WW2 British Army Battlefield Wireless Communications Equipment

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Abstract— **Features of wireless communications equipment used by the British Army during and shortly after World War Two are described, within the context of advances in technology and their influence on repair and maintenance methods.**

Keywords- Battlefield communications, wireless transceiver history, World War Two radio technology

I. INTRODUCTION

By the time of World War Two (WW2) radio communication between ground troops and between vehicles including tanks was essential, to support increased mobility, for which the previously dominant land-line based telephone links were inadequate. The paper describes some of the technical characteristics and design features of the widely-used British Army radio-transmitter sets of this period and the immediate post-war period. The material presented is based mainly on the author's experience of using them in a high-school cadet-force in the 1950s and subsequently, in the Royal Electrical and Mechanical Engineers (REME), being trained to repair them. The overall training scheme used by REME for this purpose in 1955-1957 is also outlined, when detailed repair at the individual component level, rather than replacement of plug-in modules, was the universal approach, requiring a thorough understanding of electronics.

A. Technology advances – effect upon Repair and Maintenence

The Royal Corps of Signals (founded in August 1920) was originally responsible for both the operation and repair of all army communications equipment, but in the early 1950s, responsibility for all maintenance was transferred to REME. During the period described, significant advances took place: the transition to miniature all-glass valves, the change from a.m. at frequencies within the 1-10 MHz range to f.m. in the frequency-range 38-50 MHz, and a change from continuously-tuned transceivers to crystal-controlled transceivers operating on pre-set frequency channels. At the same time, the circuit complexity increased – from six valves used in the WS 18 to fourteen in the WS 88, and environmental protection of the equipment was substantially improved; for example the WS 88, weighing 5 kg, was claimed to be 'unaffected by weather or climate' and was designed to float in water and remain operational. REME Workshop repairs to this unit were required to maintain the appropriate seals to preserve these properties. Perhaps the most innovative was the WS 10, introduced just in time to be used before the end of WW2, which provided eight speech channels over line of sight communications at 4·5 GHz, using pulse-width-modulated time-division multiplex [1].

II. WIRELESS SET NOMENCLATURE

The set-naming was based on a two digit code: The second digit indicated the application category and the first digit indicated the chronological sequence of the developments in a particular category. Thus WS 08, 18, 38, 68, 88 was a chronological sequence of developments of portable one-man transceivers. 'Missing numbers' correspond to sets which were either not widely used, or were designed but not ordered. Some later designs were slightly modified versions of US Army equipment – for example, the WS 31 was an 18 valve f.m. double-superhet transceiver, based closely on the American BC-1000 (SCR 300) later adopted by NATO and widely used for many years.

In the mid-1950s the naming scheme was replaced by one involving a letter followed by a two digit code. The letter (A - E) denoted the power consumption, and the code indicated the frequency band. For example the digits 10 to 39 covered 300 kHz to 30 MHz. The WS 88 was superseded by the A40 and the WS 19 first by the C12, and then the C13. The abbreviation WS (for Wireless Set) was replaced by SR (for Station Radio).

III. CAPABILITIES AND CONSTRAINTS

A major weight component of portable sets was the battery. Special purpose designs were usual, providing in a single package both the HT and filament supplies for the directly-heated valves (e.g. 162 V, 3 V for the WS 18 and 90 V, 1·5 V for the WS 88). In operational use, short battery life and need to supply replacements was a severe limitation of portable equipment, and efficiency, in terms of transmitter power output for battery power input, was low by modern standards.

The ~ 0·3 W sender power output of the WS 31 required a battery input power of 11.25 W, e.g. an overall efficiency of below 3%. Sets for use with vehicle batteries generally derived their HT supply from a rotary transformer or sometimes a vibrator. Directly heated valves require less power for the heater supply – for example, 100 mW for the ARP12, compared with 1.89 W for many indirectly-heated valves of the time, up to 4 W for the ARP36. Directly heated valves were therefore used in the battery-operated portable sets, while vehicle operated sets had sufficient power to use indirectly heated valves (or sometimes a mixture of both). Many used the 'Mazda octal' valve base – similar to but not interchangeable with the International Octal, used for most commercial radios of the time. To prolong battery life it was essential that the transmitter was switched to a low power consumption mode when not transmitting. Switching off the filament supply to directly-heated transmitting valves while receiving conserved power, but could not be done for indirectly-heated valves because of the much longer warm-up time.

