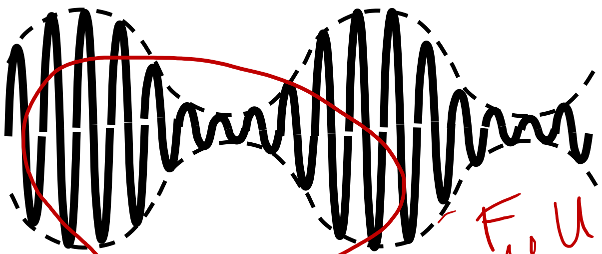
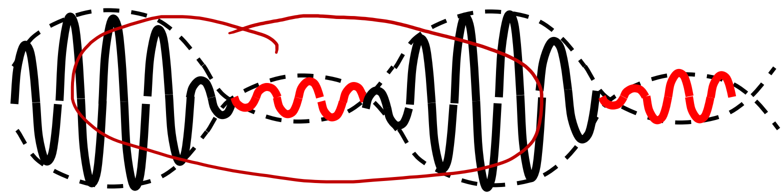
Analogue Modulation
Amplitude Modulation Schemes

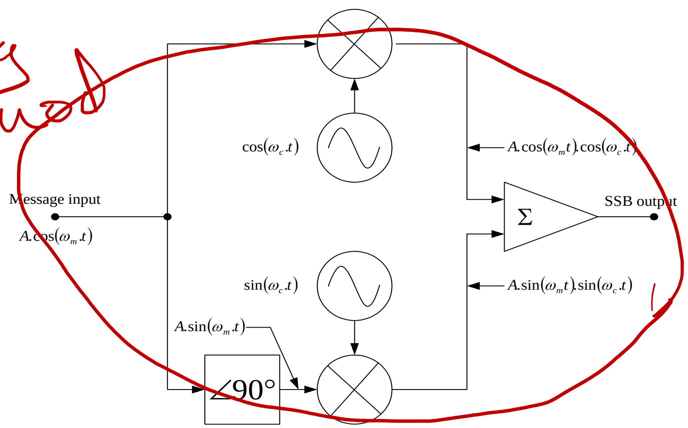


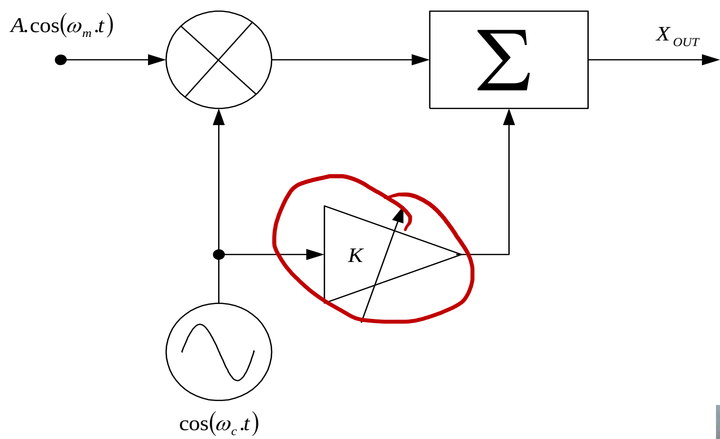
Full carrier AM

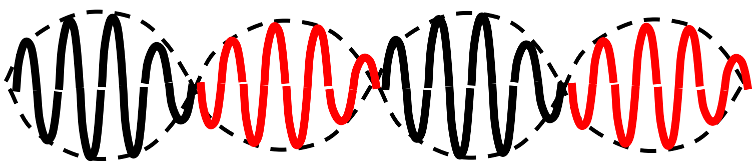


over modulated

phasing method for SSB







Suppressed carrier

Modulation

Modulation

Baseband $\Rightarrow$ bandpass format.

up conversion $\Rightarrow$ efficient radiation & propogation plus sharing of channel or spectrum

- The purpose of modulation is to facilitate transmission of information-bearing signal over a communication channel.
- Fundamental classification: Analogue v. Digital Modulations

Forms of Analogue Modulation

Continuous wave modulated (Vs digital ⇒ discrete)

- Analogue modulation is generally classified as one of two forms: Amplitude Modulation or Angle Modulation. → Frequency Modulation (FM)
- Angle modulation covers both variation of frequency and phase.
- Normally, only one property of the signal is modulated.
- We will consider Amplitude and Angle modulation separately.

Analogue Modulation Methods
Amplitude Modulation (AM)

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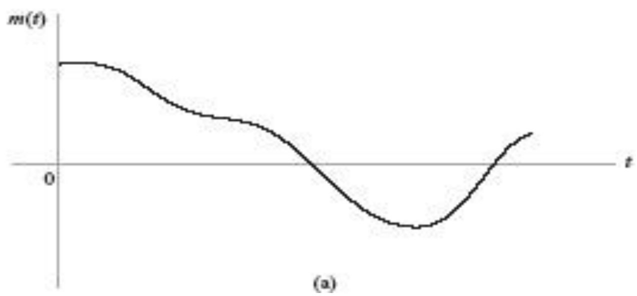
Amplitude Modulation (AM) is formally defined as a process is which the amplitude of the carrier wave *c(t)* is varied about a mean value, linearly with the message signal *m(t)*.

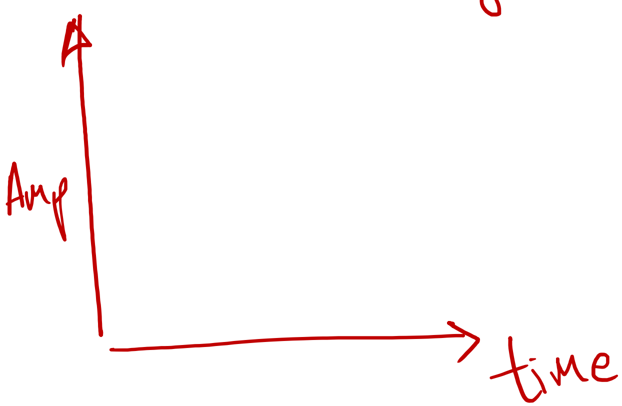
900MHz

voice, bandwidth 3kHz (min)

Amplitude Modulation Process

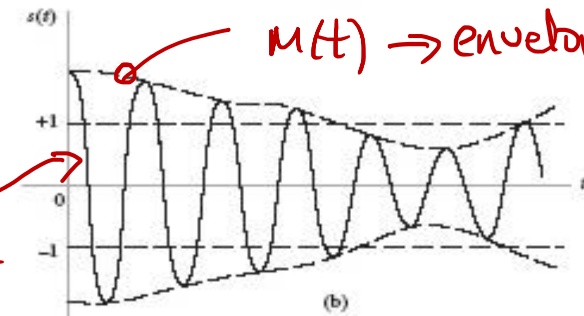


Message (m(t))



