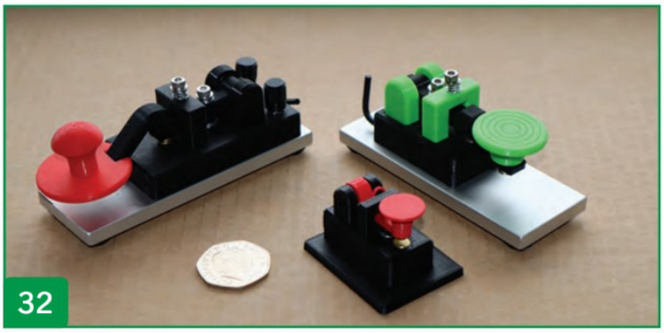
Contents

May 2021

News and Reports

Regulars

Reviews



32

28

Features

Technical Features

Cover image, His Royal Highness The Prince Philip, Duke Of Edinburgh KG KT
Design by Kevin Williams

RadCom THE RADIO SOCIETY OF GREAT BRITAIN'S MEMBERS' MAGAZINE

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RadCom is published by the Radio Society of Great Britain as its official journal and is sent free and post paid to all Members of the Society. **The June 2021 edition of *RadCom* is expected to arrive with most Members by 28 May 2021** although this can take up to a week longer in some cases; international deliveries can take longer still.

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

RADCOM (ISSN No: 1367-1499) is published monthly by the Radio Society of Great Britain and is distributed in the USA by RRD/Spatial, 1250 Valley Brook Ave, Lyndhurst NJ 07071. Periodicals postage pending paid at So Hackensack NJ. POSTMASTER: end address changes to RADCOM c/o RRD, 1250 Valley Brook Ave, Lyndhurst NJ 07071

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New Products

New Spiderbeam telescopic poles

Spiderbeam has introduced two new Mini Spiderpole telescopic antenna poles. These smaller sizes, 10 metre and 7 metre, plus an optional carrying case, make them ideal for outdoor or portable operations. Although they are light and small enough to fit in any suitcase, they are developed to be rugged and durable. These Mini poles use a fixed screw bottom cap that is flat and padded inside. This gives the pole a stable stand and prevents the mast from unwanted extraction while hiking.

Spiderbeam fibreglass poles are extremely strong, with a much greater wall thickness than the usual 'fishing rod' types. A special reinforcing winding technique is used where several layers of fiberglass are wound in alternating direction providing greatly increased lateral and linear strength. Stronger joints are achieved by a much larger overlap between the individual tube segments than usual.

Prices start at £59.95 with the optional carrying case priced at £14.95. The new Spiderpoles are available from UK distributor NEVADA Radio. You can read more at www.nevadaradio.co.uk.

SDRplay announces new website

UK-based SDR receiver manufacturer, SDRplay, has completely revamped their website. Because new SDR receiver products are all about the software, then owners of their RSP hardware need ready access to the latest features. With that in mind, and based on customer feedback, SDRplay redesigned their website to make it easier for newcomers and experts alike to navigate their way to the latest software and support help they need. There are just five top level menu categories and everything is now grouped under products, purchase, software downloads, help and misc for everything else. SDRplay reports a positive reaction since launching the website in late March – the number of support tickets has dropped noticeably!

New software products that arrived in March and April via the new website include several new community plugins, including Jan van Katwijk's Weather Fax plugin for SDRuno, which is proving very popular. Check out the new website by going to www.sdrplay.com.

The RSP family of SDR receivers range in price from around £100 to £240 and are available directly from SDRplay Ltd., Martin Lynch & Sons, Moonraker, Nevada, Radioworld, SDR-Kits and Waters & Stanton.

Yaesu accessory

Martin Lynch & Sons have recently introduced another accessory for the Yaesu FT-817/FT-818ND portable QRP transceivers.

The MyDEL brand Leg-Pegs is a neat retractable pair of folding feet that allow the transceivers to be tilted up when placed on a flat surface. Unlike wire bale-type versions, this design allows the user to fold away the stand when not in use. Better still, you can still use the Yaesu CSC-83 carry case without removing them. In stock at £19.95 plus P&P you can find more information at HamRadio.co.uk/LegPeg.

Portable automatic tuner for the IC-705

The Icom AH-705, a HF/50MHz automatic antenna tuner for the IC-705, is now available from Icom UK dealers. The AH-705 is a small portable antenna tuner that has been designed to work between the 1.8-50MHz bands using a long wire element. It can be powered either by alkaline batteries or DC 13.8V supply. Latching relays are used for saving power consumption. The unit has been designed to IP54 dust-protection and water-resistant construction for outdoor use and the compact design fits in the optional LC-192 multi-function backpack. The AH-705 has a suggested retail price of £309.60 including VAT. You can read more on the Icom UK website at www.icomuk.co.uk.

Direct-sampling SDR

The ELAD FDM-S3 is the latest of the FDM-Sx series. Featuring up to 24MHz of instantaneous bandwidth, the direct sampling wideband receiver covers 9kHz to 108MHz, with optional downconverters promised to extend the range even higher. Up to four independent receivers can be supported simultaneously, a feature that has previously only been available on much more expensive receivers.

Sampling rate is variable between 98 and 122MHz, depending on the band range, which makes it possible to select more-favourable divider ratios for downsampling.

The standard version of the receiver has a temperature compensated crystal oscillator (TCXO) with very good frequency stability. For the ultimate performance there is a version with an oven controlled crystal oscillator (OCXO) that gives even better stability, though at the cost of slightly increased power consumption.

An embedded Reference Clock Manager Module allows a choice between two reference clocks: an optional global navigation satellite system disciplined oscillator (GNSSDO) or a 10MHz external reference signal.

Antenna connections are via SMA, with two for HF (to 54MHz) and one for VHF (to 108MHz). Interface to your host PC is via a high speed USB 3.0 connection, and the receiver runs from 8 to 16V DC.

Weighing in at just 2.15kg and measuring 230 x 60 x 155mm, the Elad FDM-S3 is available from Martin Lynch & Sons. www.hamradio.co.uk/sdr-elad/elad/elad-fdm-s3-sdr-radio-pd-8570.php

Antennas

Height and its effect on a Yagi array

When using an antenna, some of the radiated RF energy is reflected off the ground and modifies the antenna's radiation pattern. The effect of the ground beneath the antenna is this month's theme.

Antenna's radiation pattern with changing AGL

As an indication of how ground reflections can affect an antenna's radiation pattern, this is easier to consider by using a representative example. Therefore, a three element horizontally polarised Yagi array was modelled using MMANA-GAL **[1]**. The antenna model was optimised at 7λ/6 above ground level (AGL) (where λ was the wavelength of operation) and gave a predicted a gain of 12.6dBi, a front to back ratio (F/B) of 14dB and SWR of 1:1.

At λ/2 AGL: The three element Yagi array's predicted horizontal and vertical radiation patterns when modelled at λ/2 AGL are shown in **Figure 1**. The antenna model predicted a gain of 11.6dBi and an F/B of 22dB. The predicted SWR was 1.18:1, indicating the array was a reasonable match to a 50Ω feeder cable.

At λ/2 AGL, this may seem quite low to the ground to install the three element Yagi array. However, if the array was for the 20m band, this is representative of it being installed at around 10m AGL. On 6m, the Yagi array would be around 3m AGL.

Referring to Figure 1, in the vertical plane the array has developed one forward lobe ahead of it with a rear lobe behind it. The forward lobe is orientated to the horizon at around 28°, however the forward lobe's vertical beamwidth is about 30° and so most of the RF energy radiated by the array is between 12° and 42°, as shown. Therefore, the orientation of the forward lobe allows RF energy to be directed towards the horizon at a reasonably low angle ahead of the antenna. This tends to favour both E and F-layer propagation, allowing shorter and much longer skip stations to be worked depending on the conditions. The array's rear lobe is not extensive, indicating why the F/B is around 22dB. Therefore, when working stations ahead of the array, this F/B provides a reasonable immunity against stations located to the rear of the array, provided they not radiating significant powers close to same operating requency.

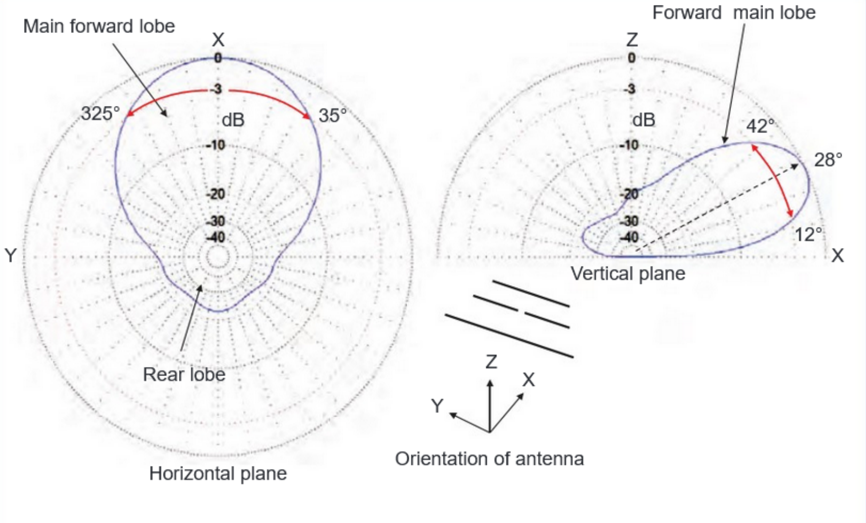

FIGURE 1: MMANA-GAL prediction of the array's radiation patterns at λ/2 AGL.

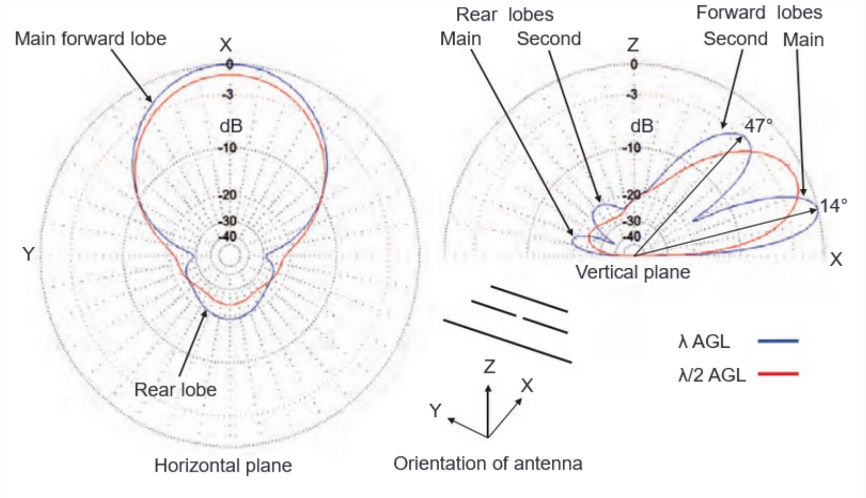

FIGURE 2: The array's predicted radiation patterns at λ/2 and λ AGL.

The horizontal plane shows the main forward lobe has most of the RF energy radiated between 325° and 35°, giving a beamwidth of about 70°. In a similar way as the vertical plane radiation pattern, the array's rear lobe is not extensive.

At 1λ AGL: The same Yagi array's predicted horizontal and vertical radiation patterns when modelled at 1λ AGL are shown in **Figure 2**. This is representative of a 20m band Yagi array installed at around 20m AGL or a 6m band Yagi array at around 6m AGL. The array's predicted gain was about 12.6dBi, its F/B was 19dB and SWR was 1.12:1, indicating the array was a reasonable match to a 50Ω feeder cable. To provide a comparison with the array at 1λ AGL, the predicted radiation patterns for the array at λ/2 AGL are shown in Figure 2.

At 1λ AGL, in the vertical plane the array has developed two forward lobes ahead of

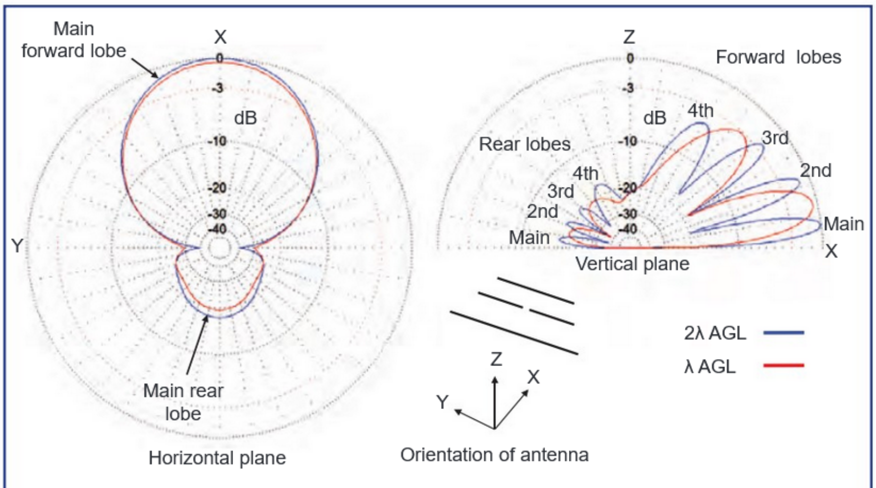

FIGURE 3: Predicted radiation patterns of the array at λ and 2λ AGL.

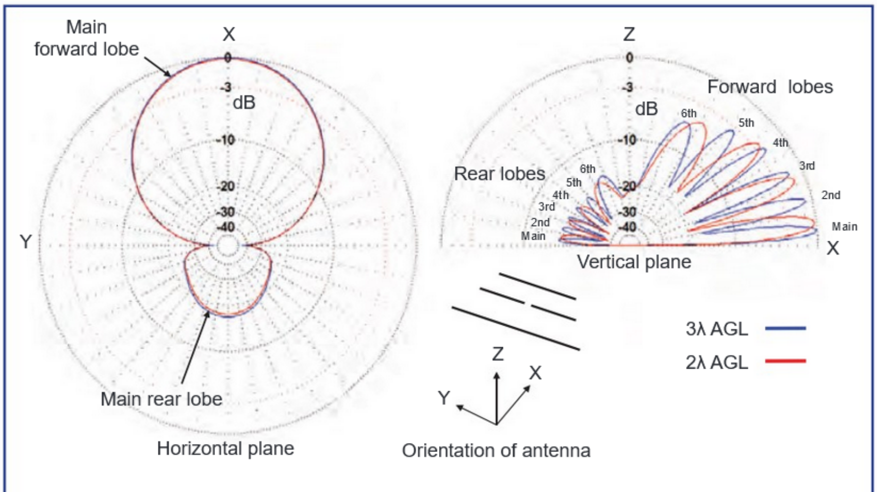

FIGURE 4: The array's predicted radiations patterns at 2λ and 3λ AGL.

it and two rear lobes behind it. The lower forward lobe is orientated at around 14° to the horizon and its vertical beamwidth is about 14° (not shown). The array has developed the majority of its gain from the lower forward lobe (ie main forward lobe). The second forward lobe is orientated at around 47° to the horizon and has a vertical beamwidth of about 20° (not shown). Therefore, the orientation of the main forward lobe allows RF energy to be directed ahead of the array at a low angle towards the horizon favouring F-layer propagation, enabling longer skip stations being worked when the conditions allow. Although the orientation of the second forward lobe is greater compared to the main forward lobe, this lobe's angle of radiation will tend to favour E-layer propagation, with medium and shorter skip stations able to be worked if conditions are suitable.

Behind the array, the prediction shows two rear lobes have developed and their extent is greater compared with the array at λ/2 AGL, indicating why the F/B has lowered to around 19dB. At 1λ AGL, the array still provides a reasonable immunity to stations located to the rear of the array when working stations ahead of it, however stations to the rear of the array may seem stronger compared to when it was installed at λ/2 AGL.

At 1λ AGL, the horizontal plane shows the extent of the main forward lobe has slightly narrowed compared to the array at λ/2 AGL, with the horizontal beamwidth now being about 66° (not shown). The narrower extent of the main forward lobe helps to explain the increase in the array's gain by about 1dB. In a similar way as the vertical plane radiation pattern, the array's rear lobe is not extensive.

At 2λ AGL: The same Yagi array's predicted horizontal and vertical radiation patterns when modelled at 2λ AGL are shown in **Figure 3**. The array's predicted gain was about 12.9dBi and its F/B was 17dB. The array's predicted SWR was 1.09:1, indicating the array's match continues to improve when using a 50Ω feeder cable. This is representative of a 15m band Yagi array installed at around 30m AGL and a 6m band Yagi array at around 12m AGL. To provide a comparison with the array at 2λ AGL, the predicted radiation patterns for the array at 1λ AGL have been shown in Figure 3.

