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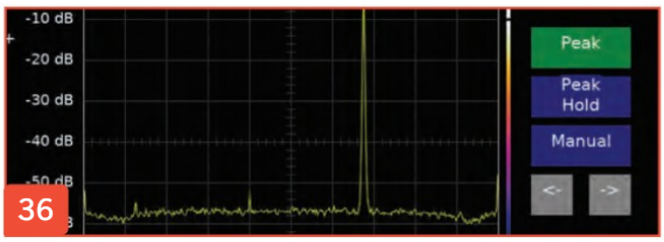

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Raspberry Pi-based home-built radio test equipment
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Managing Editor: Edward O'Neill, M0TZX, edward.oneill@rsgb.org.uk
Technical Editor: Peter Duffett-Smith, GM3XJE
Layout and Design: Kevin Williams, M6CYB, kevin.williams@rsgb.org.uk

All contributions and correspondence concerning *RadCom* should be emailed to: radcom@rsgb.org.uk. Alternatively by post to *RadCom* Editor, 3 Abbey Court, Fraser Road, Priory Business Park, Bedford MK44 3WH Phone 01234 832 700.

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Abbreviations and acronyms we use are listed at http://tinyurl.com/RC-acronyms

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New Products

Antenna Genius Antenna Switch 8:1

The Antenna Genius is an antenna switch that can switch one input to eight antennas.

Right from the beginning of the development, attention was paid to being able to operate this switch directly from a distance via an Ethernet interface. Another point was the requirement that all Genius devices such as the interface, antenna switch, rotor controller and station controller are compatible with each other.

Each Genius device has an interface (API) to work with different devices and software (eg log software, contest software and digital modes).

Antenna Genius control is officially supported by the N4PY software. Communication is via a TCP/IP connection. For more information, please consult the N4PY help files.

Available from hamradio.co.uk for £725.99.

mAT-S1500 SWR and power meter

The mAT-S1500 is designed as an accurate instrument for monitoring station performance. It uses two RF specific measurement chips, which can accurately measure the power and SWR of an RF system, but cannot display information such as spectrum and impedance.

The mAT-S1500 features a 4.3" (10.9cm) diagonal TFT colour display screen that displays the current RF power and SWR using bar and digital displays. This device is equipped with two high-capacity 18650 lithium batteries, which can operate without the need for an additional power supply.

By using the Type-C charging socket, users can easily use their phone charger to charge it. Please note, the charger is not included as an accessory to this instrument, and the user needs to prepare it themselves.

The mAT-S1500 is an automated instrument that is very easy to use. It only has one power switch and can automatically set the range based on the input RF signal. It can also automatically set the colour of the screen background based on the brightness of the ambient light, helping users to better see the display.

The shell of the mAT-S1500 is made using aluminium milling technology, which makes it very delicate and sturdy.

Available from hamradio.co.uk for £340.

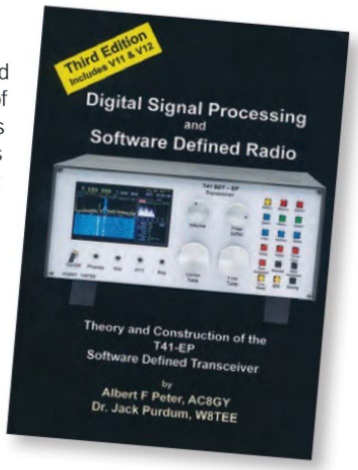
Digital Signal Processing and Software Defined Radio book

This is a new and refreshing look at the world of software defined radio (SDR). The book is based around a project transceiver called a T41 and sets out to discuss in depth digital signal processing as a product of software development. Methodologies employed include 'Object Orientated Programming' which provides a logical approach and understandability for the average user. It is set out in clearly defined chapters which discuss each of the modules required to form a working SDR (T41) transceiver. With the current level of SDR radios becoming available in both the commercial and amateur world, the book provides a solid grounding in the knowledge of how they work without going too heavily into the mathematics of SDR. Inevitably, some mathematics is needed to understand basic functions, but it is kept to a minimum.

In addition, the book provides an explanation of how microcontrollers work and their part in amateur radio today. The T41 transceiver described in the book has a full range of functionality as a CW and SSB transceiver with extra enhancements offered in the final chapters.

Who should read this book? The answer is everyone who is interested in SDR.

Digital Signal Processing and Software Defined Radio is available from Amazon.



Antennas

Welcome to our first Antennas column. To paraphrase Freddie Mercury (and Robbie Williams), let us entertain you, and make you think about the most-important part of your radio station.

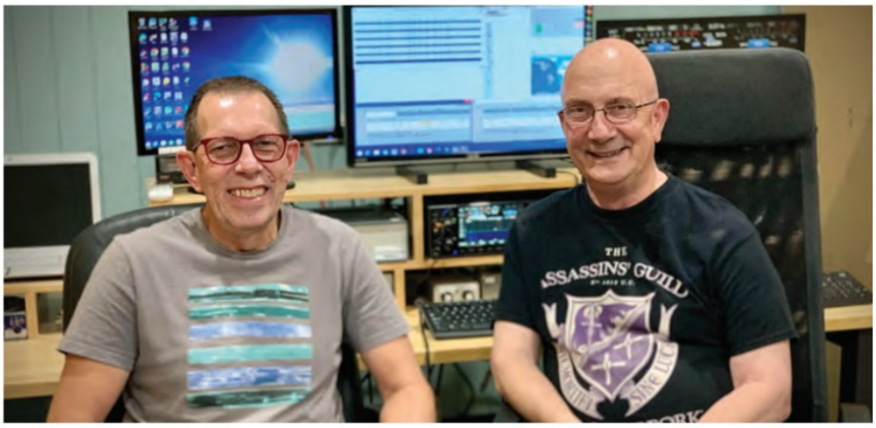


FIGURE 1: Kevin, VK6LW (ex-G4EHF) and Steve, VK6VZ/G3ZZD.

FIGURE 2: Stranded aluminium fence wire can be used for antennas and radials.

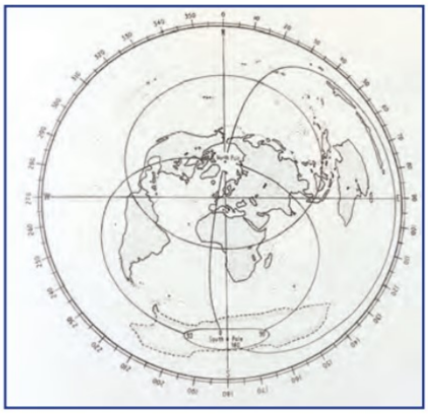


FIGURE 3: A great-circle map centred on London [10].

A bit of background

Both of us (**Figure 1**) were licensed in the UK in the early 1970s, and we lived about 30 miles apart in small suburban houses with postage-stamp sized gardens. While our HF DX dreams were big, our limited real estate made them harder to achieve; the back garden at G3ZZD was about 7m x 7m. G4EHF had slightly more room, but not enough to make G3ZZD jealous. However, there was also the front garden, and his antennas were mounted between two wooden poles at opposite corners of the 25m x 7m housing plot. Living on a plot of this size would be regarded as a luxury by many in the much-more-crowded 2020s. But while room for antennas has become even more limited, the march of technology has alleviated the position somewhat.

EZNEC changes the game

The most powerful of these technological advances is in the ready availability of antenna-modelling software, in particular the (now free) EZNEC software **[1]** written by Roy Lewallen, W7EL. When Roy retired in 2022, he decided to make the entire software free to download, and has continued to develop new versions of it (now at Pro+ v7.0). One of the principal areas where EZNEC is useful is that antenna designs can be modelled over a range of different ground conductivities which, if you have a basic knowledge of the nature of your home 'ground' and select the most appropriate one in EZNEC, can substantially improve its accuracy. We will look at this aspect of EZNEC in a future column.

Another advantage of EZNEC is its ability to let you explore the use of a single-band antenna design on other bands, and helping to tweak this design so that it will work on other bands as well as possible. However, we should point out that EZNEC is not perfect, and should not be trusted implicitly, but it does provide a very good indication of antenna performance. Both of us are practical people who like to build antennas, and have over 50 years of combined experience in doing this. By and large, any antenna design featured in this column will have been built and thoroughly tested by at least one of us.

Both of us now live in the hills east of Perth, capital of Western Australia, known as the most-isolated major city in the world; our nearest state capital is Adelaide, about 2,100km away. Tokyo and Beijing are almost 8,000km away, London and San Francisco are 14,500km and New York is 18,700km. To work DX and compete in HF contests on a worldwide basis, our antennas must work well at very long distances!

Better and cheaper materials

Those less well-off, particularly the young and impecunious, have had to be inventive with what is available in the domestic consumer marketplace. This applied to us in our early years when neither could afford the more-expensive 50Ω coaxial cable, opting instead for cheaper mass-produced VHF/UHF television RG-59 cable (75Ω), bought from the local TV shop or antenna installer. There is little reason to be afraid of using 75Ω coaxial cable, particularly in these days of transceivers with built-in antenna tuning units, as feeding a 75Ω load or antenna with a transmitter designed for a 50Ω results only in a 1.5:1 VSWR. Even today, when we both have more money, we consider using DTV cables such as RG-6 and RG-11 which offer cheaper alternatives to the 50Ω cables with comparable loss.

RG-6 has roughly the same diameter as RG-59, and its loss performance is similar to RG-213 **[2]**. Many radio amateurs are put off by the thickness of the RG-213/LMR-400 family of cables, so find RG-6 an attractive option in that it is narrower. Also, good-quality quad-shield RG-6 can handle 1kW.

RG-11 can handle similar powers as RG-213 and has lower loss. There are also simple ways of joining a PL-259 plug to both RG-6 **[3]** and RG-11 **[4]**, despite their aluminium shields.

There are eBay cable sellers in the UK selling 100m of inexpensive Freesat/Sky/Virgin-type RG-6 for about £40 (see for example **[5]**), whereas a 50m length of RG-213 can be purchased for just over £80 **[6]**. It would be worth checking if this RG-6 is quad shielded, as the price is so good. Even if you are unhappy about the risk of using it for transmitting, it would be OK for a receiving antenna.

When it comes to actual antenna or radial wire, there is a much cheaper and much lighter alternative to the often-used 14-gauge hard-drawn copper (or Copperweld). We both now use stranded 2mm diameter aluminium electric-fence wire (see **Figure 2**), of which a 400m drum can be bought from UK farm suppliers for under 40 UK pounds **[7]**. In practice this means that the aluminium wire for an 80m half-wave dipole weighs just over 250g (and costs about £4), but 14-gauge Copperweld wire weighs nearly three times as much **[8]**. VK6VZ has been using 2mm aluminium wire on an 80m half-square antenna for about two years, in wind gusts well over 100km/h, with no breakages. The antenna wire is crimped to the associated feeder and a supporting centre insulator, in a manner which we shall describe in a future column.

The best possible antenna for you

If you are an HF operator, it is nice to have an antenna that works well on all bands. However, most of us have to concentrate on a few bands, usually based on what time we have available to operate. But many radio amateurs want to have an antenna that works equally well on all the HF bands, even though their working/playing hours mean that they seldom have the time or opportunity to use them! We suggest that it may be better to have an antenna that works well on few bands, rather than all-band antenna that works equally badly on all bands. For example, if most of your operating is done on winter evenings or early mornings, having an antenna that is optimised for the 40 or 80m bands, likely to be open at that time, is clearly a good idea. However, while this may be fun (and necessary) at the bottom of the solar cycle, when we are at the top of the cycle the bands above 14MHz can be open for DX at these times, and having antennas optimised for a few of them is going to be even more fun. If you are short of space, and can only fit in one or two antennas, then follow the sun-spot numbers and change your antennas and operating patterns as the solar cycle changes.

Radio amateurs tend to use the half-wave dipole as the unit on which they base their antenna experimentation. A half-wave dipole that is relatively close to the ground, say a quarter of a wavelength or less, will radiate at a relatively-high angle and work well for contacts up to a couple of thousand km, and occasionally will get you even further. However, if you can raise your dipole up to half a wavelength, you get a bonus of up to about 6dB courtesy of ground reflection (sometimes referred to as 'ground gain' **[9]**). This applies to all horizontally-polarised antennas.

Another way you can get more gain is to use an antenna that is longer than a half-wave. We like to use wire antennas on the high HF bands that are a full-wave length (known as two half-waves in phase) or 1.25 wavelengths (known as an 'extended double Zepp' (EDZ)) in size. These can have gain over a half-wave dipole, the latter about 3dB, and radiation patterns which can be more useful than the half-wave's figure-of-eight shape. (In all discussions about antenna gain, we need to bear in mind that gain figures refer to the maximum value in the forward direction. Having an antenna with, say, a 10dBi gain figure, will not benefit you if your distant station lies along a null in the antenna pattern.)

The full-wave horizontal antenna has the radiation pattern in azimuth of a four-leafed clover on its resonant frequency; if the antenna is orientated east/west or north/south, this means that its main lobes, 60° wide, will favour a lot of the world, and is a useful radiation pattern for a DXer. In contrast, the EDZ has a much-narrower bi-directional radiation pattern at right angles to its orientation of only 38° width. This is actually narrower than that of a

Steve Ireland, VK6VZ/G3ZZD,
and Kevin Smith, VK6LW/VK6T/G4EHF
stevevk6vz@tpg.com.au

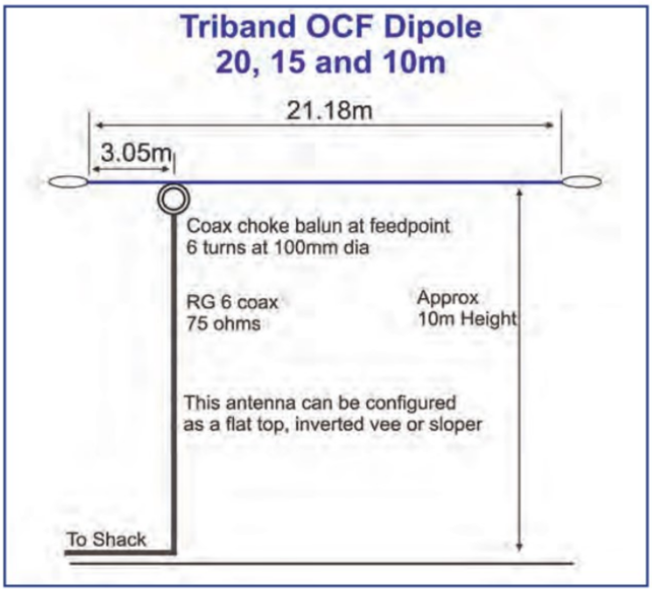


FIGURE 4: The Tri-OCF antenna.

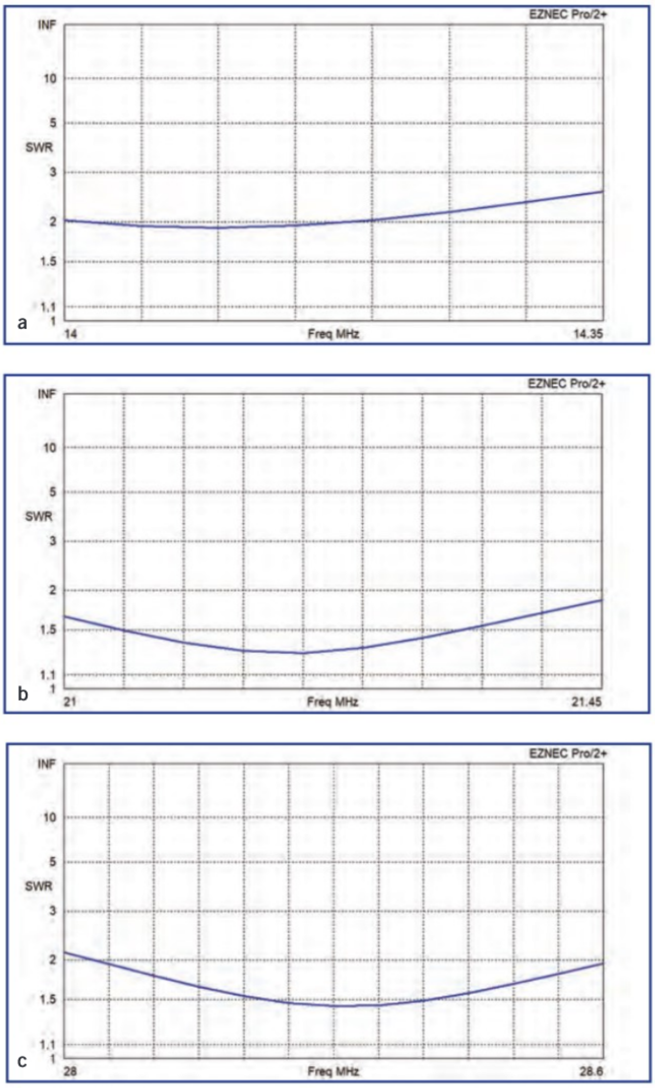


FIGURE 5: The Tri-OCF VSWR: (a) 20m, (b) 15m, and (c) 10m.

