Amplitude Modulation

EE202

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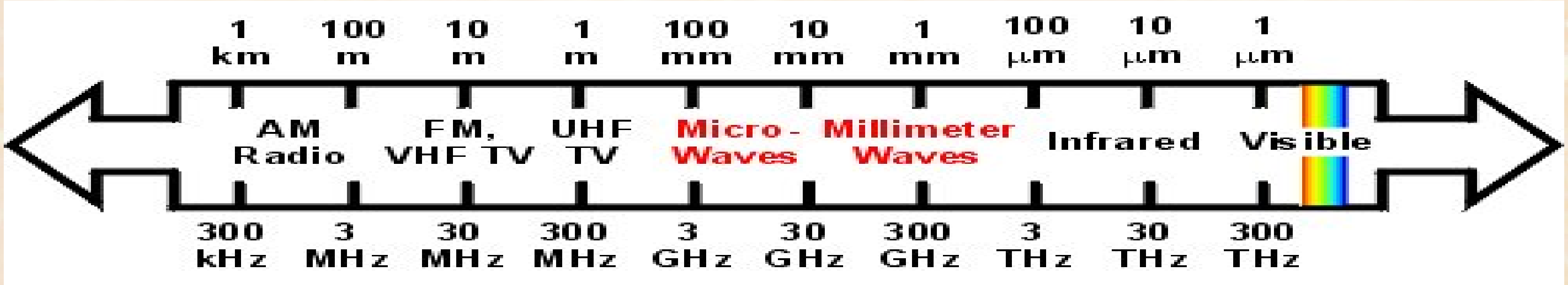
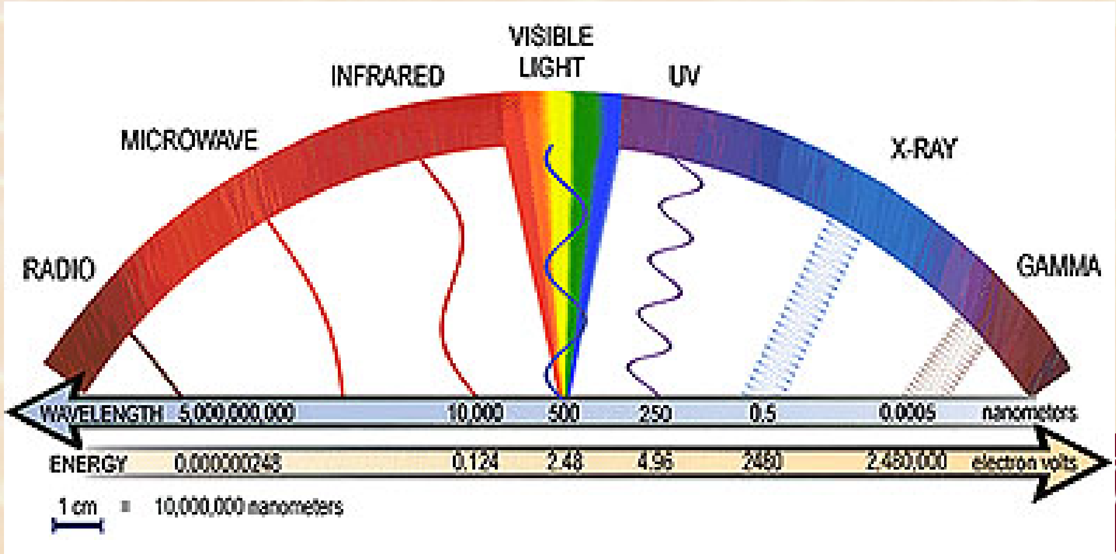
Electromagnetic Spectrum



$C = \lambda f$



Electromagnetic wave interacts with matter in different ways in different parts of the spectrum .

Surface modes (groundwave)

At lower frequencies in the and VLF (3 kHz to 30 kHz), LF(30 kHz–300 kHz) and MF(300 kHz to 3 MHz), due to diffraction radio waves can bend over obstacles like hills, and travel beyond the horizon as surface waves which follow the contour of the Earth. These are called ground waves.

AM broadcasting stations use ground waves to cover their listening areas. As the frequency gets lower the attenuation with distance decreases, so very low frequency (VLF) and extremely low frequency (ELF) ground waves can be used to communicate worldwide. VLF and ELF waves can penetrate significant distances through water and earth, and these frequencies are used for mine communication and military communication with submerged submarines.

Ionospheric modes (skywave)

At medium wave and shortwave frequencies MF(300–3000 kHz) and HF(3–30 MHz) bands radio waves can reflect or refract from a layer of charged particles (ions) high in the atmosphere, called the ionosphere. So radio waves transmitted at an angle into the sky can be reflected back to Earth beyond the horizon, at great distances, even transcontinental distances. This is called skywave or "skip" propagation.

It is used by amateur radio operators to talk to other countries, for diplomatic communications, and shortwave broadcasting stations that broadcast internationally.

Direct modes (line-of-sight)

Line-of-sight propagation means radio waves which travel in a straight line from the transmitting antenna to the receiving antenna. It does not necessarily require a cleared sight path. E.g.

garage door openers, cell phones, cordless phones, walkie-talkies, wireless networks, FM radio and television broadcasting and radar, and satellite communication, such as satellite television.

