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Radio equipment for digital tropo military tactical communication

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Summary This second article deals with the equipment in the radio cabinet and the practice associated with it. The various methods of combining are outlined and the attributes and applications of each are discussed. Salient features of the equipment and its operation are described together with aspects of maintenance and reliability. An account of the location and operation of each module is given and a final section deals with performance.

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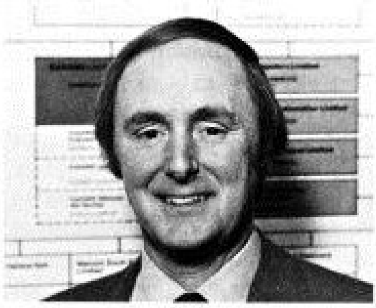
After completing postgraduate studies at Surrey University in 1962 John Rogers joined the British Post Office Research Department where he worked on log-periodic antenna design, microwave radio links and HO1 mode circular waveguide trunk systems.
Mr Rogers joined Marconi Communication Systems Limited in 1966 and between 1975–80 was Engineering Manager responsible for the development of satellite, tropo, and line-of-sight microwave systems. In this capacity he was responsible for the development of digital tactropo.
Since 1980 Mr Rogers has been responsible for the product planning associated with new microwave products.



M. H. Stears, BA
Mr Stears joined the Marconi Wireless Telegraph Company as an apprentice in 1950, and was subsequently employed in the research laboratories at Baddow. He left in 1959 to join the Plessey Company where he became group leader responsible for naval u.h.f communications. Returning to the Marconi Company in 1973 he is currently a group leader in Space & Microwave Division and is responsible for line of sight and tropospheric scatter equipment development.

D. W. Baker
Derrick Baker joined The Marconi Company in 1956, transferring to the staff of the Research Laboratories in 1960 upon completion of an apprenticeship. Apart from a short secondment to the Space Division of MCSL to assist in the Ascension Island Satellite Earth Terminal project, the period 1960–70 was spent as an engineer in the Communications Research Laboratory engaged in theoretical studies and advanced development work on a wide range of analogue and digital communication systems for both civilian and military applications. He was appointed Chief of Systems Section in 1970, which position he held until transferring in 1977 to the Microwave Development Department of Marconi Communication Systems Limited, as Group Leader of the Digital Transmission Group. In the latter post he had particular responsibility for studies and product development in support of satellite, terrestrial line-of-sight and tropospheric scatter digital transmission systems. He was recently appointed Engineering Manager of Space and Microwave Division.

Introduction

This second article describing the Marconi digital tactical tropospheric scatter equipment for military communication focuses on the radio equipment configuration and design to provide a more comprehensive understanding of the various options possible with the system. The application of new digital processing techniques to the transmission of information through the troposphere fundamentally changes the equipment concept leading to fewer modules of greater reliability, and to packages which are simpler to operate. Built-in test patterns permit the rapid diagnosis of faulty units or components thus improving the effectiveness of field maintenance. A range of equipment options allows a realistic balance between cost and performance which can be changed easily by the addition of units as budgets permit or as the system requirements change. For an introduction to tactical tropo and the technology which has led to a single-antenna, digitally secure system the reader is referred to the first article.[1]

Diversity equipment performance options

The equipment can be configured for either angle, frequency or space diversity (figure 1).

Quadruple performance can be achieved by receiving just two independent signals from the troposphere requiring a single antenna only. As explained in the first article, the digital coding and interleaving realizes an improvement in performance equivalent to another order of diversity when it follows one of the classical methods of combining. Digital processing does not actually improve the quality of the analogue signal received at the input to the demodulator, which must always be above the system's threshold, but introduces a processing gain. The improvement of dual diversity with coding and time interleaving over the classical dual diversity is shown in figure 2.

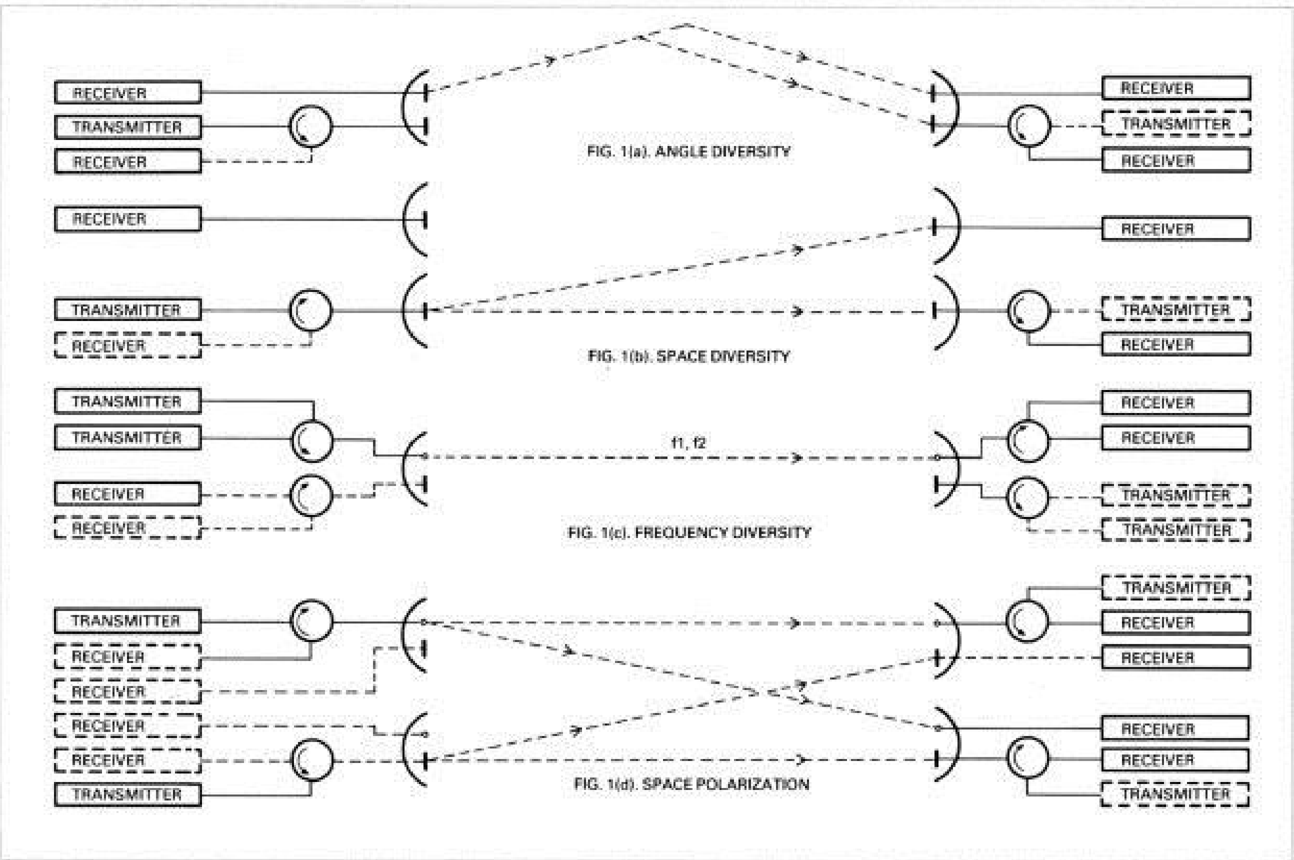


Fig. 1. Diversity configurations

Each of the classical methods of combining has its own unique advantages and cost penalties. Angle diversity (figure 1a) combines spectrum efficiency with minimum costs and is the recommended method for Field Command networks. In this configuration two independent signals are received from different scattering volumes within the troposphere using a split-beam feed which separates the two beams by one beamwidth. This method of diversity suffers most from loss, particularly over short paths, and is therefore not as efficient as frequency or space diversity. For tactical networks the improved signal strength from the shorter paths tends to compensate for the additional loss in the higher beam and in practice an averaging effect occurs giving a similar overall performance for path lengths between 50 and 250km.

