H. J. Barker

Development of communications for British forces in Germany

Summary

Without reliable and instantaneous communications at all levels of command, the effective striking power of a modern highly sophisticated and co-ordinated defence unit rapidly diminishes.

In the last decade the Ministry of Defence have placed several contracts with The Marconi Company for the planning, supply, installation and commissioning of radio-relay, tropospheric scatter with associated multiplex and voice frequency telegraph equipment, providing a complex communications system between the UK and Germany, which includes an extensive local network between bases and airfields within West Germany. Planning and provision of a military project of this type, within a specific time scale in an overseas territory, pose unique problems and offers a challenge to all concerned. This article describes the growth of the system from inception to the present time. Further expansion is currently being planned, together with an associated network, to provide a UK colour television service to troops in Germany.

Introduction

In the early 1960s, a review of communications facilities between numerous military bases in West Germany was deemed necessary. Experience was clearly showing that maintenance of old war-time equipment had become increasingly difficult and, for the efficient operation of a modern defence force, many more channels were needed as well as an improvement in availability.

Both the Army and RAF submitted modernization and expansion programmes to the Ministry of Defence (MOD) in London, and over the past ten years a complex network has been progressively established. In due course Marconi Communication Systems Limited was awarded a series of contracts by the MOD (Procurement Executive) for the study, planning, equipment supply, installation and commissioning of each of these new systems.

In addition to local circuits between bases in West Germany, direct communication has now been provided from London to Berlin, using a combination of tropospheric scatter and line-of-sight radio-relay links. Recently the Company has been invited by the MOD to plan, install and accept, with complete system responsibility, a single-channel colour television and sound service from London to the troops in remote areas of Germany. This will be the subject of a later article.

System outline

A simplified diagram of the communications network from London to Berlin is shown in figure 1. A tropospheric scatter link from the UK conveys traffic directly to West Germany, the signals are then carried by a line-of-sight microwave network. Another tropospheric scatter link carries the signals from West Germany to Berlin. Operation and maintenance of the complete network is the responsibility of the Army

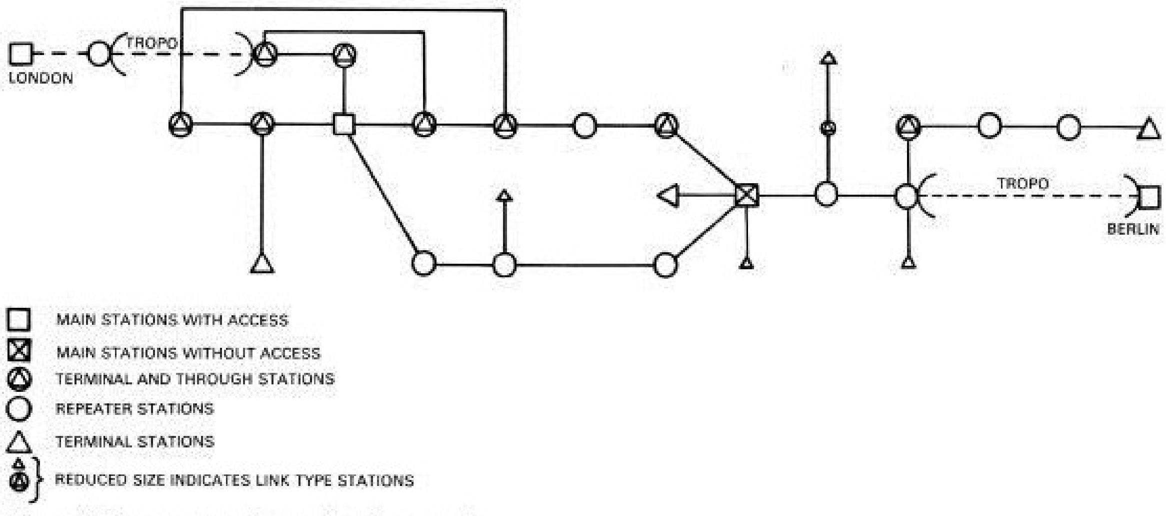

Figure 1. Present extent of overall radio network

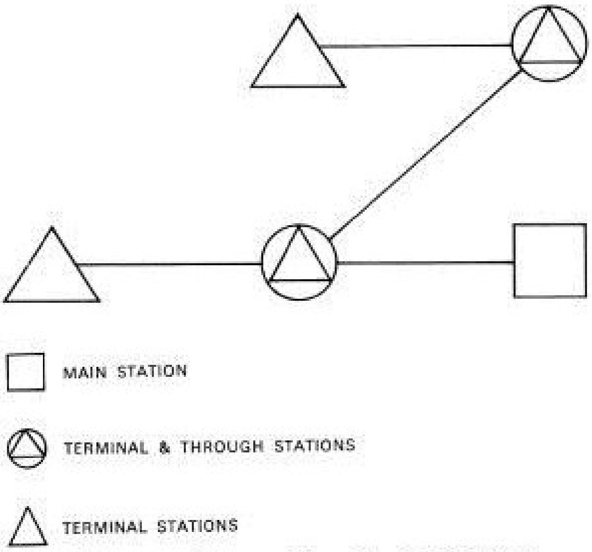

Figure 2. Form and extent of the original RAFNET

even though a high percentage of this work is delegated to civilian engineers and the German Bundespost.