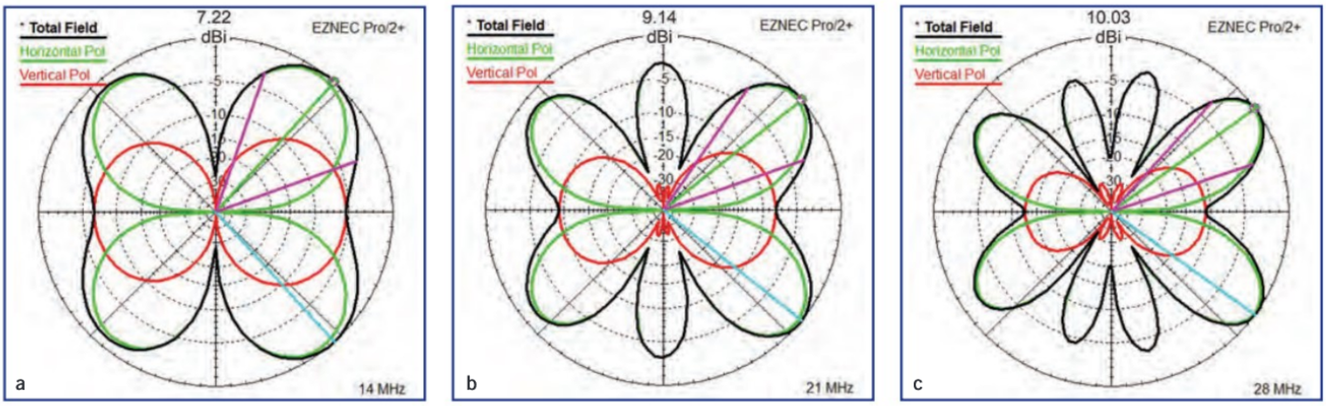


FIGURE 6: The azimuth radiation patterns of the Tri-OCF at (a) 20m, (b) 15m, and (c) 10m.

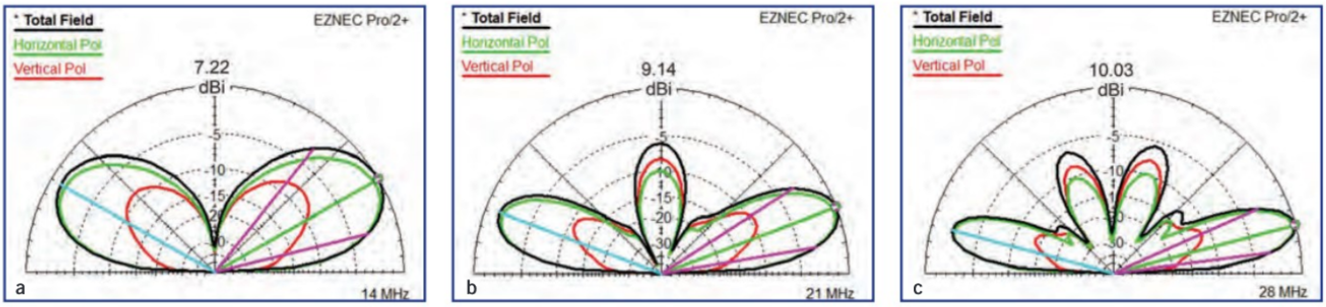


FIGURE 7: The elevation patterns of the Tri-OCF at (a) 20m, (b) 15m, and (c) 10m.

conventional three-element Yagi antenna, but the EDZ has a gain close to a that of a two-element Yagi antenna. As a result, the EDZ is ideal for someone whose passion is communicating with a particular area of the world, such as Australia, using both the long and short path. The trick is to pick the right antenna for you. To help make this choice, it is useful to have a great-circle map based on your location which shows azimuths to all parts of the world (see **Figure 3**). You can buy one **[10]** which is centred on London.

An antenna to suit the solar cycle

As a starting point for your antenna experiments, and this column, let us look at a wire antenna designed by VK6LW, called the Tri-OCF. This is based on a two half-waves driven in phase for 20m. This design also works well on 15 and 10m, where it even has a lower VSWR and lower angles of radiation than on 20m. The Tri-OCF is 21.8m long, and is a variation of the off-centre-fed dipole antenna (OCF). It is fed directly with RG-6 coaxial cable at a point 3.05m from one end, via a simple choke balun (**Figure 4**). The balun is made by winding six turns of the RG6 feeder onto a 100mm diameter former, slipping them off and then holding the turns together in a coil format by taping them together with several layers of black duct tape.

As you can see, the Tri-OCF does not need the 4:1 feed-point matching transformer which complicates most OCF antennas. However, its VSWR of 2:1 on 20m is easily dealt with by a transceiver's internal ATU. On 15 and 10m, the matching is even better, with a VSWR as low as 1.3:1 and 1.5:1 respectively (see **Figure 5(a), Figure 5(b), Figure 5(c)**). The Tri-OCF is ideally used as a horizontal antenna, but could also be configured as an inverted-v or sloper. If you can't fit in the entire 21.8m span, you can let up to three metres drop down vertically at each end.

The EZNEC azimuth and elevation radiation patterns of this antenna, mounted 10m above the ground, on the 20m, 15m and 10m bands are shown in **Figure 6** and **Figure 7**. The Tri-OCF has around the same gain as a dipole a half wave above ground on 20m, but a more useful pattern. On 15m, it offers 1.5dB gain at a low take-off angle of 21°, and on 10m it is even better with over 2dB gain at 15°.

Over the last couple of years, using a sloping Tri-OCF at an average height of 10m above ground, VK6LW has consistently worked into Europe and the USA on 20m, 15m and 10m using CW and just 5W RF output. These were not just 'search and pounce' contacts; on some occasions on 20m he was actually running a pile-up. Incidentally, the Tri-OCF will also work on 40m with an external ATU, but VK6LW says to regard this as a "serendipitous bonus" and that "your mileage may vary".

Conclusions

The Tri-OCF is intended to make a simple morning or afternoon construction project for you. At ten metres in height, the antenna has a lower take-off angle than a half-wave dipole at a similar height on 20m, 15m and 10m, offering enough gain to get you through a pile-up more quickly than most other simple wire antennas. In the coming months, we will show you a number of similarly-rewarding and easy-to-construct wire antennas. Good DXing!

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[10] https://www.rsgbshop.org/acatalog/RSGB-Great-Circle-Map-2009.html

Review

Icom meter from VE2DX Electronics

This miniature unit, type IM1-4BT (see Figure 1), can display information from a range of Icom transceivers, and measures just 54mm x 54mm x 31mm with a screen diagonal of 50mm.

Small and larger

Those of us with poor eyesight may struggle with the miniature unit, but there is also a version with a larger screen, and another which will display information on an HDMI monitor. The meter requires a 5V DC supply via a USB-C port. I found that a USB-A to USB-C lead plugged into the USB socket on the transceiver worked well. This method has the advantage that the meter switches on and off with the radio. I also tried running it from a selection of USB chargers and power banks without issues.

FIGURE 1: The Icom meter unit from VE2DX Electronics.

FIGURE 2: The configuration menu.

FIGURE 3: Operating with my IC-7610.

FIGURE 4: **The needle mode on receive with a black background.**

FIGURE 5: **The frequency and meters displayed as larger bar graphs.**

FIGURE 6: **This little box has several connection options.**

Details

Icom's remote protocol is called CI-V, which uses bi-directional serial data on a 3.5mm mono jack-plug lead. The meter works with CI-V on most recent Icom radios from the IC-746 Pro onwards. You must select the radio you wish to use in the menu. The three buttons on the front of the meter can be used to select the display mode, and to operate the menu system. Pressing the left or right buttons takes you through the different display modes. Pressing the centre button takes you into the menu (see **Figure 2**).

I initially connected the meter to my IC-7610 via a CI-V lead (not supplied). I had to set the CI-V speed to 9600 baud as it didn't work at 19200. This was because of a limitation of the chipset in the M5 stack board, and it meant that the display lagged behind slightly. The 7610 is probably not the best radio to demonstrate the usefulness of this device as it can display a lot of information on its own large screen anyway, but with other Icom radios it can display things you can't normally see. In the case of the IC-7610, it does allow me to see all the meters whilst still displaying the waterfall on the main screen (see **Figure 3**). The meter also stays alive when the radio's screen goes into screen-saver mode.

The display

There are four display modes. The first mode displays the status of almost every parameter using bar graphs and icons. The frequency is displayed in a large font size, and the mode in use, the selected filter, the preamplifier status, noise blanker status, the AGC status, and compressor status are all indicated by icons. The settings of the AF gain, microphone gain, squelch level, and noise blanker are indicated by small bar graphs. Larger bar-graphs display the S meter or power, the automatic level control (ALC), the audio compression, the VSWR, the PA current, and the supply voltage. There's a lot to see (Figure 1)!

In the two 'needle' modes, the display changes to a representation of an analogue meter showing S units on receive, and a chosen parameter on transmit (selected from the menu). This is useful, as you might have one thing on the front of the radio, such as ALC, and another on the meter, such as VSWR. A legend pops up on the screen indicating which parameter is being displayed. You can have the analogue meter with or without the frequency readout. You can select a white, yellow or black background for the analogue meter. **Figure 4** shows an example of the needle mode on receive with a black background.

The fourth mode displays frequency and shows the meters in bar-graph form, allowing them to be a bit bigger and slightly easier to read (see **Figure 5**). In all modes, the meter incorporates a high-VSWR warning feature; if the VSWR rises above 3:1, the box containing your callsign shows red, and flashes "HIGH SWR", even if you are not monitoring VSWR.

Connections

This tiny box has a lot of connectivity; USB, three CI-V ports, WiFi and Bluetooth (see **Figure 6**). Bluetooth is mainly for connecting to the IC-705 which doesn't have a CI-V socket, but it will also work with the ID-52 and ID-5100 if those radios have the Bluetooth option fitted.

Protocol

Richard, VE2DX has developed his 'TrueCIV' technology to ensure that poor signal level and interference on the CI-V bus is corrected by a process of filtering and level restoration before being passed to the next stage. You can find out more about TrueCIV and TrueTTL at **[1]**. The three-port CI-V hub built into the unit should allow three CI-V devices to be connected together, with the TrueCIV protocol ensuring error-free communication. VE2DX is introducing several new products which can be interconnected via the CI-V hub. He is also making products for Yaesu and Kenwood radios. Free firmware updates will add new features and are available at **[2]**. They come as a zip archive containing a text file with change information, and an exe file which will load the firmware into the unit. On my Windows 10 PC, I got a security warning when I ran the exe file, but going to 'run anyway' under the 'advanced' tab allowed me to continue.

The software asks for the COM port you are using, which you can find by going to 'Device Manager' in Windows, selecting 'Ports (COM & LPT)', and seeing which one pops up when you plug the meter in with a USB lead. In my case it was COM5, which I selected and then pressed the 'Burn' button, whereupon the software was loaded into the device, which then rebooted and asked for the password. Make sure you have this to hand before updating the firmware! It should be on a label stuck to the back of the unit or it may be inside the box.

Future

An upcoming feature is the remote viewing of the status of a network-connected radio, such as the IC-9700 or the IC-7610. Richard hopes to have it working by summer 2024. This will be implemented via a firmware update.

Many thanks to Richard, who is happy to provide support for his products via the 'Support' page at **[1]**, and to Martin Lynch and Sons for the loan of the review unit. The IM1-4BT is currently priced at £164.95 including VAT and is available via www.HamRadio.co.uk/IM1

References

[1] VE2DX.com

[2] VE2DX.com/support

Dave Pick, G3YXM
daveyxm@gmail.com

Design Notes

Your input please

'JNT Labs has not been as busy recently, and there often comes a limit to what I want to experiment and play around with, just for the sake of it and writing this column. And I've been more concerned with a software project in recent weeks – more about that later, perhaps. Most of what appears this month has been gleaned from comments and discussions on three different IO groups, 'RSGB Technical', 'RSGB Workshop' and 'UK Microwaves'. So, to keep this column a bit more original, can I appeal to you, the readers, to send in your ideas and projects? Home construction is still happening – you only have to look at some specialist groups to see that, but this column offers a wider audience, letting everyone else who doesn't subscribe to these email groups know what is going on.

FIGURE 1: Breadboard arrangement of an RF transformer with non-integer ratio windings, giving a ratio of 5 : 5+1+5.

Power amplifier 'unusual' turns ratio

In this column for November 2021, we looked at the PA design for the GB3MBA 50MHz beacon. There we noted that, in order to achieve a design output of 120W from a 28V rail, this required a push-pull load impedance for the MRF141G MOSFET output device of something like 10Ω, which couldn't be obtained using a simple output transformer with an integer turns ratio. It was solved by using a custom output filter that transformed the 50Ω load to around 37Ω. That in turn was transformed to the wanted R_{LOAD} by a standard 2:1 turns ratio (4:1 impedance) output transformer.

This was what appeared on a thread on the RSGB Workshop group where Steve, G8GSQ, commented: "It reminded me of something I encountered when I first started work, and don't recall having seen in articles. Apologies if it's old hat.

"Imagine a transformer made from trifilar wire wound on a core. Two wires are joined in series to make a 2:1 turns ratio. Say there are 5 turns, you have a 5:10 turns ratio. Add an extra turn at the point where you join the two wires together – now you have 5:11 turns ratio (or 5:9 if you add it as an anti-phase turn).

"Lots of permutations are available depending on the base number of turns and the number you add. The transformation doesn't always follow the maths exactly because of different coupling on the added turns. We used 6:13 to get a roughly 5:1 impedance ratio, which might have suited the beacon amp. It was on a PA output and used twin screened cable, with the screen carrying the higher current on the low impedance side."

This was too novel not to want to try out here at 'JNT Labs, so I raided the ferrites box and got out a small ferrite toroid with an Li value measured at roughly 0.3µH. (Li is the inductance of one turn, so the actual inductance for N turns is given by $L = Li \times N^2$). Five turns made from three cores of enamelled wire wound into a trifilar single cable were wrapped onto this toroid. Another single turn of thicker wire was added as Steve suggested, so a 5 : 5+1+5 winding ensued for an idealised turns ratio of 5:11, for an impedance ratio target of 1:4.84. Now 50Ω / 4.84 = 10.3Ω, so a test-load was made up from two 33Ω resistors and one of 27Ω in parallel connected to the 5-turn secondary. The 11-turn primary went to an SMA socket for testing. A photograph of this breadboard can be seen in **Figure 1**.

It is clear that, with just a few fat turns on a toroid, the coupling won't be all that tight, so I wasn't expecting a fantastic result at higher frequencies as there would be appreciable leakage inductance. With an Li of 0.3µH, the 11-turn primary would have an inductance of 36µH. If we take the usual rule of thumb for an RF transformer that the inductive reactance of the winding needs to be at least four times the working impedance, that suggests a lower working frequency of 200Ω / (2π x 36µH) = 0.88MHz, where shunt inductive reactance becomes significant.

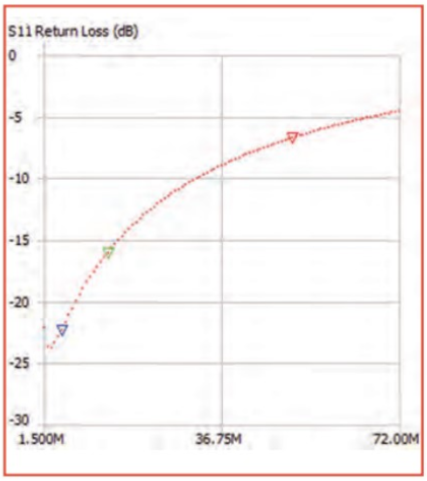


FIGURE 2: Return-loss plot for the 5:11 turns ratio transformer with a 10.3Ω load on the secondary.

Results

A Nano-VNA was used to measure the transformed impedance from this 10.3Ω load. The results can be seen as a return-loss plot in **Figure 2**, as a Smith chart in **Figure 3**, and full results tabulated for three spot frequencies in **Figure 4**. The lowest frequency measured is 1.5MHz where it is clear on the return-loss plot that the transformed match is at its best at around 2MHz, and is just beginning to worsen below this because of the shunt inductive reactance. Up to around 5MHz, the result is excellent, with a very good match

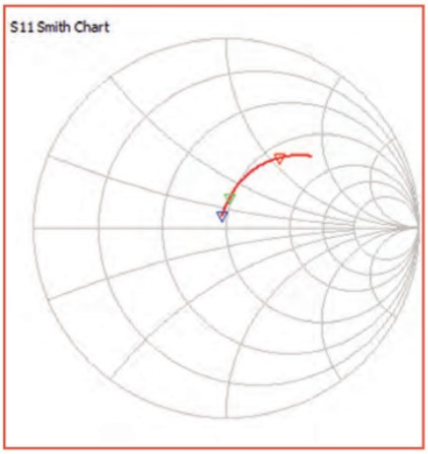


FIGURE 3: **Transformed impedance shown as a Smith chart.**

to 50Ω, but above this frequency, the series leakage inductance worsens the result, so this simple ferrite toroid arrangement is only good to about, say, 14MHz with a return loss of 16dB, or a VSWR of 1.34:1. But there's no reason why, for single frequency use, this leakage inductance couldn't be tuned out with a series capacitor. The Nano-VNA plots even give the value of capacitance required; this is the negative value of 'series C' shown in the results table of Figure 4.

If the output transformer was constructed properly, using two ferrite tubes and with better coupling between all windings to reduce the leakage inductance associated with the extra turn, there is no doubt this arrangement could be made to work over a wider bandwidth, and could easily be pushed to 50MHz or higher.

MRF300 power FET

Discussions on the same thread diverged to mention the MRF300 RF MOSFET. This is one of the more-recent RF power devices, supplied in a low-cost plastic package, with a single hole for bolting down to a heat sink. It is popular amongst constructors of home-built solid-state power amplifiers, with several suppliers producing similar kits **[1]**, using a pair of these to give 600W over the HF to 50MHz frequency range running from a 50V supply rail. Phil, G4LPP has built one and, after modifying the output filter, he also runs it at 70MHz, albeit at slightly reduced power.

