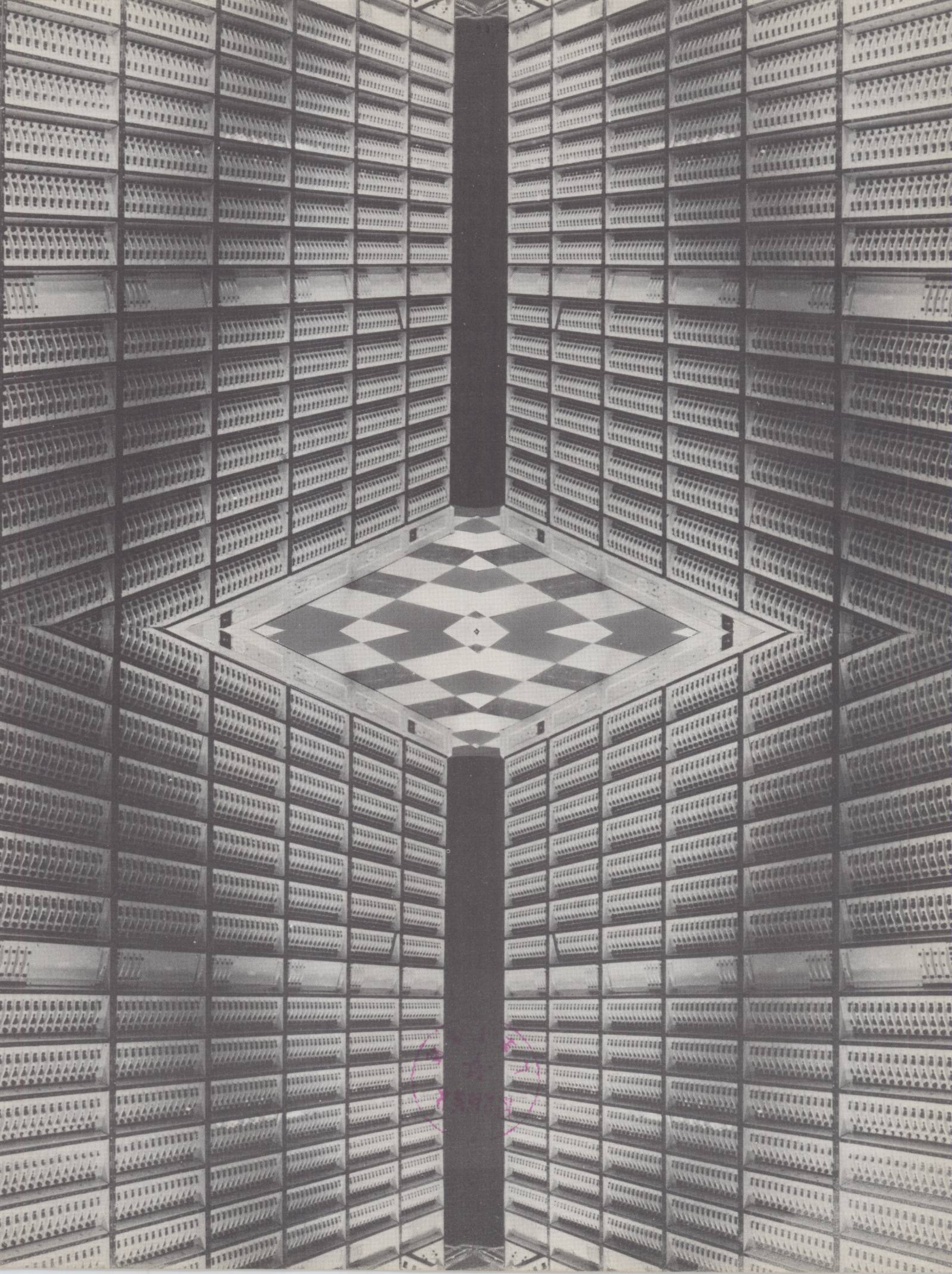
MULTICHANNEL COMMUNICATION SYSTEMS & WHITE NOISE TESTING

M. J. TANT B.Sc.(Eng) A.C.G.I.

MULTICHANNEL COMMUNICATION SYSTEMS & WHITE NOISE TESTING M. J. TANT B.Sc.(Eng) A.C.G.I.



