

The Wireless Set No 31 – Boring!

Perhaps not the best of titles! It was prompted by a fellow collector, who said, “Surely the WS31 is one of the most boring sets ever, only surpassed by the WS88, which doesn’t even manage a volume control? And why bother to restore one? You can’t get batteries, it uses vast amounts of battery power anyway, and even if you could sort all that out, you can’t use it legally, as it doesn’t cover any of the current amateur bands.”

These thoughts probably echo the sentiments of many others, judging by the current lack of interest there appears to be in this set. And yet the WS31 is of historic significance – its introduction in 1945 - 47 represented a completely new approach to short range communications by the British Army. It also represented a considerable technical advance at the time. I will be exploring these points in more detail, and in the second part of this article, I have made a start on turning the WS31 into a set that can be used – legally - on the 6 metre amateur band.

An introduction to the WS31

The WS31 is a manpack designed to be carried on the operator’s back, with a suitable carrier. It provided 41 channels, with a channel separation of 200 kHz, over the range 40 – 48 MHz and it could interwork with the WS 88 Type A. The set used FM rather than ubiquitous AM of all previous Army manpacks. The Tx power output was 300mW minimum and the Rx sensitivity 5.5 uV for 20dB quieting or better. Typical range for the set was 3 to 5 miles.

Fig.2 The WS31 Mk 2 on its carrier

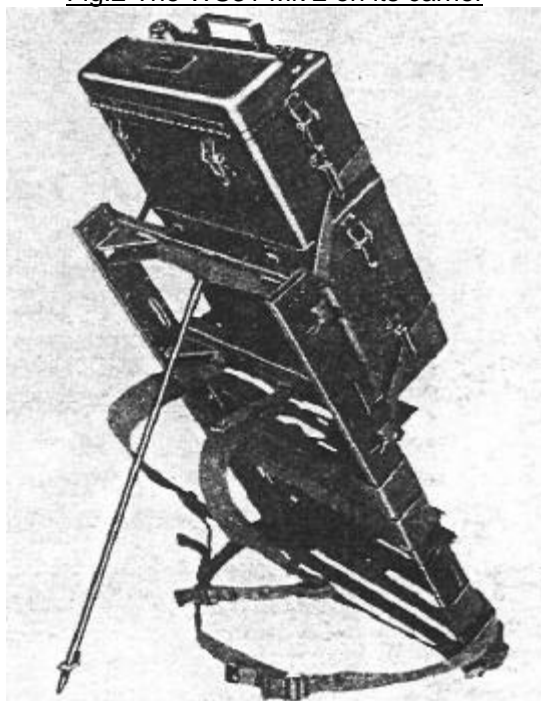
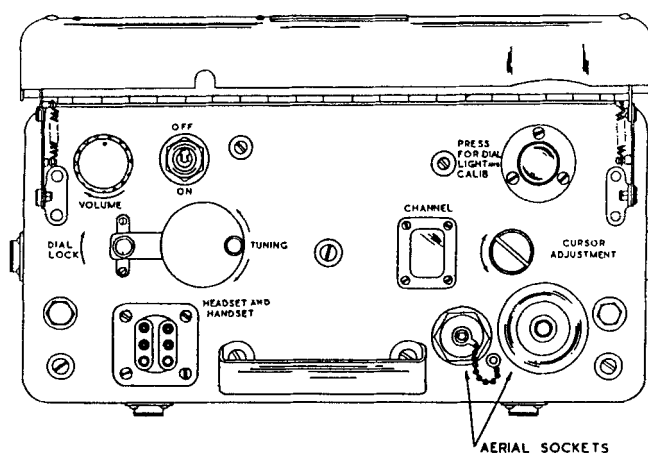


Fig.1 The WS31 Mk 2 front panel



There were two versions of the set, the Mk.1 and Mk.2, though the Mk.1 has all but disappeared, since those in service underwent a mass conversion program to turn them into the Mk.1/1, a hybrid version interchangeable with the Mk.2.

The excellence of the design meant that it has rather few knobs to twiddle (see Fig.1) – something the Army will have thought a great advantage for reliable operation in the field – but often taken to indicate a rather boring set by today’s collectors! The Mk.2 had one less knob than the Mk.1, since the squelch system was removed.

