Communication (Chapter 16):

- To allow several radio stations to broadcast, each signal has a different **carrier wave** frequency which is altered and modulated
- **Modulation** is the variation of either **amplitude** or **frequency** of the carrier wave
- The **modulated carrier wave** is the actual wave transmitted:
  - High frequency wave
  - The amplitude or the frequency is varied in synchrony with the displacement of the information signal
  - The variation represents the information signal
- The signal is present during modulation of the modulated wave
- **Amplitude modulation** (AM):
  - Amplitude of the carrier wave varies in synchrony with the displacement of the information signal
  - The frequency of the modulated carrier wave is constant
- **Frequency modulation** (FM):
  - Frequency of carrier wave varies in synchrony with the displacement of the information signal
  - The amplitude of the modulated carrier wave is constant

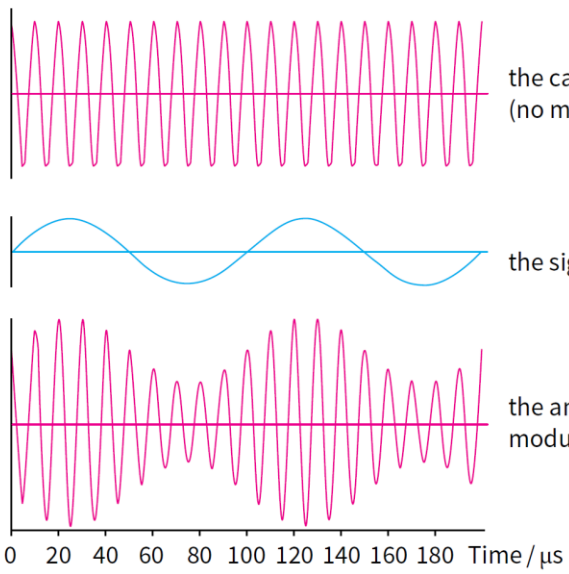


Figure 20.3 Amplitude modulation.

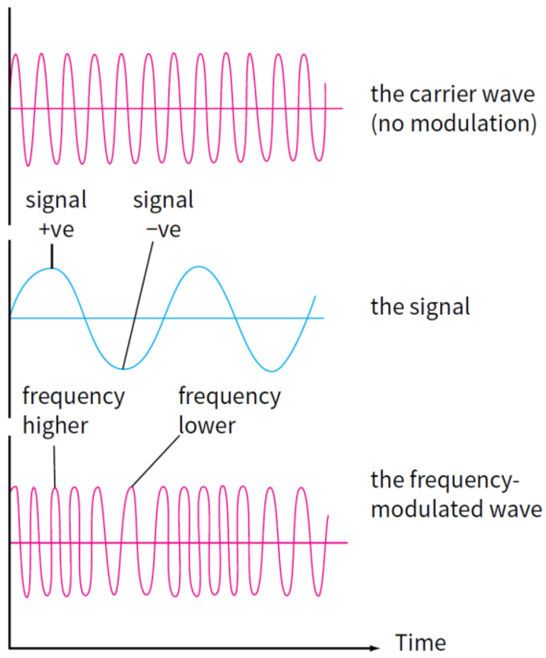


Figure 20.4 Frequency modulation.

A carrier wave of frequency 300 kHz and amplitude 5.0 V is frequency modulated by a sinusoidal signal of frequency 6 kHz and amplitude 2.0 V. The frequency deviation of the carrier wave is 30 kHz V^{-1}. Describe the modulated carrier wave produced.

Step 1 Consider the amplitude of the modulated signal. The amplitude of the carrier wave is unchanged at 5.0 V during frequency modulation. The signal alters the frequency of the

Step 2 Now consider how the signal will modify the carrier frequency. The frequency shift produced by the signal is ± 2 × 30 = ± 60 kHz, so the carrier wave varies in frequency between 240 and 360 kHz. This variation in frequency occurs 6000 times every second as the signal varies at this frequency.

