COMTROP and Digital Tropospheric Scatter Communications

B. R. Ackroyd, C.Eng, M.I.E.R.E

Summary The new H7500 Drive/receiver equipment has been designed for use in analogue/digital tropospheric scatter radio systems.

This article looks at the basic requirements of a system and the way in which the performance of a link is measured.

The equipment design is presented in some detail, from both a system and a module point of view, and analogue and digital versions are considered.

Introduction

Marconi has been involved in tropospheric scatter communications on a commercial basis since 1960. This involvement followed two years of trials over a 330km link set up in the UK, operating between Chelmsford and Devon, using a carrier frequency of 900MHz.

Since the first commercial routes were established in Korea, and between Trinidad and Barbados, the Company has designed and commissioned more than 60 systems all over the world, with single-link distances between 72km and 750km. In addition to single links, a number of multi-hop installations have been commissioned, the largest system providing communications over a distance of 2337km using six links in tandem. The early systems used f.m/f.d.m transmissions which allowed easy interfacing with other terrestrial networks.

The use of the troposphere for trans-horizon communication presents the designer with many problems, most of which are to do with the medium of transmission. The troposphere extends from the earth's surface to a height that varies between 10km and 16km, and it is in this layer of the atmosphere that forward-scattering takes place. The difficulty in using the troposphere is that it is not a settled medium, being subject to all types of weather conditions. The changes in the troposphere cause two forms of signal fading, short-term and long-term. Short-term fading lasts from a fraction of a second to several minutes, caused by the fact that, as the signal passes through the troposphere, its various frequency components arrive via slightly different propagation paths. Long-term fading lasts for periods from an hour to a day and is caused by changes in the refractive index and temperature of the troposphere.

The fading characteristics of the troposphere and its climatic dependence have led to five climatic zones being defined for the use of system designers, viz:

a) continental temperate,
b) sub-tropical,
c) maritime,
d) equatorial,
e) desert.

In addition to this, the scattering ability of the troposphere is dependent upon which portion of it is used. It is this great variability that poses the problems, and Marconi has invested substantial resources in investigating terminal designs and the equipment needed to produce a reliable communication system.

Considerable effort has been put into both characterization of the troposphere for different climatic conditions and simulation of the medium to allow link calculations to be verified, with Marconi Research being one of the world leaders in this field. Marconi Communication Systems has designed not only high-power transmitters, receivers and antennas but also electronics systems special to tropospheric scatter such as pre-detection combining and power-level control.

It is probable that, as far as analogue transmissions are concerned, simulation of the troposphere and system design have gone as far as is necessary. However, in the field of military communications, where security of information is vital, digital troposcatter has been under consideration since the early 1960s.

Digital tropospheric scatter

In designing a communication system there are two major items to be considered. Firstly, the availability of the link, defined as the percentage of time during the year that the link is usable. Secondly, the quality of the communications, which can be defined in a variety of ways depending upon whether it is an analogue or digital system.

Availability is determined by two factors:

a) equipment reliability where availability is determined as:

$$A = \frac{m.t.b.f}{m.t.b.f + m.t.t.r}$$

where m.t.b.f is mean time between failure,
m.t.t.r is mean time to repair.

b) propagation-related channel quality, where it is the condition of the troposphere that can render the channel unusable.

The availability requirements are set by the total path, which may consist of many individual links. A typical figure for a single troposcatter link is 99·96% per year.