The set complete with its accessories – see Fig.3 – is also pleasingly simple: the fewer separate bits there are, the fewer there are to get lost! The Mk 2 again was simpler than the Mk 1 in that the number of aerial types was reduced from two to one.

The history

The introduction of the WS31 represented a sea-change in the approach to short range portable communications in the British Army, but to understand why that was so it is first necessary to consider the military radio scene at the time.

During nearly the whole of WWII, the Allied forces used HF manpacks for short range communications. Sets such as the WS No’s 18, 38, 46, 48, 58, 68 and 108 will be familiar to many readers, and all feature operation in the range 1.75 – 9 MHz, using AM and CW.

The shift to FM and VHF

By the end of the 1940's the Army had moved substantially to using FM sets, operating in the low VHF bands, for similar roles. Why?

There seem to have been two factors that brought about this change:

- In the latter part of WWII, the 2 – 10MHz spectrum was severely congested, so that man-pack sets could rarely find an interference free channel [3].
- The Americans came along in 1944 with their BC1000-A (SCR-300-A) manpack, which used FM at 40 – 48 MHz, and was judged “an outstanding success” by the British Army [1].

The success of the American BC-1000 led to a decision to produce a British copy of this set, and the result was the WS No.31, which first went into service in 1947.

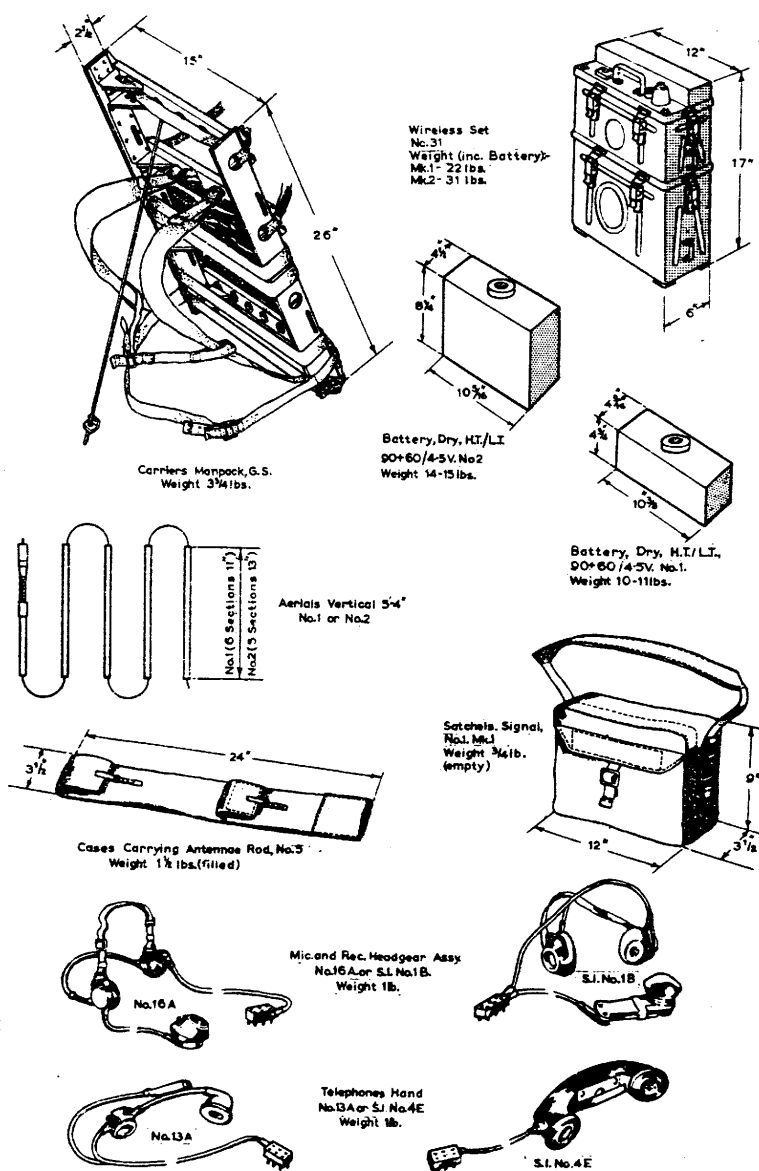
No FM here please – we're British!

