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Introduction to digital tropo for military tactical communication

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Summary This introductory article describes some of the advantages and cost savings accrued by deploying Marconi's new single-antenna secure tropo system, digital TACTROPO, in military field command networks. Special attention is given to the speed at which the system can be made operational, the level of security in various applications, and the culmination of technology which has made a single-antenna system possible.

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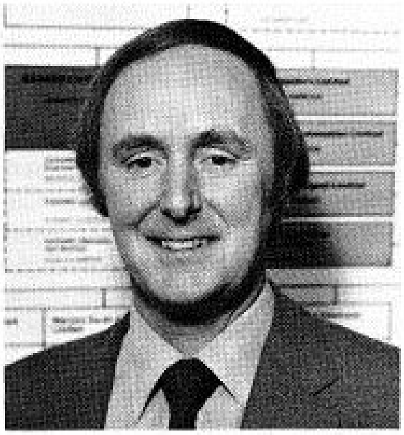
Mr Rogers joined Marconi Communication Systems Limited in 1966 and between 1975–80 was Engineering Manager responsible for the development of satellite, tropo, and line-of-sight microwave systems. In this capacity he was responsible for the development of digital tactropo.
Since 1980 Mr Rogers has been responsible for the product planning associated with new microwave products.



Introduction

This article is the first of two describing digital tropo for military communications. It outlines the advantages that digital tropo offers to the Field Command tactical network, the basic concepts realizing a single-antenna design, and the deployment and security of the system. The second article will describe the equipment hardware and the performance measurements.

Tropospheric scatter communication has advantages inherent in its mode of propagation which have led to its extensive use in military networks. However, until recently it has been unable to match the mobility and security of service which has become of such prime importance to the modern army. The introduction of Marconi's high-performance digital TACTROPO equipment, which employs a single transportable antenna for secure communication over paths of 100–250km, directly challenges the current scene which uses large quantities of line-of-sight (l.o.s) equipment and manpower in the war zone. This technological breakthrough heralds a new era in military communications.

The total complement of digital TACTROPO equipment can be transported using a single prime mover with a trailer antenna (figure 1), and the elapsed time between moving on to a previously-surveyed site and communicating is approximately 35 minutes.

The deployment of mobile tropo in a nodal network reduces the equipment and manpower to approximately one fifth of that required by its line-of-sight counterpart, reducing the overall cost for the service and its protection. This is particularly true in countries where the terrain is barren and the problem of protecting installations is acute.

Table 1: Typical manpower and equipment saving in a Field Command network

	Tropo	L.O.S
Transmitters	2	10
Receivers	2	10
Generators	2	10
Antennas	2	10
Signal operators	4	20

The troposphere cannot be obliterated and communication is rapidly restored following a nuclear blast. In this respect the survivability of a mobile or strategic tropo network is infinitely

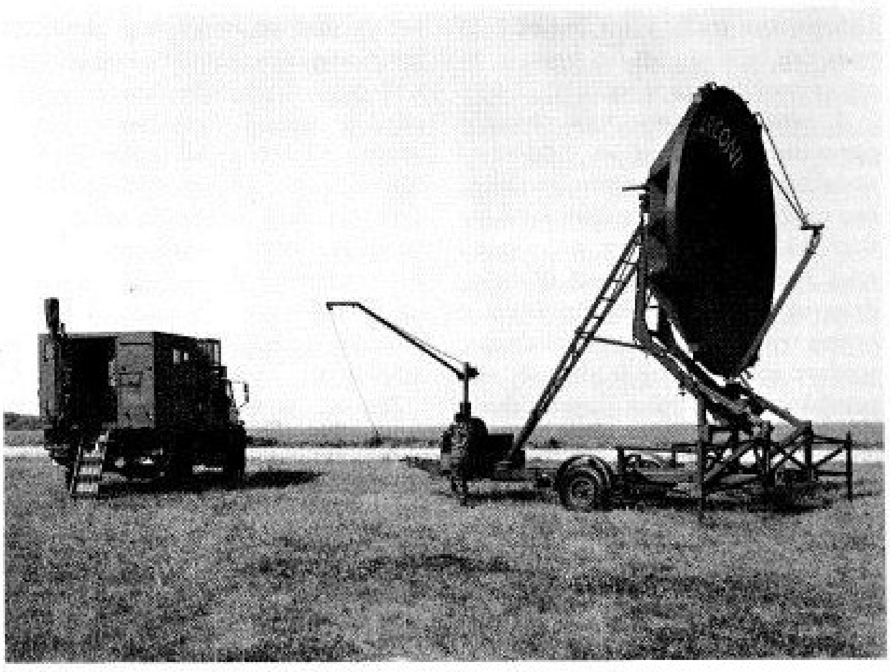


Fig. 1. Digital TACTROPO – total complement of equipment using single prime mover

