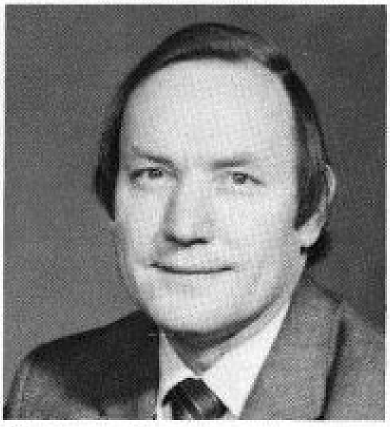
Performance measurements on a tactical tropo system

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

Summary The article reviews the changing requirements of communication systems, detailing the changes in system design and the increasing use of digital forms of communication. A description is given of the Marconi H7450 digital troposcatter equipment, together with details of the results of trials carried out over different paths and with different configurations.

B. R. Ackroyd
Brian was educated at Lord Williams Grammar School, Thame, and served a Post Office apprenticeship at Dollis Hill. He joined The Marconi Company in 1968 and worked in Space Division on the design of tracking demodulators. In 1973 he became a section leader of modem and i.f design in the space and tropo department, which involved the modems associated with INTELSAT earth stations and North Sea oil tropospheric scatter links. In 1976 he was appointed Group Leader of p.c.m at Writtle and then of the Small Station Group in Space and Microwave Division. He moved to Space and Microwave Sales in 1981 and is now Divisional Marketing Manager.



Introduction

Troposcatter communications have been in use since the first link established by Marconi between Santa Marghereta and Santa Stephano in Italy. Since that time the use of troposcatter systems for analogue and low-speed data communications has been considerably developed, with regard both to the terminal equipment available and to the study and characterization of the troposphere itself.

The development of troposcatter has put this system alongside line-of-sight (LOS) and satellite communications as one of the choices available when civil or military authorities consider the means of fulfilling their communication needs for either analogue or digital links. The advantages of troposcatter can be seen as:

a) the ability to provide secure, reliable communications over territory that is desert, mountainous or has large expanses of water where LOS cannot be used,

b) in its mobile form, the ability to provide communications for emergency services or temporary links where speed of implementation is essential and satellites may not be available,

c) the provision of communications which are more cost effective than the multi-terminal LOS used in long-haul systems, both in terms of equipment required and long-term manpower commitments.

Development of tropospheric scatter systems

The physical characteristics of the troposphere and its behaviour have been the major factors influencing the development of equipment for troposcatter systems.

The main problems arising out of this transmission medium have been high path losses and multipath fading, and technical developments have been concentrated on overcoming these. The small amount of signal scattered forward has instigated the development of efficient high-power klystron amplifiers with frequencies ranging from 900MHz to 5GHz, and to the improvement of carrier – to – thermal noise ratios by use of low-noise pre-amplifiers.

In addition, receiver improvements using threshold extension techniques and post and pre-detection combining have meant that greater distances can be covered with improved reliability.

The effects of signal fading have been reduced by a variety of diversity techniques, each of which is designed to provide signal paths through the troposphere that are uncorrelated and therefore do not fade in unison. The possible methods are diversity of:

a) space—utilizing antennas that are separated by at least 100 wavelengths,

b) polarization—the same signals being transmitted on horizontal and vertical polarization,

c) angle—where the signal is directed towards the troposphere at two different angles, giving two uncorrelated signal paths,

d) frequency—where the signal is transmitted at two separate frequencies, again spaced sufficiently apart to give low correlation between received signals.

The choice of diversity method depends upon the overall system requirements, the physical characteristics of the proposed site (it may not be possible to fit two antennas into the space available), availability of suitable frequency allocations and equipment cost considerations.

As the number of installations has increased and total area communications, such as in the North Sea, have developed, it has been necessary to investigate automatic level control both on transmit and on receive signals. The need for transmit level control arises from the high transmitted-power levels required by troposcatter systems and by the possibility of interference with adjacent communication systems when transmission medium characteristics are at or near their maximum. Level control may have to deal with a range of 70dB, though this is the worst case condition and not a normal design parameter.

