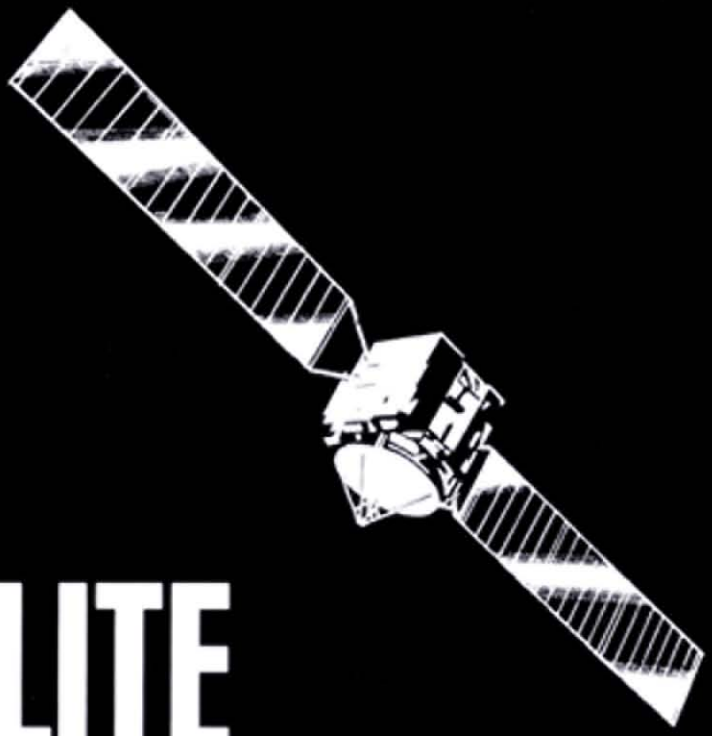
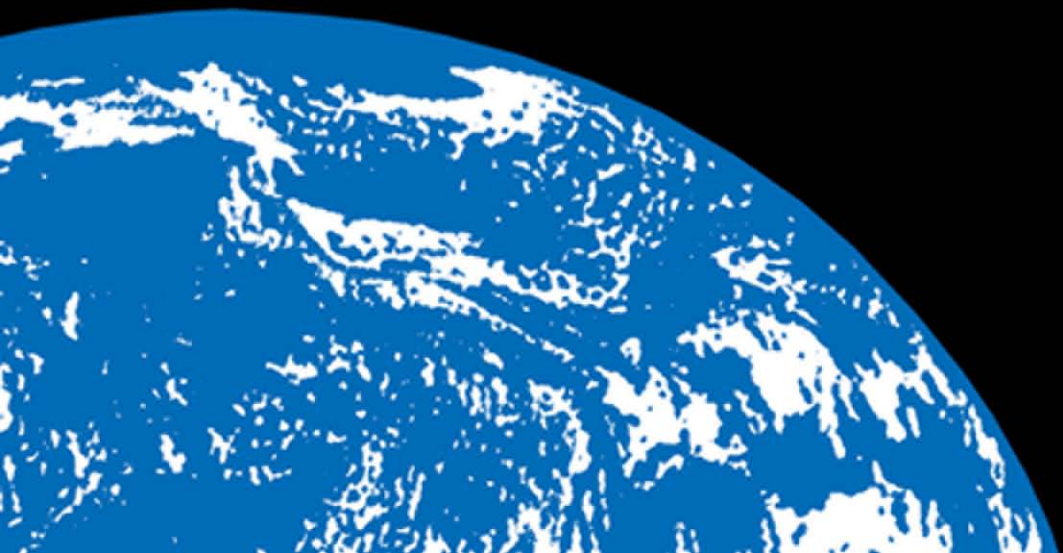


# SATELLITE COMMUNICATIONS:

## PRINCIPLES & APPLICATIONS

DAVID CALCUTT & LAURIE TETLEY



# Satellite Communications

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# Satellite Communications: Principles and Applications

