Communicating Information

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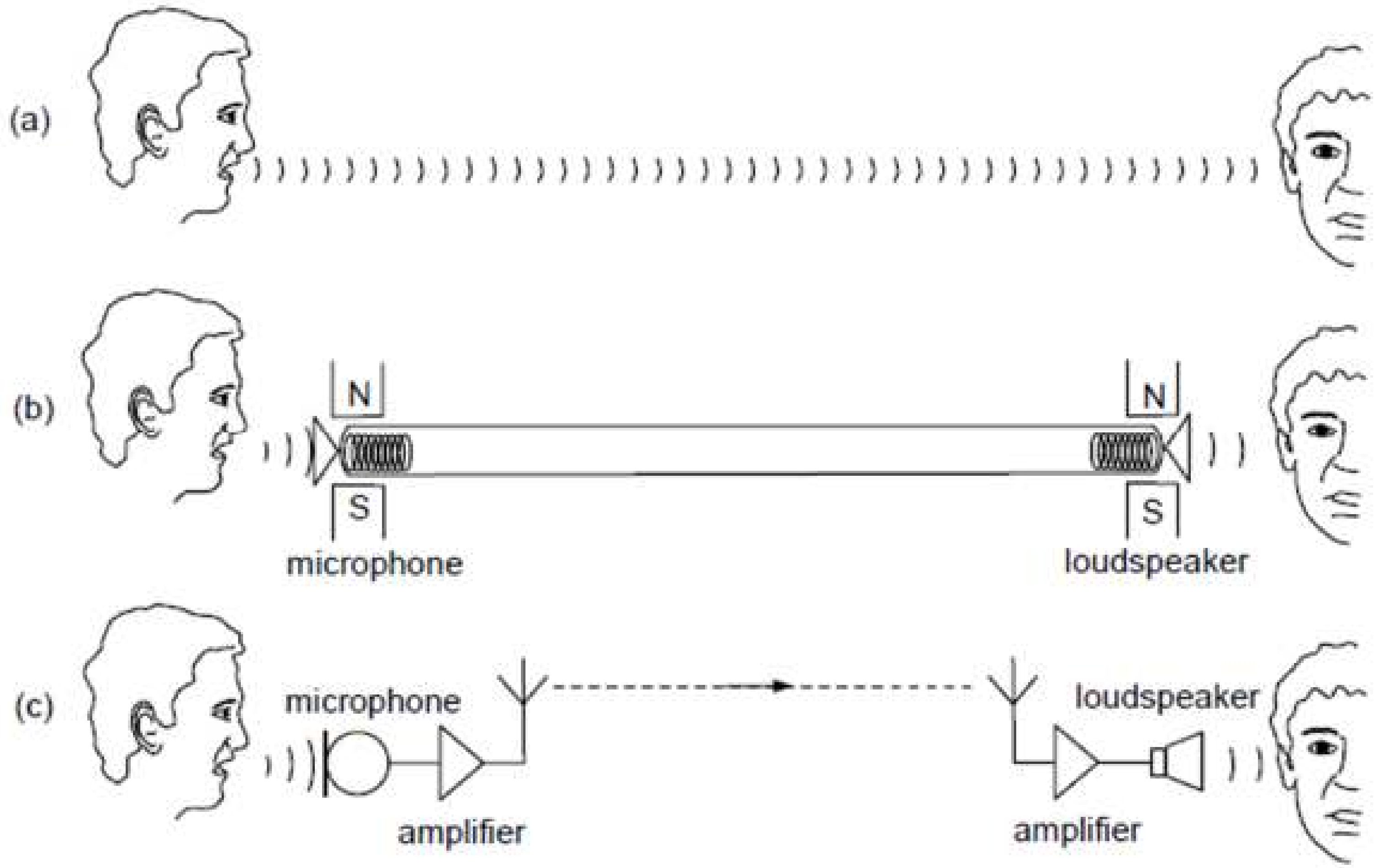
Principles of modulation, sidebands and bandwidth

