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

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New Products

AH-705 HF/50MHz Automatic Antenna Tuner

Icom has announced details of its forthcoming portable automatic antenna tuner for the IC-705. The AH-705 is a palm-sized portable antenna tuner that has been designed to work between the 1.8-50MHz bands. It can be powered either by alkaline batteries or DC 13.8V supply. Just some of its other features include latching relays used for saving power consumption, IP54 dust-protection and water-resistant construction for outdoor use and a compact design that neatly fits in the optional LC-192 multi-function backpack.

Price and availability information will be available soon, see www.icomuk.co.uk for the latest news.

Anytone AT-779 Micro FM 4m transceiver

ML&S are pleased to introduce this tiny 15W 70MHz 4m FM transceiver from AnyTone. The AT-779 is a simple entry to 4m operation, includes 199 memories, CTCSS & DCS, selectable power levels of 5, 10 or 15W output and a hard-wired DC lead and fist mic with up/down buttons. The introductory price is £79.95 and includes a PC control cable and free software via a website download. It's available now from ML&S Ltd and you can find out more at www.HamRadio.co.uk/AT779.

New off centre-fed dipole

LAMCO has launched a new range of Vine Antenna products. The new AS-OCF-404-HP is designed to work with an IC-7300 or the new FTDX10. It is a high powered, off centre-fed dipole for the 40m to 4m bands (17m, 12m with external ATU). The power rating is 1kW pep maximum and its overall length is 69 feet (21.03m). The AS-OCF-404 has a specially designed balun that offers both a 75 ohm and 200 ohm output, allowing two pairs of elements to be connected. One set of elements is a traditional dipole for 4m (70MHz) and the other an OCF dipole for HF and 6m. It retails for £159.95 and you can find out more on the LAMCO website at www.hamradio-shop.co.uk.

Twin paddle magnetic Morse key

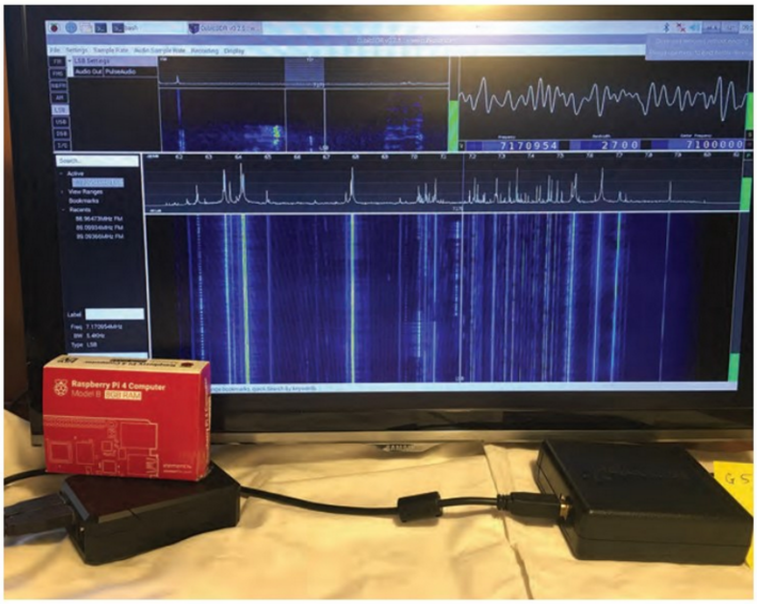
The Vine Antenna RST-TP1 is twin paddle magnetic Morse key and is one of a range of Vine Antenna Morse keys. All are precision engineered and assembled by hand for build quality and user experience. It retails for £169.95. More on www.hamradio-shop.co.uk.

End Fed City Windom

The Vine Antennas AS-CITY-80 is an End Fed City Windom, an end-fed antenna design featuring a long wire plus a resonant matching network comprising a balun, a length of RG-58 and a line isolator. The City-Window behaves much like a normal Windom but is better suited to suburbia and can be suspended from a window to a suitable anchor point. Covering the 80m, 40m, 20m, 15m, 10m (without ATU) and 30m, 17m, 12m (with ATU), it retails for £159.95. More details at www.hamradio-shop.co.uk.

Straight Morse key

The Camelback is a new miniature straight Morse key from Vibroplex, USA. It is designed for portable operations, weighing just 66g with an oval base just 50 x 25mm. With its Camelback lever arm it is constructed to be balanced and a joy to use. Separate adjustments are provided for both spring tension and sending gap. You can send some nice CW then just pop it in your pocket when you are done! The key is available for £109.95 from the Vibroplex exclusive UK distributor, Nevada. More information can be found at www.nevadaradio.co.uk.



