Chapter 8: Communication Systems (cover 8.0 – 8.5)

Modulation = process of embedding an information bearing signal into another signal.

Demodulation = process of extracting the information bearing signal.

Multiplexing = simultaneous transmission of more than one signal having overlapping spectra.

There are a large number of practical modulation/demodulation schemes. We only have time to study a few ⟶ EE 440, 544, 639, 641, 678, 679 for much more on this subject.

General (amplitude) Modulation

$x(t) \longrightarrow \otimes \longrightarrow y(t) = x(t)\,c(t) \triangleq$ modulated signal

$x(t)$: info. bearing signal

$c(t)$: carrier signal.

If $x(t) \longleftrightarrow X(j\omega)$ and $c(t) \longleftrightarrow C(j\omega)$, then

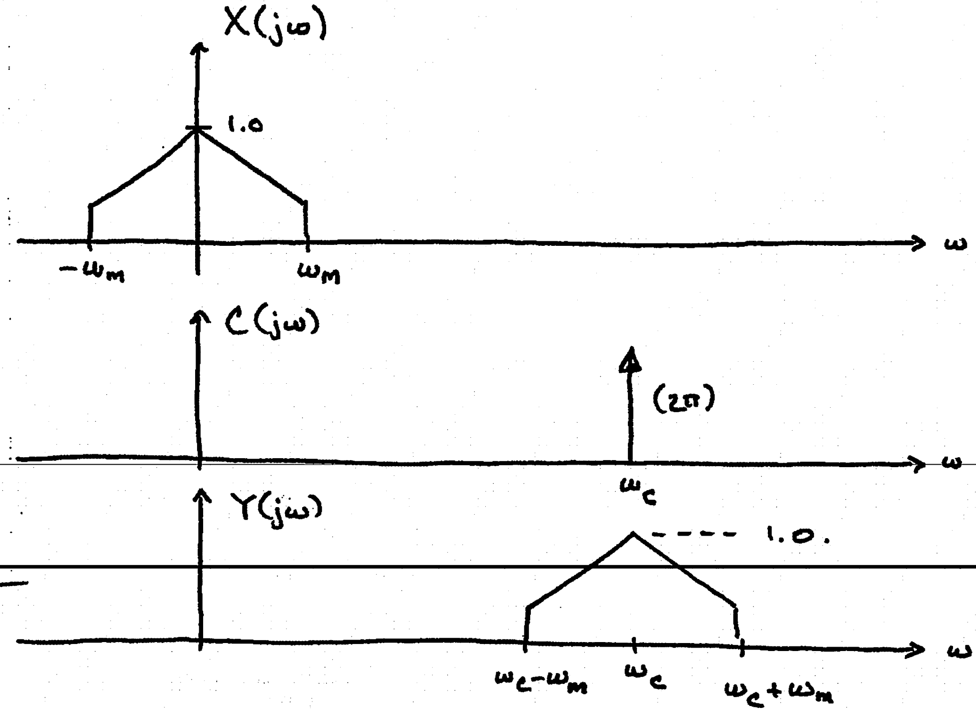
$$y(t) \longleftrightarrow Y(j\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(j\theta)\, C(j(\omega-\theta))\, d\theta$$

