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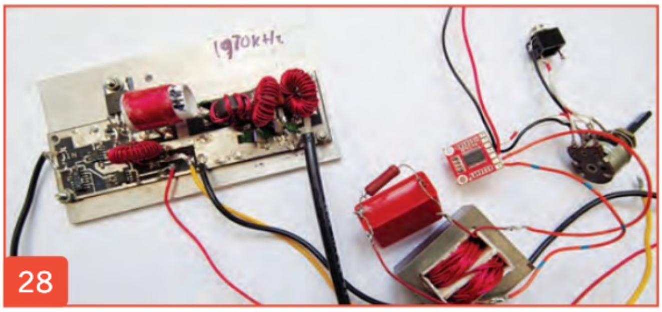

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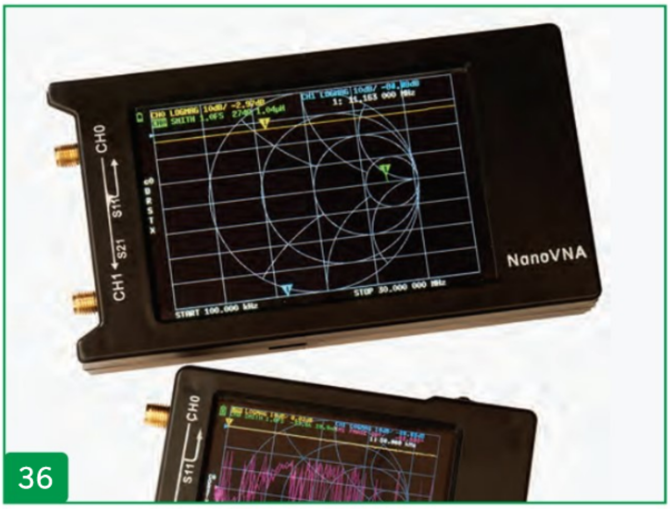

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Cover image: The Yaesu FTM300 dual band 144/430MHz C4FM/FM transceiver. Designed by Kevin Williams, M6CYB.

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

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New Products

Portable antenna system

The Comet HFJ-350M (Toy Box version) covers 1.8 to 50MHz and comes complete with a plastic carrying case for convenient transport. The antenna is in 4 parts with quick and easy assembly for when out portable. The complete assembled antenna is 1.6m long, in a quarter wave base-loaded configuration and will handle up to 100W of RF power. There is also an optional canvas carry pouch for more rugged outdoor use. The complete system sells for £149.95 and is available from Comet exclusive UK importers Nevada Radio. Read more at www.nevadaradio.co.uk.

2m high power bandpass filter

Designed by Goran, YU1CF, the BPF2 filter uses high Q coils and capacitors, with N type connectors, to achieve low insertion loss of less than 0.1dB. It can handle 1.5kW of power and covers 144 to 148MHz. The BPF2 is ideal for reducing out of band interference from other close by services and for harmonic suppression on transmit. Rejection of out of band signals starts from -31dB, rising to -90dB depending on frequency. The filter sells for £225 and is available from Nevada, see www.nevadaradio.co.uk

Verotec caseframe

The Eurotec caseframe family from Verotec is a modular multi-purpose design based on the KM6 subrack system, designed for applications that require standard 3U and 6U PCBs or modules to be housed in either a desktop, 19" rack mount or portable enclosure. Standard depths are 240, 360 and 480mm and backplane or DIN41612 connector rear extrusions can be specified. It has front trims and latching feet for desktop instrumentation use, fitted with standard 19" earpieces for rack mounting and the portable units have a locking carry handle. The top and bottom covers are readily removed for system building and servicing requirements. Three thermal management options are available; unventilated top and bottom covers, additional ½U high ventilated and a ½U ventilated top cover and a 1½U bottom cover with a front filter unit that accepts a fan tray for forced air cooling. EMC screening kits that provide enhanced attenuation levels are available.
www.verotec.co.uk.

Desktop Holder for the IC-705

The Icom MBF-705 is a desktop holder for the new IC-705 QRP SDR transceiver. The MBF-705 will position the IC-705 in a user-friendly angled position making operation easier whilst keeping your radio and desktop neat and tidy. It provides another addition to this radio and will be available from the usual amateur radio dealers. The MBF-705 will have a suggested retail price of £19.99 including VAT.
To find out more aout the Icom IC-705 or the various accessories available, go to www.icomuk.co.uk.

Antennas

10m, 6m and 4m beam antennas

During the Sporadic-E (Es) season, operating on the 10m, 6m and 4m bands can bring some surprising results and a directional antenna can provide a distinct advantage. In this two-part article I start with a summary of a 2-element Yagi beam array for the 10m band, while Part 2 next month examines Yagi beam arrays for the 6m and 4m bands.

A 2-ele beam array for 10m

The performance of a half wavelength (λ/2) dipole is enhanced by adding a second parallel element, enabling the antenna to become directional, ie a more effective radiator or absorber of RF energy in a specific direction **[1]**. When this second element's length is about 5% longer than the λ/2 dipole it acts as reflector and the antenna becomes directional ahead of the dipole. If the second element is made about 5% shorter, it acts as a director and the antenna becomes directional ahead of the director element. Either of these arrangements are the basis for a 2-element (2-ele) beam array.

The spacing between the dipole and second element determines the dipole centre's impedance **[2]** and this can be arranged to be close to 50Ω, easing matching.

The concept of a 2-ele beam array constructed for the 10m band, using the second element as a reflector, is shown in **Figure 1**. The finished antenna is shown in use in **Photo 1**.

Design and predicted performance

The 2-ele beam array for 10m was designed using the MANNA-GAL analysis application **[3]** to predict its dimensions and to model its performance at 28.5MHz.The antenna's predicted performance gave a free-space gain of about 4.3dBd (6.4dBi) and a front-to-back ratio (F/B) of around 10dB. **Figure 2** shows the antenna's predicted radiation pattern as polar plots when the antenna was modelled at 5m above ground level (AGL).

Modelling a 10m band beam array at 5m AGL might seem quite a low height for this antenna. However, at 5m AGL the antenna is close to being a half wavelength (λ/2) above the ground. Therefore, the predicted performance for the 2-ele 10m band beam array can be expected to be fairly representative of another 2-ele beam array at λ/2 AGL, for example a 20m band 2-ele beam array at 10m AGL.

PHOTO 1: The 10m band 2-ele beam array in use.

At this height above the ground, the antenna's predicted vertical radiation pattern indicates a single forward lobe with most of the RF signal concentrated between radiation angles of 15° to 45°. Such angles of radiation will tend to favour both Es and F-layer propagation and should allow shorter and longer skip stations to be worked when conditions allow. At 5m AGL, the predicted gain for the antenna was 10.8dBi, corresponding to a 30° angle of radiation. The antenna's predicted horizontal radiation pattern indicates significant RF signal concentrated ahead of the dipole, with a 3dB beamwidth of around 70°. The prediction shows no side lobes have formed, however there is a comparatively small rear lobe that gives rise to a front-to-back ratio (F/B) of around 16dB.

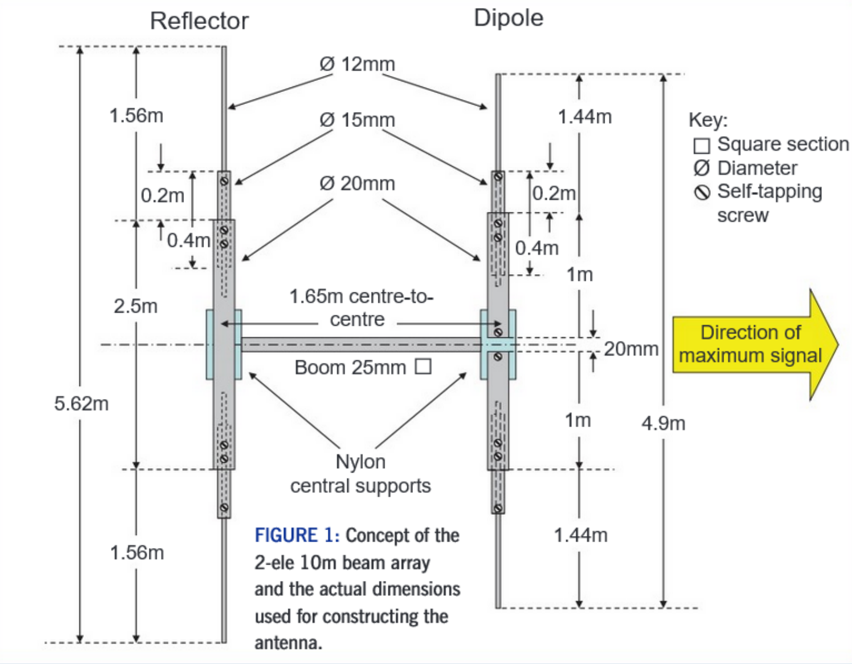

FIGURE 1: Concept of the 2-ele 10m beam array and the actual dimensions used for constructing the antenna.

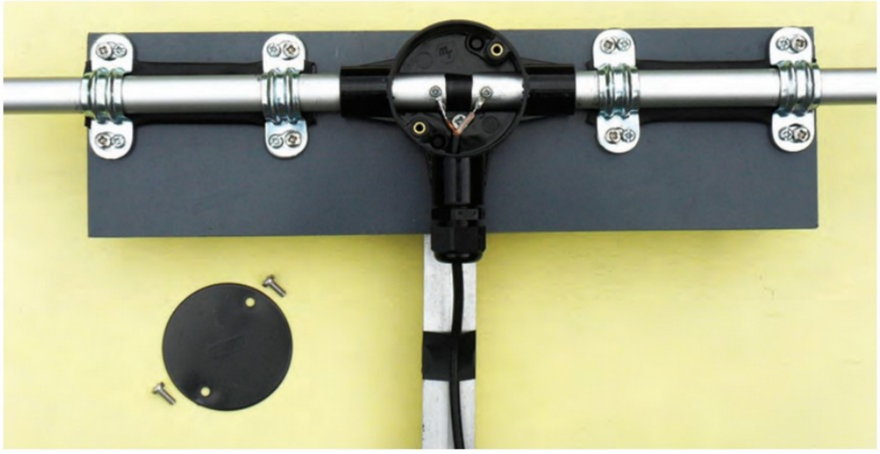

PHOTO 2: Dipole centre support of the 2-ele beam array.

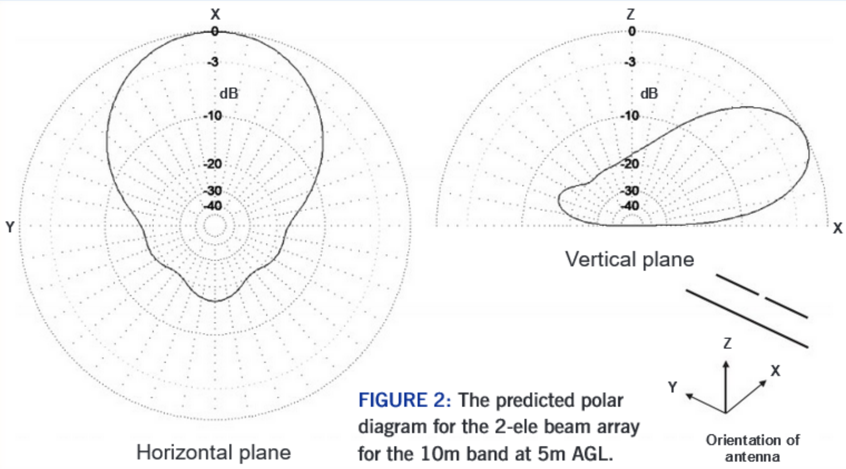

FIGURE 2: The predicted polar diagram for the 2-ele beam array for the 10m band at 5m AGL.

Construction

To minimise the antenna's weight, the two elements were made using 20mm, 15mm and 12mm diameter flush fitting aluminium tubes, allowing assembly as a telescopic arrangement.

This arrangement for the dipole's legs also provided a convenient means to vary the dipole's length to tune the antenna. Each telescopic section was clamped in place by using self-tapping screws, which were inserted into suitable holes drilled into the end of each larger diameter tube section. The concept of the arrangement used for each dipole leg is shown in Figure 1.

A central support was made for the dipole using a sturdy rectangular nylon plate with dimensions of 350mm by 100mm by 12mm. To protect the connection of the coaxial feeder cable to the dipole's feed point, a 3-way 20mm diameter electrical conduit box was mounted on the central support and this gave a snug fit for the 20mm diameter tubes used. To protect against the weather, a layer of sealant was applied to each 20mm diameter tube where it entered the electrical conduit box. In addition, a rubber gasket was included under the lid when this was screwed to the electrical conduit box's base.

To provide an insulated separator between the dipole's legs, a 100mm length of 20mm diameter plastic conduit was cut lengthwise to give a flush fit inside each dipole leg with a 20mm space left between them. Holes were drilled into the leg ends and through the separator to take self-tapping screws. Solder tabs were secured under each self-tapping screw to allow the coaxial cable's conductors to be soldered to the dipole's feed point. Four 20mm metal saddle clamps were used to hold the dipole legs in place on the central support. Additional holes were drilled into each saddle clamp and through the central support to allow M4 nuts and bolts to hold everything in place, as shown in **Photo 2**.

The reflector element's construction used a similar telescopic tube arrangement and central support as used for the dipole. However, three 20mm metal saddle clamps were used to hold the reflector element in place. The design of the reflector element's arrangement is shown in Figure 1, including all relevant dimensions (the lengths might need to be varied slightly depending on the tubing used). **Photo 3** shows the construction of the reflector element's central support.

Both central supports were fixed to the antenna's boom using M5 nuts and bolts, with the boom made from a 1.8m length of 25mm square profile aluminium tube. The space used between the dipole and the reflector was 1.65m centre-to-centre as shown in Figure 1.

Balun

The 2-ele beam was fed using 10m of RG58 coaxial cable that included a 1:1 current choke balun formed by winding the cable into an inductor. The balun comprised nine turns of the cable with an internal diameter of 50mm and was held together using insulating tape. The balun was situated as close as practical to the dipole connection **[4]**.

Tuning and testing

The antenna was clamped to a 5m extendable mast for testing and tuned to 28.5MHz using an MFJ antenna analyser. The lengths of the dipole and the reflector were varied equally to minimise the SWR. During this process, the space between the dipole and the reflector was also adjusted. Careful adjustments allowed an SWR of 1.05:1 to be obtained, indicating the antenna's feed point impedance was very close to 50Ω at the test frequency.

With the antenna at 5m AGL and having signed on in CW, the antenna was loaded with an initial power level of 10W. This was increased to 100W, with the SWR remaining low at 1.1:1. The directivity of the 2-ele beam array was checked by tuning to several 10m beacons and turning the array to monitor the level on the receiver's S-meter, with a distinct change being very evident.

On the air

During the 2020 Sporadic-E season, the 10m band 2-ele beam array was used to make many SSB contacts across Europe from Spain to Finland, with signal reports often exceeding S9. The calculated forward gain predicts that 10W at the antenna would give an ERP equivalent to more than 60W into a simple dipole – and, as antenna gain 'works both ways', you get a corresponding increase in receive performance.

Mike Parkin, G0JMI
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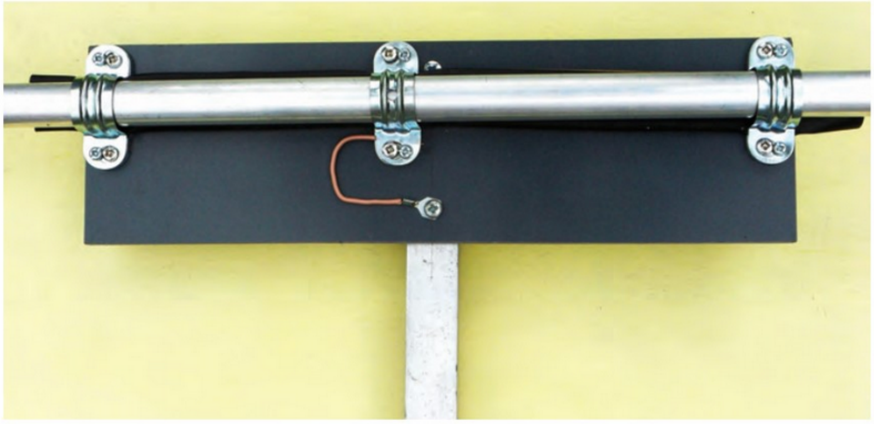


PHOTO 3: Reflector support of the 2-ele beam array.

PHOTO 4: G8XIR's 6m/4m Yagi beam antenna mounted below his 70m and 2m Yagi beams on his pump up mast.

Feedback

Kevin Church, G8XIR has kindly sent in pictures of the dual band 6m/4m Yagi beam antenna he built at his Kent home following the September 2018 *RadCom* Antennas column. Kevin says: "I finished the antenna, put it up and it works really well for its size. I can hear both Buxton beacons *[nearly 200 miles distant – Ed]* with the antenna at just 4m AGL (with my mast not up). The SWR is below 1.2:1 on both bands, which is impressive. So, I now look forward to Sporadic-E propagation when it comes!"

Photo 4 shows Kevin's 6m/4m Yagi beam antenna clamped to the mast (at its lowest position).

Errata

Unfortunately, the original September 2018 Antennas article carried an inaccuracy for the position of the 4m antenna's second director element (4m D2). **Table 1** is a corrected set of measurements and, for reference, **Figure 3** shows the general layout of the antenna.

Next month

Next month, the details for a 3-ele Yagi beam array for the 6m band and a 4-ele Yagi for the 4m band will be summarised, including the details of their construction.

References

[1] *Radio Systems TECIII*, D C Green, Section 5: Antennas, pages 84-85. Published by Pitman, 1979

[2] *Antennas* 2nd Edition, J D Kraus, Section 11.9: Arrays with Parasitic Elements, pages 476-481. Published by McGraw-Hill Book Company, 1988

[3] MMANA-GAL basic V3.0.0.31, antenna analysing application. Original code by JE3HHT. MMANA-GAL Basic and Pro by DL1PBD and DL2KQ, 1999 onwards

[4] *RSGB Radio Communication Handbook* 13th edition, edited by Mike Browns, G3DIH, Chapter 14: Transmission Lines, Table 14.1, page 14.13

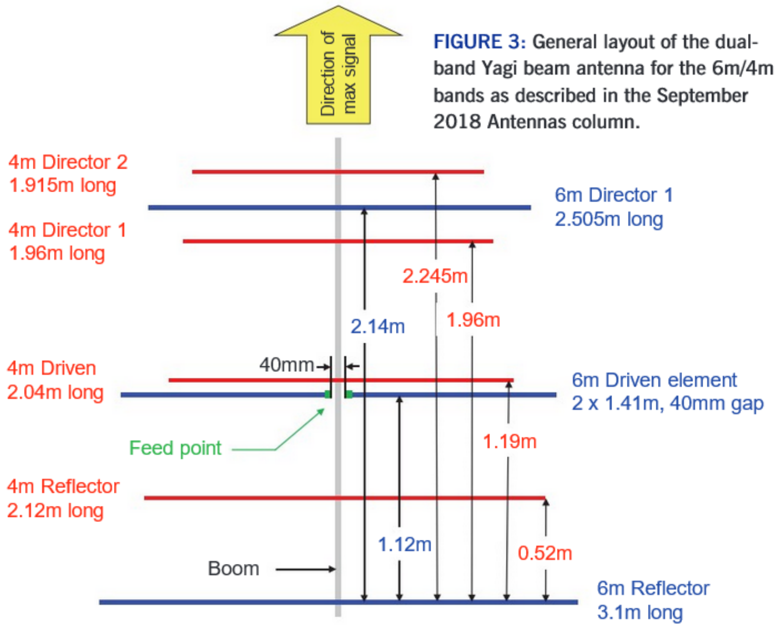


FIGURE 3: General layout of the dual-band Yagi beam antenna for the 6m/4m bands as described in the September 2018 Antennas column.

TABLE 1: Corrected 6m/4m dual-beam element actual lengths and centre-to-centre spacings. All elements are 12mm diameter. The 4m driven element is one piece because it is parasitically excited by the 6m dipole.

Element	6m element length	6m element spacing	4m element length	4m element spacing
Reflector	3.1m	0	2.12m	0.52m
Driven element	2.86m (2 x 1.41m legs with 40mm gap)	1.12m	2.04m	1.19m
Director 1	2.505m	2.15m	1.96m	1.96m
Director 2	-	-	1.915m	**2.245m**

The Yaesu FTM-300DE 144/430MHz dual-band C4FM/FM transceiver

I already have two Yaesu radios and was interested to see what this new transceiver would bring to my station.

Because we have a Fusion equipped repeater (soon to be two) here in Pembrokeshire, I use a Fusion equipped mobile in the car (FTM-7250) and in the shack (FTM-400XDE) and find them both enjoyable and useful rigs to use. Like many, I suspect, I was intrigued when the FTM-300 was announced and wondered how it would fit into the line up of the existing radios.

First of all, let's have a quick look to see what some of the Yaesu blurb has to say:

The new FTM-300DR/E provides stable and reliable 50W RF power output. As in recent YAESU mobile transceivers, the FTM-300DR/E is also equipped with a heavy-duty heat sink that includes our exclusive FACC (Funnel Air-Convection Conductor – Wind Tunnel).

Real Dual Band Operation (V+V, U+U, V+U, U+V) is available with two independent receivers, and the FTM300DR/E supports simultaneous C4FM digital monitoring for both the A and B bands.

2-inch High-Resolution QVGA Full-Colour TFT Display clearly highlights the frequency and operation bands.

With the Band Scope Function, users can monitor up to 63 channels centred around the current VFO frequency in real time. (21 channels in memory channel mode)

Memory Channel Band Auto Grouping (MBAG) is one of the advanced features of the FTM-300DR/E. Memory channels are automatically categorized in each band, and memory channels can be easily and quickly recalled by 4 Band Groups – Airband(M-AIR), VHF(M-VHF), UHF(M-UHF) and 174-400/ 480-999.99MHz (M-GEN).

