3.5 Telemetering Systems


Types: Wire telemetry and wireless telemetry

Sensors: Common sensors for both types; additionally, IC and intelligent sensors for digital instruments

Components: Collection of many components: computers, microprocessor and micro-controller systems, intelligent and common sensors and transducers, instruments, controllers, wire and wireless communication devices and components, communication protocols and software, repeaters, satellite systems, GPS systems

Displays: Computer peripherals, numeric (LED or LCD) displays

Communications: Wired base-band and multiplexed, RF, microwave, optical, sonic, satellite communications

Networking: Unlimited network capabilities

Vendors (partial list):
- Acroamatics Telemetry Systems (www.acroam.com)
- Athena Controls, Inc. (www.athenacontrols.com)
- Automated Control Systems (www.testdevices.com)
- Barton Instrument Systems Ltd (www.barton-instruments.com)
- Bristol Babcock (www.bristolbabcock.com)
- Crompton Instruments Ltd (www.crompton-instruments.com)
- Data Flow Systems, Inc. (www.dataflowsys.com)
- Datatel Telemetry Electronic GmbH (www.datatel-telemetry.com)
- D&D Security Products, Inc. (www.ddsp.com)
- Devar, Inc. (www.devarinc.com)
- Dranetz Technologies, Inc. (www.dranetz.com)
- Dwyer Instruments, Inc. (www.dwyer-inst.com)
- Dynalco Controls (www.dynalco.com)
- EMI Technologies, Inc. (www.emitechnologies.com)
- Garmin, Ltd. (www.garmin.com)
- Industrial Control Links, Inc. (www.iclinks.com)
- Industrial Instruments & Supplies, Inc. (www.iisusa.com)
- Internet Telemetry Corp. (www.itelemetry.net)
- IR Telemetrics Inc. (www.irtelemetrics.com)
- Kahn Instruments, Inc. (www.kahn.com)
- Keithley Instruments, Inc. (www.keithley.com)
- Koehler Inst. Co., Inc. (www.koehlerinstrument.com)
- Lockheed Martin Corp. (www.lockheedmartin.com)
- Microwave Data Systems, Inc. (www.microwavedata.com)
- Myers Engineering International, Inc. (www.myerseng.com)
- Nihon Kohden Corporation (www.nihonkohden.com)
- Ono Sokki Technology Inc. (www.onosokki.net)
- Philip Medical Systems (www.medical.philips.com)
- Precision Devices, Inc. (www.predev.com)
INTRODUCTION

Telemetry is a process of gathering information from remote locations. The data obtained from field instruments is transmitted to a convenient location for processing and recording purposes. Telemetry can be performed by different methods: electromagnetic, optical, electrical, sonic, Internet, etc. Recently, radio frequency (RF) and microwave telemetry methods have been used extensively. This section largely concentrates on wireless telemetry systems. However, the use of optical fiber systems allows the measurement of broad bandwidth and provides high immunity to noise and interference. Here, telemetry and telemetry systems that are based on electrical and electromagnetic principles are covered.

Electrical telemetry methods can be divided into groups depending on the transmission methods that they use. There are two basic types: wire telemetry and wireless telemetry. Wire telemetry uses wire transmission utilizing coaxial cables, twisted wire pairs, telephone systems, common communication buses, or similar communication means. It offers simple and inexpensive solutions for data flow and networking of devices. It is extensively used where the basic infrastructure and wiring systems already exist, as in the case of electric power lines that can be used as wire telemetry carriers.

Wireless telemetry is somewhat more complex as it requires radio frequency transmitters and receivers. Despite the complexity, it is widely used because it can transmit information over longer distances without wires from normally inaccessible areas. It can also operate at high speeds and can have the capacity to transmit several parallel channels of information at the same time. The applications of other wireless telemetry methods such as ultrasound and infrared radiation are limited to certain environments, such as marine telemetry.

Telemetry systems can operate repeatedly without any adjustments and calibrations under widely ranging environmental conditions, such as high-temperature and high-pressure situations. Telemetry is extensively used in space exploration and military applications for telemeasurements of distant variables or telecommandment of actuators and controllers.

Some land-mobile vehicles, such as passenger and cargo trains, also use telemetry systems, either wireless or by using some of the existing power distribution networks to transmit data to a central station. In medical applications, the use of telemetry increases the quality of life of patients, giving them mobility while still being monitored. Several medical applications are based on implanting a sensor in a patient and transmitting the data to be further analyzed and processed either by radio or by adapted telephone lines. In industrial applications, fiber optic communications are used in hazardous and electrically noisy environments.

