Optoelectronic Line Transmission

An introduction to fibre optics

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Preface

During the last few years the use of optical fibre has become increasingly popular in both commercial and military environments and although **optoelectronics** is based upon a comparatively simple technology, it is nevertheless essential for today's engineers to be aware of the basic fundamentals and capabilities of this modern technique.

In order to understand new electronic engineering principles, however, it is usually necessary for the student to have a thorough technical foundation and for the author to explain mathematical theories and progressively develop formulae etc. to enable the reader to continue his studies with a complete understanding of the fundamentals surrounding this new technology.

Although an understanding of the mathematical principles applicable to optoelectronics is of course very necessary, it is the aim of this book to provide a basic introduction as well as a background reference manual to fibre optic transmission for practising electronic and telecommunications engineers, technicians and students who would like to get to grips with this new area of communications technology.

Acknowledgements

I would like to thank my wife Claire for giving me the inspiration to work for a degree with the Pacific Western University. This resulted in a thesis which became the basis of this book. I would like also to acknowledge the help given to me by the Editor of *Electronic Technology* (Mr I. R. G. Channing) and pay a special thank you to Carol Crossfield for so painstakingly proofreading the manuscript, supplying many helpful comments but most of all, for saying that she would even have a copy when it was printed!

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Introduction

BACKGROUND

For over a century, telegraph and telephone systems have been interconnected via copper cables and radio links and these have formed the basis of all suburban, urban and national telecommunication networks.

Although line transmission technology has improved over the years, it was not until the last decade or so when revolutionary innovations caused by the development of **semiconductors, digitalisation** and **optoelectronics,** dramatically altered the method, technology and cost effectiveness of communication systems.

Of course, the transmission of information by visual means is not an entirely new concept, as man has been sending messages optically for centuries. For instance, in the sixth century BC, Aeschylus used a long chain of bonfires from Asia minor to Argos to pass on the news of Troy's downfall. In the second century BC, Polybius developed a two digit, five level code by which the whole of the Greek alphabet could be transmitted [1].

It is perhaps interesting to note that it is this last method that is generally recognised as being the first example of **optoelectronic signalling.**

The Chinese, when threatened by the Tartars, lit signal fires along the boarders of their empire, increasing brightness by artificial means to penetrate fog and rain. Gengis Khan (1115–1227) controlled and checked his horsemen by flag telegraphy. There are many examples from this particular period.

During the next few decades a number of experiments were carried out utilising various other visual methods. For example, in 1633 the Marquis of Worcester developed long distance communication systems using black and white signs, and in the papers of John Norris of Hughenden Manor in Buckinghamshire [2], there is an enigmatic comment: '3 June 1778. Did this day Heliograph Intelligence from Dr Franklin in Paris to Wycombe'. Norris built a 30 m tower on a hill at Camberley, Surrey, from the top of which he used to signal and place bets by heliograph with Lord le Despencer at West Wycombe.

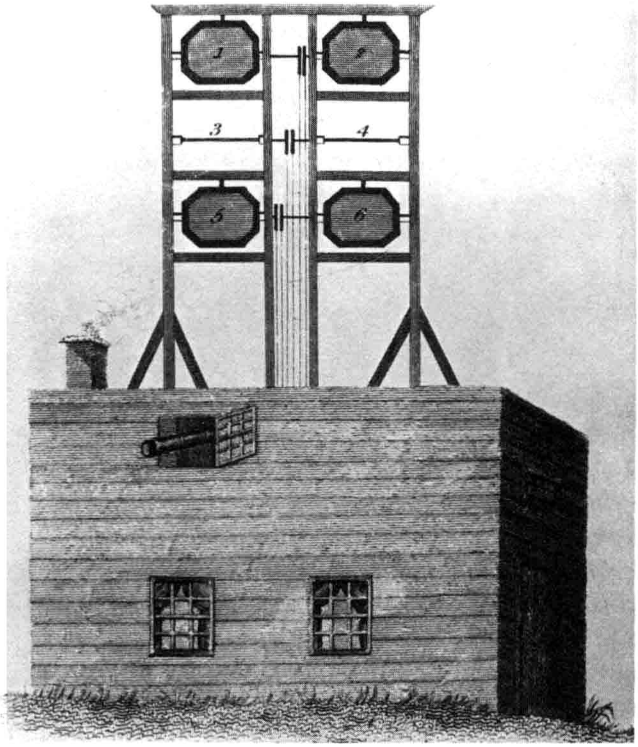
Turning the pages of history once again, it was in 1795 that Lord George Murray was commissioned to supervise the installation of a chain of shutter stations stretching from Plymouth to London [2].

