An oscillator/multiplier chain for the frequency range 2.0 to 2.6GHz

Sam Jewell, G4DDK, describes an easy-to-construct and versatile design.

INTRODUCTION

The unit described in this article was first presented in booklet form at the 1989 Sandown VHF Convention. It is basically an extension of my 1152MHz oscillator design published in *RadCom* [1], but incorporating an additional multiplier stage to 2GHz and dimensioned to fit into a readily available tin-plate box.

Comments received from a number of constructors of the original 'Sandown' unit have been incorporated into the version published here to produce what I hope will be an easy-to-construct, reproducible and versatile oscillator source for the 2GHz frequency range. Printed circuit boards are available from the RSGB microwave components service under the designation 'DDK004'.

The original board was designed for 2556MHz, its output being multiplied by four to 10,224MHz for the local oscillator of a 10GHz transverter. However, the range of adjustment of the various multiplier stage filters is such that it could be used anywhere between 2GHz and 2.6GHz, making it suitable for the local oscillator of a 2.3GHz converter or transverter. It could also be used as the local oscillator of a 2.4GHz receive converter for Oscar 13 mode S. The source could also be used as a low-power 2.3GHz personal beacon or control transmitter under the terms of the revised amateur radio licence.

To use the board as a transmitter, it must be capable of being modulated. The optional modulator circuit allows the source to be frequency modulated with either speech or frequency-shift keyed (FSK) data [2].

One unexpected use for the board has emerged. The tuning range of the final multiplier filter is such that it has been found possible to resonate it as low as 1.2GHz, allowing the final multiplier to operate as an amplifier producing 50 to 70mW output. In this form the board may be used as a low-power transmitter in the 1.2GHz band.

The output filter uses SKY trimmer capacitors, and I am indebted to J Dahms, DC0DA, and R Wesolowski, DJ6EP, for the original idea to use these low-cost trimmers to resonate microstrip lines at frequencies as high as 2.6GHz [3]. Measurements with a network analyser have shown the self-resonant frequency of these trimmers to be just high enough to make them usable at this frequency.

CIRCUIT DESCRIPTION

The circuit for the frequency source is shown in **Fig 1.** The crystal oscillator uses the Butler circuit made popular in the RSGB Microwave Committee UHF source design [2]. The advantage of this circuit is its extremely low phase noise compared with that of the more common bipolar transistor Colpitts circuit so often used in 'seventies equipment designs. Phase noise performance is at least as good as that of the popular FET Colpitts oscillator with the additional advantage of being easy to set accurately on frequency.

Using the specified coil, the oscillator can be used at any frequency between 80 and 125MHz, just by changing the resonating capacitor C3. Operation outside this range usually requires that L1 be changed.

A fifth-overtone crystal determines the oscillator frequency, with the heavily damped tuned circuit comprising C3, R4 and L1 ensuring that only the correct crystal overtone is selected. Adjustment of L1 core allows the frequency to be pulled slightly either side of the marked crystal frequency. In the unlikely event that the frequency is low even after adjustment, it may be necessary to connect a capacitor of between 10 and 33pF in the position marked Cx on the component overlay. If Cx is not required then replace it with either a 1000pF ceramic plate capacitor or a short wire link.

The circuit associated with TR2 is the limiter section of the crystal oscillator. Because of the hard limiting produced by this stage, the output spectrum is rich in harmonics. By incorporating a tuned circuit at the required harmonic frequency, a relatively high-level output is obtained up to about the fifth harmonic. In this design the output is tuned to three times the crystal frequency: 319.5MHz in the case of a 2556MHz local oscillator. A double bandpass tuned circuit consisting of C7/L2 and C8/L3 ensures adequate rejection of the unwanted harmonics.

An integrated circuit regulator IC1 provides a stabilised 9V supply for both the oscillator and the base bias for the first multiplier stage. Because of the need to maintain a 3V drop across the regulator, the minimum supply voltage to the board should be 12V. If the unit is to be powered from a car battery it may be better to use a 78L82 regulator which will provide a regulated 8.2V even with the car battery well down on charge. The effect on oscillator output power will be a loss of 1 to 2dB.

