

# TELEMETRY

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## Summary

Telemetry is the science of gathering information at some remote location and transmitting the data to a convenient location to be examined and recorded. Telemetry can be done by different methods: optical, mechanical, hydraulic, electrical, and others. More recently, the use of optical fiber systems has allowed the measurement of broad bandwidth, and high immunity to noise and interference. Other proposed telemetry systems are based on ultrasounds, capacitive or magnetic coupling, and infrared radiation, although these methods are not used routinely. The discussion in this article will be limited to the most widely used systems: telemetry based on electrical signals. We will also focus on telemetry applications in areas such as life sciences and space exploration.

## 1. Introduction

Telemetry can be done using a variety of optical, mechanical, hydraulic, electrical, and other media. The mechanical methods, either pneumatic or hydraulic, produce acceptable results over short distances and are used in environments where there is a

high level of electromagnetic interference, and in situations where it is impossible to use electrical signals for safety or security reasons: for example, in explosive environments. More recently, the use of optical fiber systems has allowed the measurement of broad bandwidth, and high immunity to noise and interference.

Other proposed telemetry systems are based on ultrasounds, capacitive or magnetic coupling, and infrared radiation. The discussion in this section will be limited to the most common systems: telemetry based on electrical signals.

The main advantage of electrical over mechanical telemetry methods is that, in practical terms, electrically-based telemetry is not limited by the distance between the measurement and analysis locations, and can be easily adapted and upgraded in already-existing infrastructures.

Electrical telemetry methods can be further subdivided depending on the transmission channel that they use, into *wire telemetry* and *wireless* (or *radio*) *telemetry*. Wire telemetry is technologically the simplest solution; its limitations are the low bandwidth and transmission speed that it can support. However, it is used when transmission can use already-existing infrastructures: most electric power lines, for example, are also used as wire telemetry carriers.

Wireless telemetry is more complex than wire telemetry because it requires a final radiofrequency (RF) stage. Despite its complexity, it is widely used because it can transmit information over longer distances, and is chosen for applications in which the measurement area is not normally accessible. It can also transmit at higher speeds and have sufficient capacity to transmit several channels of information if necessary.

Figure 1 displays a generic telemetry system. The main blocks are:

- *transducers* to convert physical variables to be measured into electrical signals that can be easily processed;
- *conditioning circuits* to amplify the low-level signal from the transducer, limit its bandwidth, and adapt impedance levels;
- a *signal-processing circuit* that can sometimes be integrated into the previously-mentioned circuits;
- a *subcarrier oscillator*, whose signal will be modulated by the output of the different transducers once processed and adapted;
- a *codifier circuit*, which can be a digital encoder, an analog modulator, or a digital modulator that adapts the signal to the characteristics of the transmission channel, in other words a wire or antenna;
- a *radio transmitter*, in wireless telemetry, modulated by the composite signal;
- an *impedance line adapter*, in the case of wire transmission, to adapt the characteristic impedance of the line to the output impedance of the circuits connected to the adapter; and
- for wireless communication, a *transmitting antenna*.

Not all these blocks need to be present to form a telemetry system.

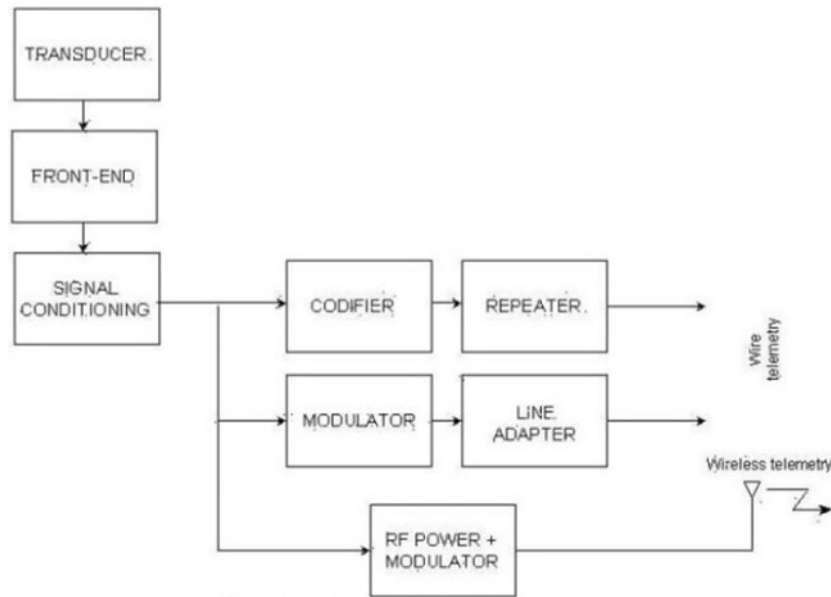


Figure 1. Basic components of a telemetry system

The receiver end consists of similar modules. For wireless telemetry, these modules are:

