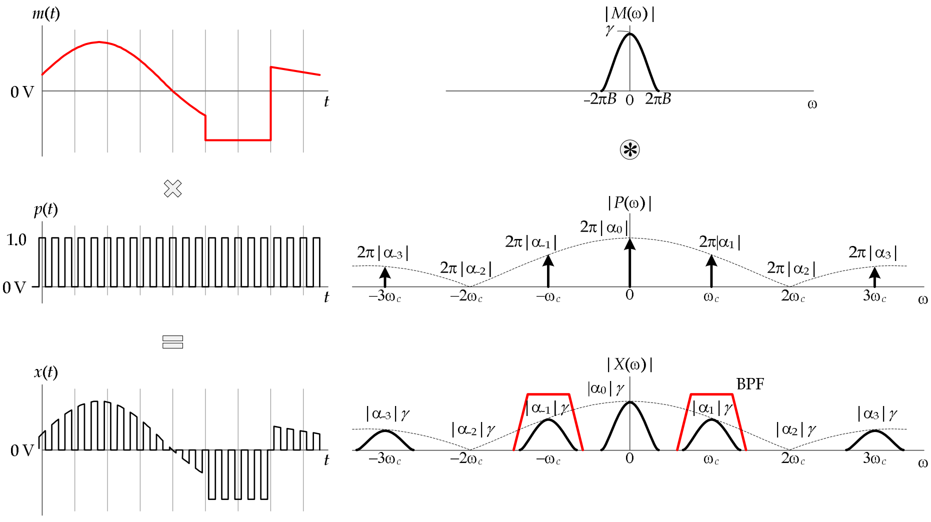
1



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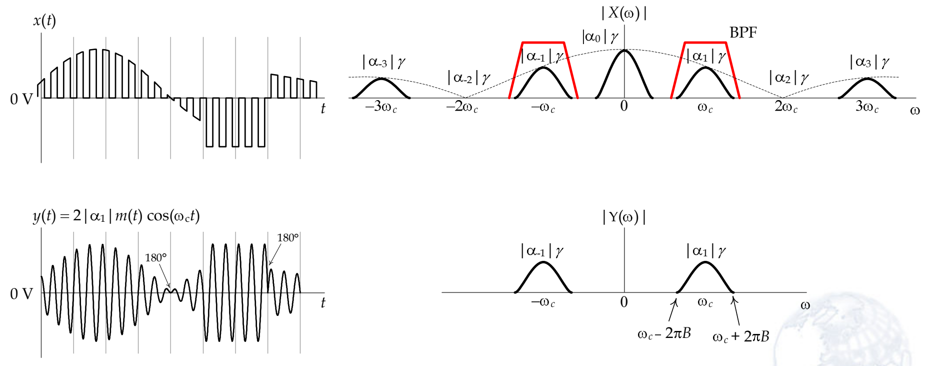
2

The BPF is *not optional!*



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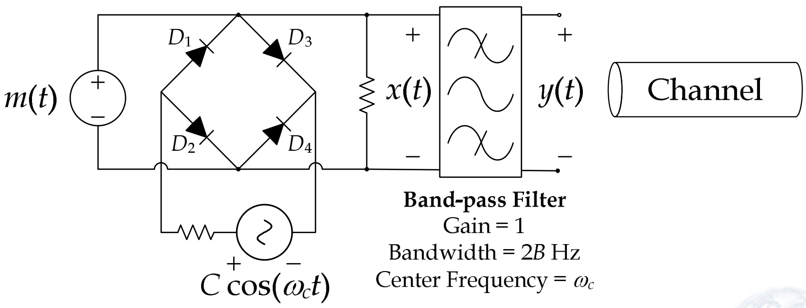
DSB-SC Switching Modulator
(*Shunt-bridge diode modulator*)



