UNLIMITED

AD-A209 863

RSRE MEMORANDUM No. 4262

ROYAL SIGNALS & RADAR ESTABLISHMENT

TACTICAL UK MILITARY SATELLITE GROUND TERMINALS - A RESEARCH AND DEVELOPMENT REVIEW

Author: P J Skilton

PROCUREMENT EXECUTIVE,
MINISTRY OF DEFENCE,
R S R E MALVERN,
WORCS.

RSRE MEMORANDUM No. 4262

UNLIMITED

CONDITIONS OF RELEASE

0040072 BR-110081

.... U

.... Y

Reports quoted are not necessarily available to members of the public or to commercial organisations.

ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 4262

TITLE: TACTICAL UK MILITARY SATELLITE GROUND TERMINALS - A RESEARCH AND DEVELOPMENT REVIEW

AUTHORS: P J SKILTON

DATE: JANUARY 1989

SUMMARY

This memorandum is intended as an introductory review of tactical satellite ground terminals in service with UK and NATO forces. Many of these equipments have derived from the RSRE research programme and current activities under this programme are included in the review. A background to the military space segment available to the UK, US and NATO provides a relevant perspective to the tactical terminal programme and future trends in space and ground segment hardware conclude the memorandum.

S80/59

THIS PAGE IS LEFT BLANK INTENTIONALLY

Contents

Tactical UK Military Satellite Ground Terminals - A Research and Development Review

Features of satellite communications (satcoms), particularly appropriate to a military role include the ability to communicate, worldwide, over long or short ranges irrespective of natural ionospheric variations, with no dependence on an existing communications infrastructure, and the ability to establish communications within minutes of a small tactical terminal arriving in location. Unlike their civilian counterparts, military ground terminals may also have to contend with an intentionally hostile electromagnetic environment, at the onset of jamming, and be required to minimise their risk of detection through interception of the uplink carrier. The military satellite system in which the terminals operate must respond flexibly to the rapidly changing requirements of users whose priorities and traffic rates must adapt to meet operational needs. Before reviewing the state of small military ground terminals a relevant perspective can be achieved through an outline of the space segment resources available to the United Kingdom, United States and NATO in the military satellite frequency bands.

1. Military Space Segment

The first experiment in space communication, using the moon to reflect signals at 112 MHz, was conducted by the US Army Signal Corps under Project Dianna - an ancient moon goddess - in January 1946. Microwave "moon bounce" experiments continued in the late 1950's and early 1960's, in both the United States and the United Kingdom[1]. In June 1964 experiments where performed by the Signals Research and Development Establishment (SRDE) and the Royal Radar Establishment (RRE), [now merged to form the Royal Signals and Radar Establishment (RSRE)] in which 800 bit/s communication at a bit error of better than 1 in 10^4 was achieved using 16 level FSK modulation of a 2.624 GHz carrier. Five-fold frequency diversity, to overcome fading and the spread of echoing depth, was employed and data rates upto 9.6 kbit/s were predicted between 12.2m (40 ft) ground stations.

SPUTNIK 1, launched in October 1957, was the earth's first artificial satellite and was soon followed by other sub-synchronous SPUTNIK satellites and by the US EXPLORER, SCORE (1958) and COURIER (1960) satellites[2]. In less than a decade after the launch of SPUTNIK 1 the basis of todays civil satellite systems was being established through the geostationary INTELSAT 1, Early Bird (1965) and INTELSAT 2 (1966-1967) series satellites. The corresponding military milestone in space communications at this time was represented by the Titan IIIC launch, on the 16 June 1966, of the first batch of six Interim Defence Communications Satellite Program (IDCSP) satellites into a sub-synchronous orbit with an orbital period of between 22 and 23 hours. In this orbit the satellite, tracked by the ground stations, drifted with respect to the earth at an average rate of approximately 1 degree per hour. On the 18 June 1966 a transatlantic link was established between 12.2m stations at SRDE Christchurch in the United Kingdom and the US Army Satcom Agency at Fort Monmouth, New Jersey, USA[3]. Five tactical quality speech circuits could be supported simultaneously between the large ground stations[4]. Each IDCSP satellite weighed approximately 37 kg and used a single omni-directional antenna fed from a 3 W Travelling Wave Tube Amplifier (TWTA). Twenty six IDCSP satellites were launched.

The UK military space programme developed in the 7/8 GHz SHF frequency band with the SKYNET satellites and that of the US with the 7/8 GHz DSCS and UHF FLTSATCOM systems, both preceded by a number of experimental satellites (LES) developed by the Lincoln Laboratories.

1.1 SKYNET

The UK SKYNET I satellite, built by Philco Ford and launched from a Thor Delta rocket on 21 November 1969, was the world's first geostationary defence satellite. Its single antenna, despun from the spin-stabilised body of the satellite, provided earth coverage and the 3 W output from the hard-limiting transponder was divided between 2 MHz and 20 MHz channels. SKYNET IIB was launched on-board a Thor Delta vehicle on the 20 November 1974. It was a larger satellite than SKYNET I (250 kg orbit mass compared with 122 kg for SKYNET I) and the communications payload, built by Marconi Space and Defence Systems, used a 16 W TWTA to feed a single earth cover antenna. The transponder of SKYNET IIB is still operating and the satellite is still used for R&D purposes 14 years after its launch.

The emphasis of the UK Defence Review in 1974 was a lessening of worldwide strategic commitments, especially East of Suez. A consequence of this was the cancellation of the SKYNET III programme, seen predominantly as a strategic resource, on the grounds that the UK's requirement for satellite communications could be more cost-effectively met through joining the US DOD and NATO programmes. However, an increasing awareness of the role of small aperture, low data rate terminals for shipborne use and tactical land use, together with increasing pressure on available US and NATO resources, was responsible for the decision in 1981 to revive the SKYNET programme with SKYNET 4.

Unlike SKYNET I and II, SKYNET 4 is 3-axis stablised; based on the British Aerospace European Communications Satellite (ECS) bus and with a Marconi Space Systems communications payload[5]. The majority of the communications capacity is at 7/8 GHz (SHF) with three 40 W TWTAs providing four channels with a total bandwidth of 340 MHz. SKYNET 4 has been designed to accommodate the requirements of all three armed services. The consequent necessary flexibility to meet this range of user requirements in terms of satellite EIRP, data rate, access schemes and response to jamming is achieved through a selection of antenna coverage, channel gain setting and detailed, flexible access planning.

A spot beam uplink antenna, specifically in support of small aperture terminals, is included in addition to an earth cover uplink horn. Downlink antenna options provide four coverage areas from whole earth to spot beam. Two earth cover UHF (250/300 MHz) channels are available and an experimental EHF (44 GHz) receiver, initially funded by RSRE to enable early experience of the future EHF band is also included. The first SKYNET 4 was launched into geostationary transfer orbit, aboard Arianne IV, on 10 Dec 1988 and the two remaining launches planned for Stage 1 of SKYNET 4 are due in 1989 and 1990. The SKYNET 4, Stage 2 and SKYNET 5 programmes are likely to show an increase in the exploitation of the EHF (20/44 GHz) frequency bands as a means of increasing the survivability of communications in the presence of uplink jamming and of reducing the vulnerability of small terminal uplinks to terrestrial intercept. At this early stage, the continuation of the more vulnerable UHF band into the SKYNET 5 programme is by no means certain. Although UHF is very attractive from the point of view of the small aperture ground terminal user, the associated, dis-proportionate implications on the satellite weight, volume and fuel, in comparison to the SHF and EHF payloads and the narrower available bandwidth, result in a high cost per circuit through the satellite.

1.2 DSCS

The US Defence Satellite Communications System (DSCS) programme started with the IDCSP and continued with the spin-stabilised DSCS II satellites the first of which was launched into a synchronous, near equatorial orbit into 1971. The early DSCS II satellites each deployed two simultaneously active 20 W TWTAs divided between four channels, configured with combinations of SHF earth cover and narrow cover antennas on the uplink and downlink. The transponder output power of the later satellites was increased to 40 W and one of the narrow cover antennas on each was defocussed to achieve a wider, area cover, footprint on the earth. The narrow cover and area cover uplinks are particularly suitable for the deployment of small aperture SHF ground terminals. The requirements of a military satellite system to provide high gain uplink antennas, thus enabling small highly mobile terminals to be deployed, with simultaneously, no constraint on the geographical area of operation, has influenced the design of the DSCS III satellites[4,6].