The use of receive level control is also necessitated by the need to accommodate the large dynamic range of input signals that can be encountered in troposcatter systems.

Digital communications

Recent years have seen an increasing interest in digital communications, the possibilities of which were initially realized in line networks. Here pulse code modulation (p.c.m) is used to give error-free performance over long distances provided the signal is regenerated at reasonable intervals.

The advantages of digital communications, especially where there is a need for information security, and for trans-horizon communications to interface with terrestrial networks, have resulted in considerable effort being put into the development of digital troposcatter systems.

Unlike the analogue frequency division multiplex (f.d.m) system, where performance is characterized by signal/noise ratio, the digital system performance is measured by bit error rate, more specifically the numbers of errors for a particular time span.

For digital troposcatter systems, a bit error rate of 1 in 10^5 can be obtained using quadruple diversity systems and be employing four-phase shift keying (p.s.k) modulation. At higher data rates, system performance is considerably affected by dispersion effects which arise from signal paths having different lengths, and which are therefore displaced in time and produce inter-symbol interference. These effects can be reduced only by adaptive modems which, depending upon transmission path characteristics, will allow up to 12M bit/s data rates to be used.

Marconi digital troposcatter equipment

Marconi Communication Systems has designed and developed a mobile troposcatter system, the H7450, that can be used for both civil and military applications, with the choice of analogue or digital modes of operation. The complete system has been described in detail in previous articles.[1,2]

The terminal equipment is shown in figure 1. The 4·5m diameter mobile antenna has been designed to fold down to a width of 2·3m for transportation either by trailer on normal roads, or by air using a C130 transport plane. Special account has been taken in the design of the antenna to ensure that it can be erected quickly and easily by two men. It can be deployed in 45 minutes on an unsurveyed site and, when suitably stayed, can withstand winds of up to 120km/h.