Communication



Communication

- Communications systems (e.g. radio, TV, telephone) send information from one place to another using electric currents or electromagnetic radiation. This information sent may be sounds, pictures or computer data.
- Any ***communication system*** must have ***transmitter and a receiver.***
- A simple system of communication at a short distance could be one person A speaking to another person B.
  - A is the ***transmitter***
  - B is the ***receiver***
  - Communication system is ***sound waves***
- For 2 people in different rooms, a system of communication could be
  - a ***microphone*** A in one room
  - a ***loudspeaker*** B in another room
  - communication system is a ***twin pair of wires***
  - the microphone converts the sound waves into electrical signals that is transmitted along the wires to the loudspeaker where it is converted back into sound waves
- Communication could also be achieved using ***radio waves***
  - the signal ***from the microphone*** would be amplified and applied ***to a transmitting aerial***.
  - the radio waves produced by the aerial would be transmitted and ***picked up by a receiving aerial.***
  - after amplification the received signals would be passed ***to a loudspeaker***

Disadvantages of such communication

- The 3 systems of communication in the earlier slide have 2 serious disadvantages:

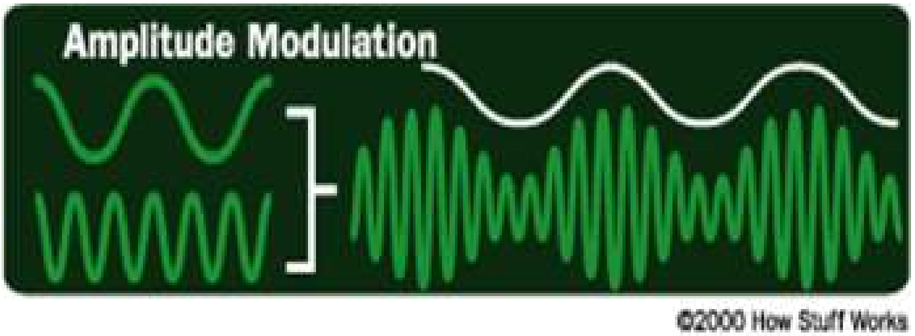
  1) the aerial required for the transmission of the low frequencies of sound waves(about 20 Hz to 20 kHz) would be very long.

  **The design of the aerial is usually ½ or ¼ of the wavelength.*

  2) If more than one radio station transmitted waves of these frequencies (20 to 20 kHz) your receiver would pick them all up at the same time. Imagine listening to a radio receiver where you hear every radio station at once.

- Nevertheless, all these problems can be solved by a process known as **modulation.**

