Amplitude Modulation

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- Amplitude Modulation (AM)
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What is Modulation

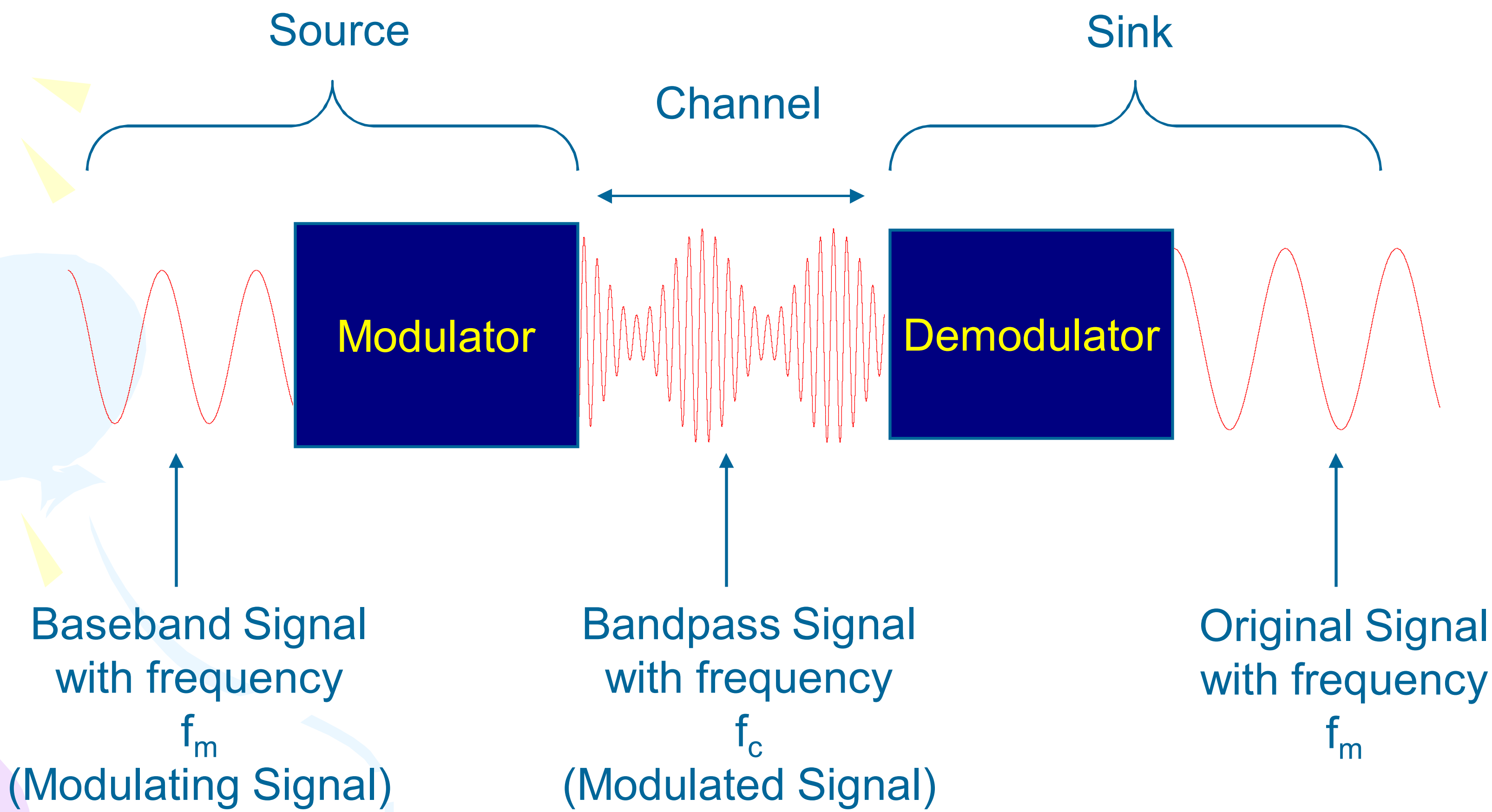
- <u>Modulation</u>
  - Amplitude Modulation is a process where the amplitude of a carrier signal is altered according to information in a message signal.
  - The frequency of the carrier signal is usually much greater than the highest frequency of the input message signal.

- <u>Why Modulation</u>
  - Reduce Antenna Size
  - Suitable for signal transmission (distance…etc)
  - Multiple signals transmitted on the same channel
  - Capacitive or inductive devices require high frequency AC input (carrier) to operate.
  - Stability and noise rejection

About Modulation

- Application Examples
  - broadcasting of both audio and video signals.
  - Mobile radio communications, such as cell phone.
- Basic Modulation Types
  - Amplitude Modulation: changes the amplitude.
  - Frequency Modulation: changes the frequency.
  - Phase Modulation: changes the phase.

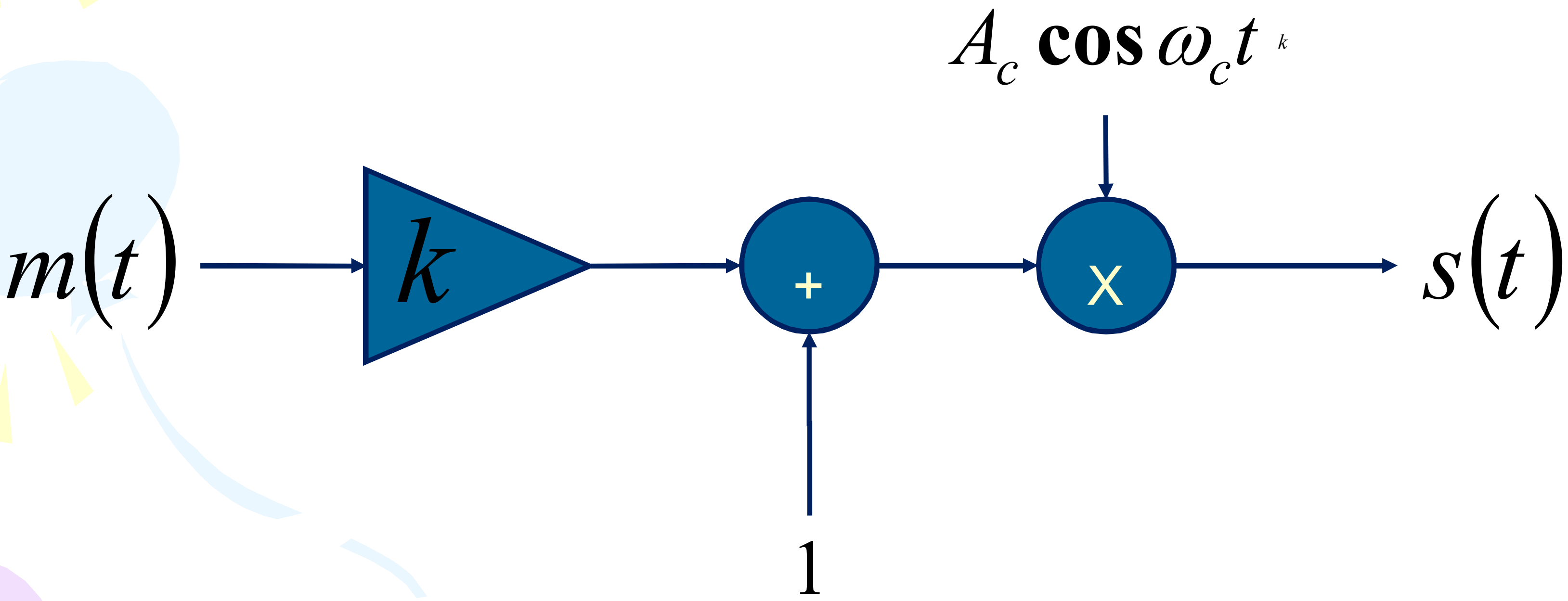
AM Modulation/Demodulation



$f_c >> f_m$

Voice: 300-3400Hz GSM Cell phone: 900/1800MHz

AM Modulation Scheme

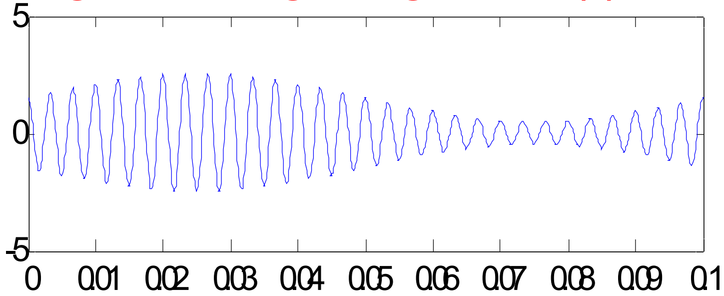


AM – Basic Definitions

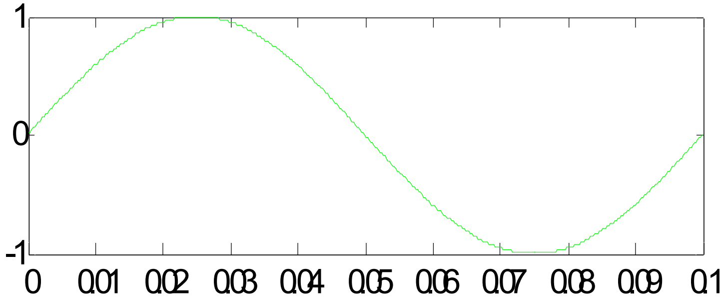
The amplitude of high-carrier signal is varied according to the instantaneous amplitude of the modulating message signal m(t).