These stations formed the Admiralty Shutter Telegraph system (Figure 1.1) and consisted of six, 3-foot square shutters in a frame measuring 30 foot by 20 foot.

By careful positioning of the shutters, a total of 63 changes were possible: sufficient to cater for the whole of the alphabet, the ten numerals, as well as a number of selected phrases.

The stations were normally manned by three civilians (one to operate the shutters, the other two to act as telescope observers) and it is recorded [3] that an average message passed from London to Portsmouth in fifteen minutes whereas a pre-arranged signal could be communicated between London and Portsmouth and acknowledged back in two minutes and between London and Plymouth, via the Blandford Racecourse station, in three minutes.

Across the channel and a few years previous to the Admiralty scheme (i.e. 1792), Claude Chappé had succeeded in passing a message between Paris and Strasburg (a distance of over 400 km) using movable signal elements. Chappé's device (the T-type telegraph – Figure 1.2) consisted of two side wings mounted at right angles to a main wing that was positioned at the top of a mast. By changing the position of the main wing with respect to the mast, varying the attitude of the side wings to the main wing by 45 degree steps, 196 different and easily distinguishable signals could be given. These signals were



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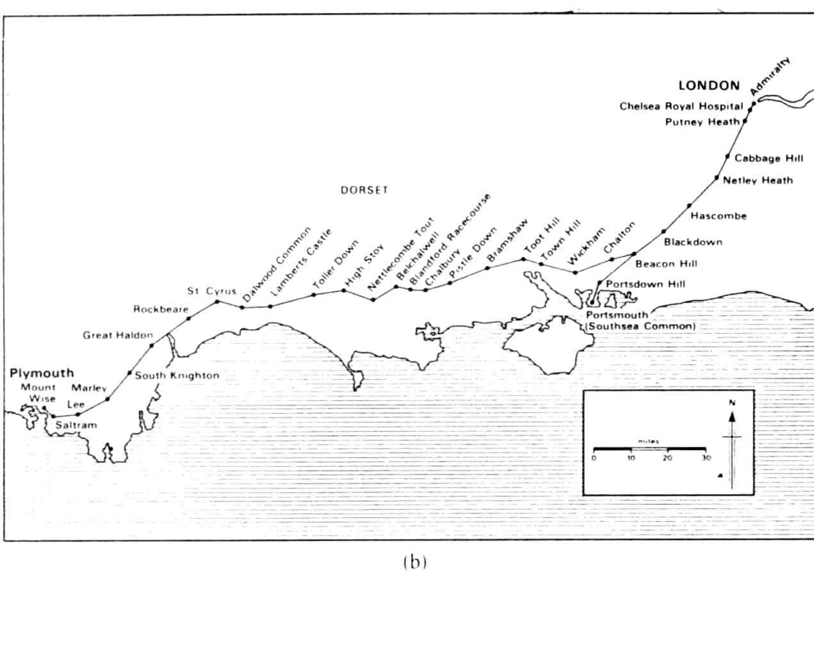


(b)

Figure 1.1
The Admiralty shutter telegraph system (a) artist's impression of a relay station (courtesy of Royal Signals Museum, Blandford) (b) map showing relay station sites between Plymouth and London

Figure 1.2
The Chappé radiated telegraph, near Waterloo (courtesy of Royal Signals Museum, Blandford)

observed from nearby stations using telescopes and then passed on to the next relay station in a similar manner [4].