Modulation


Amplitude Modulation
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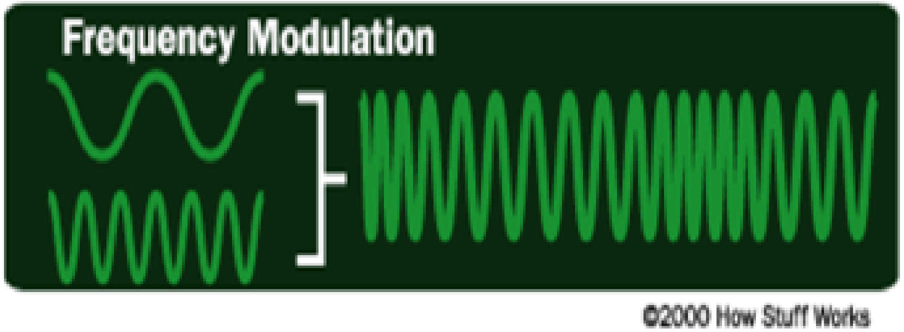
Frequency Modulation
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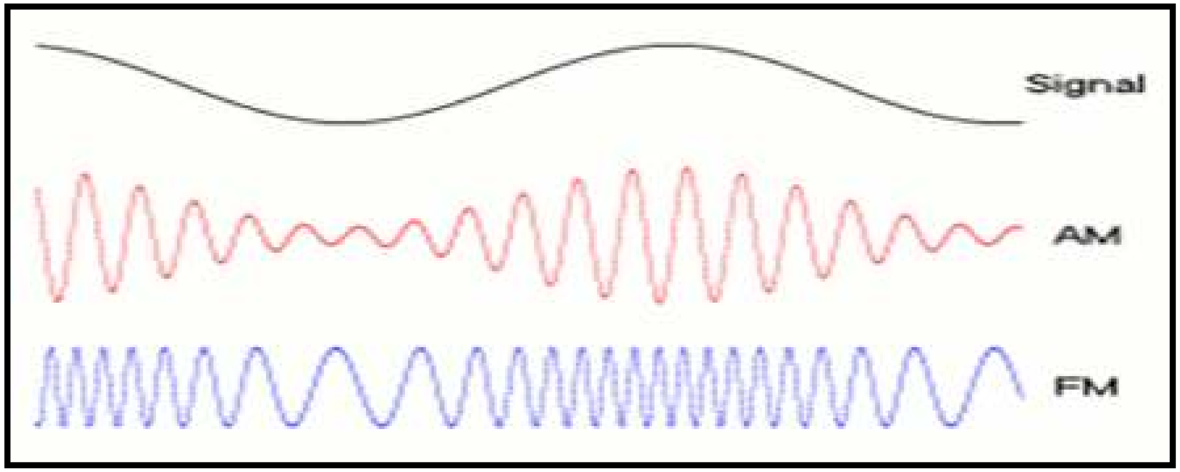
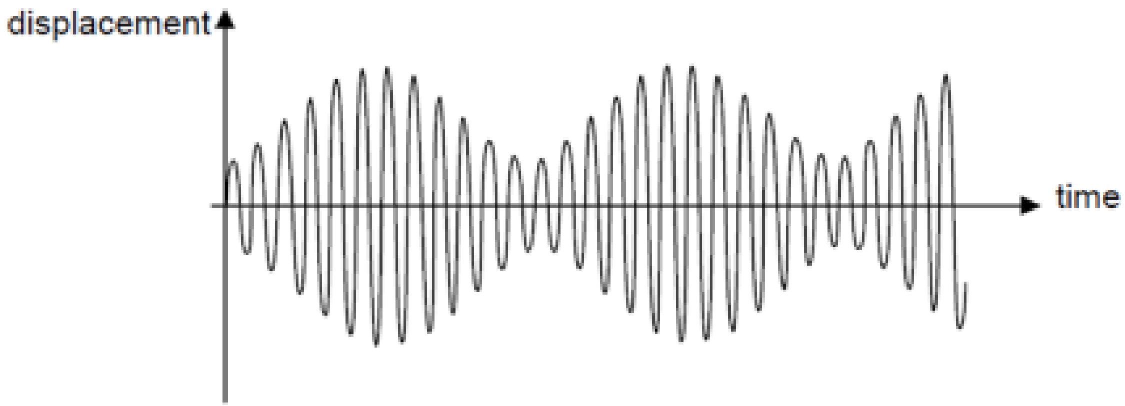

Signal
AM
FM

Modulation

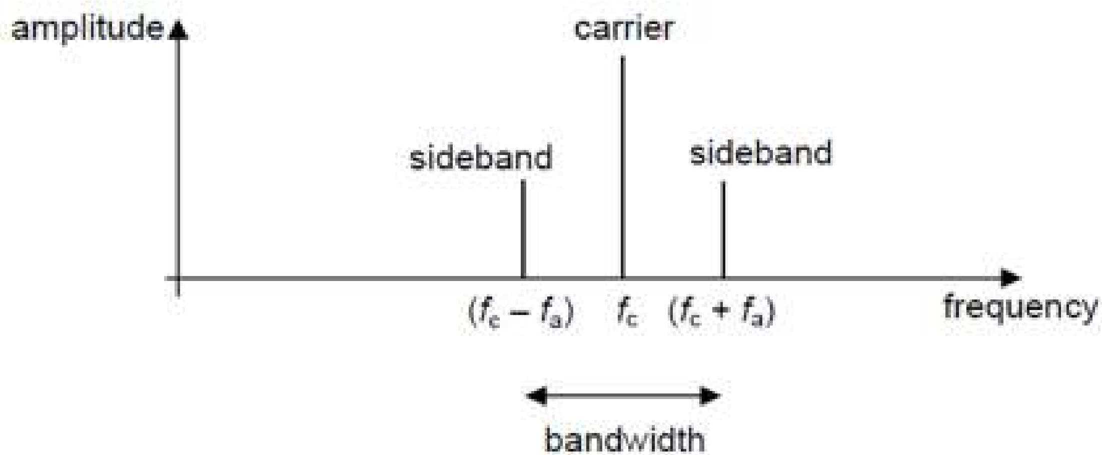
- **Modulation** (means vary) is a process whereby a high frequency wave, known as a ***carrier wave*** is transmitted. This carrier wave has either the ***amplitude varied*** or the ***frequency varied*** so as to carry information.
- In amplitude modulation (AM), the carrier wave has constant frequency. *The amplitude of the carrier wave is made to vary in synchrony with the displacement of the information signal.*
- The rate at which the amplitude of the carrier wave varies is related directly to the frequency of the information signal.
- In frequency modulation(FM), the amplitude of the carrier wave remains constant. *The frequency of the carrier is made to vary in synchrony with the displacement of the information signal.*
- The use of a carrier wave allows different radio stations in the same area to transmit at the same time, but each radio station has a different transmitting carrier wave frequency.
- The receiver is ***tuned*** or adjusted to the frequency of whichever transmitter or radio station is desired i.e. the receiver accepts the signal transmitted on that particular carrier wave and rejects all other carrier wave frequencies.