The first DSCS III was launched in October 1982. It is a 3-axis stabilised satellite with six SHF channels (two 40 W and four 10 W) giving a total bandwidth of 375 MHz and 1 UHF channel which can be configured with an SHF uplink or downlink when necessary. The SHF channels can be connected to a gimballed, spot cover downlink dish antenna, earth cover antennas or 19-element or 61-element multi-beam antennas (MBA). The MBAs, two 19-element on transmit and the 61-element on receive, are capable of forming high gain uplink and downlink spots in areas of operation and of discriminating, through steerable nulls in the antenna pattern, against interference or jamming signals from adjacent areas. The principle tactical user of the DSCS system is the US Ground Mobile Force (GMF).

1.3 FLTSATCOM

The majority of the US Navy Satellite Communications are via the Fleet Satellite Communications (FLTSATCOM) system. Four operational satellites, built by TRW, provide global coverage in the 250/300 MHz region of the spectrum[7]. The transponders are divided into 23 channels: 25 kHz wide for US Navy use; 5 kHz for the US Airforce and a single 500 kHz channel, capacity being shared between users through time division multiple access schemes. Tactical UHF ground terminals providing vocoded speech communications at 2.4 kbit/s, or high speed data transmission, can be small, light and relatively low cost. This fact together with the established UHF infrastructure seems likely to secure the future of the US UHF satellite communications programme to beyond the year 2000 through a new generation of eight US Navy satellites[8, 9], each with a total of 39 channels. An experimental EHF package (FEP) aboard a FLTSATCOM Satellite will enable some aspects of 44/20 GHz communications to be assessed[10] prior to the launch of the EHF MILSTAR satellites[11].

1.4 NATO

The earliest NATO satellites, 1A launched in 1970 and 1B launched in 1971, were similar to SKYNET I. The single antenna provided a slightly narrower beamwidth than SKYNET I and enabled communication between NATO ground stations in the US and Europe.

The current NATO III space segment is based on four Ford Aerospace, spin stabilised satellites, launched between 1976 and 1984, providing communication between 21 fixed ground terminals and several large transportable and mobile terminals[12]. The contract to supply NATO IV satellites has been awarded to British Aerospace[13]. The satellites will be heavily based on the UK SKYNET 4, ensuring interoperability and increasing shared resources in the event of failure. NATO also are planning future exploitation of the EHF military satcom frequency bands at 44 GHz and 20 GHz.

1.5 SYRACUSE[14]

The French 7/8 GHz military satellite system, SYRACUSE, consists of two 40 MHz bandwidth transponders, connected to two circularly polarised earth cover antennas, installed on the Telecom 1 commercial satellite. The next generation of SYRACUSE is planned for a 1991 launch aboard Ariane IV, as a payload on the Matra Espace Telecom 2 satellite[15]. The principle users of the SYRACUSE system are fixed and land mobile terminals plus some shipborne terminals.

As an introduction to the subject of small aperture military satellite ground terminals, the background on the supporting space segment can only be superficial. References 16 and 17 provide a more detailed discussion on the threat faced by a military satellite system and the countermeasures available within the space and ground segment design.

2. Introduction to the Military Ground Segment

In military terminology, a "tactical" Satellite Ground Terminal (SGT) is frequently defined as one having an antenna diameter of less than 2 m. A more rigorous definition of what constitutes a "tactical" equipment has of course, to be made in the context of the particular role for which the equipment is procured and the degree of covertness and flexibility required. However, the majority of the equipment described in the remainder of this memorandum will employ smaller antennas than 2 m. The majority of the equipment will also be land based.

Historically however, the first small aperture SHF military terminal to enter service with the United Kingdom forces was developed for ship-borne use by the Royal Navy. The SCOT 1 terminal[18] came into service in 1972 following prototype development by the Admiralty Research Establishment[19]. Using one of two fully stabilised 1.06 m diameter dishes (one either side of the ship to minimise the effect of blockage by the ship's superstructure) two telegraph communications channels could be supported via SKYNET 1. The 1.83 m antenna of the SCOT 2 terminal, introduced into service in 1980, provides one speech and three telegraph channels.

A SCOT enhancement programme has improved the SCOT 1 terminal G/T to 11 dBK^{-1} and resulted in greater frequency flexibility for all SCOT equipment [20].

A small aperture terminal operating in the SHF military band has also been developed for airbourne use in the UK Maritime Reconnaissance Nimrod. Details of the terminal design and performance are at references [21] and [22].

3. Background to Small Aperture Land based Terminal Developments in the United Kingdom

At the 1967 Paris Air Show a mobile SGT based on a Land Rover and trailer was demonstrated providing a telegraph circuit, via an IDCSP satellite, to a fixed SGT at SRDE Christchurch. The mobile terminal, known as IDEX[19] is shown at figure 1.

The transmitter power was derived from an air cooled, fixed tune 1 kW klystron adjacent to the trailer-mounted, front-fed 2 m dish antenna. The requirement for 1 kW uplink power from IDEX was a consequence of the low antenna gain of the IDCSP satellite (only the final IDCSP - DSCS I employed a despun earth cover antenna). The overall receiver noise temperature of IDEX was 300 degK achieved through the use of a 38 GHz klystron pumped, uncooled parametric amplifier and an 8 level frequency shift keyed (FSK) modulation scheme was employed at 50 bit/s.

Following IDEX a series of prototype Land Rover-based and transportable SGTs were developed by SRDE for use over SKYNET 1 and SKYNET 2. In March 1976 a transportable terminal was demonstrated to the Institute of Electrical Engineers (IEE) in London as part of an IEE "Centenary of the Telephone" exhibition*. The terminal comprised a single 1 m high equipment rack with separate up and downconverters, alternative 16 kbit/s binary phase shift keyed (BPSK) speech or 50 bit/s binary FSK telegraph modems and a dual waveguide run to a one-piece front-fed antenna. The 1.8 m antenna was automatically cycled in elevation, throughout a 24 hour period, to compensate for North/South satellite movement resulting from a satellite orbital inclination of up to ± 5 deg; thus maintaining the satellite within the 1.2 deg antenna beamwidth.

* NOTE: Conference Digest is No. 76/16 dated 10 March 1976 but contains no reference to the satcom demonstration.

By 1978 the prototype terminal had been redeveloped and reduced in height to approximately 600 mm by combining the upconverter, downconverter, waveguide filters and combiners into two units which, with the 20 W TWTA and speech modem, comprised the radio unit shown in figure 2. A single run of flexible waveguide from the equipment in the figure to a 1.7 m diameter, segmented splash plate fed antenna completed the most basic version of the terminal.

The terminal was deployed either in the air transportable frame shown in figure 2 or, out of the frame, in the rear of a Land Rover. In an air transportable role, a separate rack carried a speech crypto and a further rack contained a duplex 50 bit/s BPSK telegraph modem, a pair of telegraph cryptos and a teleprinter. The terminal was built as a laboratory prototype to demonstrate the feasibility of a small, highly mobile equipment capable of providing good quality secure and reliable communications over ranges previously only tactically viable through HF. However, the prototype was in great demand for participation in exercises in the United Kingdom and Germany as well as providing the communications between Zimbabwe and the United Kingdom throughout the 3 months transitional period of direct British rule leading up to independence in February 1980 and from Lusaka during the 1979 Commonwealth Prime Minister's Conference.

The origin of the military requirements which led to todays medium sized SHF tactical terminals, in service with the United Kingdom and NATO Forces, the TSC 502 and VSC 501, can be directly linked to the concept successfully demonstrated through the reliable and flexible performance of the prototype equipment in figure 2 and to the support provided by civilian and army RSRE personnel during its deployments.

4. *UK TSC 502 (Fig 3)*

The earliest tactical SHF satellite ground terminal to enter service with the British Army, was a containerised, transportable terminal designated the TSC 502 and introduced in 1980[20]. The terminal, built by RACAL SES (now RACAL Communications Ltd) has a 1.7 m segmented antenna, a 60 W TWTA, giving an EIRP of 86 dBm, and G/T of 12 dBK^{-1}. The terminal, including teleprinters, crypto, generator and spares is contained in a maximum of seven air transportable containers. As originally deployed the equipment provided simultaneous 16 kbit/s speech and 50 bit/s telegraph channels in addition to a 2 MHz spread spectrum mode, originally intended to enable multiple user access to the 2 MHz channel of SKYNET II. Configurations deployed since the introduction of the TSC 502 have provided a capability for two simultaneous 16 kbit/s speech channels or multiple 2.4 kbit/s and telegraph channels.