The British Army seems to have been reluctant to make the transition to using FM, or use frequencies above 20MHz. Walter Farrar, G3ESP, has in the past told me about some tests he was involved with during WWII, where a side by side demonstration of AM and FM was laid on for senior Army personnel. Walter relates that when the FM system produced just as good a link as the AM one, those present simply could not believe it, and were convinced that some jiggery-pokery had taken place!

Quite what led to this prejudice against FM remains a mystery at the moment – but it seems likely that if the Americans hadn't provided this demonstration of the superiority of FM VHF operation – the British Army would have taken a lot longer to reach this conclusion¹.

¹ This strange reluctance to acknowledge the performance benefits of FM continued well after WWII in other official circles. The British Police were avid supporters of AM for their VHF mobile radio operations long after it had been abandoned by others. My own mobile tests of AM versus FM operation when I worked at Pye Telecommunications in 1979, showed no advantage whatever for AM, and if anything it suffered more from vehicle ignition interference than FM.

Fig.3 WS31 with its accessories



No VHF either!

The reluctance to move from HF to VHF is more readily explainable. Over the period 1935 – 1944 there had been numerous attempts to press the frequencies above 30MHz into service – and most had failed. Sets such as WS No's 13, 24, 37 and 47 were all abandoned following trials, and it has been said about the WS19 'B' set that it was easier to shout to the guy in the next tank, than use the radio! One problem encountered was that of making the set frequency stable in a difficult environment: the WS13 was noted as going off-tune if the operator even loosened his belt! [4].

A common design feature of these early VHF sets was a very simple RF system: the Tx would

My experience of the WS 31

When I was in the CCF in the early '70s, the WS 31 and WS 88 were the mainstay sets for all exercises. Often they were deployed for other purposes as well, such as helping to run the school cross-country.

The set worked extremely well within its limitations, the main ones being its weight and bulk. In addition, to get ranges of 3 miles or more, great care had to be taken in siting the set, not easy if you are in a built-up area, or working in the dark!

My most vivid memory of the WS 31 was of using one during a night exercise on Dartmoor. It was a very dark night and I fell into a shell crater, and found myself waist deep in slimy water. The set being heavy, and the sides of the hole very slippery, I found I could not escape until hauled out by the rest of the platoon! Needless to say, the set worked quite happily throughout, despite getting a severe soaking.

use a single valve as a free-running L-C² oscillator, and the Rx would be a super-regenerative type, also L-C tuned. Such simple circuits are generally doomed to failure³. L-C tuned circuits are very difficult to keep stable in a high vibration environment (such as a manpack), and are heavily affected by surrounding objects, unless very well screened and solidly constructed. Super-regenerative receiver circuits can be very effective, but are notoriously touchy to set up, and suffer from the problem of causing interference to other receivers in the vicinity.

The BC-1000 breakthrough

Thus was the technical stage set for the arrival of the BC-1000 and its clone, the WS No.31. And the design of the BC-1000 was definitely a breath of fresh air: it still used adjustable L-C tuned circuits, but drift was dealt with partly by an effective AFC⁴ system, and partly by using a wide bandwidth IF system⁵. A built-in crystal calibrator ensured that the operator could correct any long-term drift. The previous approach of a single valve RF system was swept away: the set used a total of 18 valves, and the receiver employed a double conversion superhet design.

Astonishing performance

For the radio operators, used to fighting for air-space on the crowded HF bands, this new set

must have proved a revelation. FM signals of reasonable strength offer a very good audio signal-to-noise ratio; any interference (if there was any above 40MHz in those days!) would have been generally silenced by the capture effect (see box below), and an effective squelch system gave a totally silent background when not receiving a signal. And it worked the same – day and night⁶. Absolutely wonderful! The link quality provided by these sets was probably very similar to that of the wired telephones of the day – simply astonishing!

