Telecommunication

Name _____ Date _____

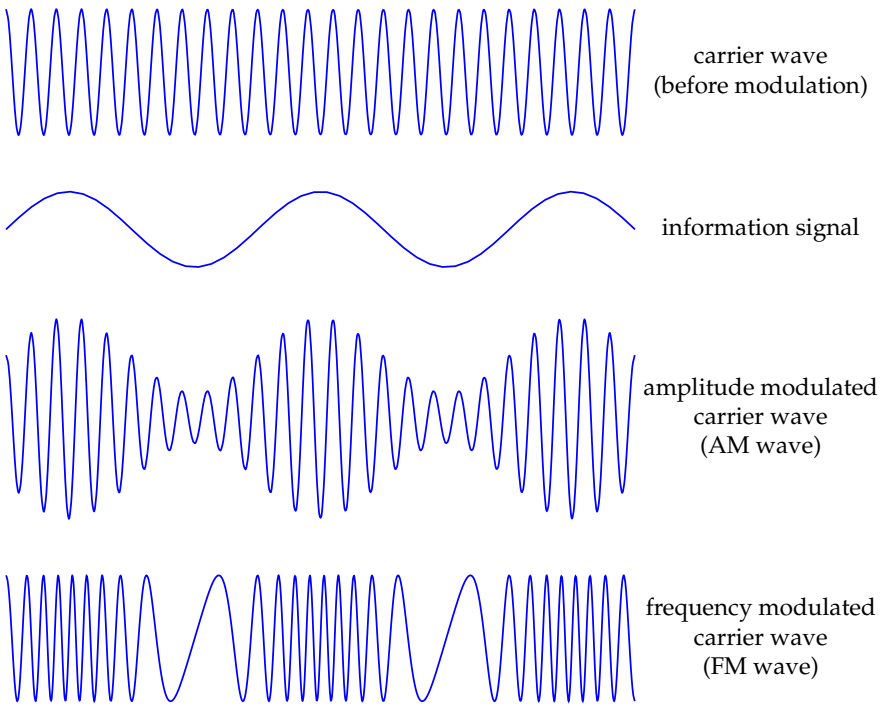
By the end of this topic I can...

- describe amplitude and frequency modulation, and find the bandwidth of an AM wave
- compare analogue and digital signals; convert binary numbers; describe ADC and DAC
- compare communication channels, radio paths and satellites
- use the decibel scale for attenuation, gain and signal-to-noise ratio

Telecommunication is transmitting ___information___ by electromagnetic means over long distances, with minimal loss of signal strength and ___noise___. Three key parts: the ___modulator/demodulator___, the ___ADC/DAC___ converters, and the communication ___channel___.

Modulation

___Modulation___ means varying the ___amplitude___ or the ___frequency___ of a carrier wave in synchrony with the ___displacement___ of an information signal.



- **reasons for modulation**: a carrier has a shorter wavelength, so a ___shorter aerial___; each signal can have a different carrier frequency, so many signals can share the air ___without interfering___; modulated waves are less affected by ___noise___; transmission over ___long distances___ is possible

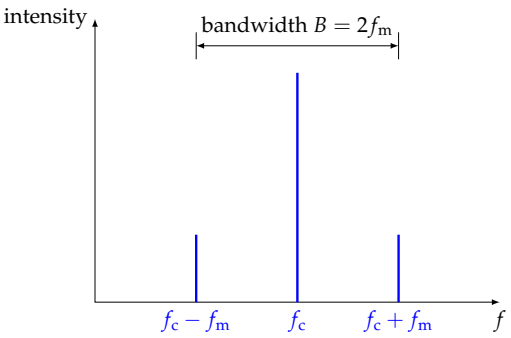
Amplitude modulation (AM)

• the carrier frequency is unchanged. The amplitude varies with time according to the information signal, whose waveform gives the envelope.