Multichannel Communication Systems and White Noise Testing

M. J. Tant, B.Sc.(Eng.), A.C.G.I.

Further copies are obtainable at £2 from Publicity Department, Marconi Instruments Limited, St. Albans, Herts. AL4 0JN.

First Printing, July 1974.

Printed in England by White Crescent Press Limited, Luton.

Contents

Introduction

THE transmission of telephone channels by assembly into multichannel basebands using frequency division multiplex (f.d.m.) was first achieved commercially in 1918. At that time there were less than 20 million telephones. Now there are in excess of 300 million. The fast rate of expansion particularly in international traffic has necessitated the establishment of recommendations to ensure system compatibility and acceptable levels of quality. The quality of transmission is principally a function of the interference noise generated by the system within the particular telephone channel and noise performance objectives are an essential part of the system recommendations. Evaluation of system noise performance by loading the baseband with white noise to simulate the telephone traffic was first demonstrated in 1955. Since then the practice of white noise testing has been universally accepted as an indispensable part of research, development, production, commissioning and maintenance of multichannel f.d.m. systems.

This booklet has been produced as an aid to the 'student' of multichannel technology in that it summarizes the history of f.d.m. and describes briefly the various current transmission techniques both in cable and radio systems. The somewhat bewildering quantity of different measuring units encountered in today's telephone industry are also defined. For the practising telephone engineer the latter half of the booklet includes, in summary form, the currently published noise objectives for multichannel systems together with past and present recommendations for white noise testing. The accuracy of noise power ratio measurement is affected by a relatively large number of different factors which are quantified. Charts and tables are included to enable the engineer involved in white noise loading to apply measurement corrections where maximum accuracy is required.

Section 1 Multichannel telephony systems using frequency division multiplex

1.1 Brief history of frequency division multiplex telephony

One hundred years ago there were no telephones. Today the telephone is an essential part of most people's lives throughout the world. Since Alexander Graham Bell's remarkable invention in 1876, the telephone has become a vital and indispensable part of economic and social progress. By 1920 there were about 20 million telephones throughout the world and during 1972 the total exceeded 300 million. The last ten years have seen the number of telephones double and expansion may be expected to continue at a rate in excess of 6% per annum; a rate which has been exceeded every year since World War II. Such a level of expansion could never have been achieved without the ability to transmit more than one telephone channel simultaneously over a wire, cable or radio carrier. This multichannel capability is achieved using a process known as multiplexing.

The first practical telephone circuits, however, consisted of a single grounded wire with a telephone connected at either end. This very limited arrangement was superseded in 1878 by the first local exchange (switching office) enabling several telephones to be connected via a switchboard. The service was soon extended by connecting local exchanges together and later long distance trunks were established between the main exchanges of each region (trunk exchanges or toll offices). Grounded wire circuits were extremely susceptible to interference and by 1900 they had mostly been replaced by two wire systems where one wire provided the current return path. Putting the wire pairs into cables served to remove some of the considerable number of lines from view but the problem of having to enlarge the outside wire equipment to satisfy increasing demand for more circuits still remained. A method of increasing the channel capacity without having to add thousands of miles more of wire was sorely needed.

Experiments had taken place in the late nineteenth century into multiplexing systems but the development of successful systems had to await the beginnings of electronics in the early 1900's. The first commercial multiplex system is believed to have been in the USA where a four two-way channel open-wire system started operation in 1918 between Baltimore and Pittsburgh. Channel separation was by frequency division; a multiplexing technique described further in section 2. Prior to World War II most development was towards increased efficiency of multiplex systems on open wire and multipair cables since it was these two forms of line which provided almost all of the telephone circuits. The bandwidth limitations of these lines limited multiplexing to about 24 channels.

