Data Acquisition is simply the gathering of information about a system or process. It is a core tool to the understanding, control and management of systems or processes. Information such as temperature, pressure or flow is gathered by sensors that convert measurements into electrical signals. Sometimes only one sensor is needed, such as when recording local rainfall. Sometimes hundreds or even thousands of sensors are needed, such as when monitoring a complex industrial process. The signals from sensors are transferred by wire, optical fibre or wireless links to an instrument which conditions, amplifies, scales, processes, displays and stores the sensor signals. This is the Data Acquisition instrument.

In the past Data Acquisition equipment was largely mechanical, using clock work and chart recorders. Later, electrically powered chart recorders and magnetic tape recorders were used. Today, powerful microprocessors and computers perform Data Acquisition faster, more accurately, more flexibly, with more sensors, more complex data processing, and elaborate presentation of the final information.

Data Acquisition can be divided into two broad classifications – real time data acquisition and data logging. Real time data acquisition is when data acquired from sensors is used either immediately or within a short period of time, such as when controlling a process (Frey and Williams 1994). Data logging on the other hand is when data acquired from sensors is stored for later use (Frey and Williams 1994). In reality, there is a continuum of devices between real time data acquisition and data logging that share the attributes of both of these classifications.

Data logger can be pictured as a black box recorder in airplanes. These black box data loggers mainly record voices in the control deck and the plane’s state variables. Data loggers can be used for all types of data acquisition purposes and some of the sensing devices that can be connected to them include:
- Temperature sensors
- Pressure sensors & strain gauges
- Flow and speed sensors
- Current loop transmitters
- Weather & hydrological sensors
- Laboratory analytical instruments
- And much more...

Successfully collecting physical data with a data logger or computer-based system involves several components. Beginning with the physical parameters being measured and working toward the computer, a data acquisition system will be comprised of four fundamental components (Frey and Williams 1994).
1. Sensors / Transducers
2. Signal Conditioning
3. Analogue-to-Digital Conversion (A/D)
4. Software
25.1 Sensors / Transducers

When taking measurements, the first consideration is the physical parameter to be measured and recorded. It could be temperature, pressure, acceleration, sound intensity, wavelength of light, or almost anything. The first component in a computer-based data acquisition system is used to convert these physical parameters to some type of electrical signal (Frey and Williams 1994). Sensor is the generic term for any device that can sense physical phenomena. A transducer is a sensor that responds to these phenomena by producing appropriately scaled electrical signals (Frey and Williams 1994).

Some common examples of environmental transducers include:
1. Submersible water level sensors, which use a piezo-resistor whose electrical resistance changes when pressure is applied. Because water pressure is directly related to the depth of water above the point of measurement, this device can be used to measure the pressure exerted by water.
2. Electrical conductivity meters, which use magnetic coils to measure the electrical conductivity of the water. The ability of water to carry an electrical current is directly related to the amount of dissolved salt in the water. Therefore the output of this transducer can be either electrical conductivity or salt concentration.
3. Water turbidity meters, which use a miniature optical radar system to measure the amount of back scatter produced by suspended particles in the water. This system works on the same principle as car headlights reflecting off fog. When the water is clear very little light produced by the device's special light source is reflected back to the sensor; however when the water is very dirty, most of the light from the device is reflected back to the sensor.

A thermocouple is a good example of a simple transducer. A thermocouple is simply the junction of two different metals. The junction of these two metals produces a very small electric voltage. The strength of this voltage depends on the temperature of the junction between the two metals. Any two dissimilar metal wires will produce this voltage; however, certain types of thermocouples are used because of their output voltage strength. The voltage must be big enough so other instrumentation can utilise it for display and control purposes. In addition to being a strong enough signal it should also have a linear relationship to the temperature.