The development of the WS31

The WS31 started life as a close copy of the BC-1000, but after some year's experience in the field, a Mk 2 version was designed, and went into service in 1956. In addition, some of the shortcomings of the Mk 1 set were thought serious enough to put nearly all the Mk 1 sets through a conversion program to make them interchangeable with, though not identical to, the Mk2 set. These converted Mk 1 sets were designated Mk1/1 – and these are still fairly common, the author having several examples. The changes made to the Mk 1 set to convert it

The 'capture effect'

FM with deviation higher than the modulation frequency (certainly true for the WS 31) and monitored on a Rx with good limiting (also true of the WS31), will 'lock on' to the strongest signal present. An interfering signal on the same channel may be only 3dB weaker than the wanted one – and yet will be completely inaudible.

This is known as the 'capture effect', and leads to the notion of 'frequency re-use', where the same channel in neighbouring areas (in radio range) can be used simultaneously without causing mutual interference. This of course, provides vastly more usable radio channels in the same limited spectrum.

² 'L-C' is an abbreviation for 'inductor-capacitor', as opposed to a quartz crystal as the frequency determining element.

³ It is worth noting that the WS17 succeeded with VHF (AM) operation using very simple circuits where other attempts had failed. It is not a 'manpack' set, however, being better described as a "luggable set", designed to stay put in one place for long periods. The WS17 was designed by an amateur with 5m experience before the start of WWII [5] – and no doubt written off as a 'quirk' by S.E.E. whose WS 13 had been such a failure.

⁴ Automatic Frequency Control. This is a control loop that keeps the Rx closely netted to that of the incoming signal.

⁵ The IF bandwidth is required to be at least 30KHz at the –6dB points.

⁶ Ranges of HF sets at night were even more curtailed by the heavy sky-wave interference they would pick up from hundreds of miles around.

to Mk 1/1 were:

- Removal of the squelch system: no documents traced so far explain exactly why the use of squelch fell out of favour in the British Army for many years (until the introduction of the A41 No.2 in fact) – see inset box “To squelch – or not to squelch?”
- Aerial output impedance changed from high to low, and a coax socket to allow the connection of a remote aerial was added;
- On/off switch added in the HT and LT supply circuits; strangely, various versions of the Mk.1 circuit seem to exist, two of which suggest (see refs [2], [7]) that the existing on/off switch was totally ineffective – the heater circuit was continuously powered once the battery was connected! The EMER issued well before this modification [8] shows a different circuit with no apparent problem, so quite what the truth was behind this change, remains a mystery.
- Improving the reliability of the 6.815 Mc/s xtal oscillator circuit, by altering some component values.

The Mk 2 set incorporated all these changes and added a send/receive relay to switch off the HT to the PA, and Tx mixer. A problem had been found with the Tx mixer taking an appreciable time to switch off after returning to receive mode: the pressel switch previously only switched the heaters, and these take time to cool off, allowing the 4.3 MHz oscillator to continue running for some time, and blocking reception.

The physical details of the set and its accessories may be seen in Figs.1-3 A conversion kit was provided to turn the set into a ground or vehicle station, mainly consisting of various aerial mountings and a vehicle mounting carrier (Carriers, Set, No.62).

Transmitter circuit design

The fairly simple block diagram of the Tx is shown in Fig.4. The master oscillator and

To squelch – or not to squelch?

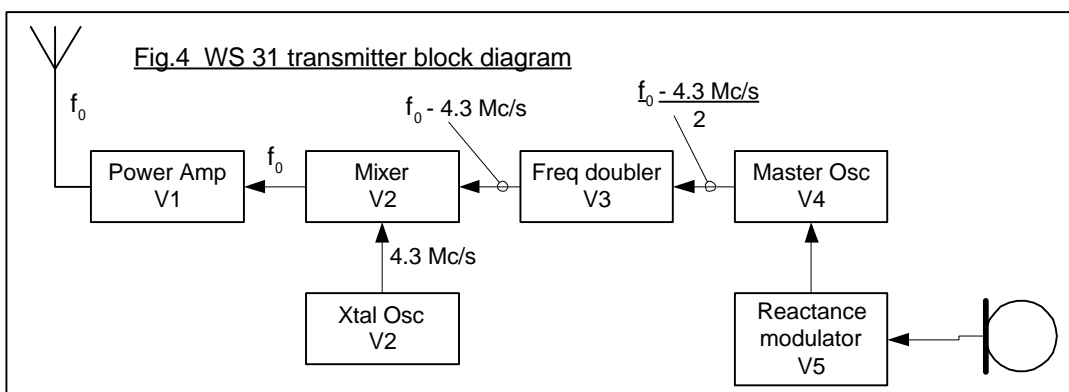
Something prompted the Army to go to a lot of trouble to remove the squelch system from the Mk 1 WS31s. It can't have been some fault in operation, since once gone, the squelch stayed out in the WS31 Mk2, and its successor the A41 No.1. The Americans kept the squelch system first on the BC-1000, and then the range of sets that succeeded it, the PRC8-9-10 series.

