Fundamentals of Communications Engineering

Department of Communications Engineering, College of Engineering, University of Diyala, 2016-2017

Class: Second Year
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Room: Comm-02

Lecture: 14

Communication Systems

"Attention, the Universe! By Kingdom, right wheel"

First telegraph message sent on line of 16 Km in 1838 By Samuel F.B. Morse.

Source → Destination

communication system

* A communication system conveys information from its source to a destination some distance away.

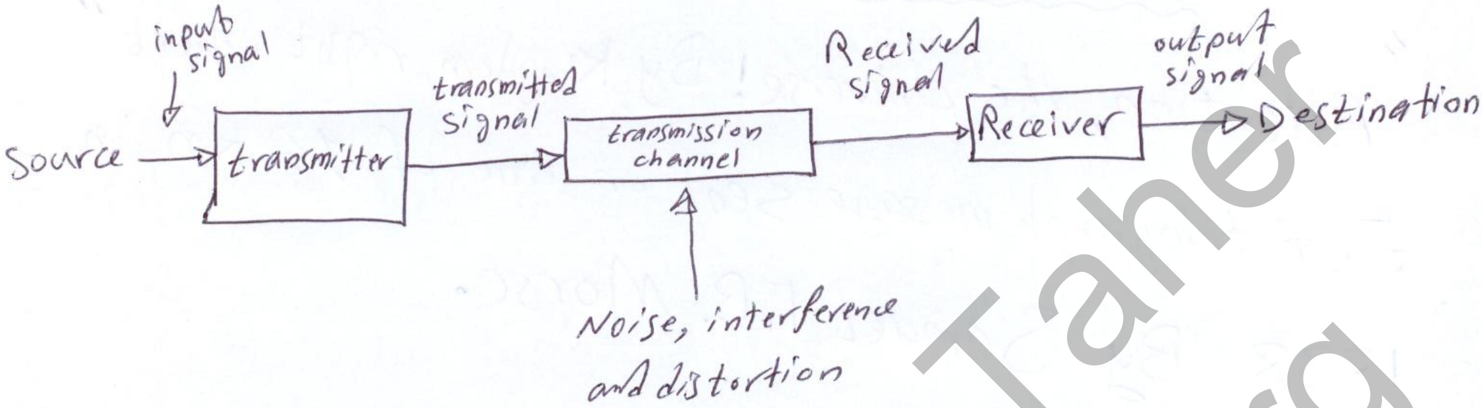
Source → Input transducer → (Input signal) → Communication system → (output signal) → output transducer → Destnation

Transducer: convert the message to electrical signal. OR vice versa.

* Analog message is a physical quantity that varies with time.

* Digital message is a sequence of symbols selected from a finite set of discrete elements.

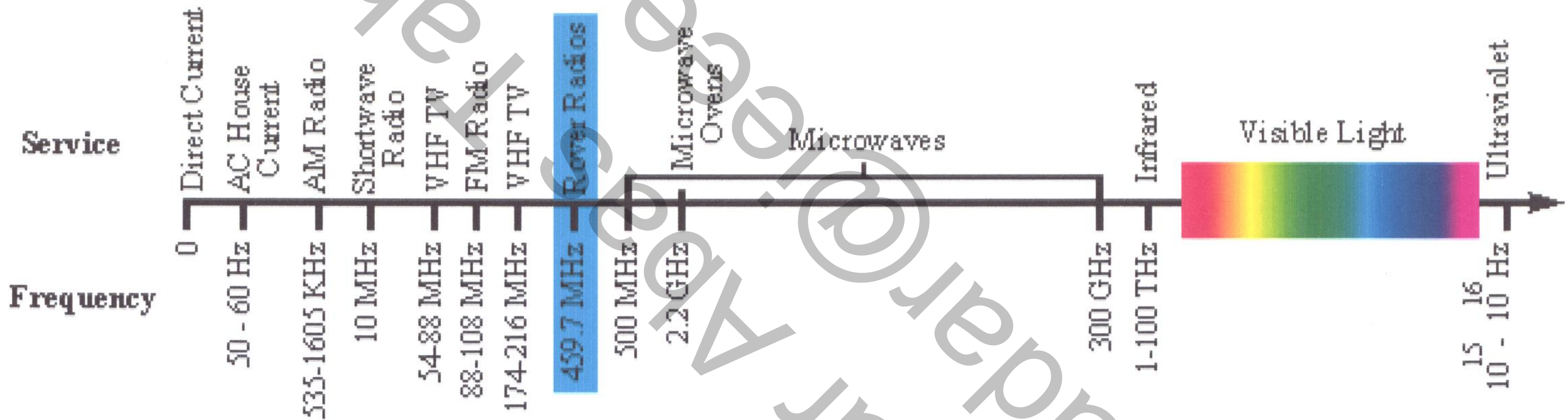
Elements of a Communication System :