Soon after World War II wideband transmission mediums started coming into service. These had capacities of several hundreds of channels and were transmitted either over coaxial cable or microwave radio. For example, the Bell L1 cable system with a capacity of 600 channels was operating coast to coast in the USA by about 1948. The TD-2 microwave radio system, also of 600 telephone channels capacity per radio channel, commenced operation in 1950. Currently, coaxial systems providing up to 2700 channels are common. 10 800 channel (60 MHz) cables are coming into service and systems in excess of 20 000 channels (150 MHz) are under development. Microwave radio is common up to 1860 channels using both terrestrial links and communications satellites and some 2700 channel systems are in service.

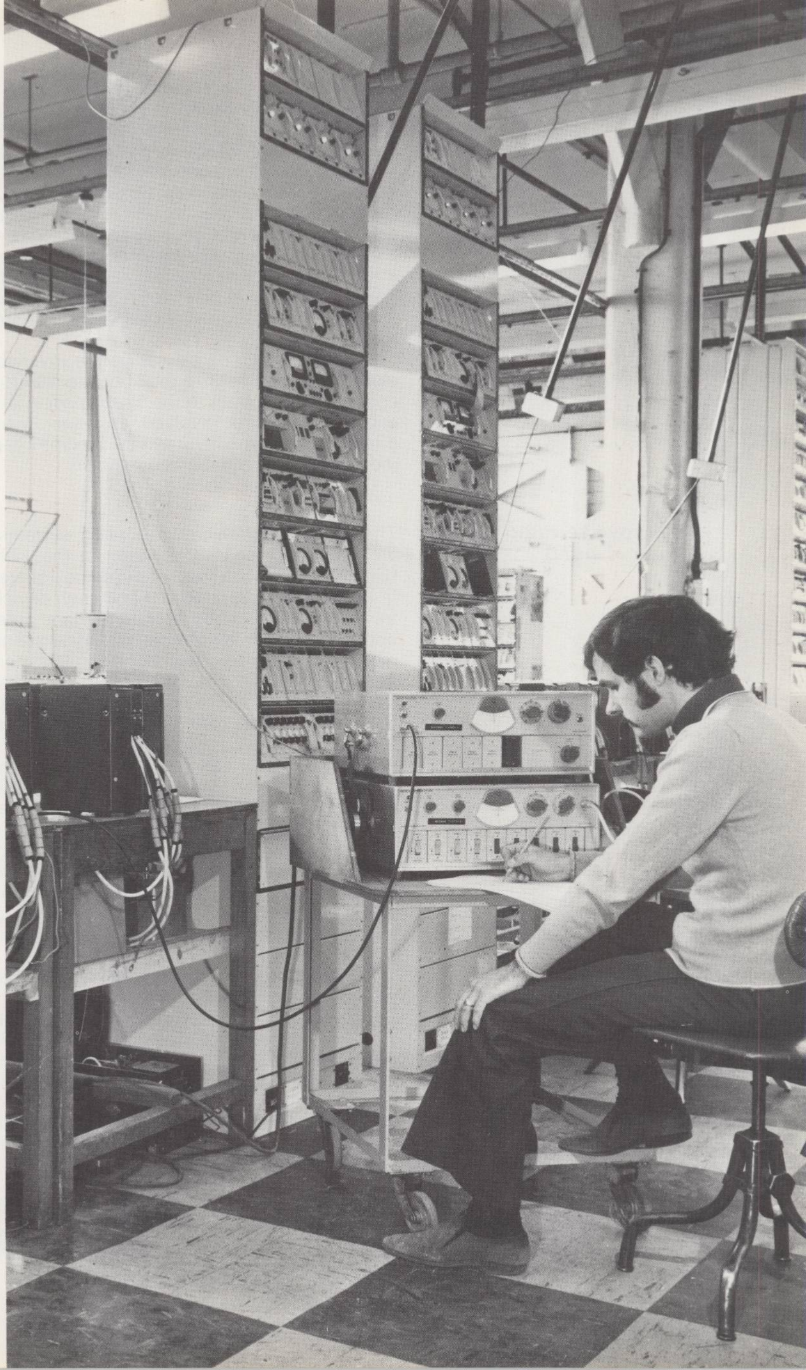
1.2 Low capacity systems

The wideband transmission media of coaxial cable and microwave radio have now largely replaced the open wire and cable pair systems previously used in trunk circuits. There are, however, still many low capacity systems in use, principally in areas of low population density and for connection between local exchanges. Where the number of subscribers exceeds the open wires available and party lines are not desirable it may sometimes be more economic to add a multiplex facility than to erect further lines. Such systems variously called 'station' or 'subscriber' carrier may vary from providing one additional two way channel up to a maximum of twelve. Repeaters may be spaced typically at 1 to 3 mile intervals. Prior to the general use of multiplex systems many circuits were carried in multipair cables. These consisted of as many as 96 twisted pairs within one cable sheath. Dependent upon the quality of cable these can now handle up to 120 channels per pair with repeaters every 3 to 6 miles. Opposite directions of transmission are usually accommodated in separate cable sheaths. Such cables are frequently used between local exchanges and from local to trunk exchanges.

1.3 Coaxial cable systems