Although by now this is a well-established design amongst the QRO cognoscenti, it is worth saying more about the MRF300 device. The single-hole-mounting TO247 package has already been mentioned, but there are two big differences in packaging over conventional power MOSFETs. The first is that the source is connected to the metalized underside, meaning that an insulated pad is not required. The source connection is bolted firmly down to the grounded heat sink. This means that the source is now the middle connection of the three tabs, rather than the drain as in conventional power MOSFETs in this type of package.

The second major difference is that the MRF300 is supplied in two connection variants with the two outer tabs for drain and gate mirror imaged. The MRF300AN device has the connections Gate-Source-Drain (looking from the top) while the MRF300B has them laid out D-S-G. This vastly simplifies the PCB layout for high-frequency amplifiers when a matched A/B pair are used, since the PCB can be laid out symmetrically for push-pull operation. The pictures and diagrams in **[1]** show this clearly. The final advantage of the plastic TO247 package is that it makes the device considerably cheaper than if the same semiconductor chip was housed in a ceramic package, although it may well slightly lower the maximum useable frequency. The device data sheet does, however, indicate it can give useful performance at 144MHz.

General use

The datasheet for the MRF300 **[2]** is quite comprehensive, and it suggests several configurations for different frequency bands, including 50MHz and 144MHz. Up to 50MHz, it shows a gain of typically 27dB to 28dB for 320W CW output, from a single device used in the suggested circuit and layout. This falls to 23dB at 144MHz for the same power output. Had I known about this device a couple of years ago when building the GB3MBA amplifier (and more to the point, not already had several MRF141Gs languishing in the junk box), it would probably have been a contender for that. A single device capable of 300W from a 50V supply could be used in a high-reliability 100W PA running from a lower voltage rail. So let's do a paper design exercise, in the same way as described for GB3MBA.

A single-ended stage, powered from a supply voltage V_{DD}, delivers a maximum power of $V_{DD}^2/(2R_L)$, where R_L is the transformed load resistance. The device is designed for a 40V to 50V supply, and as we're running 'backed off', lets use 40V, and design for 120W output. That means that the value of R_L is $R_L = 40^2/(2 \times 120W) = 6.67\Omega$. This is not a push-pull configuration, and does not need a broad-band match, so a simple L-C network will suffice, like that shown in **Figure 5**. The simplest matching network is a series-L / shunt-C, making use of L1 and C1 in that diagram only, with C2 not part of the matching network and just there for DC blocking. To match 50Ω to 6.67Ω at 50.5MHz, the component values needed can be obtained from any RF calculator tool, Smith chart simulator or from the basic equations.

Marker 1			
Frequency:	50.8500 MHz	VSWR:	2.706
Impedance:	60.5+j56.1 Ω	Return loss:	-6.739 dB
Series L:	175.49 nH	Quality factor:	0.927
Series C:	-55.822 pF	S11 Phase:	52.48°
Parallel R:	112.46 Ω	S21 Gain:	-86.903 dB
Parallel X:	379.91 nH	S21 Phase:	171.46°
Marker 2			
Frequency:	14.1900 MHz	VSWR:	1.374
Impedance:	49.9+j15.9 Ω	Return loss:	-16.043 dB
Series L:	178.89 nH	Quality factor:	0.32
Series C:	-703.23 pF	S11 Phase:	81.40°
Parallel R:	54.97 Ω	S21 Gain:	-89.908 dB
Parallel X:	1.9278 µH	S21 Phase:	50.44°
Marker 3			
Frequency:	2.91000 MHz	VSWR:	1.138
Impedance:	48.2+j6.06 Ω	Return loss:	-23.825 dB
Series L:	331.17 nH	Quality factor:	0.126
Series C:	-9.0325 nF	S11 Phase:	103.45°
Parallel R:	48.913 Ω	S21 Gain:	-91.919 dB
Parallel X:	21.273 µH	S21 Phase:	-87.56°

FIGURE 4: **Complete VNA results for three spot frequencies.**

For a series-L/shunt-C configuration, these are L1 = 53.7nH and C1= 161pF. These are perfectly reasonable values to work with, and both easily capable of working at the voltages and currents seen in a 100W amplifier. But the snag, with a simple two-component matching network, is that L and C both need to be carefully tweaked for optimum output. Although adjusting the value of the capacitance isn't too difficult by adding or removing small ones in parallel, tweaking a substantial inductor made of thick wire isn't at all easy to get right. A 50nH inductor, suitable for a few amps of circulating current, will have something like one turn of 2mm diameter wire and have a diameter of 20mm – hardly adjustable! If this were made as lengths of PCB track, even worse.

The solution is to bring C2 into play as part of the matching network, allowing L1 to take on just some approximately-correct value, after which the exact match is then trimmed by adjusting C2 and C1. If done carelessly, a value of L1 significantly higher than that needed for the two-component solution can be made to tune up, but this can end up with a very high Q network with tight tuning and high circulating currents and voltages. These might be a lot more than wanted in practice, and result in extra loss. So ideally keep L1 to just a bit higher than the minimum defined by the L-match. A set of values for matching 50Ω

Andy Talbot, G4JNT
andy.g4jnt@gmail.com

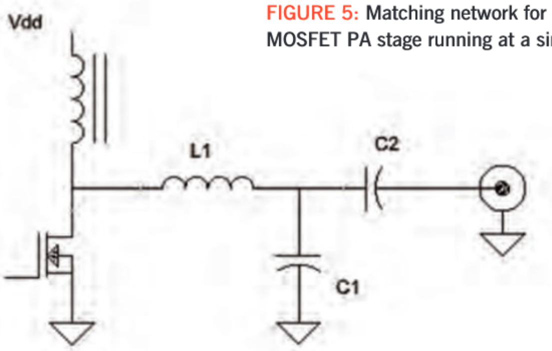


FIGURE 5: **Matching network for a single-ended MOSFET PA stage running at a single frequency.**

to 6.67Ω with increasing matching network Q are shown in **Table 1**. Note how the first line, with L1 = 54nH, is so close to the optimum two-component case that the series output C2 at 644pF, with a reactance of just 4.9Ω, is almost verging on just being there for DC blocking. Now we have more leeway in allowing L1 to be fixed at just whatever value it turns out to be, then tweaking C1 and C2 for best performance.

A broad-band transformer could still be used for a PA using a single device, but that seems to be rarely done in practice unless broad-band operation is needed. It is a bit of a waste of ferrite when it only has to run at one single frequency, and will still need capacitors to block DC.

Heat sinking

One thing you DO NOT DO is to just bolt these devices onto a heat sink with a bit of heat conducting gunk. The metallic underside is connected to the source, and for proper RF connection needs good electrical contact with the heat sink, which in turn has to be in good contact with the ground plane of the amplifier PCB, both thermally and electrically. The usual type of heat-sink compound is not electrically conductive, and would degrade the RF low-loss connection. A horror story from someone who had better remain anonymous detailed how he just bolted an MRF300 to a black anodised heat sink, powered up, and then observed the magic smoke until the devices went pop.

The correct way to use these devices is to mount them on a copper heat spreader of several millimetres thickness. Copper has innumerable advantages here. It is an excellent heat and electrical conductor, it is moderately soft so can deform around small irregularities and partially fill gaps after the devices are bolted down, leaving less space that has to be filled with some sort of seating compound, and it is easy to solder to. High-power RF devices are nowadays often soldered to heat spreaders using low-melting-point solder, usually supplied as a paste using a hotplate. This approach is practically essential for UHF power amplifiers, where the gaps in all ground-plane connections need to be at an absolute minimum, and the ceramic-cased transistors are forgiving of being raised to soldering temperatures. The plastic-cased MRF300 devices are not quite so happy being mounted this way; it is not a good idea to get them as hot as a ceramic-cased transistor can be allowed to go. There is now quite a range of low-melting-point alloys around, some liquid at room temperature, and any search engine primed with terms like 'low melting point alloy' will find plenty of suggestions to try. G4LPP used a compound called 'liquid metal', which is an alloy of gallium, indium and a few other metals, and is a fluid at room temperature. An example from one supplier can be seen at **[3]**. Phil used this in the way you would use normal heat-sink compound as a gap filler where, being a pure metal alloy, it does not have the poor electrical conductivity of traditional products used here. Beware of using the term 'liquid metal' on its own in a search engine. That will throw-up a whole range of adhesives, paints and other compounds that are not suitable for this purpose.

Of course, if you're really brave and are quick, plastic (epoxy) cased devices are routinely raised to normal soldering temperatures during reflow surface-mount construction. So, at a push, it may even be OK to solder these down using normal solder plus liquid flux, using a hotplate. Once in place, cool them as quickly as possible (not by quenching, please!) so the device does not remain at an elevated temperature for too long. However, it's on your own head if you want to try this to save the effort of obtaining low-temperature alloys.

Table 1: Values of L and C in the matching network.

L (nH)	C1 (pF)	C2 (pF)
54	154	644
60	124	136
70	100	81
80	85	62
90	74	51

More PICkit alternatives

In the January 2024 column, Colin, G3YHV, provided details of alternative driver software for the PICkit-2 and PICkit-3 PIC programmers, giving these older units a new lease of life and the ability to use them with the more-recent processors. Now Colin has provided details of another PIC programmer project, one aimed at Raspberry-Pi users. The following was sent to him: "We have been working on a new product: the PICkitPlus PHAT for Raspberry Pi. It is a PICkit 2/3 alternative that plugs into the Raspberry Pi GPIO header.

"The product has been in development for over a year, and we are now looking for a small number of beta testers prior to official release. If you would like to participate, please read the attached document and let us know of your intention by the 18th of June.

"Please tell us:

1. your programming, testing and/or electronics experience;
2. what Raspberry Pi models you have;
3. if you have a multi-meter, logic analyser and/or oscilloscope; and
4. which model of PHAT you would like: the Full PHAT or the PHAT Zero.

"The product is currently in an early beta stage, and we are looking for a small number of testers. If this sounds like something that would interest you, please let us know.

"Please email us at pickitplus@anobium.co.uk ."

That deadline is approaching even as I write, so will be well past when you are reading this. Perhaps by then the PICkit Hat Plus will have been announced, or nearly so.

References

[1] https://qrpblog.com/2019/10/a-600w-broadband-hf-amplifier-using-affordable-ldmos-devices/. A 600W power-amplifier kit covering 1.8MHz to 50MHz (and higher, see text).

[2] https://www.nxp.com/docs/en/data-sheet/MRF300AN.pdf MRF300 datasheet

[3] https://unitednuclear.com/chemicals-metals-c-69/liquid-metal-alloy-gallium-indium-tin-p-1354.html. Liquid metal (trade mark Galinstan), but there are others.

EMC

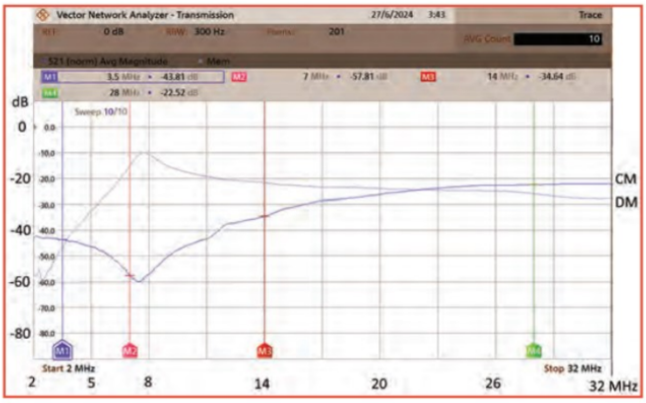


FIGURE 1: Test results for BSP inline filter.

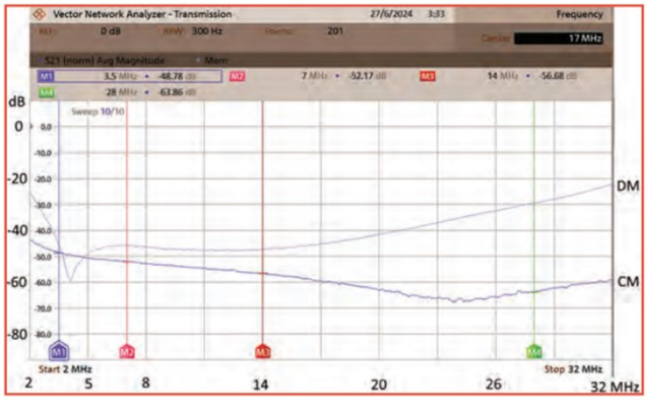


FIGURE 2: Test results for Schaffner filter.

This month's column looks at fibre to the premises (FTTP) and the likely benefits for EMC. We also look at how RF Interference filters work and how they are tested, including tests of an in-line filter that can be used to reduce RF interference from a piece of equipment.

Fibre broadband

In the UK, as well as other countries, copper telephone wires are being phased out and they are being replaced by optical fibre to the premises (FTTP). In the UK, this is called 'Full Fibre' or 'Ultrafast full fibre broadband' to distinguish it from what is called 'Fibre broadband' but it is only fibre from the telephone exchange to the street cabinet (FTTC). The problem with FTTC, from an EMC point of view, is that it uses VDSL2 transmission or, in some cases, G.fast on existing copper wires from the street cabinet to the customer's premises. This can radiate broadband noise in amateur radio bands up to and including 10MHz or 14MHz in some cases. This is a particular issue with VDSL in the UK where the capability to 'notch' amateur radio bands at specific locations does not appear to be available in the UK, unlike some other countries such as Germany and Switzerland.

The retirement of copper Plain Old Telephony Service (POTS) in the UK was planned to be completed by December 2025 but this has been put back to Jan 2027. Full fibre offers two advantages from an amateur radio EMC point of view. First, it is completely immune to RF breakthrough of amateur transmissions, unlike VDSL and G.fast, and, secondly, it eliminates VDSL interference to amateur radio reception. There is a potential downside however which is that it will increase the number of 'wall wart' type switching power supply units that are used in a typical UK home. These are a potential source of RFI if they are non-compliant with applicable EMC standards.

An FTTP installation includes an outdoor Customer Splice Point (CSP) box similar to the one shown in **Photo 1**. This joins the fibre optic cable from the street to a fibre 'patch cable' that comes through a hole in the wall to an indoor Optical Network Terminator (ONT) box.

Photo 2 shows a full fibre broadband installation (not BT/Openreach) alongside a copper VDSL2 installation with a Master Socket 5C which is now redundant. The ONT is the black Nokia box on the wall, in this case a model G-240G-E. The yellow cable from the ONT leads to a Wi-Fi router provided by an Internet Service Provider (ISP), not BT.

The wired telephone is also redundant and, although both the ONT and the router have RJ11 sockets for analogue telephones, it appears that these sockets are not operational on this particular network. If you want to keep a land-line phone then it appears that you need to subscribe to a separate Voice over Internet Protocol (VoIP) service and you either need to buy a new VoIP phone or you need to buy a VoIP Analogue Telephone Adaptor (ATA) to use existing analogue phones such as DECT cordless or wired. In either case, this would involve a third 'wall wart'-style power supply unit that consumes a few more watts of continuous load and could also be a potential source of RF interference if it is not well designed. The whole system also has no battery back-up in the event of a power cut, but that's another story.

PLC declining?

Power Line (Tele)Communications (PLC/PLT) is widely used for home powerline networking, for example to get a wired Ethernet network connection from one room to another. The effects of PLC/PLT on parts of the short wave radio spectrum, including broadcast bands, are well known. Some amateur radio bands are 'notched' but not all and we have seen RFI from PLT on some bands including 3.5MHz and 50MHz.

New ultrafast full fibre broadband installations normally come with a new router that typically meets Wi-Fi6 standard and operate in the 2.4GHz and 5.8GHz bands. Getting adequate Wi-Fi coverage in different rooms in a house is often done using wireless Wi-Fi extenders which do not use PLC/PLT so with any luck, PLC/PLT interference may eventually be a thing of the past along with VDSL noise.

Mains filters

Virtually all DC power supply units for electronic products are switching power supplies and switching power supply units need mains RF interference filters to avoid radiating RF interference. Even a small 5W mobile phone charger can produce a large amount of RFI if the mains filtering is inadequate and as for certain makes of car battery chargers and solar PV systems, well that's another story.

Let's start by looking at how mains RF filters work. **Photo 3** shows a mains filter on a separate board and something like this should be

PHOTO 1: An outdoor Customer Splice Point (CSP) box.

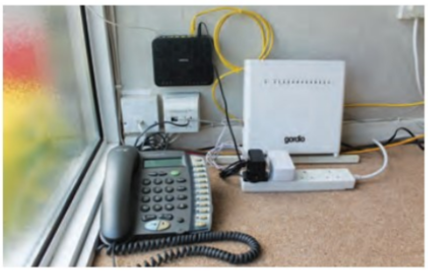


PHOTO 2: A full fibre broadband installation alongside a copper VDSL2 installation.

included on the PC board in most switching PSUs. The mains live and neutral wires pass through windings on a ferrite ring core. On one side of the filter, there is a relatively-large capacitor such as 470nF between live and neutral and, on the other side of the filter, there are two smaller capacitors such as 2.2nF, one from live to earth and one from neutral to earth. The windings on the ferrite ring are connected so that the mains currents in the live and neutral wires cancel out. This prevents the core from being saturated by the 50Hz mains current. This is sometimes called a current compensated inductor or common-mode choke because it is effective at suppressing common-mode currents, that is on live and neutral together relative to earth. It is these common-mode currents that cause most of the problems with RF interference below 30MHz.

The capacitors are safety critical, the smaller capacitors must be Class Y rated to ensure that they will not fail short-circuit as this would create an electric shock hazard. The larger capacitor must be Class X2 rated to ensure that it will not fail in a way that causes a fire risk by placing a short circuit between live and neutral.