- a receiving antenna designed for maximum efficiency in the radiofrequency band used;
- a radio receiver with a demodulation scheme compatible with the modulation one; and
- demodulation circuits for each one of the transmitted channels.

For wire telemetry, the antenna and the radio receiver are substituted by a generic front-end to amplify the signal, and adapt the line impedance to the input impedance of the circuits that follow. Transmission in telemetry systems, in particular wireless ones, is done by sending a signal whose analog variations in amplitude or frequency are a known function of the variations of the signals from the transducers. More modern digital telemetry systems send data digitally as a finite set of symbols, each one representing one of the possible finite values of the composite signals at the time that it was sampled. 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 radiofrequency signal. As the bandwidth increases, the contribution made by 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 principal limitations of wireless telemetry systems. In some applications, the transmission to the receiver is done on base band, after the conditioning circuits. The advantage of base-band telemetry systems is their simplicity, although they are normally limited to only one channel at low speeds because of the use of base-band transmission.

Often a measurement system needs to acquire either different types of signal or the same type of data at different locations in the process that is being monitored. These different information signals can be transmitted using the same common carrier by *multiplexing* the data signals. Multiplexing allows different signals to share the same channel. Multiplexing techniques can usually be regarded as either *frequency-division multiplexing* (FDM) or *time-division multiplexing* (TDM). In FDM different subcarrier

frequencies are modulated by the different measurement channel signals, which causes the information spectrum to shift from base band to the subcarrier frequency. Then the subcarrier frequencies modulate the RF carrier signal, which allows the transmission of all desired measurement channels simultaneously as shown in Figure 2. In TDM, the whole channel is assigned to each measurement channel, although only during a fraction of the available time. TDM techniques use digital modulation to sample the different measurement channels at different times. These samples are then applied sequentially to modulate the RF carrier, as shown in Figure 2.

Almost all instrumentation and measurement situations might involve the use of a telemetry link. Telemetry is widely used in space applications, either for telemeasurement of a distant variable or telecommandment of actuators. In most of these types of telemetry application, it is very important to design systems that minimize the consumption of power. Some land-mobile vehicles, such as trains, also use telemetry systems; these are either wireless or use existing power wires to transmit data to the central station and receive its commands. In clinical practice, the telemetry of patients improves both their quality of life and their mobility, as patients do not need to be connected to a measurement system in order to be monitored.