3W audio power speaker ensures a clear and crisp audio – that has been specifically tuned for quality audio. Two individual external speaker jacks are provided. Users can output the VFO A and B band Receiver to separate speakers or mix A and B signals when a single external speaker is used.

The Yaesu FTM300 has a main unit and a head unit for easy mounting in a vehicle.

Built-in Bluetooth unit is installed in the FTM-300DR/E. This enables the hands-free operation with the YAESU SSM-BT10 or a commercially available product. The SSM-BT10 is equipped with a PTT button and also supports VOX operation. Using the new USB charger cable – SCU-41 with the controller of the FTM-300DR/E, the SSMBT10 can be easily charged. The SSM-BT10 works for approximately 20 hours on single charge.

The FTM-300DR/E supports both the WiRES-X Portable Digital Node function and Fixed Node function with the HRI-200. Since simultaneous C4FM monitoring on both VFO A and VFO B is possible, users can enjoy both WiRES-X communications on one channel while monitoring another local channel at the same time.

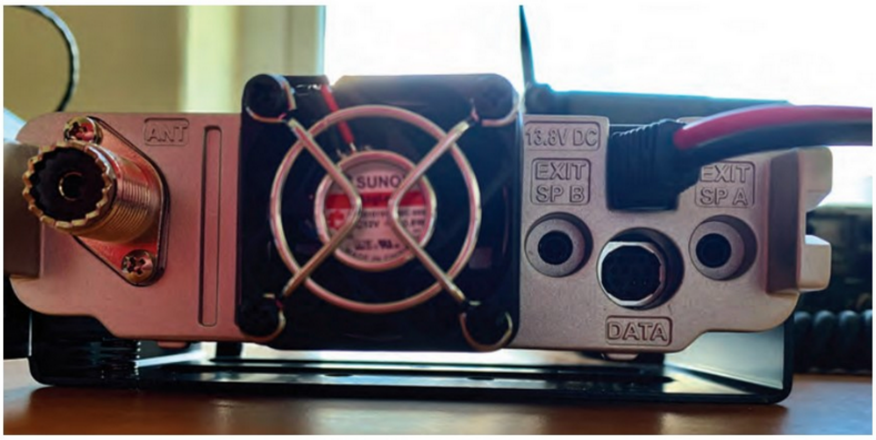
Other advanced features of the new FTM-300DR/E include; DG-ID (Digital ID); Group Monitor; positional awareness from the built-in 66ch High Sensitivity GPS receiver enabling Real Time Navigation; Backtrack feature; a GPS Terminal for an external GPS receiver; 1200/ 9600 ARRS data modem for APRS mode; Voice Recording of both Received and Transmitted audio; save and load data including configuration and memory channel information to a micro SD card; Snapshot function using the optional MH-85A11U camera microphone.

First impressions

The main unit feels of good solid construction. The head unit though, felt a bit less substantial. There's absolutely nothing wrong with it, but it does feel a bit less robust than the head unit on the old FTM-400, it is a bit smaller too. You can cut that both ways – it's great news if you are planning to fit it into a car. Or, it's a bit smaller for fat fingers! The colour display is pleasant to look at and easy to read.

Of course, I was keen to try the FTM-300 out, so I moved the shack FTM-400 aside and connected up it up. There's a supplied cable between the head and main unit. In fact, there's two. A short one, if you want to mount the head unit directly onto the main unit and a long one (3m) if you want to mount the head unit away from the main unit. By the way, if you do mount the head unit directly onto the main unit, you can't then access the main microphone connector. If you are going to use the Bluetooth headset

It was fairly easy to set up the APRS function and there's a full APRS manual you can download.



The rear of the FTM300.

that's no problem and there's also a data connector on the side of the head unit where you can attach, for example, the Yaesu Camera Snapshot microphone, enabling (low resolution) images to be sent whilst the rig is in C4FM data mode.

I wanted to use the supplied microphone, so kept the short cable between the head and main units so that I could plug the microphone into the main unit.

The FTM-300DR claims a feature called E2O-II (Easy to Operate-II) so I was interested to see whether I needed to resort to the manual to get on the air. Well, actually I *did* get the book out – on switch on, you need to set the callsign that will be used on Fusion. Although it wasn't at all difficult, I did quickly check how to enter my callsign and set it.

On the air

I was pleased to find though, that I could work out how to set the repeater shift and CTCSS tone without too much difficulty. I was then able to set up some of my local and not-so-local repeaters. EI7MLR, some 80 plus miles away came up on first call on 70cm. Power levels on the FTM-300 on both bands are 50W/25W/5W. I'm always sorry if there is no 10W level for a Foundation licensee to use.

Taking advantage of the dual receivers, with one side of the radio on EI7MLR, I placed the other receiver on 144.800MHz (APRS) and switched the APRS packet modem on. The GPS receiver quickly locked onto the satellites (the radio's control head was close to the shack window), thus determining my position and enabling the APRS display to show distance and bearing to stations that were received. It was faintly disconcerting to have the APRS display updating (and beeping) whilst I was transmitting on EI7MLR. I found that I could switch off the beep produced on an incoming APRS beacon. Although I found it fairly easy to setup the APRS functionality, it's worth mentioning that APRS is only quickly mentioned in the Operating Manual supplied with the rig, but there's a full APRS manual that you can download from the Yaesu website that is full of information if you want to get the best out of the APRS features.

While I was over on the GB3SP repeater trying out the C4FM capability, Peter, GW4VRO asked me if the FTM-300 can receive C4FM on both Bands A and B. The answer is yes and I was able to try that out. However, what the rig will not do is to receive two C4FM signals on Bands A and B simultaneously (which contradicts the Yaesu blurb, but not the manual). Another enjoyable QSO during the review period was with Endaf, N6UTC (MW1BQO) on his morning commute in Los Angeles – digital voice is really very good for this sort of thing.

It's worth mentioning that the C4FM digital mode works surprisingly well mobile. I'm quite often surprised to find that although FM signals are scratchy and weak, C4FM in the same place can be much more readable. If you've used the C4FM digital mode before then there are no surprises with the FTM-300 and everything seemed to work as it should.

Transmitted audio quality reports on both FM and C4FM were good. I had to remember, though, to keep the microphone further away from my mouth on C4FM than on FM, otherwise the audio became rather 'breathy'. On receive, received audio was easy to understand although the tone was not quite as full as some of the other receivers in the shack. Perhaps an external loudspeaker would help resolve this minor criticism. Talking of external loudspeakers, remember that you can feed audio from one side of the radio to one speaker and from the other side of the radio to a second speaker – there are two speaker jacks. If you are 'only' using one speaker then audio from the two sides of the radio is mixed together.

Bluetooth as standard

With Bluetooth built as standard into the FTM-300, you can use a Bluetooth headset (Yaesu offer such a product), or many cars have a Bluetooth audio system that you may be able to connect to. Please note the use of the word '*may*' – as past experience (not with the FTM-300) suggests that not all Bluetooth in-car audio systems are equal. If in doubt, ask your dealer, who may be able to help. Peter, GW4VRO gave me some useful feedback on the Bluetooth features and wrote, '*It works very well with the built*

Tim Kirby, GW4VXE
longworthtim@gmail.com

The Yaesu FTM300 is a dual band transceiver, 144 and 430MHz bands.

in Bluetooth with very good reports on audio quality. One little quirk with regards to Bluetooth operation, if you are running with both VFOs active (which I generally do) and both bands are in use, you cannot turn down the volume on one band from the volume control if you want to have a QSO on the other band. I tend to just spin the VFO of the band I don't want to get over this issue'.

The FTM300's Portable Digital Node

Several recent Yaesu Fusion radios offer functionality called a 'Portable Digital Node'. In short, this allows you to connect the radio to the Yaesu Wires-X network through an internet connected Windows computer, running the Wires-X node software. The Wires-X software can be set up to connect to Wires-X equipped repeaters, nodes or rooms.

This can work in two ways. The first is 'Direct Mode' which means that the rig acts as a speaker/microphone, with no RF being produced. The second method is 'Access Point' mode, which turns your FTM-300 into a local Wires-X node that you can set up in your house, for example and use a Fusion equipped handheld outside or around the house to communicate through the FTM-300 into the Wires-X network.

To connect the FTM-300 to a USB port on my computer, I used an SCU-20 connection cable that had been supplied with my FTM-400XDE. If you plan to use the Portable Digital Node functionality with your FTM-300 and do not already have one of the SCU-20 cables you will have to buy one as an extra as it did not appear to come with the FTM-300.

Using the Portable Digital Node functionality I was able to connect initially to the GB3SP repeater in South Pembrokeshire, through the internet, using the FTM-300 as a 'terminal' in Direct Mode and then, switching to Access Point mode, using the FTM-300 on a dummy load as a local repeater, accessed by my FT-2 Fusion-enabled handheld. This worked well. I also used the Wires-X software to connect to the very busy 'America Link' room where stations from all over America (and indeed, across the world) could be heard.

If you want to read more details about the operation of the Portable Digital Node functions, you can download the Instruction Manual from the Yaesu website (under Digital, look for the HRI-200, select the 'Files' tab and you will find 'Wires-X Portable Digital Node Function Instruction Manual' listed. There, you can see much more detail about setting up the Portable Digital Node capabilities, which I have necessarily skimmed over here. Once set up, though, it's very easy to use and I find quite helpful at times, such as when you are away from home and would like to connect to your home area Wires-X equipped repeater.

Other features

Something else that I enjoyed was the Band Scope feature. Just set the centre frequency on the VFO, tap the 'Disp' key and you will see a simple Band Scope displayed where 61 channels are shown and you can see where activity is in the band. If you are in memory mode, 21 channels are displayed. It isn't possible to tell from the Band Scope what frequency is busy, but you can rotate the 'VFO' towards it and once the busy channel is in the centre of the display you are on frequency, so in practice you can find the channel pretty quickly. The Band Scope was particularly useful, I found, in the air band, for finding frequencies that are in use.

In an unfamiliar area in the amateur bands, of course, it would be great for finding out local repeaters and other frequencies in common use.

If you have a micro-SD card installed in the rig, you can use the Voice Recorder function that allows you to record traffic as WAV files on the card. You can configure the rig to record both transmitted and received audio, or just received audio. Using the micro-SD card, you can then move the files onto a PC (using a suitable adapter) to review the audio.

For those with the correct licenses and permissions, the FTM-300 will receive on both airband (8.33kHz channels are supported) as well as the marine band and it appears to perform well there. In fact, receive coverage is wide, from 108-999.99MHz. Scan speed is quite fast, so you will not miss much.

The FTM-300 has some useful memory grouping features so that you can scan all channels, all 144MHz channels, all 432MHz channels, all airband channels, all 144 and 432MHz channels as well as all custom channels. This is a nice feature – over time, I find I end up with a lot of memories in a radio but don't always want to be scanning all of them.

In conclusion

Overall, the FTM-300 is an enjoyable rig to use. It's well made, well designed and is simple to use, yet has some complex capabilities. The rig's excellent APRS capabilities are also a real positive – allowing you to park one side of the rig on APRS and monitor activity there with the other side of the rig scanning memories or monitoring a particular channel.

Like Yaesu's other Fusion rigs, you will obviously get more out of the rig if you have a Fusion-enabled repeater close to you, but if you do not and are interested in Fusion and Wires-X then the Personal Digital Node capability will allow you to put a toe in the water.

Including Bluetooth as standard is very positive for those wishing to use the rig mobile, allowing the use of Bluetooth headsets or (many) in-car systems.

The rig could be used as a base station or mobile – its excellent scanning speed makes sure you won't miss what's going on.

At a price of £399.95, the rig represents a fair investment and there's an interesting comparison with the older FTM-400XDE at around £420, which has fairly similar facilities including a touch screen, but no Bluetooth. If space is as at a premium as is likely in mobile situations, the smaller head unit of the FTM-300 may prove useful.

My thanks to Yaesu UK for the loan of the FTM-300, which I thoroughly enjoyed.

Design Notes

Tone measurement and DDS drive

Last time we looked at a couple of ways to derive an analogue or digital representation of the tones output on a soundcard from datamode software and showed how this could be used to generate an RF waveform carrying the frequency shift modulation without any need for upconversion in an SSB transmitter. To round off, here is a gold-plated solution – use the measured value of the tone frequency to drive a direct digital synthesiser, a DDS.

When used to measure tone frequency, the Compare/Comparator module present in many of the variants of the PIC processor delivers a value equal to the number of processor clock cycles in one cycle of the tone input. We'll call this value M (for *measured*). So

$$M = \frac{F_{PROC}}{F_{TONE}}$$

For a normal 32-bit DDS like the ubiquitous AD9850, to generate a frequency F_{OUT} when clocked at DDS_{CLK}, we need to send it a value

$$N = \frac{F_{OUT}}{DDS_{CLK}} \times 2^{32}$$

To keep things simple, let's also for now assume we want to use the DDS output directly, with no RF multiplication, and transfer the generated tone directly to the carrier (exactly as if it were going through an SSB transmitter). First of all, we calculate N_0 for our 'dial frequency' (ie what the DDS needs to generate if tone input were at zero frequency). This is given by

$$N_0 = \frac{F_{OUT}}{DDS_{CLK}} \times 2^{32}$$

Now we calculate the change in this value, N_X needed if the RF is shifted in value by the tone frequency being measured. Rearrangement of the two equations given above eliminating F_{TONE} itself gives

$$N_X = \frac{F_{PROC} \times 2^{32}}{DDS_{CLK} \times M}$$

The two processor clock frequencies and the constant can all be lumped together into a single value specific to this setup, which we'll call K. So now all we have to do is to measure the tone frequency to get M, divide this into the pre-calculated constant K and add the carrier value N_0. So

$$N = N_0 + N_X = N_0 + \frac{K}{M}$$

If we take some values typical for an AD9850 with a 125MHz clock and a PIC running with a 3.6864MHz clock as adopted last month, we get a value for K of 126663740 (to the nearest integer). So all the PIC now has to do is read the tone frequency, then divide K (which is a 32-bit number) by the measured M. As shown last time, M ranges around a few thousand so it can be represented by a 16-bit number. This division is easily within the capabilities of even the mid-range PIC family and can be done in about a thousand clock cycles, or less than 270μs. The 32-bit addition only takes a few tens more clock cycles, leaving plenty of time to send the value of N to the DDS – even if this has to be done by bit-banging. The whole process fits into the time for one cycle of the fastest tone likely to be seen in practice.

A practical demonstrator using the same hardware as described last month, using these same numbers, was connected to an AD9850 DDS module, generating RF at 7.05MHz. The system showed it could follow all the WSJT-X modes even including the Gaussian shaped waveform of FT8. MSK144 wasn't tried as it is not an MFSK mode. All modulation types decoded perfectly. A screenshot of the regenerated signal using the QRA64E mode can be seen in **Figure 1**. Where the frequency from the DDS is subsequently multiplied or divided to get the final RF, this can be reflected by changing the value of K appropriately, with no additional processing needed in the PIC. PIC assembly code for the 16F628 processor illustrating the techniques described can be found at **[1]**.

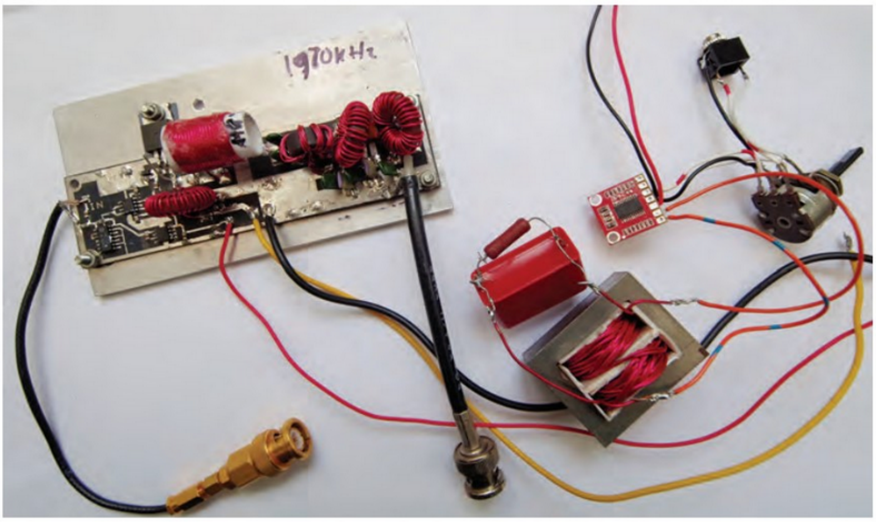


PHOTO 1: Class E transmitter breadboard and a switch mode 10 watt audio amplifier, both run from a 12V supply. The small mains transformer shown is rewound as a modulation transformer.

Top Band AM

In September's Last Word, Alan, G3PNQ mentioned Top Band (160m) AM operation and how a return to using it might tempt random listeners to experience amateur radio via medium-wave radios. I can't say I agree with the casual listener idea and I doubt any modern MW radio would even receive a 1.8MHz signal unintentionally; they will now probably be using direct conversion and DSP. And do we really want to let just anyone hear a typical Top Band conversation these days?

However, the idea of Top Band AM does have a certain nostalgic appeal and could form part of a simple homebrew project covering a variety of difficulty levels.

Back in the 1970s, before G8IMR (later 'JNT) got his licence, Top Band AM was the

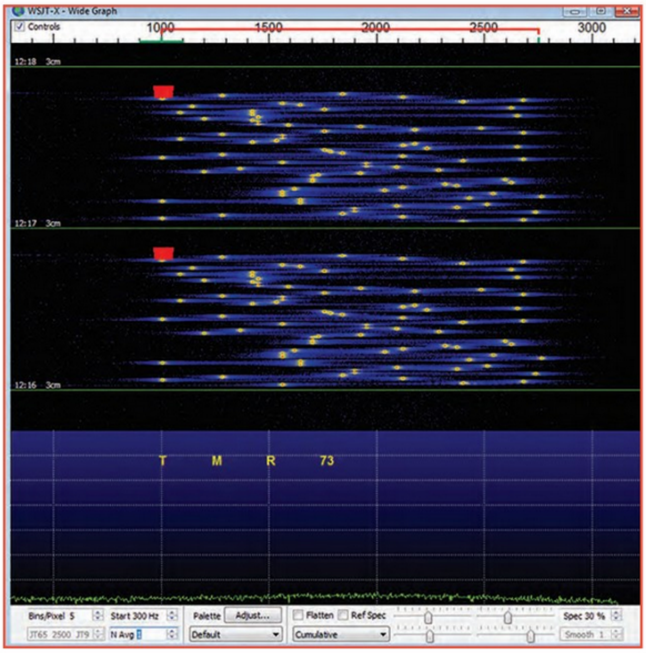


FIGURE 1: A QRA64-E signal, regenerated from the PC tone output with a PIC used to measure the tone frequency, driving an AD9851 DDS. The technique works for all the WSJT-X modes that employ Multiple Frequency Shift Keying.

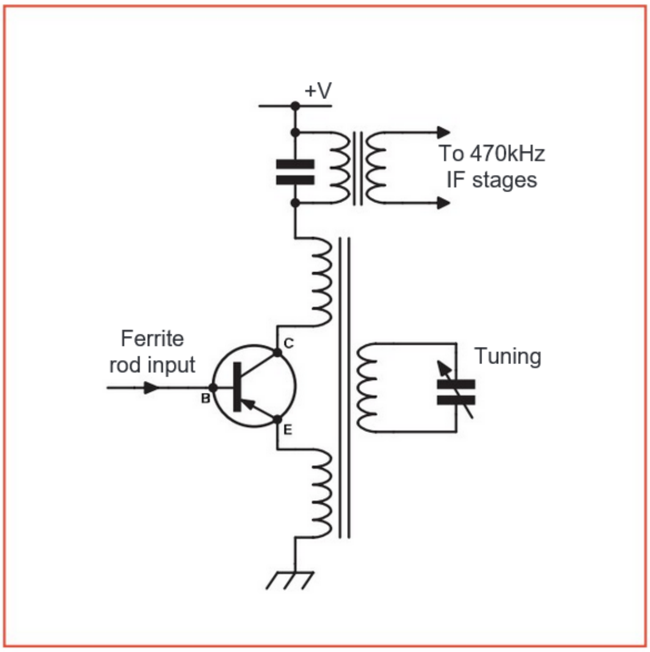


FIGURE 2: The self-oscillating bipolar mixer typically used in AM radios of the 1960s and 1970s when there weren't too many signals around to generate multiple mixer products. Often the device was an AF117 germanium bipolar transistor.

norm for local nets and nattering. I spent ages listening to the locals on a homebrew receiver using Denco coils and a Mullard IF strip, all with far too much gain. (Hands up anyone who remembers Denco coils and the Mullard IF strips?)

At that time, in the Birmingham area, the local electronics surplus stores were selling the guts of a medium wave radio – they had bins full of modules. These had a nice slow motion cord drive and decent audio amplifier. They were called the 'Discatron' **[2]** module and a large number of the local amateurs converted them to Top Band receivers. Brian Benbow, G4ASJ (in whose DIY shop I had a Saturday job) introduced me to them and gave me one. He used one in his 160m mobile setup that he occasionally operated outside the shop. He had also made a portable 160m AM Rx.

The idea was to rewind the ferrite rod antenna to resonate at 1.9MHz, then find the point on the tuning dial where the LO tuned to the image response based on the 470kHz intermediate frequency. Or was it the second harmonic of the LO that was used? I suspect many constructors weren't sure how their radio tuned; **Table 1** illustrates why this anomaly arises. The oscillator and mixer in AM radios of that era were often combined into a single device, a self-oscillating germanium bipolar transistor. Oscillator feedback was from collector to emitter via the oscillator tuned circuit, with the RF input from the ferrite rod antenna going in on the base, as shown in **Figure 2**. So it's hardly surprising that plenty of LO harmonic mixer products are to be found. Anyway, whichever LO product I used it worked fine. Fifty years ago electrical noise was a lot lower than it is now and it was possible to hear all the locals using just the ferrite rod antenna. The length of wire hanging out of the window **[3]** was superfluous. When I tried connecting it to the receiver via an extra loop of a few turns on the ferrite rod things got a lot worse, from chronic overload. The 14-year-old me didn't know much about overload and intermodulation products back then, so it was a complete mystery why connecting a wire antenna made things so much worse.