- A carrier wave (only has 1 frequency, f_c) which is **amplitude modulated** by a single audio frequency, f_m, is equivalent to the carrier wave frequency together with two sideband frequencies (($f_c - f_m$) and ($f_c + f_m$))

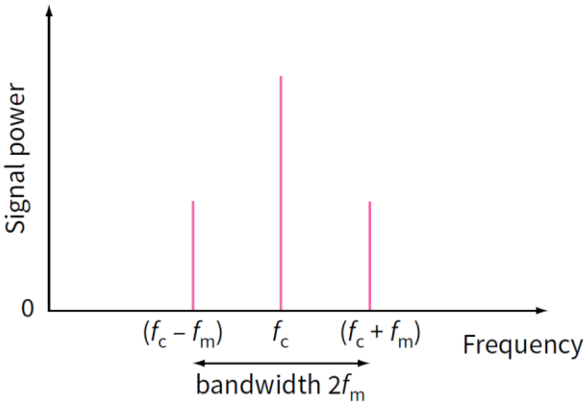


Figure 20.5 The frequency spectrum of a carrier wave modulated in amplitude by a signal of one frequency.

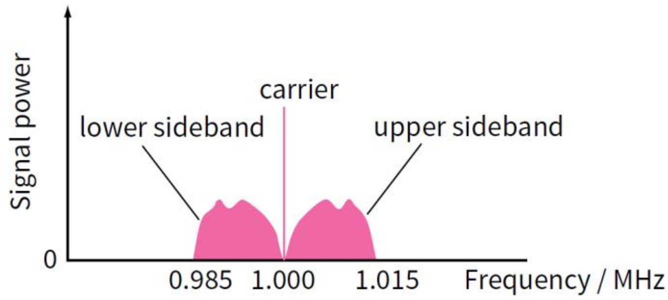


Figure 20.6 The frequency spectrum for an amplitude-modulated wave.

- When music is transmitted, the carrier wave is modulated by a range of frequencies which change with time, resulting to a band of frequencies (upper and lower sidebands), stretching above and below the carrier frequency by the value of the highest modulating frequency
- Figure 20.6 shows the frequency spectrum for a carrier wave of frequency 1 MHz modulated with frequencies between 0 and f_m = 15 kHz = 0.015 MHz; the highest frequency present in the spectrum is ($f_c + f_m$) = 1.015 MHz and the lowest frequency is ($f_c - f_m$) = 0.985 MHz
- **Bandwidth** of a signal is the range of frequencies occupied by the amplitude-modulated waveform, the difference between the highest-frequency and lowest-frequency signal component:
  - E.g. fig 20.6, bandwidth = 1.015 – 0.985 = 0.030 MHz
  - E.g. fig 20.5, bandwidth = ($f_c + f_m$) – ($f_c - f_m$) = $2f_m$
- Whereas in FM carrier wave has more than two sideband frequencies for each signal frequency, hence requires a greater bandwidth for each radio station

- Modulated carrier waves are used, rather than the direct transmission of electromagnetic waves having audio frequencies due to:
  - Shorter aerial required
  - Longer transmission range / lower transmitter power / less attenuation
  - Allows more than one station in a region
  - Less distortion
- Advantages of FM:
  - Electrical interference affects AM more than FM
  - Higher bandwidth can be used, due to greater range of frequencies available, hence better quality of sound
- Advantages of AM:

- The actual receiver and transmitter used for AM are less complicated and cheaper than for FM transmission
- The bandwidth needed for each AM transmission is less than FM transmission, hence more stations are available in any given frequency range
- AM transmissions use lower frequencies than FM, hence can be diffracted, so can cover a larger area than FM transmissions, for the same power output

- **Digital signal**: signal consists of a series of 1s and 0s
- **Analogue signal**: signal that is continuously variable, having a continuum of possible values

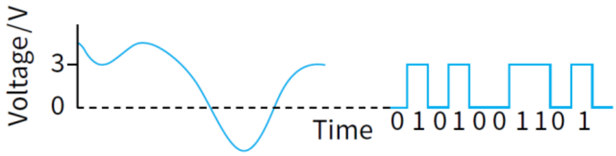


Figure 20.8 Analogue and digital signals.

- **Noise**: unwanted power on signal that is random
  - Amplification of a signal amplifies the noise at the same time
  - Regeneration will remove the noise from a digital signal
- Advantages of data transmission in digital form compared to analogue:
  - Noise can be eliminated, signal can be regenerated
  - Extra bits can be added to check for errors
  - Multiplexing possible
  - Digital circuits are more reliable / cheaper
  - Data can be encrypted for security
- The digital transmission of speech or music involves analogue-to-digital conversion (ADC) before transmission and digital-to-analogue conversion (DAC) after reception

Decimal number	Binary number	Decimal number	Binary number
0	0	6	110
1	1	7	111
2	10	8	1000
3	11	9	1001
4	100	10	1010
5	101	11	1011

Table 20.2 Binary and decimal numbers.

