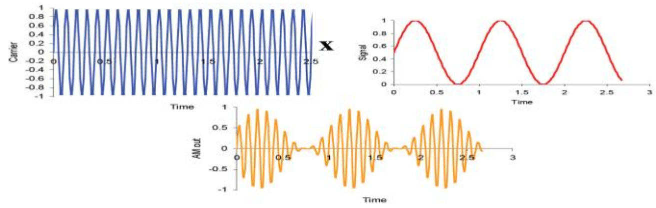
Summary of lecture 4 (12th December 2019)

Modulation

Modulation involves modifying the properties (amplitude, frequency, phase, duty-cycle) of a 'carrier' waveform in order to transmit a 'signal' waveform (e.g. data). This allows a high-fidelity representation of the original signal waveform to be reconstructed at a remote location or after transmission through a 'noisy' or non-linear (generating additional frequency components) medium. Some modulation methods are suitable for carrying multiple data channels and/or broadcasting to unspecified remote recipients, i.e. TV/radio.

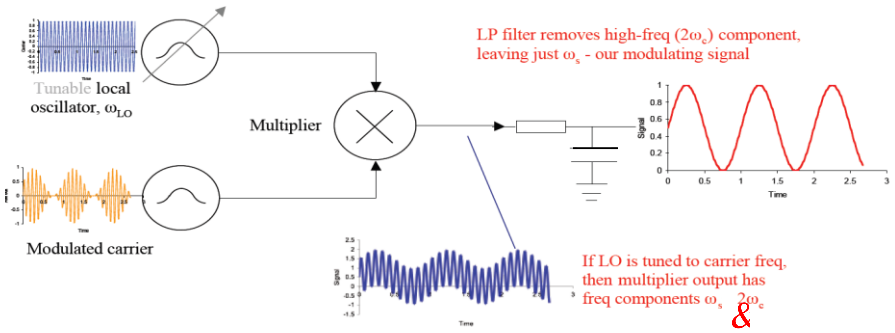
Three types of modulation are commonly employed: Amplitude modulation, Frequency (or phase) modulation, and Pulse-width modulation.

Amplitude modulation (AM):



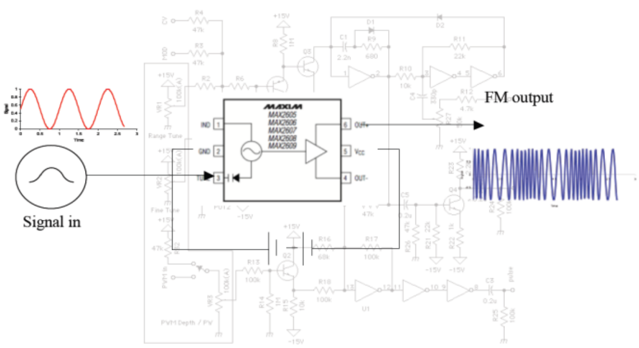
As the name suggests, we modulate the *amplitude* of a high-frequency *carrier* according to the instantaneous amplitude of the signal to be transmitted. The carrier frequency must be far higher than the signal frequency. In this simple case the modulated waveform has two frequency components, 'sidebands', at $\omega_{carrier} \pm \omega_{signal}$. The signal is efficiently demodulated by 'Heterodyne detection' using similar circuitry (modulator and oscillator) to the modulation circuit.

The multiplier now produces a waveform with frequency components $2\omega_{carrier}$ and ω_{signal}. By filtering out the high-frequency ($2\omega_{carrier}$) component, the original signal is recovered.

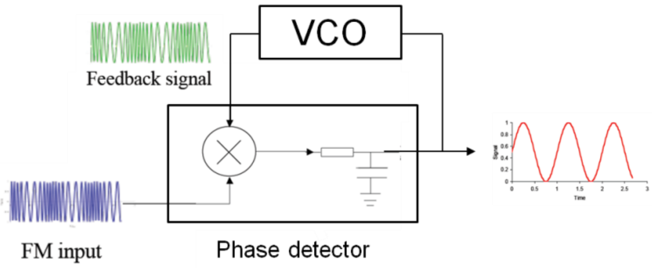


Frequency modulation (FM):

Here we modulate the *instantaneous frequency* of a carrier wave by a factor (the 'modulation-index') proportional to the instantaneous *amplitude* of the *signal* to be transmitted. This is achieved using a 'voltage-controlled oscillator' (VCO).

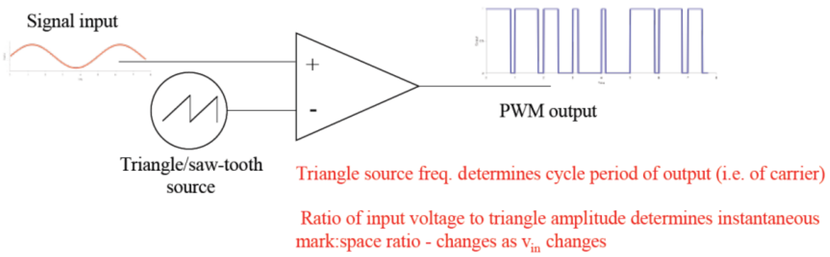


Demodulating an FM signal is acheived using a 'phase-locked loop' (PLL). A PLL consists of a 'phase detector' and a VCO in a negative feedback loop. When the Feedback signal and FM input are equal, the error-signal is zero. The



product of these waves again gives a waveform with frequency components $2\omega_{carrier}$ and ω_{signal}, and as for an AM signal, filtering out the high-frequency ($2\omega_{carrier}$) component recovers the original signal. The original signal output from the phase detector necessarily drives the VCO to produce a feedback signal which is identical to the FM input signal – as this was produced by a VCO.

Pulse-width modulation (PWM):



PWM involves modulating the 'duty-cycle' or 'mark-to-space ratio' of a square-wave by the instantaneous amplitude of the signal to be transmitted. A PWM signal is produced by feeding the signal into a comparator which is referenced against a high-frequency saw-tooth (triangle) wave. The PWM signal is easily demodulated simply be passing through a low-pass filter. This filter should have corner frequency lower than the carrier (saw-tooth) frequency, but higher than the highest frequency component t of the signal.

PWM is an efficient way of controlling the power output to a load. It is used in class-D audio amplifiers, to control the intensity of LED lighting, and as the heater output from a temperature controller.

Pros and cons:

Amplitude modulation:

- Simple implementation, multiple broadcast channels
- Prone to interference

Frequency modulation:

- Immune to interference, multiple broadcast channels
- Large bandwidth requirement, more complex to implement

Pulse-width modulation:

- Efficient, immune to interference/distortion, simple to implement
- Single channel only