Case: Amplitude Modulation with $c(t) = e^{j\omega_c t}$

Have $c(t) \longleftrightarrow C(j\omega) = 2\pi\,\delta(\omega-\omega_c)$

$$\therefore\ Y(j\omega) = X(j(\omega-\omega_c))$$

Typical Pictures

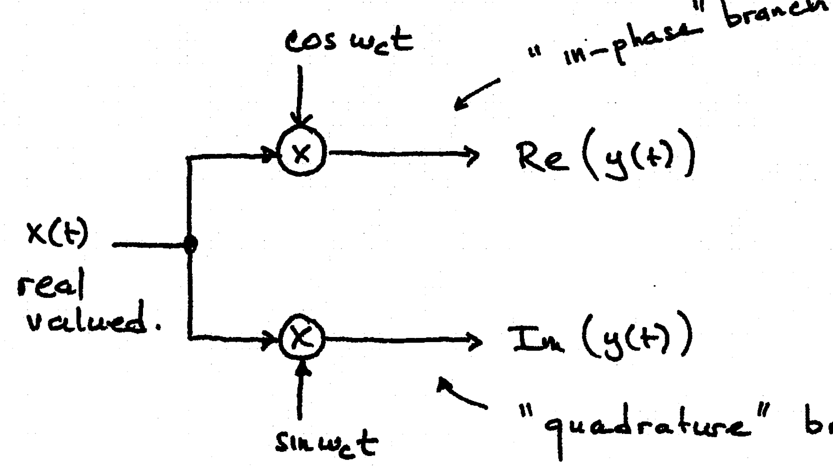


$\omega_c >> \omega_m$ is typical.

Now the signal is centered around the carrier frequency.

The modulator may be implemented with real arithmetic operations using

$$e^{j\omega_c t} = \cos \omega_c t + j \sin \omega_c t$$



Quadrature modulator

Very Simple Demodulator $x(t) = y(t)\, e^{-j\omega_c t}$

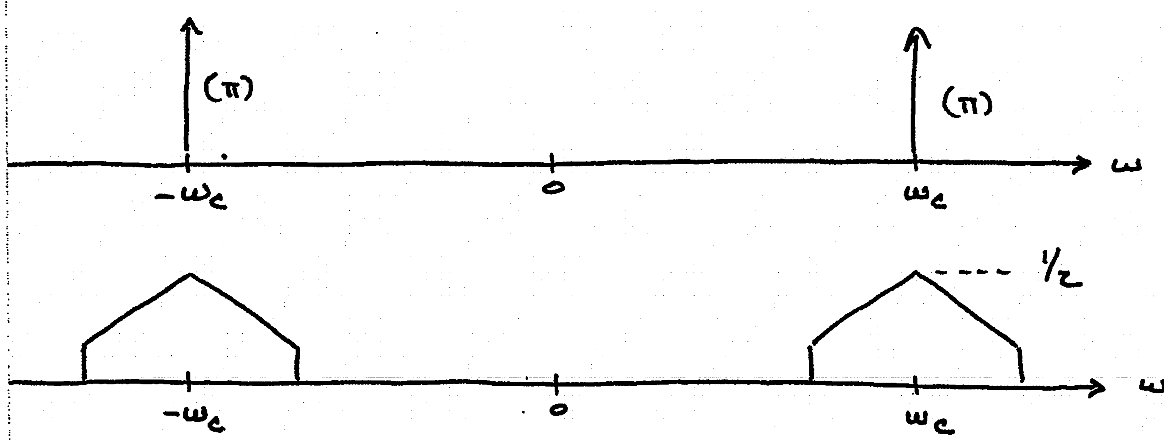
Case: Amplitude Modulation with $c(t) = \cos(\omega_c t)$

$$C(j\omega) = \pi\left[\delta(\omega-\omega_c) + \delta(\omega+\omega_c)\right]$$

$$\therefore\ Y(j\omega) = \tfrac{1}{2} X(j(\omega-\omega_c)) + \tfrac{1}{2} X(j(\omega+\omega_c))$$

Typical Pictures

$X(j\omega)$ same as before



Now need $\omega_c > \omega_m$ for recoverability by simple demod (else sidebands overlap).

Demodulation for Sinusoidal AM

There are two types:

1. synchronous (or coherent) = receiver has exact knowledge of carrier phase + freq.
2. asynchronous (or non-coherent)