Napoleon, who quickly recognised the importance of optical signalling, established telegraph stations in the countries in which he was campaigning and equipped his armies with optical telegraph equipment (**telegraph ambutantes**), similar to Col John Macdonald's **Anthropological Telegraph** illustrated in Figure 1.3.

In Prussia, General Freiherr von Muffling carried out a number of trials during the period 1819 to 1830 utilising optical telegraph systems. The success of these studies led to the construction of the first telegraph line between Berlin and Potsdam. During this time various **heliograph** and **signal lamp systems** were also developed enabling signalling over distances of around 100 kilometres.

Although heliograph communications were, by that

Figure 1.3
Colonel John Macdonald's Anthropological Telegraph (courtesy of Royal Signals Museum, Blandford)

time, well advanced it is interesting to note that Henry Coxwell, aware that heliography could only be used on cloudless days, developed **balloon signalling** in the 1850s [5].

Figure 1.4 represents Coxwell's method of adapting semaphore arms of various shapes and symbols to convey, according to preconcerted arrangement, any required information to those on the ground.

A few years later (1870) John Tyndall gave a presentation to the Royal Society showing that light would follow a curved jet of water [4] [6]. But it was not until the 1880s that Graham Bell (in conjunction with Sununer Tainter) successfully modulated a beam of sunlight using a diaphragm mirror [7]. The action of the **photophone** is very simple (Figure 1.5a). Rays of sunlight (or powerful light source) are reflected by a flat mirror (h) into a system of lenses (a and b) that form a beam of light onto a silver coated glass plate (H). A person speaking into the mouthpiece of the transmitter (see also Figure 1.5b) causes the silver coated plate to vibrate which in turn causes the reflecting surface of the plate to change shape. This effects the strength of the light rays which are compressed by a second set of lenses (c) and then reflected to the receiver.

At the distinct end (see also Figure 1.5c) the light rays are received by a silver-coated copper parabolic reflecting mirror (P), and by using a sensitive selenium-photoresistor (S) (comprising a cylinder of copper plates, separated by strips of mica and filled with selenium – whose resistance varies according to the quantity of light that strikes it) connected to a battery and a telephone instrument (t), the system is able to reproduce the speaker's voice.

All of these methods were of course affected by the visual transparency of the medium through which they were being propagated (ie, air) and fog, rain, storms, cloud and snow were some of the problems to be contended with.

