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Introductory Topics in Electronics and Telecommunication

SIGNALS

S I Units

Signals

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Preface

This is an introductory book on the important topic of *Signals*. Electrical signals in various forms are used extensively in the fields of Electronics and Telecommunications, and the book endeavours to present the basic ideas in a concise and coherent manner, by bringing together closely related subject matter, all under one heading. Moreover, to assist in the assimilation of these basic ideas, many worked examples from past examination papers have been provided, to illustrate clearly, the application of the fundamental theory. The book is the first of six dealing with the fundamental topics of telecommunications and electronics.

The early chapters of the book are devoted to an analysis of the various types of signals and a study of their particular characteristics. Subsequent chapters deal with the transmission of signals and the signal techniques employed in various applications. The book ends with an introduction to the important subject of Information Theory, which deals with the general problem of the transmission of information in any communication system.

This book will be found useful by students preparing for London University examinations, degrees of the Council of National Academic Awards, examinations of the Council of Engineering Institutions and for other qualifications such as Higher National Certificates, Higher National Diploma and certain examinations of the City & Guilds of London Institute. It will also be useful to practising engineers in industry who require a ready source of basic knowledge to help them in their applied work.

Acknowledgements

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F.R.C.

Symbols used in the book

τ	duration of time
ω	angular frequency
$\delta(t)$	Dirac delta function
σ	real number
λ	wavelength
α, β, γ	angles
$\mathscr{F}[f(t)]$	Fourier transform of $f(t)$
$\phi(\omega)$	phase angle
$\frac{\mathbf{V}_0}{\mathbf{V}_i}$	phasor voltages
Δx	increment of x
$L[f(t)]$, $\mathscr{L}[f(t)]$	Laplace transform of $f(t)$
$\mathscr{L}^{-1}[F(S)]$	Inverse Laplace transform of $F(S)$

Abbreviations used in the book

C.E.I. Part 2	Council of Engineering Institutions examination in Communication Engineering, Part 2.
L.U. B.Sc(Eng) Tels.	University of London, B.Sc(Eng). Examimation in Telecommunications, Part 3.

Contents

1
Introduction

The communication engineer is concerned with the transmission and reception of signals. A signal is an electrical voltage or current which varies with time and is used to carry messages or information from one point to another. A message is usually in the form of words or coded symbols and the amount of information it contains is of great importance in communications.

In practice, it is more convenient to handle information by converting it into a signal. The signal is then transmitted over a communication system to the receiving end, where it is transformed back to the original information or message. The schematic arrangement of a typical communication system is shown in Fig. 1.

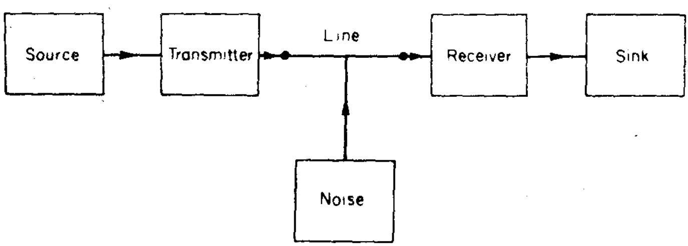


Fig. 1 Typical communication system

The source generates the message signal which is processed by the transmitter and sent along a line. At the receiving end, the message is extracted and sent to its final destination (sink). During transmission and reception, noise is picked up from various sources and can be represented as a single noise source.

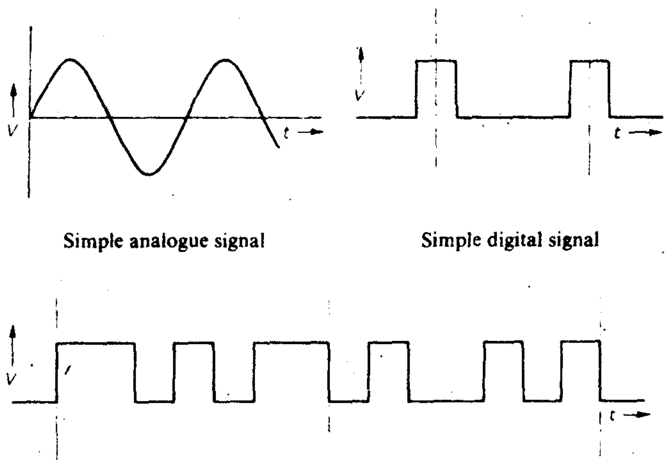
1.1 Types of signal

There are two main types of signals—the *analogue* signal which varies continuously with time, and the *digital* signal which is discontinuous vith time.

