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Module 1: Signals

1.1: Introduction

For ages human beings have been qualitatively dealing with natural physical phenomena. Gradually with growing intelligence, they started studying the phenomena so as to cope up with them in a better way; either to derive benefits out of them or protect themselves from their ill effects. The techniques of handling, studying, modeling and learning from physical phenomenon have been improved over time. Also with advances in science and engineering, human beings have invented and engineered many processes and phenomenon in addition to the natural ones. As a result of the advances, the early techniques of handling, studying, modeling and learning them have also evolved and become more scientific and quantitative. These techniques require quantitative measurements of different parameters related with the processes or phenomenon. Representation of physical quantities or objects in terms of numbers (counting and measurement) is a very old science and was invented even before the invention of zero. However, measurement of parameters and entities with an engineering perspective is comparatively a modern aspect. In the modern science of measurements, parameters like accuracy of measurements, resolution, precision and repeatability play a very important role. These parameters for a particular measurement process or application depend upon the context and application itself. However, all such quantitative measurements of process or application parameters generate sets of numbers called observations or readings or in general data. The observations or readings may be taken with different precision or resolution, at different accuracies or even in different number representation systems. **These sets of observations or readings are called DATA.**

Examples of such data sets can be given as below;

1. Temperature readings taken after each half an hour on a particular day
2. Grades of all students of a particular class and semester in all the semester subjects
3. Stock exchange Index values of a national stock exchange over one year
4. Performance of a student in all the subjects of a degree course
5. Balance sheet of a particular company
6. Account statement of a bank account
7. Readings of a laboratory experiment

It is quite obvious that the data set examples enlisted above may not make any sense without a description or title of the data set; may be in brief or in adequate details. For example, if only the numbers of the first example data set quoted above are provided without specifying that these are the temperature readings taken at half hour duration on a specific day and date, the bare set of numbers will be meaningless. Or if a set of grades is provided as said in the second example without specifying the names or roll numbers of the students and the respective subjects, the data set will be meaningless. **Thus an unlabeled data may be meaning less. It is also obvious that, the sequence of the data elements is also very important.** If the sequence is changed or the readings are scrambled, the complete data set may loose its significance and become redundant. Thus not only are data sets important but the relations of each individual data element with other data elements and with the label are also very important. **These relations of the data elements with each other and with the label carry information. In other words, information can be defined, in a way, as relations between the data elements and their labels.** Thus all the data sets described in the above examples will have some information only if their integrity (no tampering) and labels are intact.

The semantically higher level of information is what we call knowledge. In simpler words, knowledge may be defined as inferences, findings or summary of the obtained information. However, the terms information and knowledge have been used interchangeably in many literatures. We are living in the information and knowledge age backboned by technologies like internet and mobile communication. Essentially, these technologies facilitate sharing of data, information and knowledge all over the globe. Obviously the data, information and knowledge need to be processed, communicated or transported to different places in some form for their effective and quick sharing for the benefit of mankind. **Thus, the electronics and communication technologies provide a means of processing and communicating these recently discovered precious entities; data, information and knowledge all over the globe in electronic form at very high speeds.**

However the data or information can't be communicated, transported or transmitted in their original form for various reasons. The reasons may be non-technical like confidentiality of the information which demands some type of coding, encryption or representation in some different form. However when it comes to communication of data or information in electronic form, obviously they need to be converted to proportional electronics quantities like voltage, or current waveforms or may be proportional charge or may be electro-magnetic fields. It must, however, be remembered that there are some other non-electrical or electronic forms of data or information communication. Here, we will keep our discussions restricted to electrical forms of communication. In addition to the conversion into electronic form, data or information may be further coded or encrypted before transmission or communication. Accordingly while receiving, they need to be decoded or decrypted followed by their conversion into their original non-electrical form. The representation of data or information using electrical form make them suitable for transmission over longer distances in addition to their decoded representation in electrical form. When large volumes of data are to be transmitted they are initially converted into small data packets or even bits and then transmitted packet by packet or bit by bit. **Thus an entity representing some information may be called a signal.** In case of electronic communication of data or information, the signal is usually an electronic voltage/current waveform or a sequence of samples represented by discrete numbers. **In other words, a ready to communicate form of the data or information is a signal.**

Detailed theories of signal communication, information and the relation between them have already been developed. They are out of scope of this material. Here we intend to introduce the concepts of signals and spectra in brief.

