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# Preface

The influence of telecommunications has increased steadily since the introduction of telegraphy, radio and telephony. Now, most of us are directly dependent on one or more of its many facets for the efficient execution of our work, at home, or in our leisure.

Consequently, as a subject for study it has become more and more important, finding its way into a large range of higher education courses, given at a variety of levels. For many students, telecommunications will be presented as an area of which they should be aware. The course they follow will include the essential features and principles of communicating by electro-magnetic energy, without developing them to any great depth. For others, however, the subject is of more specialized interest; they will start with an overview course and proceed to specialise in some aspects at a later time We have written our book with both types of student in mind We have brought together a broader range of material than is usually found in one text, and we have tried to combine an analytical approach to important concepts with a descriptive account of system design. In several places we have stressed the approximate nature of analysis, and the need to exercise engineering judgement in its application. The intention has been to avoid too much detail, so that the text will stand on its own as a general undergraduate level introduction, and it will also provide a strong foundation for those who will eventually develop more specialized interests.

We have assumed that the reader is familiar with basic concepts in electronic engineering electromagnetic theory, probability theory and differential calculus.

Chapter begins with the theoretical description of signals and the channels through which they are transmitted. Emphasis is placed on numerical methods of analysis such as the discrete Fourier transform, and the relationship between the time and frequency domain representations is covered in detail. This chapter also deals with the description and transmission of information bearing signals.

Chapter 2 is concerned with analogue modulation theory. In this chapter there is a strong link between the theoretical concepts of modulation theory and the practical significance of this theory. This chapter assumes that the reader has a realistic knowledge of electronic circuit techniques.

Chapter 3 is devoted to discrete signals and in particular the coding and transmission of analogue signals in digital format. This chapter also emphasises the relationship between the theoretical concepts and their practical significance.

Chapters 4 and 5 are concerned with the performance of telecommunications systems in noise. Chapter 4 covers the performance of analogue systems and concentrates on the spectral properties of noise. Chapter 5 covers the performance of digital systems and is based on the statistical properties of noise. This chapter also deals in detail with the practical implication of error corrections codes, a topic which is often ignored by more specialised texts in digital communications.

In Chapter 6 the elements of high-frequency transmission line theory are discussed, with particular emphasis on loss-less lines. The purpose is to introduce the concepts of impedance, reflection and standing-waves, and to show how the designer can influence the behaviour of the line.

Basic antenna analysis, and examples of some commonly used arrays and microwave antennas, are introduced in Chapter 7, while Chapters 8 and 9 describe the essential features of waveguide-based microwave components. A fairly full treatment of the propagation of signals along a waveguide is considered from both the descriptive and field-theory analysis points of view.

Telephone system equipment represents the largest part of a country's investment in telecommunications, yet teletraffic theory and basic system design do not always form part of a telecommunications class syllabus. Chapter 10 is a comprehensive chapter on traditional switching systems and the techniques used in their analysis. Care has been taken to limit the theoretical discussion to simple cases, to enable the underlying concepts to be emphasised.

Chapter 11 is devoted to television systems. In a text of this nature such a coverage must be selective. We have endeavoured to cover the main topics in modern colour television systems from the measurement of light to the transmission of teletext information. The three main television systems, NTSC, PAL and SECAM, are covered but the major part of this chapter is devoted to the PAL system.

One of the outstanding major developments in recent years has been the production of optical fibres of extremely low loss, making optical communication systems very attractive, both technically and commercially. Chapter 12 discusses the main features of these systems, without introducing any of the analytical techniques used by specialists. The chapter is intended to give an impression of the exciting future for this new technology.

We cannot claim to have produced a universal text! some omissions will not turn out to be justified, and topics which appear to be of only specialized interest now may suddenly assume a much more general importance. However, we hope that we have provided in one volume a coverage which will find acceptance by many students who are taking an interest in this stimulating and expanding field of engineering.