The first multiplier stage uses a BFR91A as a very efficient frequency doubler. Its output circuit consists of a double-tuned stripline filter at 639MHz (for the 2556MHz version). Trapezoidal capacitors are used to provide very effective decoupling at the emitter of TR3 and at the supply end of L4.

The second multiplier is similar to the previous stage, but doubling from 639MHz to 1278MHz. The transistor selected for this stage is the BFR96. Alternatively a BFR91A could be used but the output level is usually less than the BFR96 provides.

The final stage doubles from 1278 to 2556MHz using a second BFR91A. This device replaces the BFG91A originally specified for this stage, but which was found to be only conditionally stable.

Later development work showed the need to use decoupling capacitors with low equivalent series resistance in the 2.6GHz stage to overcome tuning difficulties. The normal trapezoidal capacitors of the type used in the previous stages have proved to be inadequate in this stage. This has been overcome by extra decoupling using ATC porcelain chip capacitors soldered across C24 and C29, on the groundplane side of the PCB.

A three-stage stripline filter is used at the output of TR5 to ensure adequate rejection of the half-frequency drive signal. SKY trimmers are used to resonate this filter. Other types of capacitor have been tried without success.

At the very highest end of the range, the trimmers will be *very* close to their minimum value, so the filter becomes very sensitive to stray capacitance. For this reason it is essential to use a

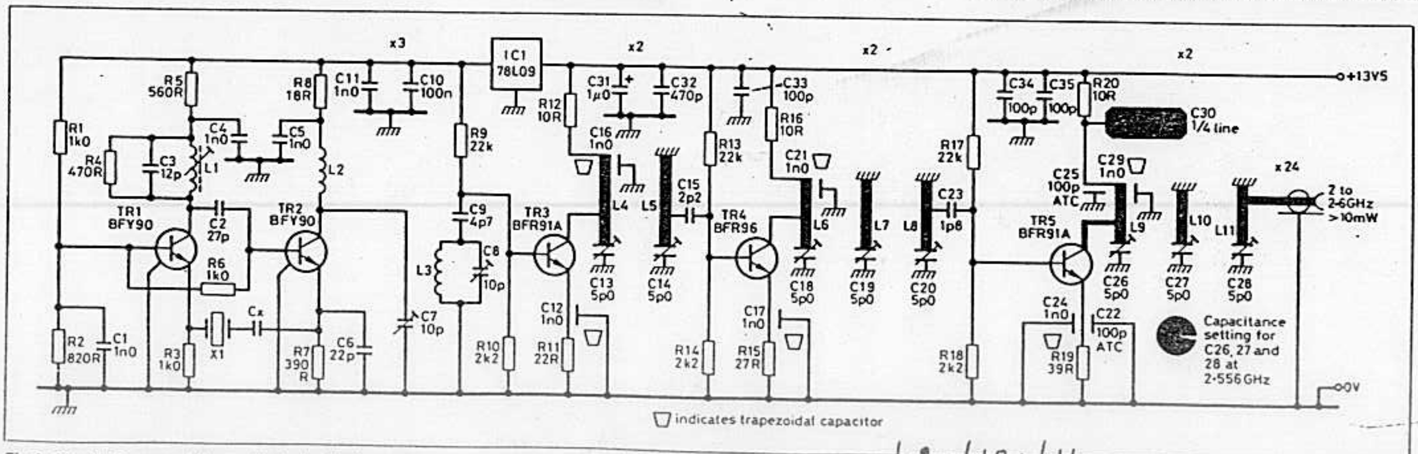


Fig 1. Circuit diagram of the oscillator/multiplier chain.

3.006 GHz 7 mW

X1 = 125.250

L1 = 518 5,5 & 6,8 pF = C3

L9, L10, L11

C30 1 mm plus court

L10 0,5 mm plus court

C26 / C27 / C28 0,5 à 2,2 pF

(Johanson 7002)

R15 4,15V / (3006 7mW)
R19 4,1V
R7 3,75V
R3 3,25V

BFR96
BFR91A

at 106.5MHz and not on some other adjacent frequency. Switch the supply off and then on, and check that the oscillator restarts. If not, then slightly turn the core of L1 and try again. Exact frequency setting is not too important at this stage, as it is to some extent influenced by the settings of the following stage.