Frequency Band use :

0 — 300 Hz	Extremely Low Frequency (ELF)
300Hz — 3 KHz	Voice Frequency
3KHz — 30KHz	very Low frequency (VLF)
30KHz — 300 KHz	Low Frequency (LF)
300KHz — 3 MHz	Medium Frequency (MF)
3 MHz — 30 MHz	High Frequency (HF)
30 MHz — 300 MHz	very high frequency (VHF)
300MHz — 3GHz	Ultra high Frequency (UHF)
3GHz — 30 GHz	Super high Frequency (SHF)
30 GHz — 300 GHz	Extremely high frequency (EHF)

Frequency Spectrum



Designation	Band
Direct Current (DC)	0 Hertz
Very Low Frequency (VLF)	3 - 30 KHz
Low Frequency (LF)	30 - 300 KHz
Medium Frequency (MF)	300 - 3000 KHz
High Frequency (HF)	3 - 30 MHz

Designation	Band
Very High Frequency (VHF)	30 - 300 MHz
Ultra High Frequency (UHF)	300 - 3000 MHz
Super High Frequency (SHF)	3 - 30 GHz
Extreme High Frequency (EHF)	30 - 300 GHz
Microwave Frequencies	500 MHz - 300 GHz

The institute of electrical and electronics engineering (IEEE) has defined the frequency spectrum as:-

1 – 2 GHz	L - Band
2 – 4 GHz	S - Band
4 – 8 GHz	C - Band
8 – 12 GHz	X - Band
12 – 18 GHz	K_u - Band
18 – 27 GHz	K - Band
27 – 40 GHz	K_a - Band
40 – 75 GHz	V - Band
75 – 110 GHz	W - Band

Some Applications

AM broadcast 530 KHz — 1700 KHz

Broadcast television 54~88 MHz , 174–216 MHz , 470–698 MHz.

FM broadcast 88–108 MHz.

Cell phones ~750–850 MHz , ~1700, ~1950, ~2100 MHz

GPS (non-military) ~1.5 GHz.

Satellite radio ~2.3 GHz.

Wireless Computer Networks ~2.4 & ~5.8 GHz.

Satellite TV ~12 GHz.

Fixed point-to-point Links ~1 ~ 90 GHz.

Modulation : why?

to transmit a signal which is usually baseband low frequency, where the antenna size will be in the order of hundreds of meters.

Antenna length $= \frac{\lambda}{2}$ almost or usually.

where λ = wavelength of the message

$$\lambda = \frac{c}{f_m}$$

where c is the light speed $= 3 \times 10^8$ m/s

and f_m is the frequency of the message signal in Hz.

for example. to transmit the message $x(t) = 2\cos(2\pi 3t)$, then:

$$\lambda = \frac{3 \times 10^8}{3} = 1 \times 10^8 \text{ m}$$

$$\therefore L_{Antenna} = \frac{\lambda}{2} = 50 \times 10^6 \text{ m}$$

or

Antenna length $= 50,000$ km. [is it logical?]

Hence?

Modulation now is necessary because it translates the low frequency message signal to a suitable higher frequency. Accordingly the antenna size will be small and practically realiable.