Fast forward to now. Medium Wave radios can still be picked up at boot sales and even reasonably modern ones with synthesised LOs may be persuaded to work, provided they use a superhet architecture and are not direct conversion. Remember, it's the *image* response you're looking for; for a 470kHz IF the dial will be reading 870 – 1060kHz with the LO ranging over 1340 – 1530kHz. Don't go for the second harmonic of the LO option: modern radios will (hopefully) have better mixers than their decades-old counterparts so that solution will not work as well as it used to. If you do end up with a direct conversion type receiver, it may be worth trying second or third harmonic of the LO – both of these lie in the MW tuning range. The modern background noise level is high enough that the ferrite rod can probably be rewound and tweaked on noise alone.

Such a conversion – always assuming a suitable donor radio can be found – might make an interesting demo project for a club or local group to play with. There is only one, simple, construction task: disconnecting and rewinding the ferrite rod.

TABLE 1: Key frequency relationships for the Discatron and similar receivers. All frequencies in kHz.

Dial frequency	670	765	870	1060
Local oscillator for 470kHz IF	1140	1235	1340	1530
LO second harmonic	2280	2470	-	-
Top Band frequency	1810	2000	1810	2000

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Transmitters

A Top Band AM transmitter can make for a fascinating basic project that could adopt any number of technologies in its various parts. It is particularly attractive as the maximum power allowed on most of that band is only 32W (or 15dBW) peak, so there is no need to go for higher and higher power on a whim. Generating AM comes with its own set of challenges though, especially if you want to do it all from a 12V supply.

Firstly, the RF part. It 'always used to be done' with a Class-C output stage, valve or transistor, with the AM applied as a high level modulation. This is probably still the easiest way to generate AM and we now have access to better transmitter architectures like Class-E and high efficiency switch mode audio amplifiers. Back in the those earlier days, constructors were less worried about matching transmitters into 50Ω and often made the output matching front-panel-variable to be able to cope with a variety of antenna types and load impedances. This was especially so for mobile operation, where all sorts of wonderful and weird antennas were strapped to cars. The output tuning was adjusted for a dip in supply current coinciding with a peak in RF output. Who cared what he output VSWR was? So long as the PA device ran at its proper loading current and gave RF output it was *working*. A comment made on one of the Groups from builders of such transmitters in the past said that sometime more output power than might reasonably be expected could often be obtained. Is it not unreasonable to assume they were inadvertently getting efficient Class-E switch mode operation by fluke of getting the right output match settings?

Class-E switch mode transmitters may be one of the easiest types of PA stages to get going if you use a scope to get the right switching waveform. I described a Class-E transmitter for Top Band in the October 2010 Design Notes and this can also be found near the beginning of the Design Notes book *Design Ideas for Radio Amateurs*. A follow-up can be found in May 2013. **Photo 1** shows my breadboard prototype. Output power of Class-E adjusts perfectly with change of supply volts, so it's just *asking* for high level modulation to be applied. To achieve 100% modulation depth we need an audio power equal to half the RF output, so for a 30W maximum we only need an audio PA stage that can deliver 15W. But how to apply the modulation is not that easy.

True high level AM needs to be able to drive the voltage supplied to the RF PA stage up to twice the supply voltage – 24V for a 12V supply. This can only be achieved using a transformer, or with slightly less efficiency, a choke. I showed in the March 2015 Design Notes how small mains transformers could be rewound to become a suitable AM modulation transformer. Another route may be to use a customised switch mode amplifier modelled on a SMPSU using pulse width modulation, with audio fed into the reference input. With some judicious circuit design (almost certainly involving a PIC controller) the PSU/audio amplifier could be arranged to deliver maximum output (say 12V) with no audio input then modulate downwards, shifting the mean voltage lower as audio input increases so the highest peak is always kept at 12V That way high efficiency in both modulator and RF stage is possible. Who will come up with a working prototype? I suspect the biggest problem will be practical ones – like filtering out switching components, which will require real decoupling components and add to the overall complexity.

Websearch

[1] http://retrorewind.blogspot.com/2006/07/ipod-of-60-70s.html

[2] Some years earlier, my father had installed the aerial to use with a crystal set he'd been given so he could relive his youth. That bit of wire, just by fluke, happened to be 10m long and ended up resonant on 40m against the house 'earth'. One evening I heard what I now know to be SSB on the crystal set; it was barely intelligible garbling from a local amateur, whom I later found out was G3GVA. (The fact it was almost intelligible suggests his carrier suppression wasn't too good). It was only many years later that I appreciated just why that crystal set picked him up; that it was the antenna's 'fault' for being resonant.

[3] http://g4jnt.com/pictonemeasurement.zip PIC assembly code for audio tone measurement and control of the AD9850 DDS.

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[1] www.rsgb.org/radcompix

[2] https://tinyurl.com/RC-guidance

EMC

Measuring noise

An item in the September 2020 Design Notes gave an introduction to noise and different ways to measure noise including peak, mean and RMS. The Design Notes article is a useful background to this month's EMC Column, where we look at measuring noise in the context of EMC, including measuring background man-made and natural noise levels on amateur bands. We consider practical RF test equipment such as a spectrum analyser and we also look briefly at SDR receivers.

First, let's look at a spectrum analyser, in this case a Rohde and Schwarz FSH8. This is a professional quality portable spectrum analyser that the RSGB EMC Committee uses for various EMC investigations. It has several different types of detection including Auto Peak, Max Peak and RMS. How do these relate to each other when measuring the same noise source and what difference does averaging make to noise measurement? Let's find out.

First, we need a source of Gaussian noise. In this case we are using the front end noise of the FSH8 spectrum analyser itself with the preamp switched on and a 50Ω termination connected to the input socket. **Figure 1** shows a sweep from 3.5MHz to 3.8MHz using two different types of detector and two different sweep speeds. The resolution bandwidth (RBW) has been set manually to 300Hz, which is comparable to CW bandwidth in a typical amateur radio receiver.

Figure 1 shows four different measurements of the same noise. The lower Trace 1 (yellow) shows the noise measurement with RMS detection, which is the best way to measure noise. The upper Trace 2 (green) shows a measurement of the same noise with Max Peak detection, which is the type of detection that is normally used in a conventional analogue spectrum analyser that does not have RMS detection. In the right hand two thirds of the screen, from 3.6MHz to 3.8MHz, the total sweep time is set manually to one second, which is about three times slower than the automatic setting would use. Marker M2 is at 3.7MHz and the yellow Trace 1 (RMS) is -138.7dBm, whereas the green Trace 2 (peak) is 5.6dB higher at -133.1dBm. Both traces have a random variation of ±3.5dB to ±4dB due to the random nature of noise and the limited amount of averaging.

On the left hand third of the trace, from 3.5 to 3.6MHz, the sweep time has been set to a much slower sweep of 30 seconds total. The noise is the same across the whole 3.5 – 3.8MHz band (and beyond) but the slower sweep results in more averaging. This has two effects. Marker M1 is at 3.6MHz and at this frequency, the yellow Trace 1 (RMS) power is -139.8dBm, with a much smaller random variation of about ±0.3dB. On the green Trace 2 (peak) however, the random variation is about ±1.5dB and the power at this particular instant is 9.6dB higher, at -130.2dBm. This shows that more averaging improves the accuracy of RMS measurements but in the case of peak measurements, the difference between RMS and peak *increases*, leading to greater measurement uncertainty.

Averaging noise

As we have seen, RMS detection is a much better way to measure noise than peak detection. If true RMS detection is not available then average detection (not shown) would be the next best thing. In all cases, to reduce the random variations between successive noise measurements it is necessary to spend long enough on each frequency or to average multiple measurements on each frequency. These should both produce the same result if the averaging is done by averaging linear units, not by averaging decibels. Averaging decibels is **not** valid and it does not give the same result as averaging linear units.

Now let's look at how long we need to spend on each frequency when measuring noise. The FSH8 has a spectrum analyser mode and a receiver mode. The spectrum analyser mode sweeps from a start frequency to a stop frequency but the receiver mode steps across a number of different frequencies. For example in **Figure 2** the FSH8 has been set to step from 3.5MHz to 3.8MHz in steps of 250Hz, so it measures at total of 1201 different frequencies. The resolution bandwidth is 300Hz and the measuring time on each frequency can be set manually. In Figure 2, the measuring time (MT) is 1000ms from 3.5 – 3.6MHz, 100ms from 3.6 – 3.7MHz and 10ms from 3.7 – 3.8MHz. It can be seen that a measuring time of 1000ms gives a relatively small random variation of up to ±0.5dB whereas the shorter measurement times of 100ms and 10ms give much larger random variations. This confirms the findings of the German national amateur radio society (DARC) ENAMS system that, for 300Hz receiver bandwidth, a measurement time of 1000ms should be used on each frequency. Using a conventional receiver, this would require a measurement time of about three seconds per kHz (that's 3000 seconds, or 50 minutes, per MHz) but the DARC ENAMS system uses advanced DSP techniques to speed this up greatly.

FIGURE 1: FSH8 spectrum analyser noise floor from 3.5MHz to 3.8MHz showing the effect of different types of detector and different sweep speeds.

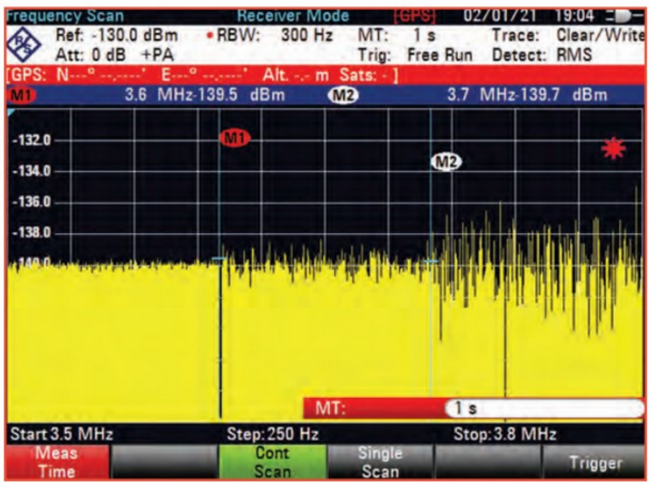

FIGURE 2: FSH8 spectrum analyser in receiver mode from 3.5MHz to 3.8MHz showing the effect of different measuring times.

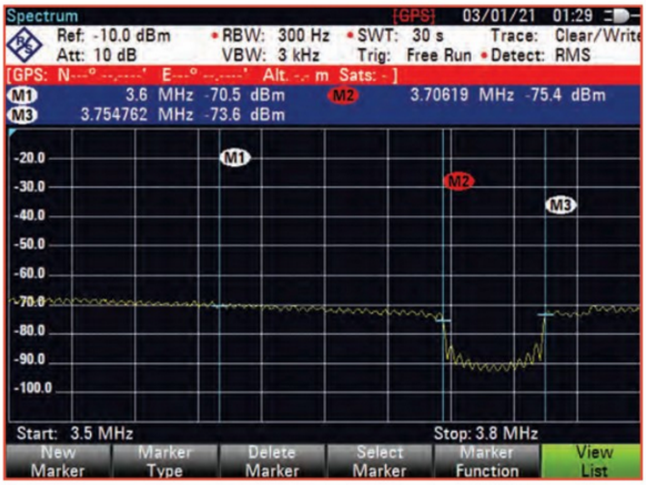

FIGURE 3: **Signals on a VDSL line showing ripples and guard band.**

Noise bandwidth

There is also something called noise bandwidth and we need to know this if we want to scale a noise measurement to a different bandwidth such as 1Hz. Noise bandwidth is generally different from RBW but further details about the difference and how to measure it are beyond the scope of this article. For a simple example, we shall assume that they are the same but please be aware that this is only a rough approximation because in reality they may differ by a significant amount.

From Figure 2, if we take the spectrum analyser noise floor as -140dBm and if we assume that 300Hz is the noise bandwidth (which is only an approximation) then we can calculate the noise power in 1Hz bandwidth by subtracting 10*log(300) = 24.8dB. That gives -164.8dBm in 1Hz bandwidth, which can also be written as -164.8dBm/Hz. For measurements of noise or noise-like signals, it is common to express the power density in dBm/Hz (although the actual measurement is typically made in a wider bandwidth than 1Hz). It is also possible to deduce the noise figure of the receiver in this way.

SDR noise measurements

A Member asks, "My SDR allows a reading of dBm (or dBμV). What puzzles me is that the reading of noise level (in dBm) does not change when I change the bandwidth. This of course is counter-intuitive – do you know what happens in an SDR on measurement?" That is a very interesting question about SDR software. What exactly is it measuring and how do SDR noise measurements correlate with spectrum analyser measurements?

One popular type of free SDR software has many useful features but it is reported to be not very useful for the measurement of band noise as it just gives the strongest FFT **[1]** 'bin' within the passband. This has two consequences. First, changing the width of the passband does not change the measured noise value; secondly, the strongest FFT bin is of the order of 10dB higher than the average value of all bins. The measured value also fluctuates a lot due to the random nature of noise. That means that it is important to select a suitable SDR program if you want to make accurate band noise measurements. I would be interested to receive information on how various SDR software measures noise and which types are suitable for measuring RMS band noise.

VDSL measurements

If we use 300Hz receiver bandwidth (or less, eg 100Hz) and if we use a long enough sweep time, such as 100 seconds per MHz, then it is possible to resolve the individual tones in a multi-carrier modulation scheme such as emissions from VDSL. The DARC ENAMS system can do this and it can also be done using a spectrum analyser. This is a simple way to distinguish VDSL noise from other sources of noise if the VDSL noise is significantly stronger than other noise sources. A more advanced and effective way to identify VDSL noise is to use the Lelantos software by G8KDF **[2]**.

Figure 3 shows an example of analysing signals directly off a VDSL line using the FSH8 spectrum analyser connected via a current transformer. Due to the current transformer the actual power levels on the line (in 100Ω) would be about 17dB higher than shown in Figure 3. The VDSL signal resembles noise as each of the multiple sub-carriers is modulated with pseudo-random data but if we average the signal enough then it shows the sub-carrier structure with a ripple at intervals of 4.3125kHz.

It can be seen that there is a downstream channel up to 3.7MHz, then there is a guard band from 3.7 – 3.75MHz, followed by an upstream channel above 3.75MHz. Although these are at a similar level in this case, the levels may be significantly different in other cases. It should also be possible to see the guard band and possibly the sub-carrier ripple for off-air VDSL signals.

Quiet line noise

Quiet line noise (QLN) is not a new radio 'Q' code; it is a term that is used in ADSL and VDSL modems. If you have an ADSL or VDSL broadband service and if you can get the QLN data from your mode/router then it is like having a spectrum analyser connected to your phone line that takes a snapshot of line noise that was present the last time the modem synchronised. It can show ADSL/VDSL signals that get onto your line via crosstalk from other lines, signals from nearby broadcast transmissions, any amateur radio transmissions and any RF interference sources (also known as Repetitive Electrical Interference or REIN).

From an amateur radio point of view, QLN data may be useful for two purposes. First, it can show if there is a continuous interference source nearby. This will typically radiate from mains wiring and it is also likely to be coupled onto phone lines (underground or overhead) then onto your phone line due to crosstalk in a multi-pair cable. Secondly, it can show the level of broadcast signals and any interference that is being picked up on an ASDL/VDSL line. This information can be used to find ways of improving line balance. Improving line balance is to everyone's advantage because it would not only improve immunity to amateur radio transmissions but it should also reduce the amount of VDSL noise radiated by the line in question.

A web page **[3]** shows how QLN data was obtained from a Billion 8800NL VDSL modem/router in the North London/South Herts area, close to a number of strong broadcast transmitters. The web page includes detailed information about the effect of MW broadcasts on VDSL bit loading. The data was obtained by making a Telnet connection to the router and using the xdslctl command **[4]**. This is for routers that use the Broadcom chipset, but only if they allow the user to access the xdslctl command – and not all do this. If you can get the QLN data for your line (and it's a big 'if') then it is possible to plot it using Excel. This could help to identify nearby RFI sources that may affect ADSL/VDSL and also amateur radio.

The QLN plot by [3] shows broadcast transmissions that the author refers to as "big signals with wide skirts", but these "skirts" are more likely to be caused by limited selectivity in the modem rather than actual sidebands of the broadcast transmitters (unless something non-linear is happening).

I would be interested to hear from anyone else who has been able to access QLN data from an ADSL/VDSL modem/router.

Websearch

[1] https://en.wikipedia.org/wiki/Fast_Fourier_transform
[2] https://rsgb.org/main/technical/emc/vdsl-interference-reporting/
[3] http://www.adsb.co.uk/blog/medium_wave_kills_vdsl.html
[4] https://forum.kitz.co.uk/index.php?topic=10289.15

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nanoVNA-H series

The availability of a Vector Network Analyser (VNA) for under £100 would have been unheard-of just a few years ago, but now there is a choice of models.

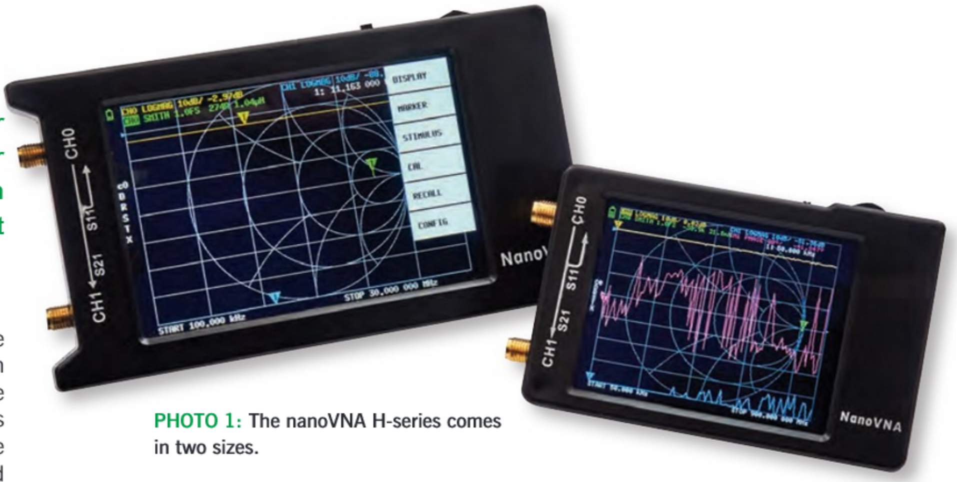

PHOTO 1: The nanoVNA H-series comes in two sizes.

In this review, I'll be taking a look at the NanoVNA-H devices that are available with either a 2.8" or 4" screen. NanoVNAs have been available for some time in various guises, but the models reviewed here are the commercialised version with improved construction that includes full screening of the sensitive input stages, as seen in **Photo 2**.

The NanoVNA-H4 is a compact, stand-alone, 2-port VNA with continuous coverage from 10kHz to 1.5GHz. The unit has an integrated 4" touchscreen display, rechargeable battery and comes complete with USB leads and a male SMA calibration set, all in a smart presentation box. In addition to its use as a handheld VNA, the NanoVNA-H can be connected to a PC or smartphone and controlled using free analysis software. The unit also stores its results as S parameters in standard format ready for detailed analysis by other software packages. In addition to a wide range of antenna and impedance matching measurements, the NanoVNA-H4 is ideal for precise performance measurement of two-port devices such as filters, duplexers, amplifiers, etc.

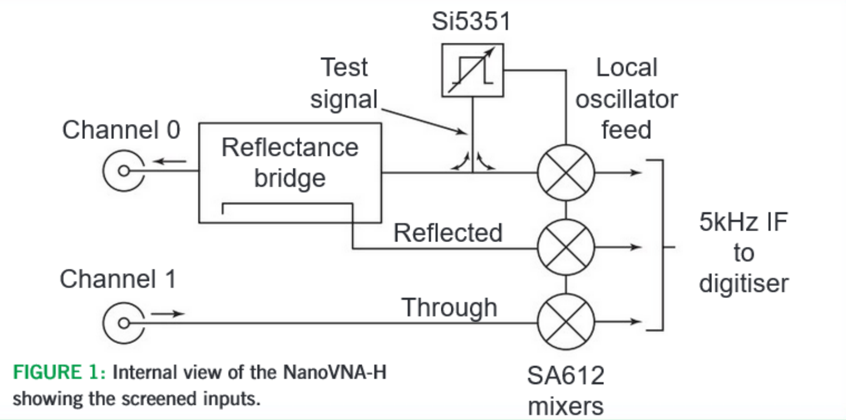

FIGURE 1: Internal view of the NanoVNA-H showing the screened inputs.

How Does it Work?

A 2-port VNA requires three measurement points as shown in **Figure 1**. The first is a sample of the reference signal that's to be sent to the Device Under Test (DUT). Next comes a sample of the measurement signal via a reflectance bridge at the point the signal connects to the DUT. This indicates the matching quality at the send channel. Finally, we need a sample of the received signal at channel 1. At the heart of these measurements is the resistive reflectance bridge that's directly connected to channel 0 and used to detect reflected signals. Using a resistive bridge is important because it provides consistent results over an extensive frequency range.

The next step in the process is to down-convert the measurement samples to a common, 5kHz IF (Intermediate Frequency) using three SA612 mixers. Digitising the mixer outputs is handled by a soundcard chip and the resultant digital output is passed to a STM32 microcontroller that handles the DSP (Digital Signal Processing) and display.

A Si5351 programmable clock oscillator provides the test signal along with the local oscillator feeds for the SA612 mixers. Anyone familiar with the Si5351 will spot that this device cannot generate the higher frequencies used by the NanoVNA-H. The solution is to make use of the strong odd harmonic content of the Si5351's square-wave output. Here's an example to show how it works.

