CHAPTER 1
Introductory Concepts

1.1 Communication Growth:

One of the basic needs for man is to communicate with one another. Man is probably the most vocal communicator. It is through communication that life - as we know it in the form of societies - has existed. Direct communication depends on sound waves spreading over short distances. When long distances are involved, we use inventions like the telegraph, the telephone and now the mobile, which have dramatically changed our life style. Surely, it has been a dream to be able to communicate with a person you choose, no matter how far apart both of you really are.

It is often said that information is power. But what is more important than information per se is the ability to use information at the right time. This means that the instantaneity of access to information is probably more important than storing information itself. It could mean the dividing line between failure and success in business, between life and death in emergencies, and between victory and defeat in battlefield.

The world of communication is open ended, and man's insatiable greed for better and more comprehensive means for communication tools knows no limit. Man seeks, ultimately, on-line and integrated communication, where audio, video and data files can be instantly exchanged. It is through this integration that we are beginning to see a personal computer acting as a means for communication and as a TV as well. We are beginning to see the interactive TV, which can exchange video and data, and which can also provide a videoconference channel and interactive websites. We are heading now toward having all this on the move, through the use of very small aperture terminals (VSAT), wireless wide area networks (W-WANs) and wireless personal communication system (PCS) protocols.

1.2 Communication Electronics:

The science of communication concentrates on the theory and the techniques used in communication, as well as the various considerations of the transmission and reception of signals. Electronics is the science of the hardware. It builds up on semiconductor physics, material science and device technology, where development of new devices and the upgrading of existing devices are involved.

The second layer of electronics is concerned with the design and use of ICs, which fulfill various signal processing requirements. An electronics-major graduate may be involved in design, maintenance, programming, or even the technical promotion of new products. Yet, another important category for electronics profession is systems engineering. Such a graduate must be familiar with the communication jargon, as well as with the electronics toolbox. The emphasis here is not on the physics of the devices - although some knowledge of device physics and device limitations is surely needed - but the main emphasis is more on how to put the pieces together. The pieces may not be at the transistor level, the IC level or even the PCB level. The pieces might be on a higher level, such as a PC, a TV, a modem, a router and so on. The objective is to put together a macro system. What is needed for this specialty is enough information about both communication theory and electronic subsystems. What is needed is a vision for creating a big system. This requires also stamina to face new situations for which prior knowledge probably is not available. This calls for continuing learning to develop growing experience to be able to cope with an ever mushrooming field. That is what communication electronics is all about.

1.3 Tenets of Communication Electronics:

Communication systems may be roughly classified to analog systems, digital systems and hybrid systems. All communication systems share common features, such as the need for modulation and demodulation. The signals to be transmitted must be borne by some kind of a carrier. At the receiver end, the signal is extracted from the carrier, and the carrier is done away with.

Systems may be classified according to the type of modulation or demodulation. But there are many common features among such modulation and demodulation techniques.

Because of the limited spectrum, the growing demand for communication services and the increasing number of beneficiaries, a variety of methods are used, involving either sharing the frequency scale (FDM) or sharing the time scale (TDM). A new technique (spread spectrum) has evolved which allows for sharing the wide spectrum through accessing different codes (CDMA). Retrieval of signals often depends on the use of a carrier, generated at the receiver and synchronized with that at the transmitter. This is called synchronous or coherent detection. It is often used in analog systems and in CDMA. Quite often, we are encountered with a hybrid system. In digital systems, RF carriers are often used. The use of a carrier is a form of analog communication, but may be used in a digital context. As we expand in more depth into the realm of communication, we find that analog and digital techniques eventually merge, thus, availing the best of the two worlds.

A common feature in all communication problems is to keep the noise level as low as possible, and be able to extract weak signals from a noisy background. Various methods for system evaluation are used for comparing different systems and techniques.

An important aspect of communication is also security and privacy. Different techniques for encryption - such as scrambling, water marking or finger printing - are often used. Such techniques are of special value in TV pay stations, banking and military security.

New trends in communication electronics stretch out to the optical part of the spectrum, using optoelectronic devices, lasers and fiber optics, in an attempt to open up new frontiers to satisfy the ever growing and insatiable demand for communication channels. The diversity and resourcefulness of communication electronics are basically responsible for placing communication at the heart of the sophisticated way of life, which is characteristic of this era as of now, and even more so in years to come.

