Signal Conditioning Circuits: Power Supplies

Electronic measurement system

- Power supply
- Transducer
- Conditioning circuits
- Amplifier
- Recorder
- Command generator
- Data processor
- Controller
- For engineering analysis - Graphs or Tables
- Process control
Chapter 3 Signal conditioning systems

Power Supplies

- Some transducers need the power supply in order to convert the sensed information from the sensor into the electrical signal.

Power supplies for instruments

1. Battery supplies
   - widely used and inexpensive
   - voltage declines after used
   - voltage regulating circuit required

2. Line voltage supplies
Zener diode

is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as “Zener voltage”.

Line voltage supplies

take the (high) voltage from a wall outlet and lower its into the desired (low) voltage. The (low) alternating voltage is converted to direct voltage and is then regulated.
**Transformer** is a device that transfers electrical energy from one circuit to another through inductively coupled conductors – The transformer’s coils.

\[
\frac{V_s}{V_p} = \frac{N_s}{N_p}
\]

**Step-up transformer** \( \frac{N_s}{N_p} > 1 \)

**Step-down transformer** \( \frac{N_s}{N_p} < 1 \)

**Rectifier** is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction.

\[
V_{dc} = V_{av} = \frac{2V_p}{\pi}
\]

\[
V_{rms} = \frac{V_p}{\sqrt{2}}
\]
Voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level.

Three pin 12 V DC voltage regulator IC.

Signal Conditioning Circuits: Bridge Circuits
Bridge circuits

- have been devised for measuring capacitance, inductance, and most often for measuring resistance. A purely resistance bridge, called a “Wheatstone bridge”, provides a means for accurately measuring resistance, and for detecting small changes in resistance.

Galvanometer

Bridge's analysis

The basic arrangement for a bridge circuit is shown in the figure below. A dc voltage is applied as an input across nodes A to D, and the bridge forms a parallel circuit arrangement between these two nodes. The currents flowing through the resistors $R_1$ to $R_4$ are $I_1$ to $I_4$, respectively. Under the condition that the current flow through the galvanometer, $I_g = 0$, the bridge is in a balanced condition.

For a balanced bridge:

$$\frac{R_2}{R_1} = \frac{R_3}{R_4}$$

If the resistor $R_1$ is a transducer, a change in resistance, associated with a change in some physical variable, causes an unbalance of the bridge.
Chapter 3 Signal conditioning systems

Bridge’s analysis

1. **Null Method**

   - $R_1$ is the resistance of the transducer
   - $R_2$ is the resistance of the adjustable resistor

   **Principle:** If the resistance $R_1$ varies with changes in the measured variable, one of the other arms of the bridge can be adjusted to null the circuit and determine resistance.

   ![Wheatstone Bridge Diagram]

   - The resistance $R_2$ must be calibrated such that the adjustments directly indicate the value of $R_1$.

   **Advantages:**
   1. No need to know the input voltage.
   2. Current detector required (Galvanometer) to detect $I_g$

   **Disadvantages:**
   1. Sensitivity depending on the galvanometer
   2. Uncertainty in the measured resistance depending on the input voltage

   **Uncertainty:** $u_R \propto \frac{1}{E_i}$
2. Deflection Method

**Principle:** a voltage measuring device is used to measure the voltage unbalance in the bridge (the voltage drop from B to C) as an indication of the change in resistance.

\[ E_o = E_i \left( \frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4} \right) \]

For identical resistors,

\[ R_1 = R_2 = R_3 = R_4 = R \]

Under balanced conditions \((I_g = 0)\),

\[ E_o = 0 \]

In an unbalanced condition,

\[ \frac{\delta E_o}{E_i} = \frac{\delta R/R}{4 + 2(\delta R/R)} \]
Advantage: can be used to measure time-varying signals, but the voltage measuring device must have the frequency response not less than that of the sensor.

Disadvantage:
1. high capability of the galvanometer required.
2. known and regulated input voltage required.