New Icom firmware updates

Icom has announced some plans to introduce new firmware updates for the IC-705, IC-7300 and IC-9700 transceivers. The updates are planned to improve user experience of data modes such as FT8. The firmware release will start with the IC-705 and then be followed by the firmware for the IC-7300 and IC-9700. The updates will be available as free downloads from www.icomjapan.com/support/firmware_driver.

Planned updates include a one-touch FT8 mode preset, the Scroll mode automatically keeps the operating signal within the scope range and a multi-function dial items improvement (new for IC-7300 and IC-9700). Icom also plans to update the RS-BA1 Ver2, CS-705 and the CS-9700 programming software.

Keep up to date with the latest available updates by going to www.icomuk.co.uk.

Raspberry Pi scripts for SDRplay RSPs

SDRplay has just released some Raspberry Pi installer scripts that allow you to add SDRplay-specific software to your existing Raspberry Pi configuration. Up until now, you either had to use the dedicated SD card images provided by SDRplay, or run a long list of commands and adjust many settings in order to get the SDR software working. All this can be a time consuming and cumbersome process that, unless you are an experienced programmer, can prove to be daunting. The installer script is an executable file that handles all this for you (it will install the software packages and tweak the settings so that everything is ready to run). The new SDRplay installer scripts are available from https://www.sdrplay.com/downloads/ (select your RSP model and choose ARM Raspberry Pi OS – then choose “API” to download them).

There is also a YouTube video guide on https://youtu.be/-KHMOVmxLEU in which SDRplay shows you how to download, extract and execute installer scripts for the SDRplay API, CubicSDR and RSP_TCP Server.

The RSP family of SDR receivers range in price from around £100 to £240 and are available directly from SDRplay Ltd, or Martin Lynch & Sons, Moonraker, Nevada, Radioworld, SDR-Kits and Waters & Stanton. Full details can be found by going to www.SDRplay.com.

Antennas

10m, 6m and 4m Beam Antennas: part 2

During the Sporadic-E season, operating on the 10m, 6m and 4m bands can bring some surprising results and a directional antenna can provide a distinct advantage. This month, Part 2 summarises Yagi beam arrays for the 6m and 4m bands.

General background

In a similar way as for the 2-element beam antenna described last month, the two Yagi beam arrays to be described were designed using the MMANA-GAL analysis application **[1]** to predict their dimensions and to model their performances at 7m above ground level (AGL). The spacing between each antenna's elements was arranged to give close to 50Ω at its dipole centre **[2]** to ease matching. Using these dimensions, each antenna was constructed and fed using 10m of RG58 coax cable. A current choke 1:1 balun was included in the coax cable by winding six turns of the cable into an inductor, with an internal diameter of 50mm and held together using insulating tape. The balun was situated as close to the coax cable's connection to the dipole as practical **[3]**. The construction of each antenna is summarised in the following sections.