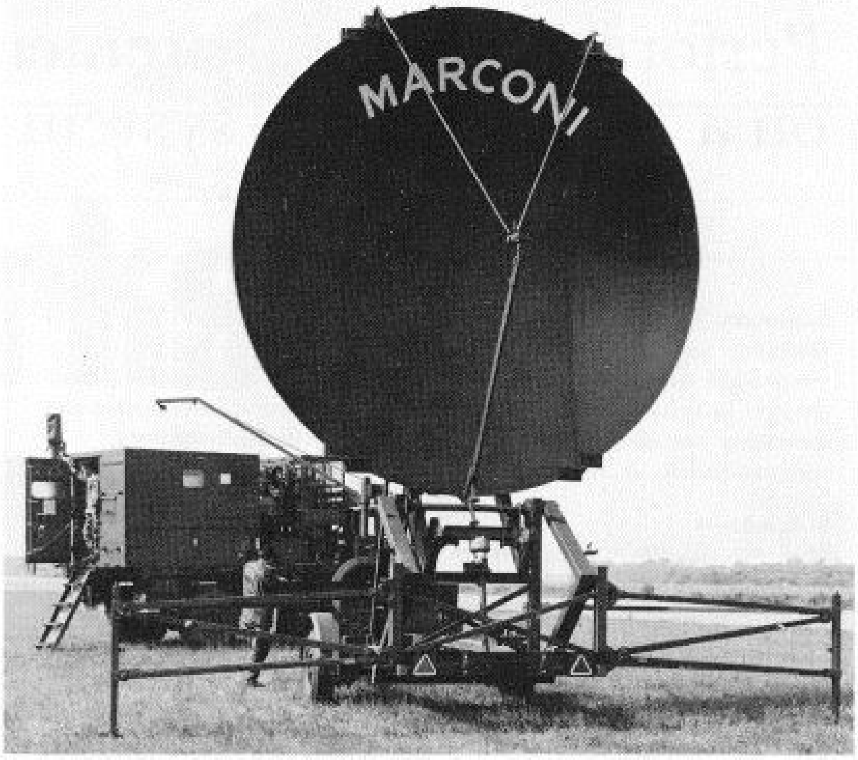


Fig. 1. Operational tactical troposcatter terminal

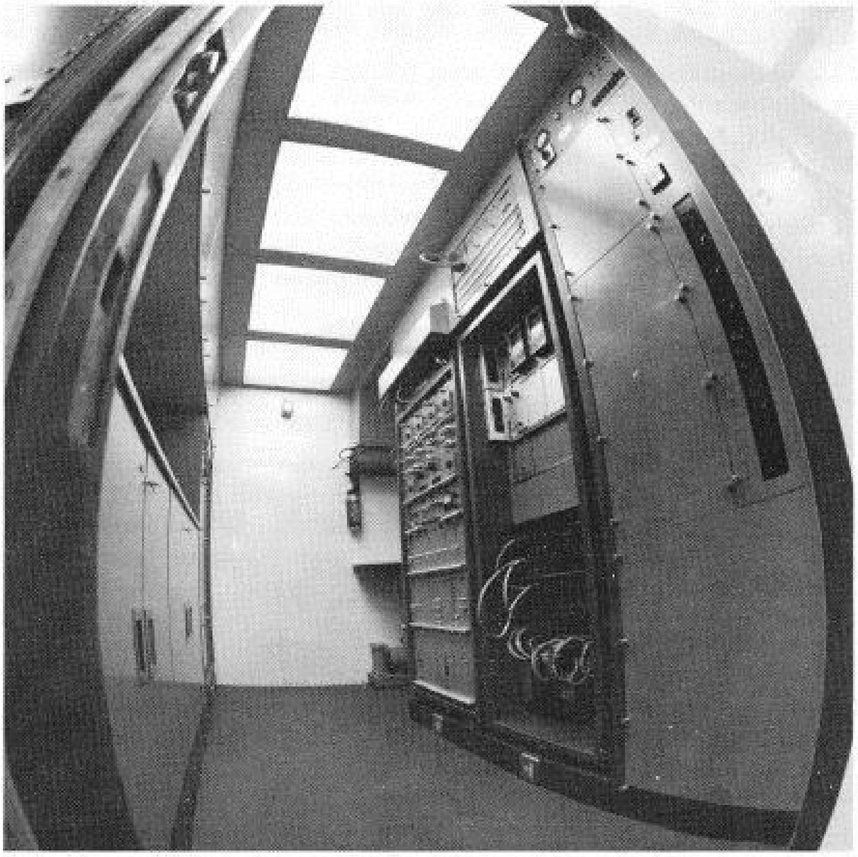


Fig. 2. View of the interior of the container

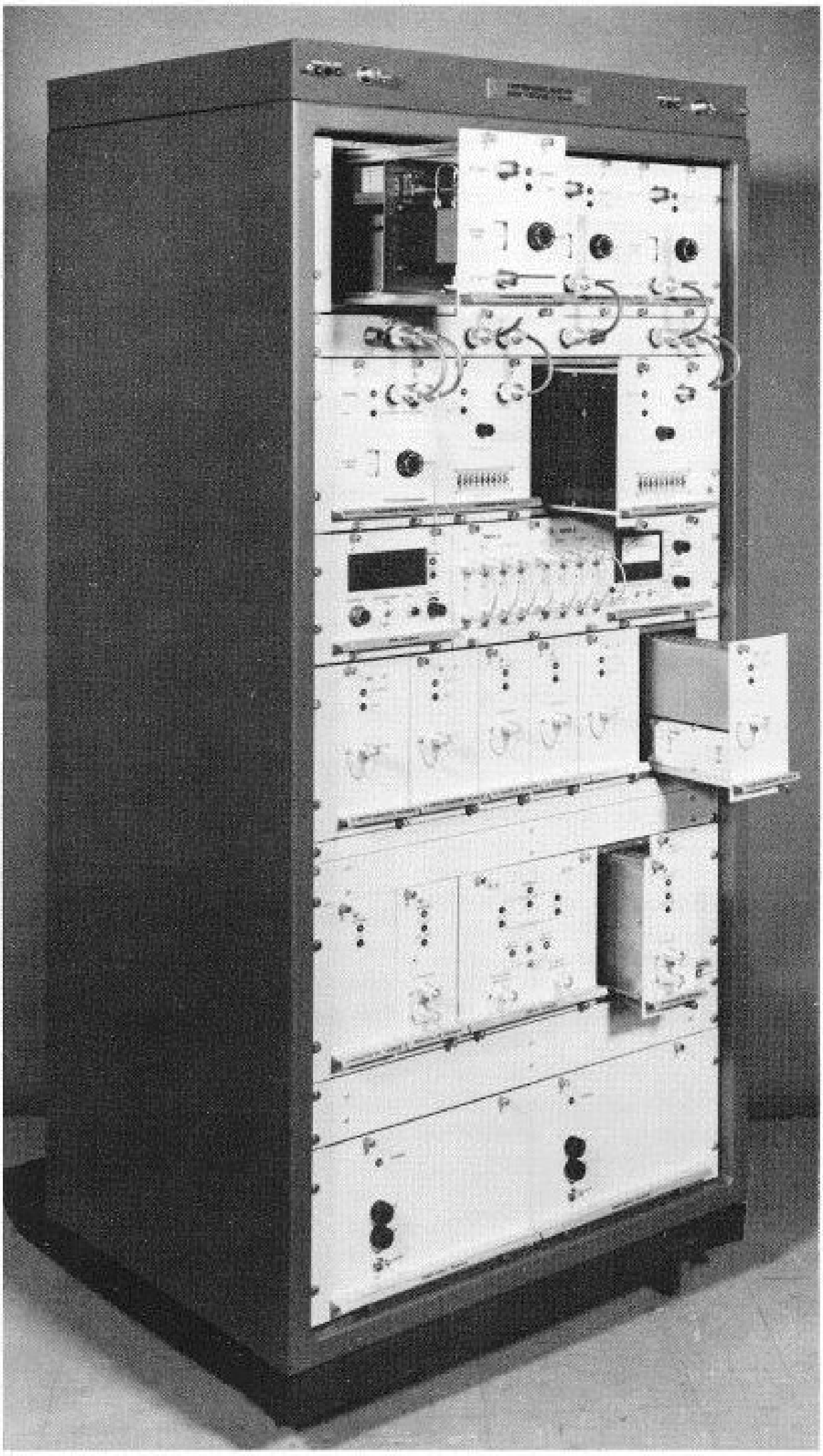


Fig. 3. H7450 low-level equipment

The radio equipment is designed to be installed in a standard ISO container, allowing a variety of system configurations to be realized (figure 2). The low-level equipment is contained in a free-standing cabinet (figure 3) which contains r.f/i.f systems for up to two transmit paths and four receive chains. Analogue or digital modulation can be provided, up to 300 analogue channels or 2048kbit/s digital using 16kbit delta modulation.

The output level from the H7450 can be 250mW or 1W, depending on the system application. The 1W output can be used for LOS applications and the 250mW output is used to drive the H3742T high-power amplifier (h.p.a) when working in a troposcatter mode. The h.p.a has an output of 1kW and a choice of frequency of 4·5GHz or 2GHz. Two amplifiers can be accommodated in the container, allowing a quad space diversity system to be configured.

The equipment can be powered from locally available mains supplies or from a 15kVA three-phase generator which provides power for the operation of the radio equipment, one h.p.a and all the auxiliary services.

As already noted the overall equipment can be used both for civil and for military applications. The digital signals can be encrypted using MARCRYP and the coding can be changed using a portable optical fill-gun which can be controlled from a central headquarters, allowing further security in the communication system.

Equipment field trials, Rivenhall/Norwich

General

The field trial activity can be divided into two distinct phases. The first, a general proving exercise, consisted of performance measurements made over the period December 1981 – January 1982. During this period a link was established between Rivenhall (Essex) and Norwich airfields, the former being a Marconi Company site used for testing radars, antennas etc.