25.2 Power Supply

Many transducers require electrical power. One of the most common methods of powering a transducer is to provide a stable DC voltage to the sensing element. This is called the excitation voltage, and is typically in the range of a few volts up to about 30 volts DC. Usually this power can be supplied from a connection to mains power, but
in a remote situation power must be provided from other sources. The most common system used to provide power to remote data acquisition systems is a solar panel and battery.

25.3 Accuracy and Its Components

One of the most important principles of measurement to remember, especially when using transducers, is that it is rare to directly measure the parameter of interest. Some common examples of daily measurement will hopefully illustrate this point.

1. When measuring the mass of an object it is common to use a set of scales. The scales, if they are mechanical, are actually measuring the compression of a spring. The compression of the spring is directly related to the gravitational force exerted by the mass on the scales. If the scales are electronic, then the scales are replaced by a crystal that creates electrical charges when it is compressed.

2. The elapsed time of an event or process is measured by counting the number of regular intervals generated by some mechanical or electronic device (a clock) between when the event or process begins and when it ends.

Measurements made by a device are related to the parameter of interest. The exact relationship must be well understood by the manufacturers of the transducer and it must be correctly calibrated to make sure the output from the transducer is a true representation of the parameter being measured. If the output from the transducer and the true value of the measured parameter were plotted on a graph, the most desirable relationship between the two would be a straight line or linear relationship. Manufacturers go to great lengths to ensure the linearity of their instruments. In spite of this, the instrument should be regularly tested and calibrated to make sure it is providing accurate data.

Accuracy is a somewhat misleading and ill-defined term. Accuracy is a descriptive term concerning the closeness of a measured value to what is regarded as a true measurement of the quantity of interest. To fully define the accuracy of an instrument or transducer, the reading presented by the device must be compared to the measurement presented by a procedure which is considered to produce the standard value for this parameter. This process is called calibration. The error between the instrument’s output and that of the standard is a measure of the instrument’s accuracy.

As an example of a standard, the definition of a second is, ‘The interval of time taken to complete 9,192,631,770 oscillations of the caesium 133 atom exposed to a suitable excitation’ (Brain 1998-2004).

Atomic clocks provide the international standard for time keeping. The standard is based on the oscillation frequency of the caesium atom. To turn the caesium atomic resonance into an atomic clock, it is necessary to measure one of its transition or
Data Acquisition

resonant frequencies accurately. This is normally done by locking a crystal oscillator to the principal microwave resonance of the caesium atom (Brain 1998-2004).

To create a clock, caesium is heated so that atoms boil off and pass down a vacuum tube. These pass through a magnetic field that selects atoms of the right energy state; then they pass through an intense microwave field. The frequency of the microwave energy sweeps backward and forward within a narrow range, so that at some point in each cycle it crosses the frequency of exactly 9,192,631,770 Hertz. When a caesium atom receives microwave energy at exactly this frequency, it changes its energy state.

At the far end of the tube, another magnetic field selects the atoms that have changed their energy state. A detector gives an output proportional to the number of caesium atoms having this altered energy state, and therefore peaks in output when the microwave frequency is exactly 9,192,631,770 Hertz. This peak is used to make the slight correction necessary to bring the crystal oscillator to the correct frequency. This locked frequency is then divided by 9,192,631,770 to give the familiar one pulse per second required by the real world (Brain 1998-2004).

The key components of accuracy are resolution, hysteresis, precision and linearity:

1. Resolution is the fineness with which a measurement can be made. For example, if a ruler is marked with millimetre graduations, it is possible by interpolation to measure objects to the nearest 0.5 mm. Thus the resolution is 0.5 mm.

2. Precision is the closeness of agreement between readings in a series of consecutive measurements made on the same parameter under the same conditions. Precision does not necessarily imply that the measurement is a true indication of the parameter’s value. It does imply that the same reading is presented for the same conditions of the system when a measurement is made. Proper and regular calibration of the instrument should ensure that the measurement is a true representation of the system’s state.