Analogue signals usually represent the variation of a physical quantity like a sound wave and are either single sine waves or a combination of them.

The digital signal consists basically of 'pulses' which occur at discrete intervals of time. The pulses may occur singly with a definite periodicity or in groups in the form of a code, as in telegraphy.

Fig. 2



Simple analogue signal

Simple digital signal

Coded signal

1.2 Examples of signals

Typical signals are those used in telegraphy,[1,2] telephony,[3,4] radio communication,[5,6] television[7,8] and radar.[9–11]

(a) Telegraph signal

A message consisting of a set of words may be transmitted by ascribing to each letter a certain coded signal. This is the basis of telegraphy and it is usually achieved by means of an electromechanical machine, somewhat like a typewriter and known as a teleprinter.

The letter *R* used in the teleprinter code* has the form shown in Fig. 3.

* See Appendix A.

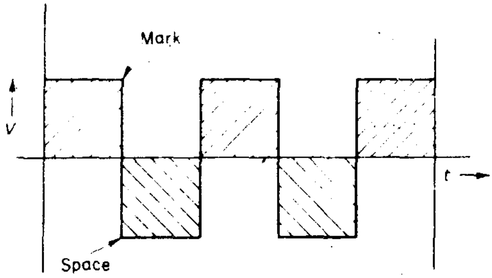


Fig. 3 Letter R

This signal has a pulse waveform with positive and negative values called *mark* and *space* respectively. The rate of transmitting the pulses is called the signalling speed and is measured in 'bauds'. The baud is defined as the number of pulses sent per second and the usual speed used in machine telegraphy is about 50 bauds.

It will be shown later that such a pulse waveform consists of a range of frequencies called the 'bandwidth' of the signal. For a 50-baud speed this is taken as 120 Hz per message for practical reasons and is known as a 'telegraph channel'.

EXAMPLE 1

Discuss the relationship between bandwidth and signalling speed in a telegraph system.

Solution

Consider a simple system in which the basic signal consists of a series of positive and negative pulses as shown in Fig. 3. The speed of signalling is defined as the number of elementary pulses sent per second and is therefore inversely proportional to pulse duration, since the narrower the pulse the greater is the number that can be sent per second.

Hence

$$\text{signalling speed} = \frac{1}{\text{duration of elementary pulse}}$$

For example, for a signalling speed of 50 bauds we have

$$\text{duration of elementary pulse} = \tfrac{1}{50} = 20 \text{ ms}$$

Now, pulse duration or time is itself *inversely* proportional to frequency and so the signalling speed is *directly* proportional to frequency. Hence, the higher the signalling speed the greater the frequency involved. In other words, the bandwidth of frequencies used is proportional to signalling speed.

(b) Telephone signal

A telephone conversation consists of speech sounds involving vowels and consonants. The speech sounds produce audio waves which cause a diagraphm to vibrate in the telephone mouthpiece, thereby producing an electrical signal. The speech sounds fluctuate considerably in form and so the telephone signal consists of a complex combination of audio-frequency sine waves. The signal obtained for uttering the vowel *E* is shown in Fig. 4.