The AM signal

$$s(t) = A_c\left[1 + k \bullet m(t)\right]\mathbf{cos}\,\omega_c t$$

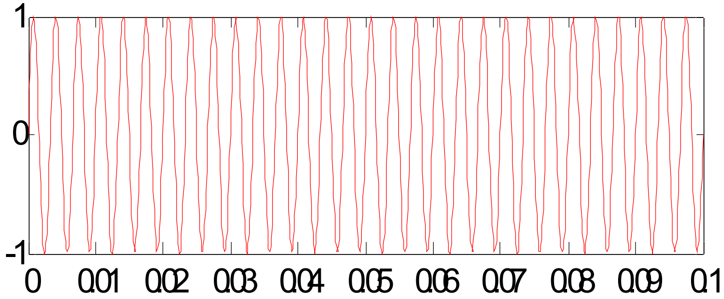


The modulating signal: $m(t)$



The Carrier Signal:

$$c(t) = A_c\,\mathbf{cos}\,\omega_c t$$



* AM Signal Math Expression *

- Mathematical expression for AM: time domain

$$S_{AM}(t) = A_c[1 + k\cos(\omega_m t)]\cos(\omega_c t)$$

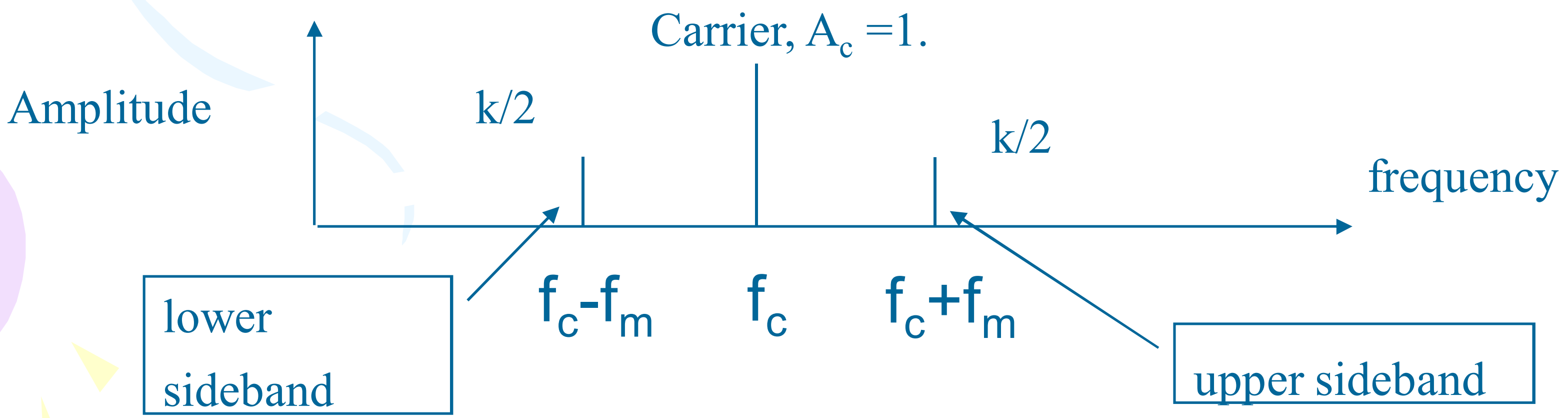
- expanding this produces:

$$S_{AM}(t) = A_c\cos(\omega_c t) + A_c k\cos(\omega_m t)\cos(\omega_c t)$$

$$\text{using} \ : \quad \cos A \cos B = \tfrac{1}{2}\left[\cos(A - B) + \cos(A + B)\right]$$

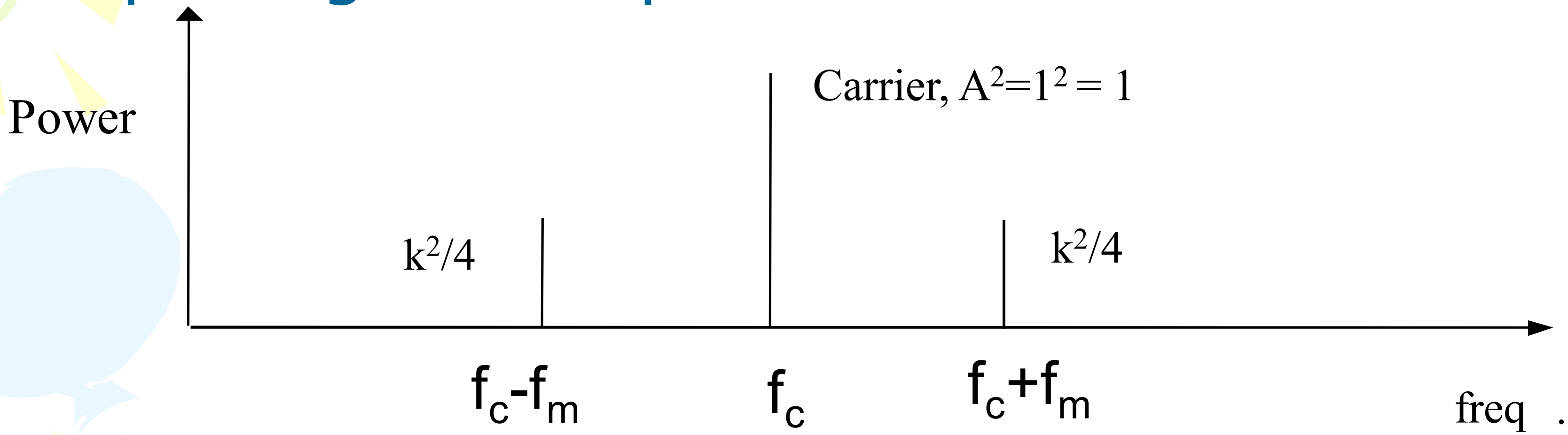
$$S_{AM}(t) = A_c\cos(\omega_c t) + A_c k/2\cos(\omega_c - \omega_m)t + A_c k/2\cos(\omega_c + \omega_m)t$$

- In the frequency domain this gives:



AM Power Frequency Spectrum

- AM Power frequency spectrum obtained by squaring the amplitude:



- Total power for AM:

$$= A^2 + \frac{k^2}{4} + \frac{k^2}{4}$$

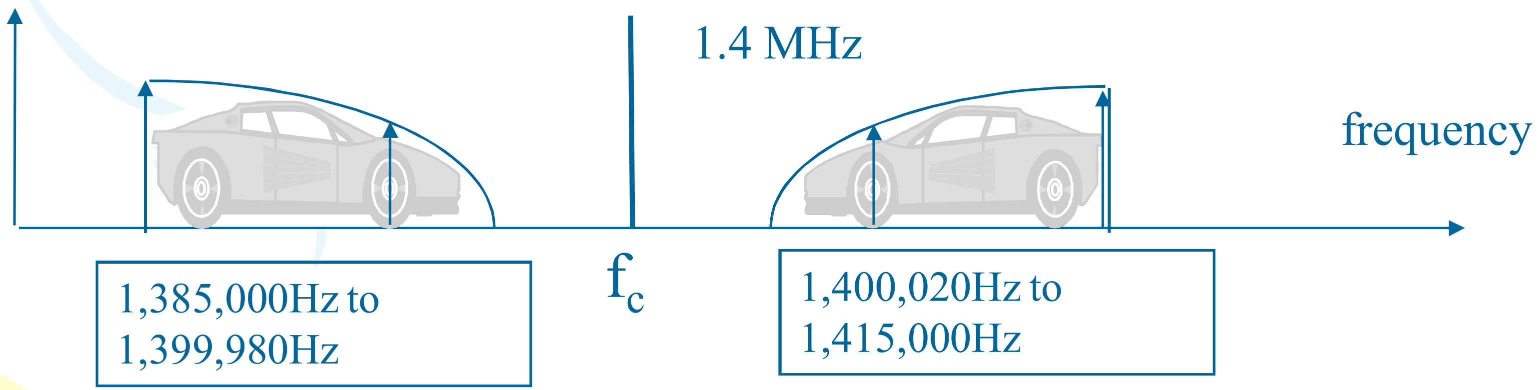
$$= 1 + \frac{k^2}{2}$$

Amplitude Modulation

- The AM signal is generated using a multiplier.
- All info is carried in the amplitude of the carrier, AM carrier signal has time-varying envelope.
- In frequency domain the AM waveform are the lower-side frequency/band (f_c - f_m), the carrier frequency f_c, the upper-side frequency/band ($f_c + f_m$).