2. Switch the multimeter to its 2.5V range (or nearest equivalent) and place the probes across R11, positive end to the emitter of TR3. Depending on the initial settings of the previous tuned circuits, a reading of a few hundred millivolts will be noted. Adjust C7 and look carefully for a small increase in the voltage reading. When the increase is seen, adjust for the peak reading. This should be obvious on a moving-coil meter but is almost impossible to see on a digital voltmeter. Now adjust C8 for a further, significant increase in the reading to around 0.7V. Confirm with the wavemeter, by placing its pick-up coil close to L3, that you have tuned the circuits to 319.5MHz and not the second or fourth harmonic of the crystal frequency.

3. Transfer the meter leads to R15 and tune first C13 and then C14 for a peak reading of 1 to 1.5V. Again confirm with the wavemeter that you have tuned to 639MHz.

4. Transfer the meter leads to R19 and adjust C18, 19 and 20 for a peak reading of 1 to 1.5V on the meter. Use the wavemeter to confirm that you have tuned to 1278MHz.

5. Connect the power meter to the output connector.

6. Tune the wavemeter to 2556MHz and place close to L9.

7. Adjust C26, 27 and 28 for a peak reading on the power meter. It will be found that these three trimmers will resonate at close to minimum capacitance, with the setting of C27 (the middle trimmer) being particularly sharp. Confirm that the peak reading is at 2556MHz by tuning the wavemeter over several hundred megahertz either side of the wanted frequency. Also note that it is very easy to mistakenly tune to 1278MHz and get 50mW or more output. This is easily avoided if the trimmers are kept close to minimum capacitance.

8. Check that the output is between 5 and 10mW.

9. Having now aligned the unit, it is worth going back over the adjustments to ensure everything is peaked.

10. Check with the frequency counter that the oscillator is oscillating on exactly 106.500000MHz. Adjust the core of L1 to achieve the correct frequency. If the oscillator has to be pulled significantly the output power may fall; also the oscillator may refuse to re-start. If this condition is encountered then connect a 10pF (NP0) ceramic trimmer in the position Cx. With the low-value capacitor in series with the crystal, no frequency error or re-starting problems should be encountered. If the problem persists then consider using a different crystal.

This concludes the alignment. If you have access to a spectrum analyser that covers the frequency range to 2.6GHz then you can selectively measure the power output and carefully re-adjust the trimmers for best spectral purity. **Fig 3** shows the output spectrum of a prototype unit.

COMPONENT SUBSTITUTION

Perhaps the most widely substituted components in this type of oscillator unit are trimmer capacitors. It is essential that only the recommended SKY types are used, except for C7 and C8 which may be either 10pF (black) SKY or the Cirkit type in the component list.

The prototype unit used Philips transistors. Motorola and Telefunken BFR96 devices have been used successfully in the TR4 position.

COMPONENT LIST

RESISTORS

R1, 3, 6	22k	R9, 13, 17	1k
R2	2k2	R10, 14, 18	820R
R4	22R	R11	470R
R5	10R	R12, 16, 20	560R
R7	27R	R15	390R
R8	39R	R19	18R

All resistors 0.25W miniature carbon film or metal film

CAPACITORS

C1, 4, 5, 11	1000p high-K ceramic plate, eg Philips 629 series
C2	27p low-K ceramic plate, eg Philips 632 series
C3	12p low-K ceramic plate, eg Philips 632 series
C6	22p low-K ceramic plate, eg Philips 632 series
C9	4.7p low-K ceramic plate, eg Philips 632 series
C15	2.2p low-K ceramic plate, eg Philips 632 series
C23	1.8p low-K ceramic plate, eg Philips 632 series
C31	1μ tantalum bead 16V working
C32	470p medium-K ceramic plate, eg Philips 630 series
C33, 34, 35	100p low-K ceramic plate, eg Philips 632 series
C10	0.1μ tantalum bead, 16V working
C12, 16, 17 C21, 24, 29	1000p trapezoidal capacitor from RSGB or Cirkit
C7, 8	10p miniature ceramic trimmer (5mm diameter) SKY (black) or Cirkit 06-10008
C13, 14, 18, 19, 20, 26, 27, 28	5p SKY trimmer (green) from Piper Communications, Didcot (0235 834328)
C22, 25	100p ATC series 100 or 130, type B (0.110 in cube) from Phase Components Ltd (0403 41862).
C30	Printed on the PCB
Cx	10 to 33p type as C2, see text
Ft	1000p feedthrough capacitor(s) for DC power input and optional crystal heater

