Electronic instrumentation

P.P.L. Regtien

Electronic instrumentation

Electronic instrumentation

P.P.L. Regtien

VSSD

Second edition 2005

Published by:
VSSD
Leeghwaterstraat 42, 2628 CA Delft, The Netherlands
tel. +31 15 27 82124, telefax +31 15 27 87585, e-mail: hlf@vssd.nl
internet: http://www.vssd.nl/hlf
URL about this book: **http://www.vssd.nl/hlf/e008.htm**
A collection of digital pictures and/or an electronic version can be made available for lecturers who adopt this book. Please send a request by e-mail to hlf@vssd.nl

ISBN 978-90-71301-43-8 Ελεχτρονιχ ϖερσιον: 978–90–6562–214–3
NUR 959
Keywords: electronic instrumentation

Preface

Electronic systems have made deep inroads into every aspect of daily life. One need only look around homes, offices and industrial plants to see that they feature almost everywhere. Indeed, it is practically impossible to name any appliances, tools or instruments that do not contain electronic components. In order to compete with rival companies or just remain a step ahead of them, the designers of technical systems and innovative products must be fully aware of both the assets and the limitations of electronic components and systems. Users of electronic systems also need to have a basic knowledge of electronic principles. In order to fully exploit an instrument's potential, to be aware of its limitations, to correctly interpret the measurement results and to be able to arrive at well-balanced decisions relating to the purchasing, repairing, expansion or replacement of electronic equipment, all users of such systems also need to have a basic knowledge of electronic principles.

This book offers such basic knowledge and provides guidance on how to obtain the relevant skills. The kinds of topics dealt with are operating principles, the performance of analog and digital components and circuits, and the precise characteristics of electronic measuring systems. Throughout the book, every endeavor is made to impart a critical attitude to the way in which such instruments should be implemented.

The book is based on various series of courses on electronics and electronic instrumentation that were given by the author during the many years when he lectured at Delft University of Technology in the Netherlands. The courses were designed for students from various departments such as: Mechanical Engineering, Aeronautical Engineering and Mining Engineering. When numbers of non-Dutch-speaking Master of Science students started to rise it became necessary to publish an English version of the book.

The particular way in which the book has been organized makes it suitable for a much wider readership. To meet the demands of divergent groups it has been structured in a modular fashion. Each chapter discusses just one particular topic and is divided into two parts: the first part provides the basic principles while more specific information is given in the second part. Each chapter ends with a summary and several exercises. Answers to all the exercises are given at the back of the book. This approach is conducive to self-study and to the composition of tailor-made course programs.

The required background knowledge is a basic grounding in mathematics and physics equivalent to any first-year academic level. No background knowledge of electronics is needed to understand the contents of the book. For further information on particular subjects the reader is referred to the many course books that exist on the subjects of electronics, measurement techniques and instrumentation.

I am indebted to all the people who contributed to the realization of this book. In particular I would like to thank Johan van Dijk who carefully refereed the original Dutch text. I am grateful also to Reinier Bosman for working out all the exercises, to G. van Berkel for creating the more than 600 illustrations, to Jacques Schievink for processing the original Dutch editions and this English version of the book and to Diane Butterman for reviewing the entire English text.

Paul Regtien
Hengelo, August 2004

Contents

1 Measurement systems

The aim of any *measuring system* is to obtain information about a physical process and to find appropriate ways of presenting that information to an observer or to other technical systems. With electronic measuring systems the various instrument functions are realized by means of electronic components.

Various basic system functions will be introduced in the first part of this chapter. The extent to which an instrument meets the specified requirements is indicated by the system specifications, all of which will be discussed in the second part of the chapter.

1.1 System functions

A measuring system may be viewed as a transport channel for the exchanging of information between measurement objects and target objects. Three main functions may be distinguished: data acquisition, data processing and data distribution (Figure 1.1).

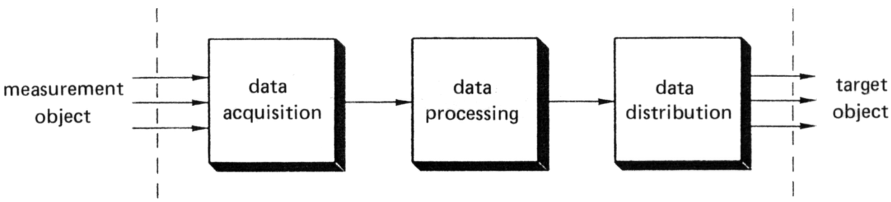

Figure 1.1. The three main functions of any measuring system.

