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Background photo courtesy ESA/Hubble, R. Sahai. This image taken with the NASA/ESA Hubble Space Telescope showcases the emission nebula NGC 2313. Designed by Kevin Williams, M6CYB.

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New Products

Yaesu FT5DE handheld

The new FT5DE is a full-featured C4FM dual band handheld transceiver with some new sophisticated functions. Even in a compact body (W62mm x D34mm x H100mm), the FT5DR/E provides 5W RF power output and achieves 1W audio power that has been tuned for quality audio. Real dual band – 144/430MHz – operations (V+V, U+U, V+U, U+V) are available with two independent receivers. Large individual LED indicators for A band and B band present the status and communication modes (C4FM or analogue) of each band instantly. The radio also supports simultaneous C4FM digital (C4FM/C4FM standby).

With rubber protection on the corner of the main body, the FT5DE has rugged and shock-resistant construction. The waterproof rating is IPX7. A high-resolution display highlights the frequency of the operational band. The colour of the operating band frequency can be selected from white, blue or red. Three touch panel keys and seven operation keys below the display offer intuitive operability. The new TOUCH & GO operation allows the user to immediately start on an often-used frequency. By pressing and holding the 'PMG' key, the frequency of the current display is registered into Primary Memory Group. After registration, pressing the 'PMG' key will display the receive status of the registered frequencies as bars on a graph (activity monitor). By simply touching the displayed bar, the user can instantly recall that frequency. (TOUCH & GO Operation)

The Band Scope function monitors in real time, up to 79 displayed channels that are centred around the current VFO frequency. The centre frequency can be tuned by the dial knob or by touching and moving the frequency of a displayed channel bar.

The C4FM digital communication features are available with the new FT5DE and it supports the WiRES-X Portable Digital Node Function as well. Some of the advanced features include: wireless hands-free operation using the optional Bluetooth® headset (SSM-BT10); VOX function; Memory Auto Grouping (MAG); VFO Band Skip function; Wide-range Rx coverage with continuous reception from 0.5MHz–999.99MHz (A Band) & 108MHz–580MHz (B Band); Built-in high-sensitivity 66 channel GPS receiver; 1200/9600bps APRS data modem; 2,200mAh high-capacity Li-ion battery pack (SBR-14LI) as standard; Voice Recording Function; simultaneous AM/FM broadcast reception while monitoring two frequency channels; micro SD card slot.

bhi Bypass Switch

The bhi Dual In-Line and Compact In-Line units don't have an internal audio bypass facility, so if you switch the power off on your bhi unit the audio will not pass directly through to your external speaker. The bhi new Bypass Switch enables you to route the audio from your radio directly through to your extension speaker without powering on your bhi unit. This can be particularly useful if you just want to listen to your radio without your bhi unit switched on. A single push button switch on the Bypass Switch provides this facility. Press the button in and the audio routes through your bhi DSP noise cancelling unit (bhi unit must powered on). Press the button again and the switch returns to the out position and the audio now routes directly between your radio and loudspeaker. This compact unit measures just 80 x 50 x 22mm and is supplied with two 3.5mm audio plug leads.

The Bypass Switch is available from bhi at www.bhi-ltd.com, 0144 487 0333 or from one of their authorised stockists. It retails for £34.95.

Clean up noisy signals

The new bhi In-Line Module cleans up noisy signals and works with most radios and receivers. It comes with the latest bhi DSP noise cancelling technology, which brings improved audio quality to the listener when operating in noisy conditions across all radio bands. The audio is clearer and more intelligible as a result. The In-Line Module accepts speaker level audio and connects in between your radio and loudspeaker. The speaker audio is muted when headphones are connected, and when the unit is switched off the audio bypass feature routes the signal directly through to the loudspeaker. The In-Line Module is powered from a suitable 10 to16V DC power supply and has a three-position switch that turns the unit on and switches the noise cancellation on and off. The 'Status' LED illuminates red when power is applied and changes to green when the noise cancellation is active. The unit has an audio input overload LED, an audio output level adjust control and comes supplied with a 3.5mm mono plug lead, fused DC power lead, User manual and 4 rubber feet. It features eight noise cancelling levels 8 to 40dB, tone reduction up to 65dB, 5W audio amplifier and an audio input overload feature

The bhi In-Line Module is available from bhi Ltd at www.bhi-ltd.com, tel 01444 870333 or from one of their authorised stockists. Price £159.95.

Portable multiband radio

Nevada is stocking new Tecsun H-501x portable multiband radio with Bluetooth. The radio is designed for both portable or desktop use with an integral tilt stand. It uses DSP technology to greatly improve sensitivity, selectivity and image rejection. Coverage includes long wave, short wave and VHF FM with multi mode capabilities including SSB reception on short wave. As you would expect from this type of radio it is packed with features such as synchronous detection, 3150 memories, two channel dual speaker for stereo reception, Local and DX input selector and multi search capabilities.

The H-501x is equipped with several useful audio features, a Bluetooth function to play music from a smartphone, tablet or other Bluetooth device, an SD slot with 16GB card included and a USB sound card function so it can be used as stereo computer speakers. The large LC display is very easy to read with extra-large digits for frequency readout and lots of information about the receiver operation, such as signal strength in dB and microvolts, battery status, receive mode and more. A unique feature of the H-501x is the dual charging facility that uses two 18650 batteries, this allows you to use one battery whilst charging the spare.

Included with the radio is a 16GB memory card, Stereo earphones, USB charger with cable and a leatherette carrying case. The Tecsun H-501x is expected to arrive during September and sell for £329.95. www.nevadaradio.co.uk.

12m Portable Mast

The Vine Antenna RST-HAMPOLE-12M is constructed from a thick heavy-duty fiberglass, making it ideal for portable operations or even use at home for temporary antenna experiments. It will support wire antennas, end fed, dipoles or off centre fed aerials. The mast is lightweight and provides an easily transportable way to support your wire antenna whether working portable or at home. It retails for £99.95 from LAM Communications. Find more information at www.hamradio-shop.co.uk.

IC-7300 RX-Antenna board

Hamtenna in Sweden has created a board to add a receive antenna connection to the IC-7300. The board is equipped with a miniaturised coaxial relay with a loss of 0.1dB at 6GHz. The board is interposed along the internal Rx line of the RTX while the normally open connection of the relay is brought to the rear panel of the radio by means of a Teflon coaxial cable and a female SMA connector. The power supply of the board is taken from the connector dedicated to the tuner, which must be removed from the rear panel to make room for the plate with SMA connector and changeover switch. The board must be fixed with the double-sided adhesive supplied without the aid of anchors or screws. Once installed, simply switch with the switch on the rear panel, the use of the main antenna (connected to the SO-239 of the radio) or the Rx-antenna auxiliary antenna connected to the female SMA on the back next to the switch to have instantaneous, no loss of insertion and automatic switching of the two antennas. It does not require any further external Rx-Tx switching relay box.

The board is priced at 1290 Swedish Krona (at the time of writing, that's roughly £110). Shipping costs are calculated individually and sent as an updated customer order that can then be canceled or confirmed. More information at http://shop.hamtenna.net/product/ic-7300-rx-antenna-board.

LDG tuner

Waters and Stanton are pleased to announce the introduction of the latest LDG tuner, designed specifically for use with the Icom IC-705. It has a wide matching range covering 160m to 6m. Although it can handle up to 125 watts, it is easily triggered by the low tune-up level from the IC-705. Latching relays result in very low power consumption and there is provision for using 8 x AA cells in the internal battery tray. The package includes a data lead to interface with the transceiver, a BNC to PL-259 signal lead and 8 x AA. The tuner is now in stock and retails for £199.95. See https://hamradiostore.co.uk/ for more information.

Antennas

Antenna tuning units: an overview

It is some time since antenna tuning unit (ATU) and HF balun designs have been overviewed in Antennas, therefore these are the theme this month.

Background

An ATU is a device used to interface the impedance transition between the transceiver and the transmission line whose load is the antenna. The purpose of the ATU is to maximise the RF power transfer between the transceiver and the transmission line/antenna for both the receive and transmit directions of transmission.

Many antennas present an impedance that is not a good match with the transmission line. This results in the impedance presented by the transmission line being affected by the antenna's impedance and this will usually comprise both a resistive and a reactive component (R ± jX). Therefore, the ATU is used:

- As a means to tune out and so reduce the effect of the reactive component of the impedance (jX) connected at its input
- To transform the resistive component of the impedance (R) presented at its input.

The effect of these actions is the ATU presents an acceptable output impedance to the transceiver that, in most cases, is ideally 50Ω resistive.

An ATU has to be able to handle a range of different transmission line/antenna loads that need to be interfaced with the transceiver. For example, these could include the direct connection of a balanced or unbalanced antenna; an end-fed wire antenna worked against an RF earth system; an antenna fed with a coaxial cable; or an antenna fed with a twin-line feeder or ladder-line.

The concept of the typical arrangement used at an amateur station is shown in **Figure 1**, where an ATU is used to match an antenna to the transceiver. In this arrangement the ATU is tuned to reduce the standing wave ratio (SWR) to a minimum between the transmission line and the transceiver, with this indicated when the SWR meter's reading is at its lowest. Nowadays, many transceivers contain an integral ATU and SWR meter, making the use of the arrangement shown less frequent than it used to be. To follow is a summary of ATU designs for use on the bands from 160m to 6m bands.

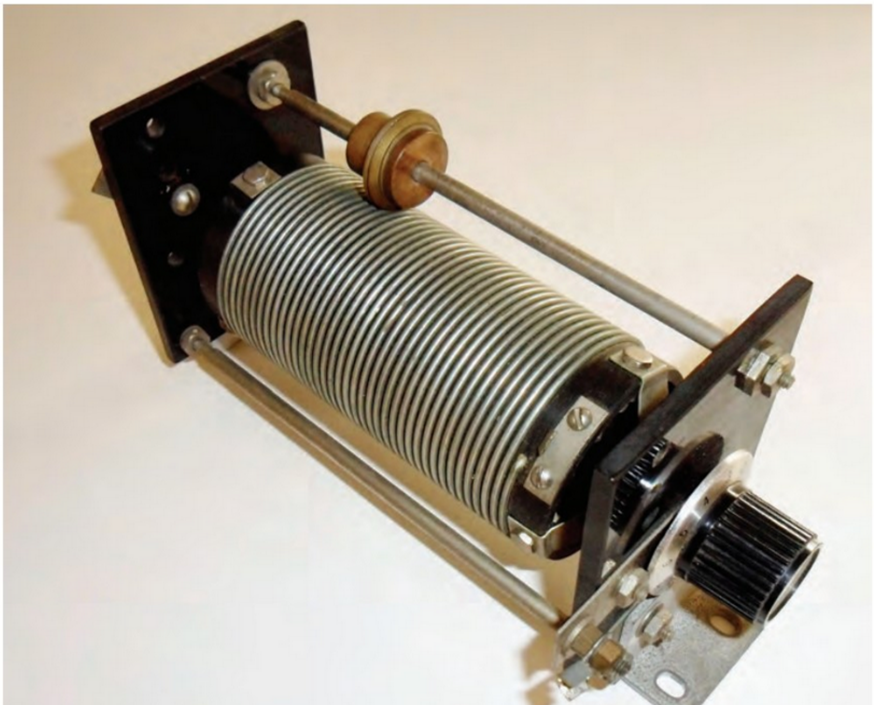

PHOTO 1: Example of a 'roller-coaster' variable inductor.

Pi-network ATU overview

The Pi-network ATU, comprising an inductor connected between two variable capacitors, was often used with older transceivers and has been included because many stations still use this form of ATU. The Pi-network has formed the basis of several commercially available ATUs, although the Transmatch technique has tended to become more widespread in recent years.

The Pi-network is theoretically capable of matching any transmitter to any antenna impedance (resistive or reactive). However, in practice the matching range is dependent on the component values used. For the widest step-up and step-down transformations, RF high-voltage variable capacitors are required that have a low to high capacitance range of several hundred picofarads (pF). Obtaining such capacitors is not as straightforward

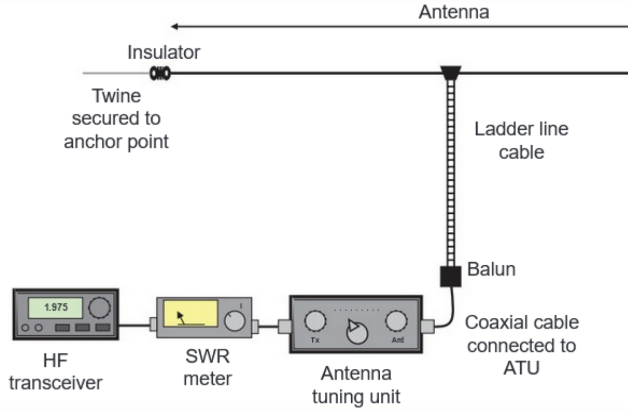

FIGURE 1: Concept of a typical arrangement for an HF amateur station, in this case a doublet antenna fed using a balanced transmission line.

PHOTO 2: Two examples of variable capacitors able to withstand higher RF voltages.

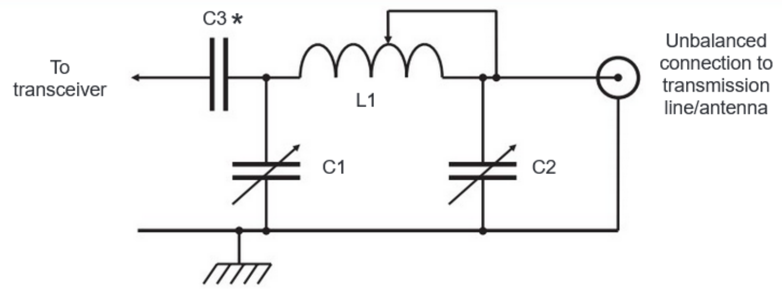

FIGURE 2: Concept of an ATU using a Pi-network circuit.

nowadays as it used to be, although they can sometimes be found at radio rallies.

The Pi-network has the advantage that it not only transforms impedance but also provides a low-pass filter, providing additional attenuation of undesirable RF harmonics. The Pi-network was frequently encountered with valve radio transmitters and the concept of this circuit is shown in **Figure 2** **[1]**. C1 and C2 are the tuning capacitors, while L1 was often a 'roller-coaster' variable inductor; a typical example is shown in **Photo 1**. Depending upon the load connected to the ATU, the tuning capacitors C1 and C2 need to be able to withstand several kilovolts of RF. This necessitates tuning capacitors whose plates are widely spaced (typically 1.5mm or above) to handle the voltages that can be involved. Examples of two suitable tuning capacitors are shown in **Photo 2**. C3 is a blocking capacitor that is needed if the Pi-network is directly connected to the output of the transmitter's power amplifier (PA) stage.

T-network ATU overview

The T-network ATU can provide an acceptably wide range of impedance transformations without using large-value tuning capacitors. The T-network is a variety of the Transmatch ATU design, which does not use the split-stator type of tuning capacitor used by other Transmatch variants. The T-network's input and output ports are both unbalanced, making its use suitable with coaxial feeder cables and unbalanced antennas. When the use of older valve transceivers was the norm, the T-network was regarded as a disadvantage because it forms a high-pass filter rather than a low-pass filter. However, nowadays low-pass filtering tends to be provided by the transceiver and so is less of a problem. While the T-network has become popular, it does suffer from losses at some transformation ratios on the higher frequencies. It is not uncommon for the T-network to 'sink' around 20% of the RF power supplied to it, depending upon the impedances it is expected to handle. This lost RF power is primarily absorbed by the inductor and care must be taken to ensure the T-network is not damaged when handling higher RF powers. These losses can be minimised by a simple modification of the T-network to an L-network using switches connected across the ends of the capacitors. The concept of a T-network that can be configured as an L-network is shown in **Figure 3** **[1]**.

Referring to Figure 3, the value of the inductance L1 is selected to suit the band to be matched to. This can be done by monitoring the noise level while in receive mode and varying L1 until the received noise level is a maximum, with C1 and C2 at their mid positions. C1 and C2 are usually maximum value types of between 200 to 400pF and rated at being able to withstand several kilovolts of RF. Once the value of L1 has been selected, using a low transmit power, C2 is varied under load until a decrease is observed in the SWR reading. C1 is then varied to reduce the SWR still further. This is an iterative process, with C1 and C2 carefully adjusted until the lowest SWR is found (usually a 1:1 match can be obtained). As a part of this process the value of L1 may need to be adjusted slightly up or down depending upon the values of C1 and C2. Once the combination of L1, C1

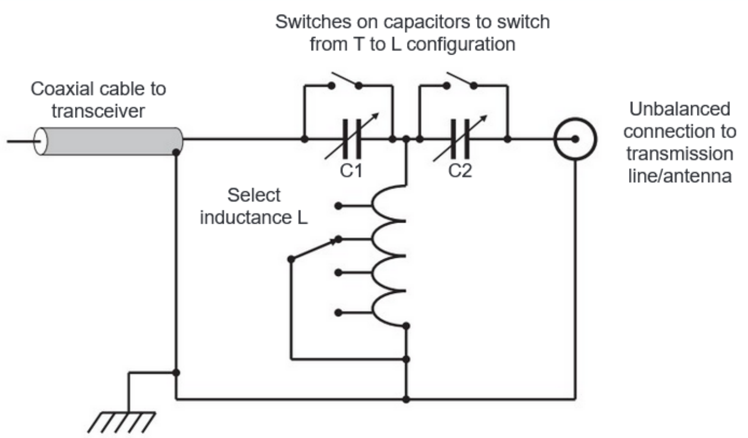

FIGURE 3: Concept of an ATU using a T-network circuit.