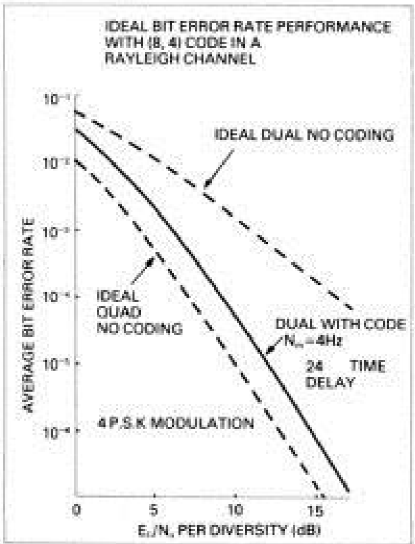


Fig. 2. Bit error rate performance

Frequency diversity (figure 1b), is the most extravagant in terms of spectrum as this method requires two independent signals at different frequencies. For decorrelation a minimum frequency separation between the two signals of 190MHz is required leading to an equipment requirement of two high-power amplifiers (h.p.a). For the additional cost the operator has an improved system over angle diversity and one which realizes a performance improvement for shorter paths, but with a single antenna.

Dual space diversity (figure 1c), needs only one h.p.a and one frequency, at the expense of requiring two antennas which receive two uncorrelated signals via different tropo paths when separated in space by approximately one hundred wavelengths. For the cost of the second antenna the system performance can then be improved well beyond quadruple performance, or the system capacity can be doubled if a further two receivers are purchased permitting space – polarization diversity to be adopted (figure 1d). Space – polarization diversity receives four independent signals permitting quadruple performance for more channels (i.e no coding) or better than quadruple performance with coding.

For all communication networks there is an optimum curve relating the trade-off in costs to the system performance or system capacity. The Marconi digital TACTROPO equipment is fully wired so that, from the cheapest system, any of the diversity schemes can be employed merely by plugging-in additional units to the basic system. Hence, when costs permit, the very cheap angle-time diversity system can be updated to a more sophisticated system giving an improved service.

As a general guide Field Command tactical networks need only the simplest configuration whilst the interconnection of fixed sites, normally demanding circuits of higher quality or greater capacity, require space-polarization diversity involving two antennas.

Physical characteristics and maintenance requirement

The operator is essentially concerned with the physical characteristics, reliability and maintenance of the equipment and this section deals broadly with these features. The total complement of tropo equipment consists of three cabinets comprising the h.p.a, radio, and multiplex/encryption units. Depending on the exact operational use, as described in the first article, the multiplex and encryption units may need to be housed in the container. The broad philosophy has been to minimize the number of equipment modules in order to reduce the problems for the operator.

Operation of the field radio equipment is simple. The job of the operator is limited to switching on the mains, tuning and the adjustment of power. All of the other start-up procedures are carried out automatically following the application of the mains to the tropo equipment. Only one tunable filter is fitted to each up and downconverter. Each filter is adjusted from the front panel using a single control knob and direct-reading frequency scale, the latter being of the expanded variety with a continuous tape allowing accurate setting without any external aid.

The frequency synthesizers are also fully controllable from the front panel. A direct reading thumbwheel switch permits coarse selection of frequency reference to a resolution of 100kHz and a single tuning knob brings the oscillator to phase lock. The operator is guided as to the direction of rotation of the tuning knob necessary for phase lock by reference to the light emitting diodes, which change colour for the in-lock condition. Realignment of the complete radio system to a new frequency is simple and after only a few minutes instruction the operation can be completed within one minute.

Frequency tuning of the klystron on the h.p.a is also by a single vernier scale permitting direct setting. A forward power monitor displays the transmitted power at the output flange of the cabinet. In order to protect the equipment against accidental misuse an arc detector and reverse power monitor are incorporated within the amplifier which automatically switch off the h.p.a if arcs or strong reflected levels are present. The analogue interface at the engineers' order wire (e.o.w) and supervisory port in the radio cabinet permits the operator to assess the quality of the circuit either by speaking or monitoring a sine wave from a loop within the radio cabinet or over the troposphere. For a more accurate assessment of the equipment performance a bit error rate meter provides the operator with a continuous monitor of the quality of the link.

Special priority has been given to the maintainability leading to a mean time to repair (m.t.t.r) of 30 minutes. Each unit incorporates the l.e.d indicators necessary to determine the unit status. A faulty unit can be withdrawn from the cabinet in its working form permitting visual inspection or replacement. This facility permits the cabinet to be used as the test frame, minimizing the cost of any additional equipment for field or base maintenace. Digital integrated circuits are not easy to test, particularly memories and microprocessing circuits, and in order to make maintenance simple a digital pattern generator is built into the hardware, permitting fault detection down to component level. The h.p.a continues the modular philosophy, the power supply, control units, and klystron can be withdrawn and replaced easily. Because of the high levels of energy stored within the h.p.a circuits access to these is prevented by a safety interlocking switch which ensures that all components have been fully discharged before repair.

All components have been especially selected for high-reliability military use. Within the design programme the hardware was subjected to the maximum shock, vibration and temperature extremes as defined by DEF 0755 for transportable systems. The mean time between failure (m.t.b.f) as calculated from MIL handbook 217C, is 3000 hours for a non-redundant system. As the tropo inherently employs redundancy for diversity, the loss of one or more paths leads to a soft failure condition.

Transportability was covered in the first article and it is sufficient to repeat that both the radio equipment and the antenna have been designed for transportation over the most hostile terrain or for the equipment to be positioned in the most remote location (figure 3). Generally, the trailer version of the antenna is not ideal for sand or jungle warfare and for this environment a lorry-mounted version of the antenna is available. A tree-guard is provided to protect the dish during movement, but if the paraboloid is accidentally holed, then the fibre glass construction on a metal backing frame permits easy and quick repair. As explained in the first article the equipment can be put into operation within 35 minutes on a pre-prepared pad or at completion of the survey. The equipment can also be completely removed from a site within 10 minutes with a knock-down time of five minutes for the antenna – this being possible by the deployment of quick release clamps interconnecting the waveguide and feed, and the motor drive on the elevation axis. If, in an emergency, the waveguide is accidentally broken before the high-power amplifier is switched off, the safety protection circuits ensure tripping within 10μs.