Photo 4 shows various RFI filters made by Schaffner with different current ratings. From top to bottom these are 10A, 6A, 3A and 1.5A. The higher current rating requires a physically larger ring core but the filters with higher current ratings generally have a lower inductance. To compensate for this, a larger value of X2 capacitor is used in the higher current filters. In this case, each winding on the 10A filter is 0.7mH compared to 0.3mH on the 6A filter, 2mH on the 3A filter and 24mH on the 1.5A filter. The X2 capacitors range from 15nF to 470nF. The Class Y capacitors are all 2.2nF except in the 10A filter where they are 4.7nF. In practice, 4.7nF is the largest Y capacitor that is used in mains filters because it passes some 50Hz mains current to earth and if there are too many mains filters on the same mains circuit then it could trip a 30mA residual current device (RCD).

In-line filter

Clearly, constructing a mains RFI filter is not a feasible 'home brew' project, it needs to be bought ready-made. Filters from Schaffner and other manufacturers that are designed for incorporating into electronic products are available from professional electronic component distributors such as Farnell or RS but if you want to add a ready-made plug-in mains filter to quieten an RF 'noisy' electronic product then the choice is limited. It used to be possible to get a large UK mains plug with a built-in RF interference filter, but these don't seem to be available any more. It is still possible to buy a four-way trailing mains socket with a built-in RF interference filter and/or a surge protector but it is important to note that a surge protector on its own does not provide any RFI filtering, it simply clamps high voltage 'spikes'.

One in-line mains filter that we did find is from Bentley Security Products (BSP) Ltd, Inline mains filter type AT-356 (see **Photo 5**). This is available from CPC-Farnell, order code HKD1117, price £23.94 inc VAT. The AT-356 is sold as a filter to improve immunity of electronic equipment by reducing spikes and fast bursts of interference on mains supply. It includes a single section RFI filter rated at 3.5A and it can also be used to reduce the amount of RFI that a piece of electronic equipment puts out into the mains. The manufacturer's data sheet specifies the performance of the filter in terms of how it reduces a fast transient spike, but it doesn't include a frequency response. We tested one and the results are given below together with a Schaffner FN 322-3/01 for comparison. The Schaffner FN 322-3/01 appears to be discontinued but the Schaffner FN9222R-3-06 is similar and is available from Farnell, RS etc together with similar mains filters from various other manufacturers.

Filter tests

The BSP filter and the Schaffner filter were tested using a R&S FPC1500 spectrum analyser that also has a built-in vector network analyser function. A limitation of this model is that the vector network analyser function is only available from 2MHz upwards, which is why the traces start at 2MHz. The stop frequency has been set to 32MHz to give 3MHz per division but offset by +2MHz, ie

PHOTO 3: A mains RFI filter PCB.

PHOTO 4: Various Schaffner RFI filters.

PHOTO 5: BSP Inline mains filter type AT-356.

5, 8, 11, 14MHz etc.

The two filters were tested for differential mode (DM) loss, that is driving a signal between live and neutral and also common mode (CM) loss, that is driving a signal on live and neutral together relative to earth. On each trace, the thicker line is CM, the thinner line is DM.

Figure 1 shows the result for the BSP inline filter. CM filtering is good in amateur bands up to 3.5MHz and is very good around 7MHz with over 50dB of rejection. It is quite good up to about 15MHz with at least 30dB rejection but not so good above 15MHz. Differential mode performance is good up to 5MHz but not so good above 5MHz. Nevertheless, if the frequencies of interest are up to 5MHz this filter may be useful if used for reducing emissions from electronic equipment, in addition to the purpose for which it is designed, ie improving immunity.

Figure 2 shows the results for the Schaffner filter. CM performance is very good at all frequencies tested. DM performance is also very good up to 21MHz with at least 40dB rejection and good up to 28MHz with at least 30dB rejection. The reduced rejection above 28MHz is unlikely to be a problem in practice because few sources of disturbance have much energy at the higher end of HF.

To conclude, the Schaffner filter, or similar, offers high performance but it would need to be fitted in an enclosure, whereas the BSP inline filter is ready to plug in if the source of disturbance has the right type of connector.

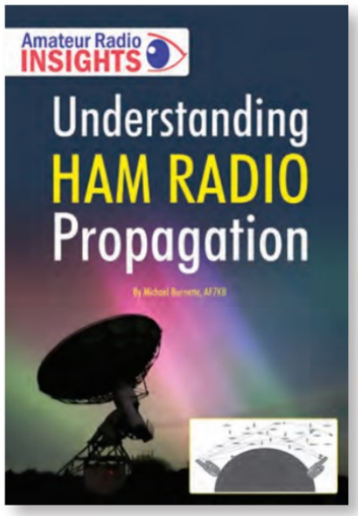
Dr David Lauder, G0SNO
emc.radcom@rsgb.org.uk

Book Review

RadCom Team radcom@rsgb.org.uk

Understanding Ham Radio Propagation

By Michael Burnette, AF7KB



This no-nonsense book seeks to explain, in simple terms, RF propagation for the radio amateur. It has a clear, partly graphical, approach to most RF scenarios. This also includes the formulae needed to achieve the required result. One such example chapter examines the 'Fresnel Zone', how it works, the implication of terrain acting upon it and the resultant signal losses. In one example, the book shows the effect of a signal being transmitted between two mountains, point to point, and then the introduction of a third mountain in between which encroaches on the Fresnel Zone created by the first two points. Although only a small ingress into the Fresnel Zone, it has the impact of a potentially-significant reduction in signal strength or total loss. With a general rule of thumb that 60% of the Fresnel Zone needs to be clear for a satisfactory signal to be received, it is easy to see why these things are so important to understand.

Simple subjects from high school physics are covered including line-of-sight communication and over-the-horizon communication. These subjects may seem elementary to us now but the book is a useful refresher.

Other subject areas covered are: ground wave propagation, tropospheric ducting, ionospheric basics, space weather and the ionosphere, HF DX, meteor propagation, auroral propagation and space propagation. To give you a feel for the level of detail the book goes into, each of those subject headings have considerable subheadings within them.

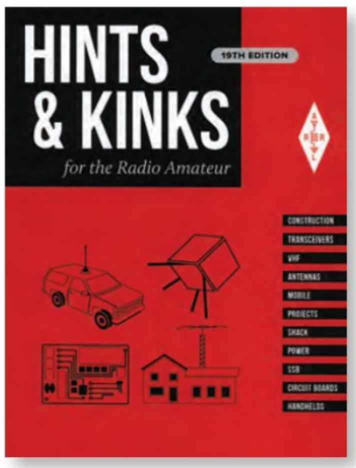
At the end of the book, a section entitled 'How we figured out This Ionosphere Stuff' then begins to look at various aspects of the history of the subject. This section contains an interesting history of propagation studies including the earliest paper from Balfour Stewart in 1882 suggesting the existence of the Ionosphere and the later papers from several learned people up to 1864, when James Clerk Maxwell formulated his now famous equations that predicted the existence of electromagnetic waves, followed in 1888 by Heinrich Hertz who proved they existed. It was then that a strange thing occurred. A chap called Marconi made a monumental achievement by transmitting radio waves across the curvature of the earth! How could this happen? This started the realisation that something in the atmosphere was reflecting the signals back to earth and further investigation was warranted. In 1902 Oliver Heaviside proposed that there was a conductive layer, and it was 'bending' the signals back to earth. This was also simultaneously confirmed by Arthur Kinnelly and so the path was set for exploration to continue into this intriguing subject.

This is a fascinating read and a worthwhile book to have on your shelf. It provides clear, concise answers to everyday questions regarding transmission requirements and considerations when designing an antenna installation.

Size 153x229mm, 152pages, ISBN: 9781 9139 9559 1
Non Members: £14.99, RSGB Members: £12.74

Hints & Kinks for the Radio Amateur (19th Edition)

By ARRL



With a name like *Hints & Kinks* who wouldn't be drawn to having a look at this book?!

The book has eight section headings covering topics from antennas to test gear.

The opening pages contain units and conversion tables and include a fairly comprehensive page of electronic symbols. Following this, the reader moves into the first chapter, or should I say extravaganza, of DIY solutions to everyday problems in amateur radio.

In the first chapter, Antennas, there is a novel solution for a radial ring earth, which employs a stainless-steel sink strainer that can be fitted exactly to the internal diameter of a pipe being used for an HF antenna. 32 holes were drilled around its outer diameter and radials were affixed using nuts and bolts. Once tuned, an efficient antenna was produced.

Another good example of home-brew engineering, or perhaps simplification of engineering, is the paper-clip paddle key. Using one large paperclip for the paddle, and two smaller ones for the contacts, all of this is screwed down onto a wooden base board and the two contact clips were tied together with a plastic tie at the top to stop movement. The result was a paddle key that is purported to be good for long QSOs at up to 20wpm.

One particular fix I really like concerns the rejuvenation of capacitors. Ceramic capacitors can be revived, not completely, but as a temporary measure, by heating the leads up with a soldering iron until they are too hot to touch.

The 19th edition of this book has gathered the best projects and solutions to problems between 2012 and 2016 and provides over 250 hints and kinks. The projects covered in the book are arranged into eight sections: Antennas, Around the Shack, Batteries and Power, Construction and Maintenance, Equipment, Interference, Restoration and Troubleshooting.

The back of the book contains an appendix with charts of RF connectors and transmission lines – a most useful reference.

I found this book to be a most unusual concoction of fixes and work-arounds and very useful indeed. Some of the things are so simple that you may never have thought of them yourself. Sometimes it's a case of 'it just works' and, using the tips in this book, you can solve an issue at a fraction of the usual price!

This is one of those books that every radio amateur should have on their bookshelf.

Size 184x229mm, 144 pages, ISBN: 9781 6259 5197 7
Non Members: £29.99, RSGB Members: £25.49

Technical

Raspberry Pi-based home-built radio test equipment

Introduction

The Raspberry Pi (hereafter RPi) family of single-board computers will be familiar to many radio amateurs, but most will have seen them used with an external keyboard, a mouse, and a display in a similar manner to a conventional PC. However, when used with a touch screen (ie without keyboard or mouse), it is well-suited to providing the basis of a simple, easy-to-construct, suite of radio test equipment. This article (and subsequent articles) will describe how to put together readily-available modules to build test equipment to meet your own requirements. Very little construction expertise is required as most of the interconnections use pre-existing connectors. There is some straightforward point-to-point wiring, and two of the optional modules can be constructed on Veroboard. You can use a commercial enclosure for the screen and RPi, or you can build your own.

The RPi 4, which was released several years ago and is due to be produced at least until 2026, has 26 general-purpose input-output (GPIO) connections, 2 USB3 sockets, 2 USB2 sockets, dedicated display and camera connectors, and 2 HDMI ports (see **Figure 1**). Together with a powerful ARM processor, this impressive array of interfaces makes it a good match for amateur-radio applications, and with a 7-inch touch-screen display added, it has been the basis of the British Amateur Television Club's (BATC) Portsdown amateur television transceiver for the last four years.

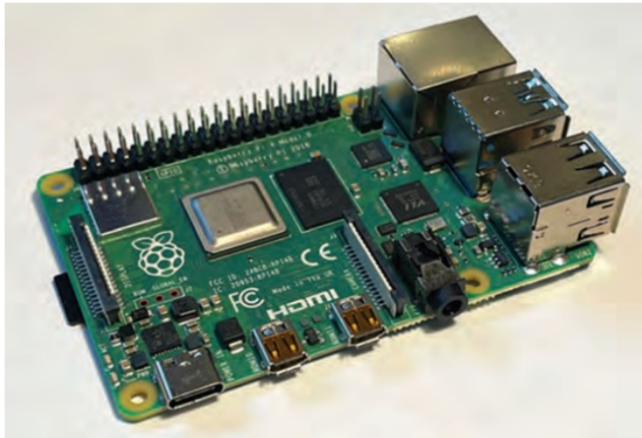


FIGURE 1: The Raspberry Pi 4.

The Portsdown system

The Portsdown system started out as a simple digital amateur-television transmitter, but has evolved to being a transceiver and a general-purpose test equipment 'appliance'. I use the word appliance as there is no computing involved in operating it; everything is controlled using touch buttons on the touch screen.

The first step in making one is to put the core system together; this involves no soldering, just connection of the RPi to the screen and power supply (see **Figure 2**). The 2GB version of the RPi 4 is adequate; there is no need for the extra expense of the 4GB or 8GB versions. The design is specific to the official RPi seven-inch touch screen. Very few other touch screens are compatible, and any that use an HDMI connection will certainly not work. The touch screen is connected to the RPi board using a ribbon cable, and only needs the ground and 5V power as additional connections; the other two wires on the cable are not required when using a RPi 4.

The build instructions for the software, which is free and open source, are straightforward and can be found at **[1]**. On GitHub, scroll down for detailed installation instructions. Alternatively, pre-built cards are available to BATC members from the BATC shop **[2]**. The main menu is displayed when the unit is switched on (see **Figure 3**). Simply touch M2 (menu 2) for the next menu, which gives access to the test-equipment capabilities (**Figure 4**). Once the required peripheral equipment has been connected, the signal generator or band viewer can be selected directly from this menu. More-advanced test capabilities can be selected from the test-equipment menu.

Test-equipment capabilities

Several test-equipment capabilities have been developed as part of the Portsdown project, and these will be described here or in subsequent articles. The test equipment is well suited to any radio amateur's test bench; it is not specific just to amateur television. The capabilities include:

- a signal generator covering 1Hz to 13.6GHz, and up to 30GHz at much-reduced power
- a band viewer which displays up to 50MHz of spectrum between 30MHz and 6GHz, and up to 30GHz at much-reduced sensitivity
- a receiver system noise-figure indication between 30MHz and 3.5GHz
- noise and carrier-level indications and comparisons between 30MHz and 3.5GHz
- power indication between 1MHz and 8GHz
- swept-frequency displays for filters between 30MHz and 3.5GHz
- a digital multi-meter display and logging for fault detection and measuring battery capacity; and
- an X-Y display and capture for older spectrum analysers

Each of these capabilities relies on external modules or interfaces that are connected for each specific role (see **Figure 5**).

When mounting the touch screen and RPi in an enclosure, remember that the USB connectors on the RPi need to be exposed for external connection, and the GPIO connections need to be available for the connection of external modules. An interface standard, using a 25-way D-type connector, has been proposed; this provides a mechanically-robust and error-free way of connecting (and powering) whatever external module is required for the task in hand. The connections are shown in **Figure 6**, and a picture of the connector mounted on the side of the enclosure is shown in **Figure 7**.

It is recommended that a 5V power supply is built into the same box as the RPi and display. This can either be a mains power supply, or one operating from a lower voltage. The output voltage should be set to exactly 5.2V, and connected directly to the RPi's GPIO pins 2 and 4 (both +5.2V) and 6 (ground). The reason for setting it to 5.2V, and connecting directly to the RPi (rather than through the USB-C power connector), is to ensure that USB-supplied peripherals receive at least 5.0V at maximum current draw.

The signal generator

The Portsdown signal generator can control a number of signal sources. It provides a touch-screen interface to allow these to be used for connection to other equipment. Selecting 'Sig Gen' from menu 2,

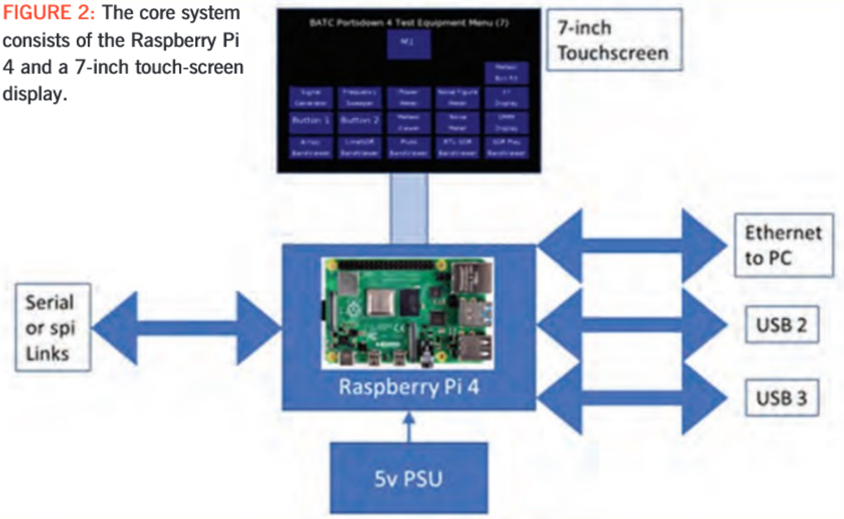


FIGURE 2: The core system consists of the Raspberry Pi 4 and a 7-inch touch-screen display.