The design and methodology required for a fully functional telemetry system depends on the application requirements and the environmental characteristics. From the applications point of view, telemetry can be grouped into four main categories: telemetry in medical and life sciences, industrial telemetry, space telemetry, and others. Application examples are provided at the end of this section.

BASIC TELEMETRY CONCEPTS

Classical Configuration

A telemetry system consists of many components, as illustrated in Figure 3.5a. The main components are:

![Telemetry System Diagram](image-url)

**FIG. 3.5a**

Basic components of a telemetry system.
1. Sensors and transducers, which convert physical variables into electrical signals for processing
2. Preconditioning circuits, which serve to amplify the low-level signals, limit their bandwidth, and realize impedance matching of inputs and outputs
3. A main signal processing unit for further signal conditioning
4. A sub-carrier oscillator, whose signal is modulated by the output of the transducer
5. A coding circuit, which can be a digital encoder or an analog or digital modulator, and which serves to prepare the signal to match the characteristics of transmission channel
6. A radio transmitter for wireless telemetry, modulated by the composite signal
7. An impedance line adapter in case of wire transmission, to match the input impedance of the line to the output impedance of the circuits
8. For wireless communication, a transmitting antenna
9. Dedicated or general computer and/or microprocessor systems with supporting peripherals

The receiving end of the telemetry system consists of similar modules. In the case of wireless telemetry, these modules are:

1. A receiving antenna suitably designed to operate in the radio frequency band of interest
2. A radio receiver with a suitable demodulation circuitry
3. Demodulation circuits for each of the transmitted channels in case of multiple transmissions
4. Computers and/or microprocessor systems with supporting peripherals

Both in wire or wireless telemetry, the transmitted signals can be analog or digital. The digital systems send data digitally as a finite set of symbols, each representing one of the possible values of the signals at the time of sampling. In case of wire telemetry, the antenna and the receiver are substituted by a generic front-end circuit to amplify and process the signals.

The effective communication distance in a wireless system is limited by the power radiated by the transmitting antenna, the receiver’s sensitivity, and the bandwidth of the radio frequency signal. As the bandwidth increases, the contribution of noise to the total signal also increases, and consequently more transmitted power is needed to maintain the same signal-to-noise ratio. This is one of the main limitations of wireless telemetry systems.

In some applications, the transmission is done on base band, after the conditioning circuits. The advantage of base-band telemetry systems is their simplicity, although because of the base-band transmission, they are normally limited to only one channel at low speeds. The base-band concept will be explained in detail in the following sections.

**Recent Trends**

Nowadays, many instruments use intelligent sensors that include not only the sensor but also the signal processors and telemetric communication capabilities in a single chip. These units are appearing in the marketplace as pressure sensors and accelerometers, bio-sensors, chemical sensors, optical sensors, magnetic sensors, environmental sensors, and so on. Some of these sensors are manufactured with RF transceivers, neural network, neural processors, vision systems, and intelligent parallel processors.

Recently, due to advances in wireless communication technology and intelligent sensors, a new class of devices, called wireless sensors, is finding extensive applications. These small sensor devices integrate micro-sensing and actuation with on-board processing and wireless communication capabilities. In many applications, due to low cost and small size, a large number of sensors can be deployed. These sensors are capable of organizing themselves into multi-hop wireless networks in environmental monitoring, surveillance, and scientific data gathering applications.

In parallel with the rapid developments in the hardware aspects of modern sensors, some new standardized techniques are emerging for intelligent sensors such as the support software and robust communications and networking components. This is making a revolutionary contribution in the development and applications of telemetry. For instance, the IEEE-1451 is a set of standards that define interfaces, network-based data acquisition, and control of sensors. This subject will be revisited later in this section.

Apart from the intelligent and sophisticated sensors, the communications capabilities of many modern electronic instruments are enhancing the widening of their application possibilities. Modern instruments have two levels of communications. The first is communication at the sensor level, which is mainly realized by intelligent sensors. The second is at the device level. At the device level, the communication takes place in wire, wireless, infrared, and sonic forms.

In the implementation of wireless communications of today’s instruments and sensors, the “Bluetooth” technology and Near-Field Communication protocols are gaining wider acceptance. Particularly, Bluetooth is considered to be a low-cost and short-range wireless technology to provide communication functionality, ranging from short length wire replacements to wide area networks. As the number of products incorporating technology such as the Bluetooth increases, the development of various types of instruments for many new applications gains momentum.

**OPERATING PRINCIPLES AND TYPES**

Telemetry can be analog or digital. Nowadays, mostly digital telemetry is used because of ease in data transmission and handling. As far as operating principles are concerned, telemetry can be divided into two main categories: base-band
telemetry and multiple-channel telemetry. These methods will be explained next, and appropriate comments will be made for their analog and digital applications.