3. Linearity is a measure of how well the instrument behaves over its full range of measurement. Generally a transducer’s output is converted to the real value of the parameter by applying appropriate (usually linear) mathematical manipulation to the signals from the circuitry. If the response of the circuitry deviates in some way from these basic relationships because of non-linear behaviour the output will have different calibration at different points along the range of the instrument’s output. In some cases non-linearity may be overcome by appropriate signal conditioning.

4. Hysteresis is an interesting property of many transducers which results in the output being dependent on whether the parameter being measured was increasing or decreasing in value at the time of measurement.

An example of hysteresis is friction in the mechanism of a set of scales. This causes a slight lag in the response of the instrument to changes in mass. Therefore if the mass on the scales was increasing at the time of weighing, the measurement indicated by the scales may be slightly less than the true value. However, if the mass was decreasing at the time of measurement due to evaporation of water, the measurement indicated
by the scales may be slightly more than the true value, in spite of the fact that the same set of scales was used in each measurement.

### 25.4 Transducer Output

The output signals from most transducers are relatively weak. Some transducers produce a proportionally scaled voltage as their output, while others produce a proportionally scaled current. For example, many environmental monitoring systems employ transducers that produce a current based output which ranges between 4 mA and 20 mA. The exact value of the current is related to the parameter being measured. It is important to note that the 4 mA output represents a zero reading in the parameter being measured. This is actually a clever way of testing whether the transducer is still working and connected properly. If 0 mA were used to represent zero output then it could be a true reading or it could actually be that the transducer has failed or the connecting cable has been broken. With this industry standard system, if there is a 0 mA output from the transducer it is immediately obvious that there is a fault in the system and the operator can be notified or the data flagged as being in error.

Clearly there needs to be some interpretation of the output signals to convert a current in the range between 4 mA and 20 mA into a meaningful measurement. Therefore the output from the transducer requires signal conditioning.

### 25.5 Signal Conditioning

In most cases, it is necessary to condition the signal before the rest of the data acquisition system can make proper use of it. Signal conditioning refers to the electronic hardware that prepares the signal from the transducer for the next piece in the system. This might be amplification, linearization, filtering or conversion from current-based to voltage-based signals (Frey and Williams 1994). Often, the signal conditioning hardware includes two or more types of conditioning. One of the most important reasons for signal conditioning is the reduction of noise.

#### 25.5.1 Noise

Noise may be generated within the electrical components as internal noise or it may be added to the signal as it travels down the input wires to the data acquisition system as external noise.

Internal noise arises from heat in the circuitry and although it can be minimized it cannot be completely removed. For example amplifiers will generate a few microvolts of internal noise which limits the resolution of the signal to this level. The
amount of noise added to the signal depends on the bandwidth of the system and the temperature. The noise power in a system is determined by:

\[ N = kTB \]

where \( N \) is the noise power (W), \( k \) is Boltzman’s constant \( (1.38 \times 10^{-23} \text{ J K}^{-1}) \), \( T \) is the noise temperature of the antenna (K) and \( B \) is the band width of the system (Hz).

Bandwidth can refer to two main concepts. In computer networks, bandwidth is often used as a synonym for data transfer rate - the amount of data that can be carried from one point to another in a given time period; however in communication systems, bandwidth refers to the range of frequencies that a signal uses on a given transmission medium. In this case, bandwidth is expressed in terms of the difference between the highest-frequency signal and the lowest-frequency signal sent along the communication channel.

Systems with narrow bandwidth will be less noisy than those with excessively large bandwidths. One of the most effective methods of reducing bandwidth in a data acquisition system is to introduce appropriate filtering systems. Filters are usually very simple circuits that limit the range of frequencies that can pass onto the next part of the system. For example the tuner of a radio is actually a filter that limits the incoming signals from all the available stations so that only one station’s signal can get to the rest of the radio circuitry.

For most data acquisition applications a low-pass filter is used to reduce noise. This allows lower frequency components through but removes the higher frequencies. The cut-off frequency must be compatible with the frequencies present in the actual signal and the sampling rate used for the analogue to digital conversion.

