Telecommunication

A Level Physics 9702

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By the end of this topic I can. . .

- describe AM and FM and find the bandwidth of an AM wave
- compare analogue and digital signals; use binary numbers
- describe ADC and DAC
- compare communication channels and satellites
- use the decibel scale

Modulation

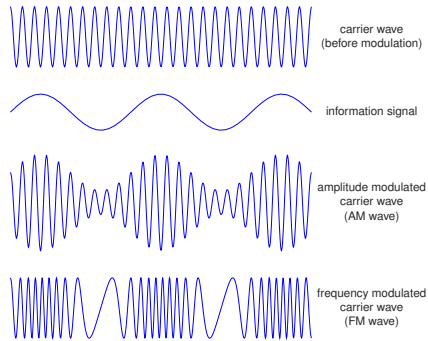
Modulation

Varying the **amplitude** or **frequency** of a carrier wave in synchrony with the displacement of an information signal.

- shorter aerial
- many signals share the air
- less affected by noise
- long-distance transmission

AM and FM waves

- **AM**: amplitude varies, frequency fixed
- **FM**: frequency varies, amplitude fixed

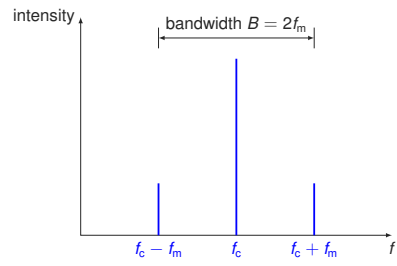


AM spectrum and bandwidth

Carrier plus two **sidebands** $f_c \pm f_m$:

$$B = 2f_{\text{m}}$$

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



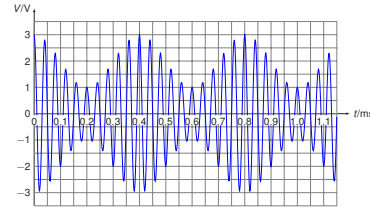
- range of signal frequencies: $B = 2f_{m,max}$
- smaller B: more channels

Example: AM channels

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.

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(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) $f_{\text{max}} = \dfrac{c}{\lambda_{\text{min}}} = \dfrac{3.0 \times 10^8}{3.0 \times 10^3} = 100\ \text{kHz},$

$f_{\text{min}} = \dfrac{3.0 \times 10^8}{1.5 \times 10^4} = 20\ \text{kHz}$

$n = \dfrac{100 - 20}{5.0} = 16$

Example: sidebands

Example: sidebands

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

Example: FM wave

Example: FM 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.

AM compared with FM

- **AM**: cheaper, narrower bandwidth, diffracts, greater range
- **FM**: less noise, better sound quality, more efficient

Analogue and digital

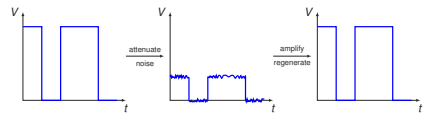
Analogue and digital

Analogue: continuous, any value. **Digital**: discrete, only 0 and 1.

- attenuation: loss of power
- noise: unwanted random interference
- digital: noise removed by **regeneration**
- analogue: noise amplified with the signal

Regeneration

- analogue: noise cannot be distinguished
- digital: any fluctuation is noise, so it is removed



Advantages of digital

- noise removed by regeneration
- reliable, simple electronics
- encryption and error checking
- higher data rate
- easy to store and process

Example: binary to decimal

Example: binary to decimal

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

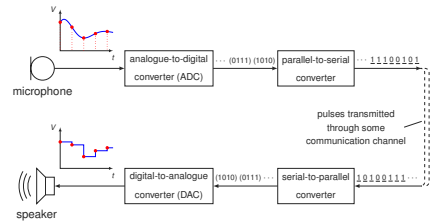
Example: decimal to binary

Example: decimal to binary

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

Analogue to digital

- ADC: **samples** at regular intervals
- each sample becomes a **binary number**
- parallel to serial: bits sent one after another
- receiver: serial to parallel, then DAC
- better: higher sampling rate, more bits



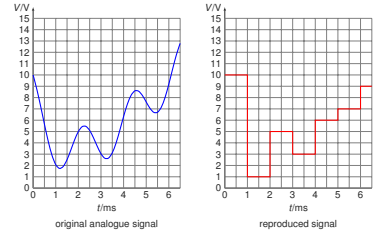
Example: ADC samples

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.

Example: ADC samples

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

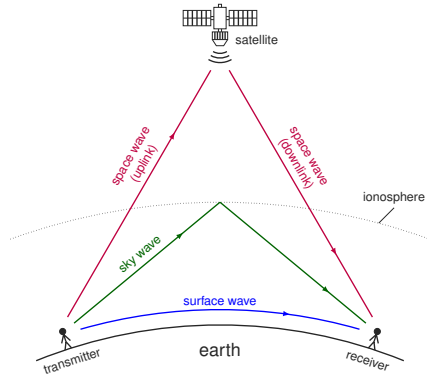
The reproduced signal is a staircase through these levels (teacher key shows it on the grid).

Communication channels

- **wire pair**: cheap; noise, cross-linking, high loss
- **coaxial**: shielded; less noise, more bandwidth
- **optic fibre**: very low loss, huge bandwidth, digital
- **radio**: surface, sky and space waves
- **microwave**: line of sight, high bandwidth

Radio waves

- **surface**: diffracts around obstacles
- **sky**: reflected by the ionosphere, unreliable
- **space**: reaches satellites, line-of-sight on the ground



Satellites

- amplify, higher bandwidth, reliable
- uplink and downlink at **different frequencies**
- **geostationary**: fixed dish; long delay; no high latitudes
- **polar**: short delay, detail; must be tracked

The decibel scale

Power ratios on a logarithmic scale:

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

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

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

- manageable numbers

Example: amplifier gain

Example: amplifier gain

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

Example: optic fibre length

Example: optic fibre length

Minimum received power: $10 \log \frac{P}{8.0 \times 10^{-6}} = 25$, so

$P = 10^{2.5} \times 8.0 \times 10^{-6} = 2.53 \times 10^{-3}$ W

Maximum attenuation: $10 \log \frac{50 \times 10^{-3}}{2.53 \times 10^{-3}} \approx 13$ dB

Length: $L = \frac{13}{0.12} \approx 108$ km

Example: repeater amplifiers

Example: repeater amplifiers

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

Key equations

bandwidth $B = 2f_{\mathrm{m}}$

channels $n = \dfrac{f_{\max} - f_{\min}}{B}$

attenuation $\text{attenuation} = 10 \log \dfrac{P_{\text{in}}}{P_{\text{out}}}$

S/N ratio $\text{SNR} = 10 \log \dfrac{P_{\text{out}}}{P_{\text{noise}}}$

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