In case of the low impedance galvanometer, $R_g$

$$I_g = E_i \frac{\delta R / R}{4(R + R_g)}$$

$$E_g = E_i \frac{\delta R / R}{4(1 + R/R_g)}$$

Example 1 Null method

A certain temperature sensor experiences a change in electrical resistance with temperature according to the equation

$$R = R_0[1 + \alpha(T - T_0)]$$

where
- $R$ = sensor resistance [Ω]
- $R_0$ = sensor resistance at the ref. temperature $T_0$ [Ω]
- $T$ = measuring temperature [°C]
- $\alpha$ = constant = 0.00395 °C⁻¹

Given:
1) $R_1 = R_2 = 500$ Ω
2) $R_0 = 100$ Ω at $T_0 = 0^\circ$C

Determine the value of $R_2$ that would balance the bridge at 0 °C.
Example 2 Deflection method

Consider a deflection bridge, which initially has all arms of the bridge equal to 100 ohms, with the temperature sensor described in Example 1. The input voltage to the bridge is 10V. If the temperature of R1 is changed such that the bridge output is 0.569 V, what is the temperature of the sensor? How much current flows through the sensor and how much power must it dissipate?

Solution

At deflection state,
\[ \delta E_o = 0.569 \ V \]

A change in the resistance of the sensor can be obtained from
\[ \frac{\delta E_o}{E_o} = \frac{\delta R/R}{4 + 2(\delta R/R)} \]
We obtain

\[ \delta R = 25.67 \text{ ohms} \]

Therefore, the temperature of the sensor is

\[ R_1 = R_0 + \delta R = R_0[1 + 0.00395(T - T_0)] \]

\[ 100 + 25.67 = 100[1 + 0.00395(T - 0)] \]

\[ T = 65\degree C \]

By Kirchoff’s law, the current flowing through R1 is given by

\[ I_1 = E_i \left( \frac{1}{R_1 + \delta R} + \frac{1}{R_2} \right) = 44.3 \text{ mA} \]

The power dissipated from the sensor is

\[ P_1 = I_1^2 (R_1 + \delta R) = 0.25 \text{ W} \]
Amplifiers

- Is a device that scales the magnitude of an analog input signal according to the relation

\[ V_o = G \times V_i \]

where \( G \) = Gain

Input voltage, \( V_i \)  
Output voltage, \( V_o \)  
Supply voltage, \( V_s \)
Types of amplifier

1. Single-ended amplifiers
   are amplifiers which amplify a single input signal. Both input and output signal voltages are referenced a common connection in the circuit called ground. (used for potentiometer circuits)

2. Differential amplifiers
   are amplifiers which amplify two input signals. All voltages are referenced to the circuit's ground point. (used for bridge circuits)

\[
\begin{align*}
V_o &= G \times V_i \\
V_o &= G (V_{i,1} - V_{i,2})
\end{align*}
\]

Operational Amplifiers (op-amp)

- An "op-amp" is a high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output.

- Characteristics of op-amps
  1. High internal gain \( G = 10^5 \) to \( 10^6 \)
  2. High input impedance \( Z_i > 10^7 \Omega \)
  3. Low output impedance \( Z_o < 100 \Omega \)
  4. two input ports, a noninverting and an inverting input, and one output port

\[
V_o = G (V_{non-inv} - V_{inv})
\]
Chapter 3 Signal conditioning systems

Inverting Amplifier:

**Circuit analysis**

Sum of currents at Node A

\[ i_1 + i_f = i_a \]

\[ i_1 = \frac{V_i - V_a}{R_1} \quad i_f = \frac{V_o - V_a}{R_f} \quad i_a = \frac{V_a}{R_a} \]

Output voltage of the inverting amplifier

\[ V_a = \frac{V_o}{G} \]

\[ G_e = \frac{V_o}{V_i} = -\frac{R_f}{R_1} \]
Chapter 3 Signal conditioning systems

Non-inverting Amplifier: 
\[ G_c = \frac{V_o}{V_i} \geq 1 + \frac{R_f}{R_1} \]

Summing Amplifier: 
\[ V_o = -R_f \left( \frac{V_{i,1}}{R_1} + \frac{V_{i,2}}{R_2} + \frac{V_{i,3}}{R_3} \right) \]

Voltage follower: 
\[ G_c = \frac{V_o}{V_i} \geq \frac{G}{1 + G} \]

Differentiator: 
\[ V_o = -R_f C_1 \frac{dV_i}{dt} \]

Integrator: 
\[ V_o = -\frac{1}{R_1 C_f} \int_0^t V_i \, dt \]

Signal Conditioning Circuits

:Filters
Filters

- In many instrumentation applications, the (dynamic) signal from the transducer is combined with noise or some other parasitic signal. These undesired signals can be eliminated with a filter that is designed to attenuate the noise signals but transmit the transducer signal without distortion.

