British Army Larkspur era C41/R222 Radio Relay: repair and testing, also incorporating the PG342 Frequency Synthesiser. Part 2

Brian Blackwell G3YVW

The original article - part 1 **[3]** described the author's Station Radio C41/R222 radio relay station addition to his Larkspur era radio collection and making operational, in both the 'terminal' and 'relay/repeater' configurations, plus its use with the Plessey PG342 frequency synthesiser. Part 2 has now been added to describe the author's newly acquired addition of the Carrier Set Telephone CST 1+4 No. 3 to his radio relay setup, briefly mentioned in part 1.

Equipment – general description

The CST 1+4 No. 3 is an integral part of the C41/R222 radio relay system (note the equipment also found use with the Station Radio B70 SHF radio relay) providing the FDM multiplexing of up to four telephony channels, including an engineering circuit. Each telephony channel may be further sub-divided to provide four teleprinters on each channel, thus up to 12 teleprinter circuits in all, using the Terminal Telegraph Voice Frequency 4/12**.** The C41/R222 was already in service (using other (older) carrier equipments) when the CST 1+4 No. 3 was introduced – in the early1960s: technical/user documentation relating to the carrier set telephone is dated 1963/1964 and it's noted that the Signal Engineering Instruction DG03 **[5]** makes references to the CST 1+4 No. 3, dated 1984.

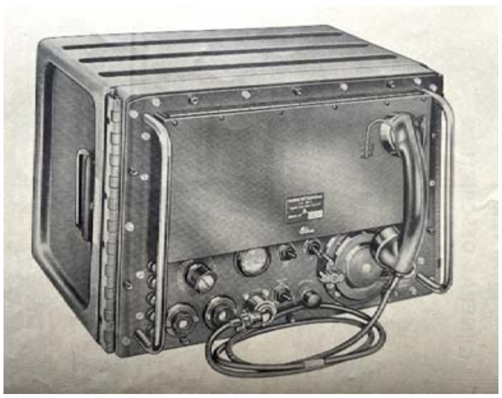

Figure 1. The Carrier Set Telephone CST 1+4 No. 3

As described in the user handbook, *The Carrier Set Telephone 1+4 No. 3 is a lightweight forward area multi-channel carrier telephone equipment designed to provide four speech circuits over line or radio relay systems.*

The carrier set telephone operates from 24 VDC (usually provided by its own external mains operated supply - see **Figure 10** – sitting on top of the carrier set), weighs 44 kg/97 lbs, and is all transistorised. The manufacturer was STC of England. When used as a terminal, one C41/R222 station would be fitted complete with the FDM carrier equipment Carrier Set Telephone CST 1+4 No. 3 – as shown in **Figure 4** in part 1 of this article, in this case in the 'fish frier' trailer. The power supply can also be seen on top of the carrier set telephone in the trailer.

Carrier frequencies used are 8 and 16 kHz and the upper and lower sidebands are used for each of the carriers. The equipment possessed various options and facilities, including 2- or 4- wire working, line or radio operation, 'out of band signalling' (switchable) **[5]** - used when the local exchange/terminal 'A' needs to call the remote exchange/terminal 'B', and a test tone. A test unit (TMS) is also provided, for both checking the carrier set and for system setting up. The baseband is 0-20 kHz which also allows for the engineering channel – see **Figure 2** for the baseband frequency allocations. Note that there are two pilot frequencies – the first is for one direction of the radio link, the second is for the 'return' direction of the link, and controls the AGC function of the receive amplifiers.

Taking delivery of the carrier set telephone and repairing

A carrier set telephone was located and then promptly purchased. It had been laying - apparently untouched, in an old unused garage/shed – full of army radio equipment from the 1950/1960's era, for many years. The carrier set was in quite good condition externally and once in the author's shack, work began on the repair/testing of it. This was not an easy task physically at the start, purely due to the weight of the unit!

Once opened, the author was pleasantly surprised by the good physical condition of the inside and of the PCBs (the unit is of a sealed type construction). The EMER for the unit **[1], [2]** and the user handbook were both very useful/essential in the repair, and included circuit diagrams and technical descriptions/operating procedures, etc.