1.2: Analog and Digital Signals

Anything which carries some labeled information can be considered a signal. Let us have a slight insight or a closer look in to the concept of signal. Let us revisit our first example of a data set considered in section 1, i.e., temperature readings taken after each half an hour on a particular day. Let us consider that a reading was taken at 12 noon and the next reading was taken at 12.30 p.m. For this duration of half an hour we have two readings say 25 degrees and 25.5 degrees. Though in this case only two readings were taken with a gap of half an hour, one could have easily taken a reading at 12.15 p.m. It can be reasonably expected that it will be somewhere between 25 degrees and 25.5 degrees. Similarly one can take the same temperature reading at 1 minute past 12 p.m. and can reasonably expect it to be very close to 25 degrees. However it may not be exactly equal to 25 degrees. Assuming that a very fast thermometer and a very precise clock is available one may even be able to take the temperature reading every one millisecond, microsecond, nanosecond etc. the only problems in this case will be how and where to store these readings, how to observe them and how to derive any conclusion from them. Because if a reading is taken after each microsecond, 10^6 readings will be generated each second. One can imagine that as we go on decreasing the duration between the two readings, the volume of number of readings taken, memory to store them and required computational capability to process them goes on increasing tremendously. Even a very fast computer may not be able to process them in reasonable time. On the other hand, when the readings of the day temperature are taken at very close intervals it can be observed that the temperatures do not vary in microseconds or milliseconds, not even in seconds. So there is no point in taking the readings after even each second and face the problem of data volumes, their storage memory, computing capability of the processing system. From our earlier experience, the temperature at 12 noon and say 1 minute past 12 noon is going to be approximately equal. Obviously the temperatures at all the milli, micro, nano, pico and whatsoever seconds between 12 noon and 1 minute past 12 noon, are going to be approximately equal to 25 degrees. Thus the signal (variable) temperature is defined at all instances of time, even the smallest possible one, whatever may be its value. Thus it can have infinite number of readings or samples even in a very small duration. Also the temperature readings can be taken with any precision provided accurate enough thermometer is available. Thus the temperature at an instant can be 25.5 degrees, or 25.557 degrees or 25.57899 degrees. At least the resolution is not limited by the nature of the variable. It may be limited by the resolution of the thermometer. **All such signals or variables which are defined for all the instances of time (independent variables) are called continuous Signals and their mathematical representations are called continuous Variables. Also the signals (dependent variables) those can have infinite resolution and are defined for all the instances of time (independent variable) like discussed above for the temperature are called Analog Signals. However it is not possible to process an analog or continuous variable in its original form with infinite resolution or infinite number of samples in the given duration as it requires infinite memory storage and infinite processing capability. Thus for processing a continuous signal, it is appropriately sampled, i.e., converted to discrete and digital form using appropriate sampling circuits and proper sampling duration i.e. duration between the successive samples.** The continuous signals can be processed using analog circuits and computers. With the popularity of digital revolution and outstanding advantages of the digital technologies, most of the modern signal processing circuits are digital.

Let us now discuss another type of a signal. The second example of the data set presented in section 1 i.e. grades of a class and semester in all the subjects, will be discussed in this section in brief. Suppose there are six subjects in the semester. Suppose a student 'A' has got six different grades for the six subjects. Thus there are six independent and discrete samples. But nothing is defined between any two neighboring samples unlike the case of temperature samples. The next student 'B' is again going to have six grade samples for the six subjects. The samples of 'A' and 'B' are totally independent. Anything between a sample of 'A' and the respective sample of 'B' is meaningless or undefined. Or for that matter, if all semester grades of a student of an eight semester course i.e. eight samples are presented in graphical form, nothing is defined between the two samples. The semester examination and resulting grade are six monthly phenomenon so one can not have anything between two successive samples. Thus the space between the two successive samples is undefined. **Such signals or variables which are defined for only predefined instantaneous values of an independent variable are called Discrete (Discontinuous) Signals. It is quite obvious that if a discrete signal is taken over a finite duration of time (independent variable), it will have finite number of samples.**