AM - sidebands and bandwidth

- Figure below shows the waveform resulting from the amplitude modulation of a high frequency carrier wave by a signal that consists of a single audio frequency.



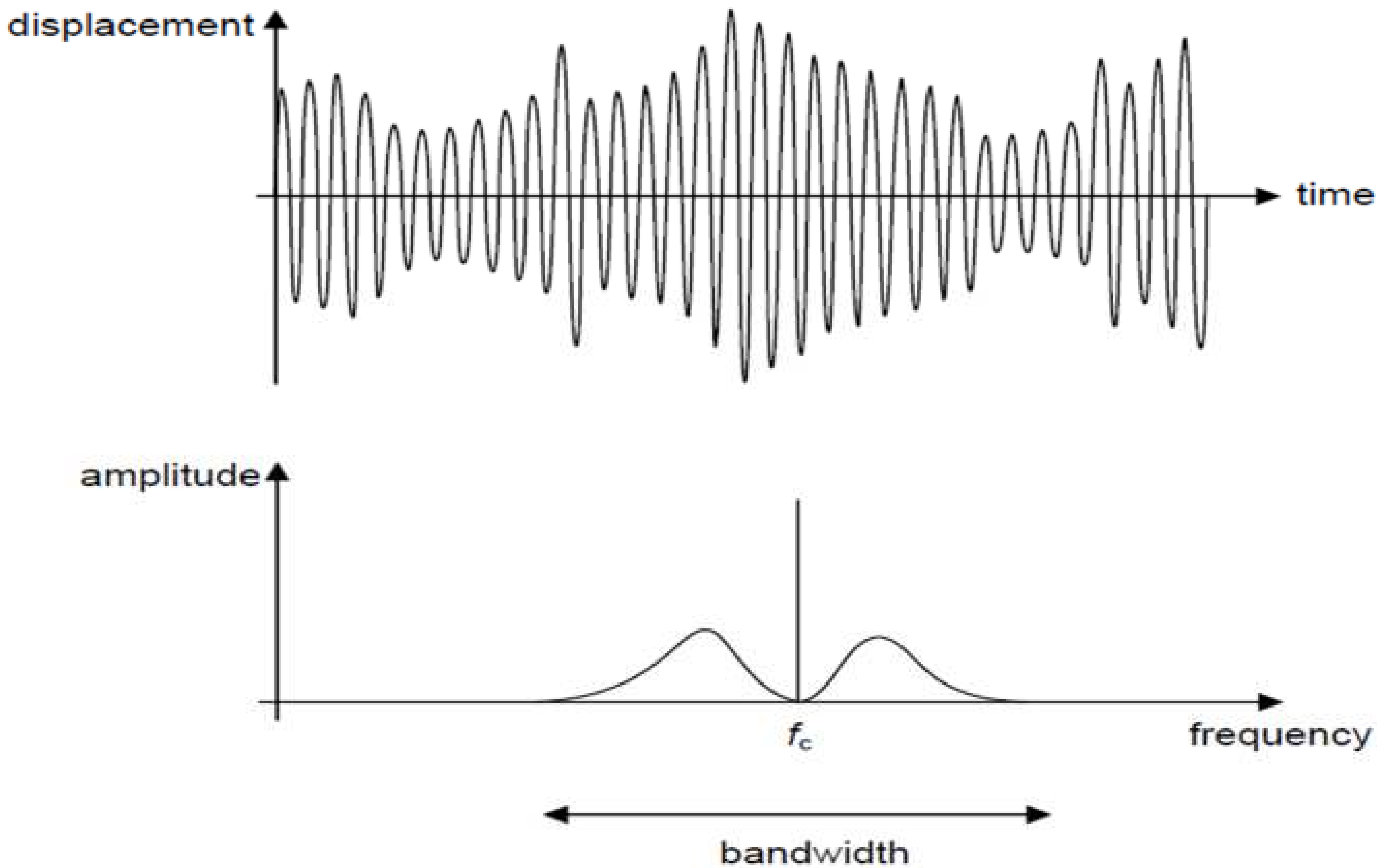
- When this waveform is analyzed in the frequency domain, it is seen to be composed of the sum of three waves of three separate frequencies. These waves are illustrated in the frequency spectrum as below. Conversion to frequency domain in done by using a very powerful mathematical tool called the Fourier transform.