AM Modulation – Example

- The information signal is usually not a single frequency but a range of frequencies (band). For example, frequencies from 20Hz to 15KHz. If we use a carrier of 1.4MHz, what will be the AM spectrum?
- In frequency domain the AM waveform are the lower-side frequency/band (f_c - f_m), the carrier frequency f_c, the upper-side frequency/band (f_c + f_m). Bandwidth: 2x(15K-20)Hz.



Modulation Index of AM Signal

For a sinusoidal message signal $m(t) = A_m \cos(2\pi f_m t)$

Carrier Signal: $\cos(2\pi f_c t)$ DC: A_C

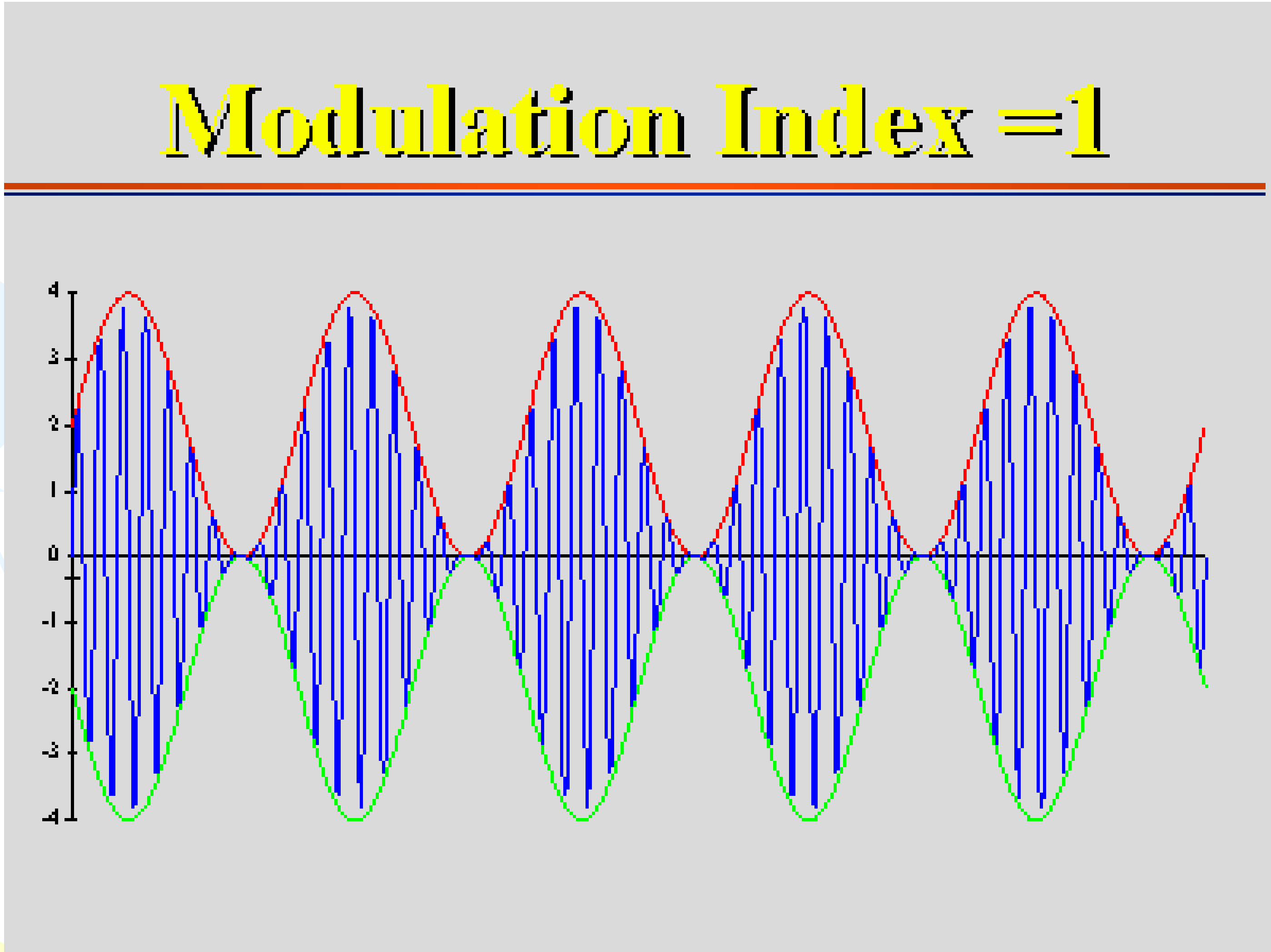
Modulated Signal: $S_{AM}(t) = [A_c + A_m \cos(2\pi f_m t)]\cos(2\pi f_c t)$

$$= A_c[1 + k\cos(2\pi f_m t)]\cos(2\pi f_c t)$$

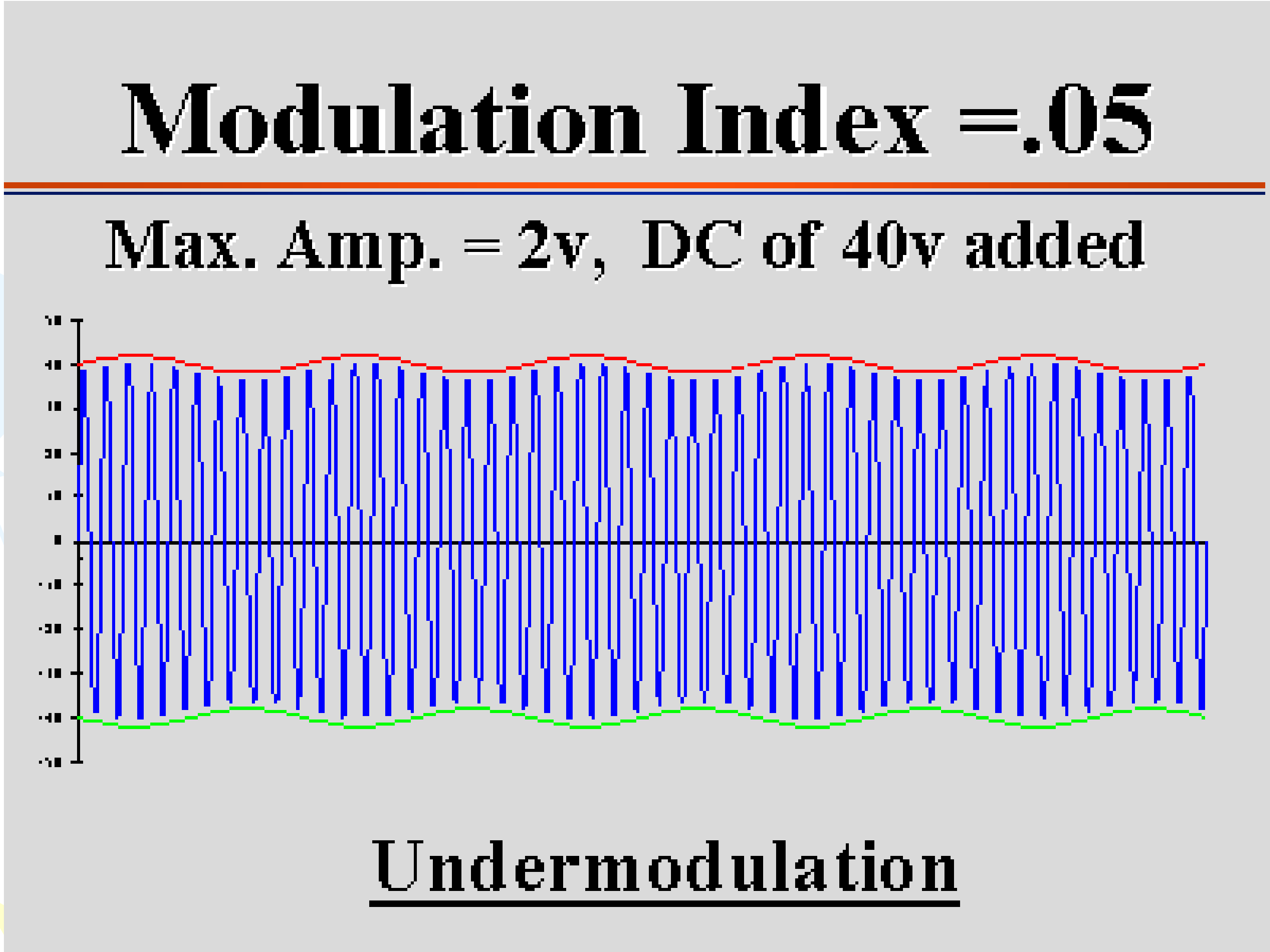
Modulation Index is defined as: $k = \dfrac{A_m}{A_c}$

Modulation index k is a measure of the extent to which a carrier voltage is varied by the modulating signal. When k=0 no modulation, when k=1 100% modulation, when k>1 over modulation.