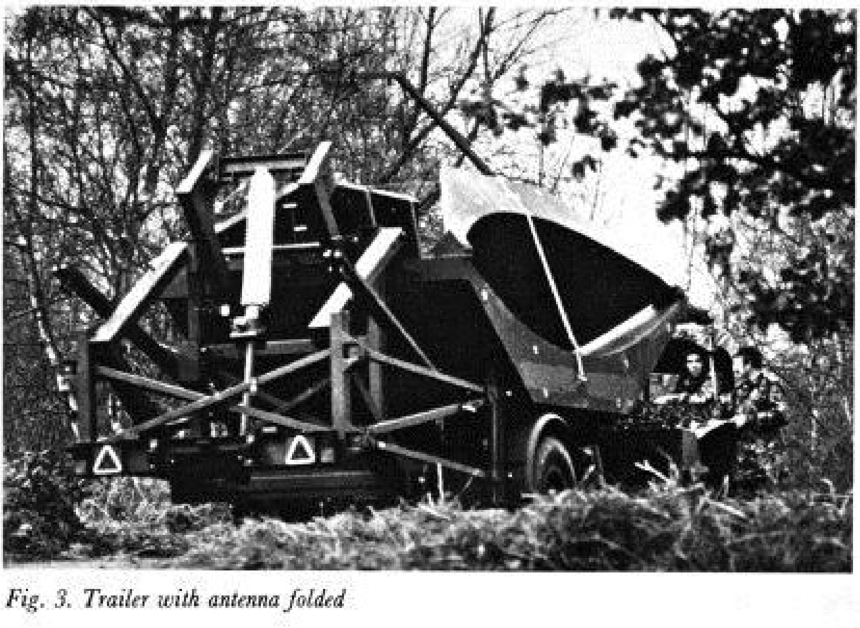


Fig. 3. Trailer with antenna folded

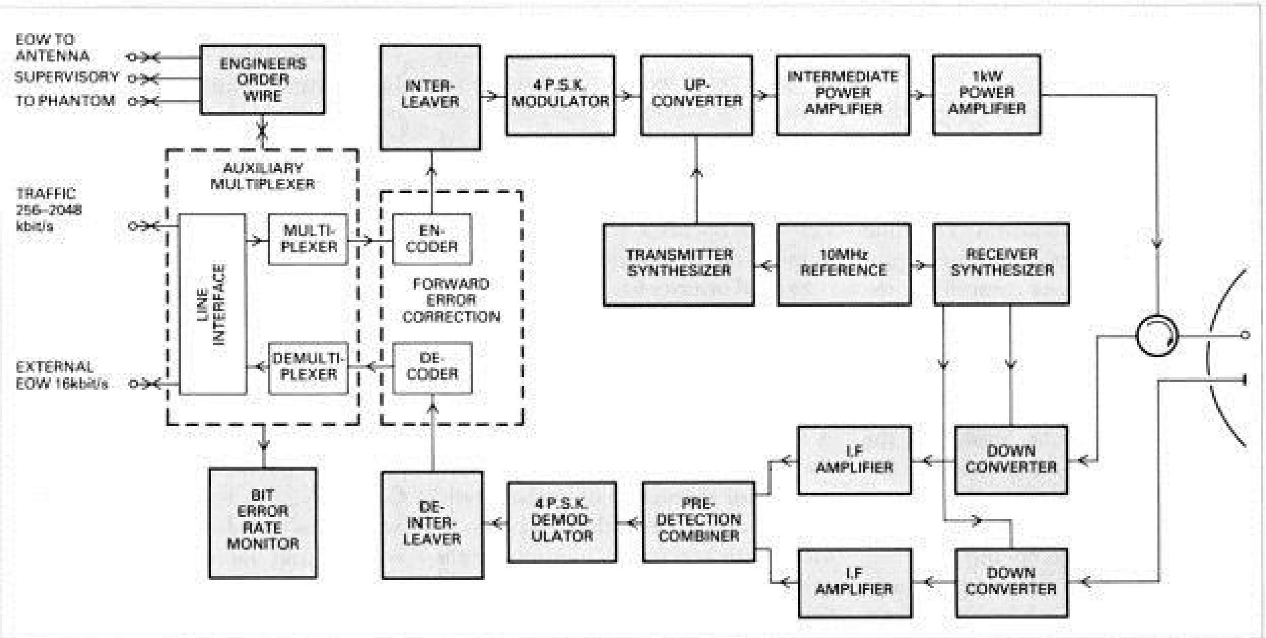


Fig. 4. Block diagram of TACTROPO radio equipment

Radio cabinet and units

The complete r.f/i.f sub-system for a single drive/receive path is shown in figure 4. Three modules form the drive chain; an upconverter which translates the 70MHz i.f signal from the modulator to the final carrier frequency; a synthesizer which provides the local oscillator for the upconversion process and an intermediate power amplifier which raises the output from the upconverter (−8dBm) to either 250mW or 1W depending upon the application. A further five modules form the receive chain; a down converter which translates the r.f signal down to i.f, the receive synthesizer, and the predetection combining system comprising three separate modules.

A full description of each of the above modules is given in subsequent sections.

Figure 5 shows the location of the modules in the cabinet. The receive downconverter modules are located in the top shelf position. Provision is made for fitting four of these to accommodate a quadruple diversity system as may be required for strategic high-capacity fixed-site applications, only two being required for Field Command tactical systems. The next shelf down accommodates the upconverters and the transmit and receive synthesizers. Mounted at the top of the cabinet, adjacent to the main electrical

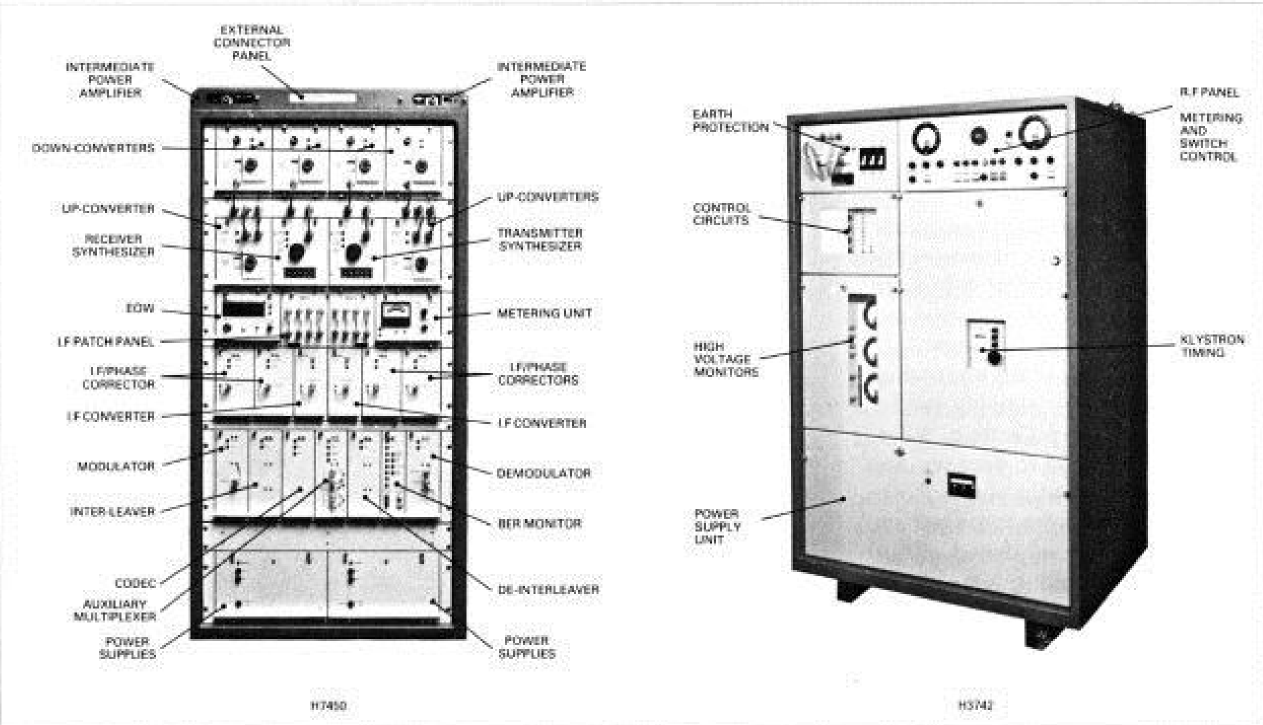


Fig. 5. Cabinet layout

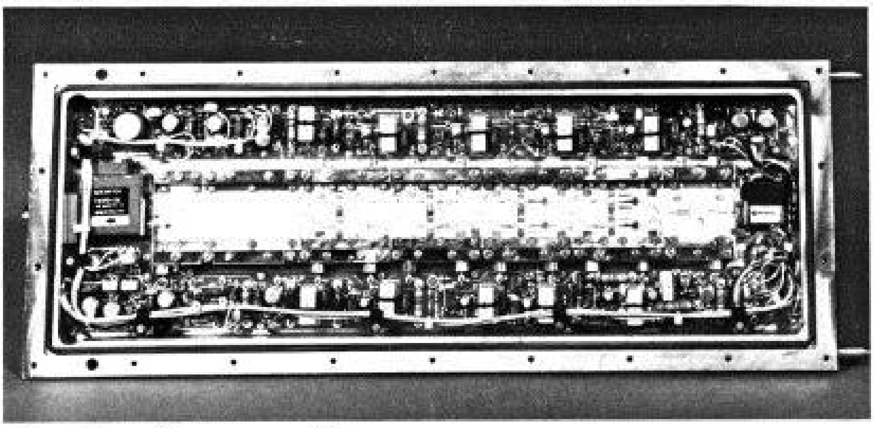


Fig. 6. Intermediate power amplifier

interface, are the two intermediate power amplifiers (i.p.a), one for each drive chain. The r.f output from the i.p.a and the r.f input to the downconverters are both mounted on the front panels and positioned thus in the cabinet, form a convenient interface for connection to the incoming and outgoing feeders.