Many low capacity systems made use of existing open wire or multipair cable lines. However, the upper frequency limits with reasonable frequency equalization and repeater spacing are about 150 kHz and 600 kHz respectively. To develop systems with greater capacity required wider bandwidths than were available on existing lines. The early coaxial cables with a bandwidth of 1,3 MHz provided 300 channels. The Bell L1 system of 600 channels was operational by 1948 (see section 1.1) and 12 MHz systems (2700 channels) are now in common use.

Coaxial cables are sometimes laid singly and sometimes combined into a single protective sheath. For example, in the USA Bell have recently completed an L4 transcontinental system of 17,5 MHz bandwidth, (3600 channels per cable or 'tube') where 20 'tubes' are combined in one protective cable sheath. This gives a total capacity of 32 400 channels in each direction plus two 'tubes' as standby. The Bell L5 system (50 MHz) has 9000 channels per tube and 22 tubes per cable sheath. This system therefore provides 90 000 two-way tele-



12 MHz
coaxial cable terminals and
line repeaters undergoing final
systems test before installation.

Photograph by courtesy of GEC Telecommunications Limited.

phone circuits plus standby. In Europe 60 MHz systems of 10 800 channels capacity are currently being installed. The British Post Office system provides up to 18 tubes in the one sheath giving 86 400 two-way telephone circuits plus standby.

Since the attenuation of cables per unit length increases with frequency and with reduction in cable size, the high capacity systems require very closely spaced repeaters and extensive frequency equalization. For example, using larger cables (2,6/9,5 mm)*, repeaters are typically spaced at 1 mile intervals on 60 MHz systems and 3 miles on 12 MHz systems. This increases to 6 miles for 4 MHz systems and 12 miles for 1,3 MHz systems. Smaller cable (1,2/4,4 mm)* requires closer repeater spacing.

High capacity coaxial cables are invariably used between close centres of high population density but the installation cost is high due both to the close spacing of repeaters and the cable laying costs involved. However, where the terrain is difficult and particularly where medium capacity is required radio systems find more frequent use.