In the vertical plane the array has developed four forward lobes ahead of it and four rear lobes behind it. The main forward lobe is orientated at around 7° to the horizon and the second forward lobe is orientated at 12°. Therefore, the orientations of the main and second forward lobes allow RF energy to be directed ahead of the array at a low angle towards the horizon and favour F-layer propagation, allowing longer skip stations to be worked when conditions allow. However, the orientations of the third and fourth forward lobes, at 38° and 59° respectively, are greater compared to the two lowest forward lobes. For the third and fourth forward lobes, their angles of radiation favour both E and possibly F-layer propagation, with medium and shorter skip stations being able to be worked if conditions are suitable.

Behind the array, the prediction shows four rear lobes have developed and their extent is greater compared with the array at λ AGL. This indicates why the F/B has continued to reduce to 17dB compared with λ and λ/2 AGL. However, the array still provides a reasonable immunity to stations located to the rear of the array when working stations ahead of it.

The horizontal plane shows the extent of the main forward lobe has continued to narrow compared with λ AGL. The horizontal beamwidth is now about 64° (not shown) and this helps explain the 0.3dB increase in the array's gain. However, compared to the horizontal plane radiation pattern at λ AGL, the rear lobe has become larger and helps to explain the reduction in the F/B by 2dB.

At 3λ AGL: The Yagi array's predicted horizontal and vertical radiation patterns when modelled at 3λ AGL are shown in **Figure 4**. This is representative of a 10m band array installed at around 30m AGL and

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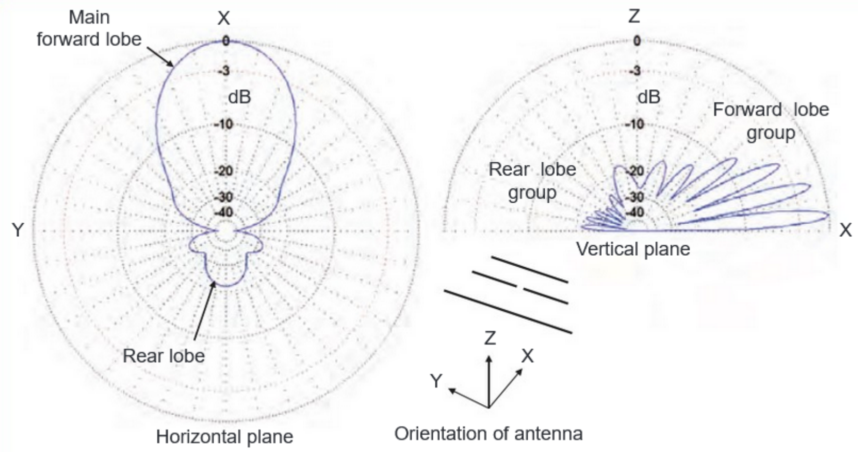

FIGURE 5: An 8 element Yagi array's radiation patterns at 3λ AGL, as predicted by MMANA-GAL.

a 6m band array at around 18m AGL. The array's predicted gain was about 13dBi and its F/B has remained at 17dB. The array's predicted SWR was 1.08:1, indicating the array was a good match to a 50Ω feeder cable. As a comparison with the array at 3λ AGL, the predicted radiation patterns for the array at 2λ AGL have been shown in Figure 4.

In the vertical plane the array has developed six forward lobes ahead of it and six rear lobes behind it. The main forward lobe is orientated at around 5° to the horizon, the second forward lobe at 14° and the third forward lobe at 24°. These orientations of the main, second and third forward lobes allow RF energy to be directed ahead of the array at a series of low angles towards the horizon. This will favour both E and F-layer propagation allowing longer and medium skip stations to be worked when conditions allow. The orientation of the fourth and fifth forward lobes, at 35° and 48° respectively, should favour E and possibly F-layer propagation, with medium and shorter skip stations being able to be worked if conditions are suitable. The orientation of the sixth forward lobe at around 65° favours E-layer propagation allowing shorter and possibly some medium skip stations to be worked when conditions allow.

Behind the array, the prediction shows six rear lobes have developed. However, their extent is not that different compared with 2λ AGL. This explains why the F/B has remained at around 17dB at 3λ AGL. Therefore, at 3λ AGL, the array still provides a reasonable immunity to stations located to the rear of it when working stations ahead of it.

The horizontal plane polar plot shows the extent of the main forward lobe at 3λ AGL is very close to that predicted at 2λ AGL. Consequently, the array's predicted gain was 13dBi at 3λ AGL and is very close to that predicted at 2λ AGL (12.9dBi). Similarly, in the horizontal plane the extent of the rear lobe is very close to that at 2λ AGL and helps explain why the F/B has not changed.

General comment: The predicted radiation patterns shown in Figures 1 to 4 were for a three element Yagi array as the antenna's height above the ground was increased. However, the manner in which ground reflections may modify the radiation patterns shown are generally representative for other beam antennas. As a comparison to the 3 element Yagi array, **Figure 5** shows the MMANA-GAL predicted horizontal and vertical plane radiation patterns for a horizontally polarised 8 Yagi array with the antenna installed at 3λ AGL. At this height the radiated RF patterns show similarities to those of the 3 element Yagi array. However, the horizontal plane radiation pattern is narrower, indicating this array's gain is much higher.

Websearch

[1] MMANA-GAL basic V3.0.0.31, freeware antenna analysing application. Original code by Makoto Mori, JE3HHT. MMANA-GAL Basic and MMANA-GAL Pro by Alex Schewelew, DL1PBD and Igor Gontcharenko, DL2KQ; 1999 onwards

Demonstrating 'EMF compliance' for RF electromagnetic fields

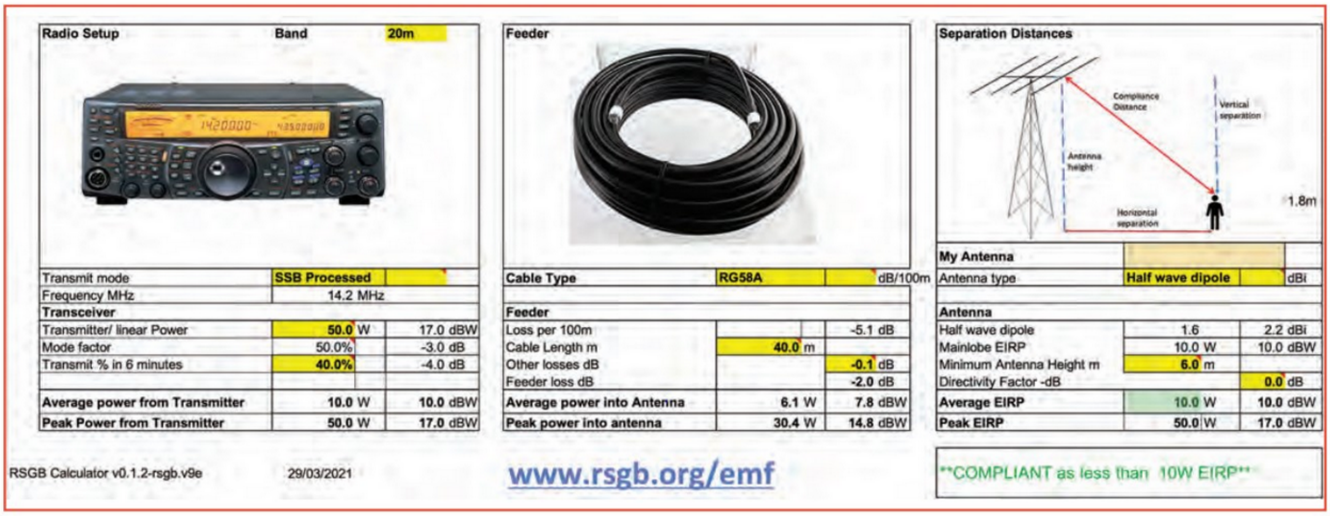

FIGURE 1: Front sheet of RSGB EMF Calculator.

Most UK amateurs will already be fully compliant with ICNIRP requirements. As this series continues, the RSGB will help you to demonstrate that for your own station.

Ofcom is introducing new licence regulations requiring ***all*** amateurs **[1]** to comply with international guidelines for limiting exposure to RF electromagnetic fields (EMF) **[2]**. Ofcom has also published a guidance document for all licensees, along with more specific guidance for amateurs **[3, 4]**.

For background to this change, see part 1 of this series in March *RadCom*, and the accompanying article online **[5, 6]**. New amateur licence conditions will come into effect from May 2021 that include a new Schedule specifically for EMF compliance.

Ofcom has taken a staged approach that allows for assessments to be completed by November 2021 for frequencies above 10MHz, and by May 2022 for frequencies below 10MHz. This staged introduction is to allow new assessment methods to be developed, especially for frequencies below 10MHz. Anticipating the need for guidance about these lower frequencies, the RSGB/ARRL EMF team [5] has already been working on the problem, and in this article we show some new options for demonstrating compliance on the bands between 1.8 and 7.1MHz.

The **assessment process** is essentially the same on all bands:

1. Define the specific configuration that you are assessing: frequency band, RF power, mode and Tx/Rx cycles, type and location of antenna, and any other details relevant for the assessment.
2. Estimate **exclusion zones** where people might be exposed above the relevant limit.
3. If you have identified exclusion zones but can be sure that members of the general public cannot access these zones by normal practical means (eg, if the zone is on the roof) then you have demonstrated compliance. If they could gain access, then include a practical plan to manage that situation – see "Managing Exclusion Zones" later.
4. Keep all the above as your compliance assessment record.

Repeat 1-4 for each different operational configuration that needs to be assessed. For example, a different frequency band, a different antenna or a higher power level, or a change of mode – all of these will change your EM fields and will need a new assessment. You may be able to save some work by assessing the most demanding configurations first. For example, if you are compliant at the highest power level that you plan to use, there is no need to assess that same case at lower power levels

Your assessment options

Ofcom guidance offers several options for making an assessment [3, 4]. Feel free to use any of them (or any combination) to assess your compliance.

Low power: If the radio equipment never transmits above 10W EIRP, the assessment can be as simple as recording that fact. You can often use the RSGB EMF Calculator (see below) for confirmation.

Manufacturer's instructions: If the manufacturer of the radio equipment (transmitter and antenna) has provided instructions to ensure that the equipment complies with ICNIRP guidelines, then you can demonstrate compliance by following those instructions. This will apply mostly to low-power hand-held radios that are supplied complete with an antenna.

RSGB EMF Calculator: RSGB is providing a calculator that covers the most important parts of assessing and recording compliance. It provides information that can then be used to define exclusion zones where people should not be present while you are transmitting. If no-one is present in the exclusion zone while you are transmitting (or if no-one could reasonably be expected to be) then compliance has been demonstrated.

Other EMF calculations: Ofcom is providing a calculator that is based on ICNIRP 1998 limits **[7]**. Ofcom will also accept results from

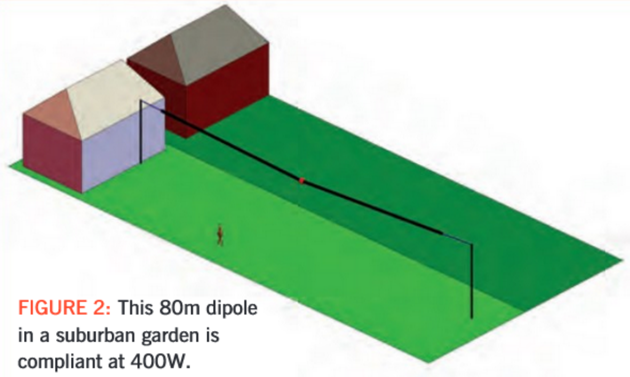

FIGURE 2: This 80m dipole in a suburban garden is compliant at 400W.

Configuration Description			Transmit power	Minimum height AGL (any part of radiating structure)			
#	Ground	V angle		160m	80m	60m	40m
1	Any (excluding Sea)	Any	Up to 10 W	2.3m	2.3m	2.3m	2.3m
			Up to 50 W	3.2m	3.0m	2.9m	2.8m
			Up to 100 W	3.7m	3.6m	3.4m	3.3m
			Up to 400 W	6.4m	5.3m	N/A	4.3m

FIGURE 3: Extract from Technical Note PAC-1, Table 2. Input assumptions are in blue, and the minimum height for 80m for this pre-assessed configuration is 5.3m.

established computer programs provided you can demonstrate that they give valid results for comparison against ICNIRP limits. Amateurs who are experienced in antenna modelling may be able to use this latter option to estimate exposure for comparison with the relevant ICNIRP limits, and thus to define three-dimensional exclusion zones.

Pre-assessed station configurations: The RSGB is developing a library of pre-assessed configurations for amateur stations, with guidance to help you to demonstrate compliance [7]. We are doing a mass of detailed work using advanced computation techniques, so that you don't have to. If your station configuration matches one of these pre-assessed cases (or can be made to do so, including any stated precautions) then you can demonstrate compliance. The RSGB will also be using the detailed data from the pre-assessed configurations to develop simple guidelines such as: "If your 144MHz Yagi is more than *x* metres above ground, you will be compliant up to RF power levels of *y* watts PEP (subject to a few other conditions)". If you can meet the relevant conditions, this may be the easiest way to establish compliance.

Managing Exclusion Zones

Output from all of the calculation methods will indicate locations where a person could be exposed to EMF above the relevant ICNIRP limit. These are then used to define **exclusion zones**.

ICNIRP EMF limits are about the exposure of **people** to EM fields. **Whenever no person is present within the exclusion zone, that in itself is sufficient to establish compliance.**

To demonstrate compliance with the EMF license conditions you will have determined where your exclusion zone boundaries are, and how you can be sure that no-one is present within them when transmission is taking place – for example, if those boundaries are physically inaccessible, or if access is limited in some other reliable way, or you ensure that you don't transmit when a person is within the zone.

The simplest type of exclusion zone is defined by the minimum distance from the antenna in any direction. When this minimum distance is based on the worst-case direction, that value will be over-cautious for other directions. If that overestimate causes no difficulty in your particular situation, then by all means use the simplified calculation. But don't forget that more advanced methods can map the field strengths much more accurately in 3D, and so give a more reliable indication of the size and the shape of the exclusion zone boundaries (see Figure 4, for example).

If you do need to operate an exclusion zone, remember that licensed amateurs have an almost unique advantage over other radio services: there is almost always a trained operator on-site who can exercise real-time supervision of the exclusion zone. Whenever necessary, be sure to include this in your compliance plan.

Measurement: Ofcom also includes on-site EMF measurement as a means of demonstrating compliance; but accurate measurements are far more difficult than most amateurs imagine. They need to follow strict engineering standards and require calibrated test equipment – all of which makes on-site measurement challenging.

The rest of this article will give some practical examples of how you can use the RSGB Calculator and/or the pre-assessed configurations to establish compliance and manage exclusion zones – see sidebar.

Introduction to the RSGB EMF Calculator

You can download the RSGB EMF Calculator and a video demonstrating its use from www.rsgb.org/emf. You can use the calculator to analyse your station configuration to determine:

- the average and peak power from your transmitter for your stated usage
- the power delivered to the antenna, which can also be used with other EMF calculation tools
- the peak and 6 min time-averaged EIRP, which can be used to demonstrate compliance – see Low Power previously
- the required separation between the antenna and any exposed person (the Ofcom "compliance distance"), which is then used to determine exclusion zones

Figure 1 shows the front sheet of the RSGB EMF Calculator, with the yellow shaded cells defining where input is required. When you have completed the assessment, save or print the worksheet as your record.

The first column in Figure 1 defines your **Radio Setup**: the frequency band, transmission mode, RF power and percentage of transmitting time within a 6-minute averaging period. Many of these values come from drop-down lists that appear when you click in the cell, or you can always enter your own custom values. In the **Feeder** column you can select the cable type and length, and any other losses that affect the power delivered from the feeder into the antenna. Outputs available from this column are the average and the peak power delivered to the antenna. In the right column you can select the antenna type, height, and an optional directivity factor (see video for details).

The calculated average and peak EIRP are then shown at the bottom of the right-hand column. You can see in the example shown that even "50W to a dipole" using processed SSB can meet the 'low power exemption' on 14MHz because the time-averaged EIRP is less than 10W. However, the calculator will also indicate other combinations of power and mode that could not claim this exemption (eg 50W on some data modes).