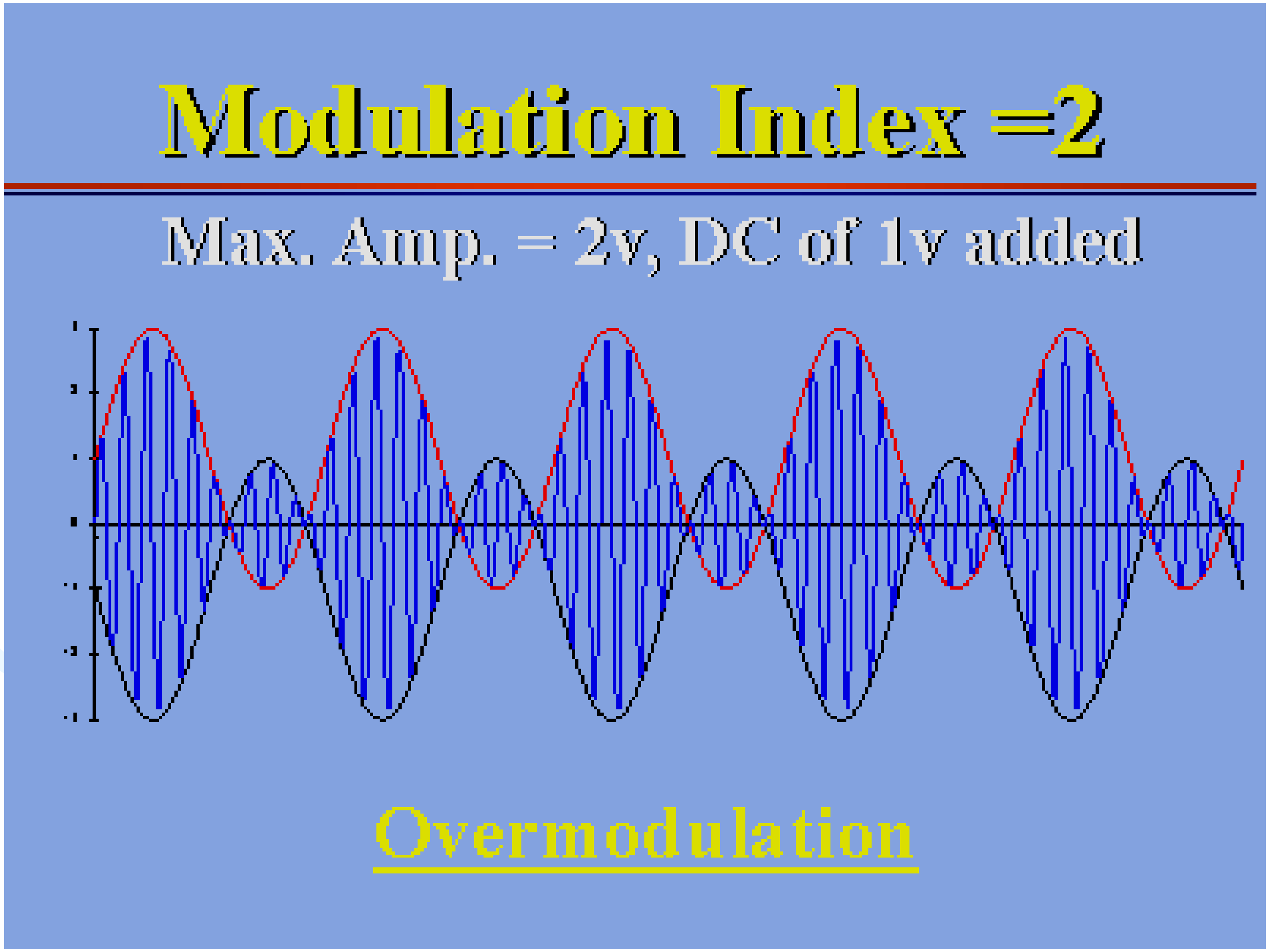
Modulation Index of AM Signal



Modulation Index of AM Signal



Modulation Index of AM Signal



Modulation Depth

$2A_{max}$ = maximum peak-to-peak of waveform
$2A_{min}$ = minimum peak-to-peak of waveform

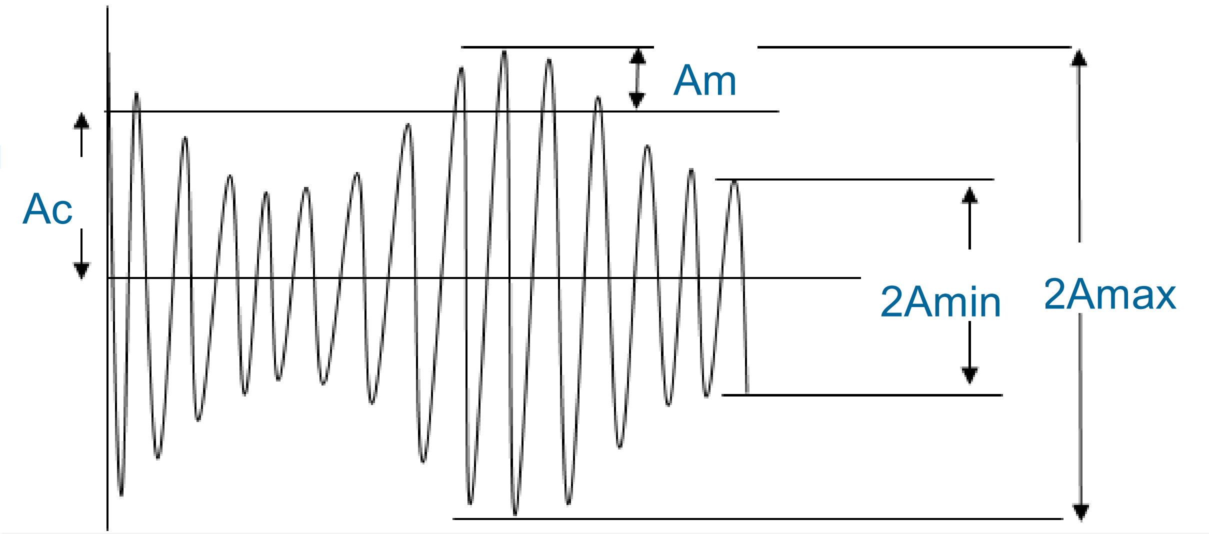
This may be shown to equal

$$k = \frac{A_m}{A_C}$$

as follows:

$$2A_{max} = 2A_C + 2A_m \qquad 2A_{min} = 2A_C - 2A_m$$

$$k = \frac{2A_{\max} - 2A_{\min}}{2A_{\max} + 2A_{\min}} = \frac{A_{\max} - A_{\min}}{A_C} = \frac{A_m}{A_C}$$



High Percentage Modulation

- It is important to use as high percentage of modulation as possible ($k=1$) while ensuring that over modulation ($k>1$) does not occur.
- The sidebands contain the information and have maximum power at 100% modulation.
- Useful equation

$$\mathbf{P_t = P_c(1 + k^2/2)}$$

P_t =Total transmitted power (sidebands and carrier)

P_c = Carrier power

AM - Modulation Efficiency

- **Definition** : The **Modulation Efficiency** is the percentage of the total power of the modulated signal that conveys information.

Only **"Sideband Components"** – Convey information

Modulation Efficiency:

$$E = \frac{\langle m^2(t) \rangle}{1 + \langle m^2(t) \rangle} \times 100$$

Highest efficiency for a 100% AM signal : **50%** - square wave modulation

Normalized Peak Envelope Power (PEP) of the AM signal:

$$P_{PEP} = \frac{A_c^2}{2} \{1 + \max[m(t)]\}^2$$

Voltage Spectrum of the AM signal**:**

$$S(f) = \frac{A_c}{2} [\delta(f - f_c) + M(f - f_c) + \delta(f + f_c) + M(f + f_c)]$$

Unmodulated Carrier Spectral Component

Translated Message Signal

Example

- Determine the maximum sideband power if the carrier output is 1 kW and calculate the total maximum transmitted power.

- Max sideband power occurs when k = 1. At this percentage modulation each side frequency is ½ of the carrier amplitude. Since power is proportional to the square of the voltage, each has ¼ of the carrier power. ¼ x 1kW = 250W Total sideband power = 2 x 250 = 500W. Total transmitted power = 1kW + 500W = 1.5kW

Example : Power of an AM signal

Suppose that a **5000-W** AM transmitter is connected to a **50 ohm** load;

Then the constant **Ac** is given by

$$\frac{1}{2}\frac{A_c^2}{50} = 5{,}000 \Rightarrow A_c = 707 \text{ V}$$

Without Modulation

If the transmitter is then **100% modulated** by a **1000-Hz** test tone , the **total** (carrier + sideband) **average power** will be

$$1.5\left[\frac{1}{2}\left(\frac{A_c^2}{50}\right)\right] = (1.5)\times(5000) = 7{,}500W \qquad \left[\langle m^2(t)\rangle = \frac{1}{2} \text{ for } 100\% \text{ modulation}\right]$$

The **peak voltage** (100% modulation) is (2)(707) = 1414 V across the 50 ohm load.