Line-of-sight transmission on the surface of the Earth is limited to the distance to the visual horizon, about 40 miles. It is the only propagation method possible at microwave frequencies (300 MHz (100 cm) and 300 GHz (0.1 cm)) and above.

Do you see them?

The Need For Modulation

- **Baseband** communication: transmit signal **as it is**

☹ **Antenna length** in the order of ¼ wavelength (= c/f)

☹ **Channel degradation**: Interference, Distortion & Noise

- **Division** of frequency bands (channels)
- Need a radio frequency (RF) **carrier**
- ⇨ modulation !

Modulation: what is it?

- Modulation is the process in which the characteristic of a carrier wave is varied in accordance with an information bearing signal.

- It generally involves translating a **baseband** signal (source) to a **bandpass** signal at frequencies **>>** **baseband** frequency.

  Baseband signal is called ***modulating*** signal

  Bandpass signal is called ***modulated*** signal

- **Demodulation** is the process of extracting the baseband message from the carrier at the receiver.

Two Types Signals

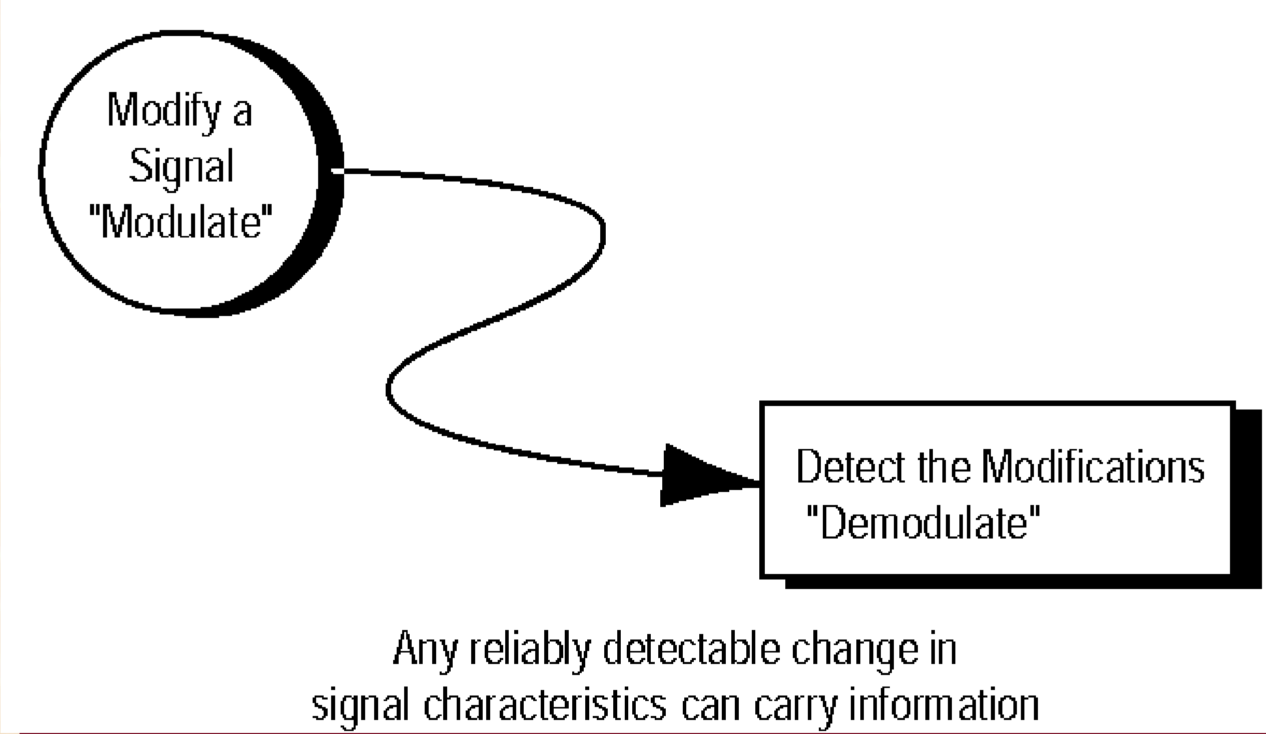
- The purpose of a communication system is to transmit information signals (baseband signals) through a communication channel.
- The term ***baseband*** is used to designate the band of frequencies representing the original signal as delivered by the input transducer
  - Eg. the voice signal from a microphone is a baseband signal, and contains frequencies in the range of 0-3000 Hz, however the audio signal can range up to 20KHz

The term *bandpass* is used to designate the band of frequencies significantly higher than that of the original signal, i.e. after **modulation**