- *Data acquisition*: this involves acquiring information about the measurement object and converting it into electrical measurement data. What multiple input, as illustrated in Figure 1.1, indicates is that invariably more than one phenomenon may be measured or that different measurements may be made, at different points, simultaneously. Where there are single data outputs this means that all data is transferred to the next block through a single connection.
- *Data processing*: this involves the processing, selecting or manipulating – in some other way – of measurement data according to a prescribed program. Often a processor or a computer is used to perform this function.

- *Data distribution*: the supplying of measurement data to the target object. If there is multiple output then several target instruments may possibly be present, such as a series of control valves in a process installation.

It should be pointed out that the above subdivision cannot always be made; part of the system may sometimes be classified as both data acquisition and data processing. Some authors call the entire system shown in Figure 1.1 a data acquisition system, claiming that the data is not obtained until the target object is reached.
In the next section the data acquisition and data distribution parts are subdivided into smaller functional units.
Since most physical measurement quantities are non-electric, they should first be converted into an electrical form in order to facilitate electronic processing. Such conversion is called transduction and it is effected by a transducer or sensor (Figure 1.2). In general, the transducer is kept separate from the main instrument and can be connected to it by means of a special cable.

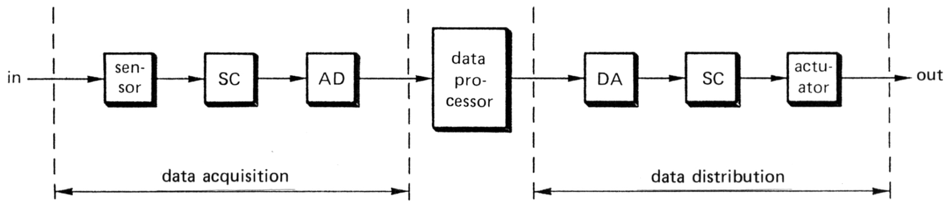

Figure 1.2. A single channel measuring system.

The sensor or input transducer connects the measuring system to the measurement object; it is the input port of the system through which the information enters the instrument.
Many sensors or transducers produce an analog signal; that is a signal whose value, at any given moment, is a measure of the quantity to be measured: the signal continuously follows the course of the input quantity. However, much of the processing equipment can only cope with digital signals, which are binary coded signals. A digital signal only contains a finite number of distinguishable codes, usually a power of 2 (for instance $2^{10} = 1024$).
The analog signal must be converted into a digital signal. This process is known as analog-to-digital conversion or, AD-conversion. Analog-to-digital conversion comprises three main processes, the first of which is sampling where, at discrete time intervals, samples are taken from the analog signal. Each sampled value is maintained for a certain time interval, during which the next processes can take place. The second step is quantization. This is the rounding off of the sampled value to the nearest of a limited number of digital values. Finally, the quantized value is converted into a binary code.
Both sampling and quantization may give rise to loss of information. Under certain conditions, though, such loss can be limited to an acceptable minimum.
The output signal generated by a transducer is seldom suitable for conversion into a digital signal, the converter input should first satisfy certain conditions. The signal

processing required to fulfill such conditions is termed signal conditioning. The various processing steps required to achieve the proper signal conditions will be explained in different separate chapters. The main steps, however, will be briefly explained below.

- *Amplification*: in order to increase the signal's magnitude or its power content.
- *Filtering*: to remove non-relevant signal components.
- *Modulation*: modification of the signal shape in order to enable long-distance signal transport or to reduce the sensitivity to interference during transport.
- *Demodulation*: the reverse process operation to modulation.
- *Non-linear* and *arithmetical operations*: such as logarithmic conversion and the multiplication of two or more signals.

It goes without saying that none of the above operations should affect the information content of the signal.

