TELEMETRY

Telemetry is defined as the sensing and measuring of information at some remote location and then transmitting that information to a central or host location. There, it can be monitored and used to control a process at the remote site. Various mediums of transmitting data from one site to another have been used. Data radio provides a wireless method for transmitting the information. Telemetry using radio waves or wireless offers several distinct advantages over other transmission methods. Some of these advantages are:

- No transmission lines to be cut or broken.
- Faster response time
- Lower cost compared to leased lines
- Ease of use in remote areas where it is not practical or possible to use wire or coaxial cables
- Easy relocation
- Functional over a wide range of operating conditions

COMPONENTS OF A TYPICAL WIRELESS TELEMETRY SYSTEM

At the remote site, a sensor or sensors are typically the data source. The output of the sensor(s) is converted to digital data by a small computer device or RTU (Remote Terminal Unit). The RTU is interfaced to a modem device that converts the digital data into an analog signal that can be transmitted over the air. The radio transmitter then transmits the signal to the host site radio receiver. Now the process is reversed. The modem takes the analog signal received and converts it back to a digital form that can be processed by the data recovery equipment.
In a typical application, the base or host site requests data from the remote site(s). The base transmits a request to the remote unit telling it to send its data. The base reverts to a receive mode and awaits the transmission from the remote site. After the remote sends its data, it goes back to a receive mode waiting for further instructions to come from the base. Once the base receives the remote site information, it may send additional instructions to that site or continue on to request data from the next remote site. This polling process continues until all the remotes in the system have sent their data.

**Classification of Telemetry Systems on the Basis of Signal Transmission Medium**

Telemetry systems were classified on the basis of the signal transmission medium or link used in Chapter-1 as under:

1. Wire-link or wire telemetry system
2. Radio or wireless telemetry system, with two special types:
   2.1. Short-range radio telemetry system
   2.2. Satellite radio telemetry system
3. Optical-fibre or fibre-optic telemetry system

_The three telemetry systems, using wire link, radio link and optical fibre link, are described in detail in Sections 3, 4 and 5, respectively._

**1. Wire-Link or Wire Telemetry System**

A basic wire-link or wire telemetry system, block schematic of which is shown below, should be seen as a specific case of the basic telemetry system with the following specifics:

(a) The signal transmission medium here is a pair of copper wires.

(b) The transmitter comprises an audio-frequency (AF) AC modulator or pulse modulator, as per the needs of the application, and an amplifier to strengthen the modulated carrier signal before sending it on the copper wire-pair. Multiplexer is not included as the only a basic (single-channel) telemetry system is being considered.

(c) Like the transmitter, the receiver also has only two elements, viz. an amplifier to carry out necessary amplification of the attenuated signal received through wire-pair and a demodulator to recover the information signal from the modulated carrier signal.

**2. Radio or Wireless Telemetry System**

Block schematic of a basic radio telemetry system is shown below. This can also be treated as a specific case of the basic telemetry system as under:

(a) The signal transmission medium here is a radio link, comprising a transmitting antenna (TA), a receiving antenna (RA) and the space between the two used for propagation of radio wave from TA to RA.

(b) The transmitter comprises a RF modulator (AM or FM type, depending on the performance, bandwidth and cost considerations) and an amplifier.
The receiver comprises an amplifier and a demodulator (AM or FM type as required to match the type of the modulator).

### 2.1 Short-Range Radio Telemetry System

The schematic given above is in principle valid for a basic short-range telemetry system also. The transmitter power may be very small as the range is very short, typically a few metres or a few tens of metres. The choice of radio frequency will be guided by the cost consideration and local requirements.

#### 2.2 Satellite Radio Telemetry System

Block schematic of a basic satellite radio telemetry system is shown below. This system can be considered as an advanced version of the basic radio telemetry system discussed earlier with the following advanced features:

(a) The communication between the transmitter and receiver takes place via a communication satellite, which is a machine that keeps rotating around the earth and is equipped with one or more transponders acting as radio-wave repeaters in the sky.

(b) The radio frequencies (RF) used are normally higher than 3.3 GHz, known as microwave frequencies.