- Two filters that utilize passive components and are commonly employed in signal conditioning include (1) High-pass RC filter and (2) Low-pass RC filter.

![RC filter circuits](image)

Unfiltered signal with low frequency variation and high frequency noise

Filtered signal

High-pass filter

High-pass filter employed to remove low frequency variation

Low-pass filter

Low-pass filter employed to remove high frequency noise
High-pass RC filters

- High-pass filter permits only frequencies above the cutoff frequency to pass.

Consider a summation of voltage drops around the loop

\[ V_i - \frac{q}{C} - Ri = 0 \]

If \( V_i = |V_i|e^{j\omega t} \) and \( q = \int_0^t i \, dt \)

The output voltage \( V_o \) is

\[ V_o = \frac{\omega RC}{\sqrt{1 + (\omega RC)^2}} |V_i|e^{j\omega t + \phi} \]

where

\[ \phi = \frac{\pi}{2} - \tan^{-1}(\omega RC) \]

\[ V_o \sim 0 \quad \text{if} \quad \omega \rightarrow 0 \]

Low-pass filters

- Low-pass filter permits only frequencies below the cutoff frequency to pass while blocking the passage of frequency information above the cutoff frequency.

The output voltage is

\[ V_o = \frac{1}{\sqrt{1 + (\omega RC)^2}} |V_i|e^{j\omega t - \phi} \]

where

\[ \phi = \tan^{-1}(\omega RC) \]

\[ V_o \sim 0 \quad \text{as} \quad \omega \rightarrow \infty \]
Cut-off frequency

* is defined as the frequency at which the ratio of the amplitudes of the output to the input has a magnitude of 0.02 (2% error).

For examples,

1. Hi-pass filter

\[ \left| \frac{V_o}{V_i} \right| = \frac{\omega C}{\omega RC} / \left[ 1 + (\omega RC)^2 \right]^{1/2} = 0.02 \Rightarrow \omega_c = 5/RC \Rightarrow f_c = 5/(2\pi RC) \]

2. Lo-pass filter

\[ \left| \frac{V_o}{V_i} \right| = 1 / \left[ 1 + (\omega RC)^2 \right]^{1/2} = 0.02 \Rightarrow \omega_c = 0.203/RC \Rightarrow f_c = 0.203/(2\pi RC) \]

Active filters

* Operational amplifiers are employed to construct active filters where select frequencies can be attenuated and the signal amplified during the filtering process.

Low-pass active filter

\[ f_c = \frac{1}{2\pi R_2 C_2} \]

High-pass active filter

\[ f_c = \frac{1}{2\pi R_1 C_1} \]
Amplitude Modulators

- Amplitude modulation is a signal conditioning process in which the signal from a transducer is multiplied by a carrier signal of constant frequency and amplitude.

\[ V_i(t) = v_i \sin(\omega_i t) \times V_c(t) = v_c \sin(\omega_c t) \]

\[ \omega_c \sim 10 - 100 \omega_i \]
Modulated signal

\[ V_o = (V_i \sin \omega_i t)(V_c \sin \omega_c t) \]

\[ V_o = \frac{V_i V_c}{2} [\cos(\omega_c - \omega_i) t - \cos(\omega_c + \omega_i) t] \]

In general, noise signals occur at 50-Hz

\[ \omega_c = 4000 \text{ Hz} \]
\[ \omega_i = 50 \text{ Hz} \]
\[ \omega_m = 3950 \text{ Hz and 4050 Hz} \]

Amplitude Modulators

Advantages

(1) Stability
(2) Low power
(3) Noise suppression

Demodulation is the process that the transducer signal is separated from the carrier signal.
Assignment #3

1. Shown that the output voltage of the summing amplifier be expressed by the equation

\[ V_o = -R_f \left( \frac{V_{i,1}}{R_1} + \frac{V_{i,2}}{R_2} + \frac{V_{i,3}}{R_3} \right) \]

2. Consider the Wheatstone bridge. Suppose \( R_3 = R_4 = 200 \, \Omega \), \( R_2 \) = variable calibrated resistor, and \( R_1 \) = transducer resistance = \( 40x + 100 \)

   a) When \( x = 0 \), what is the value of \( R_2 \) required to balance the bridge?

   b) If the bridge is operated in a balanced condition in order to measure \( x \), determine the relationship between \( R_2 \) and \( x \).
Sampling concepts

Conversion of analog signals to digital code is extremely important in any instrument system that involves digital processing of the analog output signals from the signal conditioners.