The second method of reducing internal noise is to cool the circuitry. For example, many radio telescopes and satellite dishes, like the one shown in Figure 25.1, use a cryogenically cooled feed system in order to reduce the internal noise of the system and increase its sensitivity to very low level signals from space (Electronics News 2004). Chapter 8 provides an introductory section on aperture antennae, like the dish antenna shown in Figure 25.1.

External noise is also added to a data system because the signal leads act as antennae picking up environmental electromagnetic activity. Most of this injected noise is common to both signal wires; therefore using a differential amplifier will remove most of this common mode voltage. Differences between the signal wires (for example if they are separated rather than twisted together) will lead to residual voltages being added to the signal, increasing noise. It is important when setting up automatic data acquisition systems to keep signal wires as short as possible and as far away from electrical machinery as possible.
Differential amplifiers measure the difference in voltage between two wires. By only reacting to differences on the input wires much of the injected noise can usually be eliminated from the system. Usually there is a third connector which allows these signals to be referenced to ground. The two wires go into separate high-impedance amplifiers which monitor the voltage between the input and ground. The outputs of the two amplifiers are then subtracted to give the difference between the two inputs, meaning that any voltage which is common to both wires is removed.

The ability of the amplifier to obtain the difference between two inputs whilst rejecting the common signal to both wires is defined by the common mode rejection ratio and the common mode range. A common problem when using differential amplifiers is neglecting the connection to ground. Unless some connection is made between the amplifier and ground the reference voltages are undefined quantities and may lead to some very unusual output from the amplifier.

### 25.5.2 Amplification

Amplification is used to magnify (or occasionally to reduce) an input signal. In times past, triodes (a type of valve) and transistors were used to provide amplification; however most instruments use operational amplifiers (or op-amps) to boost the outputs from transducers.

An ideal Operational Amplifier is a three-terminal device which consists of two high impedance inputs, one called the Inverting Input, marked on circuit diagrams with a negative sign, and the other one called the Non-inverting Input, marked with a positive sign (Smith 1976). The third terminal represents the amplifier output port which can both sink and source either a voltage or a current. In a linear operational
amplifier, the output signal is the amplification factor, known as the amplifier’s gain (A), multiplied by the value of the input signal. The sign of this gain factor depends on whether the input voltage is fed into the inverting or non-inverting input (Smith 1976). The gain of operational amplifiers is controlled by feedback resistors placed in the circuit around the amplifier (Smith 1976). The gain of an inverting amplifier (Figure 25.2) is:

$$A = -\frac{R_f}{R_i}$$

(25.2)

The gain of a non-inverting amplifier (Figure 25.3) is:

$$A = \frac{R_i + R_f}{R_i}$$

(25.3)

Figure 25.2: An inverting amplifier configuration.

Figure 25.3: A non-inverting amplifier configuration.
Inversion simply means that when the input voltage goes above the zero voltage point (positive) the output goes below the zero voltage point (negative) and vice versa. A nice feature of an inverting amplifier configuration is that it allows several inputs from different sources to be added together in one device. There are some other useful features about inversion, which for the moment are beyond the scope of this book.

25.5.3 Offset Adjustment

As mentioned earlier, the industry standard output from a transducer ranges between 4 mA and 20 mA, where 4 mA represents the zero value of the measurement being made. Having at least 4 mA running through the connection from the transducer identifies when the device is working properly; however it confounds the actual measurement process. The easiest way to remove this confounding influence is to add a small negative DC voltage to the input signal to shift the signal down so that the output reads zero when the input from the transducer is at 4 mA. This can be done using the adding feature of the inverting amplifier configuration mentioned earlier (Figure 25.4).