**Base-Band Telemetry**

Base-band telemetry uses a wire line to communicate the signals obtained from the sensors and transducer to some remote location. There are two basic types: amplitude-based telemetry and frequency-based telemetry.

**Amplitude-Based Telemetry**

Amplitude-based telemetry is extensively used in industry for short-distance signal transmission. In this system, the signal from the transducer is amplified, normally to a voltage level between 1 and 15 V, and is sent to the receiver through a line consisting of two wires. Figure 3.5b shows a simple voltage-based telemetry system. The permissible distance for transmission depends on the resistance of the line, the input resistance for the receiver, and the electrical noise of the environment.

The limitation on the transmission distance due to noise and impedance of the line can be partially overcome by using current signals instead of voltages, as is shown in Figure 3.5c. The basic theory is that unlike voltage, the current is not affected by noise. In addition, the drop in voltage caused by the wire resistance does not affect the transmitted signal.

However, this system requires an additional step of voltage-to-current conversion. At the receiver end, the signal is converted to voltage by using a suitable resistor. The most common method used in industry is the 4- to 20-mA current transmission. In this configuration, zero voltage corresponds to and is transmitted as a 4 mA current value, while the highest voltage is transmitted as 20 mA. Other standard current ranges are 0 to 5, 0 to 20, 1 to 50, 1 to 5, and 2 to 10 mA.

**Frequency-Based Telemetry**

Similarly to amplitude-based telemetry, frequency-based telemetry is also often used in industry for short-distance signal transmission. Frequency-based telemetry, shown in Figure 3.3d, is known to provide higher immunity to noise. In this method, the signals obtained from the measurements are converted to frequencies by voltage-to-frequency converters. A frequency-to-voltage converter puts signals back to the voltage form at the receiving end. A special form of frequency-based telemetry is pulse telemetry in which the modulating signals are in the form of a train of pulses, which will be explained in detail in the forthcoming paragraphs.

**Multiple-Channel Telemetry**

Most processes require the measurement of multiple physical variables, thus requiring special methods for handling the signals. In multiple-channel applications, the use of base-band telemetry is not economical, as it would require building a different system for each channel. Instead, multiple-channel telemetry can be configured by sharing a common transmission channel (Figure 3.5e) and by using suitable multiplexing techniques.

The multiplexing can be realized by frequency division multiplexing (FDM) or time division multiplexing (TDM). In frequency division multiplexing, different channels are assigned to different spectrum bands. In time division multiplexing (TDM), the information of different channels is transmitted sequentially.

**Frequency Division Multiplexing**

Frequency division multiplexing (Figure 3.5f) makes use of modulations of signals from each channel onto sinusoidal signals of different frequencies. The sinusoidal signals are called sub-carriers. Each modulated signal is then sent through a low-pass filter to ensure that the bandwidth limits are observed.

After the filtering stage, all the modulated signals are fed into a common summing block, producing what is known as the base-band signal. The base-band signal is then modulated by a carrier signal whose frequency and amplitude depend on the characteristics of the transmission. The carrier signal is then fed into a transmission wire or into an antenna in the case of wireless systems.

At the receiver end, the transmitted signal is detected and demodulated to separate each sub-carrier signal. This is done by feeding the signal into a bank of parallel pass-band filters.

---

**FIG. 3.5b**

A voltage-based telemetry system.

**FIG. 3.5c**

A current-based telemetry system.
Each channel is further demodulated to recover the original measurement signals. One problem with FDM systems is the cross-talk between channels. Cross-talk can be minimized by having a guard band between the spectrums of two contiguous channels. The guard band can be increased to decrease the cross-talk, but then the effective bandwidth also increases. The effective bandwidth is the sum of the bandwidth of all channels, plus the sum of all the guard bands.

The frequency and energy level of the carrier cannot be arbitrary; hence, international agreements on the use of the electromagnetic spectrum must be complied with. There are national organizations as well as international consortiums (e.g., International Consortium on Telemetry Spectrum, ICTS) to regulate the use of the electromagnetic frequency spectrum. The problem of allocation of the telemetry spectrum is common to many nations, whether telemetry is used in support of national defense, the commercial aerospace industry, or space applications.

In the United States, the Federal Communications Commission (FCC) is the body that regulates the allocation of frequencies for various communication services. For informational purposes, the most commonly used telemetry frequency bands and their intended use are shown in Table 3.5. The allocation of bands is a process subject to change from time to time.

There are three basic techniques of modulation for FDM: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). Combinations of these modulation techniques are also used—FM/FM, FM/PM, or AM/FM.