After having been processed by the (digital) processor, the data are subjected to a reverse operation (Figure 1.2). The digital signal is converted into an analog signal by a digital-to-analog or DA converter. It is then supplied to an actuator (alternative names for this being: effector, excitator and output transducer), which transforms the electrical signal into the desired non-electric form. If the actuator cannot be connected directly to the DA converter, the signal will first be conditioned. This conditioning usually involves signal amplification.
The actuator or output transducer connects the measurement system to the target object, thus becoming the instrument's output port through which the information leaves the system.
Depending on what is the goal of the measurement, the actuator will perform various functions such as, for instance: *indicating* by means of a digital display; *registering* (storing) with such things as a printer, a plotter or a magnetic disk; or *process controlling* with the aid of a valve, a heating element or an electric drive.
The diagram given in Figure 1.2 refers only to one input variable and one output variable. For the processing of more than one variable, one could take a set of single channel systems. Obviously this is neither efficient nor necessary. The processor shown in Figure 1.2, in particular, is able to handle a large number of signals, thanks to its high data processing speed. Figure 1.3 gives the layout of a multi-channel measuring system that is able to handle multiple inputs and outputs using only one (central) processor.
Central processing of the various digital signals can be effected by means of multiplexing. The digital multiplexer denoted in Figure 1.3 connects the output of each AD converter to the processor in an alternating fashion. The multiplexer may be viewed as an electronically controlled multi-stage switch, controlled by the processor. This type of multiplexing is called time multiplexing because the channels are scanned and their respective signals are successively transferred – in terms of time – to the processor. Another type of multiplexing, frequency multiplexing, will be discussed in a later section.

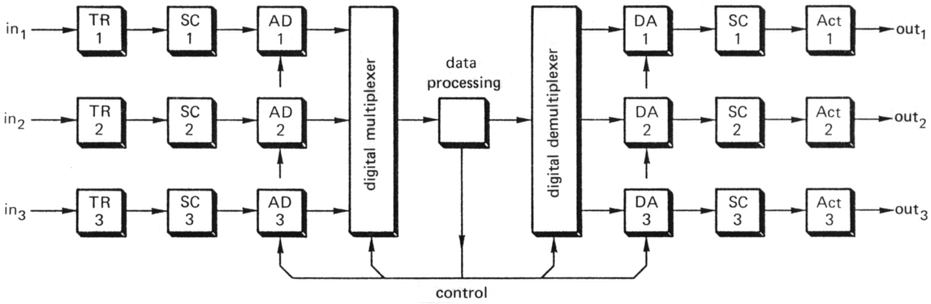

Figure 1.3. A three-channel measuring system with one central processor. TR = transduction, SC = signal conditioning.

At first sight it would appear that the concept of time multiplexing has the disadvantage that only the data taken from the selected channel is processed while the information derived from the non-selected channels is blocked. It can be demonstrated that when the time between two successive selections for a particular channel is made sufficiently short the information loss will be negligible. An explanation of what precisely is meant by “sufficiently short” will be given in Section 2.2.

Figure 1.3 clearly shows that a system with many sensors or actuators will also contain large numbers of signal processing units, thus making it expensive. In such cases the principle of multiplexing can also be applied to the AD and DA converters. Figure 1.4 shows the layout of such a measurement system in which all the conditioned signals are supplied to an analog multiplexer. It is even possible to have a central signal conditioner placed behind the multiplexer so as to further reduce the number of system components. It is possible to extend the process of centralizing instrument functions to the data distribution part of the system. An analog multiplexer distributes the converted analog signals over the proper output channels. It is not common practice for output signal conditioners to be multiplexed because multiplexers are not usually designed to deal with large power signals.

Although the functions of analog and digital multiplexers are similar, their design is completely different. Digital multiplexers only deal with digital signals which have better noise and interference immunity than analog signals. Digital multiplexers are therefore far less critical (and less expensive) than analog multiplexers. The same goes for the AD converters. In Figure 1.3 it can be seen that each AD converter has a full multiplexer cycle period in which to perform a conversion. In the system shown in Figure 1.4, the conversion ought to be completed within the very short period of time when a channel is connected to the processor. This system configuration thus requires a high speed (and a higher priced) converter. The centralized system contains a reduced number of more expensive components. Whether one opts for a centralized or a distributed system will depend very much on the number of channels.

In certain situations the measurement signals and control signals have to be transported over long distances. This instrumentation aspect is known as telemetry. A telemetry channel consists of an electric conductor (for instance a telephone cable), an optical link (like a glass fiber cable) or a radio link (e.g. made via a communication satellite). To reduce the number of lines, which are invariably expensive, the concept of multiplexing is used (Figure 1.5). Instead of time multiplexing, telemetry systems use frequency multiplexing. Each measurement signal is converted to a frequency band assigned to that particular signal. If the bands do not overlap, the converted signals can be transported simultaneously over a single transmission line. When they arrive at the desired destination the signals are demultiplexed and distributed to the proper actuators. More details on this type of multiplexing will be given elsewhere in this book.

