

# 1 Lecture 1 - Modulation

$$f(t) = \underbrace{A_c}_{\text{Amplitude}} \times \cos\left(\underbrace{\omega}_{\text{Angular frequency}} t + \underbrace{\phi_c}_{\text{Phase term}}\right) \quad (1)$$

Modulation is the process of applying information to a carrier, in this case, the carrier frequency is  $\omega_c$  (as an angular frequency) or  $f_c$  as a frequency directly where  $\omega_c = 2\pi f_c$ .

If we modify  $A$  in the above in sympathy with the information we want to send, then this is amplitude modulation.

If however we change  $\omega_c$  or  $\phi_c$  in sympathy with the information, these are forms of angle modulation - varying  $\omega_c$  is frequency modulation, varying  $\phi_c$  is phase modulation.

If the amplitude etc, varies linearly with the information then this is analogue, alternatively varying these quantities in an on/off manner or between two state is digital.

## 1.1 Amplitude Modulation

The function  $f(t)$  becomes

$$f(t) = \underbrace{A_0(1 - m \cos \omega_m t)}_A \times \underbrace{\cos \omega_0 t}_{\text{No } \phi_c \text{ term}} \quad (2)$$

$f_m$  or ( $\omega_m = 2\pi f_m$ ) is a simple sine/cosine wave modulation function

Expanding  $f(t)$ :-

$$\begin{aligned} f(t) &= A_0 \cos \omega_0 t + A_0 m \cos \omega_m t \cos \omega_0 t \\ &= A_0 \cos \omega_0 t + \frac{A_0 m}{2} \cos(\omega_m + \omega_0)t + \cos(\omega_0 - \omega_m)t \end{aligned} \quad (3)$$

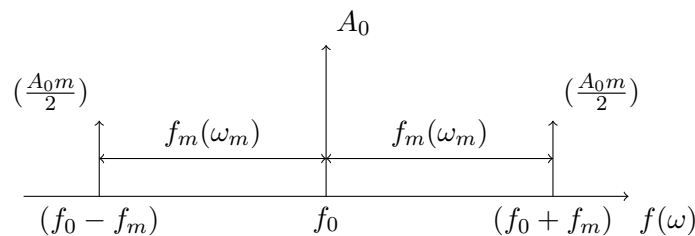


Figure 1: Spectrum of an AM signal, including sidebands

The simple process of amplitude modulation produces an upper sideband (USB) at  $f_0 + f_m$  and a lower sideband at  $f_0 - f_m$ . Note that only the sidebands contain any useful information about the amplitude  $m$  of the modulation signal.

This modulation has a power penalty because the carrier conveys no useful amplitude information itself.

$$\begin{aligned} \left( \frac{\text{Power in sidebands}}{\text{Total power transmitted}} \right) &= \frac{(0.5A_0 m)^2 + (0.5A_0 m)^2}{(0.5A_0 m)^2 + (0.5A_0 m)^2 + A_0^2} \\ &= \frac{0.5A_0^2 m^2}{0.5A_0^2 m^2 + A_0^2} \\ &= \frac{0.5m^2}{0.5m^2 + 1} \end{aligned} \quad (4)$$

$m$  = modulation depth =  $\left(\frac{A_m}{A_0}\right)$  which is a ratio of modulation voltage to the carrier voltage (or current).

It is essential not to let  $|m| \geq 1$  because this is overmodulation and it distorts the AM waveform.

Going back to equation 4 in the limit  $m = 1$  and so the ratio is:-

$$\frac{0.5 \times 1^2}{(0.5 \times 1^2) + 1} = \frac{0.5}{1.5} = \frac{1}{3} = 33.3\% \quad (5)$$