AM - sidebands and bandwidth

- The central frequency f_c is that of the high-frequency carrier wave.
- The other two are known as **sidebands** and for the AM waveform, they occur at frequencies given by $f_c \pm f_a$, where f_a is the frequency of the audio signal.
- The relative amplitude of the sidebands and the carrier depends on the relative amplitudes of the audio and the carrier waveforms. If there is no audio frequency signal, there are no sidebands!
- **Bandwidth** is the frequency range occupied by the AM waveform. This is equal to $2f_a$.
- Figure in the next slide illustrates the AM waveform and the corresponding frequency spectrum for a voice signal.

AM - sidebands and bandwidth



Relative advantages of AM and FM transmissions

- **Range**
  - AM radio transmissions on long-wave (LW), medium-wave (MW) and short-wave (SW) wavebands are broadcast over very large distances so that one transmitter can serve a large area.
  - FM transmissions have a range of only about 30 km and this range is by line-of-sight hence many transmitters are required in order to broadcast over a large area.

- **Interference and Quality**
  - AM is more susceptible to noise compared to FM.
  - Therefore, the quality of FM reception is generally better than that of AM since there will be less noise or interference.

- **Cost and simplicity**
  - It is simpler and cheaper to broadcast and receive using AM, as the AM transmitters are much simpler electronically than those for FM

Relative advantages of AM and FM transmissions

- **Bandwidth and Quality**
  - The bandwidth of AM broadcasts on the LW and MW wavebands is 9 kHz which means that the highest frequency that can be broadcast is 4.5 kHz which is quite adequate for speech but not for music for which distortion can be easily noticed
  - The bandwidth of an FM broadcast on the very-high-frequency(VHF) waveband is about 200 kHz, giving a maximum frequency that can be transmitted or broadcast of about 15 kHz hence offering higher quality.

- ***Transmission waveband and transmitters***
  - The LW waveband has a range of frequencies from about 30 kHz to 300 kHz
  - If the bandwidth of each AM broadcast is 9 kHz, then theoretically (300-30)/9 = 30 transmitters could broadcast in the same area without causing interference between each other.
  - For FM broadcasting(300-30)/200 = 1 transmitter only can broadcast in the LW band
  - Hence the number of transmitters that can share the same waveband is much larger for AM than FM
  - For this reason FM is broadcast only at frequencies in excess of 1 MHz

