Signal Attenuation

Signal attenuation

- When an electrical signal is transmitted along a metal wire, it gradually loses power, mostly as thermal energy in heating the wire. (apart from becoming distorted due to interference from other em source / cross-talk)
- Similarly, a light pulse travelling along an optic fibre loses power, mostly by absorption due to impurities in the glass and by scattering due to imperfections. Electromagnetic waves lose power by absorption and dispersion.
- A reduction in signal power is referred to as *attenuation*.
- Infra-red is prefer over UV radiation for long distance communication using optic fibres because it has lesser attenuation perunit length / longer uninterrupted length of fibre.
- In order that a signal may be detected adequately, its power must be a minimum number of times greater than the power associated with noise. Typically, this signal-to-noise ratio could be 100.
- Repeater amplifiers may be required to increase the power of a signal that is being passed along a transmission line. The gain of such an amplifier (the ratio of the output power to the input power) could be 100000.
- For a radio link between Earth and a geostationary satellite, the power received by the satellite may be 10^{19} times smaller than that transmitted from Earth.

Signal attenuation

- It can be seen from the above examples that the ratio of the two powers may be very large.
- Consequently, an extremely convenient unit by which power levels, or any other quantities, may be compared is the bel (B). The number of bels is related to the ratio of two powers P_1 and P_2 by the expression

$$\text{number of bels} = \lg(P_1/P_2)$$

- In practice, the ratios are usually expressed in decibels (dB), where 10 dB = 1 B. Consequently,

$$\textbf{number of decibels} = \mathbf{10\ lg}(P_1/P_2)$$

- The numbers involved will be smaller & more manageable. Calculations involved addition & subtraction instead of multiplication & division.

- If $P_2 > P_1$ ***the dB number is negative***
- If $P_2 < P_1$ ***the dB number is positive***

Signal attenuation

Example

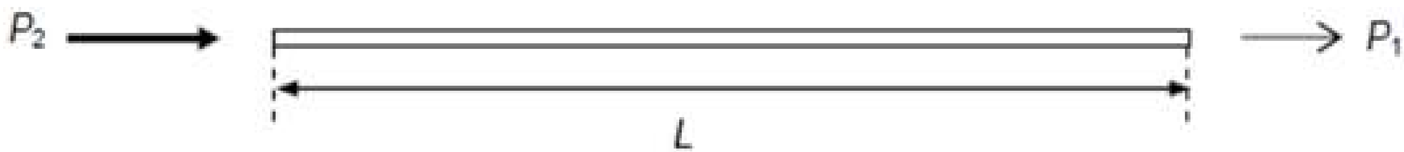
The gain of an amplifier is 45 dB. Calculate the output power P_{out} of the amplifier for an input power P_{in} of 2.0 μW.

$$\text{number of decibels} = 10\,\lg(P_1/P_2)$$

$$\begin{aligned}
45 &= 10\,\lg(P_{out} / 2.0 \times 10^{-6}) \\
4.5 &= \lg(P_{out} / 2.0 \times 10^{-6}) \\
10^{4.5} &= (P_{out} / 2.0 \times 10^{-6}) \\
P_{out} &= 10^{4.5} \times 2.0 \times 10^{-6} \\
P_{out} &= 6.3 \times 10^{-2}\ \text{W}
\end{aligned}$$

Signal attenuation

A transmission line has an input power P_2 and the power at a point distance L along the line is P_1 as illustrated in Fig. 3.17.



Then, attenuation in the line = 10 lg (P_2 / P_1) dB.

Since a transmission line may vary in length, an important feature of a transmission line is its attenuation per unit length.

$$\text{attenuation per unit length} = \frac{1}{L} 10 \lg \frac{P_2}{P_1}$$

Example

The input power to a cable of length 25 km is 500 mW. The attenuation per unit length of the cable is 2 dB km^{-1}. Calculate the output power of the signal from the cable.

signal loss in cable $= 2 \times 25 = 50$ dB

$50 = 10 \lg(500 \times 10^{-3} / P_{out})$, where P_{out} is the output power.

$P_{out} = 500 \times 10^{-3} \times 10^{-5} = 5 \times 10^{-6}$ W.