On each site the equipment consisted of a single 4·5m diameter antenna, a container having the 1kW HPA Type H3742T and H7450 low-level equipment. In addition at Rivenhall, where all measurements were made, a small caravan was used to accommodate the extra measuring equipment required for the tests. To simulate a normal operational system, the terminal equipments were powered by diesel generators.

Any trial carried out to assess equipment performance needs to measure the following parameters:

a) received signal level (single-channel and diversity combined),
b) bit error rate,
c) multipath dispersion,
d) signal fade rate,
e) weather conditions (temperature, pressure, humidity).

In these trials, the signal levels and bit error rate were recorded on chart recorders. The weather information was obtained from equipment at Norwich airport and dispersion measurements made on a RAKE receiver. The equipment was configured for dual angle diversity using a vertically offset system, transmitting from Norwich on the lower beam and receiving at Rivenhall on the upper and lower beams. In both transmit and receive directions, vertical polarization was used. The link equipment parameters were as follows:

antenna diameter	4·5m
3dB bandwidth	1·0°
antenna gain	44·3dBi (at 4·4 or 4·7GHz)
vertical offset angle	1·3°
polarization	vertical
transmit frequency	4580MHz
transmit power	1kW
path length	106 miles
scatter angle	0·9°
Tx height	52m above sea level (m.a.s.l)
Rx height	34 (m.a.s.l).

System results

Signal levels

The received signal level for both receivers was monitored for a period of eight weeks, chart recordings being taken for a few hours of each day, giving approximately 58 usable hourly samples for each receiver.

The combined signal levels were recorded, showing a high gain for the dual diversity combiner. The system was calibrated by injecting a signal generator output into one of the receivers.

Analysis of the signal level variation was carried out for both long-term and hourly median changes of level. In the short term, (6 hours), variation of about 5dB occurred whilst the long-term changes showed variations that were dependent upon the time of the year (e.g 15dB for December, >25dB for January).

A computer analysis of the practical results was made and compared with theoretical predictions. In order to do this, use was made of the Marconi NBS101 computer program. This differs from other programs presently available in that it attempts to overcome the shortcoming in existing prediction techniques by taking into account the beam broadening effect (as proposed by Hirai). Marconi Research Centre has developed the program by modifying the STC program to take this into account.

The comparison of theoretical yearly median signal levels with the values measured over the Rivenhall/Norwich link showed agreement within 0·8dB which is an excellent result.

Dispersion and fading rate measurements

General

Measurements, using the RAKE receiver, were not continuous throughout the trial but were made during a few hours of the working day. The receiver measured diversity channel sequentially rather than simultaneously, each measurement being six frames in length (with each frame giving 92s of data) and recordings being made at 2 min intervals.

The analysis of the recorded data was made on the computer using a specially written program which analysed the following parameters:

a) normalized delay power spectrum,
b) multipath spread,
c) threshold crossing rates,
d) mean time delay.

The delay power spectrum was sampled at 100ns intervals, which on this link was comparable to the expected value of 2σ. This means that the measured variations were due to two factors:

a) changes due to variations of the troposphere,
b) drift of transmit and receive clocks.

The problem caused by the sampling interval being similar to the interval 2σ can be overcome only by reducing sampling intervals.

In general the delay power spectrum showed a rapid rise to maximum power, followed by a gentle decline at long time delay with no double humping or irregularity. This result is in reasonable conformity with the classical Bello predictions.

The experimental evidence showed that the dish elevation has a great influence on the relative dispersion between beams and that great care should be taken when optimizing the system.

Figure 4 shows the distribution of threshold crossing rates and compares it to the theoretical, which assumes a Gaussian fading power spectrum. It can be seen that the two beams are similar though both are narrower than the theoretical.

Digital field trials

General

The second phase of the equipment trials was conducted over three separate links. Unlike the first proving trials the second phase was concerned with not only general link parameters but also the equipment performance when used in a digital mode of operation. The performance was therefore gauged in the following ways:

a) received signal level,
b) multi-path dispersion,
c) bit error rate,
d) synchronization performance.