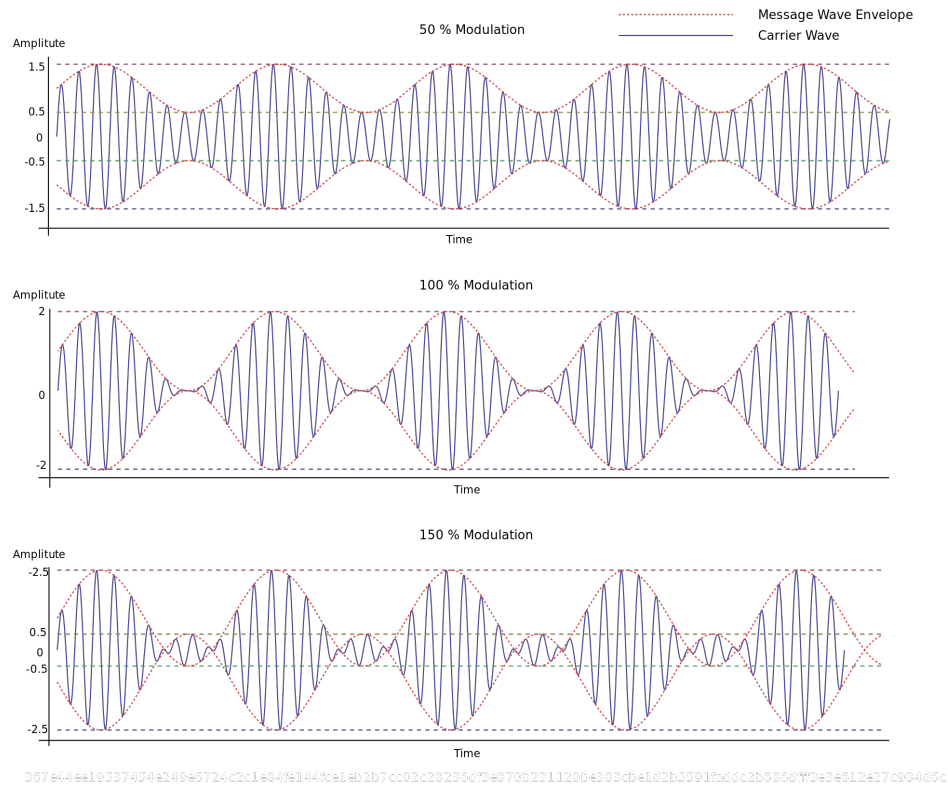
$\frac{2}{3}$  of the transmitted power is wasted.

Typically,  $m \approx 0.4$  from which we have:-

$$\frac{0.5 \times 0.4^2}{(0.5 \times 0.4) + 1} = \frac{0.08}{0.08 + 1} \quad (6)$$

so this ratio is around 0.08 ie. only 8% of the transmitted power is used, or 92% is wasted!

### 1.1.1 Waveforms



It is essential, when considering the above waveform, to have  $|m| \leq 1$  as mentioned before. Detecting AM requires an envelope detector in its simplest form:-

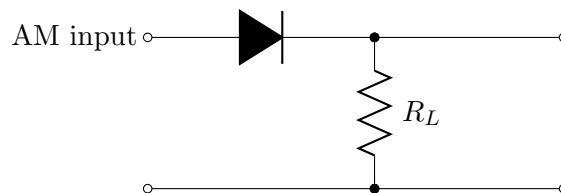


Figure 2: Simple envelope detector

A more advanced envelope detector adds a low pass filter to remove high frequency components from the carrier wave.

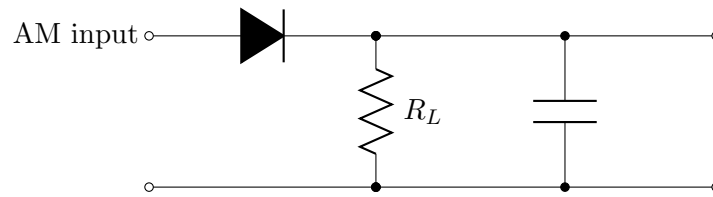


Figure 3: More advanced envelope detector using smoothing

If the carrier frequency is high compared to the modulation frequency, the recovered envelope is a "quite good" approximation to the original given a certain combination of  $R_L$  and  $C$ .

## 2 Lecture 2 - Double Sideband and Single Sideband AM

Recall AM signal (Equation 2. Power is wasted in the carrier, so a better form of A.M. could be:-

$$f(t) = A_0 \cdot \cos \omega_0 \cdot m \cos \omega_m t \quad (7)$$

Where  $m = \frac{A_m}{A_0}$  = modulating depth and  $A_m$  = amplitude of modulating signal

$$f(t) = \left( \frac{A_0 m}{2} \right) (\cos(\omega_0 + \omega_m)t + \cos(\omega_0 - \omega_m)t) \quad (8)$$

This is known as double sided sideband, suppressed carrier (DSB).

There is an important property of a DSB  $\rightarrow$  for no modulation, no signal is sent, so that it is very power efficient, but not bandwidth efficient.

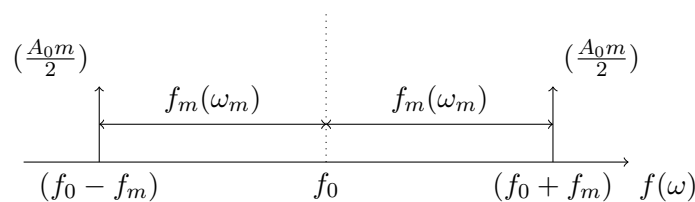


Figure 4: Spectrum of a DSB signal

The envelope of a DSB signal for a single frequency of modulation is:-

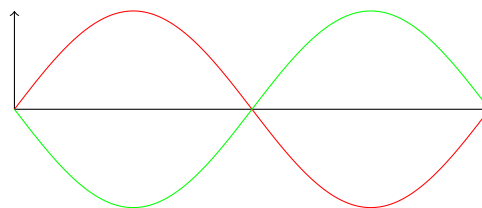


Figure 5: DSB Signal envelope

Because there is no carrier present, the envelope of the DSB waveform no longer represents the modulating function, therefore an envelope detector cannot be used to detect it - a product detector is used instead.