Signal attenuation

The signal cannot be allowed to travel indefinitely in the cable because, eventually, it will become so small that it cannot be distinguished from background noise. An important factor is the minimum *signal-to-noise ratio* that effectively provides a value for the lowest signal power allowed in the cable.

In the above example, the background noise is 5×10^{-13} W and the minimum signal-to-noise ratio permissible is 20 dB. Then if P_M is the minimum signal power,

$$20 = 10 \lg(P_M / 5 \times 10^{-13})$$

$$P_M = 5 \times 10^{-13} \times 10^2 = 5 \times 10^{-11} \text{ W.}$$

This enables the maximum uninterrupted length of cable along which the signal can be transmitted to be determined.

Maximum loss in cable $= 10 \lg(500 \times 10^{-3} / 5 \times 10^{-11}) = 120$ dB

Maximum distance $= 120 / 2 = 60$ km.

Signal attenuation

Example:

The signal input to an optic fibre is 7.0 mW. The average noise power in the fibre is 5.5×10^{-19} W and the signal-to-noise ratio must not fall below 24 dB. The fibre has an attenuation of 1.8 dB km^{-1}.

Calculate:

a) the minimum effective signal power on the cable

b) the maximum uninterrupted length of the optic fibre through which the signal can be transmitted

Solution

a) number of decibels(dB) $= 10 \lg(P_2/P_1)$

$$24 = 10 \lg(P_{min}/(5.5 \times 10^{-19}))$$

$$\mathbf{P_{min} = 1.38 \times 10^{-16}\ W}$$

b) total attenuation of signal to reach minimum $= 10 \lg(P_{input}/P_{min})$