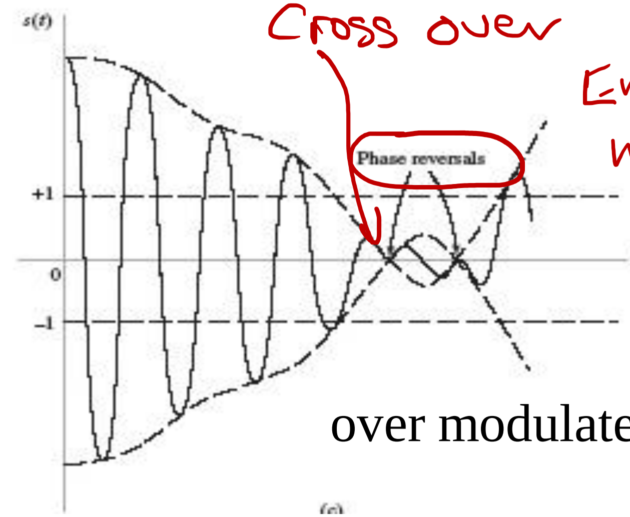
m(t) → envelope of carrier

Carrier c(t)



Note: Amp. of carrier > 0

Cross over



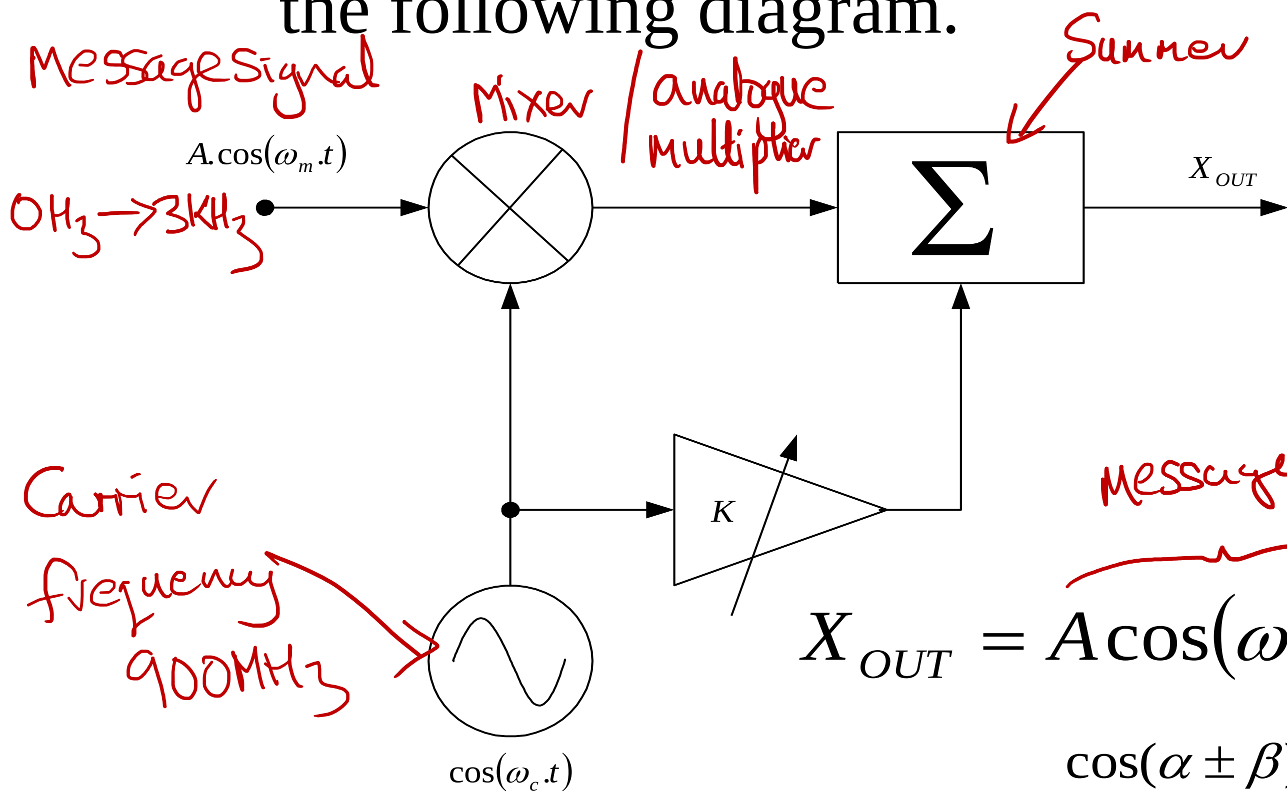
over modulated

Envelope now distorted w.r.t the message

Double Sideband Modulation (DSB)

Analogue Modulation Methods
Amplitude Modulation (AM)

- General form of amplitude modulation is shown in the following diagram.



$$X_{OUT} = \overbrace{A\cos(\omega_m t)}^{\text{Message}}\overbrace{\cos(\omega_c t)}^{\text{Carrier}} + \overbrace{K}^{\text{Constant carrier power}}\cos(\omega_c t)$$