Directly below the upconverters/synthesizer shelf are the i.f patch panel and metering units. The former enables various loop round tests to be performed to aid fault diagnosis or routine maintenance checks. Of special interest is the modem/i.f interface level which is compliant with CCIR Recommendations and thus permits use with an external modem if required e.g adaptive modems as may be required for bit rates in excess of 2Mbit/s. Measurements of receive signal level for each path, along with the combined signal level and drive output power are displayed on the metering unit. This unit also monitors the voltage rails from the power supplies located at the bottom of the cabinet. All the signal levels mentioned are also taken to the remote interface at the top of the cabinet for external chart recording or relayed via the supervisory channel.

Fitted immediately behind the patch panel is the 10MHz reference oscillator for the synthesizers and the modem. The stability of the reference is such that the worst case error of the receive i.f signal is less than 1kHz, permitting frequency diversity to be used.

The thumbwheel switches on the two synthesizers correspond to the radio frequency, i.e the sum of the local oscillator and the i.f, and this is the normal operation of the equipment. When frequency diversity is required it is possible to select the sum-and-difference component in the two upconverters from the one synthesizer, obtaining a frequency separation of 140MHz from the two drive outputs.

Intermediate power amplifier (I.P.A)

The i.p.a raises the level of the signal from the upconverter module to either 250mW when the H7450 is used in conjunction with the 1kW H3742 HPA for tropospheric scatter transmission, or to 1W for line-of-sight applications.

Figure 6 shows a view of the amplifier with the lid removed. It consists of six thin-film alumina substrate stages, each using GaAs field effect transistors (f.e.t) devices, to provide a gain of 38dB over the 4·4GHz to 5GHz frequency range. Automatic gain control maintains a constant output at the chosen power level, accommodating variations of drive level over the frequency band and preventing amplitude compression of the quadrature phase shift keyed (q.p.s.k) modulated carrier. The latter is essential to avoid spectrum spreading, which would cause interference with adjacent channels.

All amplifier stages, except the first, use two GaAs f.e.ts in a balanced configuration with a 'Lange' coupler at the input and output. This configuration permits easy replacement of substrate modules with no further alignment.

The automatic gain control (a.g.c) function is achieved using a dual gate f.e.t in the first stage amplifier. Gain is controlled by applying a d.c voltage to the second gate, derived from a directional coupler and detector placed after the final stage. The latter also serves to provide a monitor of output power to operate NORMAL and FAIL l.e.ds on the module and for an analogue display on the metering module.

An isolator at the output port of the complete amplifier ensures that it is able to withstand infinite load voltage standing wave ratios (v.s.w.r) without sustaining damage.

Up-converter module

The upconverter converts the 70MHz i.f signal from the modulator to the final modulated carrier frequency. A view of the module is shown in figure 7.

Following preliminary i.f amplification conversion to r.f is accomplished using a balanced 'rat race' Schottky diode mixer operating in a linear mode to prevent spectrum spreading of the

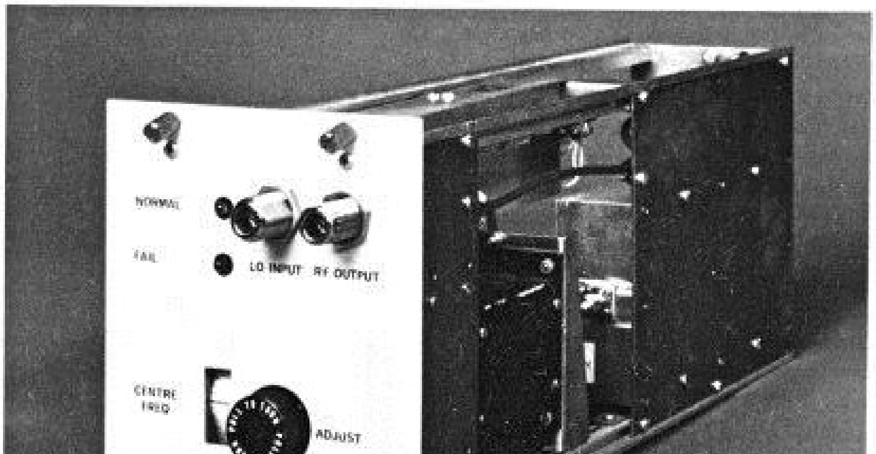


Fig. 7. Up-converter

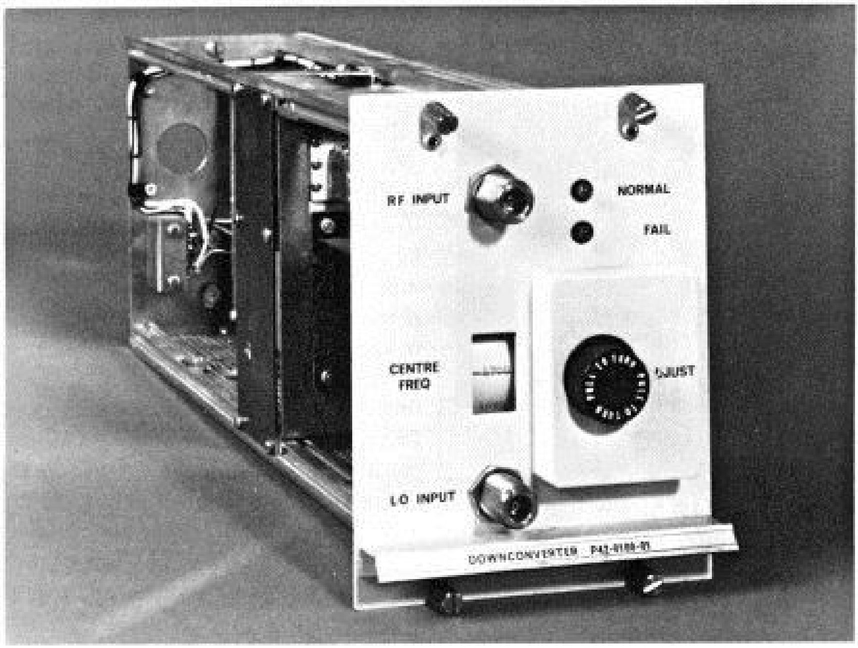


Fig. 8. Down-converter

phase shift keyed (p.s.k) digital signal. The desired mixer product is then selected by a six-pole, 20MHz wide Chebyshev filter. A low-level power output detector drives the l.e.d status indicators on the module's front panel and gives an alarm if the output power drops 6dB below the nominal level. Thus loss of either the local oscillator or the modulator signal is immediately indicated.

Down-converter

Additional to the necessity for a low noise figure is the need to protect the equipment from unwanted signals emanating from adjacent communication systems or from the transmitter diplexer to the same antenna as the receiver. A narrow band r.f filter is therefore essential at the receiver input to avoid damage or possible intermodulation distortion. The filter loss adds directly to the receiver noise and an extremely low noise figure is therefore demanded of the preamplifier for optimum threshold. GaAs f.e.ts have demonstrated their noise superiority over bipolar devices with noise figures less than 1dB under optimally-matched conditions. Such devices have been used in the downconverter low-noise amplifier to obtain a noise figure of better than 2·5dB over the entire frequency band (figure 8). The difference between the device noise figure and actual performance is the result of inability to optimally match the f.e.t for the minimum noise figure over the entire band and because of losses in the input isolator.