RAFNET

Figure 2 illustrates the stations equipped by the Company for the RAF from 1965 onwards. A minimum of 60 telephone channels were provided with up to 120 between certain bases. Since frequencies only in military bands are available, the possibility of using commercial wideband equipment developed for normal P & T civilian use was not possible, and new equipment had to be designed in our development laboratories. A combination of HM314/315 and HM514/515 equipment was supplied, the former using Heil tubes and the latter travelling-wave tubes as the main source of r.f output. Card-mounted rack type multiplex equipment was supplied by ATE Ltd with The Marconi Company being responsible for complete installation and testing of the whole system, including erection of microwave antennas and associated feeders.

At the planning stage path profiles between adjacent stations were carefully explored, large-scale maps being used to determine minimum fading margins. To ensure a high order of availability, all significant active units, including the radio equipment, were fully duplicated with automatic changeover in the event of failure. The MOD specified the highest standard of quality control scheduled for this type of system and inspectors were allocated to the project from both the MOD and the Company. Special system handbooks were compiled, the essential spares support defined and training was also provided in the maintenance of the system.

For the past ten years the network has given a high-grade reliable service, but even so, the time has now come for it to be replaced by more modern equipment as part of the STARRNET programme.

STARRNET

Although several efforts were made to provide a new Army network in Germany, it was not until 1967 that financial approval for the scheme was finally granted. Against keen competition from other UK suppliers, The Marconi Company succeeded in obtaining the contract for Phase 1 of the system. Apart from buildings provided by the Government Works Department, the Company was committed to the supply and installation of the whole system, including radio links, multiplex and supervisory equipment, towers, antennas, feeders and installation materials, the MOD issuing a small amount of directly purchased ancillary items for inclusion in the overall system. The 15 stations detailed in figure 3 are located in or near military areas, the net-

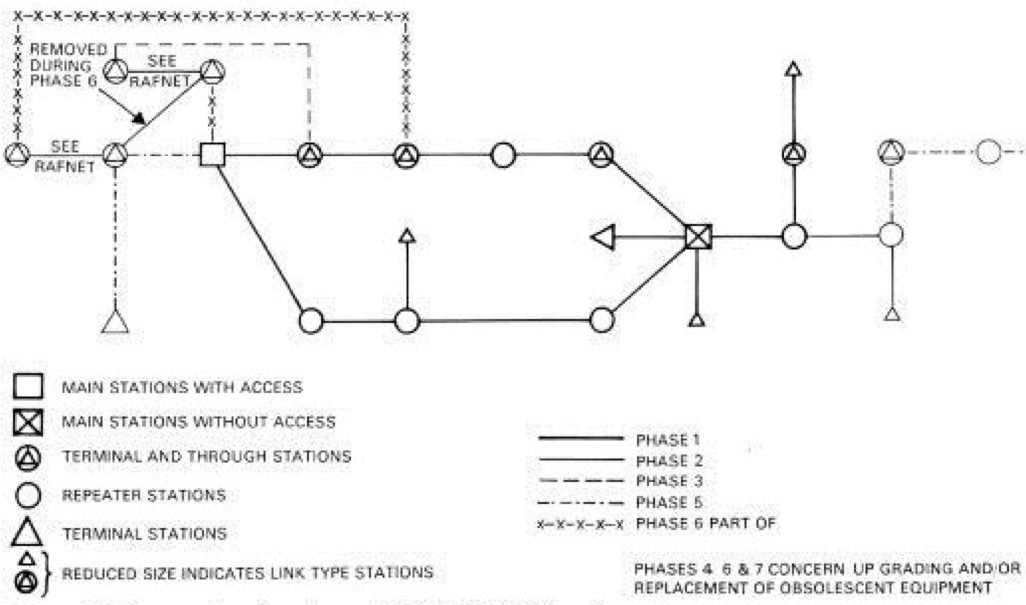

Figure 3. Diagram showing phases of STARRNET development

work providing alternative traffic routeing between Rheindahlen and Ebberg with branches to Verden, Luebbecke and Bielefeld. Some two years later Phases 2 and 3 extended the system to Deister and Hanover with increased traffic facilities between Phase 1 stations.