Continuous Signal

Discrete Signal

"discrete time series"

Discrete time series

- Suppose the transducer signal is measured repeatedly at successive sample time increments $\delta t$

$$\{y(r\delta t)\} = y(t) \delta(t - r\delta t) \quad r = 1, 2, 3, \ldots, N$$
Chapter 3 Signal conditioning systems

Sample rate

\[ f_s = \frac{1}{\delta t} \text{ [Hz]} \]

The sample rate has a significant effect on perception and reconstruction of the continuous analog signal in the time domain.

\[ f_s > 2f_m \]

\[ \delta t < \frac{1}{2f_m} \]

*** s = sampling
m = measuring

**Alien Frequencies**

- When the sample rate is less than \( 2f_m \), the higher frequency content of the analog signal will take on the false identity of a lower frequency in the resulting discrete series. A false frequency is called an "alias frequency".

Original signal
10 Hz

Interpreted signal
2 Hz
**Folding Diagram**

is the diagram that is used to find the alias frequency.

Example

\[
\begin{align*}
    f &= 10 \text{ Hz} \\
    f_N &= 6 \text{ Hz} \\
    \left[\frac{f}{f_N}\right]_{\text{axis}} &= \frac{10}{6} = 1.67 \\
    \left[\frac{f}{f_N}\right]_{\text{axis}} &= 0.33 \text{ Hz} \\
    f_{\text{alias}} &= 0.33 \times f_N = 2 \text{ Hz}
\end{align*}
\]

**Nyquist frequency and Anti-Aliasing**

- **Nyquist frequency** is the highest frequency that can be coded at a given sampling rate in order to be able to fully reconstruct the signal,

\[ f_N = 0.5 f_S \]

- **Anti-aliasing** is a process that remove signal content at and above Nyquist frequency by use of a low-pass filter prior to sampling and use an appropriate sample rate for the signal

\[ \text{Signal} = \text{Signal}_{[f < f_N]} + \text{Signal}_{[f > f_N]} \]

Anti-aliasing filter
Example

- Consider a complex periodic signal in the form

\[ y_m(t) = 10 \sin(50\pi t) + 0.5 \sin(150\pi t) + 1.2 \sin(250\pi t) \]

![Graph showing the signal](image)

Example (cont.)

- If the signal is sampled at 100 Hz

\[ f_N = 0.5 f_s = 0.5 \times 100 \text{ Hz} = 50 \text{ Hz} \]

- Observe all frequency content in the sampled signal

\[ y_m(t) = 10 \sin(50\pi t) + 0.5 \sin(150\pi t) + 1.2 \sin(250\pi t) \]

\[ f_1 = 25 \text{ Hz} \quad f_2 = 75 \text{ Hz} \quad f_3 = 125 \text{ Hz} \]

\[ f_N < f_m \quad \text{Alias frequency} \]
Example (Cont.)

- Sampled signal

\[ y_s(r\delta t) = 10 \sin(50\pi r\delta t) + 0.5 \sin(50\pi r\delta t) + 1.2 \sin(50\pi r\delta t) \]

Alias frequency = 25 Hz

Example (cont.)

- Use a low-pass filter with the cut-off frequency > 50 Hz

\[ y_A(r\delta t) = 10 \sin(50\pi r\delta t) \]
Amplitude Ambiguity

- The sampling signal can be completely reconstructed from a discrete time series, if
  - Total sample period remains an integer multiple of the fundamental period, $T_1$
    \[ mT_1 = N\delta t \]
  - Sample rate meets the sampling criterion.
    \[ f_s > 2f_m \]

Note: $N = 2^M$, $M = \#$ of sample points

Example

\[ y(t) = 10\cos(2\pi 100t) \]

- Amplitude = 10
  - Fundamental period $T_1 = 1/100$ s
  - (a) $m = N\delta t / T_1 = 2.56$  
    
    **amplitude leakage**
  - (b) $m = N\delta t / T_1 = 10.24$
    
    **amplitude leakage**
  - (c) $m = N\delta t / T_1 = 8$
    
    **No leakage**
Selecting sample rate and data number

- For an exact discrete representation in both frequency and amplitude of analog signal, both the number of data points and the sample rate should be chosen based on the following criteria: (1) $f_s > 5f_m$ (2) long total sample periods (large $N$) and (3) use of anti-alias filter.