The **peak envelope power** (PEP) is

$$4\left[\frac{1}{2}\left(\frac{A_c^2}{50}\right)\right] = (4)\times(5000) = 20{,}000W$$

The **modulation efficiency** would be 33% since $< m^2(t) >= 1/2$

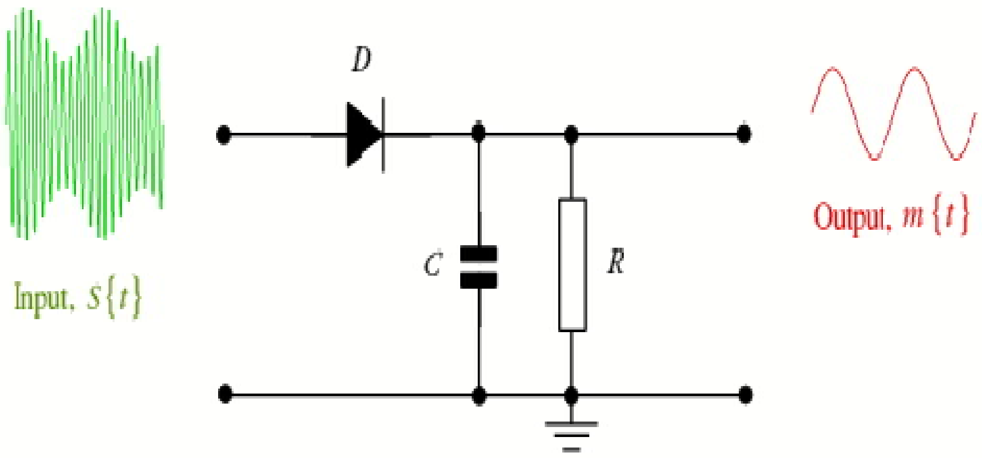
Demodulation of AM Signals

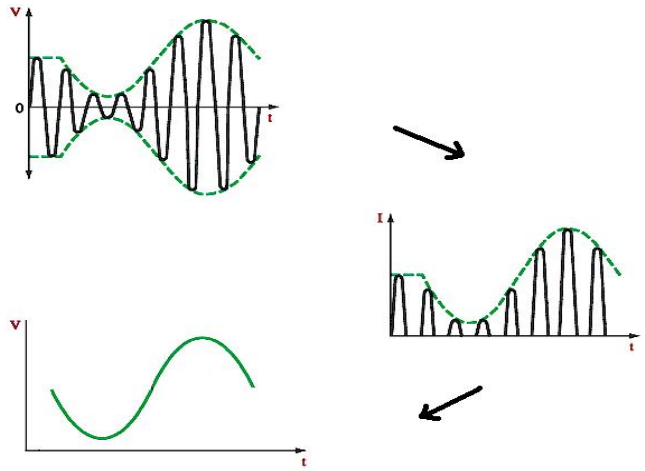
Demodulation extracting the baseband message from the carrier.

•There are 2 main methods of AM Demodulation:

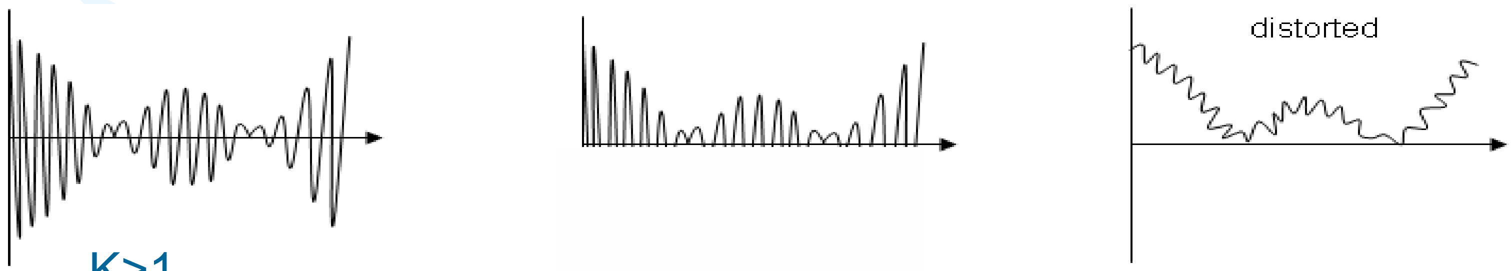
- Envelope or non-coherent detection or demodulation.
  - Square Law Detection
- Synchronised or coherent demodulation.

