Amplitude Modulation

Wei Li

weili@ieee.org

Content

What is Modulation

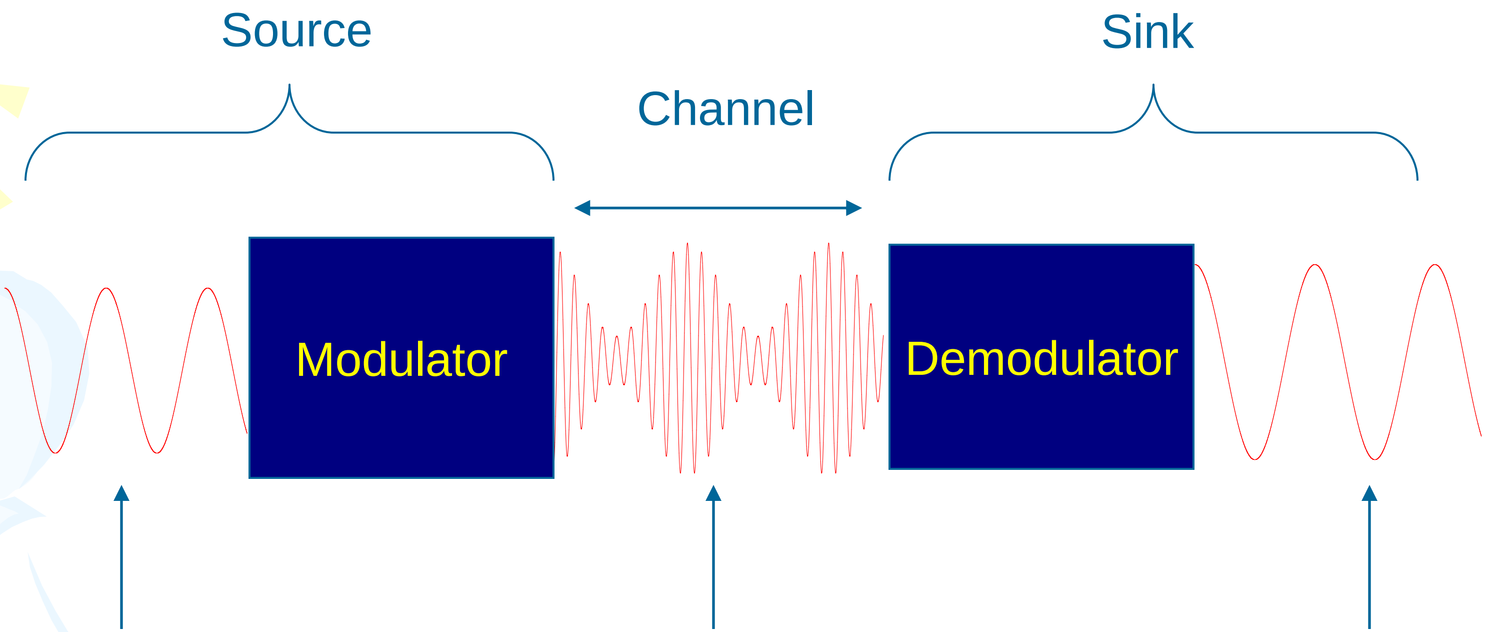
- Modulation
  - In the modulation process, some characteristic of a high-frequency carrier signal (bandpass), is changed according to the instantaneous amplitude of the information (baseband) signal.
- Why Modulation
  - Suitable for signal transmission (distance…etc)
  - Multiple signals transmitted 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



Source

Channel

Sink

Modulator

Demodulator

Baseband Signal
with frequency
f_m
(Modulating Signal)

Bandpass Signal
with frequency
f_c
(Modulated Signal)

Original Signal
with frequency
f_m

$f_c >> f_m$

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

Amplitude Modulation

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

Carrier Signal: $\cos(2\pi f_c t)$ or $\cos(\omega_c t)$

Modulating Message Signal: $m(t):\ \cos(2\pi f_m t)$ or $\cos(\omega_m t)$

The AM Signal: $s_{AM}(t) = [A_c + m(t)]\cos(2\pi f_c t)$

* AM Signal Math Expression *

- Mathematical expression for AM: time domain

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

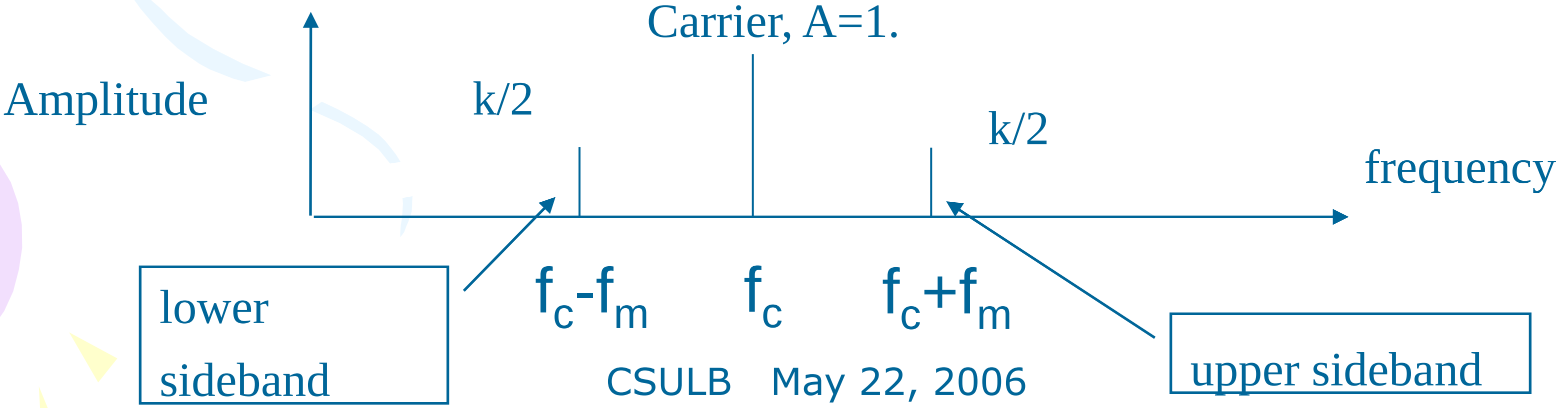
- expanding this produces:

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

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

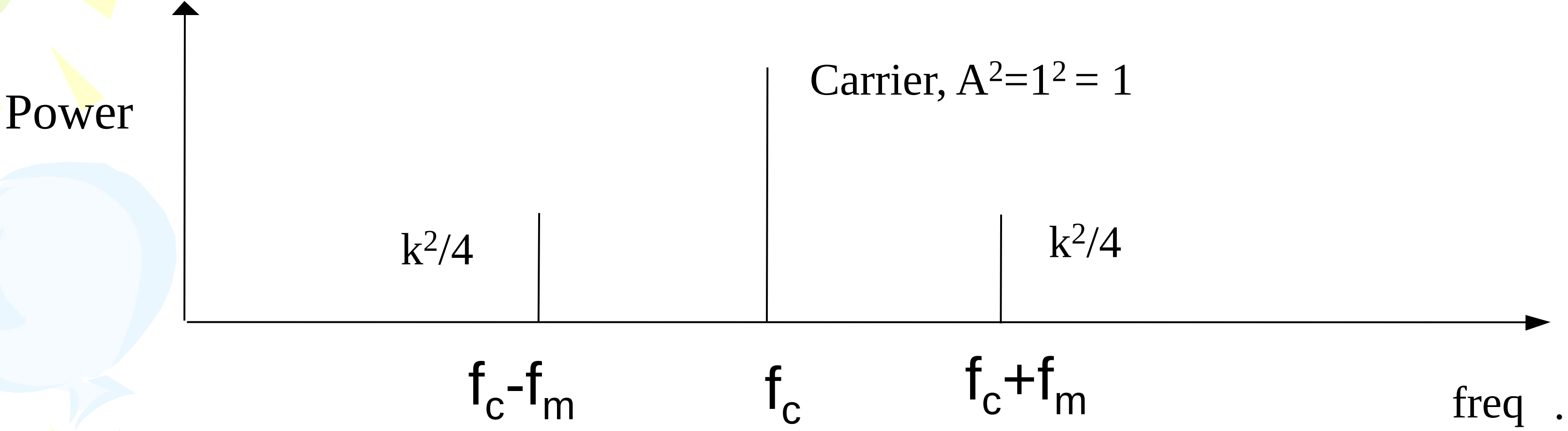
$$S_{AM}(t) = \cos\omega_c t + \tfrac{k}{2}\cos(\omega_c - \omega_m)t + \tfrac{k}{2}\cos(\omega_c + \omega_m)t$$

- In the frequency domain this gives:



AM Power Frequency Spectrum

- AM Power frequency spectrum obtained by squaring the amplitude:



- Total power for AM:

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

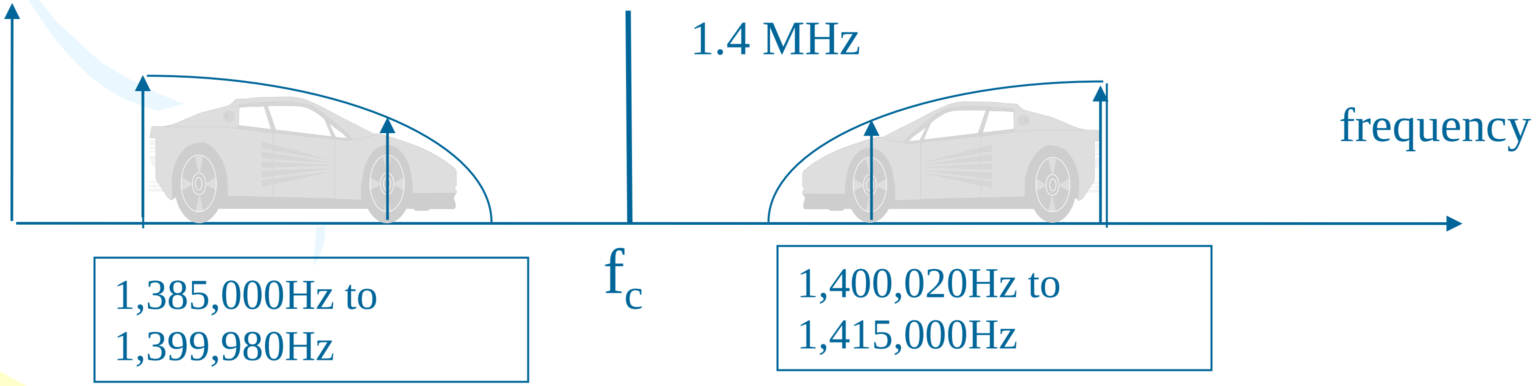
$$= 1 + \frac{k^2}{2}$$

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(25K-20)Hz.