The typical C41/R222 radio relay system would include a CST 1+4 No. 3 at each end of the radio relay chain, connecting into the terminal equipment from the (normally 2-wire) line – field telephones/switchboards etc. With telephony, for example fed into a terminal ('A') for transmitting over a link, this would then be received and demodulated at the receiving terminal ('B')/carrier set telephone and fed out to the line. Thus to fully test the carrier set (system) would require two units – one at each terminal/each end of the relay chain.

The author just possesses the single carrier set and so it was decided to fully test as far as possible, observing the FDM action and then to finally feed into the C41/R222 terminal of the author's to at least observe the operation from one of the terminal stations, albeit not received at another terminal/carrier set.

		Sideband frequencies	Signalling tone
Channel 1	-	8kc/s lower, 5-7.7kc/s	4.5kc/s
Channel 2	-	8kc/s upper, 8.3-11kc/s	11.5kc/s
Channel 3	-	16kc/s lower, 13-15.7kc/s	12.5kc/s
Channel 4	-	16kc/s upper, 16.3-19kc/s	19.5kc/s
Engineering circuit	-	0.3-3kc/s	1kc/s

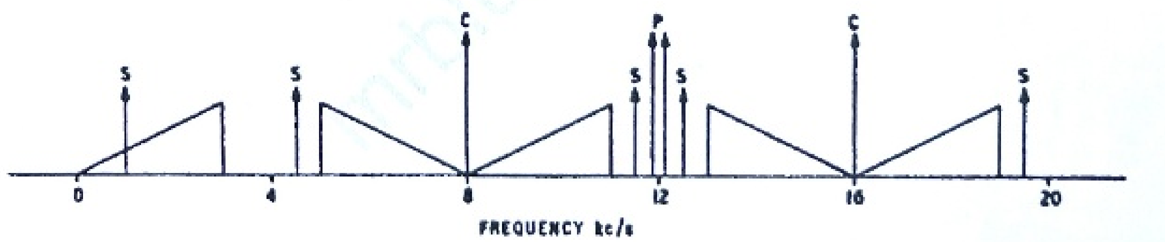

Figure 2. The frequency band arrangements/baseband showing the four channels, including the engineering channel. The signalling tones associated with each sideband/channel are also shown as are the two pilot frequencies (11.9 and 12.1 kHz). Note the lower sidebands are inverted in frequency whereas the upper sidebands are erect

To aid the checking for correct operation of the carrier set an inbuilt test unit (TMS) system with a multiway selector switch and meter are used. The PCBs can be removed (one at a time) from the unit for testing externally with the aid of a McMurdo 16-way extension cable supplied with the unit. The PCB in **Figure 3** is connected into the carrier set telephone with this connecting lead.

Figure 3. The carrier set telephone removed from its case and repairs/testing underway. Note the PCB is removed from the unit and checked externally with the aid of the extension cable supplied with the unit

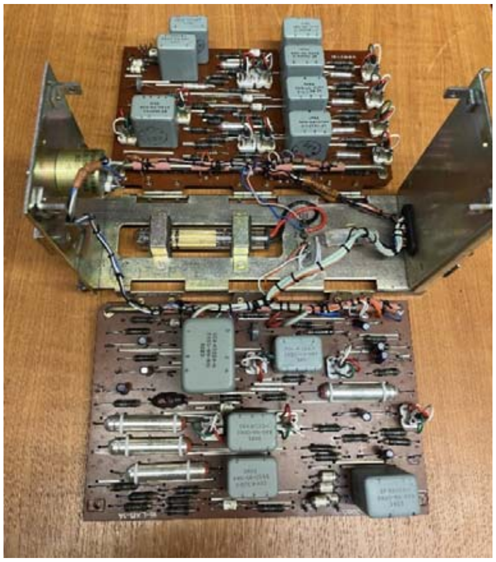

Figure 4. One of the PCBs opened out for inspection/repair. This particular PCB is the transmit amplifier, pilot oscillator and carrier supply. Note the 32 kHz crystal in the centre frame

Access to the unit (notwithstanding the weight!) was quite good and the PCBs could be opened out as shown in **Figure 4** to provide easy access for inspection/repair.