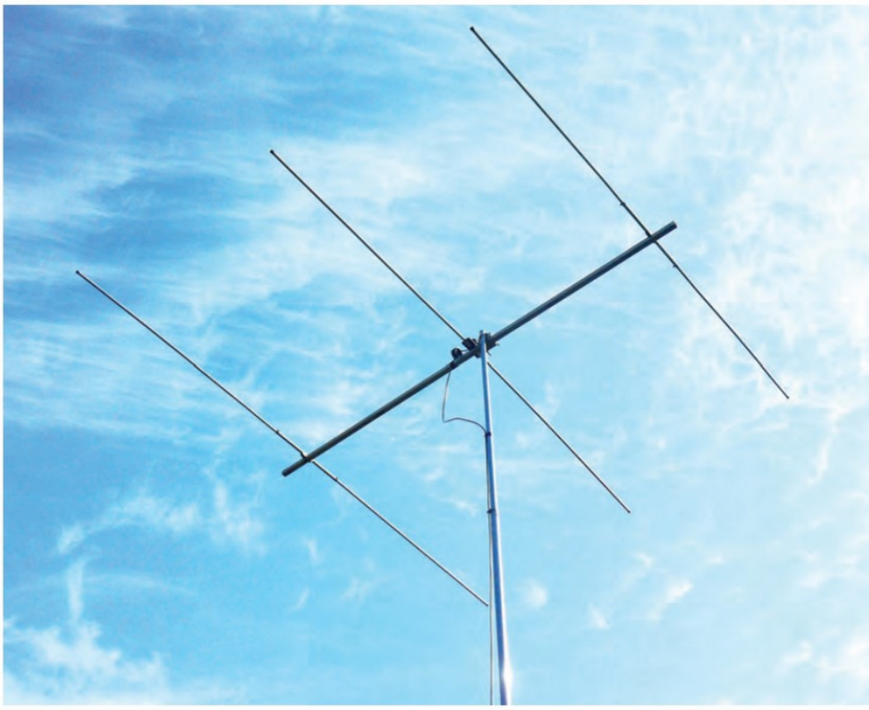


PHOTO 1: **The 3-element Yagi beam array for the 6m band in use.**

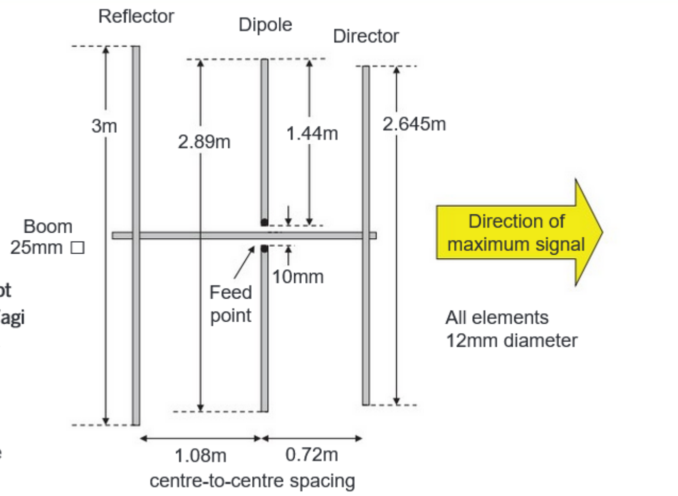


FIGURE 1: **Concept of the 3-element Yagi beam array for the 6m band and the actual dimensions used for the construction of the antenna.**

A 3-element Yagi beam array for 6m

Adding a third shorter element, or director, in front of a 2-ele beam's dipole improves the antenna's performance by further concentrating the RF signal ahead of the director element. The director is made about 5% shorter than the dipole and its addition creates an arrangement that is usually referred to as a Yagi beam array **[4]**.

The concept of a 3-ele Yagi beam array constructed for the 6m band comprising a reflector, dipole and a director is shown in **Figure 1**, which also includes the antenna's dimensions for reference. The completed antenna is shown in **Photo 1** being used during a Sporadic-E opening.

Predicted performance

The Yagi beam array's performance was predicted using the MMANA-GAL analysis application at 50.15MHz as giving a free-space gain of about 5dBd (7.1dBi) and a front-back ratio (F/B) of around 15dB. **Figure 2** shows the antenna's predicted radiation pattern as polar plots, with the antenna horizontally polarised and modelled at 7m AGL. At this height above the ground, the antenna's predicted vertical radiation pattern indicated three forward lobes with most of the RF signal concentrated in the two lower forward lobes, whose radiation angles are around 40° and 12°. At these angles of radiation, this will tend to favour the station being able to work shorter and medium skip stations when the Sporadic-E propagation conditions allow. At 7m AGL, the predicted gain for the antenna was 12.6dBi, corresponding with the lowest forward lobe at around a 12° angle of radiation. Occasionally, the conditions in the ionosphere may allow longer skip propagation to occur on the 6m

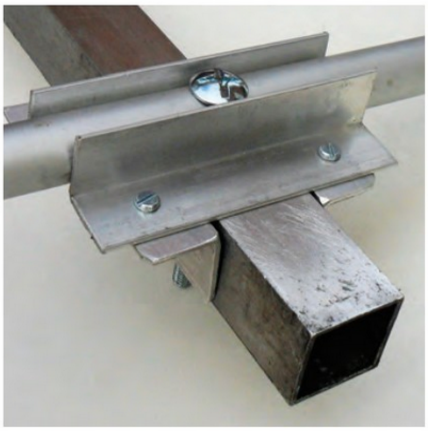


PHOTO 2: An example of one of the homebrew element clamps used for the Yagi beam array.

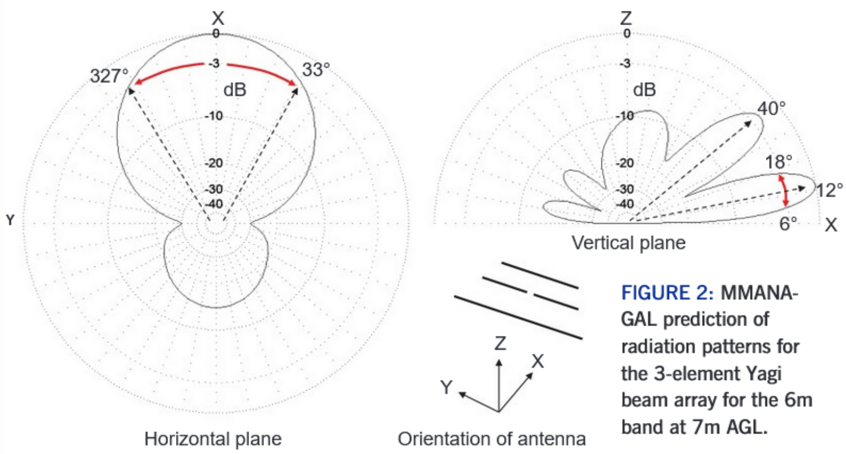


FIGURE 2: MMANA-GAL prediction of radiation patterns for the 3-element Yagi beam array for the 6m band at 7m AGL.