$$\cos(\alpha \pm \beta) = \cos(\alpha)\cos(\beta) \mp \sin(\alpha)\sin(\beta)$$

Amplitude Modulation: time domain

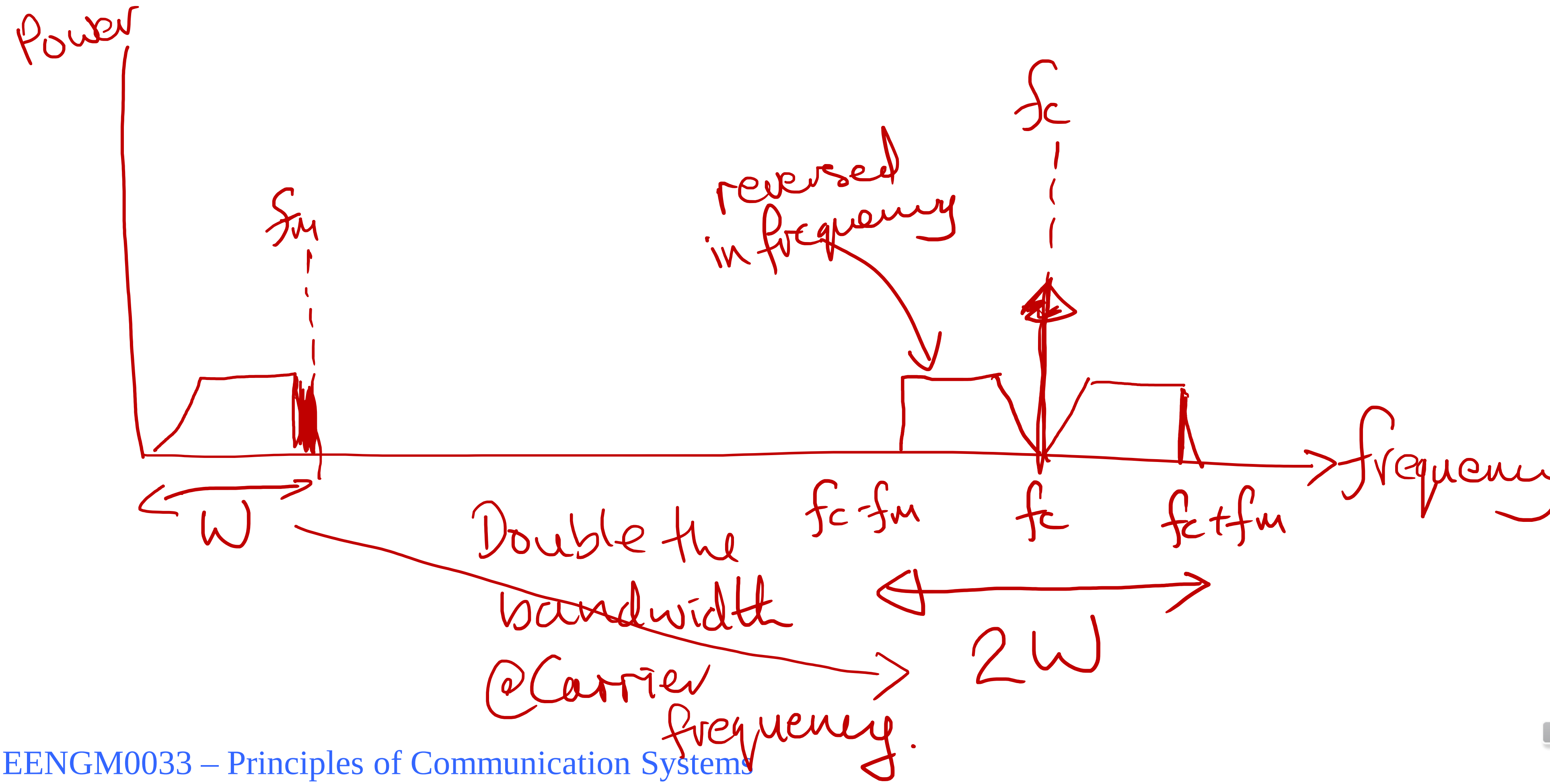
- The output of the modulation process can be described by the following equation:

Difference   Sum Frequency   weighted carrier

$$X_{OUT} = \frac{A}{2}.\cos(\omega_c t - \omega_m t) + \frac{A}{2}\cos(\omega_c t + \omega_m t) + K\cos(\omega_c t)$$

- Depending on the value of the gain constant K the resultant modulated waveform can be classified as being either:
  - Full carrier AM (FCAM) K>A.
  - Diminished carrier AM (DCAM) K<A.
  - Suppressed carrier AM (SCAM) K=0.

Amplitude Modulation: Spectrum



Amplitude Modulation

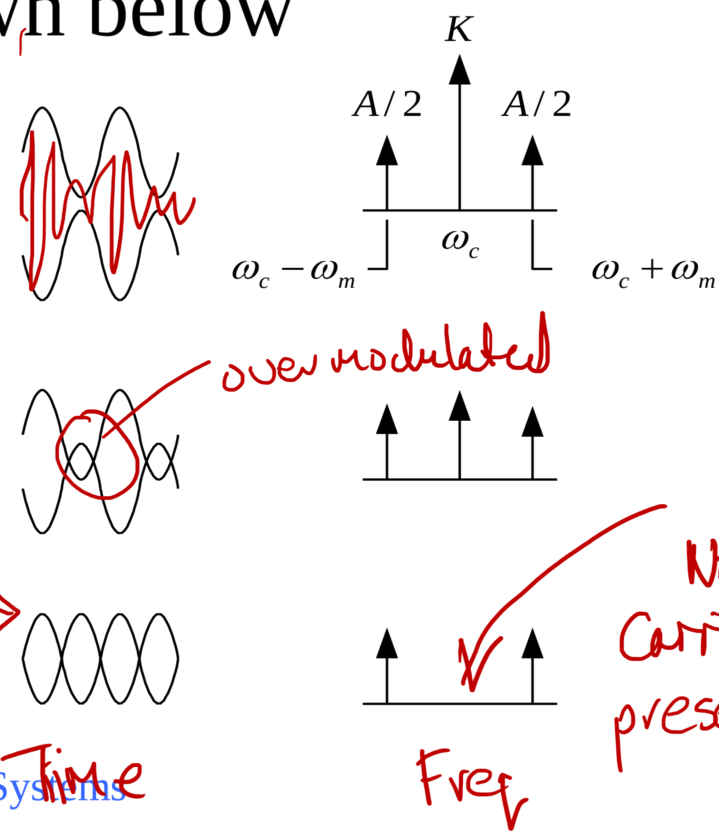
- The RF waveform, Spectrum and envelope waveforms are shown below

Power (energy) in the carrier conveys no information

Full Carrier AM

Diminished Carrier AM

Supressed Carrier AM



$\frac{1}{2}$ wave rectified $\neq$ message envelope

No Carrier present

Modulation Index

- The modulation index m is defined as the ratio amplitude of the modulating wave to the amplitude of the carrier wave:
  - In this case m = A/K

Ease to demod

Power efficiency

$M<1$ Full Carrier AM

$M>1$ DC-AM

$M=\infty$ SC-AM

Power Distribution

Power in AM Waveforms

- For full carrier AM.
  - Average power in sideband = $(A/2)^2/2$

    (a 1Ω resistor is assumed).
  - Average power in carrier = $K^2/2$

  Total average power (both sidebands)

$$= K^2/2 + 2.\,(A/2)^2/2$$

$$= K^2/2.(1+m^2/2)$$

Power in 1Ω resistor

$$\frac{1}{2\pi}\int_0^{2\pi}(Y\cos(x))^2dx = \frac{Y^2}{2}$$

power

Amp of Y

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Power wasted in Carrier

- Average power in carrier = $K^2/2$
- Average power in sidebands = $2.A^2/8$
  $= A^2/4$
- Ratio of average power in the sidebands to the average power in the carrier:
  $= (A^2/4)/(K^2/2) = m^2/2$
- Transmission Efficiency

$$\frac{\text{power in Sidebands}}{\text{Total power}} \qquad \mu = \frac{m^2}{2+m^2}$$

$m=1$ $\mu = 33\%$

$m=0.5$ $\mu = 11\%$

$m>1$ for best efficiency

Example:

Average carrier power = 40kW

$m = 0.707 = \frac{1}{\sqrt{2}}$

(a) total output power $= \frac{K^2}{2}\left(1+\frac{m^2}{2}\right) = 50\text{kW}$

(b) Tx efficiency, $\mu = \frac{m^2}{2+m^2} = \underline{\underline{20\%}}$

Power & Information Transfer

- The carrier carries no information, and thus the less power it consumes the better.
- Its presence, on the other hand, makes demodulation easier.
- The most power efficient AM waveform is thus a suppressed carrier type (SCAM).