When it comes to the value of a sample, if the resolution on the dependent variable axis is very high, we have very large number of (infinite) levels on the dependent variable axis. It again makes the processing impossible using digital machines. **Thus for processing a signal using digital machines, it must have finite resolution on dependent variable axis and also limited number of samples i.e. finite resolution on independent variable axis. This type of signal which has finite resolution on both the axes may be considered as a Digital signal. In other words, a digital signal is an appropriately**

quantized or digitized or sampled approximate form of a continuous signal. Fortunately, most of the practical or real life applications including even the scientific and engineering applications allow some inaccuracy or imprecision in measurements or decisions based on them. This is where the digital machines make space for themselves in the scientific world. **Thus a signal can also be defined as a reasonably accurate and interpretable representation of some information.**

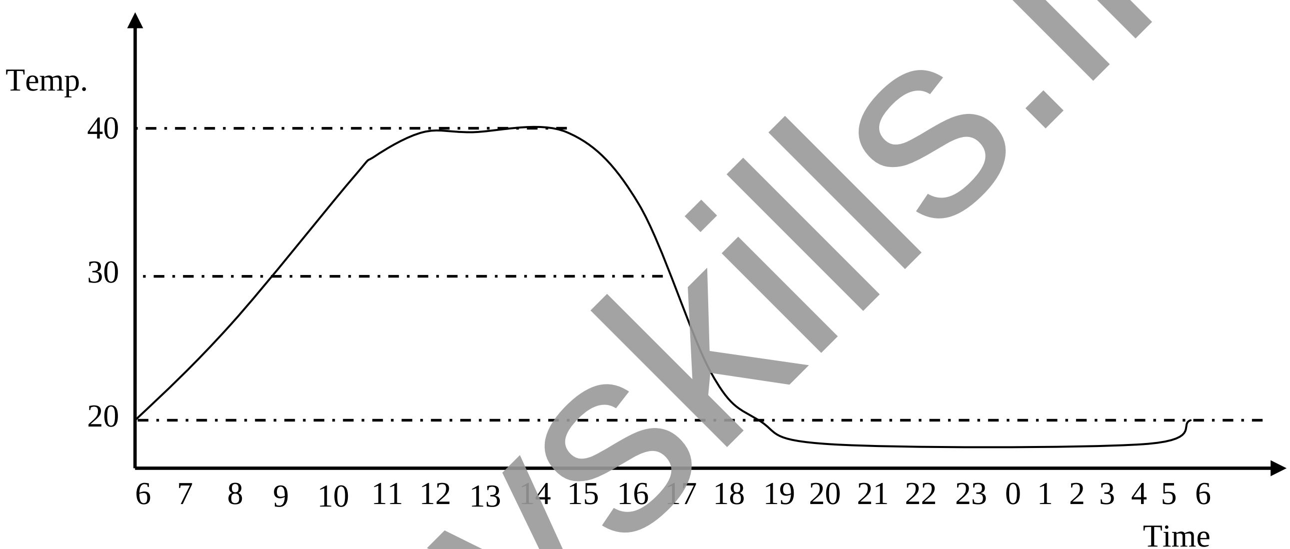

Fig. 1.1 Continuous Curve of temperature readings on a typical day each taken at one hour interval