Quality is defined in different ways. For analogue operation the quality of the link is related to the signal-to-noise ratio of the received signal relative to the threshold of the receiver. For digital systems the changes in the relative phase of the various signal components of the digital signal, due to dispersion effects within the troposphere, are of most significance and the bit error rate

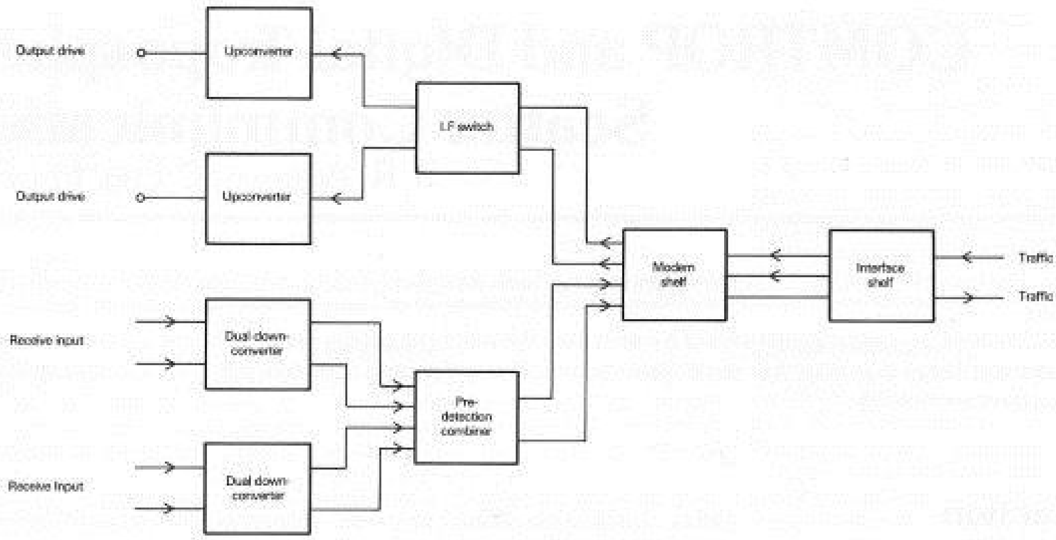

Fig. 1. H7500 Block diagram

becomes a measure of the quality of the link.

Marconi first entered the field of digital troposcatter communications with the design of a highly mobile transportable system for use as a tactical military link. The equipment has been described in detail in previous articles.[1, 2]

This equipment not only provided digital transmission, in the form of 4QPSK modems, but also allowed the use of a single antenna to give a quad diversity system that is spectrally efficient and gives a lower cost configuration than one using any of the other classical methods of diversity operation.

Although designed for military applications, Marconi Tactrop equipment can also be used in civil roles, its transportability making it suitable for any situation that requires temporary or emergency communications. However, for civil applications, the low-level equipment is somewhat over-specified and therefore more costly than necessary. This has led Marconi to take the H7450 low-level equipment, used in the Tactrop system, and redesign it for the civil market. This redesign, with cost reduction in mind, has retained many of the excellent features of the Tactrop and a description of the equipment is given below.

H7500 Comptrop equipment

The H7500 has been designed to replace the existing analogue drive and receive equipment Type H3102/12/22 and, in addition, is capable of digital operation. It has retained the modular construction system, similar to the H7450, and can be used in all three of the civil communication bands open to tropospheric scatter systems, i.e, 790MHz to 960MHz, 1·7GHz to 2·3GHz and 2·3GHz to 2·7GHz. The block diagram shown in figure 1 can apply to both analogue and digital systems simply by changing the modem and interface units. The complete cabinet (figure 2), accommodates all the equipment needed to give full quad diversity, though this can be sub-equipped when dual diversity is sufficient to give satisfactory link performance. The cabinet houses five shelves. The top shelf contains all the r.f equipment, two upconverter units, two dual downconverters and a metering/engineering order wire (e.o.w) module. Below this is the pre-detection combiner (p.d.c) shelf which contains four phase-correction units, two i.f converters, two dual combiners and a control unit. A third shelf is used to house the monitoring facilities associated with the system. It is also the interface point for the traffic inputs and output signals and the e.o.w. The overall system performance can be checked