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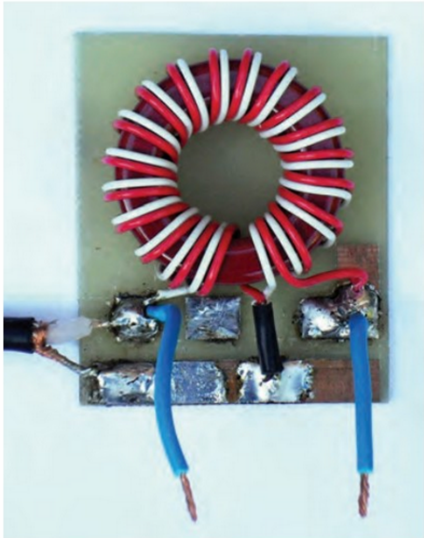

PHOTO 3: Example of 1:4 transformer T130-2 core balun.

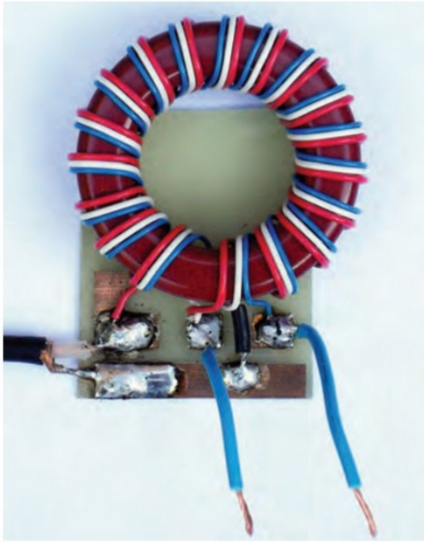

PHOTO 4: Example of 1:1 transformer T200-2 core balun.

and C2 has been found for the band in use, the transmit power can safely be increased. However, good practice is to check that the SWR has not risen when higher transmit powers are used. Commercially available Transmatch T-network ATUs usually include a tuning chart to enable L1, C1 and C2 to be approximately set for the band in use, with their values adjusted to obtain the best match.

The match obtained using either a Pi-network or T-network ATU can be affected by touching their tuning controls. To minimise this effect, long insulated plastic spindles are used to isolate the capacitors from their tuning knobs.

An example of a T-network ATU is the design by Mike Grierson, G3TSO. Full constructional details of this general purpose 160m to 10m band ATU design can be found in the *Radio Communication Handbook* **[1]**.

Interfacing with unbalanced and balanced antenna loads

The ATU is usually connected to the transceiver by means of an unbalanced 50Ω coaxial cable. However, the ATU's connection to the antenna could either be balanced or unbalanced depending the transmission line in use. If the antenna's transmission line presents a balanced load to an unbalanced ATU, then a balanced-to-unbalanced interface (or balun) should be used to improve the transition.

Transformer-type (or voltage-type) baluns using iron powder toroid cores can be constructed to cover frequency ranges from 3 to 30MHz. These are auto-transformers that have their origins in the work performed by C L Ruthroff **[2]**. They function in the same manner as their lower-frequency counterparts, however the low magnetic permeability of the toroid core allows these transformers to operate at much higher frequencies. To enable the transformer to work efficiently, it is important to maintain a high coefficient of coupling between the windings. To achieve this, the wires are laid side-by-side (in bifilar or trifilar fashion, as appropriate) to maximise the magnetic field between the windings. With these transformers, there will always be some leakage inductance and this increases in proportion to the transformer's self-inductance. Essentially, a transformer that works well at 3.5MHz may not work as well at 28.5MHz and this often shows as a worsening SWR as the frequency is increased.

The concept of two transformer baluns for impedance ratios of 1:1 and 1:4 are shown as **Figure 4 [3]**. The trifilar 1:1 ratio arrangement tends to increase the leakage inductance and this can limit its upper frequency range compared to the bifilar 1:4 ratio arrangement.

Photo 3 illustrates an example of a 1:4 impedance ratio transformer balun using a Micrometals T130-2 iron powder toroid core **[3]**. This balun comprised 17 bifilar-wound (two-wire) turns with a small gap left between each turn as shown. Plastic insulated 0.7mm diameter copper single core wire was used for the windings. In Photo 3, the stranded blue wires indicate the balanced connection to the transformer; the unbalanced connection is shown terminated by the coaxial cable. This T130-2 core based balun had a working range from 3.5MHz to 28.5MHz and was capable of handling 100W.

Photo 4 illustrates a 1:1 impedance ratio transformer balun using a Micrometals T200-2 iron powder toroid core **[3]**. This balun comprised 17 trifilar-wound (three-wire) turns with a small gap left between each turn as shown. Plastic insulated 0.7mm diameter copper single core wire was used for the windings. In Photo 4, the stranded blue wires indicate the balanced connection to the transformer, with the unbalanced connection shown terminated by the coaxial cable. This T200-2 core based balun had a working range from 3.5MHz to 14.3MHz and was capable of handling 100W.

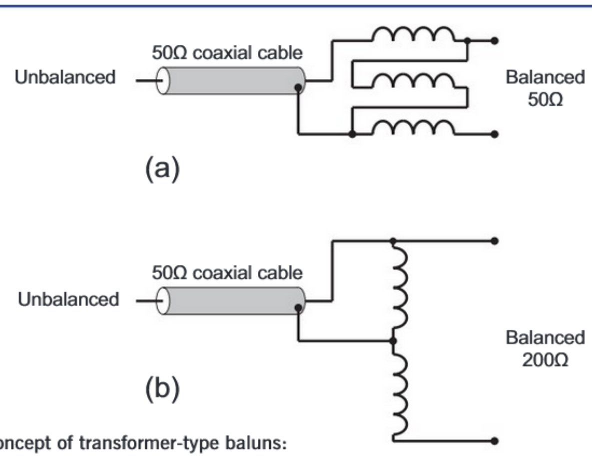

FIGURE 4: Concept of transformer-type baluns: (a) trifilar wire-wound 1:1, (b) bifilar wire-wound 1:4.

Balanced ATU designs

Next month the theme continues with an overview of balanced ATUs.

References

RSGB Radio Communication Handbook, 14th edition edited by Mike Browne, G3DIH: Section 15, Practical HF Antennas:

[1] Pages 15.38 to 15.42.

[3] Pages 15.14 to 15.15.

[2] *Some Broadband Transformers*, C L Ruthroff MIRE, published by the IRE 1959.

An SDR transceiver for the amateur bands Part 2: The Transmitter

Last month I covered the equipment needed to produce an all mode receiver covering 3.5MHz to 23cm. In this concluding article I discuss how to produce a companion low power transmitter covering the same bands.

The basis of the transmitter is a programmable SDR hardware module driven by Python software created by GNU Radio running on a Raspberry Pi (R-Pi) or Linux PC (all references to the RPi can be considered to apply equally to a Linux PC unless noted). I used a HackRF One module (but GNU radio also includes drivers for other modules including the Red Pitaya, although I have not tried using that device). I have very little knowledge of programming in Python, C or any other modern language except elementary Arduino coding. Thus I have been reliant on GNU Radio producing the code for me (with the exception of the transmit/receive frequency synchronisation, which was kindly produced for me by G8FKH).

Hardware notes

The overall block diagram of the transceiver is shown in **Figure 4**. It can be seen that the HackRF is connected to a R-Pi 4 through a USB hub. The R-Pi is running Python code that was generated from GNU Radio.

The code for the receive RTL dongle runs at the same time from the R-Pi4 using the GqRx software, as well as any MGM or remote Rx/Tx control. A point to note on the block diagram is that the only other connections are the mic and headphone. The operation of the PTT is done by a tone injection into the microphone, which is generated by pressing the PTT switch. The tone is detected and filtered off by the GNU Radio software program, which then uses its presence to switch the software from Rx to Tx in the appropriate places. If only a R-Pi is intended to run the system then access to its hardware I/O ports could provide this function (with suitable external Python code).

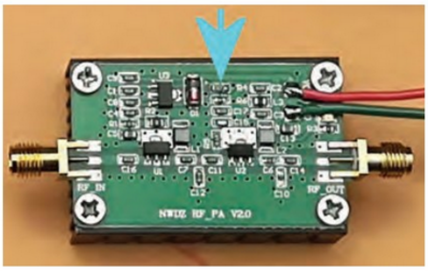

PHOTO 4: A wideband '3W' amplifier. R4 (arrowed) *must* be changed to 3k3 or 3k6 before use (see text).

The Arduino provides a hardware interface for the transmit/receive relays as well as running the code for the HF synthesiser converter covered in part 1 last month. Another point of note is the inhibit relay. This is also driven from the Arduino and is there to prevent any residual RF coming from the HackRF getting through to the receiver or Tx amp during receive. The synthesiser and Arduino must be well shielded in a separate box well away from the inhibit relay and RF amplifier.

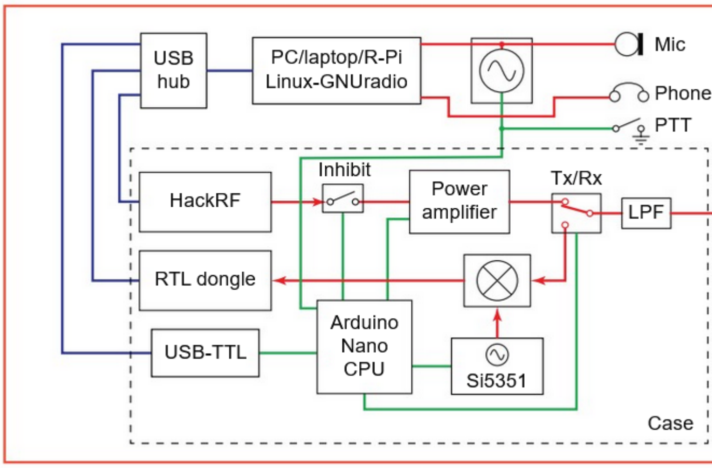

FIGURE 4: Block diagram of the SDR system.

The power amplifier I use for HF is a wideband '45W' device that is available as a kit from several eBay suppliers for under £15. It has a gain of over 60dB and can provide tens of watts output when driven directly from the HackRF. See later.

For low power and VHF working, I use a '3W' 2-700MHz wideband amp, seen in **Photo 4**, which actually works OK down to 160m and up to 70cm. Realistically it produces just over 1W up to 2m and slightly less on 70cm. It can be used on its own for QRP and MGM modes. The amplifier typically costs about £12 and comes ready built but is has a design fault and must be modified before use. As supplied, the bias to the output transistor is much too high, causing it to run very hot and die in minutes. Changing R4 (arrowed in Photo 4) to 5k6 will cure the problem. For more comments on this amplifier see **[2]**.

For UHF and microwave, I use a '6GHz' wideband amp that, for £5 or so, produces 80mW up to 2.4GHz from the HackRF. That's enough (with a good antenna) to be seen on QO-100 or to drive a power amp to 10W. The RTL receiver works up to 23cm; the mixer/synthesiser is not needed above 30MHz.

A low pass filter is absolutely essential for each band, especially as the modern semiconductors used in the RF amps produce almost perfect square waves at their output and thus contain **very** high levels of harmonics. The output power of most cheap amplifiers advertised is usually measured on the most favourable band without a filter into a probe-coupled power meter and is thus the sum of the wanted carrier plus all of the harmonics. In reality the clean carrier power available over most of the HF bands is less than half their advertised output. Suitable filter kits are available from Sotabeams and other suppliers. Ideally a 7-pole filter is required for each band; the output should be checked on each band before use on the air.

The inhibit relay can be an ordinary miniature relay for up to 2m but it is best to use a Panasonic 3GHz ARS relay. This costs a little more, at around £10, but will cover most of the useable bands and is designed to switch up to 1W if needed.

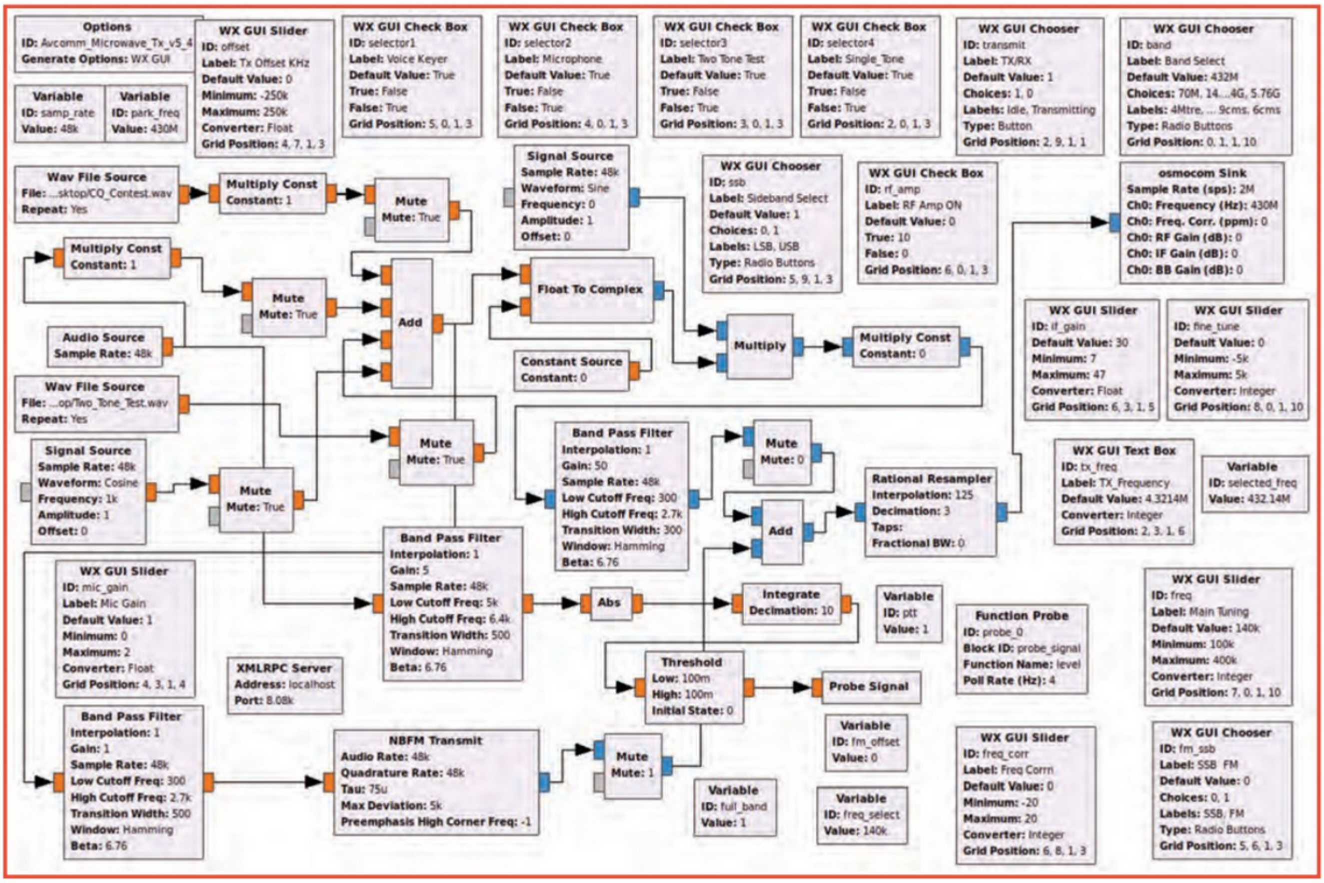

FIGURE 5: GNU Radio representation of the SDR system.

The Tx/Rx relay can be an ordinary miniature mains relay for HF but above that a form of coax relay will be needed depending on the power output.

Software environment

And so to the main 'engine' of the system: the GNU Radio software development environment. GNU Radio lets one create sophisticated software defined radio systems using flowchart-like symbols representing functional blocks and data flows. **Figure 5** shows the diagram of the complete system. The GNU radio files (and other data associated with this project) can be downloaded from **[3]**.

Briefly, audio input from a number of sources is sampled at 48kHz on the left hand side of the diagram, then passed through a series of selector switches to bandpass filters for either SSB or FM and then resampled before being passed to the Osmocom driver to operate the HackRF One. The gain parameters of the HackRF One are set to zero and the frequency 'parked' until transmission is requested. A feed from the audio source is passed through a bandpass filter to a threshold detector to initiate transmission from the microphone, as well as a transmit switch from the screen (no external connection needed).

Most of the transmission parameters can be set or adjusted from the screen window after the Python program is created for the first time. The resulting Python file can be run directly afterwards. **Figure 6** shows the on-screen operating windows together with the GqRx receiver, working on a R-Pi400.

Initial Tx frequency selection is done by clicking on one of the band selectors and then moving the tuning slider(s) to give the exact frequency required. This is fine for independent Tx/Rx working, but when using the transmitter with the RTL GqRx receiver, the transmitter can be slaved to the frequency displayed on the main receive window by pressing the 'remote control via TCP' button on GqRx, which goes grey. Then start the getGQRx_net Python program, which provides a point and click tuning facility for the system to work as a transceiver. Small adjustments (in ppm) to maintain exact frequency matching can be made on the transmitter control screen by using the Freq Corrn slider or (in 50Hz steps) by using the fine tune slider.

The PTT carrier oscillator consists only of a 4011 or 7400 CMOS quad gate connected

FIGURE 6: Screendump of the software in operation.

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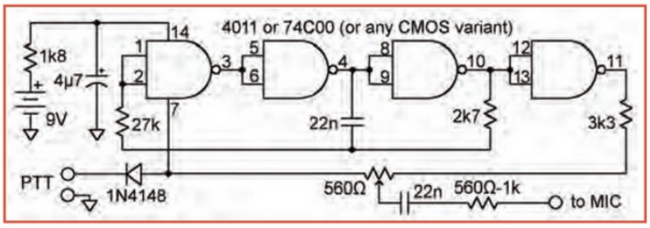

FIGURE 7: Simple 5.6kHz tone generator.