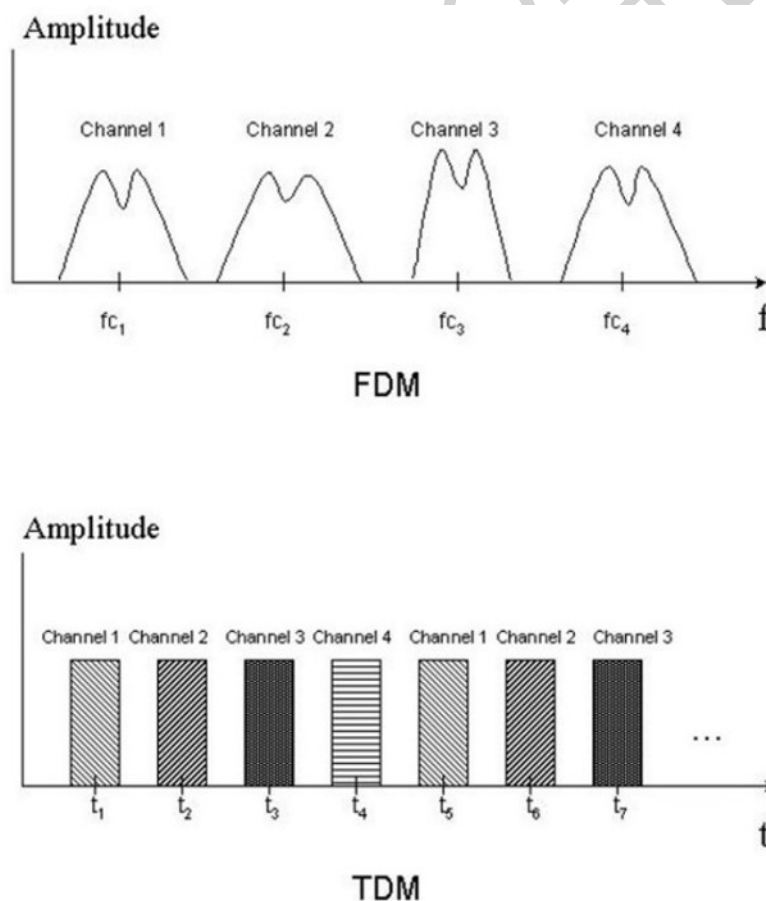


Figure 2. Basic structure of FDM and TDM systems

Several medical applications are based on implanting a sensor in a patient and transmitting the data from the receiving station to be further analyzed and processed, either by radio or using adapted telephone lines. Optical sensors and fiber optic

communications are used in industry to transmit measurements in dangerous environments (such as explosive atmospheres) where electric signals are undesirable. The designer of a telemetry system must also consider the conditions in which the system will have to operate. In most types of application, telemetry systems must be able to operate repeatedly without adjustment and calibration in a wide range of temperatures. Finally, it is important to remember that the need to allow tests to be made interchangeable at all ranges increased as different telemetry systems developed. This has led to a need to ensure compatibility between transmitting, receiving, and signal-processing equipment.

## 2. Basic Telemetry Concepts

When we need to measure variables that are distant from the place where the information is processed, we must use a system that can transmit and receive measurement data and commands. Examples of these situations include (among others): certain process industries, such as chemicals and mining; testing of systems that involve many measurement points spread over a large surface area, for example in airplane motor tests; wind tunnels; and situations where the systems to be measured are remote, such as missile and rocket testing, satellites, and so on. When the measurements transmitted consist only of binary information, the term *signaling* is sometimes used. When “yes/no” orders are transmitted, the term *remote switching* is sometimes also used. When the transmitter and the receiver are widely separated, it is common to use wire transmission systems based on coaxial cables, twisted pairs, or similar configurations. These are also used in extensive installations where there is already an adequate infrastructure. In cases where the transmitter and receiver are too widely separated for wire communication, where they are inaccessible, or where one of them is moving, we must use wireless communication or *radiotelemetry*. The main advantage of radiotelemetry is its wider bandwidth, resulting in higher-speed transmission. In specific applications it is possible to use fiber optics as the base for telemetry: this brings even higher bandwidth and very high levels of protection from noise and interference, despite its higher economic cost. Other telemetry methods are based on ultrasound, infrared radiation, or reactive coupling, but their use is very limited.

The environmental extremes in which telemetry systems must work are considered normal by telemetry users, and these are very different for each application. For example, missile telemetry equipment is heavily shielded against changes in temperature, vibration, and radiation, and is carefully calibrated over many weeks before it is used in an actual single-use missile shot. By contrast, industrial telemetry systems need to operate repeatedly without any need for adjustment and continuous calibration, and at a wide range of temperatures.

## 3. Modulation Approaches

### 3.1. Base-Band Telemetry

*Base-band telemetry* uses a wire line to communicate the signal from the transducer to the receiver after it has been processed and conditioned. We will briefly describe telemetry systems based either on amplitude or frequency.

### 3.1.1. Amplitude-Based Telemetry

Figure 3 shows a simple voltage-based telemetry system. The signal from the transducer is amplified, normally to a voltage level between 1 V and 15 V, and sent through a line consisting of two wires to the receiver. Because the low end of the scale is 1 V, this system can detect short-circuits. The main problem with this configuration is the limitation on the transmission distance imposed by the resistance of the line and the input resistance for the receiver. The connecting wires also form a loop that is very susceptible to interference from parasitic signals.