Engineering of the early phases was based on the use of Marconi Italiana MH141 radio equipment operating in the 8GHz military band and MX180 series solid-state multiplex equipment with a potential maximum traffic capacity of 300 telephone channels, or equivalent, per route. Frequency modulation is employed throughout the system, the carrier in the radio equipment being modulated at a comparatively low frequency which is then multiplied in the following stages, a small klystron in the final stage providing an output of approximately 1W at the required carrier frequency. In the interests of economy a single antenna is used for both transmission and reception, common working being achieved by the use of reversible ferrite circulators and high-grade filters to separate transmit and receive frequencies. After suitable frequency selection by filters the receive signals are frequency changed and amplified. Demodulation is obtained by conventional methods using a.m limiters, discriminators and line amplifiers.

Details of the common antenna working arrangement together with electronic switching for selection of the operational and standby equipments are shown in figure 4. The waveguide, circulator and ferrite switches subassembly has input and/or output ports which provide for the following facilities:

(1) Connection of the working transmitter and receiver to the antenna with minimum insertion loss
(2) Connection of the hot standby transmitter to the antenna with sufficiently high insertion loss to avoid interference with the working transmitter
(3) Pickup of a portion of the received r.f signal for input to the standby receiver so that, if all signals required to operate the automatic switch assembly are present, the automatic frequency control circuit in the local oscillator of this receiver is kept functioning at the correct frequency.
(4) R.F switching time of not greater than 4ms.

The switching time depends exclusively upon the characteristics of the power supply circuits for the ferrite components making up the antenna switch. In fact, transfer from one magnetization condition of ferrite to the other occurs in a few microseconds and is, therefore, of little importance in terms of overall operating time. The combination of ferrite circulators used in the arrangement shown ensures adequate transmitter to receiver protection together with rapid changeover under fault conditions.

Intermediate stations are based on the use of back-to-back terminal equipments, through traffic being connected from incoming receivers to outgoing transmitters by means of selected group and supergroup filters as appropriate. Local traffic access is fed from

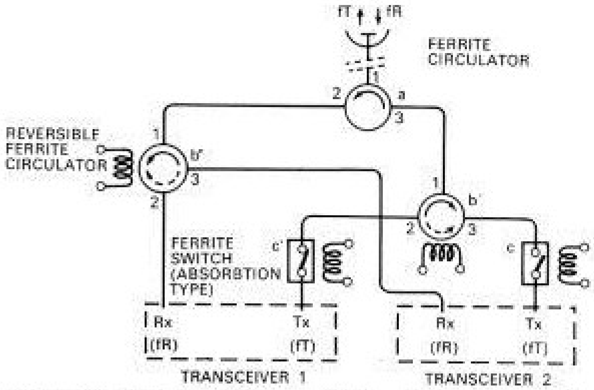

Figure 4. Simplified diagram of the r.f changeover subassembly

the incoming receiver line amplifier via filters to multiplex equipment feeding the local telephone exchange. Locally inserted traffic is, of course, coupled into the radio network via a reciprocal route. Figure 5 provides a simplified block diagram of a typical intermediate station. Although this system introduces additional modem noise at each station, as compared with a true i.f repeater system, traffic access and equipment automatic changeover arrangements can be engineered comparatively simply, standard units being used in both terminal and repeater stations.

The baseband spectrum includes an engineer's order wire (EOW) circuit which provides engineer calling and omnibus speech facilities to all stations on the network thus enabling technicians involved in operation, alignment and maintenance of the system to communicate without interference to, or interruption of, the main traffic. Limited supervisory facilities are provided to alert the system controller of faults generated on the system. In the event of a local failure, the station concerned sends a discrete frequency which gives both visual and audible alarms on the controller's desk. The engineer in charge can then interrogate the station concerned to determine which function requires attention. Up to six parameters can be monitored at each station and these normally include fire, unauthorized entry, mains power failure, radio equipment changeover, etc.

The all solid-state multiplex equipment was developed by Marconi Italiana, and has proved extremely reliable in service, so much so that spare units originally held for maintenance purposes have now been taken from stores by the customer and put into service to provide additional circuits. The suite of racks used includes channel modem units, duplicated frequency generators, pilot oscillators, out-of-band ringing facilities, terminations, 2/4 wire hybrids, channel, group and supergroup translation facilities with all necessary filters.