In Real world, there are analog and digital modulations

In analog modulation, there is three types of modulations; amplitude modulation, frequency modulation, and phase modulation.

In digital modulation, each analog type corresponds to a digital modulation type.

Modulation

Linear modulation
- Amplitude modulation methods (DSB, DSB-SC, AM, SSB, VSB)
- Digital: ASK

Angle modulation
- Frequency Modulation
- Phase Modulation
- Digital: FSK, PSK

Modulation: Is the process of locating a message signal to some new frequency location, where it can be efficiently transmitted.

In General: The carrier of the message signal is sinusoidal.

A modulated carrier is

$$x_c(t) = \underbrace{A(t)}_{\text{Linear modulation}} \cos\Big[\underbrace{2\pi f_c t}_{\text{Frequency modulation}} + \underbrace{\phi(t)}_{\text{phase modulation}}\Big]$$

* IF $\phi(t)$ constant or $\phi(t)=0$ and f_c is constant, then $x_c(t)$ represents a Linear modulation.

* IF $A(t)$ is constant and $\phi(t)$ is constant or $\phi(t)=0$, then only f_c is varied, then $x_c(t)$ is frequency modulation.

* IF $A(t)$ is constant, f_c is constant and $\phi(t)$ function of time, then, $x_c(t)$ represents Phase Modulation.

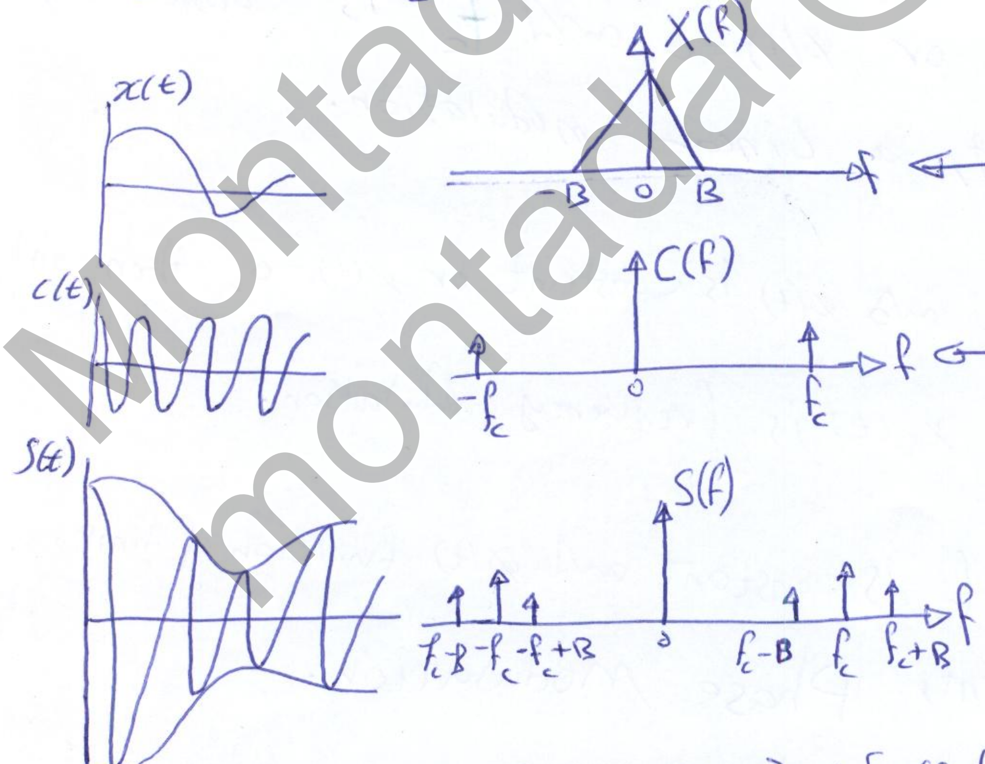
Amplitude Modulation : AM (530 KHz – 1,700 KHz)