Envelope/Diode AM Detector



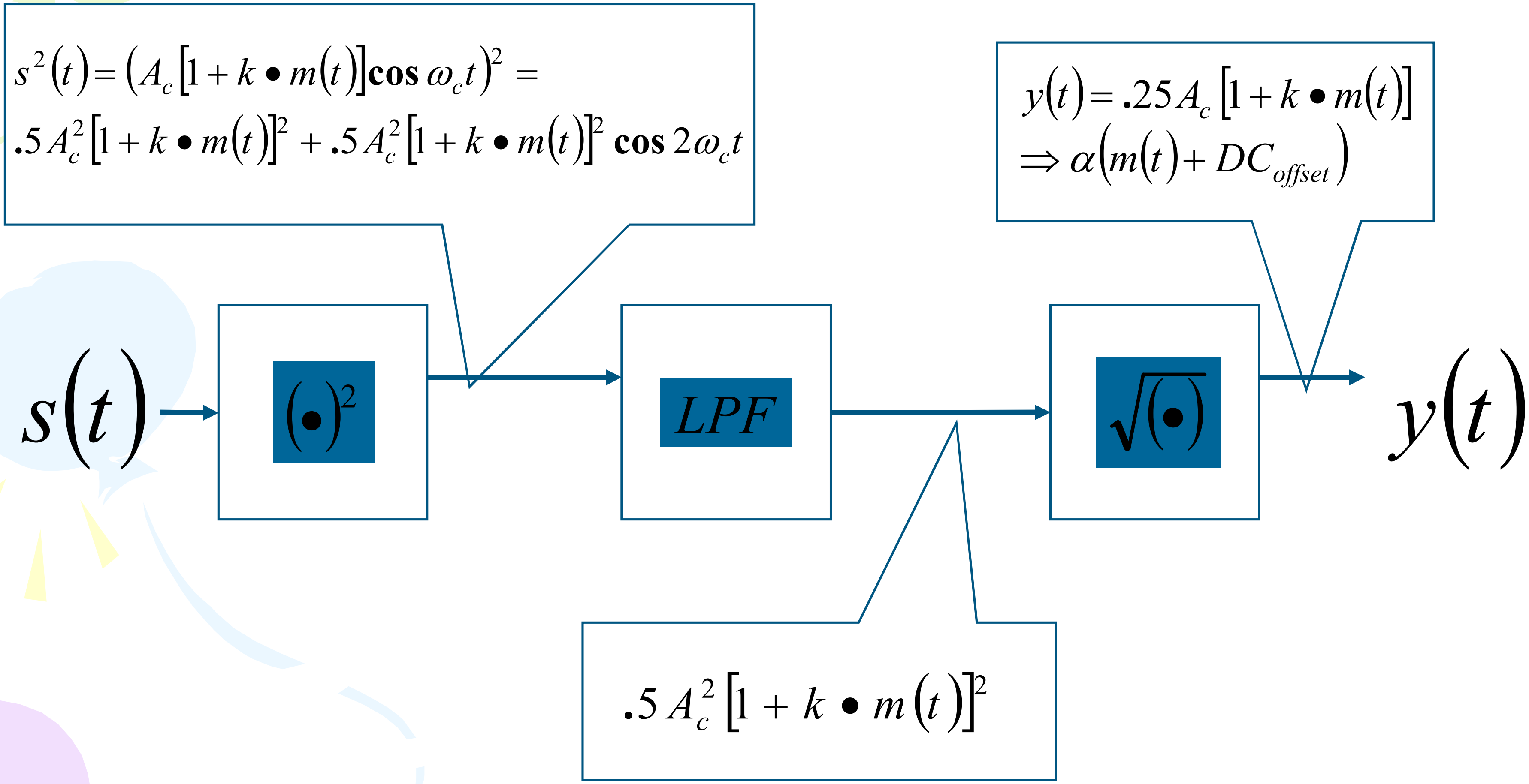


If the modulation depth is > 1, the distortion below occurs

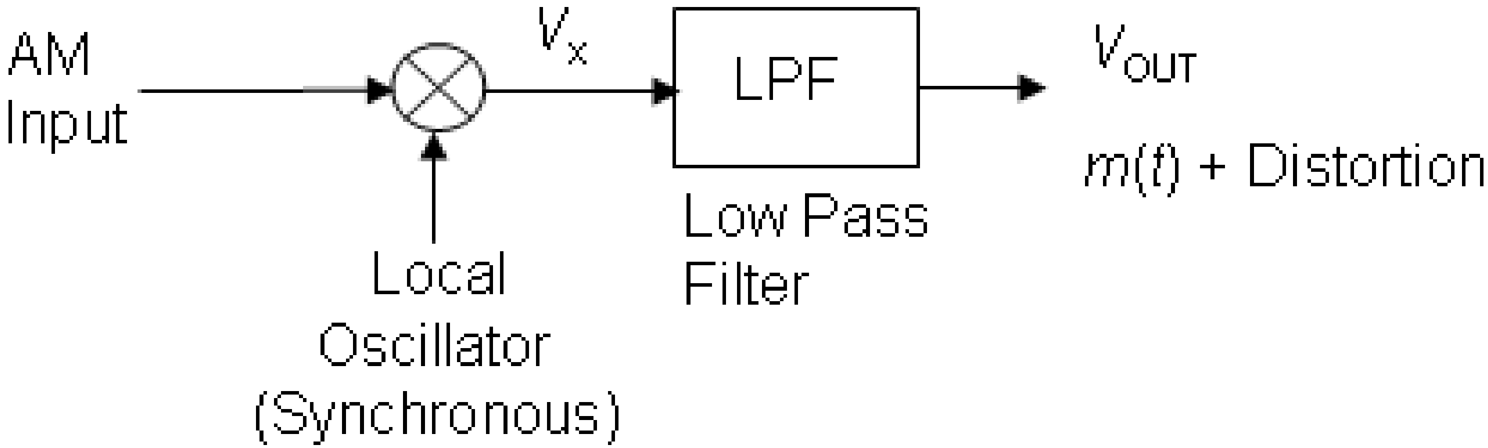


K>1

Square-Law Demodulation



Synchronous or Coherent Demodulation



This is relatively more complex and more expensive. The Local Oscillator (LO) must be synchronised or coherent, *i.e.* at the same frequency and in phase with the carrier in the AM input signal.

Coeherent Demodulation

$$s(t) = \left(A_c[1 + k \bullet m(t)]\cos\omega_c t\right) \bullet \cos\omega_c t =$$

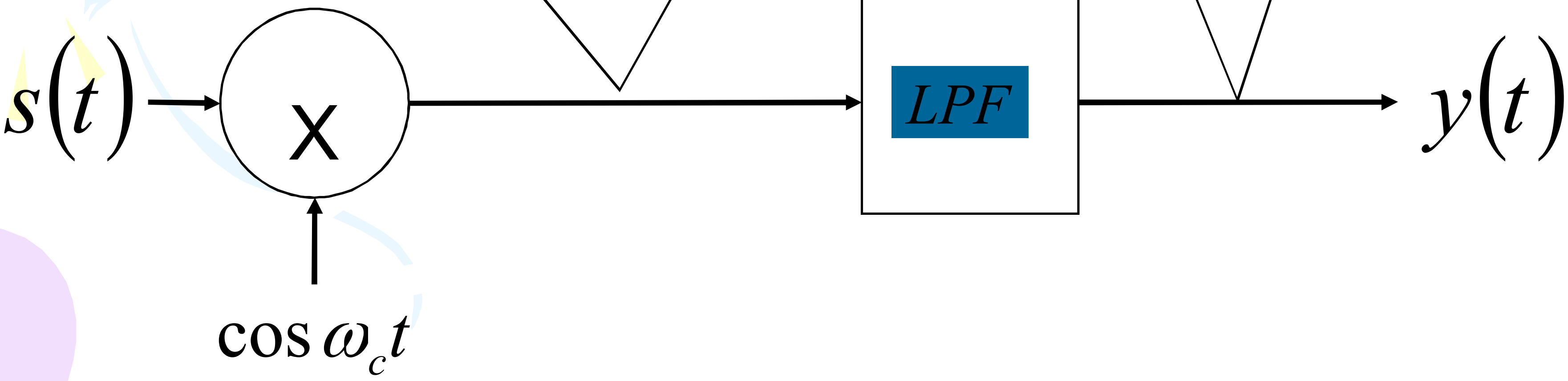
$$= A_c[1 + k \bullet m(t)] \bullet \cos^2 \omega_c t =$$

$$= A_c[1 + k \bullet m(t)] \bullet \left(\frac{1 + \cos 2\omega_c t}{2}\right) =$$

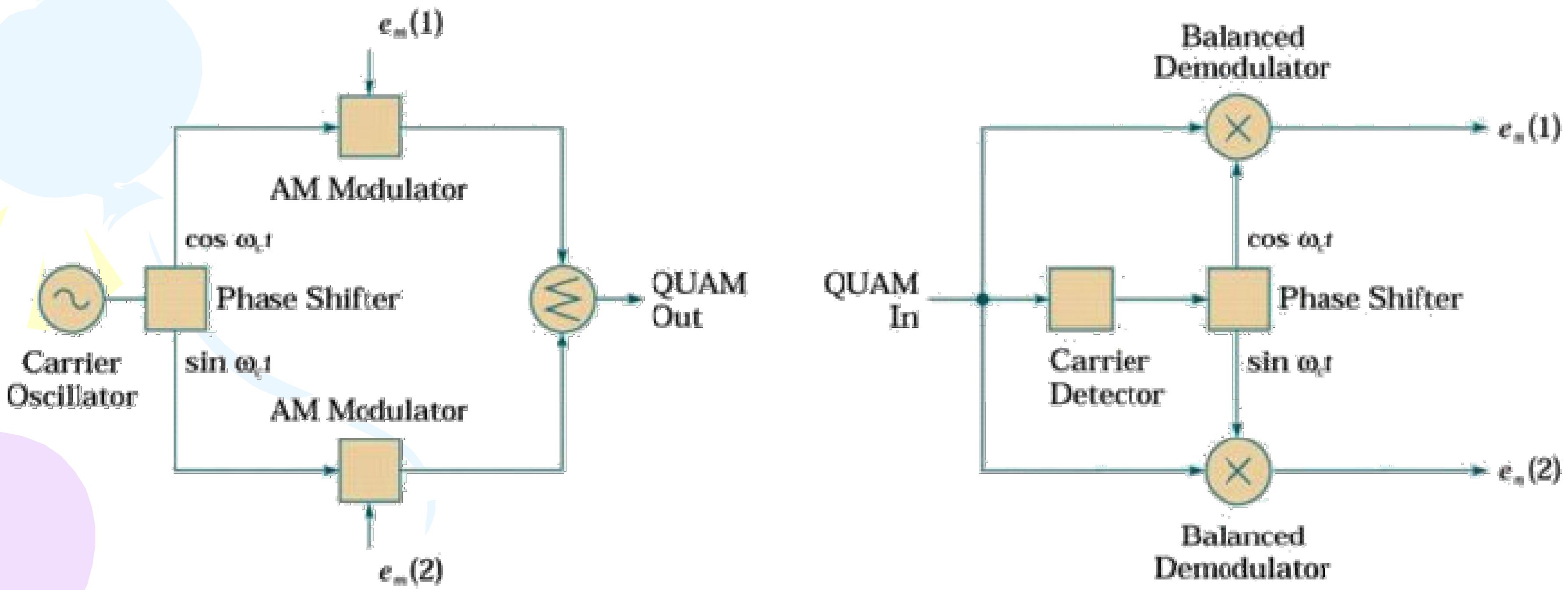
$$.5A_c[1 + k \bullet m(t)] + .5A_c[1 + k \bullet m(t)]\cos 2\omega_c t$$