• **spectrum**: for an information signal $A_m \cos \omega_m t$ on a carrier $A_c \sin \omega_c t$, the AM wave is $(A_c + A_m \cos \omega_m t) \sin \omega_c t$. Using $\sin \alpha \cos \beta = \frac{1}{2}[\sin(\alpha + \beta) + \sin(\alpha - \beta)]$:

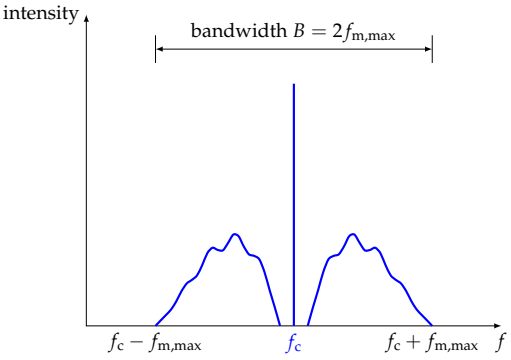
$$x(t) = A_c \sin \omega_c t + \tfrac{1}{2} A_m \sin(\omega_c + \omega_m)t + \tfrac{1}{2} A_m \sin(\omega_c - \omega_m)t$$

so the AM wave has three frequencies: f_c, $f_c + f_m$ and $f_c - f_m$ (the sidebands).



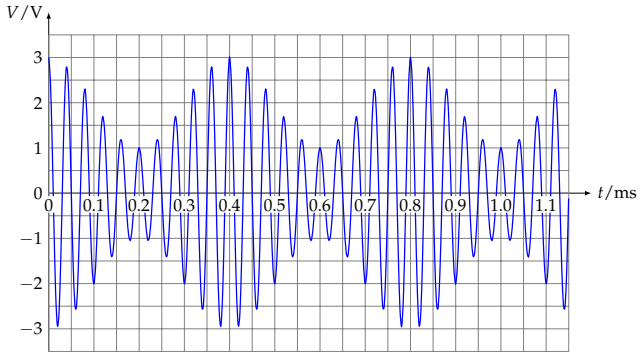
Bandwidth is the range of frequencies occupied by the modulated signal. For AM: $B = 2f_m$ (for a range of signal frequencies, $B =$ $2f_{m,max}$).

• a range of signal frequencies (music) gives two humps of sidebands either side of the carrier



• for speech $f_m \approx 10^3$ Hz, so B is a few kHz. A smaller bandwidth means more channels fit in a given frequency range:

$$n = \frac{f_{max} - f_{min}}{B}$$



Example 33.1 A radio station has carrier wavelengths available from 3.0×10^3 m to 1.5×10^4 m. The voltage of a modulated signal is shown (carrier period 0.04 ms, signal period 0.40 ms). Find (a) the carrier and signal frequencies, (b) the bandwidth, (c) the maximum number of channels broadcast at the same time.

(a) $f_c = \dfrac{1}{0.04\text{ ms}} = 25\text{ kHz}, \quad f_m = \dfrac{1}{0.40\text{ ms}} = 2.5\text{ kHz}$
(b) $B = 2f_m = 5.0\text{ kHz}$
(c) $f_{\max} = \dfrac{c}{\lambda_{\min}} = \dfrac{3.0 \times 10^8}{3.0 \times 10^3} = 100\text{ kHz}, \quad f_{\min} = \dfrac{3.0 \times 10^8}{1.5 \times 10^4} = 20\text{ kHz}$
$n = \dfrac{100 - 20}{5.0} = 16$

Question 33.1 An AM radio wave carries a single-frequency audio signal. Its power spectrum has three frequencies: 45 kHz, 50 kHz and 55 kHz. Find (a) the carrier frequency, (b) the audio frequency, (c) the bandwidth.

(a) the middle (largest) one: $f_c = 50\text{ kHz}$ (b) $f_m = 55 - 50 = 5\text{ kHz}$ (c) $B = 2f_m = 10\text{ kHz}\ (= 55 - 45)$

Question 33.2 A 200 kHz carrier is amplitude modulated by music of frequencies 30 Hz to 4000 Hz. Sketch the power spectrum and find the bandwidth.