1.4 Requirements for Communication Systems:

The objective in electrical communication is to transmit information or messages from one place to another, over short or long distances. The information could be audio, video or data. It does not matter, as long as it is an electrical signal. This information could be business transactions, education, entertainment or social services. Such a signal - in its raw form - is called baseband, which means a time signal obtained from a transducer (microphone, video camera, output interface, etc). This signal can be viewed as a function in time domain (TD). But it can also be viewed in frequency domain (FD) through Fourier Transform. The frequency domain has an eye for the information content in the signal. This information could not be seen or felt by looking at the time domain waveform. It is through FD that we can learn about the bandwidth of the signal, i.e., the range of frequency components which compose the signal.

In communication systems, it is important to match the bandwidth of the system (BW_{sys}) with the signal bandwidth (BW_{sig}). If the system has more BW than the signal, we find that noise increases. Noise is an unwanted random overhead signal, created by random fluctuations of electrons, and increases with BW. If the system has less BW than the signal, truncation of frequency components of the signal results in distortion or loss of information. For a system to have high fidelity (Hi Fi), it must be able to faithfully reproduce the original signal. For that to happen, the gain (ratio of the output to the input) must be independent of frequency, so that all frequency components of the signal are treated equally without discrimination. Secondly, the time delay introduced by the system must be independent of frequency, so that no extra leads or lags are introduced by the system, which would render the construction of the output signal different from the original input signal, due to differences in the phase (φ) relationship of the frequency components of the signal.

Since $\varphi = \omega\tau$ (where τ is the time delay.), the whole time function should be delayed in time by a constant amount τ. If the frequency spectrum of the signal can be expressed as an extent of frequency around a center frequency ω_c, this extent of signal frequency components is called the bandwidth of the signal (BW_{sig}). The communication system has a center frequency ω_o, and the range of frequencies around it over which the gain is nearly constant is called the bandwidth of the system (BW_{sys}). It is required that:

$$\omega_c = \omega_0 \qquad \text{(Tuning condition)} \qquad (1\quad 1)$$

$$BW_{sys} = BW_{sig} \qquad \text{(Selectivity condition)} \qquad (1\quad 2)$$

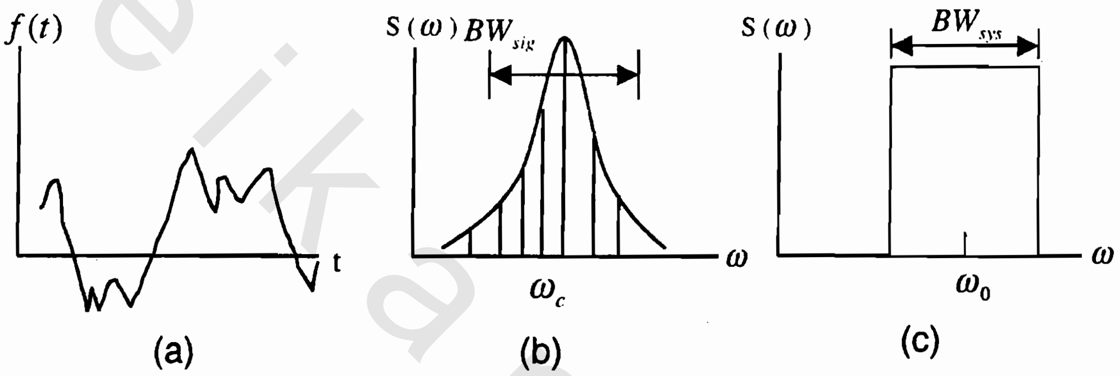


Fig. 1.1 Signal in TD and FD
a) TD signal b) signal spectrum c) band pass filter (BPF)

If ω_c is shifted from ω_o, or if $BW_{sys} < BW_{sig}$, part of the information in the signal is lost. If $BW_{sys} > BW_{sig}$, noise increases. The bandwidth (for system or signal) is usually measured between frequencies at which the value of the frequency response $S(\omega)$ drops to $1/\sqrt{2}$ of its maximum (or peak value) on both sides. These points are called 3dB points. The value of the frequency response is considered fairly flat in between these points.