Let's assume we want to measure 501MHz. As this is beyond the range of the Si5351, we can use the 3rd harmonic of 167MHz (167 x 3 = 501) as the test signal. We also need to generate a 501.005MHz local oscillator signal for the mixers, to produce the 5kHz IF. In this case, we can't use the 3rd harmonic due to mixing products that might end up in the 5kHz IF passband. Instead, we use the 5th harmonic of 100.201MHz (100.201 x 5 = 501.005MHz)

The calculation of harmonic frequencies for the Si5351 is all handled seamlessly by the STM32 microcontroller. Whilst this novel approach significantly extends the range of the VNA, there is a price to pay in the form of reduced dynamic range. As the harmonic content of the Si5351 is at a much lower level than the fundamental they are closer to the noise floor, hence the reduced dynamic range. Another limiting factor is the frequency response of the SA612 mixers. These are rated for use up to 500MHz, but the VNA runs at up to 1.5GHz. That also means a lower measurement sensitivity as mixer gain rolls off.

Whilst collecting data, the NanoVNA-H4, like most VNAs, makes a series of stepped measurements over the specified sweep range. In the case of the NanoVNA-H4 there are 101 measurement points for each sweep. This can be increased to 201 points or more when using the VNA with suitable computer software.

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Calibration and measurement planes

You may be wondering why you need to calibrate a new VNA; shouldn't it already be calibrated? You'd be right, but with a VNA, calibration is more akin to zeroing the leads on your multimeter. VNAs are extremely sensitive measuring instruments and, for accurate measurements, we need to know the precise physical location of the measurement plane. For many applications, especially at lower frequencies, we might be satisfied with the instrument's SMA sockets as the measurement plane. In that case, we use the calibration process to ensure that all the wiring inside the VNA is cancelled out. This is worth doing because the factory calibration is likely to use standard values that may differ slightly from reality. Whilst zeroing a multimeter is just a case of shorting the leads, VNA 'zeroing' or calibration is somewhat more involved as we need to apply three test conditions: short circuit, open circuit and load (50Ω). The first step is to use the menu system to set an appropriate frequency sweep range. Once set, we apply each test condition in turn, and the VNA sweeps through its operating range, storing the results. The stored results are then processed, and a correction factor calculated that is applied to any future measurements, thus providing an accurate calibration plane. Calibrating the NanoVNA-H4 was a simple menu-driven process using the supplied calibration kit and there were five calibration memories available to store the calibration for frequently used test setups. With the calibration complete, the instrument was ready for use.

I ought to talk briefly about the quality of the calibration kits. As we increase the test frequency, accurate measurements become increasingly difficult to achieve. This because tiny stray inductance and capacitance values can have a significant impact at very high frequencies. Consequently, an economy 50Ω SMA load that was fine for HF may degrade significantly at 1.5GHz. To achieve accurate results at the top-end of the VNA's range you may need to consider investing in a more expensive calibration set.

Whilst a calibration plane set at the NanoVNA-H4 SMA sockets may be adequate for many low-frequency measurements, there will be occasions when you need to move the measurement plane. For example, you may want to measure the performance of a filter that has N type connectors. In that case you could be using SMA test leads with SMA to N type adapters fitted. That combination is likely to affect the overall measurement accuracy, so it would be good practice to perform a calibration at the N type connectors. This would eliminate the effects of the test leads and adapters from the measurement. In another example, you might want to examine the matching of an antenna from inside the shack. In this case, you could perform a calibration at the far end of the feeder cable, thus eliminating it from the measurement. To avoid having to repeat calibration for every situation, the NanoVNA-H4 includes five internal calibration memories that can be quickly loaded. Another convenient feature of the NanoVNA-H4 was the use of port extensions. In cases where you are using good quality test leads, you can effectively extend the calibration plane simply by entering the port extension delay for the test lead in picoseconds (ps).

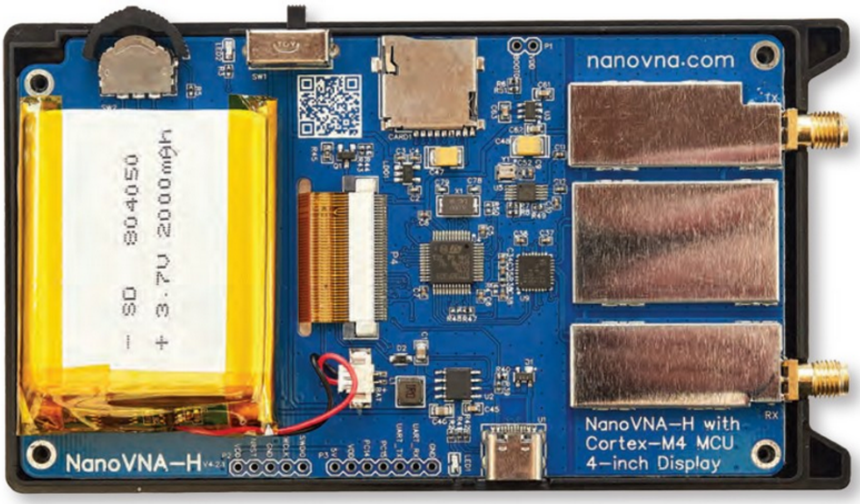

PHOTO 2: VNA measurement ports.

Using the NanoVNA-H 4

When I first started using the NanoVNA-H, I was presented with a very confusing display because all four plotting channels were active and showing a mix of line graphs and Smith chart displays. This was easily solved by using the Display menu to turn off the unwanted displays. The NanoVNA is bristling with features that are accessed using the on-screen menu system and the multifunction switch on the top panel. This switch took a bit of time to master because it had three movements; left and right to navigate and push to select. At first, I found myself selecting when I wanted to move left or right. However, once I'd spent some time getting used to the feel of the control, it proved to be an effective navigation technique. I could also use the touchscreen to navigate the menu system. A single dab on the screen opened the last used menu, and it was easy to navigate from that point. Whilst it was possible to navigate with just my finger, I found a stylus to be much more convenient and accurate. Any smartphone or drawing stylus will do the job; I used the stylus from my graphics pad. To help get to grips with the multi-layer menu system, a printed chart was supplied in the box.

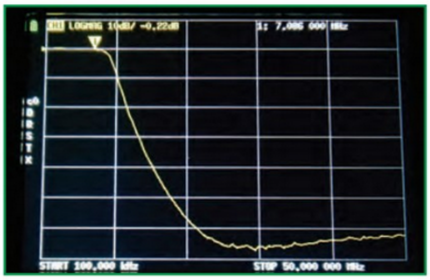

FIGURE 2: Low pass filter response.

FIGURE 3: Close-in view of the low pass filter showing insertion and return loss.

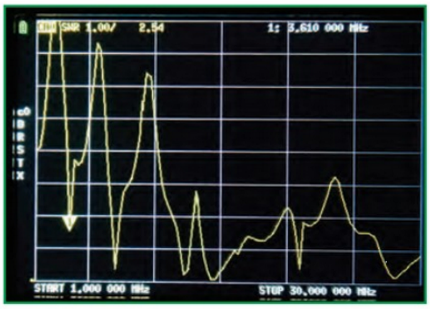

FIGURE 4: SWR response of a part-stripped HF9V antenna.

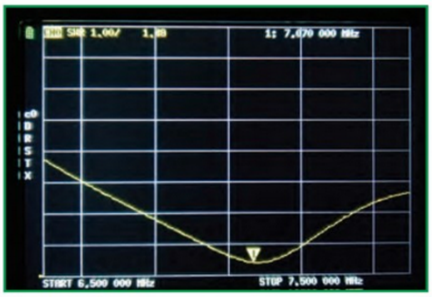

FIGURE 5: Close-in view of my HF9V on the 7MHz band.

Following calibration, I set about measuring a 7MHz low-pass filter that I'd built from a QRP Club kit. In addition to the frequency response of the filter, I wanted to check the impedance matching. I initially set the NanoVNA to sweep from 100kHz to 50MHz to give a wide view of the response. This displayed the expected response, as shown in **Figure 2**. The roughness seen to the right of the display is due to the noise floor of the VNA. This was at about -70dB, which aligns with the specifications. The next step was to take a closer look at the cut-off point, so I changed the sweep to 6.5MHz-15MHz to give smaller measurement steps. I also added markers at key points in the plot. The result is shown in **Figure 3**, where you can see that the response at 14MHz is 35dB down on 7MHz. At this point, I used the facility to plot the through response and return loss by activating two traces. This very clearly shows the return loss reducing rapidly after the low-pass cut-off and shows the value of being able to plot multiple measurements.

At the time of writing, I was renovating my Butternut HF9V antenna and had removed the 6m and 15m stubs. This was a good opportunity to use the NanoVNA-H4 to examine the antenna. I've shown the resulting SWR plot in **Figure 4**. This shows the expected response with resonances at 7MHz, 14MHz and 28MHz. However, with such sharp resonances and a relatively small number of measurement points (101), it's easy to miss the detail, so a closer look was required. I began with a sweep between 6.5MHz and 7.5MHz. This revealed a softer curve, with the best SWR of 1.35:1 at 7.07MHz – ideal for data modes operation, **Figure 5**. When making these measurements, the facility to add markers to the display was particularly helpful. I could drag the markers with the stylus and read the marker value from the information box at the top of the screen. Using these markers, I was able to quickly check the SWR for all the frequencies of interest.

For the next test, I wanted to check the frequency response of a Mini-Circuit amplifier (ZFL-500HLN). Whilst the 10MHz to 500MHz gain was specified at 20dB, I wanted to know how the performance rolled off at each end of the range. When using a VNA to measure amplifiers, it's important to ensure the amplifier is not overdriven. Particular care is needed with the NanoVNA-H4 on the higher frequency ranges due to its use of harmonics. On these ranges, the fundamental is also present in the test signal and it can be as much as 30dB stronger than the wanted harmonic test signal. To manage this on my test setup, I added an accurate variable attenuator (HP8496A) on the input feed to the amplifier. The test setup and response is shown in **Figure 6**.

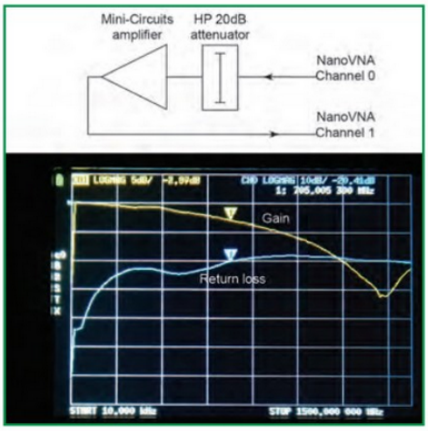

FIGURE 6: Mini-Circuits amplifier test setup and response.

Computer software

The USB-C socket on the base of the NanoVNA-H4 is used charge the internal battery but can also provide a USB serial connection to a computer. This is an important benefit and opens up more detailed analysis methods and a larger display area. The most popular PC package appears to be NanoVNA-Saver, which is a free download from https://nanovna.com/?page_id=90. Windows, Linux and MacOS are supported.

NanoVNA-Saver provides easy access to the VNA's features and makes good use of the larger screen size. You do need a fresh new calibration run, but this is a simple, wizard-driven, process and you can save different calibration files to disk.

In addition to showing greater detail in the displayed results, NanoVNA-Saver has some excellent additional features. I could configure the Analysis button to examine the VNA results and display the characteristics for several common circuit types. For example, it had a low-pass filter option where it automatically calculated the -6dB and -60dB points of my filter, along with the roll-off per octave and decade. Another great addition was Time Domain Reflectometry (TDR). TDR provided a very accurate measurement to any impedance discontinuities in the connected cable. This is great for locating faults in a feeder cable or for measuring stub lengths.

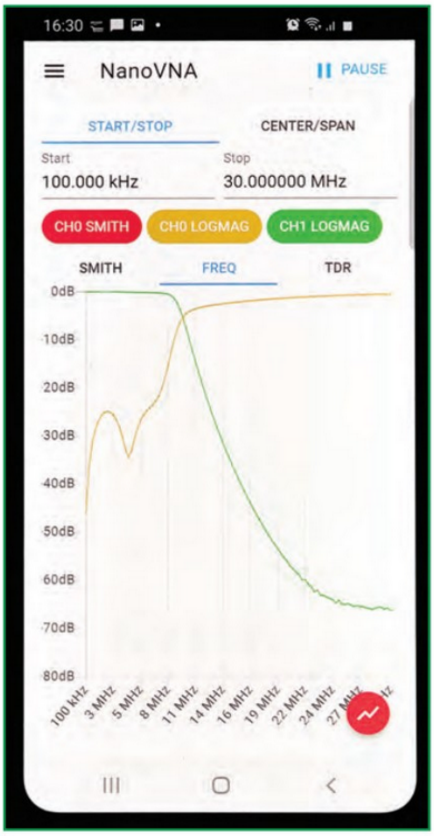

FIGURE 7: NanoVNA-4 operation from a smartphone.

Android smartphone and tablet owners are also well catered for with a NanoVNA app that enables full control with an on-screen display, **Figure 7**.

Summary

The NanoVNA-H is a remarkable little device that provides a sophisticated RF measurement tool at a very affordable price. Whilst it doesn't even pretend to rival pro gear, it *does* give every radio amateur affordable access to a powerful and versatile RF analysis tool.

Once you've mastered using the NanoVNA, you will discover a huge range of applications. Many people think of VNAs as an antenna tester but they are so much more than that. The 4" NanoVNA-H 4 is priced at £79.95 whilst the smaller 2.8" unit is just £49.95.

Both VNAs are available from Mirfield Electronics (www.mirfield-electronics.co.uk). My thanks to Mirfield Electronics for the loan of the review models. You can see more in the advert on page 39.

An easy multi-band HF antenna

Introduction

Decades of quick-setup field tests have produced an almost insultingly simple HF antenna. It's made of readily available materials but does a fairly good job on HF – and is also moderately directional. **Figure 1** shows its general arrangement: about 15m of twin flex (thin speaker cable is fine), some nylon fishing line or other lightweight, insulating string and a small weight of around 50-100g (such as a fishing weight). You'll also need a couple of spikes you can poke into the ground (old screwdrivers are ideal but skewers or tent pegs will work), a reasonable manual or automatic antenna tuner (ATU) and either a co-operative tree or an extendable painters' or window-washers' pole of 7m or so.

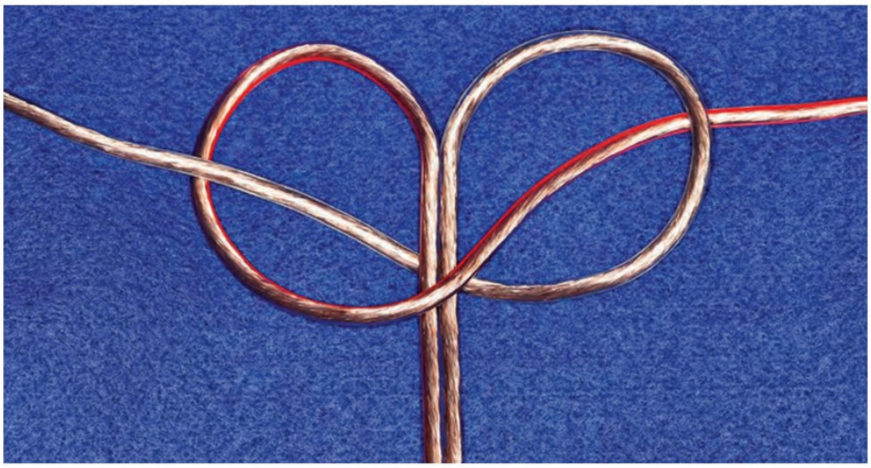

PHOTO 1: Making an Electrician's Knot in speaker cable. Photo: G1MFG.

Construction

Measure and cut off approximately 16m of twin flex, then fold it in two to find the middle. Working from one end, split the two cores apart until you reach the middle point. Then tie a figure-of-8 Electrician's Knot (also known as Underwriter's Knot **[1]**) in the middle, as shown in **Photo 1**. This will stop the wire 'unzipping' any further.

At the other end of the wire, split the cable for about 100mm, remove the insulation from about 20mm and then (optionally) tin the ends. These will attach to the antenna tuner.

Congratulations: you have made yourself a centre-fed dipole antenna, fed by a parallel wire transmission line. Where's the transmission line? It's the part of the cable you didn't split apart. Even experienced amateurs may not be aware that twin, untwisted wire such as speaker cable, 'bell wire', 'zip' cable and other similar wires have a characteristic impedance somewhere in the vicinity of 70Ω and, at least for the lower HF frequencies, isn't too lossy.

The next stage is to tie a Bowline **[2]** knot, as shown in **Figure 1** and **Photo 2**, at each of the two free ends. You can make the loop (left of the photo) any reasonable size; its purpose is just to provide an anchor point. A diameter of somewhere between a couple of fingers and a fist would be fine.

Attach one end of your nylon line to one of the Bowline knots. Reel out and cut 10m or so of the line, then attach the weight. The length you use will depend to some extent on the height of your support; it should be longer than the support point is high. Any excess can be wound up as mentioned in the next section.

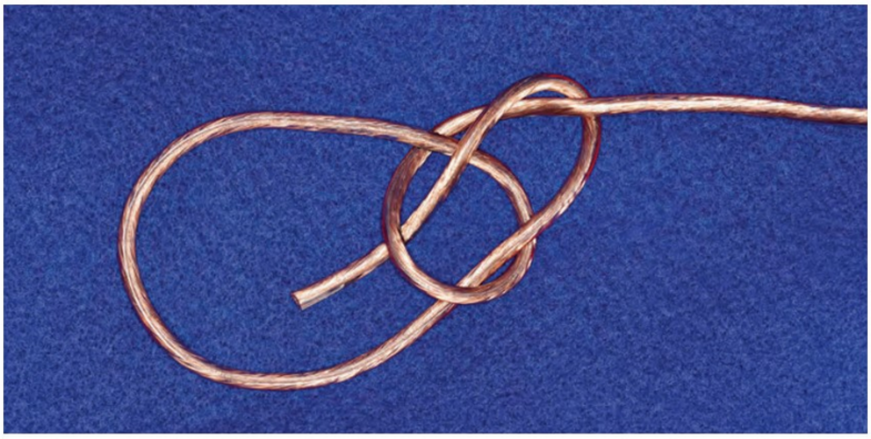

PHOTO 2: Making a Bowline Knot in a piece of insulated stranded wire (see also Figure 1). The loop on the left should remain when the knot is pulled tight. Photo: G1MFG.

Into service

DO NOT ATTEMPT TO ERECT THIS ANTENNA ANYWHERE NEAR ANY OVERHEAD POWER WIRES. Also, avoid phone wires – they may well be carrying broadband signals that will raise the noise level on your receiver.

If you have a tree handy, refer to **Figure 2**. Approach the tree with your back to the preferred direction of transmission. Lay out the nylon line reasonably straight, then toss the attached weight over any cooperative-looking branch about 5m to 10m above the ground. Use the nylon line to pull the end of the dipole up to about 5m or 6m above ground. It's OK to pull the dipole into and even part way over a shrub. Tie the nylon line to the tree trunk or shrub branches to keep it from slipping, then coil the remaining nylon line so that it doesn't become a trip hazard.

Pull the middle of the dipole (the central knot) to the ground so that the sloping half of the dipole has modest tension in it. Press one spike (such as a screwdriver) into the ground next to the knot, then tie the dipole around its handle. You're not trying to make an electrical connection to the ground. Continue running the free end of the dipole away from the tree, letting it just lie on the ground. If you prefer, you can put another spike in the ground and attach the free end to that.

If you're using a pole rather than a tree, refer to **Figure 3**. Instead of tying one end of the nylon line to the dipole, tie the centre of the line to the antenna end. Press two screwdrivers (or other spikes) into the ground about 5 to 8m apart. Tie the ends of nylon line to these. Extend the pole, place the bowline loop/nylon line over its top, erect the pole, stand it vertically, then use the dipole and the nylon line to guy it in place. Using another screwdriver or spike, tie the centre of the dipole around its handle, thus keeping the pole upright. Finish as before, running the end of the dipole away from the sloping part.

Whichever sort of support you're using, lay the transmission line on the ground, at right angles to the dipole. Attach the two wires to the balanced output of the ATU (it doesn't matter which way round), then use coax to connect the ATU to your radio. You're good to go!

Practical experiences and performance

I've had great success with this arrangement over the years. I learned the basic design as a young, newly-hired 'grunt' at the US Army Signal Labs' Field Communications Development Group. It has since performed decades of excellent service, supporting field beacon stations in support of NVIS HF DF investigations, not to mention countless portable amateur operations.

Its radiation pattern is a bit of an irregular 'peanut' shape, perpendicular to the sloping dipole arm and leaning over the part on the ground. **Figure 4** is the expected radiation pattern for 40m (7MHz), as calculated by NEC4. The solid line is in the plane of Figure 2, with the tree to the right. The dotted line is the pattern in and out of the sketch.

In a 40m CW QSO with a chap some 300km to my West, with the dipole laying north-south, I started a contact with a station some 300km to the west of me. He gave a rather weak signal report, so I asked him to wait a moment while I moved the beam – that is, pulled up stakes and laid the dipole along an east to west line. Both signal levels increased about an S unit. On HF this sort of variation can often occur by happenstance alone, but it does support the calculated pattern.

Conclusion

Keep this article in the back of your mind. It could well come in handy someday. It takes up little space and weighs almost nothing so it's the sort of thing you could easily go out /P with to a quiet spot in the countryside. There's nothing magic about the dimensions I've given – feel free to adapt them to whatever you've got. I leave the new results for you to discover. Longer dipoles can be expected to perform a bit better at low frequencies than shorter versions, but any half-decent ATU should be able to provide a match on several bands and if you live in a built-up area, you'll be amazed how much the noise level goes down if you take this aerial and your radio out to a rural area – where suitable trees are hopefully plentiful.

Websearch

[1] https://en.wikipedia.org/wiki/Underwriter's_knot

[2] https://en.wikipedia.org/wiki/Bowline

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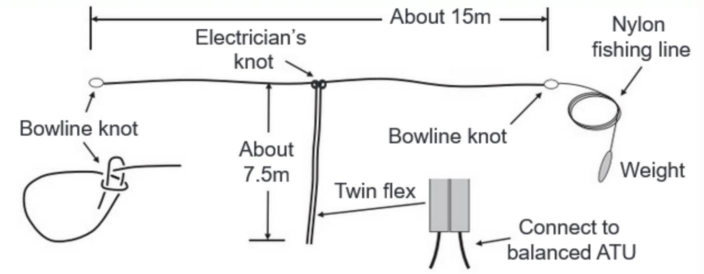

FIGURE 1: General arrangement of the antenna. Dimensions are not critical.