Data-Acquisition System (DAS)

is the portion of a measurement system that quantifies and stores data. A typical signal flow scheme is shown in the following diagram.
Signal Conditioning: Filters and Amplification

- **Filters**

  1. **Analog filters** are used to control the frequency content of the signal being sampled.
     
     Example: Anti-alias filter

  2. **Digital filters**, which are software-based algorithms, are effective for signal analysis after sampling.
     
     Example: moving-averaging scheme (for removing noise)
     
     \[
     y'_i = \frac{y_{i-n} + \cdots + y_{i-1} + y_i + y_{i+1} + \cdots + y_{i+n}}{2n + 1}
     \]
Signal Conditioning: Filters and Amplification

**Amplifiers**

All DASs are input range limited; that is, there is a minimum value and a maximum value of signal. Some transducer signals will need amplification or attenuation prior to conversion. Most DASs contain on-board instrumentation amplifiers.

\[
\text{Voltage divider for signal attenuation}
\]

\[ R_1 = 40 \, \text{k}\Omega \]
\[ R_2 = 10 \, \text{k}\Omega \]

**Shunt circuits**

An A/D converter requires a voltage signal at its input. It is straightforward to convert current signals into voltage signals using a shunt resistor.

In general, the standard current signal has a range of \(4 - 20 \, \text{mA}\).

Using a shunt resistor = 250 \(\Omega\), the current signal would be converted into the voltage signal:

\(1 - 5 \, \text{V}\)
Signal Conditioning: Filters and Amplification

- **Multiplexer**

  When multiple input signal lines are connected by a common throughout line to a single A/D converter, a multiplexer is used to switch between connections, one at a time.

- **A/D Converters**

  Convert the analog signals into the digital signals with conversion rates typically up to the 1 kHz – 10 MHz range. The input resolution, $Q$ which depends on the number of bits of the converter, is given by

  $$Q = \frac{E_{FSR}}{2^M}$$

  where $E_{FSR}$ = Full scale voltage range
  $M$ = resolution in bits

**Example**

A 12 bit A/D converter with input signal range of 0-10V.

The resolution

$$Q = \frac{10}{2^{12}} = 2.44 \text{ mV}$$

The amplifier permits signal conditioning with gains from $G = 0.5$ to 1000

The minimum detectable voltage when set at maximum gain is

$$Q = \frac{2.44 \text{ mV}}{1000} = 2.44 \mu\text{V}$$
Analog signal input connections

Single-ended connection
Suitable only when all of the analog signals can be made relative to the common ground point.

Differential-ended connection
Allow the voltage difference between two distinct input signals to be measured.

Example
A signal from the strain gage with the sensitivity $= 2.5 \mu V/\mu e$ is connected to DAS which has the 12-bit A/D converter, an input range of $\pm 5V$, and sample rate of 1000 Hz. For an expected measurement range of 1-500 $\mu e$, specify appropriate G for amplifier, filter type and cut-off frequency.
Chapter 3 Signal conditioning systems

Amplifier

Resolution = 10/2^12 = 2.44 mV

Signal Range = (1 με - 500 με) x 2.5 μV/με = 2.5 μV - 1.25 mV

G = 1000: Amplified Signal = (2.5μV – 1.25 mV) x 1000 = 2.5 mV – 1.25 V

G = 3000: Amplified Signal = (2.5μV – 1.25 mV) x 3000 = 7.5 mV – 3.75 V

Filter

Sample rate, f_s = 1000 Hz

Nyquist frequency, f_N = 1000/2 = 500 Hz

*** Low-pass filter with a cut-off frequency = 500 Hz required

*** Differential-ended connections required
Final Examination on OCT 8, 2011 (1300-1600)

- Closed books and closed notes
- Non-programmable calculators are permitted
- Electronic dictionaries are not permitted
- 7 questions (10 marks each)