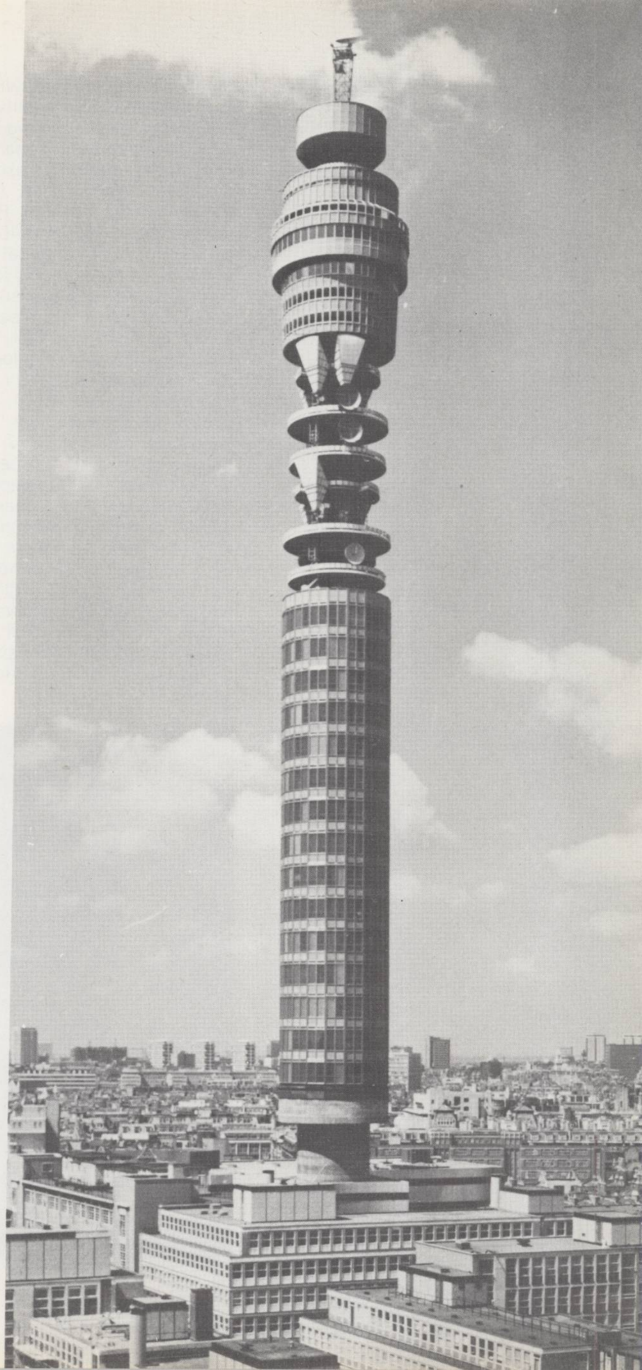
1.4 Microwave radio systems (line of sight)

The demand for microwave radio systems has steadily increased since their introduction in the 1940's. Much of the technology for microwave radio came from rapid developments in radar during World War II and such devices as the klystron, travelling wave tubes and high gain antennas were soon applied to wideband commercial systems. Such systems quickly became the 'backbone' of telephone and TV distribution systems in many nations. In the USA, for example, the Bell TD-2 system with a capacity of 600 telephone channels or one video channel per r.f. channel was first placed in service in September 1950 between New York and Chicago. By 1962, a national network had been established which carried about 90% of all inter-city video circuits and 40% of all long distance telephone circuits. Until recently, telephone companies were the most common commercial users of microwave for long distance voice, video and data transmission networks. Now, however, more and more industries are beginning to use microwave transmission for their own communication networks. These include railways, utilities such as oil, gas and electricity and more recently private business (where national regulations permit).

The baseband of a microwave link consists essentially of a number of multiplexed telephone channels or video or data. Capacities vary up to 1860 telephone channels with some 2700 channel systems. Capacities of 600, 960, 1260 and 1860 channels are common. Baseband layouts are discussed further in section 2. The baseband frequency modulates an i.f. carrier (usually 70 MHz) which is then translated to the transmission frequency. Present bands allocated to fixed microwave links are in the range from 2 GHz to 12 GHz with much traffic in the 2, 4 and 6 GHz bands.

The use of high gain parabolic or horn antennas allows 'line of sight' repeater spacing typically between 20 and 30 miles with a transmitted power in the region of 1 W. Where repeaters are situated at telephone circuit interconnection

**These dimensions are for the outside diameter of the inner conductor and inside diameter of the outer conductor respectively.*