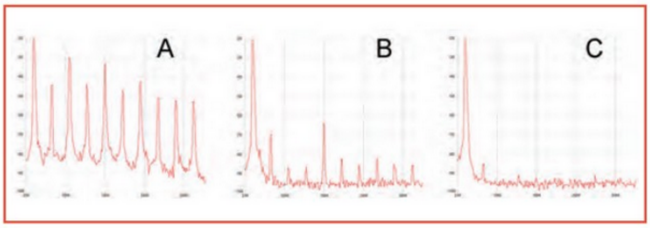

FIGURE 8: Effect of different levels of filtering: A none, B 5-pole, C 7-pole.

as shown in **Figure 7**, to produce a low level 5.6kHz tone that is added to the PC mic audio input. In part 1, I described using an Arduino to provide the synthesiser control for the mixer local oscillator. A small extension to the program can provide outputs to drive relays for the transmit/receive changeover and inhibit relays with signals in the appropriate sequence from a PTT input. If it is intended only to transmit/receive on VHF/UHF without a synthesiser/mixer for HF, then only the sequencer program must be used, but for 'HF receive only' the full transceiver program will still work.

Power amplifiers

Whilst this is capable of having reasonable QSOs using WSPR and other digital modes it is difficult to be heard whenever the bands are busy. More power can help and there are a range of options for raising the output of the HackRF One to 10W or more.

For about £20 I obtained via eBay a '45W amplifier' kit (see **Photo 5**), which I have used with some success. However, these amplifiers must NOT be used 'as supplied' for any amateur transmissions, as the output is a perfect SQUARE wave, with harmonics up to VHF – the third harmonic is less than 10dB down on the fundamental.

The actual power of the fundamental from this amplifier is around 20W on 10MHz and around 15W on other frequencies. Reducing the input power does nothing to reduce the harmonics. Even for low power, it is necessary for all harmonics to be less than -50dB (preferably -60dB). This can be achieved by using, on the amplifier output, band-specific low pass filters of at least a 7-pole design. A standard '30MHz low pass filter' is NOT adequate (except, just possibly, for 21MHz and above).

The TinySA miniature spectrum analyser and the NanoVNA mentioned in previous editions are two relatively inexpensive gadgets that enable one to produce excellent low pass filters that can transform the cheap amplifiers into useful amateur equipment.

Figure 8 shows the output of the '45W' amp (A) with no filter, (B) through a commercially available 5-pole filter and (C) with a 7-pole filter. Only then is the harmonic suppression adequate. Suitable 7-pole filters are available as kits (via eBay and elsewhere) but it is advisable to check the performance with a network analyser and, if necessary, slightly modify the component values to achieve optimum results. A switchable bank of 5-pole filters bought ready-made via eBay (**Photo 6**) proved to have an incorrect capacitor in the 80m section, which resulted in almost a short circuit at its input. The number of turns on four of the coils were not optimum either, but nevertheless it was a very useful purchase. A good site for information on the design of filters is at **[4]**.

I have also tried the '65 Watt Amplifier' bought via eBay; when driven by the wideband '3W' amplifier mentioned earlier, this can produce 30W through a decent filter. However, the (unmatched) FET's are prone to failure. I changed them for a MRF186 dual FET, then fitted a 7/10MHz 7-pole filter and mini VSWR meter as shown in **Photo 7**. PD7MAA has blogged about building this and I recommend you refer to his info.

Continued on page 87

PHOTO 5: eBay-sourced '45W' HF amplifier that required filtering.

PHOTO 6: eBay-sourced 5-pole switchable filter bank.

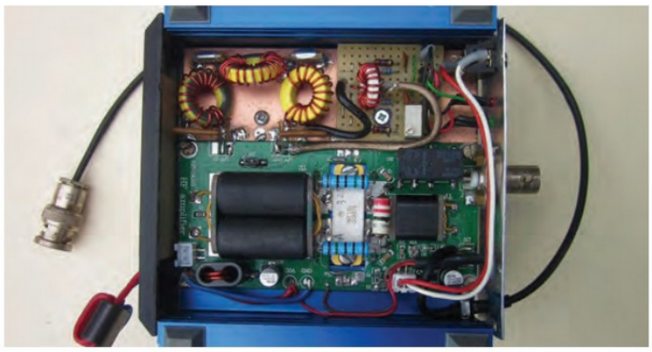

PHOTO 7: eBay-sourced '65W' amplifier for 2m with homebrew filter and SWR bridge.

PHOTO 8: eBay-sourced '100W' 70cm amplifier housed in a recycled case.

EMC

PHOTO 1: **A battery charger on test.**

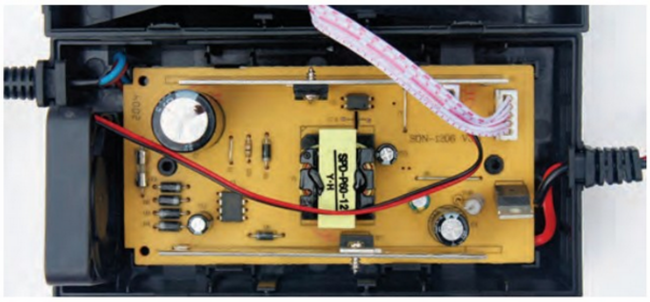

PHOTO 2: **Inside the battery charger.**

PHOTO 3: **X-ray view of a very similar battery charger (courtesy G1MFG).**

Car battery chargers, continued

The QRM Finding and Elimination article in September 2021 *RadCom* (p58-60) shows, in practical terms, just how much RF interference (RFI) some car battery chargers can produce. Chargers that do not comply with the UK EMC Regulations can be even worse than other non-compliant appliances for two reasons. First they handle more power than something small like a mobile phone charger, typically 60W vs 5-15W. Secondly, the battery that is being charged is connected to a vehicle with a large capacitance to earth, much larger than a mobile phone. This results in an RF loop that radiates RFI.

Figure 1 shows two ways in which RFI can be radiated by a car battery charger. The red dotted line shows the path of common-mode (CM) interference that comes out of the 12V DC output on the (+) and (–) wires together relative to earth. It returns via the car body, stray capacitance to earth and the mains wiring. The blue dotted line shows the path of differential mode (DM) interference that is injected into the mains between live and neutral. Due to unbalance, some of the DM is converted to CM that follows the red CM dotted line.

Not so smart?

Further to the item in June 2021 EMC column about a KMW-1210D smart fast battery charger, a Member reports that he bought two of the exact same model, KMW-1210D smart fast charger at £12.50 each on a well-known online auction site. They don't carry a brand name but the instruction sheet includes the name Shenzhen Keimai Weike Electronic Technology Co Ltd.

Our Member found that the battery chargers generated high levels of RFI from LF to 50MHz and above. He kindly sent one to the RSGB EMC Committee for testing. **Photo 1** shows the battery charger on test. The test setup is similar to Photo 5 in April 2021 *RadCom* EMC column, p 81. The charger was connected to a car battery (not shown) and the battery had a 3.5A load consisting of two 12V 21W bulbs in parallel to simulate a battery that was only partly charged. The charger produced about 6A during the test.

The box with the copper lid is a LISN (Line Impedance Stabilisation Network). This allows the RFI that the charger feeds back into the mains to be measured using a spectrum analyser or measuring receiver (not shown). This particular design of LISN can work from 150kHz to over 50MHz. It has a low 50Hz earth leakage current of <1mA; a built-in attenuator and surge limiter protects the spectrum analyser from spikes when switching mains loads on or off. A mains isolating transformer was also used for added safety.

Figure 2 shows a plot of the measured emission up to 30MHz using 9kHz bandwidth and Quasi-Peak (QP) detection. The vertical scale is 10dB per division. Red means that the EN 55014 QP conducted emission limit is exceeded. The markers M1 to M6 are set to frequencies in amateur bands and these show the emission level in dB(μV), that is dB relative to 1 microvolt. Although there are some measurement uncertainties in this test setup, it appears likely that the emissions from this battery charger exceed the EN 55014 QP limit by a substantial margin, up to about 30dB.

Photo 2 shows the main PCB of the battery charger. It is very similar to the battery charger tested in June 2021 *RadCom* EMC column in that it has *no* RFI filtering components. The AC mains input (on the left) goes via a glass fuse straight into a bridge rectifier D1-D4; there are no inductors to reduce RFI fed back into the mains. There is a fan to cool the heatsinks, powered by 12V DC with wires leading to the DC output side on the right. Ferrite-cored transformer T1 is in the centre. The five way ribbon cable connects to the display PCB (mounted above the transformer when the case is assembled). The 4-pin DIL package U2 is an optocoupler that feeds back the DC output voltage across the isolation barrier. There is slot in the PCB for safety and a space for a capacitor, C14, which is not fitted. The purpose of C14 would be to 'ground' the DC output at RF but, as there is no earth wire, mains live and neutral would be used as an RF 'earth'. C14 would be a safety critical component (it needs to be Class 'Y') so it may have been omitted to reduce cost. The result is that harmonics of the switching waveform are coupled through the inter-winding capacitance of T1 onto the DC output wires, where they cause radiated interference. The wires to the fan and the display both

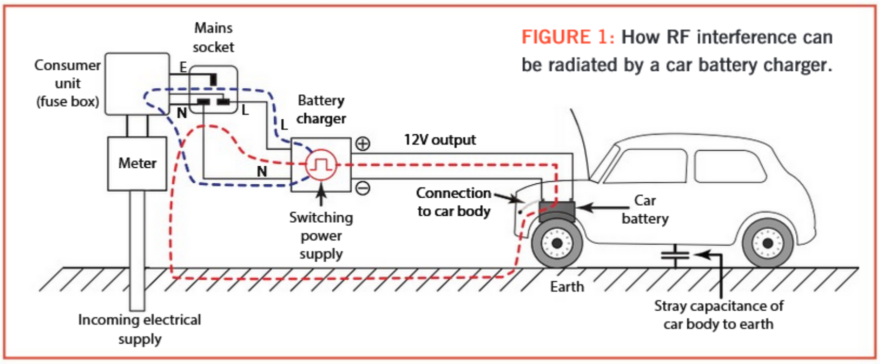

FIGURE 1: How RF interference can be radiated by a car battery charger.

FIGURE 2: Conducted emissions from a battery charger up to 30MHz.

PHOTO 4: An unsafe non-BS 1363 compliant mains plug with no fuse and a partially sleeved earth pin that is not permitted for UK sale.

PHOTO 5: A safe 2-pin UK conversion plug with fuse (the 2-pin plug is inside).

PHOTO 6: An unsafe 2-pin adaptor with partially sleeved earth pin, no fuse and unshuttered contacts that poses a shock risk.

add extra unwanted stray capacitance between the input and output sides at RF, which can further increase emissions of RFI.

An X-ray machine was used to make **Photo 3**, which gives a useful view of the PCB tracks and components when the case is closed. The machine is very useful for seeing inside other types of electronic product such as switching power supply units, chargers and other items, especially ones that cannot easily be dismantled because they are glued together or 'potted'.

Electrical safety

When looking at EMC issues with electronic products it is also worth keeping alert for any visible electrical safety issues. Problems such as inadequate insulation in the mains transformer are not visible, though others are easy to see. This article is not a complete or definitive guide to electrical safety but it does show some selected issues that have been found in practice. If you suspect any electrical safety problems on any mains powered electrical product bought in the UK, these should be reported to your local council's Trading Standards department (you may need to do this via Citizens Advice). Trading Standards are likely to give alleged electrical safety problems higher priority than alleged non-compliance with EMC Regulations.

Photo 4 shows the mains plug of the battery charger. The 'cloverleaf' shape shows that it has no mains fuse, so it does not comply with UK Regulations. There is also no BSI or ASTA licence number, so the plug does not comply with BS 1363. According to Plugsafe **[1]**, "A common indicator of a counterfeit plug is an earth pin that is partially insulated. BS 1363 requires that all power pins (the shorter pins) are partially insulated. However, earth pins must be solid brass, or, in the case of plugs intended solely for use with non-earthed devices, solid plastic. … Plugs with partially sleeved earth pins are ALWAYS counterfeit, and are not allowed to be sold (in the UK), even for non-earthed applications."

The mains cable of the battery charger is marked as 2 x 0.5mm² so if it is made of copper (not all are) then its current rating would be 3A. This is adequate for the battery charger in normal use but there should be a 3A BS 1362 fuse in the plug to protect the cable under fault conditions. When plugged directly into a UK ring main circuit the only other circuit protection is a 30A fuse or circuit breaker at the consumer unit. If for instance the bonnet of the car is closed, trapping the cable, damaging the insulation and causing a short circuit, the cable to the charger could catch fire.

Another common electrical safety problem is 2-pin mains plugs or unsafe 2-pin adaptors. In *The Plugs and Sockets, etc (Safety) Regulations 1994* (see [1]), Regulation 12 contains a prohibition on the supply of appliances referred to in Regulation 11 unless they are fitted with a standard plug (see definitions and compliance requirement in Part I) that is fitted with a fuse link conforming to BS 1362 and which is suitably rated.

Appliances with a continental 2-pin mains plug can only legally be sold in the UK if the 2-pin plug is enclosed inside a conversion plug with a fuse such as the type shown in **Photo 5**. This is not an adaptor; it encloses the non-UK plug and it can only be removed by using a tool.

If you have any electrical appliances with a moulded-on 2-pin mains plug, the safest option for UK use is to cut the plug off and replace it with a UK BS 1363 plug with a suitably rated fuse, typically 3A for low power appliances. If you use a 2-pin adaptor then this should have its own fuse and shuttered contacts. Some products with 2-pin mains plugs are supplied with an unsafe type of adaptor like the one shown in **Photo 6**. These do not comply with UK Regulations (*Plugs and Sockets, etc (Safety) Regulations 1994*) so they should NEVER be used as they have no fuse and the contacts are not shuttered. It would be possible for a child to insert a metal object such as a key into a 'live' socket. Another dangerous scenario is shown in the photo: plugging in one pin of a 2-pin plug while touching the other pin. This would result in an electric shock via an electrical path through the appliance. Some types also have a partially sleeved earth pin as seen in the photo and if used with an appliance with a non-UK 3-pin plug, the earth pin may not make contact in a UK wall socket. If you have any type of unshuttered adaptor it is strongly recommended you dispose of it (ensuring it won't be re-used) and replace it with a BSI Approved type that has a fuse and shuttered contacts.

Websearch

[1] http://bs1363.fatallyflawed.org.uk/

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DX Commander Rapide 7m antenna kit

The antenna kit as it comes out of the box.

The finished antenna is very lightweight and not too obtrusive.

The DX Commander Rapide is the latest antenna from Callum McCormick, M0MCX. Callum has built up quite a reputation for his no-nonsense vertical ground plane antennas.

These vertical ground plane antennas don't use ununs, baluns, coils or other devices, yet give low SWR figures and good performance on the bands they are designed for. The Rapide is designed to work on the 30, 20, 15, 17, 15, 12 and 10m bands. It also offers a low SWR on 6m as a bonus.

So what's its secret? The DX Commander uses multiple quarter wave elements fed against the ground or actually an extensive radial field (supplied). Callum has done extensive work on the design to ensure that there is no adverse interaction between the elements. The result is you get a no-tune multiband antenna, capable of taking the full legal limit in a lightweight package.

The antenna kit

The antenna kit, and I do mean kit, arrives in a study cardboard box. Inside is a 7m fibreglass fishing pole, two machined aluminium plates, three white ultra-high-molecular-weight polyethylene (UHMWPE) plates, a 100m reel of wire and a bag of miscellaneous connectors and fittings.

The antenna runs up to six vertical elements on the 7m pole with a single feedpoint and as Callum says, "It is similar in concept to a fan-dipole, but with the fan turned through 90 degrees on its axis with one side of the fan placed vertically".

If you are the sort of person who likes tinkering with antennas, you'll love it! If, however, you are a fit-and-forget amateur you may not. Expect to spend a good day making up the antenna, including measuring, cutting and soldering.

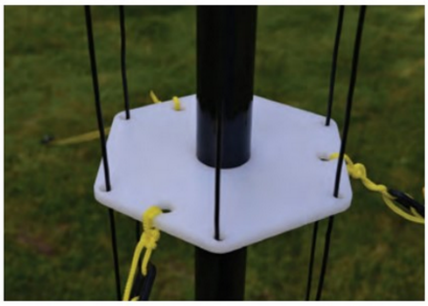
Assembling the antenna

The kit doesn't come with instructions. For this, you need to go to the DX Commander's website and download the appropriate guide. Callum says he can supply instructions with the kit if requested at the time of order. Can I also recommend that you view the appropriate DX Commander YouTube video as it will make the whole job a lot easier.

The first job is to extend the pole, twisting the sections to make it

Callum recommends supporting the antenna on two chairs while you build it.

A close-up of the driven base plate in position.



The elements are threaded through the polyethylene plastic plates.

The driven and ground plates with wingnuts and driven elements attached.

The elements are kept under tension by using elastic shock cord.

rigid. Callum then recommends that you tape these joints with either self-amalgamating or PVC electrical tape to stop the sections from collapsing.

You then unscrew the bottom of the pole and add the ground plate, plus push the driven plate down the pole and secure it with the supplied hose clamps, using rubber/PVC tubing to prevent cracking. A third clamp is placed just above the first joint. You don't have to overdo the clamps – just enough to stop them moving around.

At this point you can add the SO-239 feed point socket and the stainless steel bolts to the bottom plates using a 10mm spanner. Again, don't over-tighten these as you might strip the threads. I then added a stainless steel washer and wingnut to each bolt. I found it easier to do this now so that it is easier to add the elements when needed.

Callum recommends that you lay the extended pole out on two garden chairs or similar. This makes it a lot easier to build the antenna and attach the elements.

Now you are ready to start the build proper.

You are given a cutting chart for the various wire elements. These have to be soldered to the forked connectors that connect to the base. You also have to fold over the final 2.5-3cm of each wire to make a loop. These can be fixed using the supplied heat-shrink tubing or by using PVC insulating tape. I recommend the latter at first as it is cheap and allows you to easily make adjustments.