Path details

The details of each path are shown in Table 1. The choice of sites and equipment deployment provided a variety of conditions and highlighted the desirability of good antenna

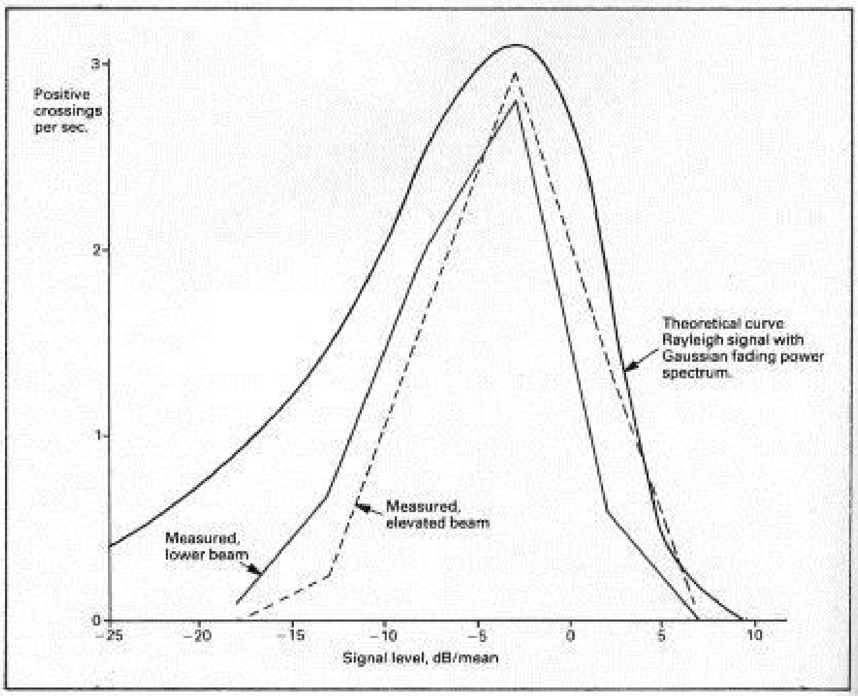


Fig. 4. Distribution of threshold crossing rates

Table 1: Path topographical details

Link	Path length (km)	Mean transmitter height (m.a.s.l)	Mean receiver height (m.a.s.l)	Distance of transmitter to horizon on GCB (km)	Distance of receiver to horizon on GCB (km)	Scatter angle (°)	Path asymmetry factor (s)
A	124	45	32	28·0	3·0	1·26	0·217
B	187	54	37	9·7	4·7	2·25	0·4905
C	189	52·4	56·4	3·6	20·0	1·39	0·5884

GCB=great circle bearing

Table 2: Systems details of each link

Link	Diversity configuration	Antenna diameter (m) Tx	Antenna diameter (m) Rx	Keying method	Coded/uncoded	Bit rates* (kbit/s)
A	Quad, dual angle, dual space	2·4	4·5 (×2)	Offset	Both	256, 512, 1024, 2048
	Dual angle	4·5	4·5	Offset	Both	
B	Dual angle	4·5	4·5	Normal/ offset	Both	1024, 2048
C	Dual angle	4·5	4·5	Normal/ offset	Both	256, 512 1024, 2048

*Refers to channel bit rates only and does not include additional 64kbit/s for framing, supervisory and e.o.w. Thus 512 coded, for example, results in a transmitted bit rate of (512+64)×2=1152kbit/s

deployment in order to achieve maximum performance.

Link details

In order to take full advantage of the trials a number of different system configurations, antenna sizes, coding, keying methods and bit rates were used. These are shown in Table 2.

Trial methods and results

Received signal levels

The prediction of troposcatter systems performance is relatively simple when there is a fixed relationship between diversity signals. However, in angle diversity systems a problem arises because of the poor correlation between the received signals from each beam. The decorrelation between angle beams means that comparison with theory is only approximate. Table 1 shows the basic topography of the links used in the tests. Table 2 gives system details. On link 'A', measurements were made on 2·4m and 4·5m diameter transmit antennas. They show that the difference in received signal level between main and elevated beams was larger than predicted.