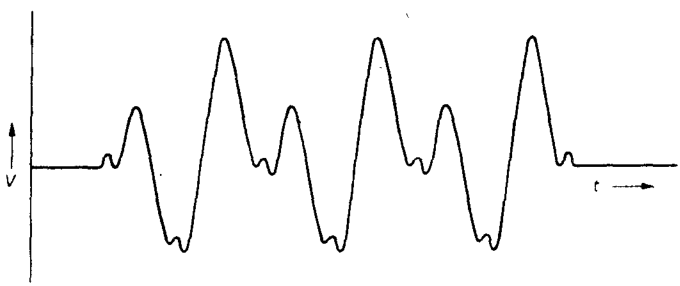


Fig. 4 Vowel E

Most of the energy in speech signals is found to be contained in the lower frequencies; for intelligible speech, it is sufficient to consider those from about 300 Hz to 3400 Hz. An overall bandwidth of 4 kHz is therefore used for each telephone message and is referred to as a telephone channel.

Alternatively, such a telephone channel may be used to carry several telegraph messages, each with a 120-Hz bandwidth. As many as 24 telegraph channels can be accomodated in one telephone channel.

(c)* Radio signal

This is generated by an oscillator and consists of a radio-frequency sine wave which is called the 'carrier wave'. In order to carry information, it is modulated by speech or music. In the case of amplitude modulation,* the carrier amplitude is varied by the modulating signal; this is shown in Fig. 5.

When the modulating signal consists of musical sounds, the frequency bandwidth of the music extends to about 10 kHz for commercial broadcasts or up to 15 kHz in the case of high-fidelity music.

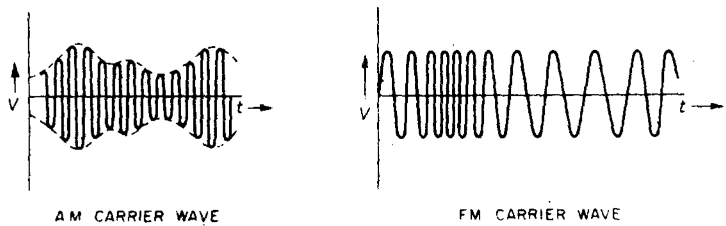


Fig. 5

(d) Television signal (black and white)

The scene to be televised consists of various shades of brightness, from black to white and varying from time to time. The television signal shown in Fig. 6 is therefore fairly complex in shape and consists of intervals

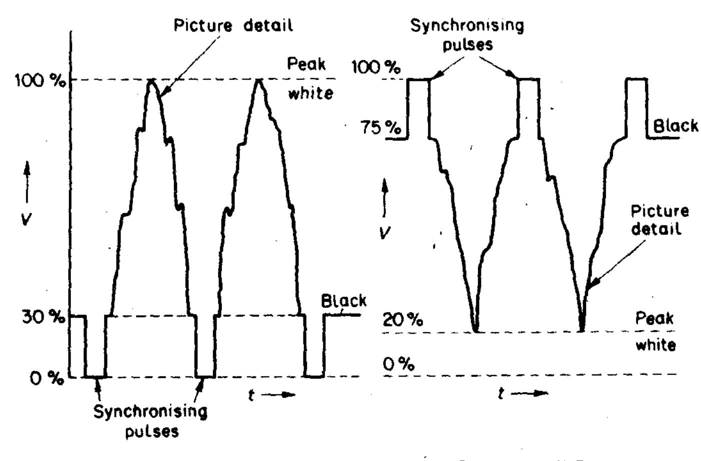


Fig. 6

* See Appendix B.

of time during which the picture detail is transmitted with its varying shades of brightness. Interleaved with this are sets of pulses for synchronising the line and field time-bases of the receiver with that of the scanning camera at the transmitter.

A typical channel bandwidth used extends from d.c. level to 8 MHz for the BBC 625-line system.

EXAMPLE 2

Discuss the frequency bandwidth required in line transmission when each of the following is transmitted:

(a) high-quality music.
(b) 12 telephone channels.
(c) 24 channels of voice-frequency telegraphy, each signalling at 50 bauds.
(d) 625-line television picture in which the picture line-scan occupies 60 μs and the aspect ratio is $\frac{4}{3}$. L.U.B.Sc(Eng) Elect. & Tels. 1964

Solution

(a) High-quality music (Hi-Fi for short) would cover a frequency band over the range of average human audibility. This extends down to about 20 Hz and up to 16 or 18 kHz. The frequency bandwidth required is therefore approximately 16 kHz or the equivalent of four telephone channels as used in line transmission.