The next stage is to fit each element to the pole. This involves fastening the elements to the correct position on the driven plate and threading it through the white plastic plate. To finish, you have to add a loop to the element and then make up a shock-cord extension that holds the wire in tension. The DX Commander uses plastic carabiners that you thread onto the 4mm shock cord. These can be quite fiddly to fit but you soon get used to it. I found that the cleaner the cut on the cord the easier it was to fit the carabiner.

Once fitted, you can then stretch and attach the carabiner to the appropriate white plate. Note: make sure you use the elastic shock cord – at my first attempt I used the non-elastic paracord, which looks identical! This is strictly for use as guylines.

It is important to get each element's tension correct, otherwise, they will move in the wind, affecting the SWR.

The only tricky part of the assembly is the 30m element, which goes up to the end of the pole, through the metal loop on the end and then back down the pole, being secured with a small piece of PVC aquarium tubing.

You also have to add a small loop to the 30m element to which an elastic shock cord is attached to equalise the tension around the pole.

There is a way to get the antenna to work on 40 metres instead of 30 metres. But the element lengths for each band will be slightly different so I didn't try it. The instructions fully explain how to do this, which also involves adding a coil to the 40m element.

Radials

Once the antenna was built I had to measure and cut 20 x 3.2m lengths of the wire to use as ground radials. These were then soldered in batches of four to the supplied fork connectors. The observant among you will have noticed that

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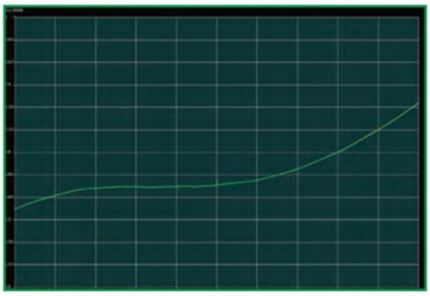
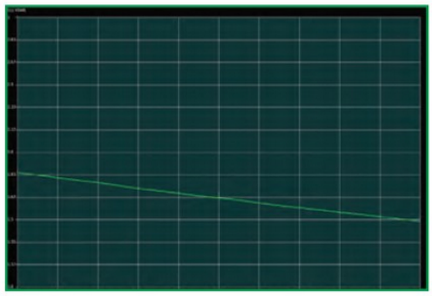
SWR Results

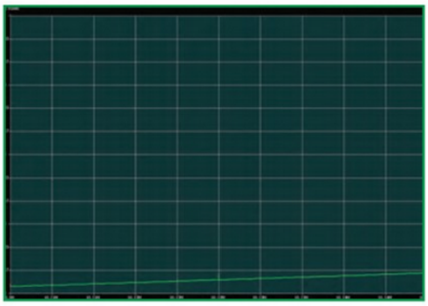
10.100MHz 1.1:1	24.890MHz 1.2:1
10.120MHz 1.1:1	24.910MHz 1.3:1
10.130MHz 1.1:1	24.930MHz 1.3:1
10.140MHz 1.2:1	24.950MHz 1.3:1
10.150MHz 1.2:1	24.970MHz 1.3:1
	24.990MHz 1.3:1
14.000MHz 1.3:1	
14.100MHz 1.2:1	28.000MHz 1.6:1
14.200MHz 1.2:1	28.250MHz 1.2:1
14.300MHz 1.6:1	28.500MHz 1.6:1
14.350MHz 1.7:1	28.750MHz 2.0:1
18.068MHz 1.8:1	29.500MHz 1.8:1
18.100MHz 1.7:1	29.600MHz 1.8:1
18.120MHz 1.7:1	29.700Mhz 1.5:1
18.168MHz 1.5:1	
	50.000MHz 1.6:1
21.000MHz 2.5:1	51:000MHz 1.7:1
21.100MHz 1.9:1	52.000MHz 2.3:1
21.200MHz 1.3:1	
21.300MHz 1.1:1	
21.400MHz 1.2:1	
21:450MHz 1.3:1	



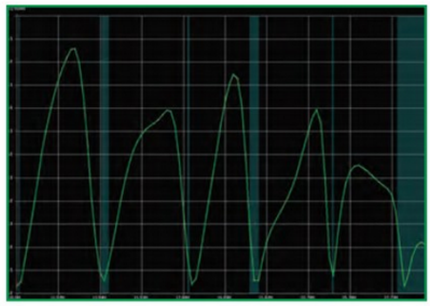
The SWR remains fairly flat across 6 metres.



On 17m the SWR good have been improved by making the element a little longer.



A scan using my nanoVNA shows a low SWR across 30 metres.



A nanoVNA scan across the whole range shows a low SWR on all bands.

there are actually *six* connectors on the base. Callum recommends you retain the final 12.8m (4 x 3.2m) of wire until you are happy that the antenna is working properly and you don't need any extra wire. Only then should you make up the final radial set.

It is then a case of sitting the antenna on its base and adding the guylines to stop it from falling over. You can use the supplied paracord to guy the finished antenna, but I had some Poundland fluorescent nylon guylines sitting around so I used them. You'll need to supply your own metal guys so make sure you get these before you start.

I then fitted the prepared radials by connecting them to the wing nuts and bolts previously fitted to the base. The end result looks very good and is very lightweight. So could you use it as a portable antenna? Yes, probably, but you would have to fix the fishing pole joints and also fit the wire elements each time you deployed it.

SWR testing

I was pleasantly surprised by the SWR test results. All bands from 30m – 10m were either good enough to work without an ATU, or would be perfectly within the range of a rig's auto ATU. My only concern was 12 metres, which was a little short and put the low SWR point a little high. I cut another length of wire and by cutting and testing, cutting and testing I managed to get the SWR down to 1.3:1 across the band.

Using my nanoVNA, I could see that for a perfect result I really needed to make the 17m element a little longer, but as the SWR was below 2:1 across the band I let it go.

I suggest that you allow plenty of time to do the setting up as it will pay dividends later.

Performance

The antenna was tested over a five-day period, often against my existing commercial 132ft end fed half wave antenna.

On 30m (which is a CW/data-mode band rather than SSB), the antenna performed well, offering a low SWR without the use of an antenna tuning unit. I easily worked a couple of SOTA stations in Switzerland and Germany on CW. On FT8 I worked DK7ZT, DH0GBC and DL2OAM (Germany), IZ8EYN (Italy), SQ8AA (Poland), MM7DXC (Scotland) and HA7TM (Hungary), all around lunchtime. I also worked A61R (United Arab Emirates) around 1625UTC one afternoon.

I think it is a solid performer on 30m and it was interesting to have a dedicated antenna for the band as it outperformed my 132ft EFHW by 1-2 S-points.

On 20m the antenna also proved to be a competent performer, also usually outperforming my existing 132ft commercial EFHW antenna by 1-2 S points. Noise-wise, it was a little worse, perhaps 1-2 S-points, but this was to be expected as verticals are notoriously noisy.

I worked SOTA station DF1AKR/P on DM/BW-066 (Großer Hundskopf) via SSB on my first call. QRP station Luca, IZ2XAO via CW was three S-points louder on the DX Commander.

On 20m FT8, I logged quite a few Indonesian stations, but wasn't able to work one. On 20m FT4 I worked 8N8OLP, the Japan Tokyo Olympics and Paralympics Commemorative station at -4dB on my first call. I was very pleased with that one!

I went on to work European Russia, Hungary, Romania, Italy and Slovenia in quick succession.

Seventeen metres was being largely dominated by Sporadic-E signals, although Chile and Indonesia were spotted on FT8 via F2-layer propagation. I managed to work Nan, JA4KX (Japan) at 6dB SNR with 50W of FT4. I also worked Vlad, UW5EJX/MM on board a tanker. I'm not sure of his actual location.

The 21MHz band and higher were mostly open to Sporadic-E contacts during the test period and the DX Commander worked well. On the 10m band FT8 I worked Johannes, 5T5PA (Mauritania) for a new one, along with a host of Europeans.

It will be interesting to see how it performs in the Autumn when 10m hopefully opens up to F2-layer propagation.

Summary

I think the DX Commander Rapide is a great antenna. It is lightweight and gets you on to at least seven bands. It is also simple to use and easy to fix – no coils, traps, baluns and other elements to worry about.

Just look at the antenna reviews on eham.net – it's five stars all the way.

If you are planning a permanent installation it is probably worth prepping your site very carefully. I would cut the grass as short as you possibly can and use wire staples to stretch out the radials. By springtime they will probably have vanished into the lawn – and away from the lawnmower blade!

The DX Commander Rapide antenna costs £179 and is available from www.m0mcx.co.uk. Our thanks to Callum for the supply of the antenna.

Design Notes

Intermodulation

This month's column comes with a more theoretical slant, but if you can wade through it you may find a delightful insight into exactly how and why intermodulation products (IMPs) are generated. Remember how to multiply out expressions and recall the trigonometric identities? Working through the process will be a good revision exercise to keep the grey cells working. I did all the maths and number crunching on IMPs while working with satellite transponder payloads over thirty years ago. Back in those days satellites usually carried multiple carrier signals, often FM, and interference and intermodulation products between carriers were rife. So a lot of work went into understanding the process.

Intermodulation products are bad, everyone knows that: unwanted frequency products that widen a signal and cause splatter. We accept, or have heard, that they are caused by non-linearities, amplifiers being overdriven and badly adjusted, but why? What is the connection? Here we'll look at the mechanism that generates IMPs and show how the latest, modern all-digital transmitters could be adapted to minimise them automatically. First we need to look at what non-linear really means.

Any RF stage, but particularly amplifiers and mixers, start to compress as their output power increases, until at some point they can generate no more power out – however much the input level is raised. **Figure 1** shows a typical input / output power curve, in dB, for a power amplifier with a nominal small signal gain of 10dB. An input level of 0dB gives an output of +10dB. But by the time the input level has reached +17dB, the output is only +26dB; the gain has been compressed by 1dB at this point. The points were generated arbitrarily so they 'looked about right', but are reasonably typical of any power amplifier stage approaching saturation. The fact that the input / output relationship does not follow a straight line *means* it is not linear. That non-linearity is what gives rise to intermodulation products, but to work out exactly what happens we need to look at the curve in more detail.

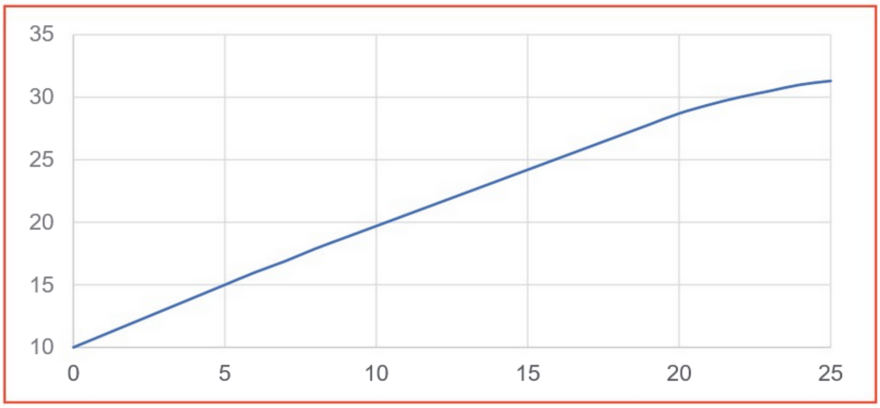


FIGURE 1: Input / output power curve expressed in dB for a typical gain stage running into compression.

Decibels are only a convenient way to look at things in practical terms. For the real analysis we need to look at the transfer equation in terms of voltage or current. The solid blue line in **Figure 2** was generated by converting the dB scales of Figure 1 to linear values by taking $10^{dB/20}$ of the values on each axis. The units are volts or amps (it doesn't matter which you use for the purposes of this analysis and the absolute values mean nothing – it is only the relative values that matter).

Polynomials

Any non-linear curve of X (input) and Y (output) can be represented by a polynomial of the form:

$Y = A + B.X + C.X^2 + D.X^3 + E.X^4$ … etc.

The coefficients of each power term, A, B, C etc are adjusted to best-fit the polynomial to the actual curve that is the transfer function of the RF stage. Fitting a polynomial curve is a complex process, but fortunately Excel has a facility to generate a best-fit polynomial, up to sixth order, for any given curve. The result for this one is shown in Figure 2 by the red dashed line that, as can be seen, lies nicely on top of the blue curve. The coefficients the Excel tool has chosen for the best fit are A = -1.0059, B = 4.69, C = -0.7144, D = 0.1238, for values up to the X^3 third order or cubic term.

Mixing sine waves

To see how new frequency terms are generated in practice, we will use an input signal consisting three sine wave signals of equal amplitude so that $X = SIN(2.\pi.F1.t) + SIN(2.\pi.F2.t) + SIN(2.\pi.F3.t)$.

F1, F2 and F3 are three close-spaced frequencies we're using to generate the IMPs. To keep things simple, this is simplified to $P = 2.\pi.F1.t$, $Q = 2.\pi.F2.t$ and $R = 2.\pi.F3.t$.

We will look only at third order IMPs, which are caused only by the cubic, X^3 term of the transfer function – please just accept this for now, as it's tedious to prove. So we now have $Y = [SIN(P) + SIN(Q) + SIN(R)]^3$. The sum of three sinewaves, cubed. We'll also leave out the fixed coefficient D as it's a constant that can be applied at the end.

Multiplying this lot out can get more than a little bit tedious, but is a relaxing task for a sunny afternoon sitting in the garden. Every term in P, Q and R is multiplied both by itself and by the others to give 27 individual terms, several of which are of the same form and can be grouped together. The result contains all similar terms for P, Q and R, of which only the first ones of each type are given here:

$SIN^3(P) … + 3.SIN^2(P).SIN(Q) + … + 6.SIN(P).SIN(Q).SIN(R) + 3.SIN(P).SIN^2(Q) + … + … + …$

In total there are six terms of the form $SIN^2(P).SIN(Q)$ each containing two of the three frequencies and each with a coefficient of 3. Then there is the single one with all three frequencies with a coefficient of 6. At this stage it may not be immediately obvious where the new frequencies (the IMPs) come from, so now we look at the trigonometric identities.

Remember $SIN(A).SIN(B) = ½ COS(A – B) – ½ COS(A + B)$ and $SIN^2(A) = ½ + ½.COS(2A)$. For simplicity, forget the ½ terms because they're always there.

Taking just one of the terms from the result of multiplying out from the polynomial:

$SIN^2(P). SIN(Q) = SIN(Q) + SIN(2.P).SIN(Q) = SIN(Q) - COS(2.P + Q) + COS(2.P – Q)$

So there is one of our IMPs: frequencies P and Q have generated a term in 2.P – Q,

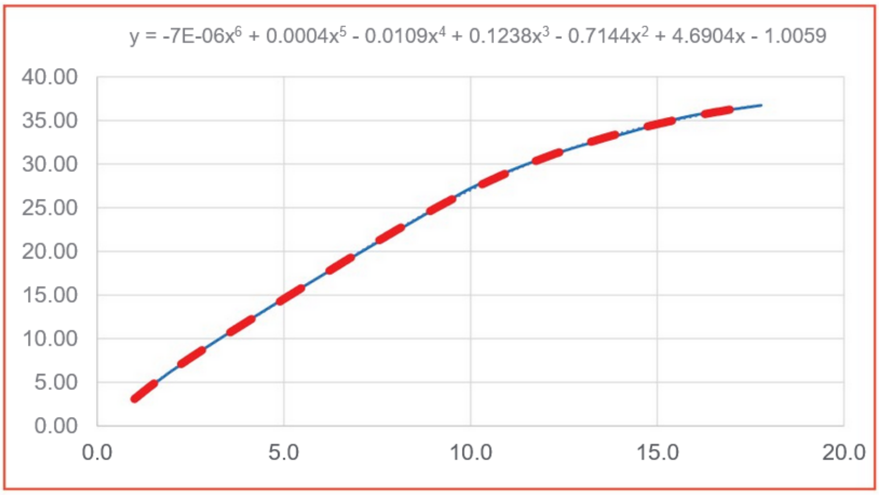


FIGURE 2: **Voltage / current version of the curve in Figure 1. Showing the best fit polynomial used for IMP level estimation.**

which lies close to the input carriers. The other terms of the form 2.P + Q lie around the third harmonics, and are not usually of interest when looking at IMPs.

All three frequencies combined in this way give six IMPs of the form 2.F1 ± F2 and all have the coefficient of 3 seen in the original expansion.

Now look at that single central term, 6.SIN(P).SIN(Q).SIN(R). By the same process of substituting trig identities this reduces to, amongst a number of other harmonic terms:
SIN (P + Q – R) + SIN (P + R – Q) +
SIN(Q + R – P).

Three more close-in products, each with twice the amplitude, or 6dB higher, on the six terms discovered earlier. So altogether that is nine third order products generated from three input frequencies.

It gets worse

Those are just third order products, formed from the cubic term of the transfer equation. If you use the fifth order product, even longer equations need to be multiplied out to get terms like SIN(3.P – 2.Q) and SIN(2.P – 2.Q + R). If you choose more than three frequencies to work with, the number of possible products grows very rapidly. Three frequencies give nine close-in 3rd order IMPs. Four frequencies give 28 close-in products; five frequencies give 55 third-order IMPs. And the number very rapidly goes up. A voice signal consists of several parallel tones in the lower end of its spectrum up to a few hundred Hz. Consider these, after being mixed up to RF, as the frequencies used to generate the close in IMPs and you'll see how they'll spread out uncontrollably either side of the wanted band.

The frequency of each IMP is easy to determine. 3rd order products are of the form 2.F1 – F2, and F1 + F2 – F3. So by considering every possibility for all input frequencies, all possible IMPs can be calculated. It is quite a straightforward job for software to step though all possible coefficients for all frequencies and extract the result. **Figure 3** is a plot of the frequencies of all the close-in IMPs up to ninth order for three equal carriers. The carriers are shown in green and the height and colour of each of the resulting IMPs represents whether it is a 3rd, 5th, 7th or 9th order product. As you can see, with even just three input tones there are an awful lot of new frequencies generated. Imagine the case with six or more input tones (such as a speech waveform), or 20, or 100 (as in an analogue satellite transponder carrying multiple telephone signals on FM carriers). **Figure 4** shows a plot generated for six carriers showing third and fifth order terms only. Note how the 3rd order terms spread the signal out to three times the original spacing. The fifth order terms increase this to five times the original spacing.