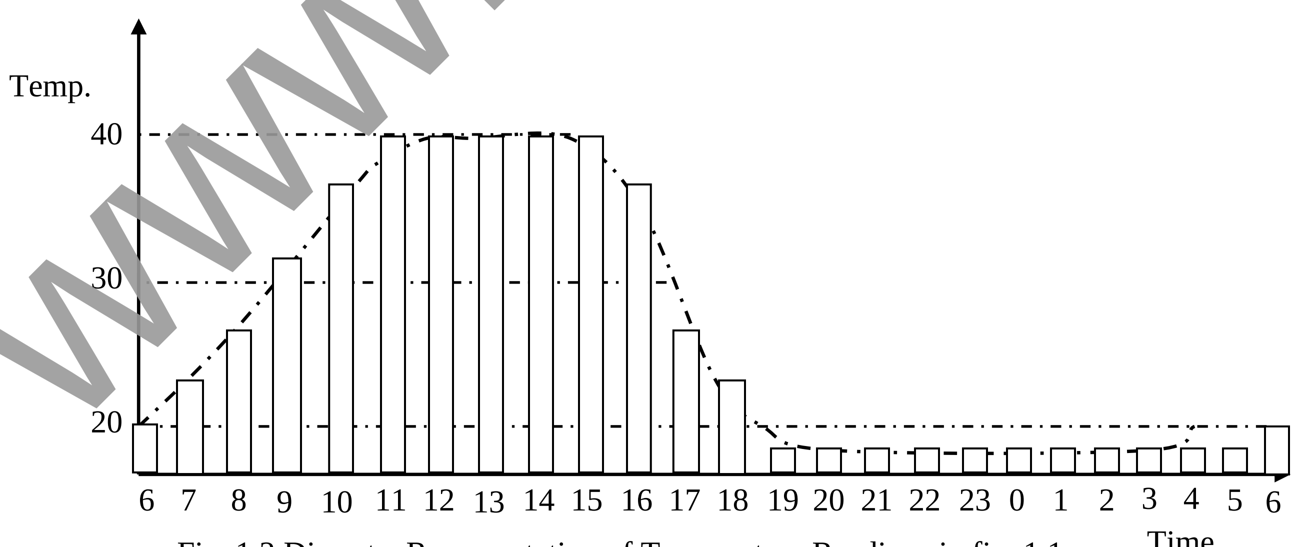

Fig. 1.2 Discrete Representation of Temperature Readings in fig. 1.1

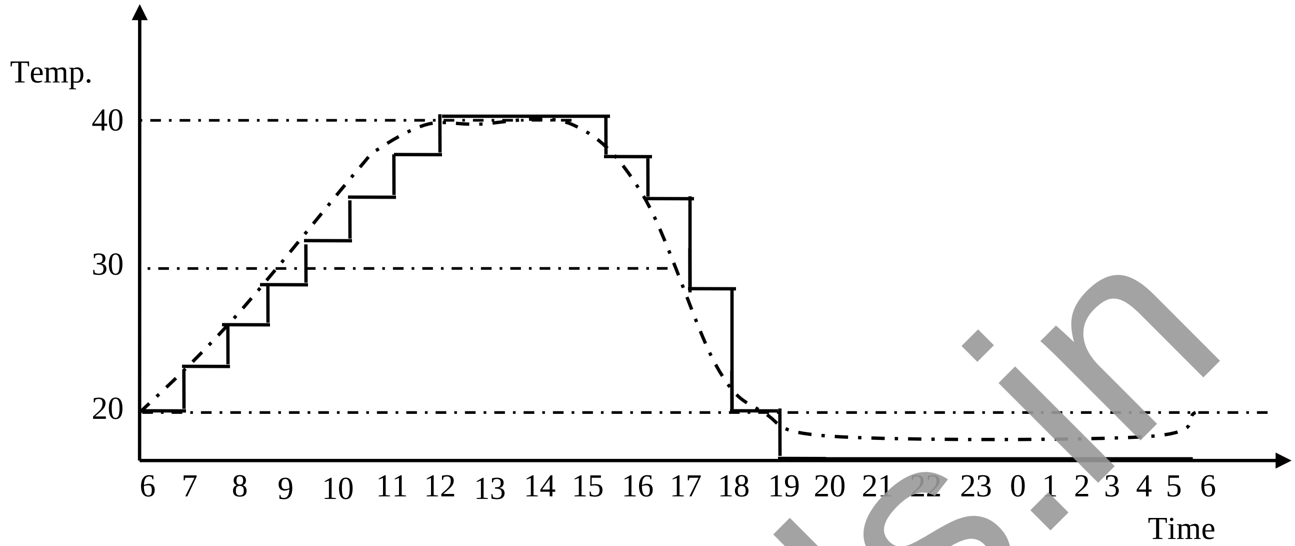

Fig. 1.3 Quantized Representation of Temperature Readings for fig. 1.1 on both axes

It should be noted that Fig 1.1 presents a continuous curve representing temperature variation over 24 hours of the day. All the values of temperature variable between the two readings are even defined in fig. 1.1. In Fig 1.2, the temperatures are defined at only hour intervals i.e. descretized. No temperature is defined between the successive bars; though practically it may be, as the temperature along a day is a continuous variable. Fig. 1.3 presents the temperature variable quantized on both the axes. Thus the intermediate values are not defined on any of the axes. In this for we have finite resolution on both the axes. This type of quantized form of a continuous variable is suitable for processing by a digital computer. This may also be called a digital signal.