COILS

L1	Toko S18 5½ turn (green) with aluminium core
L2, 3	2 turns of 0.8mm diam tinned copper wire. Inside diam 4mm. Turns spaced to fit hole spacing on the PCB. Centre of coil 4mm above the PCB. Exceptionally 3 turns required at the LF end of the range, ie below 2.2GHz output.
L4-11	Printed on the PCB.

SEMICONDUCTORS

TR1, 2	BFY90 available from Cirkit, Bonex, Piper etc
TR3	BFR91A available from Cirkit, Bonex, Piper etc
TR4	BFR96 available from Cirkit, Bonex, Piper etc
TR5	BFR91A available from Cirkit, Bonex, Piper etc
IC1	μA78L09 available from Piper, STC Components etc

MISCELLANEOUS

X1	5th overtone crystal in HC18/U case 106.5MHz for 2556MHz 90.6667MHz for 2176MHz The recommended temperature spec is 10ppm

Tin-plate box type 45 (also known as 7768) available from Piper Communications. Size 55.5mm wide, 148mm long and 30mm high. Alternatively a box could be made from offcuts of double-sided PCB material. Printed circuit board (PCB) available from the RSGB microwave component service. Order as G4DDK PCB 004. Output socket, single-hole mounting SMA, SMB or SMC (CONHEX).

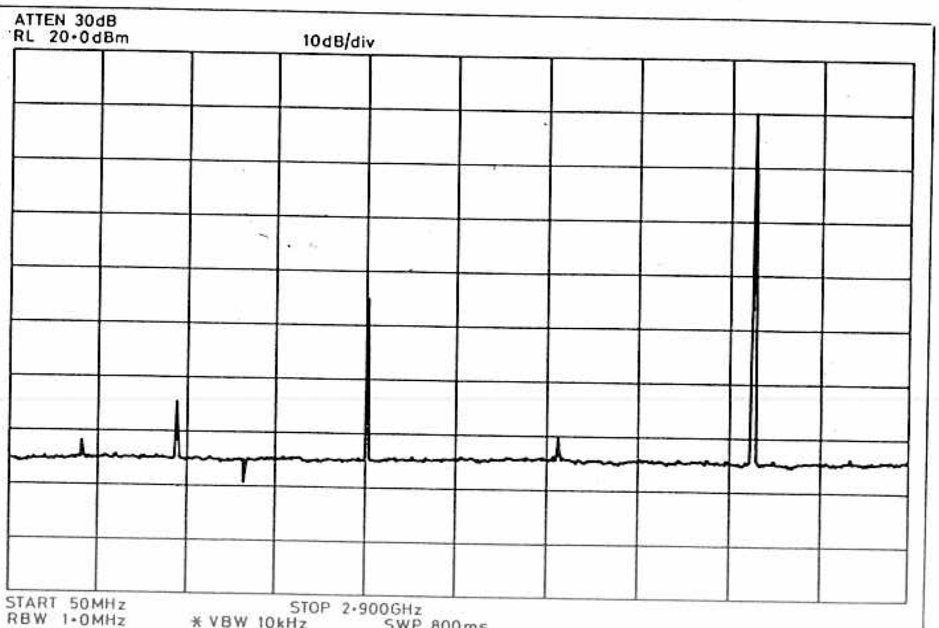


Fig 3. Output spectrum of a typical board.

