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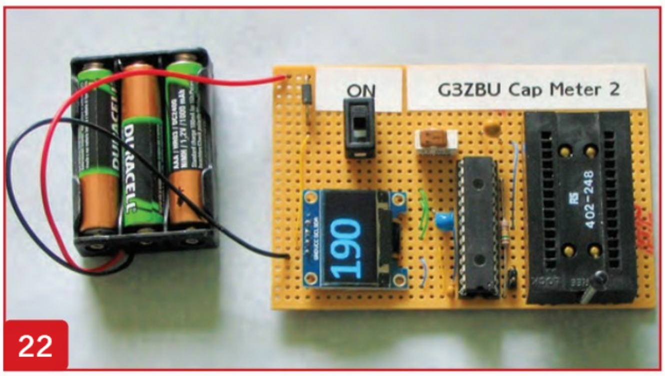

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Technical Features

Cover image, Discovery TX-500 QRP transceiver. Designed by Kevin Williams, M6CYB.

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

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New Products

DIY IC-705 3D case plans

Icom is allowing the download of 3D data of the exterior case of the IC-705 HF/VHF/UHF mobile transceiver allowing customers to create their own related accessories. The 3D data that will be made available will be compatible with several free 3D modelling softwares and 3D applications.

All users of this data will be required to agree to a memorandum stating specific rules of use before download. The principle of any items created with the data is that it will be for individual use only and not for commercial purposes.

This is the first time that Icom have done something like this and will be a test as whether they will consider disclosing 3D data for other products in the future.

To find out more including FAQs and the Icom '3D Data License Agreement' visit the IC-705 Exterior Case 3D Data Download Page at https://www.icomjapan.com/support/IC-705_STL.

D-Star with iOS/Android Apps

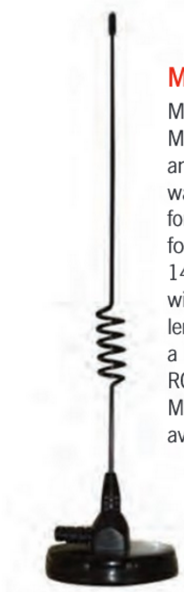
The RS-MS1i (for iOS™ devices)/ RS-MS1A (for Android™ devices) App allows your mobile device to wirelessly connect to a D-Star transceiver and remotely set DR functions, link with a map app and send/receive messages in DV mode. In addition, pictures on an iOS/Android device can be transmitted in DV Fast Data mode or DV mode.

Further details about these apps and compatibility with your radio can be found by visiting the RS-MS1i (https://icomuk.co.uk/RS-MS1i-App-Software/4163/1155/14/) or RS-MS1A (https://icomuk.co.uk/RS-MS1A-App-Software/4163/1154/14/) product pages. Alternatively, you can download the RS-MS1 brochure at https://icomuk.co.uk/files/icom/PDF/newsFile/RS-MS1.pdf.

To find out more about D-Star digital amateur radio read Icom's article, 'What is D-STAR?' at https://icomuk.co.uk/What-is-D-STAR.

MRQ213 Antenna

The Moonraker MRQ213 antenna is a stainless steel telescopic whip that is tuneable from 14MHz to 70MHz. The user simply adjusts to length for the desired frequency, making it suitable for portable use. The whip is terminated in 3/8" thread so may be used on any conventional 3/8" mount. It is 5.25m extended and 76cm collapsed, making it a very versatile antenna. Guide lengths range from 101.5cm for the 70MHz band to 505.3cm for the 14MHz band. Please note that this antenna is not designed for mobile use. It retails for £49.99 and is available from www.moonraker.eu.



Mini magmount antenna kit

Manufactured for Moonraker, the Mini-270 is a small and discreet antenna that can handle up to 50 watts. It is the perfect companion for modern dual band mobile radios for local chit chat. It covers the 144-146 and 430-435MHz bands with a VSWR of 1.5:1 or better. Its length is 49.5cm. the kit includes a magnetic mount, four metres of RG58 coax and a fitted PL259. The Mini 270 retails for £19.99 and is available from www.moonraker.eu.

LDG RF Transformers

Waters & Stanton are now stocking the complete range of LDG RF transformers. These competitively priced items comprise 1:1 and 4:1 baluns, 4:1 and 9;1 ununs, and a Line Isolator, and start at £29.95. All models are rated at 200W SSB and cover the range 1.8-30MHz. A 49:1 for EFHW antennas will be added soon. https://hamradiostore.co.uk/

New superhet video

Electronics Notes has recently launched a new YouTube video about the superhet (or superheterodyne) radio.

The superheterodyne radio has formed the basis of most radios used for amateur radio, broadcast reception, professional communications, two-way radio comms and many other applications for around 100 years. Today it is still in widespread use.

Using interviews with a number of industry experts, along with an informative narrative and many explanatory diagrams, etc, the video addresses what the superheterodyne radio is, how it works and some of the issues encountered with the radio format like the image response.

The video addresses the topics from the very basics, explaining the mixer and how this can be used to form the basis of the radio. Using some example figures to amplify the explanations, it also shows how the image occurs and how it can be reduced.

The video is useful for anyone interested in amateur radio, or radio in general and will be of particular interest to those studying for their license examinations.

Further videos on related topics like a specific video on the image response, double conversion sets, and topics like the main specifications and parameters are being created.

The video can be found at https://youtu.be/dk6DdG4vs4Y

The Electronics Notes YouTube channel can be found at https://YouTube.com/ElectronicsNotes

Mini transceivers

The ANYSECU WP-9900 is a 20/25 watt dual band mobile with small form factor for easy installation. Retailing at £99.95, it could be a great starter radio but also good for the seasoned amateur. The dual band coverage is 136 to 174MHz and 400 to 480MHz with 12.5, 20 and 25kHz channel spacing. Tuning can be done in 5, 6.26, 10, 12.5, 15 or 25kHz steps. The audio output is 2 watts. The radio measures 98 x 35 x 118mm and weighs 408g.

It retails for £99.95 from www.moonraker.eu.

Antennas

Overview of ATU types, part 2

Introduction

In October we looked at the Pi-network and T-network unbalanced ATUs. This theme continues with an overview of two ATU designs that are suitable for the direct connection of a balanced feeder/antenna.

Balanced ATU overview

Many stations prefer using a balanced HF antenna that can then be directly fed using a balanced feeder cable to avoid problems arising from common mode currents. Examples of typical balanced antennas are the half wave (λ/2) dipole and doublet antenna, which have been described previously in the Antennas column **[1]**. Therefore, the ATU used to match the balanced feeder cable to the transceiver ideally needs to have a balanced feeder/antenna connection. One technique to provide a balanced connection is to use inductive coupling to enable the feeder/antenna to be directly coupled to the ATU's main inductor.

Note: as described last month, if the ATU does not have a balanced feeder/antenna connection, then one solution is to use a 1:4 or a 1:1 balun between the feeder/antenna and the ATU to provide the interface.

The Z-match ATU

An example of a well-established design that uses inductive coupling to enable a balanced feeder/antenna to be directly matched is the Z-match ATU **[2]**. Originally, the Z-match ATU was developed from the tank circuit that was used in transmitters utilising a valve-based power amplifier. This ATU design was first produced commercially a number of years ago and many amateur stations continue to use this type of ATU.

Photo 1 shows an example of a Z-match ATU commercially made years ago by KW Electronics **[2]** and sold as the '(E-ZEE) MATCH' (though some versions lack the brackets in the name). It used long insulated spindles to isolate the tuning capacitors from their controls. As encountered with other ATU designs, this was necessary for this type of ATU to give additional electrical isolation for the user because the tuning capacitors can develop very high RF voltages across them (depending upon the impedance of the feeder/antenna connected to the ATU).

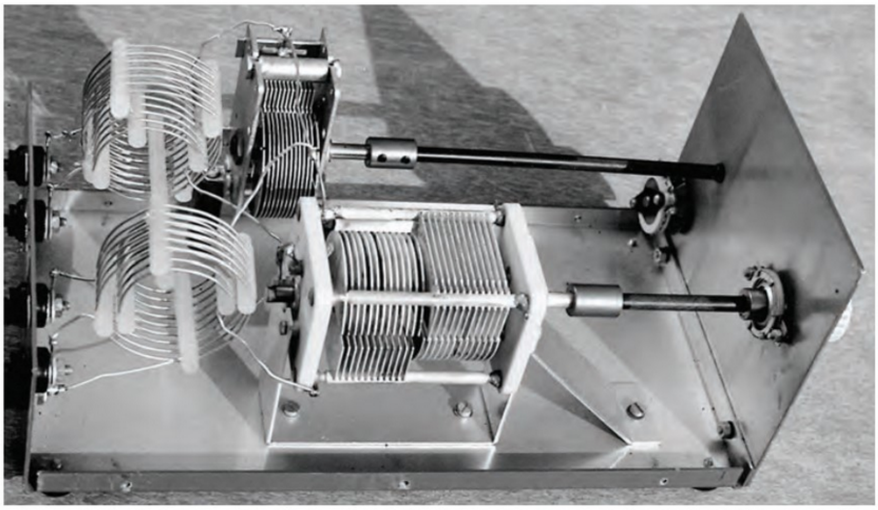


PHOTO 1: An example of the KW E-ZEE Z-match ATU showing its layout. Note the long isolating shafts.

This arrangement also provides additional separation because the match obtained may be affected by touching the tuning controls.

The operation of the Z-match ATU to be described is based on the version developed by Louis Varney, G5RV **[3]**, with the concept of this ATU's circuit shown in **Figure 1**. G5RV's redesign of the Z-match's circuit improved the efficiency of the match by using tapping points T1 and T2 on coils L1 and L2 respectively.

Referring to Figure 1, on the lower bands, from 3.5 to 10MHz, inductor L1 can be considered as being connected in parallel with both sections of C1, a twin-ganged type comprising C1a and C1b, with inductor L2 connected between them as shown. L2's inductance is much lower than L1's, making L2's reactance much smaller than that of L1. On the lower bands, this allows L2 to effectively act as a connecting lead between the top of C1a and the top of C1b. As a result, the combination of L1, C1a plus C1b becomes a parallel tuned circuit with one end earthed.

On the higher bands, from 14 to 28MHz, the active tuned circuit comprises C1a and C1b working as a split-stator variable capacitor in conjunction with inductor L2. L2 is connected between the capacitors' fixed vanes with their moving vanes earthed. The inductance of L1 is much greater than L2's inductance and may be considered as an HF choke connected across C1a. Therefore, L1

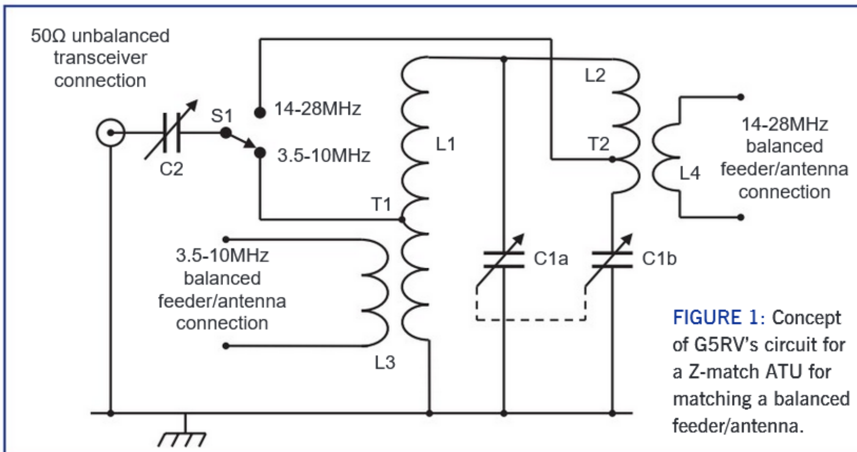


FIGURE 1: Concept of G5RV's circuit for a Z-match ATU for matching a balanced feeder/antenna.

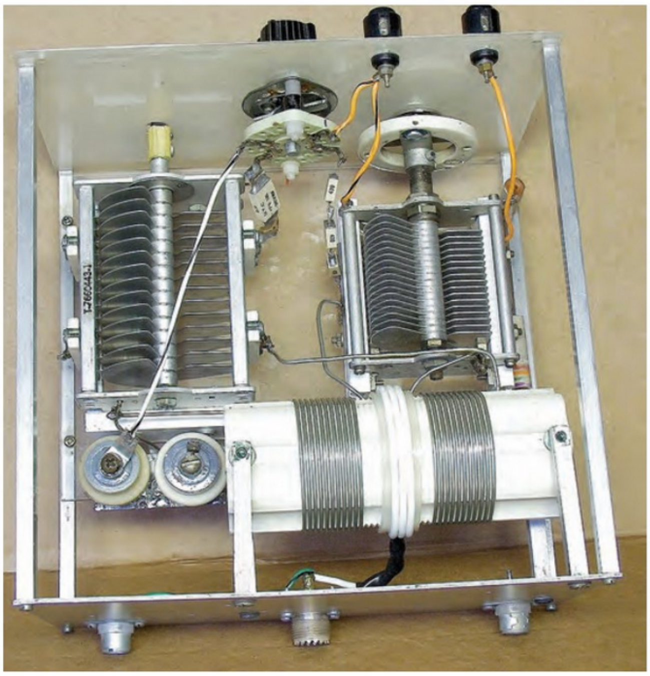


PHOTO 2: An example of an ATU based on G3GKG's design for use on the 80m, 60m and 40m bands.

PHOTO 3: G4JBE's 6m/4m/2m tri-band antenna under test.

has no appreciable effect on the performance of the split-stator tuned circuit comprising L2, C1a and C1b.

To tune the ATU, an SWR meter is connected between the ATU and the transceiver. With the transceiver on receive, the ganged capacitor C1 (ie C1a/C1b) is set to the mid position. C2 is varied until the received noise level maximises. C1 is then varied until the received noise level further increases. Using a low transmit power, C1 and C2 are varied under load until the SWR reading decreases. This is an iterative process, with the capacitors carefully adjusted until the lowest SWR is obtained. Once the combination of C1 and C2 has been found the transmit power is then increased, while checking that the SWR has not risen under the higher transmit power.

The relatively high impedance LC circuits of L1, C1a, C1b (80m to 30m bands) and L2, C1a, C1b (20m to 10m bands) should be detuned slightly *off* resonance at the frequency in use. The effect of this is to present an inductive impedance R + jX that, along with C2, forms a series resonant input circuit. When this input circuit is correctly tuned, the ATU presents non-reactive load to the transmitter's output of close to 50Ω.

Typically, for each variable capacitor, C2 is about 500pF and twin-ganged C1 is about 500pF per section. Further constructional details for the Z-match ATU design can be found in the *Radio Communication Handbook* [2].

G3GKG balanced ATU

Another example of an ATU that inductively couples the feeder/antenna to the ATU is the design by Brian Horsfall, G3GKG. The basis of G3GKG's design is a link-coupled balanced Pi-coupler that does not use taps on the coil for selecting the match. Detailed constructional details of this ATU design can be found in the *Radio Communication Handbook* [2]; the following summarises this balanced ATU design.

The concept of the ATU's circuit is shown in **Figure 2**, where variable capacitor C1 tunes the network and variable capacitor C2 tunes out any reactance at the ATU's balanced feeder/antenna input. As can be seen in Figure 2, variable capacitor C1 is a single gang unit, while C2 is a twin-gang unit. The two tuning controls provided by C1 and C2 may interact, however a good match can be obtained by rotating them alternately. Tuning the ATU is done by monitoring the match with the feeder/antenna by using an SWR meter connected between the ATU and the transceiver. Using a low transmit power, C1 and C2 are each adjusted until the SWR reading has been decreased to a minimum. With practice it is possible to obtain zero reflected power, coincident with maximum forward power. Once the match has been found the transmit power can be increased, although make sure that the SWR continues to remain low.

When the load impedance is low, the broader the tuning tends to be and more capacitance will be needed in C2. However, C2 is effectively in series with C1 to resonate the inductor and so C1's capacitance can become be quite low. Therefore for either capacitor, the lower its capacitance when loaded, then the higher the RF voltage across it will be at the chosen operating frequency and power. When the load impedance is high, the situation changes and the tuning can become more narrow and critical.

In this ATU design, often C1 is a single-gang type and is completely isolated from earth. C2 is a twin-gang type with its frame earthed, to provide an electrical centre about which the antenna's feeder is balanced. The RF voltages developed across C1 and C2 can be several kilovolts, depending on the impedance presented by the feeder/antenna. Therefore it is important that the capacitors' control shafts are insulated and this can be done by using insulated spindles to isolate the capacitors from their tuning controls, as was the case with the (E-ZEE) MATCH mentioned earlier. This arrangement also helps to avoid affecting the match obtained when touching the tuning controls (in a similar way as described for the Z-match ATU). Resistors

Mike Parkin, G0JMI
email2mikeparkin@gmail.com

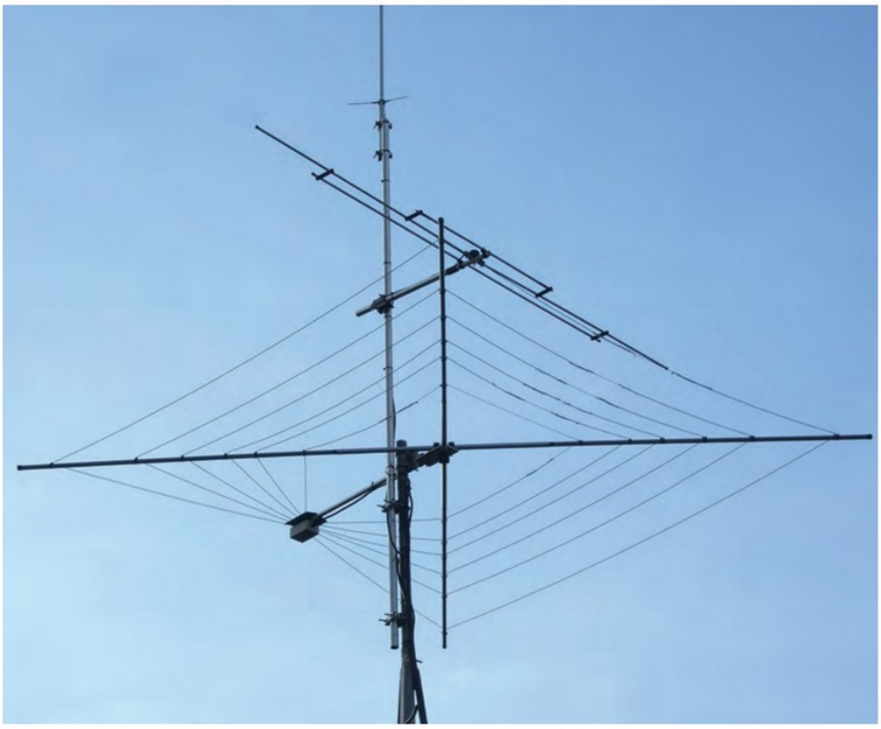


PHOTO 4: G4JBE's 6m/4m/2m tri-band antenna installed for use.

R1 and R2, across C1 and C2, provide a discharge path to prevent static building up on the antenna and feeder cable. R1 and R2 are typically around 75kΩ. Typically, capacitor C1 has a value up to about 200pF, while the twin-ganged capacitor C2 has a value of about 450pF each per section.