Why? I have not yet discovered any documentary evidence that explains this. The two theories advanced so far are:

- The squelch control could be misadjusted (or accidentally knocked) and the operator would be unable to tell that this had happened (the only way to check is to readjust it properly). As a result vital messages could be missed.
- All squelch systems have the unfortunate habit of emitting a loud noise burst at the end of a transmission, before silencing the audio system. This noise burst might have been overheard by an enemy in close proximity.

Neither explanation is terribly convincing, particularly as squelch was re-instated in the A41 No.2. It is possibly an example of a rather poor operational decision – later reversed.

frequency doubler stages are shared with the Rx, and with the Xtal oscillator (V2) on the same frequency as the Rx 1st IF, a common receive and transmit frequency is assured. The reactance modulator, V5, doubles up as the frequency control element in the AFC loop on receive, but this loop is disabled on transmit. One thing to note is that care has been taken to limit the amount of gain on any one frequency, by use of the frequency doubling and mixing scheme. Given the very open layout, with unshielded coils dotted around on the underside of the set, this is just as well, otherwise instability would have been certain.



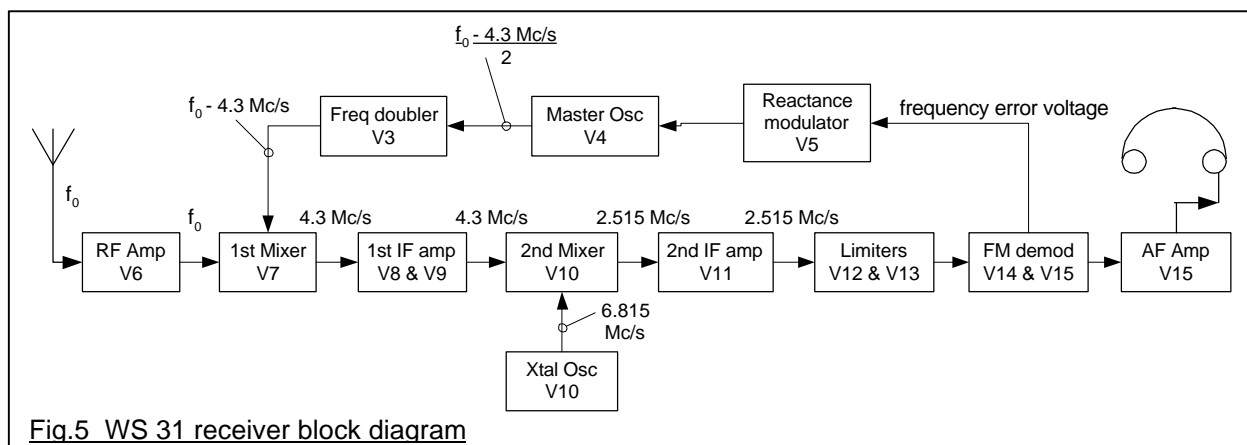


Fig.5 WS 31 receiver block diagram

One unfortunate side-effect of the design appears to be the gross inefficiency of the PA stage: the DC input power is around 4.5 watts, but the RF output is only 350mW – efficiency 8% ! With a decent class C stage, efficiencies of at least 50% are usually achieved with ease – but in this case there appears to be insufficient drive from V2 to get the PA into class C.

