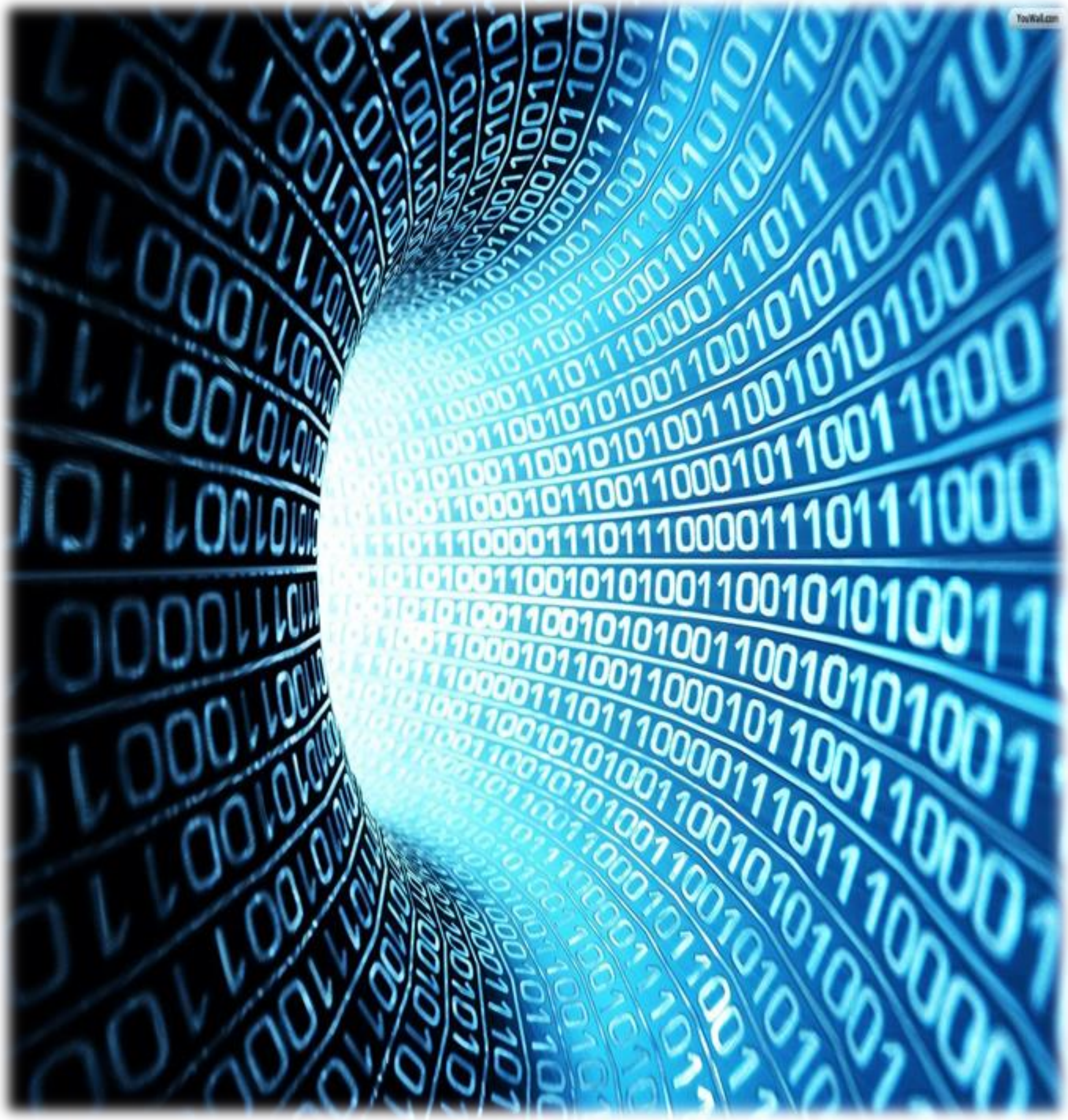
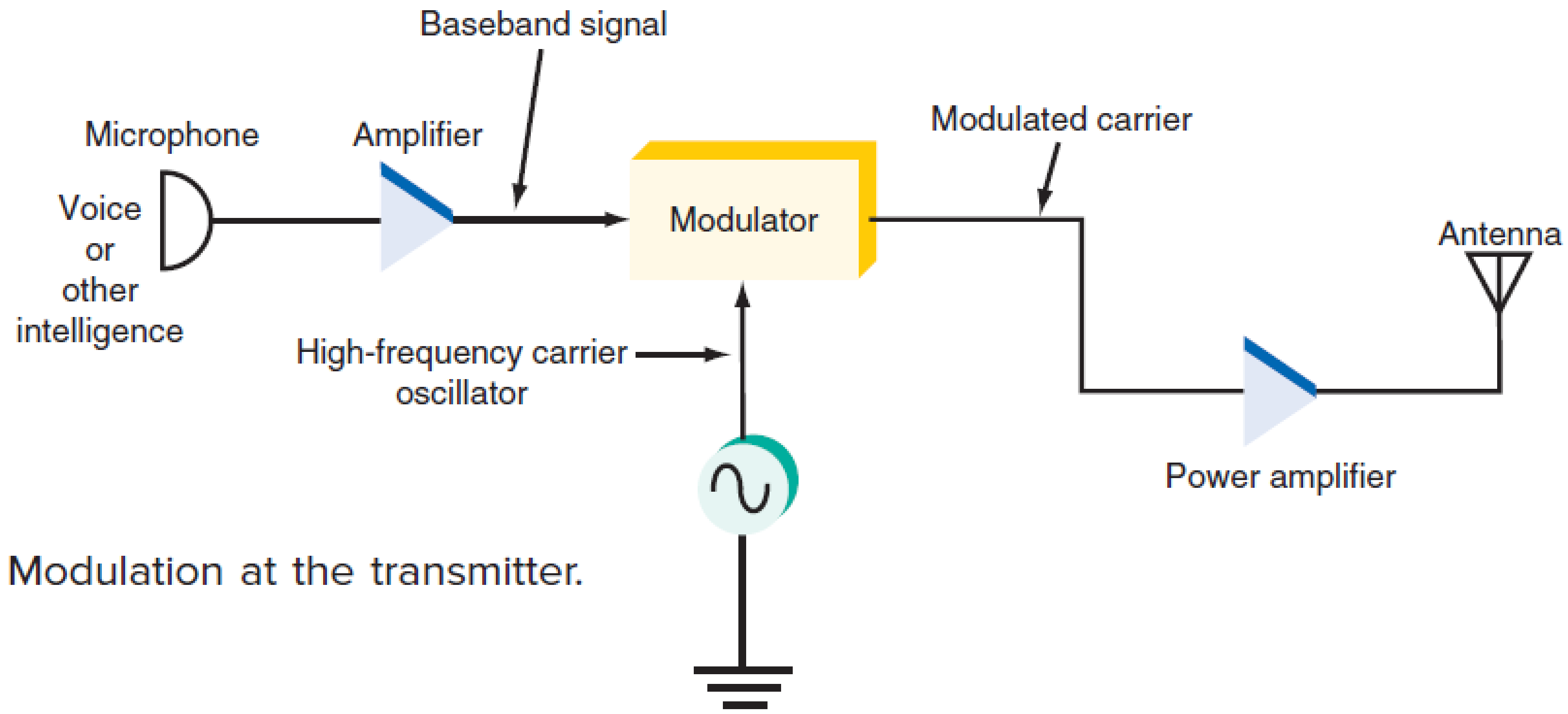