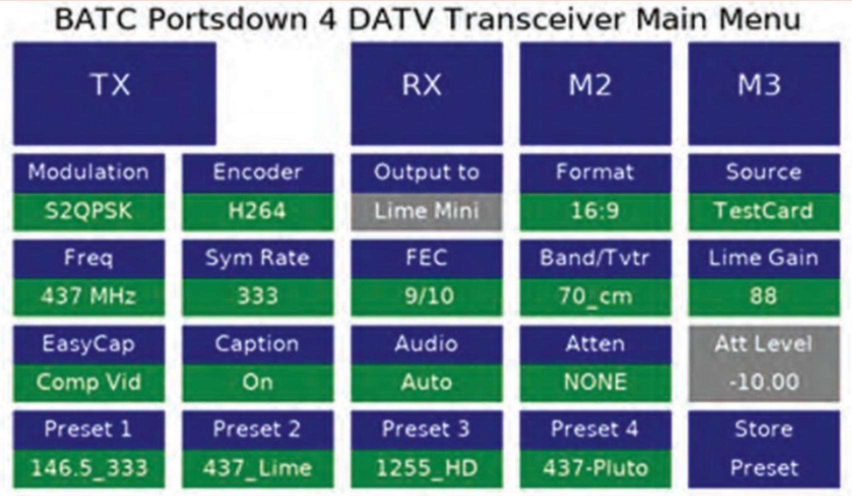


FIGURE 3: The Portsdown main menu.

or from the test-equipment menu, brings up the signal-generator main menu: see **Figure 8**. The bottom row of buttons is more or less self-explanatory. The 'Output to' button on the line above selects the desired RF signal source, and the 'Settings' button allows the reference frequency used by various sources to be set. The main control screen is selected from the 'CONTROL' button. The control screen (**Figure 9**) allows the frequency and amplitude to be set; it also allows the source to be switched on and off. A frequency and amplitude can be saved for future use. The optional signal sources and their capabilities are listed in **Table 1**.

The signal generator software can also drive a DATV Express, an Elcom microwave oscillator, and a NORT synthesized local oscillator. However, these devices are only occasionally available from surplus sources, and so are not discussed further here.

AD9850

The AD9850 is a direct digital synthesiser (DDS) with a fixed output that, in this application, covers from 1Hz to 50MHz. Modules having the IC and a clock oscillator fitted are available on eBay for under £20. A filter needs to be provided on the output to suppress the clock-oscillator signal. The AD9850 is controlled through its spi interface; the data clock needs to be connected to the RPi GPIO pin 29, the data line to RPi GPIO pin 31, and the FQ_UD line to RPi GPIO pin 8. The parallel data lines need to be hard-wired into serial data mode by setting pin 2 (D2) low, and both pin 3 and pin 4 (D1 and D0) high. The clock frequency needs to be set on the signal generator settings page. This is done by selecting 'Settings', 'Set clock for AD9850', and then 'Exit'. Set the AD9850 as the output device by selecting 'Output to' and 'AD9850 DDS'. On selecting 'Control', the desired frequency can be set, and the output turned on by selecting 'START AD9850'. The frequency can be adjusted with the output active. An external attenuator would need to be used to control the level.

ADF4351

The ADF4351 is a wide-band synthesizer covering 35MHz to 4.4GHz, with limited adjustment of the output level. Modules having the IC and reference oscillator are available on eBay for under £30, but SV1AFN sells better-quality modules with lower phase noise and higher output. The cheap eBay modules (see **Figure 10**) almost certainly use counterfeit ADF4351 ICs, and have been observed not to cover the full frequency range when used with reference oscillators above 25MHz. The exact reference oscillator frequency should be set in the 'Settings' menu. Note that the ADF4351 has a relatively-large minimum step size, so generated signals may be up to 5kHz away from the selected frequency. As with the AD9850, the spi clock and data lines should be connected to GPIO pins 29 and 31. The latch-enable line is connected to GPIO pin 33.

ADF5355

The ADF5355 is a wide-band synthesizer covering 54MHz to 13.6GHz, with limited adjustment of the output level. Modules with the IC and reference oscillator are available on eBay for around £150. Set-up and connection are similar to the ADF4351, except that the latch-enable line should be connected to GPIO pin 8.

LimeSDR

The LimeSDR is a versatile software-defined radio that comes in two major variants: the larger, more expensive, LimeSDR USB, and the smaller LimeSDR Mini. The signal-generator software works with both. The only connection required is a USB lead between the SDR and the RPi. To set up the LimeSDR, select 'Output to' and then 'Lime Mini'. On selecting 'Control', the frequency and amplitude menu will be shown with a red 'Cal Lime' button. Before using the LimeSDR, enter the desired frequency and press the 'Cal Lime' button. The SDR will calibrate (care: it outputs a burst of power at up to 10dBm as it does so), and the 'Start Lime Mini' button will become available for use. The amplitude of the output can be adjusted; the steps are uneven but a look-up table is used to estimate the output power available at that frequency and gain setting.

Dave Crump, G8GKQ
dave.g8gkq@gmail.com

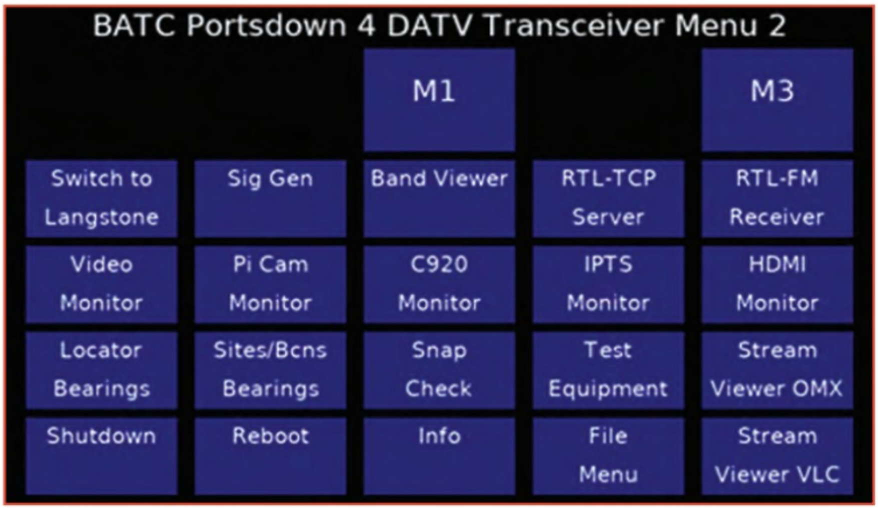


FIGURE 4: The Portsdown menu 2.

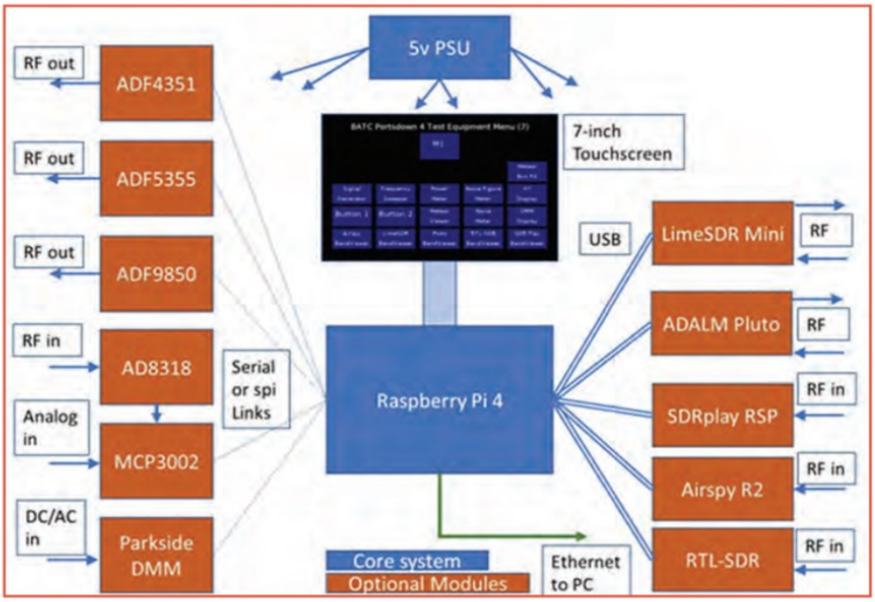


FIGURE 5: System block diagram showing the optional modules.

Pluto SDR

The Pluto SDR is more complicated than the LimeSDR in that it includes its own Linux processor. This processor must be loaded with the correct firmware; for the signal generator, any of the manufacturer's software loads, and the early ATV software 'v0.31-g9ceb-dirty' will work. When the signal generator is selected with Pluto as the desired output, a command is sent to reboot it, to make sure that its processor is in the correct state. As supplied, the Pluto covers the frequency range 325MHz to 3800MHz. It is easily possible to extend this range to cover 70MHz to 6GHz; to find the instructions, carry out a search on Google for 'pluto extended frequency range'. The gain setting on the Pluto allows the output level to be adjusted in 1dB steps; a look-up table is used to estimate the output at each frequency. Like the LimeSDR, the Pluto needs to be calibrated before it is used. Press the 'Cal Pluto' button and then the 'Start Pluto' button becomes active.

Pluto 5th-harmonic mode

The Pluto generates significant 3rd and 5th harmonics of its selected output frequency, and the 5th harmonic is slightly stronger. The signal generator has a 'Pluto 5th-harmonic' output mode, allowing frequencies in the range 6GHz - 30GHz to be generated. These signals are not strong (in the range -15dBm to -40dBm depending on the frequency), but are perfectly adequate for checking or aligning microwave receivers. The output level can be adjusted, but is not calibrated.

Limitations

The output from all of the sources described above is not spectrally pure. With the exception of the Pluto 5th-harmonic mode, the strongest signal will be on the selected frequency, but there will be harmonics and spurious emissions on other frequencies. The fundamental frequency in Pluto 5th-harmonic mode will be many times stronger than the desired signal. The frequency accuracy and stability is only as good as the reference oscillator in the source being used. Some of the sources have large minimum frequency steps. The amplitude calibration is based on experimental results on a sample of one or two output devices. It is very much a guide, and should be within ±5dB, but treat the figures with caution. Watch out for the high-power LimeSDR calibration spike. If you are using the signal generator to test a power amplifier, do not turn on the PA until after the LimeSDR has been calibrated.

In use

If you already possess any of the signal sources listed above, the Portsdown signal generator provides a convenient way to test receivers and power amplifiers on the bench without the need to invest in commercial equipment. I have also used it for aligning filters, but the sweep generator (to be described in a future article) is even better suited to this role.

BandViewer

The BandViewer was originally designed as a way of detecting digital ATV signals at signal strengths below that required for decoding. However, it excels as a spectrum analyser, covering a relatively-narrow bandwidth, but capable of being tuned over a large frequency range.

There are versions of the BandViewer for 5 commonly-used SDRs. Each SDR has different frequency coverage and maximum and minimum display widths (see **Table 2**). Once an SDR has been connected by USB, and 'BandViewer' is selected from menu 2, or from the test equipment menu, the appropriate BandViewer version for the connected SDR is started, showing a display similar to that in **Figure 11**.

The control buttons should be intuitive. The 'Settings' menu allows the selection of the centre frequency, the span width, and the SDR gain. There are also preset frequencies which can be selected from an editable list as quick alternatives to keyboard entry. The 'Markers' menu includes options to select and display the level of the most-powerful signal in the span, or to select a signal manually for level measurement. There is also a peak-hold function to show which frequencies within the band have been present since selection of the peak-hold function.

The 'Mode' menu offers the option for a 20dB full-scale range to allow easier observation of weak signals. When a LimeSDR, Pluto, or an

Standard External Interface

The Portsdown standard interface uses a female 25-way D-type connector connected to the Raspberry Pi unit as follows

25-Way Pin	RPi GPIO Pin	Function	RPi Name	Notes
1	-	Power Gnd	-	
2	-	+12v out	-	Can be +13.8v
3	-	spare	-	User-defined
4	-	spare	-	User-defined
5	-	spare	-	User-defined
6	-	+5v out	-	
7	26	Noise Source	GPIO 7	Battery load
8	29	SPI Clk out	GPIO 5	
9	31	SPI Data out	GPIO 6	
10	5	MCP3002 LE	GPIO 3	
11	3	MCP3002 Data in	GPIO 2	
12	8	ADF5355/AD9850 LE	GPIO 14	
13	6, 9, 14, 20	Digital Ground	-	
14	7	Band D2	GPIO 4	
15	12	Streaming switch	GPIO 18	
16	13	Shutdown LED	GPIO 27	
17	15	Shutdown button	GPIO 22	
18	32	Band D0	GPIO 12	
19	35	Band D1	GPIO 19	
20	36	Future use	GPIO 16	
21	37	Future use	GPIO 26	
22	38	Future use	GPIO 20	
23	40	Transmit LED	GPIO 21	
24	10	Attenuator LE	GPIO 15	
25	33	ADF4351 LE	GPIO 13	

The high-speed data signals (particularly the SPI clock and SPI data signals) have high-speed switching edges which can cause ringing (overshoot) in wiring longer than a few cm. This can cause data errors. I overcame this problem by fitting a series 220Ω resistor in all the fast-switching lines (pins 8–12, 23, 24 and 25) adjacent to the Raspberry Pi connector.

I did not fit any specific protection for the Raspberry Pi inputs or outputs. This does leave them susceptible to static and over-voltage, but they are reasonably tolerant. Remember that any inputs use 3.3V logic, not 5V.

FIGURE 6: Connections on the standard interface.

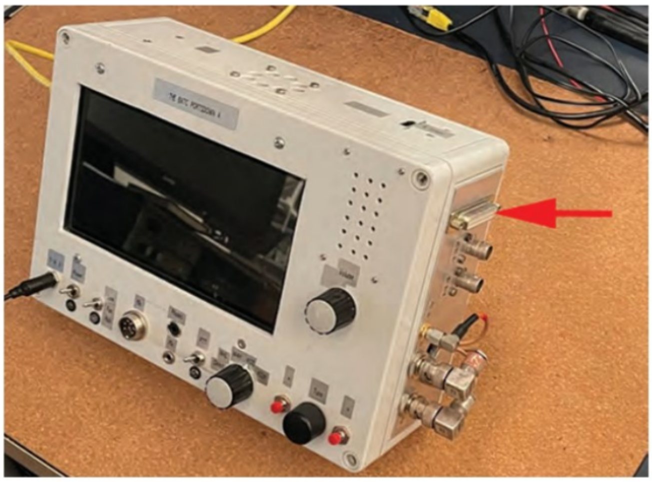


FIGURE 7: The Portsdown system in a plastic enclosure with the standard interface indicated by the red arrow.

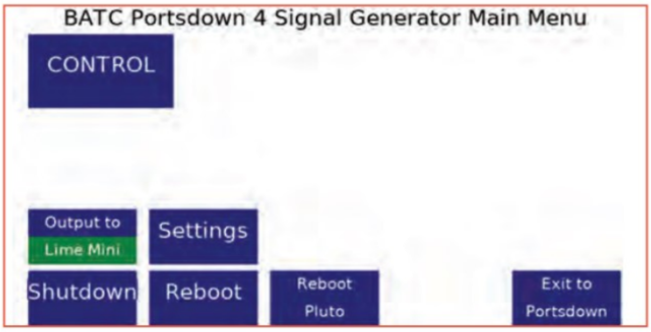


FIGURE 8: The Portsdown signal generator main menu.

SDRplay is being used, a waterfall or a mix of waterfall and spectrum displays is also available. The left and right arrows allow the centre frequency to be decreased or increased by 10% of the span for each press of the button.

The 'System' menu includes the capability to restart the application, shut down the RPi, or access the configuration menu to change the plot title or the preset frequencies.

Calibration and spurious responses

The frequency calibration is as accurate as the reference oscillator used in the SDR. The relative amplitude calibration between two signals, or one signal at changing level, is very accurate, but the absolute calibration varies with frequency and is totally dependent on the SDR.

Some of the SDRs have a lot of spurious responses; the SDRplay and Airspy have the least. The 'DC spike' at the centre frequency can be quite prominent at some gain settings. This is a feature of the SDR, and can be reduced on the Pluto or LimeSDR by re-calibrating the SDR (from the 'System' menu).

Choice of SDR

BandViewer is intended for use with existing SDRs, and it is hard-coded for each SDR, so will only work with those listed. If purchasing specifically, look at Table 2 and check prices and availability. If in doubt, start with a cheap RTL-SDR; they are good value for money. Here is some more information about the listed SDRs.

The LimeSDR Mini is expensive, but has a good frequency coverage and multiple displayed frequency spans. It needs re-calibration after large frequency changes, but offers good performance. It is also the only SDR that works with the Portsdown noise-figure meter, noise meter, and sweep generator, to be described in future articles.

The Pluto covers up to 6GHz, but only shows wider span widths. As with the signal generator, it can be operated in 5th-harmonic mode, and so can display (with much reduced sensitivity) signals up to 30GHz.

The SDRplay series of SDRs have excellent performance with coverage down to 1kHz, and are relatively free from spurious responses. Note that BandViewer is not compatible with the recently-released RSP1B or RSPdx-R2. Also, beware of the cheap SDRplay clones available, as these have much-reduced sensitivity and a lot more spurious responses; you really do get what you pay for!

The Airspy R2 has excellent performance relatively free from spurious responses, and good sensitivity, although only the wider display widths are available. Note that BandViewer does not work with other members of the Airspy family, only the R2.

The RTL-SDR is very cheap, and the official 'RTL-SDR.COM' version 3 offers good performance for its price. Note that version 4 is not compatible with BandViewer.

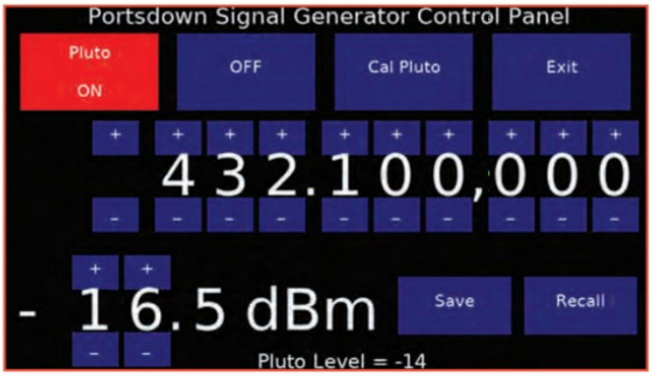


FIGURE 9: The signal-generator control screen.