Receiver circuit design

The receiver is a double-superhet design: no doubt at the time it was regarded as a little incongruous for a soldier to be carting around such a 'Rolls-Royce' solution on his back! The top side of the chassis is populated by a sea of valves and shielded IF transformers – there being a total of 8 tuned circuits at either 4.3 MHz or 2.515 MHz. These IF frequencies may look odd to our eyes, but it has to be remembered that the designers were striking out into new ground here, and no standards had been established. As it happens, the 4.3 MHz IF became something of a standard – being used in a number of later sets, including the PRC8-9-10 series, the CPRC-26, A40 and A41.

The AFC loop proved to be the key to overcoming the stumbling block of previous VHF designs: how to keep sets properly netted. Remember this would be a big problem for an operator not able to reach the tuning control, because the set is on his back! In the WS31, the Tx is free running, but the Rx automatically locks on to incoming transmissions, an error of +50 kHz being correctable.

Making a WS31 usable

The current lack of interest in the WS 31 makes it fairly easy to find good examples. The WS31 was never of much interest to the amateur fraternity, so they have usually not been hacked up. £30 will normally secure a complete specimen, and the accessories are available. I think if there is one thing that really awakens interest in a set, that is making it work, and being

able to demonstrate it on the air. That, of course, is something of a challenge with the WS31! There are three notable problems:

- The frequency range of 40 – 48 MHz does not cover any amateur bands;
- The Tx has no harmonic filtering at all;
- The batteries are no longer available.

In the remainder of this article, I intend to deal only with the first problem of the frequency coverage: a follow-up article will deal with the other points, in due course.

My good friend, Mike, G1EDP, agreed to investigate the possibility of moving the frequency coverage to include the full 6 metre band, i.e. so that channel 40 tuned to 52 MHz. Some readers may feel affronted by a proposal to modify a piece of historic wireless equipment – if so, take a look at the inset box headed, "To modify – or not to modify?"

Arranging a power supply

For bench tests and alignment, mains power supplies can be used. The voltages required are +4.5 volts at 450mA max (but allow more for switch on surge), +90 volts at 28mA, and +150 volts at 45mA.

Altering the frequency range

Mike developed a modification procedure, and tested it on both Mk1/1 and Mk2 versions of the set. In all five sets were modified, so we are confident that others will obtain similar results. The component changes are as follows:

- 1 In the Tx PA (V1) change C3 from 18pF to 10pF.
- 2 In the Tx mixer stage (V2), change C11 from 16pF to 7.5pF.
- 3 In the doubler stage (V3) change C21 from 15pF to 7.5pF.