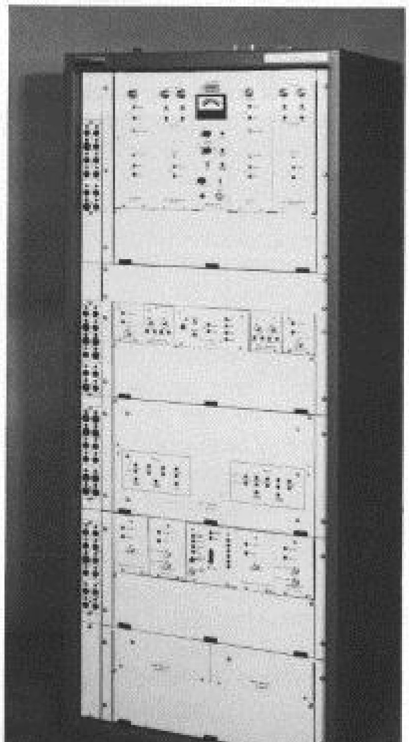

Fig. 2. A view of the H7500 Drive/receive equipment

by an r.f loop-round facility, consisting of a mixer and local oscillator. The fourth shelf contains the modems, and below that are dual power supplies connected in a redundant mode.

System description

Transmit system

The traffic inputs pass, via the interface shelf, to the modulators housed in the modem shelf. The output from the modulator is switched into the up-converter units through an i.f switch, which routes the signals to the working upconverter should one path fail. The 70MHz signal from the i.f switch is applied to an upconverter unit, where it is amplified before being mixed with the output of a phase-locked oscillator (p.l.o) to give the appropriate r.f frequency. The r.f is then filtered and amplified to a level of 0·5W before passing through a monitoring circuit to the output of the unit. The upconverter output signal can be used as the drive for a high-power amplifier or it can be applied directly to the antenna system for transmission.

Receive system

The outputs from the antenna system are fed either directly, or via a pre-selector filter, to the two dual down-converter units. Each unit contains two identical downconverters which use a common p.l.o for their mixer systems. The received signals are filtered to reduce their noise bandwidth before being applied to a low-noise amplifier (l.n.a) which effectively sets the system noise figure to less than 1·5dB. The l.n.a output is applied to a mixer, where it is mixed with the output of a p.l.o down to the 70MHz i.f, filtered after passing through an i.f pre-amplifier, and then amplified in an automatic gain control (a.g.c) amplifier which keeps the downconverter-unit output level constant.

The four downconverter outputs are routed to the p.d.c shelf, which phase-corrects the individual receiver signals, passively combines them and, in the case of a quad system, provides two inputs to the modem shelf via i.f converters housed in the p.d.c shelf.

The modem shelf contains two modulators and demodulators operating in an analogue or digital mode. The outputs from the demodulators are routed into the interface unit.

System interfaces

The interface unit has two forms, one for analogue and the other for digital operation. For analogue operation the traffic input is applied to an attenuator, allowing level adjustment in 0·5dB steps over a range of −30dB to −45dBm. The attenuated output is then fed to duplicated amplifiers, which split the signal before application to transmit combiners, where it is combined with the transmit sub-baseband signals. This signal is fed to the f.d.m modulators in the modem shelf. A turn-round switch allows a test traffic input to be substituted for the normal traffic signal. In addition to traffic signals, these amplifiers take in a pilot signal derived from a pilot generator in the interface unit. The baseband combiner card in the interface unit takes in the demodulator outputs and processes the signal in order to separate it into three components:

a) the receive sub-baseband signal,
b) an e.o.w output,
c) the traffic output.

The receive baseband signal is processed to detect the absence of pilot and/or the presence of noise. The receiver paths are muted when a high noise condition is detected or one of the pilots fails.

The digital interface shelf is designed for p.c.m and delta modulation processing. The p.c.m traffic capacity is available at three levels; 64 kbit/s, 704 kbit/s (10ch) and 2048 kbit/s (30ch). The digital interface unit takes in the traffic input and splits the signal prior to feeding it to separate auxiliary multiplexers, thus providing redundant transmit paths. The multiplexer brings together traffic, external/local e.o.w, supervisory and framing signals which, after processing, are fed to the digital modulators.