Combined with the loss of the preselector filter the noise figure of the receiver is less than 4·5dB for a minimum transmitter/receiver separation of 80MHz.

Following amplification by the low-noise amplifier (l.n.a) the r.f carrier is downconverted to 70MHz. An image suppression mixer is used in order to restrict noise from the l.n.a at the image frequency. By the adjustment of plug-in links in the mixer, image frequencies either above or below the local oscillator frequency may be suppressed, thus allowing frequency diversity operation when the received signals are separated by 140MHz, i.e plus and minus 70MHz about the local oscillator frequency.

Following mixing, an i.f pre-amplifier acts as a buffer stage to prevent the external load affecting performance.

Predetection combiner

The predetection combiner shelf unit combines the functions of i.f filtering, amplification and phase correction. The i.f filters are immediately prior to a.g.c amplification and combining. Four bandwidths are available to meet the range of digital speeds handled by the H7450. Following filtering the signal is raised in level to +1dBm for input to the active phase corrector. The a.g.c amplifier has a maximum gain of 80dB with an a.g.c range in excess of 60dB. In parallel with the main i.f amplifier is a 60dB logarithmic amplifier for monitoring the receive signal level in each path.

The actual predetection combiner comprises an active i.f phase corrector module (figure 9) for each signal path, a passive combiner, which adds the signals together, and an i.f converter (figure 10). The i.f converter's function is to restore the frequency of the combined signal from the passive combiner back to 70MHz after it has been offset to 50MHz by the action of the phase corrector module.

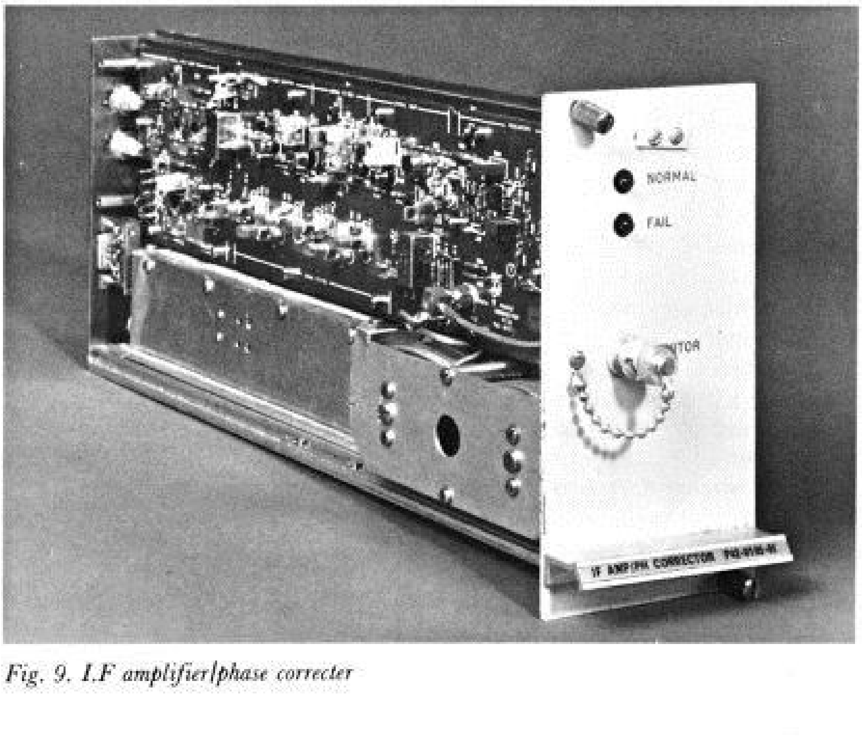


Fig. 9. I.F amplifier/phase correcter

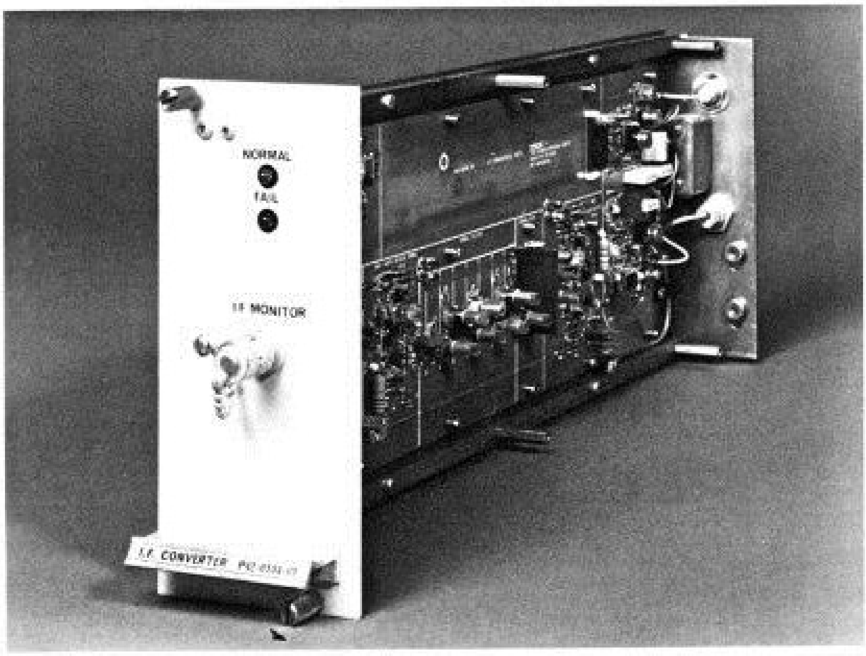


Fig. 10. I.F converter

The phase corrector is best explained by reference to figure 11a. Consider a signal of angular frequency ω_1 and arbitrary phase θ at Point A. Another signal with angular frequency ω_2 and phase ϕ is at Point B. These two signals are mixed together in Mixer 1 and the difference signal $(\omega_1-\omega_2)$ has phase $(\theta-\phi)$. This component and the original signal are mixed in Mixer 2 and the difference component again extracted. This has the form

$$\omega_3=\omega_1-(\omega_1-\omega_2)=\omega_2$$

and phase $\quad =\theta-(\theta-\phi)=\phi$

The phase of the signal at the second mixer output has no relationship to the phase of the input signal, but has the same frequency and phase as the signal at Point B thus enabling the output from Mixer 2, after filtering and amplification, to be fed back to Point B to form a regenerative loop.

The signal ω_2 (ϕ) is used as an input to several circuits of the type described, (figure 11b). Irrespective of the relative phases of the input signals, all will be translated to the output with the same phase, ϕ. Therefore when they are combined, they will add on a voltage basis. However, any noise components associated with the signals will be non-coherent and will add on a power basis. The result is an improvement in signal-to-noise ratio of the combined signal compared with that of individual signals.

A further property of the phase corrector circuit is its square law transfer characteristic. This is a natural consequence of the behaviour of a mixer run below saturation, which results in the output being proportional to the product of its two inputs. Thus, referring to figure 11b, for a constant signal at Point B, a change in level of the signal at A will result in corresponding changes in level to both inputs of Mixer 2. Hence the square law transfer characteristic which is exploited to yield maximal ratio combining. It can be shown that this form of combining yields the optimum signal-to-noise ratio.

Synthesizers

The frequency synthesizers for the transmit and receive local oscillators are identical. They provide frequency selection in 100kHz steps over the 4·4GHz to 5GHz band with a stability of 1 in 10^8.