(c) The transmitter in the sending earth-station incorporates, as shown in the figure, an intermediate-frequency (IF) modulator, an IF-to-RF up-converter and a power amplifier. The modulator typically uses FM in case of analog communication and PSK, QPSK or QAM in case of digital communication. The frequency converter comprises a mixer followed by a band-pass filter and its output is at the so-called uplink frequency.

(d) The transponder has a frequency translator (mixer plus band-pass filter) in addition to filters and a power amplifier. Its role is to receive microwave signal from one earth station, amplify, convert the high-band uplink frequency to the low-band down-link frequency, amplify and retransmit to the other earth station.

(e) The receiver in the receiving earth-station incorporates, as shown in the figure, a band-limiting filter, amplifier, RF-to-IF down-converter and an IF demodulator.
Lecture-2

3. Optical-Fibre or Fibre-Optic Telemetry System

Block schematic of a basic optical fibre telemetry system, presented in the figure below, shows the important components of the transmitter and receiver. The highlights of the system are as follows:
(a) The transmission signal is a high-intensity narrow infrared optical beam.

(b) The signal transmission medium is an optical fibre, which works on the principle of total internal reflection and thereby serves as the waveguide for the propagation of the optical beam from the transmitter to the receiver.

(c) The transmitter includes (i) a PCM modulator, which gets a digitized value of the measurand from signal conditioner-1 and produces binary voltage pulses in a coded sequence, (ii) a voltage-to-current converter, (iii) a light source, usually an injection laser diode (ILD) that converts the binary current pulses to binary optical pulses, and finally (iv) a light-source to optical-fibre coupling unit.

(d) The receiver includes components performing the complementary functions of the transmitter components in reverse order. These are:
   - optical-fibre to light detector coupling unit,
   - light detector, usually a PIN diode that detects the binary optical pulses it gets from the optical fibre and converts them to binary current pulses,
   - current to voltage converter, and
   - demodulator, which delivers digital voltage signal to the end device through signal conditioner.

In case the end device requires an analog input signal, the signal conditioner-2 would include a digital-to-analog converter (DAC). This is generally not the case as digital end devices are preferred to analog end devices these days. Thus, normally DAC is not present.

4. Further Classification of Telemetry Systems

Telemetry systems were classified in Chapter-1 on the basis of the modulation method used as under:
(i) DC telemetry systems
   1. Direct voltage telemetry system
   2. Direct current telemetry system

(ii) AC telemetry systems
   1. Amplitude modulation (AM) telemetry system
   2. Frequency modulation (FM) telemetry system

(iii) Pulse telemetry systems
1. Pulse amplitude modulation (PAM) telemetry system
2. Pulse width modulation (PWM) telemetry system
3. Pulse phase modulation (PPM) telemetry system
4. Pulse frequency modulation (PFM) telemetry system
5. Pulse code modulation (PCM) telemetry system

The same were also classified on the basis of the type of information signal as under:

(i) Analog telemetry systems
1. Direct voltage telemetry system
2. Direct current telemetry system
3. Amplitude modulation (AM) telemetry system
4. Frequency modulation (FM) telemetry system
5. Pulse amplitude modulation (PAM) telemetry system
6. Pulse width modulation (PWM) telemetry system
7. Pulse phase modulation (PPM) telemetry system
8. Pulse frequency modulation (PFM) telemetry system

(ii) Digital telemetry system
1. Pulse code modulation (PCM) telemetry system

The afore-listed telemetry systems, along with their merits and limitations, will be discussed in the following sections.

5. DC Telemetry Systems

The transmission signal for DC telemetry systems is either a DC voltage or a DC current and the signal transmission medium is essentially a pair of copper wires. Obviously no modulation or carrier is used in these systems.

5.1 Direct Voltage Telemetry System

**Principle:** Transmission signal for this telemetry system is a direct voltage (DC voltage) signal and the signal transmission medium is essentially a copper wire line, which is usually designed for a maximum voltage of about 80V.

**Sending-End Scheme:** As shown in the figure below, the transducer (sensor) converts the input physical variable (measurand) to an electrical quantity, which is either an electrical parameter or an electrical signal. This output is processed by appropriate electronic circuits (signal conditioner unit) to yield a voltage signal, typically in the range of 0-1V to 0-10V. Typically, the voltage is linearly proportional to the value of the measurand. This voltage signal is then suitably amplified to a value Vdc1 and to the copper wire link.