1.4 MHz

frequency

f_c

1,385,000Hz to
1,399,980Hz

1,400,020Hz to
1,415,000Hz

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

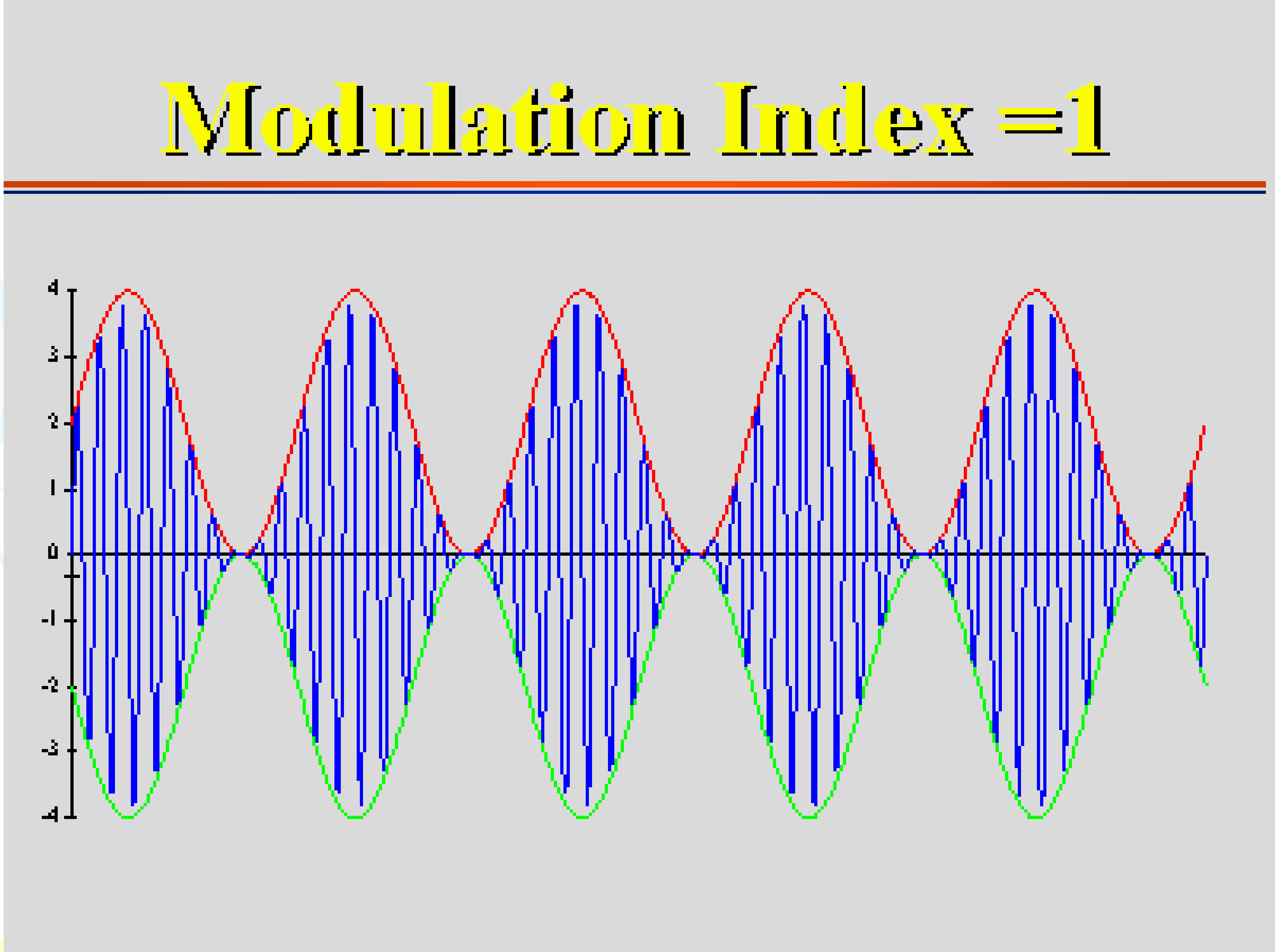
Modulated Signal:

$$S_{AM}(t) = [A_c + A_m \cos(2\pi f_m t)]\cos(2\pi f_c t)$$
$$= A_c[1 + k\cos(2\pi f_m t)]\cos(2\pi f_c t)$$

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

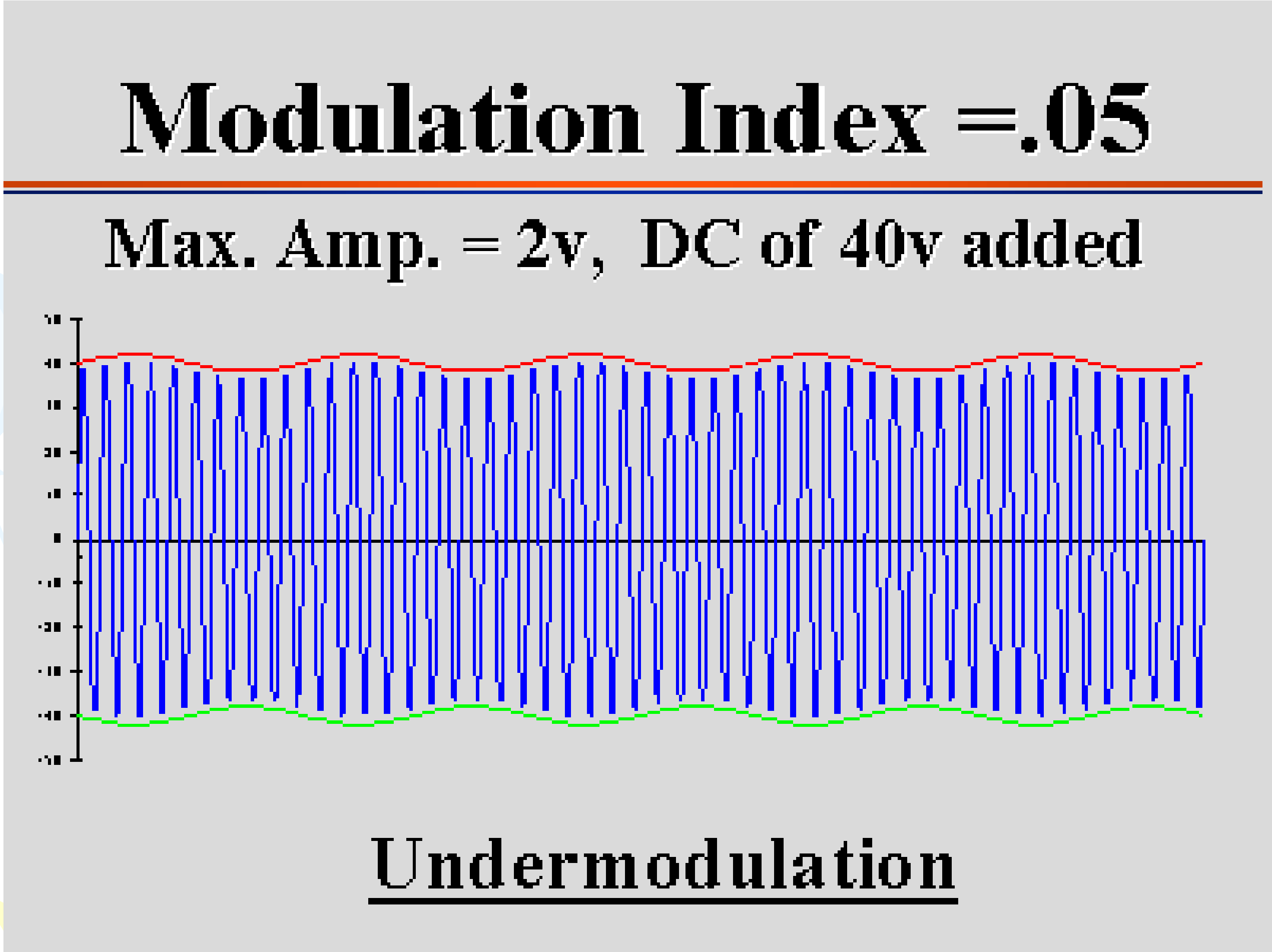
Modulation index k is a measure of the extent to which a carrier voltage is varied by the modulating signal. When k=0 no modulation, when k=1 100% modulation, when k>1 over modulation.