5. UK VSC 501 (Fig 4)

This is self-contained SGT built by RACAL Communications Ltd and based on a Land Rover and trailer. It produces an EIRP of up to 89 dBm through power combining the output of two 60 W TWTAs and an overall terminal G/T of 12 dBK^{-1} is achieved when the 1.9 m segmented, quadrupod antenna[23] is connected to the vehicle by up to 3 m of flexible waveguide. Remote operation up to 10 m is possible with an associated reduction in G/T to 9.5 dBK^{-1}. Both the 60 W TWTA development and the low noise amplifier development were sponsored by RSRE, with funding from the Ministry of Defence Directorate of Components and Valve Development (DCVD), specifically for the VSC 501 programme. For both items, developed by English Electric Valve Company (EEV) and Ferranti Microwave Division respectively, there was an emphasis on maximising efficiency and providing components sufficiently rugged to meet a military environmental specification.

The VSC 501 can be powered either from dedicated radio batteries, charged from the vehicle charging system, a mains power unit or a DC generator carried, along with spares, fuel and antenna components, in the trailer. One modem in the vehicle will provide an aggregate data rate approaching 20 kbit/s which can comprise combinations of 16 kbit/s, 2.4 kbit/s and telegraph channels. A separate modem, VSC 330, enables frequency hopped spread spectrum communication at rates down to a few bits per second under jamming conditions. Both the UK/VSC 501, described above and a NATO variant, in which only the VSC 330 modem is used, entered service during 1988.

In the ten years between the completion of the RSRE prototype equipment shown at figure 2 and the entry into service of the VSC 501, the concept of a Land Rover based terminal and related developments have formed a continuing part of the RSRE research programme.

6. Prototype, Vehicle-based SGTs

Two prototype terminals based on a fitted for radio (FFR) Land Rover were built by RACAL SES as part of an RSRE research contract between 1978 and 1980. The maximum EIRP and G/T of these terminals was 86 dBm and 12 dBK^{-1} respectively via a 1.7 m segmented antenna developed from an RSRE prototype by British Aerospace[20]. Both provided simultaneous 16 kbit/s speech and telegraph communications: initially using the 50 bit/s BPSK telegraph modem deployed with the equipment in figure 2 and subsequently using the 50 bit/s telegraph modem developed for the UK TSC 502. The later imposed BPSK modulation on the carrier at 300 bit/s to ease the close to carrier phase noise specification of oscillators within the equipment. The earliest of these prototypes was deployed in Zimbabwe in 1980 and both have been extensively evaluated and demonstrated in the United Kingdom, NATO, Cyprus and Saudi Arabia - profoundly influencing the detailed concept of the UK and NATO VSC 501 equipments.

The use of the Land Rover 16 kbit/s circuit to carry monochrome slow-scan television imagery, rather than speech, has been demonstrated by RSRE through a pair of laboratory built video codecs[24]. These codecs display a 128 x 128 pixel image containing 16 shades of grey, refreshed every 4 seconds. In an alternative, conditional replenishment mode, only pixels whose grey level has changed are transmitted. Hence small changing areas of the scene are represented as near real time movement at the receiver. An RSRE research contract with W Vinten Ltd has successfully developed a pair of codecs capable of 256 x 256 pixel resolution at 64 grey shades using DPCM coding. Conditional replenishment is retained and error protection, to ensure a good line and frame synchronisation, has been incorporated. Figure 5 shows the received image over a satellite link with a 1 in 10^4 bit error rate.

A pair of similar terminals to the RACAL SGTs were developed, under Company funding, by Marconi Defence Systems and designated MARMOSET[20]. The microwave performance of MARMOSET was virtually identical to the Racal prototypes - using the same design of EEV 60 W TWTA - but MARMOSET used a pair of identical multi-rate modems (50, 75, 2400, 16000 bit/s) to provide combinations of simultaneous speech or telegraph accesses separated by 48 kHz. A 2 MHz spread spectrum mode was also available for compatibility with the UK TSC 502.

Frequency converting the output of existing, non-satcom, military radio equipment to operate in the SHF satellite band was demonstrated by RSRE in 1982 using a simplex VHF vehicle radio[25], the Clansman UK/VRC 353 and a laboratory built adaptor. (Fig 6a, 6b). The output from a standard radio was mixed in the adaptor with a frequency tunable, phase locked signal and used to feed a 20 W TWTA and a 1.7 m segmented antenna. In the receive mode the same microwave source provided the local oscillator for downconversion to the radio input frequency. Coarse frequency tuning over the majority of the 7.9 to 8.4 GHz transmit band and 7.25 to 7.75 GHz receive band was achieved using the microwave source with fine tuning from the VHF radio. Since direct small terminal to small terminal communications are achieveable within the narrow/area cover satellite antenna footprint of DSCS II or within the spot beam of SKYNET 4, a number of Clansman adaptor terminals can operate an all informed net - identical to a conventional VHF net - whilst occupying a single frequency allocation on the satellite. Use of familiar VHF and baseband hardware, such as the crypto and telegraph adaptor, provided the advantages of established operating and maintenance procedures as well as reducing the overall cost of the SGT. The VHF radio satcom adaptor has been further developed under company funding by the Microwave Division of Ferranti Computer Systems Ltd.

Prototype adaptors have also been built and evaluated at RSRE to interface with the radio relay equipment of the Ptarmigan trunk system. These duplex adaptors convert the UHF radio relay bearer to the SHF band and, when used with 3 m or 3.7 m antennas, provide adequate link margin for good quality 256 kbit/s or 512 kbit/s satellite communications, via SKYNET or DSCS, overlaying the area communications system.

7. Satellite Communications to a Moving Vehicle

A capability for a Land Rover-based SGT, such as the VSC 501, MARMOSET or the RSRE prototype terminal, to communicate under uplink jamming conditions is provided through the VSC 330 frequency hopping, spread spectrum modem. Under non-jamming conditions, low data rate operation of this modem has been exploited to enable telegraph communications between the mobile SGT and a fixed SGT. In terms of the satellite link budget equation, the typical 40 dB gain of the segmented fixed antenna is replaced by a lower mobile antenna gain and, with a change of Eb/No value appropriate to the VSC 330 modem, a corresponding reduction in link data rate results.

Following the success of initial experiments at RSRE in which a monopole, and later bicone antenna, were used to provide duplex communications at a few bits per second via SKYNET II, a non-steerable, torroidal beam antenna was developed for RSRE by British Aerospace[26]. A dielectric radiating element, using the vehicle roof as a ground plane, produces an omni-directional pattern in azimuth and a 1 dB beamwidth in elevation of typically 45 degrees, which includes the angle subtended by the geostationary satellite, from the area of operation, and a tolerance for vehicle pitch and roll angles. The polariser and diplexer, shown in fig 7, are below the vehicle roof line and a 150 mm diameter, hemispherical radome results in a low profile installation. A gain of 4.5 dBi enables duplex communications between mobile and fixed SGTs at 16 bit/s whilst the vehicle is travelling at speeds of up to 50 mph (80 km/h) over metalled roads. The effects of doppler frequency shift and signal multipath can be accommodated within the VSC 330 modem.

To provide a higher data rate, a more directional antenna than the non-steerable torroidal beam antenna is required. An antenna to enable duplex 2.4 kbit/s communications has been developed and evaluated for RSRE by ERA[27] in conjunction with Ferranti Instrumentation Ltd. The "breadboard" model of the steerable antenna is shown in figure 8a and 8b. It is based on a hemispherical Luneberg lens, backed by a plain reflector, with a secondary reflector providing beam steering in elevation. Azimuth scanning is achieved by rotating the lens plus secondary reflector about a vertical axis through the centre of the lens. Measurements on the "breadboard" antenna and a quantitative radome design indicate a boresight gain in excess of 20 dB will be achieved in a radome height below 300 mm. Installation and trialling of a prototype antenna in an RSRE Land Rover SGT is anticipated during 1989.