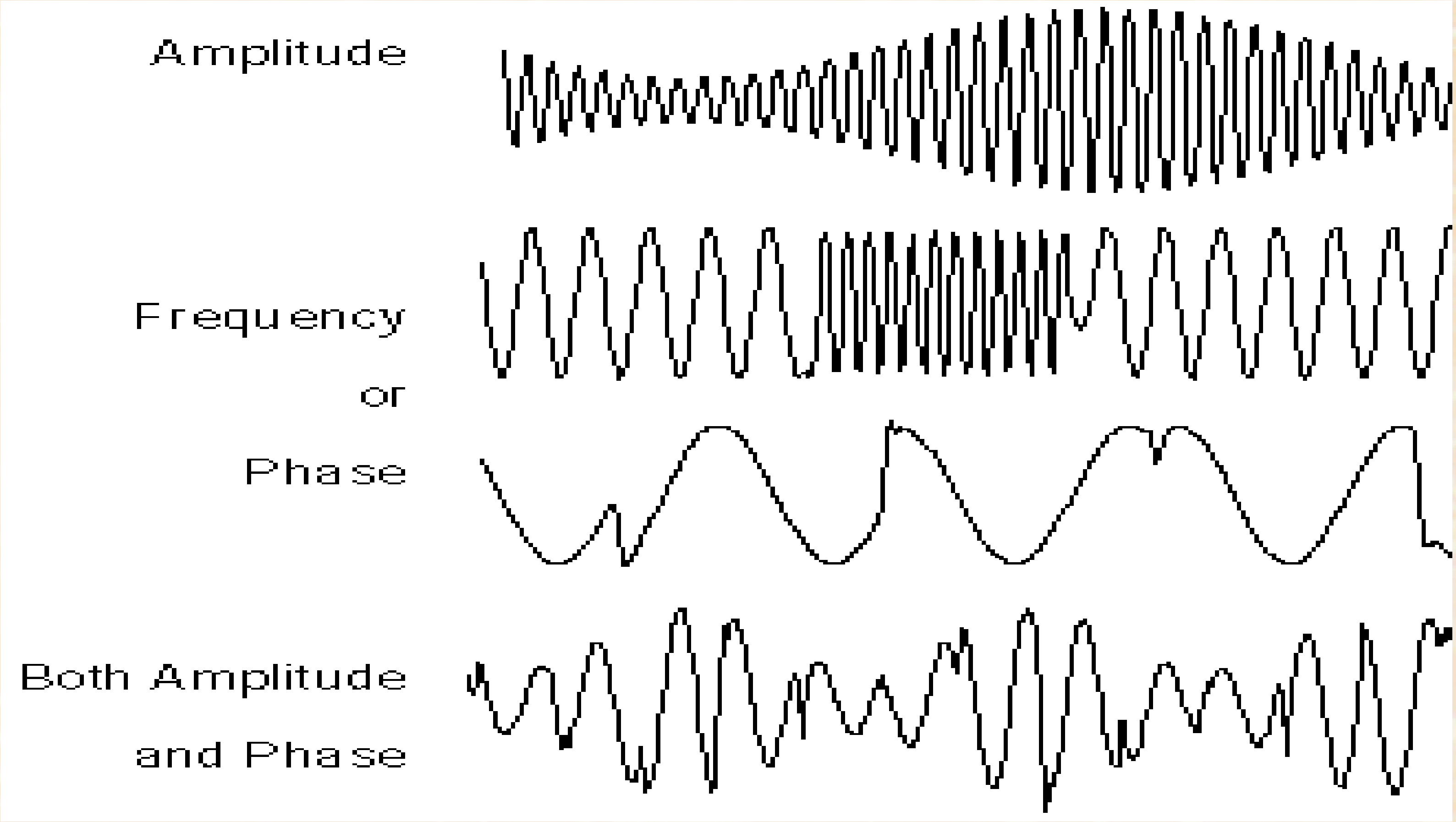
- Eg. FM radio signals centred at 96.7 MHz

Transmission of Information

- Carrier generated @ transmitter
- Carrier modulated with information
- Information can be **analogue** or **digital**
- At receiver, signal modifications detected and



Characteristics of a carrier wave



Amplitude Modulation

Amplitude Modulation

is the process of changing the amplitude of a relatively high frequency carrier signal in proportion with the instantaneous value of the modulating signal (information).