Spectrum: a tall line at 200 kHz, with sideband humps from 196.000 to 199.970 kHz and from 200.030 to 204.000 kHz.
$B = 2f_{\text{m,max}} = 2 \times 4000 = 8.0$ kHz (from 196 kHz to 204 kHz)

Frequency modulation (FM)

• the amplitude is unchanged. The frequency varies with time according to the information signal.

• the frequency deviation k (in kHz V^{-1}) is the change of carrier frequency per volt of signal: $\Delta f = k\, A_{\text{m}}$

• the FM spectrum is very complicated (you only need to know that), and each FM signal occupies a very large bandwidth

Example 33.2 A carrier of amplitude 5.0 V and frequency 80 kHz is frequency modulated by a sinusoidal signal of amplitude 3.0 V and frequency 4000 Hz. The frequency deviation is 2.0 kHz V^{-1}. Describe the modulated wave.

Amplitude stays at 5.0 V.
Maximum shift $= 3.0 \times 2.0 = \pm 6.0$ kHz, so $f_{\text{max}} = 86$ kHz and $f_{\text{min}} = 74$ kHz.
The frequency swings between 74 and 86 kHz and back, 4000 times per second.

Question 33.3 A 900 kHz carrier is frequency modulated by a 6.0 kHz, 2.5 V signal. The deviation is 30 kHz V^{-1}. (a) Find the maximum and minimum frequency. (b) Describe the changes.

(a) shift $= 2.5 \times 30 = 75$ kHz: $f_{max} = 975$ kHz, $f_{min} = 825$ kHz
(b) The frequency varies between 825 and 975 kHz, completing 6000 cycles of variation per second; the amplitude is constant.

AM compared with FM

• **AM advantages**: simpler, cheaper electronics; narrower bandwidth so more channels; lower frequency, longer wavelength, so it diffracts around barriers and one transmitter covers a greater area

• **FM advantages**: less affected by noise (noise changes the amplitude, but FM carries the information in the frequency); greater bandwidth, so better sound quality; more energy efficient (AM sidebands carry only a small fraction of the power)

Question 33.4 Suggest two reasons why FM broadcasting is more costly than AM.

FM needs more complex (more expensive) transmitters and receivers. FM has shorter range (higher frequencies diffract less), so more transmitters are needed to cover an area.

Digital transmission

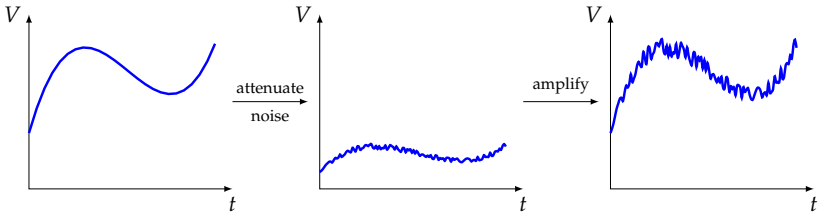
Analogue and digital signals

An analogue signal is continuous and can take any value. A digital signal is discrete: only 0 and 1 (high and low).

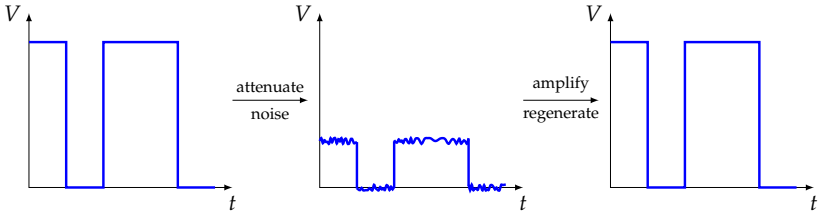
Regeneration

• attenuation: gradual loss of signal power. Noise: unwanted random interference that distorts the signal. At the receiver we want to remove the noise and amplify the signal: regeneration.