Digital transmission

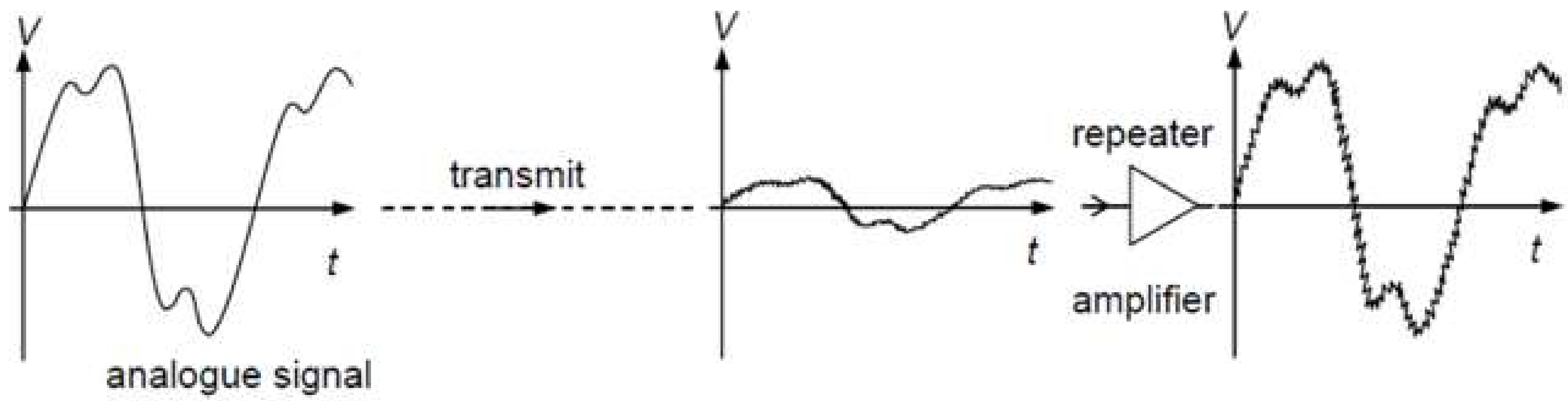
Analogue signals

- Any information that has the same variations with time as the information itself is known as an **analogue signal.**

  e.g. the signal produced by a microphone is analogous to the sound wave incident on the microphone
- Much of the information that is to be communicated in the real world is analogue information (e.g. the voltage output of a microphone that varies with time in a similar manner to the sound waveform that caused it). If this analogue signal is to be transmitted over a large distance (either by radio or by cable) it will be attenuated and it will pick up noise.
- Attenuation is a gradual reduction in signal power. This could be, for example, ohmic losses in a metal cable.
- In any electrical system there is always unwanted power present that adds itself in a random manner to the signal. This unwanted random power is called *noise* and it causes distortion of the signal.
- There are several sources of noise. One arises from the thermal vibrations of the atoms of the material through which the signal is passing. As a result, noise power cannot be totally eliminated.

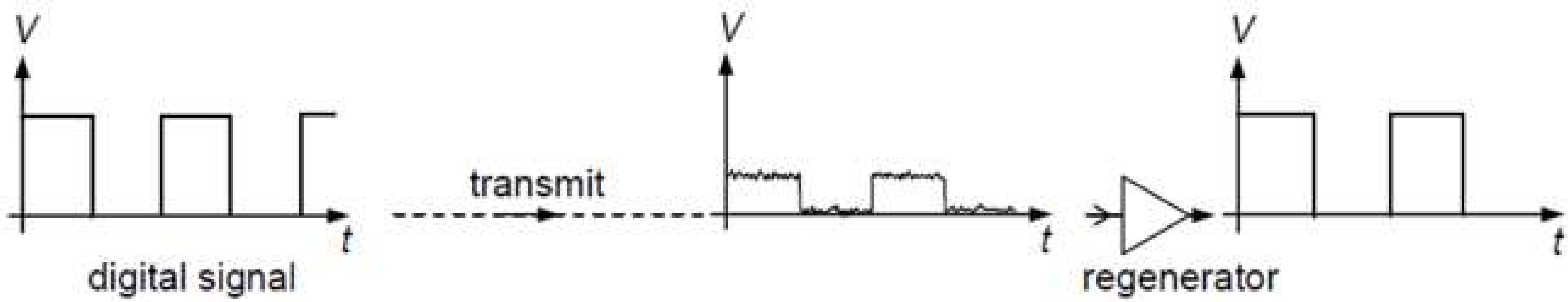
Analogue signals

- Attenuation will mean that, eventually, the signal will have to be amplified so that it can be distinguished from the background noise.
- This is achieved using a repeater amplifier that amplifies the signal before passing it further on.
- The amplifier will, however, amplify the noise as well as the original signal. After several of these repeater amplifications (required for transmission over long distances), the signal will become very ‘noisy’. This effect is illustrated in figure below.