In an attempt to overcome these problems, the possibil-

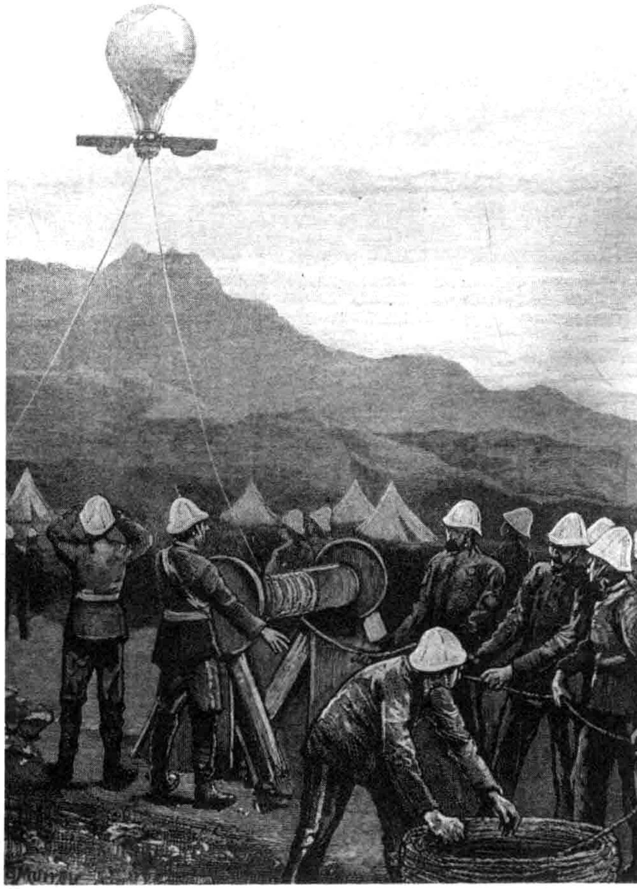
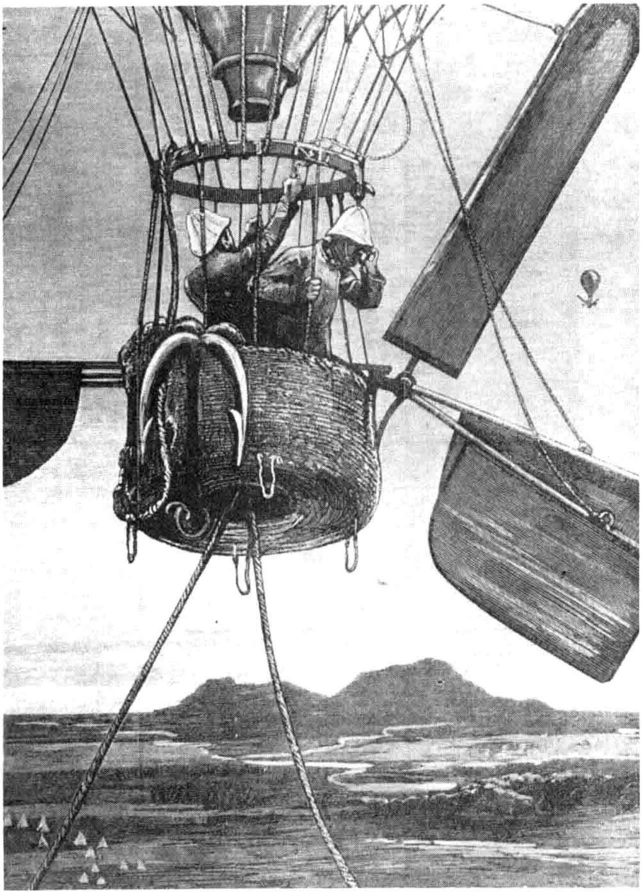


Figure 1.4 Henry Coxwell's balloon signalling (from engravings published in the *London Illustrated News*, 8 October 1879 – courtesy Royal Signals Museum, Blandford)

ity of using a **dielectric rod** as a **waveguide** was studied during the early 1900s. Although a paper was written about it in 1910, it was not until 1966 that Charles Kao and George Hockham (two scientists working for Standard Telecommunications Laboratories in Harlow) patented the principle of information transmission though a transparent dielectric medium, (ie, glass fibre). It was from these patents that the use of glass fibres actually became a viable proposition.

Since the development of **optical fibres**, which in most

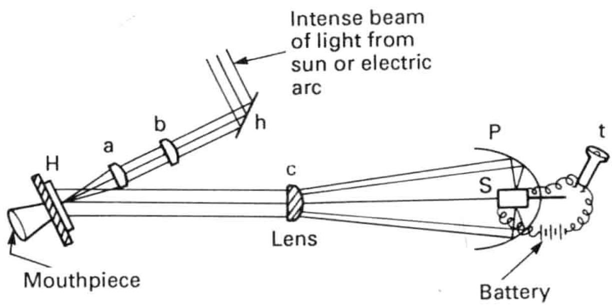


cases are no thicker than a human hair (Plate 1.1), more and more communication systems are now using fibres to pass optical signals over long distances with very little loss. (Compared to the losses experienced by electrical signals over copper lines.) Following the development of **laser diodes**, the use of optoelectronics has now become the *preferred* method for cable communication.