Amplitudes

So far we've looked at just what new frequencies are generated, and noted that some products are 6dB above others. But what of their actual amplitudes? The coefficients of the original polynomial best fit can be a guide now. The curve of Figure 1 (and 2) has a B = 4.69, which is the wanted straight line part, and D = 0.1238, the cubic or third order term. If we do a very quick hand-wavey calculation we can estimate that the ratio between these is going to be the ratio of third order terms to the wanted ones. So 4.69/0.1238, about 32dB (remember, it's a voltage or current relationship). This suggests the 3rd order IMPs will be about 32dB down on the fundamental when used at this level.

Does that sound as if it could be plausible? Yes, perhaps, on a good day, for just that single fixed amplitude three-carrier waveform.

IMPs in practice

It is not just multiple signals passing through an amplifier that generates intermodulation products. Anywhere that two or more frequencies are mixed with some non-linear component present will do it. A frequency mixer does it deliberately and all the mixer products at harmonics of LO and RF input will appear. The frequency mixing process is just the same – the primary mixer products, second order ones F1 ± F2 from the squared term of the polynomial, and so on. An harmonic mixer using, for example one that generates 3.LO – RF, relies on the fourth order term of the transfer function. They're not called IMPs in this case, but the same mechanism applies.

While a simple calculation can derive the frequencies of IMPs, only a rough estimate of levels can be obtained for anything other than constant amplitude carriers. The power of modern computers allows real time calculation of the exact signal applied to a non-linear system and so can calculate levels of IMPs for signals of different input level by looking at the waveform of the combined input in real time, in the time domain.

Even-order terms

We jumped in straightaway to look at 3rd order terms, but why not choose 2nd order ones to start with? The reason is that even-order IMPs never give close in products. 2nd-order terms are always of the form SIN(2.P) or SIN(P+Q), which are all in the second harmonic region; 4th order take values like SIN(4P), SIN (3P + Q), SIN(2P+Q + R) and so on.

Linearisation

We have seen how IMPs are generated by the combined waveform of many signals passing through a non-linear stage – one where output voltage is not a direct simple scaling of the input. What if we had a model of the non-linearity and could pre-distort the input waveform with the inverse of this? Some satellite transponders have, long ago, implemented such linearisation. Crafty analogue techniques involving feedback from the output with cancellation of the wanted signals in order to generate an 'inverted version' of the IMPs to feed forward and cancel

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those generated in the output amplifiers – usually the TWTs. Sometimes auxiliary power amplifiers were used, amplifying up *only* the distortion products (isolated by the fed-back and cancellation process), then adding at the output in such a way as to cancel those generated in the main amplifier. Such techniques are complicated and require a lot of individual setting up – not a problem in the satellite business, but of course totally incapable of being altered or tweaked once the satellite has been launched.

With all-digital signal generation, everything changes. The input waveform can be manipulated in real time. And with the aid of an output monitor, the actual compression can be measured and fed into the digital processing so there is the capability to do real time adaptive linearisation. Such techniques are routine in mobile phone systems now, where base stations have to give the highest efficiency possible to save power and heating while still being sufficiently linear for the complex waveforms now in use.

Amateur transceivers are lagging behind. There are still very few that generate the Tx waveform completely digitally. Only once these are commonplace are we likely to see decent inroads into better quality signals and more efficient PA stages. But experimental systems *are* out there, so watch this space.

Radio microphones

A comment on one of the groups followed on from a discussion about transmitter output impedance – a subject we looked at last time. Performers' radio microphones, as used on stages, can give particular problems with intermodulation. One of the steps taken to mitigate the problems is to try to make their source impedance match the antenna. Radio microphones have a particular set of mutually conflicting issues:

- Several are in use at a time, usually one per performer in a group, and all have to operate in very close proximity, perhaps less than a metre apart
- They may have to be body worn, or at least hand-held, meaning they need to be lightweight
- And as a result they need to have small batteries, making PA efficiency important
- Finally, they must have low latency (time delay) – to co-ordinate properly, singers and instrumentalists must have less than a few tens of milliseconds delay in hearing the others with whom they're playing/singing etc.

Most radio mics operate with an output power of a few milliwatts but the close proximity between the transmitters can mean the output signal from one is fed down into the PA stage of a another transmitter. High

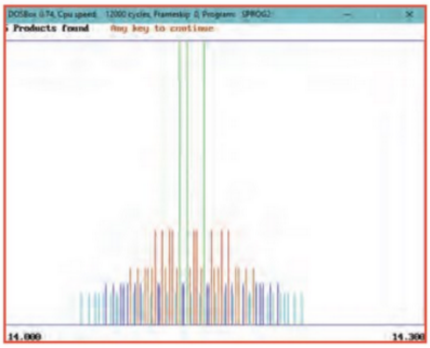

FIGURE 3: Intermodulation products generated from three carriers. The plot shows the 3rd, 5th, 7th and 9th order close-in products.

efficiency generally means Class C PA stages, which are highly non-linear. This means that any signal (from another transmitter) feeding back down into the output stage can generate IMPs. The low latency required by performers usually precludes digital modulation (which would otherwise be a good route to mitigation of IMPs by using time division multiplexing). The bulk of radio microphones still use FM – a recipe for IMP disaster. Every one of those requirements works against the others, making this seemingly simple radio communications task far more complicated than it looks.

Frequencies for each radio microphone are allocated in a way such that IMPs between them do not fall on wanted channels. For more than 'a few' channels this can mean a surprisingly large frequency grid is needed if IMPs even up to just fifth order are considered. And what if there are two or more stages (such as you would get at a music festival)? Each stage needs a different set of frequencies, all chosen for minimising intermodulation products. A look at the *UK Frequency Allocation Table*, available free from Ofcom, will show an extraordinary number of frequencies, often in the footnotes, allocated to 'SAB': Services Ancillary to Broadcasting. This is partly why. And radio microphones are not the only ones with the IMP problem. We now have video senders on cameras with a similar problem.

The original post that prompted these ponderings stated that by controlling the Tx output impedance the effect of IMP generation of received RF getting into a PA stage could be reduced. This doesn't sound too convincing if the PA stage is non-linear, but who knows … Also mentioned on the same thread were a couple of cases of military radio systems being specified for a good transmitter source match. The reasons for requiring a good match weren't made clear but, once again, knowing the likelihood of multiple transmitters in close proximity it's

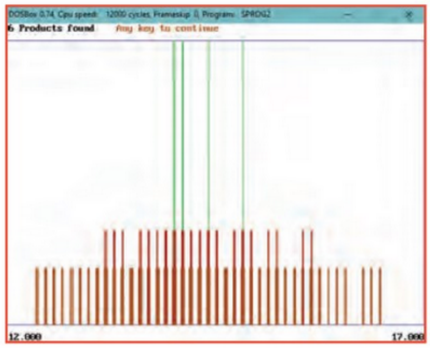

FIGURE 4: The situation of IMPs generated from five carriers showing only 3rd and 5th order close-in products. Frequency spacings have been chosen to avoid IMPs falling on top of each other.

reasonable to assume IMP issues were at the forefront of the system engineer's mind.

A tale of long ago

Back in the late 1980s / early '90s, when I was working with those satellite transponder payloads and trying to calculate mixer products and IMPs in a real scenario, personal computers were very new. I had a computer with a 20MHz processor and a 20MB hard disk; it was a PC typical of those of the day, and shared between several people in the lab. I needed to work out any troublesome frequency mixing products that could be generated by something like twenty input frequencies up to 11th order – and maybe even higher in some cases. The only programming language available on that PC was GW Basic, an old interpreted programming language. So – first shot, use a set of nested loops, calculating all frequencies from each of the inputs up to 11th order, testing if they fell within limits and storing the result to a disk file. Earlier tests with fewer frequencies and a lower maximum order had suggested the run-time for the wanted result could be a few hours – so I left it running overnight.

I came back the next morning to find the machine had crashed. So many IMPs had been found that the 20MB hard disk was full and, for some weird and wonderful reason lost in the depths of MSDOS version 3, had overwritten vital system files. That whole PC had to have its operating system restored. After much software refinement, including tests to make sure the software stopped before the disk was full, I got my answer. A later version of that very same bit of software (properly compiled now, but still written in that 16-bit programming language, which now requires a DOS emulator) was used to generate Figure 3 and Figure 4. The same calculation, 30 years later, of twenty frequencies to 11th order now takes a fraction of a second – and the hard disk doesn't even think about the size of the results file.

A look at the Retevis MMDVM Hotspot Wi-Fi Digital Voice Modem

PHOTO 1: General view of the Retevis MMDVM Hotspot.

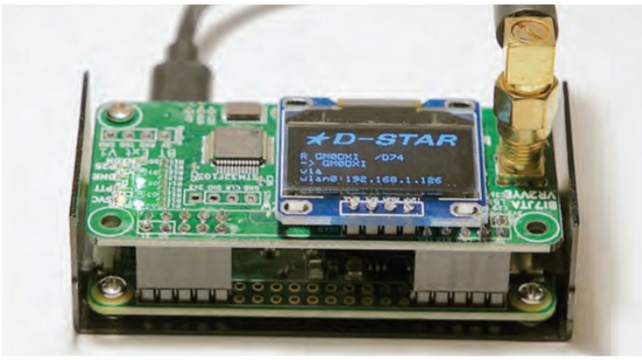

PHOTO 2: The Retevis MMDVM hotspot is a 'HAT' on a Raspberry Pi Zero W.

Introduction

For those looking at getting their first digital voice hotspot there are plenty of choices available. This article focuses on the Multi-Mode Digital Voice Modem (MMDVM) from Chinese supplier Retevis (Ailunce) **[1]**. The device will also appeal to those looking for a ready-made solution out of the box.

Do I *need* a digital hotspot?

My particular QTH is located some 35 miles South of Glasgow, surrounded by hills. Repeater coverage is pretty much non-existent. So, for me, the answer is yes.

The Retevis MMDVM hotspot is tiny, just 72 x 24 x 33mm. It's housed in a sturdy aluminium case that I think should prove durable and rugged in use. The hotspot is provided with a small, right-angle SMA antenna and a short USB A to mini USB cable so it can be powered directly from a PC or a mobile phone PSU. I bought a good quality PSU so that I can plug the hotspot permanently into the mains without tying up a USB port on my PC. There is also a small sheet in the box that lists where to get the information for setting up the hotspot.

The hotspot is configured as an RF gateway for my Kenwood TH-D74E handheld, which then connects via Wi-Fi to my home broadband router and thus out onto the internet. This setup allows for communication across the world. Other interesting possibilities include tethering the hotspot directly to a mobile phone's Wi-Fi service thereby using the phone's internet connection to provide access whilst in the car or portable in the field.

Technical specs

The hotspot can support up to six digital voice modes, including most of the popular ones: DMR, Yaesu System Fusion (YSF), P25, NXDN, D-Star and POCSAG. For the purpose of this article I am going to focus on the D-Star functionality. (It is also possible to set up the device to monitor all the supported DV modes simultaneously, but this would need radios for each of the modes.)

The brains of the device is a Raspberry Pi Zero Wireless. Added to this is a digital voice modem board (or 'HAT') connected to the general purpose input output (GPIO) port on the long edge the R-Pi circuit board (**Photo 2**). Those familiar with the R-Pi will recognise the various slots and ports that are visible through the hotspot's case. The R-Pi processor has a metal heatsink rigidly attached. Retevis has also fitted a high-quality temperature compensated crystal oscillator (TXCO), which should ensure very stable frequency operation in use.

There is also a 0.96" (22mm) OLED on the front panel that shows various status information during the hotspot's operation. A number of status LEDs also flash or remain solid during operation. The hotspot uses the Pi-Star **[2]** open source software distribution, which may be familiar to those who have used hotspots in the past. Finally, the device comes with a microSD card fitted in the R-Pi memory card slot that also comes pre-loaded with the Pi-Star software. There is some anecdotal information from Glen, VK4NGA that the unbranded SD cards supplied might have reliability issues. However, the 8GB micro SD card that came fitted to mine has worked flawlessly without any issues. But to be on the safe side I purchased a branded 16GB microSD card and re-flashed the Pi-Star image to it from the image file available from the Pi-Star website **[3]**. Information on how to do this is provided on the download page together with some help links.

I recommend balenaEtcher **[4]** to write the image file to a micro SD card. This is extremely easy to use: 1, download the Pi-Star image from [2]; 2, unzip the file, producing a .img (image) file; 3, run balenaEtcher, select the .img file as the source and your blank card as the target; 4, go make a cup of tea while balenaEtcher writes and verifies the card. Duplicating (cloning) a card is similarly straightforward, and it's prudent to do so once you've got a system running properly.

Getting registered for D-Star

Here is not the place to go into detail on how to use D-Star; you will find lots of useful information on the internet, particularly at **[5]** and **[6]**, among other places.

It's necessary to register (for free) for D-Star before you can make use of it. You can do this online at **[7]**. It is important to register once and *only* once. You can check if you're already registered for D-Star by going to **[8]**. Registering on multiple gateways will cause problems. (If you have a problem with a registration, contact the Admin for the Gateway where you first registered: you'll find this info at [8]).

Hotspot frequency

Next, you will need to choose a frequency for your hotspot. For most people it's not a great idea to use the congested 2m band. 70cm is usually a far better choice. The UK 70cm Band Plan **[9]** suggests 434.000MHz and 438.800MHz for low power non-NoV personal hotspot use. I chose to use 434.000MHz, as it seemed that frequency was not in use by any other nearby hotspots.

Documentation

A piece of paper in the box directs users to a comprehensive wiki page on the MMDVM and how to set it up **[10]** written by Winters Huang, BI7JTA. Also, Glen, VK4NGA has a YouTube channel **[11]** for those looking on how to configure their MMDVM hotspot for DMR.

I will show the basic set-up for D-Star operation here to save you hunting around the internet for information. This will also save you a lot of frustration when trying to get things working for the first time.

Setting up a DR channel for the hotspot

I chose memory Group 000 on my D-74E handheld and configured the hotspot frequency of 434.0000MHz as a digital repeater (DR) with an offset frequency of 0kHz. **Table 1** gives the settings I used – yours will be similar, but of course you'll use your own callsign.

Note that if the Tx/Rx channel on the radio was set up just as a *simplex* digital voice (DV) channel, then only your callsign and the CQCQCQ information gets sent to the hotspot, with no routing information. So, although audio can be *received* from the hotspot, no one will hear your voice on transmit going through the hotspot. This particular issue initially caused me a lot of grief, so I'm keen you do not make the same mistake as me!

Other radio settings

There are a number of other settings that need to be configured to make a successful call on D-Star using the hotspot. **Table 2** shows a summary of those I set for my Kenwood TH-D74E; other radios will be similar. Where you see my callsign, substitute your own!

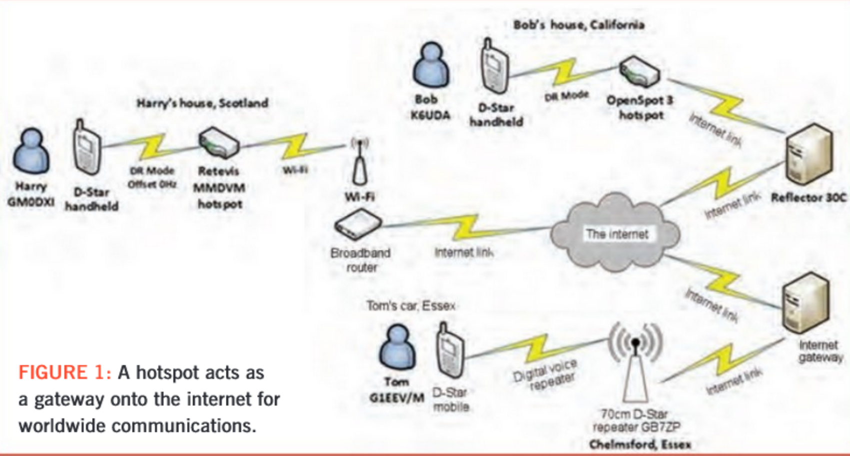

FIGURE 1: A hotspot acts as a gateway onto the internet for worldwide communications.

Glossary

BER	Bit Error Rate, used to indicate the how much data or bits are being lost
D-Star	Non-preparatory digital voice (DV) mode originally developed by the Japanese Amateur Radio League (JARL). Manufacturers presently supporting this mode include Icom and Kenwood
D-Star Plus	Enhanced features that have been added to the D-Star ecosystem since its inception such as using your D-Star radio in Terminal / Access Point mode to transmit data over the internet using a PC even when no D-Star repeater is available
DR	Digital Repeater
D-RATS	Open Source software available to download to your PC so it acts as a terminal to allow data transmissions over D-Star
DV	Digital Voice
Gateway	A D-Star feature that enables users to connect from a local Gateway-equipped repeater to any other Gateway-equipped repeater worldwide
MMDVM	Multi-Mode Digital Voice Modem – the subject of this article
Reflector	D-Star term for a 'chatroom' or conference bridge that is hosted on the internet
Registration	The process of registering your details on a Gateway to allow D-Star operation
TCXO	Temperature compensated crystal oscillator

Tx power setting

The TH-D74E handheld has a useful Extra Low (EL) power setting of 50mW on transmit, ideal for use with a hotspot when you don't *want* your signal to go too far. If you are using a mobile transceiver in the shack, use the lowest possible transmit power setting so you don't overload the front end of the hotspot's receiver.

Things to avoid

There is good advice at [5] about setting up a new hotspot, particularly avoiding initial configuration on the busy international D-Star Reflectors such as REF001C or REF030C. This should avoid you causing any unintended interference to other users. I chose the local Scottish Nets Reflector REF006A since I live in Scotland. Selecting Echo (/E) mode in your transceiver (see Table 2) will also allow you to check that the linked Reflector is receiving your transmit audio from the hotspot.