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# Preface

The advent of the satellite has revolutionized telecommunications by allowing, as it does, links to be established within the area covered by the satellite footprint (which for global coverage is typically over 40% of the surface of the earth). The satellite is particularly useful for establishing a link between areas which would be inaccessible, or at least difficult to access, by other means. The use of satellites however has brought with it new problems, such as: designing the communications sub-system to meet the requirements of the system; designing a structure which contains the communications and support sub-systems, which can be launched into the geo-stationary orbit; providing a control system which, among other things, allows the maintenance of station-keeping within fine limits for satisfactory operation.

There are constraints on the ability of the satellite to handle the traffic required by the system operators and the capacity of the satellite may be limited by the available power on the satellite or the bandwidth available for the service. Notwithstanding the problems, the communications satellite is providing the user with an effective means of transmission of telephony, video and data and is reaching a wider market than ever before. One of the factors which has brought satellite communications to the wider market has been the dramatic technological developments in the receiver noise figure at the frequencies used and this, together with high gain, means a ground station can be made available at a fraction of the cost of earlier systems. This is particularly true of stations designed to receive television signals by satellite, either directly in an individual home or by a cable network, making the system affordable by a single household.

In designing this book the authors have tried to set out the principles involved in satellite communications and to show, with reference to particular systems, how the principles are effected in practice. Because our aim is to show the communications aspect of the use of satellites, information on the launching of satellites, and the design problems associated with ensuring the structure can be accommodated within the launch vehicle, has been kept to a minimum.

The book is divided into three sections. Section one provides the principles of satellite communications and includes link parameters, multiple access techniques, modulation/demodulation methods, coding etc, and looks at earth stations and satellites in some detail. Section two looks at communications with mobile earth stations and deals with the Inmarsat systems, because of their important marine applications.

The various Inmarsat systems are explained together with details of the ground and space segments required to support the service. Other mobile earth station systems are mentioned briefly in Section three, although this section is designed to deal predominantly with the fixed satellite service and gives details of the Intelsat and Eutelsat systems, including the ground and space segment provision and information on services. Finally, a list of abbreviations is provided which gives details of all those curious acronyms and buzzwords which abound in the jargon of satellite communications.

There are a multitude of satellite networks currently in orbit operated by various

nations of the world. Because the principles are common to all communication satellites, Section one of this book could be applicable to many of the networks not mentioned by name. Omission of a particular network is not an indication of the relative merit of that network but simply an indication of the constraints on the size of this book. Named networks in Sections two and three have been arbitrarily chosen to give an indication of the application, for those systems, of the principles outlined in Section one.

The intention of the book is to explain in clear and simple terms the principles and practice of satellite communications at a level that makes it suitable for students undertaking courses at undergraduate level in this specialization, for those who simply have an interest in the topic, and for practising engineers who could use the book as a reference text.

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The Inmarsat quarterly magazine *Ocean Voice*.
The Intelsat Organization.