Amplitude Modulation Amplitude modulation makes use of the amplitude of a sub-carrier signal that changes in accordance with the value of the measured channel. The resulting signal can be expressed by:

\[ v(t) = A_c [1 + m(t)] \cos (\omega_c t) \]  \hspace{1cm} 3.5(1)

where \( A_c \) is the amplitude of the carrier, \( m(t) \) the modulating signal, and \( \omega_c \) the frequency of the carrier.

AM has limitations, particularly due to efficiency. It is possible to overcome some of the limitations by using modulation techniques, such as Double Side Band (DSB), Single Side Band (SSB), and Compatible Single Side Band (CSSB) techniques.

Frequency Modulation Frequency modulation and phase modulation techniques are by far the most common modulation scheme used in FDM telemetry systems. These modulations are inherently nonlinear. For example, the angle modulation can be expressed as:

\[ v(t) = A \cos [\omega_c t + \phi(t)] \]  \hspace{1cm} 3.5(2)

where \( \phi(t) \) carries the information on the signals from the transducers.

The value of the instantaneous frequency can be expressed as:

\[ f = \frac{1}{2\pi} \frac{d}{dt} [\omega_c t + \phi(t)] = \frac{\omega_c}{2\pi} + \frac{d}{dt} \phi(t) \]  \hspace{1cm} 3.5(3)

From these equations, it can be seen that the signal \( v(t) \) is modulated in frequency. This expression can further be modified in terms of frequency deviation \( f_m \) and modulation index \( \beta \). The frequency deviation is defined as the maximum departure of the instantaneous frequency from the carrier frequency, and the modulation index is defined as the maximum phase deviation. Now this equation can be expressed as:

\[ f = \frac{\omega_c}{2\pi} + \frac{\beta m}{2\pi} \cos (\omega_m t) = f_c + \beta f_m \cos (\omega_m t) \]  \hspace{1cm} 3.5(4)
The maximum frequency deviation is defined as $\Delta f$ and is given by

$$\Delta f = B f_o$$  \hspace{1cm} (3.5(5))

Therefore, we can express the equation for the frequency modulated signal as:

$$v(t) = A \cos \left( \omega_0 t + \frac{\Delta f}{f_m} \sin(\omega_0 t) \right)$$  \hspace{1cm} (3.5(6))

The previous equation shows that the instantaneous frequency, $f$, lies in the range $f_c \pm \Delta f$. A practical rule states that the bandwidth of an FM modulated signal is twice the sum of the maximum frequency deviation and the modulating frequency.

**Time Division Multiplexing**

Time division multiplexing (TDM) is a transmission technique that divides the time in different slots and assigns one slot to each measurement channel. The entire transmission bandwidth is assigned to the assigned channel during transmission. The measurement channels are sequentially sampled by a digital switch for a period of time ($T$). For $M$ measurement channels the period between two consecutive pulses is $T/M = 1/M f_s$, where $T_s$ is the sampling period.

At the receiver end, the original signals are recovered by separating the digital signals into different channels by synchronized demultiplexers and by low-pass filtering. Figure 3.5h shows a basic block diagram for an FDM system.

TDM systems have a number of advantages over the FDM. In FDM, sub-carrier modulators and demodulators are required for each channel, while TDM systems need only one set of multiplexer at the transmitter and one set of demultiplexer at the receiver. The TDM signals are resistant to cross-talk. However, in TDM systems, the separation between channels depends on the sampling method adopted. Since, in practice, it is impossible to produce perfectly square pulses without rise and fall times, it is then necessary to provide time guards between pulses, similar to the band guards in FDM.

Time Division Multiplexing can be achieved by either digital or analog methods, as explained below.

**Pulse Code Modulation**

Pulse code modulation (PCM) is a digital technique in which the measured signal is represented by a group of codified digital pulses. Figure 3.5i shows the basic elements of a PCM telemetry system. Two variations of PCM that are commonly used are Delta Modulation (DM) and Differential Pulse Code Modulation (DPCM).

PCM systems transmit data as a serial stream of digital words. An encoder converts the input data into a serial data
Data communication modes: synchronous or asynchronous
Data rate supported: several bps (bits per second) to several Gbps, depending on both oscillator frequency and transmission medium
Transmission medium supported: twisted pair, coaxial cable, optical, RF, or microwave, etc.
Data format: mainly based on data transmission modes and individual protocol specifications
Error detection methods: parity, block sum check, or CRC (cyclic redundancy check).
Error control methods: echo checking, automatic repeat request (ARQ), sequence number I, etc.

Generally, telemetry systems are subgrouped together to operate in nodes by the help of communication protocols, micro-controllers, and microprocessors. At the grassroots of this networking lie the fieldbus for industrial systems and other communication protocols developed by vendors to enable reliable and fast data communications among nodes, computers, and individual sensors. Volume 3 of this handbook is devoted to this subject.