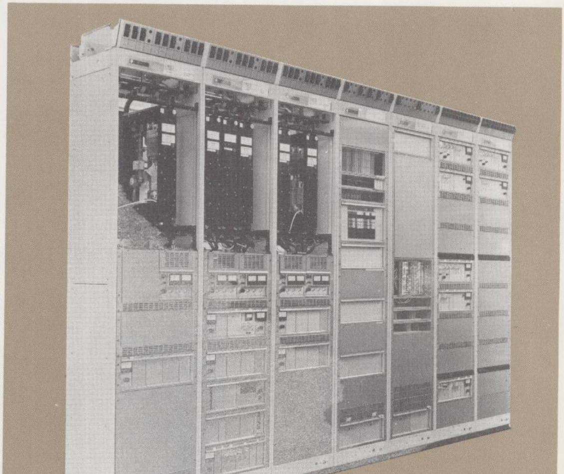
The Post Office Tower, London, showing the
microwave antennae.
By courtesy of the Post Office.

points demodulation down to baseband is required. Otherwise repeaters generally amplify the signal at i.f. although some r.f. repeaters are now coming into service. The signal is then translated to a different r.f. channel from that of the received signal. A common antenna is used for both the transmit and receive directions. Additionally, more than one r.f. carrier may be transmitted or received. RF channels are spaced at intervals ranging from 7 MHz to 40 MHz depending upon such factors as antenna type, channel capacity and r.f. carrier frequency. Three to six r.f. channels for each direction of transmission are common using a single antenna. Some systems accommodate up to 12 r.f. channels in each direction.

For example the Bell TD-2 radio system with interstitial channels allows 6000 telephone circuits in each direction on a single antenna using 10 r.f. channels plus two for protection. The more recent (1961), 6 GHz TH radio system with 1860 telephone channels per r.f. channel provides over 11 000 telephone circuits. TD-3 which came into service in 1968 utilises existing TD-2 repeater locations, antennas and feeders and provides 12 000 telephone channels using a baseband of 1200 channels per r.f. channel.

The increasing demand for microwave link capacity is filling the lower r.f. bands (up to 6 GHz) and more attention is now being given to bands up to 12 GHz. For example Bell TL-1 (1963) and TL-2 (1966) for short haul up to 250 miles with 300 and 600 channels respectively are in the 11 GHz band. It may be however, that the development of domestic and regional communications satellite systems will reduce the rate of expansion of terrestrial microwave in some areas (see section 1.7).

A suite of 960 channel, $116H_3$ radio equipment.
By courtesy of Pye Telecommunications Ltd.



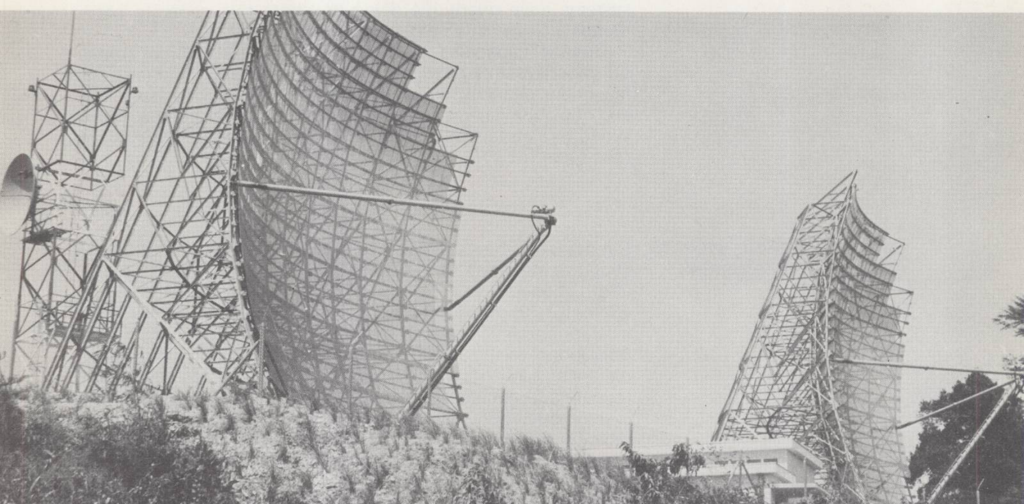
1.5 Tropospheric scatter systems (transhorizon)