Modulation Index of AM Signal



Modulation Index =1

Modulation Index of AM Signal

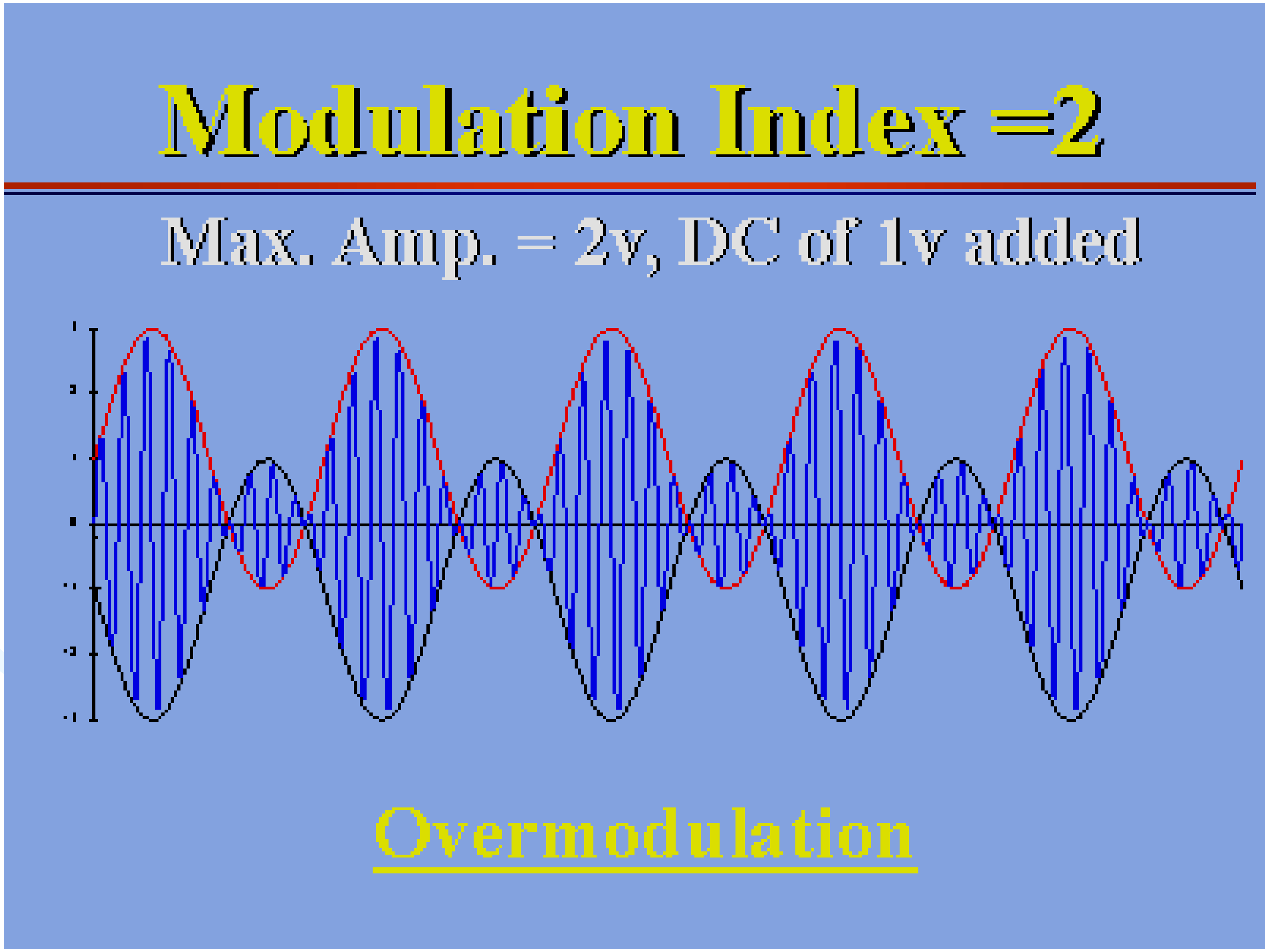


Modulation Index =.05

Max. Amp. = 2v, DC of 40v added

Undermodulation

Modulation Index of AM Signal



Modulation Index =2

Max. Amp. = 2v, DC of 1v added

Overmodulation

Modulation Depth

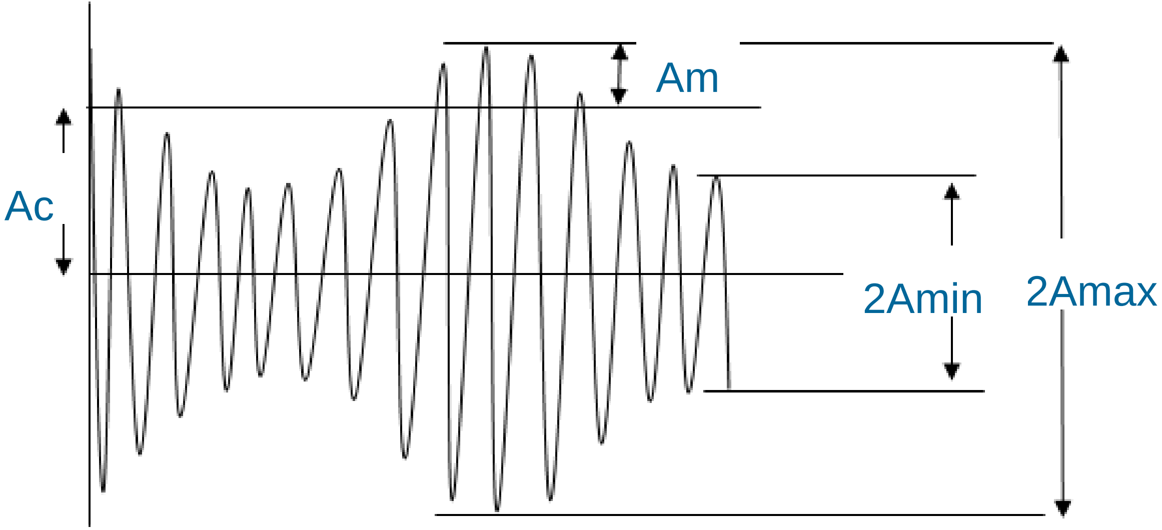
$2A_{max}$ = maximum peak-to-peak of waveform
$2A_{min}$ = minimum peak-to-peak of waveform

This may be shown to equal $k = \frac{A_m}{A_C}$ as follows:

$$2A_{max} = 2A_C + 2A_m$$