The earlier designs all provided Wireless Telegraphy (W/T) communications (e.g. Morse code) and Radio Telephony (R/T). W/T came in two forms: Carrier Wave (CW) for which the carrier was keyed on and off, and Modulated Carrier Wave (MCW) for which 950 Hz amplitude modulation was keyed on and off while maintaining a continuous carrier. Reception of CW required a Beat Frequency Oscillator (BFO) in the receiver, tunable around the intermediate frequency, which could be adjusted to give an audible tone at around 1 kHz. Operator preference and interference could be accommodated by increase or decrease of the beat frequency.

The BFO assisted with another necessary function: to support the formal protocol for establishing a group of communicating wireless sets on the same frequency. One would be designated as the master ("control station"), and all others would need to tune to it ("netting"). The master transmitter would send a burst of unmodulated carrier ("netting call") for a few seconds, and the receivers would all use their BFO to tune in to zero beat, ensuring all were operating on exactly the same frequency. The lack of frequency stability meant that this process had to be repeated from time to time.

Equipment for mobile use was almost invariably a transceiver, which is a transmitter/receiver combination so designed that the transmitter always transmits on the frequency to which the receiver is tuned. Not only does this simplify operation by having less controls, it may also reduce weight by sharing many components between the receiver and transmitter parts. For example, by having the receiver local oscillator tuned to the sum of the incoming frequency and the i.f. (as in a normal superhet) and with the BFO tuned to the i.f. (achieved during netting), the mixing of the local oscillator and the BFO on transmit produces a drive signal exactly equal to the incoming frequency (see Appendix II). The audio stages of the receiver are typically used as the microphone amplifier on transmit. Send-receive switching is often achieved by several wafer-switches on a common spindle, or, in some cases, by a multi-contact relay.

Speech input was via a carbon microphone, either a throat-contact type (which left both hands of the operator free) or a hand held type with a side pressel-switch, which turned the transmitter on and off. Some hand-held ones were moving-coil construction. Commonly used headphones were a metal-cone type of medium impedance (~30 Ω), Fig. 1, very different from the high impedance (~ 2 kΩ) flat-metal-diaphragm type usual in the 'crystal set' era.

Fig 1. Low impedance cone headphone (DLR no 5)

The simpler sets had no means of adjusting the matching between the transmitter and the aerial, but most had a system of adjustment and of aerial metering which coupled a rectified proportion of the antenna current to an ammeter, enabling tuning for maximum current. Fig. 2 shows a variometer, used with the WS 19 to add inductance to short aerials.

Fig 2. Aerial Variometer

Coverage of some short-wave broadcast bands enabled the sets to be also used to listen to the transmissions of Radio Moscow, BBC, Voice of America, etc. (not possible after the introduction of the WS 88 and WS 31)

In addition to transceivers, there were medium power transmitters capable of battlefield deployment, such as a high-power version of the WS 12 and the WS 53, used in conjunction with receivers such as the R107 (Fig. 3) until it was superceded by the much lighter R209 after the end of WW2. The WS 53 had a power output of 250 watts on R/T, giving a ground-wave range of up to 100 miles. These were normally used in vehicles equipped as communications-stations for battle commanders. The WS 12 sender should not be confused with the much later C12 transceiver which was designed as a replacement for the WS 19, and was in use from the mid 1950s to mid 1960s.

Fig. 3 R107 Communications Receiver, 1·2–17·5 MHz

Hickman [2] describes the WW2 network configurations of these sets as deployed in infantry battalion and division formations and in armoured regiments.

The later sets did not include a capability for Wireless Telegraphy communications, since Radio Telephony had by then become almost universal in the Army Communications context.

Over this period, the British Radio and Electronics industry consisted mainly of a large number of small and independent companies. These companies were capable of providing designs and prototypes for the various army communications needs, but often did not have the resources for large scale production. Some sets were therefore made overseas – for example many WS 19 sets, primarily for tank communications, were made in Canada from 1941, some with Cyrillic text labelling intended for supply to the Russian front.

IV. Valve Nomenclature

Many valves were developed specifically for military use, while others were minor variants of commercial types. At first, valves for army use had a name beginning AR (for an Army Receiving valve) or AT (for an Army Transmitting valve) – thus, ARP12 denotes a pentode for receiver applications, 12th in a sequential progression, and ATP4 denotes a transmitter pentode. The opportunity to deduce the type of valve from the name is limited. For example, AR8 is a combination double-diode-triode. Later, all valves were allocated a common Services name beginning with CV, so ARP12 became CV1331.