A comprehensive functional test procedure found both in the user handbook and the EMER provided a useful means in which to check the unit for correct operation (in conjunction with the TMS unit and meter) – the front panel layout of which can be seen in **Figure 6,** prior to setting up over a complete system.

Upon switching on (once the usual safety/preliminary checks had been carried out) all that actually functioned appeared to be only the BATT CHECK (battery check) and the RING GENR (ring generator) as observed on the TMS. So fault-finding began, only to discover quite quickly that most of the internal modules/PCBs were faulty *i.e.* those that utilised certain electrolytic capacitors (2.2 μF and 4.7 μF) – namely all of those manufactured by ITT and Hunts, and were all faulty. All of these were therefore replaced on sight – a selection of the faulty capacitors is shown in **Figure 5**.

Other faults found were a faulty diode in one of the channel balanced modulators, including a faulty balance potentiometer in the same modulator. Also discovered - as the result of a previous attempt at repair (presumably!) - a large solder ‘blob’ shorting out PCB tracks, and a transistor on a channel card signalling circuit which had previously been removed and put back the wrong way round.

Figure 5. A selection of the faulty electrolytic capacitors replaced

Figure 6. Front panel layout of the carrier set telephone showing the controls and the TMS unit/meter

When the carrier set telephone was deemed ‘repaired’ and ready for testing, the functional test procedure was used from the user handbook/EMER. As well as allowing for checking most parts of the unit, the procedure also provided for the 2-wire LINE TRANS (line-out) terminals to connect back into the 2-wire LINE REC (line-in) so essentially checking the complete transmit/receive operation of the carrier set. Thus the 4-channel FDM signal transmitted to line (including the engineering channel) is also received back into the unit to be split back into the 4 channels (and engineering channel) and demodulated.