The calculator determines a compliance distance (see graphic in **Figure 1)** between the antenna and any exposed person [2-4]. That information can be used to define the **exclusion zone** (see sidebar) if the calculated EIRP is greater than 10W. If you can be sure that no-one will be present within that zone when transmission is taking place – for example, if it is physically

John Rogers, M0JAV
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Peter Zollman, G4DSE
www.rsgb.org/emf

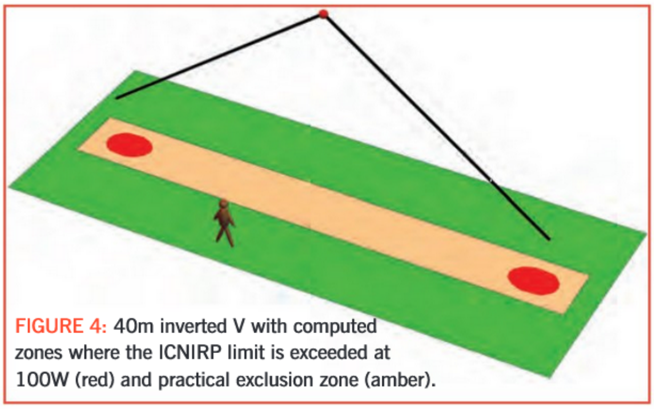


FIGURE 4: 40m inverted V with computed zones where the ICNIRP limit is exceeded at 100W (red) and practical exclusion zone (amber).

inaccessible, or if access is limited in some other reliable way – then you will have demonstrated compliance.

First look at pre-assessed configurations

The following examples are for operations below 10MHz that are not covered in the Ofcom calculator, and give you a first look at using pre-assessed station configurations to deliver a quick – and positive – assessment result. Details are in RSGB Technical Note PAC-1, *EMF Compliance Assessment of Low-band Half-wave Dipoles*, to be published online [6, **9**].

Example 1 – 80m home station: This example shows how a simple 80m station can be demonstrated to be compliant at power levels up to 400W without the need to change anything. **Figure 2** shows our test case, a half-wave dipole for 80m in a suburban garden. Details matter in EMF assessment, and all the following will prove important. At the house end, the dipole is at 6m above ground level (AGL), attached via an insulated extension 2.5m long. The far end of the dipole is 7m AGL with a similar insulated extension. The centre of the dipole sags to 5.5m AGL due to the attached coaxial feedline (not shown). The feedline drops vertically to ground and has common-mode chokes to reduce feedline radiation. Ground characteristics are unknown, except that this location is not beside the sea. RF power level could be anything up to 400W PEP, using any licensed transmission mode.

Because some of the above information is fuzzy (and in real-life assessments, is always likely to be) the data tables in PAC-1 allow you to specify the values that you do know, while choosing 'Any value' for those that you don't. We are not certain about the V-angle of the dipole, so for the moment let's assume 'Any angle' for that one. For the ground type we can choose 'Any (excluding Sea)'.

That input information leads us to Table 2 in PAC-1, and **Figure 3** shows the relevant extract. The input assumptions are highlighted in blue, and the conclusion "the minimum antenna height to remain compliant is 5.3 metres" is highlighted in red. Other constraints are set out in PAC-1, notably that precautions must be taken to suppress feedline radiation and that a horizontal clearance of at least 2.0m beyond the ends of the dipole is also required.

Since our example case meets all these conditions, and no part of the dipole is lower than 5.5m above ground, this station configuration can be declared compliant up to 400W PEP, full carrier. No further EMF precautions are required, except to ensure that all the assumed conditions continue to be met. Record that this configuration is based on 'PAC-1, Table 2, case #1' and the job's done.

Example 2 – 40m inverted-V dipole for portable operation: This example uses another pre-assessed configuration from PAC-1, this time in a portable situation where compliance with the EMF licence condition is not automatic. The key point here will be that you can still demonstrate compliance by knowing where your ground-level exclusion zone is, and not transmitting if anyone ventures into that zone.

Figure 4 shows the antenna configuration. There is a central insulated mast (not shown) with the ends of the sloping wires attached to ground stakes via insulated cord (not shown). The mast height is 8m but the ends of the dipole will be only 2.0m AGL, forming a distinct inverted-V. RF power may be up to 100W, and we make the same assumptions as for Example 1 about avoiding feeder radiation.

Compliance here is obviously not automatic because the ends of the dipole are barely above head height. Figure 4 shows in red where the computed EMF at an RF power level of 100W would exceed the relevant ICNIRP limit for someone standing at ground level. These zones are quite small, but their precise shape and size will vary with V angle, RF power and other unknown conditions such as ground conductivity. For practical access management, a much simpler exclusion zone is therefore defined as the complete strip of land beneath the dipole, coloured amber in Figure 4. If operating /P on public land, you would need to be watching that area anyway for conventional safety reasons, so the only addition for EMF compliance is not to transmit if anyone should enter.

For 100W on 40m, PAC-1 suggests the strip should be 2.2m wide, with a 1.1m extension beyond each end of the dipole. That estimate is for "Any ground conditions (excluding Sea)" so it will remain valid for most future portable operations with that antenna. There is no need to over-complicate the situation with precise measurements, barriers or signage – all that's needed is to maintain awareness while you are operating.

Conclusions

There are many practical ways to demonstrate compliance with the new Ofcom EMF licence conditions – most amateur operations **already do comply**. The RSGB will be following up the technical work with online templates and examples for the necessary records to help you demonstrate compliance.

The RSGB/ARRL EMF team are currently working on many different station configurations including HF/VHF/UHF Yagis, general wire antennas, verticals, and others.

There is no need to feel under pressure about this. We have until at least November 2021 to do assessments for frequencies above 10MHz, and until May 2022 for the lower frequencies. In the meantime, please continue to follow the RSGB EMF pages online [6] for longer articles and more detail.

Notes and references

[1] Since no amateur licence is restricted to "10W EIRP", we all need to record how we comply with this new condition. (Read the wording of reference 2 carefully.).

[2] Ofcom, Implementation of measures to require compliance with international guidelines for limiting exposure to electromagnetic fields (EMF), 1 March 2021. www.ofcom.org.uk/manage-your-licence/emf.

[3] Ofcom, Guidance on EMF Compliance and Enforcement, 1 March 2021. www.ofcom.org.uk/__data/assets/pdf_file/0025/214459/guidance-emf-compliance-enforcement.pdf.

[4] Ofcom, Ofcom's new EMF licence condition: what you need to know as an amateur radio licensee, 11 March 2021. www.ofcom.org.uk/__data/assets/pdf_file/0026/215657/What-you-need-to-know-as-an-amateur-radio-licensee-Draft-version.pdf.

[5] RSGB/ARRL EMF Team, New licence regulations for RF electromagnetic fields, *RadCom* March 2012, pages 22-24.

[6] All RSGB online publications about EMF compliance (and easy links to relevant Ofcom publications) can be found at www.rsgb.org/emf. Do not use any publication marked 'Preliminary' for your formal compliance assessment, but follow the RSGB EMF pages for updates.

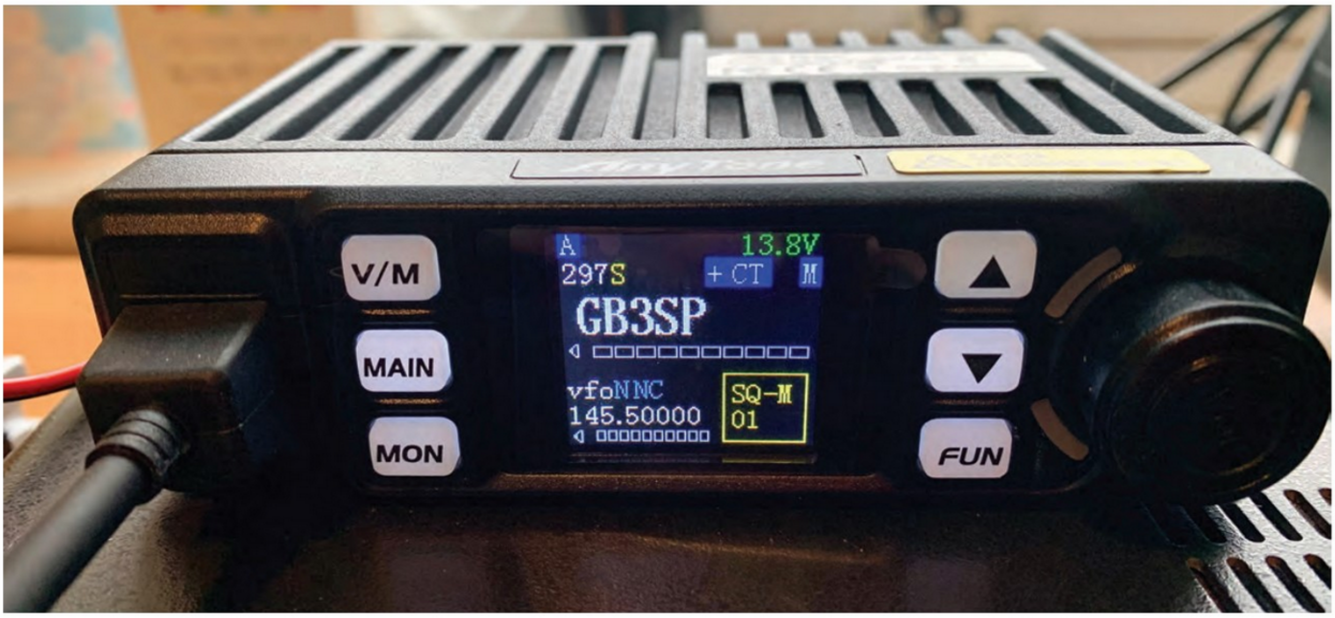
[7] Ofcom initially accepts the use of either the old ICNIRP 1998 or the ICNIRP 2020 recommendations reflecting the most up-to-date science. RSGB guidance is based on ICNIRP 2020 so that we won't need to update.

[8] Pre-assessed configurations developed by RSGB are recognised by Ofcom as a basis for amateurs to demonstrate compliance.

[9] Below 10MHz, the constraining ICNIRP 2020 limits are based on 'peak' field strengths at any moment during the transmission, so power reduction factors based on mode and transmit-percentage must not be applied in that frequency range. ICNIRP uses the word 'peak' in a very similar way to "Peak Envelope Power" (as defined on page 20 of your licence).

Review

Anytone AT-779UV 2m/70cm dual band transceiver



Measuring just 124mm (W) x 101mm (D) x 36mm (H) the Anytone AT-779UV is still a dual band VHF/UHF 25/10/5W transceiver.

The Anytone AT-779UV is a tiny radio and, with a 12V accessory plug, it would be very easy to put in and out of a car.

Anytone is a brand that, five years ago, few of us would have heard of. But, they have developed a reputation for radios that do what they should, without the quirkiness that we have seen from some manufacturers. Chris Taylor told me about the AT-779UV a few weeks ago and that he was working with Anytone to have it sent out from the factory with all the UK simplex channels and repeaters pre-programmed. I was very interested to get a chance to see the rig and try it out.

Something that Anytone have done in the last 12 months or so is upped the game on their packaging. I'm sure that many of us wouldn't worry terribly about the 'unboxing experience', but on the other hand, first impressions do count! The box is nicely printed and constructed and the rig is neatly packaged. Getting the rig out of the box, the next impression is 'that's small!' I'm fairly sure that I've had handhelds that have been bigger.

Out of the box

The power cable is terminated in what I'd call a 'cigar-lighter plug', making it easy to install quickly in a car and, of course, many 12V power supplies have a suitable socket on them. The rig feels reasonably substantially made and the microphone is also nicely finished.

The rig switches on with the large dial on the right of the rig, which you might instinctively think of being the channel change knob! It's not, it's On/Off/Volume. Channel change is achieved with the up/down keys on the front panel, or perhaps more conveniently, from the microphone. In fact, all the front panel controls, with the exception of On/Off/Volume, are accessible from the microphone.

The colour 1.44 inch TFT display is quite attractive and is easy to read. The AT-779UV has a single receiver, but you can easily set the set up with a Priority Channel. For example, I am writing this whilst listening to the local repeater GB3SP, on 70cm, with the rig checking 145.500MHz as the priority channel. I have set up 145.500 on the second VFO, so if I hear someone I want to call on simplex, I can quickly press the 'Main' button, to switch over to that VFO, call them and then move to another simplex channel, by means of the Up/Down buttons.

Chris Taylor from Moonraker has spent considerable time, working with Anytone, on the 'codeplug' to go into the AT-779UV. All UK repeaters and simplex channels are programmed up (tell Chris if there's something missing!). As you might hope, all the repeaters have the correct CTCSS tone assigned to them, so you can just find the channel for your local repeater, hit the PTT and you should be able to access the repeater.

The AT-779UV has three power levels. The specification quotes the narrow band power as being greater than 20 watts and wide band power as greater than 18W. I measured the highest power level on 2m at around 20W, the medium power at about 7W and the low power setting at about 3W,

You can change the power level to high from the microphone control at the touch of the button.

with the 70cm power being just slightly less. What makes the AT-779UV in this configuration particularly great for Foundation licence holders is that the default power for all the repeaters has been set to medium (ie the '10W' level). If you are an Intermediate or Full licensee, then you can change the power level to high from the microphone control at the touch of the button, or, if you always want to use high power on a particular repeater, you can read the config from the radio back to your computer, adjust the setting and then write the config back to the radio. As it was, I found that most of the time I could quite happily stick at using the 10W level for most of my VHF/UHF FM activity. There's no cooling fan on the AT-779UV and I found that the heatsink got quite hot at the higher power level if I 'went on a bit'. On the lower power settings this was less noticeable.

All the UK repeaters are programmed in, as are the simplex channels as well as the PMR446. PMR446 channels are set to receive only (there is a Tx Off check box that can be configured to do this on each channel). To find out what is going on at your location, just hit the scan button (Function and 4 on the microphone keypad) and the rig will start scanning through the channels. It will stop where it finds activity. Slightly curiously initially, although the repeater channels had been programmed to require the correct CTCSS tone, I found the rig would sometimes stop on a channel where there was a repeater, albeit with a different CTCSS tone. A little investigation later, it turned out that 'Squelch Type' needed to be changed from 'Carrier' to 'CTCSS/DCS' for each channel. By the time you read this, the Moonraker 'codeplug' should have been changed to reflect this.

I found the rig one of the more sensitive that I'd looked at recently, doing a good job of receiving weak signals on both 2m and 70cm. I looked at Adjacent Channel Rejection, which was quite acceptable, but if you have some strong signals locally and are using a big aerial you may notice some issues. If you are mobile or in a quieter RF landscape you shouldn't see any issues.

On transmit, there's always a lot of interest in the spurious emissions of the cheaper radios. I had a quick look at the Anytone AT-779UV using some basic test equipment. It was certainly poorer than a more expensive radio from one of the big three that I had on the bench at the same time, although not bad enough to raise serious alarm bells. It's probably unlikely that anyone would consider running an AT-779UV through an amplifier – but I'd advise against it.

Programming software

Although the rig comes ready programmed, it may be that you would like to change some settings or even add a new repeater. The rig comes supplied with a USB programming cable. At the rig end, the cable plugs into the microphone socket. Windows programming software for the AT-779UV can be downloaded from the Moonraker site (other versions of the AT-779UV software exist but seem to be aimed at a low band version of the rig). I found the software installed without any problems. The programming cable requires the Prolific drivers to be present on your computer, which as you may know, can be problematic at times. Fortunately, the correct drivers were already installed on my machine, so the programming software recognised the presence of the rig straight away and I was able to read the configuration from the radio into the software, inspect it, make any amendments and then write it back.

On the air

Transmitted audio reports using the AT-779UV were good (thank you to Steve, GW7FBV). Received audio was easy to listen to. The speaker is on the bottom of the rig, so depending on how you plan to mount or place the rig, an extension speaker may be of help. You will find that 2W of audio is available from the rig, which should hopefully be enough for all but the noisiest environments. I enjoyed having all the channels available to scan easily and, as ever, discovered some new channels to listen to. Depending on where you are, PMR446 and the marine band may be interesting to listen to – the Anytone works well as a receiver in these bands.