The design of the whole system complies with accepted international standards. Each incoming telephone channel is filtered and double frequency changed

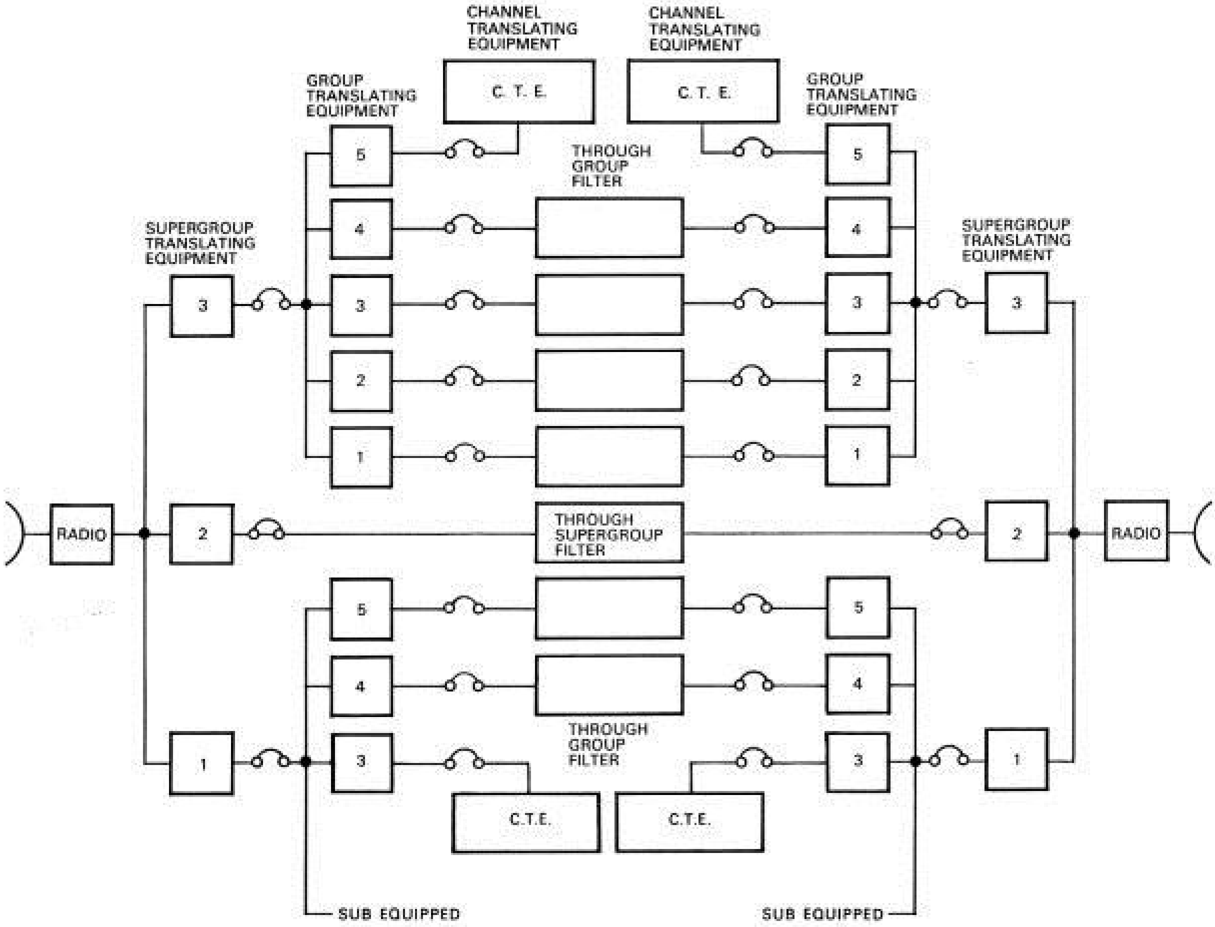

Figure 5. Intermediate back-to-back terminal repeater with local access

by mixing with appropriate internally generated frequencies, the lower sideband of the virtual carrier being selected by a bandpass filter. These channels are built up through sub-groups of three to a basic 12-channel group as shown in figure 6. Five groups are translated into the basic supergroup of 60 channels.

A combination of various pilot tones is inserted into the system between the traffic channels and extracted along the route, as needed, for synchronization of frequency oscillators, automatic gain control of traffic levels and continuity monitoring. Sections of STARRNET have now been expanded, in later phases, to carry up to five supergroups or the equivalent of 300 telephone channels. In practice a number of channels are dedicated to special traffic purposes, including voice frequency telegraph tones which permit simultaneous transmission and reception of twelve teleprinter circuits over one voice channel.

Systems the size of STARRNET cover several different administrative regions, each of which have formally to approve all constructional drawings in their respective areas. Applications for erection of towers in particular had to be supported by full drawings of steel sections proposed, with stress calculations and estimated wind head-loads for the antennas deployed. A 'Siting Board' comprising representatives of all interested departments was first convened to approve the actual area selected for erection. Soil-load bearing tests had then to be made by authorized consultant engineers before approval of the tower foundations could be considered. Quite apart from factors governing optimum radio-link performance many other points have to be taken into consideration including the security hazard to local aircraft operations, available road access and local planning permission. For these reasons erection of buildings and towers can take several months to organize before building work can commence.

