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Hirasugar Institute of Technology, Nidasoshi.

Inculcating Values, Promoting Prosperity

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ECE Dept.
PCS
IV Sem
2017-18

Department of Electronics & Communication Engg.

Course : Principles of Communication Engg-15EC45. **Sem.: 4th (2017-18)**

Course Coordinator:

Dr. V. G. Kasabegoudar

MODULE-1: Amplitude Modulation

- Introduction:
  - Definition
  - Why Modulation
  - Types
  - Applications
- Amplitude Modulation:
  - Time & Frequency – Domain description
  - Switching modulator
  - Envelop detector

Source: WITS LAB

Introduction

o Purpose of a communication system: convey information through a medium or communication channel.

o The information is often represented as a baseband signal, i.e. a signal whose spectrum extends from 0 to some maximum frequency.

o Proper utilization of the communication channel often requires a shift of the range of baseband frequencies into other frequency ranges suitable for transmission, and a corresponding shift back to the original frequency range after reception.

o A shift of the range of frequencies in a signal is accomplished by using modulation, which is defined as the process by which some characteristic of a carrier is varied in accordance with a modulating (signal)

Source: WITS LAB

Introduction (Cont'd..)

- A common form of the carrier is a sinusoidal wave, in which case we speak of continuous-wave modulation.
- The baseband signal is referred to as the modulating wave, and the result of the modulation process is referred to as the modulated wave.
- Modulation is performed at the transmitting end.
- At the receiving end, we require the original baseband signal to be restored.
- This is accomplished by using a process known as demodulation, which is the reverse of the modulation process.

Source: WITS LAB

Amplitude Modulation

- A *sinusoidal carrier wave*:

$$c(t) = A_c \cos(2\pi f_c t) \qquad (3.1)$$

A_c is the carrier amplitude
f_c is the carrier frequency
Phase is assumed to be 0.

- *AM is defined as a process in which the amplitude of the carrier wave c(t) is varied about a mean value, linearly with baseband signal m(t).*
- AM wave, in its most general form

$$s(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t) \qquad (3.2)$$

- Typically, the carrier amplitude A_c and the message signal $m(t)$ are measured in volts, in which case the k_a is measured in volt^{-1}.
- k_a: *amplitude sensitivity*.[volt^{-1}]
- $m(t)$: modulating wave; the baseband signal that carries the message.
- $s(t)$: modulated wave.
- $m(t)$ and A_c are measured in volts.

Source: WITS LAB

Amplitude Modulation

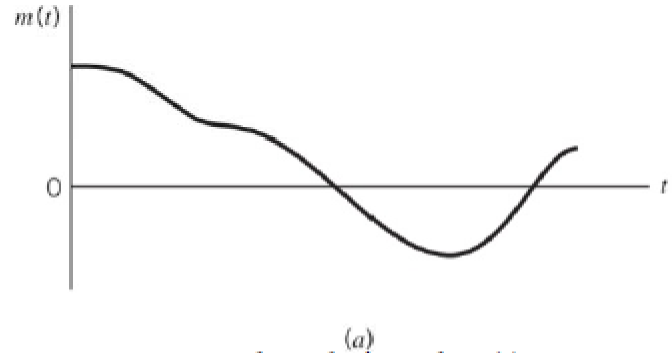
- The *envelope* of $s(t)$ has essentially the same shape as the baseband signal $m(t)$ provided that two requirements are satisfied:
  - **1.** The amplitude of $k_a m(t)$ is always less than unity, that is,

$$|k_a m(t)| < 1 \quad \text{for all } t \tag{3.3}$$

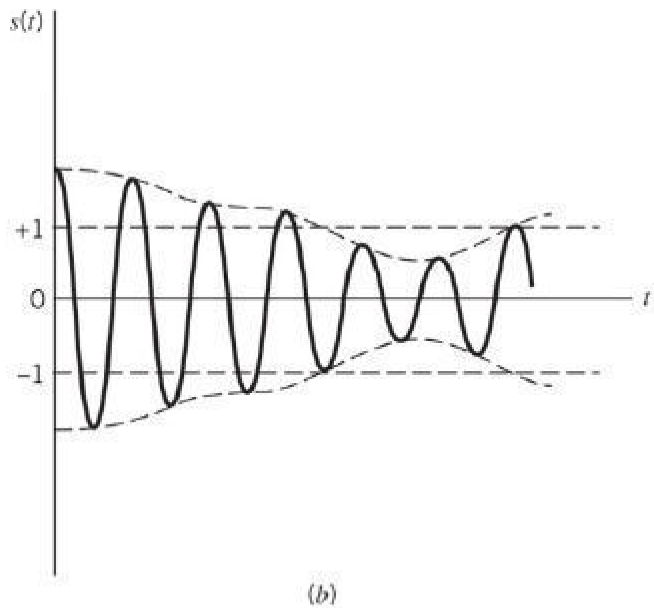
  - It ensures that the function $1+ k_a m(t)$ is always positive, and since an envelope is a positive function, we may express the envelope of the AM wave $s(t)$ of Eq. (3.2) as $A_c[1+ k_a m(t)]$.
  - When $|k_a m(t)|>1$ for any $t \rightarrow$ the carrier wave becomes *overmodulated*, resulting in *carrier phase reversals* whenever the factor $1+ k_a m(t)$ crosses zero. (*envelope distortion*)
  - The absolute maximum value of $k_a m(t)$ multiplied by 100 is referred to as the *percentage modulation*.