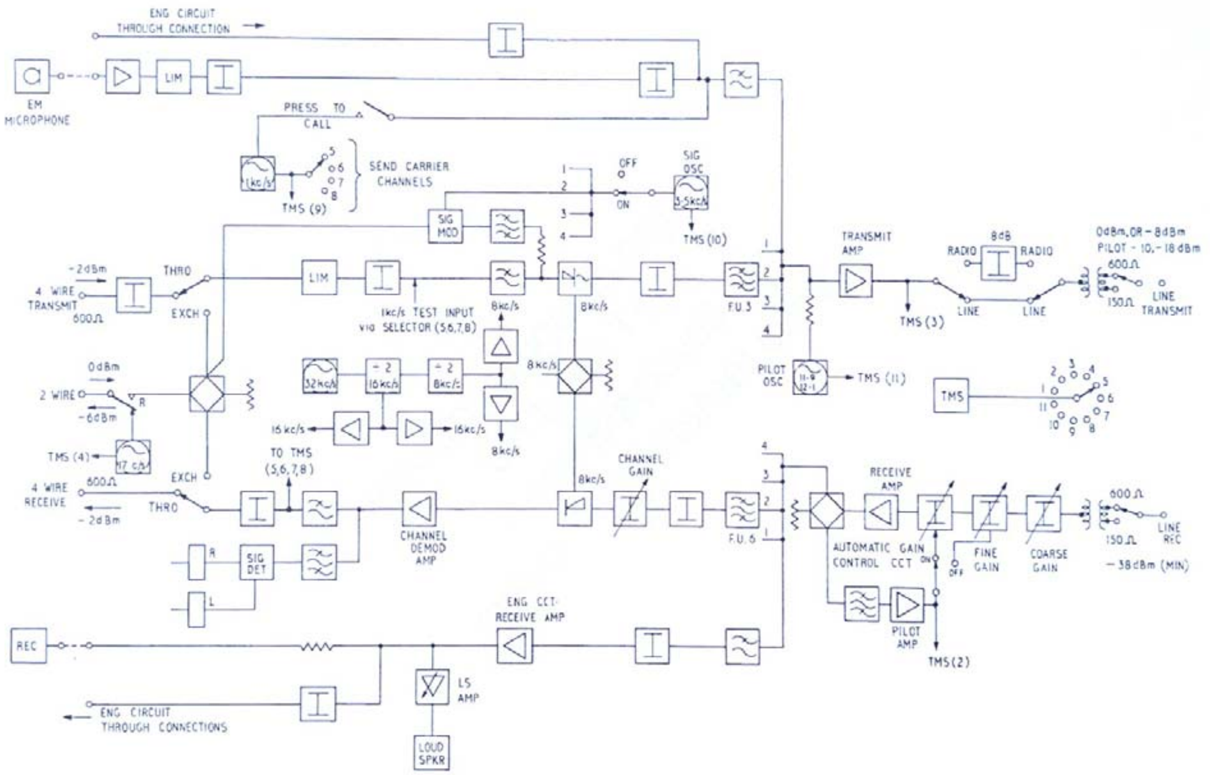

Figure 7. The CST 1+4 No. 3 block diagram. Note only channel 2 is shown, channels 1, 3 and 4 are identical except for the individual carrier frequencies and filter passbands

The engineering channel was also checked at this stage – speaking into the handset produced 'sidetone'***** in the earpiece and the PRESS TO CALL switch also functioned – producing a relatively loud tone (1 kHz) in the loudspeaker, varied by the LS VOL volume control.

*****The 'sidetone' is actually the audio received back into the LINE REC line-in terminals, so once the LINE TRANS is disconnected from the LINE REC line-in connection (as with the author's 'stand-alone/single terminal setup) no 'engineering' audio will be received, either from the microphone or from the PRESS TO CALL operation, so the complete link has to be established first.

Once the unit had been tested and set up satisfactorily in accordance with the procedure, additional checks were then carried out by the author to ascertain the unit did, in fact operate fully and at the correct frequencies. This included the production by the carrier set telephone of the correct baseband of frequencies, the signalling tones worked correctly and at the correct frequency, the pilot tones functioned correctly, including the 1 kHz test tone (also used in the setting up of a complete radio relay link).

To this end, the LINE TRANS output was monitored using a frequency counter and oscilloscope, then later a spectrum analyser. Thus all of the output channel signalling could individually be checked. At this point the LINE TRANS line-out was disconnected from the LINE REC line-in and the LINE TRANS then loaded with a 600 Ω impedance (using a CT44 AF wattmeter). 150 Ω impedance could also be used, switchable on the front panel, depending upon what type of line cable is used in operation – loaded for 600 Ω or unloaded for 150 Ω.

Using the TMS switch (in conjunction with the 1 kHz test tone) and selecting channels 1, 2, 3 and 4 – on TMS switch settings 5, 6, 7 and 8 (note from the block diagram in **Figure 7** the 1 kHz test tone is *injected* rather than monitored - all other TMS positions are monitoring) then the 1 kHz can be seen on the LINE TRANS.

Thus for channel 1 the frequency out will be the 8 kHz carrier less 1 kHz for the lower sideband and 8 kHz plus 1 kHz for the upper sideband: similarly for channels 3 and 4 with the carrier of 16 kHz.

A reasonably 'clean'/pure sinusoidal signal was monitored on the oscilloscope, bearing in mind the carrier is balanced out somewhat in the balanced modulator with the aid of a balance potentiometer.

Once these outputs were noted as satisfactory, then the pilot 'A' and pilot 'B' signals were selected and monitored (12.1 and 11.9 kHz) on the oscilloscope and also measured on the frequency counter, *i.e.* with all channels switched off (EXCH TERM) then both pilot signals are switched on in turn, both with AGC on and AGC off.

Note all these measurements are with the channel selector switch (as per procedure) still in the EXCH TERM position, *i.e.* the exchange input is disconnected and the input terminated in 600 Ω. The switch can now be set to EXCH/SIG. ON - yellow markings, when the 3.5 kHz signalling will now be seen on the oscilloscope. The frequencies can also be checked for each of the channels using the frequency counter, *i.e.* the carrier plus/minus 3.5 kHz depending upon the channel – as shown in **Figure 2**.

A Telephone Set ‘J’ field telephone (2-wire) **[4]** was now connected into a channel input – EXCH ‘A’ and ‘B’ terminals (**Figure 8**). The 3.5 kHz signalling tone output (on the appropriate carrier) could be observed on the LINE TRANS. The author could now operate the handset talk switch to speak and observe the audio out on the oscilloscope (again, the (speech spectrum) frequency depending upon which channel/carrier is used). A fairly loud sidetone (from the field telephone) was also heard.