$$2A_{min} = 2A_C - 2A_m$$

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



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

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

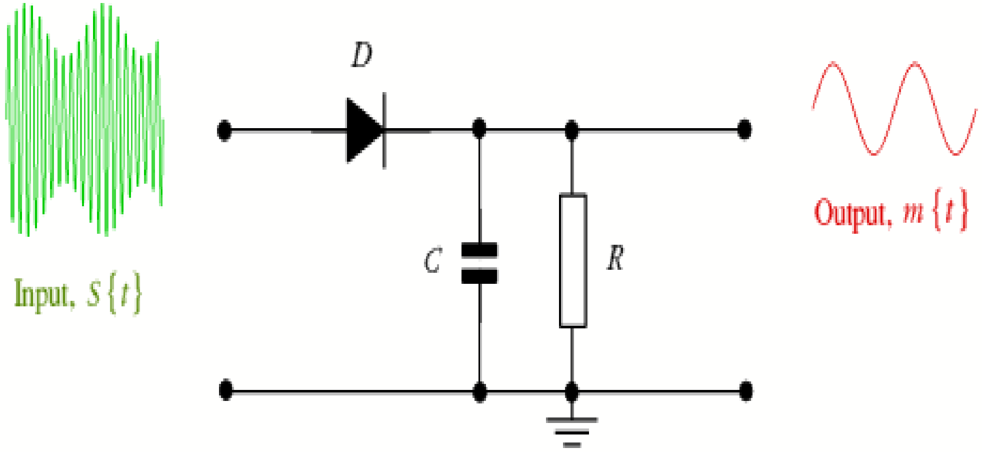
Demodulation of AM Signals

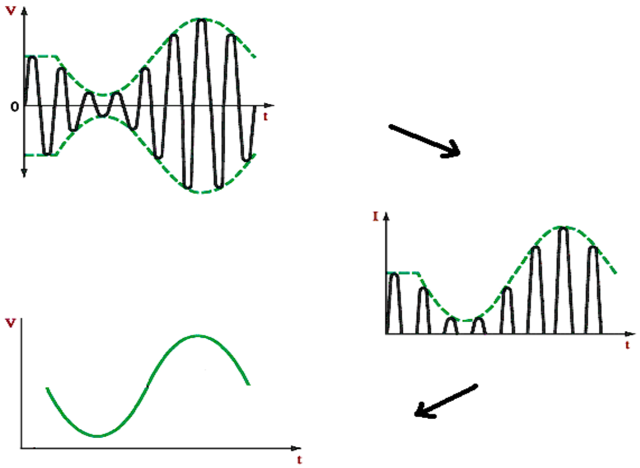
Demodulation extracting the baseband message from the carrier.

- There are 2 main methods of AM Demodulation:

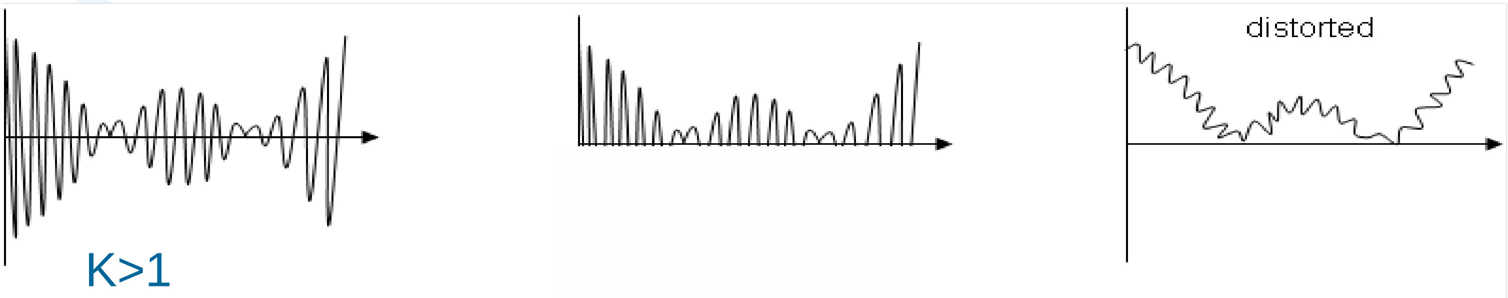
- Envelope or non-coherent detection or demodulation.
- Synchronised or coherent demodulation.