PDEU PANDIT DEENDAYAL ENERGY UNIVERSITY
NAAC A GRADE
Formerly Pandit Deendayal Petroleum University (PDPU)

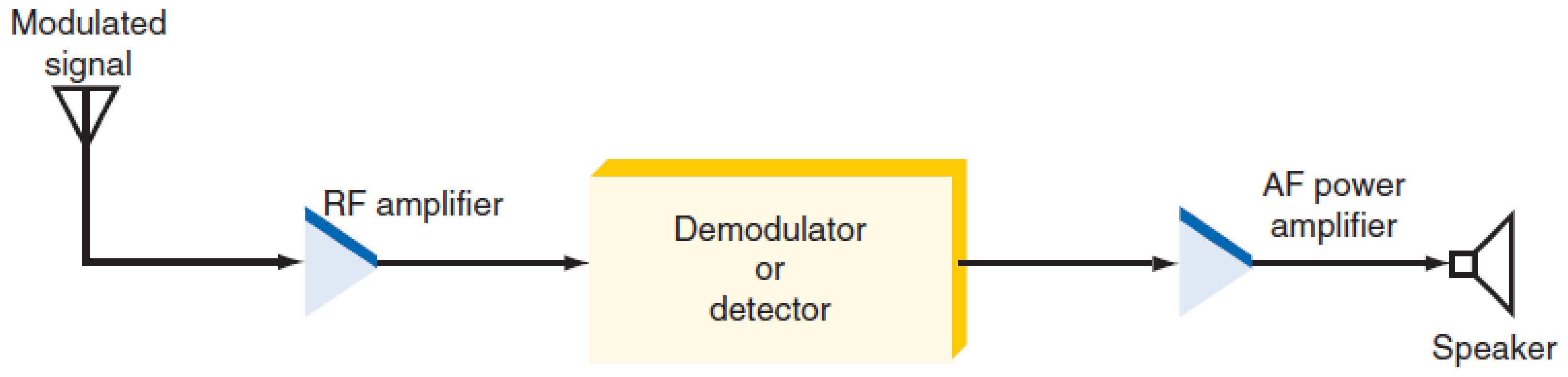
Digital Communication

Lecture-2

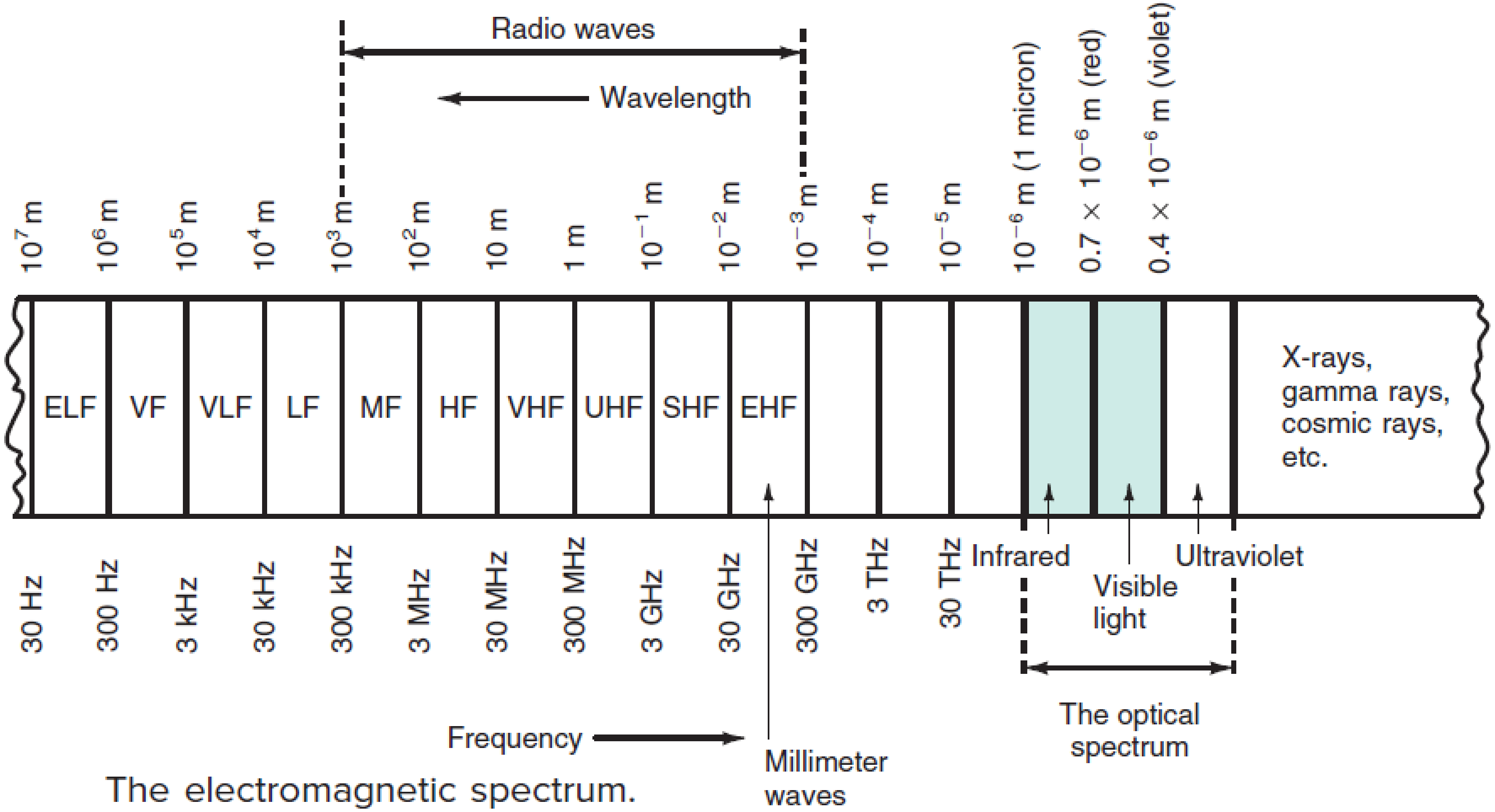
Dr. Paawan Sharma



Modulation at the transmitter.



Recovering the signal at the receiver.



The electromagnetic spectrum.

Name	Frequency	Wavelength
Extremely low frequencies (ELFs)	30–300 Hz	10^7–10^6 m
Voice frequencies (VFs)	300–3000 Hz	10^6–10^5 m
Very low frequencies (VLFs)	3–30 kHz	10^5–10^4 m
Low frequencies (LFs)	30–300 kHz	10^4–10^3 m
Medium frequencies (MFs)	300 kHz–3 MHz	10^3–10^2 m
High frequencies (HFs)	3–30 MHz	10^2–10^1 m
Very high frequencies (VHFs)	30–300 MHz	10^1–1 m
Ultra high frequencies (UHFs)	300 MHz–3 GHz	1–10^{-1} m
Super high frequencies (SHFs)	3–30 GHz	10^{-1}–10^{-2} m
Extremely high frequencies (EHFs)	30–300 GHz	10^{-2}–10^{-3} m
Infrared	—	0.7–10 μm
The visible spectrum (light)	—	0.4–0.8 μm

Various International Communication Organizations

- Federal Communications Commission (FCC) – USA
- American National Standards Institute (ANSI)—www.ansi.org
- Electronic Industries Alliance (EIA)—www.eia.org
- European Telecommunications Standards Institute (ETSI)—www.etsi.org
- Institute of Electrical and Electronics Engineers (IEEE)—www.ieee.org
- International Telecommunications Union (ITU)—www.itu.org
- Internet Engineering Task Force (IETF)—www.ietf.org
- Optical Internetworking Forum (IF)—www.oiforum.com
- Telecommunications Institute of America (TIA)—www.tiaonline.org