Source: WITS LAB

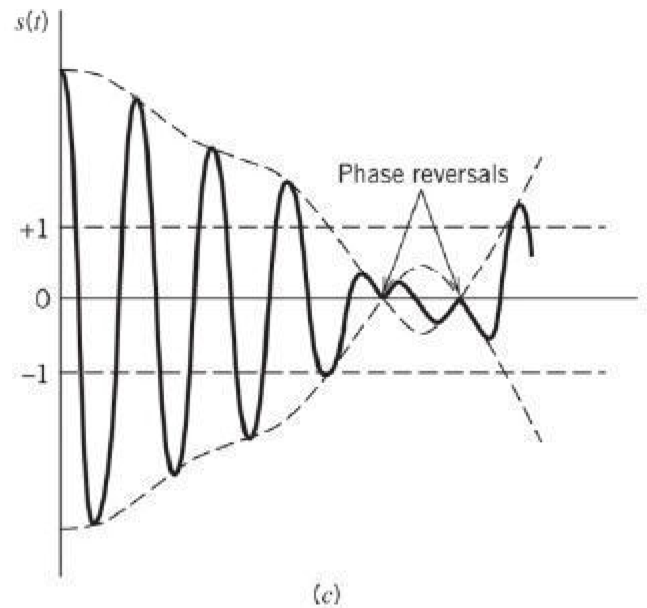
Amplitude Modulation



Baseband signal $m(t)$



AM wave for $|k_a m(t)|<1$ for all t



AM wave for $|k_a m(t)|>1$ for some t

Envelope distortion

Source: WITS LAB

Amplitude Modulation

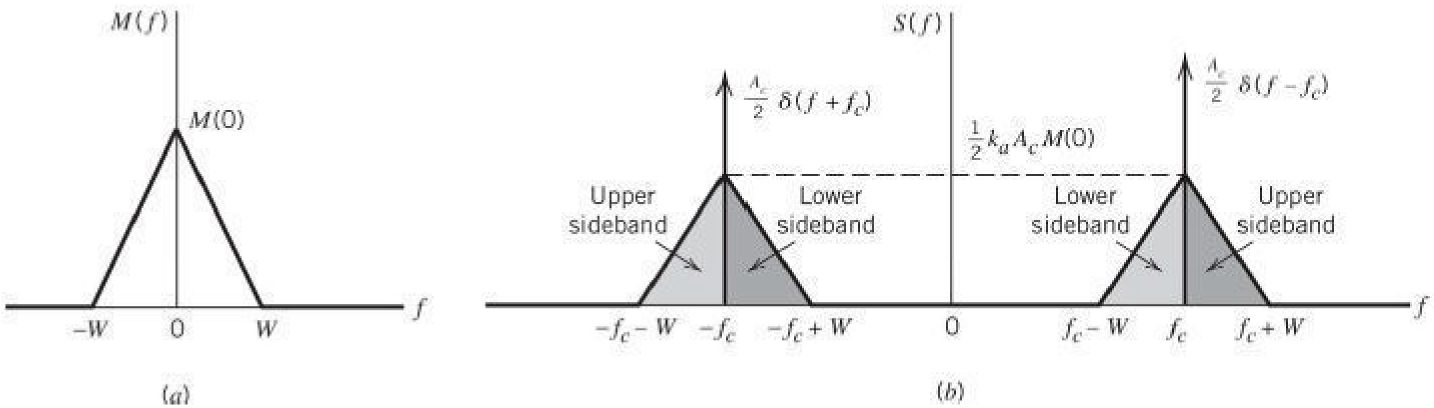
- **2.** The carrier frequency f_c is much greater than the highest frequency component W of the message signal $m(t)$, that is

$$f_c \gg W \qquad (3.4)$$

- We call W the *message bandwidth*. If the condition of Eq. (3.4) is not satisfied, an envelope can not be visualized satisfactorily.

- From Eq. (3.2), we find that the Fourier transform of the AM wave $s(t)$ is given by $s(t) = A_c\left[1 + k_a m(t)\right]\cos(2\pi f_c t) \quad (3.2)$ $\cos(2\pi f_c t) \rightleftharpoons \frac{1}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right]$

$$S(f) = \frac{A_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{k_a A_c}{2}\left[M(f - f_c) + M(f + f_c)\right] \qquad (3.5)$$



Source: WITS LAB

Amplitude Modulation

- From the spectrum of $S(f)$, we note the following:
  - **1.** As a result of the modulation process, the spectrum of the message signal $m(t)$ for negative frequencies extending from $-W$ to 0 becomes completely visible for positive frequencies, provided that the carrier frequency satisfies the condition $f_c > W$.
  - **2.** For positive frequencies: The spectrum of an AM wave above f_c is referred to as the *upper sideband*, below f_c is referred to as the *lower sideband*. For negative frequencies: The *upper sideband* is below $-f_c$ and the *lower sideband* is above $-f_c$. The condition $f_c > W$ ensures that the sidebands do not overlap.
  - **3.** For positive frequencies, the highest frequency component of the AM wave equals $f_c + W$, and the lowest frequency component equals $f_c - W$. The difference between these two frequencies defines the *transmission bandwidth* B_T for an AM wave.

$$B_T = 2W \qquad (3.6)$$

Source: WITS LAB

Queries ….?

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Source: WITS LAB

Amplitude Modulation

- Example 3.1 Single-Tone Modulation (1/3)
  - Consider a modulating wave: $m(t) = A_m \cos(2\pi f_m t)$
    - carrier wave: $c(t) = A_c \cos(2\pi f_c t)$

$$s(t) = A_c\left[1+\mu\cos(2\pi f_m t)\right]\cos(2\pi f_c t) \qquad (3.7)$$

where $\mu = k_a A_m$ → μ :modulation factor (or percentage modulation)

    - To avoid overmodulation ➔ $|\mu|<1$

  - Envelope of $s(t)$: $A_c[1+ \mu\cos(2\pi f_m t)]$

$$\frac{A_{\max}}{A_{\min}} = \frac{A_c(1+\mu)}{A_c(1-\mu)} \quad \Rightarrow \quad \mu = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$$

    - $A_{\max}$ and $A_{\min}$ denote the maximum and minimum values of the envelope of the modulated wave.

Amplitude Modulation

- Example 3.1 Single-Tone Modulation (2/3)
  - Eq. (3.7) can be represented in this form:

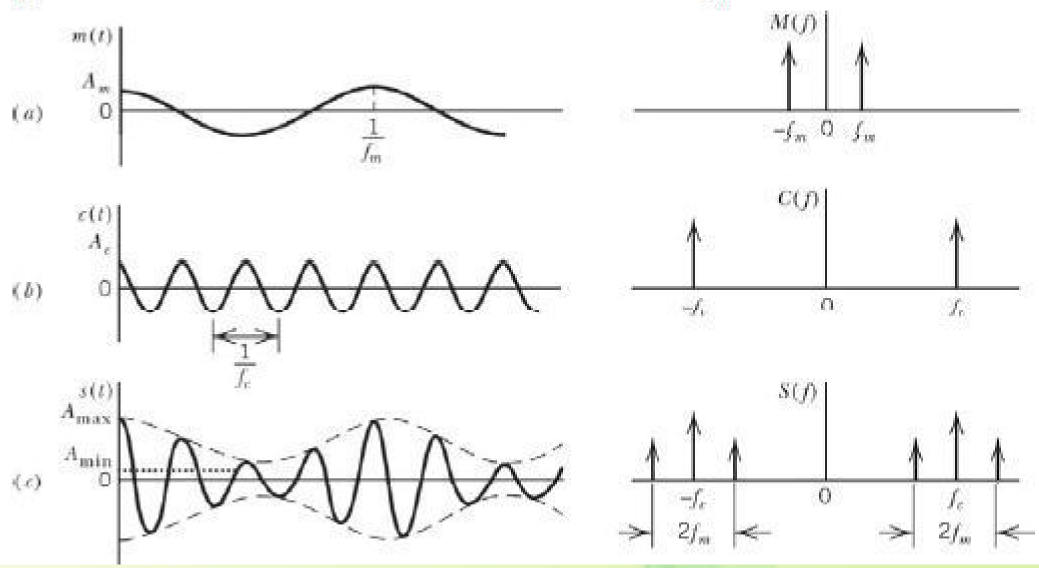
$$\cos A \cos B = \frac{1}{2}\{\cos(A-B)+\cos(A+B)\}$$

$$s(t) = A_c \cos(2\pi f_c t) + \frac{1}{2}\mu A_c \cos\left[2\pi(f_c+f_m)t\right] + \frac{1}{2}\mu A_c \cos\left[2\pi(f_c-f_m)t\right]$$

F

$$S(f) = \frac{1}{2}A_c\left[\delta(f-f_c)+\delta(f+f_c)\right] + \frac{1}{4}\mu A_c\left[\delta(f-f_c-f_m)+\delta(f+f_c+f_m)\right]$$

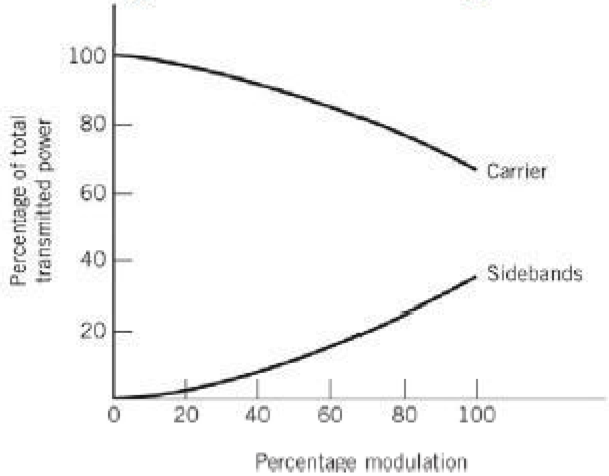
$$+\frac{1}{4}\mu A_c\left[\delta(f-f_c+f_m)+\delta(f+f_c-f_m)\right]$$