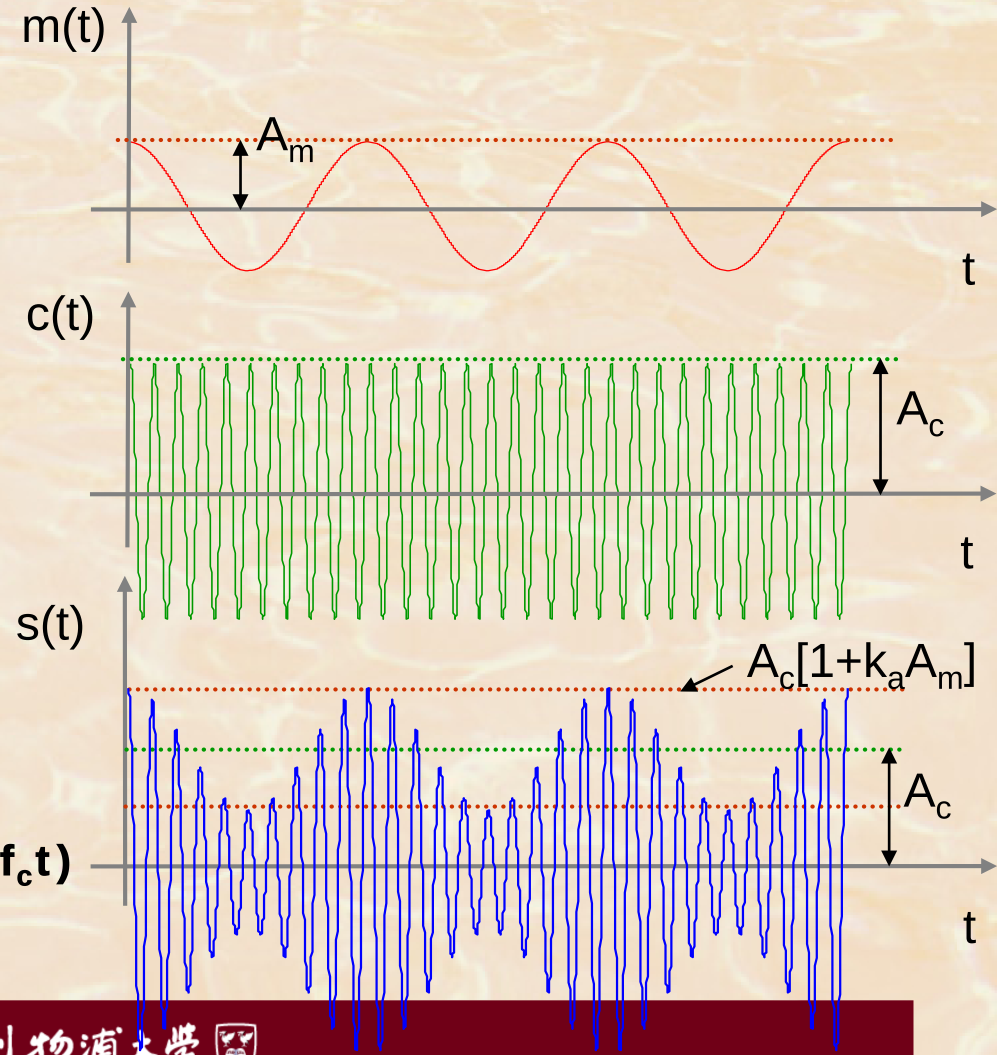
Used in commercial broadcasting of both audio and video signals.

Single Tone AM

$m(t) = A_m \cos(2\pi f_m t)$

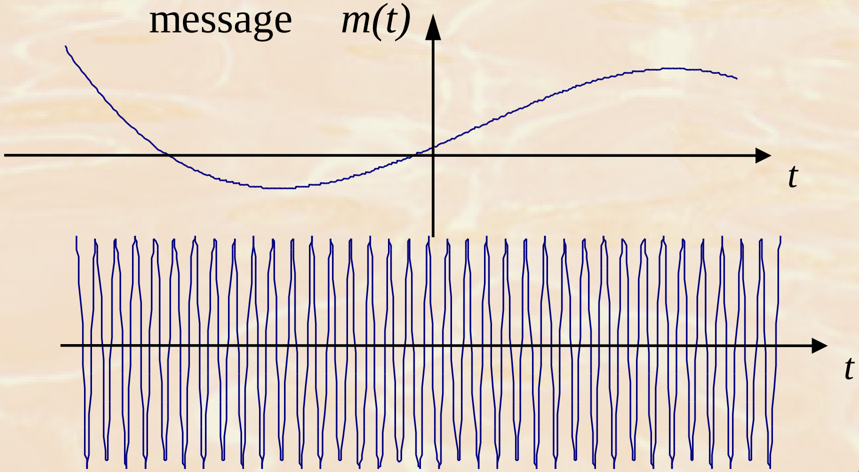
$c(t) = A_c \cos(2\pi f_c t)$

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

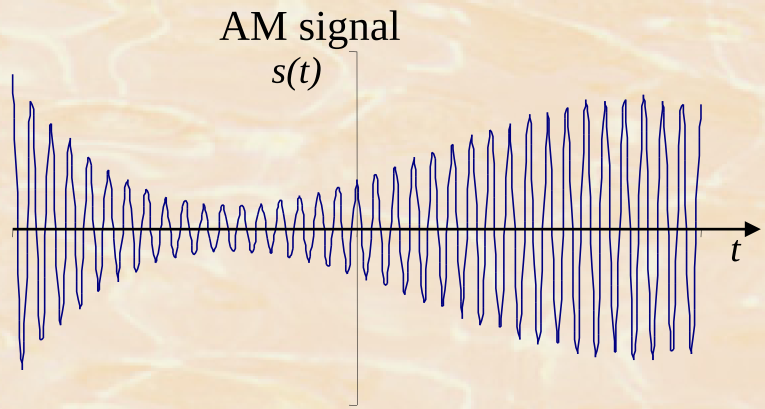


Amplitude Modulation

Amplitude modulation of a sinusoidal carrier wave, $A_c\cos(2\pi f_c t)$, by a base band signal $m(t)$ will produce a signal $s(t)$ which may be depicted as follows:



Carrier wave

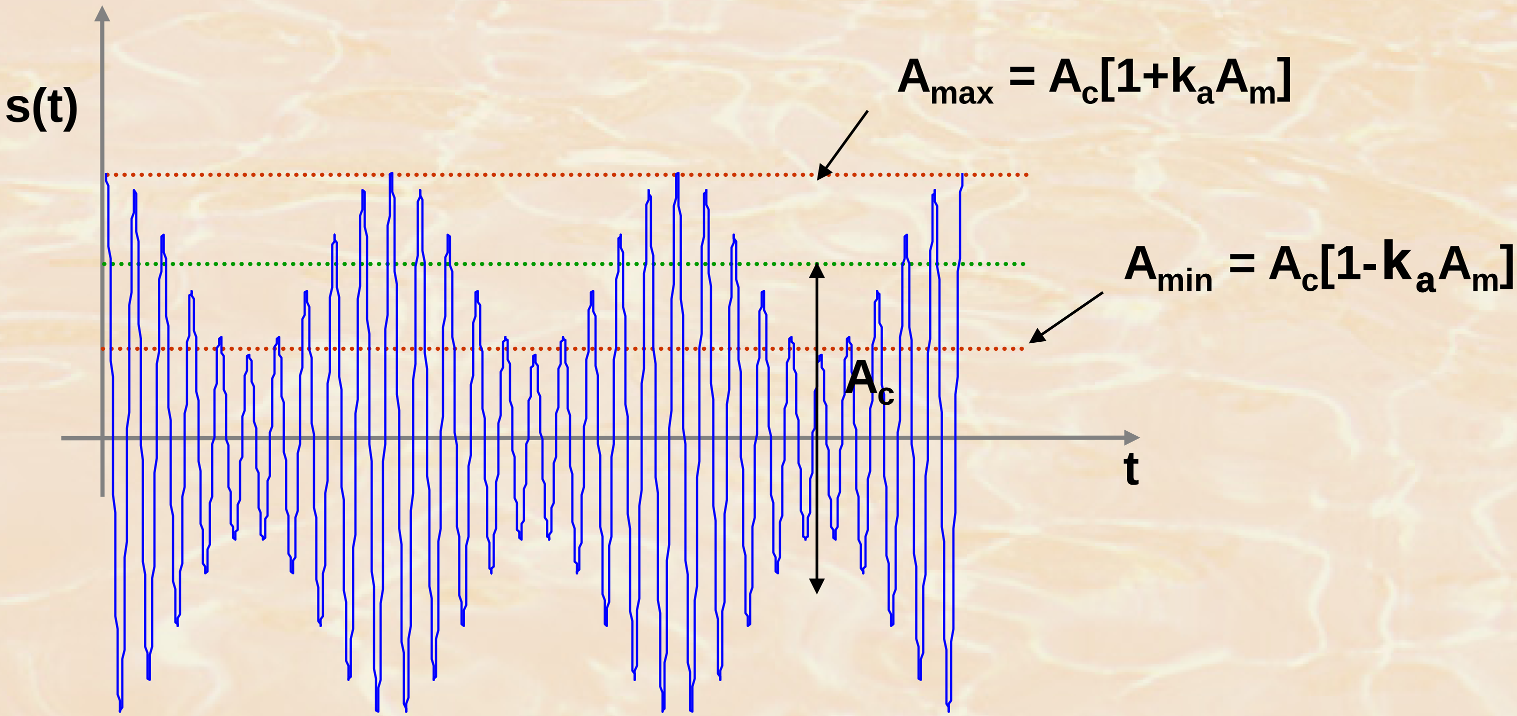


$$s(t) = A_c[1 + k_\alpha m(t)]\cos(2\pi f_c t)$$

k_a is called the modulation sensitivity/index

- Original message is simply the <u>envelope</u> of $s(t)$ if :
  - $|k_a m(t)| < 1$ so that $(1+k_a m(t))$ is positive;
  - frequency of carrier is greater than baseband bandwidth.

Percentage Modulation



Modulation index $m = (A_{max} - A_{min})/(A_{max} + A_{min}) = k_aA_m$

Modulation Index

A measure of the extent to which a carrier voltage is varied by the message signal.

Also known as modulation index or modulation factor and is symbolized by m.