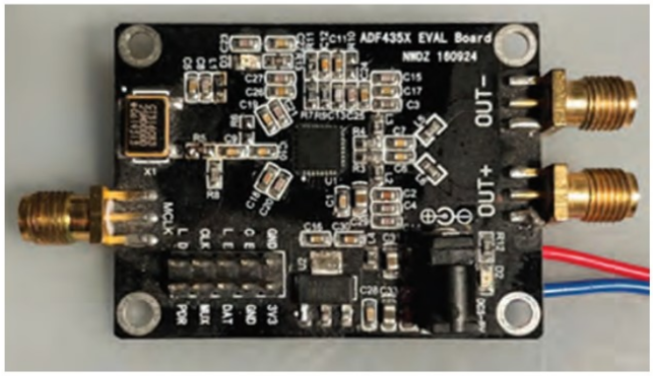


FIGURE 10: An eBay ADF4351 PCB.

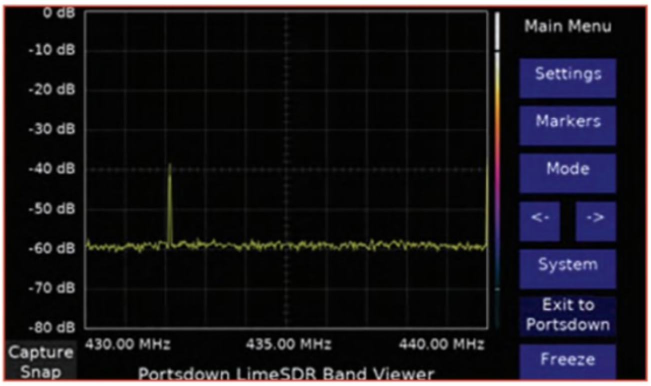


FIGURE 11: The BandViewer showing a carrier on 432.1MHz.

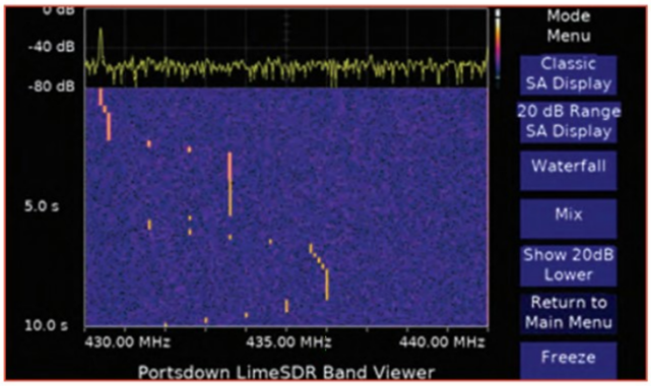


FIGURE 12: The waterfall, or a split display between the spectrum and the waterfall, is selected from the 'Mode' menu.

Waterfall capability

A waterfall display has recently been added for the LimeSDR, Pluto, and the SDRPlay. The waterfall, or a split display between the spectrum and the waterfall, is selected from the 'Mode' menu (see **Figure 12**). The characteristics of the waterfall, such as the length and colour mapping, can be adjusted from the 'Waterfall Config' menu.

System features

When specifically enabled (from the 'System' menu), all features can be controlled from a web browser. On your PC (or smart phone), enter the network IP address of your Portsdown. You can look this up from the info screen, menu 2. Then you can click on the buttons as though you were touching the touch screen. However, the screen only refreshes once per second, so some patience is required, but it does mean that you can control the signal generator or use the BandViewer (again with a one-second refresh rate) from anywhere that is connected to your domestic LAN. This can be very useful for adjusting aerials in the garden or loft. The BandViewer can be paused, or you can take screenshots of the display. These screenshots can be downloaded from the SD Card, or accessed through the web-browser interface.

Table 1: The optional signal sources and their capabilities.

Source	Frequency range	Approximate amplitude range (dBm)
AD9850	1Hz - 50MHz	Fixed at about -5
AD4351	35MHz - 4.4GHz	-9 to 0
AD5355	54MHz -13.6GHz	-8 to +5
LimeSDR	30MHz - 3.5GHz	-30 to +10
Pluto SDR	70MHz - 6GHz	-60 to + 5
Pluto SDR	6GHz - 30GHz	Less than -35

Table 2: The characteristics of each SDR.

SDR	Frequency coverage	Span widths	Notes
LimeSDR	30MHz - 3.5GHz	100, 200, 500kHz 1, 2, 5, 10, 20MHz	LimeSDR Mini or LimeSDR USB
Pluto	70MHz - 6GHz	2, 5, 10, 20, 50MHz	
Pluto 5th-harmonic	6GHz - 30GHz	2, 5, 10, 20, 50MHz	Reduced sensitivity
SDRplay	1kHz - 2GHz	100, 200, 500kHz 1, 2, 5, 10MHz	
Airspy R2	24MHz - 1.7GHz	1, 2, 5, 10MHz	Airspy R2 only
RTL-SDR	24MHz - 1.7GHz	500kHz, 1, 2MHz	Not V4

Summary

This article has described just two of the test-equipment capabilities of the Portsdown system. Future articles will describe how to use this home-built system to measure noise figure, characterise filters, and measure power. Full construction details for the Portsdown 4 are on the BATC Wiki **[3]** and there is a helpful discussion forum on the BATC Forum **[4]**.

References

[1] https://github.com/BritishAmateurTelevisionClub/portsdown4
[2] https://batc.org.uk/category/portsdown/
[3] https://wiki.batc.org.uk/The_Portsdown_DATV_transceiver_system
[4] https://forum.batc.org.uk/viewforum.php?f=103

Measuring height of reflection at HF

Sky-wave propagation at HF relies on radio waves refracted, bent downward, back to Earth. Refraction results in a curved path within the ionosphere, but a convenient simplification is to treat the path as a reflection with a sharp apex known as the virtual height [1].

Introduction

While the terms 'regions' and 'layers' are often used interchangeably, here I'll refer to the E and F regions, and F1 and F2 layers within the F region **[2]**. Virtual height, together with the operating frequency, and the reflecting region or layer's critical frequency, are key factors affecting minimum and maximum one-hop distances. Height of reflection varies with the time of day, the season, and the phase of the 11-year solar cycle. Changes in height are well illustrated by a diagram in the *Radio Communication Handbook's* Propagation chapter [1], reproduced here in **Figure 1**. These depictions represent the climate of the ionosphere, that is, they are typical of long-term behaviour. Actual day-by-day or hour-by-hour changes may be somewhat different. Consequently, the height of reflection is one of many variables constituting 'space weather'.

For ground-based routine measurements of heights, the professional instrument is the 'ionosonde'. Every 5 to 15 minutes, instruments within a global network of these specialised HF radars, typically sweeping from 1MHz to 25MHz, measure heights immediately overhead. Ionosondes have three major limitations: the measurements are for one location, are only for overhead at that location, and the global network is sparse. 37 ionosondes reported data on 20 May 2024 to the Global Ionosphere Radio Observatory (GIRO). The UK Chilton ionosonde had not reported data to the GIRO for the previous 34 days, but its latest ionogram may be available **[3]**.

In contrast to this dwindling ground-based measurement capacity, there is growing interest in space-weather measurements by the amateur-radio and citizen-science communities. One example is the 'personal space weather station' initiative from HamSCI **[4]**. Their 'Grape' project, comprising software-defined radios (SDRs) and a data acquisition and reporting system, has been designed specifically to observe changes in the ionosphere. Over 30 stations in North America are involved, measuring the Doppler shift and signal level of standard frequency transmitters WWV, WWVH and CHU. An eighteen-author scientific paper on their early results illustrates substantial collaboration between professional scientists and the amateur-radio community **[5]**.

This article shows how readily-available items, SDRs, and low-cost precision GPS-disciplined oscillators (GPSDO), with WSPR or FST4W digital communications protocols from WSJT-X, can be used to measure variations in reflection height. The morning descent of the F2 layer, and the change in height induced by the October 2023 annular eclipse over North America, are shown as worked examples.

Vertical vs oblique measurements

An ionosonde measures the virtual height h of regions and layers from the time delay of echoes:

$$h = ct/2,$$

where c is the speed of light and t the echo time delay for returns from the E and F regions and F1 and F2 layers. Reduced c in the ionosphere, a plasma, is accounted for in the electron density profile.

In contrast, height observations on an oblique path by amateurs, at least currently, measure path length change which results in a Doppler shift, rather than the absolute time of travel. We do have to assume a negligible change in ionospheric electron density as this affects the speed of light. This is normally a safe assumption, but not during extreme events such as sudden ionospheric disturbances caused by solar flares **[6]**. Changes in reflection height can be inferred using simple geometry, while absolute height can be found by adding a constant of integration. This constant could come from an ionosonde once a day. An enticing feature of the oblique path method is that multiple measurements at multiple frequencies can be made over extensive areas from one transmitter and multiple receivers.

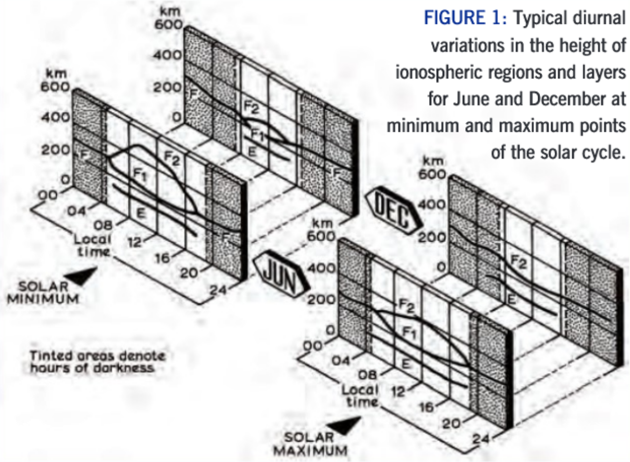


FIGURE 1: Typical diurnal variations in the height of ionospheric regions and layers for June and December at minimum and maximum points of the solar cycle.

Measuring Doppler shift

Figure 2 shows the variation of Doppler shift at 7.04MHz on a 1,310km path from G3ZIL, Southampton UK, to Gerhard, OE3GBB, eastern Austria, with time of day and day of year from mid-winter to mid summer. Many aspects of propagation can be seen, but it is the positive Doppler shift in the morning as reflection height descends, and the negative Doppler shift in the evening as reflection height ascends, that concern us here. Immediately clear is that our measurements must be both stable, and accurate, to much better than 1Hz.

The block diagram in **Figure 3** shows the equipment used to gather the Doppler data of Figure 2. The gold standard for stability and accuracy is the GPSDO. Both the QRP Labs QDX digital-modes transceiver, and the KiwiSDR receiver, have had hardware and software modifications made by their manufacturers to improve frequency accuracy and stability, and to make it easier to use external clocks.

WsprDaemon software from Rob Robinett, AI6VN, enables simultaneous multi-band recording and reporting of WSPR and FST4W spots from KiwiSDRs (8 or 14 bands), or RX888 Mk II receivers running Phil Karn's ka9q-radio (15 WSPR/FST4W bands and 10 standard time bands simultaneously) **[7]**. While wsprnet.org only reports frequencies with 1Hz resolution, WsprDaemon reports with 0.1Hz, just adequate for this study.

Doppler variation: daily pattern

Measuring Doppler shift is the first step in finding reflection height. **Figure 4** shows the Doppler shift for simultaneous FST4W-120 transmissions on the 3.5MHz, 7MHz and 10MHz bands from Tom, WO7I, to Dennis, ND7M, both in Nevada, spanning 14-15 October 2023. First, we'll look at the Doppler shift around sunrise. The 3.5MHz frequency had been open during the night on this 545km

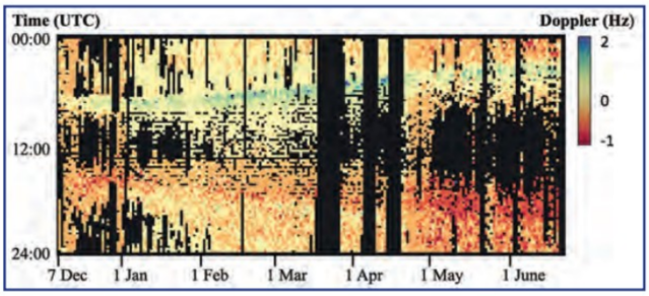


FIGURE 2: Doppler shift averaged over 15-minute intervals for 7.04MHz FST4W-120 transmissions from G3ZIL to OE3GBB over a 1310km path from December 2023 to June 2024. Black regions with no data were times of no propagation or when G3ZIL was not transmitting.

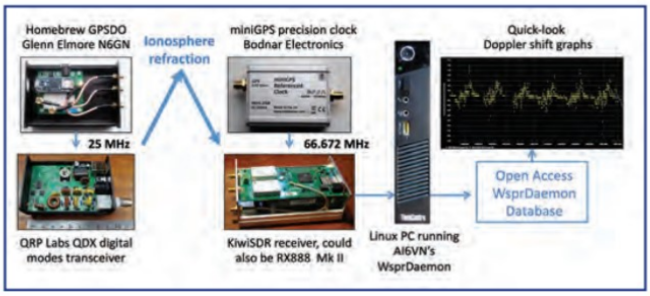


FIGURE 3: A block diagram, showing examples of general-purpose items needed to make routine simultaneous multi-band measurements of Doppler shift and signal level on the HF bands and of time-standard stations.

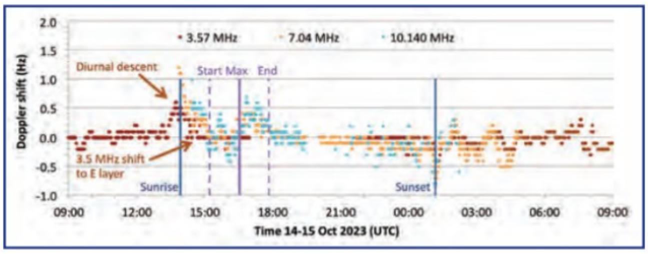


FIGURE 4: Doppler shift on the 545km path from WO7I to ND7M, both in Nevada, showing the diurnal pattern at 3.5MHz, 7MHz and 10MHz, and the effect of the annular eclipse of 14 October 2023.

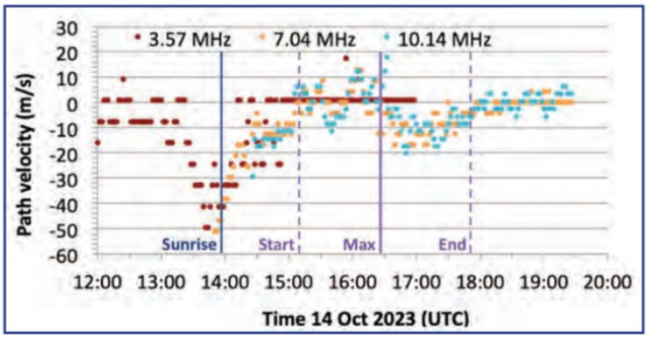


FIGURE 5: After converting Doppler shift to rate of change of path length, the measurements at three frequencies coalesced. The exception was when the 3.5MHz path reflected from the E region.

path. Doppler shift started to increase before sunrise at ground level, sunrise occurring earlier at the height of the ionosphere, reaching a maximum of 0.6Hz. The refracting F2 layer was descending, reducing the path length, and producing a positive Doppler shift. As the layer descent slowed, the Doppler shift reduced, reaching zero at 1424UTC just over an hour after it had started to rise.

The 7MHz frequency opened too late to capture the initial descent, but showed a 1.2Hz Doppler shift around the time of most rapid descent. The 10MHz frequency opened later still, but captured the later part of the F2 layer's descent.

The positive Doppler shift at 7MHz and 10MHz showed the descent of the F2 layer continuing after 1424UTC, yet the 3.5MHz Doppler shift was zero. Why the difference? These results suggest that dominant propagation at 3.5MHz shifted from the descending F2 layer to the E region, which, as in the handbooks (eg Figure 1) hardly changes height.

The 3.5MHz frequency opened before sunset, initially via E-region propagation with low Doppler shift, but by sunset all three bands were showing a negative Doppler shift from the path length increasing, ie the F2-layer reflection height rising. The initial rise was followed by at least two sinusoidal cycles with a period of about 100 minutes. These were probably caused by travelling ionospheric disturbances, fascinating features affecting propagation that have been studied by ionospheric physicists using amateur radio techniques **[8]**.

The rate of change of the path length

Focusing on the morning descent, the second step in finding reflection height is to convert Doppler shift, δf in Hz, to rate of change of path length, δP in metres per second:

$$\delta P = -c\delta f / f \; ,$$

where f is the operating frequency. Dividing by the operating frequency collapses the frequency-dependent Doppler shifts in Figure 4 onto the same pattern of path rate-of-change, irrespective of frequency, **Figure 5**.

Reflection height

This is the trickiest step, requiring simplification, trigonometry, and a single measured overhead height from an ionosonde. **Figure 6** shows the simplified geometry for a one-hop path. Reflection is shown as a sharp apex to the path at I. We know the distance, d, between WO7I and ND7M, 545km, and R, the radius of the earth, taken as 6371km. The angle θ (in radians) is given by

$$\theta = d / 2R \, .$$

Transmission path length, P, is the distance TX -> I -> Rx, which we do not know; we only know how rapidly the path changed. However, if we knew the reflection height, h, at one time, t_0, we can calculate path length at that time, P_0, from the equation:

$$P_0 = 2\sqrt{(R\sin(\theta))^2 + (h + R(1-\cos(\theta)))^2} \; .$$

For the initial height, it was convenient to take the average of the minimum virtual height (227km) and the peak height (247km) of the F2 layer at 1445UTC from the ionosonde at Point Arguello, 570km SW of the midpoint between ND7M and WO7I **[3]**.