Digital signals

- Digital signal is a signal consisting of series of pulses with discrete values. If the signal is transmitted in digital form, then it also suffers from attenuation and the addition of noise.
- However, the amplifiers that are used for amplifying digital signals are required only to produce a ‘high’ voltage or a ‘low’ voltage.
- They are not required to amplify small fluctuations in amplitude, as is the situation for amplification of an analogue signal. Since noise consists, typically, of small fluctuations, the amplification of a digital signal does not also amplify the noise.
- Such amplifiers are called *regenerator amplifiers* and are able to reproduce the original digital signal and, at the same time, ‘filter out’ the noise. This is illustrated in below.



Digital signals

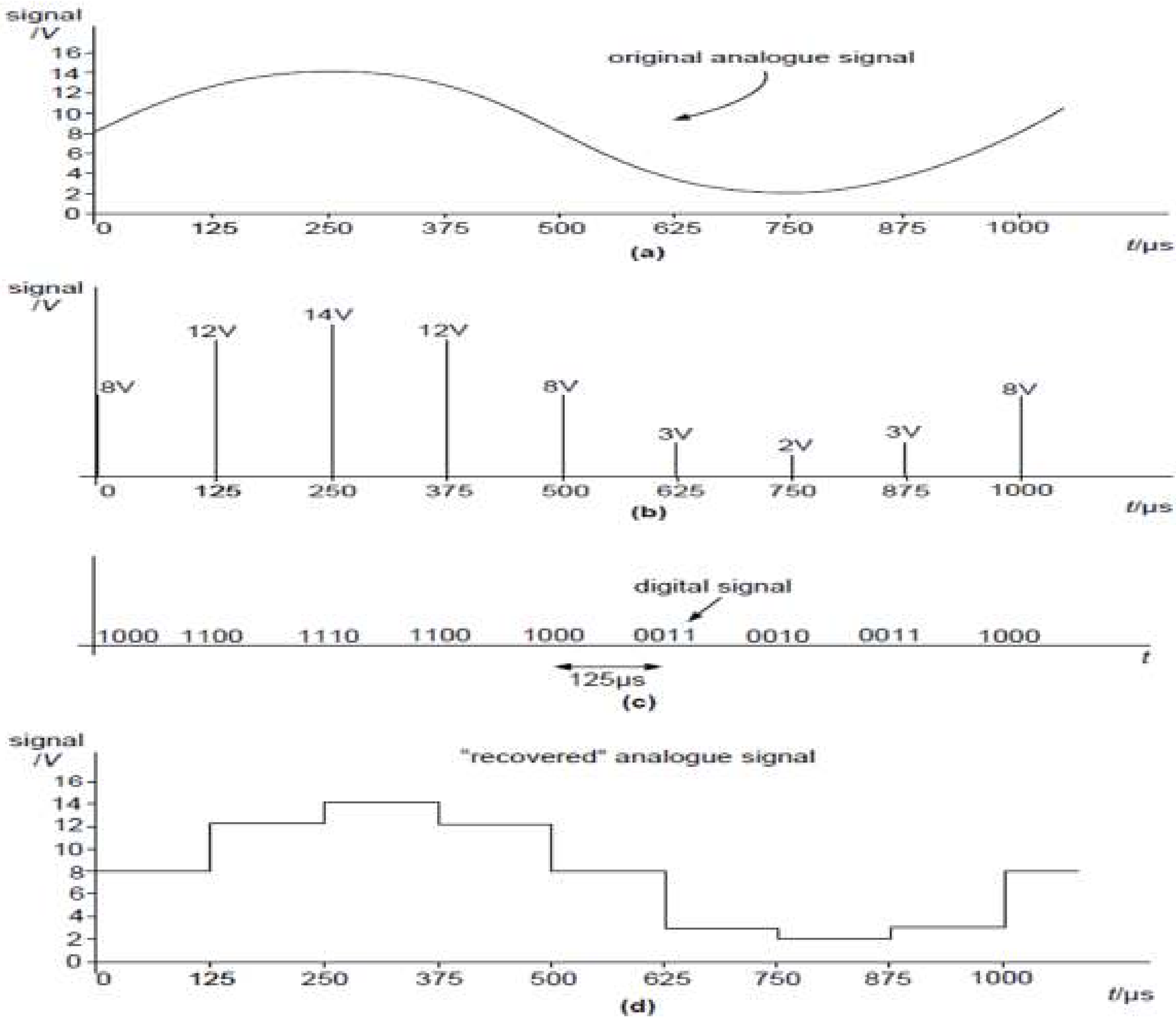
- As a result, a digital signal can be transmitted over very long distances with regular regenerations without becoming increasingly noisy, as would happen with an analogue signal.
- A further advantage of digital transmissions is that they can have extra information – extra bits of data – added by the transmitting system. These extra data are a code to be used by the receiving system to check for errors and to correct them before passing the information on to the receiver.
- The extra bits of data can also used to enhance the security of the information being sent by encryption.
- Nowadays, digital circuits are generally more reliable and cost of usage is cheaper than analogue circuits.
- It also helps in the expansion of the Internet and international calls.