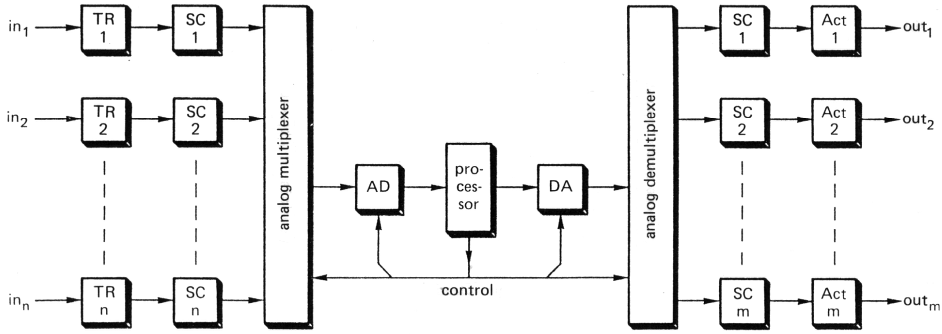

Figure 1.4. A multi-channel measuring system with a centralized processor and AD and DA-converters. For an explanation of the abbreviations see Figure 1.3.

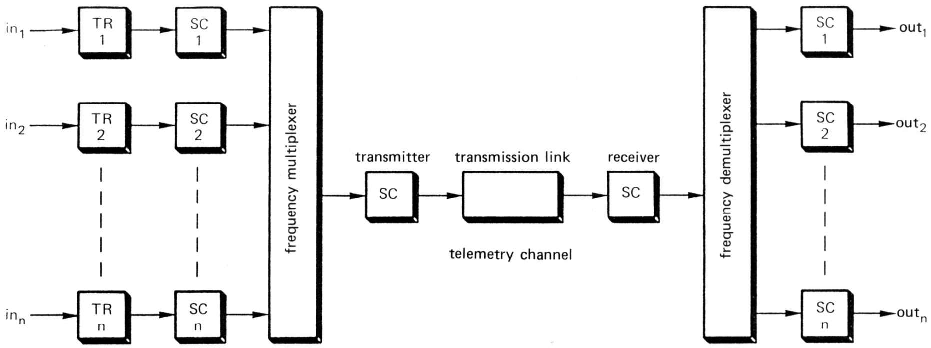

Figure 1.5. A multi-channel measuring system with frequency multiplexing.

Signals can be transmitted in analog or digital form. Digital transport is preferable if high noise immunity is required, for instance for very long transport channels or links that pass through a noisy environment.

1.2 System specifications

A measurement system is designed to perform measurements according to the relevant specifications. Such specifications convey to the user of the instrument to what degree the output corresponds with the input. The specifications reflect the quality of the system.

The system will function correctly if it meets the specifications given by the manufacturer. If that is not the case it will fail, even if the system is still functioning in the technical sense. Any measuring instrument and any subsystem accessible to the user has to be fully specified. Unfortunately, many specifications lack clarity and completeness.
The input signal of the single channel system given in Figure 1.6 is denoted as x and its output signal as y. The relationship between x and y is called the system transfer.

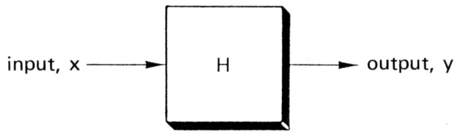

Figure 1.6. Characterization of a system with input *x*, output *y* and transfer *H*.

By observing the output, the user is able to draw conclusions about the input. The user therefore has to be completely familiar with the system's transfer. Deviations in the transfer may cause uncertainties about the input and so result in measurement errors. Such deviations are permitted, but only within certain limits which are the tolerances of the system. Those tolerances also constitute part of the specifications. In the following pages the main specifications of a measurement system will be discussed.
The user should first of all be familiar with the operating range of the system. The operating range includes the measurement range, the required supply voltage, the environmental conditions and possibly other parameters.

Example 1.1
A manufacturer of a digital temperature-measuring instrument gives the following description of the operating range:
* *measuring range: -50°C to 200°C;*
* *permitted operational temperature: –10°C to 40°C;*
* *storage temperature: -20°C to 85°C*
* *mains voltage: 220 V ±15%, 50...60 Hz; can be switched to 115 V, 127 V, 240 V ± 15%, 50...60 Hz;*
* *analog outputs: 0-10 V (load > 2kΩ) and 0-20 mA or 4-20 mA (load < 600Ω).*

All other specifications only apply under the condition that the system has never before been taken beyond its permitted operating range.