For his original ATU, G3GKG used three variable capacitors, two separate sets of inductors and several high voltage capacitors, with these components switched into circuit as appropriate to enable the bands from 160m to 10m to be covered. This resulted in the ATU needing to be switched between two ranges to select the bands from 160m to 40m or from 30m to 10m as required (as detailed in **[2]**).

Photo 2 shows a simplified version of the G3GKG design covering the 80m, 60m and 40m bands. A ceramic 2-pole multi-way switch was used to connect the fixed RF high voltage capacitors across the variable capacitors as necessary to enable the lower frequencies to be reached. This arrangement allowed the ATU to use an inductor of 11 + 11 turns, with a 3-turn link-coil as shown.

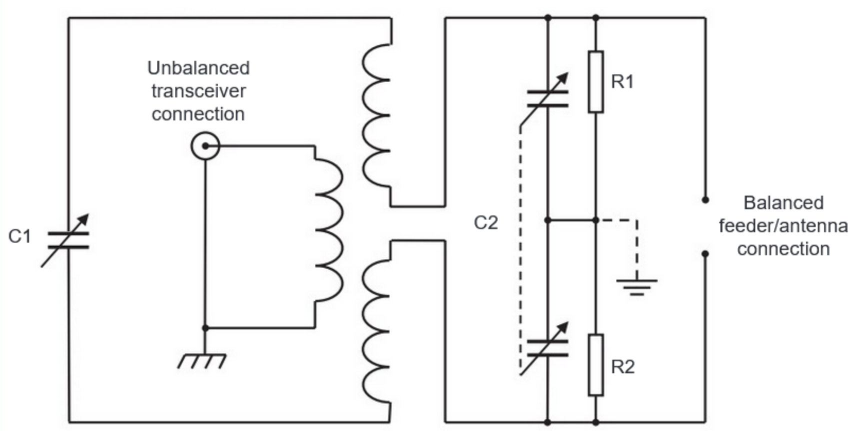


FIGURE 2: Concept of G3GKG's circuit of an ATU for matching a balanced feeder/antenna. R1 and R2 are bleed resistors to prevent static buildup and are typically 75k or so, low power.

Using an ATU on receive

The tuning process for the ATUs described was based on applying RF power and adjusting the controls to minimise the SWR on transmit. Once the best match has been obtained under transmit, the ATU is also set up to give a good match when receiving a signal and should need no further adjustment.

G4JBE's tri-band antenna

David Lacey, G4JBE, has sent in a summary of his tri-band 6m/4m/2m antenna that he built following details in the April 2021 Antennas. "The antenna has been finished and I am really pleased with the overall result. It is now ready for installation on the mast. The standing wave ratios (SWR) came in pretty low all round (see **Table 1**). The 2m element needed extending to 960mm to get it to resonate; all the other dimensions came within an odd mm of those given in the article. I am very pleased with the results. Now it's time now to get some use out of it. Thanks for the article and your replies." **Photo 3** shows G4JBE's antenna under test, while **Photo 4** shows it installed.

Many thanks for your message, David.

References

[1] *RadCom*, Antennas column, September 2016, pages 36 to 38; October 2016, pages 60 to 62; December 2017, pages 40 to 41; January 2018, pages 24 to 26

[2] RSGB *Radio Communication Handbook*, 14th edition edited by Mike Browne, G3DIH: Section 15, Practical HF Antennas, pages 15.42 to 15.46. The first article on the Z-match was in the May 1955 *QST*: "The Z match Antenna Coupler", by Allen W King, W1CJL, of Harvey-Wells Electronics, Inc in Southbridge, Massachusetts. It used 14 AWG (~1.5mm) wire for the coils and was intended for input power to an AM transmitter of 250W.

[3] 'An improved Z-match ATU', Louis Varney CEng MIEE AIL, G5RV, *RadCom* Oct 1998. *HF Antenna Collection*, edited by Erwin David, G4LQI, RSGB 1991: Section 6, p 116 to 119

TABLE 1: SWR of G4JBE's tri-band antenna.

Frequency	SWR
50.100MHz	1.43:1
70.100MHz	1.22:1
145.100MHz	1.26:1

A handheld, the ISS & me

Where we live, Robertson in the Winelands of the Western Cape Province of South Africa, it is quite rural. But we have all the facilities to make life comfortable. However, as an amateur radio operator it has its drawbacks. The number of amateurs in South Africa has shrunk. For example, apart from KE0CBM (who comes home every summer when there's no pandemic), it's been Sue, ZS1AFR and me, ZS1AFS, for a long time. Francois, ZS1FT has recently moved into town. There used to be eight other operators. Nowadays, there are few amateurs with whom we can have face-to-face contact, even when things go back to normal after Covid. But one only has to ask: there is always someone in ZS who can, and will, share his or her knowledge and give help.

HF has been in the doldrums. Fewer Europeans are pointing beams South. So now, we have an AllStar node up and running. We link into the UK Hub Net some days. Like all repeater-type modes it cannot maintain interest for long periods – especially when, occasionally, someone sits and monopolises the facility. Generally, this does not happen – but sometimes…

So, what is new that an amateur operator can do? When the Cluster shows FT-something for over 70% of the reports we know what some have done. However, FT-8 does not appeal to me. Recently, I saw it demonstrated on Zoom, during one of the evening talks at Denby Dale ARS. This only confirmed my opinion. It's probably because I'm solely a voice-mode operator these days. Long gone are the days of AMTOR when you could break into your contact's typing and he, or she, could reply in real time. And surprisingly, PSK appears to be a deserted mode! Then I heard the International Space Station (ISS) had received a new toy – a cross-band repeater.

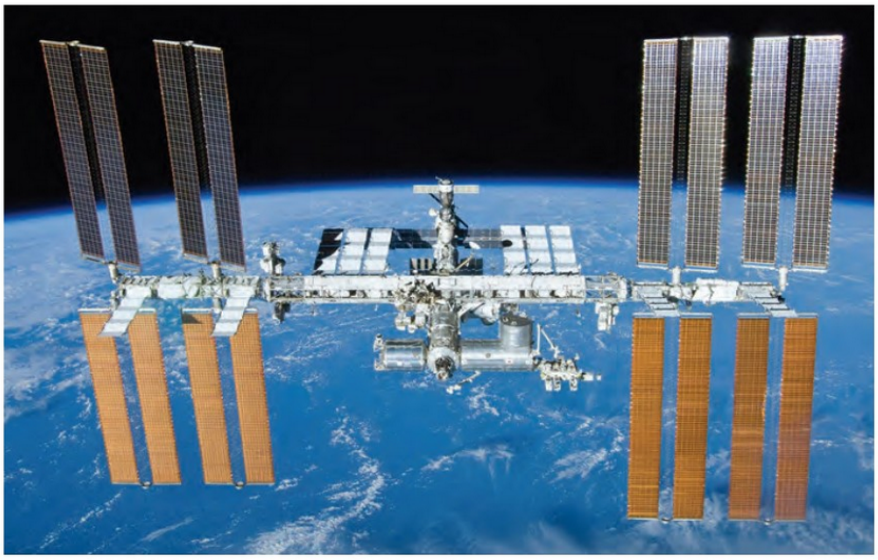


PHOTO 1: Viewed close up from this angle the ISS looks pretty big but from Earth it's just a dot of light in the sky. Photo courtesy NASA.

Life in space

On 2 September 2020, 0102GMT, the ISS Cross Band Repeater was activated. Amateur Radio on the International Space Station (ARISS) made a simple repeater a reality on the ISS! Technically, this is a big step because it simplifies the operational equipment requirements. Up to now, when working satellites the need for directional/moving antennas has been at the fore. But now equipment needs have been simplified because of the latest installation on the ISS. So, I got to wonder, could I use the gear that I have?

After setting up the downlink frequency on the right hand radio of my FT-8900 **[1]**, I was encouraged because I heard it break the squelch loads of times and could copy some operators reasonably well, using only my quad-band mobile vertical antenna (**Photo 2**) that I have fixed in the middle of a flat roof made of galvanised metal sheeting – a great ground plane!

Next move

Encouraged by the quite passable reception, I contacted Andre, ZS2BK. I could hear he was a very good signal, one that is heard fairly regularly on the ISS Cross Band Repeater. He was able to tell me where to look to check for a sighting, suggesting. I typed in ISS sightings + Cape Town (nearest city) into my browser, and up came the NASA predictions **[2]**.

The first morning Sue and I went up onto the roof to see at 0550 local time it was clear. But by the time of the pass, cloud had set in; the parapets and roof were dripping wet. The next day, 24 September 2020 (local Heritage Day), was crisp and clear. Sue managed to photograph the ISS as it appeared to come past Uranus. The disappointing aspect is that apart from the 'dots of light' there is nothing to show! Remember the ISS is only optically visible around dawn and dusk, as the sky darkens and the station passes out of the earth's shadow.

Where is it?

For passes over my location, I was told to check the AMSAT Online Satellite Pass Predictions site **[3]**. There I could ask for a number of the next sightings. It was very straightforward to use, as you can see from **Figure 1**. Just enter your location, either as your grid square or latitude/longitude and, optionally, your height above sea level (this is only important if you are on particularly high ground). You don't need to be particularly accurate with your location; even to the nearest whole degree will be close enough.

Where and when to listen

The frequencies for the ISS Cross Band Repeater are:

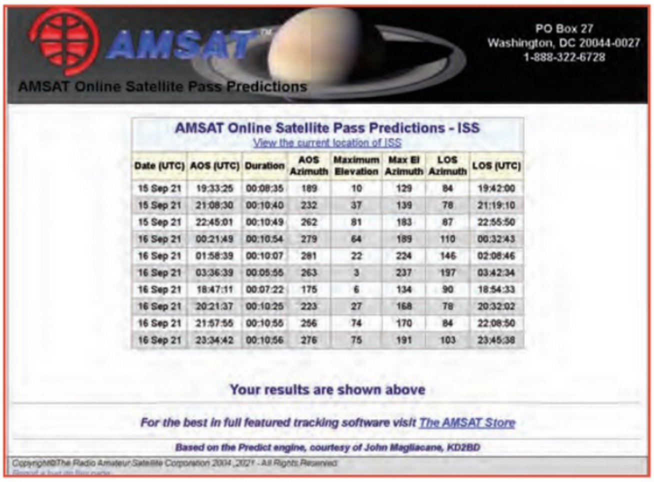
- Downlink (you listen on): 437.800MHz
- Uplink: 145.990MHz (CTCSS 67Hz)

The 67Hz CTCSS tone on uplink transmissions from Earth avoids unwanted radio signals triggering the repeater.

Find the current status of the ISS radios at www.ariss.org/current-status-of-iss-stations.html

There are many sites that let you know where the ISS is at any given time and/or send you notifications when it will come into view, including https://heavens-above.com/ and https://spotthestation.nasa.gov/

FIGURE 1: Enter your location into this simple form on the AMSAT website and click Predict.



Date (UTC)	AOS (UTC)	Duration	AOS Azimuth	Maximum Elevation	Max El Azimuth	LOS Azimuth	LOS (UTC)
15 Sep 21	19:33:25	00:08:35	189	10	129	84	19:42:00
15 Sep 21	21:08:30	00:10:40	232	37	139	78	21:19:10
15 Sep 21	22:45:01	00:10:49	262	81	183	87	22:55:50
16 Sep 21	00:21:49	00:10:54	279	64	189	110	00:32:43
16 Sep 21	01:58:39	00:10:07	281	22	224	146	02:08:46
16 Sep 21	03:36:39	00:05:55	263	3	237	197	03:42:34
16 Sep 21	18:47:11	00:07:22	175	6	134	90	18:54:33
16 Sep 21	20:21:37	00:10:25	223	27	168	78	20:32:02
16 Sep 21	21:57:55	00:10:55	256	74	170	84	22:08:50
16 Sep 21	23:34:42	00:10:56	276	75	191	103	23:45:38

FIGURE 2: Predictions will be custom-generated for the location information you've entered.

Once you click the Predict button you'll get a set of predictions like those shown in **Figure 2**. Just remember that all the times are in UTC!

You may not recognise some of the column headings. Date is pretty obvious, but the next, AOS, refers to Acquisition Of Signal – the first moment when the ISS will be visible over the radio horizon. Bumping across a couple of columns, LOS is Loss Of Signal – the moment when the ISS disappears again.

PHOTO 2: A simple mobile antenna is all I needed to listen to the ISS using my FT-8900.

Unless you have entered your latitude, longitude and altitude particularly accurately, your *actual* AOS and LOS times will probably be a few seconds different from the prediction – but given that the predictions assume you have an unobstructed view to the radio horizon, you can normally expect to pick up the signal at least several seconds after the predicted AOS time.

The other columns tell you the direction (azimuth, in degrees, clockwise from north) where the ISS will appear at AOS, its maximum elevation during the pass, and the direction when the signal disappears. One needs the directions (azimuth) of these points to plan the antenna sweep. Some people are surprised that the duration of passes is so short, typically 10 minutes or so. Although the ISS is some 420km up, that's only enough to see a circle of the ground about 3200km across – sounds like a lot, but the ISS is travelling at over 7.5km per second, so it zips in and out of sight quite quickly! Understanding this was another step towards my goal of making a contact through the Cross Band Repeater.

First attempt

On 3 October 2020 at 0733GMT, I was in the garden with my dual band handie, a Baofeng UV-5, equipped with an extended quarter wave antenna, as seen in **Photo 3**. With only about 5 watts I still was not certain it would work. I started calling CQ ZT1T /P and, on the third go, ZS2BK came back, asking me to repeat my call. Unfortunately, the alligators in ZS6 swamped me! So, although I know I got through, I had no confirmation. But I knew I had been heard.

One feature of the Baofeng UV-5 that is essential for satellite comms is the Dual Watch/Dual receive feature. This simplifies the operator's facility to monitor the downlink.

I decided to contact ZS2BK via email and ask what power he was running. He said it was just 10W. Judging by my reception report of his signal this was more than adequate, but it was obvious I needed to have a better antenna than a rubber duck. As he wrote

Tom Morgan, G0CAJ/ZS1AFS/ZT1T
info@onboardpublications.co.za

PHOTO 3: Using just my handie (with an extended rubber duck antenna) I managed to raise the ISS!

PHOTO 4: A compact HB9CV antenna significantly improved my signal into the ISS, but still only needing 5W from the handie.

in his email, "Yes, you were a bit soft on the audio. That's why I asked for a repeat". But I was delighted! What was needed was increased antenna gain.

So, out came my Wild Cat Antenna, a 2m HB9CV that gives around 4dBd gain. The transmit frequency of 145.990MHz can be less that optimum for many 2m antennas used for general working, but this antenna is quite broad band. And the HB9CV is OK for receiving 70cm. I figured with the ISS's maximum elevation of 84° (on that pass) it would be in a clear line of sight from the roof.

Second attempt

As the time of the best pass of the next day approached, Sue and I set up on the roof. She, with a camera and me trying to juggle the HB9CV and hold the handie near my mouth! It was quite tiring, but Sue managed to capture the moment for posterity in **Photo 4**.

At the appointed time, 0559GMT, I started calling CQ ZT1T/P. Nothing happened for a couple of minutes! I could hear, from the repeater output from the FT-8900 in the house, that I was getting through and easily breaking the squelch – but there was nothing! We re-checked the time and the expected azimuth and I called again. Then, crystal clear came back: "ZT1T/P **[4]** this is ZS2BK you are 59". You can imagine my delight! But I did remember to respond: "ZS2BK this is Zulu Tango One Tango Portable, you are also 59". And just like that it was over! I've not heard of anyone using only a handheld before. True, I had a small gain antenna this time, but I knew I'd previously got through with the extended rubber duck!

Quiet time

The strange thing was that there were no other signals on the repeater – a rarity when the ISS is over Europe. But after emailing Andre he told me in his email reply: "I was downloading SSTV pics from ISS and in between two pics I switched to Cross Band Repeater. I was actually surprised the Cross Band Repeater was active at the same time as the SSTV event. That's probably why the Cross Band Repeater was so quiet when I found you calling. I think OM's were listening on 145.800MHz for SSTV". It could be another learning curve for me!

Andre's audio recording facility was not running at that time. Otherwise, I would have received an audio copy of the exchange. Maybe next time? Nevertheless, nothing could take away my pleasure that I had achieved a QSO through the Cross Band Repeater on the ISS with equipment I have. I have to say that this first, for me, has been made easier and simpler through the encouragement and help from Andre, ZS2BK. As an example, he was able to tell me when there is a cargo docking: at those times both the Cross Band Repeater and the SSTV repeaters would likely be off the air.

Later passes

Just after my activity it appeared that the Cross Band Repeater was not working. Apparently there was a problem but there was no information available, even though I contacted AMSAT and a few guys I had heard on the Cross Band Repeater. Then I read that the ISS was concentrating on SSTV: also, a few days were set aside for 'proper work' by the crew. Finally, the repeater came back on, received clearly on my FT-8900. So, for the next few days I concentrated on relatively high passes that I thought I could make. Contacts with ZS2CC and others were encouraging. So, it *could* be done with the limited equipment at ZT1T.

An unexpected memento

You may imagine my surprise when Andre, ZS2BK emailed me a recorded audio clip with our 4 July 2021 contact! I realised from my reading there's a whole world of satellites out there waiting for amateurs. Hopefully, readers will have a bash. The ISS Cross Band Repeater has made it easy for me and other amateurs to dip our toes into the ether.

Have a go!

Try it for yourself. It's easy enough to hear the ISS downlink on 437.800MHz. At high-elevation passes (when the ISS is most nearly overhead) a standard rubber duck is all that's required to hear the transmissions. And, as I've shown, you only need about 5W and a simple low-gain antenna such as an HB9CV in order to get in (but don't forget the CTCSS!). Tracking the ISS across the sky is easy enough, particularly with a little practice. You do NOT need precision pointing; 'over there-ish' is good enough, and you will know when you're pointing in the right direction because you'll hear the downlink signal. Although it's obvious when you think about it, when your aerial is getting the best signal *down* from the ISS, it is also optimally aligned for the uplink.

Notes

[1] The FT-8900 is two radios in one package with a built-in duplexer. The left hand radio of my FT-8900 is used on my AllStar Link, mainly to friendly Node 40338 or the UKHub. And it's linked to the internet using the built-in 6-pin mini-DIN socket. I use the right hand side radio for the local VHF repeater when there are no predicted ISS passes. When I'm listening for the ISS, one VFO is on reception (UHF) and the other on transmission (VHF).

[2] https://spotthestation.nasa.gov/

[3] https://www.amsat.org/track/

[4] ZT1T is a special South African callsign with a unique prefix, and is a full annual licence. It is in use by ZS1AFR and ZS1AFS on HF during the Covid-19 emergency in ZS until restrictions are lifted.

Discovery TX-500 160-6m QRP transceiver

Operating the Discovery TX-500 QRP transceiver away from home is a chance to seek out a bit of nature and operate radio.

If there's one positive thing that's come out of the awful Covid-19 global pandemic, at least for me, it's been a deeper appreciation of the great outdoors.