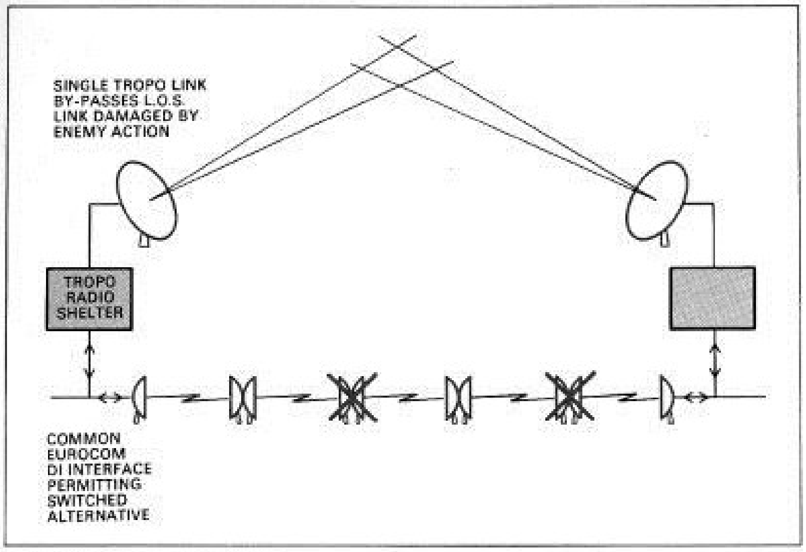


Fig. 2. Tropo as a survival link

superior to that of a satellite network where the vulnerability of the satellite limits its service to the marshalling of troops, local skirmishes and peace-keeping exercises. The multiple-satellite philosophy adopted by the major powers is beyond the resources of the majority of countries wishing to protect their borders.

In the switched-redundancy mode (figure 2), digital TACTROPO can quickly bridge sections of a damaged link which might have been sabotaged by internal forces or knocked-out by a pincer action, and this can be achieved over the most hostile terrain. The interface established by the European Standards Committee, (specification Eurocom D1) is completely compatible with the Ptarmigan radio network as adopted by the British Ministry of Defence and traffic via a line-of-sight relay can be re-routed via tropo without costly interface units.

A detached formation secretly operating away from an established nodal base, perhaps in enemy territory, can establish communication knowing that the highly-directive tropo antennas reduce the likelihood of being detected. In addition the narrow radio beams reduce the threat of electronic warfare and blocking is virtually impossible without flying directly down the radio beam.

The advent of a single-antenna transportable digital tropo system permits a degree of freedom not previously possible with a line-of-sight network and, whilst the two systems will be complementary, this new capability will reshape the pattern of military communication during the 80s.

Single-antenna technology

The single-antenna tropo link is made possible by the marriage of low-noise solid-state devices with the micro-chip memory, leading to an improved signal recovery via a high degree of digital processing not previously practicable.

The availability of the field effect transistor (f.e.t) displaying noise temperature of around 100°K improves the sensitivity of the receiver to the point where the atmospheric temperature, as seen by the antenna, becomes a dominant factor.

The deployment of diversity reception with pre-detection combining, in which radio signals received via independent paths are combined before demodulation, both reduces Rayleigh fading and improves the carrier-to-noise ratio of the combined signal. This well-proven technique, now being applied to digital transmission, has so improved the availability of civil tropospheric-scatter analogue networks that they are fully accepted as part of national and international links. Reducing the fade margin along with improving sensitivity leads directly to smaller antennas and high-power amplifiers.

Having improved the sensitivity of the radio path we can turn to the advances in digital techniques which are available to reduce the effect of inter-symbol interference and block errors which have bedevilled digital tropo over the years.