$$y(t) = .5A_c[1 + k \bullet m(t)]$$

$$\Rightarrow \alpha\left(m(t) + DC_{offset}\right)$$

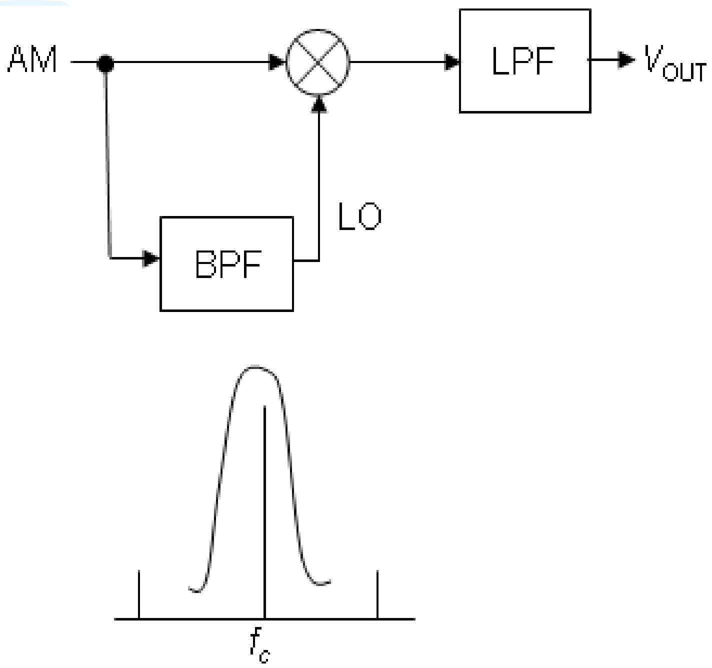


Quadrature Operation



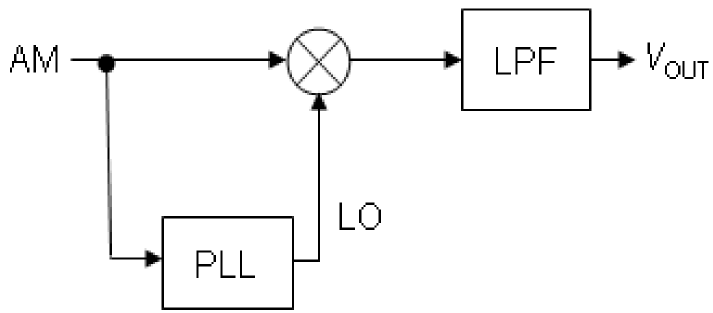
Synchronous or Coherent Demodulation

If the AM input contains carrier frequency, the LO or synchronous carrier may be derived from the AM input.



BPF – tuned to f_c

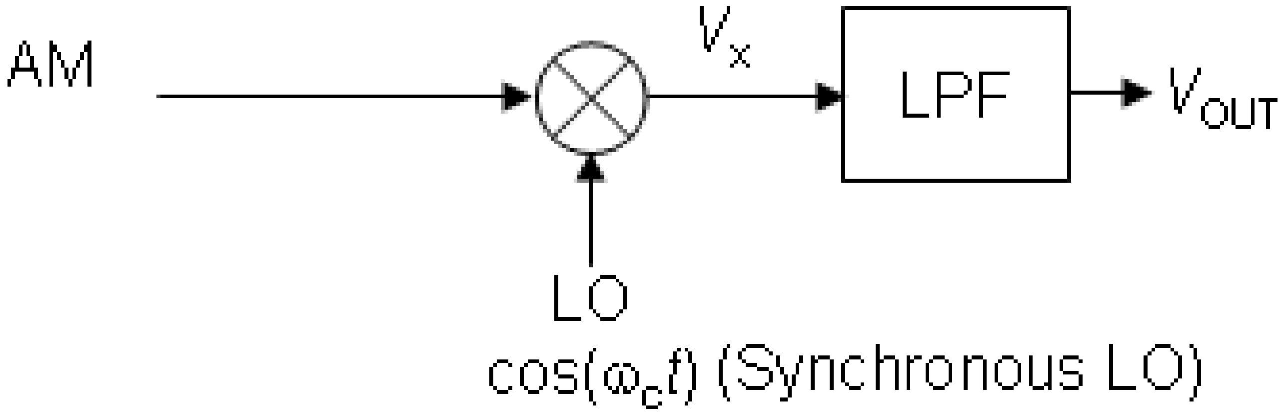
OR



Phase Locked Loop locked at f_c – regenerating a LO

Synchronous or Coherent Demodulation

If we assume zero path delay between the modulator and demodulator, then the ideal LO signal is cos($\omega_c t$).



Analysing this for a AM input = $(V_{DC} + m(t))\cos(\omega_c t)$

Coherent Detection

Assume zero path delay between the modulator and demodulator:

V_X = AM input x LO

$$= \left(V_{DC} + m(t)\right)\cos(\omega_c t) * \cos(\omega_c t)$$

$$= \left(V_{DC} + m(t)\right)\cos^2(\omega_c t)$$

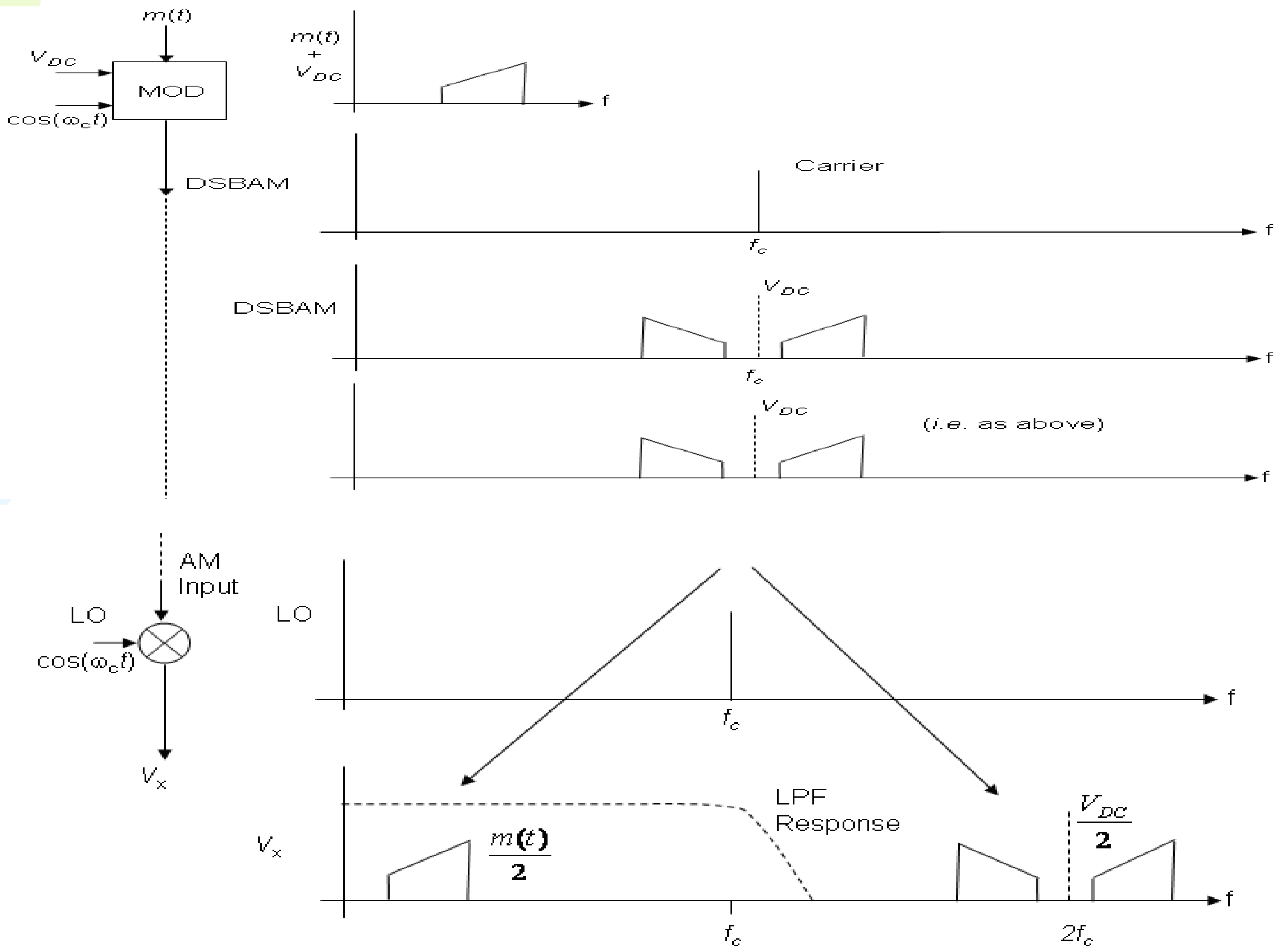
$$= \left(V_{DC} + m(t)\right)\left(\frac{1}{2} + \frac{1}{2}\cos(2\omega_c t)\right)$$

$$V_x = \frac{V_{DC}}{2} + \frac{m(t)}{2} + \frac{V_{DC}}{2}\cos(2\omega_c t) + \frac{m(t)}{2}\cos(2\omega_c t)$$

Note – the AM input has been 'split into two' – 'red part' has moved or shifted up to higher frequency: $\left(\frac{m(t)}{2}\cos(2\omega_c t) + V_{DC}\cos(2\omega_c t)\right)$

and blue part shifted down to baseband: $\frac{V_{DC}}{2} + \frac{m(t)}{2}$

Coherent Detection



Diode v.s Coherent

1. Diode-: Unable to follow fast-modulation properly
2. Diode-: Power is absorbed from the tuned circuit by the diode circuit.
3. Diode-: Distortion produced is not acceptable for some communications.
4. Diode+: Obviously simple, low cost.
5. Coherent+: Low Distortion
6. Coherent+: Greater ability to follow fast-modulation.
7. Coherent+: The ability to provide power gain
8. Coherent-: Complex and expensive