The resolution indicates the smallest detectable change in input quantity. Many system parts show limited resolution. A few examples of this are these: a wire-wound potentiometer for the measurement of angles has a resolution set by the windings of the helix – the resistance between the slider and the helix changes leap-wise as it rotates; a display presenting a measurement value in numerals has a resolution equal to the least significant digit.
The resolution is expressed as the smallest detectable change in the input variable: Δx_{min}. Sometimes this parameter is related to the maximum value x_{max} that can be processed, the so-called full-scale value or FS of the instrument, resulting in the resolution expressed as $\Delta x_{min}/x_{max}$ or $x_{max}/\Delta x_{min}$. This mixed use of definitions seems

very confusing. However, it is easy to see from the units or the value itself which definition is used.

Example 1.2
The resolution of a four-digit decimal display with a fixed decimal point in the third position from the left is 0.1 units. The maximum indication apparently equals 999.9 units, which is about 1000. The resolution of this display is therefore 0.1 units or 10^{-4} *or* 10^4.

The inaccuracy is a measure of the total uncertainty of the measurement result that may be caused by all kinds of system errors. It comprises calibration errors, long and short-term instability, component tolerances and other uncertainties that are not separately specified. Two definitions may be distinguished: absolute inaccuracy and relative inaccuracy. Absolute inaccuracy is expressed in terms of units of the measuring quantity concerned, or as a fraction of the full-scale value. Relative inaccuracy relates the error to the actual measuring value.

Example 1.3
The data sheet of a volt meter with a four digit indicator and a full-scale value of 1.999 V specifies the instrument inaccuracy as ±0.05% FS ±0.1% of the indication $\pm\frac{1}{2}$ *digit.*
The absolute inaccuracy of a voltage of 1.036 V measured with this instrument equals: ±0.05 of 2 V (the approximate value of FS) plus ±0.1% of 1 V (approximate value of the indication) plus ±0.5 of 1 mV (the weight of the last digit), which amounts to ±2.5 mV in total.
The relative inaccuracy is the absolute inaccuracy divided by the indication so it is ±0.25%.

Inaccuracy is often confused with accuracy, the latter being complementary to it. When a specification list gives an accuracy of 1%, this hopefully means that there is an inaccuracy of 1% or an accuracy of 99%.
The sensitivity of a measuring system is defined as the ratio between a change in the output value and a change in the input value that causes that same output change. The sensitivity of a current-to-voltage converter is expressed in V/A, that of a linear position sensor in, for instance, mV/μm and that of an oscilloscope in, for instance, cm/V.
A measuring system is usually also sensitive to changes in quantities other than the intended input quantity, such as the ambient temperature or the supply voltage. These unwelcome sensitivities should be specified as well when this is necessary for a proper interpretation of the measurement result. To gain better insight into the effect of such false sensitivity it will be related to the sensitivity to the measurement quantity itself.

Example 1.4
A displacement sensor with voltage output has a sensitivity of 10 mV/mm. Its temperature sensitivity is -0.1 mV/K. Since -0.1 mV corresponds with a displacement of -10 μm, the temperature sensitivity can also be expressed as –10 μm/K. A temperature rise of 5°C will result in an apparent displacement of –50 μm.

Example 1.5
The sensitivity of a temperature sensor including the signal-conditioning unit is 100 mV/K. The signal conditioning part itself is also sensitive to (ambient) temperature and it appears to create an extra output voltage of 0.5 mV for each °C rise in ambient temperature (not necessarily the sensor temperature). The undesired temperature sensitivity is thus 0.5 mV/K or 0.5/100 = 5 mK/K. A change in ambient temperature of ± 10°C gives an apparent change in sensor temperature that is equal to ±50 mK.

Mathematically, the sensitivity is expressed as $S = dy/dx$. If output y is a linear function of input x then the sensitivity does not depend on x. In the case of a non-linear transfer function $y = f(x)$, S will depend on the input or output value (Figure 1.7). Users of measuring instruments prefer a linear response, because then the sensitivity can be expressed in terms of a single parameter and the output will not show harmonic distortion. The transfer of a system with slight non-linearity may be approximated by a straight line. The user should still know the deviation from the actual transfer as specified by the non-linearity.