V. Training Environment of REME in mid 1950s

Recruits for training in 'electronic' trades were motivated by being regularly assured that they had been selected to become the most skilled of REME soldiers, and therefore superior to the electromechanical trades. The 'electronics' training establishments were based in Arborfield, Berkshire (now the locations of the REME School of Electronic and Aeronautical Engineering until a planned move to South Wales, and of the REME Museum of Technology).

No 3 Battalion at Baillieul Barracks, Arborfield was the main site for 'telecommunications training' and was divided into A Company (for theory), B Company (for practice), C Company (for administration). The progression of skills (trades) for non-commissioned officers were: Telecommunications Mechanic, Classes 1, 2, 3, Leading Artisan Sergeant, Staff Sergeant Artificer. For the lower qualifications, there was a distinction between radio mechanics and line mechanics, the latter being involved with telephony including multi-channel carrier systems and data systems such as teleprinters.

Radar training was separate (at the nearby No. 5 Battalion, Hazebrouk Barracks); there was a tendency for Radar mechanics to consider themselves superior to mere Telecommunications mechanics.

Maintenance techniques required a good conceptual understanding of all aspects of circuit operation; test points and fault-finding flow-charts were rare, and the most skilled at fault-finding relied very much on experience and a kind of intuition. Fig. 4 shows typical wiring and component layout.

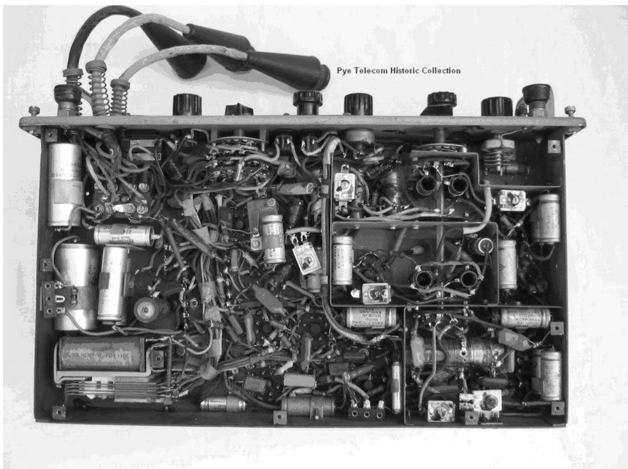

Fig. 4. Underneath the WS 22

There were no 'wobbulators' or spectrum analysers, and the ability to work with simple test equipment had to be developed. The available oscilloscopes had a maximum frequency of 5 MHz. The signal-injection philosophy was not adopted, signals were generally 'tracked' from the aerial in sequence to the receiver output. Initial general fault-finding skills were taught with the aid of a 'Blackboard superhet' – a huge standard 5 valve superhet laid out vertically in pictorial form with all parts available for test, controlled by an electro-mechanical 'telephone exchange' – the instructor used a telephone dial which enabled a variety of pre-programmed faults to be applied (one at a time) – for example, short-circuited or open-circuited components, valve failures, etc., and the student was required to find the fault in a reasonable time, standing in front of the class, and using simple test equipment, sometimes no more than an AVO 7 multimeter (Fig. 5). The current drawn by this instrument on its voltage ranges meant that measurements at high-impedance points were highly inaccurate.

Fault-finding on actual equipments was typically taught by the instructor creating one or more deliberate faults for the students to locate. Looking for freshly-soldered joints was therefore a trick that was soon learned.

'Health and safety' was not a prominent issue – perhaps because the risk of death from electrocution seemed low compared to the everyday risks of weapons training and carrying a rifle everywhere. High voltages from the anode supply to valves did represent a real danger, and maintenance on medium power short-wave transmitters involved disabling safety interlocks and working with a live 1500 V d.c. power supply rail. We were taught to keep one hand in a pocket whenever working with dangerous voltages.

Fig. 5. AVO 7 advertisement 1938

In pre-WW2 days, most civilian radios used valves having the anode connected to the top cap, so that the most readily accessible part was at around 250 V d.c. above the chassis or ground potential. (Later, it became usual for the control-grid to be taken to the top cap). In addition to the danger, touching the top caps (with or without a 'wet finger') was a standard preliminary step in fault-finding.