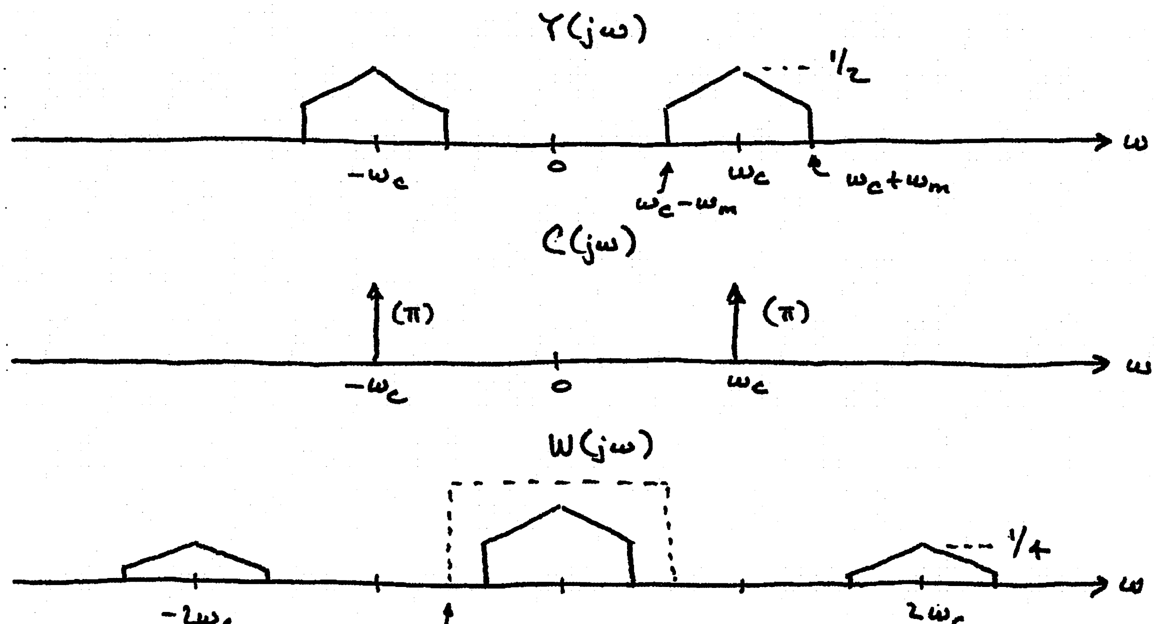
Synchronous/Coherent Demodulation

Assume $\omega_c > \omega_m$. $y(t) = x(t)\cos\omega_c t$. Consider multiplying again by $\cos\omega_c t$:

$$w(t) = y(t)\cos\omega_c t = x(t)\cos^2\omega_c t$$
$$= x(t)\left(\frac{1+\cos 2\omega_c t}{2}\right).$$

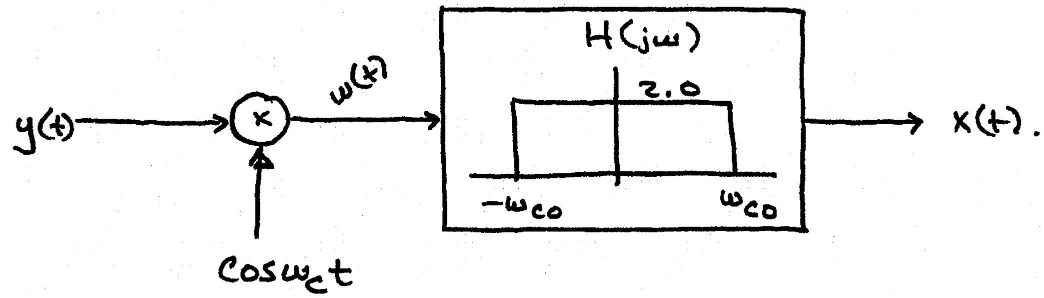
$$\therefore \quad w(t) = \underbrace{\tfrac{1}{2}x(t)}_{\text{scaled version of desired info bearing signal.}} + \underbrace{\tfrac{1}{2}x(t)\cos 2\omega_c t}_{\text{a modulated signal with carrier } 2\omega_c}$$

Look at spectral plots:



select desired portion with ideal LPF

Thus an ideal coherent/synchronous demodulator block diagram would be:



Must pick ω_{co} st $\quad \omega_m < \omega_{co} < 2\omega_c - \omega_m$

What happens if not exactly snychronous?