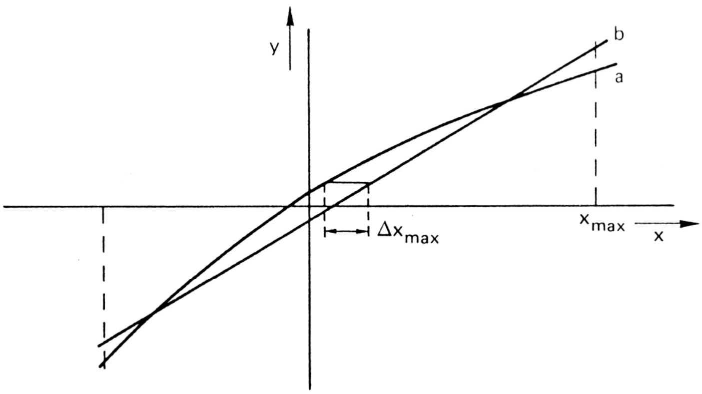

Figure 1.7. Example of a non-linear transfer characteristic, (a) real transfer, (b) linear approximation.

The non-linearity of a system is the maximum deviation in the actual transfer characteristic from a pre-described straight line. Manufacturers specify non-linearity in various ways, for instance, as the deviation in input or output units: Δx_{max} or Δy_{max}, or as a fraction of FS: $\Delta x_{max}/x_{max}$. They may use different settings for the straight line: by passing through the end points of the characteristic, by taking the tangent through the point $x = 0$, or by using the best-fit (least-squares) line, to mention but a few possibilities.
Figure 1.8 depicts some particular types of non-linearity found in measuring systems: saturation, clipping and dead zone (sometimes also called cross-over distortion).

These are examples of static non-linearity, appearing even when inputs change slowly. Figure 1.9 shows another type of non-linearity, known as slew rate limitation, which only occurs when the input values change relatively fast. The output which is unable to keep up with the quickly changing input thus results in distortion at the output point. Slew rate is specified as the maximum rate of change in the output of the system.

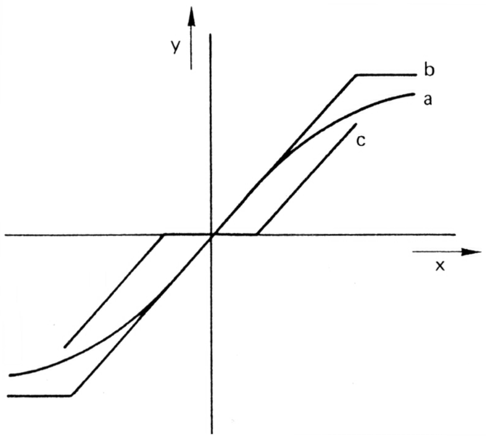

Figure 1.8. Some types of static non-linearity: (a) saturation, (b) clipping. (c) dead zone.

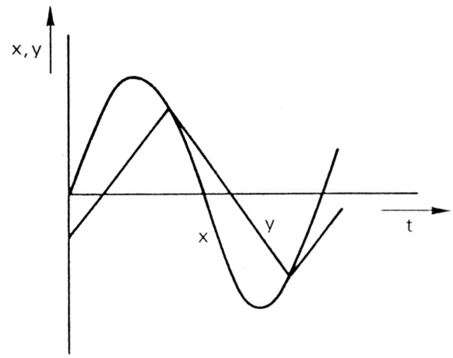

Figure 1.9. The effect of slew rate limitation on the output signal *y* at a sinusoidal input *x*.

Most measurement systems are designed in such a way that output is zero when input is zero. If the transfer characteristic does not intersect the origin ($x = 0, y = 0$) the system is said to have offset. Offset is expressed in terms of the input or the output quantity. It is preferable to specify the input offset so that comparisons with the real input quantity can be made. Non-zero offset arises mainly from component tolerances. Most electronic systems make it possible to compensate for the offset, either through manual adjustment or by means of manually or automatically controlled zero-setting facilities. Once adjusted to zero, the offset may still change due to temperature variations, changes in the supply voltage or the effects of ageing. This relatively slow change in the offset is what we call zero drift. It is the temperature-induced drift (the temperature coefficient or t.c of the offset) that is a particularly important item in the specification list.