The choice of synthesizer configuration is an extremely important consideration in ensuring that the system performance is not impaired by phase noise. Although fully electrically tuned synthesizers are attractive in that they are extremely simple to use, and the change to a new frequency is virtually instantaneous, inherently they are liable to produce phase noise. The only configuration found capable of meeting the stringent phase noise specification necessary for digital TACTROPO comprised a manually tuned r.f oscillator, phase-locked via a fixed divider to a 100MHz synthesizer module. Thus tuning is accomplished in two steps, first the synthesizer section is set to the required frequency using a direct reading thumbwheel switch and this is followed by adjusting the oscillator manual control for an 'in lock' indication. In practice this is found to be a very simple operation and the complete cycle can be accomplished in less than 30s.

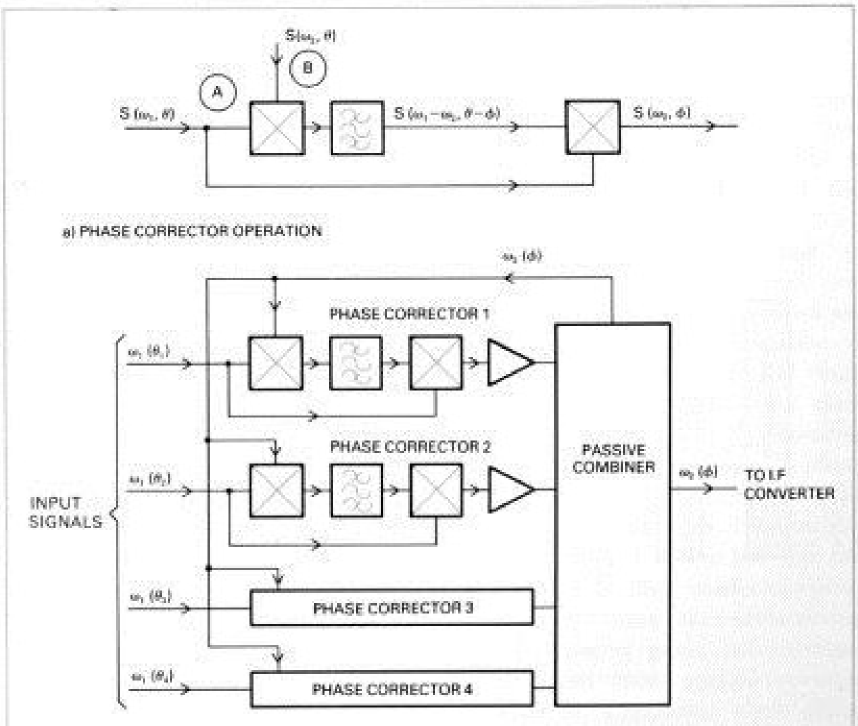


Fig. 11. Pre-detection combiner

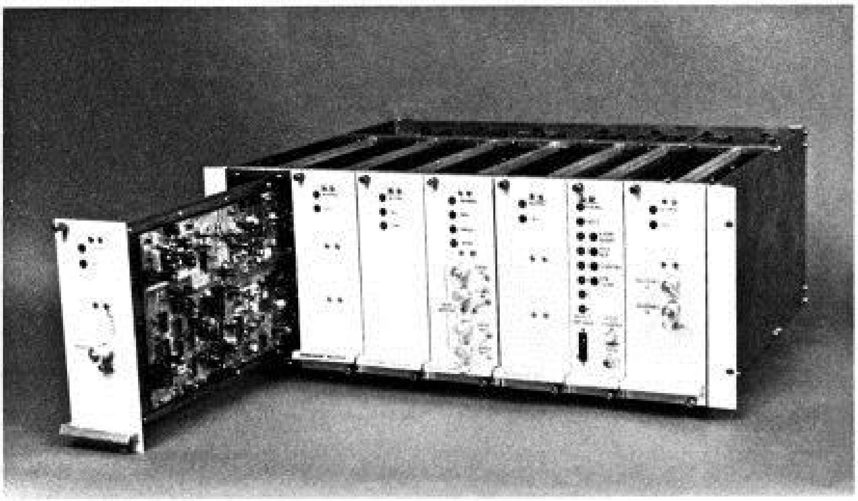


Fig. 12. Digital sub-system

Digital sub-system

The digital sub-system occupies a single shelf within the cabinet, being located immediately above the power supplies. In its most general configuration the equipment comprises the seven modules illustrated in figure 12 and depicted in block diagram form in figure 13.

As shown, the sub-system provides interfaces to the external traffic delta-multiplexer / cryptographic equipment on the one hand and 'via the cabinet patching panel' to the i.f elements of the drive/receive on the other. Twin modulator outputs are provided as required for driving two upconverters/h.p.as and on the receive side, a single demodulator input is derived from the maximal-ratio pre-detection combiner.

The digital sub-system has been designed for compatibility with the Eurocom D/1 hierarchy of traffic rates, and can thus accept multiplexed message streams at bulk rates of 256, 512, 1024 and 2048kbit/s. Using 16kbit/s syllabically companded delta modulation for the basic voice encoding process, these rates correspond to channel capacities of 16, 32, 64 and 128 channels respectively, of which a small overhead is utilized for multiplexer and crypto end-to-end synchronization. The selection of a particular transmission rate is achieved by link selection within the 'signal processing' modules and utilization of baseband filters of the appropriate bandwidth within the p.s.k modulator and demodulator.

The cryptographic equipment may be specified or not, at the user's discretion. When employed, it ensures security of the transmitted message information but does not entail any increase in the bandwidth of the radiated signal: all signalling and housekeeping functions necessary to achieve and maintain mutual end-to-end synchronization of the cryptographic equipment are incorporated within the multiplexers, in accordance with the Eurocom D/1 recommendation.

A notable feature of the digital sub-system is the provision made for transmitting voice order wire and supervisory information in addition to the incoming traffic. Such facilities are important in the operational role where it is necessary to maintain good contact between the operating staff at each end of a link, and to convey key alarm and status signals without encroaching on the number of communication channels available to the end users. An Auxiliary Multiplexer has been incorporated within the Digital sub-system to provide three additional 16kbit/s service channels which are used for such housekeeping purposes – further details are presented later.