Frequency planning within the narrow bands allocated called for considerable skill. Minimum usable Tx/Tx and Tx/Rx separation is dependent on equipment filter characteristics, antenna front to back protection, spurious radiation from tower steelwork and any other tall structure providing a reflective surface. Any non-linear component in the vicinity such as rusty bolts or fencing generate intermodulation products, e.g transmitter frequencies $2f_1-f_2$, not considered at the planning stage, can coincide with principal or second channel receiver frequency, a condition which would degrade the link performance to an unacceptable level.

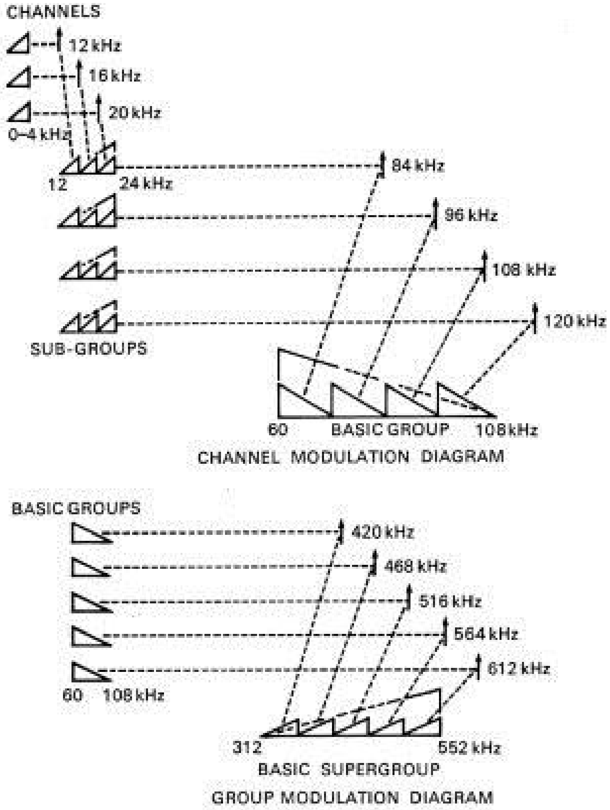

Figure 6. Channel modulation diagram showing build up of telephone channels into sub-groups, basic groups and basic supergroup

Careful design of station earthing was found to be essential as during a lightning strike, if a large potential difference is established between tower and building, major equipment damage will be caused. Where practicable the earth plate of each tower leg is bonded to an earth tape completely surrounding the equipment building, all station equipment and power supply earths being closely bonded to this station earth by low resistance conductors. The only exception to this is the traffic and v.f.t circuit earths which, for reasons of security and prevention of earth circulating currents, are connected to a separate 'communications' equipment earth system.

Our Installation Drawing Office, closely supported by project engineers, prepared equipment layout floor plans for approval by the customer, followed by detailed traffic circuit running-out schedules, power wiring diagrams and lists of installation materials. Dehydrators were fitted at every station to maintain dry air pressure in the flexible waveguide feeders to the antenna and all wiring, including connection to station distribution frames, was neatly formed and laced to everhead racking. Inevitably some building details were found to be not fully in accordance with the drawings, and in such cases installation modifications proposed on site had to be authorized on a concession basis by the senior MOD Electronic Quality Department (EQD) representative responsible for quality control and final acceptance of the project. On completion and acceptance the installation drawings were up-dated with full details of all modifications and reissued on an 'as fitted' basis. These records are held by the customer and if regularly up-dated, are invaluable when further expansion of the system is being planned at a later date.

Early in the programme, specifications for each unit were prepared, with agreed overall system performance test schedules. These were subsequently used both in the factory and in Germany as a basis for quality acceptance, all associated test equipment being rechecked and supplied with dated calibration certificates for an appropriate period. In addition to the Project Installation Manager our team included radio and multiplex engineers, inspectors, riggers, wiremen, technicians and a contracts engineer responsible for all equipment storage in Germany, recording and distribution of equipment to the correct sites as and when required. In general, equipment when accepted and approved by the resident EQD inspector at the manufacturer's factory is paid for and becomes Ministry property. It is then reissued to the Company on embodiment loan and from then onwards accurate recording of movement and disposition is a contractual responsibility.