Example 1.6

A data book on instrumentation amplifiers contains the following specifications for a particular type of amplifier:

input offset voltage:	*max. ±0.4 mV, adjustable to 0*
t.c. of the input offset:	*max.±6 μV/K*
supply voltage coeff.:	*40 μV/V*
long-term stability:	*3 μV/month*

There are two ways to determine the offset of any system. The first method is based on setting the output signal at zero by adjusting the input value. The input value for which the output is zero is the negative value of the input offset. The second method involves measuring the output at zero input value. When the output is still within the allowed range, the input offset simply becomes the measured output divided by the sensitivity.
Sometimes a system is deliberately designed with offset. Many industrial transducers have a current output that ranges from 4 to 20 mA (see Example 1.1). This facilitates the detection of cable fractures or a short-circuit so that such a defect is clearly distinguishable from a zero input.
The sensitivity of an electronic system may be increased to almost unlimited levels. There is, however, a limit to the usefulness of doing this. If one increases the sensitivity of the system its output offset will grow as well, to the limits of the output range. Even at zero input voltage, an ever-increasing sensitivity will be of no use, due to system noise interference. Electrical noise amounts to a collection of spontaneous fluctuations in the currents and voltages present in any electronic system, all of which arises from the thermal motion of the electrons and from the quantized nature of electric charge. Electrical noise is also specified in terms of input quantity so that its effect can be seen relative to that of the actual input signal.

The sensitivity of a system depends on the frequency of the signal to be processed. A measure of the useful frequency range is the frequency band. The upper and lower limits of the frequency band are defined as those frequencies where the power transfer has dropped to half its nominal value. For voltage or current transfer the criterion is $\frac{1}{2}\sqrt{2}$ of the respective nominal voltage and current transfer (Figure 1.10). The lower limit of the frequency band may be zero; the upper limit always has a finite value. The extent of the frequency band is called the bandwidth of the system expressed in Hz.

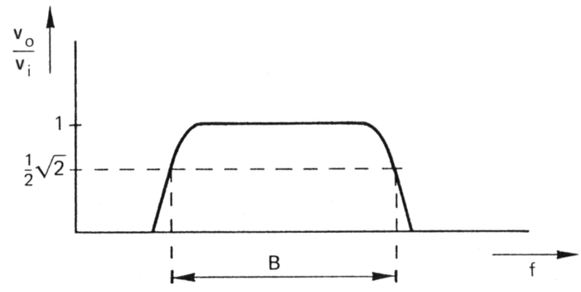

Figure 1.10. A voltage transfer characteristic showing the boundaries of the frequency band. The nominal transfer is 1, its bandwidth is B.

A frequent problem in instrumentation is the problem of how to determine the difference between two almost equal measurement values. Such situations occur when, for instance, big noise or interference signals are superimposed on relatively weak measurement signals. A special amplifier has been developed for these kinds of measurement problems, it is known as the differential amplifier (Figure 1.11). Such an amplifier, which is usually a voltage amplifier, has two inputs and one output. Ideally the amplifier is not sensitive to equal signals on both inputs (common mode signal), only to a difference between the two input signals (differential mode signals). In practice any differential amplifier will exhibit a non-zero transfer for common mode signals. A quality measure that relates to this property is the common mode rejection ratio or CMRR, which is defined as the ratio between the transfer for differential mode signals, v_o/v_d and common mode signals v_o/v_c. In other words, the CMRR is the ratio of a common mode input signal and a differential mode input signal, both of which give equal output. An ideal differential amplifier has a CMRR, which is infinite.

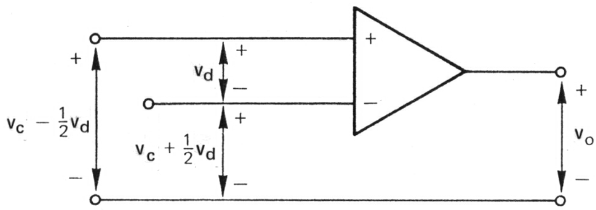

Figure 1.11. An ideal differential amplifier is insensitive to common mode signals (v_c) and amplifies only the differential signal v_d.

Example 1.7

A system with a CMRR of 10^5 is used to determine the difference between two voltages, both about 10 V high. The difference appears to be 5 mV. The inaccuracy of this result, due to the finite CMRR, is ±2% because the common mode voltage produces an output voltage that is equivalent to that of a differential input voltage of $10/10^5 = 0.1$ mV.

The final system property to be discussed in this chapter has to do with reliability. There is always a chance that a system will fail after a certain period of time. Such properties should be described according to probability parameters, one of these parameters being the reliability $R(t)$ of the system. This is defined as the probability that the system will function correctly (in accordance with its specifications) up to the time t (provided that the system has operated within the permitted range). It should be clear that R diminishes as time elapses so that the system becomes increasingly less reliable.

The system parameter R has the disadvantage that it changes over the course of time. Better parameters are the mean-time-to-failure (MTTF) and the failure rate $\lambda(t)$. The MTTF is the mean time that passes up until the moment when the system fails; it is its mean lifetime.