Signals which are received from different parts of the troposphere, within both the transmit and receive beams, can arrive at different times. When the time difference between symbols approaches one period the delayed symbol will completely corrupt the wanted symbol leading to intersymbol interference and high error rates. Whilst it is possible to arrange for each symbol to pass through an equalizer, this equipment is expensive. A simpler approach is to arrange for the symbol length transmitted through the troposphere to be as long as possible so that dispersion becomes less of a problem. Whilst this remedy suggests a reduction in channel capacity, there are a number of recovery mechanisms available for the tactical situation. Delta modulation, as used for military systems, requires only 16kbit/s per channel compared with the 64kbit/s used by pulse-code modulation. The modulation method of multi-level phase-shift keying, where one symbol contains two or more bits of information, significantly reduces the number of symbols needed to transmit the same information through the troposphere. In the equipment under discussion, four-phase modulation is adopted requiring only half the number of bits of binary phase shift keying (p.s.k).

Two further digital techniques are deployed in Marconi digital TACTROPO which both enhance the system's performance by the correction of random errors and obviate block errors. These techniques, which require the storage of 300kbit/s, have only become possible with the microchip memory which permits the activity to be contained within an area approximating 10 × 10cm.

Forward-error-correction (f.e.c) encoding is a method by which a block of coding digits is added to the message digits such that errors occurring in the message can be detected by the code and corrected. The reduction of the signal-to-noise ratio by the addition of the code word to the message stream is more than offset by the power of the error correction code and the system is comparable with an analogue f.m system where the bandwidth is increased in order to improve the signal-to-noise ratio. Digital TACTROPO employs a modified Hamming 8,4 code which, under most circumstances, will correct up to two adjacent errors in a message block of four symbols thus giving the system its high performance.

All coding systems rely on a random distribution of errors which is not compatible with a fading environment in

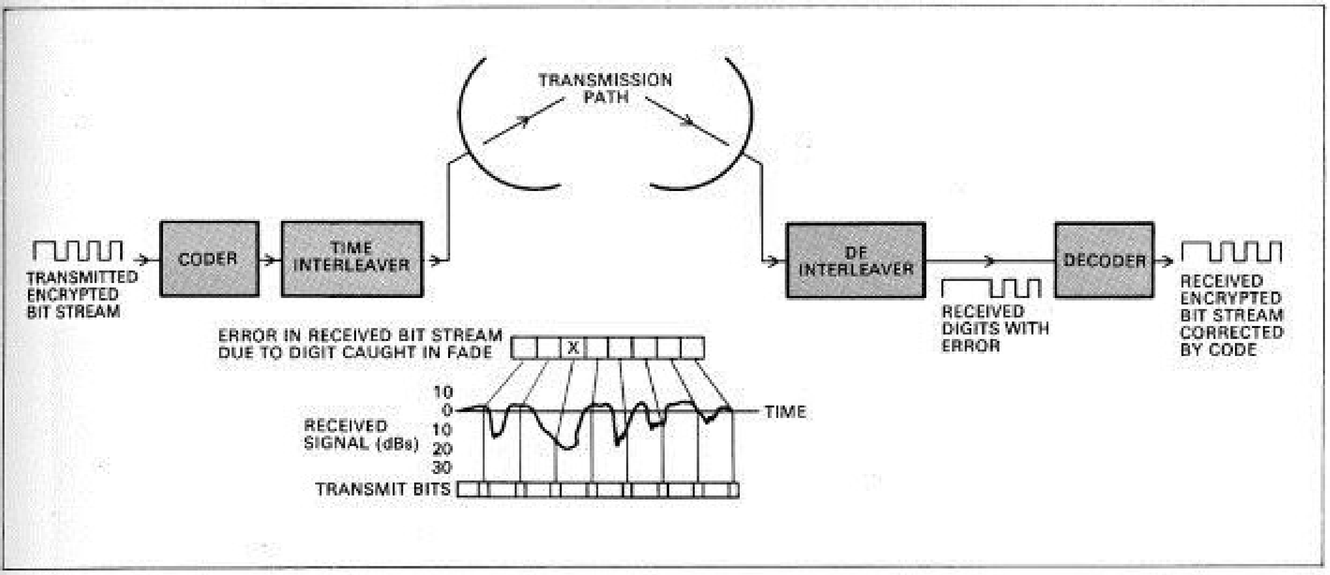


Fig. 3. Coding with time interleaving

which block errors obliterate both the message and code. The occurrence of block errors can be obviated by a process of interleaving in which adjacent bits are spaced in time to avoid being caught in the same fade, and other bits are interleaved into the time space. A separation of 24ms between adjacent bits, requiring the storing and forwarding of bits in a pre-described manner is sufficient to permit, in conjunction with the error code, a system improvement equivalent to going from dual diversity to quad diversity. Hence the improvement generated by the processing of the digits in the time domain is equivalent to the saving of one antenna, leading to a single-antenna design with, in effect, quadruple diversity performance. It is easier to follow the diagram (figure 3) if this process is understood. The input bit stream represents the encrypted bulk traffic including the order wire and supervisory channels. To this stream is added the additional bits of the forward error correction code, four code bits for each four bits of message.