$$0 \le m \le 1 \qquad \text{(why?)}$$

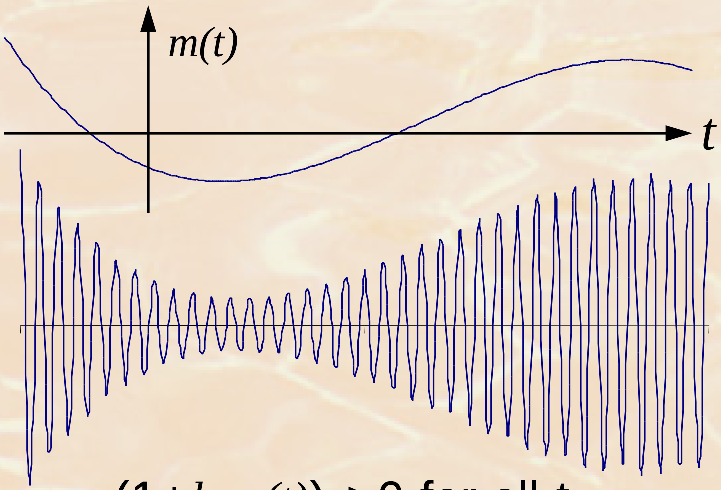
1 => 100% modulation

0 => no modulation

Over-modulated AM signal

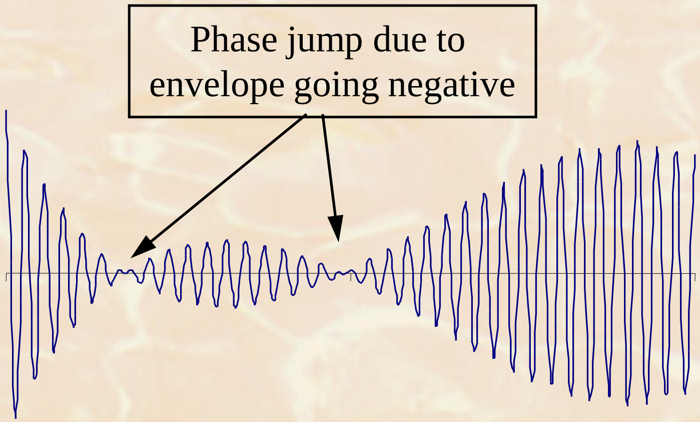
If the modulation index k_a is **too large** $(1+k_a m(t))$ may become negative leading to an over-modulated AM signal.

Envelope of over-modulated signal is **distorted** by amplitude sign change which occurs whenever $(1+k_a m(t)) < 0$.



$(1+k_a m(t)) > 0$ for all t

normal AM signal



$(1+k_a m(t)) < 0$ between 2 arrows

Over-modulated AM signal

Spectrum of single tone AM

Remember:

$$\cos(a)\cos(b) = \tfrac{1}{2}\cos(a+b) + \tfrac{1}{2}\cos(a-b)$$

we can write our amplitude modulated signal as:

$$s(t) = A_c \cos(\mathbf{2\pi f_c} t) + \tfrac{1}{2}A_c m \cos(\mathbf{2\pi f_c} + \mathbf{2\pi f_m})t + \tfrac{1}{2}A_c m \cos(\mathbf{2\pi f_c} - \mathbf{2\pi f_m})t$$

upper sideband
at f_c+f_m
carrier at f_c
lower sideband
at $f_c - f_m$

AM comprises :

– carrier wave of power $1/2\ \mathbf{A_c^2}$

– two sidebands each $1/8\ m^2 A_c^2$

at best (m = 100%) power in sidebands is one third of total power, <u>inefficient</u> ☹

VIP Math

$$\mathcal{F}(cos(2\pi f_c t)) = \int_{-\infty}^{\infty} cos(2\pi f_c t) e^{-j2\pi f_c t} dt = \frac{1}{2}(\delta(f - f_c) + \delta(f + f_c))$$

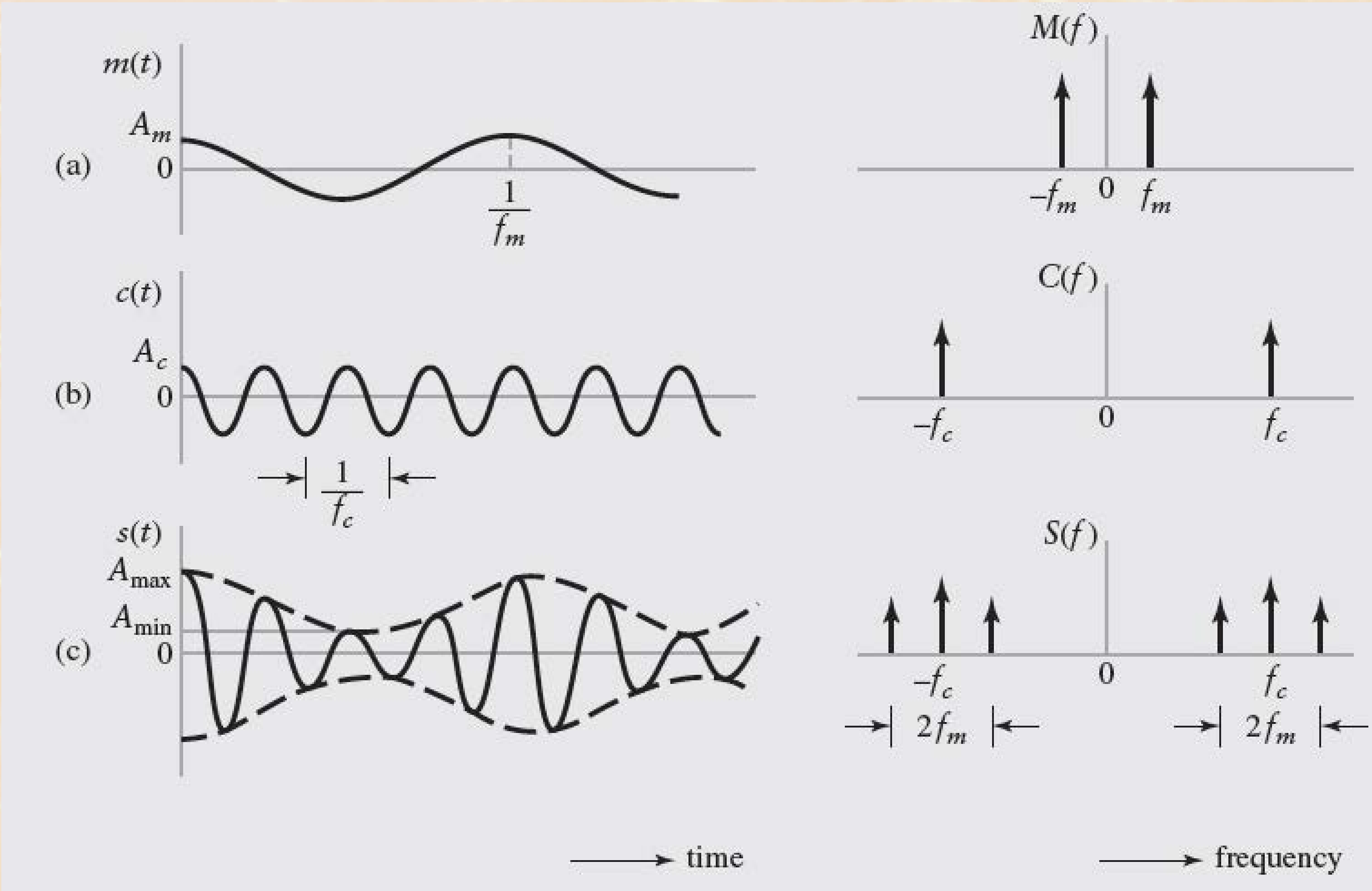
$$\mathcal{F}(sin(2\pi f_c t)) = \int_{-\infty}^{\infty} sin(2\pi f_c t) e^{-j2\pi f_c t} dt = \frac{1}{2j}(\delta(f - f_c) - \delta(f + f_c))$$