Basic principles of optical line transmission

Some **crystals**, for example **Gallium Arsenide** (GaAs) emit light at a wavelength very close to visible light when an

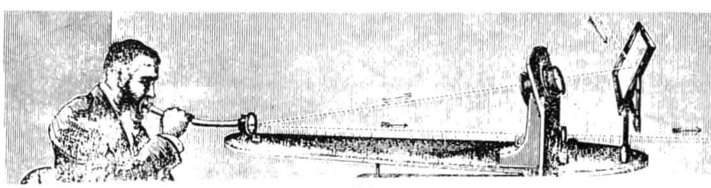
Figure 1.5
Bell and Tainter's photophone (a) component parts (b) the transmitter (c) the receiver (extracted from *Victorian Inventions* by Leonardo de Vries)



Key:

h – Flat mirror
b – Lens
a – Alum cell lens to cut off heat rays
c – Compression lens
H – Very thin mirror
P – Parabolic reflector
S – Selenium photoresistor
t – Telephone earpiece

(a)



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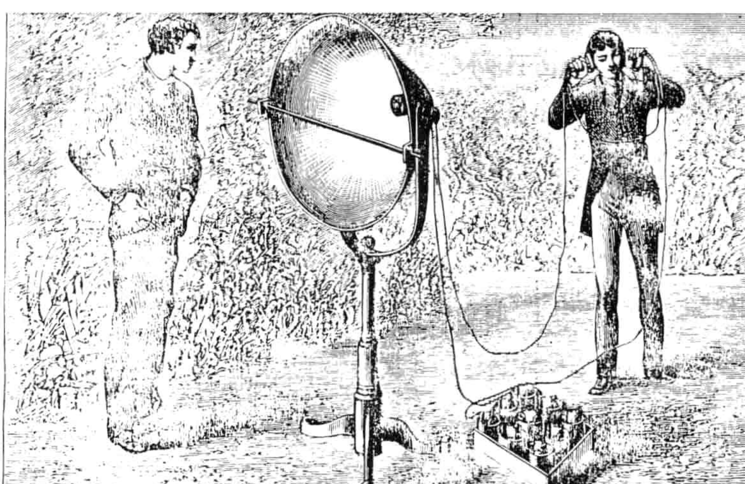

The photophone of Bell and Tainter: the receiver (1881)

(c)

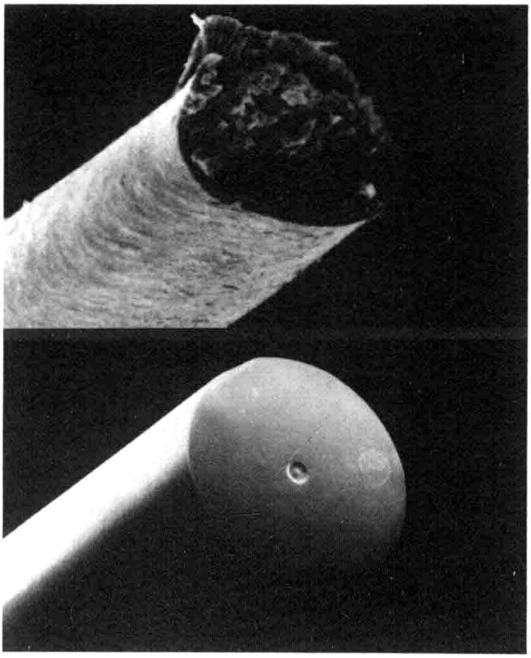

Plate 1.1
A human hair (top) and an optical fibre (bottom) (courtesy Siemens Aktiengesellschaft)

electric current is passed through them. Figure 1.6 shows the frequency and wavelength of common signalling methods as an electromagnetic spectrum.

This light emission is produced by the release of energy (**photons**) from the atoms of a material and is caused when the atoms are excited by heat, chemical reaction or some other means. Utilising this principle it is possible to communicate (for example by telephone) over an optical link, as shown in Figure 1.7.