The auxiliary demultiplexers take in the signal from the demodulator outputs, split the signal into traffic and supervisory signals, retime the signal, and monitor errors in the framing word which are relayed to the bit-error-rate (b.e.r) monitor to assess link performance and initiate path changeover as required. Turn-round testing is possible, with switch systems built into both multiplexer and demultiplexer. The whole system is capable of local and remote operation.

Maintenance facilities

Each unit has indicators, comprising front panel light-emitting diodes, which show fail or operational status. In addition to this general indication, all the critical voltages are monitored and can provide comprehensive alarm capability. In terms of system performance there are loop-round test facilities that allow r.f, i.f and baseband checks. For analogue operation a pilot signal is used, for digital, b.e.r is utilized.

Typical installation

The Comtrop equipment can be used in any system configuration, providing the designer with the choice of quad or dual diversity. The low-level equipment can be used either to drive high-power amplifiers (h.p.a), as shown in figure 3, or, if applied directly to the antenna system, to radiate the output power of 500mW, which is enough to give trans-horizon communication between North Sea oil platforms about 60km apart. A typical installation is shown in figure 4 which depicts spacing of antennas and horizontal/vertical polarizations to provide a quad diversity system.

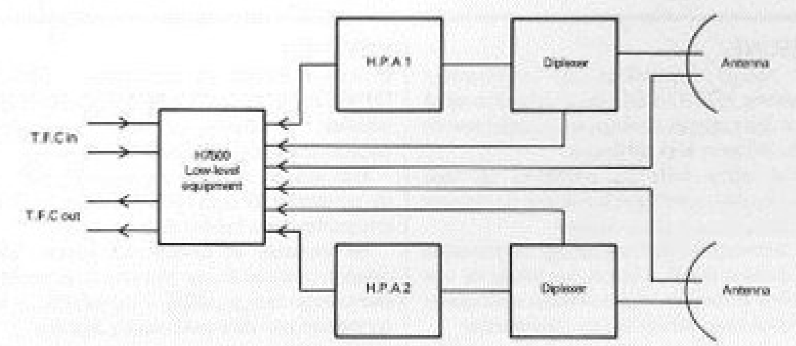

Fig. 3. A quad-diversity tropospheric scatter terminal

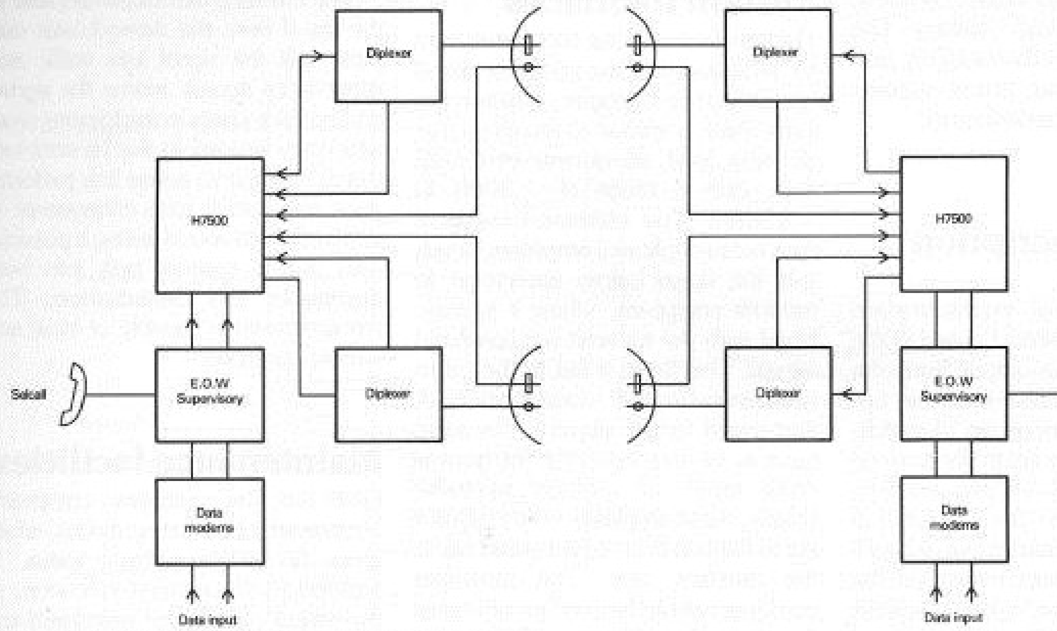

Fig. 4. A quad-diversity tropospheric scatter link

System performance

Every tropospheric scatter communication system is individually designed to suit the location of the two terminals and the climatic conditions. However, digital systems have not yet been specified as precisely as analogue, due to both the lack of data on dispersion effects and the need to consider, in addition to tropospheric characteristics:

a) bit error rate,
b) signal jitter/wander,
c) delay,
d) synchronization effects.

Errors in the signal are caused by the loss of bits from the data stream due to fading effects and this is normally specified as an average rate over a fixed period of time, e.g, $>10^{-6}$ for one minute. It is possible to calculate the signal/noise ratio that will sustain this level of error.

There are also other ways in which the signal quality can be viewed. One, as defined by the CCITT, is in terms of error-free seconds for a particular period of time and is usually expressed as percentage of minutes over the period of a year (the CCITT link criterion is 99·33%). The other way is as error-free blocks where the blocks are 1000 bits long.