- Each digit in the binary number is known as a **bit**

- The function of the ADC:
  - Samples the analogue signal at regular intervals and converts the analogue number to a digital number
- The effect of the sampling rate and the number of bits in each sample on the reproduction of an input signal:

E.g. a recording is made of some music. For this recording, the music is sampled at a rate of 44.1 kHz and each sample consists of a 16-bit word

- Suggest the effect on the quality of the recording of
  - Sampling at a higher frequency rather than a lower frequency:
    - Higher frequencies can be reproduced
  - Using a long word length rather than a shorter word length:
    - Smaller changes in loudness / amplitude can be detected
- The recording lasts for a total time of 5 minutes 40 seconds. Calculate the number of bits generated during the recording:
  - Bit rate = $44.1 \times 10^3 \times 16 = 7.06 \times 10^5\ s^{-1}$
  - Number = $7.06 \times 10^6 \times 340 = 2.4 \times 10^8$

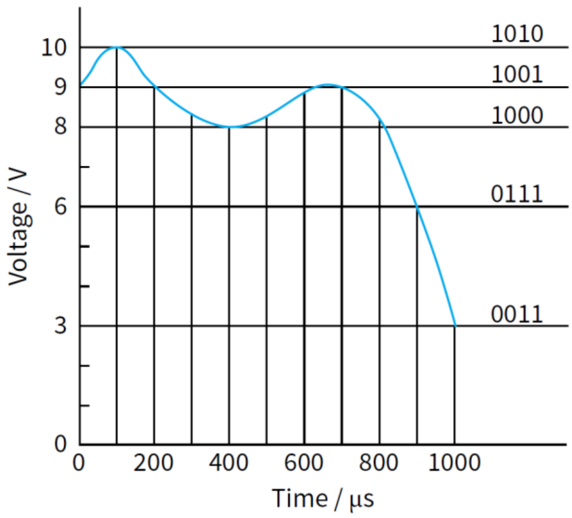


Figure 20.10 Analogue-to-digital conversion.

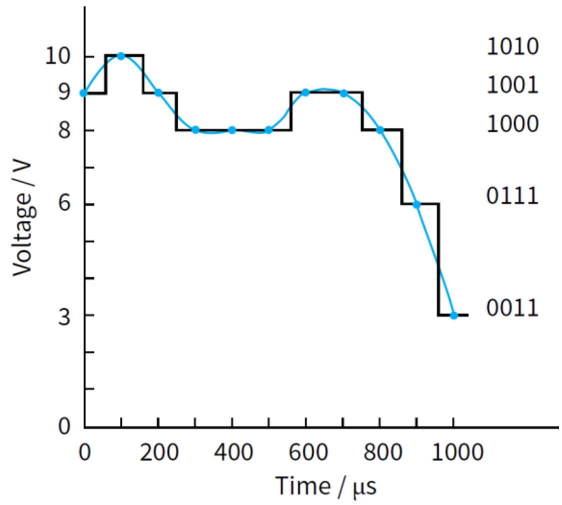


Figure 20.11 Digital-to-analogue conversion.

- There are differences in the digital signal in ADC and DAC; level of detail in the transmitted signal can be increased by:
  - Increase the number of bits in each number (similar to having an extra significant figure) to reduce **step height**, resulting to smaller changes in input signal can be seen/reproduced
  - Increase in sampling rate – the number of samples made per second, e.g. in fig. 20.10, sample is taken every $100\mu s$, so the **step width/depth** is reduced
- **Signal attenuation**: loss of signal power
  - The decrease in signal power from the transmitted value P_1 to that received P_2 can be very high, hence the ratio of P_2 and P_1 is measured using logarithmic scale
  - The logarithm to base 10 of the ratio gives the number of bels (B); when multiplied by 10 gives the number of decibels (dB)

$$\text{number of B} = \lg\left(\frac{P_2}{P_1}\right)$$

$$\text{number of dB} = 10\lg\left(\frac{P_2}{P_1}\right)$$

For example, suppose P_2 is 1000 times greater than P_1:

$$\text{number of dB} = 10\lg\left(\frac{1000}{1}\right) = 30$$

Positive number due to increase in power (amplified signal); negative number due to attenuation

A signal of power 18.0 mW passes along one cable, where the attenuation is 20 dB. It then passes along another cable, where the attenuation is 30 dB. What is the power at the end of the two cables?