(b) For intelligible speech a bandwidth of 3·4 kHz is sufficient, but to allow for filter characteristics an average of 4 kHz per channel is allocated. Hence 12 channels require 12 × 4 kHz = 48 kHz bandwidth.

(c) Since the signalling speed in bauds equals the reciprocal of the duration of the telegraph pulse,

$$\text{pulse duration} = \tfrac{1}{50}\ \text{s}$$

For a complete cycle, we require a double pulse change (+ve to −ve) for the fundamental period. Hence

$$\text{duration of cycle} = 2 \times \tfrac{1}{50} = \tfrac{1}{25}\ \text{s}$$

or $$\text{fundamental frequency} = 25\ \text{Hz}$$

These pulses are used to amplitude-modulate a VF (voice frequency) carrier tone around 500 Hz. Sum-and-difference frequencies which are called sidebands (see Appendix B) are produced about the carrier tone, to give an overall bandwidth 2 × 25 = 50 Hz.

However, to allow for filter characteristics, a bandwidth of 120 Hz is used in practice. It allows some of the third harmonic, *i.e.* 75 Hz, to be transmitted as well, which preserves the pulse squareness and so ensures the reliable operation of electro-mechanical relays (telegraph relays).

The bandwidth requirement for 24 channels is therefore 24 × 120 Hz = 2880 Hz.

(d)

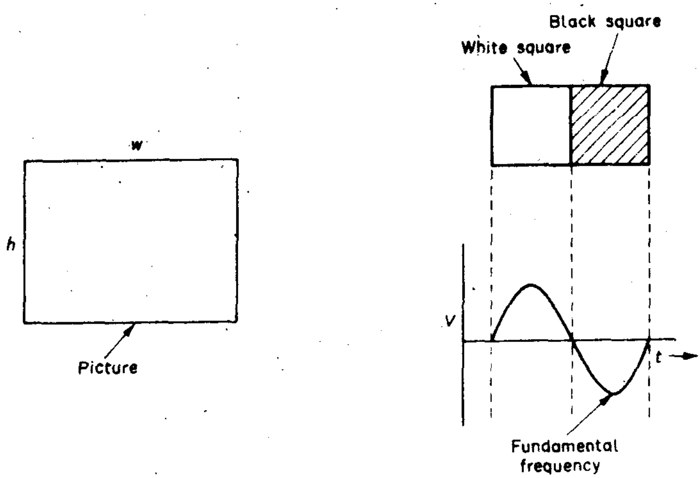


Fig. 7

Let the picture width be w and height h. Hence

$$w/h = \tfrac{4}{3} \quad \text{or} \quad h = 3w/4$$

Since the picture has 625 lines, the distance between lines is given by

$$h/625 = 3w/4 \times 625$$

For equal horizontal and vertical resolution, the width of picture element is equal to its height, and so equals $3w/4 \times 625$. Hence,

$$\text{number of elements per line} = w/\text{width of picture element} = \tfrac{4}{3} \times 625$$

Now,

$$\text{time to scan a picture element} = \frac{60 \times 10^{-6}}{\tfrac{4}{3} \times 625} = \frac{9 \times 10^{-6}}{125}\ \text{s}$$

or

$$\text{time to scan two picture elements (full cycle)} = \frac{18 \times 10^{-6}}{125} \text{ s}$$

Hence

$$\text{fundamental frequency} = \frac{125 \times 10^{6}}{18} = 7 \text{ MHz}$$

Since the average picture brightness is a d.c. signal, this must also be transmitted, and so the total bandwidth requirement is 0 to 7 MHz, i.e. 7 MHz. Because of this large bandwidth, double sideband television is not used, but a more economical system called vestigial side-band transmission.