However it must be remembered that an ideal digital signal requires a theoretically perfect step as shown in fig 1.4 in which the vertical edge has infinite slope and the horizontal edge will have exact zero slope. This ideal step can not be practically synthesized. The perfect vertical edge with infinite slope can not be achieved because the switching from low level to high level will require nonzero time. So far there is no such switching circuit that can switch between the two levels in zero time.

Thus the synthesis of ideal pulse or square wave is also not practically possible. Practically we are using close approximations of the ideal step or pulse or square wave for experimentations. Thus the vertical edges will have very high slopes (but not infinite) while the horizontal edges will have very low (or close to zero slopes). Fig. 1.4 (a) shows an ideal step while Fig. 1.4 (b) and (c) show practical steps implemented in laboratories.

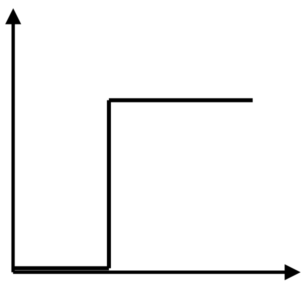

Fig.1.4 (a) Ideal Step

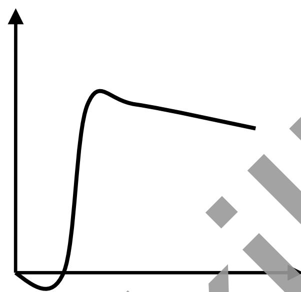

Fig.1.4 (b) An Example of a Practical Step

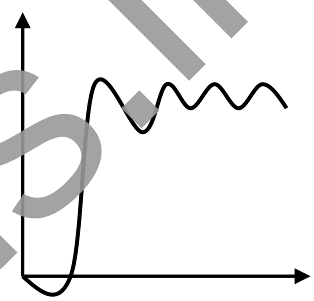

Fig.1.4(c) An Example of a Practical Step

As already discussed a few signals may be inherently discrete in nature for example while deciding grades of students, usually grades are rounded off only up to two decimal points. Or the fractional marks earned by students are rounded off to the next integer marks making them naturally quantized. Example 2 of the data set considered in section 2 is one such inherently discrete data set. For simplicity and easy understanding, we have shown grades of a student in the scale [0, 10] in the six subjects of a semester plotted in Fig. 1.5 in the form of a bar graph to represent a discrete variable. **The neighboring samples in discrete variables may not have any relation between them. On the other hand, in case of continuous variables, the neighboring samples may be closely related.**

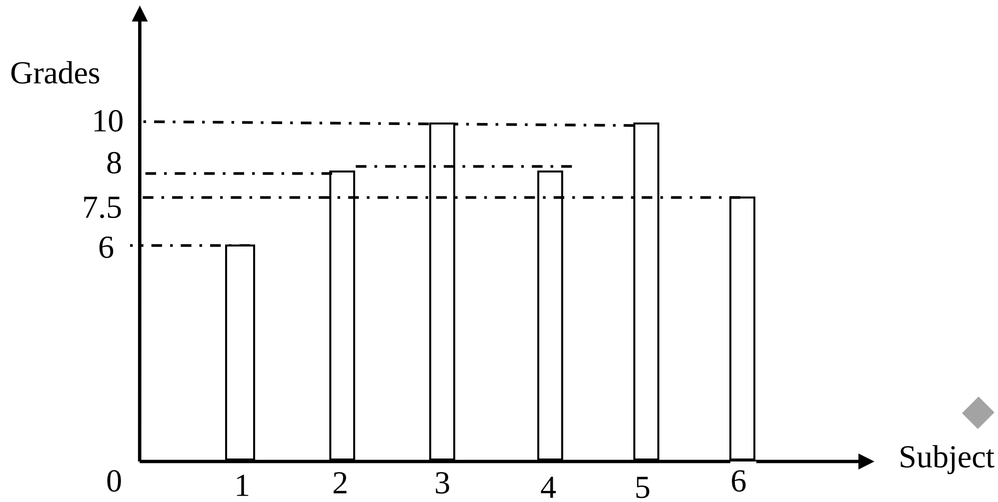

Fig. 1.5 Representation of Grades against the subject Number

It should be noted that between the two subjects, the grade is not defined. Such variables can also be represented directly using number sequences or matrices. The continuous variables are sampled on both the axes for representing them in the form of number sequences or matrices.