Fig.6 Below chassis view of WS 31 Mk 2, showing modifications for 6m operation

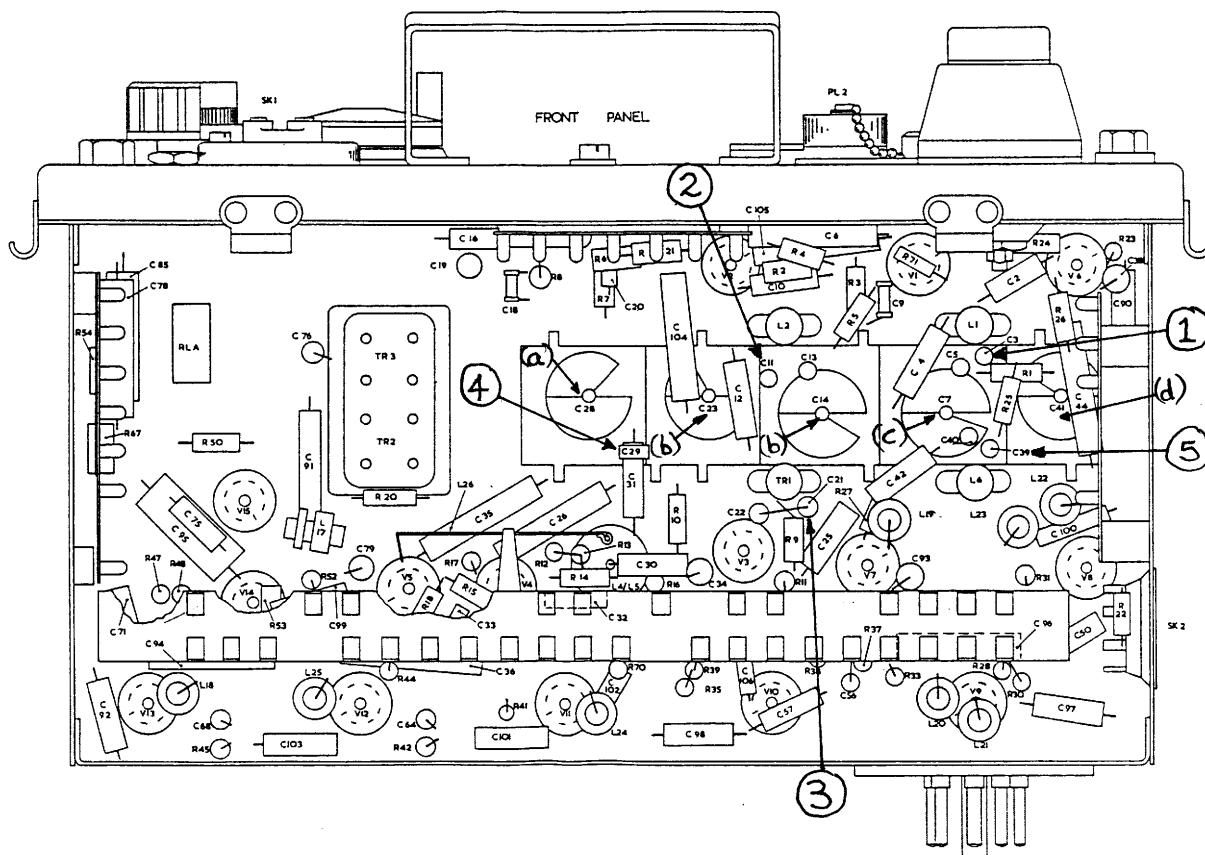
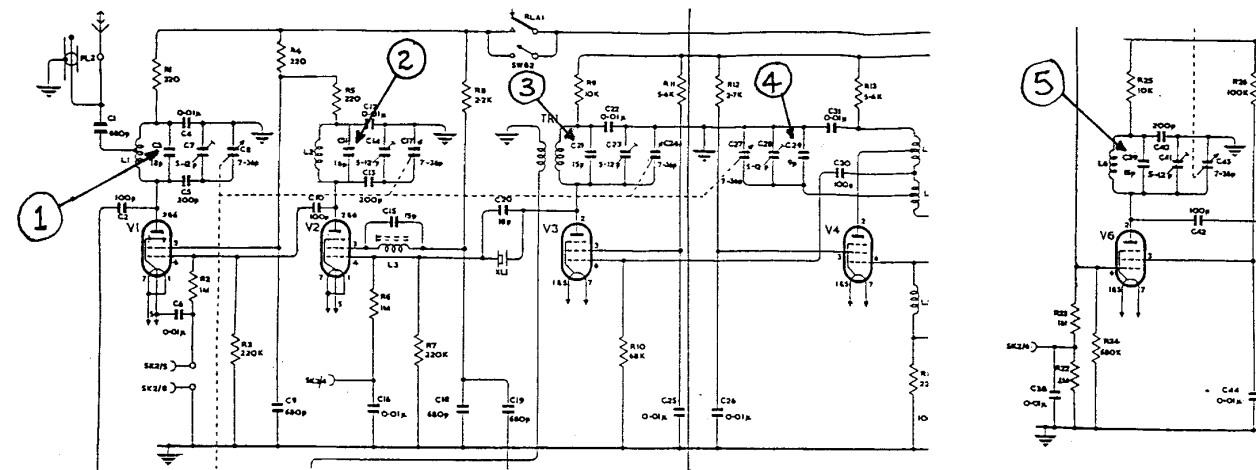


Fig.7 Partial Tx circuit, V1-4, and Rx RF amp, V6, showing location of modifications



- 4 In the master oscillator (V4), remove C29 (9pF).
- 5 In the Rx RF amplifier stage (V6), change C39 from 15pF to 7.5pF.

All these changes are easy to make, and if preferred the original components can be left in place, attached by their earthy end, with their live ends cut. The location of these changes are shown in Figs.6 and 7 above.

Before making any modifications to a set, it is very important to check that it is working correctly on its normal frequency range. Trying to align a modified set with faults present is guaranteed to lead to the tearing of hair!