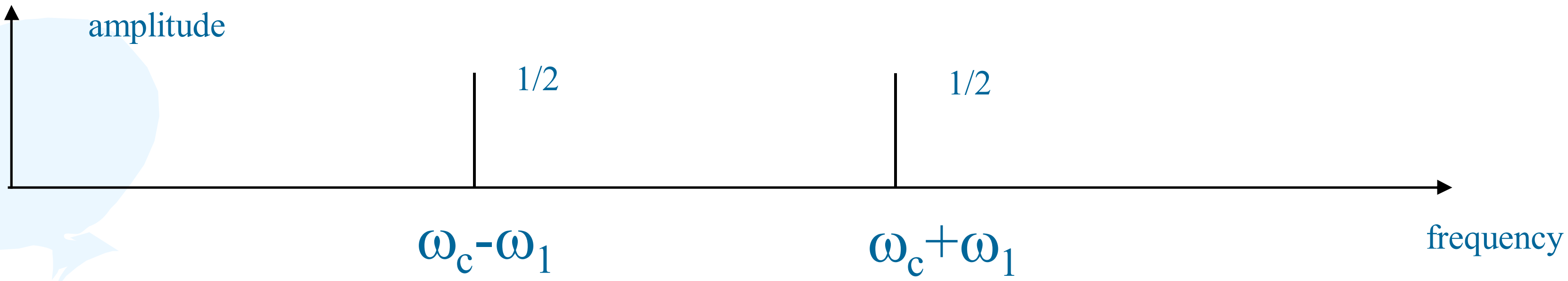
Exercises: Draw the Spectrums

a) $\cos(\omega_c t)\cos(\omega_1 t)$

from $\cos A \cos B = 1/2[\cos(A-B)+\cos(A+B)]$

we get: $\cos(\omega_c t)\cos(\omega_1 t)=1/2[\cos(\omega_c-\omega_1)t + \cos(\omega_c+\omega_1)t]$

Hence the spectrum of this is:



b) $\cos^2\omega t$

from $\cos^2 A=1/2[1+\cos 2A]$

we get: $\cos^2\omega t=1/2[1+\cos 2\omega t]$

The spectrum is thus:

Example

Suppose you have a <u>portable</u> (for example you carry it in your ' back pack') AM transmitter which needs to transmit an average power of 10 Watts in each sideband when modulation depth k = 0.3. Assume that the transmitter is powered by a 12 Volt battery. The total power will be

$$P_T = P_c + P_c \frac{k^2}{4} + P_c \frac{k^2}{4}$$

where

$$P_c \frac{k^2}{4} = 10 \text{ Watts}$$

$$P_c = \frac{4(10)}{k^2} = \frac{40}{(0.3)^2} = 444.44 \text{ Watts}$$

Hence, total power P_T = 444.44 + 10 + 10 = 464.44 Watts.

Hence, battery current (assuming ideal transmitter) = Power / Volts =

$$= \frac{464.44}{12} \text{ Amps}$$

A large and heavy 12 Volt battery!!!!

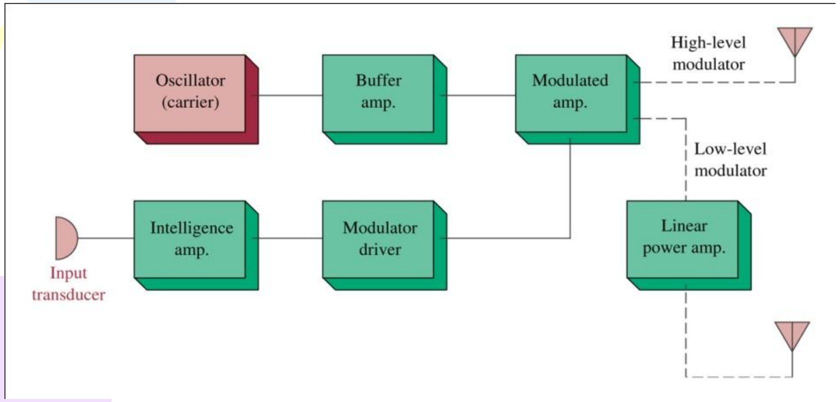
Suppose we could remove one sideband and the carrier, power transmitted would be 10 Watts, *i.e.* 0.833 amps from a 12 Volt battery, which is more reasonable for a portable radio transmitter. (Single Side Band)

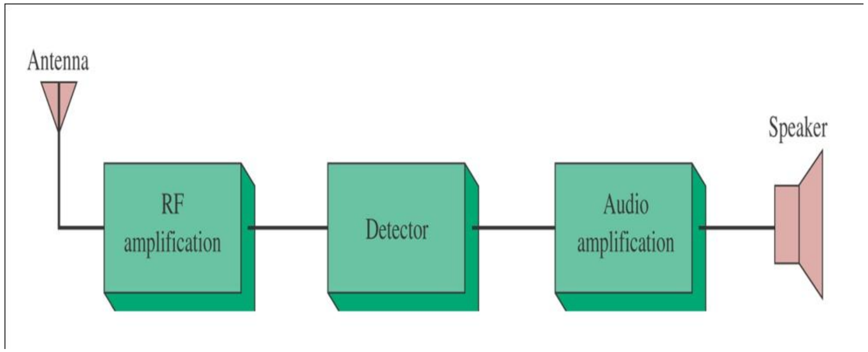
AM Transmitter and Receiver

$$S_{AM}(t) = [A_C + A_m \cos(\omega_m t)]\cos(\omega_c t)$$

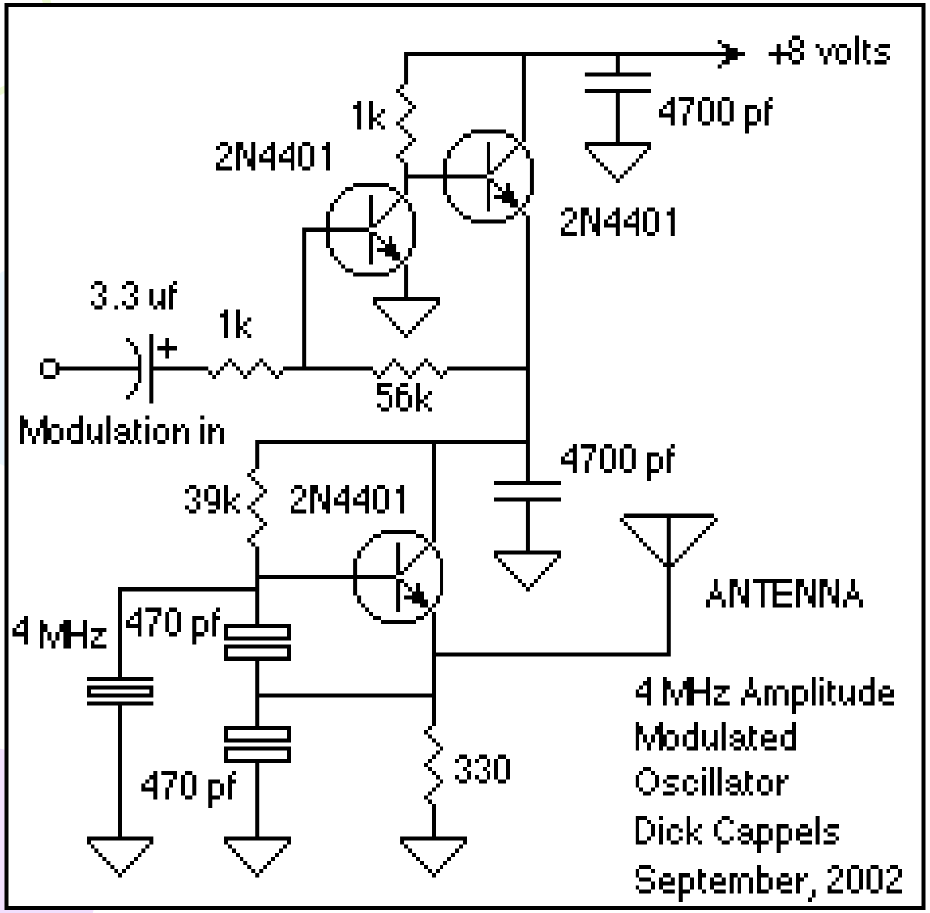
$$= A_C\left(1 + \frac{A_m}{A_C}\cos(\omega_m t)\right)\cos(\omega_c t)$$

$$= A_C\left(1 + k\cos(\omega_m t)\right)\cos(\omega_c t)$$





AM Transmitter and Receiver



Summary

- Modulation, Amplitude Modulation
- Modulation Index, Modulation Depth
- Demodulation of AM signals
- Calculation and Examples
- Math: AM Time domain+Frequency domain
- Calculation: AM Power, AM Demodulation

Next Class….

- DSB, SSB, VSB……
- FM, PM