Of course, in my world, there is no better way to enjoy the outdoors than walking, hiking and mountain biking. Between the worries of restrictions and lockdowns, I've found that Summits On The Air, Parks On The Air (POTA) and World Wide Flora and Fauna (WWFF) activities provide the perfect excuse to seek out a bit of nature and simply play radio, well-removed from the QRM that plagues so many of our homes. If we must social distance, this is surely social distancing at its best.

Fortunately, we radio enthusiasts have been lucky in that one of the most innovative areas in the amateur radio world these days is the growing portable-HF field-radio market.

Just six months or so before the pandemic went global, in June 2019, a small radio manufacturer in Russia known as lab599 (or Laboratory599) dropped hints about a rugged, weatherproof, general coverage, 10 watt output, 160-6 metre QRP transceiver they intended to bring to market: the Discovery TX-500. It looked like no other radio on the market, and the prototype images made field operators' jaws drop.

First, the form factor of this radio is quite unusual: it features top-mounted controls, generously spaced, while its overall profile is unusually thin. The outer dimensions of the radio are 90mm (3.5") x 207mm (8.1") x 21mm (0.8"), and it weighs 0.55kg (19.4oz). It is therefore readily portable. The duralumin (aluminum alloy) chassis is CNC machined with a matte black anodised finish.

Also unique to the amateur radio market, the TX-500 uses GX12 mm multipin

My Yaesu FT-817 next to the Discovery TX-500 showing the unusually small profile of the QRP transceiver.

connectors of the type widely used in aviation, commercial and military applications; they're mounted on the left and right side of the transceiver. The backlit LC display is high contrast, easy to read outdoors, and even sports a 48kHz wide live spectrum display.

More importantly, one of the very first images of the TX-500 showed the front faceplate covered with droplets of water, almost as though the radio had been caught in a downpour. This suggestion of weather-hardiness, in particular, made field operators take note! Summit and field activators have been asking manufacturers for years to design a weatherproof transceiver. Many of us – and I'm sure many *RadCom* readers will sympathise – live in areas where the weather is fickle; often while we're trying to top off a summit activation, heavy mist or rain can roll in and we must rush to protect our transceivers from water intrusion.

But, those early photos and specs from lab599 were followed by months of silence, and hopes that the new prototype would turn to reality dwindled. Since the TX-500 was such a departure from convention, many operators assumed this prototype was a one-off or would become vaporware.

Then, remarkably – in August of 2020, in the midst of the pandemic – I received a pre-production, fully-functional model of the TX-500.

At the time, lab599 only had a small handful of pre-production units available, so I could only test it for a total of *one week* – an extraordinarily short period for me, as I like to take my time to get to know a unit. So, I made the most of my week. In that brief time, I used the TX-500 heavily in the shack and activated seven individual parks for the POTA and WWFF programmes.

And what did I think? In short: even this early pre-production transceiver with an early firmware revision exceeded my expectations.

Fast forward to May of 2021, when lab599 offered me another TX-500, this time for an extended evaluation period. I paid to have it shipped via DHL from their headquarters in Russia, and it arrived in short order. As soon as I could, I began to put it through its paces.

First impressions

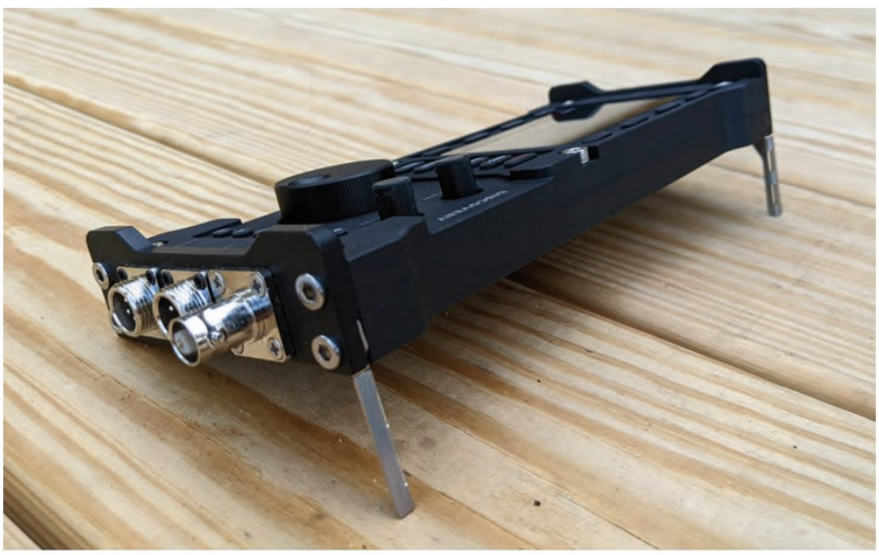
The pre-production TX-500 I received in 2020 had no accompanying packaging, as it was very much an early model. The production TX-500 arrived with full packaging, including a professionally designed box.

Normally, I pay little attention to amateur radio product packaging, but in this case I took notice. Why? Because all I've learned from lab599 so far has been that it's a company that takes product design details very seriously. As mentioned earlier, the transceiver itself is original and like nothing else I've seen on the market – it has a distinctly tactical look, yet unusually slim, thus refined and ergonomic at the same time. But the design extends beyond the radio. Even the very early TX-500 owner's manual contained professional technical drawings and graphics – indeed, among the simplest, clearest illustrations and instructions I've ever seen in an amateur radio manual.

However, it's never advisable to "judge a book by its cover," and in the case of the TX-500, the packaging is stunning. The big question was: can this slip of a radio live up to its professional image?

Design choices

The Discovery TX-500 is designed around field operation and although I've no inside knowledge, I recognised that the company obviously made some tough choices early in the game, ticking off features that will give this radio a market niche for field operations while also keeping costs in check.


The outer dimensions of the radio are 90mm (3.5") x 207mm (8.1") x 21mm (0.8").

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I've now taken the TX-500 on multiple park and summit activations. I find that, overall, the radio performs superbly in the field.

One important design choice that sets the TX-500 apart from other transceivers is its weatherproofing. To my knowledge, the transceiver hasn't been tested to meet a dust or waterproof rating; rather, the company describes the design approach thus:

"Thanks to the liquid-protected housing and the absence of through-holes, spatter resistant plugs, valcoders with sealing rings, the transceiver will work reliably in extreme conditions[...]."

Also, I noted that the company made a few design choices that carry a calculated risk.

First, they omitted an internal speaker, which is obviously a negative for most field operators. I strongly suspect this design choice had more to do with making the radio weather resistant, as a speaker is difficult and costly to protect a speaker from water/dust intrusion. If you're going to omit an internal speaker on a modern transceiver, however, doing so on a field transceiver is a safer bet, as so many field operators – myself included – prefer using headphones or earphones for sound isolation in the field. To make up for a lack of internal speaker, lab599 includes a speaker microphone with every unit. The audio fidelity of the speaker mic suits both CW and voice modes, but not higher-fidelity short wave or medium wave AM broadcasts. Lab599 also includes a breakout cable with separate microphone and headphone (⅛"/3.5mm) ports, along with a PTT button.

Speaking of cables and connections: as I mentioned, the TX-500 uses GX12 mm multi-pin connectors, and I'd venture to guess that few amateurs have any station accessories that are compatible. Fortunately, the radio package includes not only the speaker mic, but also breakout cables that accept 3.5mm ports for headphones, microphone, and CW paddles. They also include the CAT command cable, power cable, and a spare 7 pin GMX 12 connector. The owner's manual details pin configuration for each port.

Another questionable choice is this radio's lack of an internal antenna tuner (ATU) option. Many popular field transceivers like the Icom IC-703 Plus, Xiegu X5105, Elecraft KX1, KX2, and KX3 all have at least an *option* for an internal ATU. While I tend to use resonant antennas that don't require matching, an ATU is quite handy in the field, as it opens up more flexibility for both antenna options and frequency choices.

It's worth noting that even in the short period of time that the TX-500 has been on the market, a 3rd party project lead by DL4KA is designing a 60-watt amplifier and antenna tuner called the "DIY599" that has the same footprint as the TX-500 and will attach to the back of the transceiver.

Finally, the TX-500 does not have an internal battery option, however lab599 will soon produce a new custom battery pack that attaches to the back of the TX-500. This battery pack appears to match the TX-500 design so well that, when attached, it will appear to be part of the transceiver and will likely double the thickness. The battery pack will have fold-out legs and replaceable lithium-ion cells.

In the field

Besides being weatherproof and rugged, the TX-500 sports some truly field-friendly features, especially for those who enjoy activating summits and parks.

For one thing, the TX-500 is incredibly efficient in receive mode. In my experience, it has only required around 100-110mA. This means even a very modest battery will power the radio for lengthy field sessions: my 3Ah LiFePo4 battery will easily power the TX-500 for three or four lengthy field activations, possibly many more.

I also appreciate the ergonomics of the TX-500. The most commonly used features (band switching, mode switching, AF Gain, RIT, tuning rate, and filter selection) are all one button press or one knob twist away.

There are a total of eight multifunction buttons – four above and four below the display. Two of the lower buttons are used to change menu 'pages', while the remaining six are assigned features like noise reduction, voice, CW memory-keying, VOX, meter settings, and the like. I find this multi-function system quite easy to navigate in the field.

TX-500 controls are spaced generously and the buttons have a tactile response. I believe I could easily operate this radio even when wearing thin winter gloves.

Phone operators will be quite pleased with the TX-500. I find that the supplied speaker microphone works well, but since the provided adapter cables allow for standard 3.5mm accessories, even a boom mic headset can be used in VOX mode. I also like the fact that the phone op can not only adjust EQ settings on the received audio, but also on transmitted audio. I find this to be a very powerful feature on QRP radios, as tweaking transmitted audio will help one make the most of a low-power signal. Of course, the TX-500 also has speech compression to add a bit of punch and clarity to SSB transmissions.

The TX-500 also has voice-memory keying – meaning, two voice messages of up to 20 seconds each in length can be recorded and transmitted in the field by the push of a button. I use voice-memory keying quite often for calling CQ on summits and in parks, as it allows me to eat lunch or log contacts while my CQ is being transmitted. In addition, this feature will save your voice during extended contests!

CW operators will be equally pleased. Indeed, I've operated CW about 75% of the time I've had the TX-500 on the air. I appreciate the fact that keying type, pitch, weight, and speed can all be adjusted to one's liking. The TX-500 uses a legacy relay, rather than PIN diode transmit/receive switching. This means that there is a little audible mechanical click during operation. I find that it's quite attenuated, however, as the relay is so well-sealed within the TX-500 body. Do note that the TX-500 cannot offer true full-break-in QSK, as the quickest relay recovery time is limited to 100 milliseconds. This does equate to what I would term semi-break-in QSK, as it's easy to hear audio between sent words. I typically operate the TX-500 with the recovery time set to 400 milliseconds as I find it a good balance of recovery time without unnecessary T/R switching. I have noticed a bit of an audio pop during CW operation if the AF gain is near its maximum setting.

The TX-500 also has four CW keying memories allowing up to four messages to be recorded and easily played back via the touch of one (of four) button(s). In a recent firmware update a "beacon mode" was also added for the first CW keyer memory: in beacon mode, the stored message can be played back in a loop with a user-adjustable amount of time between playback, truly an invaluable tool in the field when calling CQ.

As a CW operator, I'm actually very pleased with the TX-500. Keying feels natural and it has paired well with both my paddles and my straight key.

In both SSB and CW, the operator can set four selectable filter widths and toggle them with the push of the filter button.

Even if the weather is dubious, I still go out operating.

On the air

I've now taken the TX-500 on multiple park and summit activations. I find that, overall, the radio performs superbly in the field.

I find the TX-500 has a low noise floor and sensitivity is quite good, especially for a field radio. The receiver, with occasional use of noise reduction, makes for easy signal intelligibility. I've also used the TX-500 during CW contests, and even though transceivers like the IC-705 may have even better test results in the lab, I've found that the TX-500 was quite adept at blocking adjacent signals as I tuned through RF-dense areas.

I have noted some 'clicks' or 'birdies' – especially while using headphones – as I tune the TX-500 quickly through the bands. The manufacturer acknowledges this issue, noting that it's a product of the receiver architecture and convertions in the receive path. However, these clicks are mostly outside the amateur radio bands and frankly do not bother me.

While I believe the TX-500 is best suited for field operation, it makes for a capable home station as well. The radio is so compact, and accordingly takes up so little space, it's ideal for those with radio stations that need to fit in a closet, cabinet, or even a drawer.

The fold-out legs on the back of the TX-500 prop the radio up at an angle that makes operation and viewing of the backlit display quite easy. If using the fold-out legs, I would advise setting the TX-500 on a mat or surface that doesn't easily scratch them, as the legs have no rubberised coating.

Although I have a dedicated power supply at home, I've almost exclusively operated the TX-500 from battery power. Indeed, if the TX-500 was my only radio, I'd likely skip purchasing a dedicated power supply and simply float-charge a LiFePo4 battery.

In the shack, I like pairing the TX-500 with a proper external speaker to maximise audio fidelity. I've even used the TX-500 for medium and short wave listening – it's a surprisingly good broadcast receiver with a maximum AM bandwidth of 10kHz, which is ideal.

Because my preferred modes of operation in the field are CW and SSB, my experience with the TX-500 has been limited to these modes of operation. I have not tested the TX-500 on digital modes, but it is capable of CAT control by computer using a Kenwood command set. Lab599 is continuously updating the firmware to make digital operation of this unit simpler.

Summary

You might have gathered that I like the TX-500... and you'd be correct. I do think it's a welcome arrival in the world of field radios, which is likely why it has already gathered a sizable fan base. Indeed, based on the positive reports of so many amateur radio operators, many of whom have patiently waited for this transceiver to become available, I believe it's safe to say that it will amass quite a following over the next few years.

Having now communicated with the engineers at lab599, I'm incredibly impressed that their first amateur radio transceiver to hit the market was so thoroughly well-designed. It suggested a company that had produced previous iterations of a radio and already improved upon them.

And now, I have to confess that when I head to the field, if the weather is even marginally dubious, I'll choose the TX-500 for my operations each and every time. While my key and other accessories aren't water resistant, this transceiver is, and twice already I've operated it in light rain with no issues.

Conclusion

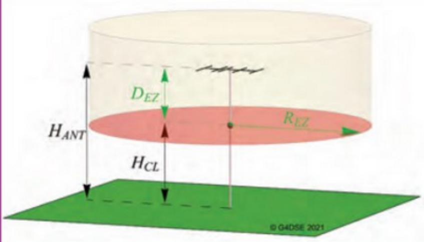
So, do I recommend the TX-500? If it's any indication, I have already arranged to purchase this unit rather than send it back to the manufacturer after the loan period. And, as a reviewer, I believe this may be the ultimate recommendation.

If you enjoy field operation as I do, I think you'll like it, too.

Nevada Radio is lab599's Exclusive UK distributor. The radio will be available from them, Waters & Stanton and selected dealers. At the time of writing, the TX-500 price is £899.

EMF Compliance Checks above 110MHz

More help and guidance to assist amateurs with compliance records for the EMF regulations from Ofcom. This article introduces a Pre-Assessed Equipment configuration (PAEC-2) for VHF and UHF Beam Antennas and additions to the RSGB Calculator to help you with these assessments.



Exclusion Zone for horizontally polarised rotatable beam antenna is a cylinder *centred on the rotator pole. All locations are for points on which a person could stand*.
H_{ANT} is the height of the antenna, H_{CL} is the height above ground of the Compliance Limit and the cylinder is defined by radius R_{EZ} and distance below antenna D_{EZ} (upper limit is $H_{ANT} + D_{EZ}$ 0.9m). Places outside the cylinder do not exceed the exposure limits.

FIGURE 1: Representation of Exclusion Zone.

Following the recent changes to the UK amateur licences we all need to check the EMF levels from our antennas to determine the EMF Exclusion Zones (EZ) – places where exposure limits can be exceeded. We must then record these Compliance Checks along with any Control Measures to ensure no member of the general public remains in these EZ's when we are transmitting.

Ofcom requires us to have compliance records in place and up to date after 18 November 2021 for any equipment which operates at frequencies above 110MHz – which for our purposes means above 144MHz. The RSGB provides EMF guidance on a dedicated RSGB web page located at **www.rsgb.org/emf** Included on that page are links to Ofcom requirements together with advice and technical papers giving details of how to conduct these Compliance Checks for the amateur bands.

You can show compliance by proving one of the following:

A: Your equipment never exceeds 10W EIRP average and 100W EIRP peak
B: Your Exclusion Zones are not accessible
C: You use Control Measures to ensure that no-one remains in an accessible Exclusion Zone when you transmit.

Exclusion Zones

Any places where compliance limits can be exceeded are called EMF Exclusion Zones (EZ). The size and shape of an EZ depends on the antenna, the frequency and the RF power level. For example, the EZ for a rotatable VHF/UHF beam antenna can be simplified to a cylindrical shape centred on the mast. Inside the cylindrical EZ the limits could be exceeded but outside it they will not be. The situation within the EZ could still be compliant if the transmission is sufficiently brief or the person moves away.

As an example, **Figure 1** shows the parameters that define the EZ for a typical rotatable VHF/UHF beam antenna, where the green area represents ground level. The EZ corresponds to the main beam field strength as the antenna is rotated around its mount. A similar cylindrical EZ can be determined for any omnidirectional antenna (eg vertical collinear, often called white stick antennas).

The height of the antenna above ground (H_{ANT}) and the power fed to the antenna will determine the extent of these EZ's. For consistency we always define the location of a person as the point on which they are standing. We can then check every point on or above ground by asking: "Would it be OK for a person to stand there?" If the answer is Yes, then that point is outside the EZ.

An important feature of the EZ is the clearance height of the base of the cylinder above ground (H_{CL}). If H_{CL} is greater than zero, compliance is achieved everywhere at ground level and up to H_{CL} above ground.

Compliance Checks

Compliance Checks are required to identify places where the EMF exposure reference levels can be exceeded.

The Ofcom guidance *What you need to know as an Amateur Radio user* identifies two simple means to carry out a Compliance Check against these exposure limits:

1: Using the Ofcom or RSGB calculator; or

2: Following a Pre-Assessed Equipment Configuration (PAEC).

These approaches are outlined in the next section. Whichever method you use, the configuration of your station needs to be recorded. The RSGB calculator is a simple way to do that and to get indication of compliance status.

Step 1 – Input the parameters that specify your station configuration, highlighted in yellow in **Figure 3**.

Step 2 – If the calculator displays **LOW POWER COMPLIANT** or **COMPLIANT EVERYWHERE AT GROUND LEVEL** in green as in **Figure 3** and **Figure 5A** then compliance is demonstrated, and you should take a record of the relevant calculator area.

In **Figure 4**, a typical roof mounted Yagi fed by a 100W transmitter shows that low power compliance is not achieved and the calculator indicates **FURTHER ASSESSMENT REQUIRED**. You can choose to use either the

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The EMF exposure reference levels are specified in ICNIRP documents (ICNIRP 1998 and ICNIRP 2020) and we can use either set of levels as the limits for compliance checks. Above 110MHz and outside the near field zone, the EMF exposure limits can be expressed as an average power density in W/m² (whole body averaged over 30 minutes, local exposure averaged over 6 minutes). The difference with frequency represents how effective the body is in absorbing energy from the field at different frequencies.