• **analogue**: noise cannot be distinguished from the signal, so it is amplified along with the weakened signal



• **digital**: the signal is either 0 or 1, so any fluctuation is noise and can be removed: the signal is regenerated



• **advantages of digital**: noise removed by regeneration; only two states, so more reliable, easier electronics; can be encrypted; extra data allows error checking; small bandwidth, so higher data rate; easier to store and process

Binary numbers

• each digit is a bit; each bit is an increasing power of 2. The left bit is the most significant bit (MSB), the right bit the least significant bit (LSB).

• an n-bit system represents 2^n different numbers; more bits means more precise voltage levels

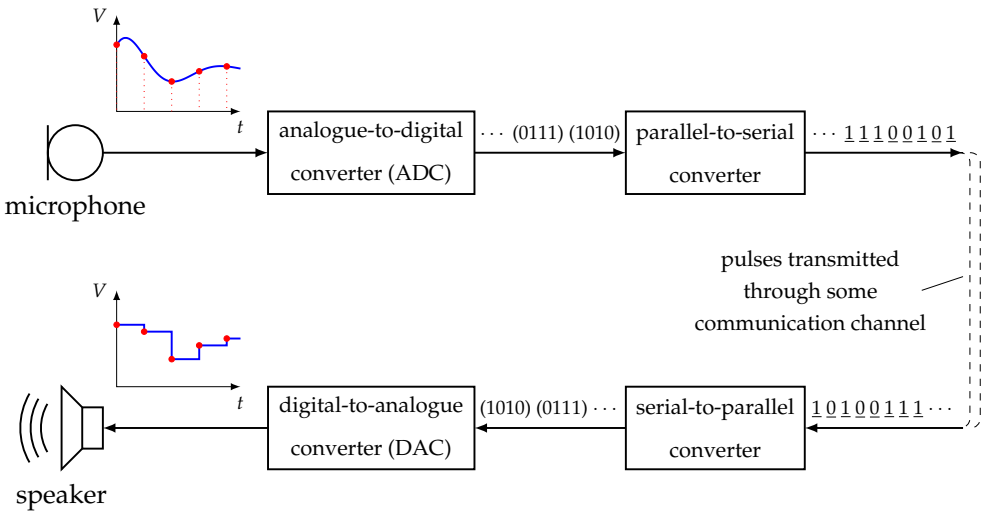
Example 33.3 Convert to decimal: (a) 11001_2 (b) 10110_2.

(a) $1 \times 16 + 1 \times 8 + 0 + 0 + 1 \times 1 = 25$
(b) $1 \times 16 + 0 \times 8 + 1 \times 4 + 1 \times 2 + 0 \times 1 = 22$

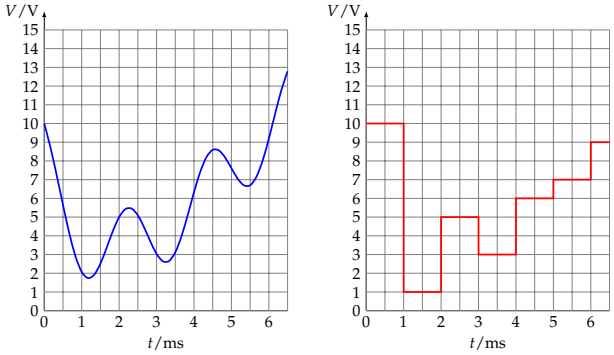
Example 33.4 Convert to binary: (a) 13 (b) 28.

(a) $13 = 8 + 4 + 1 = 1101_2$
(b) $28 = 16 + 8 + 4 = 11100_2$

Analogue-to-digital conversion



- the microphone gives an analogue signal. The ADC takes samples at regular time intervals and converts each sample to a binary number.
- the parallel-to-serial converter sends the bits of each number one after another. At the receiver, the process is reversed: a serial-to-parallel converter and a DAC reproduce the signal.
- **better quality**: increase the sampling frequency (steps narrower, detects higher frequencies), and increase the number of bits (steps smaller, more precise voltage)



original analogue signal reproduced signal

Example 33.5 An analogue signal is sampled at 1.0 kHz, each sample converted to a 4-bit number. (a) State the sample values. (b) Draw the reproduced signal on the second grid.