Applications of Communication Systems

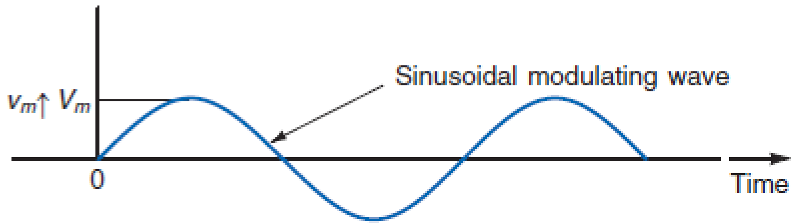
- Simplex
  - AM and FM radio broadcasting
  - Digital Radio
  - Television Broadcasting
  - Wireless remote control
  - Navigation and direction-finding services
  - Radio astronomy
- Duplex
  - Telephones
  - Internet
  - Radar etc

AMPLITUDE MODULATION

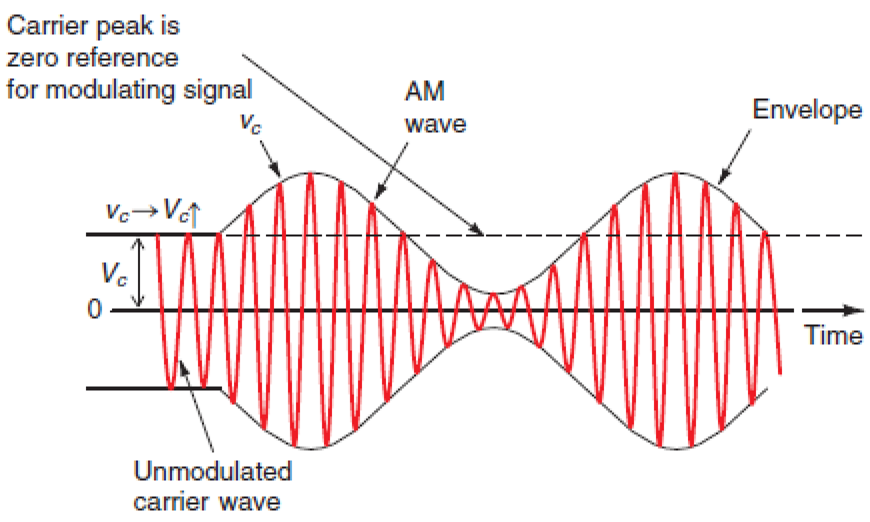
- The instantaneous value of the carrier amplitude changes in accordance with the amplitude variations of the modulating signal
- The carrier frequency remains constant during the modulation process
- An increase or a decrease in the amplitude of the modulating signal causes a corresponding increase or decrease in both the positive and the negative peaks of the carrier amplitude.

$$\boxed{v_c = V_c \sin 2\pi f_c t}$$

$$\boxed{v_m = V_m \sin 2\pi f_m t}$$



(a)



(b)

- the amplitude of the modulating signal should be less than the amplitude of the carrier, or else distortion will occur

$$V_m < V_c$$

- the value of the modulatıng sıgnal is added to or subtracted from the peak value of the carrier
- Modulated wave is given as

$$v_2 = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

- It is the second part of the expression that is characteristic of AM. A circuit must be able to produce mathematical multiplication of the carrier and modulating signals in order for AM to occur

- The circuit used for producing AM is called a *modulator.*
- Amplitude modulators compute the product of the carrier and modulating signals.
- Circuits that compute the product of two analog signals are also known as analog multipliers, mixers, converters
- A circuit that changes a lower-frequency baseband signal to a higher-frequency signal is called a modulator.
- A circuit used to recover the original intelligence signal from an AM wave is known as a detector or demodulator.

Modulation Index and Percentage of Modulation

- for undistorted AM to occur, the modulating signal voltage *Vm* must be less than the carrier voltage *Vc*.
- the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal is known as the *modulation index m* (also called the modulating factor or coefficient, or the degree of modulation), is the ratio

$$m = \frac{V_m}{V_c}$$

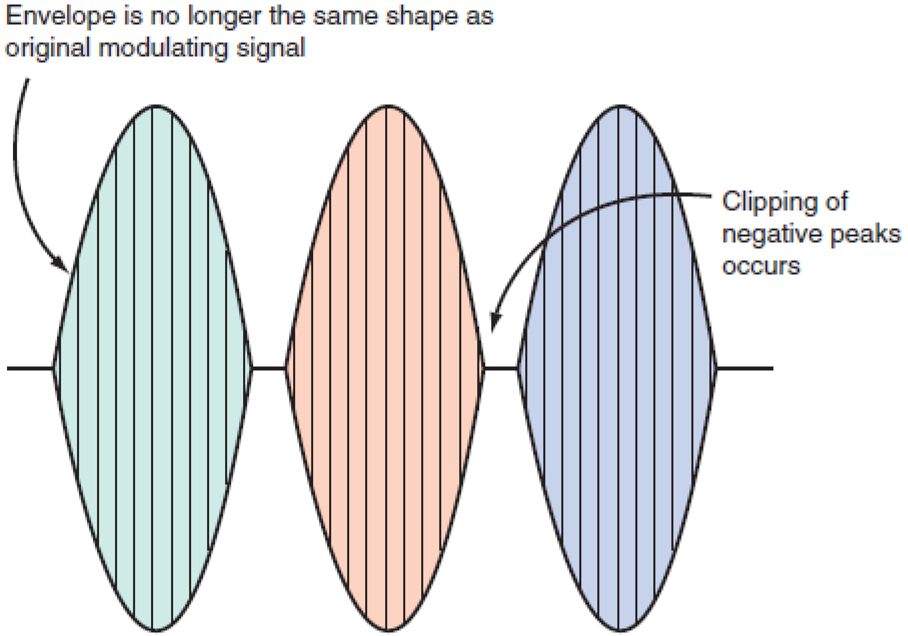
- Multiplying the modulation index by 100 gives the *percentage of modulation.*