(e) Radar signal

The location of distant targets in range and bearing by radar is usually achieved by transmitting a short periodic signal and receiving back some of the reflected signal from the target. This signal is basically a train of rectangular pulses transmitted at a low repetition frequency around 1 kHz and is shown in Fig. 8. The pulse width used varies between 0·1 μs and 10 μs in duration.

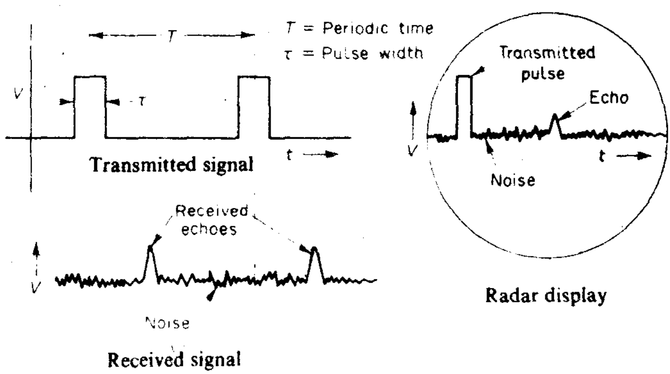


Fig. 8

Such a signal can be shown to consist of an infinite set of sine waves whose frequencies are harmonically related. The bandwidth required to receive such a signal with reasonable certainty, after reflection from a distant target, is about 2 to 5 MHz. A radar signal may also be used for velocity measurements, for example, in measuring the velocity of an aircraft. This is known as Doppler Radar and is described in Appendix F.

EXAMPLE 3

A radar transmitter is modulated at a repetition frequency of 1 kHz and transmits pulses of 4 μs duration. If the average power transmitted is 400 watts, determine (a) the duty ratio, (b) the peak power and (c) the minimum and maximum ranges.

Solution

(a) $$\text{duty ratio} = \frac{\text{pulse width}}{\text{periodic time}} = \frac{4 \times 10^{-6}}{\frac{1}{1000}} = \frac{1}{250}$$

(b) $$\text{average power} = \text{peak power} \times \text{duty ratio}$$

or $$\text{peak power} = \frac{400}{\frac{1}{250}} = 100\text{ kW}$$

(c) Electromagnetic energy travels at the velocity of 3×10^8 m/s.

Hence, $$\text{distance travelled in } 1\ \mu\text{s} = 3 \times 10^8 \times 10^{-6} = 300 \text{ metres}$$

The minimum distance is determined by the minimum time the signal takes to travel to the target and back again. This must not be less than the pulse duration or else the reflected signal will be confused with the transmitted signal which is only turned off after 4 μs.

Hence $$\text{minimum time to target} = \tfrac{4}{2}\ \mu\text{s} = 2\ \mu\text{s}$$

or $$\text{minimum distance to target} = 2 \times 300 = 600\text{ m}$$

The maximum range is determined by the maximum time taken to the target and back again. This must be just equal to the time between the first and second pulses or else, the reflected pulse will be confused with the second transmitted pulse.

Hence,

$$\text{maximum time to target} = \frac{\text{periodic time}}{2} = \frac{1}{2000} \doteq 500\ \mu\text{s}$$

or $$\text{maximum distance to target} = 500 \times 300 = 150\text{ km}$$

1.3 Spectrum of a signal

Signals can be analysed by Fourier techniques[12] into various frequency components. The total range of these frequencies represents the frequency spectrum of the signal and is of prime importance in telecommunications. An exact knowledge of such a spectrum is useful in solving problems of transmission and reception.

A signal may thus be represented in the 'time domain' as a plot of instantaneous amplitude against time or in the 'frequency domain' as a plot of its spectral component amplitudes against frequency. There is a direct link between these two representations which is obtained with the aid of Fourier techniques.

It should be noted that there are two kinds of spectra called the discrete spectrum and the continuous spectrum; these are discussed in detail in the next Chapter.