8. SHF Manpack Development

The potential for a compact, light-weight SGT for deployment with a small highly mobile patrol was realised in the UK in the mid-1970s. By mid 1978 an SHF SGT, capable of being carried and deployed by one man and providing duplex 50 bits/s telegraph communications with a large, fixed SGT via SKYNET IIB, was demonstrated by RSRE. The first equipment is illustrated and fully described in reference [28]. Powered from a 24 V, 4 Ahr rechargeable battery, the first Manpack was capable of providing 4 hours of duplex telegraph communications using a 2 W TWTA with an overall dc-rf efficiency of 20%. A second fixed frequency prototype, operating in the narrow/area coverage channel of DSCS II used a smaller, but less efficient (10%) gallium arsenide 2 W amplifier. Both laboratory prototypes included an alternative analogue speech channel. In this mode of operation, the input speech waveform was hard limited and the resulting analogue pulse width signal used, instead of the telegraph signal, to switch the binary microwave phase modulator. At the receiving modem - base station and Manpack modems being identical from the final IF stage to baseband - sufficient carrier energy was present between speech phonemes to maintain carrier phase lock and speech was recovered by filtering the output from the "data" detector.

Under an RSRE research contract with the Microwave Division of Ferranti Computer Systems Ltd further development was undertaken between 1980 and 1987 with the following key objectives:

a) Full 500 MHz frequency tuning on receive and transmit.

b) Reduced weight and volume and ergonomic improvements to the basic Manpack.

c) To demonstrate alternative antennas and modem enhancements.

Some of the achievements of this programme are described in references [20], [29] and [30] and one of the resulting commercial prototypes is shown in figure 9.

Course frequency tuning is achieved with a pair of voltage controlled phase-locked oscillators, tunable in 100 MHz steps, and a pair of UHF frequency synthesisers tunable in 10 kHz steps. A demanding specification on close-to-carrier phase noise, locking range with temperature, power consumption and internal EMC is essential to achieve the required equipment performance.

A development of the original telegraph modem, implemented in thick film hybrid circuits, has enabled a significant volume reduction over the first RSRE prototypes. The 460 mm, splash plate fed antenna and the associated lightweight rear feed, diplexer and filters set a lower limit on the overall Manpack dimensions while the remaining microwave, IF, baseband and power supply components currently fit into a 420 mm x 350 mm x 120 mm unit on the rear of the dish. Satellite acquisition is achieved using a built-in inclinometer and compass and all subsequent operator controls are grouped on the top of the equipment protected under a hinged cover.

The terminal G/T of 2 dBK^{-1} and maximum EIRP of 61 dBm provide sufficient link margin under spot beam conditions, to support data rates in excess of the 50 bit/s telegraph. Voice frequency (VF) tone outputs from a range of data devices and speech vocoders at rates of up to 2.4 kbit/s have been used over the existing analogue speech channel and specific 2.4 kbit/s and 16 kbit/s BPSK modems have also been developed. For ease of demonstration these have built as separate modules, powered from the original Manpack and interfaced at 16 kbit/s (or 2.4 kbit/s) on transmit and at 74 MHz IF on receive. The 16 kbit/s variant, shown in figure 10 provides good quality tactical speech at link bit error rates down to 1 in 100 and has also been used with the portable video codecs described in section 6 to enable transmission and reception of slow scan television imagery.

The basic 460 mm diameter rigid antenna provides a gain in excess of 27 dB over the full 500 MHz of the receive and transmit bands. To enhance the

Manpack antenna gain without detracting from the portability of the equipment, a 1.2 m diameter folding, reflective mesh antenna has been developed[30] which, purely for ease of demonstration with the prototype Manpack, can be mounted in front of and concentric with a rigid dish (Fig 11). During stowage, the antenna folds around the circular front waveguide feed and can be stored in a 180 mm diameter carrying tube. For a given data rate, the extra gain provided by this antenna enables a 6 dB reduction in satellite EIRP on the Manpack downlink and a corresponding lower Manpack uplink power; thus prolonging battery life.

Some development work has also been undertaken on dual polarisation planar array antennas with a view to determining their suitability for replacing the dish antenna in future Manpack systems[31]. Two prototypes have been produced, one 425 mm square and 15 mm thick, shown in figure 12, and a smaller 20 dB gain antenna measuring 315 mm x 260 mm. Circular polarisation is achieved through sequential rotation on the feed point to each array element in a group of four and through control of the electrical length of the microstrip feed. Corporate feed networks behind the array ground plane have been fabricated from lightweight, low loss foam dieletric triplate and feed through the ground plane to each of the groups of four elements.

Although, at present, an array antenna cannot be justified over a dish on the grounds of cost or simplicity the potential for lower volume and the ability for limited electronic counter counter measures (ECCM) are potential advantages of an array or an array-fed antenna over the existing Manpack dish. Feeding a sub-group of elements separately from the main array can enable the formation of a null in the polar diagram and provides one technique to achieve a low probability of detection (LPD) for the SGT against a hostile intercept receiver.

The use of spread spectrum techniques provides a further LPD measure by reducing the spectral power density at an interceptor. A direct sequence spread spectrum transmission has been demonstrated from the prototype Manpack using a separate, low power code generator similar in size to the data entry device in figure 9. The complexity of recovering the original data through correlation of the received, spread signal with a local replica of the spreading code is confined to the remote, large SGT where constraints on equipment size and power are not as severe as at the Manpack. The LPD advantage gained by the Manpack user over the interceptor is, at best, in the ratio of the spread bandwidth (a few MHz) to the original data bandwidth (a few hundred Hz): ie. the processing gain.

A smaller duplex circularly polarised array antenna than that shown in figure 12 has achieved a gain of 20 dB over corresponding fractions of the military satellite receive and transmit frequency bands and is a candidate antenna for very small SHF terminals such as that shown in figure 13. This equipment, developed by RSRE and designated "Satcase"[32], is a 2-frequency simplex SGT, with self-contained batteries, capable of providing 50 bit/s data communications with a large SGT. The telegraph modem uses identical hybrid circuit packages to those in the Manpack and a similar 2 W solid state power amplifier and low noise amplifier. The lower volume of the "Satcase", in comparison with the Manpack is achieved through the absence of waveguide filters, the omission of a speech channel, extensive use of thick film hybrid circuits and the use of novel, compact techniques for IF downconversion and antenna feeding.

Microwave component developments in both *low noise MMIC* (monolithic microwave integrated circuit) amplifiers[33] such as that shown in figure 14 and hybrid solid state power amplifiers now enable an even smaller version of the "Satcase" to be assembled, with virtually identical microwave performance to the equipment in figure 13, with enhanced dc-rf efficiency and capitalising on either the printed or folding antenna technologies outlined above.

Simplex rather than duplex operation of a SGT, such as the "Satcase", is essential if minimisation of size, weight and power consumption are paramount design objectives. One penality of simplex operation of a terminal employing a coherent phase modulation scheme is the time required to achieve carrier phase lock at the receiving SGT modem. The Manpack in figure 9, and the remote base station modem can take up to 40 s to acquire a carrier with a frequency uncertainty of $\pm$ 6 kHz (due to satellite doppler and worst case oscillator drift) at a threshold signal to noise ratio of 27 dBHz. At this signal to noise ratio the 40 s period is a consequence of the maximum sweep rate of the phase locked loop voltage controlled oscillator and the final loop bandwidth (300 Hz) in which detection occurs. Clearly such a delay to ensure the remote SGT modem has acquired carrier and data lock, before sending a message from the small terminal could be both operationally unacceptable, wasteful in battery life and increase the probability of intercept. To maintain the attractive features of simplex operation it is necessary to eliminate the associated problem of long carrier acquisition times at low signal to noise ratios; especially at the large SGT modem receiving the small terminal transmission.

A technique for identifying the frequency of the received signal in a 12 kHz bandwidth to within 100 Hz in less than 100 ms at 30 dBHz has been developed specifically for small terminals like the "Satcase"[34]. The technique emulates, in software and hardware, a parallel bank of filters. The 12 kHz bandwidth signal plus noise is downconverted to baseband, sampled at 24 kHz to a resolution of 1 bit and the resulting signal applied to a bank of 128 parallel filters. The build up of energy in each of the 94 Hz filters is monitored under microprocessor control and the input signal frequency estimated from the first filter response to pass a simple threshold. Final phase locking is achieved in a novel design of phase locked loop with a complimentary pull-in range of greater than 100 Hz.