Figure 8. Testing a channel on the CST 1+4 No. 3 with a field telephone – telephone set J

The operate/wind handle on the telephone set J, *i.e.* the magneto ring generator, was operated. The 3.5 kHz signalling signal on the LINE TRANS was now observed to switch on and off in ‘tandem’ (i.e. being modulated) with the ringing voltage from the Telephone set J of 17 Hz (which was a typical frequency used by most of the associated switchboards) – see **Figure 9**. At the remote terminal ‘B’ the modulated signal would be detected, which via a relay connects the carrier set telephone ringing generator to call the remote exchange.

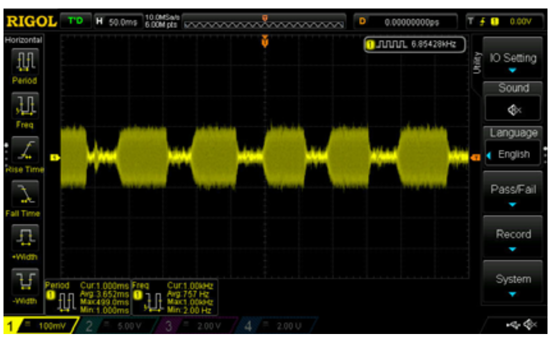

Figure 9. The 3.5 kHz ringing tone on the LINE TRANS output ‘modulated’/interrupted by the 17 Hz magneto generator from the field Telephone set J

Testing in-situ

The carrier set was now physically installed into the radio relay/terminal setup as shown in **Figure 10**.

Figure 10. The carrier set telephone now installed with the C41/R222 radio relay/synthesiser equipment (although not yet connected into the terminal) and undergoing extra testing

Further tests were now carried out (with the LINE TRANS still disconnected from the LINE REC) and monitoring the LINE TRANS with a spectrum analyser. Additionally, an extra telephone set J was utilised such that two channels could be connected (**Figure 11**).

Figure 11. The test setup with two telephone set J's, and monitoring the frequency spectrum/baseband with the spectrum analyser and additionally with the oscilloscope

Each of the 4 channels were now selected – *i.e.* switched from the EXCH TERM position to the EXCH/SIG. ON – yellow markings, thus generating the 'out of band' signalling frequency for each of the channels (refer to **Figure 2** for actual frequencies). The pilot frequency of 12.1 kHz was also selected. These can be seen on the spectrum analyser trace in **Figure 12,** with a frequency span of 20 kHz.

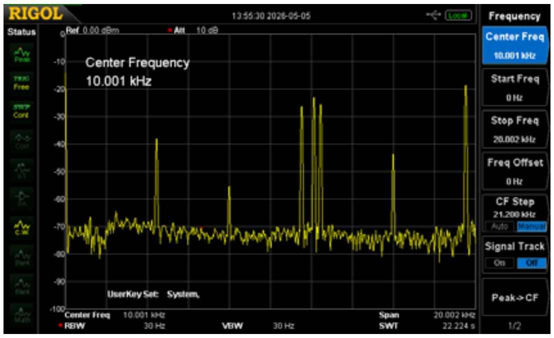

Figure 12. The spectrum analyser trace showing all signalling frequencies including the 12.1 kHz pilot tone. Note the signals at both 8 kHz and 16 kHz, with a spectrum analyser frequency span of 20 kHz – these are the internal carrier frequencies which are 'breakthrough'/leak to the LINE TRANS output

Channels two and four were now selected, with channels one and three set to EXCH TERM (*i.e*. disconnected and set internally to 600 Ω). Both of the telephone set J's were connected to channels two and four and the frequency spectrum/baseband observed on the spectrum analyser (frequency span of 20 kHz) whilst speaking into both microphones simultaneously, shown in **Figure 13**.