Detection of DSB-AM

Reception

Detection of AM Signals

Full carrier AM diode detector

- If K >A (FCAM) then standard envelope detection can be used. This has the advantage of being cheap and simple, but the cost of transmitting the carrier can be important.
- If K<A then distortion occurs with envelope detection, and coherent detection must be employed

→ Generate Local oscillator (LO) at Rx. Phased locked to the transmitter. Use a mixer to demodulate (down-conversion)

Detection of AM Signals

V

time

- envelope detection

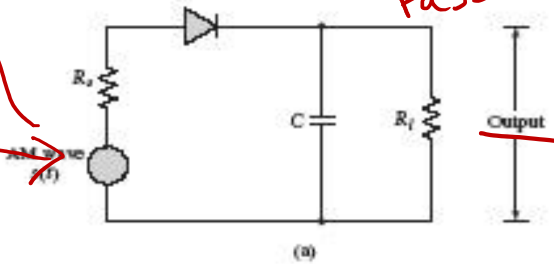
m(t)

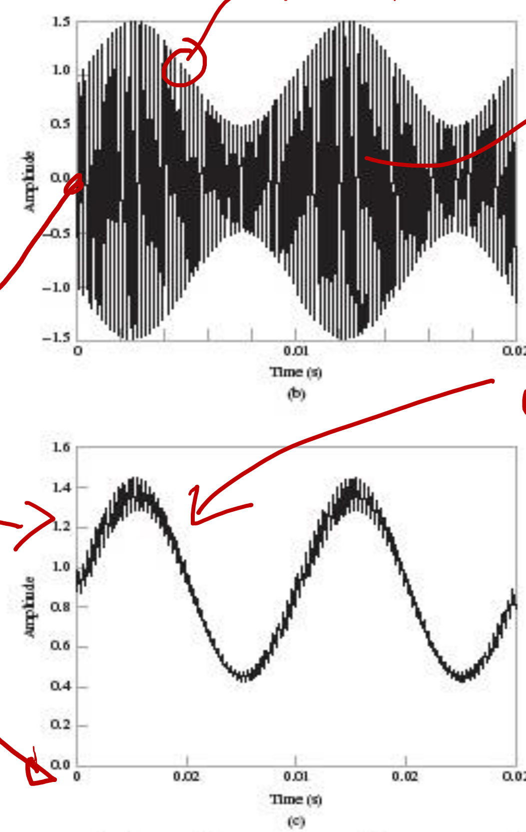
Carrier c(t)

Diode

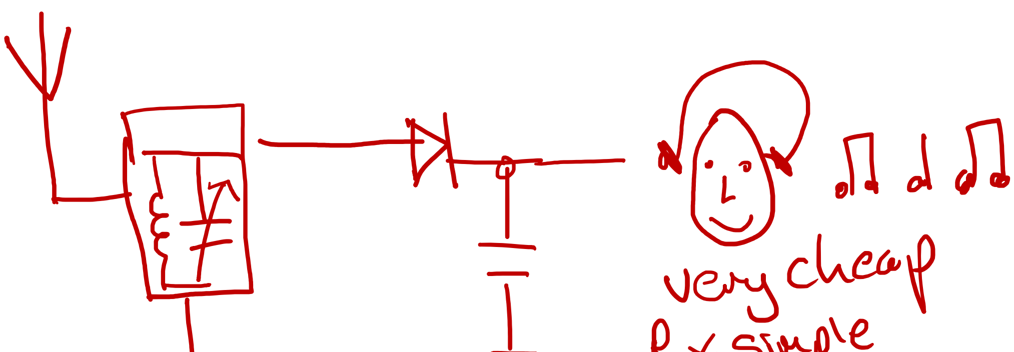
Low Pass Filter

FCAM





upper envelope + small carrier break through.



very cheap Rx simple

FIGURE 3.9 Envelope detector. (*a*) Circuit diagram. (*b*) AM wave input. (*c*) Envelope detector output

Tx not power efficient.

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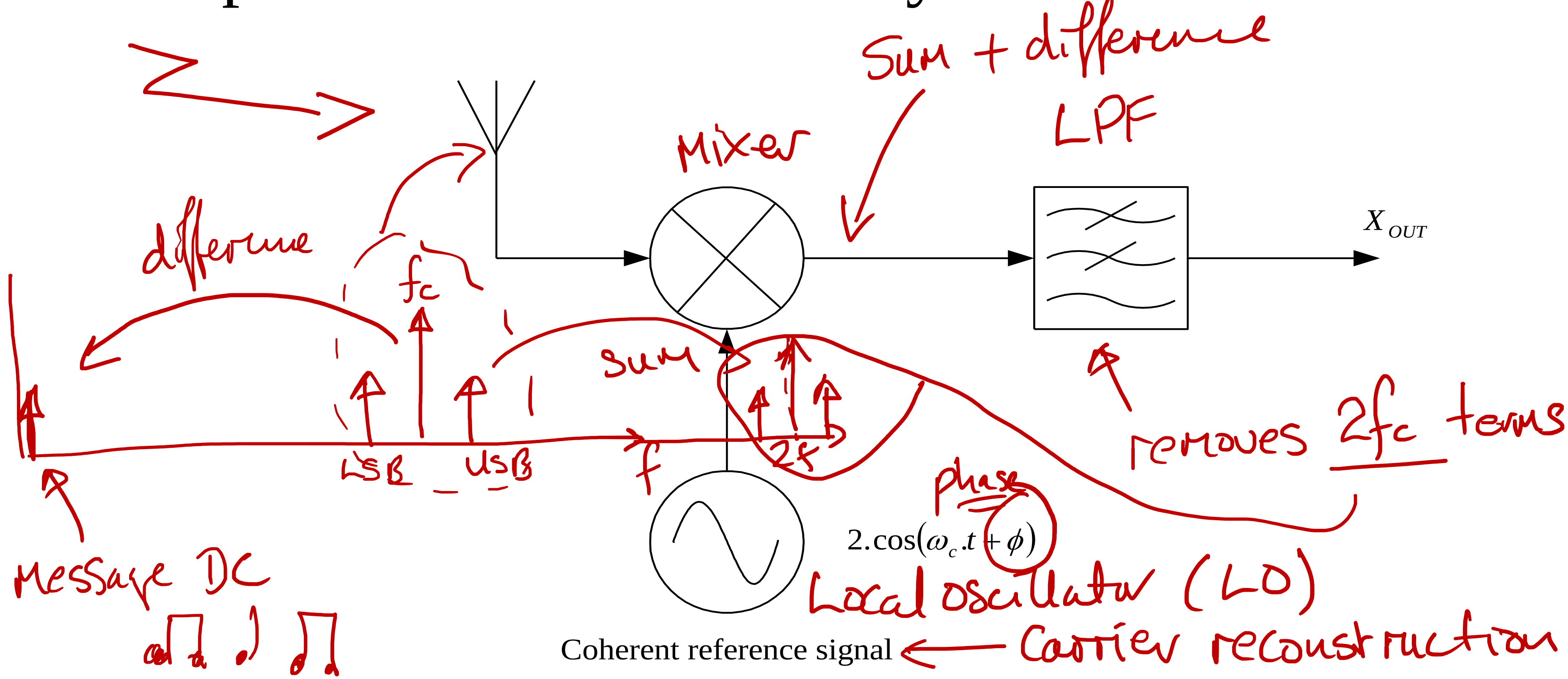
Rx Coherent

Detection of AM Signals

- A simple coherent detection system is shown below.