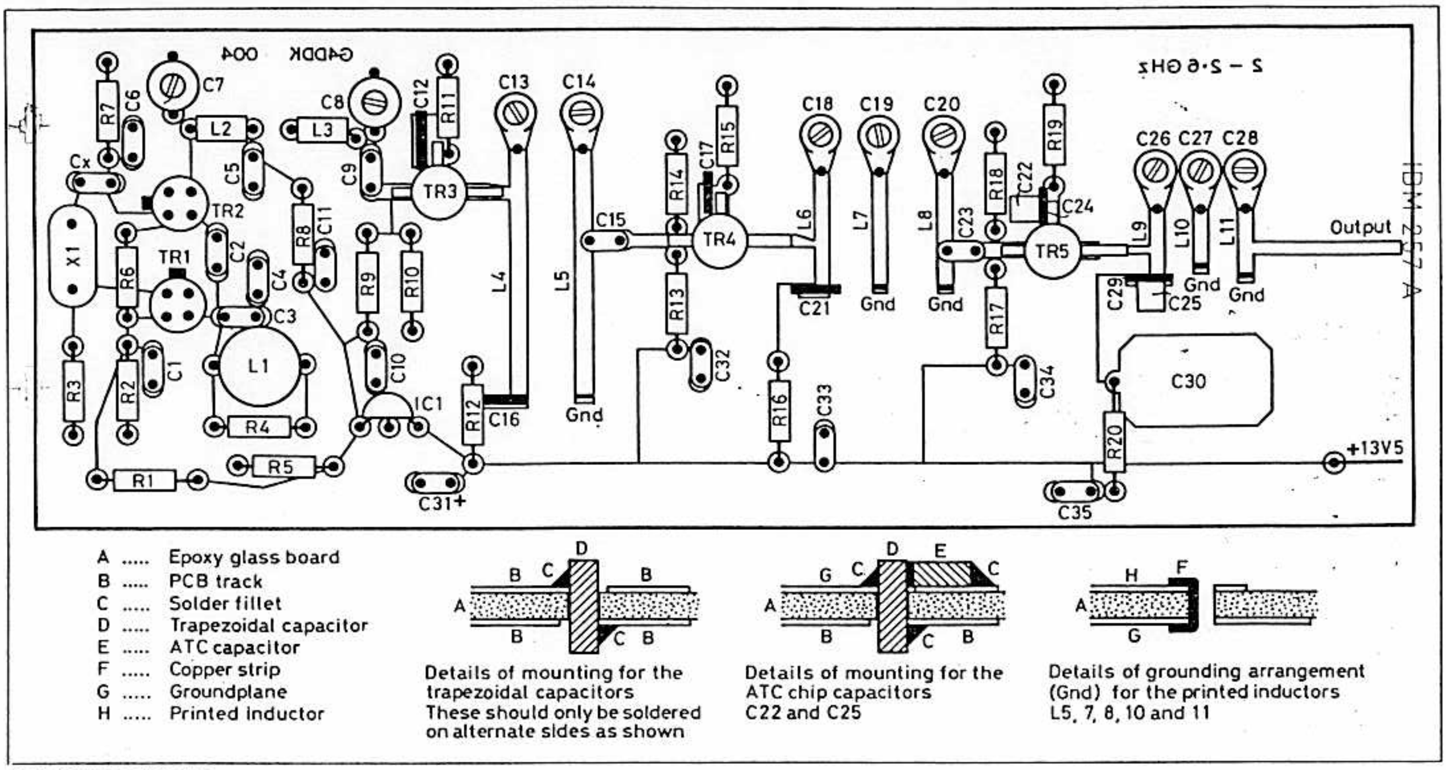


Fig 2. Component overlay.

non-metallic trimming tool when adjusting the trimmers. Ceramic blade tools are ideal but may be considered too expensive unless a number of these units is to be built, in which case the investment in time saved will more than outweigh the cost.

The output is taken from the filter via a 50-ohm miniature connector such as SMA, SMB or SMC (Conhex), although BNC is just acceptable at 2.3GHz.

CONSTRUCTION

In order to ensure reproducibility the unit is built on a purpose-designed PCB, which may be obtained from the RSGB microwave component service. The PCB is seam-soldered into a 148 by 55 by 30mm tin-plate box for screening and protection.

The output at 2.5GHz is via a miniature coaxial connector soldered to the end wall of the box. DC power is taken through a solder-in feedthrough capacitor, also in the end wall of the box. Additional feedthrough capacitors are used to connect the optional crystal heater and sensor to the temperature controller circuit [4].