+ message signal is $x(t)$
+ carrier signal is $c(t) = A_c \cos(2\pi f_c t)$
+ AM – modulated signal is comming from :

$$S(t) = A_c \cos(2\pi f_c t) + x(t)\cos(2\pi f_c t)$$

$$S(t) = A_c \cos(2\pi f_c t) + x(t)\cos(2\pi f_c t)$$

$$s(t) = [A_c + x(t)]\cos(2\pi f_c t)$$



$\leftarrow X(f)$

$$\leftarrow C(f) = \frac{A_c}{2}\left[\delta(f+f_c) + \delta(f-f_c)\right]$$

$$S(f) = \frac{A_c}{2}\left[\delta(f+f_c) + \delta(f-f_c)\right] + \frac{1}{2}\left[X(f+f_c) + X(f-f_c)\right]$$

Envelope of AM signal

It can be seen $s(t) = V(t)\cos(2\pi f_c t)$

where $V(t)$ is the envelope

$$V(t) = A_c + x(t)$$

the signal is represented by the envelope $V(t)$, which is carried by th carrier $c(t) = \cos(2\pi f_c t)$. There-fore, the message can be detected using a simple circuit consists of R & C (LPF) and diode called the Envelope detector.

* To use the Envelope Detector two conditions have to be provided :-

① $f_c \gg B$

② There should be no Zero corossing $\frac{|x(t)|_{max}}{A_c} \leq 1$

* Modulation Index :

General definition to modulation index is

$$\mu_a = \frac{\text{Maximum message Amplitude}}{\text{Maximum Carrier Amplitude}}$$

$$\boxed{\mu_a = \frac{|x(t)|_{max}}{A_c}}$$

μ_a is called : Modulation Index

Modulation Factor

Modulation depth

Degree of Modulation

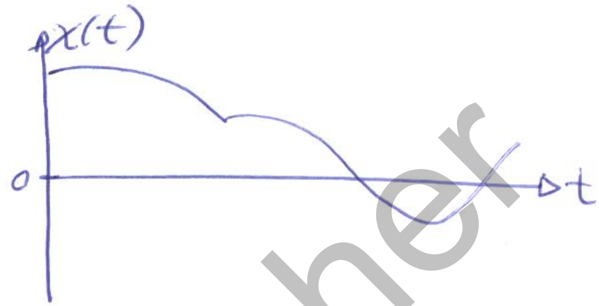
If μ_a multiplied by 100, it is called the percentage Modulation.

* Modulation index is

$$\boxed{\mu_a \leqslant 1}$$

or else distortion will happen.

* message $x(t)$:

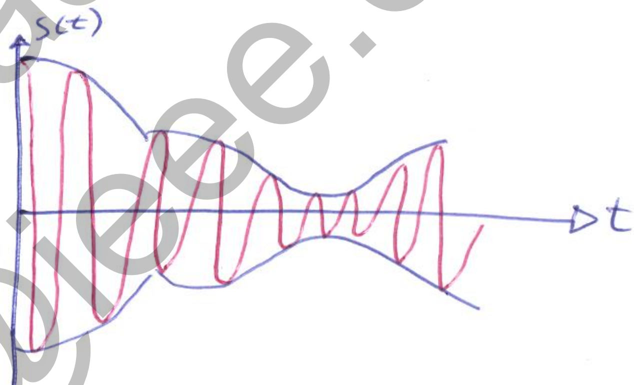


* carrier: $c(t) = A_c \cos(2\pi f_c t)$

* Modulated signal:

$$s(t) = [A_c + x(t)] \cos(2\pi f_c t)$$

$$\mu_a = \frac{|x(t)|_{max}}{A_c} < 1$$



* Modulated signal:

$$s(t) = [A_c + x(t)] \cos(2\pi f_c t)$$

$$\mu_a = \frac{|x(t)|_{max}}{A_c} > 1$$

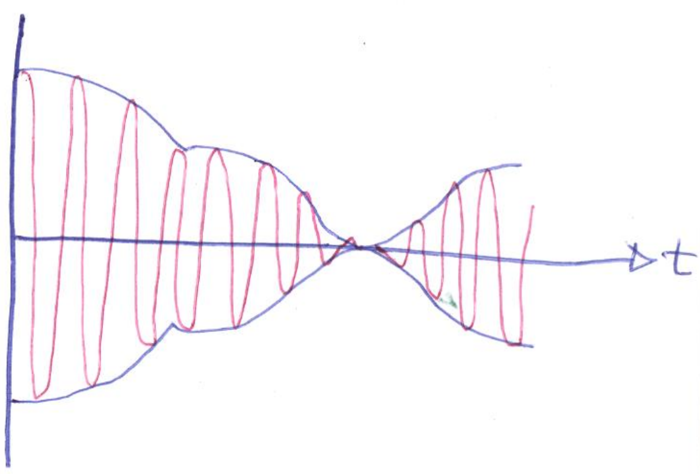
causes phase reversal, in other words an envelope distortion

* Modulated signal:

$$s(t) = [A_c + x(t)] \cos(2\pi f_c t)$$

$$\mu_a = \frac{|x(t)|_{max}}{A_c} = 1$$

or 100% modulation.



AM - Bandwidth

$$s(t) = [A_c + x(t)]\cos(2\pi f_c t) = A_c\cos(2\pi f_c t) + x(t)\cos(2\pi f_c t)$$

$s(t)$ = carrier (pure) + modulated signal

$c(t)$ $\qquad$ $x(t)\cos(2\pi f_c t)$

$\downarrow$

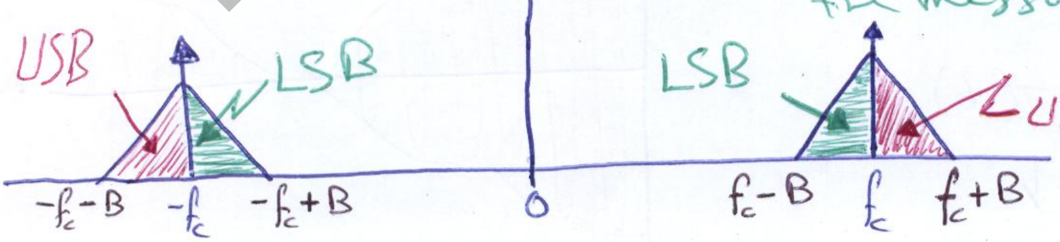
$$c(t) = A_c\cos(2\pi f_c t) \xleftrightarrow{F.T.} C(f) = \frac{A_c}{2}\left[\delta(f+f_c) + \delta(f-f_c)\right]$$

$$x(t)\cos(2\pi f_c t) \xleftrightarrow{F.T.} \frac{1}{2}\left[X(f+f_c) + X(f-f_c)\right]$$

$$\therefore S(f) = \frac{A_c}{2}\left[\delta(f+f_c) + \delta(f-f_c)\right] + \frac{1}{2}\left[X(f+f_c) + X(f-f_c)\right]$$

→ Upper sideband carrier frequency and sidebands of the message

→ Lower sideband carrier frequency and sidebands of the message.



$$\begin{array}{r} f_c + B \\ -(f_c - B) \\ \hline 2B \end{array}$$

$\therefore$ AM BW = 2B Hz.

Single-Tone AM

* Spicial case of AM modulation is when the message signal is Sinusoidal

$$\boxed{x_m(t) = A_m \cos(2\pi f_m t)}$$

A_m : is the message amplitude

f_m : is the frequency of the message

$$s(t) = [A_c + x(t)]\cos(2\pi f_c t) = A_c \cos(2\pi f_c t) + x(t)\cos(2\pi f_c t)$$

$$s(t) = A_c \cos(2\pi f_c t) + A_m \cos(2\pi f_m t)\cos(2\pi f_c t)$$

$$= \cos(2\pi f_c t)\left[A_c + A_m \cos(2\pi f_m t)\right]$$

$$= A_c\left[1 + \frac{A_m}{A_c}\cos(2\pi f_m t)\right]\cos(2\pi f_c t)$$

Thus, in single-tone AM modulation

$$\boxed{\mu_a = \frac{A_m}{A_c}}$$

$$\therefore \boxed{s(t) = A_c\left[1 + \mu_a \cos(2\pi f_m t)\right]\cos(2\pi f_c t)}$$