For economy some civilian radios used a live-chassis construction with metalwork connected to one side of the mains power supply, and series-connected valve heaters – so as to avoid the cost of a mains transformer. The common use of two-pin mains plugs meant that this metalwork was equally likely to be connected to the live or the neutral of the supply. By contrast with these early civilian radios, many of the military wireless sets were relatively safe to work on.

Typical courses were from six weeks duration to nearly a year. 'Military activities' (formal parades, marching around, wearing army boots, etc) were kept to a minimum, though the philosophy was that each person was first of all a 'fighting soldier' and technical expertise was secondary.

Courses normally involved some weeks of theory followed by some weeks of practice. Failure in one of the many examinations required the student to drop back and repeat the failed part, and several failures would mean demotion to a lower grade course or even transfer to some other, less demanding trade. Excellent results could, unusually, result in transfer to a higher level course. The curriculum was taught in a sequential way, unlike the parallel teaching of typical civilian schools or universities where many different subjects taught by different people are 'multiplexed' over each week of the timetable. At Arborfield, the class in which the student was enrolled would typically meet a new instructor early on a Monday morning and would stay continuously with the same instructor for the length of the course module which he was teaching until the examination two or three weeks later, with only short interruptions for such weekly events as 'padre's hour', current-affairs classes, and some university-style laboratory sessions. All instructors were male, with a very few being civilians.

The laboratory sessions included detailed study and adjustment of actual equipment. For example we were required to carry out i.f. alignment of the R208 Communications Receiver, measuring sensitivities and bandwidths of each stage. The R208 covers 10-60 MHz, with an i.f. of 2 MHz.

An important text book for basic theory was the Royal Signals Handbook [3], agreed to be somewhat out of date. The even more out-of-date Admiralty Handbook was also a useful theory-reference [4].

These were intended to be replaced by the Services

Textbook of Radio [5], a large multi-volume project which failed to live up to expectations. This was commissioned just at the time when technology was beginning to change rapidly, with increased miniaturisation, the use of transistors, and a maintenance philosophy of replacing faulty modules rather than detailed repairs. Volume 3 ‘Electronics’ allocated only one chapter (less than 10% of the book) to semiconductors, mostly about rectifiers and diodes, of which only 3 of 20 pages were devoted to the transistor. As a result, it was soon obsolete as an electronics textbook. Training included receiver-alignment and the calibration and repair of all test-equipment including signal generators, impedance bridges, wavemeters, etc.

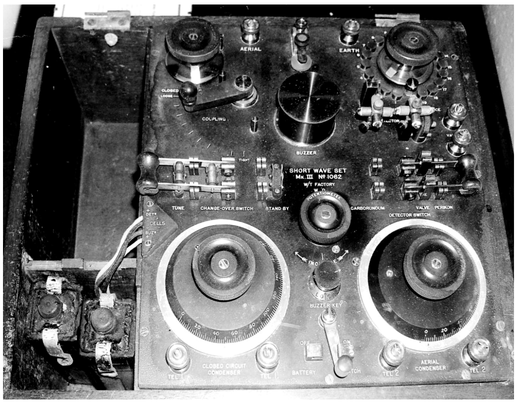

Fig. 6. 1915 short-wave crystal receiver for use in trench warfare

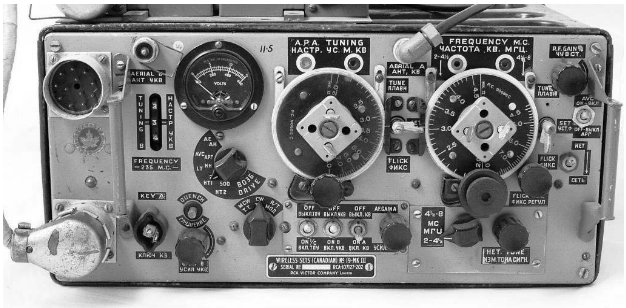

Fig. 7. WS 19, designed 1940 for use in tanks and other vehicles

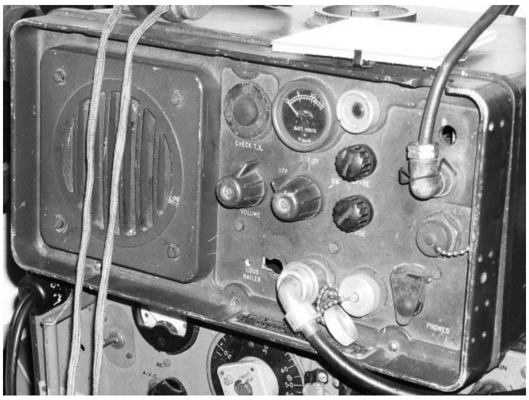

Fig 8. B44, introduced ~ 1960 (VHF/AM)