Overall

The Anytone AT-779UV is a tiny radio! The fact that it is supplied with a 12V accessory plug means that it would be very easy to put in and out of a car, even a hire car for some listening as you were travelling around. With Moonraker's 'codeplug' of all UK repeaters and simplex channels pre-loaded, scanning is very straightforward and you should soon find any activity. With the ability to scan all channels, you should have the fun of noticing repeater channels which are normally quiet coming into life as conditions improve.

RF performance on receive is remarkable value for the money, with very good sensitivity. With only basic RF testing facilities available for my review, I felt the level of spurious outputs on transmit was acceptable but it would be nice to see it lower.

Foundation licensees may find the default power level of 10W as set in the Moonraker codeplug in the AT-779UV very convenient.

I enjoyed the AT-779UV. It's well set up out of the box to allow you to make the most of the VHF/UHF FM activity in your area – and beyond! Many thanks to Chris Taylor of Moonraker for the opportunity to look at the rig. It's available at £89.95 from Moonraker Ltd, www.moonraker.eu.

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CWMORSE
3D printed keys and paddles

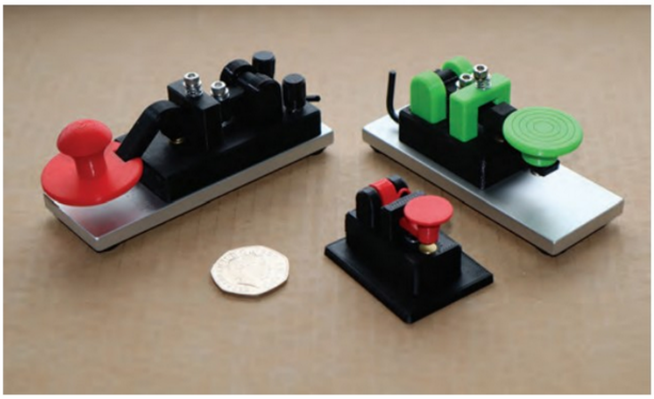

PHOTO 1: The mini, micro and nano straight keys.

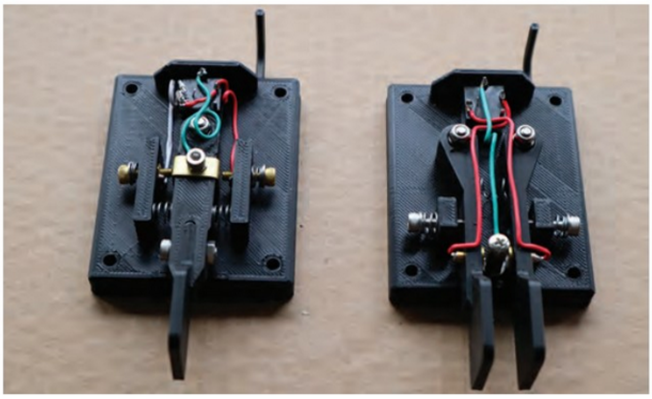

PHOTO 2: Internal view of the paddle keys.

PHOTO 3: Single and dual lever paddle keys.

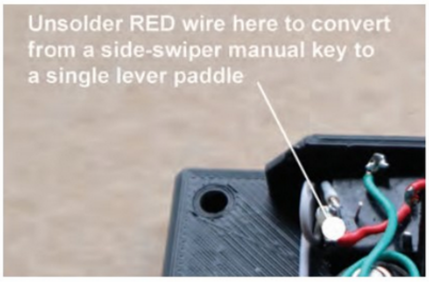

PHOTO 4: Converting to 'paddle' mode.

PHOTO 5: Using a gel pad to secure keys and paddles.

3D printers are commonplace these days so it was inevitable that someone would decide to make Morse keys using one.

I first noticed the 'cwmorse' range of keys and paddles on the Martin Lynch & Sons stand at Newark in 2019 and, recently, had the chance to spend some time with samples of their range.

Being small and light they are primarily aimed at back-packing and SOTA types, but the paddles do have an optional heavy base for home use. Conventional metal Morse keys, even old WWII ones, can fetch crazy prices these days, so a low-cost key would be attractive for newcomers to the mode if their 'action' was reasonable.

Straight keys

A Morse key is essentially nothing more than a rocker switch, so it is surprising how different designs can have a decidedly different 'feel' to them if the mass distribution or length of the arm is altered. Each style of key/paddle has its own band of users who consider theirs to be the best.

Because these 3D printed keys have virtually no mass I was expecting them to all 'feel' exactly the same, but that was not the case and I did have a definite favourite.

All of the keys have tiny ball-race bearings. A range of colour options are available and the brighter ones would make them easy to see when packing up at dusk after portable activity. Two different knob styles are available. With the exception of the 'nano', all keys and paddles are supplied with an Allen key for adjusting tension & spacing. The mini key has binding posts for connecting to the rig but all the other keys and paddles have a 3.5mm jack socket.

The arm of the 'mini' key is curved; reminiscent of the 'camelback' style of key. Being made from plastic this means it flexes under pressure so there is a slight cushion effect when pressing the key. Personally, I was not too keen on that, but others might prefer it.

The 'nano' key is really small, and also really basic. There is no provision to adjust either tension or spacing but I still found it OK to use. A little too small for my clunky fingers though. Younger, smaller, hands, would fare better.

PHOTO 6: Paddle mounted on optional steel base.

After trying all three keys for a while, I came to the conclusion that the 'micro' was my personal favourite. I have a CW sked every Sunday with a friend in GM that usually lasts 90 minutes or so, and I used a 'micro' key for the whole time in one of them. I was quite comfortable using it, although my old arm tired towards the end. Apparently my sending sounded nice, even though it has been five years since I last used a straight key.

PHOTO 7: The cwmorse practice oscillator.

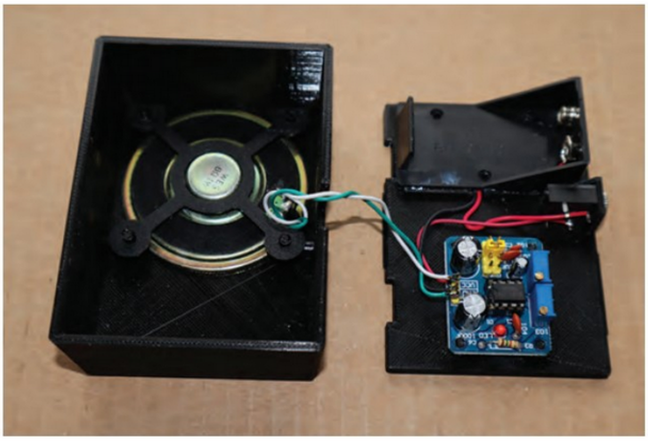

PHOTO 8: Internal view of the practice oscillator.

At the time of writing the 'Mini' retails at £36.96, the 'Micro' at £31.95, and the 'Nano' at £19.95

In addition to the three straight keys I was sent the two paddles in the 'cwmorse' range.

Paddle keys

Single and dual lever versions were provided, but the single lever one is actually wired as a side-swiper manual key (aka cootie) rather than a paddle. Fortunately you can easily change it to be used as a paddle on an el-keyer by cutting one wire. There is enough room inside the case to put a small jumper connection if you plan on using the paddle in both modes. Both models are supplied with Allen keys to adjust spacing but I found it easy enough to adjust them using my fingers.

As you will see from the picture of the insides, neither paddle has a way of adjusting the spring tension but, in use, I did not find that to be a problem. If I remember correctly at least one highly regarded, and much more expensive, paddle has a fixed spring tension. Although not visually obvious, there are roller bearings at the pivot points of both paddles. A 3.5mm socket connects them to the outside world.

I spent a while trying to get my head around using the single-lever one as a side-swiper manual key. I have never tried this before and, unfortunately, I could not make the necessary mental leap in the time available, so I converted it to paddle mode and used it that way.

Because I prefer small contact gaps I have always been sceptical of a single lever paddle's ability to return exactly to the centre. With this one I found that with very small gaps, releasing the single paddle resulted in the occasional overshoot past the centre, with the opposite contact being briefly made. But I quickly became accustomed to the different tension and spacing compared to those on my own paddle.

Even without the optional steel base I found both paddles comfortable to use for long periods, resting my left hand on the case while sending with my right, but there is an optional steel base available that fits either version of the paddle for home use. It costs £26.95 at the time of writing.

If you plan to alternate use of these paddles between home and /A or /P use, having to remove and replace those four bolts may be a chore so I thought I'd mention a technique I have previously used on a full sized key when operating /A.

One of the sticky gel pads intended for temporarily attaching a smartphone to the dashboard of a car works really well for keeping keys and paddles in place. I found it especially useful when trying the 'nano' straight key.

At the time of writing both paddles retail for £42.95.

Practice oscillator

In addition to the keys and paddles I was sent a practice oscillator from the same USA manufacturer, which retails at £34.95. The outer case is 3D printed. It requires a 9V PP3 battery to be fitted. There are no controls on the case to adjust the audio volume or tone frequency, just a 3.5mm jack socket to connect your key.

Not really much to say, other than it works. It is based on the popular NE555 timer IC, and you will find dozens of examples of that IC being used for this application on the web. The PCB looks to be a really good quality one.

Although there are no controls on the outside, there are a couple of multi-turn pots on the circuit board. Based on the circuit diagrams I found on the web, one should alter the tone frequency and the other the volume. The pot nearest to the battery does alter the tone, from about 450Hz to just over 1kHz. I expected the other pot to alter the sound level, but it did not seem to.

The board is glued to its plastic mounting pillars so I couldn't remove it to check the circuit wiring without damage. I did ask the manufacturers in the USA if the volume could be altered, but at the time of writing had not heard anything.

I think a volume control and headphone socket would be really useful and there is plenty of room in the case so it should be a simple job to add them.

Conclusions

I have to admit when I first saw this range of 3D printed keys on the Martin Lynch & Sons stand at the National Hamfest I dismissed them, and even when I took them out of the packaging to do this review I still had my doubts. But having actually used them I have to admit that they are quite good, and not just for portable use. For anyone new to CW – and it seems many people have used lockdown to learn Morse code – they are more than adequate.

The use of brass contacts may cause a few raised eyebrows, but the silvered contacts on my Kent paddle and Junker need occasional cleaning so, if necessary, an occasional wipe with something like Brasso is no hardship.

If you can afford high end keys and paddles there is definitely a certain pleasure to be gained from using a precision piece of engineering, and they are definitely easy on the eye. But having used these 3D printed units, I do now wonder if the actual operating improvement gained over these units by high-end units is really as much as I'd previously convinced myself it was.

I would like to thank Martin Lynch & Sons for the opportunity to try out the 'cwmorse' range. You can find out about these keys at www.hamradio.co.uk.

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Mounting a rooftop beam

It's well known that since it improves reception as well as transmission, a high gain directional antenna (with a short, low-loss feedline) greatly enhances overall station performance. Although a free-standing tilt-over telescopic tower is an excellent support for a large beam, local planning authorities may prohibit the erection of such a structure in a residential area. A rooftop-mounted antenna can be much cheaper and has less visual impact, particularly if it is supported by a plain tubular mast and the rotator is concealed inside the attic instead of exposed at the masthead. With this configuration the mast is particularly stable, no foundation concreting or guys and anchorages are required, and the rotator is fully protected from the weather and readily accessible for maintenance. The antenna itself can be assembled comfortably at shoulder height while standing on the roof, and then simply slid up the mast to the operating level when completed.

[Although the arrangements shown in this article may be of a lower visual impact this does not automatically mean that UK Planning Permission is not required. It is also strongly recommended that the strength and stability of the roof materials and construction should be professionally assessed before embarking on any works – Ed]

PHOTO 1: **Attic mast mounting provides an inexpensive and stable support for a large HF/VHF/UHF rooftop array.**

PHOTO 2: **Tidy rooftop antenna installation with no external rotator.**

Examples

Photo 1 shows a rooftop-mounted antenna array comprising a 5-element HF tribander and circularly polarised 2m and 70cm crossed Yagis for Oscar working. Only the elevation rotator for the satellite antennas is mounted on the main mast; the azimuth rotator for the assembly is fixed to the floor inside the attic. The crossboom for the satellite antennas is attached behind the reflectors of each Yagi and the assembly is balanced by a cylindrical cement counterweight. The roof of this house is surfaced with traditional interlocking terracotta tiles that can be removed and replaced without any tools.

Photo 2 shows my antenna installation at another QTH, where the roof is clad with flat synthetic tiles secured to the horizontal battens by galvanised steel hooks. In this case a later version of the HF beam is surmounted by a plain F9FT 9-element Yagi for 2m. The configuration inside the attic is shown in **Photo 3**. The rotator is secured to the concrete attic floor and the mast is supported by a bearing on a small platform attached to two horizontal collar beams that bridge a pair of rafters just below the ridge.

Mast

Many different grades of aluminium alloy tubing with different properties are available. My choice, 6060 or 6082 T6 porthole-extruded tubing with outside diameter 60mm and wall thickness 5mm, is inexpensive and ideal for rooftop mast use. This diameter is compatible with a wide range of rotators and accessories, such as bearings, antenna mast clamps, collars and roof entry flashing. T6 alloy is solution heat treated and artificially aged; it has excellent corrosion resistance. The tubing is rigid and strong enough to support

PHOTO 3: Mast base with rotator in the attic.

a large HF beam, and as it weighs less than 2.5kg/m it is light enough to be carried and installed by one person.

My experience suggests that planning permission is generally granted most readily if the antenna is not much higher than the chimneys. A 5m long tube allows about 2–2.5m to be located in a typical attic and 2.5–3m above the roof, resulting in a very stable mast with negligible sway and torsion in high winds. If required for the mounting of a lighter VHF or UHF antenna, the height can be extended elegantly by inserting the end of a length of 50mm diameter tube inside the main mast. The diameter of the end of the extension tube should be turned down by about 0.4mm to obtain a smooth sliding fit. If this is not possible the wider tube can be slotted to allow the narrower one to be inserted.

To prevent the ingress of water the 60mm plastic top cover from a standard aerosol spray makes a durable mast cap. As shown to the right of **Photo 4** it can be fitted with nails to prevent birds perching on the mast top and depositing detritus on the antenna and the roof. The 80mm long galvanised nails are secured inside the cap with epoxy. A conical protective collar is also required to make the roof entry point rain-tight. The Letrona LT 55-66 split type shown on the left of Photo 4 can be attached to the mast after installation, without having to be slipped over the top. It should be sealed with silicone before being secured with a stainless steel hose clip. Self-sealing synthetic collars are also available, and one of these can be mounted under the metal cone for extra security.

PHOTO 4: Mast components. (Left) Split sealing cone. (Right) Bird-resistant cap.

Location

When planning a rooftop installation, start by choosing the location of the mast centreline at the level of the upper bearing. This should be three or four tile courses down from the ridge of the roof, to avoid the complication of displacing tiles near the ridge, which are often cemented in place. It should be as close as possible to a main rafter, or to a collar beam if there is one. To minimise the loss in the feedline, choose a location that keeps the coax run to the shack as direct (ie short) as possible. And to avoid subjecting the antenna to the potential for corrosive fumes, locate it well away from any chimneys.

A small vertical pilot hole can be drilled from inside the roof to determine the optimum location relative to the tiles, and to ensure that the mast won't interfere with any of their horizontal supporting battens (see Photo 3). In the case of interlocking roof tiles, the exact position of the mast centreline will be determined by the shape of the roof entry flashing kit, which normally replaces a single tile. There is more freedom with flat tiles or slates, which can be cut anywhere, but preferably where only two tiles overlap. With this type of roofing, an additional metal flashing plate must normally be cut to fit on top of the roof entry kit after it has been placed in position on top of the tiles (see **Photo 5** and **Photo 6**).

To avoid galvanic corrosion, avoid contact between metals with very different anodic indices if they will be exposed to the weather. Traditional lead roof entry flashing is compatible with tin plate and aluminium alloy, but not with copper or zinc (including galvanised steel). Copper can be mated with stainless steel, but will rapidly corrode any zinc with which it is in electrical contact, since the electropotential difference is about one volt.