Significant advances in the technology of SHF Manpack equipment have been pioneered by RSRE since the initial UK development in 1978. The Australian Advanced Engineering Laboratory in Canberra developed an SHF Manpack in the early 1980s[35] but the project has not been publicised in recent years. One consequence of a proliferation of small Manpack terminals is the requirement to monitor and manage satellite accesses to maximise the available power (or bandwidth). Laboratory schemes have been built and simulated[36], which if embodied at the design phase of future systems, should have a mimimal overhead in terms of the very small aperture terminal equipment and which will provide a means of managing and engineering circuits from such equipments.

9. UK PSC 505

The first SHF Manpack SGT to be procured for operational rather than research use is the UK PSC 505[20,37]. It is produced by Ferranti Computer Systems Ltd and based very closely on the prototype equipment shown in fig 9. Considerable further development has been necessary to meet environmental requirements for ruggedness and temperature extremes and advantage has been taken during the development to incorporate experience gained from field trials of the earlier RSRE equipment. The communications capability however is unchanged: either 50 bit/s data from a dedicated data entry device or an analogue channel for voice or VF tone data terminals. The full PSC 505 system includes the fixed base station equipment in addition to the Manpack terminals.

10. UHF Manpack Development

Small aperture UHF Manpack SGTs have been widely deployed by US Forces within the US FLTSATCOM system. Typical of current UHF Manpack equipments are the Motorola LST-5B and Cincinnati Electronics PSC-3 or HST-4A[20,38]. Both equipments are capable of one-to-one communications via a nominal 25 kHz FLTSATCOM channel at 16 kbit/s or of 2.4 kbit/s data or vocoded speech, using a separate 2.4 kbit/s vocoder, via a 5 kHz channel. Battery powered and usually employing a 6 dB gain, folding cross-dipole antenna such equipments can provide secure speech or data communications from anywhere within the earth cover satellite antenna footprint.

When only low data rate telegraph communications are required, lower power, smaller and lighter SGTs than either of the above examples become possible. The development of such equipments, potentially for use in a highly mobile long range patrol role, has formed part of the RSRE research programme since the early 1980s[32]. Following development of three laboratory standard prototype terminals at RSRE, in which the demodulation and final IF stages were implemented in thick film hybrid circuits, a research contract was let with the Microwave Division of Ferranti Computer Systems Ltd which resulted in equipments suitable for field trials[20].

These SGTs, designated UST-1, are simplex in operation and tune in 10 kHz steps (optional 5 kHz) over the UHF receive (240-270 MHz) and transmit (270-310 MHz) frequency bands. A 2 W RF output and noise figure of 3 dB enable a satellite link margin in the region of 12 dB over the 50 bit/s, BPSK threshold when used in a dedicated 25 kHz channel with the 6 dB gain cross dipole antenna shown in fig 15. The keypad on the UST-1 is used to enter operating frequencies and test routines; a separate data entry device is used to compile and edit messages for transmission and store received messages. Although technically feasible to integrate the data terminal with the UST-1, with no increase in volume, preferred options for further development of the UST-1 have provided a range of data terminal interfaces and operator selection of 75 or 300 bit/s operation.

The usual technique for sharing a nominal 25 kHz UHF channel between a number of users, or nets of users, is through a time division multiple access scheme. When a number of low data rate, low bandwidth, users require simultaneous use of a 25 kHz channel, limited frequency division multiple access is possible. The hard limiting, bandpass characteristic of the UHF 25 kHz satellite channels results in simultaneous, frequency separated, shared channel operation between two signals of significantly different uplink EIRP, being to the detriment of the smaller signal[39]. Depending on the ratio of uplink EIRPs, the smaller of two signals can be supressed with respect to the larger by up to 6 dB at the output of the limiting transponder. Hence although shared channel operation of the UST-1 is feasible, careful access planning is necessary to ensure an adequate link margin always exists on the circuit to the smaller SGT. However, the low power, narrow band transmission from the UST-1 enables multiple nets of UST-1s, each of course with similar uplink EIRP, to be operated within a single, clear satellite channel without detriment to any single net.

11. Future Trends

From the viewpoint of the tactical SGT user the UHF satellite band offers the advantages of very small, relatively low cost ground equipment which is easy to use. For example, since the 1 dB beamwidth of the antenna in fig 15 is approximately 70 deg, antenna pointing is an easy task. A fundamental limitation on UHF communications is the limited bandwidth and limited number of discrete channels available within the UHF military band. Even with multiple access schemes, the cost of a UHF circuit through the satellite is high in comparison with the larger number of circuits feasible via the wider bandwidths available at SHF or EHF.

Particularly relevant to military applications is the vulnerability of the UHF band to exploitation. The wide antenna beamwidth renders the associated SGT uplink vulnerable to terrestrial or airborne intercept and df (direction finding). Other satellites in the geostationary arc or low earth orbiting satellites will also fall within the radiation pattern of the uplink antenna providing a potential baseline from which to df the SGT. Vulnerability to uplink jamming is also an undesirable feature of UHF military satcoms. The hard limiting characteristic of the UHF satellite channel only requires an uplink jammer to radiate a few more decibels EIRP than the legitimate channel user, to enable the jammer to capture the majority of satellite downlink EIRP and cause the legitimate circuit to fail.

One role for UHF in future systems may be to provide a protected wide area broadcast. A system can be envisaged in which the weakest features of UHF are mitigated and the advantages of low cost, small ground segment hardware perpetuated. A protected SHF or EHF uplink carrying the broadcast data could be downconverted, despread and possibly demodulated on board the satellite and remodulated onto a UHF downlink. The earth cover downlink could then be received on similar, receive-only equipment to that discussed in Section 10. The only remaining vulnerability of such a system, which is peculiar to UHF, is the vulnerability of the receive-only terminal to local downlink jamming. Military roles can be envisaged in which the limitations of UHF will be acceptable, and to some extent overcome, thus ensuring the continuation of UHF military satcoms for the forseeable future. However, to releive frequency congestion at UHF and to obtain improved ECCM performance it is equally certain that future military satcoms systems, and the associated small aperture terminals, will develop predominantly in the SHF and EHF bands.

In 1967 the 2 m antenna and 1 kW output of the SHF tactical SGT in fig 1 were essential to support a 50 bit/s telegraph circuit. By 1983 similar and enhanced data rates could be supported by the SHF Manpack equipment in figs 9 and 10. This dramatic reduction in size and power output of the ground segment equipment has been possible through improvements to the satellite G/T and EIRP; partly as a consequence of higher gain, narrow cover satellite antennas. Multibeam array antennas, such as those on DSCS III or high gain mechanically steerable antennas providing spot coverage, and the ability for on-board changes in the uplink/downlink connectivity are likely to feature in future military satellites; driven in part by the operational requirements of small apterture, battery powered terminals such as those described in Section 8.

Antenna developments are also likely to influence the design of medium sized (1.5 m to 2 m) tactical SGTs. The ability of an array fed, dual reflector SHF antenna to scan its main beam over $\pm$ 6 deg in azimuth and elevation, with less than 1 dB gain variation, has been demonstrated through an RSRE research agreement with University College, London[40,41]. This degree of electronic beam steering is sufficient to maintain the satellite on boresight of the SGT antenna, without manual repointing, throughout a typical 24 hour cyclic satellite movement. The narrower beamwidth of a similar diameter EHF antenna would render such a capability essential rather than desirable and an array-fed single or dual reflector antenna could be a cost-effective alternative to electro-mechanical tracking.

Adaptive beamforming algorithms and associated beamformer hardware for use with array or array-fed antennas can be expected to find application with 2 m or smaller terminals. This will enable the tactical terminal to simultaneously access more than one satellite or enable the positioning of nulls in the antenna polar diagram in the region of downlink jammers or multipath signals[41]. Implementation of the algorithm at a microprocessor level of cost and complexity and, for a microwave beamformer, the development of low cost MMIC or hybrid microwave modules remain challenges for future system designers.