The eight-bit block, consisting of the message and code, is transmitted with a 24ms delay between each adjacent bit in order to avoid more than two bits being destroyed due to a fade. The next eight bits are interleaved to form a composite bit stream. It is seen that the third bit is destroyed during transmission due to a fade and that following reception and the reassembly of the bits in the correct order the third bit is still in error. The decoder however corrects the bit in error and the final received bit stream emerging from the decoder is identical to that of the input.

Deployment of digital TACTROPO in military networks

Two main communication infrastructures are used in military communications which can be divided broadly into 'Strategic' and 'Tactical'.

Strategic networks interconnect ministries, regional command centres, air bases, and surveillance and detection centres whereas the tactical network interconnects the Field Command comprising of Corps, Divisional and Brigade HQ.

Strategic networks interconnect fixed locations within a country or within an alliance (when they may extend to other continents). Important stations in the system are connected to at least two nodes of a high-level mesh network. Stations which can be temporarily isolated without paralysing the system may be connected to the high-level node via a single spur. When these networks extend for many thousands of kilometres, spanning several countries, a high-performance analogue f.m or 64kbit/s p.c.m circuit is required to ensure adequate quality. Whilst the Marconi digital TACTROPO can be supplied with an analogue modem or a higher-performance digitally-adaptive p.c.m modem to meet the strategic requirement, the purpose of this article is to discuss its role in the Field Command tactical networks where 16kbit/s delta modulation speech is the recommended Eurocom standard.

The tactical infrastructure forms a network interconnecting the Corps, Divisional, and Brigade HQ. This network is transportable but requires to be more mobile the closer the equipment is to the front line. Each major path is connected to at least two nodes of the mesh networks as in the strategic service, and the ability to restructure the network as the battle moves assumes major importance. Special attention has been given both to the mechanical and electrical design of digital TACTROPO which permits it to be operational within 35 minutes of establishing the correct transmit bearings.

Antenna

The transportable antenna forms an integral part of the digital TACTROPO system and has been designed for optimum performance in a cost-effective tactical network. At 4·5m diameter the antenna can either be trailer- or lorry-mounted, fully erected in less than 15 minutes, and aligned for high-performance communication over a span of 250km in less than 35 minutes. The weight, balance and integrated mechanical aids permit this performance to be achieved with only two trained operators. The stability outriggers, levelling jacks and level sensors unfold from the main chassis. A unique feature of the design is the folding reflector in which the two sides unfold to form a parabolic dish. A built-in hoist is provided to facilitate this operation (figure 4).

Whilst the antenna can be raised manually by operating a worm and wheel, a hand-held electric motor accomplishes this operation in less than two minutes. The feed horn with supporting tripod is permanently stowed in the dish for transportation and again

Fig. 4. The 4·5m Tactical Tropo Antenna R2100

the unfolding of this is designed to minimize the time required to deploy.

Two feed horns are available enabling the system to be operated in either frequency- or angle-diversity mode. Sixteen metres of waveguide are stowed on the trailer and can be assembled using quick-release clamps to provide the connection to the radio cabin. Two flexible drives permit an operator to align the antenna in azimuth and elevation from a standing position on the main trailer chassis.

When the antenna is stowed for transit the trailer version is 7·6m long, 2·3m wide and 2·9m high and can be towed across country at a speed of 25km/h. Alternatively it can be transported by rail or in a C130 transport aircraft.

The antenna will remain free-standing in winds of 63km/h and when stayed will withstand winds of 120km/h. It will remain operational in temperatures between −30°C and +55°C and the construction of the dish permits easy repair.

So often new technology has only been applied to the electronics in military networks. In digital TACTROPO extensive effort has been directed towards ensuring that the mechanics are really compatible with a transportable 'fast-into-action' system.