1.5 High Fidelity (Hi Fi):

Hi Fi performance requires that the system be distortion - free. Distortion may arise due to deviations from linearity.
In a linear system,

$$V_0 = AV_{in}, \qquad (1-3)$$

where V_{in} is the input signal, and V_o is the output signal.
If V_{in} is made up of different frequency components, such as

$$V_{in} = V_1 \sin\omega_1 t + V_2 \sin\omega_2 t \qquad (1-4)$$

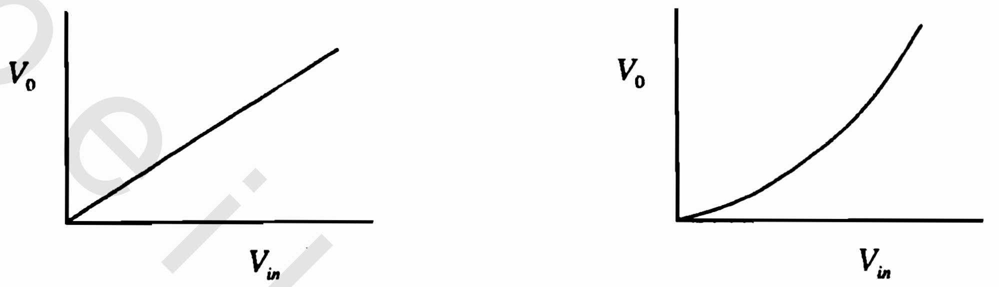
Then,

$$V_0 = AV_1 \sin \omega_1 t + AV_2 \sin \omega_2 t \qquad (1-5)$$

This means that the frequencies of the output are the same as the frequencies at the input.

If the system is nonlinear (Fig. 1.2b),

$$V_O = AV_{in} + BV_{in}^2 + CV_{in}^2 + ... \qquad (1-6)$$



(a) (b)

Fig. 1.2 Linearity vs. nonlinearity

a) linear system b) nonlinear system

Thus,

$$V_o = A(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t) + B(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t)^2$$
$$+ C(V_1 \sin \omega_1 t + V_2 \sin \omega_2 t)^3 + ... \qquad (1-7)$$

We see that additional frequencies will appear at the output, in addition to ω_1 and ω_2 (such as $2\omega_1 - \omega_2$, $2\omega_1 + \omega_2$, $2\omega_2 + \omega_1$, $2\omega_2 - \omega_1$, ... etc). These frequencies cause distortion in the signal.

Hi Fi performance also requires that the system be noise - free. An increased system bandwidth generates more noise. It is found that the noise power $P_n = kTB$, i.e., noise power increases linearly with bandwidth B and temperature T, where k is Boltzmann constant.

When the signal is weak - which is usually the case - the job of the amplifier is to bring up the level of the signal to a level suitable for perception. But the amplifier never improves the quality of the signal, which is usually measured by a figure of merit, called signal to noise ratio (S/N or SNR). In fact, as we use amplifiers, we introduce more noise at the output, due to the randomness of the electrons in the amplifier, hence, degrading S/N.

In the limit, when the signal is buried in noise, no amplifier will be of help to extract the signal from the overwhelming noise background. More sophisticated techniques are used, then, other than simple amplification, such as the use of phase locked loops (PLL) or code division multiplex access (CDMA).

1.6 Design Considerations:

It appears that several considerations have to be taken into account in the design of a communication system:

1- What kind of bandwidth is required?
2- How flat is the system transfer function (relation of V_o / V_{in} versus frequency)?
3- How sharp does the transfer function roll off at both sides?
4- How much delay is introduced?
5- How fast does the system respond to fast variations in the input? It is found that this response time is linked to the bandwidth. The higher the bandwidth, the shorter the response time.
6- How much distortion is introduced by the system?
7- How much noise is generated in the system?
8- What kind of modulation and demodulation technique is used? It is found that coherent detection is the best in terms of saving power and reducing noise effect. Choice of modulation scheme depends on the comparison of signal to noise ratio (S / N). High quality signal processing requires increased bandwidth. Yet, it requires a mechanism which reduces the noise.
9- There is always multiplicity of solutions. Evaluation usually depends on the specific application and operation conditions.
10- New techniques in communication do not drive old ones out of the way. For example, new digital innovations still use RF analog carriers. Compatibility has to be watched for, though, as users of old models should still receive information, as has happened in the case of the evolution of TV from black and white to color.

The field of computers, electronics, communication and signal processing are strongly merging. Fast developments in hardware make old techniques better, and make possible new techniques as in spread spectrum.

In short, the specific area of communication electronics strikes the right balance between communication and electronics, as needed to implement a real life system, with high performance, ease of operation for the nonspecialists and low cost needed for consumer-oriented proliferation of communication tools and techniques.