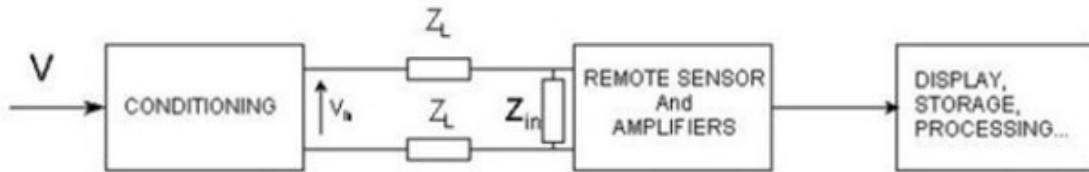


Figure 3. Structure of a voltage-based telemetry system

The limitations on transmission distance caused by line impedance in previous systems are resolved by using a current signal instead of a voltage, as shown in Figure 4. This requires an additional conversion module after the signal-processing circuits from voltage to current. At the receiver end, the signal is detected by measuring the voltage across a resistor: the most widely-used current values in industry are 4–20 mA. This means that 0 V are transmitted as 4 mA, while the highest voltage value is transmitted as a 20 mA current. The advantage of transmitting 4 mA for 0 V is that it allows easy detection of an open circuit in the loop (0 mA). Other standard current values are 0–5 mA, 0–20 mA, 10–50 mA, 1–5 mA, and 2–10 mA. In addition, voltage drops caused by wire resistance do not affect the transmitted signal, allowing the use of thinner wires. Since this is a current mode, the parasitic voltages induced in the line do not affect the signal either. Current-based telemetry allows the use of grounded or floating transmitters with few modifications.

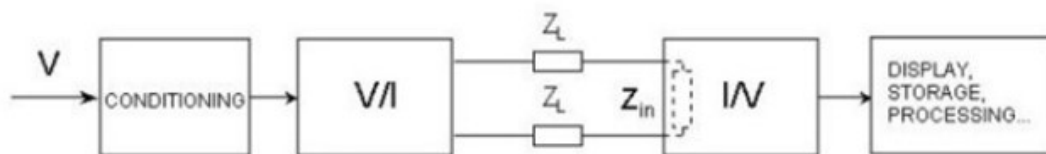


Figure 4. Structure of a current-based telemetry system

### 3.1.2. Frequency-Based Telemetry

Frequency-based transmission (Figure 5) is known to have higher immunity to noise than amplitude-based transmission. It is used in the presence of inductive or capacitive couplings due to this property. It also offers the possibility of isolating the receiver from the transmitter. The signal at the output of the conditioning circuit modifies the frequency of the telemetry signal, normally using a voltage-to-frequency converter. A frequency-to-voltage converter in the receiver performs the opposite function. A special type of frequency-based telemetry is *pulse telemetry*, in which the modulating signal

changes certain characteristics of a train of pulses. Because of its importance and widespread use, pulse telemetry will be analyzed in depth in the following sections.

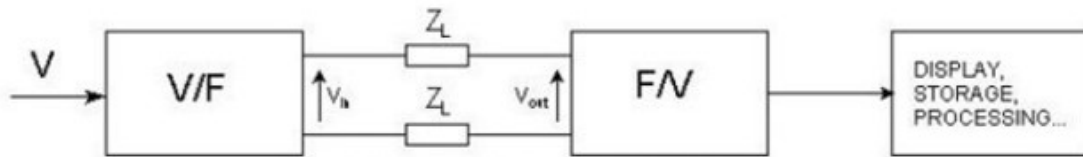


Figure 5. Structure of a frequency-based telemetry system

### 3.2. Multiple-Channel Telemetry

Most of the industrial processes in which telemetry is used require the measurement of different physical variables in order to control the process, the measurement of only one physical variable at different locations, or (normally) a combination of both. Base-band telemetry is not an option for these multiple-channel measurements as it would require building a different system for each channel. *Multiple-channel telemetry* is achieved by sharing a common resource (transmission channel), as shown in Figure 6. The sharing of the transmission channel by all the measurement channels is termed *multiplexing*. There are two basic multiplexing techniques: *frequency-division multiplexing* and *time-division multiplexing*. In frequency-division multiplexing (FDM), different channels are assigned to different spectrum bands and the composite signal is transmitted through the communication channel. In time-division multiplexing (TDM), the information from different channels is transmitted sequentially through the communication channel.