Radio

The radio shelter is designed to house the multiplexer, encryption units, radio cabinet and high-power amplifiers (figure 5). The actual manner in which this equipment is configured may vary between the semi-permanent status for a Corps HQ and the mobile status for a Brigade HQ. At a Corps HQ the radio shelter and antennas forming the two branches of a mesh network may be separated from the operators by 2km and for further safety may be separated from each other. In this mode of operation the multiplexer and encryption units are positioned at a Communication Centre in a radio village and the multiplexed encrypted signal is relayed to the radio shelter via a line or optical link at the bulk bit rate of 256–2048kbit. On entering the radio cabin the line code is removed and the signal converted to the Eurocom D1 interface of alternate mark inversion.

An auxiliary multiplexer, which is housed in the radio cabinet, multiplexes a 16kbit/s engineering order wire (e.o.w) and supervisory channel to the incoming bit stream. A further 16kbit/s channel is also made available for patching through the e.o.w of a line-of-sight network which may interface with the tropo. Forward error correction encoding and interleaving is applied to the composite signal which then modulates a four-phase shift-keyed modulator. The p.s.k signal is converted to the radio frequency, amplified to 1kW and transmitted via the antenna. The receiver recovers two signals which have arrived by independent paths either separated in frequency, angle or space giving the first order of diversity. These are combined at i.f, demodulated, and de-interleaved to form a composite signal including the error code. The forward-error-correction code is then used to correct any errors in the message resulting from the transmission, giving a performance similar to quadruple diversity. The f.e.c bits