$$= 10 \log((7.0 \times 10^{-3})/(1.38 \times 10^{-16}))$$

$$= 137 \text{ dB}$$

maximum uninterrupted length = total attenuation / attenuation per unit length

$= 137/1.8 =$ **76 km**

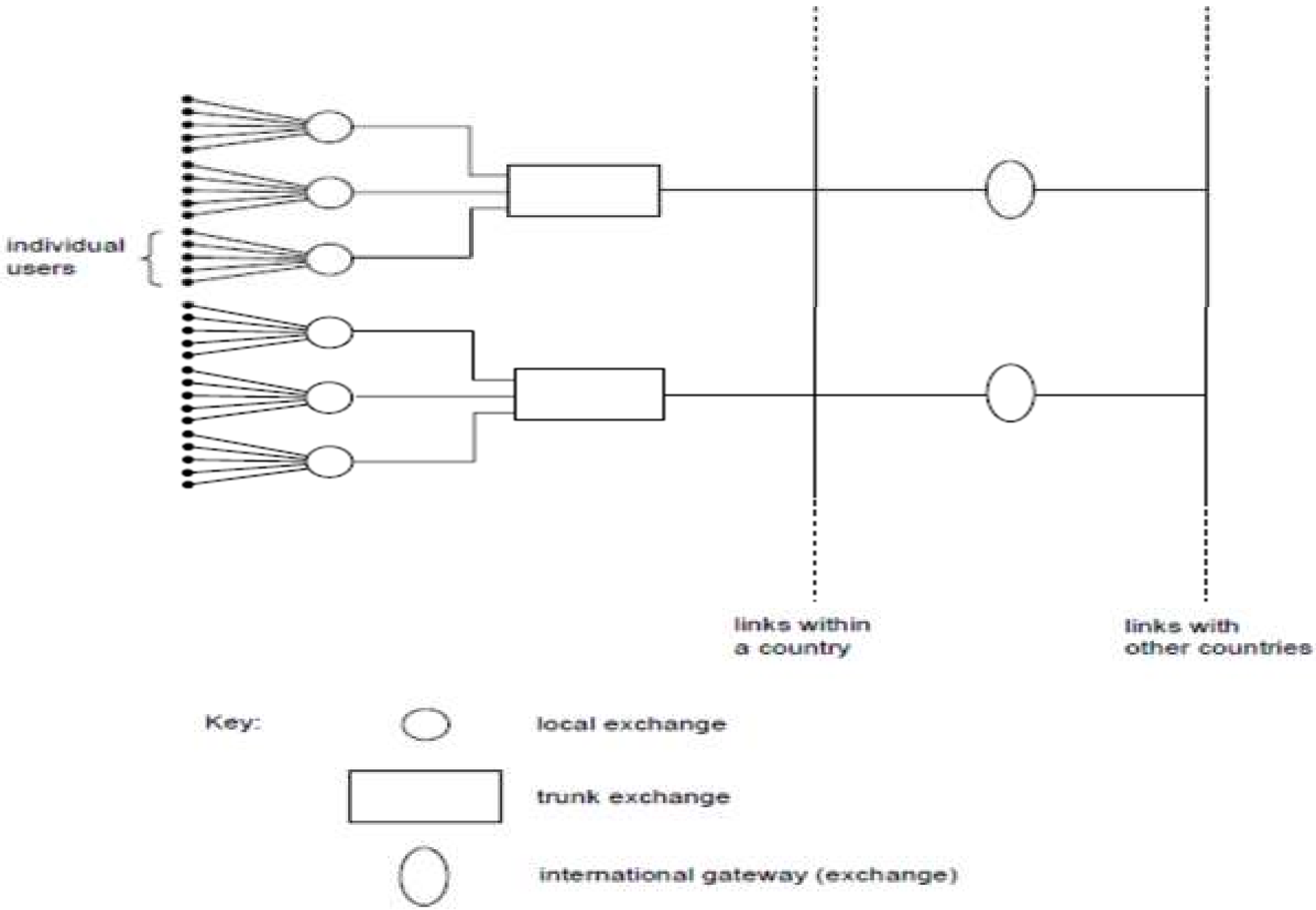
The Mobile Phone Network

The mobile phone system & PSTN

- In the early days of telephones, each telephone user was connected to all other users by their own cables. This was feasible only where the number of users was small as in, for example, a single building.
- As telephones became more popular and widespread, connections between individual users became impractical.
- Consequently, the telephone exchange was developed. The caller would contact the telephone exchange and, at the exchange, the connection to the other user would be made by a person known as an ‘operator’.
- If the call was not a local call served by that particular exchange, then the local exchange would contact the other user’s local exchange via a trunk exchange. Trunk exchanges were connected via trunk lines and hence the expression ‘trunk call’ for any long-distance call.
- In essence, the Public Switched Telephone Network (PSTN) uses the same principles of exchanges but has developed with modern technology and the number of users. For example, switching is no longer achieved using operators. Electromagnetic relays have been replaced by solid-state devices and international ‘exchanges’, or gateways, have been introduced.