Source: WITS LAB

Amplitude Modulation

- Example 3.1 Single-Tone Modulation (3/3)



$$\text{Carrier power} = \frac{1}{2}A_c^2$$

$$\text{Upper side-frequency power} = \frac{1}{8}\mu^2 A_c^2$$

$$\text{Lower side-frequency power} = \frac{1}{8}\mu^2 A_c^2$$

- In any case, the ratio of the total sideband power to the total power in the modulated wave is equal to

$$\mu^2 / \left(2 + \mu^2\right)$$

  - Depend only on the modulation factor μ.
  - If $\mu=1$, the total power in the two side frequencies of the resulting AM wave is only one-third of the total power in the modulated wave.
  - When the percentage modulation is less than 20 percent, the power in one side frequency is less than 1 percent of the total power in the AM wave.

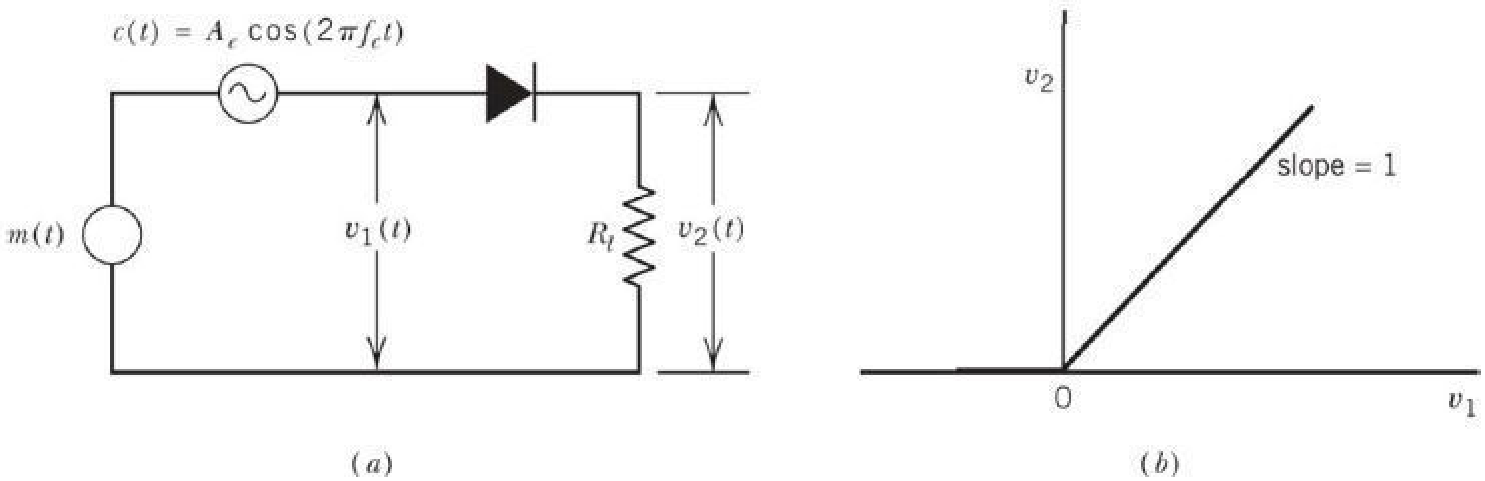
Source: WITS LAB

Amplitude Modulation

- Switching Modulator (1/4)
  - One way to generate an AM wave: *Switching Modulator*.
    - Assume carrier wave $c(t)$ is large in amplitude and the diode acts as an *ideal switch*.

$$v_1(t) = A_c \cos(2\pi f_c t) + m(t) \tag{3.8}$$

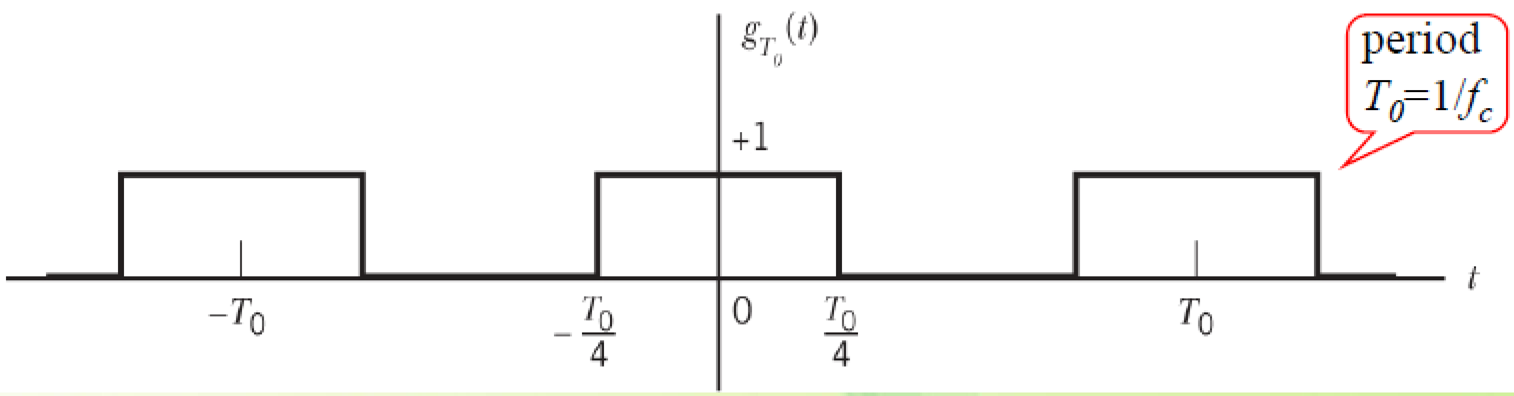
$$v_2(t) \approx \begin{cases} v_1(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases} \tag{3.9}$$



Amplitude Modulation

- Switching Modulator (2/4)
  - From Eq. (3.9), load voltage $v_2(t)$ varies periodically between the values $v_1(t)$ and zeros at a rate equal to the carrier frequency f_c.
  - By assuming a modulating wave that is weak compared with the carrier wave, we have effectively replace the nonlinear behavior of the diode by an approximately equivalent piecewise-linear time-varying operation.
  - We may express Eq. (3.9) mathematically as

$$v_2(t) \approx \left[A_c \cos(2\pi f_c t) + m(t) \right] g_{T_0}(t) \qquad (3.10)$$



Source: WITS LAB

Amplitude Modulation

- Switching Modulator (4/4)

$$g_{T_0}(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\left[2\pi f_c t(2n-1)\right] \qquad (3.11)$$

- Substituting Eq. (3.11) in (3.10), $v_2(t)$ consists of two component
  - A desired AM wave:

$$v_2(t) \approx \left[A_c\cos(2\pi f_c t) + m(t)\right] g_{T_0}(t) \quad (3.10)$$

$$\frac{A_c}{2}\left[1 + \frac{4}{\pi A_c} m(t)\right]\cos(2\pi f_c t) \quad , \quad k_a = \frac{4}{\pi A_c}$$

  - Unwanted component, the spectrum of which contains
    - Delta function at 0, $\pm 2f_c$, $\pm 4f_c$ and so on.
    - Occupy frequency intervals of width $2W$ centered at 0, $\pm 3f_c$, $\pm 5f_c$ and so on, where W is the message bandwidth.
    - Be removed by using a band-pass filter with mid-band frequency f_c and bandwidth $2W$, provide that $f_c > 2W$.