Band MHz	50	70	144	435	1296	2000 to 6000
Power Density W/m² (30 min whole body)	2	2	2	2.18	10	10
Power Density W/m² (6min local exposure)	10	10	10	10.8	27.6	40

FIGURE 2: General Public ICNIRP 2020 exposure levels above 50MHz.

Name	Callsign	Date of Compliance Check	Station Address
Radio Make	Model		

www.rsgb.org/emf

Notes Click on yellow boxes to select your station setup and operating conditions. Fill in the beige boxes and export or print this sheet to a PDF file as as a record of your compliance checks.

Radio Setup	Band	2m
Transmit Mode	FM	
Frequency MHz	145.5 MHz	
Transceiver		
Transmitter/ linear Power	10.0 W	10.0 dBW
Mode factor	100.0%	0.0 dB
Transmit % in 6 minutes	50.0%	-3.0 dB
Average power from Transmitter	5.0 W	7.0 dBW
Peak Power from Transmitter	10.0 W	10.0 dBW

Feeder		
Cable Type	RG213	dB/100m
Feeder		
Loss per 100m		-8.6 dB
Cable Length m	0.0 m	
Other losses dB		0.0 dB
Feeder loss dB		0.0 dB
Average power into Antenna	5.0 W	7.0 dBW
Peak power into antenna	10.0 W	10.0 dBW

My Antenna		
Antenna type	Vertical dipole	dBi
Antenna polarization	Vertical	
Antenna parameters		
Vertical dipole	1.6	2.2 dBi
Mainlobe EIRP	8.2 W	9.1 dBW
Directivity Factor -dB		0.0 dB
Height of Antenna m	1.8 m	
Average EIRP	8.2 W	9.1 dBW
Peak EIRP	16.4 W	12.2 dBW

Interpreting the calculator results. First check if low power compliance is flagged in box to right. If not then choose one of the methods below to demonstrate compliance. You can use either the calculator or PAEC's for your compliance check and to define any needed Exclusion Zones.

LOW POWER COMPLIANT
no further assessment needed as average power < 10W EIRP & peak power < 100W EIRP

FIGURE 3: 10W FM handheld (2m and 70cm bands) with supplied antenna and 50% talk time is "low power compliant". This shows that handhelds with average power of 5W and using the supplied antenna are compliant due to their low EIRP. You can copy this worksheet to prove your compliance.

My Antenna		
Antenna type	10 Element Yagi	dBi
Antenna polarization	Horizontal	
Antenna parameters		
10 Element Yagi	25.7	14.1 dBi
Mainlobe EIRP	573.9 W	27.6 dBW
Directivity Factor -dB		0.0 dB
Height of Antenna m	7.0 m	
Average EIRP	573.9 W	27.6 dBW
Peak EIRP	1913.2 W	32.8 dBW

FURTHER ASSESSMENT REQUIRED
Use one of the methods below

FIGURE 4: Calculator output for 100W base station (2m band) 15m RG213 feeder to mast mounted Yagi on chimney using SSB processed with 60% talk time.

Guidance below from PAEC-2 for Exclusion Zones for horizontal beam antennas above 50 MHz Using ICNIRP 2020 limits	
Minimum antenna height for ground level compliance [= D_EZ]	2.9 m
COMPLIANT EVERYWHERE AT GROUND LEVEL as antenna higher than minimum required	

FIGURE 5A: Output when antenna height is greater than required height.

Guidance below from PAEC-2 for Exclusion Zones for horizontal beam antennas above 50 MHz Using ICNIRP 2020 limits	
Minimum antenna height for ground level compliance [= D_EZ]	2.9 m
To achieve compliance at ground level raise antenna height or reduce power	
Radius Exclusion Zone [R_EZ]	8.6 m
Bottom of Exclusion Zone [H_CL]	0.0 m
Top of Exclusion Zone	4.9 m

FIGURE 5B: Calculator output when required height is not achieved.

Ofcom Compliance Distance calculation or follow the appropriate pre-assessed setup to determine any needed EZ's. In this case, with the antenna at 7m, the PAEC-2 method shows the minimum height condition is met and so the **COMPLIANT EVERYWHERE AT GROUND LEVEL** is indicated in **Figure 5A**.

Note, this article uses illustrations from RSGB Calculator v11. If you have already done your Compliance Checks using V10a or later, those remain valid.

Step 3 – If neither **LOW POWER COMPLIANT** or **COMPLIANT EVERYWHERE AT GROUND LEVEL** is indicated, then you need to define an appropriate Exclusion Zone.

If the antenna from **Figure 4** was instead mounted on a mast only 2.9m above ground level then the calculator would give the indication shown in **Figure 5B**. In this case a cylinder of height 4.9m and radius of 8.6m needs to be subject to control measures to ensure exposure limits are not exceeded. Alternatively, as suggested raising the antenna would give compliance at ground level.

If the EZ specified includes areas where people could be present, you need to implement Control Measures to ensure you do not transmit if anybody is remaining inside the EZ. Increasing the mast height or reducing the transmitter power will reduce the size of the EZ needed at ground level – or better still, eliminate it completely as shown in **Figure 1**.

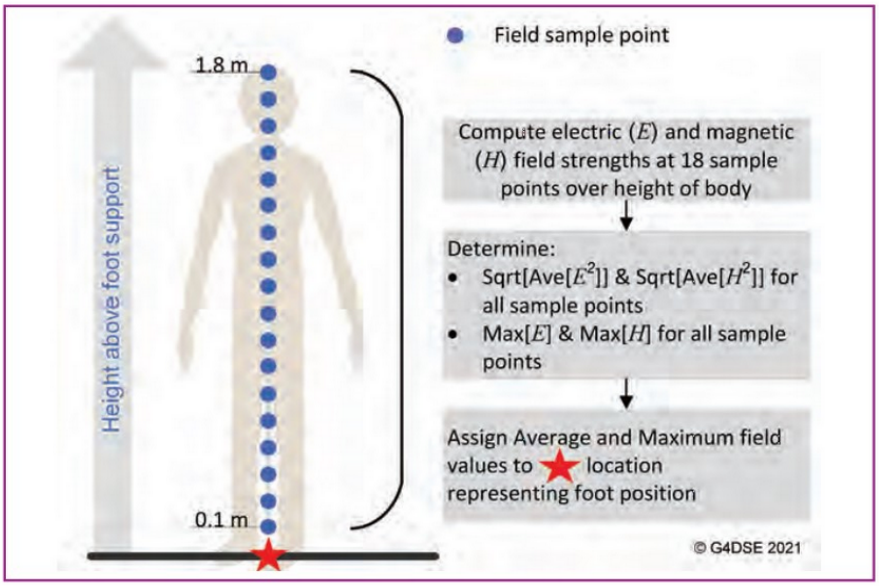


FIGURE 6: Field strength sampling to determine spatial-peak and average values consistent with the ICNIRP exposure definitions

In this example you would have two different options for determining the EZ. The first uses the algorithm in the Ofcom calculator which gives a "Compliance Distance". You need to make sure people are not remaining within that compliance distance long enough to exceed the exposure limits.

The RSGB/Ofcom calculators use formulae defined in recommendation ITU-T K.52. They are conservative (ie they may give a larger CD than needed) because of assumptions in the formulae. First the EIRP calculated is assumed to be radiated from an isotropic antenna giving the same EM field strength in all directions. It is also assumed that the power density decreases with distance by the inverse square law in all directions. This is partly valid for rotatable antennas as it gives the answer for all possible beam pointing directions. However, for areas out of the main-beam elevation pattern this set of assumptions may give excessively conservative compliance distances which you might not be able to achieve. Careful choice of a directivity factor may help reduce the conservatism, but these factors are difficult to find (or justify) for many antenna types. Second the ground reflection factor is assumed to be 0.6 under all circumstances, whereas detailed analysis shows this leads to an overestimate of the EMF exposure for many situations.

Step 4 – Use the full approach described in the relevant PAEC

If you can neither achieve the Compliance Distance given by the RSGB/Ofcom calculator nor implement the needed Control Measures, then you should use the more detailed analysis from a Pre-Assessed Equipment Configuration. For VHF/UHF beam antennas that would be PAEC-2, as introduced in the next section. The PAEC-2 method gives a more accurate estimate of the EZ, which might well allow you to demonstrate compliance where the RSGB/Ofcom calculator would not.

The updated RSGB calculator v11 can help you with this, as you have already entered your specific station configurations and calculated many of the parameters needed by these more advanced methods. The rest of this article outlines what PAEC-2 is about.

Using Pre-Assessed Equipment Configurations for Compliance Checks

RSGB volunteers have developed methods to model the EMF exposure to determine compliance contours more accurately.

First, we take the field strengths from the NEC antenna model at tens of thousands of points in space and convert them to whole-body average or spatial peak values as shown in **Figure 6**.

Next the spatial-peak and whole-body average values are compared against their

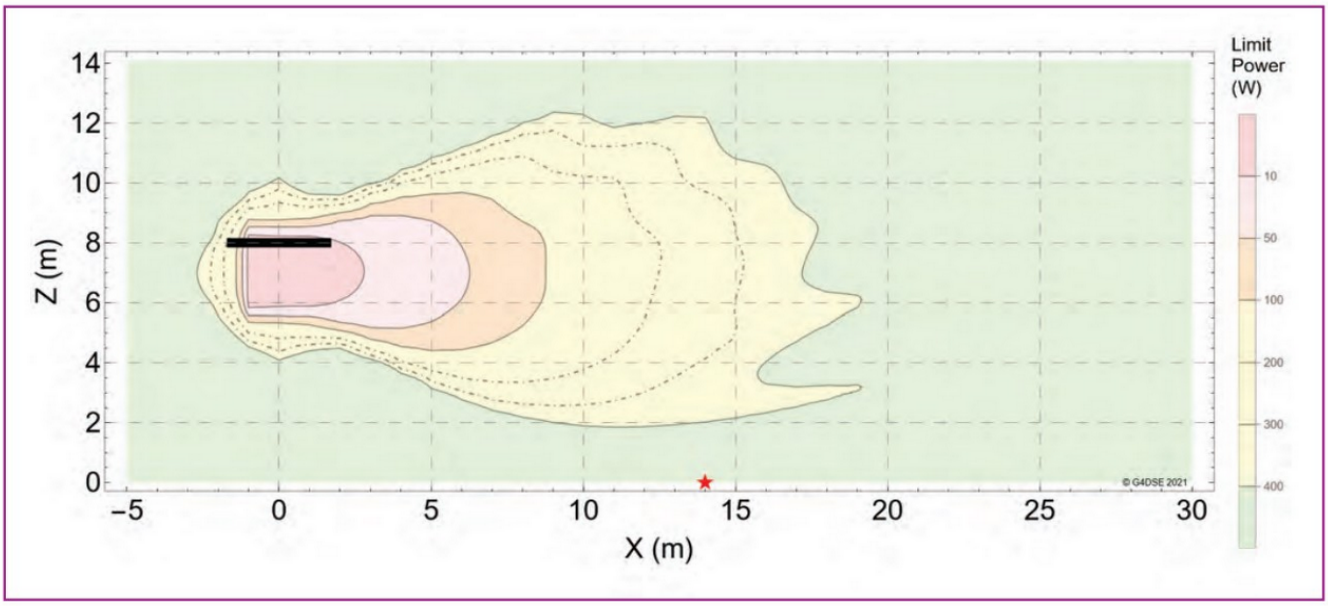
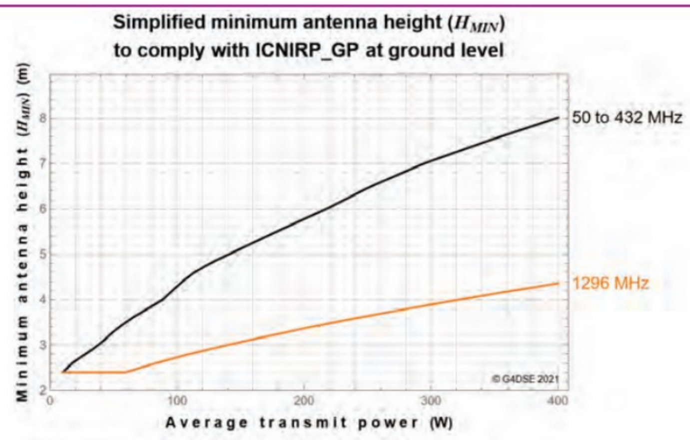


FIGURE 7: 8 element 2m Yagi at 8.0m showing vertical compliance contours for different transmit powers (Note: The Z axis for contours represents the foot position of a standing person as Figure 6).



Band	H_{MIN} over 'Rich soil' for ICNIRP_GP					
	10W	20W	50W	100W	200W	400W
50 to 432 MHz	2.4	2.7	3.3	4.3	5.8	8.1
1296 MHz	2.4	2.4	2.4	2.8	3.4	4.4

FIGURE 8: Minimum antenna height for compliance everywhere at ground level.

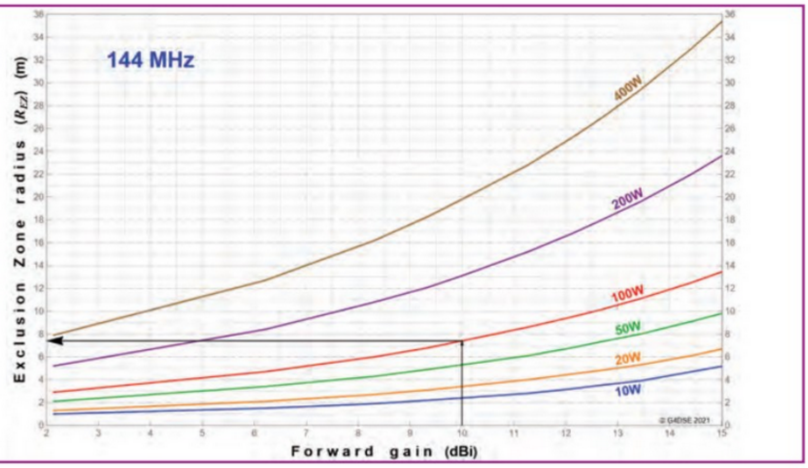


FIGURE 9: Exclusion Zone radius R_{EZ} for antenna above H_{MIN} needed to show compliance (eg 10dBi antenna @100W gives R_{EZ} of 7.4m).

respective reference levels. For each point, transmit powers are determined that would just be compliant with each reference level. For any point, the lowest compliant power is recorded and used to plot compliance contours for different power levels input to the antenna. This more detailed and accurate modelling replaces the conservative assumptions in the Ofcom calculator. A typical result is shown in **Figure 7** as an elevation plot through the centre of the antenna main beam. Coloured contour shading shows the areas around the antenna that are not compliant at various levels of RF power. As expected, the smallest non-compliant area is the one for 10W that hugs the antenna itself, and as the power level increases the non-compliant areas grow larger. The green area shows all places where compliance is achieved even with average transmit powers of 400W. Since **Figure 7** is a complicated shape, we draw a simpler EZ shape around it (**Figure 1**) to include all locations where the stated average transmit power might result in exposure above the limit.

Having applied this modelling to over 4000 different antenna height/type configurations, we have derived tables and graphs showing minimum antenna heights and EZ radii and heights that show compliance. The derivation of these parameters is explained in PAEC-2 that can be found on www.rsgb.org/emf. This also gives detailed step by step instructions on how to do an EMF compliance check. Example graphs are shown in **Figures 8 and 9**. First you need to know the average power input to the antenna which can be found using the RSGB calculator middle column labelled feeder.

Figure 8 allows the minimum height to be read of the vertical axis using the average power to the antenna represented by its forward gain on the horizontal axis. The minimum height for EMF compliance is often not difficult to achieve – though for radio communication the old saying "the higher the better" still applies!

Figure 9 allows the radius of the EZ (R_{EZ} measured from the centre of rotation) to be read off the vertical axis, as a function of antenna gain and averaged RF power. Use the next higher power curve than your actual averaged power. The example shown is for a 2m horizontal beam with 10dBi gain with 100W average power at the antenna. NB: the results from **Figure 9** are subject to the antenna being higher than the 4.3m minimum derived from **Figure 8**.

For the example shown in **Figure 9**, follow the black arrows. From the forward gain axis follow the 10dBi gain line up to the red line for 100W average transmit power, and then track across leftward to the vertical EZ radius axis to read off the radius value of 7.4m. Combine this with the heights of the exclusion zone derived from **Figure 8** to define the cylindrical EZ.

Conclusions

Two simple approaches are given in this article to perform Compliance Checks in accordance with the revised EMF licence conditions. Both approaches use the RSGB calculator to input your station configuration. The first approach then uses the Ofcom method to determine a "Compliance Distance".

The second approach uses the same calculator input data to derive the parameters needed to use a Pre-Assessed Equipment Configuration to determine your EMF Exclusion Zone. This article focuses on the use of PAEC-2 for VHF/UHF beam antennas.

If locations within the Compliance Distance or the EZ around your antenna are not accessible, then you have successfully checked compliance. Otherwise, you should implement Control Measures to ensure nobody remains in the EZ when you transmit. Alternatively increasing the antenna height or reducing transmitter power will make the EZ's smaller.

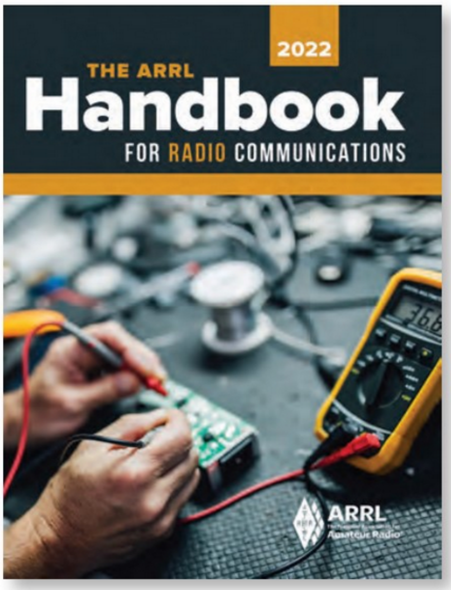
If you want to find a local amateur to help you with these Compliance Checks, speak to your RSGB District Representative who will identify someone or help you themselves. To contact your District Representative use the email address given on https://rsgb.org/main/about-us/regional-managers or see Club Calendar on pages 85 - 88 of this issue of *RadCom*.

Websearch

Links to all references in this article can be found on **www.rsgb.org/emf**

Book Review

ARRL Handbook 2022



Edited by H Ward Silver, N0AX

The ARRL Handbook For Radio Communications 2022, to give the book its full title, is the latest incarnation of a legendary book that has been in continuous publication – and revision – since the days of Marconi. This, the 99th edition, genuinely covers just about everything you could want to know about amateur radio. Running to nearly 1300 pages, its 28 packed chapters explain from the basics right up to the most advanced levels of our hobby.

This year, the *ARRL Handbook* has been updated with a lot of new and revised material on topics including 3D printing; amplifier linearity; batteries for portable operations; safety; propagation for Cycle 25; and much more. The list of contributing amateurs reads like a who's who of ham radio and includes, among many others, Joe Taylor, K1JT; Carl Luetzelschwab, K9LA; Rob Sherwood, NC0B; Paul Wade, W1GHZ; plus many more similarly talented and distinguished authors.