Overmodulation and Distortion

- The modulation index should be a number between 0 and 1.
- If the amplitude of the modulating voltage is higher than the carrier voltage, *m* will be greater than 1, causing *distortion* of the modulated waveform
- This is overmodulation (m >1)
- The ideal condition for AM is

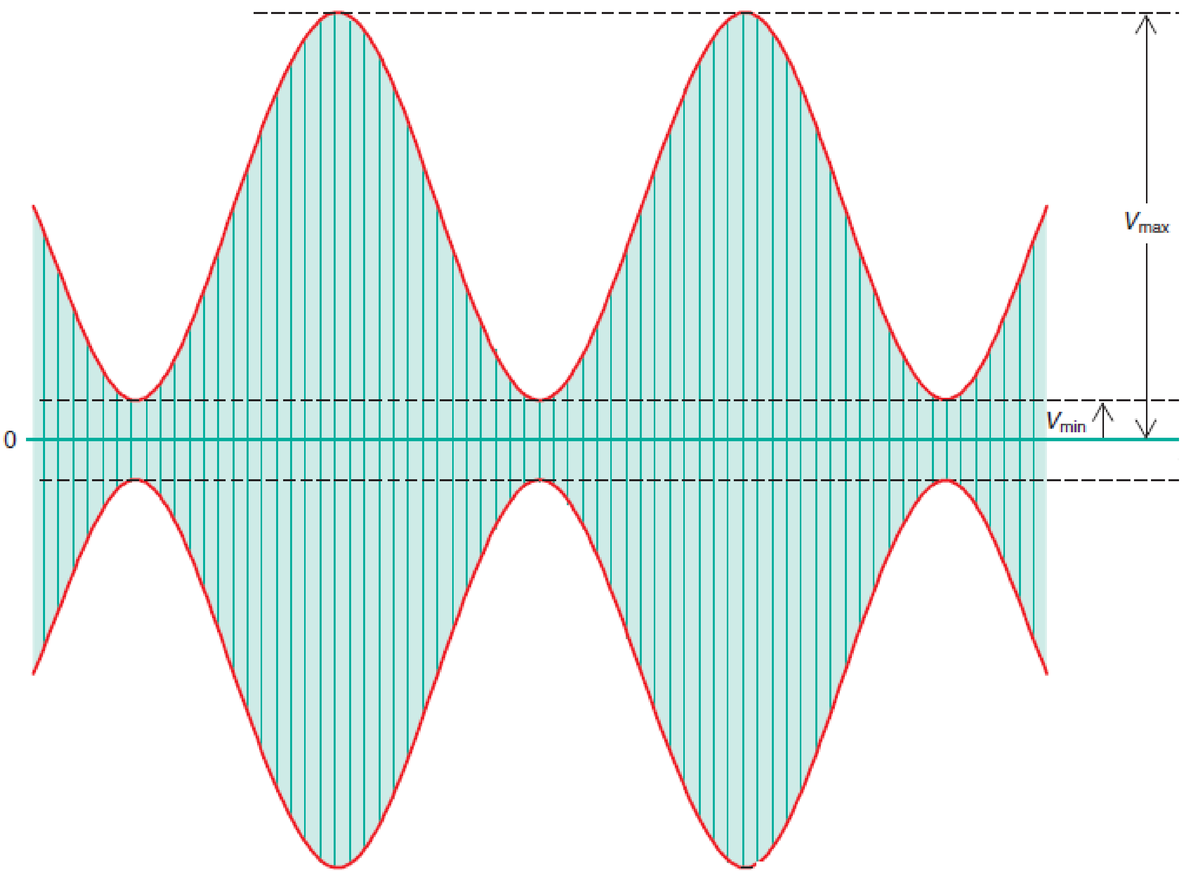
when $V_m = V_c$, or $m = 1$, which gives 100 percent modulation. This results in the greatest output power at the transmitter with no distortion.

Distortion of the envelope caused by overmodulation where the modulating signal amplitude V_m is greater than the carrier signal V_c.



$$v_2 = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t$$

An AM wave showing peaks (V_{max}) and troughs (V_{min}).



- Let V_{max} & V_{min} denote maximum and minimum amplitude of modulated wave
- $V_{max} = V_c + V_m$
- $V_{min} = V_c - V_m$
- Hence,

$$V_m = (V_{max} - V_{min})/2$$

$$V_c = (V_{max} + V_{min})/2$$

$$\therefore m = \frac{V_m}{V_c} = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

Sidebands and the Frequency Domain

- Whenever a carrier is modulated by a signal, new signals at different frequencies are generated
- These new frequencies, which are called *side frequencies,* or *sidebands,* occur in the frequency spectrum directly above and below the carrier frequency.