Manufacturers offer a bewildering range of buses and protocols, but all protocols comply with the ISO reference model. Some of the typical protocols used in telemetry are: IEC 60870-5 series protocols, ISO 9506, IEC 62056, Bluetooth, and IEEE 802.11.

ISO Reference Model
ISO reference model layout for the protocols is shown in Table 3.5. The reference model has seven layers, of which each is an independent functional unit. Each layer uses functions from the layer below and provides functions for the layer above. The lowest three layers are network-dependent layers; the highest three layers are network-independent layers (application-oriented); and the middle layer (transport layer) is the interface between the two.

All digital devices need to obey the ISO reference model when communicating with each other. In some applications, some of the seven layers of the ISO reference model may be omitted, as in the cases of many fieldbuses.

Bluetooth
Bluetooth is a protocol based on the ISO reference model; it is used in digital telemetry systems. Initially, Bluetooth was mainly aimed at bringing short-distance wireless interfaces to consumer products on a large scale. As the number of products incorporating Bluetooth wireless technology increased, the development of various types of instruments for a diverse range of applications became widespread.

However, Bluetooth did not escape competition. ExtremeTech reports that Sony and Philips have agreed to jointly work on “Near-Field Communication,” a potential competitor to Bluetooth in the short-range personal area network (PAN) market. Also, the IEEE just recently adopted and approved protocols and standards for Near-Field Communication.
the Bluetooth protocol under its WPAN standards, the IEEE-802 series of protocols.

Many Bluetooth products are appearing on the marketplace, from the chip level to sophisticated devices. On the chip level, a typical example of Bluetooth products is an under-$5 chipset from Texas Instruments. It provides up to 1 Mbps for fast data transmission.

On the device level, Sony has introduced in Europe and Japan the ultra-compact fixed lens DSC-FX77 camera with a built-in Bluetooth communication protocol. Many chip-level products target Bluetooth specifications. Point-to-multipoint applications consisting of a base-band controller with flash memory, a reference crystal, and an RFCMOS (radio frequency complementary metal-oxide semiconductor) transceiver.

In some cases a two-chip approach is chosen to ensure a good level of performance and reliability in RF-intensive environments. The architecture is based on independent silicon optimization with digital circuits in standard CMOS and analog parts in BiCMOS (bipolar metal oxide semiconductor) or RFCMOS, enabling cost and size reduction.

IEEE 802.11 The IEEE 802.11 is a high-bandwidth standard for transfer of large amounts of data; it is extensively used in telemetry systems. It handles spread-spectrum and high-data bursts easily. The IEEE 802.11b standard is supported by three chips compared to two chips or the single-chip solution of Bluetooth. 802.11b is designed as a communication channel to host processors running TCP/IP (transmission control protocol/internet protocol). The encryption length is 64 bits.

IEEE-1451 The IEEE-1451 standard aims to make it easy to create solutions using existing networking technologies, standardized connections, and common software architectures. The standard allows application software, field network, and transducer decisions to be made independently. It offers flexibility to choose the products and vendors that are most appropriate for a particular application.

As an example, Bluetooth finds wide applications in wireless smart sensor and transducer networks. Interfacing of IEEE-1451 Smart Transducer nodes to a Bluetooth network is gaining momentum. This involves a detailed study of the network communication models specified for smart transducer communication as well as the Bluetooth protocol stack.

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Space Data Systems). CCSDS is a telemetry and telecom software library that provides a reference implementation of the international protocol standard for the transmission and reception of data in radio communications with spacecraft.

This library supports the full set of uplink and downlink virtual channels. It has a frame-acceptance and reporting mechanism (FARM) that supports a sliding window specified within the standard. The library has been written in the C programming language for execution on various computers running the SunOS4, SunOS5, AIX, and VxWorks operating systems.

**MLS-STD-1553** The *MLS-STD-1553* standard addresses the acquisition of all the traffic flowing on MIL-STD-1553–type data buses for telemetry and recording purposes. Up to eight data buses within a single system can be used. Constraints such as RF bandwidth and recording times are defined.

As the application of telemetry widens, many forms of supporting hardware and software appear in the marketplace offered by different vendors and organizations. Although most of these products are supported by the existing standards, in some cases new standards appear in lieu of new developments.

**Networks**

The network is an essential element of telemetry systems. A network includes many instruments, controllers, microprocessors, and computers. The hardware architectures of a network can be centralized, decentralized, hierarchical, or distributed. Many different network topologies exist, as illustrated in Figure 3.5k.