Continuing developments in SHF and EHF low noise amplification and power generation will continue to enahance the reliability and link margins of future systems. High electron mobility transistor (HEMT) technology can yield typically a 1 dB improvement in the receiver noise figure of SHF equipments such as the VSC 501 or PSC 505 and a low noise HEMT amplifier, rather than mixer, front end is likely to feature in 44 GHz spacecraft receivers well before the end of the century. Solid state power combined amplifiers at SHF have been demonstrated at 20 W, and proposed at 60 W, over 7.9-8.4 GHz. Although their overall dc-rf efficiency does not compete with a TWTA, in terms of reliability and lower volume there should be an improving margin in favour of the solid state source for tactical ground equipment.

A trend towards EHF for future military satcom systems will be driven by requirements for the improved ECCM features available at EHF[16,17,42]. The EHF uplink band centred on 44.5 GHz, provides 2 GHz of bandwidth over which the uplink can be hopped; forcing any jammer to similarly spread its energy. Despreading and filtering the hopped signal onboard the satellite has the effect of removing the majority of the jamming signal, enabling the reconstituted communications signal to be downlinked, in either spread or unspread mode, at EHF or SHF or to provide a UHF broadcast.

A lower vulnerability to detection through intercept of the SGT uplink is achieved at EHF than SHF. For a given antenna diameter the half power beamwidth of the main antenna lobe is reduced in the ratio of the uplink frequencies (ie. 44 GHz/8

GHz) thus reducing the vulnerability to airborne intercept. The signal received at a terrestrial interceptor will be reduced by the increased terrain and atmospheric losses at EHF. These will be to the greater disadvantage of the land-based receiver, dependent on sidelobe radiation at a degree or so elevation angle, than to the user whose main beam is unlikely to fall below a 10 deg elevation angle.

The increased atmostpheric loss at EHF, particularly during heavy rain will, for a given link margin, yield a lower overall availability for EHF than SHF communications[42]. For circuits with a high availability requirement (eg. greater than 95% availability) the concept of dual band (SHF/EHF) operation is feasible: the SHF frequencies being the first intermediate frequency of an EHF terminal and the dual band antenna having separate SHF/EHF feeds and exploiting the properties of dichroic surfaces[43].

EHF component development is already sufficiently mature to have resulted in the first commercial products. Driven by the MILSTAR[11] programme in the US and the Skynet 4 EHF payload in the UK[5], development of solid state and TWTA power sources at 44 GHz and low noise amplifiers at 20 GHz has yielded some of the first critical building blocks of the next generation of small aperture military ground terminals.

12. Acknowledgements

Thanks are due to past and present staff of the Satellite Communications Division of RSRE for thier help in compiling some of the background aspects of this memorandum and in particular to the late Mr A C (Tony) Hay for his assistance in identifying and dating many of the pre-1980 equipments described.

The views expressed in this memorandum are those of the author and should not be interpreted as formal UK Ministry of Defence Policy.

13. References

1. Dalziel R, Williams D: "Correlation Signalling Applied to Moon Echoes", Int Conf on Satellite Communications, 22-28 November 1963, IEE London.

2. Martin J: "Communication Satellite Systems", Prentice Hall, 1978.

3. Thomas E H: RSRE Report 78008, March 1978.

4. Powers Lt Gen W D; Hartigan A M: "The Defence Satellite Communications System", Signal, 53-59, July 1985.

5. Dawson T W G, McLaurin D E, Painter M J: "Skynet 4 Defence Communication Satellite Project", Military Microwaves Conference, 20-22 october 1982, London.

6. Hilsman Lt Gen L T, Garcia Lt Cdr A R: "Defence Satellite Communication system: Another Milestone", Signal, 23-26, Sept 1983.

7. "Satellites - The Military Role", Miltronics, 151-156, October 1983.

8. Microwave Systems News and Communication Technology, 93, May 1988.

9. Aviation Week and Space Technology, 22, 8 August 1988.

10. Microwave Systems News and Communication Technology, 50, May 1988.

11. Schultz J B: "MILSTAR to Close Dangerous C^3I Gap", Defence Electronics, 46-59, March 1983

12. Endean R P J: "An Overview of NATO Communications and Trends", Military Microwaves Conference, 33-40, 1986.

13. International Defence Review, 268, 3/1987.

14. "French Dilemma Over Military Comsats", Satellite Technology, 19-22, April 1985.

15. "Milsatcom and its Future", International Defence Review, 485-488, 5/1988.

16. "Satellite Communication Systems", IEE

Telecommunications Series 18,
Peter Perigrinus Ltd, 1987, Chapter 16,
"Military Satellite Communications", by
Tozer T C.

17. Haworth D P, Walbridge M R: "Rationale for Future Use of EHF for Military Satcoms", Military Microwaves Conference, London, 1988.

18. "Satellite Systems for Mobile Communications and Surveillance", IEE Conference Publication Number 95, London, March 1973.

19. "Skynet", IEE Conference Publication Number 63, London, April 1970.

20. Janes Military Communications, Ninth Edition 334-341, 1988.

21. Longhurst D W, Cummings D: "Satellite Communications for Military Aircraft", Military Microwaves Conference, London, 1984.

22. Cummings D, Wildey C G: "Military Aeronautical Satellite Communications", Proc IEE, 133, Part F, No 4, July 1986.

23. Mortensen N P K: "Stability and Pointing Accuracy of a Tactical Satellite

Communications Antenna", International Conference on Antennas and Propagation, York, March-April 1987.

24. Wells P: Unpublished RSRE Report.

25. Skilton P J: "Recent Developments in Small Mobile Military Satcom Terminals", IEE Comms '82, Birmingham, April 1982.

26. Harris R L, Braddock P W, Smith R F, Skilton P J, Slingsby C G, Perkins S J, James G E: "Satellite Communications to a Vehicle on the Move", IEE Conference on Satellite Systems for Mobile Communication and Navigation, London, 7-9 June 1983.

27. Sidat M S, Davis I, Brain D J: "Steerable, Low-Profile, Stabilised Antenna for a Mobile SATCOM Terminal", International Conference on Antennas and Propagation, York, March-April 1987.

28. Jones C H: "A Manpack Satellite Communications Earth Station", Rad & Elec Eng, 51, No 6, 259-271, June 1981.

29. Skilton P J, Westall I L: "MANPACK SHF Satellite Ground Terminal", Military Microwaves Conference, London, 1982.

30. Skilton P J, Anderson A McK: "A Folding Antenna for SHF Satcoms", IEE Colloquium Digest No. 1987/62, 14 May 1987.

31. Owens R P, Smith A C: "Dual Band, Dual Polarised Microstip Antenna for x-Band Satellite Communications", Military Microwaves Conference, Brighton, June 1986.

32. Skilton P J, Smith A C: "Miniature Portable Satcom Terminals", IEE Colloquium Digest No 1986/118, 11 November 1986.

33. Suckling C W, McGuiness D: "A Three Stage 30 dB MMIC Amplifier for SATCOMS", IEE Colloquium Digest No 1985/26, March 1985.

34. Lutterell S F, Pritchard J A S: "The Rapid Acquisition of Low Signal to Noise Carriers", IEE Proc F, to be published.

35. Electronics Weekly, 13, 18 March 1981.

36. Perkins S J: Unpublished RSRE Report.

37. "Special Forces Mansat", Defence Attache, 5/1986.

38. Microwave Systems News and Communication Technology, 111-117, November 1986.

39. Jones J J: "Hard Limiting of Two Signals in Random Noise", IEEE Trans on IT, Jan 1963.

40. Pearson R A, Davies D E N, Cullen A L: "An Array Fed Dual Reflector Antenna for Limited Sector Electronic Beam Scanning", International Conference on Antennas and Propagation, York, March-April 1987.

41. Smith A C, Skilton P J: "The Added Value of Array Antennas to Land-Based MILSATCOMS", IEE Colloquium Digest No. 1988/13, 21 Jan 1988.

42. Cummings W C, Pravin C J, Richardi L J: "Fundamental Performance Characteristics that Influence EHF MILSATCOM Systems", IEEE Trans on Comms, COM-27, 10, Oct 1979.

43. Smith A C, Gibbs J A: "Aspects of Multiband Antennas for Use in Military Satellite Communication Ground Terminals", IEE Colloquium on Multiband Antennas, 8 Dec 1987.