Envelope/Diode AM Detector

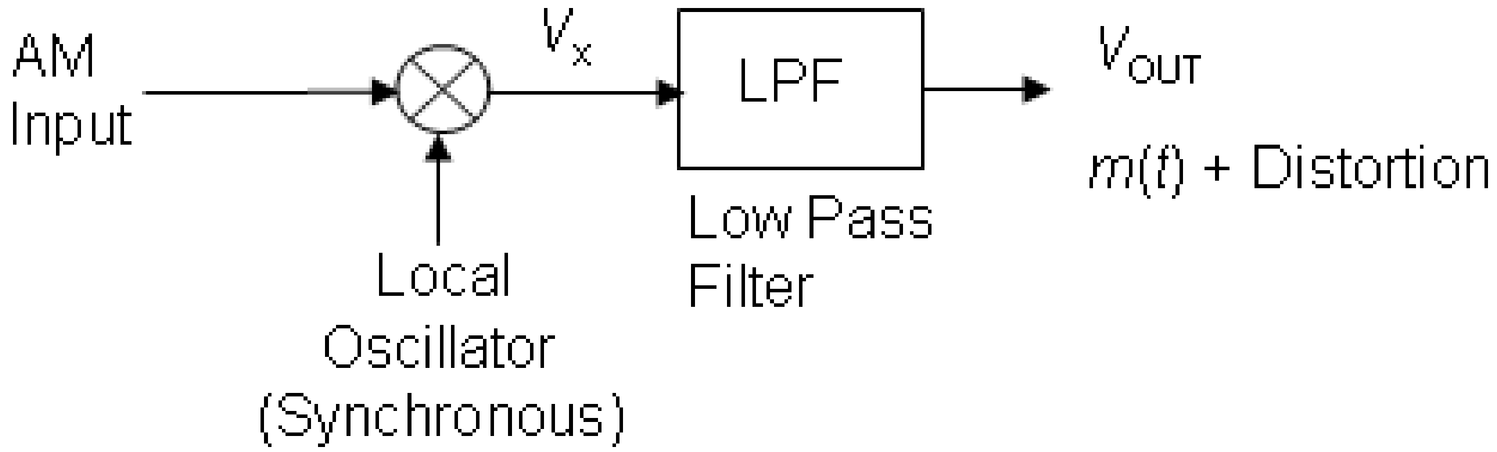




If the modulation depth is > 1, the distortion below occurs



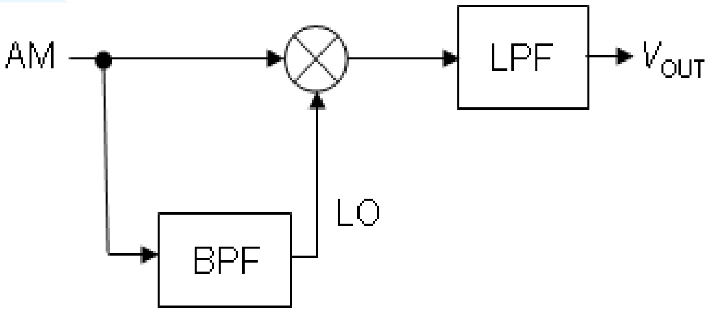
Synchronous or Coherent Demodulation



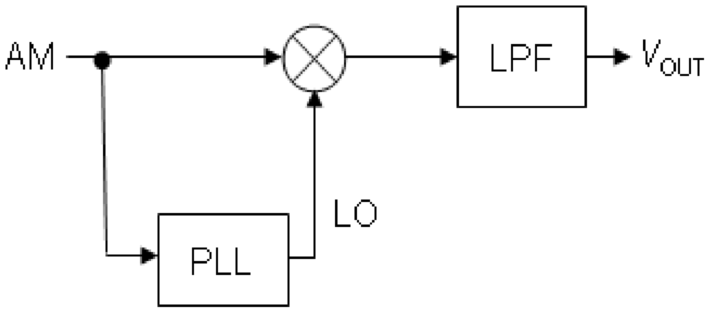
This is relatively more complex and more expensive. The Local Oscillator (LO) must be synchronised or coherent, *i.e.* at the same frequency and in phase with the carrier in the AM input signal.