Some of the difficulties encountered on this project included installation in sub-zero weather, antennas accidentally mounted to shoot in the wrong direction, circulating earth currents causing unacceptable level of hum and many other incidents common to overseas installation, all of which were eventually overcome. Each phase of the system was formally accepted, the necessary documents being signed and exchanged at a meeting held in Germany attended by senior officers from BAOR, MOD (PE) London and The Marconi Company.

During the last three years further contracts have been received for Phases 4–7 of the system. Phase 4 covered the supply and installation of additional multiplex equipment on the northern route. Supergroups 3 and 4 have now been added providing available traffic capacity up to 240 channels. As identified on figure 3 considerable extension of the network was included in Phase 5 of the programme. For this phase a new design of all solid-state microwave radio equipment employing avalanche diodes for the final power amplifier was selected. An improved receiver mixer circuit was also used to reduce the premixer filter noise factor to 11dB. Due to the proven reliability of the MX180 series of multiplex equipment, further racks were purchased for this latest expansion of the network rather than experimenting with new types which would have involved additional training and spares holdings.

The existing south-about route was also upgraded to provide a higher performance over the much extended network. In accepting the contract we had to guarantee a very exacting error rate between the ends of the network. Following equalization and careful alignment of the system the required performance was easily achieved.

In Phase 6 the original RAFNET equipment is being progressively replaced with new radio equipment similar to Phase 5 above, again with Marconi Italiana MX180 multiplex. The current Phase 7 project includes supply and installation of additional access facilities along the route, suitable differential phase and amplitude equalisers being developed to provide an acceptable error rate when handling high speed data traffic. A number of other changes and improvements, including an additional link, have been brought into service as the system developed and finance became available. STARRNET has reduced considerably the number of telephone circuits rented from the German Post & Telegraph Department by BAOR and the cost of installing STARRNET is therefore being recovered by these annual savings.

BERRNET

Communications between the main area of British Forces Germany and Berlin are also important and in 1969 the Company was asked to plan, supply and install a tropospheric scatter link out to West Germany. The number of suitable sites was very limited since, for best performance, a small elevation take-off angle for the antennas, preferably negative, is desirable. Eventually a workable site in West Germany was found and linked into the STARRNET network by an additional microwave link.

The engineering of a tropospheric scatter link depends on the propagation conditions, the reliability required and the traffic capacity. Since larger capacity systems require greater bandwidth with a correspondingly higher noise level, it is possible to exchange the number of channels for signal-to-noise ratio and/or reliability, the cost being otherwise related to channel miles. For any prescribed requirements the system variables are the transmitter power, antenna size and order of diversity. The receiver noise factor may also be improved by the use of tunnel diode or parametric amplifiers.

For BERRNET the system had to be capable of handling a minimum of 36 telephone channels over a path of approximately 160 miles with an availability of better than 99 per cent of the time. Engineering calculations showed that a quadruple diversity system in the 4.5GHz military band using 1kW power amplifiers and 30ft diameter antennas would be necessary. At that time no suitable Marconi radio equipment was available and REL Type 2600 series was therefore specified and supplied. The four antennas, each assembly consisting of 12 metalized glass-fibre petals, were supplied by Comelit of Italy. To achieve high availability from rapidly changing very low level signals refracted from the troposphere, diversity operation and the use of low noise receivers is essential.

Quadruple diversity, normally employed for important trunk routes, can be engineered by using frequency, space and/or polarization methods. For the BERRNET system space and frequency diversity is used by deploying two suitably-spaced antennas at each station, and transmitting the same intelligence on two different frequencies.

To conserve the frequency spectrum, at such a high premium these days, polarization/space diversity is also often used in planning new quadruple diversity systems, but this arrangement demands more complex antenna feed designs. A simplified diagram of several practical diversity options is given in figure 7.

Since path attenuation of the system exceeds 200dB under median conditions, increasing to approximately 217dB for 99 per cent of time, careful planning was necessary to achieve best possible signal-to-noise ratio. Each antenna has a nominal gain of 36dB reference isotropic whilst feeder, filter and antenna coupling losses amount to approximately 6dB per path. With a transmitter output power of +30dBW the net equipment gain, using similar antennas at both ends of the system, is 96dB. Tunnel diode amplifiers are fitted as receiver pre-amplifiers, giving a noise factor of 4.5–5.0dB in the 4.5GHz band. Alternatively, the use of parametric amplifiers would give a further improvement of 2–3dB, but the extra capital cost and complexity of maintenance involved is only justified if more cost-effective methods of system performance enhancement have already been utilized.