Time Domain

Detection of AM Signals

- The output of this detector is given by:

phase

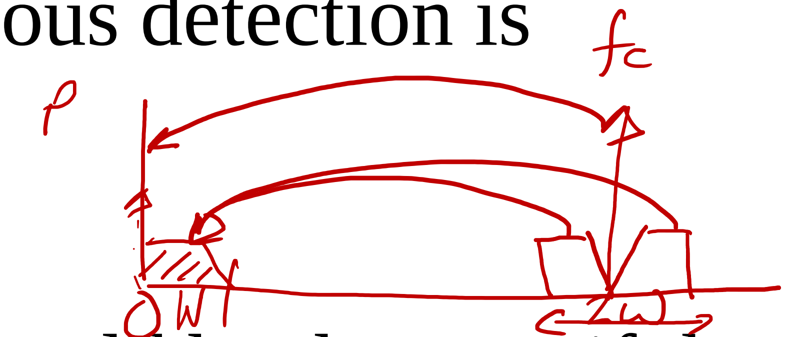
$$X_{OUT} = A/2.cos(\omega_m t + \varphi) + A/2.cos(\omega_m t - \varphi) + K.cos(\varphi)$$

$\rightarrow\ 0^{\circ}$

•The first two terms are the message and the third term is a DC offset.

Detection of AM Signals

- If $\varphi = 0^{\circ}$ then perfect synchronous detection is achieved.
- If $\varphi = 90^{o}$ then output is zero.
- If φ varies with time (such as would be the case if the local oscillator were drifting with respect to the carrier oscillator) then the output will cycle between a minimum and a maximum.



- Coherent Rx will operate if Carrier power $= 0$

Single Sideband Modulation (SSB)

SSB ⇒ Tx only one sideband

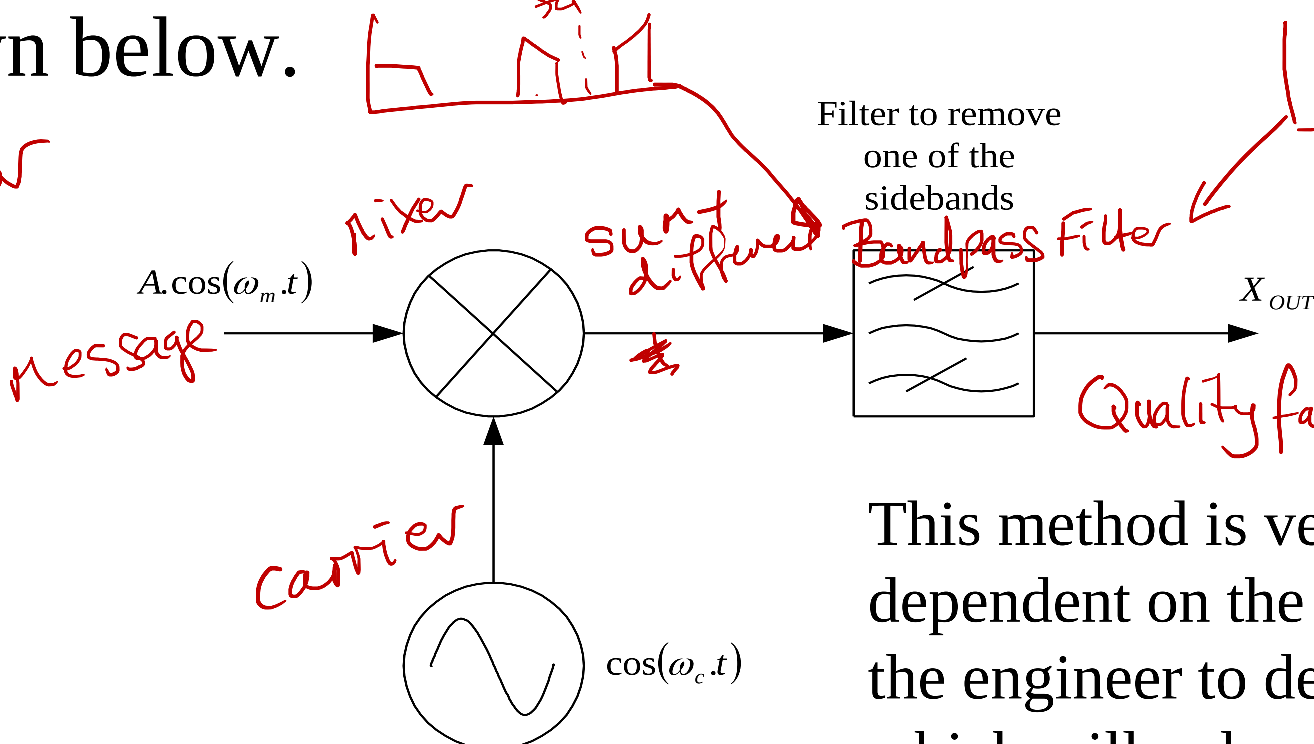
Single Sideband Modulation

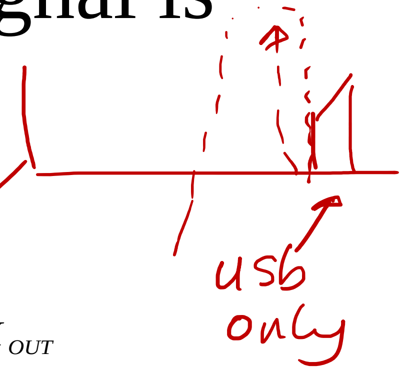
- If the carrier term can be eliminated the power efficiency of the AM transmission will be increased.
- One of the sidebands can be eliminated. This will greatly increase the bandwidth efficiency of the modulation. At RF (carrier frequency) ⇒ bandwidth W
- The resultant modulation is referred to as being Single Sideband (SSB).

Single Sideband Modulation

- A possible method of generating a SSB signal is shown below.