Like microwave line of sight systems tropospheric scatter systems became feasible due to the intense development effort applied to microwave devices during World War II. Microwave radio of the type described in the previous section is limited in its single 'hop' range to line of sight or near line of sight*, that is about 20 to 30 miles. Tropospheric scatter systems however rely upon the fact that the troposphere (that region between the earths surface and the stratosphere) scatters microwave signals and a small proportion are deflected back to earth in the forward direction. The combination of high transmitter power, large antenna systems and very sensitive receivers therefore allows transmission well beyond line of sight, hence the term transhorizon. The first practical 'tropo' system was proposed by Bell in 1952. Known as 'Pole vault' it was adopted by the USAF and installed along the east coast of Canada from Newfoundland to Baffin Island. Operation commenced in 1955 and the route consisted of 9 spans giving a total length of 1600 miles. Telephone capacity was 36 channels.

The main applications of tropo are due to its ability to span up to 500 miles without intermediate repeaters. This is of particular advantage where the path lies over inhospitable terrain whether of a geological or political nature. Also, where it is impracticable to lay a submarine cable (see section 1.6), the medium capacity of up to 300 channels of tropo makes it particularly suitable for communications across water. For

Microwave paths do in fact curve slightly by refraction due to the changing density of air with altitude. Their range is therefore slightly in excess of that based upon a straight line path.

The twin 60′ aerials of the Guyana-Trinidad tropo link at Mont Bleu, Trinidad. With a single span distance of 345 miles, the system has a capacity of 72 telephone channels.
Photograph by courtesy of Cable and Wireless Limited.



example, tropo links have been installed along the Aleutian Island chain to Alaska (1400 miles – 9 spans); from North to South Japan thence via Taiwan to the Phillipines; and from Crete to Cyprus (350 miles – 1 span).

Military organisations were quick to see the security advantages of tropo. For example, the Dew Line system across Northern Canada (1958) when connected with the Dew East system (1962) across the North Atlantic forms an early warning chain from UK to Alaska which is over 5000 miles in length. More recently, however, many more commercial as well as military systems have been installed. The 1960's saw sustained expansion in excess of 20% p.a. and by the late 1960's there were well over three million telephone circuit miles of tropo.

Due to the high path loss of this mode of transmission (typically 200 to 250 dB), very high transmitter power is required. This varies from about 200 W for low capacity short range systems (up to about 100 miles) through typical powers of 1 kW to 10 kW. Exceptionally 50 kW or 100 kW may be used for long spans up to 500 miles. Typical spans are however about 150 miles in length. High gain parabolic antennas are used which may vary in diameter between 30 ft and 120 ft and most transmissions are in the 900 MHz and 2 GHz bands though other bands up to 8 GHz exist.

The nature of tropospheric scatter makes it very susceptible to severe fading and diversity transmission/reception is invariably used to maintain adequate quality of service. The main diversity parameters are space, frequency, and angle (of the antenna). In space diversity the receive antennas should be at least 100 wavelengths apart and with frequency diversity at least 1% frequency separation is required. Many systems have quadruple diversity where two separate parameters are diversified e.g. space/frequency.

Channel capacities may be as low as six ('Thin Line' Tropo) but most systems provide up to 132 telephone channels. The maximum capacity presently available is 300 channels. Like line of sight microwave radio tropo may in the future be superseded to a certain extent by communications satellite systems (see section 1.7).

1.6 Submarine cable systems (submerged repeater)

Submarine cables for telegraphy were first developed before even the invention of the telephone.* The much greater bandwidth of telephone transmission prevented the use of telegraph cables for this purpose except over short distances. For example a telephone link between the UK and the Continent became operational in the 1920's. Multichannel capability over longer distances had to await the development of submerged cable repeaters to equalize the cable's frequency characteristics and restore the attenuated signal level. The first repeaters were developed by the British Post Office in 1943 and the first deep water repeater system was laid between Florida and Cuba in 1950 by A.T. & T.

This system utilized separate cables for either direction, each of 24 channel capacity (with 4 kHz spacing). In the same year

**The first successful transatlantic telegraph was laid in 1866.*