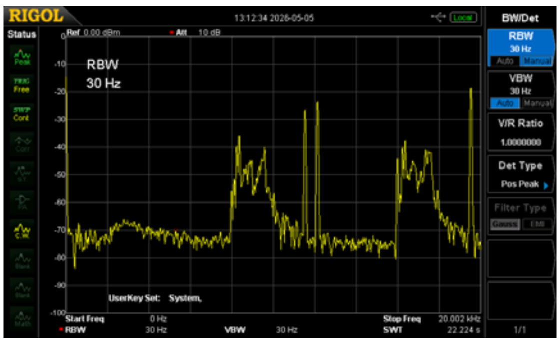

Figure 13. The voice frequencies visible on the baseband for channels two and four, with a spectrum analyser frequency span of 20 kHz.

Channel two sideband frequency range 8.3 to 11.0 kHz, with a 11.5 kHz signalling tone: channel four sideband frequency 16.3 to 19.0 kHz with a 19.5 kHz signalling tone. Note the pilot frequency of 12.1 kHz is also shown

Other checks carried out (before reconfiguring the author's C41/R222 'relay' setup into a 'terminal' setup) included feeding in various frequencies on the baseband LINE REC input to correspond to the four channels (including the engineering channel) checking for the correct audio out from the relevant channel, as received on the earpiece of a telephone set J when connected to that channel - fed from the 600 Ω balanced signal output from the Wayne Kerr S501 video signal generator.

System testing with the C41/R222 terminal

The LINE REC and LINE TRANS connections were now connected to the LINE IN connection on the R222 receiver. Both the carrier set line-in and line-out signals are connected to this 4-way connector on the R222, with the routing of the signals from the RF receiver section on line-in; then to the RF transmitting section on line-out, carried out internally using a separate external connection TO SENDER to the C41 transmitter.

The system was powered up, using the Marconi TF2018 to supply an RF input signal to the R222 (52.2198 MHz) and the C41 transmitter RF out (86 MHz) was connected to the CT211 HF wattmeter, Racal frequency counter and the Racal deviation meter. All input/output signal and power levels as before with the previous terminal testing in part 1. The final system test configuration can be seen in **Figure 15**.

Note the C41 (and R222) both have a deviation monitor setting on their respective meter selector switches, but an additional Racal meter was used here by the author as a double-check. **Figure 14** shows the carrier set telephone connected into the radio relay terminal setup, and powered from its own (original) 24 VDC supply sitting above. The C41 and R222 oscillator frequencies were set as before, that is, the R222 using its own crystal and the C41 using the Plessey frequency synthesiser.

Note the switch settings on the front panel in **Figure 14**:

Channels 1 and 4 – EXCH (SIG ON): both channels enabled (telephone set J inputs) with signalling on

Channels 2 and 3 – EXCH (SIG OFF): both channels enabled (video signal generator inputs) with signalling off

Pilot A and AGC signal on

Selector switch to REC PILOT: monitors the LINE REC input, and the REC GAIN COARSE (and FINE) controls set to give a meter reading accordingly in the central white area

The LINE/RADIO selector switch set to LINE 150 Ω*****

*****Note both LINE/RADIO impedance positions were additionally tested (with 150/600 Ω) – with appropriate adjustments on the R222 attenuator during later tests for correct deviation because the RADIO switch position on the carrier set telephone introduces an 8 dB attenuation.

Figure 14. Final settings for the testing with the radio relay terminal. Note the meter selector switch is set at REC PILOT, thus monitors (and checks) the REC LINE signal in for the correct level (meter indicator central/in the white zone)

Function checks were carried out satisfactorily using the RF signal generator feeding into the R222 and modulated - firstly at 1 kHz modulation frequency which checked the engineering channel operational, and then the modulation frequency increased to 6 kHz which caused a 2 kHz tone to sound in the channel one telephone set J (8 kHz carrier minus 6 kHz, inverted channel).

Testing for the transmitting section, *i.e.* the telephone J inputs to two of the channels, and feeding out into the C41 via the LINE TRANS output of the carrier set telephone was then seen to modulate the transmitter appropriately, from the voice signals. The ‘fixed’ tones from one of the pilot oscillators (12.5 kHz), and the 3.5 kHz signalling frequency from each of the channels one and four connected in circuit (with the telephone set J’s) also produced an appropriate deviation on the transmitter output and was adjusted on the R222 to produce a deviation of ±15 kHz.