Alignment

After changing the component values, re-alignment must be carried out: we chose to make channel 40 tune exactly to 52.0 MHz,

To modify – or not to modify?

Some collectors maintain that to do anything other than restore equipment as near to its original condition as possible is irresponsible vandalism. Better that the set should gather dust on a museum shelf, than be modified in any way, even to make it legally usable!

While agreeing that it is very easy to irrevocably damage old equipment, and thus further reduce the number of intact samples available to posterity, I think *some* limited modifications may be considered to make a set fully usable again. I have evolved the following set of guidelines to decide when such modifications are justified:

1. The changes must be easily reversible. (This rules out holes in the chassis and similar.)
2. The changes must be the minimum possible to make the set usable and in particular avoid causing interference to other users of the spectrum.

Rule 1 ensures that the set is readily returnable to its original condition. The kind of butchery that we often see – holes in the chassis and the like – cannot be countenanced under any circumstances.

Rule 2 says ‘don’t be tempted to start “improving” the set with modern day components and techniques’. It entirely defeats the object of trying to demonstrate what historic equipment was capable of – because the result no longer is a piece of historic equipment!

though a frequency just inside the 6m band could be selected, if preferred. The following procedure aligns the set on 52 MHz:

- a) Set the tuning dial to channel 40. Power the set up, in receive mode. Monitor the frequency of the master oscillator (V4) with a frequency counter (or suitable receiver). If using a counter, a small inductor at the end of a length of coax may be used as a pickup probe. Adjust the trimmer capacitor, C28, to give 23.85 MHz on the counter. Care needs to be taken that presence of probes and trimming tools do not result in a frequency error.
- b) Connect the aerial socket to a 50 ohm dummy load. Using a high resistance voltmeter (e.g. DVM) connect it to pin 5 (-ve) of SK2 (the octal test socket on the side of the chassis) and to chassis (+ve). Go to transmit. Adjust trimmer capacitors C14 and C23 for maximum reading on the voltmeter, which should be 10 volts or more.
- c) Move the –ve lead of the voltmeter to SK2 pin 6, and adjust trimmer capacitor C7 for maximum, again in transmit mode. The reading should be 20 volts or more, and it may be necessary to adjust C41 as well to

achieve this. This completes the alignment of the transmitter.

- d) Move the –ve lead of the voltmeter to SK2 pin 3 (final limiter grid), and adjust trimmer capacitor C41 for maximum reading on the voltmeter. This adjustment is made on noise, but a signal at 52 MHz can be injected at the aerial socket from a generator, if preferred. This completes the alignment of the receiver.

Results

The receiver sensitivity remained unchanged by this modification, which is not surprising for a mere 8% frequency change. Similarly on transmit, the output power was very similar. A slightly annoying birdy can be heard on 51.6 MHz, which turned out to be the 12th harmonic of the 4.3 MHz IF signal: in practice this is not a significant problem.

One oddity that was noted, which applied to both modified and unmodified sets, is that the PA tuning (C7) point for maximum RF output power depends on the type of load presented – a torch bulb and a 50 ohm power meter (the bulb is presumably somewhat reactive) giving different tuning points. The EMER requires the use of a power meter or dummy load, and it seems necessary to stick to this advice.

That concludes the first step in returning a WS 31 to full working order – at least on a mains power supply. A later article will deal with the design and construction of a portable power supply for the set.

Richard Hankins, G7RVI***References***

- [1] “Wireless for the Warrior”, Volume 2, Louis Meulstee, WS 31, Historical Development.
- [2] *ibid*, WS31 Mk 1 circuit diagram (Fig 31-7)
- [3] *ibid*, WS 88, Historical Development.
- [4] “Wireless for the Warrior”, Volume 1, Louis Meulstee, WS 13
- [5] “On the back of an envelope.....how the Wireless Set No.17 was born”, Stanley Lewer, G6LJ, Radio Bygones, Issue 41, June/July 1996
- [6] “User Handbook for Wireless Set No.31 (Manpack) Mks 1 & 2”, W.O. Code 1204, 1957
- [7] “Low Power Wireless Sets”, Royal Signals Trade Training Notes, Vol.9
- [8] WS 31 EMER, tels F362, Issue 1, 14th April 1948