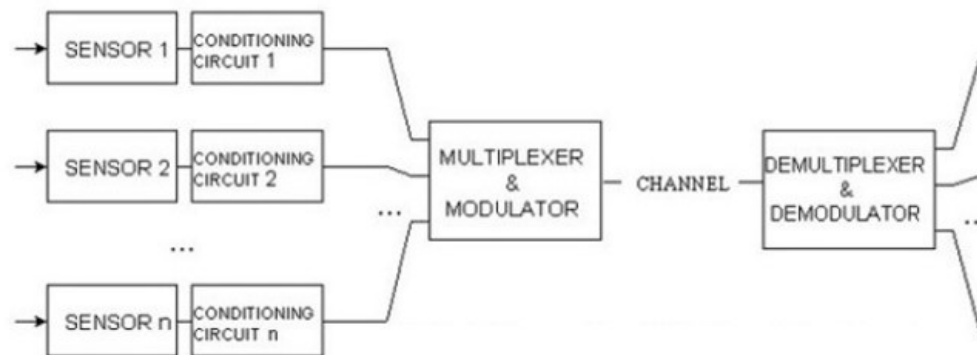


Figure 6. Block diagram of a multiple-channel telemetry system

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## Bibliography

IRIG Standards (1997). *Test Methods for Telemetry Systems and Subsystems. Document 118-97*. Telemetry Group, Range Commanders Council, US Army White Sands Missile Range. [This document describes the structure of telemetry systems.]

IRIG Standards (1998). *Telemetry Applications Handbook. Document 119-88*. Telemetry Group, Range Commanders Council, US Army White Sands Missile Range. [Explains telemetry applications and standards.]

Mackay R.S. (1993). *Biomedical Telemetry*. Piscataway, NJ: IEEE Press. [This book is focused on biotelemetry for animals and humans.]

Pallas-Areny R. and Webster J.G. (1991). *Sensors and Signal Conditioning*. New York: Wiley. [This book covers the basic principles of designing the different subsystems of a telemetry system.]

Pollack M.W. (1896). Communications-based signaling: Advanced capability for mainline railroads. *IEEE Aerospace and Electronic Systems Magazine* 11(11), 13–18. [Describes lesser-known applications of telemetry.]

Rezazadeh M. and Evans N.E. (1990). Multichannel physiological monitor plus simultaneous full-duplex speech channel using a dial-up telephone line. *IEEE Transactions on Biomedical Engineering* 37, 428–432. [Explains how multiple channels can be sent through a phone line.]

Shults M.C., Rhodes R.K., Updike S.J., Gilligan B.J., and Reining W.N. (1994). A telemetry instrumentation system for monitoring multiple subcutaneously implanted glucose sensors. *IEEE Transactions on Biomedical Engineering* 41, 937–942. [Describes a biotelemetry application.]

Tang A., Smith B., Schild J.H., and Peckham P.H. (1995). Data transmission from an implantable biotelemeter by load-shift keying using a circuit configuration modulator. *IEEE Transactions on Biomedical Engineering* 42, 524–527. [Describes more biotelemetry applications and constraints.]

Taub H. and Schilling D.L. (1986). *Principles of Communication Systems*, 2nd edn. New York: McGraw-Hill. [Covers the basic principles of frequency- and time-modulation.]

Uglow K.M. (1957). Noise and bandwidth in FM/FM radio telemetry. *IRE Trans. Telemetry and Remote Control*, 19–22. [This article analyzes how noise affects the integrity of telemetry signals.]

## Biographical Sketch

**Dr. Albert Lozano-Nieto** is an Assistant Professor of Engineering at the Pennsylvania State University, Wilkes-Barre Campus, where he is responsible for the Biomedical Engineering Technology and Electrical Engineering Technology programs. His research interests are focused on electrical impedance physiological measurements in humans, the study of biological effects of microwave and other non-ionizing radiation, and the development of new learning techniques in engineering technology and clinical engineering. His professional experience includes the evaluation of commercial pacemakers, testing of electronic equipment for compliance with the European Union electromagnetic compatibility regulations, and the development of instrumentation to measure body-fluid shifts using bioimpedance techniques for the European Space Agency. He is a member of the IEEE, AAMI, and ASEE.