Setting up the hotspot

Now let us move onto setting up the hotspot and getting to grips with programming the Pi-Star software. The first task is to plug in the hotspot (using mini USB port for power) using a spare USB port on your computer. I used a Windows 10 desktop PC, though a laptop or a Mac would work fine too. After a few minutes the hotspot will boot into what is called Access Point (AP) mode, signified by a solid green LED and a smaller red LED slowly blinking in the background.

As the R-Pi-Z W has no physical Ethernet port, the initial setup has to be done using a wireless (Wi-Fi) connection and you need to connect your PC to the temporary Wi-Fi

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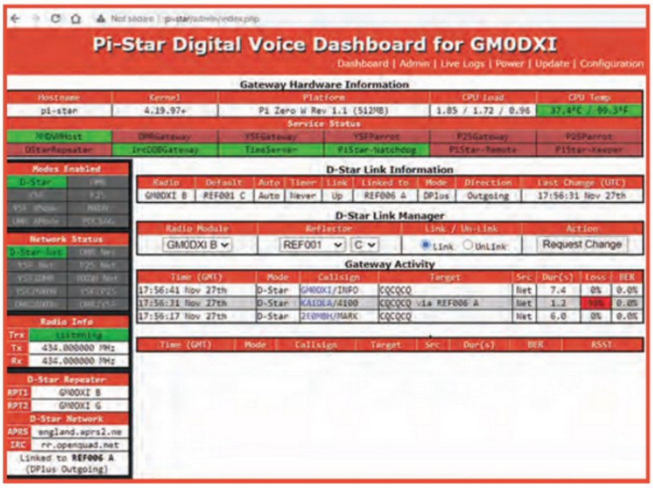


FIGURE 2: Unconfigured Pi-Star configuration screen, with default settings.

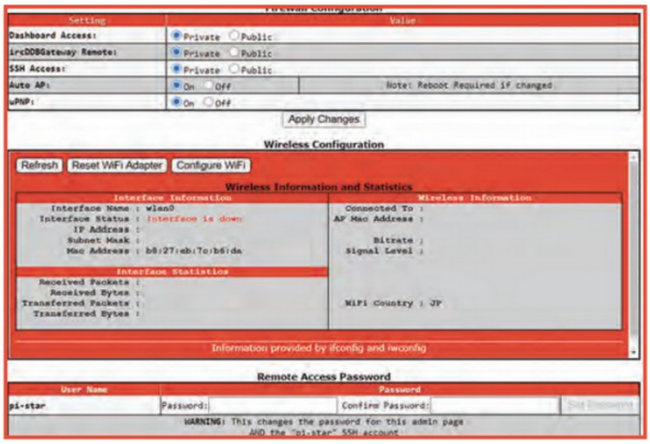


FIGURE 3: Wi-Fi Settings section – unconfigured state.

access point that the hotspot creates. Once the boot sequence is completed, left-click on the Wi-Fi Connection icon on the Task Bar of your PC and Connect to the Wi-Fi connection listed as 'Pi-Star-Setup'. The password to connect is 'raspberry', all in lowercase. Once the computer has connected to the hotspot in AP Mode the Pi-Star Configuration screen will be displayed, in its un-configured state, as shown in **Figure 2**.

The next step is to connect to your hotspot to your local Wi-Fi network so it can access the internet (and hence the D-Star network, Gateways and so on).

From the Configuration Screen, scroll down to the Wireless Information section, as shown in **Figure 3**. It will show the hotspot's MAC address and report, in red text, that the wlan0 interface (the interface that connects to your Wi-Fi) is down. Click on the Configure Wi-Fi button and enter the SSID of your router and its password.

TABLE 1: Memory channel settings (see text).

Field	Content	Comment
Memory channel	0000	Choose a spare channel in your memory list – I chose 0000
Receive frequency	434.0000MHz	The frequency you chose for the hotspot
Transmit frequency	434.0000MHz	Same as the Receive frequency
Offset frequency	0Hz	There is no offset, so 0Hz
Offset direction	Minus	Doesn't matter for 0Hz, can be plus or minus
Operating mode	DR	Digital Repeater mode
Name	Pi-Star	You can call it anything you like
Your callsign	GM0DXI	Your callsign, UPPER CASE (eg GM0DXI for me)
RPT1 callsign	GM0DXI B	Your callsign, in UPPER CASE, with the *eighth* character set to B (for module B on the hotspot, 70cm)
RPT2 callsign	GM0DXI G	Your callsign, in UPPER CASE, with the *eighth* character set to G (to set the hotspot as a Gateway)
Group	GRP-0	Just the group of memories on the D74 that I allocated to the hotspot
Comment		Optional, something meaningful to you, eg My D-Star Hotspot

TABLE 2: Specimen TH-D74E digital menu settings. Other radios will be comparable.

Menu no	Setting	My entry / settings	Comment
610	[my callsign]	GM0DXI /D74	Enter your callsign in UPPER CASE. Text after the / is optional but on transmit will be displayed to all parties (and on the Pi-Star dashboard).Many people put their name, or maybe (as here) their radio type.
611	Tx Message 1	Harry QTH Scotland	Optional text message to enrich your location info; will be displayed to all parties on Tx.
612	Direct reply	On	Optional setting that allows you to reply to a received call to your callsign directly via DR or DV modes using the PTT button on your radio.
1	Destination select individual	CQCQCQ	Allow specific actions on the 'To' destination. CQCQ is a general call on D-Star. Follow with /U unlinks the linked Reflector on transmit; follow with /I (capital i) plays back the information of the destination on your radio on transmit; follow with /E to perform an Echo test on transmit to the currently linked reflector – you'll hear your own transmission played back to you: useful to test if your setup is working OK.
1	Reflector	Use Reflector	Set this to ensure the radio uses the Reflector set on the hotspot.
2	Route Select	Over Gateway	Set this to ensure your transmissions route out to the internet via the Gateway that has been programmed into the hotspot (GM0DXI /G in my case).
3	Repeater Info	Repeater info R1	Information displayed on the TH-D74E radio confirms that the current repeater selected is my hotspot (ie RPT1=GM0DXI /B).
4	TXCS	UR TX settings	Information displayed on the TH-D74E radio confirms the current repeater settings. UR:CQCQVQ – general voice call traffic; R2:GM0DXI G – RPT2 as Module G, acts as a Gateway; R1:GM0DXI B – RPT2 as Module B selected for 70cm transmit; MY:GM0DXI – my callsign, sent on transmit.
5	DV <=> DR	DR	DR – hotspot is treated as a local repeater as far as the TH-D74E radio is concerned.
6	Voice <=> Data	Voice	Voice – I'm using voice on the D-Star Network (it is possible to use data with open source software such as D-RATS but that's outside the scope of this article).

Reboot the hotspot by disconnecting the power and reconnecting it. To check the Wi-Fi configuration worked, open a new browser window on your PC and enter the hotspot's configuration URL, which is http://pi-star/admin/configure.php (I recommend saving this as a favourite in your browser to make it easier to return to the Dashboard on subsequent occasions). Assuming the setting-up was successful, you'll see your Wi-Fi settings info in the Wireless Configuration section.

The next recommended step is to let the hotspot check it has the latest version of the software (and update itself if necessary). From the main Menu Page, select the Update option. Once the check (and any update) completes the hotspot will restart and refresh the Configuration page.

The remainder of setting up the Pi-Star software is via the Configuration Menu. Make the required changes to each section, one section, at a time then use the Apply button within each section to save the changes. **Table 3** summarises the settings I used.

Receive offset frequency

As well as checking the basic settings on your radio (as discussed earlier) there is another reason why the hotspot might not be unable to hear the transmissions from your radio: a (possibly small) mismatch between the receive frequency on the hotspot and the transmit frequency from your radio. This might also be manifested as a high bit error rate (BER) that is displayed on the Pi-Star Dashboard when you transmit. The BER figure will be highlighted as a red text box on the Pi-Star Dashboard. Should this be the case then setting an initial RX offset frequency on the hotspot might well cure the issue. To do this, select the Expert Menu and MMDVM Host Sub Menu off the main configuration page to add an offset Rx frequency. I would recommend 500Hz is initially chosen as a first try for the Rx offset. Finer adjustments can then be made if needed. In my own case the hotspot appeared to be bang on frequency, so I did not need to make any Rx offset adjustments, which is ideal (so the Rx Offset Setting was left as 0).

In operation

Once I had confirmed that my audio was being received across the network (using the /E setting as discussed earlier), I initially connected to the Scottish Nets Reflector REF006A and put out a general call. Greenock-based Barry, MM6BFH came back to me and we had a great chat about this Reflector and some of the nets that are held on Friday nights. This was the first of many D-Star chats I've had via my hotspot.

Summing up

The Retevis MMDVM is a great entry into the world of hotspots especially if your access to local repeaters is limited. Yes, there will be an initial investment in time for programming up the Pi-Star software and setting up a repeater channel on your transceiver. In terms of financial cost, the Retevis board is something like US$180 plus shipping and taxes. A cheaper alternative may be to use a different MMDVM board with your own Raspberry Pi W – I've seen basic kits with cases from about £30 on eBay, with complete, assembled units starting around the £80 mark. These use the same software so everything I've said about configuring the Retevis unit will apply to these others.

Websearch

[1] https://www.retevis.com/mmdvm-hotspot-wifi-digital-voice-modem/
[2] https://www.pistar.uk/
[3] https://www.pistar.uk/downloads/
[4] https://www.balena.io/etcher/
[5] http://www.dstarinfo.com/
[6] https://icomuk.co.uk/What-is-D-STAR
[7] https://regist.dstargateway.org/Dstar.do
[8] https://regist.dstargateway.org/regcheck/index.php
[9] https://rsgb.org/main/operating/band-plans/
[10] https://www.bi7jta.org/wiki/index.php?title=Main_Page
[11] https://www.youtube.com/channel/UC3E7YxNtplFvqTIR962U7Tw

TABLE 3: Summary of Pi-Star configuration screen settings.

Config screen section	Setting	Comments/info
Gateway Hardware Info		No settings in this section; it's just general information about the Pi-Star hardware & software
Control Software	Controller Software	Select MMDVMHost (DV Mega minimum firmware 3.07 required)
	Controller Mode	Select option 'Simplex mode'
MMDVMHost Configuration	D-Star mode	Select option 'D-Star', leave the Hangtime settings for RF and Net at 20, keep all other DV modes such as DMR Mode unselected
	MMDVM Display Type	Select OLED Type 3
	Port	Leave as None
	Nextion Layout	Leave as G4KLX
General Configuration	Hostname	I left this setting as "pi-star" though you could call yours anything meaningful
	Node Callsign	Enter your own callsign
	Radio Frequency	I chose 434.000.000MHz (see text)
	Latitude, Longitude	Enter your latitude and longitude (in degrees)
	Town, Country	Enter your location info
	URL	Any URL you want – I put in my QRZ.com page
	Radio/Modem type	From the pull-down menu, select STM32-DVM / MMDVM_HS-Raspberry Pi Hat (GPIO)
	Node type	Select 'Private'
	APRS Host	Leave as 'england.aprs2.net'
	System Time Zone	Leave as 'Europe / London'
	Dashboard language	Leave as 'english_UK'
D-Star Configuration	RPT1 Callsign	Enter your own callsign (in UPPER CASE) with 'B' form the pull-down menu as module B (70cm)
	RPT2 Callsign	Enter your own callsign (in UPPER CASE) with 'G' form the pull-down menu as model G (Gateway)
	Remote Password	Leave as-is
	Default Reflector	Choose as default Reflector for when the hotspot boots up. Your choice.
	ircDDBGateway Language	Leave as 'English_(UK)'
	Time Announcements	I set mine to 'on' so the hotspot transmits the time every hour
	Use D-Plus for XRF	Leave as 'D-Plus'
Mobile GPS Configuration		I did not touch any settings here as the hotspot is being used only at home, ie not mobile
Firewall Configuration		Put all 'Access' settings as 'Private' as it's your own private hotspot
Wireless Configuration		These were done during the initial setup
Remote Access Password		I left these as the defaults; if you change them then do make sure you note them somewhere.

'Oscar': a broadband regenerative preselector, part 1

Introduction

The preselector you see in **Photo 1** is actually the latest of a series of circuits I've been working on for several years. This all started when I fell in love with an old Hammarlund SP-600JX about 50 years ago, but it belonged to another fellow; I had to wait some 20 years before I could afford to buy one. Buying led to restoring and *that* led to a whole family of radios of the sort we often affectionately call 'boat anchors'. They may not have all the pizzazz of newer units, but they still have plenty of magic and charm. So I figured I'd build a 'boat anchor buddy', a specialised unit made up of a collection of circuits that might help them out a bit in one way or another. Other folks have done similar things, but I just wanted to put my own mark on the designs, borrowing from others where I needed to. I've been doing this for a while now and this is just the latest upgrade to one of my designs. It is affectionately named after one of our cats, Oscar. It's offered here as my latest (but not last) preselector design iteration, hoping that others will also tinker with the design as well. And although the unit described here is meant to cover a lot of HF real estate – about 3 to 33MHz – it's really even better when devoted to a single band, where things can be tweaked to perfection over a narrower frequency range. Add to that is the simplicity and flexibility of the overall design, something I'll get into a bit further along.

PHOTO 1: The front of the completed 'Oscar' preselector.

The preselector network

Figure 1a shows a simplified schematic of the basic input-output network for this design. If you consider just L1, L2, and C1 you're looking at a basic 3-element matching network. As you may be aware, all 3-element networks like this are actually two L-networks in series. And that's true here too. But where our typical capacitor input Pi-networks are two low-pass L-networks and the capacitor input T-network is two high-pass L-networks, you can see in **Figure 1b** that here we have one high-pass network in series with a one low-pass network. That makes it a bandpass network, and I use two of them back-to-back. The only real design constraint for the circuit in Figure 1b is that the input impedance must be lower than the output impedance. So when I design my preselectors I run them with a rather high 'virtual' impedance at C1. And since it can literally be any arbitrary value I choose, I can make it high enough to give me any design Q I need – all while keeping to an overall 50Ω in-and-out configuration.

The simple maths that drives the design is shown in **Figure 2**. The equations can be found in several places, and I use what's in my *ARRL Handbook* in the chapter on RF Techniques and tabulated as 'Type 3' in their table of matching networks **[1]**. Once I decide on an initial design point (frequency, RL and Q) I build up a small table of inductance and capacitance values required in a spreadsheet program like Excel and then test the tunability of my choices from the table in James Tonne's enormously useful (and free) program ELSIE **[2]**. Generally, for a specific frequency range I tend to choose starting component values from the lower end of the tabulated range. I like to tweak the values to keep the bandwidth as small as practical over the tuning range I want. (I should add that this might at first seem to be ill-advised, but I have found that, as

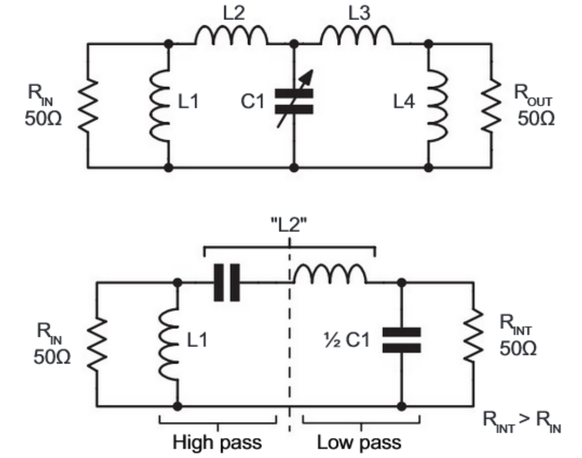


FIGURE 1: Top: a) the basic double-ended bandpass networks; bottom: b) how this type of network evolved.

I tune C1 in ELSIE I'm really also varying the 'effective' values of Q and the assumed RL impedance at C1. The results I experience in practice indicate that the inductors and capacitors have never read a textbook and just adjust these values to keep me happy.) I generally design around a starting Q value of 20 or more, then

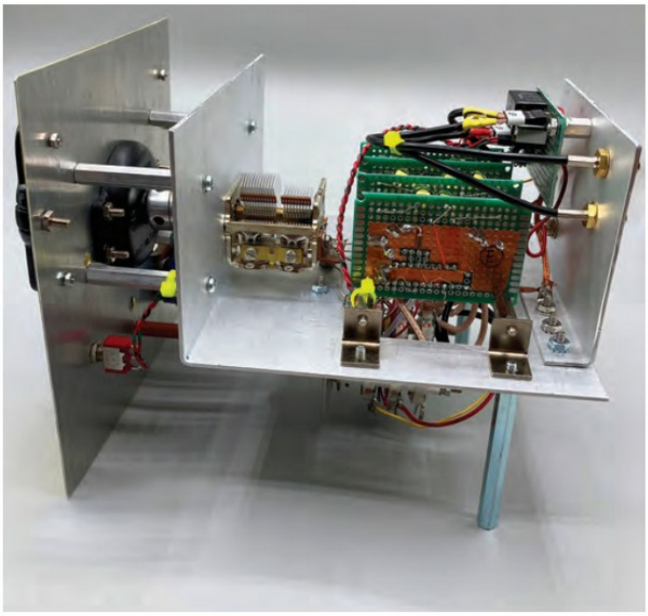


PHOTO 2: Side view of the preselector, showing the chassis and band-selecting modules, band selector switch (under the chassis) and the small auxiliary board that hold the relay and other components.