Samples every 1.0 ms; $2^4 = 16$ levels (0 to 15 V); values are rounded down.

t/ms	0	1	2	3	4	5	6
sample/V	10.0	2.0	5.0	3.0	6.3	7.6	9.2
level/V	10	2	5	3	6	7	9
binary	1010	0010	0101	0011	0110	0111	1001

The reproduced signal is a staircase through these levels (teacher key shows it on the grid).

Communication channels

Wire pairs

- two insulated wires twisted together (noise is picked up equally and can be cancelled)
- **advantages**: low cost, easy to install
- **disadvantages**: affected by noise; cross-linking (a signal induces a copy in a nearby circuit); low security; high attenuation (radiates energy)
- **uses**: telephone to socket, amplifier to loudspeaker

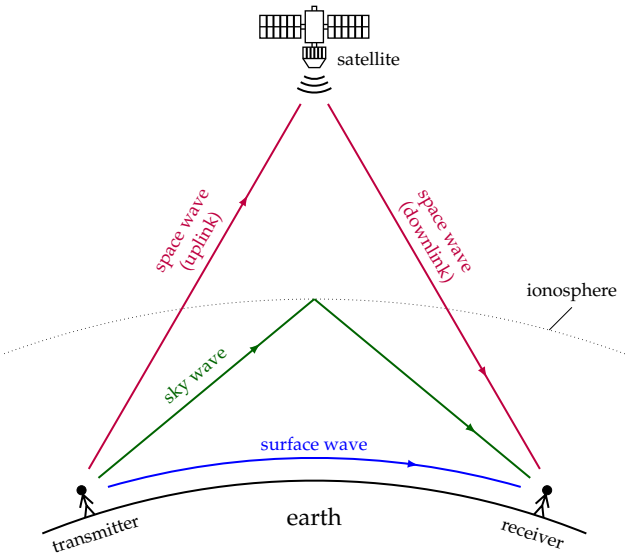
Coaxial cables

- a central core (the signal wire) shielded by an outer conductor that is earthed; it is the return path and stops interference reaching the core
- **advantages**: less noise and cross-linking; less attenuation; greater bandwidth; higher security
- **uses**: TV to aerial, computer to projector, landline to local exchange

Optic fibres

- a core with a higher refractive index than the surrounding transparent cladding, so light stays in the core by total internal reflection
- **advantages**: very low attenuation; very little noise (immune to electromagnetic interference); very large bandwidth; ideal for digital (light pulses switch rapidly); low weight and cost
- **uses**: internet broadband, transcontinental communication

Radio waves and microwaves



- **surface wave** ($\lambda \approx 0.1$ to 10 km, 30 kHz to 3 MHz): travels close to the ground; long wavelength so it diffracts around obstacles
- **sky wave** ($\lambda \approx 10$ to 100 m, 3 to 30 MHz): reflected by the ionosphere, travels far by multiple reflections; not very reliable (depends on the atmosphere)
- **space wave** ($\lambda \approx 10$ cm to 10 m, 30 MHz to 3 GHz): passes through the atmosphere to satellites; short wavelength means little diffraction, so on the ground it must be line-of-sight
- **microwaves** ($f \approx 3$ to 300 GHz, $\lambda \approx 0.1$ to 10 cm): high frequency gives a large bandwidth and data rate, but line-of-sight only. Uses: Wi-Fi, Bluetooth, mobile phones, satellite links.

Communication satellites

• **advantages over sky waves**: the satellite amplifies the signal; higher frequencies give greater bandwidth; consistent, not weather-dependent

• uplink and downlink use different frequencies: the uplink is greatly attenuated and the downlink greatly amplified, so the same frequency would let the downlink swamp the uplink

• **geostationary**: equatorial orbit, period 24 hours, west to east, fixed above a point. *Pros*: dish can be fixed, no tracking. *Cons*: very high orbit (over 6 earth radii), so a long time delay; cannot cover high latitudes.

• **polar**: pass over the poles at about 1000 km. *Pros*: shorter delay; better surface detail (maps, weather). *Cons*: not synchronous, so must be tracked, and the channel must be swapped between satellites.