Source: WITS LAB

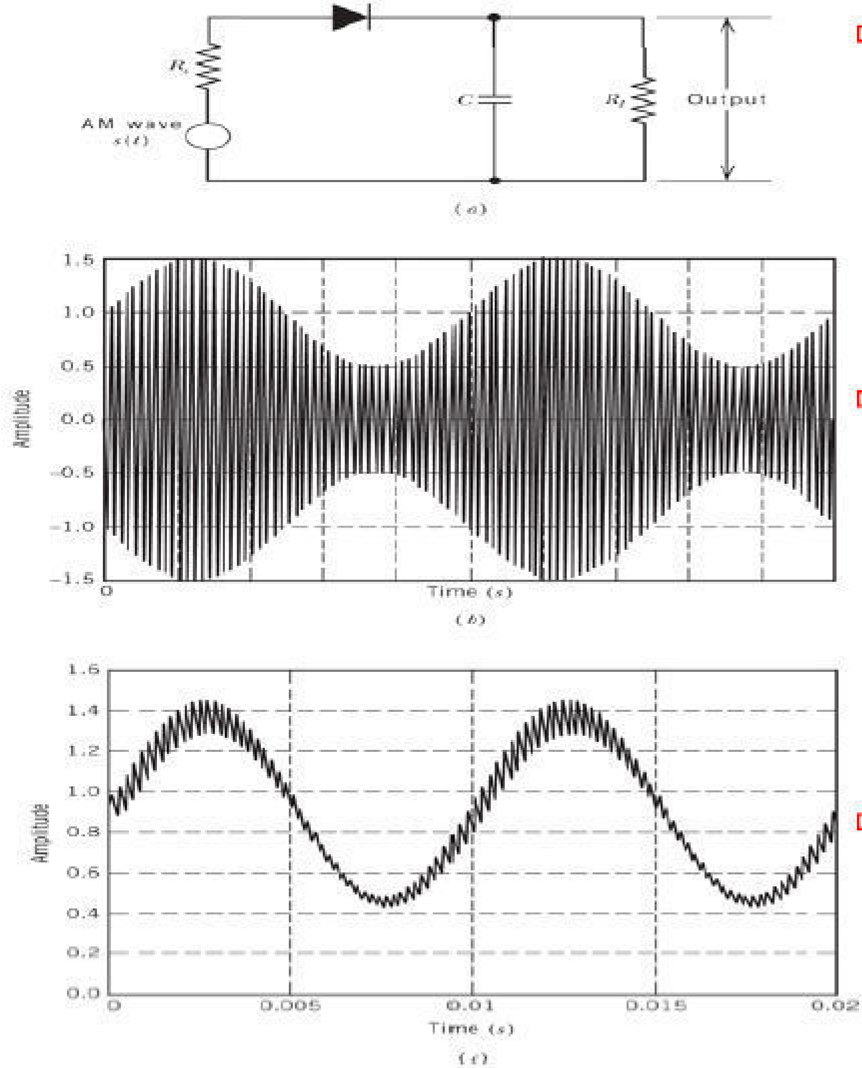
Amplitude Modulation

- Envelope Detector (1/2)
  - The process of *demodulation* is used to recover the original modulating wave from the incoming modulated wave.
  - One way to demodulate an AM wave: *envelope detector*.
    - Consist of a diode and a resistor-capacitor (RC) filter. (see next page)
  - The operation of envelope detector:
    - On a positive half-cycle of the input signal, the diode is forward-biased and the capacitor C charges up rapidly to the peak value of the input signal.
    - When the input signal falls below this value, the diode becomes reverse-biased and the capacitor C discharges slowly through the load resistor R_l. The discharging process continues until the next positive half-cycle.
    - When the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.

Source: WITS LAB

Amplitude Modulation

- Envelope Detector (2/2)



Envelope detector circuit diagram, assuming the diode is ideal, having a constant resistance r_f when forward biased and infinite resistance when reverse-biased.

A sinusoidal AM wave with 50 percent modulation.

Envelope detector output contains a small amount of ripple at the carrier frequency; this ripple is easily removed by the low-pass filter.

Source: WITS LAB

Queries ...?

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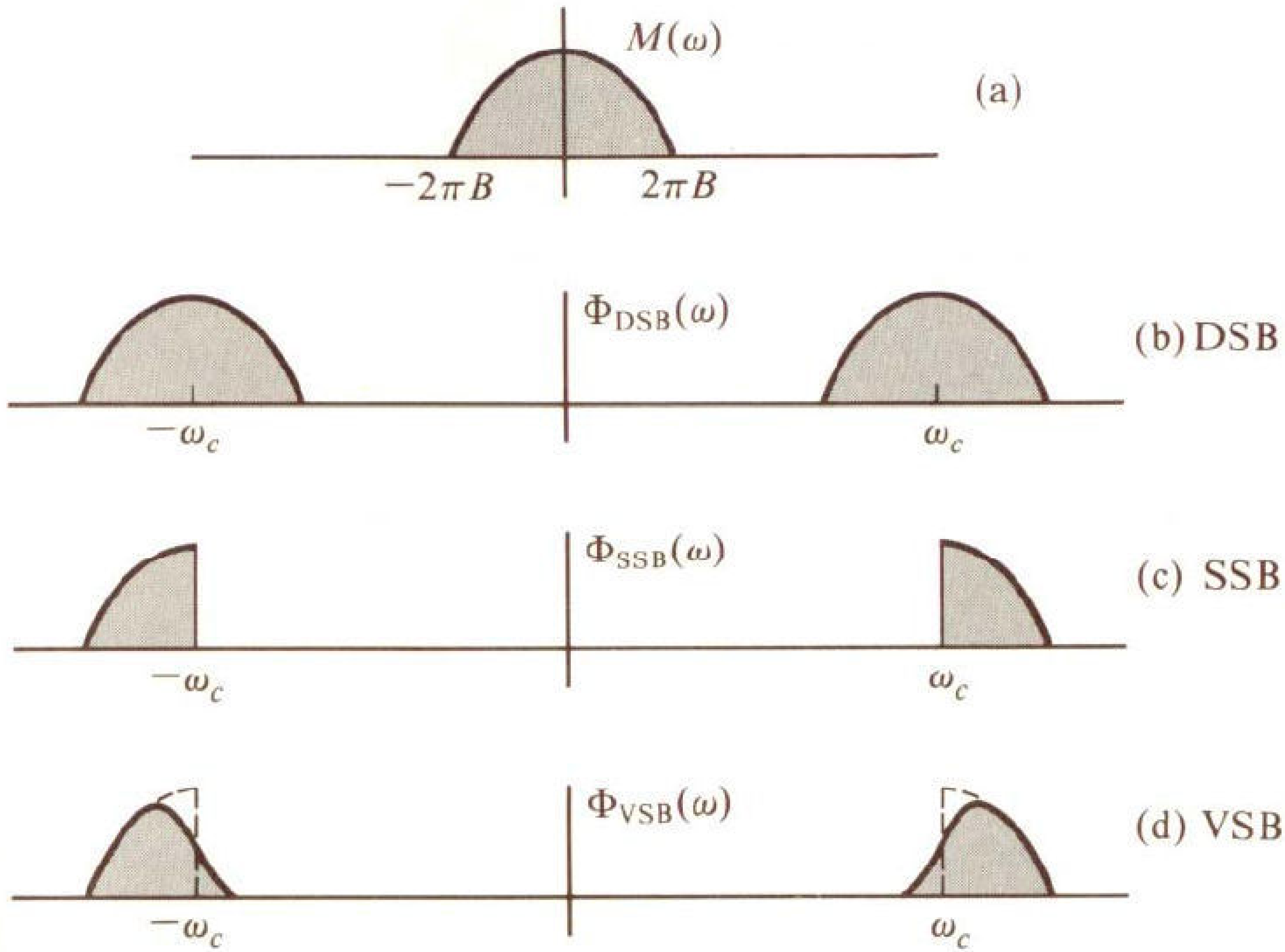
Source: WITS LAB