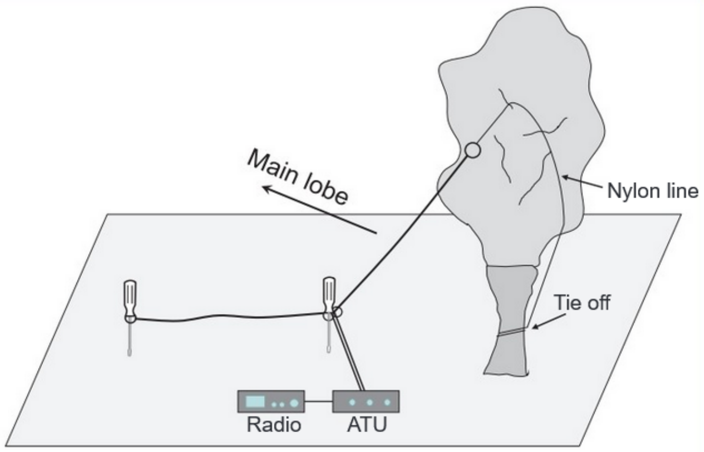

FIGURE 2: General arrangement when using a tree for support.

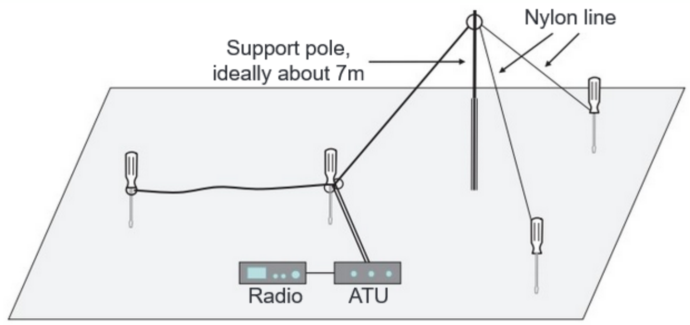

FIGURE 3: Using a pole for support, with the antenna forming one of the three guys.

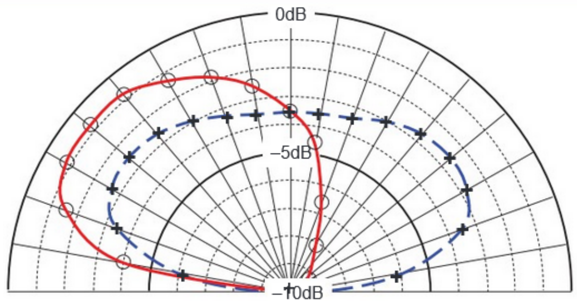

FIGURE 4: Expected radiation pattern on 40m, as calculated by NEC4.

RSGB Band Plan 2021

The following band plan is largely based on that agreed at IARU Region 1 General Conferences, with some local differences on frequencies above 430MHz.

EFFECTIVE FROM 1st JANUARY 2021 UNLESS OTHERWISE SHOWN

136kHz	NECESSARY BANDWIDTH	UK USAGE
135.7-137.8kHz	200Hz	CW, QRSS and Narrowband Digital Modes

Licence Notes: Amateur Service – Secondary User. 1 watt (0dBW) ERP.
R.R. 5.67B. The use of the band 135.7-137.8kHz in Algeria, Egypt, Iran (Islamic Republic of), Iraq, Lebanon, Syrian Arab Republic Sudan, South Sudan and Tunisia is limited to fixed and maritime mobile services. The amateur service shall not be used in the above-mentioned countries in the band 135.7-137.8kHz, and this should be taken into account by the countries authorising such use. (WRC-12).

472kHz (600m)	NECESSARY BANDWIDTH	UK USAGE

IARU Region 1 does not have a formal band plan for this allocation but has a usage recommendation (Note 1).

472-479kHz	500Hz	CW, QRSS and Narrowband Digital Modes

Note 1: Usage recommendation – 472-475kHz CW only 200Hz maximum bandwidth, 475-479kHz CW and Digimodes.
Note 2: It should be emphasised that this band is available on a non-interference basis to existing services. UK amateurs should be aware that some overseas stations may be restricted in terms of transmit frequency in order to avoid interference to nearby radio navigation service Non-Directional Beacons.
Licence Notes: Amateur Service – Secondary User. Full Licensees only, **5 watts EIRP maximum**. Note that conditions regarding this band are specified by the Licence Schedule notes.
R.R. 5.80B. The use of the frequency band 472-479kHz in Algeria, Saudi Arabia, Azerbaijan, Bahrain, Belarus, China, Comoros, Djibouti, Egypt, United Arab Emirates, the Russian Federation, Iraq, Jordan, Kazakhstan, Kuwait, Lebanon, Libya, Mauritania, Oman, Uzbekistan, Qatar, Syrian Arab Republic, Kyrgyzstan, Somalia, Sudan, Tunisia and Yemen is limited to the maritime mobile and aeronautical radionavigation services. The amateur service shall not be used in the above-mentioned countries in this frequency band, and this should be taken into account by the countries authorising such use. (WRC 12).

1.8MHz (160m)	NECESSARY BANDWIDTH	UK USAGE
1,810-1,838kHz	200Hz	Telegraphy
1,838-1,840	500Hz	Narrowband Modes
1,840-1,843	2.7kHz	All Modes
1,843-2,000	2.7kHz	Telephony (Note 1), Telegraphy 1,836kHz – QRP (low power) Centre of Activity 1,960kHz – DF Contest Beacons (14dBW)

Note 1: Lowest LSB carrier frequency (dial setting) should be 1,843kHz. AX25 packet should not be used on the 1.8MHz band.
Licence Notes: 1,810-1,850kHz – Primary User: 1,810-1,830kHz on a non-interference basis to stations outside of the UK. 1,850-2,000kHz – Secondary User. 32W (15dBW) maximum.
Notes to the Band Plan: As on page 48.

3.5MHz (80m)	NECESSARY BANDWIDTH	UK USAGE
3,500-3,510kHz	200Hz	Telegraphy – Priority for Inter-Continental Operation
3,510-3,560	200Hz	Telegraphy – Contest Preferred. 3,555kHz – QRS (slow telegraphy) Centre of Activity
3,560-3,570	200Hz	Telegraphy 3,560kHz – QRP (low power) Centre of Activity
3,570-3,580	200Hz	Narrowband Modes
3,580-3,590	500Hz	Narrowband Modes
3,590-3,600	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)
3,600-3,620	2.7kHz	All Modes – Automatically Controlled Data Stations (unattended), (Note 1)
3,600-3,650	2.7kHz	All Modes – Phone Contest Preferred, (Note 1) 3,630kHz – Digital Voice Centre of Activity
3,650-3,700	2.7kHz	All Modes – Telephony, Telegraphy 3,663kHz May Be Used For UK Emergency Comms Traffic 3,690kHz SSB QRP (low power) Centre of Activity
3,700-3,775	2.7kHz	All Modes – Phone Contest Preferred 3,735kHz – Image Mode Centre of Activity 3,760kHz – IARU Region 1 Emergency Centre of Activity
3,775-3,800	2.7kHz	All modes – Phone contest preferred Priority for Inter-Continental Telephony (SSB) Operation

Note 1. Lowest LSB carrier frequency (dial setting) should be 3,603kHz.
Licence Notes: Primary User: Shared with other user services.
Notes to the Band Plan: As on page 48.

5MHz (60m)	AVAILABLE WIDTH	UK USAGE
5,258.5-5,264kHz	5.5kHz	5,262kHz – CW QRP Centre of Activity
5,276-5,284	8kHz	5,278.5kHz – May be used for UK Emergency Comms Traffic
5,288.5-5,292	3.5kHz	Beacons on 5290kHz (Note 2)
5,298-5,307	9kHz	
5,313-5,323	10kHz	5,317kHz – AM 6kHz maximum bandwidth
5,333-5,338	5kHz	
5,354-5,358	4kHz	Within WRC-15 Band
5,362-5,374.5	12.5kHz	Partly within WRC-15 band, WSPR
5,378-5,382	4kHz	
5,395-5,401.5	6.5kHz	
5,403.5-5,406.5	3kHz	

Unless indicated, usage is All Modes (necessary bandwidth to be within channel limits).
Note 1: Upper Sideband is recommended for SSB activity.
Note 2: Activity should avoid interference to the experimental beacons on 5290kHz.
Note 3: Amplitude Modulation is permitted with a maximum bandwidth of 6kHz, on frequencies with at least 6kHz available width.
Note 4: Contacts within the UK should avoid the WRC-15 band (5351.5 - 5366.5 kHz) if possible
For the latest current guidance refer to the RSGB website
Licence Notes: Full Licensees only, **Secondary User, 100 watts maximum**. Note that conditions on transmission bandwidth, power and antennas are specified in the Licence. For the latest current guidance, refer to the RSGB website
Notes to the Band Plan. As on page 48.

7MHz (40m)	NECESSARY BANDWIDTH	UK USAGE
7,000-7,040kHz	200Hz	Telegraphy – 7,030kHz QRP (low power) Centre of Activity
7,040-7,047	500Hz	Narrowband Modes (Note 2)
7,047-7,050	500Hz	Narrowband Modes, Automatically Controlled Data Stations (unattended)
7,050-7,053	2.7kHz	All Modes, Automatically Controlled Data Stations (unattended), (Note 1)
7,053-7,060	2.7kHz	All Modes, Digimodes
7,060-7,100	2.7kHz	All Modes, SSB Contest Preferred Segment Digital Voice 7,070kHz; SSB QRP Centre of Activity 7,090kHz
7,100-7,130	2.7kHz	All Modes, 7,110kHz – Region 1 Emergency Centre of Activity
7,130-7,200	2.7kHz	All Modes, SSB Contest Preferred Segment; 7,165kHz – Image Centre of Activity
7,175-7,200	2.7kHz	All Modes, Priority For Inter-Continental Operation

Note 1: Lowest LSB carrier frequency (dial setting) should be 7,053kHz.
Note 2: PSK31 activity starts from 7,040kHz. Since 2009, the narrowband modes segment starts at 7,040kHz.
Licence Notes: 7,000-7,100kHz Amateur and Amateur Satellite Service – Primary User. 7,100-7,200kHz Amateur Service – Primary User.
Notes to the Band Plan: As on page 48.

10MHz (30m)	NECESSARY BANDWIDTH	UK USAGE
10,100-10,130kHz	200Hz	Telegraphy (CW) 10,116kHz – QRP (low power) Centre of Activity
10,130-10,150	500Hz	Narrowband Modes Automatically Controlled Data Stations (unattended) should avoid the use of the 10MHz band

Licence Notes: Amateur Service – Secondary User.
Notes to the Band Plan: As on page 32.
The 10MHz band is allocated to the amateur service only on a secondary basis. The IARU has agreed that only CW and other narrow bandwidth modes are to be used on this band. Likewise the band is not to be used for contests and bulletins. SSB may be used on the 10MHz band during emergencies involving the immediate safety of life and property, and only by stations actually involved with the handling of emergency traffic. The band segment 10,120-10,140kHz may only be used for SSB transmissions in the area of Africa south of the equator during local daylight hours.

14MHz (20m)	NECESSARY BANDWIDTH	UK USAGE
14,000-14,060kHz	200Hz	Telegraphy – Contest Preferred 14,055kHz – QRS (slow telegraphy) Centre of Activity
14,060-14,070	200Hz	Telegraphy 14,060kHz – QRP (low power) Centre of Activity
14,070-14,089	500Hz	Narrowband Modes
14,089-14,099	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)
14,099-14,101		IBP – Reserved Exclusively for Beacons
14,101-14,112	2.7kHz	All Modes – Automatically Controlled Data Stations (unattended)
14,112-14,125	2.7kHz	All Modes (excluding digimodes)
14,125-14,300	2.7kHz	All Modes – SSB Contest Preferred Segment 14,130kHz – Digital Voice Centre of Activity 14,195 ±5kHz – Priority for DXpeditions 14,230kHz – Image Centre of Activity 14,285kHz – QRP Centre of Activity
14,300-14,350	2.7kHz	All Modes 14,300kHz – Global Emergency Centre of Activity

Licence Notes: Amateur Service – Primary User. 14,000-14,250kHz Amateur Satellite Service – Primary User.
Notes to the Band Plan: As on page 48.

18MHz (17m)	NECESSARY BANDWIDTH	UK USAGE
18,068-18,095kHz	200Hz	Telegraphy – 18,086kHz QRP (low power) Centre of Activity
18,095-18,105	500Hz	Narrowband Modes
18,105-18,109	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)

18,109-18,111		IBP – Reserved Exclusively for Beacons
18,111-18,120	2.7kHz	All Modes – Automatically Controlled Data Stations (unattended)
18,120-18,168	2.7kHz	All Modes, 18,130kHz – SSB QRP Centre of Activity 18,150kHz – Digital Voice Centre of Activity 18,160kHz – Global Emergency Centre of Activity

Licence Notes: Amateur and Amateur Satellite Service – Primary User. The band is not to be used for contests or bulletins.
Notes to the Band Plan: As on page 48.

21MHz (15m)	NECESSARY BANDWIDTH	UK USAGE
21,000-21,070kHz	200Hz	Telegraphy 21,055kHz – QRS (slow telegraphy) Centre of Activity 21,060kHz – QRP (low power) Centre of Activity
21,070-21,090	500Hz	Narrowband Modes
21,090-21,110	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)
21,110-21,120	2.7kHz	All Modes (excluding SSB) – Automatically Controlled Data Stations (unattended)
21,120-21,149	500Hz	Narrowband Modes
21,149-21,151		IBP – Reserved Exclusively For Beacons
21,151-21,450	2.7kHz	All Modes 21,180kHz – Digital Voice Centre of Activity 21,285kHz – QRP Centre of Activity 21,340kHz – Image Centre of Activity 21,360kHz – Global Emergency Centre of Activity

Note 1: 21,125-21,245 is also designated for use by amateur satellites
Licence Notes: Amateur and Amateur Satellite Service – Primary User.
Notes to the Band Plan: As on page 48.

24MHz (12m)	NECESSARY BANDWIDTH	UK USAGE
24,890-24,915kHz	200Hz	Telegraphy 24,906kHz – QRP (low power) Centre of Activity
24,915-24,925	500Hz	Narrowband Modes
24,925-24,929	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)
24.929-24.931		IBP – Reserved Exclusively For Beacons
24,931-24,940	2.7kHz	All Modes – Automatically Controlled Data Stations (unattended)
24,940-24,990	2.7kHz	All Modes, 24,950kHz – SSB QRP Centre of Activity 24,960kHz – Digital Voice Centre of Activity

Licence Notes: Amateur and Amateur Satellite Service – Primary User. The band is not to be used for contests or bulletins.
Notes to the Band Plan: As on page 48.

28MHz (10m)	NECESSARY BANDWIDTH	UK USAGE
28,000-28,070kHz	200Hz	Telegraphy 28,055kHz – QRS (slow telegraphy) Centre of Activity 28,060kHz – QRP (low power) Centre of Activity
28,070-28,120	500Hz	Narrowband Modes
28,120-28,150	500Hz	Narrowband Modes – Automatically Controlled Data Stations (unattended)
28,150-28,190	500Hz	Narrowband Modes
28,190-28,199		IBP – Regional Time Shared Beacons
28,199-28,201		IBP – World Wide Time Shared Beacons
28,201-28,225		IBP – Continuous-Duty Beacons
28,225-28,300	2.7kHz	All Modes – Beacons
28,300-28,320	2.7kHz	All Modes – Automatically Controlled Data Stations (unattended)
28,320-29,000	2.7kHz	All modes 28,330kHz – Digital Voice Centre of Activity 28,360kHz – QRP Centre of Activity 28,680kHz – Image Centre of Activity
29,000-29,100		All Modes – See Note 1 regarding 29,000-29,510kHz
29,100-29,200		All Modes – FM Simplex – 10kHz Channels
29,200-29,300		All Modes – Automatically Controlled Data Stations (unattended) 29,270kHz – Internet Gateways Channel 29,280kHz – UK Internet Voice Gateway (unattended) 29,290kHz – UK Internet Voice Gateway (unattended)
29,300-29,510		Satellite Links
29,510-29,520	Guard Channel	
29,520-29,590	6kHz	All Modes – FM Repeater Inputs (RH1-RH8)
29,600	6kHz	All Modes – FM Calling Channel
29,610	6kHz	All Modes – FM Simplex Repeater (parrot) – input and output
29,620-29,700	6kHz	All Modes – FM Repeater Outputs (RH1-RH8)

Note 1: Experimental wide bandwidth operation within 29,000 - 29,510 must be on a non-interference basis to other stations, including the amateur satellite service segment at 29300 - 29510 kHz.
Licence Notes: Amateur and Amateur Satellite Service – Primary User: 26dBW permitted. Beacons may be established for DF competitions except within 50km of NGR SK985640 (Waddington).
Notes to the Band Plan: As on page 48.

50MHz (6m)	NECESSARY BANDWIDTH	UK USAGE
50.000-50.100MHz	500Hz	Telegraphy Only (except for Beacon Project) (Note 2) 50.000-50.030MHz reserved for Synchronised Beacon Project (Note 2) Region 1: 50.000-50.010; Region 2: 50.010-50.020; Region 3: 50.020-50.030 50.050MHz – Future International Centre of Activity 50.090MHz – Inter-Continental DX Centre of Activity (Note 1)
50.100-50.200	2.7kHz	SSB/Telegraphy – International Preferred 50.100-50.130MHz – Inter-Continental DX Telegraphy & SSB (Note 1) 50.110MHz – Inter-Continental DX Centre of Activity 50.130-50.200MHz – General International Telegraphy & SSB 50.150MHz – International Centre of Activity
50.200-50.300	2.7kHz	SSB/Telegraphy – General Usage 50.285MHz – Crossband Centre of Activity
50.300-50.400	2.7kHz	MGM/Narrowband/Telegraphy 50.305MHz – PSK Centre of Activity 50.310-50.320MHz – EME 50.320-50.380MHz – MS
50.400-50.500		Propagation Beacons only
50.500-50.700		All Modes 50.520MHz – FM/DV Internet Voice Gateway 50.530MHz – FM/DV Internet Voice Gateway 50.540MHz – FM/DV Internet Voice Gateway 50.600-50.700MHz – Digital communications 50.630MHz – Digital Voice (DV) calling
50.700-50.900	12kHz	50.710-50.890MHz – FM/DV Repeater Outputs (10kHz channel spacing)
50.900-51.200		All Modes
51.200-51.400	12kHz	51.210-51.390MHz – FM/DV Repeater Inputs (10kHz channel spacing) (Note 4)
51.400-52.000		All Modes 51.410-51.590MHz – FM/DV Simplex (Note 3) (Note 4) 51.510MHz – FM Calling Frequency 51.530MHz – GB2RS News Broadcast and Slow Morse 51.650 & 51.750MHz – See Note 5 (25kHz aligned) 51.970 & 51.990MHz – See Note 5

Note 1: Only to be used between stations in different continents (not for intra-European QSOs).
Note 2: 50.0-50.1MHz is currently shared with Propagation Beacons. These are due to be migrated to 50.4-50.5MHz, to create more space for Telegraphy and a new Synchronised Beacon Project.
Note 3: 20kHz channel spacing. Channel centre frequencies start at 51.430MHz.
Note 4: Embedded data traffic is allowed with digital voice (DV).
Note 5: May be used for Emergency Communications and Community Events.
Note 6: Digital experiments to support innovation may occur at 50.6, 51.0 or 51.7MHz with a 100kHz maximum bandwidths of 50, 200 and 400kHz respectively on a non-interference basis.
Licence Notes: Amateur Service 50.0-51.0MHz – Primary User. Amateur Service 51.0-52.0MHz – Secondary User. 100W (20dBW) maximum. Available on the basis on non-interference to other services (inside or outside the UK).
Notes to the Band Plan: As on page 48.

70MHz (4m)	NECESSARY BANDWIDTH	UK USAGE (NOTE 1)
70.000-70.090MHz	1kHz	Propagation Beacons Only
70.090-70.100	1kHz	Personal Beacons
70.100-70.250	2.7kHz	Narrowband Modes 70.185MHz – Cross-band Activity Centre 70.200MHz – CW/SSB Centre 70.250MHz – MS Centre
70.250-70.294	12kHz	All Modes 70.260MHz – AM/FM Calling 70.270MHz MGM Centre of Activity
70.294-70.500	12kHz	All Modes Channelised Operations Using 12.5kHz Spacing 70.3000MHz 70.3125MHz – Digital Modes 70.3250MHz – DX Cluster 70.3375MHz – Digital Modes 70.3500MHz – Internet Voice Gateway (Note 2) 70.3625MHz – Internet Voice Gateway 70.3750MHz – See Note 2 70.3875MHz – Internet Voice Gateway 70.4000MHz – See Note 2 70.4125MHz – Internet Voice Gateway 70.4250MHz – FM Simplex – used by GB2RS news broadcast 70.4375MHz – Digital Modes (special projects) 70.4500MHz – FM Calling 70.4625MHz – Digital Modes 70.4750MHz 70.4875MHz – Digital Modes

Note 1: Usage by operators in other countries may be influenced by restrictions in their national allocations.
Note 2: May be used for Emergency Communications and Community Events.
Licence Notes: Amateur Service 70.0-70.5MHz – Secondary User: 160W (22dBW) maximum. Available on the basis of non-interference to other services (inside or outside the UK).
Notes to the Band Plan: As on page 48.