THIS PAGE IS LEFT BLANK INTENTIONALLY

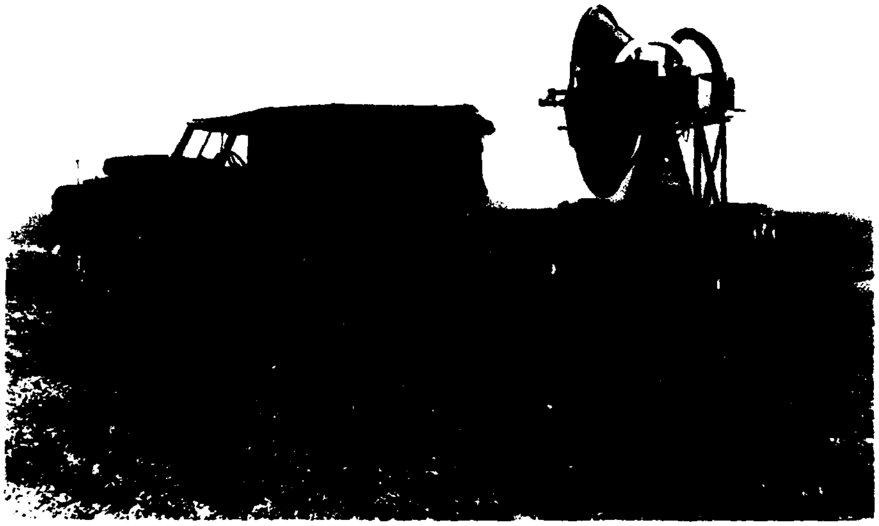


Fig 1. IDEX, a 1 kW fixed tune klystron provided the uplink signal. 1967.

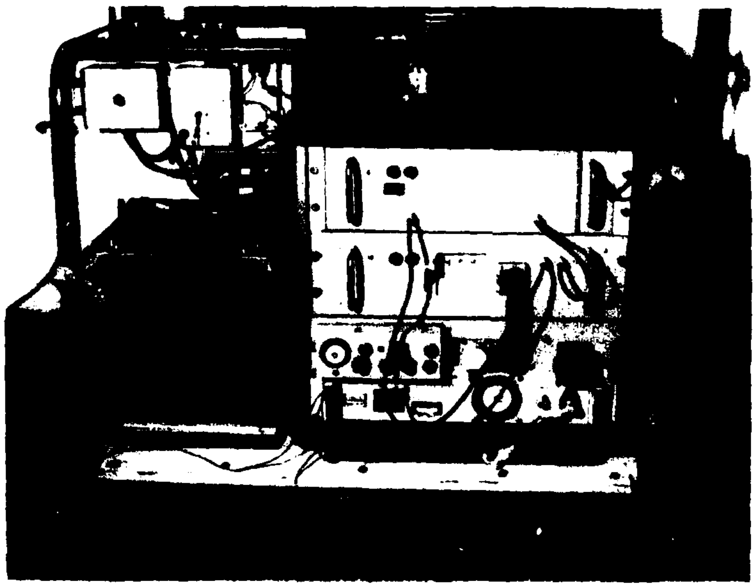


Fig 2. A prototype air transportable SGT. The right hand equipment rack could be removed for vehicle installation. 1978.

Fig 3. UK TSC 502.

Fig 4. UK VSC 501.

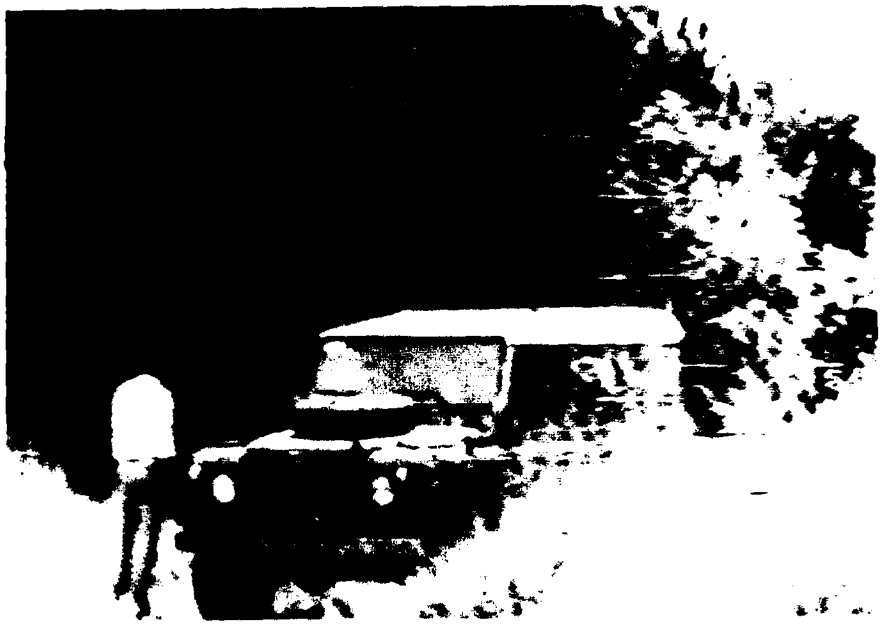


Fig 5. A slow scan TV image received at a small aperture SGT via a 16 kbit/s link at a 1 in 10^4 bit error rate.

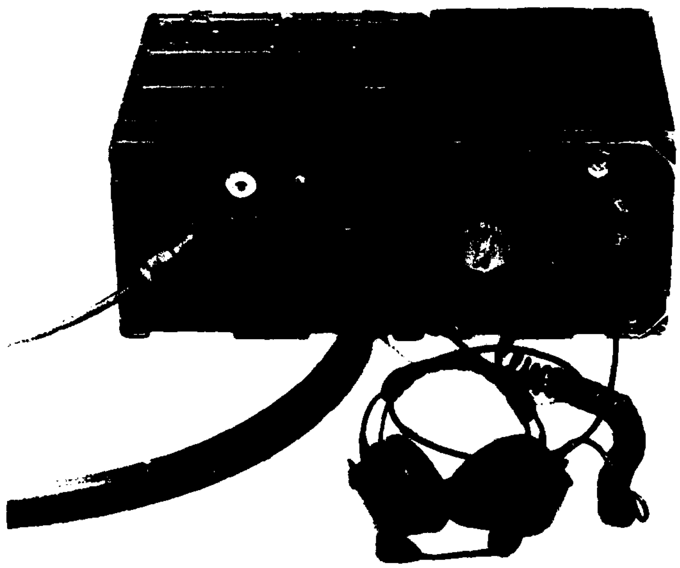


Fig 6a. A prototype satcom adaptor (left) for an in-service VHF radio.

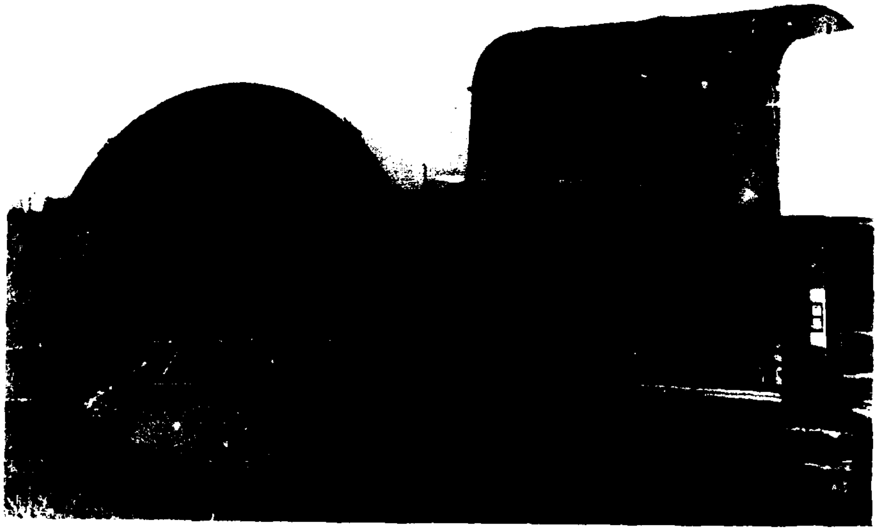


Fig 6b. A vehicle installation of the satcom adaptor.