TYPES OF AMPLITUDE MODULATION

- Three modified forms of amplitude modulation:
  - *Double sideband-suppressed carrier* (*DSB-SC*) *modulation*, in which the transmitted wave consists of only the upper and lower sidebands.
    - Transmitted power is saved through the suppression of the carrier. The channel bandwidth requirement is $2W$.
  - *Vestigial sideband* (*VSB*) *modulation*, in which one sideband is passed almost completely and just a trace, or *vestige*, of the other sideband is retained.
    - The required channel bandwidth is in excess of the message bandwidth by an amount equal to the width of the vestigial sideband.
    - Suited for the transmission of wideband signals such as television signals.
  - *Single sideband* (*SSB*) *modulation*, in which the modulated wave consists only of the upper sideband or the lower sideband.
    - Suited for the transmission of voice signals by virtue of the *energy gap* that exists in the spectrum of voice signals between zero and a few hundred hertz.
    - The minimum transmitted power and minimum channel bandwidth: its principal disadvantage is increased cost and complexity.

Source: WITS LAB

Spectra of the various modulated signals



Source: WITS LAB

Double Sideband-Suppressed Carrier Modulation

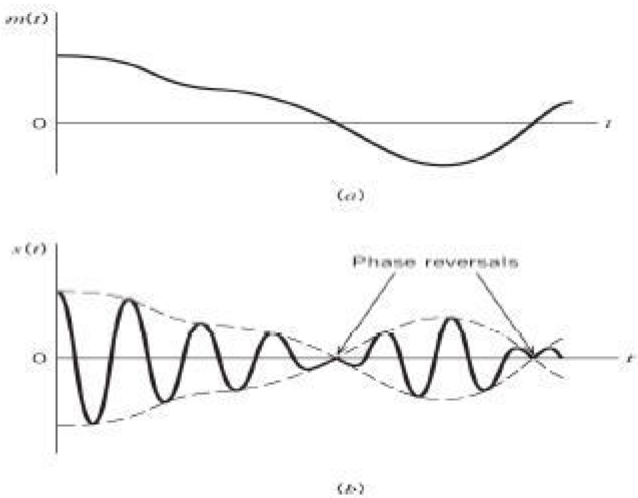
- *Double sideband-suppressed carrier (DSB-SC) modulation.*
  - Product of the message signal $m(t)$ and the carrier wave $c(t)$:

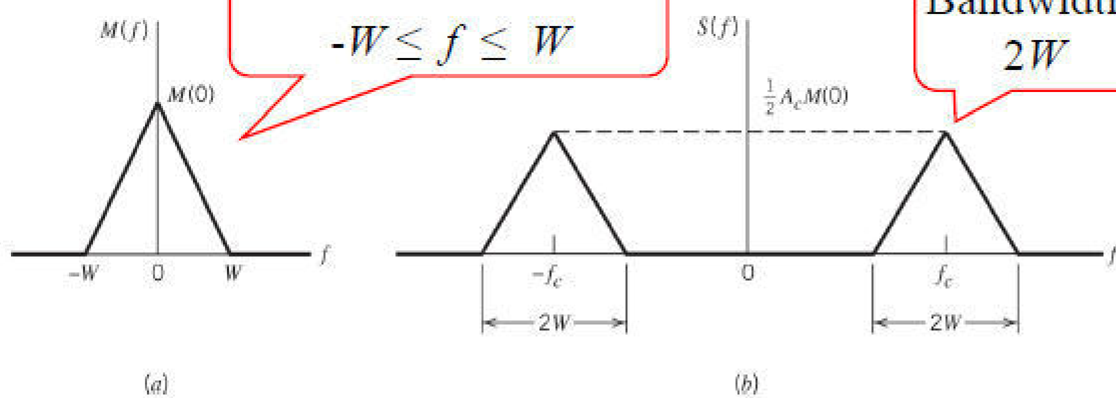
$$s(t) = c(t)m(t) = A_c \cos(2\pi f_c t)m(t) \qquad (3.14)$$

- The modulated signal $s(t)$ undergoes a *phase reversal* whenever the message signal $m(t)$ crosses zero.
- The envelope of a DSB-SC modulated signal is different from the message signal.

F

$$S(f) = \frac{1}{2}A_c\left[M(f-f_c)+M(f+f_c)\right] \qquad (3.15)$$





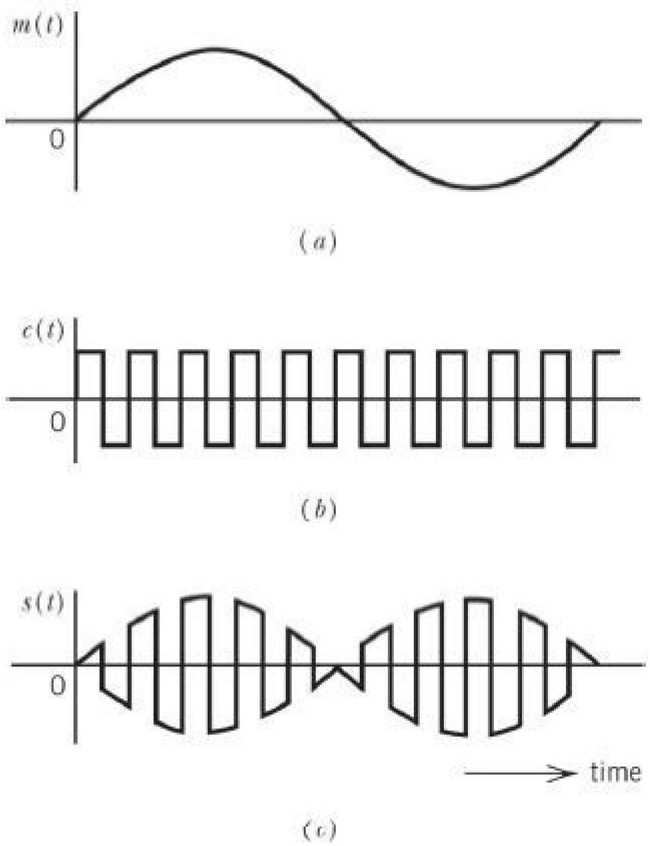
limited to the interval $-W \le f \le W$