1.3. Spectra of Signals

It has been observed that most of the physically existing natural and human interpretable signals like temperature, pressure, air density, wind speed, humidity, sound and audio signals are available in the low frequency band**. Biomedical signals in general have frequencies less than** 20 Hz **. Typically the sensor or transducer output signals have less than 100 Hz frequency. Human speech bandwidth is about 4Khz. The audio signal bandwidth is** 20 Hz **to** 20 KHz **. Thus core information is carried most of the times by this band of low frequencies. This band of low frequencies is called 'Base Band' and the respective signals are called 'Base Band Signals'.** However, a few signals specially based on optical principals like; television, video, high definition TV signals require a considerably high frequency band to accommodate the information. The video signal bandwidth may be in the range of $250\,\text{KHz}$ to 5MHz. The frequencies beyond $20\,\text{KHz}$ are called radio frequencies.

Spectra of a signal is nothing but its representation in frequency domain. According to fourier transform, every complex signal or waveform contain many frequencies (sinusoidal and cosinusoidal) in addition to its fundamental frequency and a DC component. But every component has different amplitude. Spectrum is a plot of amplitude of each frequency component against its frequency. The spectra is also called spectrum or frequency domain representation. It is quiet obvious that the continuous signals have slow or gradual variations. Thus their high frequency contents are less. Thus the spectrum of continuous baseband signals is crowded around lower frequencies. The higher frequency contents are much less. Most of the times the high frequency contents in the base band signals represent noise. In other words, the spectrum of continuous signals is expected to contain only a few frequencies related to the type of signals as already discussed earlier. **But the amplitudes of these selected frequencies are going to be arbitrarily large. The energy of the signal is divided only among a few frequency components. Thus the spectrum of continuous signals is not smooth or continuous.**

In case of discontinuous or discrete signals, due to the steep edge the signals contain very high frequencies in addition to the low frequencies containing information. Thus spectrum of the discrete signals contain a broader range of frequencies. Their energy is divided in many frequency components. Thus amplitude of each individual frequency component is comparatively less. But they have more uniform amplitudes. **Thus the**

spectrum of discrete signals contain a wider band of frequencies compared to continuous signals.

The problem with the low frequency signals is that they can not be transmitted in their original form for various reasons. The main reason is that, low frequencies decay very fast in the medium and hence are not suitable for transmission to longer distances. Usually these low frequency signals are band shifted using a process called modulation and are then transmitted over the channel. At the receiving end they are retrieved back using a process called demodulation. Thus a wide band of frequencies is utilized in electronic communication: lower frequencies (base band) are used for accommodating the information and higher frequencies are used as carrier for carrying the base band signals to longer distances. Higher frequencies are also used as operating frequencies for digital machines and computers in addition to their application as carrier frequencies. A few higher frequencies are also used in biomedical applications like X-rays and CT-scanners due to their better penetrating capabilities. The frequencies beyond 20KHz i.e. radio frequencies are further divided in different bands based on their applications and features; for example the visible light band corresponds to a particular range of frequencies. The complete spectrum of frequencies and the band names if any are presented in Table 1.1 given below.