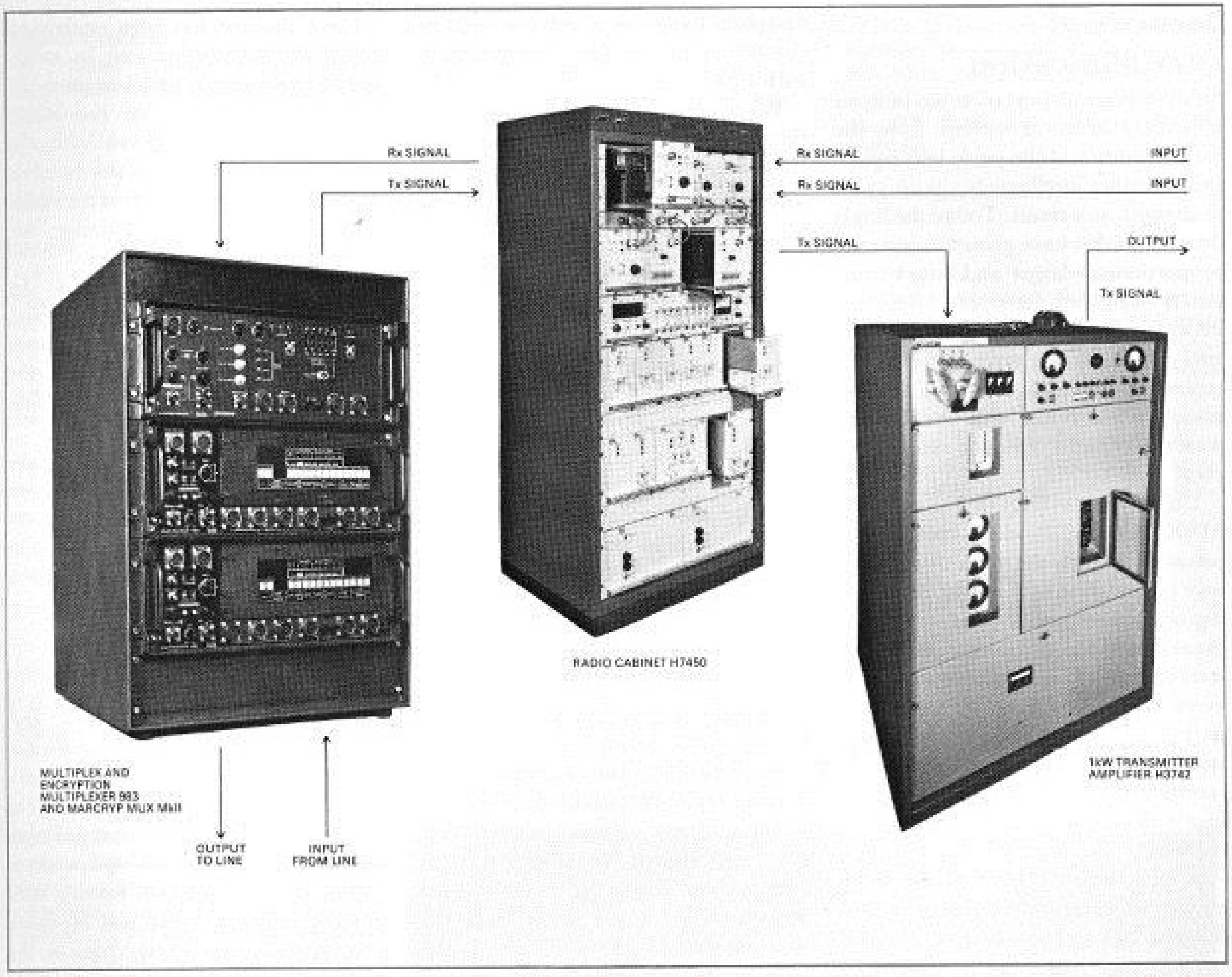


Fig. 5. Radio equipment housed in the radio shelter

along with the e.o.w and supervisory channels are removed from the received bit stream leaving the encrypted traffic which is relayed back to the radio village. In this mode of operation the encrypted line signal ensures both line and link security. However, the 2km connection from the communication centre of the radio village is one of high risk and every precaution is taken to minimize detection from radiation.

When the radio equipment is deployed in the more mobile role nearer the front line of a battle, or in the role of suppressing guerilla action or local border disputes, it is unlikely that a separate communication centre would be established in a distant radio village and in this mode the radio shelter houses the cypher, multiplex and radio equipment. At the connection to the shelter each field telephone circuit is filtered, after which it is patched to an appropriate radio circuit, multiplexed, encrypted and transmitted/received as before. This mode of operation restricts absolute security to those circuits and facilities originating from within the radio shelter, as the local field network is basically insecure. However, in many operations the encryption of the radio link is of prime importance in order to prevent the leakage of intelligence to the enemy's surveillance network, and the security of any local field network can be contained by appropriate screening along with operator discipline.

Special attention has been given to the following features of the radio shelter which have not always been considered in the design of military equipment. The size of the preferred shelter at 2991mm long by 2438mm wide and 2438mm high follows the worldwide acceptance of the ISO Specification as used by all civil container lorries and therefore the shelter can be transported by land, sea and air in its standard form without the provision of a special frame or supports. Electrically the shelter contains the necessary protection against the electro-magnetic pulse resulting from a nuclear blast. In addition the double-skin radio screen attenuates any leakage by more than 80dB. Along with these features the shelter is air-conditioned for the comfort of the operators, protected against sand storms and contains all the normal facilities afforded to military shelters as used by the British Ministry of Defence.

Generator

When operating, the prime power requirement is around 11kVA covering one high-power amplifier, radio equipment, multiplexer, air conditioning, lighting, service points etc. To cover the inrush this requires a 15kVA three-phase generator. Many defence establishments have preferred generator sizes which do not necessarily match the exact requirement and for many ministries the standard 24kVA generator would be assigned to this equipment. The generator supplied is fitted on skids and can be transported in front of the radio cabin using a Bedford 4 × 4 vehicle.

Security of communication

Security of communication has been an important factor in warfare from the earliest times and the party best equipped to gather intelligence always gains in strength as a result. Today the funds devoted to this have grown to gigantic proportions as larger and larger computers have been deployed to decipher information. Fortunately, the cost of encryption is many times less than the cost of decipherment using the adopted discipline in which both the friendly transmitter and receiver know the code.

Digital TACTROPO employs MARCRYP, a fully-digital encryption process, in which the multiplexed message is combined with a long, complex, digital key sequence produced by a generator in the equipment. A further level of security is gained by encrypting every new transmission by a different part of the encryption sequence. At the receiver the message is recovered by combining the received encrypted message with an exact replica of the coding sequence.

A new code is inserted into the encryption equipment using an optical fill-gun. This system has been designed to ensure that new codes are controlled by a higher command. The pocket-size fill-gun is optically loaded by a new code from a key Management Unit housed at a site well to the rear of the battlefield, away from any sensitive areas, and where it can be fully protected. The fill-gun is then used to program the encryption unit optically with the new code which in turn is stored awaiting a controlled system switch-over to the new code. On return of the fill-gun the code is rechecked to ensure that no errors have occurred in transit. The management unit also checks that the gun has been used exactly the right number of times.