**Receiving-End Scheme:** To maintain simplicity of the system, the end device at the receiving end is a permanent-magnet moving-coil (PMMC) voltmeter. This type of meter has two important advantages of high sensitivity and scale linearity. The meter measures the voltage at the receiving end of the line, Vdc2. Its scale is calibrated in terms of measurand (M), so that the user can read the value of M directly.

**Transmission Error:** The voltage at the receiving end is given by  \( V_{dc2} = V_{dc1} - IR \)

Where I is the line current and R is the resistance of the line. The IR drop can be accounted for in the calibration of the complete telemetry system. However, R changes with the ambient temperature and thus calibration remains valid only for the temperature at which the
calibration was carried out. Any variations in the temperature would, therefore, lead to a telemetry error (specifically the transmission error part). To control or minimize this error, one has to minimize I, R and the temperature variations to which the wire line is subjected.

Based on the foregoing analysis, the following measures can be recommended for minimizing transmission error in this telemetry system:

(a) The resistance of the PMMC voltmeter should be maximum for a minimum value of the line current, I.
(b) The telemetry system should be used for short distances only to ensure a low value of the line resistance, R.
(c) Only an underground cable, as against open wires, should be used because the former is not directly exposed to the usually large variations in ambient temperature.

**Merits/ Advantages:** The obvious merits of direct voltage telemetry system are
1. Simplicity of the system and its components
2. Low cost of the system as there are no specialized components

**Demerits/ Disadvantages:** The demerits of this telemetry system are
1. It can be used only for short distances as both the error and the cost of line increase with the length of the wire line.
2. As the line current is small, the leakage currents could become comparable and thereby cause a large error in the meter reading.

**Application:** Because of the above demerits, this type of telemetry system is not favoured in practice.

### 5.2 Direct Current Telemetry System

**Principle:** Transmission signal for this telemetry system is a direct current (DC current) signal and the signal transmission medium is essentially a copper wire line. The most commonly used current signal is 4-20mA, but sometimes other ranges like 0-20mA or 0-10mA are also used in industry.

**Sending-End Scheme:** As can be seen in the figure below, this telemetry scheme is very similar the direct voltage telemetry scheme discussed earlier. The obvious difference in the sending-end

schemes is that the direct current system employs a voltage to current converter while the direct voltage system uses a voltage amplifier.

**Receiving-End Scheme:** The end device is a PMMC milli-ammeter as it has to read the value of the line current at the receiving end, Idc2, which is in milli-ampere range. Its scale is calibrated in terms of the measurand (M), so that the user can read the value of M directly.

**Transmission**
Transmission Error: As illustrated in the above figure, the line current at the receiving end is given by
\[ I_{dc2} = I_{dc1} - I_{leakage} \]
where \( I_{dc1} \) is the line current at the sending end and \( I_{leakage} \) is the small current leaking from one wire of the line to the other wire or to the ground due to a finite value of insulation resistance. This reduction in the line current from \( I_{dc1} \) to \( I_{dc2} \) due to leakage can be accounted for in the calibration of the complete telemetry system. However, the leakage current changes with the ambient temperature and thus calibration remains valid only for the temperature at which the calibration was carried out. Any variations in the temperature would, therefore, lead to a telemetry error (specifically the transmission error part). To control or minimize this error, one has to minimize the leakage current and the variations in the temperature to which the wire line is subjected. Therefore, the following measures can be taken to minimize transmission error in the direct current telemetry system, which are similar to those identified for the direct voltage system:
(a) The insulation resistance between the wires of the line and that between each wire and earth should be maximum for minimizing the leakage.
(b) The telemetry system should be used for short distances only, because the value of \( I_{leakage} \) is the product of the leakage current per unit length of the given wire cable and its total length.
(c) Only an underground cable, as against open wires, should be used as the former is not directly exposed to the usually large variations in ambient temperature.

Merits/Advantages: The merits of direct current telemetry system are
1. Simplicity of the system and its components
2. Low cost of the system as there are no specialized components
3. The line current is much more than the leakage current and, therefore, the latter has insignificant effect on the accuracy of measurement.
4. The “live-zero” system, like the popular 4-20mA signal system, can readily differentiate between a zero input (i.e. zero value of the measurand) and an open or short circuit in the line.