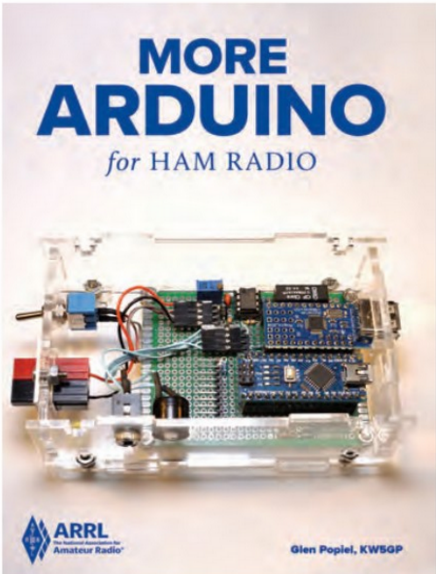
Constructional projects have always been a strong feature of the *ARRL Handbook* and this edition is no different. Antenna-related projects alone include a palm-size Z-Match ATU, an automatic antenna selector, a Raspberry Pi-based server/client for rotators and there are many other project areas of differing complexities, starting from a handful of components on perfboard. And even seasoned constructors will probably learn something from the Construction Techniques chapter…

The electronic supplement to the *ARRL Handbook* includes all the content of the main book in a fully-searchable PDF, plus seven further chapters (actually, they're called supplements, not chapters – but they run to some 250 more pages) and a plethora of useful files such as PCB etching patterns and templates, program examples, construction details and other useful information.

Although I say much the same every year, the *ARRL Handbook* is one of those books that I believe every amateur should either own or have access to via a shared club purchase: although the price may appear substantial, you do get an incredible amount of information for your money.

Size 208x274mm, 1280 pages, ISBN: 9781 6259 5150 2
Non Members: £49.99, RSGB Members: £42.49

More Arduino for Ham Radio



By Glen Popiel, KW5GP

Whether or not you've been 'bitten by the bytes bug' you are unlikely not to have heard the word Arduino – it has become a catch-all term for an entire ecosystem of small, inexpensive and easily-programmed microprocessors that are readily dedicated to single tasks and embedded within projects. Several *RadCom* articles have used Arduino devices and I can confidently predict there will be many more.

This book builds on two earlier volumes by the same author, though it's definitely not necessary to have read them in order to get the most out of this latest release. But whereas the previous books concentrated on the simpler Arduino Uno and Nano, this time more powerful devices are used to tackle slightly more computationally intense challenges.

Projects, though, and learning, are what the book is all about. And after a handful of chapters on the Arduino family, programming and construction techniques, we start into the projects themselves. There's an interesting selection ranging from a controller for Peltier coolers to rotator control projects, a USB CW keyboard, CAT display and even a RTTY reader, to name but a few. I liked the look of the latter, which includes a small colour LCD screen to show the decoded text. Like other projects, KW5GP walks us through the hardware and software building blocks, bringing them all together into a useful whole. We learn how the software works too, with descriptions, flowcharts and listings. You'll be pleased to know that the software can be downloaded (no boring typing!) and, like the hardware, is all open-source.

I found this quite a fascinating book. It's remarkable just how much can be achieved with very modest expenditure; this book will encourage you to experiment not only with the designs as presented but also to extend and adapt them to your own taste. All in all, good fun – particularly on those evenings when the propagation isn't co-operating!

Size 208x275mm, 384 pages, ISBN: 9781 6259 5147 2
Non Members: £39.99, RSGB Members: £33.99

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Design Notes

A junk box 50MHz power amplifier

A discussion about research into meteor scatter (MS) propagation, looking to map random reflections or 'pings', suggested a few MS beacons on the 50MHz band would be useful. These would need to radiate nominally upwards from a wide beamwidth antenna with about 100 watts. 100% duty cycle plain carrier is the optimum signal for such measurements; no clever modulation and just a minimum of statutory identification by on-off Morse. For single-carrier use a high efficiency is desirable to lower overall power consumption and reduce heat dissipation. Linearity is not necessary so a Class C PA is preferable.

Not having anything that would generate more than 5W on that band, thoughts at 'JNT Labs immediately turned to how I could put together such an amplifier. The JNT junk box is *very* well stocked with odd parts garnered over more than half a century of hoarding and over-purchasing, so here is my attempt at a suitable PA without having to actually *buy* anything specifically for this project.

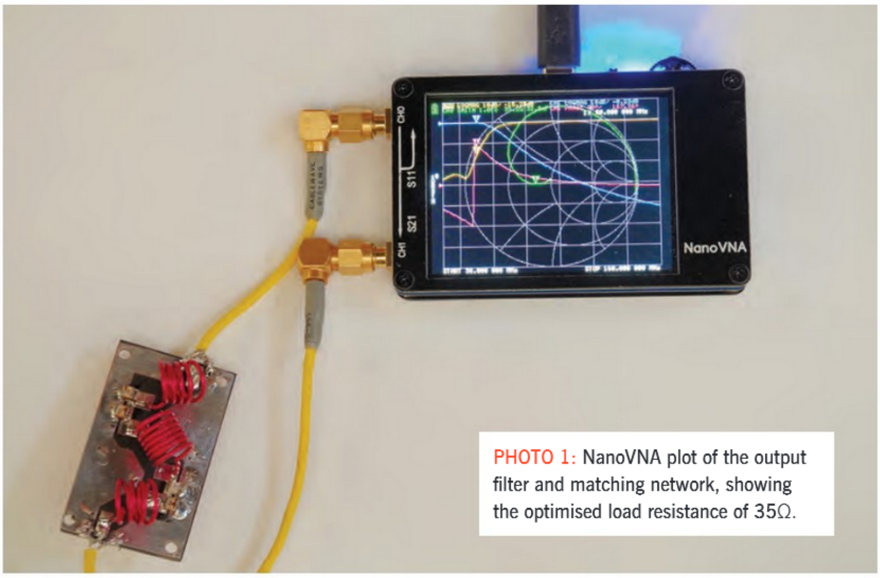

PHOTO 1: NanoVNA plot of the output filter and matching network, showing the optimised load resistance of 35Ω.

I had been given several MRF141G power MOSFETs. These are quite old (date coded 1990) dual devices designed for use in push-pull amplifiers up to 175MHz running from a 28V rail with a maximum of 300 watts output. As such, they ought to be pretty reliable at the 100W level. Push-pull amplifier design, at least for frequencies up to 144MHz using MOSFETs, is pretty well standardised now **[1]** and 100W is a quite mundane requirement. A step down balun (or, strictly speaking, an 'unbal') transformer, usually of 9:1 impedance ratio, supplies balanced RF drive to the gates, which are 'slugged' with a few ohms resistance connected between the two gates. This resistance, transformed back by the 9:1 unbal transformer, mostly defines the input impedance. At the other end of the MOSFETs the output (antenna) load resistance is transformed in a similar balun arrangement, to present a balanced load to the two drains that is suited to the wanted power output and supply voltage. At HF this output transformation / balun would usually be a transmission line transformer wound on a ferrite core to raise the common mode impedance of electrically short lengths of line. At low powers, for ease of construction it may even be wound as a conventional transformer. At VHF, especially for higher powers, the ferrite often can be dispensed with and the lengths of transmission lines are just wound into coils to give sufficient common mode impedance. For single frequency usage, residual common mode impedance can be tuned-out, allowing quite short lengths of coax to be used in the output matching network. I had a few ferrite cores that were recovered from an old plasma welder than ran at 13.56MHz, so these would do as common mode chokes and a simple coax line transformer would suffice.

Some very crafty and weird-looking arrangements are to be found in high power MOSFET amplifiers. The whole aspect of transmission line transformers for power amplifiers is a subject in its own right; we'll look at these next time so there's no need to go into details here. But, topology of the matching network aside, here is design problem number one: the load.

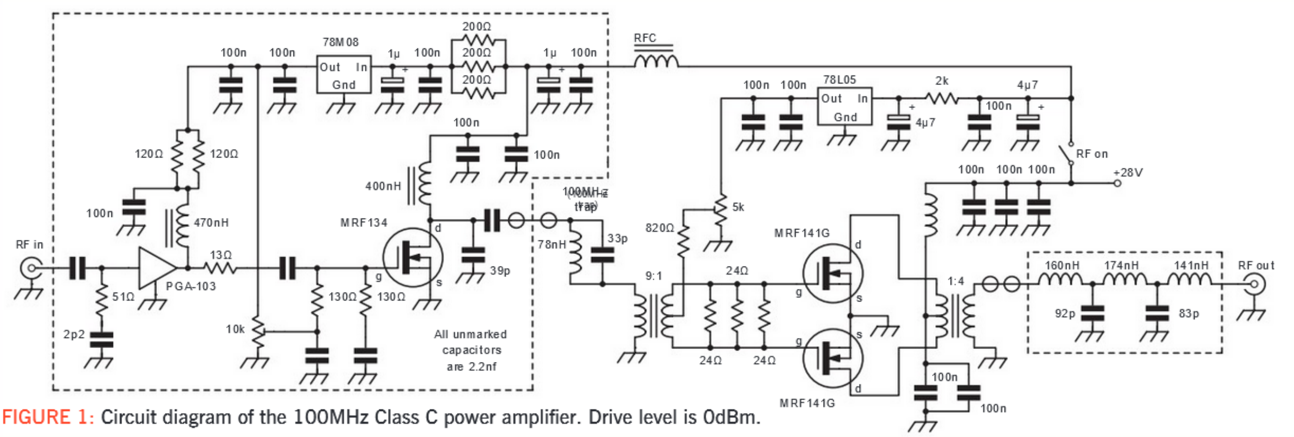

FIGURE 1: Circuit diagram of the 100MHz Class C power amplifier. Drive level is 0dBm.

Optimum load resistance

The output transformer / balun can only take on impedance transformation ratios that are the square of the whole numbers that are the turns ratio, hence impedance ratios of 1:4, 1:9, 1:16 etc. Normally only 1:4 and 1:9 are used in PA designs; any departure away from these values needs a bit of extra L/C or transmission line or multi-stage matching.

With a 28V supply rail and allowing for losses, let's say that a 25V swing is available at the MOSFET drains. That defines the peak sine wave amplitude that, in a single-ended amplifier, would deliver a maximum power of 25^2 x R_{LOAD} / 2. In a push-pull amplifier the voltage swing is doubled, so the maximum power equation becomes 25^2 x 2 / R_{LOAD}, with R_{LOAD} across the two devices. If the balun ratio is 1:4 with a 50Ω load then R_{LOAD} is 12.5Ω, resulting in a maximum power of 100 watts. That's almost sufficient for what is needed here, but with no scope for additional losses or any design margin. It really needs to be designed for at least 120W in order to guarantee 100W. A 1:9 transformer gives R_{LOAD} = 5.556Ω and a resulting maximum power output of 225W. This is the standard arrangement for an MRF141G running at the 200-300W output level in linear service.

For the initial tests a 1:9 transformer on a ferrite binocular core was used to investigate what the PA could do. Drive at up to 5W came from my Elad FDM duo. The 28V I used was a switch mode one rated for up to 5.5A output; it could actually deliver up to 6A before current limiting set in, with the output voltage gently dropping. As the MRF141G is rated for an absolute maximum of 32A drain current this PSU definitely wasn't going to destroy the FETs! Increasing the drive level allowed me to get up to around 160W output for about 3W of drive. Beyond this the PSU was current-limiting, but it was clear the amplifier was doing what it was supposed to. Input VSWR – as shown on the FDM-Duo display – was around 1.6:1. Quite acceptable, so the input matching network was fine. But backing off from 160W to get an efficient 100W would be quite tricky.

Backing off the bias to give Class C operation could be made to work, sort-of, just, but the drive level had to be maintained at a very constant level so this wasn't a satisfactory route. Reducing the supply volts and operating the device at close to saturation would be ideal, but I didn't have a PSU that could go low enough at this current – the lowest my SMPSU could be set to was 23.4V. In a more polished, non-junk-box design, that would probably be an ideal solution. Varying the output level of a Class C amplifier by controlling supply voltage is the classic amplitude modulator, but I wanted a simpler alternative.

Harmonics

Being a push-pull design, even-order harmonics are cancelled. Checking this power amplifier when driven from the FDM-Duo showed that the unfiltered output at 100MHz was quite low, at around -60dBc. That is good, as this frequency unfortunately sits where it can be harmful in a domestic situation: on top of Band 2 FM radio (and, more specifically, on top of Classic FM at 100 – 102MHz). The third harmonic was slightly lower than expected at around -25dBc. As the PA was into saturation due to the PSU current limiting and reduced supply voltage, I would have expected a level of perhaps -18dBc (a true square wave would be -13dBc, and is the maximum level of 3rd harmonic possible from a broadband push pull PA). Whatever the harmonics levels are, a low pass filter is essential on the final version. But before finalising the output stages, I shall digress.

The driver

To avoid having to continually use the FDM-Duo to drive the unit while testing and playing around, I needed a driver stage that could deliver a few watts into 50Ω. The junk box threw up a couple of desoldered ex-equipment (and very battered-looking) MRF134 MOSFETs (date coded 1995) that, by a process of chance, serendipity and Zen just happened to be exactly what was needed. They are rated for up to 5W output from a 28V rail. Applying the equation for load resistance P_{MAX} = V_{DD}^2 / 2 x R_{LOAD} just happens to give the fortuitous result that a 50Ω load on a 28V supply rail will work for up to about 7W out. Having already determined that the input match to the PA wasn't that far removed from 50Ω, it looked like no matching would be needed on the output. Even better still, the test circuit in the data sheet suggested that just using a 68Ω resistor on the gate gave suitable operating conditions, so the input could be defined at a reasonable match, again without any extra matching network. The mutual conductance, G_M of this device is 0.1S (100mA/V), so with a 50Ω load it would present a voltage gain G_M x R_{LOAD} of around 5. So with Z_0 in and out already defined as 50Ω, the gain could be reasonably confidently predicted to be something in the region of 14dB. For 3W (+34dBm) out and 14dB gain I'd need to drive it with around +20dBm. Once again the infinitely-deep junk box **[2]** came to the rescue with a few PGA-103 MODAMP devices left over from a previous project. These can give a little bit more than 100mW, with a gain in excess of 20dB. So the input drive needed would be less than 1mW – ideal. The two stage driver was built on a custom PCB and, when tested, easily gave in excess of 4W with a drive of -4dBm. As a single-ended amplifier stage running into saturation, it also gave an awful lot of second harmonic!

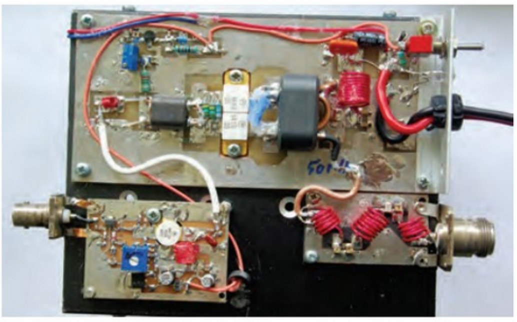

PHOTO 2: The 50MHz power amp's three units: the 5W driver, main power amplifier and output filter with L/C matching.

100MHz

At this point, for testing purposes, the PA output just had the 1:9 transformer and no filtering. Connecting the driver to the PA resulted in a nice output with lots of watts at 50MHz for just -4dBm input power; but quite a few of those watts were at 100MHz. I knew the push-pull stage wasn't generating this second harmonic (which was at a level only 15dB below the wanted signal at 160W output). The MRF141G was perfectly capable of amplifying those from the driver almost as well as it did the wanted signal, so the harmonic energy had to be removed before the drive was applied to the PA. A parallel tuned circuit forming a trap at 100MHz sufficed and, with a bit of optimisation (squeezing the turns while viewing the output on a spectrum analyser), the 100MHz level dropped to -70dBc. And this is still with no output filter.

Output filter and tank circuit

I was still getting a lot more power than needed and couldn't reliably wind it back. So how about adding LC matching to increase the load impedance for a lower output power? The simple L-match needed for this could be incorporated into the output low pass filter. Initially I kept the 1:9 transformer and looked at filter designs that would allow a matching network to be added. To get 120W from 28V would require a load impedance at the devices of around 10Ω. After going through the 1:9 transformer this would mean a load resistance of 90Ω, which would need to be transformed down to 50Ω. A simple L-match with a shunt C of 31pF and a series L of 141nH would work. BUT…

An L-match network in low pass configuration requires the shunt C to be on the high impedance side. September's Design Notes discussed transmitter output impedance and we recall that when the output devices saturate the output impedance becomes quite low – it becomes a voltage source. Here we are quite deliberately running in that state, so a substantial portion of third harmonic that needs to be removed is being generated from a low

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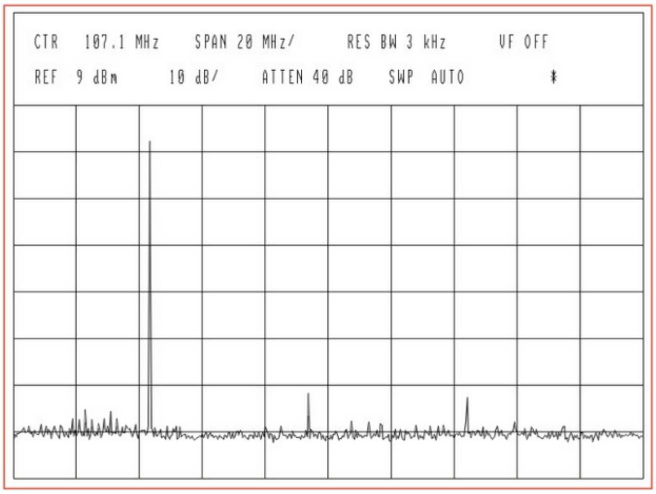

FIGURE 2: Output spectrum showing second and third harmonics at around -55dBc.

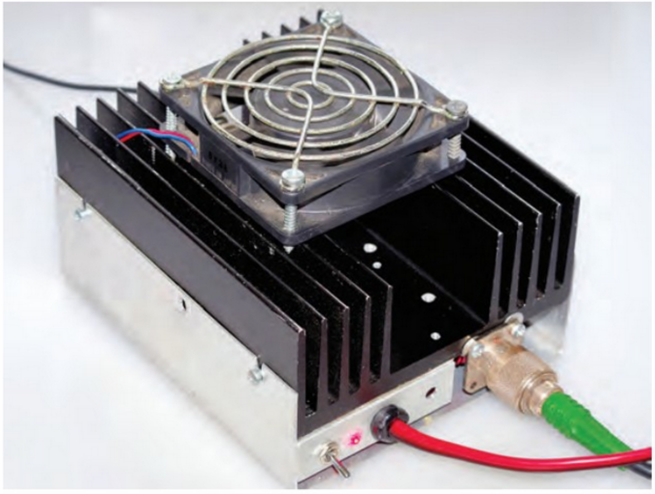

PHOTO 3: Finished amplifier showing heatsink and fan.

impedance. The last thing we want to do is to use a filter / matching network that presents a shunt capacitance on its input, since the impedance lowers with increasing frequency. Our third harmonic component, coming from a low impedance source, would result in high current and low efficiency. For filtering harmonics from a low impedance source, we need a filter with an inductor on the input – a Tee design. There is no simple low pass matching network that can have a series inductance on the high impedance side. The AADE filter design package **[3]** can design unequally terminated T-network filters, but the designs it gives for even-order ones need the shunt element on the higher impedance port. It, in effect, builds an L-matching network into the filter elements. Forcing an odd-order design with these impedance values, which would necessarily have to have a series L on the input, always resulted in a network that, when analysed backwards, gave a load resistance some way away from that desired.