144MHz (2m)	NECESSARY BANDWIDTH	UK USAGE
144.000-144.025MHz	2700Hz	All Modes – including Satellite Downlinks
144.025-144.100	500Hz	Telegraphy (including EME CW) 144.050MHz – Telegraphy Centre of Activity 144.100MHz – Random MS Telegraphy Calling, (Note 1)
144.110-144.150	500Hz	Telegraphy and MGM EME MGM Activity
144.150-144.400	2700Hz	Telegraphy, MGM and SSB 144.250MHz – GB2RS News Broadcast and Slow Morse 144.260MHz – See Note 10 144.300MHz – SSB Centre of Activity 144.370MHz – MGM MS Calling
144.400-144.490		Propagation Beacons only
144.490-144.500		Beacon guard band 144.491-144.493 Personal Weak Signal MGM Beacons (BW: 500Hz max)

144.500-144.794	20kHz	All Modes (Note 8)
		144.500MHz – Image Modes Centre (SSTV, FAX, etc)
		144.600MHz – Data Centre of Activity (MGM, RTTY, etc)
		144.6125MHz – UK Digital Voice (DV) Calling (Note 9)
		144.625-144.675MHz – See Note 10
		144.750MHz – ATV Talkback
		144.775-144.794MHz – See Note 10 144.794-
144.990	12kHz	MGM Digital Communications (Note 15)
		144.800-144.9875MHz – MGM/Digital Communications
		144.8000MHz – Unconnected Nets – APRS, UiView etc (Note 14)
		144.8125MHz – DV Internet Voice Gateway
		144.8250MHz – DV Internet Voice Gateway
		144.8375MHz – DV Internet Voice Gateway
		144.8500MHz – DV Internet Voice Gateway
		144.8625MHz – DV Internet Voice Gateway
		144.9250MHz – Digital Usage
		144.9375MHz – Digital Usage
		144.9500MHz – Digital Usage
		144.9625MHz – FM Internet Voice Gateway
		144.9750MHz, 144.9875MHz To Be Decided (Note 11)
144.990-145.1935	12kHz	FM/DV RV48-RV63 Repeater Input Exclusive (Note 2 & 5)
145.200	12kHz	FM/DV Space Communications (eg ISS) – Earth-to-Space
		145.2000MHz – (Note 4 & 10)
145.200-145.5935	12kHz	FM/DV V16-V47 – FM/DV Simplex (Note 3, 5 & 6)
		145.2250MHz – See Note 10
		145.2375MHz – FM Internet Voice Gateway (IARU common channel)
		145.2500MHz – Used for Slow Morse Transmissions
		145.2875MHz – FM Internet Voice Gateway (IARU common channel)
		145.3375MHz – FM Internet Voice Gateway (IARU common channel)
		145.5000MHz – FM Calling (Note 12)
		145.5250MHz – Used for GB2RS News Broadcast.
		145.5500MHz – Used for Rally/exhibition Talk-in
		145.5750MHz, 145.5875MHz (Note 11)
145.5935-145.7935	12kHz	FM/DV RV48-RV63 – Repeater Output (Note 2)
145.800	12kHz	FM/DV Space Communications (eg ISS) – Space-Earth
145.806-146.000	12kHz	All Modes – Satellite Exclusive

Note 1: Meteor scatter operation can take place up to 26kHz higher than the reference frequency.
Note 2: 12.5kHz channels numbered RV48-RV63. RV48 input = 145.000MHz, output = 145.600MHz.
Note 3: 12.5kHz simplex channels numbered V16-V47. V16 = 145.200MHz.
Note 4: Emergency Communications Groups utilising this frequency should take steps to avoid interference to ISS operations in non-emergency situations.
Note 5: Embedded data traffic is allowed with digital voice (DV).
Note 6: Simplex use only – no DV gateways.
Note 7: Not used.
Note 8: Amplitude Modulation (AM) is acceptable within the All Modes segment. AM usage is typically found on 144.550MHz. Users should consider adjacent channel activity when selecting operating frequencies.
Note 9: In other countries IARU Region 1 recommends 145.375MHz.
Note 10: May be used for Emergency Communications and Community Events.
Note 11: May be used for repeaters in other IARU Region 1 countries.
Note 12: DV users are asked not to use this channel, and use 144.6125MHz for calling.
Note 13: Not used.
Note 14: 144.800 use should be NBFM to avoid interference to 144.8125 DV Gateways.
Licence Notes: Amateur Service and Amateur Satellite Service – Primary User. Beacons may be established for DF competitions except within 50km of TA 012869 (Scarborough).
Notes to the Band Plan: As on page 48.

146MHz IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE

Access to this band requires an appropriate NoV, which is available to Full Licensees only

146.000-146.900MHz	500kHz	Wideband Digital Modes (High speed data, DATV etc)
		146.500MHz Centre frequency for wideband modes (Note 1)
146.900-147.000MHz	12kHz	Narrowband Digital Modes including Digital Voice
		146.900
		146.9125
		146.925
		146.9375 Not available in/near Scotland (see Licence Notes & NoV terms)
		146.9500
		146.9625
		146.9750
		146.9875

Note 1: Users of wideband modes must ensure their spectral emissions are contained with the band limits.
Licence Notes: Full Licensees only, with NoV, 50W ERP max – not available in the Isle of Man or Channel Isles. Note that additional restrictions on geographic location, antenna height and upper frequency limit are specified by the NoV terms.
It should be emphasised that this band is UK-specific and is available on a non-interference basis to existing services. Upper Band limit 147.000MHz (or 146.93750 where applicable) are absolute limits and not centre frequencies. The absolute band frequency limit in or within 40km of Scotland is 146.93750MHz – see NoV schedule
Notes to the Band Plan: As on page 48.

430MHz (70cm) IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE
430.0000-431.9810MHz		430.0125-430.0750MHz – FM Internet Voice Gateways (Notes 7, 8)
All Modes		
		430.250-430.300 MHz UK DV 9 MHz reverse-split repeaters – Outputs
		430.4000-430.7750 – UK DV 9MHz Split Repeaters – inputs
Digital Links		
430.6000-430.9250		430.8000MHz – 7.6MHz Talk-through (Note 10)
Digital Repeaters		430.8250-430.9750MHz – RU66-RU78
		7.6MHz Split Repeaters – outputs
		See Licence Exclusion Note; 431-432MHz
		430.9900-431.9000MHz – Digital Communications
		431.0750-431.1750MHz – DV Internet Voice Gateways (Note 8)
432.0000-432.1000	500Hz	432,0500MHz Telegraphy Centre of Activity Telegraphy, MGM
432.1000-432.4000	2700Hz	
		432.2000MHz – SSB Centre of Activity
SSB, Telegraphy		432.3500MHz – Microwave Talkback (Europe)
MGM		432.3700MHz – Meteor Scatter Calling
432.4000-432.4900	500Hz	Propagation Beacons only
432.4900-432.9940	25kHz	432.491-432.493MHz Personal Weak Signal MGM Beacons (BW: 500Hz max)
		432.5000MHz – Narrowband SSTV Activity Centre
All Modes	(Note 11)	432.6250-432.6750MHz Digital
Non-channelised		Communications (25kHz channels)
		432.7750MHz 1.6MHz Talk-through – Base TX (Note 10)
432.9940-433.3810	25kHz	433.0000-433.3750MHz (RB0-RB15) – RU240-RU270
FM repeater outputs	(Note 11)	FM/DV Repeater Outputs (25kHz channels) in
in UK only (Note 1)		UK Only
433.3940-433.5810	25kHz	433.4000MHz U272 – IARU Region 1 SSTV (FM/AFSK)
	(Note 11)	433.4250MHz U274
FM/DV (Notes 12, 13)		433.450MHz U276 (Note 5)
Simplex Channels		433.4750MHz U278
		433.5000MHz U280 – FM Calling Channel
		433.5250MHz U282
		433.5500MHz U284 – Used for Rally/Exhibition Talk-in
		433.5750MHz U286
433.6000-434.0000		433.6250-6750MHz – Digital Communications
All Modes		(25kHz channels)
433.8000MHz for		433.7000MHz-433.7750MHz (Note 10)
APRS where 144.8000MHz		433.8000-434.2500 MHz Digital communications
cannot be used		& Experiments
		434.0000 Low Power Non-NoV Personal Hot-Spot usage
434.0000-434.5940	25kHz	433.9500-434.0500MHz – Internet Voice Gateways (Note 8)
	(Note 11)	434.3750MHz 1.6MHz Talk-through – Mobile TX (Note 10)
		434.4750-434.5250MHz DV Internet voice gateways (Note 8)
434.5940-434.9810	25kHz	434.6000-434.9750MHz (RB0-RB15) RU240-RU270
FM repeater inputs in	(Note 11)	FM/DV Repeater Inputs (25kHz channels) in UK
UK only		Only (Note 12)
435.0000-436.0000		Satellites only
436.0000-438.0000		Satellites and Experimental DATV/Data
		437.0000 Experimental DATV Centre of Activity (Note 14)
438.0000-440.0000		438.8000 Low Power Non-NoV Personal Hot-Spot usage
		438.0250-438.1750MHz – IARU Region 1 Digital Communications
All Modes		438.2000-439.4250MHz (Note 1)
		438.4000MHz – 7.6MHz Talk-through (Note 10)
		438.4250-438.5750MHz RU66-RU78 –
		7.6MHz Split Repeaters – inputs
		438.6125MHz – UK DV calling (Note 12) (Note 13)
		438.8000 Low Power Non-NoV Personal Hot-Spot usage
		439.2500-439.3000MHz UK DV 9MHz reverse-split repeaters – Inputs
		439.6000-440.0000MHz – Digital Communications
		439.4000-439.7750MHz – UK DV 9MHz split repeaters – Outputs

Note 1: In Switzerland, Germany and Austria, repeater inputs are 431.0500-431.8250MHz with 25kHz spacing and outputs 438.6500-439.4250MHz. In Belgium, France and the Netherlands repeater outputs are 430.0250-430.3750MHz with 12.5kHz spacing and inputs at 431.6250-431.9750MHz. In other European countries repeater inputs are 433.0000-433.3750MHz with 25kHz spacing and outputs at 434.6000-434.9750MHz, ie the reverse of the UK allocation.
Note 2: 430-440MHz FM/DV maximum bandwidths are 12.5 or 25kHz as appropriate
Note 4: Not used.
Note 5: In other countries IARU Region 1 recommends 433.4500MHz for DV calling.
Note 7: Users must accept interference from repeater output channels in France and the Netherlands at 430.0250-430.5750MHz. Users with sites that allow propagation to other countries (notably France and the Netherlands) must survey the proposed frequency before use to ensure that they will not cause interference to users in those countries.
Note 8: All internet voice gateways: 12.5kHz channels, maximum deviation ±2.4kHz, maximum effective radiated power 5W (7dBW), attended only operation in the presence of the NoV holder.
Note 10: May be used for Emergency Communications and Community Events.
Note 11: IARU Region 1 recommended maximum bandwidths are 12.5 or 20kHz.
Note 12: Embedded data traffic is allowed with digital voice (DV).
Note 13: Simplex use only – no DV gateways.
Note 14: QPSK 2 Mega-symbols/second maximum recommended.
Licence Notes: Amateur Service – Secondary User. Amateur Satellite Service: 435-438MHz – Secondary User. Exclusion: 431-432MHz not available within 100km radius of Charing Cross, London. Power Restriction 430-432MHz is 40 watts effective radiated power maximum.
Notes to the Band Plan: As on page 48.

1.3GHz (23cm)	NECESSARY BANDWIDTH	UK USAGE
1240.000-1240.500MHz	2700Hz	Alternative Narrowband Segment – see Note 7 – 1240.00-1240.750MHz
1240.500-1240.750		Alternative Propagation Beacon Segment
1240.750-1241.000	20kHz	FM/DV Repeater Inputs
1241.000-1241.750	150kHz	DD High Speed Digital Data – 5 x 150kHz channels
All Modes		1241.075, 1241.225, 1241.375, 1241.525, 1241.675MHz (±75kHz)
1241.750-1242.000	20kHz	25kHz Channels available for FM/DV use

All Modes		1241.775-1241.975MHz
1242.000-1249.000 ATV		TV Repeaters (Note 9) New DATV Repeater Inputs Original ATV Repeater Inputs: 1248, 1249
1249.000-1249.250	20kHz	FM/DV Repeater Outputs, 25kHz Channels (Note 9) 1249.025-1249.225MHz
1250.00		In order to prevent interference to Primary Users, caution must be exercised prior to using 1250-1290MHz in the UK 1260.000-
1270.000 Satellites		Amateur Satellite Service – Earth to Space Uplinks Only
1290.000		
1290.994-1291.481	20kHz	FM/DV Repeater Inputs (Note 5) 1291.000-1291.375MHz (RM0-RM15) 25kHz spacing
1291.494-1296.000 All Modes	All Modes	Preferred Narrowband segment
1296.000-1296.150 Telegraphy, MGM	500Hz	1296.000-1296.025MHz – Moonbounce
1296.150-1296.800 Telegraphy, SSB & MGM (Note 1)	2700Hz	1296.200MHz – Narrowband Centre of Activity 1296.400-1296.600MHz – Linear Transponder Input 1296.500MHz – Image Mode Centre of Activity (SSTV, FAX etc) 1296.600MHz – Narrowband Data Centre of Activity (MGM, RTTY etc) 1296.600-1296.700MHz – Linear Transponder Output 1296.741-1296.743MHz Personal Weak Signal MGM Beacons
1296.800-1296.994		1296.750-1296.800MHz – Local Beacons, 10W ERP max 1296.800-1296.990MHz – Propagation Beacons only Beacons exclusive
1296.994-1297.481	20kHz	FM/DV Repeater Outputs (Note 5) 1297.000-1297.375MHz (RS1-RS39)
1297.494-1297.981 FM/DV simplex (Notes 2, 5, 6)	20kHz	FM/DV Simplex (Notes 2, 5 & 6) 25kHz spacing 1297.500-1297.750MHz (SM20-SM30) 1297.725MHz – Digital Voice (DV) Calling (IARU recommended) 1297.900-1297.975MHz – FM Internet Voice Gateways (IARU common channels, 25kHz)
1298.000-1299.000 All Modes	20kHz	All Modes General mixed analogue or digital use in channels 1298.025-1298.975MHz
1299.000-1299.750 All Modes	150kHz	DD High Speed Digital Data – 5 x 150kHz channels 1299.075, 1299.225, 1299.375, 1299.525, 1299.675MHz (±75kHz)
1299.750-1300.000 All Modes	20kHz	25kHz Channels Available for FM/DV use 1299.775-1299.975MHz
1300.000-1325.000 ATV		TV Repeaters (UK only) (Note 9) New DATV Repeater Outputs Original ATV Repeater Outputs: 1308.0, 1310.0, 1311.5, 1312.0, 1316.0, 1318.5MHz

Note 1: Local traffic using narrowband modes should operate between 1296.500-1296.800MHz during contests and band openings.
Note 2: Stations in countries that do not have access to 1298-1300MHz may also use the FM simplex segment for digital communications.
Note 5: Embedded data traffic is allowed with digital voice (DV).
Note 6: Simplex use only – no DV gateways.
Note 7: 1240.000-1240.750 has been designated by IARU as an alternative centre for narrowband activity and beacons. Operations in this range should be on a flexible basis to enable coordinated activation of this alternate usage.
Note 8: The band 1240-1300MHz is subject to major replanning. Contact the Microwave Manager for further information.
Note 9: Repeaters and Migration to DATV, inc option for new DATV simplex are subject to further development and coordination.
Note 10: QPSK 4 Mega-symbols/second maximum recommended.
Licence Notes: Amateur Service – Secondary User. Amateur Satellite Service: 1,260-1,270MHz – Secondary User Earth to Space only. In the sub-band 1,298-1,300MHz unattended operation is not allowed within 50km of SS206127 (Bude), SE202577 (Harrogate), or in Northern Ireland.
Notes to the Band Plan: As on page 48.

2.3-2.302GHz IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE

Access to this band requires an appropriate NoV, which is available to Full licensees only. Please note that the current NoVs last for up to three years prior to expiry.

2300.000-2300.400MHz	2.7kHz	Narrowband Modes (including CW, SSB, MGM) 2300.350-2300.400MHz Attended Beacons
2300.400-2301.800MHz	500kHz	Wideband Modes (NBFM, DV, Data, DATV, etc) Note 1
2301.800-2302.000MHz	2.7kHz	Narrowband modes (including CW, SSB, MGM) EME Usage

Note 1: Users of wideband modes must ensure their spectral emissions are contained within the band limits.
Note 2: Full licensees only with NoV, 400 watts maximum, not available in the Isle of Man. Note additional restrictions on usage are specified by the NoV terms. It should be emphasised that this is UK-specific and is available on a non interference basis to existing services.
Notes to the Band Plan: As on page 48.

2.3GHz (13cm) IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE
2,310.000-2,320.000MHz (National band plans)	200kHz	2,310.000-2,310.500MHz – Repeater links 2,311.000-2,315.000MHz – High speed data Preferred Narrowband Segment
2,320.000-2,320.800	2.7kHz	2,320.000-2,320.025MHz – Moonbounce 2,320.200MHz – SSB Centre of Activity
2,320.800-2,321.000 Beacons exclusive		2,320.750-2,320.800MHz – Local Beacons, 10W ERP max 2,320.800-2,320.990MHz – Propagation Beacons Only
2321.000-2322.000	20kHz	FM/DV. See also Note 1
2,322.000-2,350.000		Wideband Modes including Data, ATV
2,390.000-2,400.000		All Modes
2,400.000-2,450.000MHz Satellites		2,435.000MHz ATV Repeater Outputs 2,440.000MHz ATV Repeater Outputs

Note 1: Stations in countries which do not have access to the All Modes section 2,322-2,390MHz, use the simplex and repeater segment 2,320-2,322MHz for data transmission.
Note 2: Stations in countries that do not have access to the narrowband segment 2,320-2,322MHz, use the alternative narrowband segments 2,304-2,306MHz, 2,308-2,310MHz and 2400-2402MHz.
Note 3: The segment 2,433-2,443MHz may be used for ATV if no satellite is using the segment.
Licence Notes: Amateur Service – Secondary User. Users must accept interference from ISM users. Amateur Satellite Service: 2,400-2,450MHz – Secondary User. Users must accept interference from ISM users. Operation in 2310-2350 and 2390-2400 MHz are subject to specific conditions and guidance In the sub-bands 2,310.000-2,310.4125 and 2,392-2,450MHz unattended operation is not allowed within 50km of SS206127 (Bude) or SE202577 (Harrogate). ISM = Industrial, scientific and medical.
Notes to the Band Plan: As on page 48.

3.4GHz (9cm) IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE
3,400.000-3,400.800MHz	2.7kHz	Narrowband Modes (including CW, SSB, MGM, EME) 3,400.100MHz – Centre of Activity (Note 1)
3,400.800-3,400.995		3,400.750-3,400.800MHz – Local Beacons, 10W ERP max 3,400.800-3,400.995MHz – Propagation Beacons Only
3,400.000-3,401.000MHz	200kHz	3,401.000-3,402.000MHz Data, Remote Control
3,402.000-3,410.000 All Modes (Notes 2, 3)		Wideband Modes including DATV Repeater Outputs

Note 1: EME has migrated from 3456MHz to 3400MHz to promote harmonised usage and activity.
Note 2: Stations in many European countries have access to 3400-3410MHz as permitted by CEPT ECA Table Footnote EU17.
Note 3: Amateur Satellite downlinks planned.
Licence Notes: Amateur Service – Secondary User. Subject to specific conditions and guidance.
Notes to the Band Plan: As on page 48.

5.7GHz (6cm) IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE
5,650.000-5,668.000MHz		All Modes
Satellite Uplinks		Amateur Satellite Service – Earth to Space Only
5,668.000-5,670.000	2.7kHz	5,668.200MHz – Alternative Narrowband Centre
5,670.000-5,680.000		All Modes
5.755.000-5,760.000		All Modes
5,760.000-5,762.000	2.7kHz	Narrowband Modes (including CW, SSB, MGM, EME) 5,760.100MHz – Preferred Centre of Activity
5760.800-5760.995 Propagation Beacons		5,760.750-5,760.800MHz – Local Beacons, 10W ERP max 5,760.800-5,760.995MHz – Propagation Beacons Only
5,762.000-5,765.000		All Modes
5,820.000-5,830.000		All Modes
5,830.000-5,850.000 Satellite Downlinks		All Modes Amateur Satellite Service – Space to Earth Only

Licence Notes: Amateur Service: 5,650-5,680MHz – Secondary User. 5,755-5,765 and 5,820-5,850MHz – Secondary User. Users must accept interference from ISM users. Amateur Satellite Service: 5,650-5,670MHz and 5,830-5,850MHz – Secondary User. Users must accept interference from ISM users. Unattended operation is permitted for remote control, digital modes and beacons, except in the sub-bands 5,670-5,680MHz within 50km of SS206127 (Bude) and SE202577 (Harrogate). ISM = Industrial, scientific and medical.
Notes to the Band Plan: As on page 48.

10GHz (3cm) IARU Recommendation	NECESSARY BANDWIDTH	UK USAGE
10,000.000-10,125.000MHz All Modes		Note 4 10,065MHz ATV Repeater Outputs
10,225.000-10,250.000 All Modes		10,240MHz ATV Repeaters
10,250.000-10,350.000 Digital Modes		
10,350.000-10,368.000 All Modes		10,352.5-10,368MHz Wideband Modes (Note 2)
10,368-10,370MHz Narrowband Telegraphy EME/SSB	2.7kHz	10,368-10,370 Narrowband Modes (Note 3) 10,368.1MHz Centre of Activity
10,368.800-10,368.995 Propagation Beacons		10,368.750-10,368.800MHz – Local Beacons, 10W ERP max 10,368.800-10,368.995MHz – Propagation Beacons Only
10,370.000-10,450.000 All Modes		10,371MHz Voice Repeaters Rx 10,425 ATV Repeaters
10,450.000-10,475.000 All Modes & Satellites		10,400-10,475MHz Unattended Operation 10,450-10,452MHz Alternative Narrowband Segment (Note 3) 10,471MHz Voice Repeaters Tx
10,475.000-10,500.000 All Modes and satellites		Amateur Satellite Service ONLY

Note 1: Deleted.
Note 2: Wideband FM is preferred between 10,350-10,400MHz to encourage compatibility between narrowband systems.
Note 3: 10,450MHz is used as an alternative narrowband segment in countries where 10,368MHz is not available.
Note 4: 10,000-10,125MHz is subject to increased Primary user utilisation and NoV restrictions.
Note 5: 10,475-10,500MHz is allocated ONLY to the Amateur Satellite Service and NOT to the Amateur Service.
Licence Notes: Amateur Service – Secondary User. Foundation licensees 1 watt maximum. Amateur Satellite Service: 10,450-10,500MHz – Secondary User. Unattended operation is permitted for remote control, digital modes and beacons except in the sub-bands 10,000-10,125MHz within 50km of SO916223 (Cheltenham), SS206127 (Bude), SK985640 (Waddington) and SE202577 (Harrogate).
Notes to the Band Plan: As on page 48.