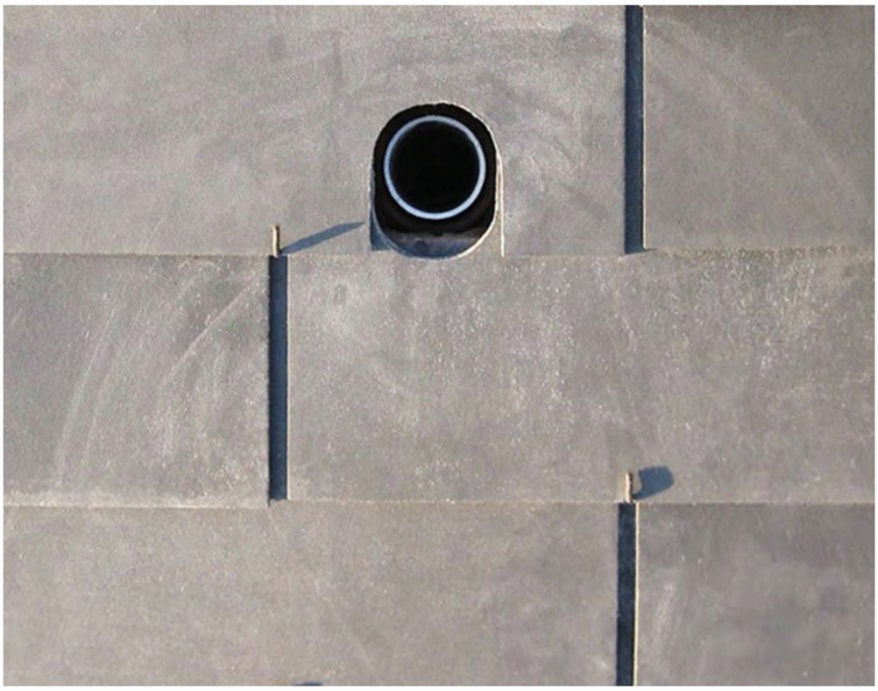

PHOTO 5: Mast location relative to tiles.

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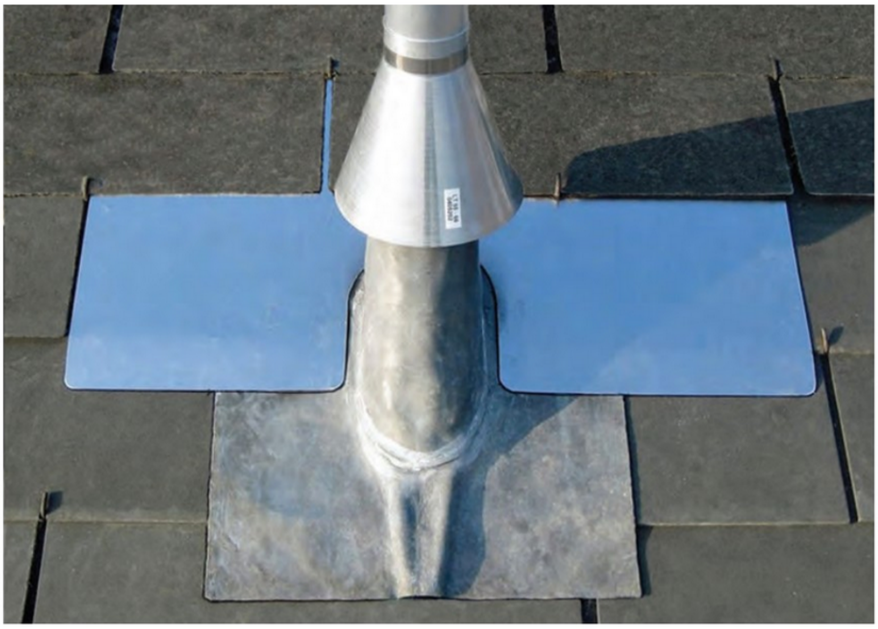

PHOTO 6: **Roof entry flashing with coax tunnels.**

PHOTO 7: **(Upper) Tile installation pry bar. (Lower) Slate ripper.**

Tiles or slates that are secured by hooks can be easily removed by pushing them upwards until they clear the hooks and then lifting them out. After cutting, they can be manoeuvred back over the inaccessible upper battens by a simple 2.5mm thick metal pry bar, curved and filed to a chisel edge at one end (see **Photo 7**, upper). Tiles or slates that are secured by nails rather than hooks can be removed with the aid of an inexpensive slate ripper tool (see Photo 7, lower). After cutting, they can be glued back in place with a hybrid polymer adhesive, or secured by nails in the gap between the tiles above them. In the latter case the nail heads must then be covered with a slater's sealing slip or equivalent.

Upper bearing

A diecast aluminium thrust bearing such as the Yaesu model GS-065 can be used to support the mast at roof level. Note that in this application, the bearing prevents sideways movement but doesn't support any vertical load, since the entire weight of the assembly rests on the rotator on the attic floor.

As it is very strong but easily cut and drilled, high quality 25mm plywood is an excellent material for making the bearing support platform (see **Photo 8**). Longer M8 x 40mm bolts than those supplied with the bearing will be required to attach it to the platform, and M8 hex-head wood screws with large diameter coach body washers and galvanised steel reinforcing nail plates can be used to secure the platform to the roofing structure. Long M8 screws can also be used to tie the beams to the rafters in the vicinity of the bearing platform. Finally, shims should be inserted to make the platform exactly horizontal, as checked with a spirit level.

Rotator mounting

Any thermal insulation material should be removed from the attic floor in the area where the rotator is to be located. An HF beam can weigh well over 20kg, not counting a full party of migrating sparrows or the ice load in winter, while a VHF Yagi weighs about 3.5kg – and a Yaesu G-2800DXC rotator itself weighs about 6.5kg. A concrete floor requires no reinforcement but a wooden one should be strengthened with a sturdy board to spread the load over the ceiling joists if the mast is to support a large array.

It is essential that the axis of the rotator be vertical and perfectly aligned with the upper bearing. Once the platform has been installed, a plumbline can be suspended from the bearing to mark the position for the centre of the rotator on the attic floor. The rotator can be bolted to a thick 25 x 25cm plywood baseplate that is secured to the floor by four M8 screws (see **Photo 9**). A spirit level can then be used to adjust shimming washers on the screws between the floor and the baseplate until it is exactly horizontal.

To set the full scale adjustment on some controllers the rotator must be turned through exactly 360º. To allow the controller to be operated in the attic for such tests, insert pairs of multipole plugs and sockets in the control cable near the rotator in the attic and near the rig in the shack. If there is access through a skylight near the mast, the controller can then even be used on the roof while checking the movement of coax cables and monitoring the beam direction. Many smartphones incorporate a magnetometer that can be used to set up the beam compass alignment with applications such as EA4EOZ's HamGPS, which also indicates your Maidenhead locator and GPS altitude.

Low-loss 50Ω coax such as Ecoflex typically has a diameter of 10–15mm. As shown in Photo 6, tunnels can be formed in the roof entry flashing to permit the passage of coax cables that are routed through the roof. This avoids sharp bends in the large diameter coax if it is passed through the flashing with the mast. To allow some overlap, rotators can normally turn through about 450º. The cables should be routed most directly when the beam is at mid-rotation, with adequate slack to allow it to turn through 90º beyond the selected heading limit. Ensure that there are no ladder clips or other obstructions on the roof that could snag the coax as the beam rotates.

PHOTO 8: **Upper bearing platform secured to twin rafter collar beams.**

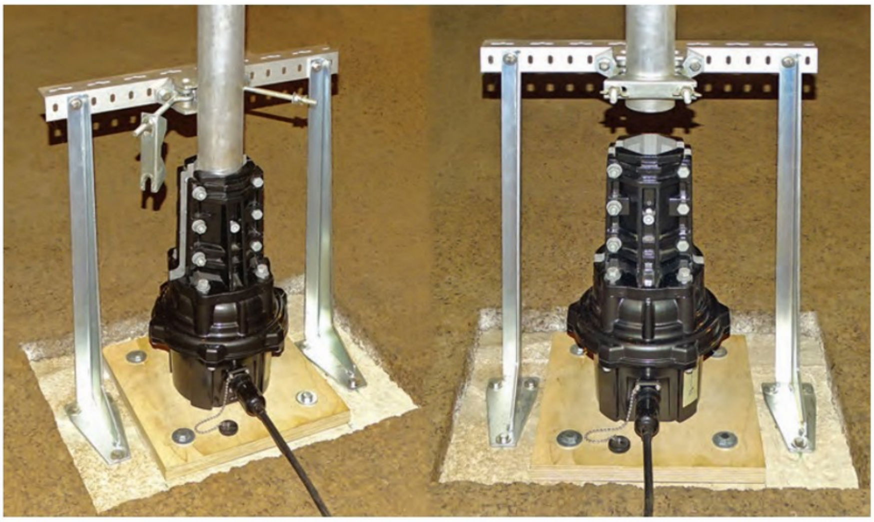

PHOTO 9: **Attic-mounted rotator. (Left) In service. (Right) Freed from the mast for maintenance.**

Maintenance

I have twice encountered issues with the potentiometers in Japanese rotators. In one case the pot became 'noisy', resulting in unreliable and fluctuating bearing indications, while in the second case the track became open circuit. With a mast-head rotator, the antenna array may have to be dismounted to remove the rotator for service. But with the rotator mounted in the attic, it can be easily accessed for re-lubrication or repair. All that is required is a simple gantry or bracket positioned above the rotator to hold the base of the mast assembly while the rotator is removed.

One convenient arrangement is shown in Photo 9. The gantry is composed of a pair of sturdy steel shelf brackets, which support a short crossmember fitted with a saddle clamp that can be secured by wing nuts. During normal operation the clamp is open, so that mast rotation isn't impeded. For maintenance, the rotator clamps are released and the mast is lifted up to clear them and secured with the gantry clamp instead. The rotator can then be safely removed from under the mast and taken to the workbench for dismantling and repair.

Safety

As with any antenna installation involving working with cumbersome components at height, safety should be the first priority. I have found the following tips useful but they are not exhaustive. You are responsible for your own safety.

Wear non-slip rubber-soled shoes and never venture on to a pitched roof when it is wet. Move cautiously to avoid tripping on any ladder clips, tile hooks or other irregularities, and use a chicken ladder if the pitch exceeds about 25º or the roofing material is too fragile to support direct footfall without risk of damage.

When working in an unlit attic, set up at least two portable lamps to provide shadowless illumination. Beware of dangers such as rusty nails with protruding points that can be difficult to spot – and think twice when about to stand up after working in an area of low headroom!

Never saw or cut old roofing material that may contain asbestos fibres. Wearing a face mask and protective gloves, remove it, wrap it in plastic and take it to a recycling centre that is equipped to dispose of it safely. Compatible modern asbestos-free replacement material is readily available and can be cut without health risks, using ordinary woodwork tools.

Building and insurance regulations vary with locality, but unless there are special risk factors they don't usually require the installation of lightning conductors on ordinary family houses of maximum height 30m. But it's advisable to connect any external metallic antenna mast to your earth bonding point by a separate conductor of at least 6mm^2 section, not just relying on the coax from the shack or the mains earth wiring.

Finally, beware of over-confidence! During the rush to prepare for the start of ITV transmissions in the 1950s, I helped out a technician installing domestic TV antennas during evening overtime. Having carried out dozens of these installations every week, he was rather impatient with the old gentleman who laboriously explained to him that he could only walk on the beams in his attic, not on the plasterboard between them. A few minutes later there was a loud crash and a leg appeared through the ceiling! Take care…

Technical

Replacement display for the Standard C58

I bought my C58 2m transceiver new in 1981 but over about 10 years the LCD display became unreadable. *(This was not uncommon with early generations of LCD – Ed).* Standard was acquired by Yaesu and the C58 replaced by the FT-290 – electronically almost identical but physically slightly larger. The FT-290 display was also prone to failure and a replacement display for that radio using 7-segment LEDs has previously appeared in *RadCom* **[1]**. Similar work was carried out by ZS1KE **[2]** between 2015 and 2019. **Photo 1** shows my (modified) Standard C58 and **Photo 2** shows the failed original display – note how segments are partially 'lit' even though it is disconnected from all circuitry. The C58 front panel display aperture is a mere 20 x 8mm and the original display has only 4 characters, plus a row of fixed values, to show memories, and various 'significant' dots.

Both the Yaesu and Standard use a custom chipset to process and display the frequency and other information. The display module is provided with four data lines, a chip select (CS) and strobe (STB). Six bytes of data are passed for each display cycle, of ~1.3ms, enabled by the CS line. These are passed as twelve nibbles *[sometimes 'nybble', to match 'byte' – Ed]*, each nibble is validated by the STB line. In the C58, unlike the Yaesu, the ~8μs strobe pulses are equally spaced at ~100μs intervals. **Table 1** shows the data line relationships, for 146.000MHz.

This gives, in hexadecimal: 30; 30; 30; B6; 20; 20. The first four bytes contain the frequency information, as ASCII equivalent values (when viewing the six least significant bits). They are sent with the least significant value first. The MSB in the fourth byte signifies the decimal point. Hence, we have 6.000 (MHz).

Various bits within each of the six bytes are used to provide other information, as shown in **Table 2**.

Three other lines are provided to the display module: 5V, LCD bias and a clock. These three lines and the data are provided on two connectors to the motherboard, which can be seen in **Figure 1**.

PHOTO 1: **My vintage Standard C-58 (after the display modification).**

The design

The replacement display is limited by available space and the viewing aperture. A MIDAS brand 8 character x 2 line display (MC20803A6W-GPR) was chosen for its small size and a custom PCB was designed to support this with a PIC based microcontroller (PIC16F627A-I/SO).

With eight characters available, I decided to display the whole frequency. On the original display, one cannot see the MHz value when the radio is selected to 100Hz steps. The odd and even MHz ranges are indicated by

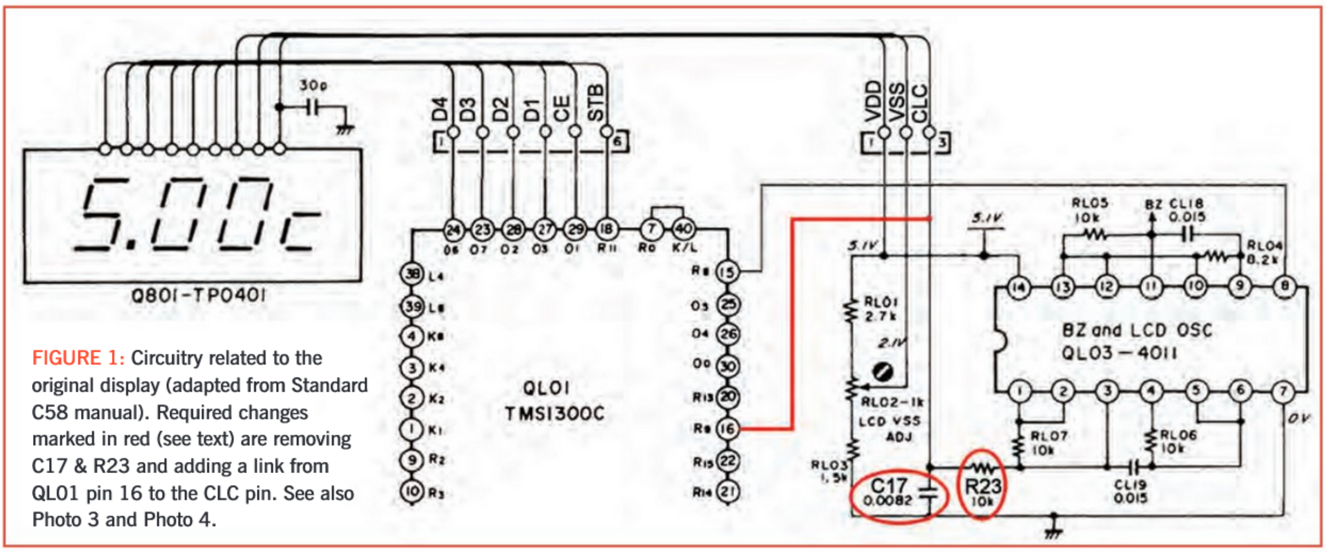

FIGURE 1: Circuitry related to the original display (adapted from Standard C58 manual). Required changes marked in red (see text) are removing C17 & R23 and adding a link from QL01 pin 16 to the CLC pin. See also Photo 3 and Photo 4.