Example 1.8

An incandescent lamp is guaranteed for 1000 burning hours. This means that lamps from the series to which this lamp belongs will burn, on average, for 1000 hours. Some lamps may fail earlier or even much earlier while others may burn longer.

The failure rate $\lambda(t)$ is defined as the fraction of failing systems per unit of time relative to the total number of systems functioning properly at time t. The failure rate appears to be constant during a large part of the system's lifetime. If the failure rate is constant in terms of time, it is equal to the inverse of the MTTF.

> ***Example 1.9***
> *Suppose an electronic component has an MTTF equal to 10^5 hours. Its failure rate is the inverse, 10^{-5} per hour or 0.024% per day or 0.7% per month. Thus, if one takes a certain collection of correctly functioning components 0.024% will fail daily.*

The failure rate of electronic components is extremely low when used under normal conditions. For example, the failure rate of metal film resistors with respect to an open connection is approximately 5×10^{-9} per hour. The reliability of many electronic components is well known. However, it is very difficult to determine the reliability of a complete electronic measurement system from the failure rates of the individual components. This is a reason why the reliability of complex systems is seldom specified.

SUMMARY

System functions

- The three main functions of an electronic measurement system are
  - data acquisition
  - data processing
  - data distribution
- The conversion of information of a physical quantity into an electrical signal is known as transduction. Transduction is carried out with an input transducer or sensor. The inverse process is carried out with an output transducer or actuator
- The main operations completed with analog measurement signals are: amplification, filtering, modulation, demodulation and analog-to-digital conversion.
- AD conversion comprises three elements: sampling, quantization and coding.
- Multiplexing is a technique that facilitates the simultaneous transport of various signals through a single channel. There are two different possible ways of doing this: by time multiplexing and by frequency multiplexing. The inverse process is called demultiplexing.

System specifications

- The main specifications of any measurement system are: operating range (including measuring range), resolution, accuracy, inaccuracy, sensitivity, non-linearity, offset, drift and reliability.
- Some possible types of non-linearity are: saturation, clipping, dead zone, hysteresis and slew rate limitation.
- The bandwidth of a system is the frequency span between frequencies where the power transfer has dropped to half the nominal value or where the voltage or current transfer has dropped to $\frac{1}{2}\sqrt{2}$ of the nominal value.

- The common-mode rejection ratio is the ratio between the transfer of differential mode signals and common mode signals, or: the ratio between a common mode input and a differential mode input, both producing equal outputs.
- Noise is the phenomenon of spontaneous voltage or current fluctuations occurring in any electronic system. It fundamentally limits the accuracy of a measurement system.
- The reliability of a system can be specified in terms of the reliability $R(t)$, the failure rate $\lambda(t)$ and the mean-time-to-failure MTTF. For systems with constant failure rate, $\lambda = 1/\text{MTTF}$.

EXERCISES

System functions

1.1 What is meant by multiplexing? Describe the process of time multiplexing.

1.2 Discuss the difference between the requirements for a multiplexer used for digital signals and one used for analog signals.

1.3 Compare an AD converter in a centralized system with that of a distributed system from the point of view of the conversion time.

System specifications

1.4 What would be the reason for putting a factor $1/\sqrt{2}$ in the definition of the bandwidth for voltage transfer, instead of a factor $\frac{1}{2}$?

1.5 What is a differential voltage amplifier? What is meant by the CMRR of such an amplifier?

1.6 The CMRR of a differential voltage amplifier is specified as CMRR > 10^3, its voltage gain is $G = 50$. The two input voltages have values $V_1 = 10.3$ V, $V_2 = 10.1$ V. What is the possible output voltage range?

1.7 The slew rate of a voltage amplifier is 10 V/μs, its gain is 100. The input is a sinusoidal voltage with amplitude A and frequency f.
a. Suppose $A = 100$ mV, what would be the upper limit of the frequency where the output would show no distortion?
b. Suppose $f = 1$ MHz; up to what amplitude can the input signal be amplified without introducing distortion?

1.8 A voltage amplifier is specified as follows: input offset voltage at 20°C is < 0.5 mV, the temperature coefficient of the offset is < 5 μV/K. Calculate the maximum input offset that might occur within a temperature range of 0 to 80 °C.

1.9 The relation between the input quantity x and the output quantity y of a system is given as: $y = \alpha x + \beta x^2$, with $\alpha = 10$ and $\beta = 0.2$. Find the non-linearity relative to the line $y = \alpha x$, for the input range $-10 < x < 10$.