Data Logger

Data Logger คืออุปกรณ์อิเล็กทรอนิกส์ซึ่งทำหน้าที่บันทึกและจัดเก็บข้อมูลที่ตรวจวัด จากเครื่องมือวัดหรือเซนเซอร์ต่างๆ ปัจจุบัน Data logger ใช้เพื่อฐาน ของระบบประมวลผลแบบดิจิตอล ส่วนประกอบที่สำคัญคือไมโครโปรเซสเซอร์ หน่วยความจำ และเซนเซอร์ สามารถแบ่งออกได้เป็น 2 ลักษณะคือ

- General purpose types
- Specific devices

ข้อดี
1. ทำงานด้วยตัวเอง (Stand-alone)
2. เคลื่อนย้ายง่าย (Portable)
3. บันทึกข้อมูล 24 ชั่วโมง
4. สามารถใช้กับ DC power

Data logger

**Key features**
- Small truly portable data logger
- 4 to 8 universal analogue inputs (current, voltage, resistance, temperature) plus 8 digital inputs
- 16 derived/calculated channels
- 2 alarm outputs and 2 pulse counter inputs (1 to 64 kHz, 1 at 100 kHz)
- Configured via large easy-to-read graphical display
- 0.1% accuracy
- Up to 1.8 million readings
- Supplied with SQUAREVIEW set-up/download software

**Technical specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of analogue channels</td>
<td>8 single ended or 4 differential inputs</td>
</tr>
<tr>
<td>Channel expansion</td>
<td>Yes</td>
</tr>
<tr>
<td>Universal Input</td>
<td>Yes</td>
</tr>
<tr>
<td>Voltage Ranges: Differential and Single Ended</td>
<td>6 to 25, -0.6 to 2.4, 20.3 V, -0.15 to 0.15, -0.075 to 0.075</td>
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<tr>
<td>Common mode</td>
<td>70 V</td>
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<tr>
<td>Current Ranges: Differential (Requires external 10V shunt)</td>
<td>4 to 20mA, 1.5mA</td>
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<tr>
<td>Thermocouple Ranges: Differential and Single Ended</td>
<td>-200 to 1372°C, K-type</td>
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<tr>
<td>Resistance Ranges, all 2 wire</td>
<td>0 to 1250Ω, 0 to 5000Ω</td>
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<tr>
<td>Current ranges</td>
<td>0 to 100 mA, 0 to 1000 mA</td>
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<tr>
<td>Pt100/1000, 2-wire</td>
<td>0 to 100°C, U &amp; UM-type</td>
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<tr>
<td>Internal reference temperature</td>
<td>-50 to 100°C</td>
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<tr>
<td>Pulse Count Ranges</td>
<td>0 to 100 kHz (1 input)</td>
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<tr>
<td>Digital State/Event Ranges</td>
<td>0 state inputs or 1 x 8 bit binary</td>
</tr>
<tr>
<td>Digital/Alarm Outputs</td>
<td>2 open drain FETs, 18V, 0.1A</td>
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<tr>
<td>A/D Resolution</td>
<td>24 bit</td>
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<tr>
<td>Accuracy</td>
<td>±1.1% at range + 0.1% of reading</td>
</tr>
<tr>
<td>Clock Resolution/Accuracy</td>
<td>1s to 16384 Megahertz - each input sampled at a maximum rate of 1 reading per second. Double speed (manual reject off) - one input can be sampled at 10 readings per second and all others are sampled at a maximum rate of 1 reading per second</td>
</tr>
</tbody>
</table>
**Grounds, Shielding, and connecting wires**

- การเชื่อมต่อสายสัญญาณในอุปกรณ์อิเล็กทรอนิกส์อาจเป็นสาเหตุของการเกิดสัญญาณรบกวน (noise) ในระบบ
- สัญญาณรบกวนจะมีผลมากในสัญญาณที่มีกำลังต่ำ (< 100 mv)

**วิธีป้องกันสัญญาณรบกวน**

1. ใช้สายสัญญาณให้สั้นที่สุด
2. ไม่ให้สายสัญญาณอยู่ใกล้แหล่งสัญญาณรบกวน
3. ใช้ชีล (shield) ป้องกันและต่อสายลงดิน (ground)
4. บิดสายเป็นเกลียว