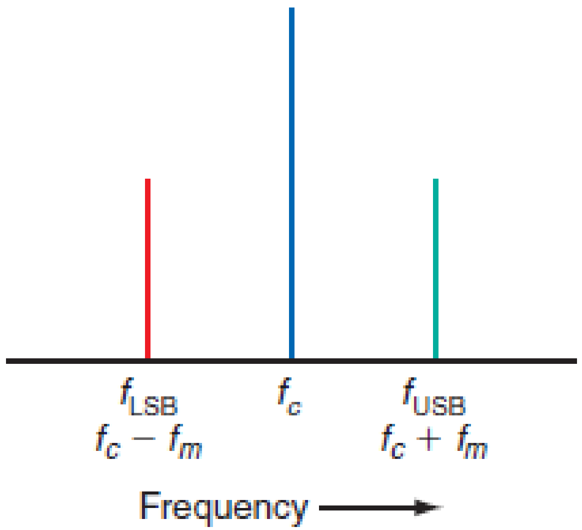
$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

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

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t(f_c - f_m) - \frac{V_m}{2} \cos 2\pi t(f_c + f_m)$$

The upper sideband f_{USB} and lower sideband f_{LSB} are computed as

$$f_{USB} = f_c + f_m \qquad \text{and} \qquad f_{LSB} = f_c - f_m$$



A frequency-domain display of an AM signal

AM Power

- The AM signal is a mixture of the carrier and the two sidebands, and each of these signals produces power in the antenna.
- The total transmitted power P_T is simply the sum of the carrier power P_c and the power in the two sidebands P_{USB} and P_{LSB}

$$P_T = P_c + P_{\mathrm{LSB}} + P_{\mathrm{USB}}$$

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2} \cos 2\pi t (f_c + f_m)$$

- Here, V_c and V_m are peak values of the carrier and modulating sine waves, respectively.
- For power calculations, rms values must be used for the voltages, can convert from peak to rms by dividing the peak value by $\sqrt{2}$

$$v_{AM} = \frac{V_c}{\sqrt{2}} \sin 2\pi f_c t + \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c + f_m)$$

- The power in the carrier and sidebands can be calculated by using the power formula $P = {V^2}/{R}$ where P is the output power, V is the rms output voltage, and R is the resistive part of the load impedance, which is usually an antenna.

$$P_T = \frac{(V_c/\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} = \frac{V_c^{\,2}}{2R} + \frac{V_m^{\,2}}{8R} + \frac{V_m^{\,2}}{8R}$$

$$V_m = mV_c$$

$$P_T = \frac{(V_c)^2}{2R} + \frac{(mV_c)^2}{8R} + \frac{(mV_c)^2}{8R} = \frac{V_c^2}{2R} + \frac{m^2V_c^2}{8R} + \frac{m^2V_c^2}{8R}$$

$$P_T = \frac{V_c^2}{2R}\left(1 + \frac{m^2}{4} + \frac{m^2}{4}\right)$$

$$P_T = P_c\left(1 + \frac{m^2}{2}\right)$$

- Also,

$$P_T = I_T^2R$$

$$\text{where } I_T = I_c\sqrt{(1 + m^2/2)}$$

- Here I_c is the unmodulated carrier current in the load, *m* is the modulation index, R is antenna impedance

$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

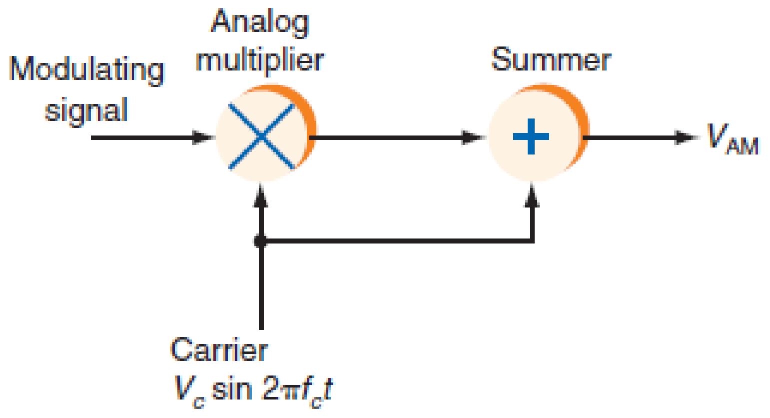
$$m = V_m / V_c, \text{ and so } V_m = mV_c.$$

Then substituting this for V_m in the basic equation yields

$$v_{AM} = V_c \sin 2\pi f_c t + (mV_c \sin 2\pi f_m t)(\sin 2\pi f_c t).$$

Factoring gives $v_{AM} = V_c \sin 2\pi f_c t(1 + m \sin 2\pi f_m t)$.

Block diagram of a circuit to produce AM.