Causes of attenuation

• wire pair and coaxial cable: heat (resistance) and radiation of energy

• optic fibre: scattering by impurities and defects (infra-red is used because its longer wavelength is scattered less)

• radio waves and microwaves: absorption by the atmosphere

The decibel scale

Engineers compare powers, often very large ratios, so use a logarithmic scale: $\text{ratio in dB} = 10 \log \frac{P_1}{P_2}$

• $\text{attenuation} = 10 \log \frac{P_{\text{in}}}{P_{\text{out}}}$ $\text{SNR} = 10 \log \frac{P_{\text{out}}}{P_{\text{noise}}}$

$\text{gain} = 10 \log \frac{P_{\text{out}}}{P_{\text{in}}}$

• dB has no true unit: it just reminds us the ratio is on a log scale

• **why use dB**: gives more manageable numbers; ratios in dB can be added and subtracted (since $\log x + \log y = \log xy$)

Example 33.6 A signal of power 0.040 mW enters an amplifier of gain 36 dB. Find the output power.

$10\log\dfrac{P_{\text{out}}}{0.040}=36$, so $\dfrac{P_{\text{out}}}{0.040}=10^{3.6}$
$P_{\text{out}}=10^{3.6}\times 0.040\approx 159$ mW

Example 33.7 An optic fibre has attenuation 0.12 dB km^{-1}. The input power is 50 mW and the noise at the receiver is 8.0 μW. The signal-to-noise ratio must be at least 25 dB. Find the maximum length.

Minimum received power: $10\log\dfrac{P}{8.0\times 10^{-6}}=25$, so $P=10^{2.5}\times 8.0\times 10^{-6}=2.53\times 10^{-3}$ W
Maximum attenuation: $10\log\dfrac{50\times 10^{-3}}{2.53\times 10^{-3}}\approx 13$ dB
Length: $L=\dfrac{13}{0.12}\approx 108$ km

Example 33.8 A 60 mW signal travels along 94 km of cable with attenuation 3.2 dB km^{-1}. Repeater amplifiers of gain 27 dB are placed every 8.0 km. Find the received power.

Cable attenuation: $94 \times 3.2 = 300.8$ dB.
Number of amplifiers: $94/8.0 = 11.75$, so 11. Gain $= 11 \times 27 = 297$ dB.
Net attenuation $= 300.8 - 297 = 3.8$ dB: $\log \dfrac{60}{P_{\text{out}}} = 0.38$, so $P_{\text{out}} = \dfrac{60}{10^{0.38}} \approx 25$ mW

Question 33.5 A 5.0 km cable has attenuation 12 dB km^{-1}. The received power is 2.9×10^{-7} W. Find the input power.

Total attenuation $= 5.0 \times 12 = 60$ dB, so $\dfrac{P_{\text{in}}}{P_{\text{out}}} = 10^6$
$P_{\text{in}} = 10^6 \times 2.9 \times 10^{-7} = 0.29$ W

Question 33.6 A 28 mW signal passes along two cables with attenuation 29 dB and 38 dB, then an amplifier of gain 43 dB. Find the output power.

Net: $-29 - 38 + 43 = -24$ dB, so $\dfrac{P_{\text{out}}}{P_{\text{in}}} = 10^{-2.4}$
$P_{\text{out}} = 28 \times 10^{-2.4} = 0.11$ mW

Question 33.7 A 12 mW signal is sent along an optic fibre. Noise at the receiver is 0.75 μW and the signal-to-noise ratio must not fall below 35 dB. The maximum uninterrupted length is 48 km. (a) Find the minimum acceptable received power. (b) Find the attenuation per unit length.

(a) $P = 10^{3.5} \times 0.75 \times 10^{-6} = 2.4 \times 10^{-3}$ W (2.4 mW)
(b) attenuation $= 10 \log \dfrac{12}{2.37} \approx 7.0$ dB over 48 km: $\dfrac{7.0}{48} = 0.15$ dB km^{-1}