The microphone in the telephone set converts speech, (ie, sound waves), into electrical energy. A **multiplexer** is used to combine this with other similar **information channels** together to form an **information group**. This is **coded** (if required) and amplified prior to being converted into light signals by an **optoelectric crystal transducer** (usually a light emitting diode or laser diode) and transmitted over an optical fibre waveguide. This fibre, of approximately 0.1 mm in diameter, is drawn from high

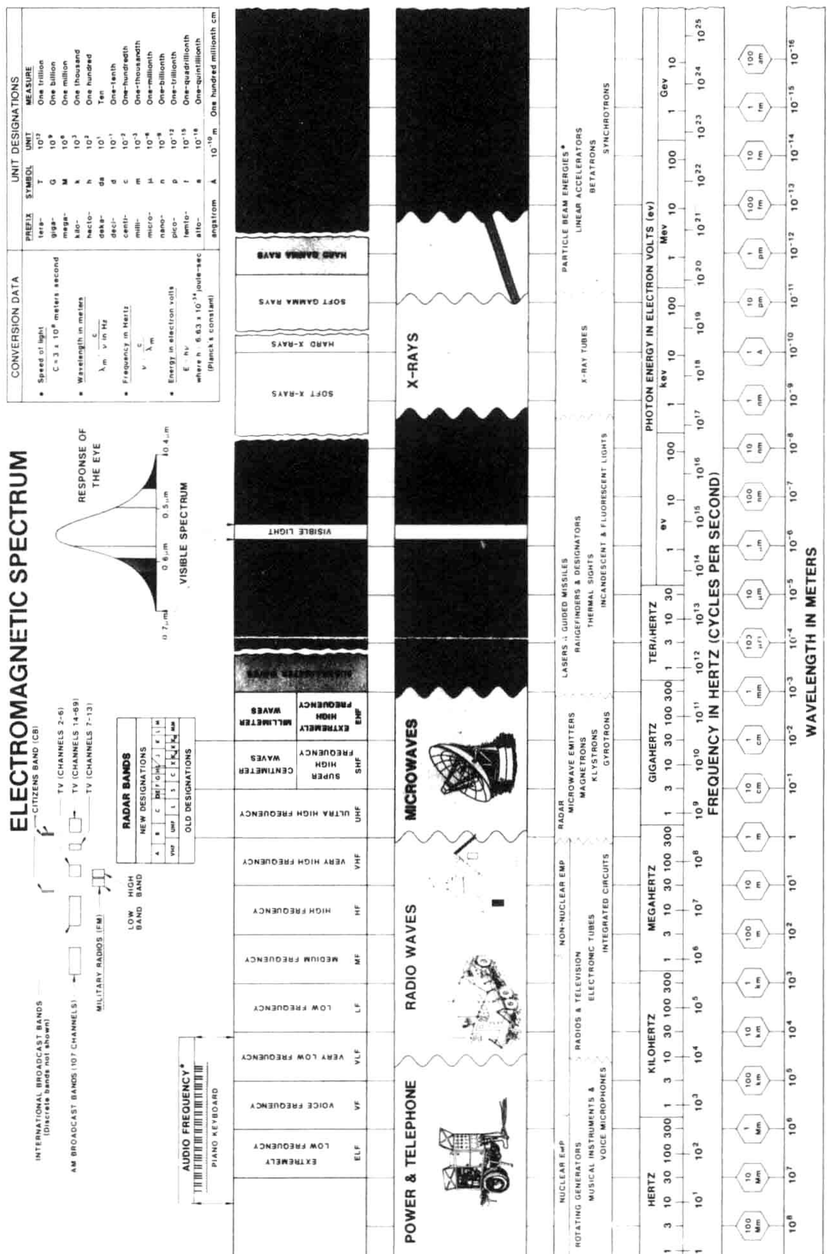

Figure 1.6 Electromagnetic spectrum, showing wavelengths and frequencies of common signals methods courtesy of BDM International Inco