Figs. 6, 7, 8 illustrate the progression in technology, construction methods, and operator skills needed for army communications equipment, leading to sets with a minimum of operator controls, preset switched tuning, and maintenance by diagnostic test points and replaceable plug-in modules not designed for field or even workshop repair.

A. Some specific examples (see also [6], [7])

WS 18: A back-pack transceiver, with a two valve (AR8, ATP4) transmitter and a four valve (three ARP12, AR8) receiver. The complete equipment is installed in a metal box, carried as a back-pack, with the receiver above the sender, and the battery below. When mobile, it needs two people (one to carry, one to operate).

The 6·0–9·0 MHz range includes the 49 m and 41 m broadcast bands, permitting its use for general short-wave reception. Fig. 9, 10 show, respectively, the sender and receiver front panels.

It was a development by Pye Radio Co. of the WS 8, made by Murphy Radio Co. until 1940, with many similarities in concept and appearance,

Fig. 9. WS 18 sender

Fig. 10. WS 18 receiver

WS 19: Perhaps the most ‘famous’ of WW2 sets, also designed by Pye Radio Co., particularly popular with hobby groups which preserve and use historic military radios. It was for tanks and other armoured vehicles.

The frequency range of the main ‘A’ set is 2·5–6·25 MHz for the first version, made by Pye Radio, the Mk II extended this to 2·0–8·0 MHz. An ingenious mechanical ‘flick’ scheme enables tuning to be switched rapidly between two previously-set frequencies. Nine indirectly-heated valves are used, with an ATS25 beam tetrode (similar to the 807 and CV124) for the main transmitter power-amplifier valve, operated in Class ‘C’.

The range of ~15 km from the 5W output can be boosted by ‘RF Amplifier No2 (in a metal box similar in size and shape to the WS 19) to 35W giving a range of ~70 km.

The amplifier uses four ATS25 valves (the later Mk 3 uses two, but achieves the same power output)

The WS 19 also contains a VHF ‘B’ set for inter-tank communications, operating at 240 MHz, which was seldom used and considered obsolete by the mid-1950s, and an intercom amplifier for communications within a tank. The ‘B’ set has a super-regenerative receiver, using a CV6 triode valve, which is distinctive in having both anode and grid brought out to top caps.

WS 38: A pouch transceiver, weighing 10 kg, range 7·3–9·0 MHz, 200mW Transmitter output, Receiver i.f. 285 kHz. Five valves, of which two are shared between transmitter and receiver.

Fig. 11 shows the primitive tuning arrangement.

Well over 100,000 had been manufactured by the end of WW2.

Interworking with WS 18 was commonplace over the shared part of the frequency range

A WS 38 AFV variant allowed infantry to tank communications, and a later (Mk. III) version had an improved construction and tuning control, a more elegant appearance, and could be operated ‘remotely’ while carried on the back.

Fig. 11 WS 38

WS 62: A tropicalized transceiver, mainly for vehicle use, but could be carried, and would float and support 9kg. 1·6–4·0 MHz and 4·0–10·0 MHz (the upper range for emergency use only because of poor performance). ~14 mile range on R/T with 14 ft (4.2 m) aerial. Operated from a 12 V vehicle battery with a rotary transformer to generate 300 V HT. The WS 62 was a development of the WS 22 general purpose set, using a much lighter weight (aluminium) casing.