![Figure 25.4: An offset adjusting inverting amplifier.](image_url)
The output from the amplifier circuit in Figure 25.4 is:

\[ V_{out} = -\frac{R_2}{R_1} V_{in} - \frac{R_1}{R_4} V_{DC} \]  

(25.4)

Where \( V_{DC} \) is provided by an adjustable voltage divider \( R_4 \). The circuit is set up and adjusted while the transducer is reading a zero input (i.e. 4 mA).

### 25.6 Digital Data Acquisition

Most data analysis, particularly for very large quantities of data, involves computer systems. By their very nature, computers cope with numbers rather better than with constantly changing voltages or currents. Therefore an integral component in most data acquisition systems is a circuit that converts an incoming voltage into a number. This process begins with a sample and hold system that feeds a sampled voltage into circuits called analogue-to-digital converters (A/D converter) (Vandoren 1982). It is common to have several transducers, which are measuring several parameters, feeding into a single data acquisition system. Therefore multiplexing is used to sample across several input channels is used to sequentially acquire data from each transducer in turn (Vandoren 1982).

#### 25.6.1 Sample and Hold Circuits

As the name indicates, a sample and hold circuit is a circuit, which samples an input signal and holds onto its last sampled value until the input is sampled again. Sample and hold circuits are commonly used in analogue to digital converts, communication circuits, etc. A typical sample and hold circuit stores charge in a capacitor (Figure 25.5). It uses electronic switching arrangements, commonly provided by a field effect transistor (FET), to connect or disconnect the capacitor from the input signal at regular time intervals. To sample the input signal the switch connects the capacitor to the input signal, via a buffer amplifier. The buffer amplifier charges or discharges the capacitor so that the voltage across the capacitor is proportional to the input voltage. In hold mode the switch disconnects the capacitor from the buffer. The capacitor is invariably discharged by its own leakage currents and useful load currents, but the loss of voltage (voltage drop) within a specified hold time remains within an acceptable error margin. The resulting output from the sample and hold circuit has a staircase appearance that approximates the analogue input (Figure 25.6). The staircase approximation of the input signal becomes a better approximation to the real signal when the sampling rate is high.
25.6.2 Aliasing

Aliasing refers to an effect that causes different continuous signals to become indistinguishable (or aliases of one another) when they are sampled. For example, Figure 25.7 shows a continuous sinusoidal signal that has been sampled at regular time intervals. However, Figure 25.8 shows another sinusoidal wave that passes through each sample point from the first signal. The two waves are “aliases” of one another. Aliasing can be avoided by ensuring that the sampling frequency is greater than twice the frequency of the highest frequency signal in the original data. This is referred to as the Nyquist sampling rate (Nyquist 2002).
25.6.3 Multiplexing

Multiplexing is sending multiple signals or streams of information on a carrier at the same time in the form of a single, complex signal and then recovering the separate signals at the receiving end (Taub and Schilling 1971). For data acquisition from multiple input devices, multiplexing can be achieved by using the equivalent of a multi-way switch that polls each input one after the other in sequence. Technically this is referred to as time-division multiplexing because each input is allocated a set amount of time to communicate with the remainder of the system.
25.6.4 Analogue-to-Digital Conversion

For digital data acquisition that directly interfaces with a computer, such as can be found in many laboratories, Analogue to digital conversion is typically handled with a plug-in board or card. They are commonly referred to as DAQ-boards or DAQ-cards. In a stand alone data logging system, these circuits are hard-wired into the system itself.

An analogue to digital converter (Figure 25.9) works by comparing digital numbers with the sampled input signal. It actually uses a digital to analogue converter (D/A) to help in this process. The D/A converter is another clever application of a summing inverting amplifier (Figure 25.10) that can build an equivalent voltage from a stored binary number. The input from the D/A converter is fed from the output of the A/D converter. The output from the D/A converter is compared with the input signal. If the output from the D/A converter is too low, the comparator boosts the A/D counter so it adopts a higher digital number. If the output from the D/A converter is too high, the comparator reduces the A/D counter so it adopts a lower digital number. When the digital number is as close as possible to the input signal’s value, the digital number is transferred along a bus system to some storage device or computer.