On Link 'B', good correlation between theory and measured results was achieved when using the NBS 101 prediction.

On Link 'C', the frequency and quantity of measurements was insufficient to provide a valid comparison against theory.

Multipath dispersion

For this series of trials the RAKE receiver was used to measure multipath characteristics each hour. The period for each measurement was 92s.

Link 'A' Results

On this link, two antennas were involved, 2·4m and 4·5m diameter. Cumulative distributions of 2σ were plotted and show a good normal distribution.

When results from the two antennas were compared it was shown that the dispersion spread decreases as the antenna size increases. In addition, it was found that median dispersion does not decrease significantly as the antenna beamwidth decreases. This is shown in Table 3 where all of the prediction methods show that median values should decrease as the antenna size increases.

Error rate and synchronization performance

The frame word data in the auxiliary multiplexer was used to obtain a measure of the error rate. The following information was derived:

a) percentage of time that the Bit Error Rate (BER) did not exceed 10^{-3} over a one minute period,

b) percentage of time that the BER did not exceed 10^{-5} over a one minute period,

c) percentage of error-free seconds,

d) percentage of error-free minutes,

e) mean time between loss of synchronization (MTBLOS).

The error rate results are very dependent upon the propagation conditions prevailing during the digital transmission. This means that to make a direct comparison between the various modes of transmission is very difficult.

An attempt was made to select results with similar propagation conditions and it was found that normally keyed quadrature phase shift keying (q.p.s.k) was generally better than offset keying. Coding of signals appears to improve bit error rate marginally up to

Table 3: Comparison of measured and predicted medians

Link	Tx Antenna dia (m)	Prediction method: Bello	Collin	STC	Baddow	Measured
A	2·4	26	39	78	130	106
A	4·5	23	31	50	83	108
B	4·5	54	95	91	106	126
C	4·5	92	152	120	169	182

bit rates of 512kbit/s. This coding improvement is removed when 1 or 2Mbit/s data is transmitted because of the effects of multipath fading.

It is interesting to note that the practical measurements agree with the results obtained on the Marconi simulator.

Comparison of theoretical models and measured results

Once again, the assessment of measured results against theoretical models proved to be difficult due to the decorrelation between the two angle beams, which was a noticeable feature of the median signal level results.

The theoretical predictions assume conditions where the upper beam is 3dB lower in level than the main beam. This means that measured performance appeared to be pessimistic, relative to the theoretical predictions, because the upper beam level was at times up to 20dB down on the main beam.

In order to ensure that the comparisons are reasonably valid it was necessary to choose the samples for analysis on a random basis.

Each of the three paths was analysed for at least two different forms of transmission. For Link 'A' the system variation was between dual or quad diversity, for Link 'B' the system was kept in dual diversity whilst changes were made to coding and bit rate. On Link 'C' the parameter varied was the keying as shown in Table 2.

A typical set of results shown in figure 5 shows the system to be limited by link dispersion even though the thermal/noise ratio was good. The model shows that it is possible to predict what it is that is limiting link performance, i.e. dispersion, thermal noise or both.