Fast into action

This key feature was of prime consideration during the design of digital TACTROPO the objective being that the time to become operational should be similar to that of a line-of-sight system.

Knowing the co-ordinates of both sites the azimuth angle of shoot is determined and the antenna positioned within its ±5° azimuth traversing range. The antenna is then erected as described following which the angle of elevation is set for the radio horizon to within plus or minus half a beam width.

Whilst the antenna is being aligned, the power generator is run up to power the radio, and the radio sub-system is aligned utilizing the built-in test equipment (BITE) and high-power dumping facilities provided in the r.f container.

Finally the waveguide between the radio cabin and antenna is connected, after which both parties should be ready for aligning.

Alignment is always conducted using the receiving antenna. Radio contact is made via the h.f transmitter/receiver provided and the far terminal is asked to transmit. The receiving terminal is aligned for maximum signal with its transmitters muted and then the reverse procedure is applied to the far terminal.

Alignment is made very simple, as described, by the deployment of two flexible drives which permit the operation to be done from a standing position on the main chassis of the trailer.

Azimuth and elevation metering is built into the design along with an antenna unit displaying the individual and combined signal strengths of the diversity paths. Another feature of the antenna unit is its on-line bit error rate display giving the operator a comprehensive assessment of the link's performance from the aligning position.

Once the link has been established direct communication can be maintained between the two sites using the engineer order wire. As the 16kbit order wire is multiplexed with the traffic the performance of this circuit is a good subjective measure of the radio. Following local communication the link is ready to accept traffic.

It is estimated that surveying, the establishment of the correct bearing, and site preparation could take as long as 25 minutes. A further 35 minutes are required to position and commission equipment ready for traffic.

In most armies the advance and fall-back tactics are planned long before any likelihood of action and often pre-prepared pads have been built reducing the surveying and site preparation time to minimal proportions.

Conclusion

This first article has described the deployment and advantages of Marconi's single-antenna digital TACTROPO in the tactical role of field-command nodal networks. Whilst the equipment is expected to complement existing line-of-sight networks there will be many new applications where tropo is the preferred carrier for the main nodal infrastructure due to the overall saving in costs that digital TACTROPO offers.

Performance

Table 2: Typical performance of a single-antenna system for 99% speech and data availability, Maritime Temperate Climate

Radio frequency	4·4–5·0GHz
Capacity	15–128 channels
Facilities	
Voice	16kbit delta modulation
Data	2·4kbit
Telex	50–100 Baud
Encryption	2^{30}bit sequence 122^{144} key variables
Performance	
Range	250km
Voice	1 in 10^{-3}bit error rate
Data	1 in 10^{-8}bit error rate
Prime power	11kVA
Environmental	
Operating	−30 to +55°C
Vibration	Def. Spec. 0755 lorry transported
Shock	Def. Spec. 0755 lorry transported
Operators	3 trained personnel
Time into action	35 minutes (following survey)
Weight	
Antenna	2400kg
Container	2400kg

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RÉSUMÉ

Cet article d'introduction présente certains des avantages et des économies réalisés par le déploiement du nouveau système, digital TACTROPO, de relais troposphériques de sûreté à antenne unique de chez Marconi dans les réseaux de commandement militaire en campagne. Il insiste spécialement sur la vitesse à laquelle ce système peut être rendu fonctionnel, sur le niveau de sécurité obtenu dans les différentes applications ainsi que sur las culmination de la technologie qui a permis de réaliser un système à antenne unique.

ZUSAMMENFASSUNG

Dieser einleitende Artikel behandelt einige der bei der Anwendung von Marconis neuem zuverläßigen Tropo-System mit Einzelantenne, digital TACTROPO, entstehenden Vorteile und Kostenersparnisse. Besondere Beachtung gilt der Schnelligkeit, mit der das System betriebsfertig gemacht werden kann, dem Sicherheitsniveau bei unterschiedlichen Anwendungen sowie der Anhäufung an Technik, die ein Einzelantennensystem ermöglicht hat.

RESUMEN

Este articulo introductorio describe algunas de las ventajas y economías de costo que surgen del despliegue del nuevo sistema troposférico fiable de antena única de Marconi, digital TACTROPO, en redes de mando en campos militares. Se da atención especial a la rapidez con que puede ponerse en operación el sistema, al nivel de seguridad en differentes aplicaciones, y a la culminación de la tecnología que ha hecho posible la realización de un sisterma de antena única.

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