Our WSPR and FST4W measurements are 120s apart. After two minutes, the path length, P_t, would become

$$P_t = P_0 + 120\delta P \; ,$$

which is simply the path velocity multiplied by the time interval, added to the initial distance. We then rearrange the equation for P_0 to estimate the reflection height, h_t, at time t, as follows:

$$h_t = \frac{1}{2}\sqrt{P_t^2 - (2R\sin(\theta))^2} - R(1-\cos(\theta)) \; .$$

Gwyn Griffiths, G3ZIL
gxgriffiths@virginmedia.com

After repeating the summation and height calculation for each successive two-minute interval, we have a time series of reflection heights, **Figure 7**. The blue vertical line at 1445UTC shows when we took the 237km reference height from the Point Arguello ionosonde. The 3.5MHz data usefully covered the 100km descent from 325km to 225km. As the 7MHz path, then 10MHz, opened they traced a similar descent. During descent, the inferred virtual height at all three frequencies lay just below hmF2, the height of the F2 layer peak electron density, rather than its minimum virtual height h'F2. After 1700UTC the picture changed: the reflection heights followed h'F2.

Effects of the annular eclipse

Magenta lines on Figures 4 and 5 show the times of the start of the eclipse, maximum obscuration (91%), and end. While small, at no more than 0.7Hz, there was a clear, consistent, pattern to the Doppler shift at 7MHz and 10MHz. After conversion to path velocity, Figure 5, while there was some scatter, both frequencies showed approximately the same path velocity pattern during the eclipse.

Figure 8 shows the reflection height centred on the time of maximum obscuration. Also shown is the average reflection height from the same equipment the following day. The disturbance caused by the eclipse stands out. As the eclipse started, diurnal descent was held in check: the effect of the rising Sun appeared to be balanced by the dimming effect of the eclipse. From halfway between the start and the point of maximum obscuration, the dimming more than countered the rising Sun: the F2 layer rose, as it does each evening. After maximum obscuration, the reflection height descended, ending close to its value measured the following day. The maximum height change was 30-35km.

To verify these results from FST4W transmissions, the magenta trace in Figure 8 shows the same analysis applied to continuous Doppler-shift measurements of WWV's 10MHz signal received by the HamSCI Grape receiver at St. George, Utah, an 830km path with its midpoint 680km east of the WO7I to ND7M midpoint. The difference between reflection height measured by the two systems at the eclipse maximum was only 2 km, and the later peak on the WWV to St George path was mostly because maximum obscuration was seven minutes later.

End note

Studies of changes in the height of ionospheric reflection can now be made with easily available receivers and transmitters using the WSPR or FST4W modes. The necessary precision does require GPS-disciplined oscillators, but these are readily available and affordable items. The data reporting path via WsprDaemon is well proven and, as we've seen, the mathematics to go from measured Doppler shift to reflection height is straightforward. It has never been easier for a radio amateur to study this fascinating aspect of space weather.

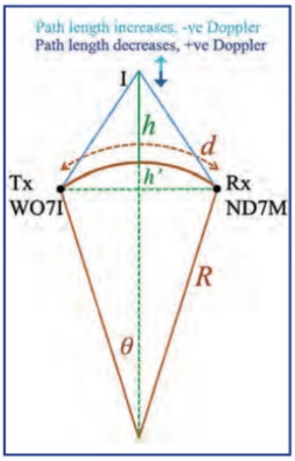


FIGURE 6: Simplified geometry for a one-hop path to convert from path length to reflection height.

Acknowledgment

I am grateful to Rob Robinett, AI6VN, for WsprDaemon and the WSJT-X development team for FST4W. Specific data for this article came from Tom Bunch, WO7I, using the WsprSonde transmitter from Paul Elliot, WB6CXC, and the receivers of Dennis Benischek, ND7M, Lee Phebus, KF7YRS, and Gerhard Burian, OE3GBB. Ionosonde data from Point Arguello via GIRO was released under CC-BY-NC-SA 4.0 license, with gratitude to the Point Arguello team.

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[3] Global Ionosphere Radio Observatory ionosonde database at https://giro.uml.edu/didbase/. The latest Chilton ionogram may be available at https://www.ukssdc.ac.uk/cgi-bin/digisondes/latest_view2gif.pl?Station=chilton (registration needed)

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[8] Frissell, N.A. et al., 2022. First observations of large scale traveling ionospheric disturbances using automated amateur radio receiving networks. Geophysical Research Letters, 49(5), p.e2022GL097879. Available at https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GL097879

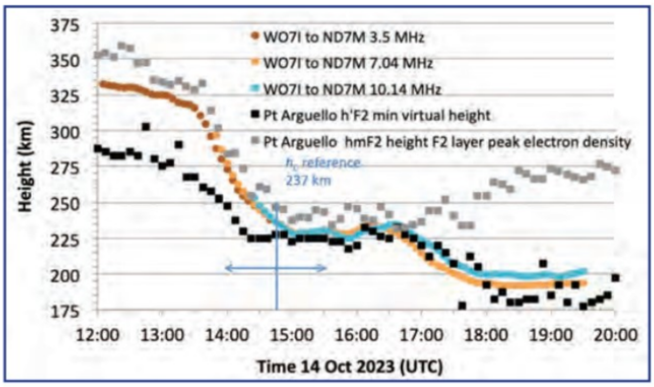

FIGURE 7: Reflection heights at three frequencies on the 545km path from WO7I to ND7M, calculated from the observed Doppler shift and a single reference height from the Point Arguello ionosonde at 1445UTC on 14 October 2023. Also shown are the F2 layer minimum virtual height, and peak electron density height, as reported by the ionosonde.

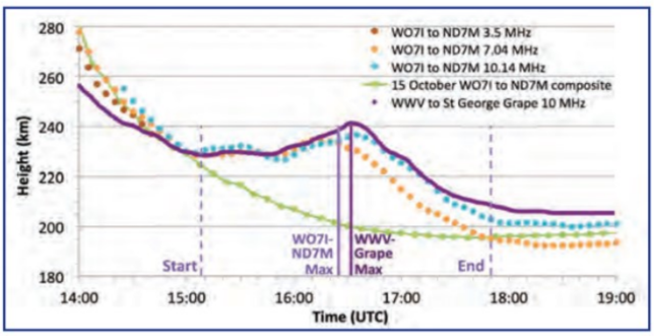

FIGURE 8: FST4W Doppler-derived reflection heights during the 14 October 2023 eclipse on the 545km path from WO7I to ND7M, and on the 830km path from continuous Doppler measurements of WWV 10MHz to the Grape receiver at St George, Utah. Comparison with the computed height for 15 October shows the effect of the eclipse in raising the height of reflection.

Review

FNIRSI DPOX180H handheld oscilloscope

An oscilloscope is a useful instrument for the amateur radio shack and, like many other amateurs, I have owned at one time or another some bulky and old, but still useable, examples.

After downsizing my shack space considerably, I decided it was time to buy a small modern handheld device as a second oscilloscope, and there are many to choose from, including a number from various Chinese manufacturers.

Introduction

I spent some considerable time reading and watching reviews of various models on YouTube. I came across the FNIRSI DPOX180H, which seemed to offer good performance at a relatively low cost. In this review, we'll look at the features of this instrument with a view to using it in the radio amateur's shack.

Features

The FNIRSI DPOX180H is a handheld two-channel oscilloscope measuring just 140mm x 9mm x 35mm and weighing about 283g. The case is of high-quality plastic construction with a rubber buffer around the sides, and fits nicely into the palm of the hand (see **Figure 1**). The screen is a digital phosphor multi-colour display usually only seen on oscilloscopes of much higher cost, and measures 60mm x 45mm (320 x 240 pixels). Input connections are via BNC female sockets on the top of the instrument, which are recessed for safety whilst testing high voltages (see **Figure 2**), although this does make it somewhat difficult to attach and remove BNC leads. There is also a rudimentary signal generator built into the unit, the output of which is available from rather crude protruding terminals either side of the USB C charging/data port.

The unit has a rather flimsy pop-out tabletop stand. A basic multi-language instruction manual is included in the package, although this does not list the specifications which are printed instead on the bottom of the box. Also included in the box are a USB C lead (possibly only wired for charging), a two-pin AC charger (type A), and two good-quality 200MHz BNC probe leads with selectable x1 or x10 settings (with compensation trimmer). The unit will run for approximately 3h-4h on the internal lithium-ion battery. Firmware updates are available. At the time of writing this review, there doesn't appear to be any PC-control software available.

The analogue bandwidth is specified to be 180MHz, with a maximum sampling rate of 500MSa/s. The vertical amplifiers have a rise time of 1.8nS with sensitivity settings of 5mV to 10V per cm. The time base ranges from 5ns to 50s per division. The storage depth is 120k points, and the accuracy is ±2%. There are up to 90 sheets of screen storage available. Other specifications can be seen at **[1]**.

In use

The FNIRSI is reasonably straightforward to use, although some time is needed to become familiar with the menu as the manual doesn't cover the full capabilities of the instrument. After switching on, there is a brief interlude before the boot-up screen appears with both channels active in DC input mode. The screen brightness is excellent and will allow use outside even in sunlight. I found the control buttons to be responsive, except perhaps the ON/OFF button; this really could have been better placed as it could easily be switched on accidentally if placed in a bag or a box. If you intend to use the instrument outside, it would be advisable to buy a hard-shelled case to avoid accidental switch-on. There are dedicated menu shortcut buttons for each channel, measurement parameters, and trigger settings, which negate the need to scroll through the menu. The oscilloscope defaults to the boot-up screen when switching on each time, which is somewhat inconvenient, although you can save your usual settings and load them after switch-on. It took me a while to work out how to switch between channel traces, but eventually discovered that this was done by pressing the MOD/OK button.

The oscilloscope allows a range of parameters to be displayed on the screen at any one time, including (amongst others) rms voltage and average voltage. These can be selected by pressing the 'MEAS' (measure) menu shortcut button.

Trigger options include mode (auto, single, normal), trigger edge, and HF rejection. There isn't an option for trigger hold-off adjustment. There is no provision for external triggering. The unit has menu options for baseline calibration and instrument calibration, during which you are prompted to remove any probes and the USB data/charging lead. Presumably the calibration involves the use of some internally-generated wave from the built-in signal generator. The instrument also has a crude FFT function which cannot be adjusted in any way and is more of a gimmick which doesn't really provide any useful information.

FIGURE 1: **FNIRS DPOX180H fits nicely in the hand.**

FIGURE 2: **Input sockets and output ports.**

Test measurements

I carried out several tests with the instrument to examine the claimed specifications and determine just how useful this would be for typical measurements by radio amateurs. Some of the measurements were compared with those made using an old, but recently-calibrated, SCOPEX 4D10B oscilloscope (10MHz bandwidth). RF measurements were made using BNC patch leads (RG8 mini) with adapters where needed.

RF voltage measurements

The first test was to check the claimed bandwidth of 180MHz; this required turning off one channel as the bandwidth drops with both active (the bandwidth with both channels active is 125MHz as the Nyquist limit is approached **[2]**). I fed a 180MHz sinusoidal signal at -17.5dBm from my Tiny SA Ultra into the instrument using a BNC T-piece and 50Ω load. Whilst the signal was resolved, there was considerable jitter on the display, and the voltage reading was high, showing 108mV peak-to-peak (pp) instead of the expected value of around 84mV pp. I then tried it with a 144MHz signal, this time with a carrier generated by my Yaesu FT-817 connected to a 50Ω load. There was considerably less jitter at 144MHz compared with the 180MHz signal, although once again the voltage reading was on the high side. The display showed 48.6V pp, suggesting that my FT-817 was putting out around 5.9W, when in fact it was just under 5W as measured on my Bird 43 watt meter. I moved on to a test at 70MHz; this time the displayed trace was stable, and the pp voltage reading was 49.7V, giving about 6.2W,

FIGURE 3: A two-tone SSB test at 144MHz using a Yaesu FT-817.

FIGURE 4: A two-tone SSB test at 1.81MHz using a Yaesu FT-710.

close to the 6W reading of my Bird meter. Finally, I fed a carrier at 1.8MHz into the instrument which gave 43.9V peak-to-peak; this was in close agreement with my SCOPEX 4D10B oscilloscope, and gave a calculated output power of 4.8W, compared with 4.5W on the Bird meter.

Voltage sensitivity

The specification claims a minimum voltage sensitivity of 5mV/cm, which is unusual for an instrument in this price bracket. I made several measurements of a sine wave generated by my Tiny SA Ultra spectrum analyser, which also has a built-in signal generator. A 500kHz output at -36dBm into a 50Ω load was measured at 11.2mV pp on the FNIRSI, and at about 11mV on my SCOPEX, both slightly above the theoretical value of 10.02mV pp, although it should be noted that the output from the Tiny SA Ultra will not be as precisely calibrated at this level compared to a dedicated more-expensive signal generator. Changing the output to -46dBm gave 4.5mV pp on the FNIRSI and about 4mV pp on the SCOPEX (theoretical value 3.2mV pp). It was noted that the FNIRSI displayed a stable and well-defined sine-wave trace on the 5 mV/cm scale.

DC voltage measurements

Several DC voltage measurements were taken from 6V up to 28V using the supplied probes. These all agreed within one decimal place with my digital multi-meter, although the V/cm scale needed to be set at a level closest to the measured voltage (eg 10V/cm scale when measuring 13.8V DC), otherwise a low reading was obtained.

Two-tone linearity tests

A useful test with an oscilloscope is to check the linearity of a transmitter, and so I wanted to see how the FNIRSI would perform. I started by looking at linearity in the 144MHz band, comparing the output from a Spectrum Communications two-tone generator between the FNIRSI and the SCOPEX 4D10B. The peak voltages and pattern shape were in close agreement. I then fed the minimum output from the generator into the microphone socket of my FT-817 and obtained the trace shown in **Figure 3**. Whilst there was some jitter in the display at 144MHz, together with a tendency for the output voltage to read high, the FNIRSI was useable at 144MHz for qualitative assessment such as might be seen in two-tone testing.

I carried out the same test on several other bands, including 70MHz, and 1.81MHz, all of which were done at low power. The two-tone tests at 70MHz and below all produced stable, jitter-free, waveforms. The 1.81MHz two-tone test is shown in **Figure 4**. The 1.81MHz test was also repeated on the SCOPEX 4D10B (10V/cm scale) for which there was reasonable agreement with the FNIRSI (**Figure 5**).

Signal generator

The built-in signal generator of the unit is accessed by pressing the 'GEN' button. The maximum frequency was found to be 20MHz, and whilst the output is reasonably stable across the whole frequency range, there is no apparent way to adjust the output level, which is around 1V pp. There are fourteen waveforms available, including sine and square waves. It is worth mentioning that there is signal output present on the generator pins even when the unit is not in generator mode.

Data storage and manipulation

The FNIRSI allows screenshots to be saved as bitmap (.bmp) files, as well as whole traces which are stored as .wav files. Saved .wav files may be manipulated after reloading. Screenshots and saved waveforms can be transferred to a PC via a USB C cable. USB sharing needs to be enabled in the menu settings for data transfer to a PC. I saved several screenshots but was unable to download these to a PC using the low-quality supplied USB C cable. I tried a good quality USB C lead, and this worked fine. It may be that the supplied USB C lead is wired for charging only. I also downloaded several saved .wav files, but these files were not recognised by any of the media apps on my PC.

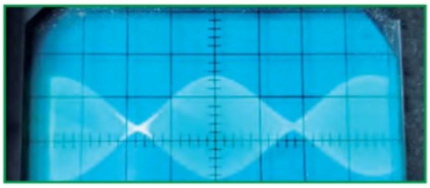

FIGURE 5: A two-tone SSB test at 1.81MHz using a Yaesu FT-710 measured on a SCOPEX 4D10B oscilloscope.

There is a dedicated data browser in the menu system, and this is easy to use.

Conclusion

The FNIRSI DPOX180H is well priced given its specifications and represents excellent value for money. However, this is not a high-end oscilloscope, but will serve well for the straightforward measurements at frequencies up to about 50MHz. I didn't do much testing with both channels active for this review, as the screen became rather crowded.

There are some limitations to the use of this instrument, including a tendency to random crashing, necessitating a reboot. Taking all the pros and cons into account, a portable oscilloscope such as this would be a useful addition as a second instrument, or as an entry-level instrument. There are two full reviews on YouTube that are worth watching before considering purchase at **[2]** and **[3]**.

The FNIRSI DPOX180H costs around £90 and is available on Ali Express and Banggood. There are also some UK sellers on EBay.

References

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Andy Gilfillan, G0FVI
andrew.gilfillan@ntlworld.com

The CW Spotter

Here is something for fans of CW to help pick out weak signals in a noisy background. The 'CW Spotter' locks onto the signal and provides an LED indication when within a few Hz of the desired sidetone frequency.

FIGURE 1: The completed CW Spotter.

Introduction

This isn't an original design, but it encompasses more-recent technologies with surface-mount components. The circuit is based on the LM567 IC which was originally designed by National Semiconductor, now part of Texas Instruments. National Semiconductor released this chip as a general-purpose PLL tone decoder in the 1970s. Although tone detectors for CW have been published based on this and similar ICs, I wanted a bespoke unit into which I could plug a headphone jack, and listen to the received audio without interrupting the detector function. This led me to design a PCB primarily using surface-mount components to fit rather neatly into an anodized aluminium enclosure measuring just 55mm x 25mm x 85mm, with bespoke silk-screened end panels to give it a professional look (see **Figure 1**).