PHOTO 2: **The original Standard C-58 display had deteriorated badly.**

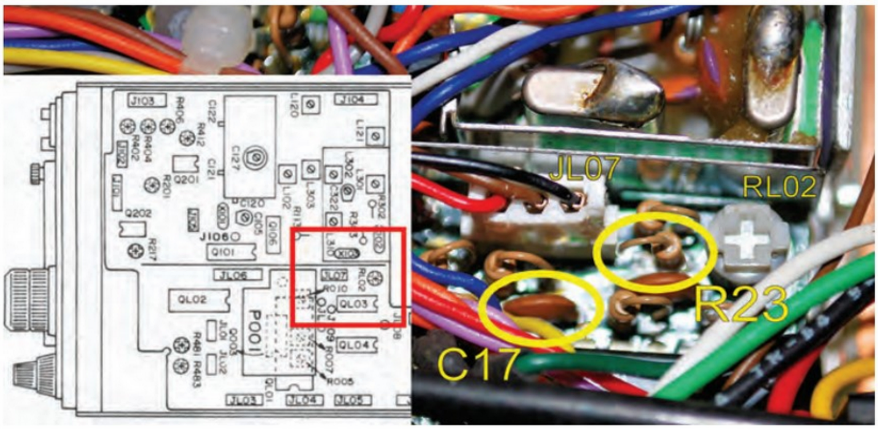

PHOTO 3: **Remove C17 and R23.**

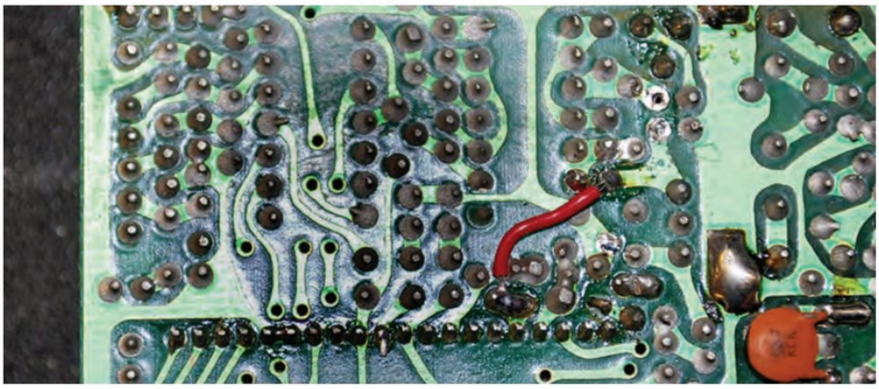

PHOTO 4: **New connection linking the now-unused clock line to QL01 pin 16.**

a dot, but there is no indication whether this is within the 144–145MHz or 146–147MHz range. This information *is* however available on the PLL motherboard, on pin 16 of the processor QL101. Since the clock is no longer needed, its connection (CLC) was repurposed to provide the required band-indicating signal. To facilitate this change, RL23 and CL17 were removed from the circuit board and a link added from the CLC connector to pin 16 of the CPU (QL01). (Pin 16 is one of the lines that control the high and low band VXOs). Figure 1, **Photo 3** and **Photo 4** show the necessary modifications.

A small, very simple PCB was designed to hold the PIC circuit seen in **Figure 2**. I used the free DesignSpark software from RS Components **[3]** and you can download my design and other relevant files at **[4]**. The circuit is fairly straightforward, as all the clever stuff is done in the software. The diodes, C2 and R1 are there to facilitate in-circuit programming.

It is important to note that the design requires the display module to be connected on the opposite side of the board from the copper. This is to maintain a minimum overall thickness of the assembly and, of course, to wire it correctly. In my prototype the circuit board to LCD PCB connections were made with individual wires, however it may be possible to source PCB connector strips with 1.27mm (0.05") spacing. All of the other components are surface mounted on the copper side.

Installation

Disconnect the old display and transplant the wires to the new board using Figure 1, **Figure 2** and **Figure 3** as a guide. The board is a bit of a squeeze to fit in the space vacated by the original display but it does tuck in nicely, as can be seen from **Photo 5** and **Photo 6**.

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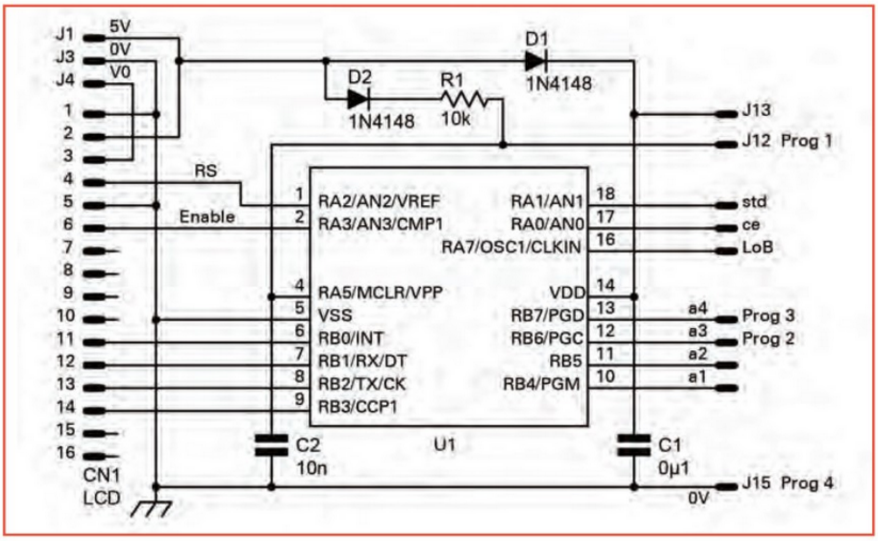

FIGURE 2: **Circuit diagram of the PIC/display board.**

Parts list

U1	PIC16F627A-I/SO or PIC16F628A-I/SO
LCD	MC20803A6W-GPR (Farnell 2425673)
D1 & D2	1N4148WS-E3-08
C1	100nF (SMT0805 ceramic)
C2	10nF (SMT0805 ceramic)
R1	10k (CRG0805)

Firmware

The firmware for driving the display was written using assembly language. It was programmed into the PIC directly using my old Velleman K8048, through the ICSP connector. Various other designs of programmer and software may be found by searching the internet.

I have made the assembly language file and the assembled code (ready to program into a PIC) available via [4].

Conclusion

The Standard C58 may be an old all-mode radio but it is still capable of providing decent service. Hopefully my modification will inject a new lease of life into a few and, maybe, inspire others to create similar modifications for other vintage radios with duff displays.

Websearch

[1] Replacement display for the FT-290R, David Crump, G8GKQ, *RadCom* December 2016 (page 60)

[2] www.retro.co.za/zs1ke/FT-290R/reverse-engineer.html

[3] https://www.rs-online.com/designspark/pcb-software

[4] https://rsgb.org/main/publications-archives/radcom/supplementary-information/

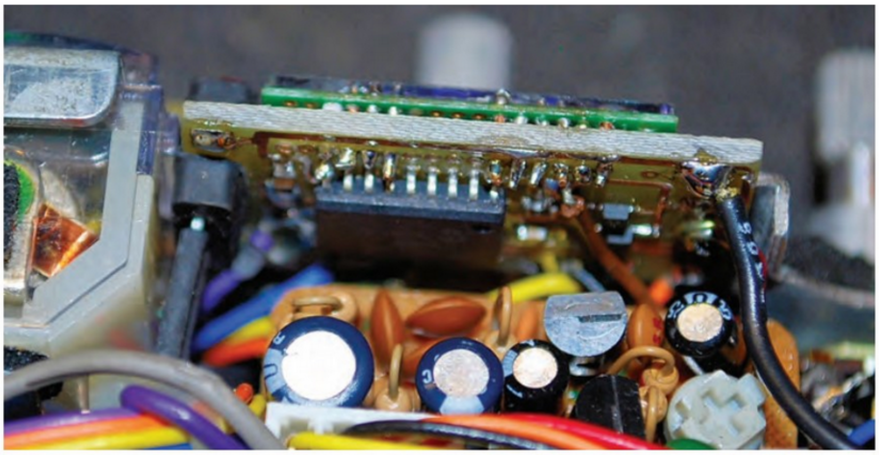

PHOTO 5: PCB in place, seen from the reverse (ie from the 'inside' of the radio looking out).

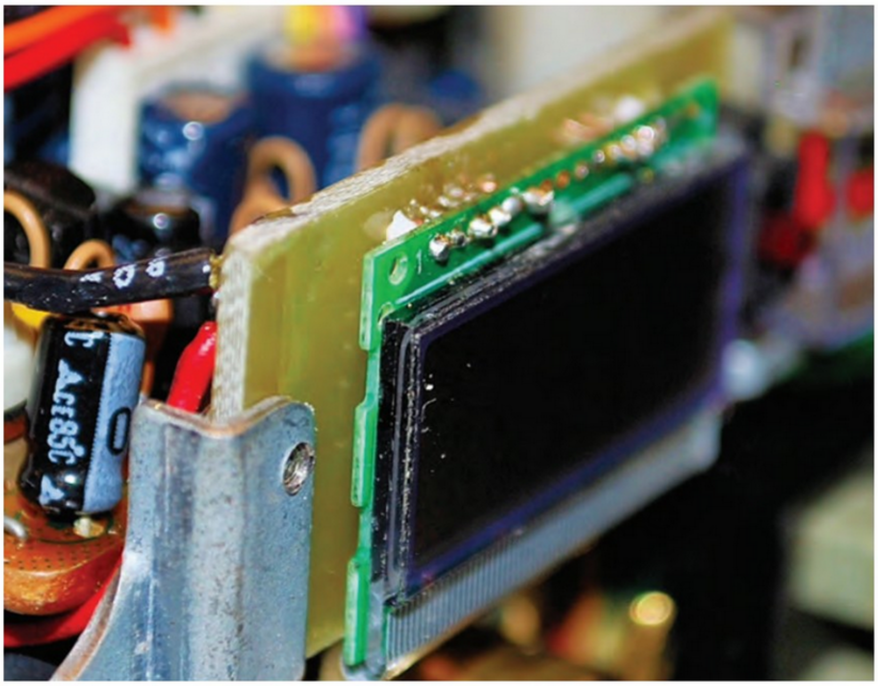

PHOTO 6: PCB in place, seen from front.

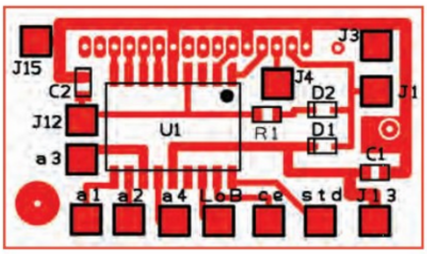

FIGURE 3: PCB details. The board is 36mm x 20mm. Download the files from [4] (see text).

TABLE 2: Information contained in other bits (x=not relevant / don't care).

Bit	D4	D3	D2	D1
1	Scanning	M5	1	1
2	x	x	x	x
3	M4	M3	1	1
4	x	x	x	x
5		M2	1	1
6	x	x	x	x
7		M1	1	1
8	x	x	x	x
9	0	Odd MHz	1	0
10	0	0	0	Pulse for memory entry
11	0	0	1	Undisplayed 100Hz
12	0	0	0	0

TABLE 1: Data line relationships representing 146.000MHz.

Bit	D4	D3	D2	D1	Nibble
1	0	0	1	1	3
2	0	0	0	0	0
3	0	0	1	1	3
4	0	0	0	0	0
5	0	0	1	1	3
6	0	0	0	0	0
7	1	0	1	1	B
8	0	1	1	0	6
9	0	0	1	0	2
10	0	0	0	0	0
11	0	0	1	0	2
12	0	0	0	0	0

How to be Es ready this season...

The new summer season for Sporadic-E (Es) is upon us, and this is probably a good time to go over how to use the website propquest.co.uk.

Propquest has been around for a few years now and has continually evolved as a propagation tool for HF and Sporadic-E (Es) propagation. This is a short review of the main features, which can make the 2021 Es season more productive and focusses upon how to use it. Do take time out to read the 'About' section for the site, which contains more detailed information that you'll need to see how it works. However, we've been busy adding new features and I want to introduce them for this year's Es activity.

The site began as a vehicle for showing the HF propagation graphs of the critical frequency of the ionospheric F2 layer (foF2) measurements at three of our closest ionosonde stations at Chilton, Fairford and Dourbes, see **Figure 1**. These show the latest values of foF2 for a vertically launched signal, plus various MUF for paths up to 3000km that intersect the F layer more obliquely and thus can support higher frequencies.

You can use these graphs to see when the HF bands are opening up, but keep in mind that the daytime D layer absorption will reduce the activity locally on the LF bands up to about 40m and they do not necessarily show conditions along a multi-hop route.

Local LF nets and contests like the RSGB 80m CC can be strategised by noting where the foF2 is trending and working the G stations before the band 'goes long' when only the higher MUF graphs remain above 3.5MHz, explaining why only eastern European and Scandinavian stations are workable at 1000km plus ranges.

You can separate out the main parameters for local net conditions and UK contests by selecting the NVIS tab (NVIS = **N**ear **V**ertical **I**ncidence **S**kywave), see **Figure 2**, which shows the foF2, fxI (spread F index) and foEs, from which you need at least one to be above the band in use for successful inter-G QSOs.

This NVIS graph, which contains an foEs plot, can give an early sign that Es prospects are about to pick up once values climb above about 6MHz.

Now to detail the two primary sections of Propquest in a Sporadic-E context.

Es blog tab

The Es blog tab has been a valuable pathway for explaining how the jet stream forecast charts for the current day are likely to impact the chances for Es. The blog runs during the main season from May to early September. The main thing to draw from the charts, see **Figure 3**, is where the jet streams, shaded green to yellow/orange, are located and if there are any changes in location during the day. You can see the type of information by looking back at previous years' May-Sep Es blogs. Jet streams (fast flowing currents of air in the upper atmosphere around 10-12km altitude) are known to be associated with the location of Es; not a guarantee, but it's a good starting point,

FIGURE 1: **Graphs of foF2, foEs and F2 Maximum Useable Frequency (MUF).**

FIGURE 2: **NVIS parameters, foF2, fxI and foEs.**

especially if the jet streams are within the ideal radial ring distance markers for the mid-point of an Es path.

Es Probability Index

The recently added section is labelled EPI, which stands for Es Probability Index and is designed to show where the chances of Es occurring is greatest, see **Figure 4**. This Index encompasses many of the varied parameters which are believed to be a factor in the formation of Es. The EPI data plot covers the period ±12 hours from now, in hourly steps, and allows you to see how the pattern has evolved and will evolve. The two main variables are the meteorological input, ie position of jet streams; and the time of day, which controls the 'windows of opportunity' when Es is enhanced by the movement of the tidal winds in the E region. These are very important for determining the when and where of Es. The EPI maps are updated four times a day as each new meteorological model output becomes available. This new feature has been designed to allow users to save details of an Es QSO and take a screen grab showing how it relates to the EPI.

The first step is to add your callsign and locator to the settings panel on the LHS and click 'GO'. I should say that you can also enter a latitude and longitude instead of locator and it will fill in a new locator for you. Either way, this places two circles around your location that define a typical range window for Es to appear at mid-point; giving a total path length of 1400-2400km. (On some browsers the map may vanish at this point, so just move it a fraction to the right and it will come back… it's on the urgent fix list!) You will then be able to see if any 'hot spots' of the EPI index occur within the radial rings. A brief testing period at the end of last year suggests that yellows are potentially FT8 opportunities, orange/red marginal CW/SSB and purple/silver strong probability; this relationship will be updated as new examples become available. Please remember this is an expectation of location of Es and other variables may be against it, such as Kp index (a planetary measure of how disturbed the earth's magnetic field is), meteor input, solar activity etc. The Kp index is shown to allow you to make appropriate allowance for this factor not directly embodied in the EPI shading; Kp 2 or less is good, and Kp 4 and above not so…

Anyway, on with the next steps… let's say you have just worked a station on 6m Es, and you have exchanged the standard reports and locator; we can now complete the fill-in for the DX station. Again, we add the callsign and locator of the station worked, plus select the band used. The EPI map will then show the path and the QSO details appear in the box at the bottom left of the map. This shows callsigns, locators and the band/distance and time of QSO. You can adjust the time in the settings panel if the QSO was not at the time you entered the details. Another useful feature is to vary the search radius rings to highlight the half distance by selecting the 100km increment either side of the half distance. Now the final step is that the download button between the radial ring controls can be used to save a .png image of the EPI plot of your QSO.

This is early days for the EPI and it will doubtless change as the new season gives us additional data to fine-tune the parameters of the EPI; a verification scheme is currently being looked at. Future developments will include a way of adding multi-hop paths; although the longer paths can presently be added, you will have to be content with the first hop circles for now. Incidentally, a detailed article on Sporadic-E can be found in the Spring edition of *RadCom Plus*, published in May.