Suppose: $\quad \cos\omega_c t$ used in modulator

$\cos(\omega_c t + \theta)$ used in demodulator

Then

$$w(t) = x(t)\cos\omega_c t\cos(\omega_c t + \theta)$$

$$= \frac{1}{2}\cos\theta\, x(t) + \underbrace{\frac{1}{2}x(t)\cos(2\omega_c t + \theta)}_{\text{can be removed by filtering just as before.}}$$

Now at output of LPF with gain 2 we get

$$\tilde{x}(t) = \cos\theta\, x(t)$$

instead of $x(t)$.

Asynchronous / Non-Coherent Demodulation

Commonly used in systems needing simple / low cost receivers as avoids need for precise synchronization of trans/rec. oscillators.

eg. AM radio 540 – 1600 KHz.

EE 402 digital AM Tx/Rx

Suppose $x(t) > 0$ and $\omega_c \gg \omega_m$. Then the modulated signal $y(t) = x(t) \cos \omega_c t$ will look like:

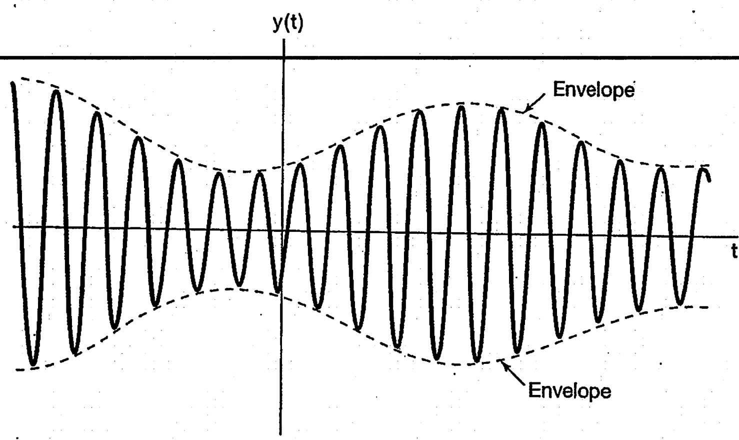
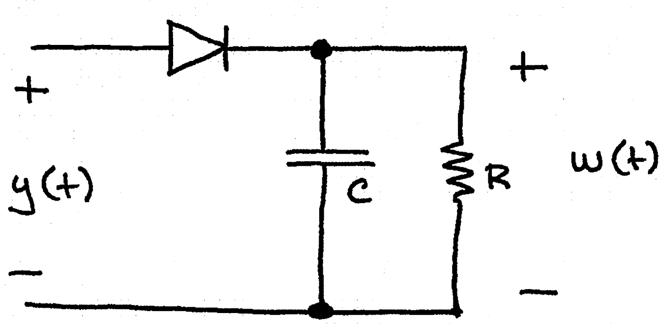
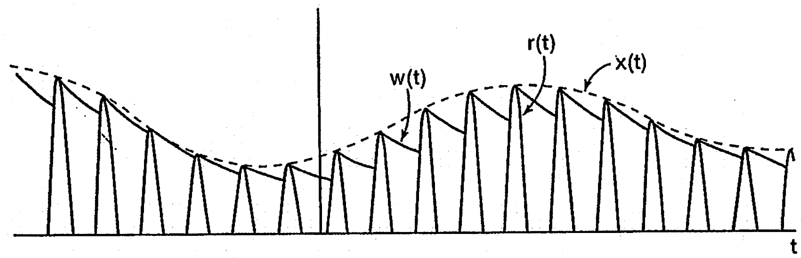


Figure 8.10 Amplitude-modulated signal for which the modulating signal is positive. The dashed curve represents the envelope of the modulated signal.

Observe that envelope has the same shape as desired info. bearing signal. A circuit that will detect the envelope is:





(b)

Figure 8.11 Demodulation by envelope detection: (a) circuit for envelope detection using half-wave rectification; (b) waveforms associated with the envelope detector in (a): $r(t)$ is the half-wave rectified signal, $x(t)$ is the true envelope, and $w(t)$ is the envelope obtained from the circuit in (a). The relationship between $x(t)$ and $w(t)$ has been exaggerated in (b) for purposes of illustration. In a practical asynchronous demodulation system, $w(t)$ would typically be a much closer approximation to $x(t)$ than depicted here.