The group arrangement of telemetry systems results in many advantages. For example in message sharing, because all the nodes are connected together by one single transmission medium, nodes can demand information from another node to implement strategies, for setting and resetting, for alarms, and so on. Also, due to the simple data transmission medium and the node configuration, any problem from sensors or transmissions can be isolated, thus helping maintenance without affecting the performance of the network.

**Telemetry Equipment and Hardware**

As stated previously, a telemetry system consists of a collection of components such as computers, micro-controllers, wire and wireless transmitters and receivers, transceivers, repeaters, receivers/decoders, sensors, actuators, measurement instruments, controllers, signal converters, plug-and-play components, and protocol converters. Most of these components can be bought off the shelf or can be designed from their basic components. A list of the manufacturers and suppliers of telemetry systems and components is provided on the first page of this section.

If a system is to be designed from the basic principles, there are many single-chip RF transceivers available. A typical example is the LMX3162 from National Instruments. This transceiver is a 48-pin 7 mm × 7 mm × 1.4 mm monolithic device operating at 2.45 GHz wireless systems. It contains phase locked loop (PLL) transmit and receive functions. The 1.3 GHz PLL is shared between transmit and receive sections. The transmitter includes frequency doublers and a high frequency buffer. The receiver consists of a 2.5-GHz low noise mixer, an intermediate frequency (IF) amplifier, a high-gain limiting amplifier, a frequency discriminator, a received signal strength indicator (RSSI), and an analog DC compensation loop. The circuit has on-chip voltage regulation, which allows the use of supply voltages ranging from 3.0 to 5.5 V. Such chips are extensively used in personal wireless communication systems/networks (PCS/PCN), and wireless local area networks (WLANs).

If the data need to be transmitted for long distances in which transmitter and receivers are out of range, wireless bridges and repeaters can be employed. Wireless bridges and repeaters provide long-range point-to-point or point-to-multipoint links. Some of these devices use direct sequence spread spectrum (DSSS) radio technology operating at typical frequencies (i.e., 2.4 GHz). Data may be transmitted at speeds up to 11 Mbps. These bridges comply with standards such as IEEE-802.11b, connecting one or more remote sites to a central server or Internet connection.

On the other hand, industrial plug-and-play or long-range wireless communication devices are offered by many companies such as Microwave Data Systems, Inc. Typical products provide point-to-point and point-to-multipoint communication of data with frequencies from 200 MHz to 2.4 GHz and speeds up to 8 Mbps. Such devices are used for health monitoring and other civil, military, and industrial applications. Networks of low-cost wireless sensors enable monitoring of large civil structures with a large number of sensing nodes.
A typical single-unit data logging transceiver is a wireless data communications device that can serve multichannel sensor arrays to a remote data acquisition system hosted by a computer or a microprocessor. The frequency of transmission is 916 MHz, narrow-band. The RF communication link operates with 19,200 baud, and the device is capable of triggering a sample to be logged (typically from 30 m), or requested data to be transmitted.

A typical application of wireless data logging on a triaxial MEM accelerometer is illustrated in Figure 3.51. These accelerometers have flash memory (typically 2 to 8 Mbytes). The nodes in the wireless networks may be assigned with 16-bit address lengths, hence are able to connect with thousands of multi-channel sensor clusters. They are powered by 3.1- to 9-V lithium ion AA-size batteries. They draw about 10 mA and contain 10- or 12-bit A/D converters. The dimensions of the total package are 25 mm × 40 mm × 7 mm.

### Sensor Networks

Nowadays, geographically distributed sensors can be networked as distributed sensor networks (DSN). The networking requires intelligent sensors that may obey some form of a hierarchical structure.

In recent years, an IEEE-1451 compatible interface between the Internet/Ethernet serial port websensors has been developed. These sensors have direct Internet address. The interface is realized in IEEE-451 Network Capable Application Processors (NCAP). The NCAP connects the Internet through Ethernet. NCAP is a communication board capable of receiving and sending information using standard TCP/IP format. The sensor data are formatted to and from the serial port by one of the followings, RS232, RS485, TII, Microlan/1-wire, Esbus, or I2C.

The future of sensors will probably be shaped by how they interface into the network to share information. Nevertheless, the importance of sensor networks has been understood by many vendors; hence, the vendors promote proprietary solutions to connect smart sensors into TCP/IP-based networks. As was explained earlier, developments are taking place at both low-level interfaces and at high-level interfaces.

### TELEMETRY APPLICATIONS

Telemetry finds a wide range of applications in medicine and life sciences, in industry, in the military, in space exploration, and in other fields.

**Medical and Life Science Applications**

In recent years, medicine and life sciences have benefited considerably from the use of telemetry techniques. Telemetry has proven to be particularly important in those situations where it is desirable to leave the subjects in a relatively normal physiological and psychological state with minimum interference with their normal pattern of activities. It finds extensive applications in remote locations, where health and safety are the prime concerns. For example, for humans working in hazardous environments, the telemetry of their vital signs is a way to ensure their safety.