Signal jitter is the short-term rapid variation in the transition point of the digital signal, whereas wander is a very slow change in the signal caused by clock drift, etc, and by long-term tropospheric path changes. These characteristics are defined in CCITT Recommendation Q503.

Transmission delay can be introduced by the medium of communication and the terminal equipment. This delay can mean that echo-suppressors and specific error techniques have to be introduced to reduce delay effects.

In any digital system, synchronization may be lost, producing serious disruption in the signal path and a high error rate. It is therefore necessary to design a system for minimum slippage which, in the case of a tropospheric scatter link, is one slip every 500 hours.

Future trends

For tropospheric scatter systems in general, the advantages to be gained by their use are well known; their ability to give over-the-horizon communication across sea, inhospitable terrain or hostile environment puts them in a unique position.

Future systems will follow the trend, already established, towards digital communications, allowing simple interconnection into terrestrial networks. The majority of systems operate below 2 Mbits/s, but this, too, is changing as communication needs expand. This move towards higher bit rates necessitates the design of special modems or receivers which will remove the effects of dispersion on the signal and so allow operational links working at data rates of more than 12 Mbit/s.

RÉSUMÉ

Le nouvel appareillage de commande/récepteur H7500 a été conçu pour être utilisé dans des systèmes analogiques/numériques de radio diffusion troposphérique.

Cet article traite les conditions de base requises d'un système et la manière de mesurer les performances d'une liaison.

La conception de l'appareillage est présentée en quelque détail, à la fois des points de vue système et module, et des versions analogiques et numériques sont prises en considération.

RESUMEN

El nuevo equipo de transmisión/recepción H7500 se ha diseñado para emplearse en los sistemas analógicos/digitales de radiocommunicación por dispersión troposférica.

Este artículo examina los requisitos básicos de un sistema así como la manera de medir el comportamiento funcional de un enlace.

Se presenta el diseño del equipo con detalles, tanto en lo que respecta a un sistema como en lo que se refiere a un módulo, y se consideran modelos analógicos y digitales.

ZUSAMMENFASSUNG

Die neue Treiber/Empfängerausrüstung H7500 ist besonders zur Anwendung bei tropospärischer Streufunkübertragung bestimmt.

Der Aufsatz erörtert die grundlegenden Anforderungen sowie die Art und Weise, mit der die Leistung einer Funkstrecke gemessen wird.

Die Konstruktion der Ausrüstung wird im Einzelnen beschrieben, sowohl vom Standpunkt des Systems wie auch des Moduls, und es kommen analoge und digitale Ausführungen zur Betrachtung.