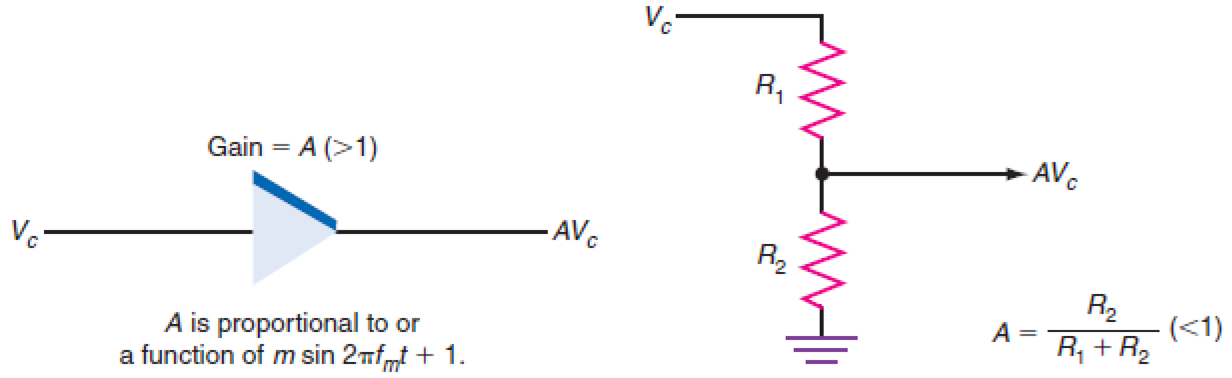


AM in the Time Domain

- a circuit that can multiply the carrier by the modulating signal and then add the carrier
- One way to do this is to develop a circuit whose gain (or attenuation) is a function of $1 + m \sin 2\pi f_m t$.
- If we call that gain *A*, the expression for the AM signal becomes

$$v_{\mathrm{AM}} = A(v_c)$$

Multiplying the carrier by a fixed gain *A*.

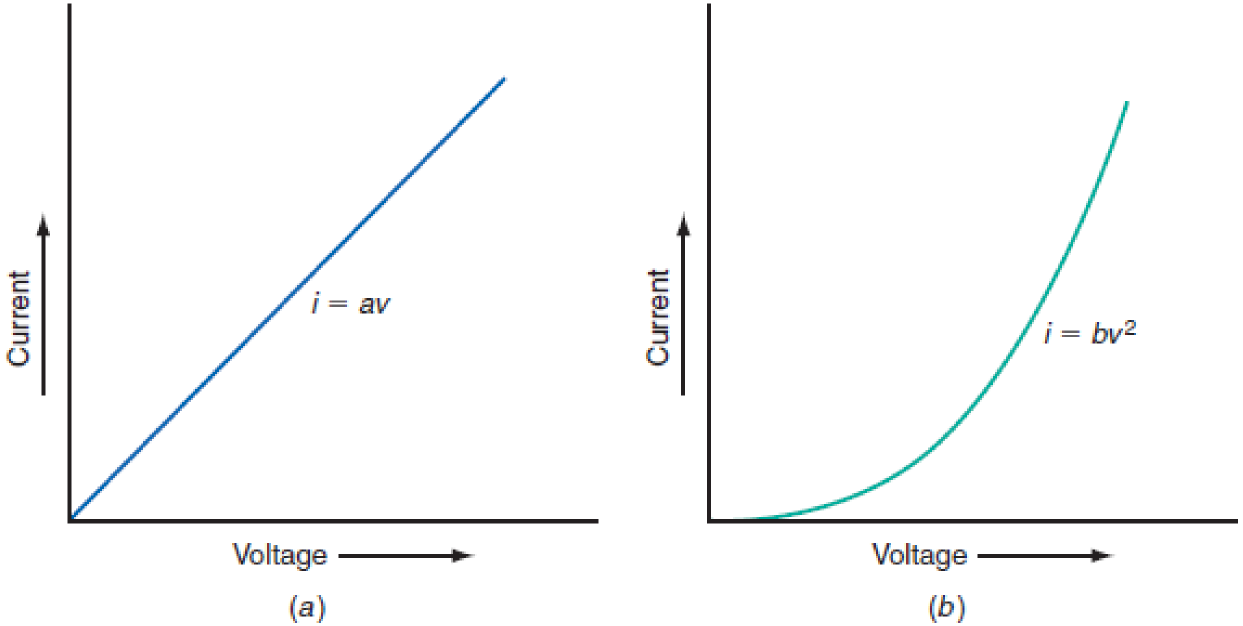


- Now, if the gain of the amplifier or the attenuation of the voltage divider can be varied in accordance with the modulating signal plus 1, AM will be produced.
- Hence, the modulating signal is used to increase or decrease the gain of the amplifier as the amplitude of the message signal changes
- The modulating signal could be made to vary one of the resistances in the voltage divider, creating a varying attenuation factor
- Many circuits allow gain or attenuation to be varied dynamically with another signal, producing AM (eg. Using varistor)

AM in the Frequency Domain

- Another way to generate the product of the carrier and modulating signal is to apply both signals to a nonlinear component or circuit, ideally one that generates a square-law function.