Figure 25.9: Analogue to digital converter diagram.

Figure 25.10: Example of a 4-bit digital to Analogue converter.
The vast majority of DAQ boards and cards have either 12-bit or 16-bit resolution. This translates to being able to distinguish either 4096 or 65536 individual units of measure respectively. Ultimately this ability to subdivide the full range of the transducer’s output into small subdivisions determines the resolution of the final data. The number of divisions that can be distinguished is:

\[ R = 2^N \]  

(25.5)

Where \( R \) is the number of divisions and \( N \) is the number of binary digits that can be produced by the A/D converter.

Consider the case of a thermocouple that has a full scale capability of 0 to 1000 degrees. If a 12-bit A/D converter is used, then the 12-bit A/D converter will split the measurement range into 4096 steps with each step being (1000 degrees)/4096 or about \( \frac{1}{4} \) of a degree. That will be the finest resolution of the temperature available from this system.

### 25.7 Software

There are plenty of software products available for data analysis. Many of these are system-specific. By far, the most common solution used by engineers for PC-based DAQ systems are the graphical DAQ software languages. These are designed to reduce the programming time and minimize the expertise required.

Popular examples of this type of DAQ software are: LabVIEW, Agilent VEE (previously known as HP VEE), DasyLab, and MatLab. Many engineers program the software themselves. Others will hire system analysts or programmers to do the programming for them.

Probably one of the most useful software tools for analyzing data is a simple spreadsheet. In conjunction with proper geo-referencing using latitude and longitude or some other map grid system, data that has been summarised using a spreadsheet may also be exported into a Geographic Information System (GIS) for further spatial analysis.

Hopefully it is clear from this discussion that data acquisition can be an expensive process in terms of both time and equipment. Therefore every effort should be made to protect and preserve both the system and the data. One of the biggest problems with long term field based data acquisition systems is lightning.
25.8 Lightning Protection

One of the most destructive environmental phenomena is lightning. Lightning occurs as a result of unstable upper atmospheric conditions. The first stage of a lightning strike is a series of stepped downward leaders moving from the clouds toward the ground. These leaders are invisible to the naked eye. Prominent features such as buildings and trees develop high positive charges which emit upward moving streamers competing with each other for connection with the downward leaders. When connection occurs, a path to ground is formed for the lightning current. This return stroke is the lightning flash that is visible to the eye, as seen in Figure 25.11.

During lightning storms, huge voltage differences develop between the air and the earth. Huge voltage differences can also build up in the ground itself. It is possible to receive a severe or even fatal shock because of these voltage differences in the earth, even if the victim is some distance from where lightning struck the ground. There have been many instances where cattle have been killed during lightning storms because the voltage difference between their front and hind feet is enough to cause lethal electrical currents to flow through their bodies.

Voltage differences in the ground cause electrical currents to flow through the soil. When these currents are intercepted by something which is a better conductor than the soil, they will flow through the object rather than the soil. This causes current surges through telephone wires and sensor cables. Longer cables tend to capture ground currents from distant lightning strikes better than shorter cables and can therefore cause considerable damage to a data acquisition system. The same can be said about people who are holding onto cables during lightning storms.

Figure 25.11: Lightning over Sydney harbour.
The problem with lightning strikes is voltage differences between one part of a system and another. This voltage difference gives rise to unwanted current flowing through the system. These currents cause damage to equipment and place personnel in danger.

By knowing the nature of lightning it is possible to develop a strategy to redirect unwanted currents away from vital parts of the system.

The first strategy is to capture the lightning strike. Rather than trying to eliminate the strike, it is better to adopt a more subtle approach and provide a predictable path that diverts it away from the more vulnerable parts of the system. A structure may be protected by erecting a lightning rod adjacent to it. A lightning rod will provide a cone of protection, as shown in Figure 25.12, having a base radius of approximately twice the height of the rod itself.