Frequency Contents in Single-Tone AM

$$s(t) = A_c\left[1 + \mu_a \cos(2\pi f_m t)\right]\cos(2\pi f_c t)$$

$$= A_c \cos(2\pi f_c t) + A_c \mu_a \cos(2\pi f_m t)\cos(2\pi f_c t)$$

$$= A_c \cos(2\pi f_c t) + \frac{A_c \mu_a}{2}\left[\cos(2\pi f_c t + 2\pi f_m t) + \cos(2\pi f_c t - 2\pi f_m t)\right]$$

or

$$s(t) = A_c \cos(\omega_c t) + \frac{A_c \mu_a}{2}\cos(\omega_c t + \omega_m t) + \frac{A_c \mu_a}{2}\cos(\omega_c t - \omega_m t)$$

(1) we have f_c : pure carrier frequency having amplitude A_c.

(2) we have $f_c + f_m$: Upper sideband frequency with amplitude $\frac{A_c \mu_a}{2}$.

(3) we have $f_c - f_m$: Lower sideband frequency of amplitude $\frac{A_c \mu_a}{2}$.

Power Contents of AM

$$s(t) = \underbrace{A_c \cos\omega_c t}_{\text{carrier-power}} + \underbrace{x(t)\cos\omega_c t}_{\text{Two-sidebands power}}$$

∴

carrier power $\boxed{P_c = \frac{A_c^2}{2}}$ — P_c

sidebands power: There are two sidebands USB & LSB

$$\boxed{P_{USB} = P_{LSB} = \frac{P_s}{2}}$$

where P_s is the total sidebands power

$$\boxed{P_s = P_{USB} + P_{LSB}}$$

P_s = mean square value of $x(t)\cos(2\pi f_c t)$

$$P_s = \frac{1}{2\pi}\int_0^{2\pi} x^2(t)\cos^2(2\pi f_c t)\,dt = \frac{1}{2\pi}\int_0^{2\pi} \frac{1}{2}\left[2\cos^2(2\pi f_c t)\right] x^2(t)\,dt$$

0 or filter out

$$P_s = \frac{1}{2\pi}\int_0^{2\pi} \frac{1}{2} x^2(t)\,dt + \frac{1}{2\pi}\int_0^{2\pi} \cancel{x^2(t)\cos(2\cdot 2\pi f_c t)}\,dt$$

$$\boxed{P_s = \frac{1}{2\pi}\int_0^{2\pi}\left[\frac{1}{2}x^2(t)\right]dt}$$

Thus, total power in AM signal is

$$\boxed{P_t = P_c + P_{USB} + P_{LSB} = P_c + P_s}$$

The Power Efficiency now is

$$\boxed{\eta = \frac{P_s}{P_t} \times 100\%}$$

Maximum $\eta \simeq 33\%$ and other power is wasted.

power in Single-Tone AM

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

$$\therefore \; P_s = \frac{1}{4} V_m^2$$

Hence $P_{USB} = P_{LSB} = \frac{P_s}{2} = \frac{1}{8} V_m^2$

$$P_t = P_c + P_s = \frac{A_c^2}{2} + \frac{1}{4} V_m^2$$

$$P_t = \frac{A_c^2}{2}\left[1 + \frac{1}{2}\frac{V_m^2}{A_c^2}\right]$$

$$\boxed{P_t = P_c\left[1 + \frac{\mu_a^2}{2}\right]}$$

This is a power with respect to $1\,\Omega$ resistor.

For a message signal of current:

$$i_m(t) = A_m \cos(2\pi f_m t) \text{ Ampers}$$

$$\therefore \; P_{USB} = P_{LSB} = \frac{1}{8} V_m^2 R$$

For a message signal of voltage

$$v_m(t) = A_m \cos(2\pi f_m t) \text{ volts}$$

$$P_{USB} = P_{LSB} = \frac{V_m^2}{8R}$$