Demerits/Disadvantages: The only demerit or limitation of this telemetry system is that it can be used only for short distances because (a) the error due to leakage can become substantial if the length of the wire line is large, and (b) the cost of the line increases directly with its length.
Application: Because of the above merits and limitation, this type of telemetry system is very popular for in-plant telemetry where the distances are generally short.

Lecture-3

6. AC Telemetry Systems
The transmission signal for AC telemetry systems is a modulated AC (sinusoidal) signal. The type of modulation is either amplitude modulation (AM) or frequency modulation (FM). The signal transmission medium is either a pair of copper wires, which would use an audio-frequency (AF) carrier, or a radio link, which would need a radio-frequency (RF) carrier.

6.1 AM Telemetry System
Principle: Transmission signal for this telemetry system is an amplitude-modulated AC signal. Generally an AF sinusoidal signal is used as the carrier and a wire line as the transmission medium.

Sending-End Scheme: This system is preferably used with variable-inductance transducers, either single or complimentary-paired ones. These transducers need to be connected in an AC-excited Wheatstone bridge. The best frequency of excitation is typically a few kHz, which falls in AF range. A simple AM telemetry system based on these considerations is shown in the figure below. A complementary pair of inductive transducers, T1 & T2, forms two adjoining arms of the bridge, while the remaining arms are two fixed identical resistances, R1 & R2. The output of the bridge, which is the out-of-balance voltage, has obviously the same frequency as that of the excitation source (oscillator), while its amplitude increases with the variation of the transducer inductance, or in other words with the value of the measurand applied to it. Thus the bridge output is an amplitude-modulated AF signal, where the value of the measurand is causing the modulation. This signal is amplified in an AC amplifier to the desired level of amplitude before sending it on the wire line.

Receiving-End Scheme: For the reasons given under Direct Voltage Telemetry System, the end device is a PMMC voltmeter. Since it can read only a DC or a unidirectional voltage, a rectifier is placed before the meter. Because of the mechanical inertia of its moving parts, the meter responds to the average or peak value of the rectified voltage waveform. Its scale is calibrated in terms of the measurand (M), so that the user can read the value of M directly.
Transmission Error: If we compare the performance of the AM telemetry system with that of the direct voltage telemetry system, the voltage drop in the present case will be more because the line inductance in addition to line resistance will cause this drop. Consequently the variation in voltage drop and the error will also be higher.

The measures to be taken to minimize transmission error in the AM telemetry system are identical to those identified for the direct voltage system. These are as follows:
(a) The resistance of the PMMC voltmeter should be maximum for a minimum value of the line current.
(b) The telemetry system should be used for short distances only to ensure a low value of the line impedance.
(c) Only an underground cable, as against open wires, should be used because the former is not directly exposed to the usually large variations in ambient temperature.

Merits/ Advantages: The obvious merits of AM telemetry system are
1. Simplicity of the system and its components
2. Low cost of the system as there are no specialized components

Demerits/ Disadvantages: The demerits of AM telemetry system are
1. It can be used only for short distances as both the error and the cost of line increase with the length of the wire line.
2. As the line current is small, the leakage currents could become comparable and thereby cause a large error in the meter reading.

**Application:** Because of the above demerits, AM telemetry systems are not in common use. It may be useful only where inductive transducer suits the given measurand and the distance is short.

### 6.2 FM Telemetry System

**Principle:** Transmission signal for this telemetry system is a frequency-modulated AC signal. Generally a RF sinusoidal signal is used as the carrier and a radio link as the transmission medium.

**Sending-End Scheme:** FM telemetry has been largely used for short range radio telemetry and a simple telemetry system of this type is shown in the figure below. It can be best understood with reference to the basic telemetry system given in the first Section. A transducer converts the given physical variable (measurand) into an electrical output, which is conditioned/processed by an appropriate signal conditioner to yield a dc voltage proportional to the value of the measurand, M. This voltage signal is used for the frequency modulation of a radio-frequency (RF) carrier. The frequency-modulated radio-frequency (FM-RF) signal is applied to a transmitting antenna. Amplification after modulation is generally not required as a small transmitter power is sufficient for short-range radio transmission.