Step 1 Apply the decibel equation to each cable in turn.

In the first cable, if the input is P_1 and the output P_2, then:

$$20 = 10\lg\left(\frac{P_1}{P_2}\right)$$

Hint: *Notice that both sides of the equation produce a positive number since* $P_1 > P_2$.

In the second cable, the input is P_2, the output of the first channel. If the output is P_3, then:

$$30 = 10\lg\left(\frac{P_2}{P_3}\right)$$

Step 2 Add the two equations; this gives:

$$50 = 10\left[\lg\left(\frac{P_1}{P_2}\right) + \lg\left(\frac{P_2}{P_3}\right)\right]$$

Applying the 'log of a product rule' gives:

$$50 = 10\lg\left(\frac{P_1}{P_2} \times \frac{P_2}{P_3}\right) = 10\lg\left(\frac{P_1}{P_3}\right)$$

This shows that the total attenuation of the two cables is 50 dB, equal to the sum of the attenuations of the consecutive channels. Hence you can add attenuations to find the total attenuation (but be careful if a signal is being both amplified and attenuated).

Step 3 We have $P_1 = 18$ mW and we need to find P_3. Substituting gives:

$$50 = 10\lg\left(\frac{18}{P_3}\right)$$

so:

$$\lg\left(\frac{18}{P_3}\right) = \frac{50}{10} = 5$$

Taking inverse logs, or pressing the inverse lg button on your calculator, gives:

$$\left(\frac{18}{P_3}\right) = 10^5$$

$P_3 = 1.8 \times 10^{-4}$ mW

You could apply the decibel equation to each cable in turn and use the output of the first cable as the input to the second cable. You should find that the result is the same.

- Attenuation per unit length, units: dB km^{-1}, given by:

$$\text{attenuation per unit length (dB km}^{-1}) = \frac{\text{attenuation (dB)}}{\text{length of cable (km)}}$$

- When a signal travels along a cable, the level of noise is important, hence the signal-to-noise ratio, in dB, given by:

$$\text{signal-to-noise ratio} = 10\lg\left(\frac{\text{signal power}}{\text{noise power}}\right)$$

- In analogue signal, at regular intervals along a cable, repeaters amplify the signal and noise – multiplying both signal and noise by the same amount keeps the signal-to-noise ratio the same
- Regeneration of a digital signal at the same time as amplification removes most of the noise, ensuring that the signal-to-noise ratio remains high
- Regenerator amplifier do not amplify the noise that has been picked up on digital signals as for digital, only the 1 and 0 / 'high' and 'low' are necessary, variation between 'highs' and 'lows' caused by noise not required

The input signal to a cable has power 1.2×10^{-3} W. The signal attenuation per unit length in the cable is $14\,\text{dB km}^{-1}$ and the average noise level along the cable is constant at 1.0×10^{-10} W. An acceptable signal-to-noise ratio is at least 30 dB.

Calculate the minimum acceptable power for the signal and the maximum length of the cable that can be used without a repeater.

Step 1 The signal-to-noise ratio must be at least 30 dB. Hence, using:

$$\text{signal-to-noise ratio} = 10 \lg\left(\frac{\text{signal power}}{\text{noise power}}\right)$$

we have:

$$30 = 10 \lg\left(\frac{P}{1 \times 10^{-10}}\right)$$

where P is the minimum acceptable power. Solving for P gives:

$= 1.0 \times 10^{-7}$ W

Step 2 A repeater is needed to regenerate the signal when the signal-to-noise ratio falls to 30 dB, i.e. its power is 10^3 times the noise level, and this is 1.0×10^{-7} W. We can calculate the attenuation needed to reduce the signal to this level:

$$\text{attenuation} = 10 \lg\left(\frac{1.2 \times 10^{-3}}{1.0 \times 10^{-7}}\right)$$

$$= 41\text{ dB}$$

Hence the length of cable is $\frac{41}{14} = 2.9$ km.