Summary: In this topic, initially we discussed concepts of data set and information. Further the concept of signal was elaborated as carrier of information followed by definition of base band signals. Then we have presented the types of signals as continuous and discrete signals with adequate discussion on them. Further we discussed the spectrum of the continuous and discrete signals in brief. Finally, complete general frequency spectrum has been presented along with feature or title of each frequency band

Table 1.1 Complete Frequency Spectrum with a few Applications Identified so far

Sr. No.	*Band*	*Frequency Band (Hz)*	*Wavelengths (Cm)*	*Applications*
1	Biomedical	$< 60Hz$		Biomedical instrumentation
2	Human speech	$< 4KHz$		Telephone networks
3	Audio	20Hz-20 KHz		Audio and music systems
4	Radio Frequencies	$< 3\times10^{9}$	$> 10Cm$	Wireless, TV communications
5	Microwave	$3\times10^{9} - 3\times10^{12}$	$10 - 0.01Cm$	Wireless communications
6	Infrared	$3\times10^{12} - 4.3\times10^{14}$	$0.01 - 7\times10^{-5}$	Optical Sensors
7	Visible	$4.3\times10^{14} - 7.5\times10^{14}$	$7\times10^{-5} - 4\times10^{-5}$	Television and other optical systems
8	Ultraviolet	$7.5\times10^{14} - 3\times10^{17}$	$4\times10^{-5} - 10^{-7}$	spectro-fluorometry, photo-catalytic reactions, air purifier etc.
9	X-Rays	$3\times10^{17} - 3\times10^{19}$	$10^{-7} - 10^{-9}$	Medical Imaging
10	Gamma Rays	$> 3\times10^{19}$	$< 10^{-9}$	Cancer therapy, other applications similar to X-rays

Practice Questions

1. For ages human beings have been dealing with natural physical phenomenon
   a) Quantitatively
   b) Rationally
   c) Qualitatively
   d) Analytically

2. Set of numbers generated by quantitative measurements of a parameter are called
   a) Observations
   b) Precision
   c) Resolution
   d) None of the above

3. Which one of the answers in incorrect? Information cannot be communicated in it's original form because of these reasons
   a) Channel bandwidth limitation
   b) Confidentiality
   c) Limitation of time
   d) Limitation of power

4. When it comes communication in electronic form, information is converted to these forms;
   a) Pressure
   b) Voltage
   c) Mass
   d) Acceleration

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- Certified Tally 9.0 Professional
- Certified Treasury Markets Professional
- Certified Wealth Manager

Foreign Trade
- Certified Export Import (Foreign Trade) Professional

Hospitality
- Certified Restaurant Team Member (Hospitality)

Human Resources
- Certified HR Compensation Manager
- Certified HR Staffing Manager
- Certified Human Resources Manager
- Certified Performance Appraisal Manager

Logistics & Supply Chain Management
- Certified International Logistics Professional
- Certified Logistics & SCM Professional
- Certified Purchase Manager

Law
- Certified IPR & Legal Manager

Life Skills
- Certified Business Communication Specialist
- Certified Public Relations Officer

Media
- Certified Advertising Manager
- Certified Advertising Sales Professional

Office Skills
- Certified Data Entry Operator
- Certified Office Administrator

Project Management
- Certified Project Management Professional

Real Estate
- Certified Real Estate Consultant

Information Technology
- Certified Android Apps Developer
- Certified ASP.NET Programmer
- Certified Basic Network Support Professional
- Certified Business Intelligence Professional
- Certified C# Professional
- Certified CAD Professional
- Certified Cloud Computing Professional
- Certified Computer Fundamentals (MS Office) Professional
- Certified Core Java Developer
- Certified CSS Designer
- Certified Data Mining and Warehousing Professional
- Certified DHTML & Javascript Developer
- Certified Django Developer
- Certified DTP operator
- Certified E-commerce Professional
- Certified E-Governance Professional
- Certified Enterprise Applications Integration Specialist (Biztalk)
- Certified Ethical Hacking and Security Professional
- Certified Facebook Apps Developer
- Certified Grid Computing Professional
- Certified Hadoop and Mapreduce Professional
- Certified HTML Designer
- Certified HTML5 Developer
- Certified iPhone Apps Developer
- Certified IT Support Professional
- Certified J2ME Programmer
- Certified Joomla Developer
- Certified Linux Administrator
- Certified Magento Professional
- Certified MySQL DB Administrator
- Certified Network Security Professional
- Certified Open Source CMS (Drupal) Professional
- Certified PHP Professional
- Certified PL/SQL Developer
- Certified Python Professional
- Certified Router Support Professional
- Certified Selenium Professional
- Certified SEO Professional
- Certified Software Quality Assurance Professional
- Certified Software Security Professional
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