24GHz (12mm) IARU Recommendation	UK USAGE
24,000.000-24,050.000MHz Satellites	24,025MHz Preferred Operating Frequency for Wideband Equipment 24,048.2MHz – Narrowband Centre of Activity 24,048.750-24,048.800MHz – Local Beacons, 10W ERP max
24,048.800-24,048.995 Propagation Beacons	24,048.800-24,048.995MHz – Propagation Beacons Only
24,050.000-24,250.000 All Modes	

Licence Notes: Amateur Service: 24,000-24,050MHz – Primary User: Users must accept interference from ISM users. 24,050-24,150MHz – Secondary User. May only be used with the written permission of Ofcom. Users must accept interference from ISM users. 24,150-24,250MHz – Secondary User. Users must accept interference from ISM users. Amateur Satellite Service: 24,000-24,050MHz – Primary User: Users must accept interference from ISM users. Unattended operation is permitted for remote control, digital modes and beacons, except in the sub-bands 24,000-24,050MHz within 50km of SK985640 (Waddington) and SE202577 (Harrogate).
ISM = Industrial, scientific and medical.
Notes to the Band Plan: As on page 48.

47GHz (6mm) IARU Recommendation	UK USAGE
47,000.000-47,200.000MHz	47,088.2MHz – Centre of Narrowband Activity
47,088.000-47,090.000 Narrowband Segment	47,088.8-47,089.0MHz – Propagation Beacons Only

Licence Notes: Amateur Service and Amateur Satellite Service – Primary User. Unattended operation is permitted for remote control, digital modes and beacons, except within 50km of SK985640 (Waddington) and SE202577 (Harrogate).
Notes to the Band Plan: As on page 48.

76GHz (4mm) IARU Recommendation	UK USAGE
75,500-76,000MHz All Modes (preferred)	75,976.200MHz – IARU Region 1 Preferred Centre of Activity
76,000.000-77,500.000 All Modes	
77,500-78,000 All Modes (preferred)	77,500.200MHz – Alternative IARU Recommended Narrowband Segment
78,000-81,000 All Modes	

Licence Notes:
75,500-75,875MHz Amateur Service and Amateur Satellite Service – Secondary User.
75,875-76,000MHz Amateur Service and Amateur Satellite Service – Primary User.
76,000-77,500MHz Amateur Service and Amateur Satellite Service – Secondary User.
77,500-78,000MHz Amateur Service and Amateur Satellite Service – Primary User.
78,000-81,000MHz Amateur service and Amateur Satellite Service – Secondary User.
Unattended operation is permitted for remote control, digital modes and beacons, except within 50km of SK985640 (Waddington) and SE202577 (Harrogate).
Notes to the Band Plan: As on page 48.

134GHz (2mm) IARU Recommendation	UK USAGE
134,000-134,928MHz All Modes	
134,928 -134,930 Narrowband Modes	IARU Region 1 Preferred Centre of Activity
134,930 -136,000 All Modes	

Licence Notes: 134,000-136,000MHz Amateur Service and Amateur Satellite Service – Primary User. Unattended operation is permitted for remote control, digital modes and beacons, except within 50km of SK985640 (Waddington) and SE202577 (Harrogate).

THE FOLLOWING BANDS ARE ALSO ALLOCATED TO THE AMATEUR SERVICE AND THE AMATEUR SATELLITE SERVICE

122,250-123,000MHz – Amateur Service only, Secondary User
136,000-141,000MHz – Secondary User
241,000-248,000MHz – Secondary User
248,000-250,000MHz – Primary User

Note 1: Access to frequencies >275 GHz by Full Licensees is also possible by NoV.
Notes to the Band Plan: As on page 48.

NOTES TO THE BAND PLAN

ITU-R radio regulation RR 1.152 and Recommendation SM.328 (extract):

Necessary bandwidth: For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

Foundation and Intermediate Licence holders are advised to check their Licences for the permitted power limits and conditions applicable to their class of Licence.

All Modes: CW, SSB and those modes listed as Centres of Activity, plus AM. Consideration should be given to adjacent channel users.

Image Modes: Any analogue or digital image modes within the appropriate bandwidth, for example SSTV and FAX.

Narrowband Modes: All modes using up to 500Hz bandwidth, including CW, RTTY, PSK, etc.

Digimodes: Any digital mode used within the appropriate bandwidth, for example RTTY, PSK, MT63, etc.

Sideband usage: Below 10MHz use lower sideband (LSB), above 10MHz use upper sideband (USB). Note the lowest dial settings for LSB Voice modes are 1843, 3603 and 7053kHz on 160, 80 and 40m. Note that on (5MHz) USB is used.

Amplitude Modulation (AM): AM with a bandwidth greater than 2.7kHz is acceptable in the All Modes segments provided users consider adjacent channel activity when selecting operating frequencies (Davos 2005).

Extended SSB (eSSB): Extended SSB (eSSB) is only acceptable in the All Modes segments provided users consider adjacent channel activity when selecting operating frequencies.

Digital Voice (DV): Users of Digital Voice (DV) should check that the channel is not in use by other modes (CT08_C5_Rec20).

FM Repeater & Gateway Access: CTCSS Access is recommended. Toneburst access is being withdrawn in line with IARU R1 recommendations.

Beacons Propagation Beacon Sub-bands are highlighted – please avoid transmitting in them!

MGM: Machine Generated Modes indicates those transmission modes relying fully on computer processing such as RTTY, AMTOR, PSK31, JTxx, FSK441 and the like. This does not include Digital Voice (DV) or Digital Data (DD).

WSPR: Above 30MHz, WSPR frequencies in the band plan are the centre of the transmitted frequency (not the suppressed carrier frequency or the VFO dial setting).

Transmitter setup and Linearity: Close attention should be given to power amplifier linearity to control the final transmitted bandwidth and avoid spectral regrowth affecting adjacent users. In particular this can be a major issue when operating digital modes. It is recommended that operators do not use more power than is necessary, and that care is taken to ensure sound cards, interfaces, and other equipment are properly set up so as to minimise the potential for interference.

CW QSOs are accepted across all bands, except within beacon segments (Recommendation DV05_C4_Rec_13).

Contest activity shall not take place on the 5, 10, 18 and 24MHz (60, 30, 17 and 12m) bands.

Non-contesting radio amateurs are recommended to use the contest-free HF bands (30, 17 and 12m) during the largest international contests (DV05_C4_Rev_07).

The term 'automatically controlled data stations' includes Store and Forward stations.

Transmitting Frequencies: The announced frequencies in the band plan are understood as 'transmitted frequencies' (not those of the suppressed carrier!).

Centre of Activity (CoA): A guide to where users of a particular mode or activity tend to operate. The bandplan does not give such users precedence over other modes or activities.

Unmanned transmitting stations: IARU member societies are requested to limit this activity on the HF bands. It is recommended that any unmanned transmitting stations on HF shall only be activated under operator control except for beacons agreed with the IARU Region 1 Beacon Coordinator, or specially licensed experimental stations.

472-479kHz: Access is available to Full licensees only – see licence schedule for additional conditions.

1.8MHz: Radio amateurs in countries that have a SSB allocation ONLY below 1840kHz, may continue to use it, but the National Societies in those countries are requested to take all necessary steps with their licence administrations to adjust phone allocations in accordance with the Region 1 Band Plan (UBA – Davos 2005).

3.5MHz: Inter-Continental operations should be given priority in the segments 3500-3510kHz and 3775- 3800kHz. Where no DX traffic is involved, the contest segments should not include 3500-3510kHz or 3775-3800kHz. Member societies will be permitted to set other (lower) limits for national contests (within these limits). 3510-3600kHz may be used for unmanned ARDF beacons (CW, A1A) (Recommendation DV05_C4_Rec_12).

5MHz: Access is available to Full licensees only – see licence schedule for additional conditions.

7MHz: The band segment 7040-7060kHz may be used for automatic controlled data stations (unattended) traffic in the areas of Africa south from the equator during local daylight hours. Where no DX traffic is involved, the contest segment should not include 7,175-7,200kHz.
10MHz: SSB may be used during emergencies involving the immediate safety of life and property and only by stations actually involved in the handling of emergency traffic.
The band segment 10120kHz to 10140kHz may be used for SSB transmissions in the area of Africa south of the equator during local daylight hours.
News bulletins on any mode should not be transmitted on the 10MHz band.

28MHz: Operators should not transmit on frequencies between 29.3 and 29.51MHz to avoid interference to amateur satellite downlinks.

Experimentation with NBFM Packet Radio on 29MHz band: Preferred operating frequencies on each 10kHz from 29.210 to 29.290MHz inclusive should be used. A deviation of ±2.5kHz being used with 2.5kHz as maximum modulation frequency.

1.3GHz
The band is subject to re-planning. It is also shared with air traffic radar.

2.3GHz (2310-2350 & 2390-2400MHz)
Operation is subject to specific licence conditions and guidance – see also the Ofcom PSSR statement.

3.4GHz (3400-3410MHz)
Operation is subject to specific licence conditions and guidance — see also the Ofcom PSSR statement.

Innovation Bands: 70.5-71.5MHz, 146-147MHz, 2300-2302MHz and >275GHz
Access to these bands requires an appropriate NoV, which is available to Full licensees only.

The latest band plan information, including the master Excel files, can be found in the Operating section of the RSGB website. Please ensure you only refer or link to the *current* Band Plans. Remove / delete any older versions you have locally or online.

Technical

Poor man's multi-band HF beam

A poor man's multi-band HF beam

Many of us have restricted space and may only be able to erect a simple wire antenna for use on the HF bands. As we cannot control the direction in which we have maximum signal (one can't rotate a garden!), this puts us at the mercy of the orientation of the wire and the chosen operating band when we want to contact someone who is located in a specific direction. Although not a complete answer, by simply shifting the feed point of the antenna it is possible to alter the radiation pattern to improve the signal in otherwise unserved directions.

Figure 1 shows the patterns of radiation from a horizontal wire, normally used as a half-wave dipole on 7MHz, when driven on 14.2MHz. The black trace is the consequence of driving the antenna conventionally at the centre. In this case, currents in each half of the wire are in phase. The radiation fields from each half, therefore, add in broadside directions such that useful radiation is restricted to a relatively narrow azimuth range. When the wire is driven from an alternative position, 25% from one end, the currents in each half are of opposing phase and of near equal amplitude, causing minimal broadside radiation. (Astute Members may recognise this configuration as similar to the arrangement often referred to as a Windom antenna, although Mr Windom employed a single wire feeder that radiated).

At a distant receiver, located in directions off-broadside, the radiation from one half will now be delayed by having further to travel relative to that from the other half such that the two radiation fields are only co-phased, resulting in maximum field intensity, at angles ±40° from broadside. This pattern is shown by the blue line in Figure 1.

When the radiating element is driven off-centre, the impedance at the drive point is unbalanced. There is, therefore, some common mode current causing radiation from and reception by the feedline. However, in this case, when a vertical feed line was included in an EZNEC model of the antenna it had negligible effect on the blue radiation pattern.

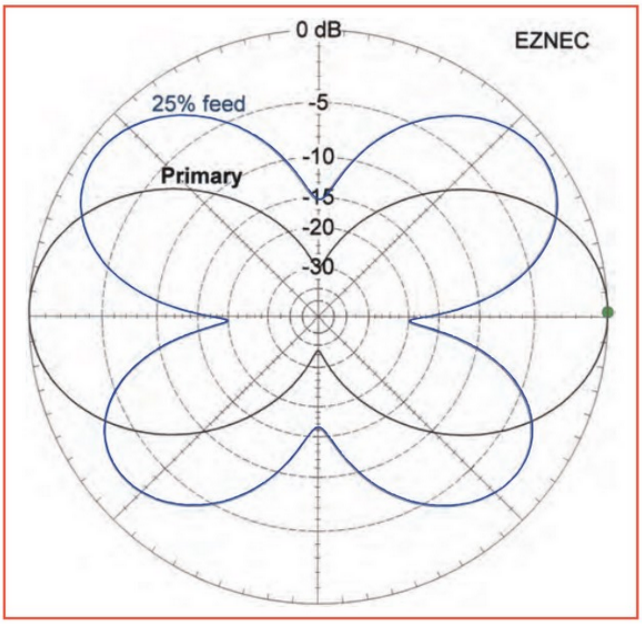

FIGURE 1: Effect of alternative feeds on 20m dipole. Black: normal centre feed. Blue: off-centre feed at 75%/25%.

Practical deployment

This antenna may be most usefully employed by arranging to switch between the two conditions illustrated by Figure 1. For example, in the UK if the wire runs N-S the radiation pattern favours the Caribbean or South Asia when driven at the centre of the wire, but it serves North and South America or the Middle East and Australia when driven 25% from one end. Take-off angle in the vertical plane depends on the height of the wire in terms of wavelength. 12m is a convenient height for many domestic locations but 18m will give gain of just over 9dBi on 14MHz at 14° elevation. This includes the typical effect of ground reflection and is coincident with minimum wasteful near-vertical incidence (NVI) radiation here and on 7MHz.

The 14MHz patterns of Figure 1 are repeated at 18MHz, with more gain, but for a symmetrical pattern on 21MHz the wire was reduced to 19.2m (63ft). The low elevation patterns on 24 and 28MHz now have maximum broadside radiation with off-centre feed and maximum in the quadrants when the wire is centre-fed. At high vertical angles the centre-fed pattern peaks off the ends of the wire on these two bands. On the 10MHz band there is not much difference between radiation patterns when switching the feed point. However, the high feed point voltages expected here are likely to restrict input power on this band if you choose to use relay switching similar to the type I shall describe.

Because SWRs are quite high in either driving situation the feeders need to be ribbon or ladder-line type to minimise their attenuation. Coax is really not suitable. An antenna tuner with balun is also necessary. This will normally require adjustment when the feed point is altered, even if the frequency is not changed. Where it suited the orientation of the wire we could use a single feed line by permanently adopting one of the two alternative radiation patterns of Figure 1. One may otherwise be prepared to control the radiation pattern by dropping the antenna to shift the feeder connection. This could confirm the benefit of pattern switching if it is doubted.

Relay switching

To readily switch between patterns we will need a pair of feeders and suitable relays for disconnection of the unused feeder and to simultaneously short circuit the unused feed point. **Figure 2** shows the arrangement that I used for relay switching. Unless low power operation is intended the two relays need to be high voltage types and environmentally protected. Vacuum relays are desirable (and they become essential for high power) but when bought new, even from China, suitable double pole vacuum relays such as the appropriately-rated Gigavac type G12SP-12VDC are expensive and would belie my article's title. Surplus Russian military relays and USA Jennings types removed from redundant equipment may be found at rallies or in a search of the internet.

With the exception of 10MHz, the maximum calculated feed point voltage on our bands for a 20m wire of 2mm diameter occurs

Tony Preedy, G3LNP
g3lnp@talktalk.net

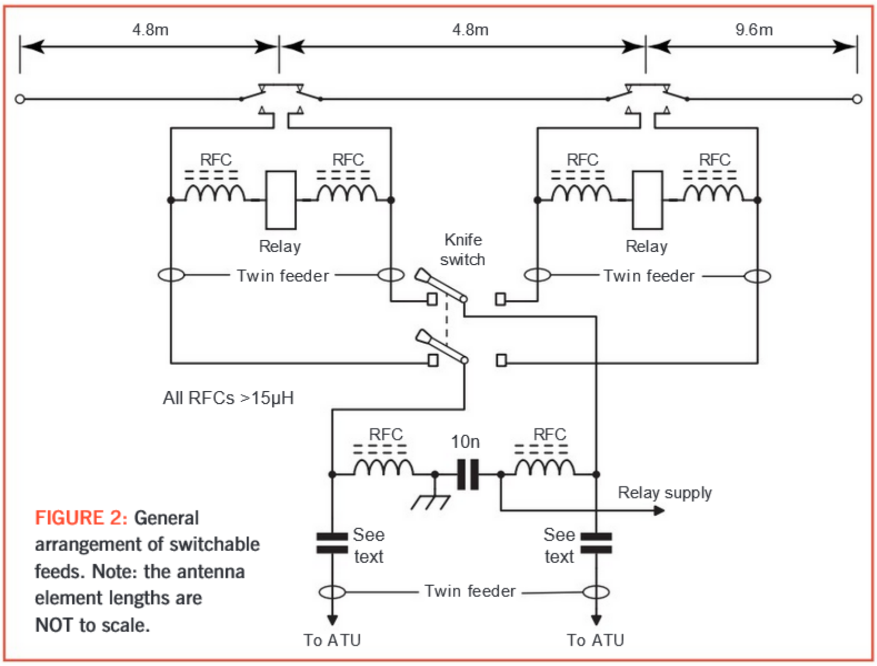

FIGURE 2: General arrangement of switchable feeds. Note: the antenna element lengths are NOT to scale.

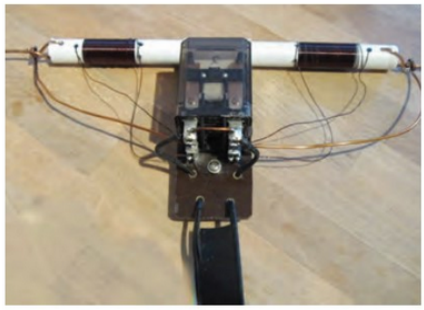

PHOTO 1: General arrangement of one of the relay-switchable feeds. Note that the two chokes wound on the white plastic rod are used to feed the relay and are not part of the radiating array.

on 14MHz when driving the centre of the wire. Here it is about 750V per side when the antenna is driven at 400W. As we are not live-switching, we may use inexpensive conventional heavy duty relays (because we are primarily concerned with their ability to withstand high potentials). I used Schrack type RM805024, which were available to me. These are rated for switching a load of 25A at 250V AC but are insulated for 1000V. For best environmental protection these particular relays needed to be mounted with their connections pointing down. I added a covering of black insulation tape to try and keep the weather out.

More appropriate relay types would be the encapsulated 600V T92 series made by Potter and Brumfield, stocked by RS and others. These are tested with DC at 1500V across contacts, 2000V between contact sets and 4000V between contacts and coil. The corresponding RMS ratings are 0.7 times these values, which implies these relays could withstand up to about 1kW in this application.

The relay coils need to be driven via a pair of chokes that, to ensure they do not pass too much RF current, should be of at least 15μH inductance. Because they have to withstand high potentials they need lots of turns and hence a small diameter. Based on 10V per turn at 400W, 15μH chokes may be formed from 0.5mm enamelled wire, wound as a coaxial pair of single-layer solenoids each of ~70 adjacent turns on a 15mm tube or rod of insulating material such as fibreglass. The former for the chokes may then become the feed-point insulator. The choke windings should be covered with black insulation tape or similar to protect the enamel from solar radiation. *['Liquid Electrical Tape', a paint-on, self-curing rubber compound might also be a suitable option, as might be self-amalgamating tape – either would also keep the weather out. Ed].* My relays were attached to a piece of insulation board. The board was attached to the insulator/choke with a pair of plastic P clips. Four holes were drilled in the board to terminate the 450Ω ribbon feeder.

Beware that the cheaper ribbon feeders, made with copper plated steel or aluminium conductors may restrict the voltage at the relay coils due to their increased DC resistance. They perform OK at RF because the skin effect means only the thin copper plating layer actually carries the RF signals.

The feeders may be of any length. At the ground the feeders may be selected with another high voltage relay or by a high voltage switch such as a knife switch or a rotary ceramic wafer type (as used in valve linear amplifier pi tank circuits). This area also introduces the relay control voltage via a pair of chokes similar to those at the antenna. Blocking capacitors are required to prevent the relay coil voltage from reaching the balun. These must be 1000pF or more and be capable of passing up to 5A of RF current (at 400W; more at higher powers) in a worst case of feeder length. A 0.01μF RF by-pass capacitor of 50V rating is required to filter residual RF current from the DC supply. It is advisable not to use a switch mode supply for the relays as this may introduce QRM.

Conclusion

If you have the option to set up an antenna in this fashion I do recommend you give it a go. You can experiment without expensive high voltage relays and switches, simply by physically moving the feeder and making the appropriate connections.

Lasers for making cases?

I have been playing with a sub-£300 40W CO_2 laser cutter and suspect it may hold promise for making neat custom cases for projects. Thus far I have only made tiny, simple test boxes from inexpensive thin plywood, mainly because there are online box designers that magically produce the cutting files. It's not much of a leap of imagination though to an entire bespoke project case laser-cut from acrylic sheet and complete with all necessary holes and even engraved labels.

If you have been experimenting along these lines then I'd like to hear from you, with a view to putting together an article for *RadCom*. Please get in touch via giles@rsgb.org.uk – thanks.

Giles Read, G1MFG, *RadCom* Technical Editor

Understanding LoRa(part 2)

Last month I hope I whetted your appetite to experiment with LoRa. In this second and concluding part I explain the hardware and software required, then lead you through the process of building your own pair of nodes with which to experiment. Even if you have never programmed a device like this before, this article will talk you through every step and hopefully get you 'on the air' with LoRa.