1. Begin construction by marking the inside of the tin-plate box where the PCB is to be mounted. The groundplane side of the board should be 15mm from the rim of the box. Do not solder the two halves of the box together at this stage.

2. Mark the end wall of the box where the output connector is to be mounted. Also mark the location of the feedthrough capacitors. Drill holes to accept the spill of the connector and all the feedthrough capacitors, even though you may not presently intend to use them all.

3. Carefully file a small area from two corners of the PCB to clear the overlapping edges of the box.

4. Spot-solder the PCB into one half of the box. Placing the soldered half of the box down on its rim, jig the other half of the box into place, checking for good alignment of the edges. If necessary, file the edges of the PCB for a good fit. Check that the two lids fit correctly.

5. Solder the overlapping edges of the box together before finally seam-soldering the PCB into place.

6. Solder the output socket into place, taking care to ensure that the spill of the output socket lays flat onto the output stripline from L11.

7. Solder the feedthrough capacitor(s) into place in the end wall of the box.

8. Populating the PCB with components (**Fig 2**) should be done in the following order.

- (i) Grounding strips for L5, 7, 8, 10 and 11
- (ii) Trapezoidal capacitors
- (iii) L2 and 3
- (iv) Resistors
- (v) Capacitors
- (vi) L1
- (vii) Trimmer capacitors
- (viii) Transistors
- (ix) IC1
- (x) Crystal

9. Connect the power feedthrough to the main power pad (near C30) with a short length of insulated wire.

10. Now that construction is complete, carefully inspect the assembled board for correct component placement, damaged components or poor solder joints.

The board may be cleaned of flux residue using a solvent such as acetone. This *must* be applied carefully with a cotton bud, as most solvents of this type will dissolve the plastic SKY trimmers!

ALIGNMENT

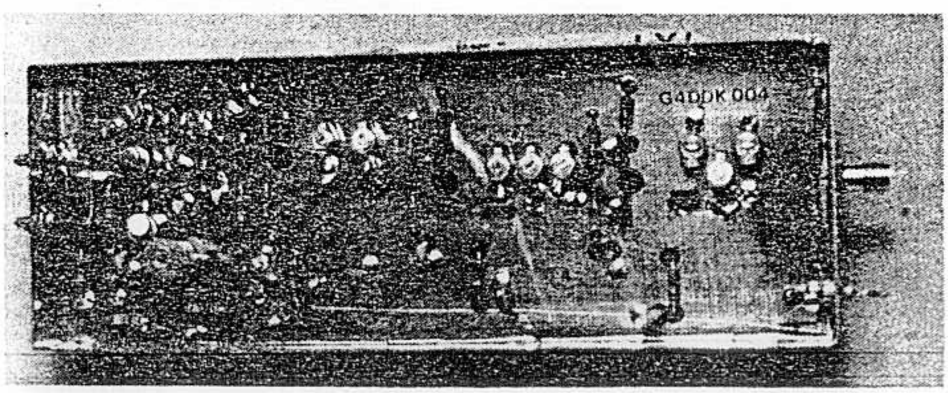
The following items of test equipment are regarded as essential for alignment:

Moving coil multimeter (20,000 ohms/volt)
Absorption wavemeter(s) covering 90MHz to at least 2.6GHz
Power meter with full-scale sensitivity of <100mW at 2.6GHz
Frequency counter (preferably to 2.6GHz, but 110MHz will do)

Before starting alignment, set all trimmer capacitors to minimum capacitance and set the core of L1 level with the top of the coil former. Connect a 13.5V supply to the unit and check that the total current drawn is less than about 200mA. If the current is significantly higher than this, switch off and check for short-circuits or incorrectly placed components. When you are satisfied that the current is within limits, check that the voltage at the regulator end of R5 is 9V. If significantly different, check for faults and correct before proceeding.

The frequencies quoted in the following instructions assume that the unit is to be aligned to 2556MHz.

1. Tune the wavemeter to 106.5MHz and place its pick-up coil close to L1. Turn the core of L1 until the wavemeter registers the presence of a strong oscillation. Confirm that the oscillation is



The completed unit.