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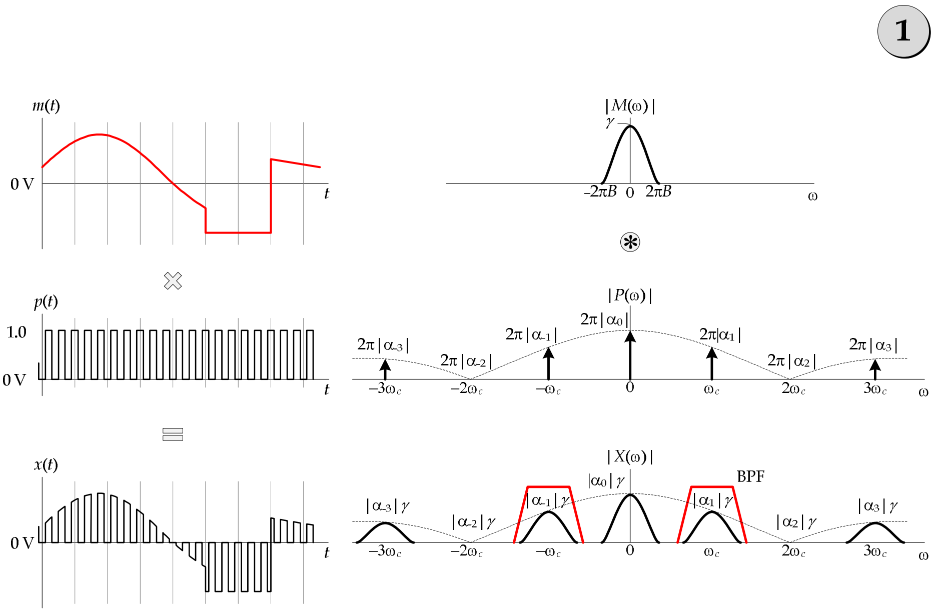

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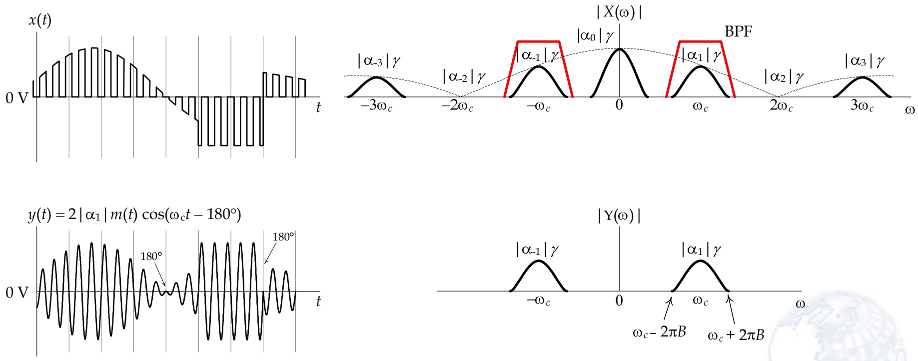
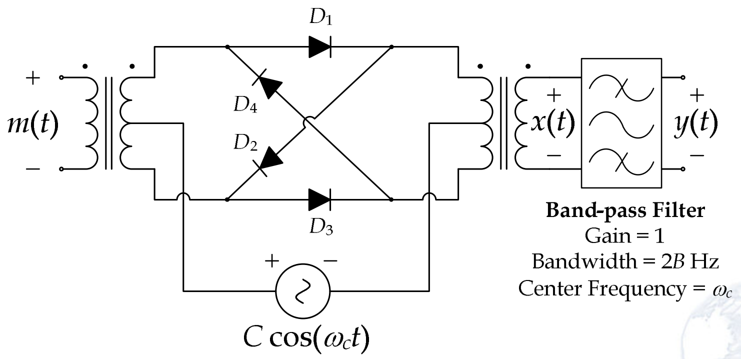
2

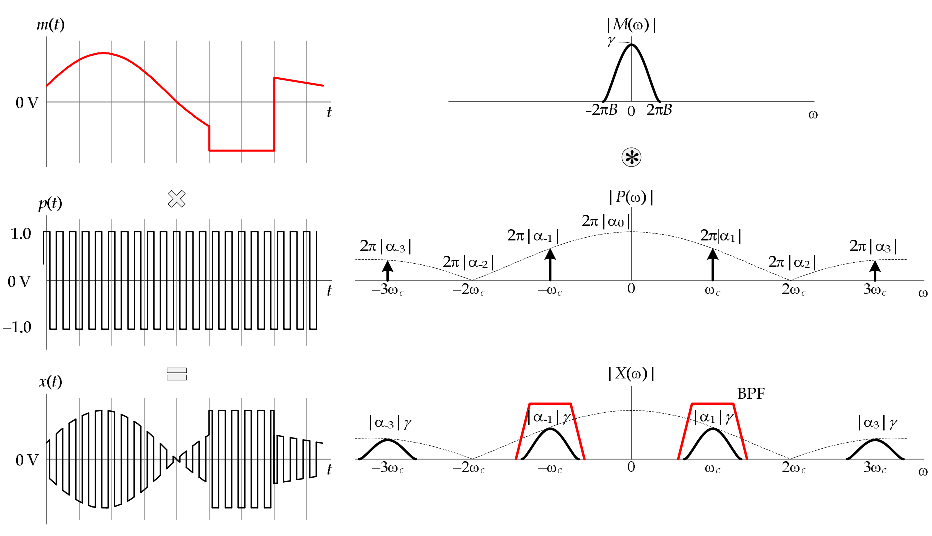
The BPF is *not optional!*



DSB-SC Switching Modulator (*Ring modulator*)