Other factors which have been

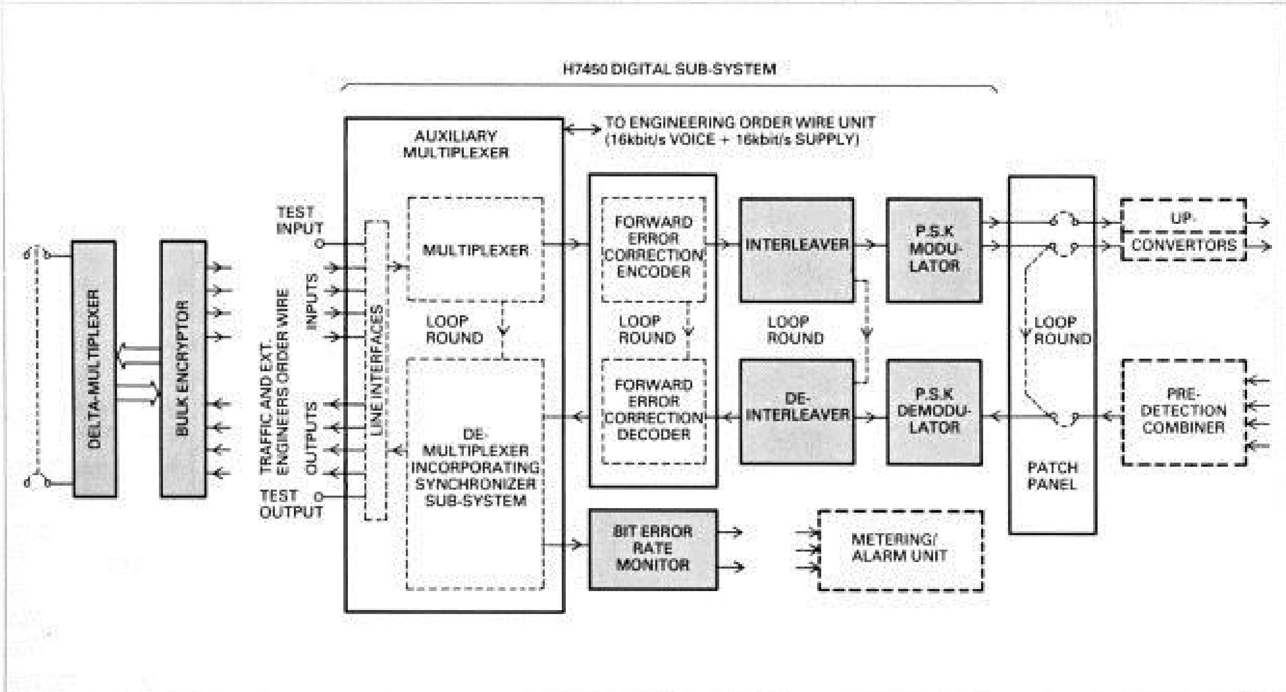


Fig. 13. Block diagram of traffic multiplexer and H7450 digital sub-system

influential in determining the overall configuration of the digital sub-system are:
1) the utilization of a conventional, rather than an adaptive, p.s.k modem and
2) the desire to achieve operational compatibility with dual-diversity r.f equipment configurations (as well as quadruple) at average bit-error rates down to 1 in 10^3.

The former constraint imposes an upper bound on the feasible signalling speed due to the multipath propagation dispersion encountered in the transmission medium. However, for moderate channel capacities and for the link deployments envisaged for tactical applications, the approach provides a compact and cost-effective solution to the problem of conveying digital information via the 'hostile' tropospheric scatter propagation medium.

The second factor, together with the recognition that, at the moderately low information transmission rates encompassed, the intrinsic communication system is power limited, has promoted the use of forward-error-correction coding. This reinforces the processing gain of the maximal ratio predetection combiner and leads to an overall performance – for dual diversity configurations using only one antenna per terminal – approaching that of a conventional quadruple-diversity system.

In the event that the r.f/i.f subsystems are configured for conventional quad diversity, the forward error correction codec and the associated interleaver and de-interleaver may be omitted; the basic link performance under these circumstances is such as to enable the overall performance objectives to be achieved without the need for the additional performance enhancement – and unavoidable bandwidth expansion – provided by the coding process.

In the event that the three coding-related optional modules are not fitted, the Auxiliary Multiplexer interfaces directly with the P.S.K Modulator and Demodulator, 'bridging units' being used to provide continuity of the shelf wiring. The Bit Error Rate Monitor depicted in figure 12 constitutes an important item of built-in test equipment and provides a continuous indication to the user of the link overall performance. Details of these, and of the other modules which have been mentioned, follow.

Auxiliary multiplexer/de-multiplexer

This module, which incorporates the baseband interface circuitry, combines and distributes the various information-bearing signals. In addition to the incoming (rate selectable) traffic signal the Multiplexer accepts two 16kbit/s order wire inputs – one from the EOW Unit, one externally derived – and a further 16kbit/s digital stream conveying encoded supervisory information. These signals are multiplexed, together with an internally generated 16kbit/s framing signal, to produce a composite output signal for further processing.

Synchronous transmission is employed, the multiplexer timing subsystem being locked to the incoming traffic clock. This gives the important advantage of avoiding problematical justification processes. However, due provision – in the form of buffer stores and phase-locked timing extraction circuitry – is made at both the transmitter and the receiver to counter the problems of systematic jitter.

On the receive side, the various signals are de-multiplexed and routed to the relevant output ports. However, it is necessary first to acquire and then to maintain correct frame lock, and this is accomplished by the all-important synchronization subsystem. The latter is required to function correctly under extreme fading conditions, even when the link 'instantaneous' bit error probability is such that speech is rendered temporarily unintelligible. Sophisticated digital processing circuitry – operating on the framing sequence – is utilized to achieve this objective.

PSK modulator and demodulator

The digital modem is of the four-level coherent phase-shift-keying variety. It can operate in both the 'conventional' and 'offset' modes and over a range of field-changeable signalling speeds. The latter embrace the traffic rates given earlier (plus the Auxiliary Multiplexer 64kbit/s net 'overhead') and the optional use of forward-error-correction coding. The coding doubles the transmission rate.

To maximize the tolerance to propagation-induced signal distortion, a modem filtering scheme featuring low inter-symbol interference is employed. A cosine roll-off spectrum with 100% roll-off factor is produced at the regenerator input, the critical filtering being shared equally between the transmitter and receiver. The actual filters are implemented in baseband form and incorporate simple group-delay equalizers. The low-pass solution obviates complex, expensive, high-Q filters centred on the i.f of 70MHz and has advantages in respect of freedom from quadrature distortion, etc.

The PSK Modulator is of the linear variety and the Demodulator is of a particular configuration which promotes the use at the receiver of the stated low pass 'channel shaping' filters. The incoming 70MHz signal is translated down to baseband, filtered, then upconverted to 3MHz. The normal processes of carrier and clock recovery and coherent detection are then implemented at this convenient frequency and are followed by regeneration and differential decoding. Although a 'near-zero' intermediate frequency is employed within the demodulator, no attempt is made directly to achieve true coherence with the incoming 70MHz signal in the downconversion process.

Carrier recovery invokes the X4/÷4 principle with a high-Q crystal filter being used to enhance the signal-to-noise ratio. This circuit also acts as a frequency discriminator and produces an automatic frequency control (a.f.c) voltage to control the oscillator in the demodulator front-end downconverter. The feedback path incorporates a track-and-hold circuit which 'freezes' the control voltage under deep fade conditions when the normal a.f.c is ineffective, thereby minimizing frequency drift.

The 'distortionless' method of clock-recovery is employed, high-pass 'pre-filtering' being used prior to the non-linearity. Clock information is derived from both the I and Q channels, the timing signals being combined to enhance the signal-to-noise ratio before being applied to the phase lock loop (p.l.l) which determines the overall noise bandwidth. The combining arrangement differs between the 'normal' and 'offset' modes of operation, account being taken of the timing signal changing phase relationships. In the 'offset' mode, special provision is made to counteract clock phase inversions induced by cycle-skip events in the carrier-recovery subsystem.

To reduce clock cycle-skipping to an acceptably low level, the p.l.l bandwidth is made as small as possible without jeopardizing the ability to track systematic jitter. However, to obviate problems during sustained fades, the loop control voltage is disabled – using a second track-and-hold circuit – and the loop enters the 'flywheel' mode whenever the Demodulator input signal-to-noise ratio falls below a pre-determined threshold level. Flywheel periods of up to 10s, during which time the voltage controlled oscillator (v.c.o) phase drift was held to within 90°, have been achieved. Bit count integrity is thus preserved when normal timing recovery is resumed.

FEC codec and interleaver/ de-interleaver

The forward error correction encoder and decoder are housed within a single module. They implement a rate-½ block code derived from the classic Hamming (7, 4) code. The derived (8, 4) code was previously known to detect all double errors in a codeword but is, in fact, capable of correcting certain double error events. The design of the code has been optimized for the present application to capitalize on this ability.

In spite of the use of interleaving the sustained fades which can be encountered in the tropo medium cause error doublets (i.e errors in adjacent bit positions) to arise within a given codeword with significantly greater probability than other double-error combinations. By concentrating the decoder's double-error-correcting capability on the error doublets, a superior overall system performance is achieved. With the implemented design, the decoder can correct five out of the set of seven error doublets which can occur.