Due to the close integration with STARRNET and its excellent performance record within BAOR the Marconi Italiana MX180 series multiplex equipment was again selected. Some of the voice channels are dedicated to voice frequency telegraph (v.f.t) and others to specialized Army traffic. EOW and supervisory facilities are also integrated into the complete network so that similar fault conditions on BERRNET are transmitted over the line-of-sight links and automatically displayed to the Controller. Special precautions were taken to prevent mutual interference between the tropospheric scatter link and STARRNET, including the muting of radio noise caused by a fault in one section which would otherwise completely immobilise the EOW omnibus network. At the time of this installation it was difficult to determine whether these large narrow beam antennas had been correctly aligned to give optimum performance, but subsequently new techniques were introduced to prove this point. During the past six years BERRNET has proved to be a very useful link into Berlin and integration with the complete network has been satisfactorily accomplished. Occasionally, however, particularly during winter propagation conditions, short periods of deep fading have occurred and in consultation with BAOR, methods for increasing system margins have been suggested. The modifications made have produced sufficient improvement to make the selection of a new site unnecessary.

UK – Germany

At the beginning of this decade MOD gave careful consideration to selecting the best method of linking the UK to the British Forces in West Germany. It was agreed that, if viable, a tropospheric scatter system would, in the long term, be the most cost effective and

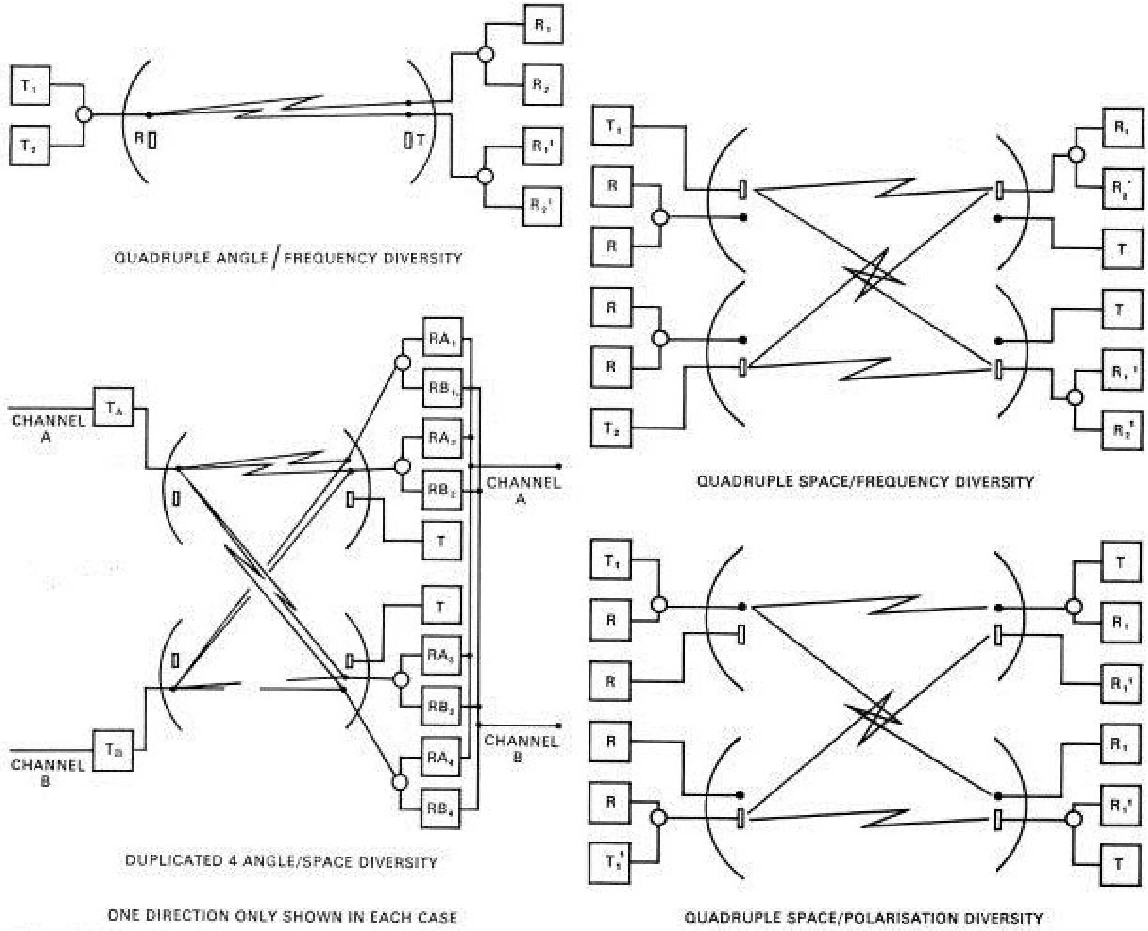

Figure 7. Simplified diagram of diversity options

acceptable solution, being entirely under army control. The alternatives of renting international cables or using at least 12 line-of-sight links through the Low Countries were discarded on the grounds of cost and maintenance problems.