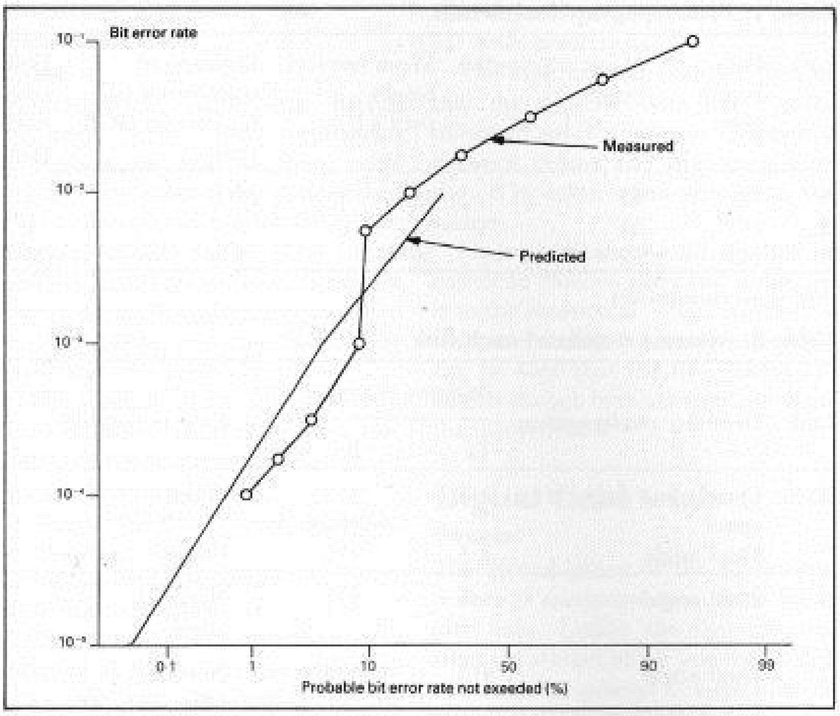


Fig. 5. Bit error rate performance of Link 'B'

Trial conclusions

The main conclusions to be drawn from the trials are:

a) the use of troposcatter links for digital transmission can provide a high-quality system for a variety of link conditions and signal parameters,

b) the effect of multipath is to degrade the system performance and normal methods, such as coding, can give only marginal improvement,

c) coding on transmitted signals can give an improvement in bit error rate for bit rates up to 512kbit/s. Above that rate the coding in fact gives a degradation in performance,

d) the use of offset keying does not provide an improvement over normally keyed systems.

Future possibilities

With the ever increasing need to provide systems capable of transmission of higher bit rates, e.g 4Mbit/s (120 channels), it will be necessary to overcome the effects of multipath distortion produced by frequency selective fading.

There are a number of possible methods for achieving this improvement, each having its own advantages and disadvantages and a future article will deal with this topic. However, it is in this area of development that digital troposcatter systems will move forward, for it is the transmission medium that is always the limiting factor and the development history of troposcatter has been the search for new types of equipment and systems that will overcome the effects of fading etc. The described digital system represents another step forward in the design of such systems, giving improved performance, greater flexibility and ease of operation.

References

1. J. D. Rogers: 'Introduction to digital tropo for military tactical communication', *Communication & Broadcasting*, Vol.6, No.3 (June 1981), pp.3–9.
2. J. D. Rogers, M. H. Stears, D. W. Baker: 'Radio equipment for digital tropo military tactical communication', *Communication & Broadcasting*, Vol.7, No.1 (September 1981) pp.61–71.

RÉSUMÉ

L'article examine les modifications qui apparaissent dans les exigences concernant les systèmes de communication, exposant en détail les changements apportés à la conception des systèmes et l'usage croissant qui est fait des formes de communication numériques. Une description est donnée du matériel de tropodiffusion numérique Marconi H7450, ainsi qu'un exposé détaillé des résultats obtenus au cours d'essais réalisés sur divers chemins de propagation et au moyen de diverses configurations.

RESUMEN

El articulo revisa los requisitos de cambio de los sistemas de comunicacion, detallando los cambios en el diseño de sistemas y el uso creciente de las formas digitales de comunicación. Se da una descripción del equipo Marconi digital H7450 de dispersión troposférica, junto con detalles de los resultados de pruebas realizadas sobre trayectorias diferentes y con configuraciones diferentes.

ZUSAMMENFASSUNG

Der Aufsatz erörtert die wechselnden Anforderungen der Kommunikationssysteme und befasst sich im Einzelnen mit den Änderungen der Systemkonstruktion und der steigenden Anwendung digitaler Kommunikationsformen. Das digitale Troposcattergerät Marconi H7450 wird beschrieben sowie die Ergebnisse der über verschiedene Pfade ausgeführten Versuche mit verschiedenen Anordnungen.