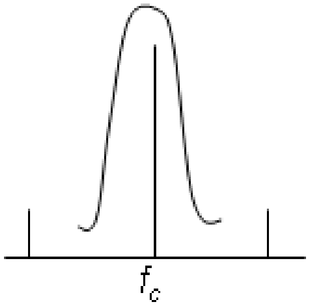
Synchronous or Coherent Demodulation

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



OR



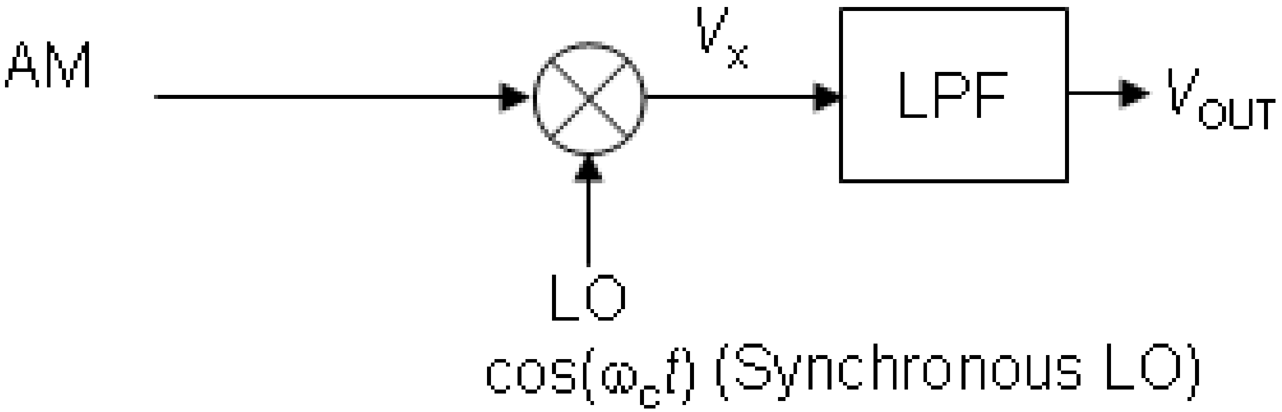


BPF – tuned to f_c

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

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

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

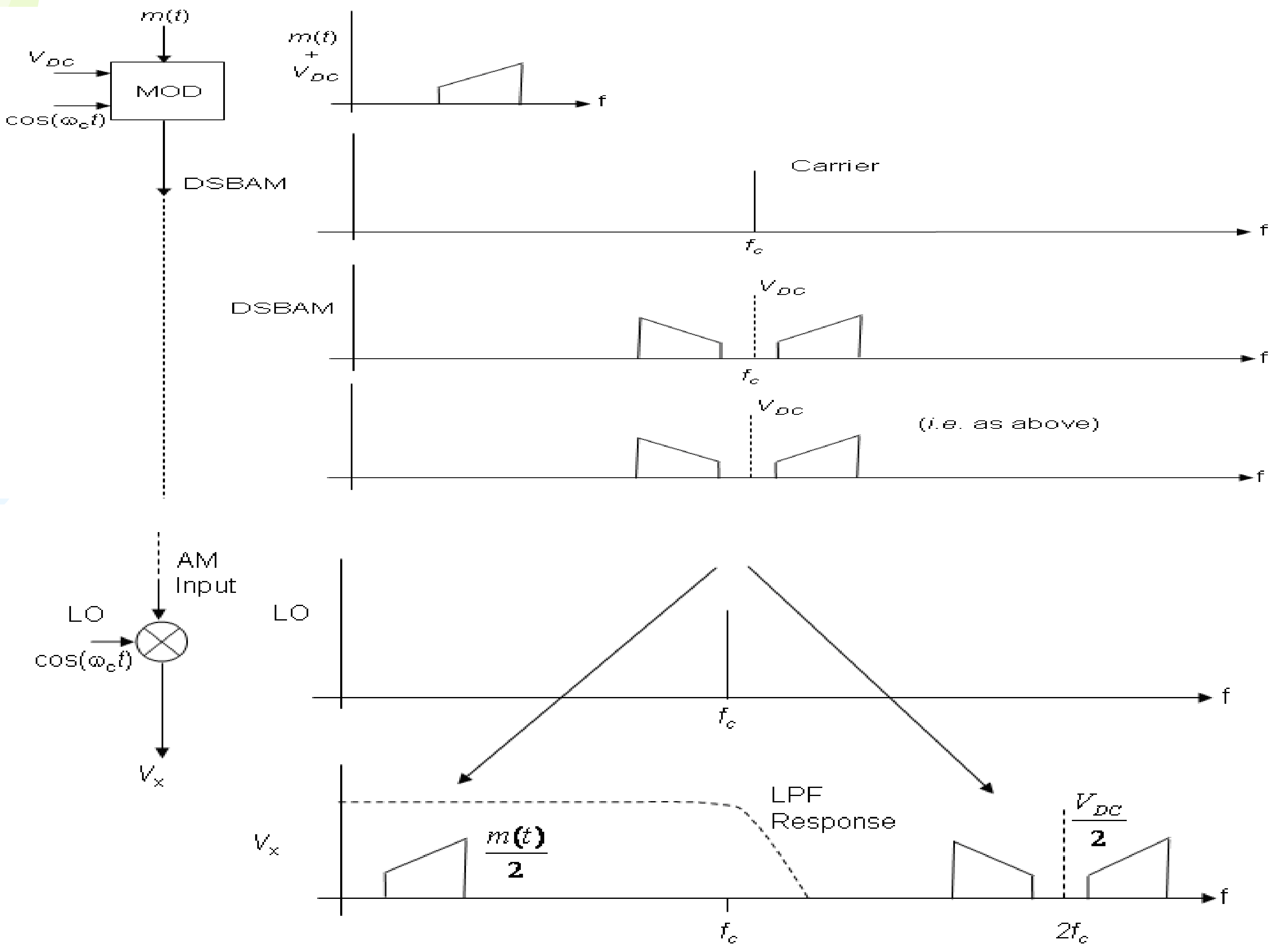
$$= (V_{DC} + m(t))\left(\frac{1}{2} + \frac{1}{2}\cos(2\omega_c t)\right)$$