Suitable sites for tropospheric scatter stations were studied, and path performances calculated, but due to the importance of providing a completely reliable service for 99.9 per cent of time, MOD decided to ask for a radio survey before inviting tenders for the working system. The resulting report was used to calculate the equipment needed to provide the performance demanded.

The Marconi tender offered a frequency/space quadruple diversity system using four 10kW amplifiers and 60ft antennas raised on self-supporting steelwork so that the reflector centres are 60ft above ground level. In June 1970 the Company was awarded the contract for the complete project, the target commissioning date being March 1972. Figure 8 is a photograph of the completed installation at the UK end of the circuit.

The link is equipped for 60 speech channels, some of which are again dedicated to teleprinter and data traffic using MX180 series equipment. Since delivery was needed before our own latest development of 2GHz tropo equipment for North Sea oilfields had been completed, American REL 2700 series units were supplied. The path length to West Germany is approximately 220 miles, and this time eight parametric amplifiers, one per receiver, were specified to enhance performance. The antenna reflectors are illuminated by high efficiency dual polarized feed horns, connection to the radio equipment being via flexible elliptical waveguide type EW20.

Incoming power supplies are connected to 55kVA transformers and 50kVA prime voltage regulators to ensure a stable input to the radio equipment. The 10kW transmitter output klystrons are water cooled using heat exchangers mounted in an adjoining well-ventilated room.

The link is required to have a 99.75 per cent probability of achieving a service availability of 95 per cent and a 95 per cent probability of a service availability of 99 per cent of each and every hour of the year. Availability in respect of telegraph and data channels is

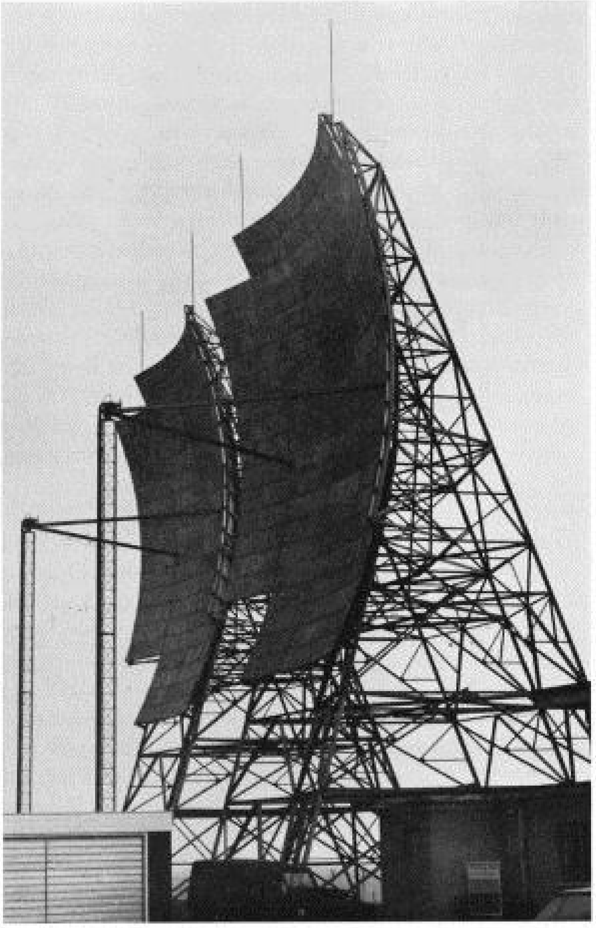

Figure 8. View of the UK tropospheric scatter antennas and station building

assumed to mean an error probability of less than 1 character in 10,000 at 15k bit/s.

Following the installation in 1972, system-evaluation trials were conducted over the next 12 months using special test equipment, including the Wareham test set C452. Analyses of these recordings on the company's computer at Baddow showed that the specified performance had been met with adequate margins. Subjective assessment based on numerous daily telephone calls from London also confirmed the excellent quality and low noise characteristics of the system. Consideration is currently being given to increasing the traffic capacity to 120 channels and initial calculations show that only minor modifications will be necessary to provide the wider bandwidth required to expand the system.

Conclusion

The work done by The Marconi Company over the past decade on behalf of the Ministry of Defence has resulted in the provision of a complete communications network from London to Berlin, with many internal routes for BAOR in Germany. When planning and working for the first phase of STARRNET all those years ago, probably no single person envisaged how this network would grow into its present size. Now the provision of television for the BAOR troops, largely based on an overlay of STARRNET and worth over £5m to the Company, is with us. We hope that further extensions now being discussed will also eventually materialize, bringing greater facilities to our Forces in Germany.

Acknowledgement

This work has been carried out with the support of Procurement Executive, Ministry of Defence.