Tx Modulator





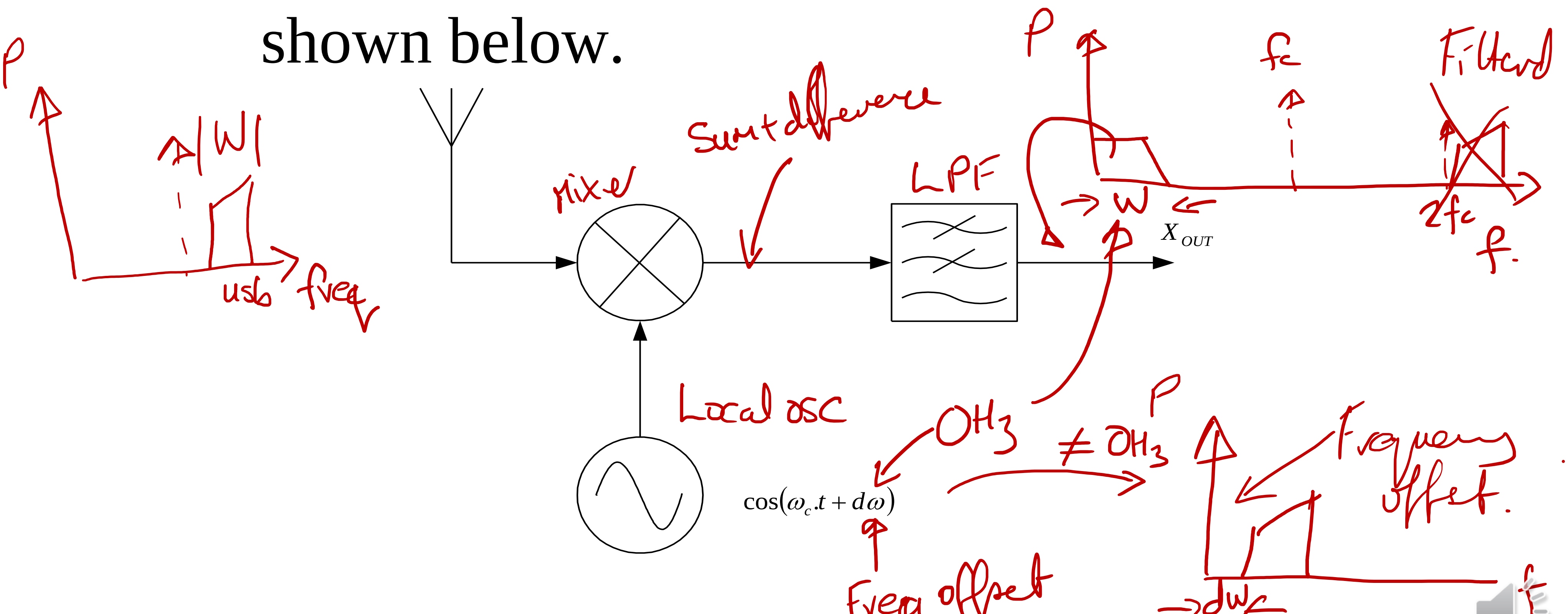
Quality factor $Q = \frac{f_c}{BW}$

This method is very dependent on the ability of the engineer to design a filter which will only select the appropriate sideband. $\Rightarrow$ v.high Q

Rx

Single Sideband Detection

- A method of detecting single sideband signals is shown below.



Single Sideband Detection

- An analysis of this process shows that the output contains a term of frequency $(\omega_M + d\omega)$ where $d\omega$ is the frequency error in the local oscillator and ω_M is the required message frequency.
- It can be seen that frequency error here is not as critical as with synchronous AM detection.
- For SSB, the frequency error just adds to he message frequency. With synchronous AM detection the signal went up and down in amplitude at a rate determined by the frequency error.

Single Sideband Detection

- With analogue voice channels a frequency error of up to 30 Hz. can be tolerated without loss of intelligibility.
- In simple SSB receivers manual adjustment of the of the local carrier is possible.
- In more sophisticated systems, a low level pilot tone is sent alongside the message signal.

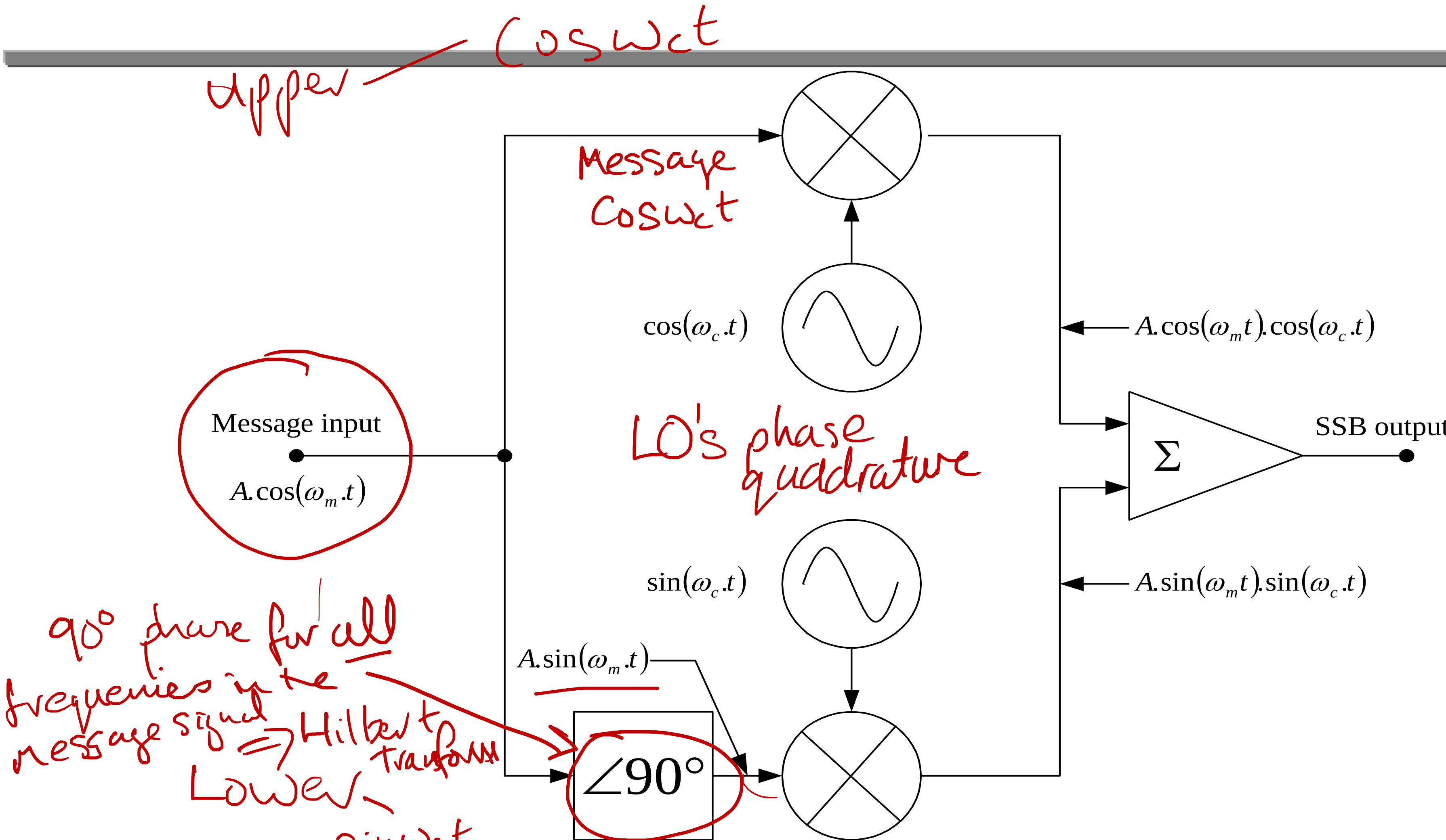
SSB Generation

Tx / Modulator

Generation of SSB signals

- Filter Method:
  - Difficulty in realising a filter with sufficiently sharp cut off at the carrier frequency to remove the sideband entirely.
- Alternative methods of generating a SSB signal:
  - Phasing Methods
  - Weaver Method

Generation of SSB signals (phasing method)



Phasing method for generating SSB

- Assuming that the message signal is a cosine waveform with amplitude A and frequency ω_m.