**Receiving-End Scheme:** The receiver selects the desired signal by employing a band-pass filter. This signal, being a FM-RF signal, is demodulated using a frequency demodulator thereby recovering the information signal. Signal conditioner-2 conditions/processes the information signal to make it compatible to the given end device. The end device thus gets the intended information, that is, the value of the measurand.

**Transmission Error:**

Since the information (value of M) resides in the frequency, and not the amplitude of the transmission signal, no telemetry error results from the attenuation or variations in the attenuation of this signal during its propagation. However, some error can occur due to selective fading of the radio signal during bad weathers if the telemetry system is used outdoor and due to high-frequency noise. Standard solutions to both the problems are available with radio communication engineers and, therefore, not dealt with here.
Merits/ Advantages: The merits of FM telemetry system are as under:
1. The most important advantage is that it can be used conveniently wherever it is difficult or impossible to access the sensor output with wire leads.
2. The system and its components are quite simple.
3. The system is inexpensive as only ordinary/standard components are used.
4. As the information (value of M) resides in the frequency, and not the amplitude of the transmission signal, no telemetry error results from the attenuation or variations in the attenuation of this signal during its propagation.
5. It can be easily extended to a multi-channel telemetry system using frequency division multiplexing (FDM), in which case each channel uses a carrier of different radio frequency.

Demerits/ Disadvantages
1. In outdoor telemetry applications, its performance can be problematic in bad weathers.
2. It can become expensive when used with long range-range transmissions in commercial radio frequency band.

Application: Because of the above merits, almost all short-range radio telemetry systems are FM telemetry systems
Lecture-4

7. Analog Pulse Telemetry Systems

PFM, PAM, PWM and PPM type pulse telemetry systems are all analog telemetry systems, while the fifth type, i.e. PCM telemetry system, is the only digital telemetry system. Of the four analog systems, only the PWM telemetry system of multi-channel type has some significance for industrial application and will, therefore, be discussed here. Although PAM telemetry is rarely used by itself, it forms the basis of the PWM telemetry systems and then take up a multi-channel PWM telemetry system. The PCM or digital telemetry system will be dealt with in the next Section.

7.1 Multi-Channel PAM Telemetry System

**Principle:** Transmission signal for PAM telemetry takes the form of amplitude-modulated pulses and multi-channel operation is achieved through time-division multiplexing (TDM).

- **Sending-End Scheme:** A 4-channel PAM telemetry system is shown in the figure below. It can be seen that the four physical variables or measurands, M1 to M4, are applied to appropriate transducers, T1 to T4, respectively.
- The transducer outputs are processed in suitable signal conditioners, SC-1 to SC-4, respectively, such that their outputs are the dc voltages, V1 to V4, proportional to M1 to M4, respectively.
- These voltage signals are applied to a 4-channel multiplexing switch (which is an integrated circuit device) at its input terminals, IN1 to IN4. The multiplexing switch functions under the control of a clock and makes one of the inputs available at a time at the output terminal, OUT, for a short duration equal to the time period of the clock.
- The switch normally functions in a cyclic order. The output of the switch is thus pulses with their amplitudes modulated by the input signals in cyclic order. The output is thus a time-multiplexed PAM signal, shown in the figure as a sequence of amplitude-modulated pulses, P1 to P4.
- It is expected that the first telemetry channel should always connect the first measurand at the sending end to the first PMMC voltmeter at the receiving end. Similar thing should be true for other channels too.
- To that end, the de-multiplexing switch in the receiving station should run in synchronism (both in terms of frequency or rate and phase or position). This is achieved by generating a synchronization pulse (sync pulse) before the start of each cycle of the multiplexing switch and adding this pulse to PAM signals before transmitting them to the receiving end, as shown in the block schematic.
- The sync pulse has the same width or duration as do the PAM pulses, but its amplitude is much larger than the maximum amplitude of any PAM pulse. 15
- **Receiving-End Scheme:** The receiver gets the sync pulse as well as PAM signals. The sync pulse is identified by a sync pulse detector (on the basis of amplitude) and delivered to the synchronization circuit, which acts on the de-multiplexing switch to synchronize it in frequency and phase with the multiplexing switch.
The time-multiplexed PAM signal (sequence of amplitude-modulated pulses, P1 to P4) is applied to the de-multiplexing switch, which outputs the pulses P1 to P4 at its output terminals, OUT1 to OUT4, respectively.