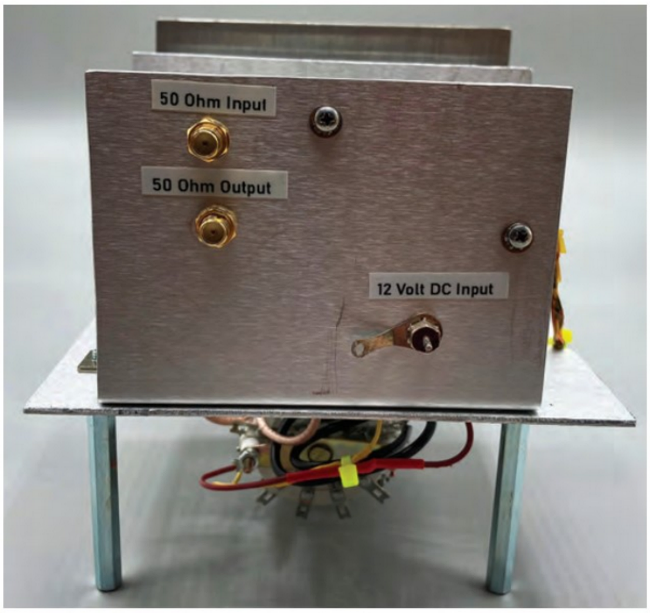
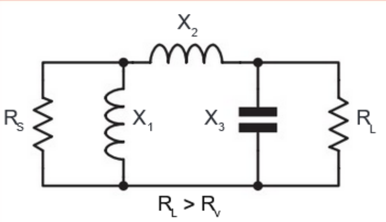


PHOTO 3: The rear panel of the unit. Input and Output are actually interchangeable, but I like to keep consistent labelling.



$$X_1 = \frac{R_S}{\sqrt{\frac{R_S}{R_L}(Q^2+1) - 1}}$$

$$X_2 = \frac{R_L Q}{(Q^2+1)}\left(1 - \frac{R_S}{X_1 Q}\right)$$

$$L = \frac{X_L}{2\pi f} \qquad C = \frac{1}{2\pi f X_c} \qquad X_3 = \frac{-R_L}{Q}$$

FIGURE 2: Basic equations to design a network as shown in Figure 1. Remember that C1 in Figure 1a is actually twice the value obtained when calculating X_3 here.

tweak away. For my purposes I like to have the preselectors to have -3dB bandwidths of less than 500kHz during the design phase. This is arbitrary, of course, but narrower bandwidths lead to higher predicted losses overall – and a highly attenuating preselector isn't very useful. I aim for ELSIE-reported losses in the 1-2dB range when I'm designing.

Adding regeneration

I have designed and built several incarnations of this design for my boat anchor receivers, trying to improve on things each time. One particularly useful iteration was developed for a more modern receiver design and is described on the informative blog site **[3]** of Dave Richards, AA7EE. In all of my previous designs I have followed the circuit of Figure 1b with an amplifier built from one or two MMICs, similar to what can be found on that blogsite. This works well, by the way, in case you're not ready to tackle a regenerative circuit. In fact, the final 'Boat Anchor Buddy' will have a switchable MMIC amplifier to help pull out weaker signals.

This time I decided not to go that route for a preselector. The current design is my response to the question that arose when I went back over the receiver design I described in that blogsite, looking for new ideas. The receiver there is often referred to as a 'WBR', but is best described as an infinite-impedance detector in tandem with a Q-multiplier **[4]**. I just wondered what I could do if I added a similar Q-multiplier to my preselector. Short answer: it worked!

Construction notes

The schematic for my current version of the preselector is shown in **Figure 3**. For simplicity I have shown only one of the regenerative stages (labelled 'Band-select module'); there's one for each band, since coupling, tuning and feedback components vary. For all it does, it is deceptively simple.

A few points about the design. First, if you're acquainted with regenerative designs, then you're also probably aware that they can be difficult to make operate reliably over a large frequency range. Not *impossible* – it has been done, to be sure – but a good design must have enough residual gain to oscillate when the regeneration voltage is increased, no matter the frequency. One secret weapon, for me at least, turned out to be the BC546CT transistor. This has unusually high gain (h_{FE} ~500) along with a high f_T (~300MHz), making it a good choice here. (I did experiment with a batch of 2N3904s, but even after sorting them by h_{FE} I couldn't get the bandwidth I wanted.) Also, the coupling capacitance and feedback capacitors turned out to be rather important to overall operation (gain and selectivity) as the width of the band increased. On the highest band I had to do a lot of experimentation to make it 'behave' from about 13.8MHz to 33MHz.

My unit uses small trimmer caps (denoted as C2 in Figure 3). These can help set regeneration sensitivity, but they're even more useful as a way to set the upper frequency limit of a particular band. If you don't have access to trimmers on the order or 50-75pF, I

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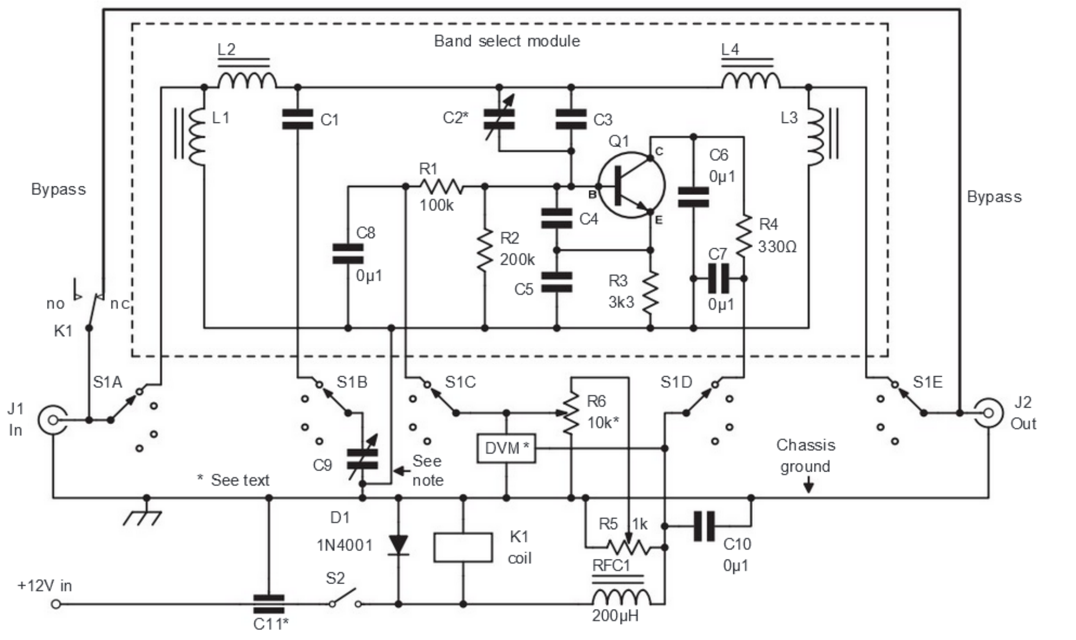

FIGURE 3: Complete schematic for the 'Oscar' preselector. Important note: all 'ground' wires connect together on the rear of C9.

find that a reasonable substitute is any small capacitor around 20-30pF. I should add that, as I've bought capacitors over the years for these units, I've found that the 5% tolerance C0G or NP0 capacitors – which have little temperature dependence and good tolerance – are very affordable.

Another thing I've learned about wide-bandwidth regenerative designs is that having a good regeneration pot is key to the operator's sanity. Trying to tweak a single-turn pot to find just the right spot can be frustrating, especially if the regeneration bias has to change considerably as frequency changes.

A few years ago I bought several 10kΩ 10-turn pots via eBay to use in my projects – and I use one here, although here a 1kΩ pot would work just as well, since the transistor bias current is so low. The less-expensive multi-turn pots (as you'll find on eBay and that I use) work OK here, but if you go that route do buy a few more than you need so that you have some spares; sometimes they're OK for this purpose but those on the budget market are often 'seconds' and some might not turn out to be useful. But in any case it is a very good thing to be able to 'creep up on' the oscillation threshold in a more controlled fashion and a 10-turn unit really helps.

You'll also notice a range-setting trimpot, R5, in Figure 3. In my design I set it to deliver a little over 6V to R6. This was to keep the useful range of that regeneration control as broad as possible. That means it maximises the number of turns required per volt of bias change to the transistor base.

I also often use a small 10-turn counting knob (sometimes sold with the 10-turn pots) in my designs so I can remember (or at least record) the regeneration bias settings for each band, though in truth my original design for one memorable regen had no such frills; I just backed off the pot to a low value and crept the voltage slowly up until I found the setting I wanted, judged by listening to the radio's output. Not elegant, but still entirely effective. In this case, however, I used a small LED voltmeter, just because I had a few sitting around in my shack.

Each band operates a bit differently, so making a little table of approximate pre-oscillation voltages makes things a bit easier.

The front panel seen in Photo 1 is a temporary one, by the way. I make these from thin sheet aluminium (0.025", 0.64mm, roughly 22SWG) and it later becomes the drilling template for the final unit installation. Also, looking at the frequency dial in the Photo 1, it might seem that I forgot a band. I didn't; one PCB turned out to be just redundant enough in frequency coverage to not be included here.

In the other photos you can see that I left room to add another band later on. In **Photo 2** (side view) you see the 'chassis' that holds the tuning capacitor and the band-specific PCBs. Beneath that chassis is the selector switch. The other controls attach to the front panel. At the upper right is the PCB containing the bypass relay and a few other items that steer the signals to the selector switch and the trimpot that provides stepped-down voltage for the regeneration control.

Photo 3 shows the back panel. I like to use SMA connectors (they save space) but really that choice is up to you, the builder. Add 12 volts DC and you're in business.

I might even make one last PCB for 160m, so I can pick up our local city emergency station at 1.68MHz.

Next month we'll conclude with the rest of the constructional information, a look at how to use the preselector, and its measured performance.

References

[1] Most recent editions of the *ARRL Handbook* have this information; I'm using the 2016 edition and it is on page 5.25 of Chapter 5, RF Techniques

[2] Elsie electrical filter design program: http://tonnesoftware.com/elsie.html – you don't need to purchase the key; the free version will take you rather far. For this circuit you'll need to do a manual parts entry.

[3] Guest Post – N6JJA's WBR-Oscar Regen Receiver – Dave Richards, AA7EE: https://aa7ee.wordpress.com/2018/12/13/guest-post-n6jjas-wbr-oscar-regen-receiver/

[4] Hayward, W; Campbell, R; and Larkin, B, *Experimental Methods in RF Design* (ARRL, 2005), Chapter 1, page 1-11

Review

The RF Explorer handheld spectrum analyser WSUB1G+

The RF Explorer handheld spectrum analyser with its good quality carry case.

Until recently, a spectrum analyser was a pretty expensive piece of equipment and it's probably fair to say that a majority of amateurs didn't have access to one in the shack.

Things have changed in recent times and there are a number of lower and medium cost options available that allow you to view the RF spectrum around you.

Why might you want one? You might like to look at the output of your transceiver and look at the level of various harmonics or other spurii. Similarly, if you are tuning an output stage, you can use the device to minimise spurious outputs. If you are suffering interference on a particular band, a handheld unit allows you to walk around and establish the source of interference. You could use one when viewing a potential operating site to see what other signals are present.

The RF Explorer WSUB1G+ SLIM is a handheld device that offers spectrum analyser features as well as a bit of new functionality called the 'Ham Field Meter' that was developed in response to the Ofcom EMF requirements announced earlier in the year. We'll come to what the unit can (or can't) do in that regard later on in this article.

Some of the highlights in the spec are:

- Frequency band: 0.05 – 960MHz
- High capacity internal Lithium battery for 20 hours+ of continuous run, rechargeable by USB
- Can be extended with internal Expansion Modules for additional band and functionality
- Graphics LCD 128x64 pixels, great visibility outdoors

- Internal lithium ion 1800mA/h rechargeable battery
- Pocket size and light-weight
- Solid metal case

First impressions

The unit comes nicely boxed and presented, which makes a good first impression. It has a solid and chunky feel to it. There's a simple keypad on the front of the set, a liquid crystal display, a USB connector on the side as well as an SMA connector for the input. Two aerials came with the WSUB1G+, a 'rubber duck' type antenna that is recommended for 400-900MHz and a telescopic antenna described as a 'wideband 144/433MHz'. Actually, the telescopic antenna looked like it might be quite good on a 2m/70cm antenna when you wanted a little more gain, but that's another story. A carrying case for the unit and all the accessories is provided, which is of good quality.

The WSUB1G+ has an internal battery charged by USB. Slightly curiously, I felt, when the USB cable is plugged in, the display lights up and you need to turn the unit on to allow charging to take place.

The range of 50kHz to 960MHz is a useful one, although in a perfect world, I'd have liked it to cover the 3rd harmonic of a 70cm transceiver.

Getting started

There's no instruction book included with the unit, but a Quick Start guide points you, by URL or QR code, at https://www.rf-explorer.com/start. This is a good reference point to getting started. I chose to update the firmware on the device to the latest level before doing anything else. There are firmware uploaders for Windows, Mac OS and Linux. There's a slight caveat for Mac OS in that there are issues with Catalina and above. I got around this by using a Windows virtual machine on my Mac. Since then, RF Explorer has produced its own virtual machine that you can download and run, which gives you all the tools, including Firmware Updaters and Spectrum Analyser software all ready to go.

Updating the firmware was relatively simple. You'll need the serial number of the device and the software goes off and registers it to your email address, which you have to confirm. It's a bit long winded but it worked just fine. Once that's done, you can download the latest firmware onto the unit, hold your breath as it reboots and hopefully comes up again! I experienced no problems and the process was very smooth. There are videos available on the RF Explorer site to guide you through the process that you may find reassuring and helpful.

If you've purchased the 'Ham Field Meter' expansion, you'll need to enable this. You will have been provided with a software key, a series of letters and numbers, which will be shown on your invoice. You'll need to plug this into the setup routines to enable the functionality on the unit. Once again, this will be registered to your email address, which you need to confirm. It is a little long-winded and if I'm honest, slightly tiresome, but it did work just fine. Once this is applied, the unit can be restarted and you'll see 'Ham Field Meter' on the menu and you'll be able to select it, change bands and so on. We'll look at that in a moment.

Cautionary words!

Reading through the introduction on the Setup web page, the reader is cautioned that the unit is very sensitive and not to place it too close to strong RF fields. I was faintly alarmed by this, as one of the things that I'd planned to do was to use the unit with a handheld transceiver close by to look at the outputs as well as the RF field strength. I phoned Gary Spiers at Martin Lynch & Sons and asked him if I was going to run the risk of blowing the unit up if I did! Gary and I discussed this and decided that we should try it and fortunately, all was well. If you are going to do a direct connection to the unit, rather than an aerial, you should definitely be cautious. The WSUB1G+ does have a built-in attenuator that you may even choose to use when you are using one of the reference aerials, if you are very close to your RF source and you expect the signal strength to be very high.

Using the Spectrum Analyser

The menu system on the WSUB1G+ is reasonably intuitive, although it took me a little while to get used to it. I set up the Spectrum Analyser to operate between 144 and 146MHz, with a centre on 145MHz and popped the 2m/70cm telescopic aerial onto the input socket and set it running, sat on the desk.

A quick flick on the 2m FM handheld showed a good strong signal. The frequency displayed was a little bit out, showing 145.513MHz (when I keyed up on 145.525MHz). What did impress me though, was the sensitivity of the unit. I soon realised I could see an occasional peak on the display a little way below 145MHz. A quick bit of investigation revealed that this was the APRS digipeater on Mount Leinster in Ireland, some 85 miles away. There is nothing much in the way between me and Mount Leinster and perhaps conditions were above average, but I was still more than happy with that.

The LC display on the unit is quite easy to read, but Gary had recommended that I try the PC-based Spectrum Analyser software. As I use OS X Big Sur, I needed to use the software via the Virtual Machine provided by RF Explorer. This turns out to be very straightforward once installed and I was soon able to see the spectrum displayed on my computer screen. If you're using Windows or Linux, you should be able to install the RF Explorer software directly onto your machine.

The software is fairly well featured, so that you can save data, you can set markers and choose display modes of Real Time, Average, Max Peak, Max Hold and Minimum.

I was impressed that the software was able to record the data you received and play it back, as well as pausing to allow you to investigate momentary signals that you might have otherwise missed.

If there was a way to click on the display and have it display the frequency and level you'd clicked on, I couldn't find it, which I

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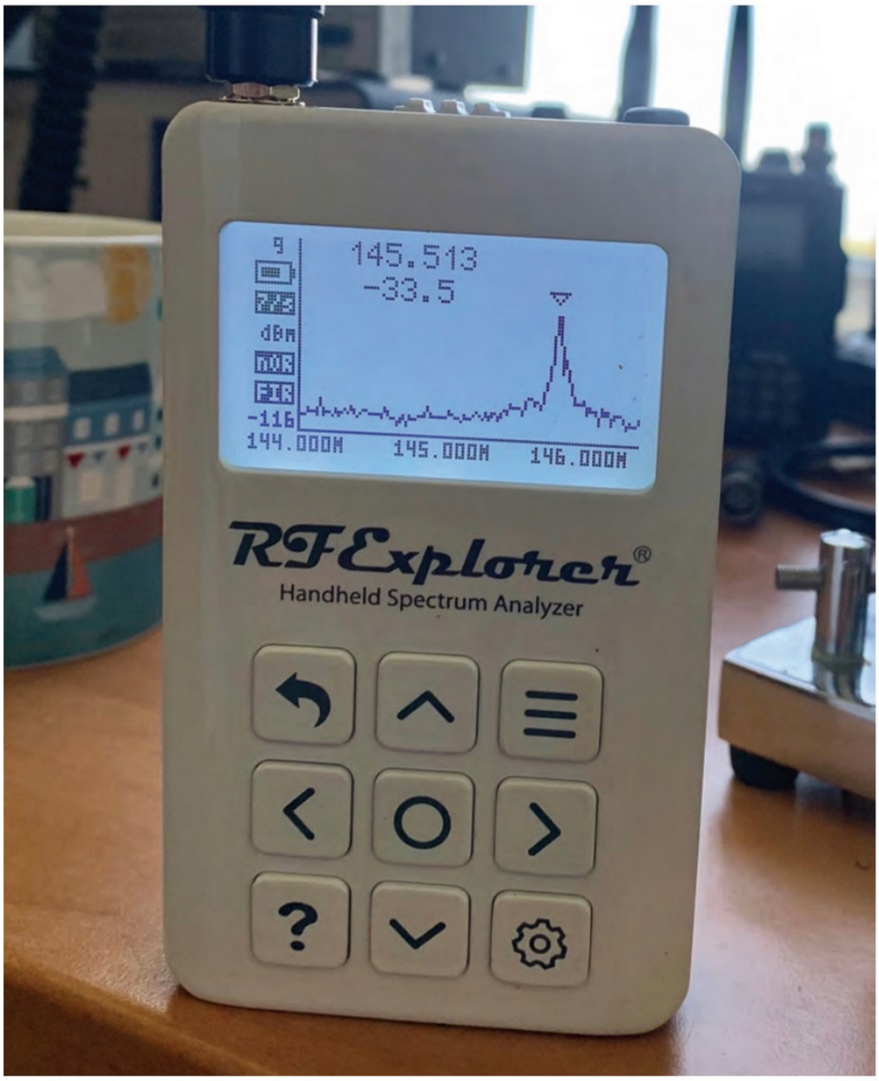

I set up the Spectrum Analyser to operate between 144 and 146MHz, with a centre on 145MHz.

thought was a little disappointing as this can be very useful.