**Medical Telemetry**

Medical telemetry is used to detect the regular and/or irregular functioning of the human body. A patient’s vital signs, such as electrocardiogram (ECG) waveforms, are monitored continuously and the information is transmitted to a central station for observation and recording. Often wireless telemetry is selected to free patients from being bedridden, thus giving them freedom to move about.

Over the past several years, manufacturers have made tremendous strides in improving the design and functionality of
telemetry systems, allowing more acute patients to become ambulatory during recovery. These systems are now capable of monitoring several different parameters, from ECG waveforms, arrhythmias, and heart rate to pulse oximetry and other vital signs.

Many medical telemetry systems consist of a small digital transmitter worn by the patient, a set of sensors for gathering patient vital signs, a distributed transmitter, and receiving systems. Displays, controls, and recordings are often controlled from a central computer, which is located at the nursing station, where telemetry units dedicated to the diagnosis and treatment of life-threatening illnesses are also located.

A telemetric nurse-based biomedical instrumentation system is illustrated in Figure 3.5m, where (1) shows the telemetry bedside monitor of a patient. It has a 7-inch CRT screen with two waveforms. Vital signs can be graphically or tabularly displayed. The vital signs of patients, such as electrocardiogram (ECG) waveforms, and data can be transmitted, normally wireless, to a remote station for observation and recording.

In Figure 3.5m (2), a patient transmitter for a wireless bedside monitor is illustrated. The base station, in Figure 3.5m (3), can monitor waveforms, data, trends and alarms of up to eight telemetry patients. It has dual-antenna diversity reception, 100-arrhythmia event memory, and a vital signs list.

The use of wireless medical telemetry systems is on the rise worldwide despite a growing problem with electromagnetic overcrowding on the airwaves. Different countries approach congestion of the airwaves in different ways. Some countries assign less crowded regions of the electromagnetic spectrum to telemetry services while others concentrate on the development of modulation and compression techniques to limit bandwidths.

In the United States, the Federal Communications Commission (FCC) is the agency responsible for assigning portions of the electromagnetic spectrum to users other than the federal government. The FCC has issued new rules for medical telemetry in which it assigns portions of the spectrum to telemetry services to operate on an interference-protected basis. In this approach, hospitals will have reasonable assurance that the next generation of medical telemetry devices will operate in this expanded spectrum with minimal interference.

One application of telemetry is the cardiac pacemaker. A bidirectional telemetry process is initiated by the cardiologist when a special signal is sent to the pacemaker. Each pacemaker that is carried by a patient has a different identification code set by the cardiologist before implantation. The typical data from the pacemaker include voltage, impedance, and current consumption of the battery, battery charge level; voltage and current levels; and width, rate, and energy of pulses to record the electrical activity of the heart. All this information can be read and interrogated.

In many cases, especially for patients who are located in rural or isolated areas, monitoring of physiological parameters by wireless transmission is not possible. In these cases, public telephone networks are used for telemetry purposes; the data obtained from the patient is transmitted over telephone lines. However, this approach needs careful attention since the transmission of multiple physiological channels can be problematic in terms of recovering useful information due to frequency band limitations of telephone lines. In this telemetry, speech and data are transmitted simultaneously. This requires an increase in bandwidth, which is achieved by suitable processing devices.

**Life Sciences and Bio-Telemetry**  
Telemetry is extensively used in diverse range of life science applications. Telemetry systems equipped with radio transmitters implanted or attached to marine and land animals allow the study of their biological functions and behavior without disturbing their normal way of living. Implanted transmitters have been used to study animals. The transmitter surgically implanted in the body of the animal supplies valuable information on animals’ survival patterns.

In life science applications, the range of the transmitter of the telemeter is an important parameter. The range can be from a few centimeters in laboratory experiments to several miles for tracking wildlife. Another critical parameter is the selection of the sensors and transducers that can accurately sense the desired range and at the same time can be protected from corrosion and harmful body fluids. The operating temperature of the sensor can vary from sub-freezing temperatures in the North to the temperature of the deserts. Temperature is important because the life of the batteries powering the telemetry system is largely dependent on the operating temperature.

Figure 3.5n illustrates an implantable sensor/telemetry transmitter to measure the temperature, gross motor activity,
and heart rate of an animal. This sensor/transmitter arrangement does not require a battery.

**Industrial Telemetry**

Telemetry is extensively used in industrial applications. Industrial telemetry enables the automatic and remote monitoring and recording of process variables. By using telemetry, operational efficiencies and safety can be improved. Some applications include oil and gas operations, medical equipment, utilities production and consumption, and intelligent transportation systems.