These pulsed signals are interpolated by the signal interpolators, SI-1 to SI-4 thereby producing continuous voltage signals, V1 to V4, proportional to P1 to P4, respectively.

Finally, these voltages are read on respective PMMC voltmeters which are calibrated in terms of values of the measurands M1 to M4.

Merits/ Advantages: The advantage of PAM telemetry system over the PWM and PCM telemetry systems is that it is relatively simpler and cheaper.
Demerits/ Disadvantages: The disadvantage can be understood from the simple fact that attenuation and changes in attenuation of the signal can result in much larger errors with PAM signals (because information is contained in the amplitude of the pulses) than with PWM and PCM signals (as no information is contained in the amplitude of the pulses).

Application: Because of the above disadvantage, PAM telemetry systems are rarely used.

8.1 Single-Channel PWM Telemetry System
Principle: Transmission signal for PWM telemetry (also known as PDM telemetry) takes the form of width-modulated (or duration-modulated) pulses.

- Sending-End Scheme: A single-channel PWM telemetry system is shown in the figure below. It can be seen that the physical variable or measurand M is applied to an appropriate transducer, the output of which is processed suitably by the signal conditioner to produce a dc voltage, Vdc, proportional to M.
- This voltage is applied to a pulse-width modulator to produce PWM signal, which is transmitted to the receiving end after necessary amplification and/or conversion of the signal by the transmitter. The nature of signal conversion will depend on the signal transmission medium as explained earlier.

![Block schematic of single-channel PWM telemetry system](image-url)
- Receiving-End Scheme: The receiver recovers the PWM signal from the received signal, which is applied to a pulse shaper to make the amplitude of these pulses constant (independent of the attenuation suffered during transmission) and their edges sharp.
- These perfectly-shaped width-modulated pulses are then input to a low-pass filter as shown in the block schematic. The filter produces a d.c. voltage, \( V_{dc} \), proportional to the pulse width of the input pulses, and thus proportional to \( M \).
- This d.c. voltage is read on a PMMC voltmeter serving as the end device at the receiving end. The voltmeter is calibrated in term of the value of the measurand \( M \), so that the user can read the value of \( M \) directly on this voltmeter.

**Pneumatic signals:**
- These are the signals produced by changing the air pressure in the signal pipe in proportion to the measured change in a process variable. The pneumatic signal range which is the common industrial standard is 3-15 psig.
- The 3 corresponds to the lower range value (LRV) and the 15 corresponds to the upper range value (URV). It is still a very commonly used signal type. However, since the invention of electronic instruments in the 1960s, the lower costs involved in running electrical signal wire through a plant as opposed to running pressurized air tubes has made pneumatic signal technology less popular.

![Image of Pneumatic Type Pressure Transmitter](image-url)
MULTIPLEXING
Multiplexing means combining multiple streams of information for transmission over a shared medium.

Types of Multiplexing
- Frequency Division Multiplexing.
- Wavelength Division Multiplexing.
- Time Division Multiplexing
- Statistical Time Division Multiplexing.
- Code Division Multiplexing.

Frequency Division Multiplexing (FDM)
- It is the basis for broadcast radio.
- Several stations can transmit simultaneously without interfering with each other provided they use separate carrier frequencies (separate channels).
- In data communications FDM is implemented by sending multiple carrier waves over the same copper wire.
- At the receiver’s end, demultiplexing is performed by filtering out the frequencies other than the one carrying the expected transmission.
- Any of the modulation methods discussed before can be used to carry bits within a channel.
Illustration of the basic FDM demultiplexing where a set of filters each selects the frequencies for one channel and suppresses other frequencies.