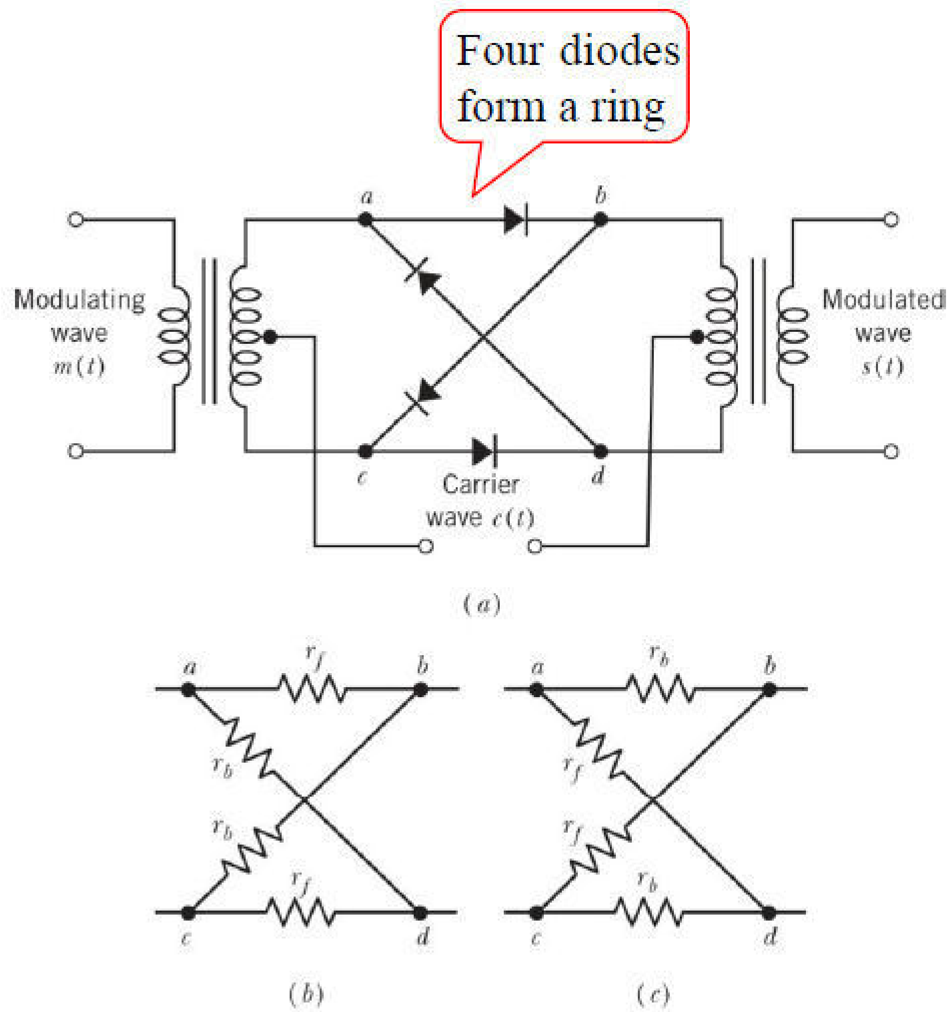
Bandwidth: $2W$

Source: WITS LAB

Double Sideband-Suppressed Carrier Modulation

- Ring Modulator (1/4)





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3.3 Double Sideband-Suppressed Carrier Modulation

- Ring Modulator (2/4)
  - Ring modulator is one of the most useful product modulator, well suited for generating a DSB-SC wave.
    - The diodes are controlled by a square-wave carrier $c(t)$ of frequency f_c, which is applied longitudinally by means of two center-tapped transformers.
    - If the transformers are perfectly balanced and the diodes are identical, there is *no* leakage of the modulation frequency into the modulation output .
  - The operation of the circuit.
    - Assuming that the diodes have a constant forward resistance r_f when switched on and a constant backward resistance r_b when switched off. And they switch as the carrier wave $c(t)$ goes through zero.
    - On one half-cycle of the carrier wave, the outer diodes are switched to their forward resistance r_f and the inner diodes are switched to their backward resistance r_b. On the other half-cycle of the carrier wave, the diodes operate in the opposite condition.

Double Sideband-Suppressed Carrier Modulation

- Ring Modulator (3/4)
  - The output voltage has the same magnitude as the output voltage, but they have opposite polarity.
  - In fact, the ring modulator acts as a *commutator*.
  - Square-wave carrier $c(t)$ can be represented by a Fourier series:

$$c(t) = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\left[2\pi f_c t(2n-1)\right] \qquad (3.16)$$

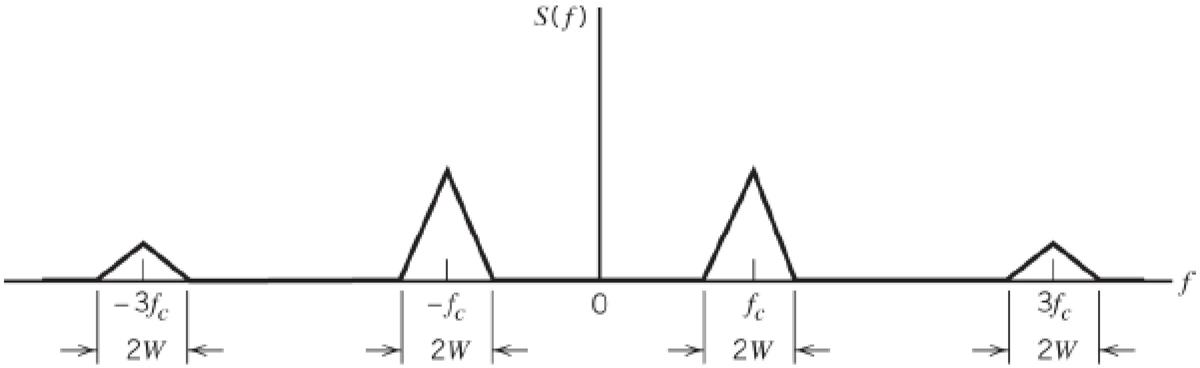
  - The ring modulator output is therefore

$$s(t) = c(t)m(t) = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\left[2\pi f_c t(2n-1)\right]m(t) \qquad (3.17)$$

  - It is sometimes referred to as a *double-balanced modulator*, because it is balanced with respect to both the baseband signal and the square-wave carrier.

Double Sideband-Suppressed Carrier Modulation

- Ring Modulator (4/4)
  - Assuming that $m(t)$ is limited to the frequency band $-W \le f \le W$, the spectrum of the modulator output consists of sidebands around each of the odd harmonics of the square-wave carrier $m(t)$.
  - To prevent sideband overlap ➔ $f_c > W$.
  - We can use a band-pass filter of mid-band frequency f_c and bandwidth $2W$ to select the desired pair of sidebands around the carrier frequency f_c.
    - The circuitry needed for the generation of a DSB-SC modulated wave consists of a ring modulator followed by a band-pass filter.