where

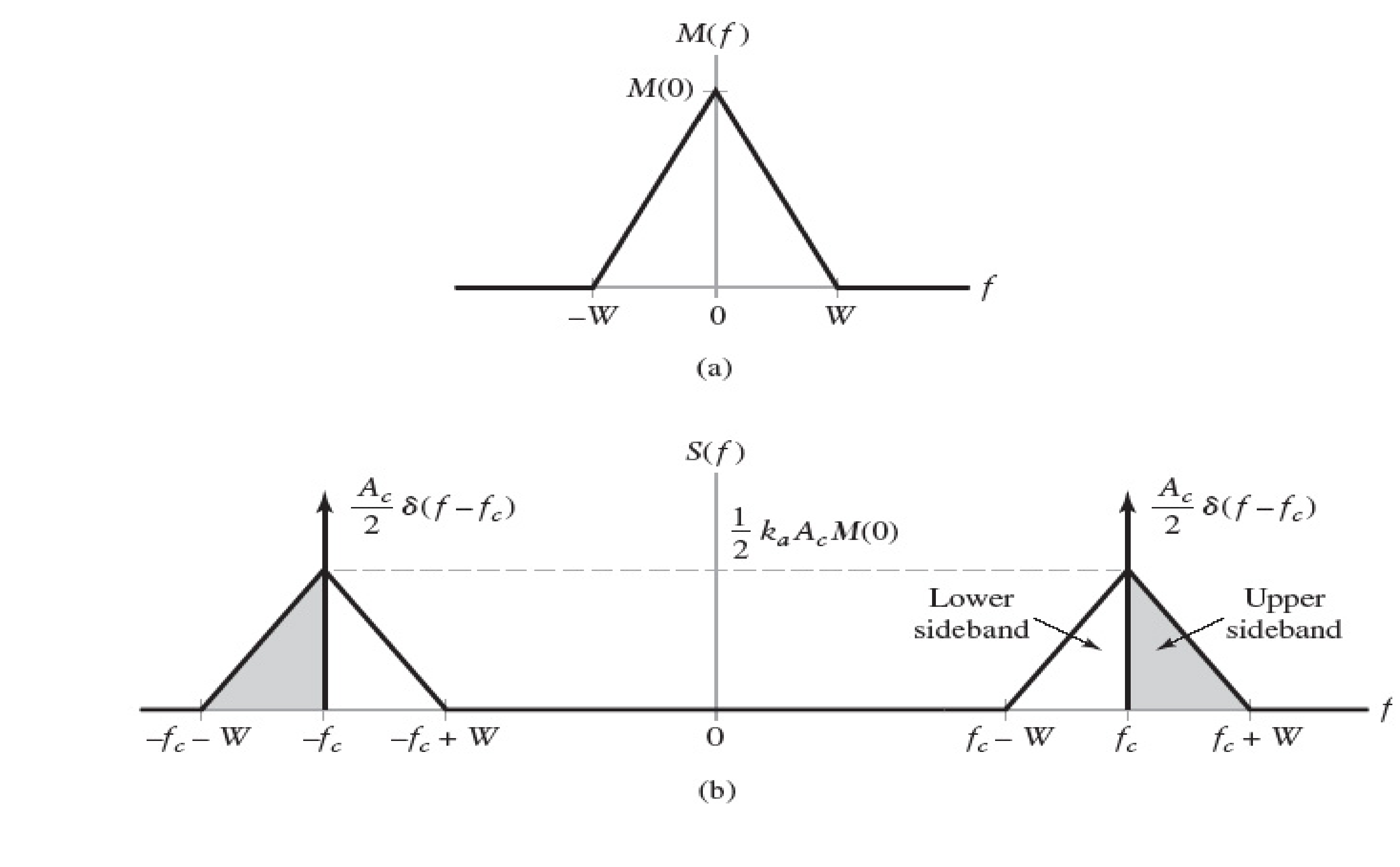
$$cos(2\pi f_c t) = \frac{1}{2}(e^{j2\pi f_c t} + e^{-j2\pi f_c t})$$