The side-tone detector, or 'CW Spotter', uses the LM567CM variant general-purpose tone decoder in surface-mount SOIC 8-pin silicon. This has excellent performance even in quite adverse signal-to-noise ratios (SNR). The manufacturer claims that it will typically lock on to tones with -6dB SNR buried in wide-band noise, ie it can resolve a signal 6dB below the noise floor. The IC architecture, shown in **Figure 2**, includes an integrated voltage-controlled oscillator (VCO), together with I and Q phase detectors that are designed to saturate an open-collector output when the input signal is within the pass band. The VCO frequency is adjustable, and set by an external timing resistor and capacitor. Tone-detection bandwidth is determined by an external capacitor, and this can be quite narrow, from 0 to 14% of the received tone frequency.

Details of the circuit

The circuit diagram of the CW Spotter is shown in **Figure 3**. The incoming audio-frequency signal from the receiver is looped through to an external speaker and a tip-switched headphone socket. For safety, the speaker ground is independent and floating, thus there is no direct connection between the speaker and the external supply ground. R5 is normally fitted to connect both speakers in the user's stereo headphones. R6 is an optional ground which I have not fitted. Because I've employed a floating ground, C1 gives us a signal return path for the LM567 IC.

The CW spotter has been optimized to cover from about 450Hz to 1.05KHz, 500Hz to 1KHz being the design goal, with a detection bandwidth of less than 40Hz. The IC is tolerant of quite large input signals (±8.5V is claimed). However, the band width is affected if the I and Q phase detectors are overdriven. To achieve a narrow bandwidth, we must restrict the input to the phase detectors, and RV1 allows you to adjust the input to about 100mV rms.

The PLL VCO frequency is controlled by C7, R2, and RV2. These are the LM567 timing components that set the internal VCO to the desired side-tone detection frequency. The component values are given by the equation

$$F_0 \approx 1.0 / (1.1*(R2+RV1)*C7),$$

where F_0 is the frequency in Hz, R2 and RV1 are expressed in Ω, and C7 in F. C6 is the loop filter capacitor and sets the detection bandwidth. For input values less than 200mV rms, the bandwidth, BW, is given as a percentage of F_0 by

$$BW (\%) = 1070 * \sqrt{(V_{in}/(F_0*C6))},$$

where bandwidth is expressed as a percentage, C6 is expressed in μF and V_{in} in V rms. Rearranging this equation, we get

$$C6 = V_{in} *1070^2/(BW^2 * F_0).$$

As an example, for 30Hz bandwidth with F_0 = 1kHz, set $C6 = 0.1*1070^2 /(3^2 *1000) \approx 12.7\mu F$.

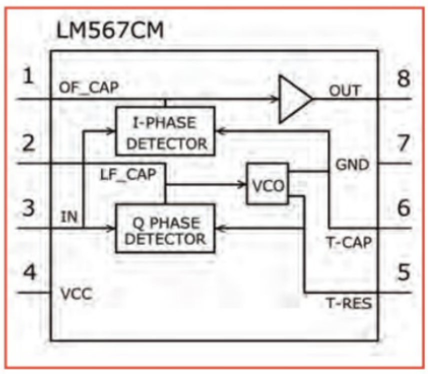

FIGURE 2: The LM567 architecture.

The output filter capacitor at pin 1 of the LM567 is specified by the manufacturer as twice the loop capacitor value but, in practice, I found that this increased the detection time. Using the same value as the loop filter capacitor gave a better performance and faster reaction time. The output pin (8) of the LM567 is an open collector and, when a valid input is detected, this pin is driven low and turns on the LED.

The 6V DC power is supplied by an L78L06ABUTR SOT89 6V 100mA linear regulator, quite suited to low-power applications such as this. The drop-out voltage of the regulator is 1.7V, and its input is protected from reverse polarity by an SMD diode D2. The operational range of the 'CW Spotter' is from 8.4V DC, so it can easily be powered from a PP3 9V battery, or from your transceiver's 13.8V DC supply.

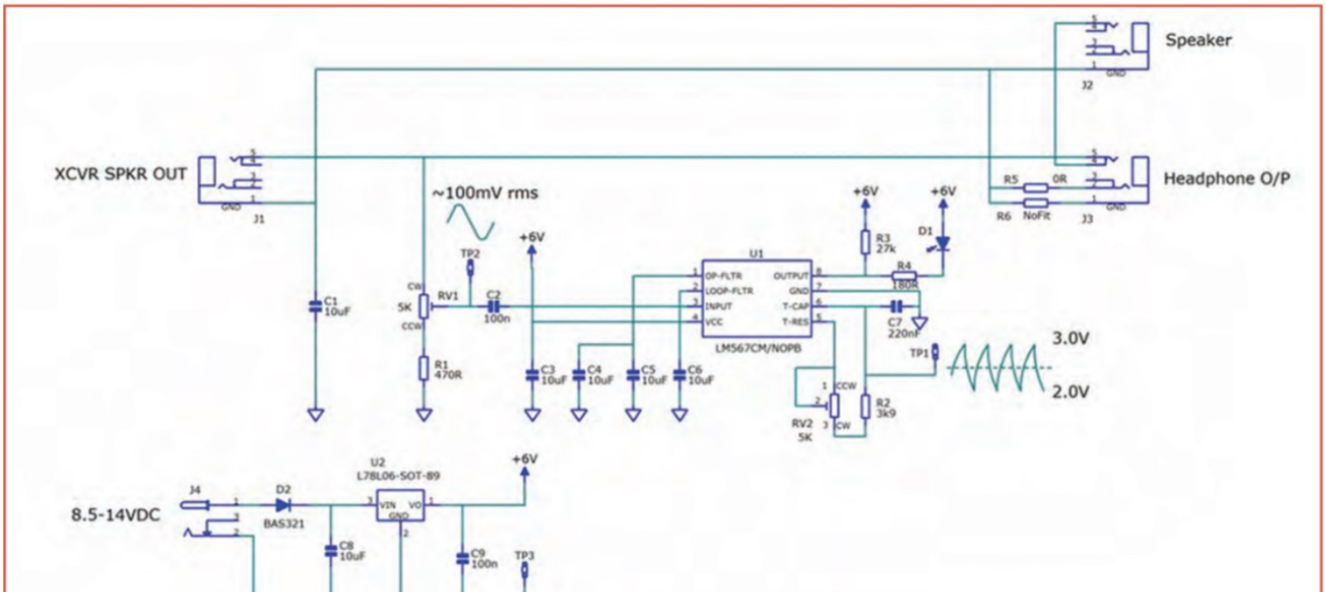

FIGURE 3: The circuit diagram of the CW Spotter.

Setting it up

No test equipment is really necessary to set up the VCO frequency, but there is a choice between two procedures. Using test equipment, remove the input from the transceiver port and monitor the VCO frequency at TP1, which is typically 1V pp centred on 2.5V DC (**Figure 4**). Adjust the side-tone frequency using the multi-turn potentiometer RV2. Alternatively, apply a sinusoidal side-tone input to the transceiver socket. This can be direct from your transceiver, but just ensure you're not transmitting when setting up! The level can be from a few tens of mV to 1V rms. Set RV1 fully clockwise (ie to the maximum level), and adjust RV2 until the LED turns on. Note that the capture range of the CW spotter with a large input signal is quite large, so reduce the input level to the detection threshold by adjusting RV1 counter clockwise when the side tone is detected, and re-adjust RV2 until it reliably detects a small signal at the side-tone frequency plus or minus a few tens of Hz.

Finally, with the CW spotter connected to your transceiver's external loudspeaker socket, and with your external loudspeaker plugged into CW Spotter's SPKR port, adjust your receiver audio to a comfortable level. Tune into some active CW activity, and re-adjust RV1 so that the LM567 input is typically 100mV rms. This completes the setting-up procedure.

Testing

I conducted some tests with a continuous 700Hz tone added to white noise. This yielded a detection threshold SNR of -6.09dB. The bandwidth was 17Hz with the VCO set at 700Hz and with a signal input at the detection threshold at -6dB SNR, that is the LED activated at 693Hz (frequency adjusted low to high) and at 710Hz (frequency adjusted high to low in 1Hz steps).

In operation, when a valid tone is applied, the detector requires a minimum number of cycles before it can drive the output low and illuminate the LED. From the manufacturer's data with a narrow-band configuration, it can take typically 70 cycles to detect a valid input. A test therefore was devised to simulate the conditions seen when a Morse code signal is received at a speed of 30 words per minute (wpm) using a function generator. 500Hz was chosen as the test tone as it has the longest cycle period of 2ms. This was combined with white noise at -6dB SNR with a 60-cycle burst (60*0.002ms) at a repetition period of 160ms. This simulated a 30wpm repetitive dash. The detector bit error rate was quite acceptable even down to 40-cycle bursts of 80ms.

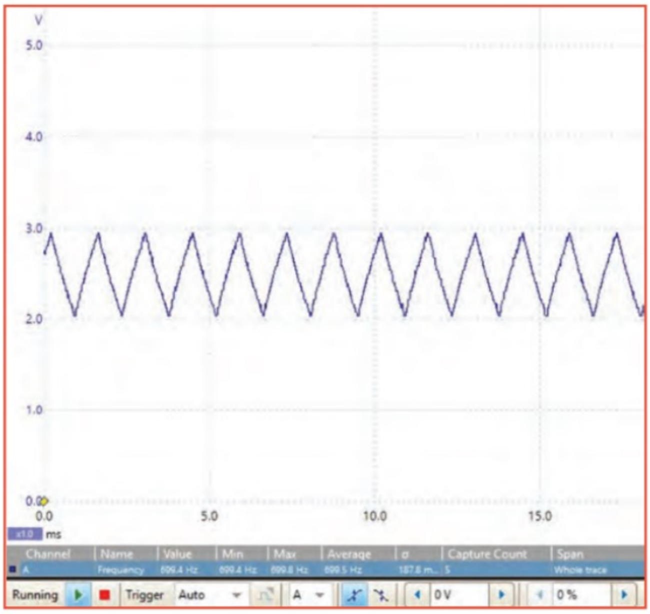

FIGURE 4: An oscilloscope display of the voltage on TP1.

The top assembly is shown in **Figure 5**. The only components that are not SMD are the connectors, the LED, and the VCO timing capacitor. Here it was thought expedient to use a through-hole 5% film capacitor for the timing, as it was less expensive and easier to find than an SMD equivalent part. Once assembled (see **Figure 6**), the PCB slides elegantly into a Hammond extruded aluminium enclosure, and front and rear panels provide a professional-looking finished assembly that matches the case (Figure 1 and **Figure 7**).

David A Allen, G8LHD
david.camtech@outlook.com

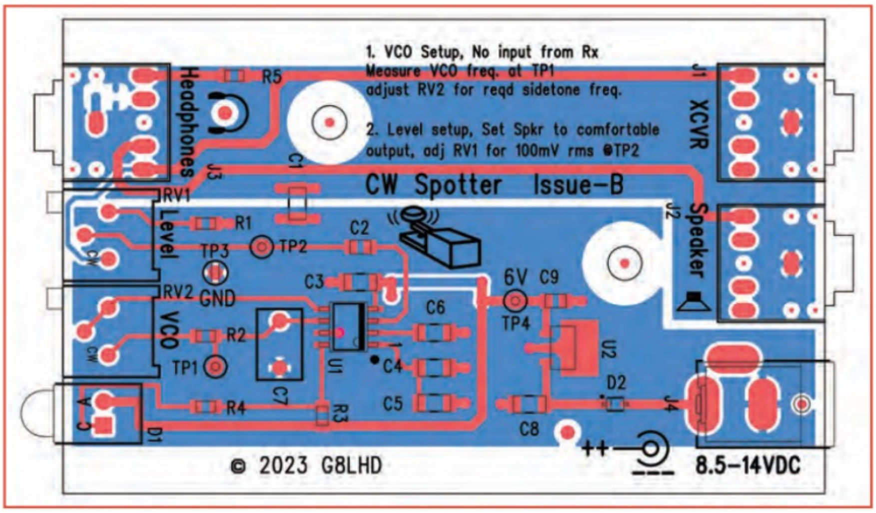

FIGURE 5: The top side of the PCB.

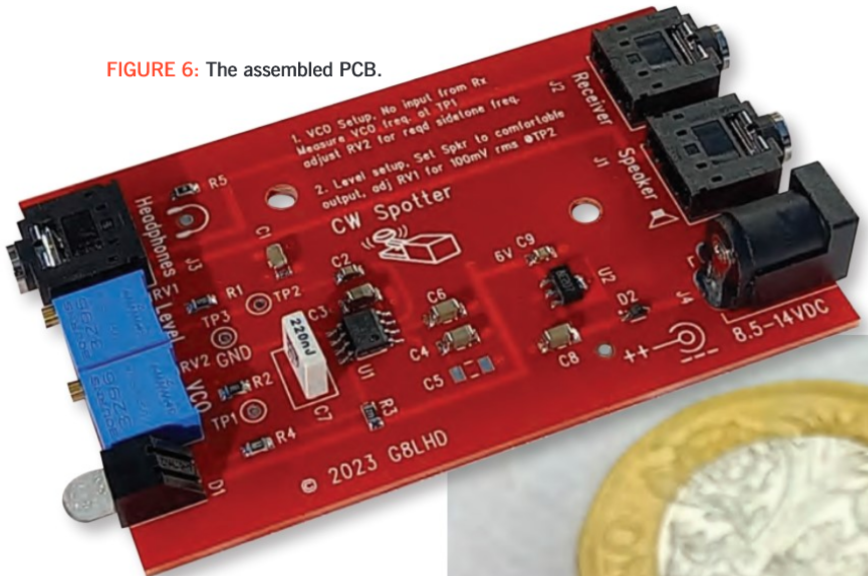

FIGURE 6: The assembled PCB.

FIGURE 7: The rear panel of the CW spotter.

An even-smaller version

After fitting the device into a standalone case, I wondered just how small I could make the PCB, throwing away all the connectors. Well, it didn't take long to realise the 'CW MicroSpotter' (see **Figure 8**). This was built onto a board measuring just 31mm x 16mm and no more than 5mm thick. It still has the onboard regulator together with the tone decoder. To keep the height down, the timing components for the VCO are laid horizontally from the edge of the board, the PCB itself being only 16mm x 22mm. Connections are on solder pads on the back of the PCB to save on the size and cost of a connector.

The MicroSpotter also has an additional on-board surface-mount LED to aid testing, and there is provision to drive an external LED. The whole assembly is small enough to fit inside a rig with just power, ground, loudspeaker, and the off-board LED hook-up required.

In use

In the shack, I have found the 'CW Spotter' to be an excellent aid to zero-beat signals. It's a nice little accessory for CW operation, and I find it easier than spotting with my rig's built-in zeroing aid, or indeed trying to listen to the zero beat of the side tone and the station I'm trying to hear.

I can supply a set of PCBs for the cased and MicroSpotter versions, and a component-buying guide. Drop me an email if you are interested.

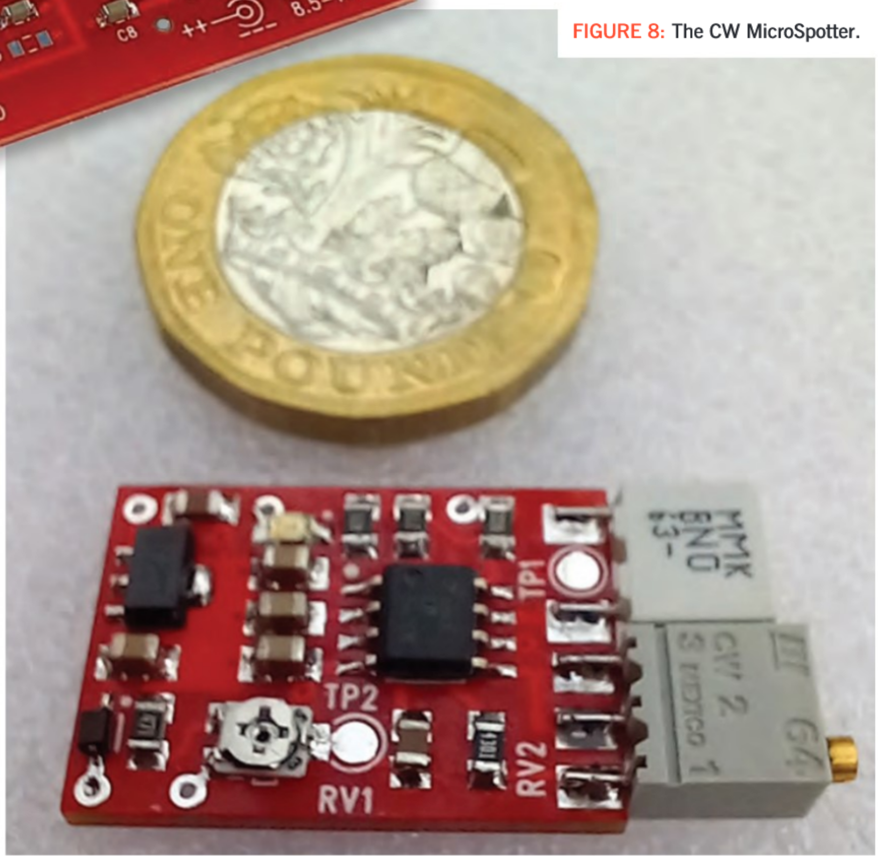

FIGURE 8: The CW MicroSpotter.