The carrier set telephone was then set in accordance with the Signal Engineering Instruction RD 03 for the C41/R222 and CST 1+4 No. 3 regarding the single channel test tone. The TEST TONE was switched on and the meter selector switched to channel 4 (all other outputs from the carrier set telephone switched off). The C41 deviation was measured and adjusted (using the attenuator controls on the R222) to produce ±15 kHz deviation as specified. Each of the other channels were individually checked for the same deviation.

As the Signal Engineering Instruction states: *The loading factor for a 4-channel system is 12 dB, and the corresponding deviation produced by a test tone on a single channel is ±15 kHz: For the SR C41, in the narrow band condition for 4-channel working, the maximum deviation is ±60 kHz. All channel levels are thus designed to produce and accept one-fourth of the total, and must be adhered to.*

With the TEST TONE now switched off, channels 2 and 3 were checked in turn with 0 dBm from the signal generators to give ±15 kHz deviation on the C41. Only slight adjustments were required on the R222 attenuators. With one channel selected, ±15 kHz deviation was obtained and with both channels selected, ±30 kHz deviation was observed.

As a rough/’sanity’ check/function test, all channels were now selected (no signalling or pilot tones on). Channels 2 and 3 producing ±30 kHz deviation, then with simultaneous speaking into both telephone set J microphones (two people required!) on channels 1 and 4, approximately ±60 kHz deviation was observed.

Figure 15. The final ‘operational’ setup of the radio relay terminal complete with frequency synthesiser and carrier set telephone/PSU

Conclusions

The addition of the carrier set telephone 1+4 No. 3 has essentially completed the author’s radio relay setup, notwithstanding there is a carrier set telephone 1+4 No. 3 missing from the ‘other’ terminal ‘B’ of the system/radio relay link, but the current addition serves to adequately demonstrate the overall operation for the author.

Future additions may include (if items exist/available) the addition (as well as another carrier set telephone 1+4 No. 3) the Terminal Telegraph Voice Frequency 4/12 channel equipment and associated superposing transformer – but without any teleprinters(!) and possibly an additional frequency synthesiser such that all four units of the radio relay (C41s and R222s) are synthesiser controlled.

Any additional work on the carrier set telephone 1+4 No. 3 would possibly be the investigation of the *relatively* high breakthrough of the 16 kHz carrier signal, but would not take place unless the unit needed to be opened for other (fault) reasons, due to the difficulty in removing the unit from its position and opening (2-man job!).

Addendum

It is ironic that now the complete system is fully repaired and 'up and running' that the author recently obtained one box (NoS) of a two-box set at a radio boot sale of the C41/R222 station radio testing kit, which included the hard to find test crystals of 50, 75 and 100 MHz for the transmitter C41 and the receiver R222, as can be seen in **Figure 16.**

Also obtained – post repairs, with the carrier set, was a full set of operational crystals that were issued with the C41/R222, as shown in **Figure 17**.

Figure 16. The recently acquired C41/R222 testing kit

Figure 17. The recently acquired crystal set

Additional Acknowledgements (for this current part 2 article)

The REME Museum (Archivists), Lyneham for locating and providing EMER R194

https://groups.io/g/wireless-set-no19

www.royalsignals.org.uk

Thanks to Andy Harris 2E0BAY for locating and providing the CST 1+4 No. 3 and 'suggesting' to the owner - that all of the equipment did not need to "go for scrap…"

Additional References (for this current part 2 article)

1. TELECOMMUNICATIONS EMER R190-R193, Carrier Set Telephone 1+4 No.3, (https://groups.io/g/wireless-set-no19, www.royalsignals.org.uk file reference: 1968, 1969, 1970).

2. TELECOMMUNICATIONS EMER R194 Technical Handbook – Field and Base Repairs, Carrier Set Telephone 1+4 No.3.

3. B. Blackwell G3YVW. 'British Army Larkspur era C41/R222 Radio Relay: repair and testing, also incorporating the PG342 frequency synthesiser' (Part 1).

4. User Handbook for Telephone Set J, Army code 60803, 1971, (https://groups.io/g/wireless-set-no19, www.royalsignals.org.uk file reference: 1600).

5. SIGNAL ENGINEERING INSTRUCTION, GENERAL, DG03, Army code 14400, dated 1984