The mobile phone system & PSTN

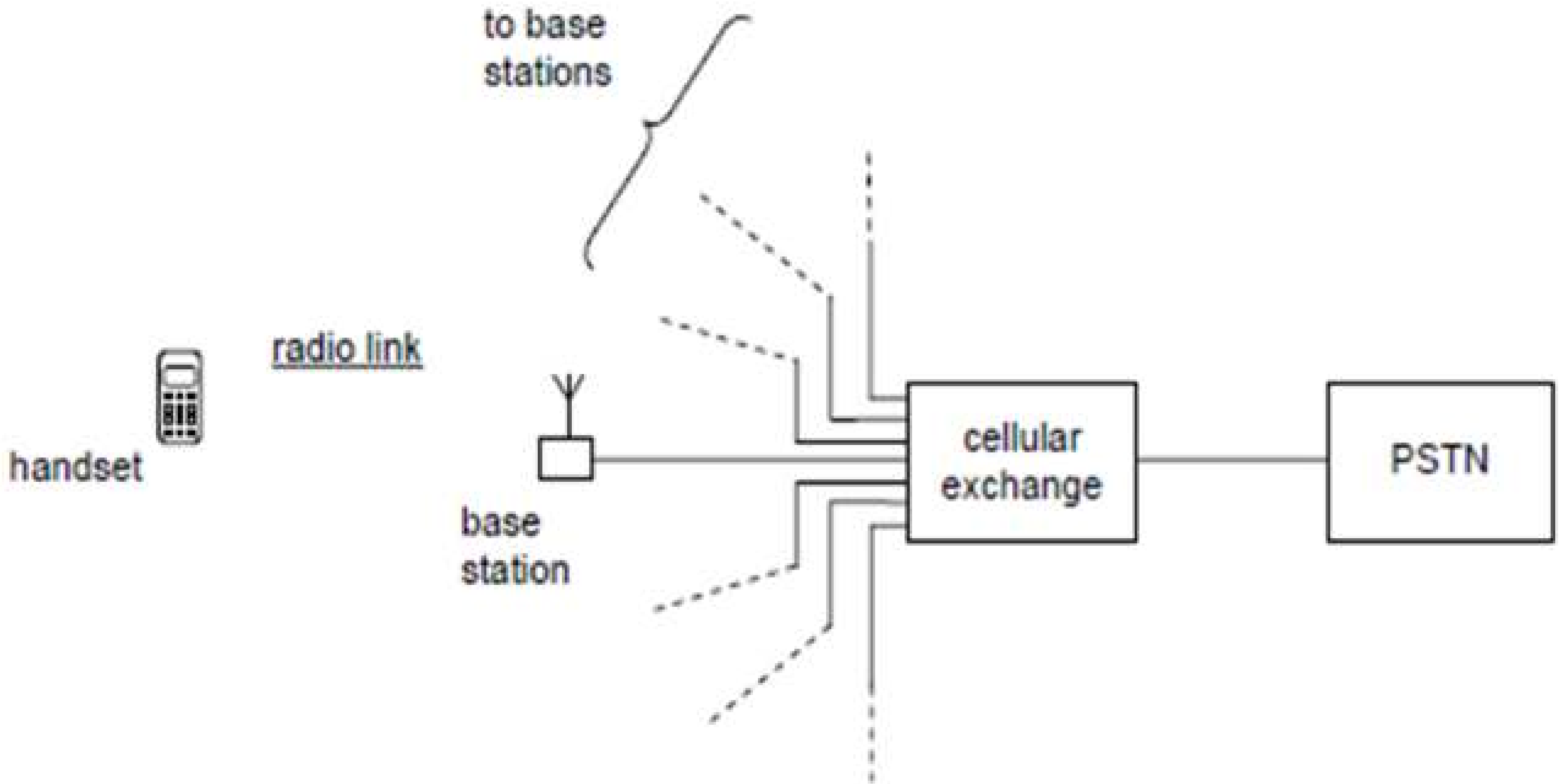
- The PSTN is illustrated as below.



The mobile phone system & PSTN

- In the system illustrated in previous slide, the user is connected to the PSTN via the local exchange. Each user has a ‘fixed line’ to the local exchange, resulting in the user having limited mobility whilst making the call.
- During the 1970s and 1980s, mobile phone systems were developed that did not have a permanent link to a local exchange.
- Basically, a mobile phone is a *handset* that is a radio transmitter and receiver. When a call is to be made, the user makes a radio-wave link with a nearby *base station*. This base station is connected by cable to a *cellular exchange*.
- The cellular exchange then allows connection to be made to the PSTN.
- This is illustrated in the following slide.