To illustrate the operation, instead of a DSB being the input, simply use a carrier frequency with no modulation

The output after filtering is  $\left( \frac{A_0 E}{2} \right)$  which is proportional to  $A_0$ , the signal amplitude.

Replace the simple input by:-

$$A_0 \cos \omega_0 t \times \cos \omega_m t \quad (9)$$

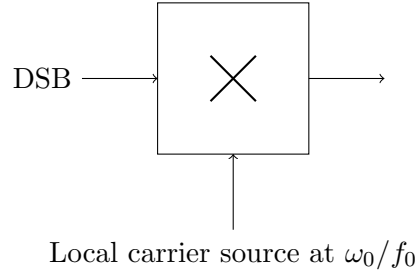


Figure 6: Product detector/mixer/multiplexer with simple input

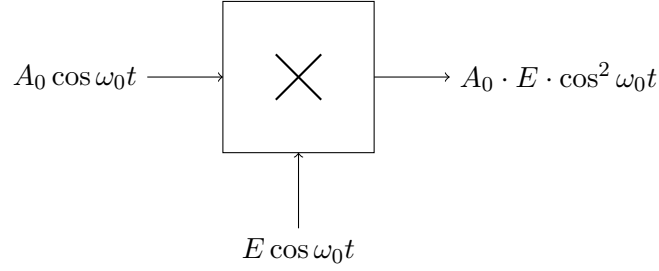


Figure 7: Product detector/mixer/multiplexer with real input

output is

$$(A_0 \times \cos \omega_0 t \times \cos \omega_m t)(E \times \cos \omega_0 t) = A_0 E \cos^2 \omega_0 t \times \cos \omega_m t \quad (10)$$

$$= \left( \frac{A_0 E}{2} \right) (1 + \cos 2\omega_0 t) \times \cos \omega_m t \quad (11)$$

After low pass filtering to remove all frequencies above  $\omega_m$ :-

$$OP = \left( \frac{A_0 E}{2} \right) \times \cos \omega_m t \quad (12)$$

which represent the modulation function directly.

This system can be improved even further because bandwidth is wasted. Bandwidth is important because it is a scarce resource.

If we consider the expanded form of that for DSB:-

$$f(t) = \left( \frac{A_0 m}{2} \right) \cos(\omega_0 + \omega_m)t + \left( \frac{A_0 m}{2} \right) \cos(\omega_0 - \omega_m)t \quad (13)$$

If we filter carefully, then we need only send either the USB or LSB.

Filtering therefore reduces the badnwidth, as each sideband carries the same information (each has an "m" term). Difficulty arrises in obtaining sharp cuttof filters. The PHASING METHOD can be used to generate SSB (single side band).

$$E_0 = E_1 + E_2 \quad (14)$$

$$\begin{aligned} E_1 &= [A_0 \cos \omega_0 t] \times \left[ \cos \omega_m t + \frac{\pi}{2} \right] \\ &= A_0 \cos \omega_0 t \times \sin \omega_m t \end{aligned} \quad (15)$$

$\therefore$

$$E_2 = A_0 \sin \omega_0 t \times \cos \omega_m t \quad (16)$$

$\therefore$

$$\begin{aligned} E_0 &= A_0 \times [\cos \omega_0 t \times \sin \omega_m t + \sin \omega_0 t \times \cos \omega_m t] \\ &= A_0 \sin (\omega_0 + \omega_m) t \end{aligned} \quad (17)$$

USB, no filtering needed.

Similarly, the LSB can be generated by changing the sign of the second term above (on the first term).

The method works very well only when a single frequency of modulation is used. In practise, a range of frequencies is used and it is very difficult to obtain a 90° phase shift over a range of frequencies.

## 2.1 Vestigial Sideband

Remember all the abbreviations, "in case they get slipped into a question" This is an approximation to SSB which has been used extensively in analogue T.V. for many decades. Basically, a DSB/C (Double Sideband with Carrier)

The main benefits are: simplicity and cheapness compared to SSB, when using valve/vacuum tube technologies.

The disadvantage is carrier still there, wasting power, but allowing an envelope detector (cheap, easy to make) to be used.