After faffing about with weird and wonderful L/C networks designed semi-empirically, I admitted defeat and changed the output matching to 4:1. The size of the holes in the output ferrite core meant the transformer could now be made using pairs of lengths of 0.085 semi-rigid coax in parallel, giving a 25Ω transmission line, resulting in slightly lower loss.

Now the 1:4 transformed load resistance for a 120W design level at 28V supply would be in the region of 40Ω. AADE now appeared quite happy designing both odd- and even-order filters with a series L. The final version adopted, a 5th order Tee-network Chebyshev with load impedances of 35Ω and 50Ω, gave the right result when the actual transformed impedance was recalculated using Netcalc **[4]**.

The filter was constructed on a small dedicated PCB using air wound inductors and high quality ATC capacitors (see this month's GHz Bands for a broad sourcing hint). Some playing around with parameters using the AADE software allowed a filter design that could make use of values of ATC capacitors I had left over from a previous high power amplifier project, connected in parallel. The inductors were wound with 1mm enamelled wire on an 8mm drill former. They were initially designed using Rayner's Formula **[5]** to get approximate starting values for the number of turns and length, then squeezed or stretched to get near to the right value using a G4HUP LCR meter.

The combined filter and matching was set up by connecting a NanoVNA to the load port and a 50Ω load on the output. The inductors were adjusted until the VNA showed a value of something like 35Ω resistive. The filter and the impedance plot on the NanoVNA can be seen in **Photo 1**.

Complete Design

Figure 1 shows the complete circuit diagram of the final version of the power amplifier, which can be seen in **Photo 2**. The completed assembly showing the fan and surplus heatsink is in **Photo 3**. The output spectrum of **Figure 2** shows the second and third harmonics at levels that meet the ITU requirements for amateur equipment **[6]**.

It its present form – which is really only a breadboard – the unit comfortably delivers 100 watts from a drive level of between -4 to +1dBm, so it is well and truly into saturation. Minor adjustment of the first two inductors in the output filter affects the load resistance seen by the MRF141G and this can be adjusted for a few percent change in power and load current; fine-tuning for best efficiency. The best condition was found, then the power supply voltage backed off to get 100W, although in practice this turned out to be very close to 28V. The current draw of the whole amplifier, including the fan, was just about 6A.

The only component to run significantly hot is the ferrite core of the output transformer, suggesting it is not the correct material for this frequency – after all, it came from a power amplifier running at 13.56MHz. After 30 minutes of continuous carrier output the temperature of the ferrite was sitting at an estimated 70-80°C, while the heatsink, with the fan in use continuously, was a very comfortable 37°C. It may be worth my while investigating air cored transmission line transformers instead of using a ferrite one. Components around the PGA-103 in the driver are close to their maximum dissipation so a final version needs to put more attention into this area.

References

[1] These days on the surplus market there are old mobile phone base station amplifiers containing FETs for this sort of level, but operating at UHF. With a bit of care the devices can be turned into useful power amplifiers. I did manage to make one for 144MHz delivering 70 watts from a dual FET designed for 900MHz. It had a ridiculous gain, needing less than 100mW to get 70W output and required feedback, resulting in higher drive, to tame stability. However, it then proved a bit delicate and after a bit of overdrive went pop! But worth considering if you have the devices and no other use for them.

[2] By now, fans of Harry Potter may suspect there is some connection between the 'JNT junk box and Hermione Granger's Beaded Handbag. Readers can rest assured that no magic portal exists between the two. https://harrypotter.fandom.com/wiki/Hermione Granger%27s beaded handbag

[3] http://www.ke5fx.com/aadeflt.htm

[4] http://www.ifwtech.co.uk/g3sek/netcalc/netcalc.htm

[5] Rayner's Formula for inductors was originally published with dimensions in inches and a coil specified by its radius. That used nice whole numbers that were almost certainly rounded. So when converted to millimetres, the new equation can itself be quite justifiably rounded to $L\ (nH) = N^2 \times D^2 / (0.46 * D + G)$, where D is the diameter and G is the length of the winding in millimetres, with N turns. It's only a starting point, but does usually get to within 10-20% of the wanted inductance.

[6] Recommendation ITU-R SM.329-10 (02/2003) *Unwanted emissions in the spurious domain* https://www.itu.int/dms pubrec/itu-r/rec/sm/R-REC-SM.329-10-200302-S!!PDF-E.pdf

Technical

'Oscar': a broadband regenerative preselector – Part 2

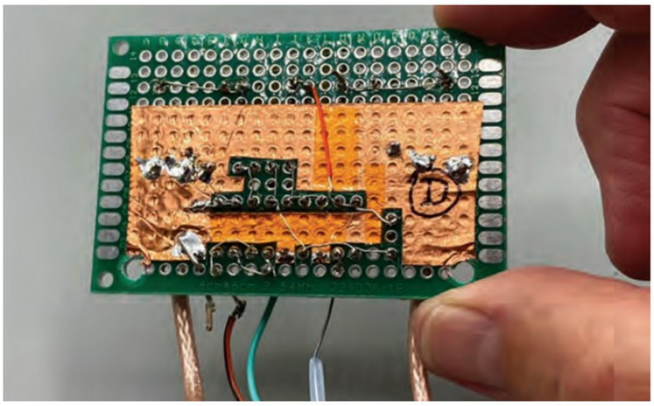

PHOTO 4: Underside of a typical board in this unit. I use small-gauge wire for interconnects.

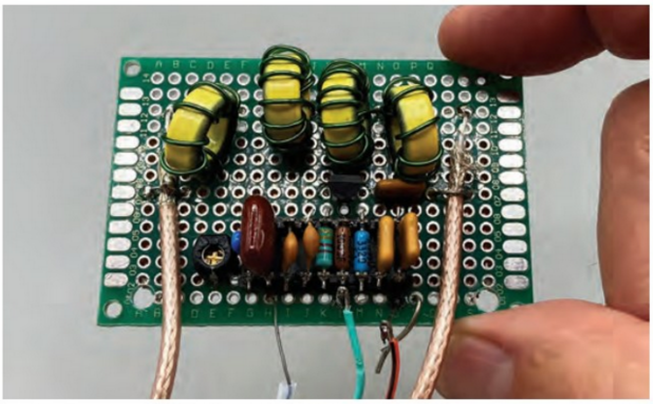

PHOTO 5. Top side of a typical board. The network is at the top, the Q-multiplier is below. In practice, there's no real reason to require coaxial cable for these interconnects, as long as you keep them short (<10cm or so).

In the first part of this artcle last month we looked at the design issues and rationale for the 'Oscar' regenerative preselector and made some general remarks about construction.

The rest is pretty straightforward. **Photo 4** and **Photo 5** show how I constructed the preselector band-changing boards. I've been using this technique quite successfully for a long time, at frequencies from audio to well over 100MHz. I get prototype-grade PC boards with 0.1" hole spacing and apply a ground plane on one side using copper foil tape, as evident in Photo 4. Then I lay out the circuitry, using a scalpel to cut away areas that aren't connected to ground. I prefer to connect leads on the top surface, just as a general practice. I generally use wire-wrapping wire for the interconnections, usually #28 or #30. It has a good Kynar insulation. Having a few different colours to hand keeps confusion to a minimum, but any thin (and preferably solid) wire should work well. You can perhaps also see the component header I used in these boards. In my experience they're relatively inexpensive, especially when you consider the amount of time they can save. When I'm doing a lot of testing and swapping of components they do make life easy – and they work well throughout the HF bands and even in the VHF (if you're careful). Also, I've built prototypes of this circuit using a variety of inductor types, from home-built adjustable-core units to toroids. All types tested work well. I'm listing my winding instructions in the parts list in **Table 1** for the toroids, since they're so easily obtained, inexpensive and easy to work with. For my own preference I always check my work on any inductor with my trusted LCR meter friend, a Peak LCR45. I like to squeeze or separate turns to make matched pairs, but I've also found that this is, in large part, overkill. Measurement just verifies that I wound the inductors correctly. I usually begin with the guidance on www.toroids.info and go from there. It's always a bit of a surprise to learn that two toroids that have been wound seemingly identically can have significantly different inductances.

The items are mounted to something stable and conductive. I salvaged part of an old cover (from a laser, of all things) to use as a chassis. I got the rotary switch and tuning cap off eBay, but everyone's junk box is different and that's part of the fun. I added, as shown in Figure 3, a relay to allow the preselector to be bypassed just by turning off the 12 volt feed.

There's no reason that any unit, when carefully constructed, won't perform at least as well as mine. I just happen to have the components and equipment at hand – my legacy of going to swap meets and over 40 years of digging through items thrown out at work.

I should also add that my own workshop is pretty well equipped, but there's no reason that you need all that stuff to make this circuit work for you. Far from it. Remember that the regenerative nature of the preselector means that it can also act as a signal source; a nearby receiver can tell you quickly both where the preselector is operating as well as what regeneration bias is needed to just make the oscillations very small or even gone. And as far as overall or 'final' testing goes, I prefer to just put it in series with an antenna coupler (to get the input closer to 50Ω) and then right into a receiver. The fancy equipment is a big help at times, but I don't listen to my spectrum analyser: I listen to my radios.

TABLE 1: 'Oscar' preselector parts and coil winding.

Band	f(low)	f(high)	L1, L3	L2, L4	Coupler	C(fb), ea	Bandwidth	L1 winding	L2 winding	Notes
A	2.78MHz	5.3MHz	1.6µH	10.4µH	300pF	390pF	30kHz at 3.5MHz	18T#24-T50-6	14T#24-FT37-61	Best above 3MHz
B	5.33MHz	10.4MHz	0.81µH	5.5µH	315pF	390pF	60kHz at 7MHz	4T#24-FT37-61	10T#24-FT37-61	Series cap 750pF
C	9.37MHz	15.48MHz	0.21µH	1.62µH	315pF	270pF	33kHz at 14MHz	7T#24-T50-6	18T#24-T50-6	Series cap 750pF
D	12.55MHz	20.28MHz	0.16µH	0.80µH	315pF	270pF	70kHz at 14MHz	6T#22-T50-6	13T#22-T50-6	Series cap 750pF
E	16.2MHz	31.9MHz	0.09µH	0.47µH	315pF	100pF	55kHz at 28MHz	4T#22-T25-6	10T#22-T50-6	Series cap 750pF
F	25.26MHz	36.9MHz	0.08µH	0.40µH	315pF	100pF	60kHz at 28MHz	5T#24-T50-10	11T#24-T50-10	Series cap 180pF

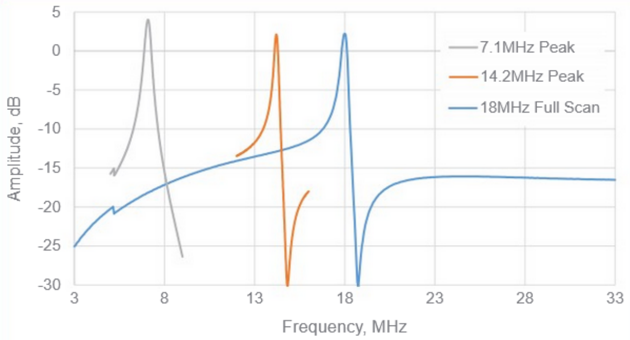

FIGURE 4: Typical performance at a few different frequencies, measured using my DSA's tracking generator.

TABLE 2: My own list of regeneration bias settings by band.

Band	Low end	High end	Low end freq	High end freq
1	5V	3.3V	3.05MHz	7.95MHz
2	3.9V	3.5V	4.85MHz	9.50MHz
3	2.3V	2.2-2.3V	9.00MHz	19.80MHz
4	6V	2.9V	13.6MHz	32.9MHz

TABLE 3: Parts list.

Part	Value	Notes
Band 1 C1	None; short with wire	
Band 2-4 C1	750pF ceramic 50V	
Band 1 C4	1000pF ceramic 50V	
Band 1 C5	47pF ceramic 50V	
Band 2 C4	330pF ceramic 50V	
Band 2 C5	330pF ceramic 50V	
Band 3 C4	270pF ceramic 50V	
Band 3 C5	56pF ceramic 50V	
Band 4 C4	200pF ceramic 50V	
Band 4 C5	60pF ceramic 50V	27pF parallel with 33pF
C2, all bands	75pF trimmer (eg Murata)	Or you can swap in/out fixed caps
C3, all bands	390pF ceramic 50V	
C6, 7, 8, all bands	0.1μF X7R 50V	
C9	15-424pF variable	
C10	0.1μF X7R 50V	
C11	1nF feedthrough	Or just 1nF to ground
D1	1N4001	
J1 & J2	SMA F bulkhead to RG316	Or whatever type you prefer
K1	12V SPDT or DPDT relay	Not very critical, many choices
Band 1 L1	1.6μH (*)	5T #24 on FT37-61, wide
Band 2 L1	0.81μH (*)	4T #24 on FT37-61, wide
Band 3 L1	0.21μH (*)	7T#24 on T50-6
Band 4 L1	0.09μH (*)	4T #22 on T37-6
Band 1 L2	10.4μH (*)	14T #24 on FT37-61
Band 2 L2	5.5μH (*)	10T #24 on FT37-61
Band 3 L2	1.62μH (*)	18T #24 on T50-6
Band 4 L2	0.47μH (*)	10T #22 on T50-6
* Nominal values measured at 200kHz using PEAK LCR45. Squeeze or spread windings to get as close as possible to nominal values and matched pairs. Other coil winding formulae are OK, and even slug-tuned inductors work well. I'm just including toroids because they are easily obtainable and inexpensive.		
R1 all bands	100kΩ, 1/4W, 1%	5% is OK
R2 all bands	200kΩ, 1/4W, 1%	5% is OK
R3 all bands	3.32KΩ, 1/4W, 1%	3.3KΩ, 5% is OK
R4 all bands	332Ω, 1/4W, 1%	330Ω, 5% is OK
R5	1kΩ linear trimpot	
R6	10kΩ linear 10-turn pot	Single-turn OK but harder to use
S1	6P4T rotary switch, 'Band'	5P4T would be even better
S2	SPST toggle switch	Regeneration
RFC1	20T #24 on FT37-43	
Q1 all bands	BC546CT	
DVM	Any small 0-30V 3-wire LED DVM, or an analogue meter	

Operation

This unit operates like a regenerative receiver, of course. I've found that I get good performance just at or slightly below the oscillation threshold, the point where one hears that familiar 'squegging' or a loud squeal from a receiver. Yes, the gain above that point is higher and the bandwidth becomes quite small, but using this preselector as a truly oscillating Q-multiplier – that is, well above the oscillating threshold – takes patience. Sometimes you can look for signals that aren't right at the peak of the oscillations, but just off to the side where the squealing isn't noticeable. Tuning is then done with care, since that noisy peak is not far away. Also, with increased regeneration well above that threshold you might notice a fair amount of microphonics (scratch the chassis and you'll hear it in your headphones), typical of regens and not very desirable. Another good reason to use regeneration bias level that are a bit lower.

You may have noticed from Figure 3 that the input and output are interchangeable. It works best for 50Ω (or thereabouts) terminations on both sides. I like that feature and I've built antenna couplers to help enforce that. In fact, those slick little SDRs don't like anything *but* 50Ω, so this circuit is ideal to use with them.

In general operation for this unit, turn the regeneration voltage control to a low value and tune the preselector until you hear an increase in signal in your receiver. Then slowly advance the regeneration control until it just starts to oscillate, then perhaps back it off a bit – and you're there. At those settings, the -3dB bandwidth should be on the order of 200-300kHz and the gain on the order of 5-10dB. With a little practice it's really quite easy to use. For reference I've included my settings as **Table 2**, but your settings *will* be different.

Performance

Figure 4 illustrates typical performance at three different tuned frequencies. The results here have been adjusted to remove the amplitude of the tracking generator on the Rigol DSA815-TG spectrum analyser. It isn't perfect, and at the top end of each band the peaks broaden somewhat, but you can see that this circuit does a reasonable job as a band-by-band preselector, also giving attenuation of a few S-units to nearby strong signals. This data was taken by adjusting the regeneration voltage to just below the noticeable oscillation point.

It's worth noting, just from my own experience, that sometimes this is about all one needs to pull out a weak signal nowadays. I live in a town full of solar panels and car chargers, making for a very high (S5 to S7) background noise level with what seems to be vast bandwidth. All that RF energy tends to swamp out the front end of a receiver unless you can attenuate the noise that surrounds the desired frequency. This is especially true of older receivers that may have poor (or non-existent) AGC or even AVC (automatic volume control) circuits.

Adaptations

I'm not finished with this design. I'll keep tweaking component values until I convince myself to move on to the next project. I encourage other builders to do the same kind of experimentation, especially if you decide to incorporate a one- or two-band preselector into your next QRP rig. The only 'magic' in this design is 'persistence', meaning that it will improve the longer you work on it. And as one added attraction, if you use only side of the network shown in Figure 1, you can design the output of the bandpass network for the approximately 1500Ω input impedance for an SA612 mixer to build a simple superhet receiver with a tuneable front end. I think I'll add that to my list of future projects…

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SWR and where has the reflected power gone

Introduction

There has been considerable discussion in recent times about SWR and reflected waves. I read, in the May *RadCom*, "The watt-less reflected wave is a convenient mathematical concept that has become corrupted into reflected power" and that reflected waves are waves of voltage and current but not power. Also, that "The direction of power travel in a transmission line is always from the source to the load though the reflected wave does travel from the load to the source". These statements seem to suggest that a reflected wave has no power. Tony Preedy, G3LNP (*RadCom* April 2021) believes that there is no reflected power and that this concept comes from the resemblance to standing waves on the strings of musical instruments. So I ask, what is the cause of the standing waves on the strings, is it not due to energy reflected from the ends of a firmly fastened string? When we see light reflected from an object, any object, are we going to think that the reflected light is only a wave with no energy?

The Simple Case

The analogy by Paul Brooking, G4SHH (*RadCom*, March 2021) of using a 1 microsecond pulse into a one mile cable is absolutely correct as is his statement that reflected power actually exists. Bob Richardson, G3XMB is also close to the mark. He suggests that the reflected wave upon travelling towards the source seeing a mismatch of the cable and source impedance will be reflected again towards the load. This would only be correct if the source presented either an open or short circuit to the reflected wave, but I suspect G3XMB is fully aware of this. In practice this is not the case and some power would be reflected and some power would be absorbed in the output resistance of the source. Bob is absolutely correct in that he accepts that a reflected wave is not merely a voltage or current wave but real power. We know that a reflected wave is voltage and current 180 degrees out of phase with each other ie. real power returning to the source and this would be the case in a simple configuration with just the transmitter, transmission line and antenna.