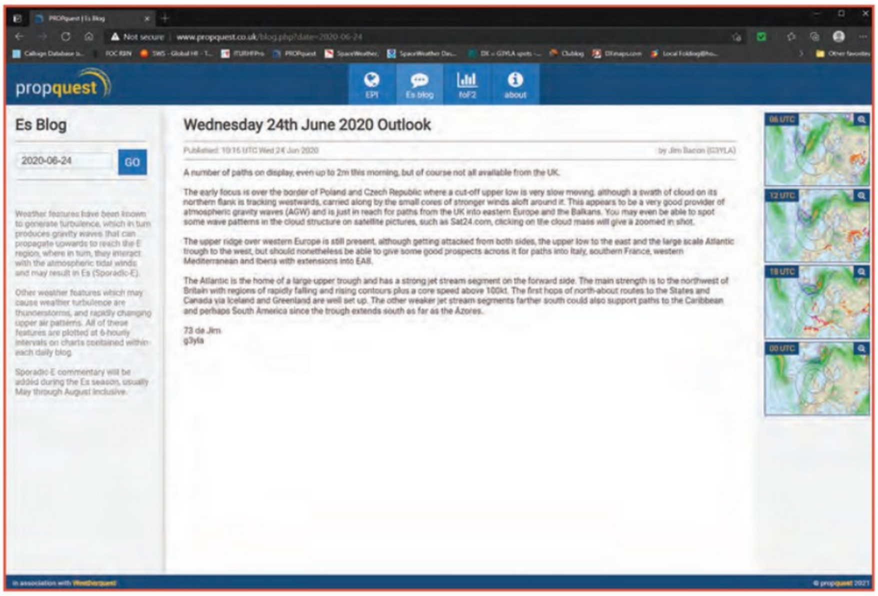

FIGURE 3: Es Blog plus jet stream charts (click to expand on the website).

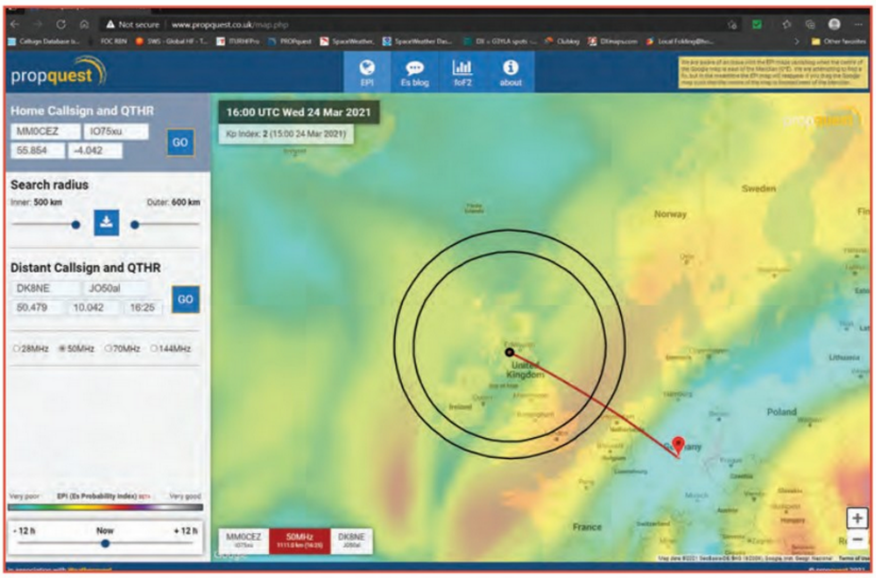

FIGURE 4: Plot of FT8 Es QSO on EPI map.

Get in touch

Please let me know if you have any requests for new features. Development depends upon the much-valued programming support of my colleague Dan Holley and Weatherquest for hosting the website, plus the many other resources in the science community who make their data available for amateur radio use.

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How the SWR meter works

Recent correspondence in The Last Word has indicated that there remains some confusion on the topic of standing waves in a transmission line. I hope this may shed some light.

It is easy to be confused by the reference to reflected power when dealing with transmission lines and antennas. A misconception in my youth used to be that this was power that did not reach the antenna. To add to my confusion was inference by one author that reflected power was either absorbed by the transmitter or reflected back towards the load if the transmitter impedance was not the same as the line impedance. The following description may help others to understand why neither of these can be true.

Standing waves

The earliest method of measuring the electrical conditions on a live transmission line relied on a coupled short section of short-circuited line driving a current meter. For high power applications this was mounted on a trolley that could be wheeled along an open twin-wire line to reveal the local current.

Unless the line was terminated with its characteristic impedance, the indicated current changed between maximum and minimum values every quarter wavelength. The line voltage varied in a similar way but went up where the current went down. *The variations were caused by the line transforming the termination impedance to different values along its length.*

These were called *standing waves*. This is presumably because of an, analogous, relationship with the stationary waves supported on flowing water when encountering an obstacle (for example, where a river becomes shallow). The ratio between maximum and minimum current, or maximum and minimum voltage, is the standing wave ratio, SWR. To help understand this concept it was assumed that a wave of voltage was reflected from the termination of a transmission line. The local line voltage was to be the sum of the forward and reflected waves. Similarly, a standing wave of current is generated – but but these are waves of voltage and current, not power.

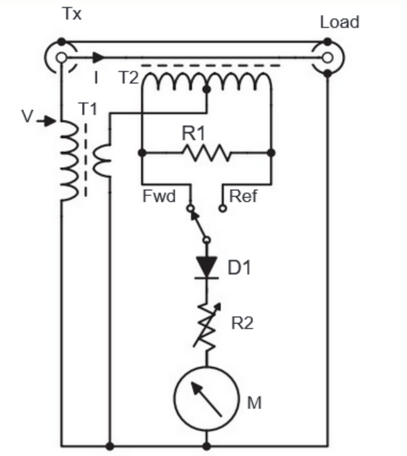

FIGURE 1: SWR meter circuit.

Dissipation due to SWR

SWR causes extra attenuation due to dissipation of power from the transmission line or feeder. Dissipation is proportional to the square of current, I. Therefore, the power, dissipated from a maximum current segment of line is not neutralised by reduced dissipation from a similar segment of minimum current, a quarter wave away. Consequently a transmission line has increased loss due to dissipation when standing waves are present. There will be a similar effect caused by increased dielectric loss due to the voltage SWR. However, at HF, dissipation from resistance of the line is usually the most significant cause of attenuation. A short line, much less than a quarter wave (as we might use on the lower HF bands), will therefore have less attenuation when it has a SWR due to termination by a high impedance than when the same SWR is due to a low impedance because less of its length carries high current.

Directional couplers

When the coupled line section that was driving the current meter was terminated with its own characteristic impedance, the indication became dependent on which end was terminated. The coupled section was then called a *directional coupler* because turning it around to face in the opposite direction produced a different current indication. From the water analogy it reinforces the concept that this was due to an interfering wave, moving in the opposite direction to the flow, resulting from reflection at an obstruction.

The watt-less, 'reflected' wave is a convenient mathematical concept that has become corrupted into reflected 'power'. Alternatively, it might be helpful to think of the observed (electrical) current variations as the result of the resistive component of the load impedance being transformed by the transmission line to different values, at the points of measurement. Similarly, the voltage variations are due to the changes in the local conductance component of the admittance, also known as the parallel aspect resistive component of impedance. The Smith chart illustrates this concept perfectly.

When using a directional coupler it was no longer necessary to move the indicator along the line to see the SWR. A linear version, suitable for coaxial feeder cables, followed. This consisted of a short, terminated conductor located between the coaxial inner and outer conductors of the line, driving a current meter. A disadvantage of this arrangement is its frequency-dependent sensitivity.

Reflection coefficient

The ratio between the hypothetical 'reflected' wave and the forward wave on a transmission line is, for obvious reasons, called the reflection coefficient. It is designated Γ (or, sometimes, p).

When a line of impedance Z_0 supports voltage V and current I at the point of measurement the forward wave is proportional to V + Z_0 x I and the 'reflected' wave is proportional to V – Z_0 x I.

Therefore,

$$\Gamma = \frac{V - Z_0 \times I}{V + Z_0 \times I}$$

$$SWR = \frac{\Gamma + 1}{\Gamma - 1}$$

(Equation 1)

The SWR meter

The SWR meter – despite the simplicity of its basic circuit, shown in **Figure 1** – is an analogue computer that performs the calculations necessary to solve Equation 1. Unlike the linear directional coupler it does this without dependence on frequency.

Transformer T1 may be wound in the form of a long solenoid to minimise the inter-turn voltages that may be present on a mis-terminated transmission line. It may alternatively be replaced by a capacitor voltage divider.

Transformer T2 is wound on a toroid, through which the inner conductor of the feeder passes to form the primary single turn. There is often an electrostatic screen between windings to minimise inaccuracy (poor return loss) due to inter-winding capacitance.

We can put some values to the components in the circuit. For convenience we will make the turns ratio n of both, series connected, transformers T1 and T2 equal to 100. R1 is then 2 x Z_0 = 100Ω. Other values may be used for R1 providing appropriate adjustment is made to the turn ratios of the transformers.

Deflection at the measuring instrument M, after calibration with resistor R2, is the reflection coefficient Γ. M is, however, scaled non-linearly to directly show SWR. At zero deflection, when Γ = 0 it reads SWR of 1.0, at half scale when Γ = 0.5 it reads SWR of 3, and at full scale when Γ = 1 it reads SWR of infinity (∞).

When power is supplied by a transmitter to a load via the SWR meter, the switch receives a voltage at pole Fwd that is a sample of the forward wave. This is the sum of the line voltage sample V/n and half the voltage due to transformed feeder current I/n that appears across R1. Switch pole Ref receives a voltage sample of the 'reflected' wave due to the difference between the samples from T1 and the opposite polarity end of T2's secondary winding.

The requirement to calibrate M by operating the switch and adjusting R2 may be eliminated by connecting a crossed needle or twin coil dynamometer instrument via individual diodes at FWD and REV.

The computation

For those interested in seeing how the circuit uses the data, there follows an example of the calculations involved in reaching an SWR reading. *j* may be ignored by those not familiar with complex algebra. (*j* is a mathematical operator that has the magnitude of √-1. In this application it shows the part of an impedance that is reactive and in which current is 90° out of phase with applied voltage). It will help to know Ohm's Law and Pythagoras' Theorem for the relationship between sides of the right-angled triangle formed by in-phase and quadrature currents and potentials.

Let us make the load Z from a resistance r of 50Ω in series with jx of 50Ω reactance. This is the impedance that we would expect to see, at the half power bandwidth frequency increment, above the resonant frequency of a simple antenna that presented a load of 50Ω resistance at its resonant frequency.

For ease of calculation, we will make the transmitter voltage V = 100.

The complex line current *I* is, therefore

$$\frac{V}{Z} = \frac{V}{r+jx}$$
$$= \frac{100}{50+j50}$$
$$= \frac{100\times(50-j50)}{(50+j50)\times(50-j50)}$$
$$= 1-j1 \text{ amps}$$

(The trick of 'rationalisation' was used, to ease division by a complex number, whereby upper and lower lines of the equation were multiplied by its conjugate; 50-j50).

From Pythagoras, the vector representing the magnitude of

$$I = \sqrt{(1^2 - j^2\times 1^2)}$$
$$= \sqrt{1+1}$$
$$= \sqrt{2}$$
$$= 1.41 \text{ amps}$$

This is the current that causes dissipation of power P, in r, the resistive part of the load. Without the reactance, SWR would be 1.0 and P would be

$$\frac{V^2}{r} = \frac{100^2}{50} = 200\text{W}$$

With the reactance present, the power at the load is

$$P = I^2 r$$
$$= 1.414^2 \times 50$$
$$= 100 \text{ watts}$$

Hence the *half power* bandwidth, because the final stage of a transmitter is assumed to supply a constant voltage.

Observe that despite the SWR, all of the power supplied by the transmitter reaches the load and no power is available for 'reflection'.

The sample of line current at half of T2 secondary is

$$= 0.5\times I\times R\times\frac{1}{n}$$
$$= 0.5\times 1.41\times\frac{100}{100}$$
$$= 0.71\text{V}$$

but this is the vector sum of in-phase and quadrature (90°) components. The components are respectively, therefore, by Pythagoras:

$$0.71\times 0.7 \text{ and } -j0.71\times 0.7$$
$$= 0.5V \text{ and } -j0.5V$$

Now we add the in-phase and quadrature components of the forward samples before their vector resultants at FWD are converted to DC by the diode.

The in-phase sum of the samples is 1+ 0.5 = 1.5V

The quadrature sum is 0 – *j*0.5 = –*j*0.5V

The resultant forward vector sum is, from Pythagoras:

$$\sqrt{1.5^2-(j^2\times 0.5^2)}$$
$$= \sqrt{2.25-(1\times 0.25)}$$
$$= 1.581\text{V}$$

(Equation 2)

After rectification, by the diode, this provides the full-scale reference at M when set by adjustment of R2.

Now the difference vectors at Ref:

In-phase difference = 1.0 – 0.5 = 0.5V

Quadrature difference = 0 – *j*0.5 = –*j*0.5V

From Pythagoras their resultant 'reflected' vector sum is:

$$\sqrt{0.5^2+(-j^2\times 0.5^2)}$$
$$= \sqrt{0.25+(1\times 0.25)}$$
$$= \sqrt{0.5}$$
$$= 0.707\text{V}$$

(Equation 3)

M shows the reflection coefficient:

From Equation 2 and Equation 3:

$$\Gamma = \frac{0.707}{1.581}$$
$$= 0.447$$

of full scale.

From Equation 1:

$$SWR = \frac{\Gamma+1}{\Gamma-1}$$
$$= \frac{1+0.447}{1-0.447}$$
$$= \frac{1.447}{0.553}$$
$$= 2.616$$

The calculation may be confirmed by driving, via a 50Ω SWR meter, an inductor or capacitor having reactance of 50Ω in series with a 50Ω dummy load. For example, 450pF at 7.07MHz.

Differences for resistive loads

For a purely resistive load the calculations are much simpler because the *j* operator is not then involved.

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Design Notes

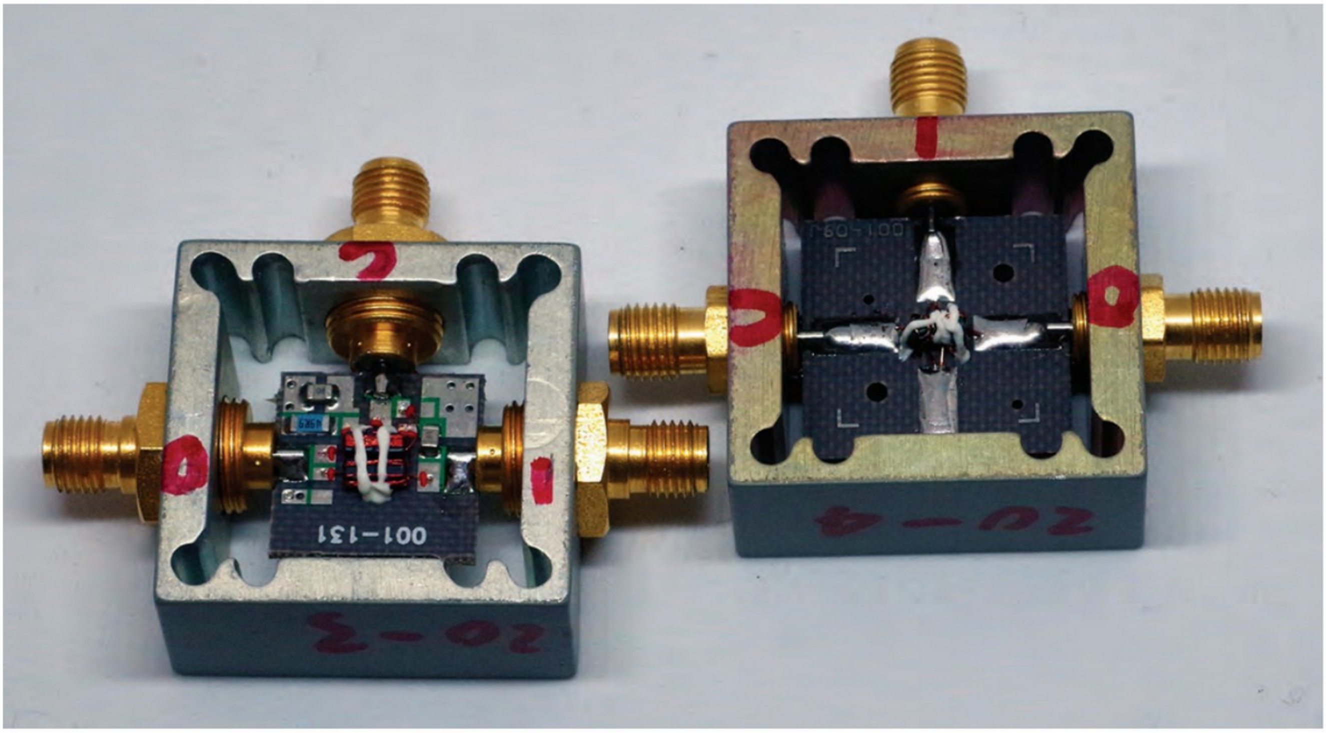

PHOTO 1: **The internals of two Mini-Circuits 20dB directional couplers, each covering around 200kHz up to VHF.**

Splitters and combiners

A discussion about splitters for feeding stacked antennas (and their use as combiners for paralleling two identical power stages) mentioned the problems obtaining the high frequency, dual ended high power 100Ω resistor needed. The splitter being discussed, the classic Wilkinson (used to combine two ports into one) is shown on the left of **Figure 1**. Although these resistors do exist they are expensive and are a bit delicate if overloaded. Since in normal operation the resistor shouldn't be dissipating any power, or at least only a small amount, it seems a bit wasteful. It is only when things go wrong, such as one of the two antennas breaking or one of the two power amplifiers failing that the resistor is called upon to dissipate any significant power.