There are many different types of industrial telemetry systems, since they are offered by a diverse range of vendors competing for the same market. SCADA, which is discussed below, is an example of a well-established telemetry system.

Modern industrial systems use computers, remote terminal units (RTUs), programmable telemetry controllers (PTCs), and so on. PTCs consist of modular intelligent units that can handle multiple inputs (typically 128 I/O) for networking purposes. Remote terminal units can handle virtually thousands of digital and analog inputs and outputs. Some RTUs support local, public switched telephone networks (PSTN), private wire (PW) systems, leased lines (LL), and radio communications.

**SCADA Systems**

SCADA stands for **System Control and Data Acquisition**. SCADA consists of a collection of computers, sensors, and other equipment interfaced by telemetry to monitor and control processes. The uses of SCADA systems are endless as they are only limited by the designer’s imagination. Some typical applications include high- and low-voltage power distributions, broadcasting stations, and environmental measurements.

An example of SCADA applications is in water management. Water conservation is critical not only in drought-stricken areas but everywhere, as water is becoming a limited resource due to increases in consumption. Application of SCADA systems enables the remote and effective monitoring and controlling of water levels.

Another application of SCADA in industry is digital pager alarming systems. If an unusual situation occurs in a process, the SCADA system can alert key personnel by sending messages to their pagers. SCADA systems also archive information and generate reports and graphs that are critical to processes.

An important advantage of SCADA systems is that the existing sensors in an application can be incorporated into the overall SCADA system. In doing so, the SCADA system simply adds a new level of intelligence and provides additional capabilities to the existing controls in the plant. In addition to lowering the cost of implementing new technological solutions in existing plants, it can also help to centralize the controls to a central commanding post. SCADA systems can be equipped with alarms so that if one of the subsystems fails, corrective actions can be taken without delay.

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**Space Telemetry**

The need to control and gather information from objects put into space is one of the earliest applications of telemetry systems. In the U.S., the current industrial and commercial telemetry standards are largely derived from the telemetry of missiles and other unmanned space objects. Today, telemetry finds extensive applications in space exploration and military use.

In manned space flights, telemetry is used to detect the potential onset of distress and take the necessary precautions. The astronaut’s EKG, blood pressure, respiratory rhythm, and other life functions are monitored continuously and telemetered to earth. During the first manned landing on the moon, the voices of the astronauts were combined with 900 other signals, some of them physiological parameters from the astronauts. These complex signals transmitted to Earth, at about 2.2 GHz, were picked up by the ground station in California and relayed to the space flight center in Houston. The different signals were separated and human physiological parameters were extracted as the command ship orbited around the moon.

There are numerous satellite systems around the Earth relying on telemetry systems for spacecraft management. Onboard, they have a Telemetry, Tracking and Command (TT&C) system that supports the daily functioning of the spacecraft. The functions of the TT&C system are numerous. It monitors the performance of satellite subsystems, transmits the data to satellite control centers, supports the determination of orbital parameters, and performs control functions issued by the command center.

The information received from the satellites is used for operational and failure diagnostic purposes. The commonly monitored parameters include voltages, currents, and temperatures of

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The information received from the satellites is used for operational and failure diagnostic purposes. The commonly monitored parameters include voltages, currents, and temperatures of
all the major subsystems; the switch status of communication transponders; the pressure in propulsion tanks; and the outputs from altitude sensors.

In modern satellite systems, distributed telemetry systems in modular forms are favored. In this configuration, digital encoders are located in each satellite subsystem and the data from each encoder are sent to a central encoder via a common, time-shared bus. This method reduces the number of wire connections and improves the reliability of the whole telemetry system. Modular design also permits the easy expansion of the initial design and facilitates easy testing during the satellite assembly phase.

Typical space telemetry data processing equipment is shown in Figure 3.5p. This data processor is a virtual machine environment (VME) based system using open architecture and operating systems. It is used in applications where extensive real-time processing of single to multiple streams in complex formats is required. It is capable of real-time data display and recordings.

Other Applications

Apart from medical, life sciences, industrial, and space applications, telemeters are used in many novel applications. For example, vibrations and additional stresses of power lines due to wind and snow can be monitored to prevent fatigue and failure. In this case, the telemetry systems are used as a watchdog before a problem occurs. Some of the telemetry applications are listed below, but such applications are limited only by the imagination of the designer:

- Determination of levels and flow rates of rivers and lakes
- Computer and other equipment fault information systems
- Vending machines connected to mobile phones
- Electric meters interrogated for billing purposes
- Water and gas flow meters monitored for billing and fault diagnosis
- Personal security systems, etc.

Bibliography