Inclusion of a coupling device (ATU)

We now progress to using a matching or coupling device, commonly (but incorrectly) referred to as an Antenna Tuner. So what happens to the reflected wave/power, or where does the power (energy) go? Well, it goes back to the antenna but, in the words of famous professor Julius Sumner Miller, "Why is it so?"

In the following and in accord with the superposition principle I shall treat the forward and reflected waves/power as separate waves of the same frequency that will add or subtract as vectors when these are incident on the same point. Also where the waves meet the coupling device it will be assumed to be at the effective impedance transition plane within the coupling device. This can be seen in **Figure 1**.

The reflected power from the antenna (PR1) returning to the source now meets the coupling device and sees an impedance that is the result of some output impedance of the source transformed by the coupling device to some other impedance. This means that some power will be re-reflected back to the antenna from impedance transition plane (PR2) and the remainder transferred to the source side of the coupler for travelling towards to source via impedance transition plane (PR3). With an SWR meter between the source and the coupler and the coupler adjusted for an SWR of 1:1 there is no power indicated as going towards the source and yet we know that some of the reflected power must have been transferred through the coupler impedance transition plane towards the source. So where has it gone?

When the coupler is correctly adjusted for an SWR of 1:1 not all the forward power (PF1) is transferred from the source side to the antenna side of the coupler. Some (hopefully most) is transferred to the antenna side of the coupler (PF2) and the remaining power (PF3) is reflected back toward the source from the coupler impedance transition plane and with correct adjustment the voltage is 180° out of phase and equal in amplitude with the voltage of the reflected power (PR3) from the antenna that is transferred from the antenna side of the coupler to the source side of the coupler via the impedance transition plane. The voltage therefore cancels but not the power; we can cancel voltage or current (as in the case of a short or open circuit respectively at the end of a transmission line) but not both as this would cancel power, and power is energy. This voltage cancellation is destructive interference. This destructive interference occurs at the impedance transition plane of the coupler so that the in phase and 180° out of phase voltages cannot be individually detected by an SWR meter. We must remember a fundamental law of physics, the conservation of energy (ie, energy can neither be created nor destroyed). When we appear to cancel energy by destructive interference in one point it will always manifest somewhere else. Such is the case here, because the energy can go in only one of two directions it manifests as constructive interference in the opposite direction. The resultant power is 'interference energy'. This interference energy then travels towards the antenna from the impedance transition plane and adds to the forward power. It is almost as if the reflected power on the source side of the coupler sees a short circuit and is thus reflected back to the antenna.

So far we have only discussed the first reflection but the power returned to the antenna is then subject to another reflection, a number of reflections occur but obviously there is a practical limit when the reflected power becomes too small to be considered. See Photo 6 in the excellent article by Paul Brooking, G4SHH 'Impedances and Reflections on Transmission Lines' in the July *RadCom*.

Practical effects

Once we understand this it is easy to see why the source impedance and length of cable between source and coupler may affect the coupler settings. This is because these affect the impedance seen by the power reflected from the antenna at the coupler and thereby the reflected power transferred through the coupler impedance transition plane towards the source. This power then needs to be cancelled (destructive interference) by the forward power from the source reflected at the coupler impedance transition plane which is determined by coupler settings. Similarly the length of cable between antenna and coupler affects the phase of reflected power transferred through the coupler impedance transition plane towards the source thus also requiring correct coupler settings for destructive interference to occur.

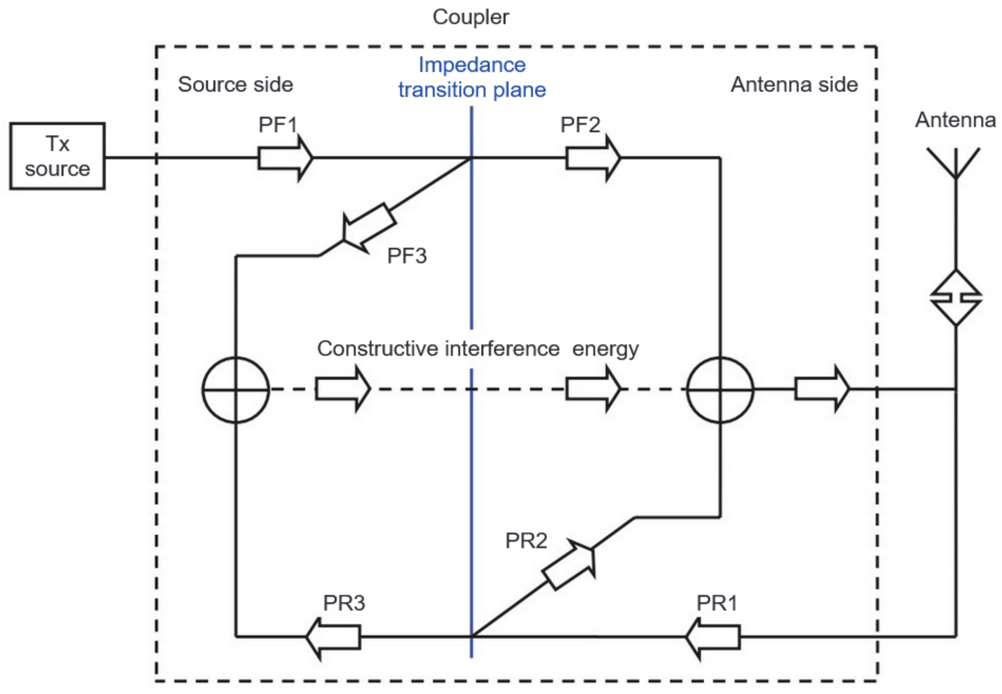

FIGURE 1: **Visualising the powers discussed in the text.**

An experiment easy to do to prove that the reflected wave is real power. Place an SWR meter in both the transmitter side and antenna side of the coupler. Adjust the coupler for an SWR as close as possible to 1:1. On the source side read the forward power. On the antenna side read the forward and reverse power. Say we have 100 watts forward on the SWR meter at the transmitter side of the coupler and on the antenna side we have some reflected power, say 20 watts, then the forward power on the antenna side will indicate 120 watts real power (allowing for some loss). The power delivered to the antenna is therefore 120 watts forward - 20 watts reflected = 100 watts. The 20 watts reflected is real, genuine power.

Conjugate matching

Our ultimate objective is an impedance match between the transmitter cable and antenna cable at the coupler and that is just what these reflections are doing for us. The vector sum (and therefore the impedance) that is the result of the forward and reflected waves at the coupler to antenna cable interface is where we are looking for an impedance match. This impedance match will then also reflect a 50Ω resistive impedance to the transmitter side of the coupler. This is when we will have a resultant conjugate match in a properly matched system. As an example of a conjugate match assume a 1:1 VSWR then the impedance looking into the coupler at that point will be R-jX = 75-j125Ω. This is what is known as a conjugate match. The reactance cancels and the resistive component is transformed to the input resistance of the coupler, ie 50Ω. Maybe the principle of the conjugate match is all most of us want to know and for most practical purposes would be sufficient knowledge.

I have performed a quick and simple test using a nanoVNA (50Ω source) at the input of a Kenwood AT200 ATU connected to a coax cable with a 40m antenna at 7.3MHz and adjusted for a VSWR of 1.084:1 (as close to 1:1 as I could practically achieve). Then measured the impedance looking into the antenna side of the ATU with the input terminated in 50Ω and then measured the impedance of the coax cable with antenna, giving these results:

- ATU input impedance looking into input with output connected to coax cable and antenna = 47.8-j3.28Ω
- ATU impedance looking into output of ATU with input terminated in 50Ω = 75.1+j136Ω
- Impedance looking into coax cable with antenna = 70.6-j126Ω

The results, 75.1+j136Ω and 70.6-j126Ω, is a close conjugate match considering the ATU input would not be exactly 50Ω with an SWR of 1.084:1.

Technical

Digital voltmeter accuracy – what do you *need*?

I have been looking at buying a new digital multimeter. These are usually known as DMM (digital multimeters) or DVM (digital voltmeters). The prime selection considerations should be whether the features offered by a particular multimeter meet your needs. For example, would the ability to measure capacitance or temperature be valuable? Would a low impedance range (thus imposing a load when measuring battery voltages) be useful? Do you need to measure high voltages? Some meters have dual scales and include the ability to measure the DC component and the AC ripple at the same time. Some meters can log readings over minutes or hours and output the data over a USB or wireless connection. Generally, the more you pay, the higher the quality – and the more features you get.

It is definitely worthwhile buying a meter capable of 'True RMS' measurements. True RMS meters measure the real "heating value" of non-sinewave signals, such as pulse trains or audio modulation. If you measure the true RMS voltage across a known resistance you can calculate the dissipated power. Older 'average reading' meters simply cannot measure non-sinewave AC signals correctly. But True RMS meters vary in their frequency range – some only work accurately up to a few hundred Hz, whereas others work to 100kHz or more. (None do True RMS at RF).

There are different sizes of handheld DVMs ranging from tiny pocket models like the one seen in **Photo 2** that are designed for quick checks, up to quite large models with that even have built-in printers or thermal imaging cameras. And there are bench models too, often used in service workshops, manufacturing facilities and laboratories.

Almost any DVM will be just fine for average amateur radio use. You don't need to pay top dollar for an expensive laboratory-grade meter if you are only going to use it occasionally to test a cable, check a 13.8V power supply, confirm the odd resistor value or to see if the battery from your handheld radio is charged up. A handheld model is probably the best for casual use because you can take it outside to check your earth connections or RF feeder cables.

Accuracy

My intention for this article is to talk about the three ways that the accuracy of digital multimeters are specified by the manufacturers. I found the numbers confusing, so I did some research. The following is all about measurement accuracy on the voltage ranges. Most datasheets use the same system, 'percentage plus digits' or 'percentage ± range' to describe the accuracy of the current, resistance, capacitance and temperature ranges. Some even publish separate specs for each multimeter range. I don't have space to discuss them all. The calculations are the same, just with different input numbers.

PHOTO 1: There's a bewildering array of digital multimeters on the market. But which one would be right for you? (Photo courtesy J C Barros via Wikimedia Commons, CC BY-SA 2.0).

The numbers game

The first thing of importance is 'digits and counts'. Digital multimeters have traditionally been grouped according to the number of digits they can display. Typically, this would be 3½, 4½, 5½, or 6½ digits. Note that these terms all use ½ to represent a partial digit, not 0.5.

For a '3½ digit' meter, the leading (most significant) digit can only be blank (0) or a 1. It is called the '½ digit', and is followed by three full (0-9) digits. The largest number that can be displayed is 1999. A 4½ digit meter can display either a one or a blank followed by four (0-9) digits. So, the maximum number that can be displayed on a 4½ digit meter is 19999.

This way of classifying multimeters has become confusing because the first digit can be higher than one. Commonly it will be a three (oddly, usually 32xx count), a five (50xx count) or a six (60xx). There was a move to classify these meters as 3¾ digit etc but this has fallen out of favour and now many manufacturers use the 3½, 4½, 5½ digits nomenclature to describe meters where the first digit can be greater than one. For example, Yokogawa describes their TY520 meter as a 3½ digit meter when it is actually a 6000 count meter.

PHOTO 2: An inexpensive, pocket-size, 3½ digit DMM with captive leads – ideal for many quick checks.

'Counts' is a better way to describe the meter's display, although it does not cover all situations. Some meters calculate to a higher (or lower) resolution than they display on the front of the meter. If the multimeter can calculate and display numbers up to 1999, like a standard 3½ digit meter, it has a count of 1999+1 = 2000. If the meter can display up to 5999 it has a count of 6000 and if the maximum display is 19999 the count is 20,000.

The count sets the ranges of the multimeter. If the count is 2000, the ranges will be, for example, a two-volt range (0-1.999 volts), a twenty-volt range (0-19.99 volts) and a 200-volt range (0-199.9 volts).

If the count is 6000, the ranges will be multiples of 6. For example, a six-volt range (0-5.999) volts, a sixty-volt range (0-59.99 volts, and a six hundred volt range (0-599.9 volts). Note the way that the number of decimal places reduces as the range increases. The number of decimal places is the resolution of the meter. The *count* sets the ranges of the multimeter; the *resolution* is how fine the displayed measurement is.

If you are measuring 13.8 volts on a 6000 count meter, the display will show 13.80 volts on the sixty-volt range. The resolution is the smallest change in voltage that can be measured, in this case 0.01 volts (10mV). On this meter, if the input is less than 59.99V, you will be able to see voltage variations as small as a 100th of a volt. If the input voltage reaches 60 volts, the range would (need to) change to the six hundred volt range, and the display would become 60.0 volts. The resolution has reduced to 0.1 volts (100mV), so now you will only be able to see voltage variations as small as a tenth of a volt. This is the main reason to buy a meter with a 6000 count instead of a 2000 count. The resolution of a 2000 count meter would reduce at 20 volts instead of 60 volts. A 6000 count meter can read 240 volts to a 10th of a volt resolution. A 2000 count meter can't.

You'll notice I said "need to". All but the simplest DMMs these days have a feature called 'auto-ranging' – in other words, they automatically select the most appropriate magnitude range for the voltage, resistance or frequency etc being measured. But few (if any) fully auto-range on current, because shunt sensors for the most sensitive ranges would be instantly destroyed if one tried to measure a high current. Auto-ranging usually takes a moment or two to choose the right range and so most auto-ranging DMMs will have a 'range hold' control and, possibly, a 'range' control to select the desired range, such as the example in **Photo 3**.

Accuracy

The specification sheets for most handheld DVMs state the accuracy as a 'percentage of the input value plus so-many digits'. This is because the least significant digit, the lowest resolution number, can be affected by noise and miscounts in the meter ADC circuitry. The displayed reading might be accurate to 2% but the lowest digit might be reading one or two digits higher or lower. My Escort 97 meter, the one I am replacing, has a voltage range accuracy of ±2% ±4 digits. To calculate the overall accuracy on a particular range you also need to know the meter count or the number of decimal places (resolution) on the range used for the measurement. The Escort 97 is a 4000 count meter so a 13.8V input voltage will be displayed as 13.80 volts. The display is showing two decimal places. Therefore, the resolution is 0.01 volts.

The percentage error is 2% of 13.8 volts = ±0.276 volts

The 4 digit error times the resolution = ±0.04 volts

So, the overall maximum possible error is plus or minus 0.316 volts (316mV), an overall error of ±2.29% (0.316 / 13.8 x 100). That means with a 13.80V input, the meter could read anything from 13.48 volts to 14.12 volts.

By the way, if you see a digits number of 10, it means that the last displayed number is meaningless since it could display any digit between 0 and 9. The meter is not necessarily inaccurate, but you can't trust the last displayed digit.

Better multimeters (mostly 5½ or 6½ digit bench multimeters) quote the accuracy in terms of; 'a percentage of the input value, plus a percentage of the range.' This is easier to calculate since you don't need to worry about counts and resolution. A typical high-quality meter might have a 0.015% input accuracy plus a 0.003% range accuracy. Let's assume that we are measuring 13.80V using the 50 volt range.

The percentage error is 0.015% of 13.8 volts = ±0.0021 volts

The range error is 0.003% of 50 volts = ±0.0015 volts

So, the overall maximum error is plus or minus 0.0036 volts (3.6mV). An overall error of ±0.026%. That means the meter could read anything from 13.7964 to 13.8036 volts. You can see that this meter is far more accurate than my old Escort meter.

Some meters combine the two methods and quote the accuracy as; a percentage of the input value, plus a percentage of the range, plus digits. To work out the accuracy, you can do the % input + % range calculation and then add the digit calculation.

Very good multimeters (always 5½ or 6½ digit bench multimeters) quote

PHOTO 3: This auto-ranging 3½ digit DMM also includes a non-contact infrared thermometer. (Photo courtesy Becky Stern via Wikimedia Commons, CC BY-SA 2.0).

the accuracy in terms of the 'input value error in ppm plus the range error in ppm.' An error described in ppm is parts per million, rather than a percentage (which is parts per hundred). We are now talking about very small errors (and very accurate meters). The method is the same, but the error numbers are much smaller. A typical meter might specify an input accuracy of ±25ppm, with a range accuracy of 8ppm. The input is 13.80V and the meter is set to the 50 volt scale. The error voltage is

$$(\text{input\_V} \times (\text{input ppm} / 1 \times 10^{6}) + \text{range\_V} \times (\text{range ppm}/1 \times 10^{-6}))$$
$$= 13.8 \times (25 / 1 \times 10^{-6}) + 50 \times (8 / 1 \times 10^{-6}) = 745.0\mu V$$

The overall maximum error is plus or minus 0.000745 volts (0.745mV, or 745μV), an overall error of ±0.005%. That means with a 13.80V input the meter could read anything from 13.79926 to 13.80075 volts. Pretty close!

My old meter has an accuracy of ±2.29% but many new handheld meters manage better than 0.5% and some are better than 0.05%. A good bench meter will have an accuracy of 0.02% to 0.01%. And a very good meter could have an accuracy of 0.005%, or even better.

Other factors

I have not talked about temperature stability but this generally goes in hand with accuracy. A meter with good accuracy numbers is likely to have good temperature stability as well. Price is usually a good indicator of the quality but shop around if you are buying a used meter. There is a fantastic resource on EEVblog by 'Wytnucls' at [1] that lists the specs of some 400 hand held and bench DMMs from 80 manufacturers. Some of the models listed go up to 8½ digit count!

For amateur radio use, I recommend a meter with at least 6000 counts that has the features that you need. Voltage (AC and DC), current (not all DMMs measure AC current), resistance (maybe with a continuity buzzer) would be the basic feature set. Some DMMs include a bargraph-type display that makes it much easier to see the effect of adjustments without having to do mental arithmetic. Other common features include a battery test function (usually for 1.5 and 9V batteries), a diode test feature (for reading forward voltage and checking for shorts), NPN/PNP transistor tester (and, rarely, FET tester), a simple signal generator, frequency meter, capacitance meter, temperature measurement (via a type K thermocouple, a thermistor or even non-contact infrared). Choose wisely; only buy the features you'll really need.

Websearch

[1] https://tinyurl.com/EEV-meters

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Technical

Amateur radio and the arrival of the transistor

Introduction

For many young and not-so-young radio amateurs the thermionic valve – with its high anode voltage and glowing cathode heater – is a thing of the past. It is associated now with bulky equipment burdened with heavy transformers and, whether receivers or transmitters, a tendency to drift in frequency as everything warmed up. But it has only recently been dropped from the amateur radio exam curriculum because valves are no longer used in most modern amateur radio equipment **[1]**. The transistor, in its many configurations, has taken its place – although there is a substantial cohort that still draws pleasure from using transmitters and receivers that are built around the shack-and-heart-warming pleasure of the incandescent valve.

The valve may be a thing of the past but for many, although it has gone, it is far from forgotten. In its final manifestations it had reached a peak of functionality and, in some cases, complexity, such that one might wonder what further potential it could have had if the invention and rapid development of the semiconductor had not undermined and usurped its dominant position. There was a multitude of factors driving the transition from valve to transistor, not least of which were the small size of the new arrival, its low power consumption and the future promise of improved reliability. But there were hurdles; from the first experimental example, made in 1947 at the Bell Laboratories, there was the challenge of producing a practical device with known parameters, then scaling things up to manufacture it in useful quantities. The earliest examples were expensive and this was, for a short while, a barrier to their wider adoption, but as the cost fell and there was a greater consistency in the quality and operating characteristics of the product, the transistor soon found its way into many areas that hitherto had been the domain of the thermionic valve. Eventually, of course, with the miniaturisation of components and circuitry, it has multiplied its way into places where the valve could never have gone.