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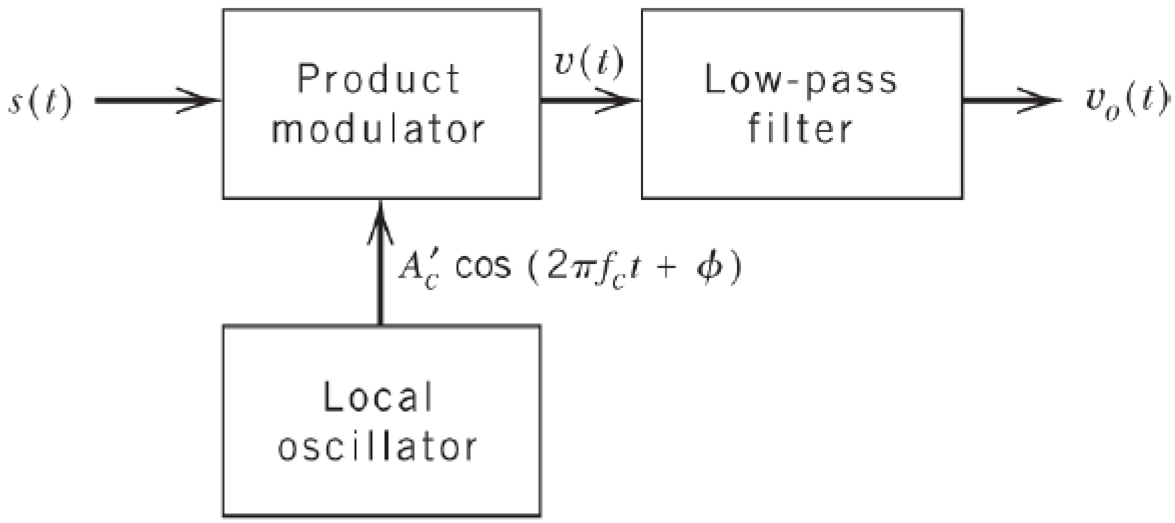
Source: WITS LAB

Double Sideband-Suppressed Carrier Modulation

- Coherent Detection (1/4)



- It is assumed that the local oscillator signal is exactly coherent or synchronized, in both *frequency and phase*, with carrier wave $c(t)$ used in the product modulator to generate $s(t)$. This method of demodulation is known as *coherent detection* or *synchronous demodulation*.

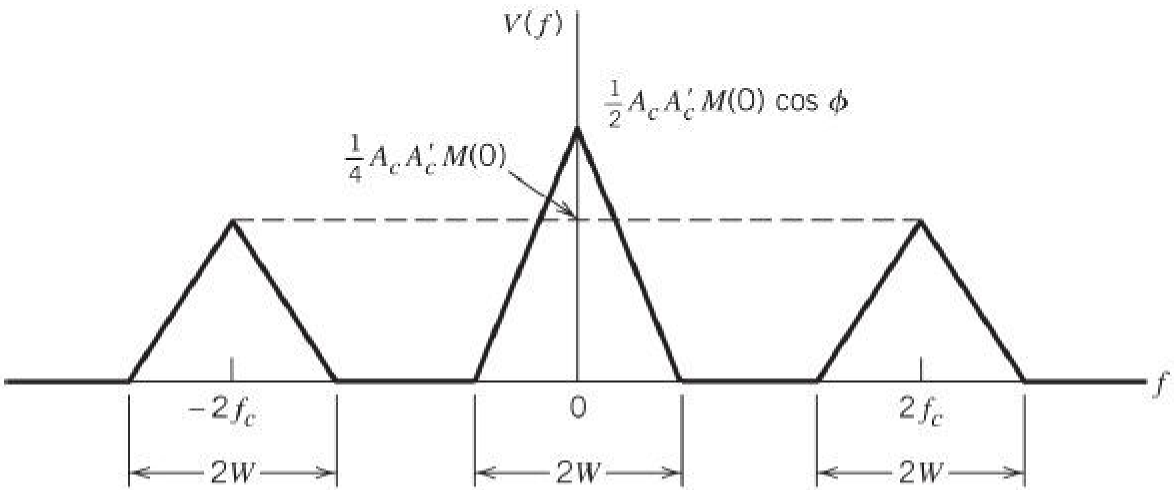
Double Sideband-Suppressed Carrier Modulation

Coherent Detection (2/4)

For a more general demodulation process, we assume ϕ is a arbitrary phase difference.

$s(t) = A_c \cos(2\pi f_c t) m(t)$

$$\begin{aligned}\upsilon(t) &= A_c' \cos(2\pi f_c t + \phi) s(t) \\ &= A_c A_c' \cos(2\pi f_c t)\cos(2\pi f_c t + \phi) m(t) \qquad (3.18) \\ &= \frac{1}{2} A_c A_c' \cos(4\pi f_c t + \phi) m(t) + \frac{1}{2} A_c A_c' \cos\phi\, m(t)\end{aligned}$$



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Double Sideband-Suppressed Carrier Modulation

- Coherent Detection (3/4)
  - The first term in Eq.(3.18) is removed by low-pass filter, provided that the cut-off frequency of this filter is greater than W but less than $2f_c - W$. This is satisfied by choosing $f_c > W$. Therefore:

$$\upsilon_o(t) = \frac{1}{2} A_c A_c' \cos\phi \, m(t) \qquad (3.19)$$

    - $v_o(t)$ is proportional to $m(t)$ when the phase error ϕ is a constant. Attenuated by a factor equal to $\cos\phi$.

$$\begin{cases} v_{o\_max} = \frac{1}{2} A_c A_c' m(t), \text{when } \phi = 0 \\ v_{o\_mim} = 0, \qquad \text{when } \phi = \pm\frac{\pi}{2} \qquad \text{(quadrature null effect)} \end{cases}$$

    - When the phase error ϕ is constant, the detector provides an undistorted version of the original baseband signal $m(t)$.

Source: WITS LAB

Double Sideband-Suppressed Carrier Modulation

- Coherent Detection (4/4)
  - In practice, we usually find that the phase error φ varies randomly with time, due to random variations in communication channel. The result is that at the detector output, the multiplying factor $\cos\varphi$ also varies randomly with time, which is obviously undesired.