- Rather than a single frequency, each channel is assigned a contiguous range of frequencies.
- Channels are separated from each other by guard bands to make sure there is no interference among the channels.
- Why is a range of frequencies assigned rather than a single frequency?
  - Sender can do FDM within its channel to increase the data rate. For example, it can split its channel into $K$ subchannels and transmit $1/K$ of the data over each subchannel. This will result in a $K$-fold increase of the data rate.
  - Spread spectrum: Transmit the same information over $K$ separate subchannels. If there is interference in one of the subchannels, the receiver can tune in one of the other subchannels.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequencies Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100 KHz - 300 KHz</td>
</tr>
<tr>
<td>2</td>
<td>320 KHz - 520 KHz</td>
</tr>
<tr>
<td>3</td>
<td>540 KHz - 740 KHz</td>
</tr>
<tr>
<td>4</td>
<td>760 KHz - 960 KHz</td>
</tr>
<tr>
<td>5</td>
<td>980 KHz - 1180 KHz</td>
</tr>
<tr>
<td>6</td>
<td>1200 KHz - 1400 KHz</td>
</tr>
</tbody>
</table>

An example assignment of frequencies to channels with a guard band between adjacent channels.
Wavelength Division Multiplexing

- In optical transmissions, FDM is known as *Wavelength Division Multiplexing* (WDM). With light different frequencies correspond to different colors.
- Several transmissions can be send over the same fiber by using different light colors, and combining into a single light stream.
- Prisms are used as multiplexors and demultiplexors.

Illustration of prisms used to combine and separate wavelengths of light in wavelength division multiplexing technologies
Time Division Multiplexing (TDM)
- It means dividing the available transmission time into time slots, and allocating a different slot to each transmitter.
- One method for transmitters to take turns is to transmit in *round-robin* order.

![Illustration of TDM concept](image)

Illustration of the Time Division Multiplexing (TDM) concept with items from multiple sources sent over a shared medium

Code division multiplexing (CDM)
- Used in the cellular phone system and in some satellite communications.
- Each sender is assigned a unique binary code: its *chip sequence* (with -1 representing 0).
- Chip sequences for different senders are *orthogonal* vectors.
- A one is sent as a chip sequence. A zero is sent as the opposite of the chip sequence.
- Lower delay than TDM in high utilization networks.
Modulation:
Modulation is the process whereby some characteristic of one wave is varied in accordance with some characteristic of another wave. The basic types of modulation are angular modulation (including the special cases of phase and frequency modulation) and amplitude modulation. In missile radars, it is common practice to amplitude modulate the transmitted RF carrier wave of tracking and guidance transmitters by using a pulsed wave for modulating, and to frequency modulate the transmitted RF carrier wave of illuminator transmitters by using a sine wave.

Modulation of Digital Data:
In order to get a digital signal into the air (through an antenna) it has to be modulated first. The modulation assumes a high frequency (radio frequency) sinusoidal oscillation, called carrier, into which the data signal is somehow “impressed” before being sent to antenna. Antenna transforms the electric oscillations into electromagnetic waves (radio waves). Radio waves propagate from transmitting antenna to all receiving antennas, where they induce electrical signals equal (although attenuated and delayed) to the signal in transmitting antenna. Each receiver then needs to take the impress off the carrier and thus recover the original data signal. This process reversed to modulation is called demodulation.

Digital Modulation Basics
- The bit rate defines the rate at which information is passed.
- The baud (or signalling) rate defines the number of symbols per second. Each symbol represents $n$ bits, and has $M$ signal states, where $M = 2^n$. This is called $M$-ary signalling.
- The maximum rate of information transfer through a baseband channel is given by:
  - Capacity $fb = 2W \log_2 M$ bits per second
  - where $W$ = bandwidth of modulating baseband signal

Amplitude Shift Keying (ASK)

Baseband Data

1 0 0 1

ASK modulated signal

- Pulse shaping can be employed to remove spectral spreading.
- ASK demonstrates poor performance, as it is heavily affected by noise and interference.
Frequency Shift Keying (FSK)

Baseband Data

\[
\begin{array}{c}
1 \\
0 \\
0 \\
1
\end{array}
\]

FSK modulated signal

\[
\begin{array}{cccc}
& f_1 & f_0 & f_0 & f_1 \\
\end{array}
\]

where \( f_0 = A \cos(2\pi f_0 t) \) and \( f_1 = A \cos(2\pi f_1 t) \)

- Bandwidth occupancy of FSK is dependant on the spacing of the two symbols. A frequency spacing of 0.5 times the symbol period is typically used.
- FSK can be expanded to a M-ary scheme, employing multiple frequencies as different states.