The way in which the transistor was taken up, first by the general public, is of interest and this article looks at this before discussing how the transistor found its way, with some delay, into the world of amateur radio.

PHOTO 1: Replica model of the first transistor.

The discovery that began it all

The first news of the realisation of a working transistor device came in a short paper **[2]** by John Bardeen and Walter Brattain of the Bell Telephone Laboratories, published in July 1948 (some six months after the actual discovery). It was headed "The Transistor, A Semi-Conductor Triode" and opened with a brief description that indicates that the authors realised the importance of the discovery:

"A three-element electronic device which utilizes a newly discovered principle involving a semi-conductor as the basic element is described. It may be employed as an amplifier, oscillator, and for other purposes for which vacuum tubes are ordinarily used. The device consists of three electrodes placed on a block of germanium as shown schematically in Fig 1"

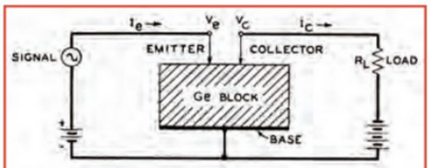

FIGURE 1: Schematic diagram of the 'semiconductor triode' (from *Phys Rev* July 1948).

(see **Figure 1** here, which is a copy of the drawing in the original paper).

In the concluding paragraph of the paper William Shockley's contribution was noted, almost as an afterthought, although Shockley was a key player in the discovery:

"We wish to acknowledge our debt to W. Shockley for initiating and directing the research program that led to the discovery on which this development is based."

The curious experimental prototype survives; a replica is shown in **Photo 1**. It achieved the very close spacing between the two contact points by fixing a narrow strip of gold foil around the lower edge of a triangular piece of Perspex and cutting a tiny gap in the strip, where it was then pressed onto a small slab of germanium that formed the base. Keeping the pressure of the point contacts down on the germanium was a 'spring' formed using, we are told, a bent paper clip!

Word gets out

It is clear from the journals of the period that there was scant appreciation by the public of the sweeping changes that the transistor would bring as it moved from germanium into silicon and from single discrete devices into the miniaturisation of junctions, components and the interconnections that go into the production of integrated circuits. But behind the scenes, those working on the theoretical side of electronics soon picked up on the significance of the 'semiconductor triode' and there were those who appreciated what the switching properties of the transistor might offer in the development of the electronic computer, wherein valves presented insuperable problems of reliability, power consumption and speed.

It took until October of 1948 for the news of this revolutionary device to be noted in Britain, by *Wireless World* **[3]**:

"Working in Bell Telephone Laboratories, J. Bardeen and W. H. Brattain have developed a three electrode germanium crystal contact device, known as the Transistor......"

This was followed by a detailed explanation based on the original paper but with closing paragraphs indicating the need for further development:

"If satisfactory circuit techniques can be developed to meet the conditions of low input

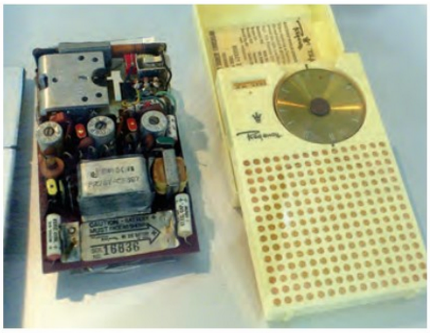

PHOTO 2. The Regency TR-1 circuit board and case, on display in the Deutsches Museum.
Image: 'Theoprakt' via Wikimedia Commons, CC BY-SA 3.0.

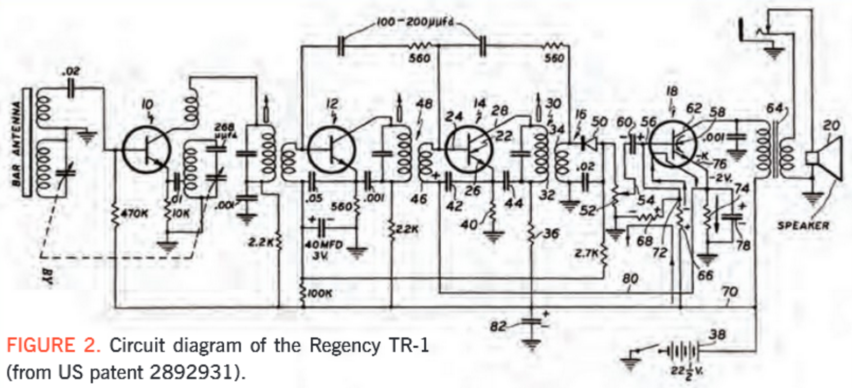

FIGURE 2. Circuit diagram of the Regency TR-1 (from US patent 2892931).

and high output impedance and positive feedback, and if signal/noise ratio is not unduly low, there would seem to be many applications in which Transistors could usefully take the place of valves. Bell Telephone Laboratories have already constructed an experimental radio receiver with a power output of 25mW, using Transistors throughout and have also demonstrated a repeater amplifier and an A.F. oscillator. The D.C. power consumption is 0.1 watt, and the overall efficiency is 25 per cent."

At the fifth post-war exhibition of the Physical Society held in London in 1950, *Wireless World* reported **[4]** that:

"The applications of germanium are no longer confined to the diode. The crystal triode, or transistor, is on its way to practical use. The G.E.C. Research Laboratories demonstrated its characteristics on an oscilloscope and showed experimental equipment embodying it. A three-stage a.f. amplifier with a gain of 6dB and an input impedance of 1kΩ was shown."

William Shockley's contribution

Of greater importance than the point-contact germanium transistor demonstrated by Bardeen and Brattain was the result of work carried out by William Shockley. He recognised that the use of germanium as a semiconductor for transistors was something of a *cul-de-sac* because the future development of the device lay with silicon as a semiconductor; this in turn led to the more robust PNP and NPN junction transistors and the subsequent invention by Jack Kilby and Bob Noyce of the concept of the microchip.

Bell Laboratories were not slow in spreading the word, devoting the July 1949 issue of their *Journal* **[5]** to a series of papers giving a detailed account of the transistor and its properties, with Shockley's name on two of the papers and Bardeen's on one.

There was an editorial note "regarding Semiconductors" which stated that:

"All but one of the papers that comprise this issue discuss practical applications of semiconductors and touch upon their properties as employed in rectifying devices, detectors, and in a new amplifying unit – the so-called transistor. These semiconductor papers all relate to one another and present, as a whole, a current but well developed account of the behaviour and uses of these very promising additions to today's vast array of electrical appliances."

Development of this new device was rapid and it has been noted **[6]** that,

"By 1953, The Engineering Index, an annual compendium of scholarly monographs in technical fields, listed more than 500 papers on transistors and related semiconductor devices. A year later there were twice as many, a year after that even more."

The transistor goes public

The earliest commercial application of the transistor was in hearing aids. These had been using miniature valves that, although remarkably small, still made considerable power demands. In short, batteries did not last long. Bell Labs encouraged the use of transistors in hearing aids by waiving the right to royalties and by 1952 a number of designs were on the market in America. These were more expensive than the valve units but they had the advantage of lower running costs **[7]**. But the first wider public demonstration of the advantages of the transistor came in 1954 with the manufacture in America of a miniature transistor radio, the Regency TR-1 **[8]**, seen in **Photo 2**, which used four point-contact transistors made by Texas Instruments. Because of the limited frequency response of the transistors at that time the two stages of IF operated at a low frequency of 232kHz. At $49.95 it was not cheap and it had an indifferent performance, but thousands were sold and very soon there were other manufacturers coming in on the act.

The TR-1 was a superhet using a basic circuit design, reproduced in **Figure 2**, but sufficiently compact to fulfil the boast that it would "fit into the pocket".

In the UK the first production transistor portable receiver was manufactured by Pye in 1956. It was not as small or indeed as successful as the Regency TR-1 but improved designs soon followed and sounded the death-knell for the battery-hungry miniature-valve portables that had dominated the post-war market for over a decade, which soon ceased to be made. By 1960 the market was awash with an ever-changing range of transistor portables, all using an ever-improving device that was under serious development to increase its power handling properties and raise its high-frequency response.

Typical of these early transistor radios was the Ever Ready 'Sky Leader' of 1958 (**Photo 3**), which closely followed their series of portable miniature-valve radios (the Sky King, Sky Countess, Sky Captain and Sky Baronet, all of which, because they consumed large quantities of batteries, were the principal reason why Ever Ready was in the radio business). The Sky Leader, with its six transistors, was a sophisticated superhet receiver that used a ferrite rod antenna and push-pull output stage. Initially it was made with an aluminium chassis (**Photo 4**) even though Ever Ready valve radios had already switched to using printed circuits.

As the 1960s saw the rise of popular music the transistor radio became, for many, an essential part of life.

Amateurs & the era of the transistor

But the public embrace of the transistor is a separate story. What, we might ask, was happening in the amateur radio world? There the valve was king and, in the aftermath of the war, the radio shacks of the United Kingdom were brimming with high quality, high voltage ex-military equipment. The Admiralty, for instance, had been selling off "electronic scrap" at 50s (£2.50) per hundredweight

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PHOTO 3: The Ever Ready 'Sky Leader' of 1958.

PHOTO 4: The double aluminium chassis of the Ever Ready 'Sky Leader'. Later models made use of printed circuit boards.

(51kg). Much similar surplus "scrap" was also coming from the army and air force, often in the form of brand-new transmitters, receivers and test equipment **[9]**. Ex-military equipment was still readily available well into he 1960s.

What was the amateur to make of the three short paragraphs in *The Short Wave Magazine* of February, 1953 entitled Coming – The Era of Transistors **[10]**, where the following observation was made?

"It is widely held that the coming developments in the application of transistors will revolutionise the science of electronics, particularly in the field of computer design and in Service equipments where light weight, minimum power requirements, expendability [*sic*] and simplified construction are of prime importance."

But how could this tiny, low voltage device ever handle the power needed for a transmitter? This would have been the key radio amateur question. Years of research had perfected the thermionic valve in its many sophisticated forms. There was almost certainly some resistance to thinking that this tiny newcomer could ever replace the refined hardware, the familiar world of 'boat anchor' radios.

First transistor transmitters

In *Shortwave Magazine* for December of 1953 **[11]** there was news of a transistor transmitter, but it was tiny:

"Working from first principles, and using a circuit of his own design, G5CV (Godalming) has succeeded in working telephony on 3608kc with a transmitter using only a single transistor; it runs at an input of 0.02 watt with power from a 22½ volt deaf-aid battery. It is believed to be the first time phone has been possible with a transistor-oscillator, and reports on the signal from any distance are particularly requested by G5CV…"

This was followed a month later **[12]** with news of "Another transistor transmitter":

"…we hear from G3CCA (Leicester) that he has had on the air, for the past four months on the 1.7mc band, a five-transistor transmitter using GET-1s, with which he is working local CW and phone with an input of half-a-watt at 50 volts. Ten CW and fifteen phone QSOs have been made with this equipment … G3CCA is preparing a lecture, 'Transistors and their Applications to Amateur Radio', for the Leicester Radio Society."

Experiments continued and in February, 1954 there was news **[13]** of J M Osborne, G3HMO (Buckingham) achieving both CW and phone contacts with an input power of just 20 milliwatts to a single *home-made* transistor. His activities were presented the following month in *Short Wave Magazine*'s first long article concerning transistors **[14]**, in which were presented circuits for both a transmitter and a receiver (**Figure 3**). The article opens with "Transistors have come to stay…" and there is also mention of home-made transistors, which may sound absurd bearing in mind today's cost of pennies per device, but price was much more of a barrier at that time. As Osborne says:

"The cost of a commercially-made transistor is high. The only English one available to the public is the GET-1 at £3 and the delivery (at the end of 1953 anyhow) is about two months. RCA transistors are priced at £6 to £12, according to type, and require a licence to import. So there's a lot to be said for making one's own transistors." *[For context, in 1953 RSGB annual Membership was 15s (75p) – Ed].*

The high price of transistors in 1954 is underlined by a report **[15]** about the new germanium transistor, the GET-2 manufactured by General Electric Co, which was priced at 37/6 (£1.88) each.

The point-contact transistor was, in essence, a simple device and one that could even be made at home, as shown in one of the Bernards Radio Manuals published in 1954 **[16]** in which the author, J S Kendall, offered detailed instructions because, as he stated in the opening chapter, "…commercial versions are extremely expensive and in short supply."

A leading article by J M Osborne in *Short Wave Magazine* **[17]** showing how to make point contact transistors illustrates that the potential of semiconductor technology was being recognised by Austin Forsyth, G6FO, the editor, who also included a preface to the article, observing that:

"The whole subject of transistors and the techniques surrounding their application on our HF bands opens up an entirely new field of amateur interest…"

1954 was also the year when the RSGB *Bulletin* published **[18]** two simple transistor transmitter circuits, one for 160 metres using a Mullard OC-50; the other for 80 metres.

Enthusiasm for transistors continued in *Short Wave Magazine* with the introduction **[19]** of a regular column entitled Transistor Topics, which was intended, as the editor stated, to "gather together the experiences of other transistor-transmitter operators, so that this feature will mirror progress and development in an important new branch of the Amateur Radio art."

Practical Wireless seem to have been rather slow in featuring articles about the transistor. There were none in 1954 and only three in 1955, the last in November showing a three-stage receiver – essentially a crystal set with three stages of audio amplification.

Over the next decade there was a growing number of transistor-related circuits and articles aimed at the radio amateur in most of the journals concerned with electronics.

A significant contribution to the adoption of transistors by those wishing to build their own transmitters and receivers came through the Bernard's Radio Manuals. These were inexpensive booklets that had published many circuits of valve radios but then in 1954 came the first [16] of many on the subject of transistors. But it was the work of the late Clive Sinclair, who wrote a whole series beginning in


PHOTO 5: Eddystone EC-10.

1959, that put a wide range of circuits, along with detailed descriptions, into the hands of the amateur constructor.

By June of 1963 the status of the transistor was summed up in an editorial in *Practical Wireless* headed "The Transistor Revolution":

"One major development in recent years was, of course, the reappearance of the semiconductor device in the guise of the transistor. At first, many people were highly sceptical about the transistor, considering it an interesting, but limited, innovation. And for a while it did appear that so far as the radio amateur was concerned the new device was indeed strictly limited, being suitable only for pocket portables and similar pieces of equipment where the criterion was simply that of miniaturisation. But things moved on. The laboratories produced bigger and better transistors; types that could operate on the short wave bands and, later, types suitable for use in VHF receivers. And all the time the power ratings were pushed up. […] whatever reservations may have once existed, the semiconductor now looks all set to win its battle not only for recognition but for supremacy."

The transistor enters the shack

There is little doubt that there was a delay in the use of transistors in equipment manufactured for radio amateurs. When compared with the take-up of transistors in radios for the general public, the amateur radio lobby was behind the curve. But this was probably understandable because a high frequency response with low noise levels was particularly important for short-wave receivers; for transmitters, the ability to handle high power was crucial. One might also argue that the use of valves was so well understood and deeply embedded in the practice of amateur radio that it could have created a certain resistance to change.

One of the first transistor short-wave receivers aimed at the amateur market was the Heathkit 'Mohican' GC-1A, which was introduced in 1962. It was a good-looking design that came, of course, in kit form. There were ten transistors in a superheterodyne circuit with a BFO and three stages of IF amplification.

This was followed a couple of years later by the Eddystone EC-10 (**Photo 5**), from a

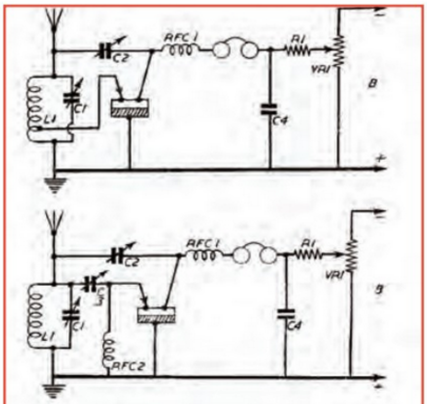

FIGURE 3: Transistor receiver circuits used by G3HMO in February 1954, as published in *Short Wave Magazine*.

famous company that had a long history of manufacturing valve radios. These were well known for their flywheel tuning arrangements and large 'slide-rule' scales. They were also heavy. The EC-10 was a scaled down version in both weight and size, which was helped by the use of transistors. And of course, it used batteries that were fitted inside the steel case. It covered the amateur bands up to 30MHz and also the medium wave broadcast frequencies.

The Eddystone EC-10 appeared on the market in 1964 and it is of interest to note that Pat Hawker, G3VA, writing **[20]** in that year on the subject of transistor transmitters, observed that:

"… at one time the amateur tended to be ahead of low power military and commercial equipment, and even recently the SSB transceiver has blazed the way for others in the communications business. But now, in the swing to transistors, the professionals are setting the pace."

In amateur radio equipment, valves gradually gave way to transistors as the latter improved and sophisticated variations, including integrated circuits, became available. In 1970 the Yaesu FT-101 series of transceivers entered the market. These were entirely solid state (apart from the driver and finals, which at the time needed to be valves to handle the transmitter power). It was a design that was steadily revised over more than a decade – but always with valves in the finals.

Also from the Yaesu stable in 1976 was the FRG-7 communications receiver, a solid-state triple conversion superhet that featured the famous Wadley Loop **[21]**. **Photo 6** shows an early example without the additional bandspread control.

There was undoubtedly within the amateur radio fraternity a deep resistance to abandoning the use of valves, although the major manufacturers of amateur equipment were not slow in realising the advantages of the transistor in terms of reliability, miniaturisation and reduced production costs. But for many


PHOTO 6: The Yaesu FRG-7 short wave receiver.

amateurs, even now, there is considerable affection for the memory of the warm glow of a valve superhet although the majority of operators these days would, understandably, not care to trade in their latest modern solid-state base station for anything other than a brief and very temporary trip down memory lane, patrolling the bands with an AR88 or working an 80m contest using a Racal RA-17.

References

[1] With the notable exception of higher power HF linears, although semiconductor-based amps are now comparably priced
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[8] More about the TR-1 can be found in Kiver, M S, *Transistors in Radio, Television, and Electronics*, McGraw-Hill, 1959
[9] J Clarricoats, *World at their Fingertips* (1967), RSGB, p203
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[12] *Short Wave Magazine* Vol XII, January 1954, p664
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[14] *Short Wave Magazine* Vol XII, March 1954, p10-15
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[16] J S Kendall, *Practical transistors and transistor circuits*, Bernard's Radio Books, No 128 (1954)
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[18] RSGB *Bulletin* March & April 1954 (reprinted in *RadCom*, Vol 89 No 7, July 2013 p24)
[19] *Short Wave Magazine* Vol XII, May 1954, p163-6
[20] RSGB *Bulletin*, April 1964, p223
[21] https://en.wikipedia.org/wiki/Wadley loop