# List of symbols

| | |
|---|---|
| $C$ | capacitance per unit length of transmission line |
| $A$ | telephone traffic, in erlangs |
| $\alpha$ | attenuation coefficient on a transmission line |
| $\alpha$ | traffic offered per free source |
| $B$ | bandwidth of a signal or channel |
| $B$ | call congestion |
| $\beta$ | phase constant on a transmission line |
| $\beta$ | modulation index |
| $c$ | velocity of light in free space |
| $C(n)$ | discrete spectrum |
| $C_n$ | $n$th harmonic in a Fourier series |
| $\delta_s$ | skin depth |
| $\delta(t - t_0)$ | impulse function at $t_0$ |
| DFT | discrete Fourier transform |
| $E$ | time congestion |
| $E(f)$ | energy density spectrum |
| $E_N(A)$ | Erlang's loss function |
| $E(N, s, \alpha)$ | Engset's loss function |
| $\varepsilon$ | permittivity |
| $\varepsilon_0$ | permittivity of free space |
| $\eta_0$ | fee space characteristic impedance |
| $\eta$ | Single sided power spectral density of white noise |
| $F$ | noise figure of a network |
| $f_0$ | fundamental frequency of a periodic wave |
| $f_c$ | cut-off frequency |
| $f(t), h(t)$ | general function of time |
| $F_v(v)$ | cumulative distribution function |
| $G$ | conductance per unit length of transmission line |
| $\gamma$ | propagation coefficient on a transmission line |
| $G(f)$ | power spectral density |
| $G(i)$ | probability of any $i$ devices being busy |
| $H$ | magnetic field |
| $H_{av}$ | entrophy of a message (bits/symbol) |
| $H(f)$ | Fourier transform of $h(t)$ |
| $H(i)$ | probability of a particular $i$ devices being busy |
| $h(k)$ | discrete signal |

| | |
|---|---|
| $[i]$ | probability that a network is in state $i$ |
| IDFT | inverse discrete Fourier transform |
| IF | intermediate frequency |
| $I_0(x)$ | modified Bessel function |
| $J_n(\beta)$ | Bessel functions of the first kind |
| $k_c$ | $2\pi/\lambda_c$ |
| $L$ | inductance per unit length of transmission line |
| $\lambda$ | likelihood ratio |
| $\lambda$ | wavelength |
| $\lambda_c$ | cut-off wavelength |
| $\lambda_{cm}$ | cut-off wavelength of the $TE_{mn}$ or $TM_{mn}$ mode |
| $\lambda_g$ | guide wavelength |
| $\lambda_i$ | call arrival rate in state $i$ |
| $\lambda_0$ | free space wavelength |
| $L(f)$ | frequency domain output of a network |
| $l(t)$ | time domain output of a network |
| $m$ | depth of modulation |
| $\mu$ | permeability |
| $\mu_i$ | call departure rate in state $i$ |
| $\mu_0$ | permeability of free space |
| $N$ | number of devices |
| $n$ | refractive index of glass fibre |
| $N_i$ | normalised noise power at the input of a network |
| $N_0$ | normalised noise power at the output of a network |
| $n_0$ | refractive index of free space |
| $n(t)$ | elemental noise voltage |
| $P$ | power in a signal |
| $P_e$ | error probability |
| $P(f)$ | transfer function of a network |
| $p'_{nm}$ | root of $J'_n(k_c, a)$ |
| $\psi$ | angle of reflection coefficient |
| $p(t)$ | impulse response of a network |
| $p_v(v)$ | probability density function |
| $R$ | resistance per unit length of transmission line |
| $R_h(\tau)$ | autocorrelation function of $h(t)$ |
| $\rho$ | reflection coefficient at transmission line load |
| $s$ | mean call holding time |
| $S$ | number of traffic sources |
| $S$ | voltage standing wave ratio (VSWR) |
| $S_c$ | normalized carrier power |
| $S_i$ | normalized signal power at the input of a network |
| $\sigma$ | rms voltage of a random signal |
| $S_o$ | normalised signal power at the output of a network |
| SNR | signal to noise ratio (power) |
| $T$ | period of a periodic wave |

| | |
|---|---|
| $\tau$ | dummy time variable |
| $T_e$ | effective noise temperature of a network or antenna |
| $TE_{mn}$ | transverse electric waveguide mode |
| $TM_{mn}$ | transverse magnetic waveguide mode |
| $T_s$ | standard noise temperature (290 K) |
| $V$ | peak voltage of a waveform |
| $v$ | transmission line wave velocity |
| $V_1$ | incident (forward) voltage on a transmission line |
| $V_2$ | reflected (backward) voltage on a transmission line |
| $v_g$ | group velocity |
| $V_n(t)$ | bandlimited noise voltage |
| $v_{ph}$ | phase velocity |
| $W$ | highest frequency component in a signal |
| $x(t)$ | amplitude of in-phase noise component |
| $y$ | mean call arrival rate |
| $y(t)$ | amplitude of quadrature noise component |
| $Z_L$ | transmission line load impedance |
| $Z_0$ | characteristic impedance of a transmission line |

# Contents

# 1 Signals and channels

## 1.1 Introduction

Telecommunication engineering is concerned with the transmission of information between two distant points. Intuitively we may say that a signal contains information if it tells us something we did not already know. This definition is too imprecise for telecommunications studies, and we shall devote a section of this chapter to a formal description of information. For the present it is sufficient to say that a signal that contains information varies in an unpredictable or random manner. We have thus specified a primary character of the signals in telecommunications systems; they are random in nature.