Phase Shift Keying (PSK)

Baseband Data

\[
\begin{array}{c}
1 \\
0 \\
0 \\
1
\end{array}
\]

Binary PSK modulated signal

\[
\begin{array}{cccc}
s_1 & s_0 & s_0 & s_1 \\
\end{array}
\]

where \( s_0 = -A \cos(2\pi c t) \) and \( s_1 = A \cos(2\pi c t) \)

- Binary Phase Shift Keying (BPSK) demonstrates better performance than ASK and FSK.
- PSK can be expanded to a M-ary scheme, employing multiple phases and amplitudes as different states.
- Filtering can be employed to avoid spectral spreading.
Transmission Channel:

Communication channels and medium
A physical medium is an inherent part of a communications system
– Wires (copper, optical fibers), wireless radio spectra.
Communications systems include electronic or optical devices that are part of the transmission path followed by a signal
– Equalizers, amplifiers, signal conditioners (regenerators)
– Medium determines only part of channels behavior. The other part is determined how transmitter and receiver are connected to the medium and what is transmitted in the channel
– Therefore, by telecommunication channel we refer to the Combined end-to-end physical medium and attached devices
Often the concept “Filter” models a channel. This is due to the fact that all telecommunication channels can be always modeled as filters. Their parameters can be
– deterministic
– random
– time variable
– linear/non-line
Wireless I/O

- Wireless I/O products connect directly to sensor and control signals and transmit the signal values by radio to the receiving module. The received I/O signals are either re-created as replicated values (e.g. 4 - 20mA) or, via gateways, as databus/protocol value (e.g Modbus TCP, EtherNet/Ip, etc.). Our industrially proven WIBNet protocol is used in the wireless I/O range to provide reliable communications. In practice, wireless I/O networks can be as simple as point to point monitoring of a small amount of I/O (e.g. level, flow) or more complex monitoring and/or control of point to multi-point applications with sizeable I/O counts and/or protocols (incorporating our gateway product range). Wireless I/O products differ in terms of one or two way communications, frequency, TX power and number of I/O points.

- Wireless I/O, also known as radio telemetry, connect directly to sensor and control signals, and transmit the signal values by radio. The signals are either re-created as similar signals, or output as a data connection — Ethernet, Profibus, Modbus etc. Wireless I/O networks can be as simple as two units transferring a small number of signals from one point to another, or they can be complex data-acquisition networks with multiple “master” interfaces to external systems.

Wireless Gateways provide wireless connectivity between data buses - connectivity between devices using the same data bus, or between different data buses (Ethernet to Profibus to DeviceNet to Modbus etc). Wireless gateways are similar in operation to wireless modems, however gateways only provide a register interface to the data bus, transferring I/O registers only.
Wireless Gateway

Wireless Modem transmit serial or Ethernet data, providing a wireless extension of the data link. Example applications are PLC to PLC connections (point-to-point), connecting SCADA to a group of PLCs (point-to-multipoint), or forming a wireless PLC LAN (multidrop). Wireless modems transmit the data with minimal transformation.

Wireless System Architecture

Weidmuller’s solutions enable innovative WIB-net™ communications protocol specifically designed for highly reliable and secure operation on open license-free radio bands. Weidmuller wireless units form a WIB network—Wireless Information Backbone. A WIB is an effective plant-wide wireless information network for transferring data and connecting signals and data buses in a highly efficient exception-reporting, peer-to-peer network. WIB-net provides the following features.

- **Exception-reporting transmissions for maximum wireless efficiency**
  Wireless messages are only transmitted whenever a signal value changes, yielding effective real-time performance. Integrity check messages ensure reliable operation of the wireless network as well as signal link accuracy. Exception-reporting reduces signal traffic to messages of only real significance.
• **Error-checking with automatic re-transmission for high reliability operation**
  WIB-net will send and then re-transmit up to five times. After the fifth attempt, a communication failure status is logged and an alarm set externally.

• **Listen-before transmit wireless operation to maximize the chance of successful message transmission.**

  . **Peer-to-peer networking for maximum network flexibility**
  Each Weidmuller wireless gateway and transceiver unit can transmit/receive directly to/from any other wireless gateway and transceiver, and can transmit/receive to/from multiple wireless units. There are no master units and no slaves. Any module in a network can talk to any other. Input signals can be transmitted to multiple destinations.