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# Contents

# Abbreviations used in the text

| | |
|---|---|
| A/D | Analogue-to-digital signal conversion |
| ADE | Above decks equipment |
| ADM | Adaptive delta modulation |
| ADPCM | Adaptive differential pulse code modulation |
| AFC | Automatic frequency control |
| AFTN | Aeronautical fixed telecommunications network |
| AM | Amplitude modulation |
| AOR | Atlantic Ocean Region |
| AORE | Atlantic Ocean Region East |
| AORW | Atlantic Ocean Region West |
| APC | Adaptive predictive coding |
| APK | Amplitude phase keying |
| ARQ | Automatic request repeat |
| ASK | Amplitude shift keying |
| BDE | Below decks equipment |
| BER | Bit error rate |
| BPSK | Bipolar phase shift keying |
| C/N | Carrier-to-noise ratio |
| $C/N_o$ | Carrier-to-noise density ratio |
| $C/IM_o$ | Carrier-to-intermodulation noise density ratio |
| C/I | Carrier-to-interference power ratio |
| CBT | Carrier and bit timing |
| CCC | Intelsat Control Co-ordination Centre |
| CCIR | International Radio Consultative Committee |
| CCITT | International Telegraph and Telephone Consultative Committee |
| CCS | Command Co-ordination System |
| CDMA | Code division multiple access |
| CEPT | European Conference of Postal and Telecommunications Administrations |
| CES | Coast earth station |
| Codec | Coder/decoder |
| COMSAT | Communications Satellite Corporation |
| COSPAS | Cosmicheskaya Sistyeme Poiska Avariynich Sudov |
| COSPAS-SARSAT | International satellite based emergency alerting and locating system |
| CSC | Communications system control |
| CSC | Common Signalling Channel |
| CSM | Communication system monitoring |
| CW | Continuous wave |
| D/A | Digital-to-analogue signal conversion |

| | |
|---|---|
| DAMA | Demand-assigned multiple access |
| dB | Decibel |
| DCE | Data circuit terminating equipment |
| DCME | Digital circuit multiplication equipment |
| DM | Delta modulation |
| DNI | Digitally non-interpolated |
| DPCM | Differential pulse code modulation |
| DS | Direct sequence |
| DSBSC | Double sideband, suppressed carrier |
| DSI | Digital speech interpolation |
| DTE | Data terminal equipment |
| $E_b/N_o$ | Energy per bit/noise density ratio |
| EBU | European Broadcasting Union |
| $E_c/N_o$ | Energy per symbol/noise density ratio |
| EDI | Electronic data interchange |
| EGC | Enhanced group call. Group calling on Inmarsat-C |
| EIRP | Effective isotropic radiated power |
| EME | Externally mounted equipment |
| EPC | Electronic power conditioner |
| EPIRB | Emergency position indicating radio beacon |
| ESA | European Space Agency |
| Eutelsat | European telecommunications satellite organization |
| FANS | Future air navigation systems |
| FCC | Federal Communication Commission |
| FDM | Frequency division multiplex |
| FDMA | Frequency division multiple access |
| FEC | Forward error correction |
| FET | Field effect transistor |
| FM | Frequency modulation |
| FSK | Frequency shift keying |
| FSS | Fixed Satellite Service |
| $G/T$ | Receive gain/system noise temperature ratio |
| GaAs | Gallium arsenide |
| GEO | Equatorial geostationary orbit |
| GES | Ground earth station |
| GMDSS | Global Maritime Distress and Safety System |
| GNS | Global Network Service |
| HF | High frequency |
| HPA | High-power amplifier |
| HSD | High-speed data |
| IBS | Intelsat Business Service |
| ICAO | International civil aviation organization |
| IDR | Intermediate digital rate |
| IESS | Intelsat Earth Station Standards |
| IF | Intermediate frequency |
| IM | Intermodulation |
| IMBE | Improved multi-band excitation |
| IMN | Inmarsat MES identification number |
| IMO | International Maritime Organization |
| Inmarsat | International maritime satellite organization |
| Intelsat | International telecommunications satellite consortium |