Use only the specified Toko green coil for L1. Attempts to use other coils in the same series to overcome frequency-setting problems have been largely unsuccessful. If you need to operate at a frequency far removed from 106MHz then change the value of C3, not the coil.

CONCLUSION

A number of these units have been successfully built by microwave enthusiasts both in this country and in The Netherlands. Results have been quite consistent, with between 10mW and 20mW output at 2556MHz achieved with careful alignment.

My own unit is currently driving a 2556MHz amplifier to 150mW output [5]. This in turn drives a 3dB splitter, giving two outputs at 75mW for use in the up and down converters in my G3WDG-based 10GHz transverter. A Murata posistor crystal heater provides open-loop control of the crystal temperature. With this arrangement frequency drift due to crystal self-heating and ambient temperature. With this arrangement, frequency from switch-on. Without temperature control, oscillator stability has proven adequate for portable operation at 10GHz, even with the unit exposed to a North Sea coastal gale!

REFERENCES

[1] 'A local oscillator source for 1152MHz,' Sam Jewell, G4DDK, 'Microwaves', *Radio Communication* February 1987, p128, and March 1987, pp199-201.

[2] 'A high-quality UHF source for microwave applications', Microwave Committee, *Radio Communication* October 1981, pp906-910.

[3] 'Ein 6cm Transvertersystem moderner Konception', Roman Wesolowski, DJ6EP, and Jurgen Dahms, DC0DA, *cq-DL* 12/87, pp755-759.

[4] '10GHz Transverter in Microstripline-technik', Peter Vogl, DL1RQ, *Dubus* 2/86, pp115-147.

[5] 'A GaAs FET amplifier for 2556MHz', Sam Jewell, G4DDK, *RSGB Microwave Newsletter 5/89*, pp3-6. □

BOOK REVIEW

BRITISH INTELLIGENCE IN THE SECOND WORLD WAR

Volume 4, Security and Counter-Intelligence

by: F H Hinsley and C A G Simkins

First edition 1990. Published by HMSO, xii + 408 pages. £15.95

Younger members may be puzzled to find in *RadCom* the review of a book about spies, double agents and the use of signals intelligence in counter-intelligence operations a half-century ago. The reason is simple. This is the first book that explains officially how, 50 years ago, over 1000 pre-war amateurs and listeners with the ability to copy morse code became Voluntary Interceptors, the secret listeners of the Radio Security Service. Many of them were subsequently specially enlisted into the Special Communication Units, nominally part of the Royal Corps of Signals (as it then was) but in reality working under the direction of British Intelligence as MI8(c). In perhaps their own "finest hour", a large number of amateurs and members of the RSGB participated in the secret struggle between Allied Intelligence and Counter Intelligence and the German Abwehr (military intelligence) and the more ruthless Reichsicherheitshauptamt (RSHA).

As radio operators, they worked under the 'need to know' principle that left most of them largely in the dark as to whom they were listening to and the uses that were made of their intercepts. This new, and long overdue, "official history" has been compiled from official records but with the stipulation that names and places remain secret even though many of these have appeared in other recent publications. Nevertheless, it provides much previously unpublished information on the origins of RSS, the importance of the ISOS, ISK, ISOSOLES decrypts in running the "double agents" by the Twenty (XX) Committee and the work of the SCIU detachments on the Continent in the final months of the war.

ISOS (Intelligence Service Oliver Strachey) were the decrypts of the Abwehr messages sent between their main centres using what they believed to be a secure hand cipher that was broken at Bletchley Park from early 1941 in the section headed by career cryptoanalyst Oliver Strachey. ISK (Intelligence Service "Dilly" Knox) were decrypts of Abwehr Enigma traffic broken from early 1942, including the GGG Enigma traffic between Madrid and Berlin. ISOSOLES were the decrypts of SD (RSHA) traffic.

The book shows that as early as 1928, a sub-committee of the Committee of Imperial Defence recognised that for the wartime interception of illicit transmissions that might be made from the UK, "the War Office should use voluntary and unpaid enthusiastic amateurs of unimpeachable discretion". But it was a decade before this was followed up. "In 1933 it was decided that, under War Office direction, the GPO should be responsible for the manning, maintenance and technical operation of what became known as the Radio Security Service, but it was not until 1937 that the GPO was authorised to build three fixed intercept and D/F stations." The first of these was not operational until December 1938, "and only then was approval finally given for the establishment of a network of fixed and mobile stations supplemented by an auxiliary observer corps of amateur operators".