![Figure 25.12: Cone of protection provided by lightning rod.](image)

A lightning rod in combination with a good earthing system, like that shown in Figure 25.13, will intercept the strike and safely conduct the energy to earth, away from sensitive parts of the system.

![Figure 25.13: Lightning rod with multiple earth connections to provide good dissipation of energy.](image)
The first strategy is to protect people. Personnel protection is a two fold process:

1. **Holding a common voltage** - The objective of this approach to lightning protection is to hold all parts of the system at the same voltage until the energy from the lightning strike has time to dissipate. In remote areas this can be accomplished by:
   - Installing multiple earth spikes on the system. This is even more effective if the earth spikes are arranged in a loop around any structures that people may touch, as shown in Figure 25.14. This will effectively hold the structure and a sizeable volume of soil around it at the same voltage, reducing the risk of shock.
   - Electrically connecting structures together using lengths of electrical cable will ensure that the entire structure remains at the same electrical voltage. This will stop currents flowing from one place to another and it will reduce the risk of electrical shock.

![Figure 25.14: Loop earthing system designed to protect personnel who are touching conductive structures.](image)

2. **Eliminate earth currents** - Because the soil itself can sustain sizeable voltage differences between one location and another, it is possible that a current may be set up in a long cable which has been earthed at both ends. It is better to totally isolate one end of the cable and solidly earth the other to a common earth point.

The objective of isolation is to provide an electrical break between two systems, yet still allow signal transfer to take place across this break. Isolation is only possible when both sides of the isolation point have independent power supplies. In an instrumentation system it is impossible to isolate between the logger and the probes, because the probes take their power supply from the logger.
The only part of the system where this technique could be used effectively would be at the interface between the data transmission system and the data logging system. One technique which could provide good isolation is to use optical coupling between the output of the data logger and the telephone line.

Normal monolithic opt-coupling devices are not effective. Experience shows that for large voltage surges these devices self destruct. One option could be to install short lengths of optical fibre to provide isolation. Another option is to use radio links or mobile telephones to link the data logger to a central computer system.

25.8.1 Some Notes on Earthing Systems

The best way to protect a circuit against lightning strike is to ensure there is a direct path to earth other than through a person or a vital circuit. This is normally achieved by enclosing the circuit in a metal container and connecting the container directly to the earth via a copper strap.

One of the major problems with earthing is that soil is not always a good conductor. Soil resistivity varies greatly from one location to another. For example, saturated soils near rivers may have a resistivity of less than 1.5 ohm metres. In the other extreme, dry sand can have resistivity values as high as 10,000 ohm metres. Soil type profoundly affects the quality of any earthing system. Table 25.1 shows the electrical resistivity of several common soil types.

<table>
<thead>
<tr>
<th>Type of Soil or Water</th>
<th>Typical Resistivity (Ohm metres)</th>
<th>Usual Limits (Ohm metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Water</td>
<td>2</td>
<td>0.1 to 10</td>
</tr>
<tr>
<td>Clay</td>
<td>40</td>
<td>8 to 70</td>
</tr>
<tr>
<td>Ground well and spring water</td>
<td>50</td>
<td>10 to 150</td>
</tr>
<tr>
<td>Clay and Sand mixture</td>
<td>100</td>
<td>4 to 300</td>
</tr>
<tr>
<td>Shale, slate, sandstone etc.</td>
<td>120</td>
<td>10 to 1,000</td>
</tr>
<tr>
<td>Peat, loam and mud</td>
<td>150</td>
<td>5 to 250</td>
</tr>
<tr>
<td>Lake and creek water</td>
<td>250</td>
<td>100 to 400</td>
</tr>
<tr>
<td>Sand</td>
<td>2,000</td>
<td>200 to 3,000</td>
</tr>
<tr>
<td>Moraine gravel</td>
<td>3,000</td>
<td>40 to 10,000</td>
</tr>
<tr>
<td>Ridge gravel</td>
<td>15,000</td>
<td>3,000 to 30,000</td>
</tr>
<tr>
<td>Solid granite</td>
<td>25,000</td>
<td>10,000 to 50,000</td>
</tr>
<tr>
<td>Ice</td>
<td>100,000</td>
<td>10,000 to 100,000</td>
</tr>
</tbody>
</table>
Soil moisture content is also important. Soils normally contain some salt. When water enters the soil profile, salt is dissolved to form an electrolyte (a solution containing charged particles). These charged particles can drastically reduce the soil’s resistivity, as shown in Table 25.2. Table 25.3 demonstrates the influence temperature has over soil resistivity.