| | |
|---|---|
| IOR | Indian Ocean Region |
| ISDN | Integrated services digital network |
| ISL | Interstation signalling link |
| ISO | The international organization for standardization |
| ITA | International telegraph alphabet code |
| ITU | International Telecommunications Union |
| LAN | Local area network |
| LES | Land earth station |
| LHCP | Left-hand circular polarization |
| LNA | Low-noise amplifier |
| LO | Local oscillator |
| LRE | Low-rate encoding |
| MAC | Multiplexed analogue components |
| MCPC | Multiple channels per carrier |
| MCS | Maritime communications sub-system |
| MES | Mobile earth station |
| MIC | Microwave integrated circuit |
| MSK | Minimum shift keying |
| MSS | Mobile Satellite Service |
| NBDP | Narrow band direct printing |
| NCC | Network Control Centre |
| NCS | Network co-ordination station |
| O-QPSK | Offset quadrature phase shift keying |
| OCC | Operations Control Centre. Inmarsat |
| PC | Personal computer |
| PCM | Pulse code modulation |
| PFD | Power flux density |
| PLL | Phase-lock loop |
| PM | Phase modulation |
| PN | Pseudo-random noise |
| POR | Pacific Ocean Region |
| PSDPN | Packet switched public data network |
| PSK | Phase shift keying |
| PSTN | Public switched telephone network |
| QPSK | Quadrature phase shift keying |
| RF | Radio frequency |
| RHCP | Right-hand circular polarization |
| S/N | Signal-to-noise ratio |
| SACE | Signalling and access control equipment |
| SAW | Surface acoustic wave |
| SCC | Satellite Control Centre |
| SCPC | Single channel per carrier |
| SCPT | Single carrier per transponder |
| SDMA | Space domain multiple access |
| SES | Societé Europeanne des Satellites |
| SES | Ship earth station |
| SIS | Sound in synchronization |
| SMATV | Satellite master antenna TV |
| SMS | Satellite multiservice system |
| SNG | Satellite news gathering |
| SOLAS | Safety of Life at Sea Convention |

| | |
|---|---|
| SS | Switched satellite |
| SSAM | Single sideband amplitude modulation |
| SSB | Single sideband |
| SSBSC | Single sideband, suppressed carrier |
| SSMA | Spread-spectrum multiple access |
| SSPA | Solid-state power amplifier |
| TDM | Time division multiplex |
| TDMA | Time division multiple access |
| TT&C | Telemetry, tracking and control |
| TTC&M | Telemetry, tracking command and monitoring |
| TVRO | TV receive-only |
| TWTA | Travelling-wave tube amplifier |
| UTC | Co-ordinated universal time |
| UW | Unique word |
| VCO | Voltage controlled oscillator |
| VDU | Video display unit |
| VSAT | Very small aperture terminal |
| WAN | Wide area network |
| WARC | World Administrative Radio Conference |

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# Section One
# COMMUNICATIONS PRINCIPLES APPLICABLE TO SATELLITE OPERATION

## Introduction

Man, by nature, is gregarious and inventive. The ability to communicate has developed with time from the sign language of civilization's dawn to the spoken and written word developed using a multitude of languages across the world. The urge for man to communicate has progressed to the point where communication from one site to another can be achieved using either land links, a terrestrial radio link, a satellite link or a combination of these. The information to be transmitted could be speech, data or video; it is even feasible for machines to 'talk' to each other across vast distances for the benefit of man who utilizes the data.

This section of the book looks in detail at the principles that are applicable to satellite communications. Sections two and three show how the principles are applied in practice to satellite communications by international and regional system operators.

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# 1
# Basic principles

## 1.1 Introduction

Consider the situation where two persons are the only occupants of a large room. They are conversing quietly at one end of the room. A communication link has been established. Suppose one of the occupants moved to the far end of the room leaving the second occupant at the near end; communication would still be possible although both persons would probably need to raise their voices to be heard. There is a limit to the separation distance the two talkers could endure while still being able to make sense of what they heard. Speech causes compression and rarefaction in the air and these perturbations spread out from the speaker, with a very limited range. The range could be increased by converting the speech signal to an electrical signal, by means of a microphone, and transmitting the electrical signal by way of, say, a telephone link utilizing a cable or radio connection between the speakers. Speech is reconstructed at the receiving end by means of a loudspeaker.

Returning to the two conversationalists in the large room, what would be the effect of adding an extra hundred or so people in the room, all of them striking up conversations with near neighbours? Our two conversationalists could probably still converse provided they were close together. If each were constrained to be at opposite ends of the room the likelihood is that neither would hear the other because their speech would be ineffective in the presence of the noise produced by others in the room. The twin requirements of communication over long distance have been established—there is a need to modify the information from its original form to a form that will travel long distances and to do so in the presence of interference of any kind.