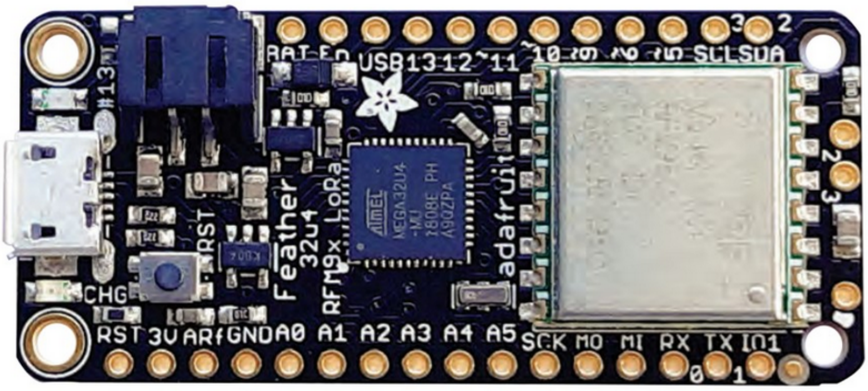

PHOTO 1: Adafruit LoRa Feather.

What do I need?

There are really two key components to build a LoRa node. The first is a SemTech LoRa transceiver [5]. You can't build this yourself – it is proprietary – but you can buy them cheaply enough (often for well under £5). On its own though, the LoRa transceiver is not enough: you need to couple it with a 'brain', or microcontroller, to control it.

It is possible to connect a LoRa board to a variety of development boards that contain microcontroller devices (including the BBC micro:bit, and the Arduino and its clones). You can also use single-board computers, such as the Raspberry Pi. Although I have all of these devices in the shack, my own use has focussed on Arduino-type devices and that is where I will focus in this article, particularly concentrating on a development board known as an Adafruit Feather. It doesn't matter if you are not familiar with any of these devices – there are absolutely loads of tutorials on the internet, with example code to download and use or modify. It is perfectly possible to play with LoRa with NO previous coding experience: this part of the article is to guide you to do exactly that.

Photo 1 shows an Adafruit LoRa Feather. This contains a 32u4 microcontroller and the SemTech LoRa chip on one board. It also has a built in connection for a LiPo battery, which is easily recharged through the on-board USB port. In this picture, the SemTech LoRa transceiver is on the daughterboard largely obscured by the metal shielding can. The advantage of this solution is that everything you need is contained on the one board, minimising the need for additional wiring and reducing the space required. I now use this board extensively. They cost around £33.

Whether you have a BBC micro:bit, Raspberry Pi or some other board you wish to use, you can adopt a similar approach to the Adafruit board by purchasing a LoRa add-on board. These often take the form of a daughterboard that sits on top of the processor board, connecting via header pins, and are known as Hardware On Top, or 'HAT'. The advantage is that a HAT greatly reduces the need for inter-wiring and similar boards exist for many of the popular single board computers. However, the code in this tutorial is NOT directly transferrable to these other devices.

Let's build!

We are going to build and code a pair of LoRa nodes to act as a matching pair. We will, initially at least, code them as a simple range tester, but the beauty of these devices is that you can later re-code them to do whatever you want. For example, I use a pair of nodes to transmit weather data to my house from the bottom of my field (where no Wi-Fi is available). Effectively, once you have your nodes established and become familiar with them, the code can be amended to read data from just about any sensor and transmit it to your receiving node. You might then choose to take action based on that data. Again, don't be put off it you have never programmed before as there are literally hundreds of tutorials on the internet. I will signpost some of these later on.

Hardware

For this project I am going to use two of the Adafruit Feather 32u4 RFM96 LoRa radio for 433MHz [6]. Be careful when purchasing, as there are several variations of this board. If you follow the link you will be fine. Adafruit has an excellent tutorial on the boards, with pinout details, power information and example code [7]. You could just use their code instead of mine, but I think mine will be somewhat easier for beginners to follow as it is a more basic example and specific for the board we are using. In addition, I have added code that allows you to play with all of the modulation parameters described in the first part of the article.

For this range tester we will use two transceiver boards but will use one as a transmitter and one as a receiver. With different code it is possible to send and receive acknowledgements (using them both as transceivers) but I want to keep this tutorial as simple as possible to encourage as many people as possible to have a go.

I have chosen 433MHz boards as I find the range is generally better, despite the lower power restrictions for licence-free use. Also, as 433MHz is in the middle of an amateur band there is no likelihood of making illegal transmissions from boards intended for a different region. We amateurs can legally experiment with using much higher transmit powers, provided we abide by the other terms of our licences (eg no airborne operation, even though standard, licence-exempt operation may permit that). My prototype 433MHz range testers are seen in **Photo 2** and we'll build a similar pair in this article.

Photo 3 shows an internal view of the receiver. The only wiring difference from the transmitter is the small black piezo sounder behind the power switch. I added this

PHOTO 2: **My prototype 433MHz range testers.**

because it can be difficult to see the LED in bright light as you move around and a beep is a useful extra. Make sure you use a low current (piezo not mechanical) buzzer that will run from 3.3V.

Figure 5 shows one possible layout of the receiver using breadboard, though in my case I just used point-to-point wiring. The LED and piezo sounder are connected to Analog Pin 0 of the Feather and indicate successful reception, flashing and beeping on receipt of a packet. The antenna connection is via solder pads on the underside of the board (see **Photo 4** and description later). For the transmitter, just omit the piezo sounder (although there's no harm in keeping it). The LED is still used to indicate a packet being sent.

The Adafruit tutorial page makes it clear that this circuit is NOT suitable for alkaline or NiMh batteries. A 3.7V lithium-polymer (LiPo) battery with JST (Japan Solderless Terminal) connector is used and this plugs directly into the JST connector on the Feather. It is essential to ensure that the polarity of your battery connector matches the polarity of the Feather. There is no 'gold standard' and you have a 50-50 chance of it being disastrously wrong. Buying both items from the same source greatly increases the likelihood they will match.

When the Feather is plugged into 5V USB, the battery will charge using the Feather's on-board charging circuit. However, you can power the board by simply using USB if you prefer. (You could use a USB battery pack, but be aware that the current consumption of the Feather is so low that some USB battery packs will go to sleep rather than power the device). You can get around this by artificially increasing current draw, eg by simply putting a resistor across the supply (perhaps start with 220Ω, which will draw about 23mA from a 5V supply).

You can see that I use Analog Pin 0 of the Feather, when set to HIGH, to flash an LED and sound a buzzer via a 220Ω (or similar) resistor. You can, as I did, insert another LED in the power line to show the device is switched on. I have left this out of the diagram for clarity.

For an antenna you have two simple choices really, you can use a proprietary antenna for the frequency or simply a length or two of wire. Photo 4 shows the relevant pads. The two rectangular pads are ground and the small square / through hole are the coax centre. You could simply solder two quarter wave wires to these pads, or solder coax directly. I chose to solder on a Hirose U.FL **[8]** socket, allowing me to connect a U.FL to SMA pigtail. The SMA socket has a bulkhead mounting, allowing me to swap antennas easily.

As you might expect, the use of only the 'centre' connector, ie without ground plane, is much less efficient. If you are using a commercial stubby whip antenna you could use either a metal case or 'rats-tail' arrangement for the ground plane.

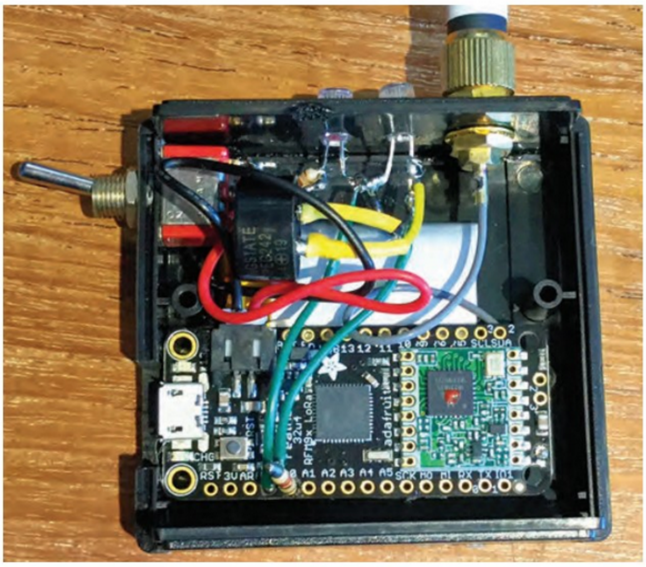

PHOTO 3: **Internal view of the range tester receiver. The transmitter is similar. The LiPo battery is the silvery rectangle under the PCB.**

I have experimented with a number of antennas from small whips to 'puck' type antennas, collinears, and 10dbd gain Yagis. To stay legal one must adjust the power output in the software to maintain an effective radiated power (ERP) of no more than 10dbm or, if operating at higher ERP under your amateur licence, ensure you identify your callsign in the packets. There's more on antennas and signal strengths later.

If you only want to experiment across a desk, you can simply temporarily solder a 50Ω resistor in place of the antenna. Enough signal will 'leak out' for (very) short-range working, and you won't run any risk of damaging the output stage if it unexpectedly transmits. Remove the resistor of course when you're ready to attach an antenna.

I mounted my devices in small plastic instrument cases that measure about 60mm square. I used hot-melt glue to secure the battery and Feather, drilling the case for the switch, LEDs and antenna. A slot was cut in the side of the case to access the USB port for charging.

Software

This description is aimed at those who have not programmed an Arduino-type device before, as I want to encourage as many people as possible to have a go. The description is part step-by-step and part by reference to existing tutorials – there is little point in re-inventing the wheel and it helps to keep the article reasonably short.

First, some essential prerequisites. You need a programming environment on your computer and a suitable USB A to Micro USB data cable. Please make sure the cable you have is suitable for data and is not just a charging cable. This is a very common error made by beginners and can cause much frustration! Many cheap phone charging cables do not do data. Buy a decent quality one. It's easy to tell if you have the right type because if you use it to connect between an Android device and a PC, the computer can only 'see' the device through a data cable.

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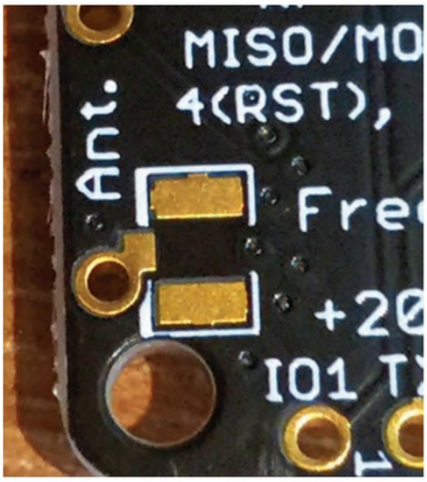

PHOTO 4: Antenna pads. The through-hole is signal; the rectangular pads are ground.

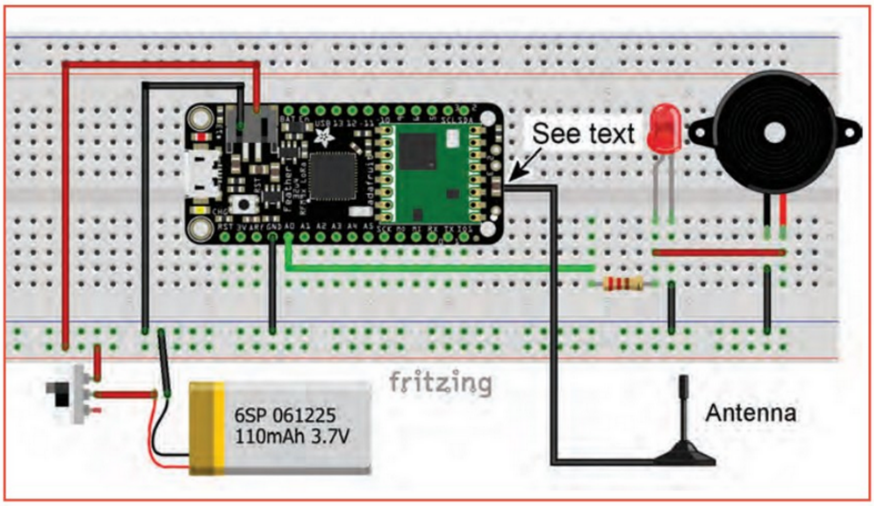

FIGURE 5: One possible layout of the receiver.

We are going to use the Arduino IDE (Integrated Development Environment) as our programming environment. The IDE can be downloaded on Windows, Mac and Linux, including Raspberry Pi OS. You need to download the IDE, rather than use the web-based version, in order to properly program the Adafruit Feather. The best route to do this is described in the Adafruit tutorial [7], beginning at **[9]**, Arduino IDE setup, plus following stage 'using with Arduino IDE.' You do not need to upload the example 'Blink' sketch unless you wish to do so. At this stage we are going to leave the Adafruit tutorial. There is example radio code on the tutorial you may wish to try, but I feel it is a little complex to easily follow.

Having downloaded the IDE and had our board recognised, we next need to add a new 'library' for our example code to work. A library is a repository of code where other programmers have done much of the 'heavy lifting' for us, developing code that we can use much more easily than starting from scratch. With the IDE open, navigate to the top menu to Sketch > Include Library > Manage Libraries. There is a 'Filter your search…' bar in the top right. Click in it, type 'lora' and press enter. Scroll down a number of libraries until you find the entry 'LoRa' by Sandeep Mistry. Hover your mouse over this library and click 'install'. Now close the IDE and re-open it. Navigate to Files > Examples and scroll down the list. You should see the LoRa library present there, with a number of provided examples for that library.

We are not going to use the basic examples provided as they are a little limiting. Rather we are going to use a modified version of them that I wrote, as this will provide you with a little more room to experiment.

Transmitter software

As a first step, take the board you are going to use as your 'transmitter' and connect it via USB to your computer. Make sure there is an antenna connected! Navigate in the IDE to Tools > Board and ensure you have selected Adafruit Feather 32u4, then navigate to Tool > Port and ensure you have selected the serial port your board is connected to (there should be a tick alongside it).

Next, navigate to Files > New and you will get a blank screen. Then, in your browser, navigate to my personal repository on github **[10]**. There you will find three files. Open the Transmitter file, RadCom_LoRa_433_TX.ino. Select all the content of the file and copy and paste it into the Arduino IDE, then save that file within the IDE with any name you choose.

You will see that there is a lot of 'normal' text mixed in with the code, in the form of notes prefixed with '//'. These are comments that are not executed in code – they are there for explanation. Hopefully they will give you an idea of what the code is doing as well as tell you the parameters that you can change, as explained in part one of this article.

The modulation factors you can change are all set to be at the 'lower' or 'minimum robustness' end of the spectrum in this sample code, as this is just how I last used it. Working on the premise that you should not use more power than you need, I would recommend you start with these parameters as per the example code, then work up from there in your experimentation. Remember to mirror EXACTLY changes in both the Tx *and* Rx software, otherwise the system simply won't work.

Now the code from my GitHub repository is in your Arduino IDE and you have saved it and made any amendments you wish, you need to upload it to the Feather.

At the top of the IDE, just underneath the menu headings are some symbols. First click the symbol of a tick. This verifies the code is correct and compiles it into a format the board can understand. If this goes without a hitch, it should say 'Done Compiling' in the green bar beneath the code. If this does not work and you get an error message, check the code to make sure you have not made any accidental mistakes or changes – code is very 'picky' about the correct syntax. If you cannot resolve it, try copying in my code again without making any changes and compile again.

IMPORTANT: *as soon as the code is uploaded the board begins transmitting*, so ensure you have an antenna connected before you take the next step. Failure to do so could wreck the board. Click the right facing arrow to the right of the 'tick.' This should upload your code to the board and you should get a message saying it has been successful.

Next navigate to Tools > Serial Monitor. A pop-up window will open showing the transmitter output and verifying it is working. The LED should also flash each time a packet is sent.

Receiver software

At this point I recommend you disconnect your transmitter board for the time being. In the IDE, navigate to File > New. A new window will open. Close the old Transmitter window. From my GitHub repository [10] copy the code for the Receiver – RadCom_LoRa_433_RX.ino – and paste it into the new window, naming and saving the file. Follow the previous instructions to upload the file to the Receiver board. Assuming

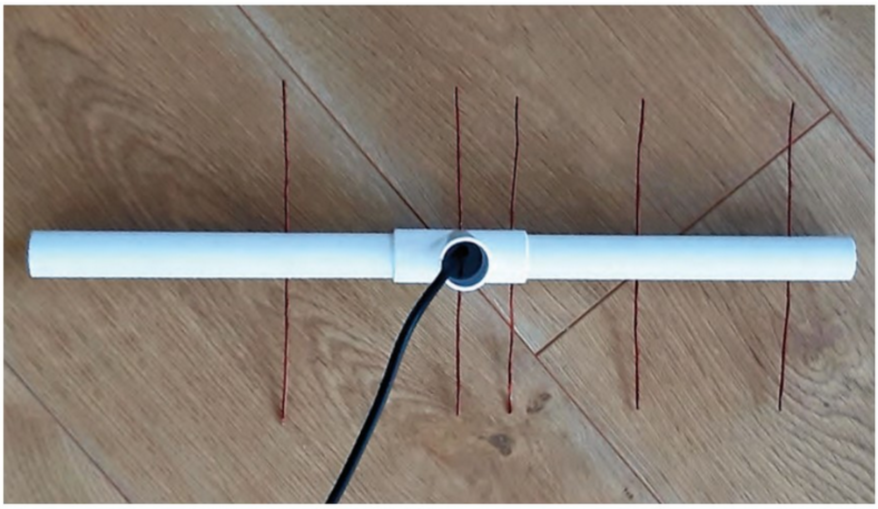

PHOTO 5: A simple 5-element Yagi constructed from bits of scrap.

you have been successful, open the serial monitor (Tools > Serial Monitor). Power up your transmitter (either use a Li-Ion battery using the JST connector, or to another USB power supply) then wait to hear your receiver beep and flash and for data packets to appear on your serial monitor. You should see data accompanied by the number of the packet, the Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR).

Congratulations, you now have a working LoRa transmitter and receiver!

You can now begin to experiment with different modulation factors, powers and antennas, remembering to keep the ERP below 10dBm if not operating under an amateur licence. The RSSI and SNR figures will help you gauge the relative strength and readability of your signal. Any missed packets will be obvious by a gap in the consecutive packet number sent with each transmission.

Understanding RSSI and SNR

Many of us may very well confine our assessment of signal strength to either our ears or readings from our radio's S-meter. When operating with LoRa though we have two main, quantitative indicators of reception: receive signal strength indication (RSSI) and signal to noise ratio (SNR). One could argue that it's also possible to derive a 'goodness' measure from the number of corrupted data packets, but that is outside the scope of this article.

A signal above -100dBm (RSSI) such as -90dBm should be considered as good. A signal between -115 and -100dBm, can be thought of as mediocre; below -115dBm is weak. I have personally received signals with a (reported) RSSI of -130dBm from time to time, but they are rare.

The second indication of 'received strength' is the signal to noise ratio (SNR). This describes the amount of RF noise compared to the wanted signal. Typically, a SNR of above 0 is considered as good, and anything below -4 as bad. The lower the SNR, the more challenging reliable reception will be.

What I encourage you to do is to experiment with all the modulation settings that I described in the first article and play around to assess the impact of each. You are sure to find that, for example, increasing the Spread Factor will increase both RSSI and SNR on weak signal paths.

Bear in mind that whilst it is perfectly possible to receive very weak signals with low RSSI and SNR, the reliability of those signals reduces significantly at the same time.

In the commercial Internet of Things (IOT) world, where LoRa is used significantly, it is considered that an RSSI of -120 and SNR of -10 will result in a weak signal with many packets being lost. At the other end of the scale an RSSI of -80 and SNR of 10 would be considered good and strong, with the Tx and Rx probably within just a few metres of one another.

Very recently, in my own work with my weather station project, I realised I was missing some packets. They were not making it from the bottom field through the 60cm-plus thick stone house walls. I thought of merely increasing SF and CR (see first article) but these would significantly increase power consumption, as each packet would take longer to transmit. As this is a battery and solar powered project, this was undesirable. Instead, I took advantage of my amateur license and built a Yagi antenna from scrap to provide gain, without increasing battery consumption.

More on antennas

Using an online Yagi calculator **[11]** for the design information, some scrap 21.5mm overflow pipe for the 'boom' and some stiff 1.6mm enamelled copper wire fpr the elements, I made the 5 element Yagi seen in **Photo 5**.

Using a normal 70cm transmitter and SWR meter for measurements, I was able to trim the homebrew antenna to achieve an SWR of 1.2:1 at my desired frequency. The calculator suggests a gain of nearly 8dB over a dipole. By fixing this next to my transmitter my weak signal problems were solved, with no increase in battery budget. Why not try for yourself? Even a simpler antenna such as a corner reflector or a J-pole (Slim Jim) would be a manageable size on 433MHz and will improve range. Anything that works on 70cm will be fine for 433MHz LoRa under an amateur licence. Have a go!

What next?

Experimenting with range is one thing, but the real power of LoRa is in transmitting data from sensors and other devices either to other nodes or into the cloud. There are lots of resources online to help you explore this further.

Sadly I am not able to help with individual queries about any difficulties you may have, but if you follow the instructions carefully you should be OK, plus, if you get any errors you don't understand, remember to check for typos in the code and use the internet and forums for help. Searches on the Arduino forum often provide answers. I hope you are encouraged to have a go!

Websearch

[5] LoRa is a trademark of the Semtech Corporation
[6] https://shop.pimoroni.com/products/adafruit-feather-32u4-rfm96-lora-radio-433mhz-radiofruit
[7] https://learn.adafruit.com/adafruit-feather-32u4-radio-with-lora-radio-module/overview
[8] https://en.wikipedia.org/wiki/Hirose_U.FL
[9] https://learn.adafruit.com/adafruit-feather-32u4-radio-with-lora-radio-module/setup
[10] https://github.com/BrendonHills/RadCom_LoRa
[11] www.changpuak.ch/electronics/yagi_uda_antenna_DL6WU.php

Looking for inspiration about how else to use LoRa? See www.hackster.io/projects/tags/lora

Info and guidance for Raspberry Pi users is at https://learn.adafruit.com/lora-and-lorawan-radio-for-raspberry-pi

Info for the BBC micro:bit and connecting to The Things Network is at https://learn.pi-supply.com/make/getting-started-with-the-microbit-lora-node/