$$sin(2\pi f_c t) = \frac{1}{2j}(e^{j2\pi f_c t} - e^{-j2\pi f_c t})$$

Power in single tone AM



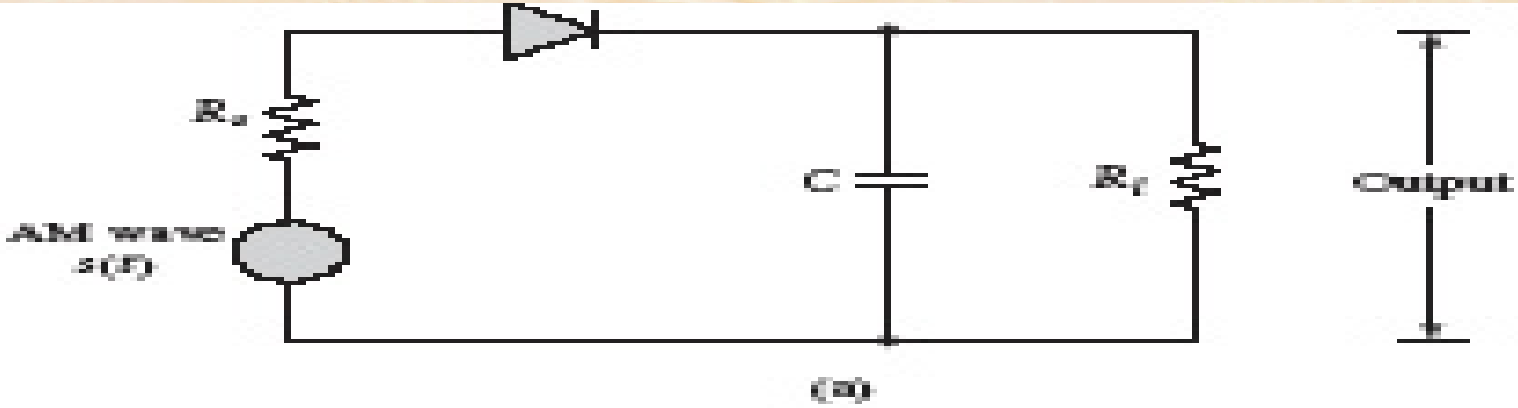
The spectrum of AM signal



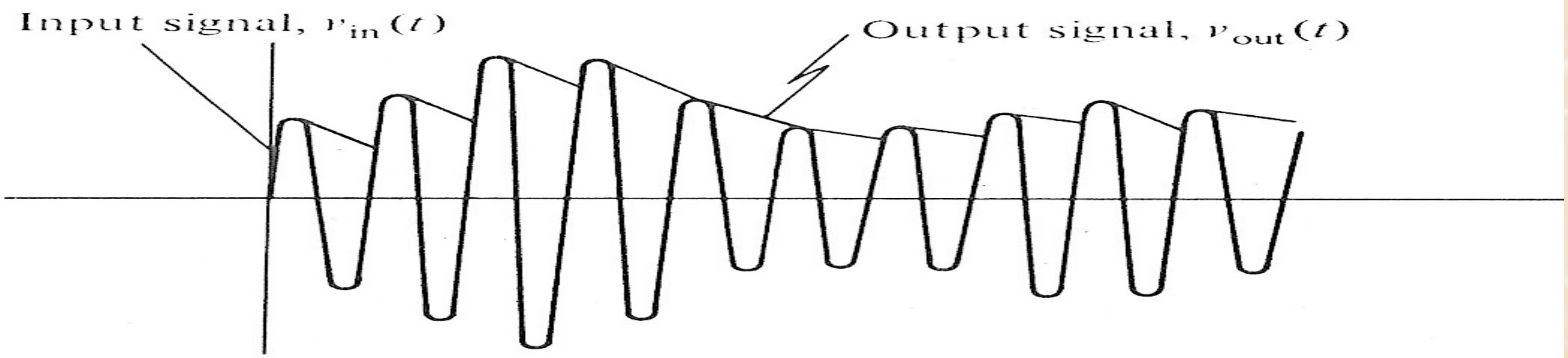
Spectrum of AM signal (2)

- AM is **wasteful** of bandwidth because:
  - Carrier frequency contains power which must be sent by the transmitter but there is no information in this signal
  - Identical information is contained in the upper and lower sideband
  - If base band bandwidth is w, the AM signal occupies a bandwidth of 2w (from f_c-w to f_c+w)
- AM is widely used for broadcast radio because of **simplicity** in receiver design (only an envelope detector is needed)

AM Receiver: Envelope Detector



(a) A Diode Envelope Detector



(b) Waveforms Associated with the Diode Envelope Detector

Double sideband and single sideband

More efficient usage of bandwidth and transmitter power can be achieved by filtering out the un-needed frequency components from the transmitted spectrum but these need more complicated receivers.

Examples of such techniques include:

- Double sideband suppressed carrier (DSB-SC) which removes the carrier frequency from the transmitted signal
- Single sideband (SSB) transmission which filters out both the carrier and either the lower sideband or upper sideband

SSB and DSB receivers must multiply the received signal with a local oscillator to recover the base band signal.