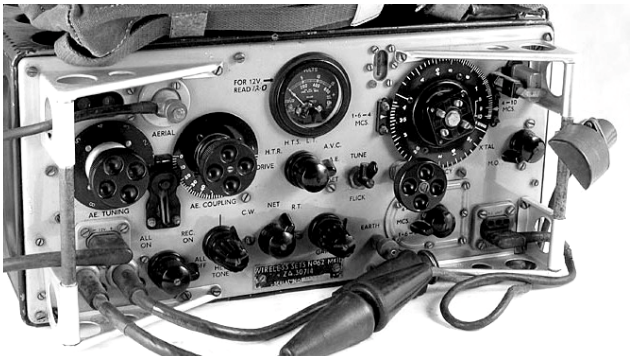

Fig. 12 WS 62: Note similarities to WS 19 in the front panel

WS 68: A development of WS 18, almost identical but for lower frequencies (1·75–2·9 MHz or 3·0–5·2 MHz) to avoid congestion and give a longer range. An additional feature is an option for crystal control of the Master Oscillator. An 11 ft (3.3 m) rod aerial can give a range of 8 km (e.g. more than WS 18) from the 250 mW output.

WS 88: Similar in size and shape to the WS 38, and available by 1947, this overcame congestion in the low HF band by moving to VHF and using f.m. Initial versions had adequate frequency stability over a 3 week period, which was a huge change from the continual frequency drift accepted for previous transceivers, and crystal-control was introduced in later versions. Weighing 5 kg, and using 4 preset frequencies in the 40 MHz region with 15 kHz max deviation, it can achieve a 1 mile range in open areas with its 250 mW output, with a battery life of 24 hours for a 1/5 transmit/receive ratio.

Fig. 13. Contol panel of WS 88

The battery was carried in a similar-sized pouch to the receiver. There are two types of WS 88 with different pre-set frequencies: A for infantry, B for mortar groups. A large proportion of the internal chassis is taken up by the 14 miniature glass valves. The crystal controls the local oscillator of the receiver and automatic frequency control of the transmitter is achieved by a signal from the discriminator which alters the frequency of a variable reactance valve in the transmitter (also used to provide frequency modulation from the microphone). Interworking with the later WS 31 is possible, because the four WS 88 frequencies are a subset of the 41 channels of the WS 31.

The extreme simplicity of the controls compared to earlier sets can be seen from Fig. 13. One switch turns the set on and off, the other selects one of four channels. Send-receive switching is by a press-lever on a cable (not shown).

WS 31: A tropicalized and splash-proof short-range (~12 km) VHF f.m. transceiver, weight 11 kg, covering 40–48 MHz. Continuously tunable, providing 41 channels spaced by 200 kHz, 500 mW transmitter output. A double superhet with i.f. of 4·3 MHz and 2·515 MHz and, compared to the earlier transceivers, notable for its circuit complexity. An adjustable squelch circuit is included to cut out the high frequency noise produced by an f.m. receiver when no input signal is being received. 18 valves, of which three were used for the squelch circuit. On later versions, the squelch control is absent. Automatic frequency control is included to provide compensation for tuning errors of up to one quarter of a channel-division. A 4·3 MHz crystal oscillator is used for the transmit mixer, and a 6·815 MHz crystal oscillator for the receiver second mixer (using a heptode valve to provide both oscillation and mixing). The 4·3 MHz oscillator also provides a means of calibration by providing audible beat frequencies at specific points on the frequency dial when a 'calibrate' button is pressed.

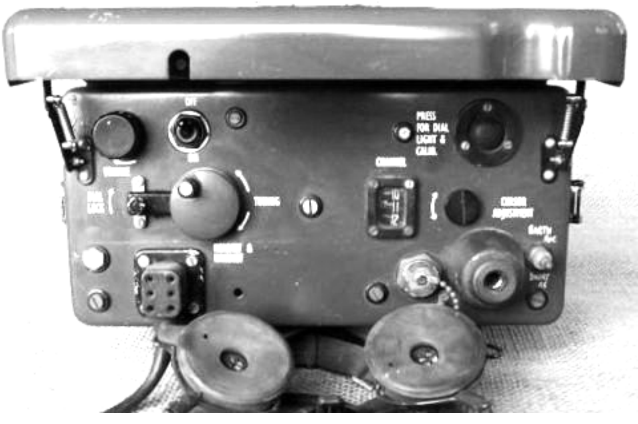

Fig 14. WS 31 (a later version without squelch control)

WS 10 Mk I (used during last stages of WW2). Two transmission frequencies, 4·547 GHz and 4·762 GHz, with a different magnetron (CV79 or CV89) for each one, conveying the microwave output via a circular waveguide to parabolic aerials. The magnetron power output is 200 mW, giving a line-of-sight range of around 50 miles. The Mk II version is tunable and uses a velocity-modulated valve (CV228, Heil tube), giving much increased power output but was not introduced until after WW2.