Recruitment of amateur radio enthusiasts into RSS finally began in June 1939. RSS was under the control of the War Office as part of MI1(g) until November 1939 when it became MI8(c), still within the War Office. The original brief (not included in the book) of the "Illicit Wireless Intercept Organisation" was defined as "to intercept, locate and close down illicit wireless stations operated either by enemy agents in Great Britain or by other persons not licensed to do so under the Defence Regulations, 1939".

During 1940, as the extent of Abwehr communications was unravelled by RSS, the work was extended to the interception and location of the communications of the Abwehr, and to associated enemy intelligence and security agencies anywhere in the world. It has soon became clear that the amateurs were outperforming the GPO interceptors in this work. By autumn 1940, RSS had about 1000 interception and technical staff "provided, not entirely to the satisfaction of MI8, by the GPO" and another 1000 part-time VIs (mostly amateurs recruited by Lord Sandhurst with the assistance of Arthur Watts, G6UN, (1939 President RSGB) and drawing on the Society's membership lists).

In October 1940, MI8 proposed that administrative control should be transferred to MI5 (the Security Service) but in January 1941, Lord Swinton (Chairman of the Security Executive) decided that RSS should be taken over "lock, stock and barrel" by SIS (MI6), and the transfer was effected in May 1941 when the GPO's agency for the provision of personnel and equipment was terminated: "The best of the operators from the PO staff and the VIs were enlisted ("for special duties") into the Royal Signals. Better equipment was obtained, some of it from the USA, and new intercept stations (Hanslope Park, later Forfar, etc) established."

RSS/SCU3/SCU4 thus for technical services became part of Section VIII (Brigadier (Sir) Richard Gambier-Parry, ex-G2DV) of MI6/SIS; working closely in conjunction with Section V (counter-intelligence external) and MI5 Division B1.

With BP progressively breaking into and reading the Abwehr traffic, the RSS intercepts played a vital role in enabling British Intelligence to gain a virtually complete insight into the activities of the Abwehr. It also enabled them to monitor the remarkable success of their running of the turned Abwehr agents, whose case officers also drew on RSS, in the operation of the radio links with Abwehr control stations in Hamburg, France and Spain.

Appendix 3, "Technical Problems Affecting Radio Communications by the Double-Cross Agents" is ascribed to "a former MI5 officer from his personal experience" (whom we can safely assume to have also been a life-long, still active G2-two-letter amateur). This Appendix describes how the Germans supplied their radio agents with HF/CW transmitters covering about 5-7MHz at powers of about 3 watts (battery sets) or 5-10 watts (mains). Under MI5, "case officers" double agents were encouraged to operate their own radios with an RSS operator sitting beside him or her, listening to ensure that nothing was sent to reveal that the agent was under control. It was also to become familiar with the "fist" of the agent so that contacts could be continued if there was subsequently any suspicion that the real agent was becoming uncooperative. In practice, a small number of pre-war British amateurs spent many hours at the keys of German agent radios right up to May 1945.

The book shows vividly how British Intelligence succeeded in controlling every radio agent sent into the UK by the Germans (though not "Sonya" who, married to an Englishman, successfully ran a clandestine station for the Russian GRU/NKVD services from near Oxford - an operation NOT mentioned in this book!).

Appendix 3 also reveals that to ensure that important deception traffic, in connection with "Overlord" (the D-Day Normandy invasion) from the Spanish double agent "Garbo", reached the Abwehr in Spain without delay, he reported to his masters that he had obtained a powerful transmitter. This was in fact a BC610 (Hallicrafters HT4) 600-watt transmitter, operated at 100 watts. It was finally moved to "the flat on top of MI5's London HQ, a very convenient arrangement for everyone concerned."

The now diminishing number of former VIs and members of the SCU 3, 4, 10, etc, may regret that it has been necessary to wait over 40 years for this "official" public recognition of their work as secret listeners.

G3VA