The Interleaver and De-interleaver are a necessary adjunct to the FEC Codec: although block codes can perform well when errors are uniformly distributed in time, the coding gain falls rapidly in the presence of error bunching. Since, in the tropo environment, fades can persist for periods which are long compared with the 8-bit codeword duration, multiple bit errors within a codeword arise with significant probability, particularly when the system is operating near to threshold. To counter this problem, time-dispersal of the coded message sequence is invoked; the individual bits forming a given codeword are transmitted with a prescribed minimum spacing between any two elements. Bits from other codewords are interleaved into the resulting 'guard times' to preserve the net transmission rate.

The Interleaver provides the above function at the transmitter, with the De-interleaver being used in a complementary manner at the receiver, i.e to re-order the received bits into the original sequence for application to the FEC Decoder. Extensive computer simulations have established that for tropo systems operating in the 4GHz to 5GHz band, an interleaving delay of about 25ms is the optimum for the particular code described earlier. This results in a total processing delay for any given codeword of 168ms.

At the maximum transmission rate entailed, the stated interleaving delay produces a requirement for the interleaver and de-interleaver each to store in excess of 350kbit of information. With a temporary storage requirement of this magnitude, it is impractical to utilize shift registers as the memory elements and use is therefore made of 16kbit random access memories (RAMs). In their fully-equipped versions, the interleavers and de-interleavers each accommodate 24 such devices together with the associated programmable read only memory (PROM) based control sub-system.

Bit error rate monitor

Overall performance monitoring is accomplished by processing the received framing information. The synchronization sub-system within the Auxiliary Demultiplexer detects transmission errors by correlating each received framing word with a stored, uncorrupted replica, and routes corresponding 'bit error' pulses to the bit-error-rate (b.e.r) monitor.

To facilitate statistically reliable computation of the short-term average b.e.r over the operational range of interest, the monitor is provided with four switch-selectable 'timebases'. Thus, error pulses can be accumulated over repeated (contiguous) observation intervals of either 1·25s, 12·5s, 125s or 1250s (20 min). Each count is processed to produce a smoothed b.e.r indication, i.e one averaged over the selected observation interval.

To alert users to poor propagation conditions – or possible equipment faults – threshold counters are incorporated which trigger an alarm output when a given b.e.r is exceeded. The threshold value can be preset over a wide range.

Performance

The performance of a tropospheric scatter system, like any other radio system, depends on the path co-ordinates, frequency of operation, fading characteristics, dispersion and the physical parameters of the equipment.

Peculiar to the tropo path is the long term variation of the scattering losses resulting from changes in temperature, pressure and windspeeds giving a statistical distribution about the median path loss for various service availabilities and for different world zones. Graphs and formulae enabling the calculation of tropo paths are published by CCIR and the National Bureau of Standards. As the improvement from coding is generally independent of the median loss the calculations can be treated separately except in relation to the short term fading rate.

Hence the link budget enables the calculation of the signal-to-noise ratio at the output of the demodulator channel shaping filters, which directly determines the unprocessed bit error rate. This is a function of the physical characteristics of the equipment i.e antenna gain, output power, feeder losses, noise figure, bandwidth etc, along with the path loss and diversity option.

To this bit error rate is added the improvement due to coding and time interleaving for the short term cyclic variation of the received signal following combining.

As all of these functions can be computed a hand-held programmed calculator is available for the operator permitting a very quick evaluation of the overall path characteristics and optimization of position and take-off angle. In may cases, as discussed in the first article, pre-surveyed locations would be adopted but the use of TACTROPO is not restricted to these.

Link budget for 16-channel system

Received carrier to noise ratio=

+ve	Transmitter power	30dBw
+ve	Antenna gain 4·5m	89·7dB
−ve	Aperture medium coupling loss	L_{am} db
−ve	Feeder losses	1·5dB

−ve Receiver noise figure 4·5dB
−ve median/r.m.s conversion 1·6dB
+ve Noise density 10 log KT 204dB
−ve Bandwidth for 640kbit/s
−ve 10 log 640/2kbit/s 55dB
−ve Path loss 99% availability
L_p dB 84% service probability

Carrier to noise ratio=
$261\cdot1-(L_p+L_{am})$ dB

Typical performance

Table 1 compares the measured bit error rate for a 16-channel coded system against typical path losses for smooth earth, zero take-off angle and negligible dispersion due to multipath as would be expected at this bit rate. The measured results include the implementation margins for the combining efficiency, modem and coding.

TACTROPO is also available in the frequency band 2·3−2·7GHz using exactly the same equipment housing but with new plug-in converters, synthesizers, and klystron, and the table shows that this frequency has particular attractions to desert climates where the overall path loss can be higher.

Conclusion

The two articles which have introduced digital TACTROPO provide sufficient information to enable a potential user to assess whether this method of communication is matched to the scenario being considered. Whilst the equipment is intended as a low-cost rugged, secure, Field Command unit for the transmission at the low to medium bit rate, the equipment is equally capable of being upgraded for higher bit rates by the inclusion of the more expensive adaptive modem. The equipment brings together the latest technology of the optical encryption gun, complex digital processing, low noise and high power transistors.

Over the next decade digital TACTROPO will continue to improve as more powerful methods of signal processing are applied to match the problems of dispersion which occur at higher bit rates. One of the advantages of the Marconi digital TACTROPO is that the radio has been designed with sufficient bandwidth to ensure that future developments can be incorporated at very low cost.

Reference

1. J. D. Rogers: 'Introduction to digital tropo for military communication'; *Communication & Broadcasting*, Vol.6, No.3, pp.3–9.

Table 1: Typical performance of digital TACTROPO

Frequency	Path length, km	99% L_p+L_{am}, dB	Carrier/Noise ratio, dB	E_b/N_o, dB	Measured b.e.r at 640kbit/s
Maritime temperate climate – 16-channel + EOW + supervisory coded transmission					
5·0GHz	100	230·5	30·6	27·6	
5·0GHz	150	240·9	20·2	17·2	$1\cdot5\times10^{-5}$
5·0GHz	200	245·9	15·2	12·2	3×10^{-4}
5·0GHz	250	248·2	12·9	9·9	$1\cdot5\times10^{-3}$
Desert climate 16-channel + EOW + supervisory coded transmission					
2·7GHz	100	236·25	24·8	21·8	1×10^{-6}
2·7GHz	150	246·25	14·8	11·8	5×10^{-4}
2·7GHz	200	252·5	8·6	5·6	5×10^{-3}

RÉSUMÉ

Ce second article traite du matériel de la boîte radio et du fonctionnement qui lui est relatif. Les diverses méthodes de combinaison y sont expliquées et les attributs et applications de chacune d'entre elles y sont discutés. Les traits caractéristiques du matériel et de son fonctionnement sont décrits, ainsi que certains aspects de son entretien et de sa régularité de fonctionnement. L'emplacement de chaque module est indiqué, avec son fonctionnement. La dernière partie traite des données relatives à la performance du matériel.

ZUSAMMENFASSUNG

Dieser zweite Artikel befasst sich mit der Ausrüstung im Radiogehäuse und der damit verbundenen Praxis. Es werden die verschiedenen Kombinationsmethoden angeschnitten und die jeweiligen besonderen Eigenschaften und Anwendungen besprochen. Ausserdem werden hervorstechende Merkmale der Ausrüstung und ihrer Wirkungsweise beschrieben und Bezug auf Wartung und Zuverlässigkeit genommen. Es wird über die Lage und Wirkungsweise jedes Moduls berichtet, und ein letzter Abschnitt befasst sich mit den Leistungsdaten.

RESUMEN

Este segundo artículo trata del equipo de la caja de radio y la práctica relacionada con el mismo. Se exponen a grandes rasgos los diferentes métodos de combinar y se discuten los atributos y aplicaciones de cada uno. Se describen las características principales del equipo y su funcionamiento juntamente con los aspectos de entretenimiento y seguridad funcional. Se da informe de la situación y funcionamiento de cada módulo y una sección final trata de los datos de actuación.