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

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

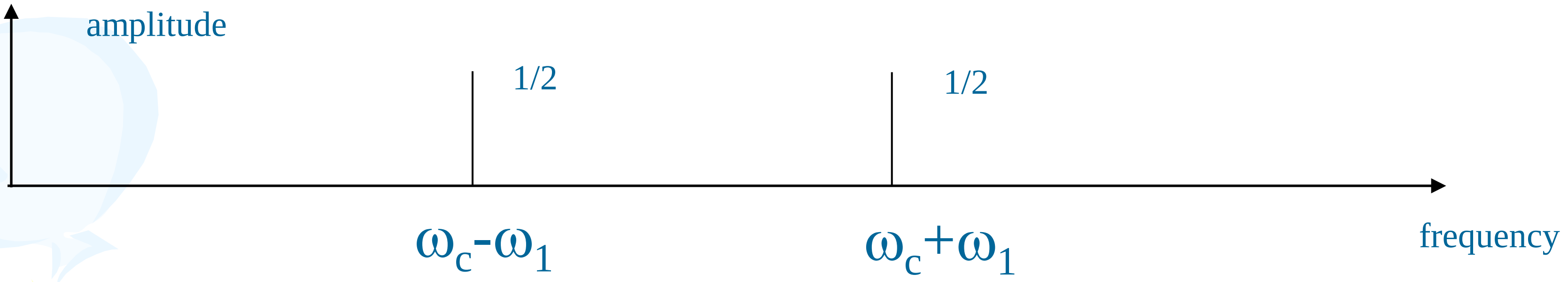
Exercises: Draw the Spectrums

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 portable (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 =

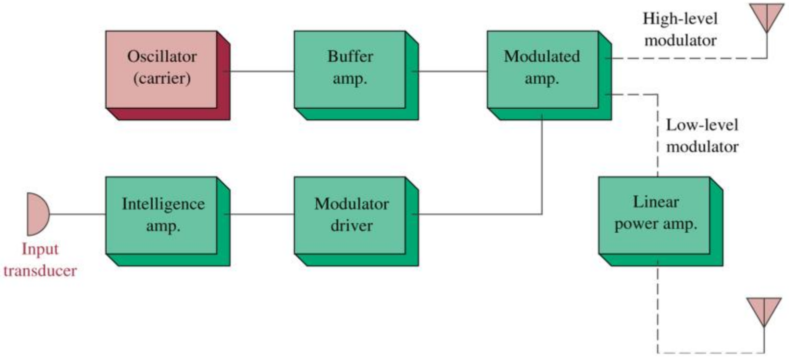
$$= \frac{464.44}{12} \text{ Amps}$$

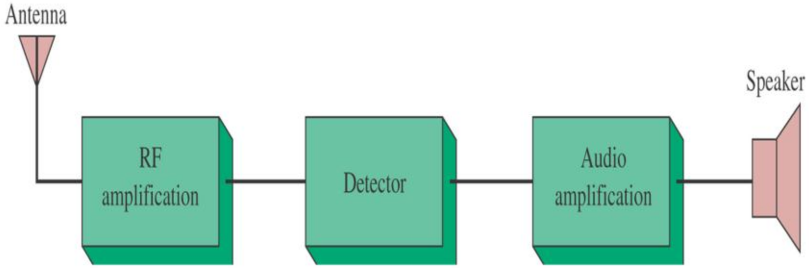
A large and heavy 12 Volt battery!!!!

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)

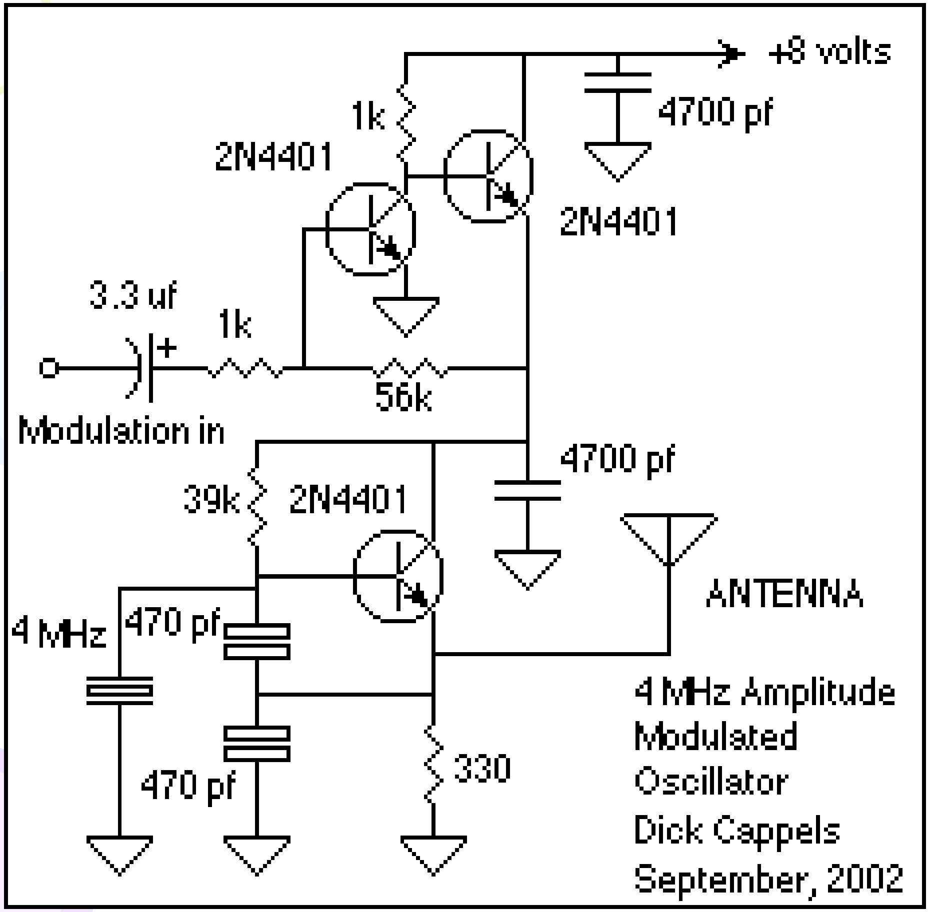
AM Transmitter and Receiver

$$
\begin{aligned}
S_{AM}(t) &= [A_C + A_m \cos(\omega_m t)]\cos(\omega_c t) \\
&= A_C\left(1+\frac{A_m}{A_C}\cos(\omega_m t)\right)\cos(\omega_c t) \\
&= A_C\left(1+\mathrm{k}\cos(\omega_m t)\right)\cos(\omega_c t)
\end{aligned}
$$





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