1



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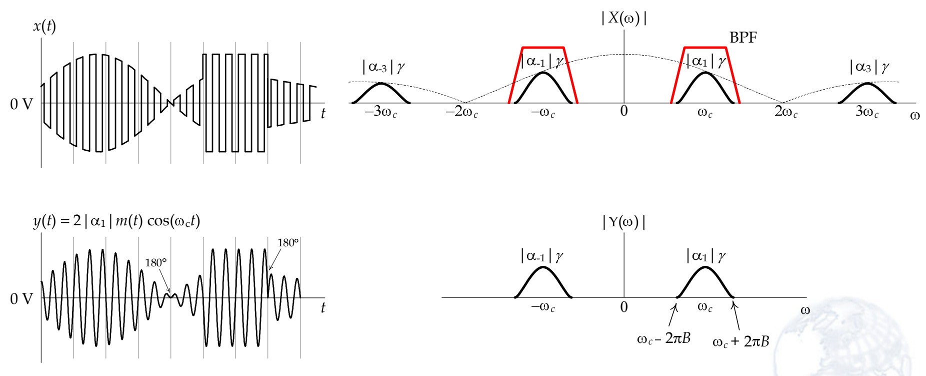
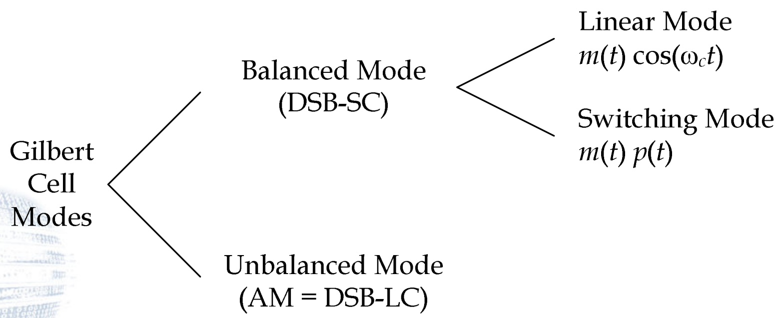
The BPF is *not optional!*



Gilbert Cell as Switching Modulator

- It is recommended to use the Gilbert Cell (MC1496) in the switching mode, rather than the linear mode.



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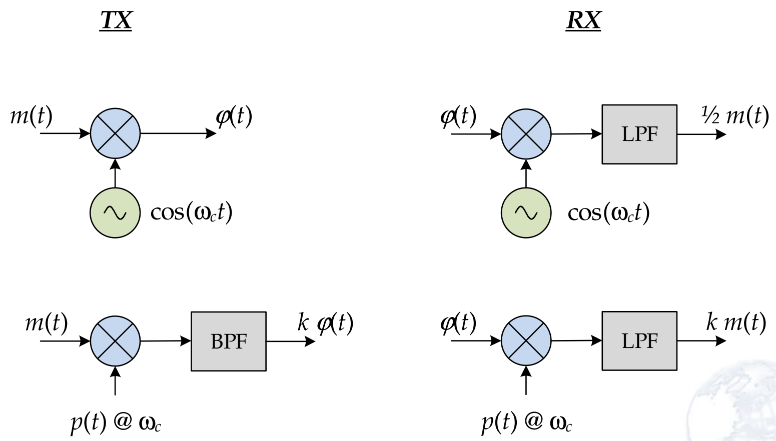
DSB-SC *Summary*