Then the message signal $m(t) = A.\cos(\omega_m.t)$

Then the output of the top balanced modulator is:

$$A.\cos(\omega_c.t).\cos(\omega_m.t)$$

Whilst the output of the bottom balanced modulator is:

$$A.\sin(\omega_c.t).\sin(\omega_m.t)$$

Phasing method for generating SSB

- Summing gives:

$$A.[\cos(\omega_c.t).\cos(\omega_m.t) + \sin(\omega_c.t).\sin(\omega_m.t)]$$

$$= (A/2).[\cos(\omega_c+\omega_m).t + \cos(\omega_c-\omega_m).t + \cos(\omega_c-\omega_m).t \ - \cos(\omega_c+\omega_m).t\ ]$$

$$= \boxed{A.(\cos(\omega_c-\omega_m).t\ )}$$

ie only the lower sideband remains.

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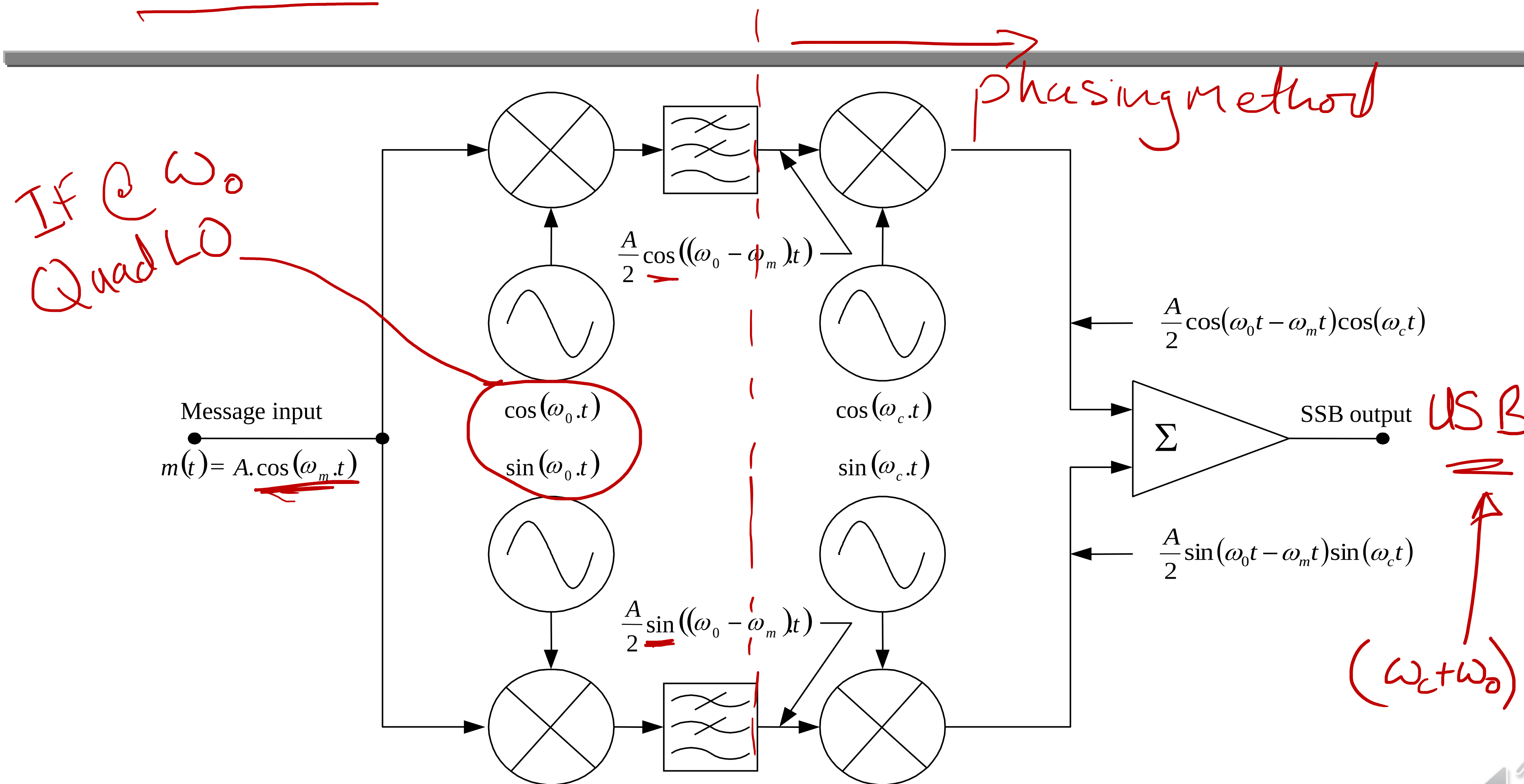
Phasing method for generating SSB

- It can be seen that by subtracting the output of the lower balanced modulator at the summing node, then the upper sideband would remain.
- The only drawback with this arrangement is the necessity for providing a circuit to give a 90° phase shift for the whole of the baseband signal

digital Hilbert transformer
or Weaver upconverter

Weaver's method for generating SSB



Weaver's method for generating SSB

- If the input signal is given by:

$$m(t) = A.\cos(\omega_m.t)$$

- The output from the top balanced modulator is:

$$e_{a1} = A\cos(\omega_o.t).\cos(\omega_m.t)$$

- The output from the bottom balance modulator is:

$$e_{b1} = A\sin(\omega_o.t).\cos(\omega_m.t)$$

Weaver's method for generating SSB

- These signals will have sum and difference frequency components, therefore the signal that passes through the low pass filter in the top signal path is:

$$A/2.\ \cos(\omega_o\text{-}\omega_m).t \qquad I$$

And the corresponding signal on the bottom path is:

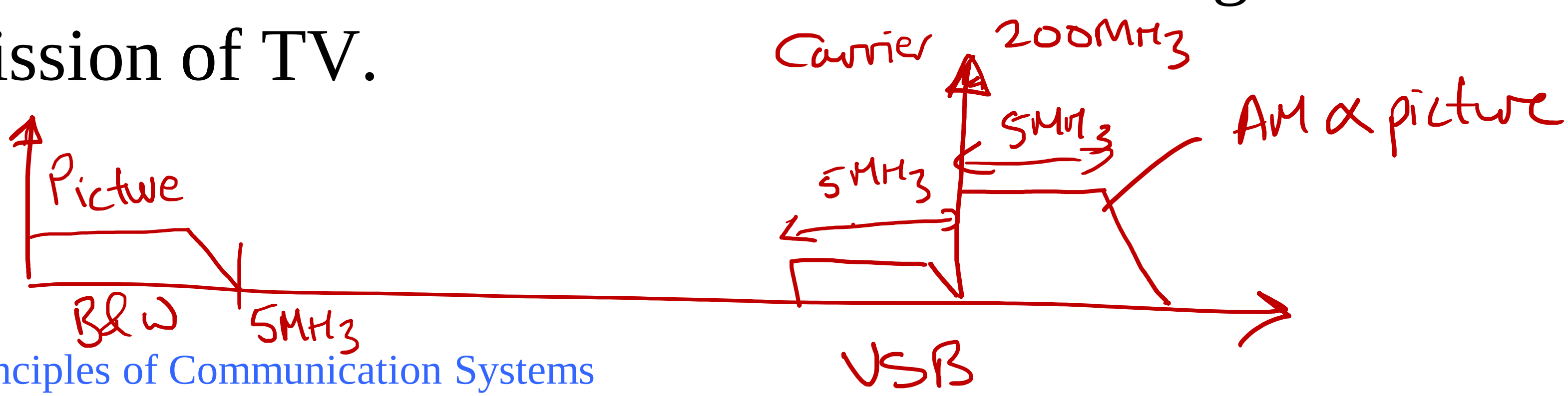
$$A/2.\ \sin(\omega_o\text{-}\omega_m).t \qquad Q$$

Weaver's method for generating SSB

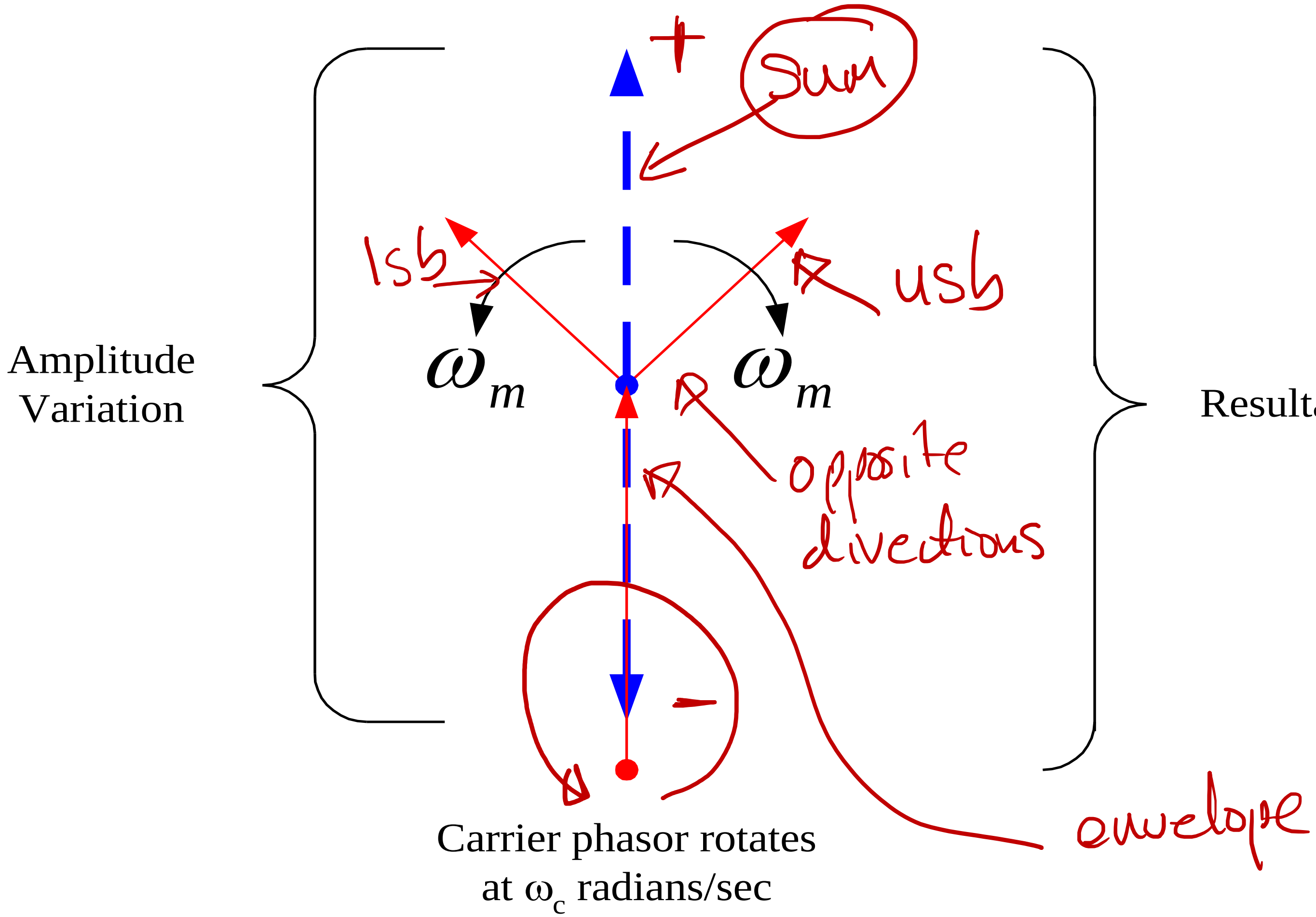
- At this stage it can be seen that we have two signals that are at right angles to one another (albeit at a frequency of $\omega_o - \omega_m$).
- The generation of SSB modulation, from this point on, is the same as the phasing circuit discussed previously.

Vestigial Sideband SSB

- With this method of modulation part of the second sideband is preserved to make the required cut off specification of the filter less stringent.
- Either the upper sideband is selected via a high pass filter or the lower sideband via a low pass filter.
- Vestigial sideband transmission ~~is~~ was used in analogue transmission of TV.



AM Phasor diagram



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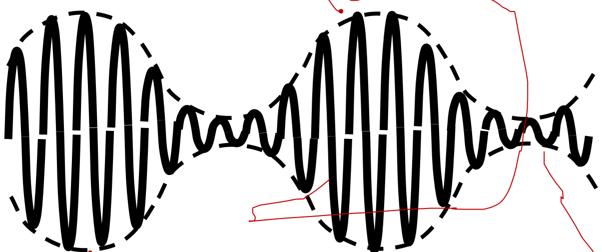
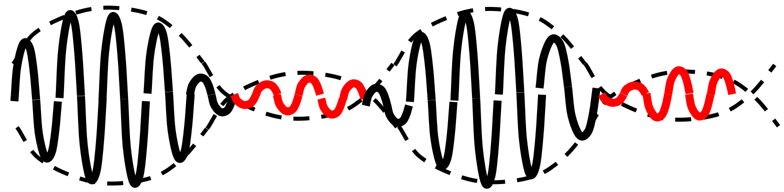
Amplitude Modulation Schemes





FC AM