Fig. 15 WS 10 trailer and aerials

For each of the eight speech channels, the pulse width is 3.5 µs, varied by modulation ±2.3 µs. A 20 µs synchronising pulse is added to each 111 µs frame containing the eight channel pulses. Amplification of the incoming frequency was not possible, so the incoming signal is converted to a 45 MHz i.f. using a crystal mixer and the 3rd harmonic of a tunable ~1500 MHz triode oscillator.

VI. Trends and Conclusions

As army battlefield radio equipment developed, technology advances enabled sets to be operated with less expertise (for example, continuous, unstable tuning replaced by stable crystal controlled switching between a few preset frequencies), and needing much less expertise to maintain, with intricate fault-finding and repair of faulty parts being superceded by simpler fault detection systems and replacement of faulty modules instead of repair. Clearly this led to lesser requirements for theoretical understanding and practical skills. Even in mid 1950s the need for a three week course including transmission line theory and m-derived filter design was being questioned. However, the much greater complexity and reliance on electronic and computer technology in modern warfare has resulted in a completely different operational and maintenance environment, although one in which the expertise of REME is still crucial in the British Army. The present day military communications framework would have been unimaginable in the 1940s and 1950s. System complexity and integrated circuit electronics makes local repairs and ad-hoc improvisation impossible, despite the need for battlefield survival of communications equipment in a destructive environment.

VII. ACKNOWLEDGEMENTS

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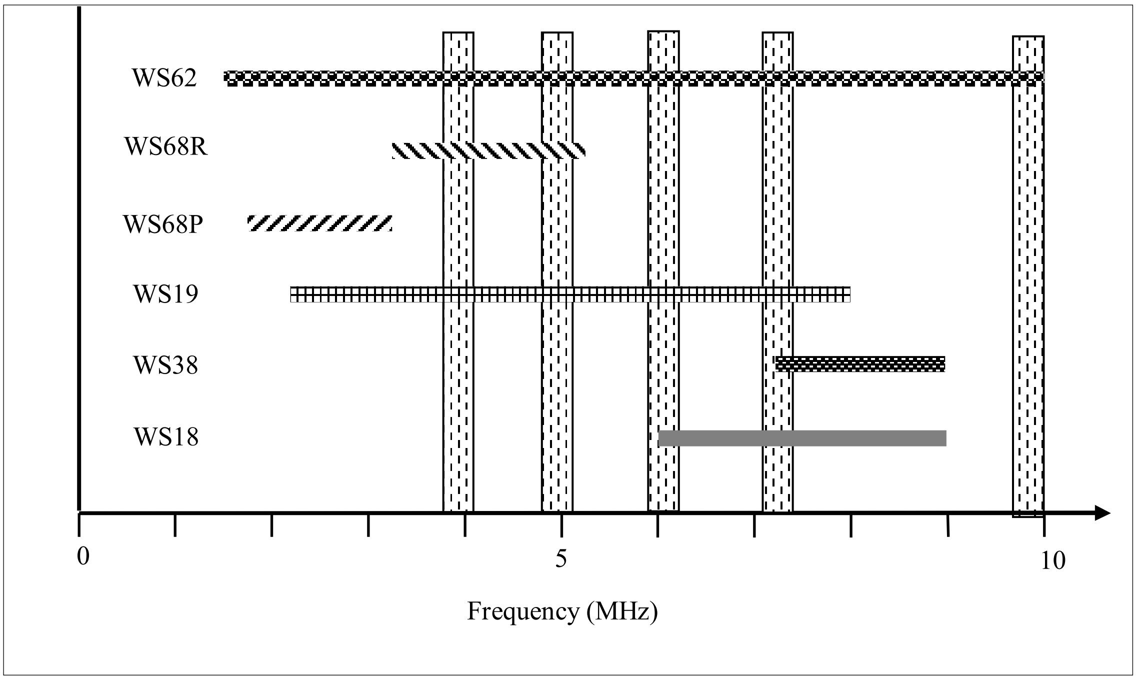
APPENDIX I FREQUENCY RANGES
(overlaps with the 75, 60, 49, 41 and 31 metre broadcast bands illustrated by the vertical bars)



APPENDIX II TRANSCEIVER PRINCIPLE
(LO = local oscillator, Tx – Transmitter, Rx =Receiver)