On reading this, John, G0JLF wrote: "No one seems to have mentioned using a coax rat-race combiner / splitter rather than a Wilkinson". Murray, G6JYB then noted that "A great advantage of hybrids vs Wilkinson is that it you can monitor the waste port dummy load to detect fault conditions and shut down quickly for self-protection from either a PA or antenna problem". The configuration discussed, the 180° hybrid or rat-race coupler, is shown on the right of Figure 1. Like the Wilkinson, it uses 70.7Ω coax, but this time in a ring 1.5 wavelengths around with four ports. The fourth port is connected to a load, just a normal dummy load – and everyone should have one of those! Note how the load is λ/4 from OP1 and 3λ/4 from OP2. This half wavelength difference means that provided the outputs have the same mismatch, the reflected power from each of them will cancel at the load. It is only when the outputs have unequal mismatches that the reflections do not cancel, resulting in power dissipated in the dummy load.

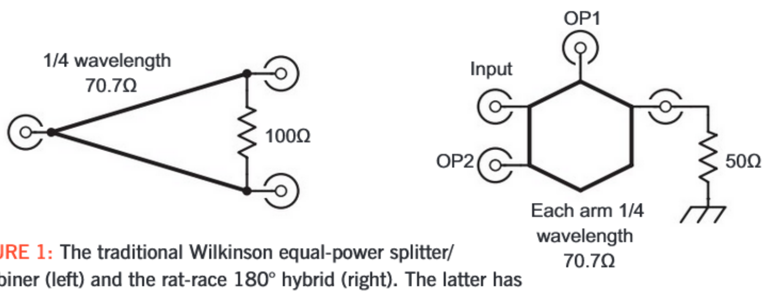

FIGURE 1: **The traditional Wilkinson equal-power splitter/ combiner (left) and the rat-race 180° hybrid (right). The latter has a normal 50Ω load instead of a balanced 100Ω resistor and could prove easier to construct, even though it requires 70.7Ω coax.**

Monitoring the power dissipated in the termination can be done with a diode probe across the load. Or, for high power, a coupler and diode detector. To be fair, measuring

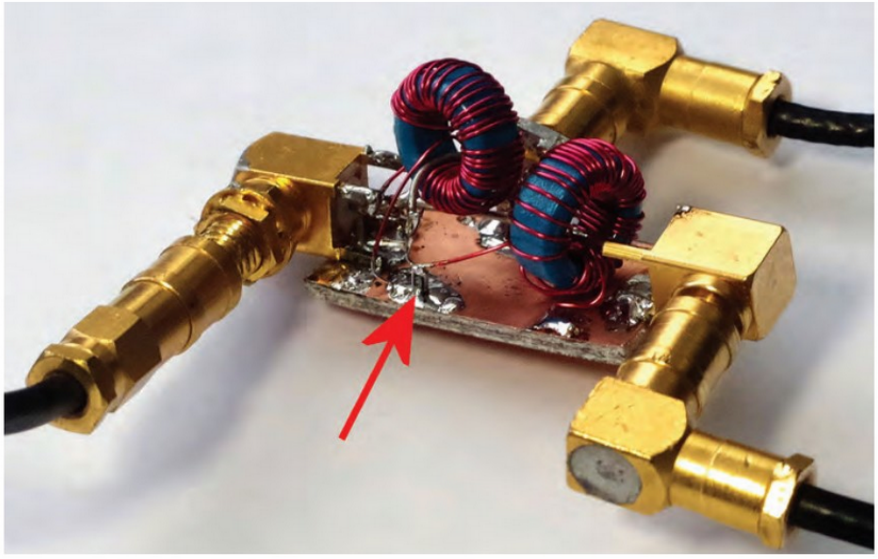

PHOTO 2: 30dB coupler built to the same configuration as the ZFDC-20-4. There are 31 turns on each toroid. The arrow indicates the load resistor (see text).

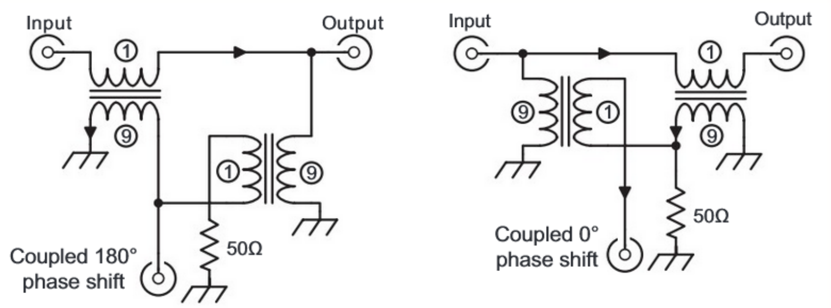

FIGURE 2: Circuit diagrams of two Mini-Circuits 20dB directional couplers, ZFDC-20-3 and ZFDC-20-4, both covering MF to VHF frequency bands.

the voltage across the balanced load in a Wilkinson could be done the same way, but then both DC leads coming from the detector would have to be very well decoupled at RF with series chokes, which will all start to get a bit messy.

Packaged directional couplers

Recently I was doing some tests on 137kHz with G0API using the FST4W weak signal mode. This involved my progressively reducing power each transmission period until John's copy failed; I was down to 50mW at the end of the test. To set the power output an oscilloscope was used to measure the voltage from the PA output, with a calculation needed every time the level was changed. It would have been nice to have an inline power meter that could cover the power levels in use, from around 2W right down to a few milliwatts. I already had a power meter using an AD8307 log-power device with LCD readout directly in dBm. This covered the range -70dBm to +16dBm, so just add a directional coupler on the PA output and we're away.

In the junk box I found a some Mini-Circuits directional couplers. Two packaged ones; a ZFDC-20-3 rated for 200kHz to 250MHz and a ZFDC-20-4 covering 1 – 1000MHz. There was also one with through-hole connections, a PDC-20-5 that, according to the data sheet, claimed operation over the extraordinarily wide range of 100kHz to 2000MHz. All these units were specified at 20dB coupling, so were ideal to go with my power meter. Going down to below 137kHz, the PDC-20-5 looked perfect. The data sheet gave a maximum rating for this device of 0.5W when used at the lower frequency end and 2W at higher frequencies. Not enough for my longer-term needs, but enough to be going on with at the power levels needed at the time. So I wired it into circuit, even changed the PIC code in the power meter so it took the coupling coefficient into account and had what I thought was a nice new QRP inline power meter for LF to VHF. But it wasn't to be.

At 137kHz the forward power was reading perfectly and agreeing with my scope measurement up to around 100mW of RF. Above that level, odd things happened. As the power was increased, the reading on the LCD went back down. Even worse, the trace on the scope was showing considerable distortion. After checking it really wasn't the PA giving trouble, it was clear the directional coupler was saturating at a power level appreciably below what the data sheet suggested it should – and there was something in the path inside the coupler that upset the power passing though it. Changing frequency and testing at 475kHz showed proper operation ensued up to 1W so it was very definitely ferrite saturation.

The two packaged couplers have broadly similar specification and were easy to open up to see what was inside. **Photo 1** shows the innards of each. It is a bit difficult to see what is going on, especially as the ZFDC-20-4 (the one with smaller ferrites in a blob of silicone) has its load resistor on the underside. Tracing out their circuit diagrams by judicious use of a magnifying glass showed the two slightly different circuit arrangements shown in **Figure 2**. Both versions generate a signal that is derived from a step-down transformer connected across the input/output added to a voltage derived via a current transformer and load resistor from the RF current in the through path. By making these equal, the two voltages add when power flows from input to output ports and cancel when power flow is in the opposite direction. This is the same principle as the classic HF SWR bridge. By choosing the turns ratio of the two transformers appropriately the coupling factor can be varied. For 20dB coupling, a turns ratio of 9:1 is used. (This should theoretically be 10:1 for 20dB coupling, but the reduced ratio compensates for resistive losses.)

So, it is clear what was happening. The ferrite in the voltage transformer was saturating, generating harmonics and shunting the fundamental frequency component – giving the distorted waveform. So if I want coverage at 137kHz at up to several watts a homebrew version is needed, made with larger cores. And I might as well go for reduced coupling to cope with high power, a 30dB ratio would allow powers

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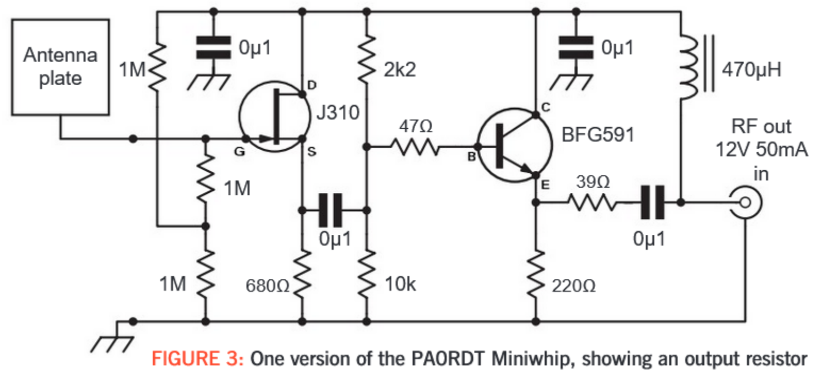

FIGURE 3: One version of the PA0RDT Miniwhip, showing an output resistor that doesn't appear on many published designs. It performs a number of useful functions, not least as a fuse for protection from accidental reverse power from a transmitter being applied.

up to +46dBm (40W) with the existing AD8307 device. A design made from 10mm diameter toroids in N30 material can be seen in **Photo 2**. Each toroid carries 31 turns to get the 30dB coupling. It is just possible to make out the 49.9Ω load resistor (arrowed), standing up on end on the front edge of the PCB. At 137kHz, obvious non-linearity set in at around 40W, roughly where it would be expected based on core size and frequency **[1]**. Only a quick test was done on directionality, but no change was seen on a scope trace of the coupled signal when a load was placed on or removed from the output port. At less than 1% change in amplitude, it suggests a remarkably good level of directivity of at least 40dB has been achieved.

The different configuration of the two Mini-Circuits couplers is interesting. To all intents and purposes they swap over the positions of the coupled port and the load resistor. Also significant is that in the ZFDC-20-4, the circuit on the left of Figure 1 (and copied for my 30dB design), the coupled output is in-phase with the input waveform. But in the ZFDC-20-3 there is a 180° phase shift. Trace through the circuits looking at the polarity of the windings and it is clear why this occurs. So there is no reason why the internal resistor couldn't be replaced by a fourth port on the unit to use an external termination, or to allow the two ports to be swapped. In the 'JNT junk box there is yet another Mini-Circuits coupler, a ZFDC-20-1H rated for 30 – 400MHz that does indeed have four SMA connectors, one of which is labelled 'Term'.

Is that a slight feeling of slight *déjà vu*? Four ports, one in phase and one 180° out of phase; where have we just read that? If the turns ratio on each of the transformers is 1:1, the coupling becomes 3dB and we have a splitter with 0° and 180° ports. It's the rat-race coupler all over again, but this time done with ferrite cores.

Active antennas

For receiving on the LF to HF bands an active antenna (or E-field probe) is in use by a number of stations. One of the most popular of these is the PA0RDT Miniwhip and innumerable versions with many minor variations to the original design have been built. Search the internet for 'PA0RDT Miniwhip'. The circuit diagram of my version is shown in **Figure 3**. One component that I chose to incorporate but which doesn't appear on most of the published designs is the 39Ω resistor from the emitter of the output driver; it is there for several reasons. Firstly, it allows a decent output match. The output impedance of an emitter follower is only a few ohms, so it seems sensible to improve the match of this to a long feeder (even if the amplitude is reduced by around 6dB). Who knows what the impedance of the following receiver is, so best to keep at least one end of the system matched. There's plenty of signal, so the loss is unimportant. Secondly, if the E-probe is presented with a massive electric field overload (such as that from a nearby transmitter), it will try to send as much power out to the feeder as it can. Should the feeder to the receiver be of a such length that it presents as a low impedance to the probe (it 'should' be 50Ω, but who knows what it will be in practice, especially at overload levels or with the system in Tx) the probe will try to deliver this power into the low impedance and possibly damage itself into the process. The output resistor protects against too much power being forced into a low impedance. Thirdly – and this actually happened at the time of those tests with G0API mentioned earlier – without it, if we accidentally put 20W of RF into the wrong BNC connector on the antenna patch-panel and send it up to the Miniwhip it dies. Very quickly.

Fully expecting to have to replace the BFG591 device, and possibly the J310 FET as well, I was pleased to see that the only component to have failed, and visibly so, was that small 39Ω surface mount resistor. Once replaced, the Miniwhip was working as well as it ever did. So that is its most useful job – a fuse for protection against accidental reverse RF being sent up the feeder.

More on voltage regulator protection

After reading the comments about susceptibility of voltage regulators to over-voltage, Nigel Pritchard, G8AYM emailed to say: "It is not widely known that there has been a range of specialised voltage regulators made by ST Microelectronics specifically for automotive applications and these have existed since as far back as the 1980s. These devices have to withstand voltage transients sometimes exceeding 100V, both positive and negative, and I was personally involved in technically supporting these devices with all the major vehicle manufacturers for exactly the purpose of withstanding unpleasant electrical environments.

"The automotive electronics has to withstand the case where the alternator load suddenly drops (this can happen for a variety of reasons) and gives rise to sharp transients on the battery rail due to what is referred to as 'load-dump'. It is notable that no other passive components were used in these applications, although sometimes an input (or output) decoupling capacitor was used, depending on the application, but by no means essential. Whether the voltage regulator device was 'standard' or 'low-drop' might affect the need of a capacitor on the input or the output due to the different topology inside the chip (one uses NPN series pass elements while the other uses PNP series pass). A voltage regulator used by [a certain US car manufacturer] in their dashboard electronics in the 1980s employed no other components than the regulator device itself and it had to withstand input terminal transients of +120/-80V as I recall.

"I note that devices such as I used to work with still exist on the market, examples being the L2600 family (L2610 and L2605, 10V and 5V respectively) and also the L4700 series. Anyone interested in such devices should check out the current ST website under 'Automotive Products / Linear Regulators', where a large number of newer devices can be found. Being now retired from silicon I'm not still up with the latest products in this sphere. You'll need to read the specifics about the load-dump characteristics because, as usual, it's a time/energy issue and you need to be sure it fits the EMC requirements. The automotive environment is potentially pretty nasty electrically but it's possible that it still does not meet your needs… Best to check".

Note

[1] Saturation in ferrite cores can be determined from the equation $V_{RMS} = 4.44 F \cdot N \cdot Ae \cdot B$ with F in Hz, N the number of turns, Ae the core cross section in m^2 and B the maximum allowed flux density. Using 31 turns on a core of Ae = $10mm^2$ at 137kHz with Bmax = 0.1 Tesla this comes out at 19V, or 7W in a 50Ω system. Full saturation of the ferrite occurs at about 0.25 – 0.3 Tesla, so at around 40W. Exactly the situation that was observed.