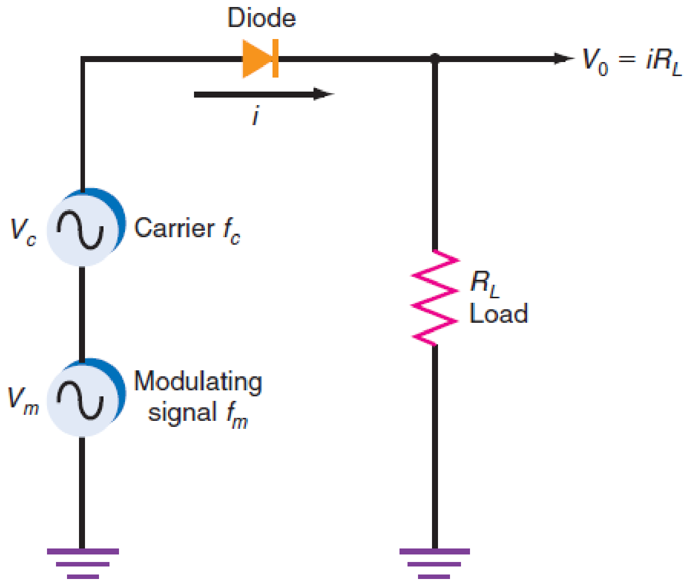
Linear and square-law response curves. (*a*) A linear voltage-current relationship. (*b*) A nonlinear or square-law response.



- A common nonlinear component is a diode that has the nonlinear parabolic response
- A *square-law function* is one that varies in proportion to the square of the input signals. For eg. a diode gives a good approximation of a square-law response. BJTs FETs can also be used.
- The current variation in a typical semiconductor diode can be approximated by the equation

$$i = av + bv^2$$

where *av* is a linear component of the current equal to the applied voltage multiplied by "*a*" and bv^2 is second-order or square-law component of the current.



- To produce AM, the carrier and modulating signals are added and applied to the nonlinear device.
- The voltage applied to the diode is then

$$v = v_c + v_m$$

- The diode current is then

$$i = a(v_c + v_m) + b(v_c + v_m)^2$$
$$i = a(v_c + v_m) + b(v_c^2 + 2v_c v_m + v_m^2)$$

- Substituting the trigonometric expressions for the carrier and modulating signals,

$$i = aV_c \sin \omega_c t + aV_m \sin \omega_m t + bV_c^2 \sin^2 \omega_c t + 2bV_cV_m \sin \omega_c t \sin \omega_m t + b\upsilon_m^2 \sin^2 \omega_m t$$

$$i = a\upsilon_c \sin \omega_c t + a\upsilon_m \sin \omega_m t + 0.5b\upsilon_c^2(1 - \cos 2\omega_c t) + 2b\upsilon_c\upsilon_m \sin \omega_c t \sin \omega_m t + 0.5b\upsilon_m^2(1 - \cos 2\omega_m t)$$

Carrier

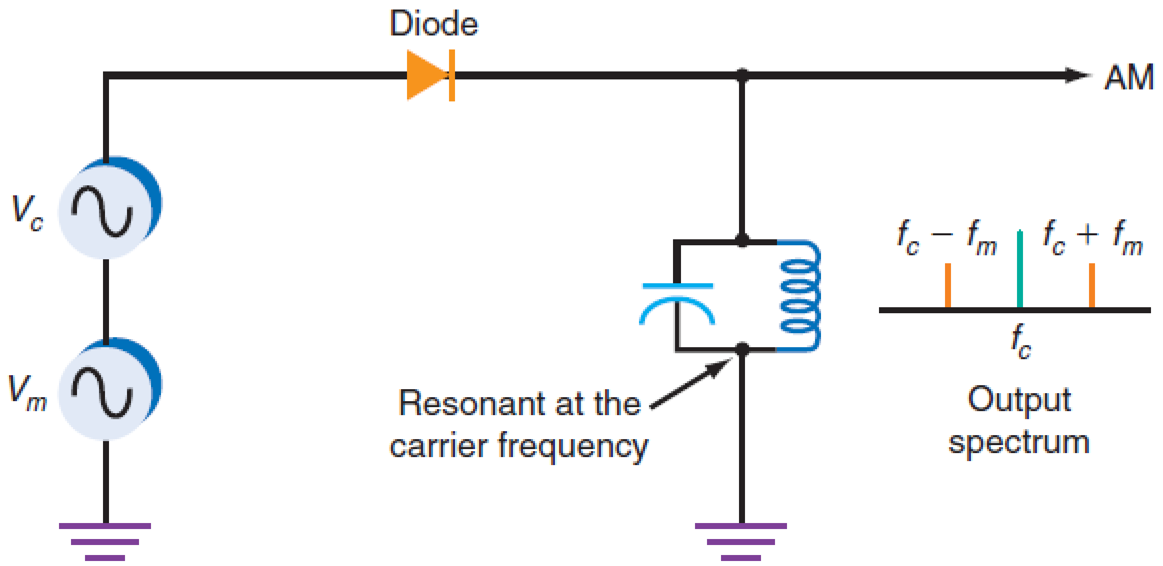
Modulating

Harmonic of Carrier

Carrier-Modulating Multiplication (side-bands)

Harmonics of Modulating

- Modulating Signal and Harmonics of modulating/carrier signal can be easily filtered out
- For eg a tuned LC circuit can act as a BPF
- This circuit is resonant at the carrier frequency and has a bandwidth wide enough to pass the sidebands



THANK YOU