There's the capability to save 'Presets' that is as you might expect, a configuration that you might save for a particular band or range, meaning you can just load up the preset rather than having to set the individual parameters each time you use the WSUB1G+. On the Virtual Machine, there's a Preset Manager which allows you to manipulate these as well as loading and saving to files.

That's a flavour of the spectrum analyser functionality.

What about the Ham Field Meter?

Perhaps the most important thing that I can say to start with, with all the focus on the new Ofcom EMF licence clauses is that Ofcom will not be interested in the readings from the Ham Field Meter. If you need to have a discussion with an Ofcom field officer about EMF exposure, the only they that they will be interested in will be the output from the Ofcom EMF Calculator spreadsheet. Please do not think that using the Ham Field Meter functionality on the WSUB1G+ is any sort of short cut to proving compliance with the requirements as it's not.

That's not to say, however, that the Ham Field Meter functionality is not interesting or useful. It's all very straightforward. Once in this mode, you can switch between the different amateur bands using the left and right keys on the WSUB1G+ and it will display an RF power reading for the band you are in, in nW/m^2.

It's important to realise, that this figure is relatively meaningless. However, as long as you take your measurements using the same antenna on the WSUB1G+ in the same place, then the figure is relative. For example, if using one roof antenna on 2m with a power of 25W output and you see a value of 20nW/m^2 in the shack, if you then change the antenna on the roof (in the same place) and take another reading, using the same output power you now see a value of 35nW/m^2 in the shack, that is an indication that something has changed and you should revisit your Ofcom spreadsheet for 2m and take account of the new antenna.

So, what the Ham Field Meter readings are giving you is a relative, rather than an absolute figure. I was interested to see what readings I might get from being close to a handheld (as you would, in day-to-day use) compared to higher power through the aerial on the roof.

Using a 70cm handheld at 5W through the 'rubber duck' aerial, I got a reading of 11nW/m^2 whereas, running 50W to an aerial on the roof gave a reading of 8nW/m^2.

With the 'aerial on the roof' scenario, you could take readings in different parts of the house, or by the boundary of your property, to see how these change with distance from the aerial. It can be interesting to see.

Although a bit of a 'blunt instrument', you could probably use the Ham Field Meter to visualise the pattern of a Yagi antenna. At a distance of a few metres from the antenna, take a reading in front of the antenna, one to the back and then off the side, all the same distance away from the antenna. What do you see? Is it what you expected?

If you are designing Yagis, then this isn't going to help much, but if you are teaching students (or yourself) about radiation patterns of beam aerials, it might be helpful. Again, at the same distance from the antenna, what happens if you add some more directors? What's the reading then? This sounds fun!

Overall

Having spectrum analyser functionality available can be really useful as I indicated earlier on. There are different ways of doing it, depending on how much you want to spend. The WSUB1G+ is what I'd term 'medium cost'. It's a highly portable unit, but you can also connect it up to a computer and get a larger display and a few more features. If you don't have a spectrum analyser available, this could be a good place to start, particularly if you don't need to look at frequencies higher than 960MHz.

The Ham Field Meter functionality, although, as discussed, not a way of proving your compliance with the Ofcom EMF clauses, can be an interesting and fun way of visualising the strength of RF fields.

Particular thanks to Gary Spiers at Martin Lynch & Sons for his support and advice during the review period. The WSUB1G+ costs £179.95 including VAT for the basic model and £219.95 with the Ham Field meter extension pack.

Are Aerials Imaginary?

Mysterious j numbers explained

Your radio is useless without an aerial. You know that the aerial is real, as are the QSOs you have with it, yet try to calculate what's happening and you hit a snag.

What good is maths?

Some people enjoy mathematics as an interest in its own right. As for the rest of us, it's just another tool of the engineer's trade. Maths can model real world phenomena and hence enable us to predict and even control what goes on.

If you'd care to examine a teacup, you'll observe that the rim is a circle. You'll accept that a tape measure thrown round the rim would yield the circumference and a ruler across the mouth of the cup could measure the diameter. Then, the ratio of the circumference to the diameter could be calculated by dividing the former by the latter.

Except you can't, not in our limited numbering system. This ratio is the same for every circle but you can't write it down precisely. This number has to be given its own name, pi (from the Greek alphabet, π). The cup's real, so's the tea, but the calculation hits a snag.

Calculations and electronic components

We need to know what's going on in electronic equipment: there's no place for guesswork in designs. Maths should do this for us.

Take a simple resistor. Putting a voltage across it forces a current through it. Again there's a ratio: voltage divided by current gives the value of resistance – and this is Ohm's Law, which appears in the Foundation course. No snags here, the maths is spot-on.

But try this with a capacitor or inductor and it doesn't work. The measured resistance of these components varies with frequency (and is actually called reactance). Even applying a simple battery causes a varying current, for example as a capacitor charges up. Hence the voltage or current change over time. The maths to model this gets complicated and we end up needing something that, like pi, doesn't exist in our limited numbering system. The capacitor or inductor is real, as is the current flowing, but the calculation hits a snag. We need the square root of negative numbers.

What's the square root of negative 1, then? It's the number that, when multiplied by itself, gives -1. Trying 1 squared (1 times 1) gives positive one. Then trying -1 squared (-1 times -1) also gives positive one. You can't do it. We have to imagine we've done it and give the square root of -1 its own symbol which is *i* (because it's imaginary) – not a Greek letter this time. Only it's confusing, because we're radio (not maths) amateurs and, to us, I stands for current. So *we* change *i* into *j* to avoid confusion.

Imaginary happenings in aerials

From the radio signal's point of view, an aerial looks just like a collection of familiar components. Depending on frequency, it presents a combination of various amounts of resistance, capacitance and inductance.

To maximise the amount of our hard-won radio energy that gets into the aerial from the transmitter, the aerial has to match what the transmitter's output is expecting (for typical modern rigs that's 50Ω pure resistance). Anything else is a 'mismatch' and wastes power, manifested as a high reading on an SWR (standing wave ratio) meter. In particular, common aerials for below 30MHz only offer this 50Ω perfection at one fundamental frequency, so an aerial matching ('tuning') unit is needed to keep the SWR down.

What if it *won't* match? Knowing if the aerial has too much inductance (is too long) or capacitance (too short) assists attempts at matching or even re-design. These days, aerial (vector network) analysers and numerical method modelling software are all readily available to the hobbyist – as long as we understand why they give answers containing *j*. Also, there's no need to be frightened by the Smith chart because it's just a graphical representation that includes the real and *j* parts of impedances.

Mix and (mis)match

In a shop, the bill for buying two sticks of chalk and one piece of cheese does not say "Three items @ £1 each = £3 total". Instead, the same bill itemises the purchase as "2 chalks @ 75p and 1 cheese @ £1.50". Chalk and cheese can't be mixed but they can appear together in the final calculation, each in their own right. Likewise for resistance and reactance. At a given frequency, the measured resistance of an aerial is actually called 'impedance', which is composed of pure resistance and reactance. Resistance is just a number of ohms, but reactance is a *j* quantity (positive if inductive, negative if capacitive) and *also* measured in ohms.

Aerial example

Perhaps an aerial analyser shows a result of 50 + *j*80 at 3.5MHz. The simple resistance number and the imaginary *j* number have to be shown separately and, just like chalk and cheese, can't be mixed together. This aerial has inductive reactance – it's too long. It could be redesigned by shortening. Alternatively, we now know to introduce capacitance to achieve a match. Keeping the *j* numbers together, they can be combined amongst themselves (but not with the resistance). If we can adjust an aerial matching unit to give the amount of capacitance that achieves a reactance of -*j*80 then this will solve the problem because

$50 + j80 + (-j80)$

$= 50 + (j80 - j80)$

$= 50$

which signifies the pure resistance your transmitter is designed for. See how the resistance term stays in one place, then the *j* reactance values are combined in another place, keeping themselves to themselves and never getting mixed up.

I've talked of aerials because that's where we as radio enthusiasts are most likely to encounter impedances made of real (resistive) and imaginary (reactive) parts, but this applies to any reactive elements such as a tuned circuit.

Godfrey Manning
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Surrey Radio Contact Club
John, G3MCX, 020 8688 3322
1, 8, 15, 22, 29 Net 144.6125MHz D-Star 7.30pm. Net 145.35MHz FM 8pm
3, 10, 17, 24, 31 Net 1905kHz LSB 9.30am
4 Construction Contest, Trinity School, 8pm
5, 12, 19, 26 Net 51.55MHz FM 8pm
6, 13, 20, 27 Net 28.078MHz JS8 10am
7, 14, 21, 28 Net 70.30MHz FM 8pm
18 Chat, Fix-it and Skills, John, G8MNY

REGION 11: SOUTH WEST & CHANNEL ISLES

RR: Dean Brice, G0UIL, RR11@rsgb.org.uk

Cornish Radio Amateur Club
Steve, G7VOH, 01209 844 939
1, 8, 15, 22, 29 Net 145.350MHz at 8pm
5, 12, 19, 26 Net 70.425MHz at 8pm
7, 14, 21, 28 Net 29.150MHz at 8pm

Gordano Amateur Radio Group
Malcolm, G4KPM, 07971 431125
27 Meet at 8pm The Ship BS20 8JT

Guernsey ARS
Tom, 2U0TKB, 0778 140 5083
1, 8, 15, 22, 29 Meeting, the Bunker, Beau Sejour Leisure Centre from 7.30pm.
5, 12, 19, 26 Net from 8pm on 145.525MHz
7, 14, 21, 28 DMR net on GB7GY on Talk Group 23515, time slot 1, from 8pm local time. All welcome

Isle of Avalon ARC
Matt, 2E0FNT, 0730 554 9614
1, 8, 15, 22, 29 Club meetings at Site 2, Common Moor Drove, Glastonbury BA6 9AF 7.30pm
5, 6, 12, 13, 19, 20, 26, 27 Net 145.475MHz 9pm
7, 14, 21, 28 Zoom meeting 8.30pm (see club website for details)

Newquay & District ARS
www.newquayradioclub.co.uk
13 New premises, Trevisker St Eval Community Centre, PL27 7TU at 7pm

Riviera ARC
rivieraarc@gmail.com
3, 10, 17, 24, 31 Net 8-9pm on GB7TQ
6, 13, 20, 27 Net 8-9pm on 145.425MHz
7, 21 Face to face meeting at the Precinct Community Centre, St Marychurch 7pm

Weston Super Mare RS
Barry, M0JOG, 0750 066 8674
4, 11, 18, 25 Club meeting 7.30
7, 13, 21, 28 club net GB3WB from 8pm

REGION 12: EAST & EAST ANGLIA

RR: David De La Haye, M0MBD, RR12@rsgb.org.uk

Bishop's Stortford ARS
www.bsars.org
6, 13, 20, 27 Net from 8pm on 145.5625MHz FM

Chelmsford ARS
Colin, G0TRM, secretary@g0mwt.org.uk
3, 10, 17, 24, 31 144.060MHz CW net 8pm
4, 11, 18, 25 On air Morse training. 7.30pm 3542kHz CW. 8.15pm 3555kHz GB2CW slow Morse transmission. 8.30pm QRS for the new operator
5 Zoom evening, CARS AGM 7.30pm
7, 14, 21, 28 On air Morse training. 7pm Skype CW classes. Join the conversation
12 Club open net, 8pm, GB3DA
19 Club OPEN NET, 8pm, GB3ER
26 Club open net, 8pm, 3756kHz

Essex Ham
Pete, M0PSX, news@essexham.co.uk
2 Essex YL net on GB3DA, 8pm
3 Start of Foundation Online Course – enrol free at hamtrain.co.uk
4, 11, 18, 25 Net on GB3DA, 8pm, with chatroom and audio feed at www.essexham.net
16 Essex CW ARC committee operating their Annual CW Boot Camp

Harlow & District ARS
Gary, secretary@g6ut.com
1, 8, 15, 22, 29 Club meeting 8pm

South Essex ARS
Terry, G1FBW, 0798 607 0040
Net Monday-Friday hosted by Brian, G7IIO at 3.30pm on 145.325MHz FM 3
12 Club night talk about Radio broadcast and a tour of Ofcom, Baldock by Pete, M0PZT
26 Net on GB3DA at 8pm.

Thames ARG
Mark, M0IEO, TargRadio@outlook.com
1 Power Supplies, John M0LFX
8, 15, 22, 29 net via GB3DA from 8pm

Thurrock Acorns ARC
Iain, G4JMM, acorns@taarc.co.uk
1, 8, 15, 22, 29 Net, starting at 7pm on 145.500MHz FM
5 SSTV net from 7.30pm on 144.500MHz
26 Net, starting at 7.30pm on 144.300MHz SSB
28 Zoom talk on digital voice modes, 7.30pm

Next deadline
22 September (November issue)
send your copy to radcom@rsgb.org.uk

REGION 13: EAST MIDLANDS

RR: Mark Burrows, 2E0SBM, RR13@rsgb.org.uk

Bolsover ARS
Alvey, G4KSY, 01246 827135
6, 20 Club meeting at 8pm Bainbridge Hall
14, 21 Zoom meeting from 7pm

Kettering & District ARS
Les, 2E0MNZ, les@moylehousehold.co.uk
3, 10, 17, 24, 31 Breakfast meeting from 10am to 12 noon
5, 12, 19, 26 Meeting from 7pm to 9pm
7, 14, 21, 28 Club net from 7pm on 145.300MHz

Lincoln Short-Wave Club
Pam, G4STO, 01427 788 356
2 SES Sturton and Stow Village Show, Sturton 1.30 - 4.30pm
6, 13, 20, 27 Club meeting in the BSA village hall 7.30pm
7, 21 Net GB3LM 8pm
9 Surplus Equipment Sale - booking in of equipment from 12 noon
14, 28 Net on 145.375MHz from 8pm
16, 23, 30 Shack maintenance from 10am
18 Committee meeting 7.30pm

Nunsfield House ARG
Paul, G1SGZ, pr@nharg.org.uk
1, 8, 15, 22, 29 Club meeting, 8pm
4, 11, 18, 25 Net, 9.30am, 3745kHz. Shack night and club net from 8pm on 433.450MHz
7, 14, 21, 28 Net from 8pm on 145.325MHz

RAF Waddington ARC
Bob, G3VCA, 0797 116 6250
1, 8, 15, 22, 29 Club meeting at the Pyewipe, at 7.30pm
4, 11, 18, 25 Net on 145.325MHz at 7.30pm, all welcome

South Kesteven ARS
Stewart, M0SDM, 07944085113
1, 15 Club night 8pm
8, 22, 29 Net via GB3GR at 8pm, all welcome to join in.

South Normanton Alfreton & District ARC
Alan, M0OLT, secretary @snadarc.com
Watch Facebook for field days.
4, 11, 18, 25 Meeting from 7.30pm
5, 12, 19, 26 Club net 7pm 145.450MHz±

Welland Valley ARS
Peter, G4XEX, 01858 432 105
4 Table top sale/Open evening
18 Club on air night 145.275MHz FM

SDR Transceiver *continued from page 30*

For 4m, 2m and 70cm I use '100W' amp kits based on the MRF186 and MRF9180, available via eBay. They are more difficult to construct than their HF counterparts but do include SWR couplers and quite effective 7-pole low-pass filters on the boards. Once constructed, the amplifiers sit nicely within old linear amplifier cases sourced from a rally, to which I fit 50mm or 60mm fans to aid dissipation. The 70cm version is shown in **Photo 8**. 4m requires some modification to the 80-170MHz circuit, adding negative feedback across the MRF186 and re-designing the low pass filter.

23cm is more difficult as there are no kits commonly available so I made my own, still using the MRF186, based on a design by K5TRA **[5]**. This produces up to 30W after its comb line (band pass) filter. For 13cm I use a Spectrain amplifier from a job-lot kindly organised by G7LRQ, set up according to F5DQK/F6AJW's info (in French) at **[6]**.

Finally, for 9cm I have a Stealth model SM3437-43 20W amplifier, which can be driven to full power from a small Chinese 6GHz amp after the Hack-RF One. So, all bands from 1.8MHz to 3.4GHz covered by one homebrew SDR transceiver.

Websearch

[2] https://yo5pbg.wordpress.com/2019/10/28/the-ultrawideband-1-1000mhz-nwdz-rf-pa-2-0-initial-tests-and-improvements/
[3] http://avcomm.eu or http://www.zen112890.zen.co.uk/g3wjg/menu.html
[4] https://rf-tools.com/lc-filter/
[5] https://tinyurl.com/v7wz27n3
[6] https://tinyurl.com/fxkddrw