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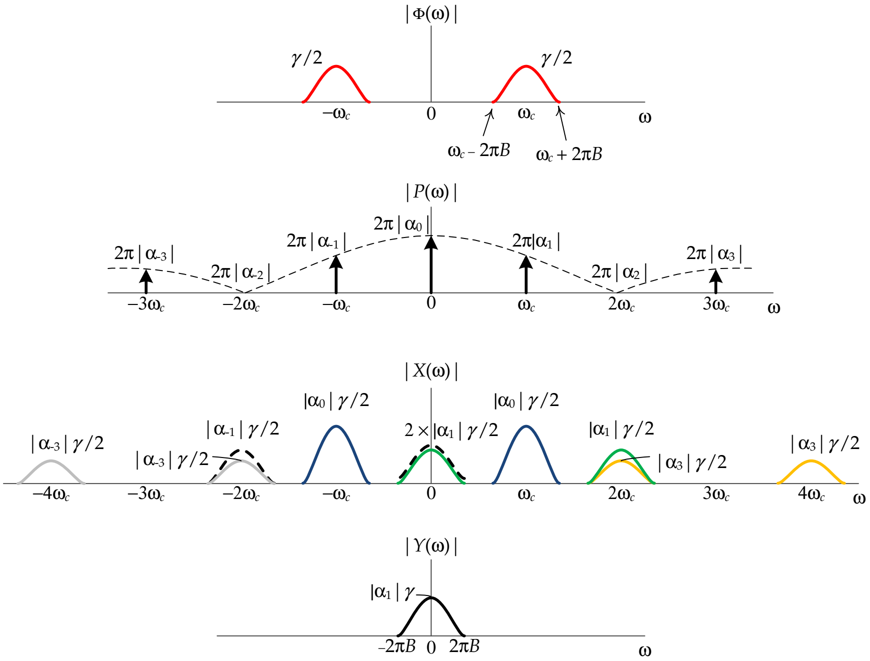
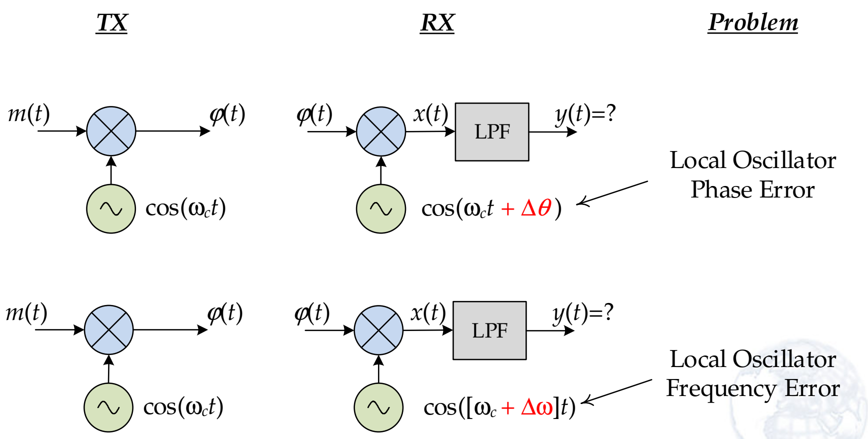
Homework

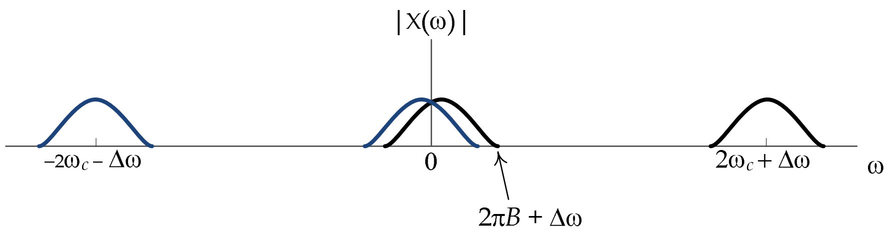
- If we use a switching **de**modulator (say a series-bridge diode demodulator), answer the following:
  - What are the specifications of the filter?
  - What is the value of k in the output $y(t) = k\, m(t)$ if the input is $\varphi(t) = m(t) \cos(\omega_c t)$
  - What is the value of k in the output $y(t) = k\, m(t)$ if the input is $\varphi(t) = 2\,|\alpha_1|\, m(t) \cos(\omega_c t)$
  - Sketch the Fourier transform of the solution.



Synchronizing Oscillator at the RX



Frequency Error at the Receiver



To avoid problems due to phase and frequency errors

- Solution **#1**: Use a PLL (Phase-Locked Loop) at the RX. A PLL can, by observing $\varphi(t)$, recover the exact frequency and phase of the carrier at the TX, and hence use these values at the RX. The PLL is called a **carrier-recovery circuit** (*complex* and *expensive*). The receiver in this case is known as **synchronous** or **coherent** receiver.
- Solution **#2**: Do not generate a carrier at the RX. Rather, let the TX send an extra copy of the carrier (e.g., DSB-LC) to help the RX demodulate $\varphi(t)$. The RX is known as **asynchronous** or **incoherent** receiver (*cheaper*), but the TX is *power inefficient*.