The mobile phone system & PSTN

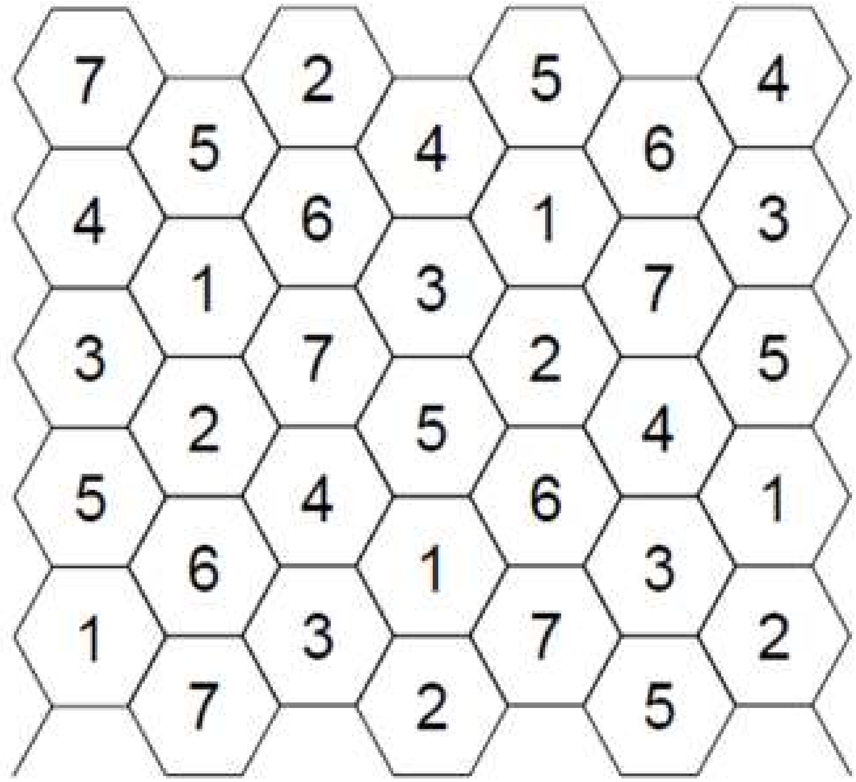


The mobile phone system & PSTN

- The popularity of mobile phones means that large numbers of people use a mobile phone system at the same time.
- However, the range of carrier-wave frequencies for linking between the mobile phone and the base station is limited.
- Consequently, each mobile phone cannot have its own carrier frequency. This means that the same carrier frequencies must be used by many mobile phones at the same time. This is achieved by dividing a region into areas called cells, with each cell having its own base station, usually located near the centre of the cell. The aerial at the base station transmits in all directions so as to cover the whole cell, but not to overlap too far into neighbouring cells. In this way, the whole country is ‘covered’.
- The base stations operate on UHF frequencies whereby they have a limited range and are low-power transmitters which are also the reason why the region is divided in to cells. The UHF frequencies also mean that the aerial in the mobile phone is conveniently short! UHF frequencies gives large waveband which allows for more carrier frequencies.
- Neighbouring cells cannot use the same carrier frequencies, otherwise interference would occur at the boundaries between cells. A possible arrangement of cells is shown in diagram in the next slide.

The mobile phone system & PSTN

- Although each cell is approximately circular (depending on the flatness of the land), the cells are shown as a 'honeycomb' so that the cells fit together.
- The number in each cell represents a particular range of carrier frequencies that would be allocated to each cell. Neighbouring cells do not have the same range of carrier frequencies.
- What happen when a handset is switched on? When a handset is switched on, it transmits a signal to identify itself. This signal is received by a number of base stations, from where it is transferred to the cellular exchange.
- A computer at the cellular exchange selects the base station with the strongest signal from the handset. The computer also allocates a carrier frequency for communication between the base station and the handset.



- In order to maintain a continuous signal, during the communication between the handset and the base station, the computer at the cellular exchange monitors the signal from the handset. If the user of the handset moves from one cell to another, the signal strength changes. The call from the handset is then re-routed through the base station with the greater signal.

The mobile phone system & PSTN

- **Roles of the Cellular Exchange**

  1) permits entry to PSTN
  2) selects base station for any handset
  3) allocates a carrier frequency/channel
  4) monitors handset signal to re-allocate base station
  5) keeps track of the handset's location in a database