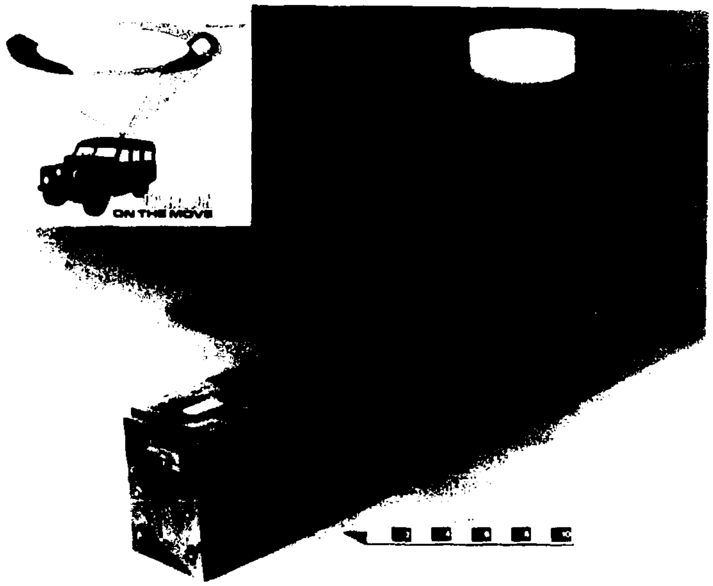
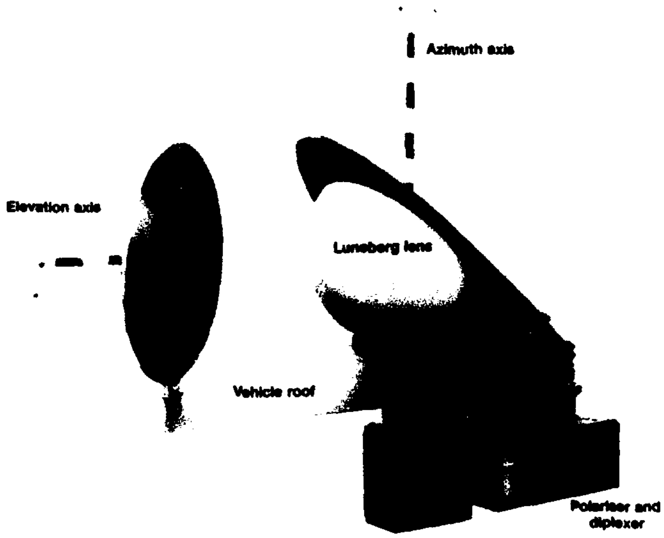
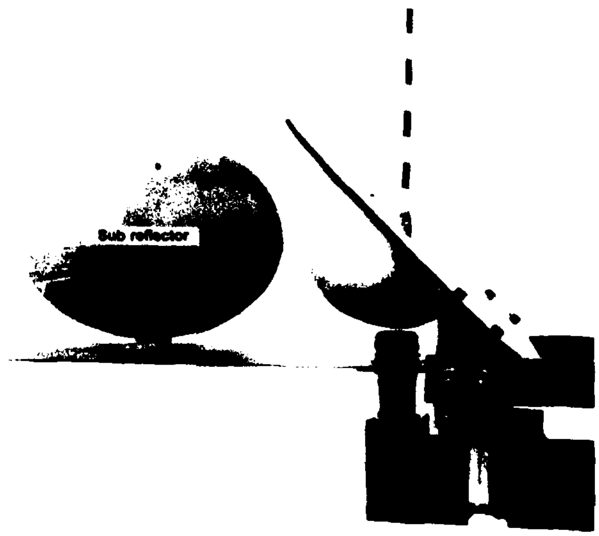


Fig 7. Polariser, diplexer and feed for the toroidal beam, roof mounted antenna. Inset, the resulting beam pattern.



(a)



(b)

Fig 8. A "breadboard" model of a low profile, roof-mounted antenna for 2.4 kbit/s communications with a moving vehicle.

Fig 9. A commercial prototype SHF Manpack providing either 50 bit/s data or an analogue channel.

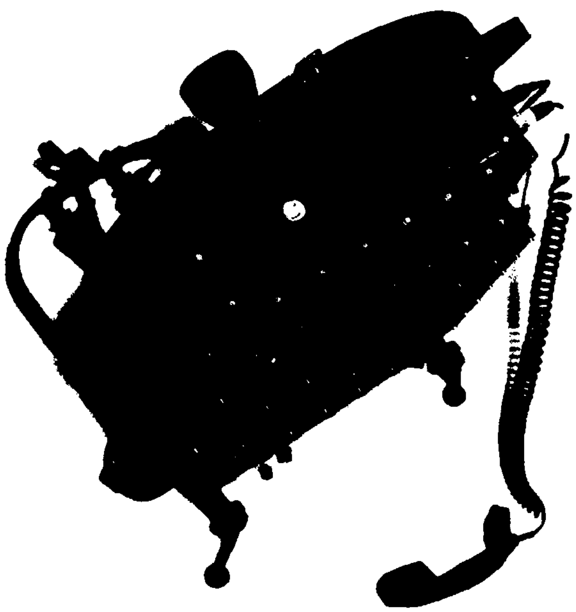


Fig 10. A 16 kbit/s modem evaluated as an additional module to the existing SHF Manpack.

Fig 11. A 33 dB gain, folding mesh antenna using the existing polariser and splash-plate feed.

Fig 12. A prototype printed array antenna developed as a potential alternative to the front-fed Manpack dish antenna.

Fig 13. The "Satcase", a prototype SHF SGT, typical of the equipment that would benefit from printed antenna technology.

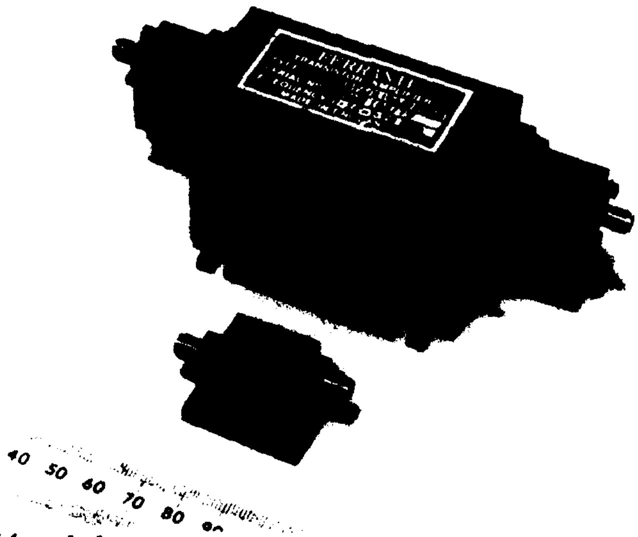


Fig 14. A low noise MMIC satcom amplifier developed for RSRE by Plessey Research Caswell. Rear - the LNA used in the "Satcase".

Fig 15. The UHF UST-1 satcom equipment with a commercial 6 dBi folding antenna.

DOCUMENT CONTROL SHEET

Overall security classification of sheet ......UNCLASSIFIED..

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R) (C) or (S))

1. DRIC Reference (if known)	2. Originator's Reference MEMO 4262	3. Agency Reference	4. Report Security Classification U/C
5. Originator's Code (if known) 7784000	6. Originator (Corporate Author) Name and Location ROYAL SIGNALS AND RADAR ESTABLISHMENT ST ANDREWS ROAD, GREAT MALVERN WORCESTERSHIRE WR14 3PS		
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location		

7. Title
TACTICAL UK MILITARY SATELLITE GROUND TERMINALS - A RESEARCH AND DEVELOPMENT REVIEW

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers) Title, place and date of conference

8. Author 1 Surname, initials SKILTON, P J	9(a) Author 2	9(b) Authors 3,4...	10. Date 1989.01	pp. ref. 57
11. Contract Number	12. Period	13. Project	14. Other Reference	

15. Distribution statement
UNLIMITED

Descriptors (or keywords)

continue on separate piece of paper

Abstract

This memorandum is intended as an introductory review of tactical satellite ground terminals in service with UK and NATO forces. Many of these equipments have derived from the RSRE research programme and current activities under this programme are included in the review. A background to the military space segment available to the UK, US and NATO provides a relevant perspective to the tactical terminal programme and future trends in space and ground segment hardware conclude the memorandum.

S80/48