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**Data logger (ต่อ)**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
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<tbody>
<tr>
<td>No. of Inputs</td>
<td>4</td>
</tr>
<tr>
<td>Data Scaling</td>
<td>Yes</td>
</tr>
<tr>
<td>Data Statistics</td>
<td>Yes from within 2, 3, 4... channels, 16 channels</td>
</tr>
<tr>
<td>Calculated Channels</td>
<td>Yes, up to 16</td>
</tr>
<tr>
<td>Memory Internal</td>
<td>1MB (1 to 1.8 million readings)</td>
</tr>
<tr>
<td>Display/Keypad</td>
<td>128×64 dot graphical display, 4 button keypad</td>
</tr>
<tr>
<td>Internal Battery</td>
<td>2 C cells</td>
</tr>
<tr>
<td>Battery Life</td>
<td>Up to 5 days with continuous usage whilst sampling all channels once per second</td>
</tr>
<tr>
<td>External Power</td>
<td>Yes, 8 to 28V dc &amp; USB when plugged in</td>
</tr>
<tr>
<td>Sensor Power Output</td>
<td>5V at 50mA, external 5-28V at 100mA when connected</td>
</tr>
<tr>
<td>Networking</td>
<td>Via RS232 to Ethernet adapter (Newport, part no. 22000-01)</td>
</tr>
<tr>
<td>Modem Support</td>
<td>Via RS232 modem (GSM Modem, part no. 22000-02)</td>
</tr>
<tr>
<td>Actions &amp; Triggers</td>
<td>As SQ22000G6 although two alarm outputs</td>
</tr>
<tr>
<td>PC Setup</td>
<td>Yes, SquareView compatible</td>
</tr>
<tr>
<td>Front Panel Setup</td>
<td>Via 4 integral 4 keys. All essential functionality available via key pad + e.g. channel configuration, start / stop logging etc. Other advanced functions e.g. calculated channels and channel descriptions are available via connection to a PC running SquareView</td>
</tr>
<tr>
<td>Stored setups</td>
<td>5</td>
</tr>
<tr>
<td>Third Party Programming</td>
<td>As 2000 driver suite allows</td>
</tr>
<tr>
<td>Operating temp</td>
<td>-20 to 55°C</td>
</tr>
<tr>
<td>Dimensions</td>
<td>W175 x D135 x H55mm, Weight 6.7kg</td>
</tr>
</tbody>
</table>
Ground and Ground loop

- **Ground** คือจุดอ้างอิงในวงจรไฟฟ้าใช้ในการเปรียบเทียบแรงดันไฟฟ้า โดยทั่วไป Ground จะเป็นเส้นทางเดินของกระแสลงสู่พื้นดิน (earth ground) ซึ่งมีค่าแรงดันไฟฟ้าเท่ากับศูนย์

- **Ground potential** อาจมีค่าต่างกันขึ้นกับจุดเชื่อมต่อ (เช่น ลูกลวง อาคาร และพื้นดิน)

- **สายดินที่ความยาวมากๆ** อาจเป็นที่เหมือนกับเสาอากาศ (Antennae)

**Ground Symbols**

Ground loop

- **Ground loop** เป็นสาเหตุมาจากการเชื่อมต่อ ground ของหลายๆวงจรเข้าด้วยกัน โดย Ground potential ของวงจรที่เชื่อมกันมีค่าไม่เท่ากัน

- ผลต่างของศักย์ไฟฟ้าที่เกิดใน Ground loop ส่งผลให้มีการไหลของกระแสในสายสัญญาณนำไปสู่สัญญาณรบกวนระบบ
วิธีป้องกัน ground loop

- มีการต่อสายดินเพียง 1 จุด (single-point ground)
- ใช้ Isolation transformer (1:1 power transformer AC signal ผ่านได้ทันที)
- ใช้ Shield ป้องกันสัญญาณส่วนงานจากสัญญาณส่งที่มีกำลังต่ำ

![Diagram of ground loop prevention](image)

การต่อ Shield ป้องกันที่ไม่ถูกต้อง

การต่อ Shield ป้องกันที่ถูกต้อง

(ต่อ ground ของ Shield ใกล้กันหรือต่อสายที่สัญญาณส่งบางเส้น)