These random signals can be broadly subdivided into discrete signals that have a fixed number of possible values, and continuous signals that have any value between given limits. Whichever type of signal we deal with, the telecommunication system that it uses can be represented by the generalized model of Fig. 1.1. The central feature of this model is the transmission medium or channel. Some examples of channels are coaxial cables, radio links, optical fibres and ultrasonic transmission through solids and liquids. It is clear from these examples that the characteristics of channels can vary widely. The common feature of all channels, however, is that they modify or distort the waveform of the transmitted signal. In some cases the distortion can be so severe that the signal becomes totally unrecognizable.

In many instances it is possible to minimize distortion by careful choice of the transmitted signal waveform. To do this the telecommunications engineer must be able to define and analyse the properties of both the signals and the channels over which they are transmitted. In this chapter we shall concentrate on the techniques used in signal and linear systems analysis, although we should point out that many telecommunications systems do have non-linear characteristics.

## 1.2 The Frequency and Time Domains

The analysis of linear systems is relatively straightforward if the applied signals are sinusoidal. We have already indicated that the signals encountered in telecommunications systems are random in nature and, as such, are non-deterministic. It is often possible to approximate such signals by periodic functions that themselves can be decomposed into a sum of sinusoidal components. The signal waveforms are functions of time and the variation of signal amplitude with time is known as the 'time domain representation' of the signal. Alternatively, if a signal is decomposed

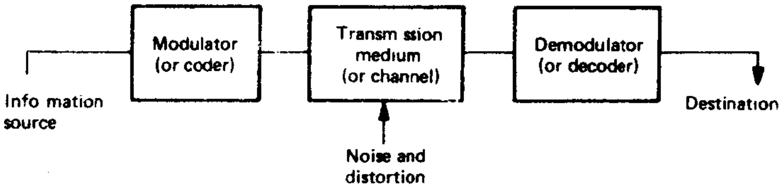


Fig. 1.1 Basic elements of a telecommunications system.

into a sum of sinusoidal components, the amplitude and phase of these components can be expressed as a function of frequency. This leads us to the 'frequency domain representation' of the signal.

The relationship between frequency domain and time domain is an extremely important one and is specified by Fourier's theorem. The response of a linear system to a signal can be determined in the time domain by using the principles of convolution, and in the frequency domain by applying the principle of superposition to the responses produced by the individual sinusoidal components. We will consider the frequency domain first, as this makes use of the theorems of linear network analysis which will be familiar to readers with an electronics background. Time domain analysis is considered in detail in Section 1.11. Frequency domain analysis will be introduced using traditional Fourier methods and we will then develop the discrete Fourier transform (DFT) which is now an essential tool in computer aided analysis of modern telecommunications systems.

## 1.3 Continuous Fourier Analysis

Fourier's theorem states that any single valued periodic function, which has a repitition interval $T$, can be represented by an infinite series of sine and cosine terms which are harmonics of $f_0 = 1/T$. The theorem is given by Eqn (1.1).

$$h(t) = \frac{a_0}{T} + \frac{2}{T}\sum_{n=1}^{\infty}(a_n \cos 2\pi n f_0 t + b_n \sin 2\pi n f_0 t) \qquad (1.1)$$

where $f_0 = 1/T$ is the fundamental frequency. The response of a linear system to a waveform $h(t)$ that is not a simple harmonic function is found by summing the responses produced by the individual sinusoidal components. The term $a_0/T$ is known as the dc component and is the mean value of $h(t)$.

$$\frac{a_0}{T} = \frac{1}{T}\int_{-T/2}^{T/2} h(t)\,\mathrm{d}t$$

i.e

$$a_0 = \int_{-T/2}^{T/2} h(t)\,\mathrm{d}t \qquad (1.2)$$