Things to note in the Figure:

1. ~~$r(t)$ is half-wave rectified version of $y(t)$.~~
2. circuit time constant RC should be set fast enough to follow the envelope but too slow to follow the carrier ie

$$\frac{2\pi}{\omega_m} \approx RC \gg \frac{2\pi}{\omega_c}$$

3. usually would further filter $w(t)$ to reduce the carrier ripple.

<u>The conditions for envelope detection (again):</u>

$\omega_m \ll \omega_c$ is most often satisfied.

$x(t) > 0$ is not usually true so modify signal by adding DC term

$$x(t) + A > 0$$

If $K \geq |x(t)|$ then must pick $A > K$.

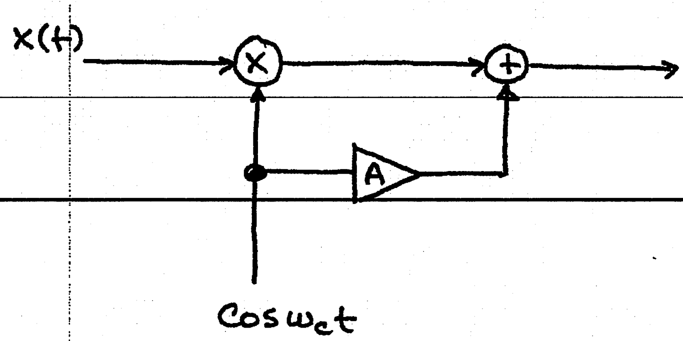
$$\frac{K}{A} \triangleq m \triangleq \text{modulation index}$$

$m = \frac{1}{2}$ (50% modulation)

$m = 1$ or > 1 needed for envelope detection to work well.

↳ (100% modulation)

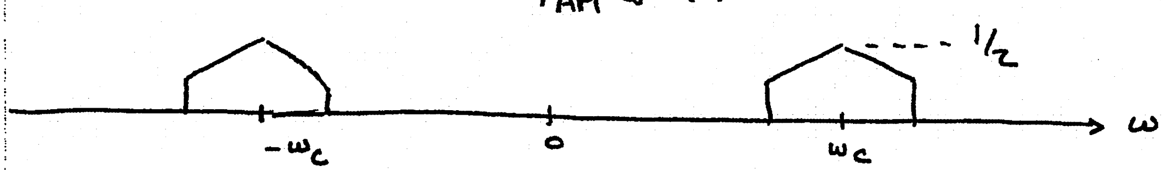
So the modulator becomes:



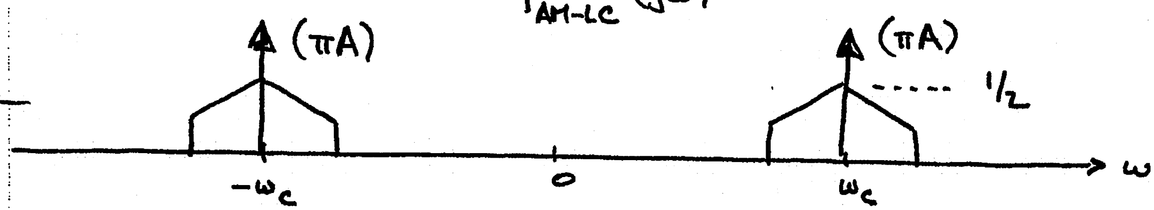
$y(t) = (A + x(t)) \cos \omega_c t$

The spectra are: $Y(j\omega) = \frac{1}{2} X(j(\omega - \omega_c)) + \frac{1}{2} X(j(\omega + \omega_c))$
$+ \pi A\, \delta(\omega - \omega_c) + \pi A\, \delta(\omega + \omega_c)$

$Y_{AM}(j\omega)$.



$Y_{AM\text{-}LC}(j\omega)$



Here power is transmitted in the carrier which is not related to info. content. A classical engineering tradeoff.