**Table 25.2:** Variation of soil resistivity with moisture content (Source: AS/NZS 1768:2007 2007).

<table>
<thead>
<tr>
<th>Moisture Content (% of weight)</th>
<th>Typical soil resistivity of clay mixed with sand (Ohm metres)</th>
<th>Typical soil resistivity of sand (Ohm metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10,000,000</td>
<td>----</td>
</tr>
<tr>
<td>2.5</td>
<td>1,500</td>
<td>3,000,000</td>
</tr>
<tr>
<td>5</td>
<td>430</td>
<td>50,000</td>
</tr>
<tr>
<td>10</td>
<td>185</td>
<td>2,100</td>
</tr>
<tr>
<td>15</td>
<td>105</td>
<td>630</td>
</tr>
<tr>
<td>20</td>
<td>63</td>
<td>290</td>
</tr>
<tr>
<td>30</td>
<td>42</td>
<td>----</td>
</tr>
</tbody>
</table>

**Table 25.3:** Variation of resistivity with temperature in a mixture of sand and clay with a moisture content of 15% by weight (Source: AS/NZS 1768:2007 2007)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Typical value of soil resistivity (Ohm metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>72</td>
</tr>
<tr>
<td>10</td>
<td>99</td>
</tr>
<tr>
<td>0 (Water)</td>
<td>138</td>
</tr>
<tr>
<td>0 (Ice)</td>
<td>300</td>
</tr>
<tr>
<td>-5</td>
<td>790</td>
</tr>
<tr>
<td>-15</td>
<td>3,300</td>
</tr>
</tbody>
</table>

The Lightning Protection Standard (2007) specifies that the maximum earth resistance for an earthing system for lightning protection purposes should be 10 ohms in dry soil. Earth resistance can be measured using a special type of meter called a mega. Where the desired resistance can not be obtained by installing one earth rod, it is possible
to reduce the overall resistance by installing additional earthing rods. The overall resistance will be higher than would be expected from simple resistor theory because of interference from one rod to the next within the soil. To minimise interference the distance between electrodes should be at least twice the length of the rod in the ground, as shown in Figure 25.15.

Figure 25.15: Installation of multiple earth stakes at a data acquisition station.

To protect equipment from damage due to lightning strikes and other electrical surges it is essential to use a transient barrier. A transient barrier is designed to prevent very high voltage pulses from passing through to sensitive electronic equipment from external wires and cabling. When the transient barrier is operating normally, signals pass through the barrier without change. When a high voltage surge, which is greater than the transient barrier’s rating, arrives on the line, the barrier will conduct the surge currents in the line to ground.

The protection level of the barrier specifies the method used by the transient barrier to do this. A protection level 3 is the recommended rating for data logging applications. The voltage at which the transient barrier begins to conduct to ground must also be specified (Cody 1993).

Once the data has been acquired and stored by the acquisition system it must be made available to the landscape manager for analysis. Often this involves connecting a portable computer to the system and downloading the data from the logger to the computer. Many large scale systems such as the national weather monitoring network cover far too large an area to do this effectively. Therefore they use data communication systems. Data communication will be discussed in the next chapter.

References

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