- **Roles of the Base Station**

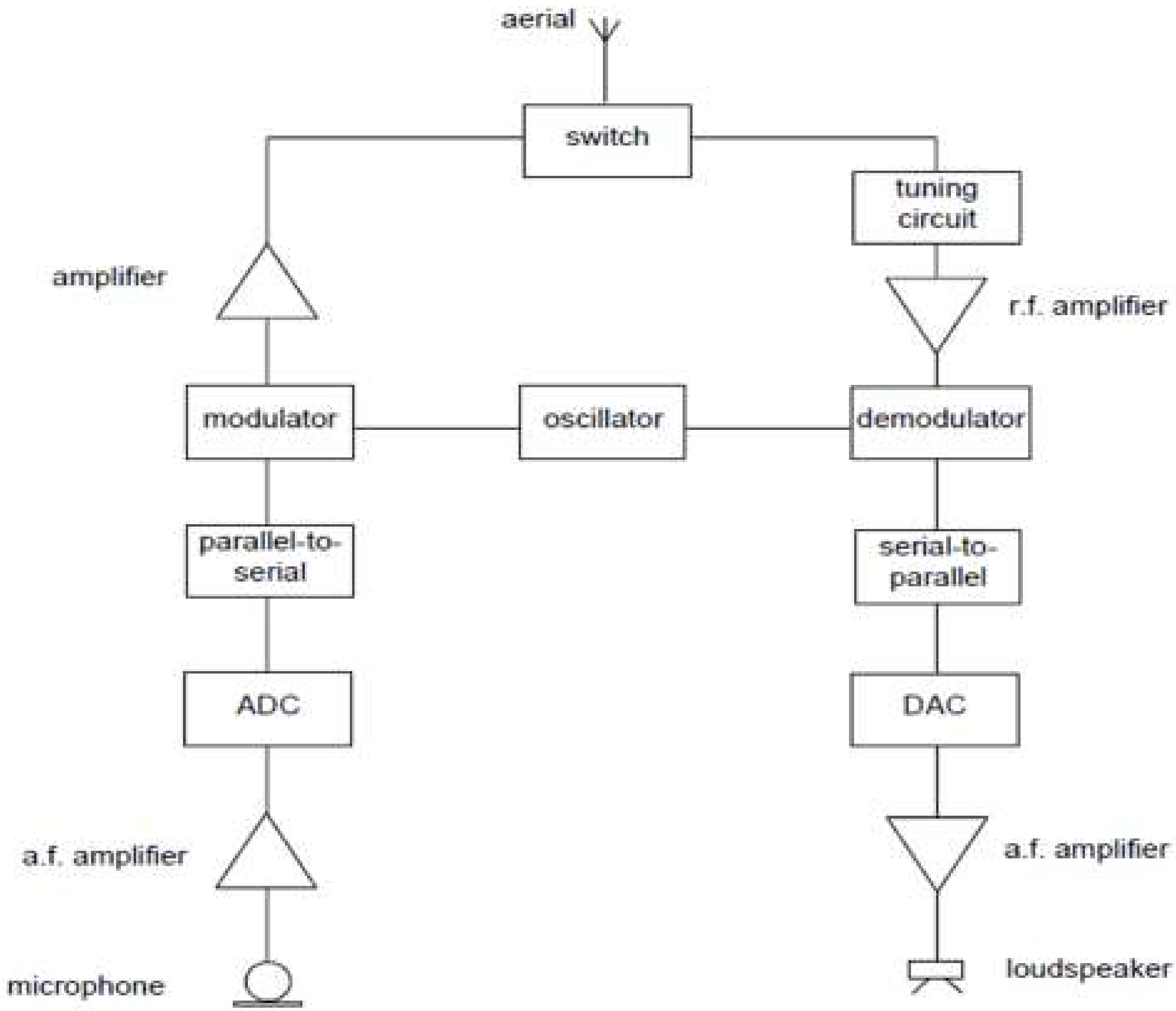
  1) detects signal from handset
  2) sends out signal to the handset
  3) transmits information between the handset and the cellular exchange

- **Why the country is divided into a number of cells.**

  1) Carrier frequencies can be re-used simultaneously without interference so that number of handsets possible is increased
  2) lower power transmitters so less interference
  3) Since UHF used so must be line-of-sight/short range/handset aerial

The mobile phone system & PSTN

- A mobile-phone handset is, in its simplest form, a radio transmitter and receiver. A simplified block diagram of its circuitry is shown in figure below.



The mobile phone system & PSTN

- The caller speaks into the microphone. This produces a varying signal voltage that is amplified and converted to a digital signal by means of the ADC.
- The parallel-to-series converter takes the whole of each digital sample voltage and then emits it as a series of bits. The series of bits is then used to modulate the chosen carrier wave.
- After further amplification, the modulated carrier wave is switched to the aerial where it is transmitted as a radio wave. The switch connecting the aerial is used so that only one aerial is required for transmission and reception.
- On receipt of a signal at the aerial, the signal is switched to a tuning circuit that selects only the carrier-wave frequency allocated to it by the computer located at the cellular exchange.
- This selected signal is then amplified and demodulated so that the information signal is separated from the carrier wave.
- This information signal is in digital form. It is processed in a series-to-parallel converter to produce each sample digital voltage from the series of bits received and then in a digital-to-analogue converter (DAC) to provide the analogue signal.
- After amplification, the analogue signal is passed to a loudspeaker.