If the cable is 10 km in length, the total attenuation is:

$14\,\text{dB km}^{-1} \times 10\,\text{km} = 140\,\text{dB}$.

The signal of power 1.2×10^{-3} W is attenuated to a power P where:

$$140 = 10 \lg\left(\frac{0.0012}{P}\right)$$

$P = 12 \times 10^{-17}$ W

You can see that the power in the signal is much smaller than the minimum acceptable power – it is even smaller than the noise level. The signal-to-noise ratio is now $10 \lg(12 \times 10^{-17} / 1.0 \times 10^{-8}) = -79$ dB, smaller than the acceptable +30 dB. A repeater is needed well before the end of the 10 km of cable.

- Different channels of communication:
- ❖ Wire-pairs:
  - ➢ Application: linking a land telephone to the local exchange
  - ➢ The potential difference between the two wires is the signal
  - ➢ Each wire acts as an aerial, picks up wanted electromagnetic waves and distorts the signal
  - ➢ However when two wires are close together, each wire picks up an equal amount of electrical interference, hence no additional potential difference between the two wires and so having the wires close together reduces the interference

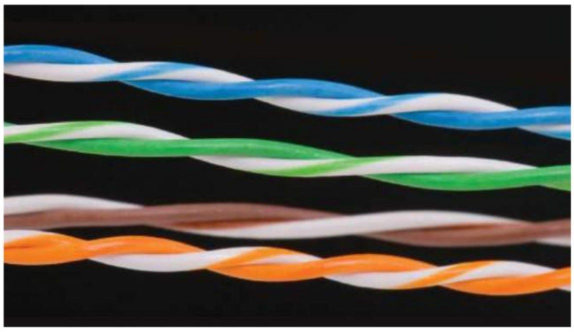


Figure 20.14 Twisted wire-pairs in a computer network.

  - ➢ A wire-pair is the cheapest transmission medium
  - ➢ Has a small bandwidth

- Reflections occur due to poor impedance matching
- Wire-pairs are easily 'tapped' hence low security
- Suffers from **cross-linking** where signal in one pair is picked up by a neighbouring wire pair, resulting to crosstalk
- Large attenuation / energy loss due to the changing currents in the wires produce electromagnetic (EM) fields, hence acting as aerials – requires energy EM waves might pass from one wire-pair to another, leading to crosstalk

❖ Coaxial cables:

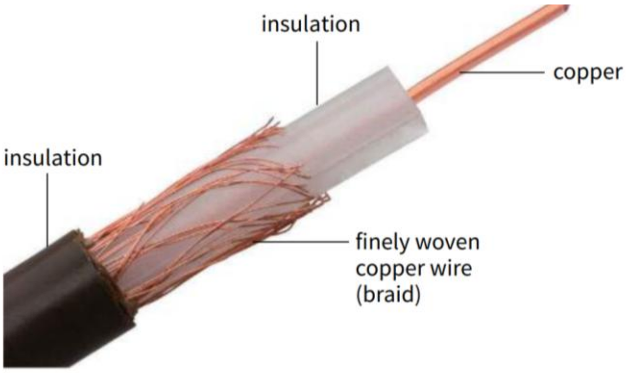


Figure 20.15 Coaxial cable.

- Application: connecting an aerial to a television
- The copper core and the finely woven copper braid are the two conductors that transmit the signal
- Less cross-linking (crosstalk) than wire-pair, as copper wire braid is earthed and shields the core from noise / external signals
    - The copper braid acts as 'return' conductor for signal, shielding from noise/crosstalk/interference
- Greater bandwidth than wire-pair
- Has less attenuation per unit length than a wire-pair, as it prevents any emission of EM waves
- Can transmit data faster, over longer distances, with less electrical interference / noise
- More expensive than a wire-pair

❖ Radio waves:

- Electromagnetic waves covering a vast range of wavelengths; used in a variety of communication depending on frequency, there are three types:

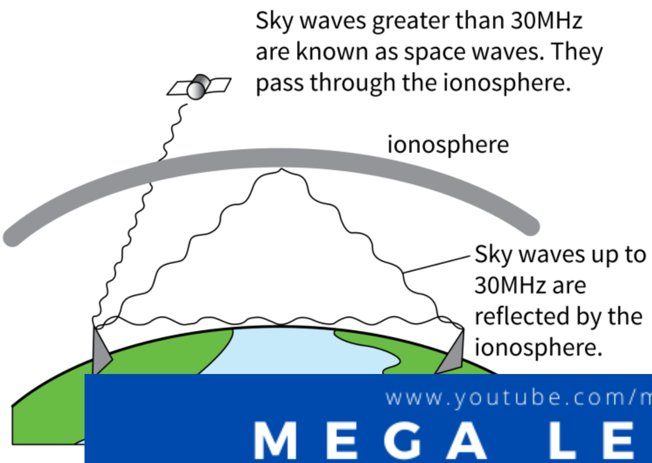


Figure 2

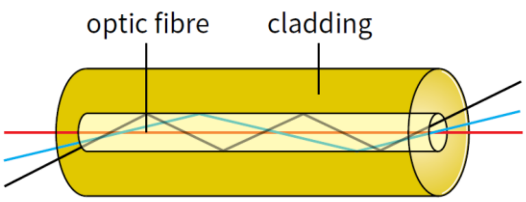
- Surface waves travel close to the surface of the earth, low frequencies of up to 3 MHz (medium-wave and long-wave bands), diffract around the surface of the Earth due to their long wavelengths, giving them a long range of travel; used in AM radio transmissions
  - Adv: very large range
  - Dis: attenuation and distortion significant
- Sky waves, above 3 MHz (high-frequency band), travels almost in straight lines, less diffracted, hence travels shorter distances; using total internal reflection from a layer of charged particles in the atmosphere known as ionosphere; used in short-wave radio broadcasts
  - Adv: large range
  - Dis: substantial attenuation in the ionosphere; unreliable due to unpredictable ionosphere conditions and interference
- Space waves are sky waves, above 30 MHz (very-high-frequency and ultra-high-frequency bands), which pass through the ionosphere; the transmission is line-of-sight, o, if the receiver and transmitter are on the Earth's surface, there must be a clear line between the receiver and the transmitter; used in satellite television transmissions
  - Adv: ionosphere has no effect, so more reliable; can be used by satellites
  - Dis: small range (for ground-based stations)

- Microwave links, above 1 GHz, able to pass through the ionosphere to reach satellites in space
  - Application: linking a ground station to a satellite
  - The satellite receives a space wave from a transmitter on Earth, the uplink, with a carrier frequency in the microwave region; due to significant attenuation between a geostationary satellite and Earth, the uplink and downlink frequencies must be different, as the signal must be amplified greatly before transmission back to Earth, and if the signals are the same, the uplink signal would be swamped by downlink signal
  - The use of ionospheric reflection of radio-waves for long-distance communication been replaced by satellite communication due to:
    - Unreliable communication because the ion layers vary in height/density
    - Cannot carry all information required, as bandwidth is too narrow/low
    - Coverage is limited due to poor reception in hilly areas

- For the satellite dish to always point towards the satellite, geostationary satellite is used
- Polar-orbit satellites used for surface observation and as weather satellites
- Compared to a geostationary satellite, polar-orbits satellite:
  - Travels from pole to pole, with a shorter period of orbit
  - Os at a smaller height above the Earth and can detect objects of smaller detail

- Is not always in the same position relative to the Earth, hence dishes must be moved
- Has smaller time delays

- Optic fibres:
  - Consists of a thin glass core surrounded by a material of slightly lower refractive index called the cladding, to cause total internal reflection
  - Advantages of coaxial cables for the transmission of data:
    - Large bandwidth / carries more information
    - Low attenuation of signal, so repeater and regeneration amplifiers can be further apart
    - Low cost than the same length of copper wire
    - Smaller diameter, easier handling, easier storage, less weight
    - High security / no crosstalk
    - Low noise / no EM interference



- Method to convert decimal into binary number: internet / past papers
- The bit on the left-hand side of a binary number is the **most significant bit** (MSB) and has the highest value

Radiation	Wavelength range / m
radio waves	>10^{6} to 10^{-1}
microwaves	10^{-1} to 10^{-3}
infrared	10^{-3} to 7×10^{-7}
visible	7×10^{-7} (red) to 4×10^{-7} (violet)
ultraviolet	4×10^{-7} to 10^{-8}
X-rays	10^{-8} to 10^{-13}
γ-rays	10^{-10} to 10^{-16}

Table 13.3 Wavelengths (in a vacuum) of the electromagnetic spectrum.