The block diagram of Fig. 1.1 is frequently used to represent a communications link.

The function of the transducer is to convert the input data to a form suitable for transmission. An example of a transducer is the telephone, which contains a microphone to convert the compression and rarefaction associated with the air close to a speaker's mouth to an electrical signal containing frequencies in the audio band which

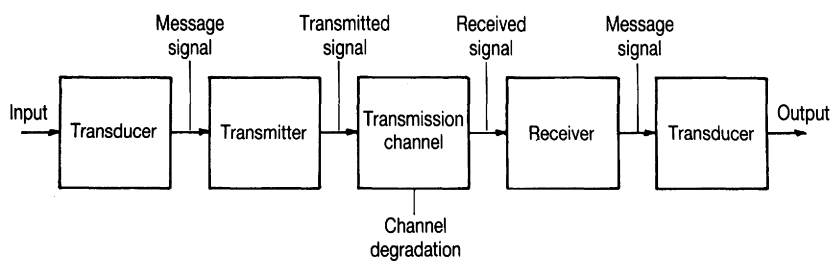


**Fig. 1.1** Block diagram representation of a communications link

ranges from dc up to about 20 kHz. Not all of this frequency band need be used for an audio baseband however, since the range contains many harmonics which could be eliminated without seriously affecting the intelligibility of the speech. Typically, the speech range is from 300 – 3000 Hz. Other transducer inputs may contain other information such as telex, computer data, facsimile, television signals, telemetry, navigational information etc. The message signal could be analogue or digital in form.

Speech is a form of analogue signal containing wide variations in amplitude with time. The output of a teleprinter on the other hand has characters represented by a series of binary digits (bits) which can have a fixed level to represent binary 1 and another to represent binary 0. Speech too can be digitized for transmission and this is becoming the rule for latter-day transmission purposes.

The transmitter converts the input message signal to a form suitable for feeding to the transmission channel. A carrier frequency of a value suitable for transmission is modulated by the transducer output signal. Modulation is a systematic variation of some parameter of the carrier, i.e. its amplitude, frequency or phase, according to a function of the input message signal.

Why is a carrier used and why is it modulated? Among the reasons are:

- the requirement for transmission over long distances;
- to minimize interference over the channel;
- to enable several transmissions to exist in a single channel (multiplexed signals);
- for channel assignment;
- to overcome equipment limitations.

The transmitter may perform other functions such as filtering, amplification and connection of the output signal to the channel input, which could be a radiating element (antenna).

The channel could be a line link such as that between two telephone subscribers, a radio link such as that between a commercial radio transmitter and a domestic radio receiver or a communications satellite link. In all cases the channel will affect the signal and cause it to be degraded as it continues along its path. The degradation could be noise but there are other forms of interference which may help to distort the required signal.

The function of the receiver is to extract the required signal at the output of the channel and reconvert it, using demodulation, to the original baseband signal. Some amplification may be necessary to restore what could be a very weak signal to a level suitable for demodulation. Since the receiver itself is noisy it is often a delicate matter to restore the signal to a value sufficiently above the noise level. The signal-to-noise (S/N) ratio at the receiver output is often quoted as a means of establishing how well the receiver achieves its purpose.

The output transducer completes the link. Its function is to restore the form of the original input data. This could be a speech signal via a loudspeaker, the printed output of a teleprinter, data input to a computer etc.

This book is mainly concerned with the satellite communications link and all of the chapters and sections that follow will enlarge on the above with particular reference to the requirements of satellite links to fixed and mobile stations.

## 1.2 Why use satellites?

Long distance communications have been established in the past using terrestrial connections such as HF radio links or submarine telephone links. Indeed, long distance telephony cables still operate successfully on transoceanic routes with increased