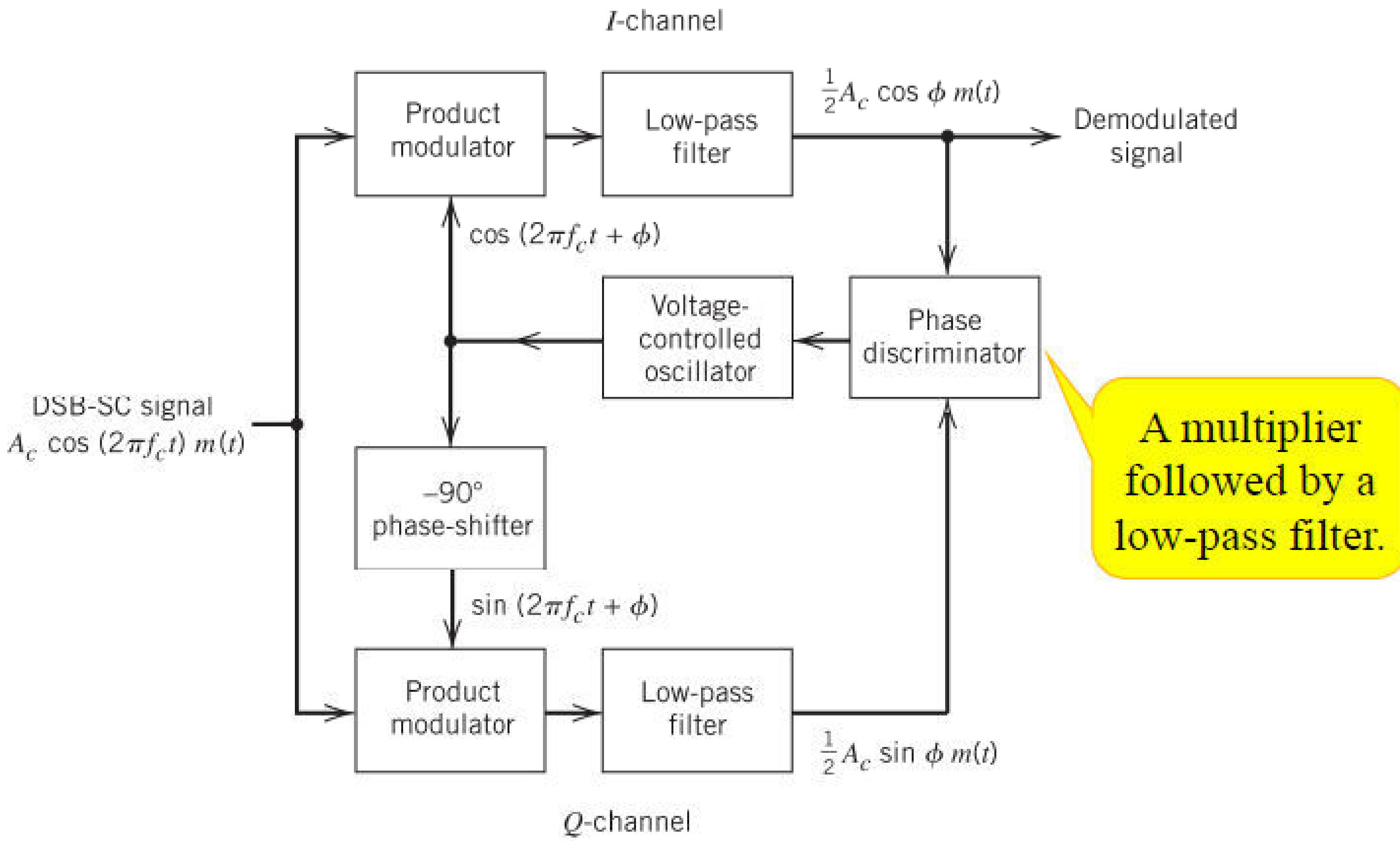
- Provision must be made in the system to maintain the local oscillator in the receiver in *perfect synchronism*, in both frequency and phase, with the carrier wave used to generate the DSB-SC modulated signal in the transmitter.

- The resulting system complexity is the price that must be paid for suppressing the carrier wave to save transmitter power.

Source: WITS LAB

3.3 Double Sideband-Suppressed Carrier Modulation

- Costas Receiver (1/2)
  - One method of obtaining a practical synchronous receiver system, suitable for demodulating DSB-SC waves.



Source: WITS LAB

Double Sideband-Suppressed Carrier Modulation

- Costas Receiver (2/2)
  - The frequency of the local oscillator is adjusted to be the same as the carrier frequency f_c, which is assumed known *a prior*.
  - In the upper path is referred to as the *in-phase coherent detector* or *I-channel*, and that in the lower path is referred to as the *quadrature-phase coherent detector* or *Q-channel*. These two detectors are coupled together to from a negative feedback system designed in such a way as to maintain the local oscillator synchronous with the carrier wave.
  - By combining the *I*- and *Q*-channel outputs in *phase discriminator* (which consists of a *multiplier* followed by a *low-pass filter*), a dc control signal is obtained that automatically corrects for local phase errors in the *voltage-controlled oscillator* (VCO).

Double Sideband-Suppressed Carrier Modulation

- Outputs of Product Modulator
  - I-Channel $A_c \cos(2\pi f_c t) m(t) \cos(2\pi f_c t + \phi) = \frac{1}{2} A_c m(t) \{\cos(4\pi f_c t + \phi) + \cos\phi\}$
  - Q-Channel $A_c \cos(2\pi f_c t) m(t) \sin(2\pi f_c t + \phi) = \frac{1}{2} A_c m(t) \{\sin(4\pi f_c t + \phi) + \sin\phi\}$
- Outputs of Low-Pass Filter
  - I-Channel $\frac{1}{2} A_c m(t) \cos\phi$
  - Q-Channel $\frac{1}{2} A_c m(t) \sin\phi$
- Output of Multiplier

$$\left\{\frac{1}{2} A_c m(t) \cos\phi\right\} \cdot \left\{\frac{1}{2} A_c m(t) \sin\phi\right\} = \frac{1}{8} A_c^2 \left[m(t)\right]^2 \sin 2\phi$$

Source: WITS LAB

Queries …?

Department of Electronics & Communication Engg.

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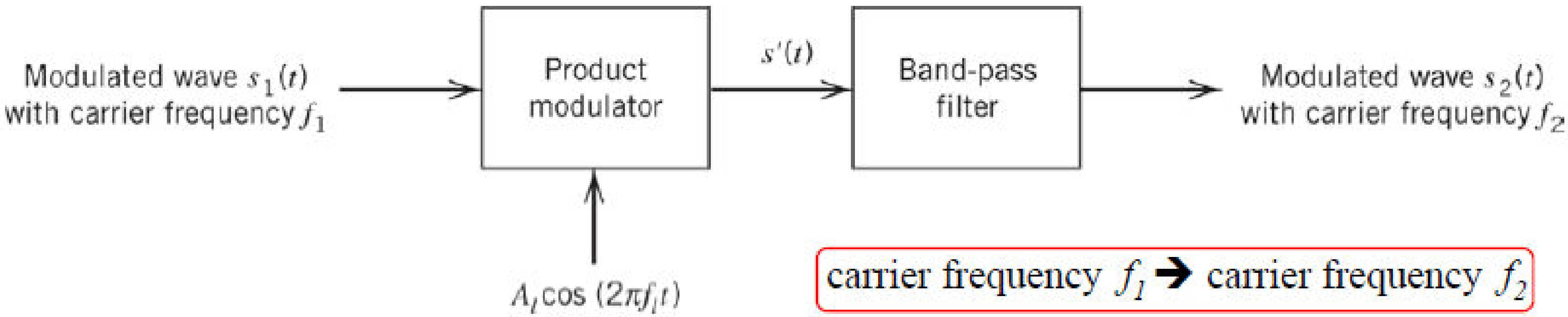
MODULE-1: Amplitude Modulation

- Frequency Translation
- Exercise Problems and Solutions

Source: WITS LAB

Frequency Translation

- The basic operation involved in single-sideband modulation is in fact a form of *frequency translation*.
  - SSB modulation is sometimes referred to as *frequency changing*, *mixing*, or *heterodyning*.
- The *mixer* consists a product modulator followed by a band-pass filter.
  - Band-pass filter bandwidth: equal to that of the modulated signal $s_1(t)$ used as input.



carrier frequency f_1 → carrier frequency f_2

Source: WITS LAB

Frequency Translation

- Due to frequency translation performed by the *mixer* : We may set

$$\begin{cases} f_2 = f_1 + f_l \\ f_l = f_2 - f_1 \end{cases}$$

assume $f_2 > f_1$
translated *upward*

or

$$\begin{cases} f_2 = f_1 - f_l \\ f_l = f_1 - f_2 \end{cases}$$

assume $f_1 > f_2$
translated *downward*

$$s_1(t) \times A_l \cos(2\pi f_l t) = m(t)\cos(2\pi f_1 t) \times A_l \cos(2\pi f_l t)$$

$$= \frac{1}{2} A_l m(t)\left[\cos\left(2\pi(f_1 + f_l)t\right) + \cos\left(2\pi(f_1 - f_l)t\right)\right]$$

  - The band-pass filter rejects the unwanted frequency and keeps the desired one.
- Mixing is a linear operation.

Source: WITS LAB

PROBLEMS

Source: WITS LAB

Queries ….?