- However, the disadvantage of digital over analogue form is the extra circuitry required such as ADC & DAC.
- On the social aspect, it gave lesser job opportunity in the telephone industry,

Digital signals

- The electrical signals derived from speech or music are analogue audio-frequency signals. The voltage generated varies continuously. To convert an analogue signal into a digital signal involves taking samples of the analogue waveform (i.e. measuring its instantaneous voltage) at regular intervals of time. The instantaneous or sample voltage is converted into a binary number that represents its value.
- For example, if the instantaneous value of the analogue signal is 6 V, the binary number could be 0110. For an instantaneous value of 13 V, the binary number could be 1101.
- Note that a binary digit is referred to as a ***bit*****.** The most significant bit (MSB) – the bit representing the largest decimal number is written first. The bit representing the lowest decimal number (1) is known as the least significant bit (LSB) and is written last.
- A digital signal consists of a series of 'high' and 'low' voltages. A 1 represents a 'high' voltage and a 0 represents a 'low' voltage. A 4-bit system is used in the example. In reality, 8 or more bits would be used for any sampling.

Use of ADC on transmission & DAC on reception of digital signals



Use of ADC on transmission & DAC on reception of digital signals

- Fig. (a) shows an analogue signal of frequency 1 kHz. This signal is sampled every 125 μs (a sampling frequency of 8 kHz). The sample voltages are shown in Fig. (b). The sampling frequency is provided by a very high frequency clock. The clock is of high frequency so that the highest frequency component in the information signal can be detected.
- It should be noted that the value given to the sampled voltage is always the value of the nearest increment ***below*** the actual sample voltage.
- In this particular example, an analogue signal of 14.3 V would be sampled as 14 V and one of 3.8 V would be sampled as 3 V. The resulting digital signal is shown in Fig. (c). Each number is a group of 4 bits and these groups are separated in time by 125 μs.
- The choice of sampling frequency is important. A lower sampling frequency means that less information can be gathered from the analogue signal.
- More than eighty years ago, it was shown by Nyquist that, in order to be able to recover the analogue signal from its digital conversion, the sampling has to occur at a frequency greater than twice the highest frequency component in the original signal.

Use of ADC on transmission & DAC on reception of digital signals

- As a result, in the telephone system, the highest frequency is restricted to 3.4 kHz because the sampling frequency is 8 kHz. In the manufacture of compact discs, the highest frequency is 20 kHz and the sampling frequency is 44.1 kHz.
- After the analogue signal has been converted to a 4-bit digital signal by the **analogue-to-digital converter (ADC),** the digital signal is transmitted.
- The original signal can be recreated by passing the 4-bit numbers into a **digital-to-analogue converter (DAC).**
- This is illustrated in Fig. (d) where the original analogue signal of Fig. (a) has been recreated.
- The output of the DAC is 'grainy' and is not smooth because the number of bits limits the number of possible voltage levels (with 4 bits there are 2^4 = 16 levels; with 8 bits, there are 2^8 = 256 levels).
- As described above, a higher sampling frequency also enables more detail of the analogue signal to be recovered.

Use of ADC on transmission & DAC on reception of digital signals

- As a summary, in order to improve the quality of the received analogue signal, two changes can be made.

  1.) Make the time interval smaller by increase the sampling frequency / sampling rate.

  By doing so, we are able to cover the smallest peak – trough time interval.

  2.) Make the voltage interval smaller by increasing the number of bits used in the DAC.

  By doing so, we are able to cover the smallest peak – trough voltage interval.