band. If this happens the lower lobe, whose beamwidth is from 6° to 18° (ie 12°) may favour longer skip stations to be worked, if conditions are suitable. The antenna's predicted horizontal radiation pattern indicates significant RF signal concentrated ahead of the director, with a 3dB beamwidth from 327° to 33° (ie 66°). The prediction shows no side lobes have formed and a comparatively small rear lobe, giving rise to a F/B ratio of around 14dB.

Construction

Using the MMANA-GAL predicted dimensions, a 3-ele Yagi beam array for the 6m band was constructed using 12mm diameter aluminium tubing for the elements. The array's elements were supported by mounting them on a boom that was made from a 1.9m length of 25mm square profile tube. To hold the reflector and director elements in position, two clamps were made from aluminium L-sections that were held together using M3 nuts and bolts. Each clamp used two 60mm long L-sections spaced 25mm apart, providing a snug fit on the boom. Two other 90mm long L-sections were situated across these and spaced 12mm apart, allowing a snug fit for the element. A 6mm hole was drilled through the element's centre and the boom with a M6 bolt and nut used to secure everything in place. **Photo 2** illustrates one of the element's clamps for reference. To support the dipole, a commercial dipole centre was used, obtained from an online supplier. Details of the dimensions of the aluminium tubes and boom used to construct the 3-ele Yagi beam array are summarised in **Table 1**.

Testing and tuning

The Yagi beam array was clamped to a 5m extendable mast to allow it to be tested and adjusted. Using a MFJ antenna analyser, the antenna was tuned to 50.155MHz, with an SWR of close to 1:1 being obtained. With the antenna at 5m AGL and having signed on in CW, the antenna was loaded initially at a power level of 10W, which was increased to 100W with the SWR continuing to remain low. The directivity of the 3-ele Yagi beam array was checked by tuning the transceiver to a beacon and turning the antenna to monitor the change in level on the transceiver's S-meter.

A 4-ele Yagi beam array for 4m

Adding a second director element in front of the existing director of a 3-ele Yagi beam array further enhances the antenna's performance as an effective radiator or absorber of RF energy. The addition of this extra element creates a four element Yagi beam array.

The concept of a 4-ele Yagi beam array constructed for the 4m band comprising a reflector, dipole and two directors is shown in **Figure 3**, where the antenna's dimensions are also included. The completed antenna is shown in **Photo 3**.

Predicted performance

When modelled at 70.15MHz using MMANA-GAL, the 4-ele Yagi beam array's predicted performance gave a free-space gain of about 7dBd (9.1dBi) and a front-back ratio (F/B) of around 13dB. **Figure 4** shows the array's predicted radiation pattern as polar plots with the antenna modelled horizontally polarised at 7m AGL. At this height above the ground, the antenna's predicted vertical radiation pattern indicates three forward lobes whose radiation angles are around 48°, 27° and 8°. Such angles of radiation will tend to favour the station working shorter and medium skip stations when the Sporadic-E propagation conditions allow. At 7m AGL, the predicted gain for the antenna was 14.8dBi, corresponding with the lowest forward lobe at around 8° angle of radiation. The antenna's predicted horizontal radiation pattern indicates significant RF signal concentrated ahead of the directors, with a 3dB beamwidth from 28° to 332° (ie 56°). The prediction shows small side lobes have developed either side of the rear lobe. In a similar manner to the horizontal polar plot for the 6m band 3-ele Yagi beam array previously described, the rear lobe is comparatively small, giving rise to a F/B ratio of around 13dB.

Construction

Using the MMANA-GAL predicted dimensions, a 4-ele Yagi beam array for the 4m band was constructed using 12mm diameter aluminium tubing for the elements. To support the elements, the antenna's boom was made from a 2m length of 25mm square profile tube. To hold the reflector and directors in position, three clamps were made up using the same technique as described previously for the 6m Yagi beam array. Similarly to the previous antenna, the 4m Yagi beam array used a commercial dipole centre to support the dipole. Details of the dimensions of the aluminium tubes and boom used to construct the 4-ele Yagi beam array are summarised in **Table 2**.

Testing and tuning

The Yagi beam array was tested on 70.15MHz using an MFJ antenna analyser, with an SWR of better than 1.05:1 obtained after adjustment. When the antenna's tuning

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PHOTO 3: The 4-element Yagi beam array for the 4m band in use.

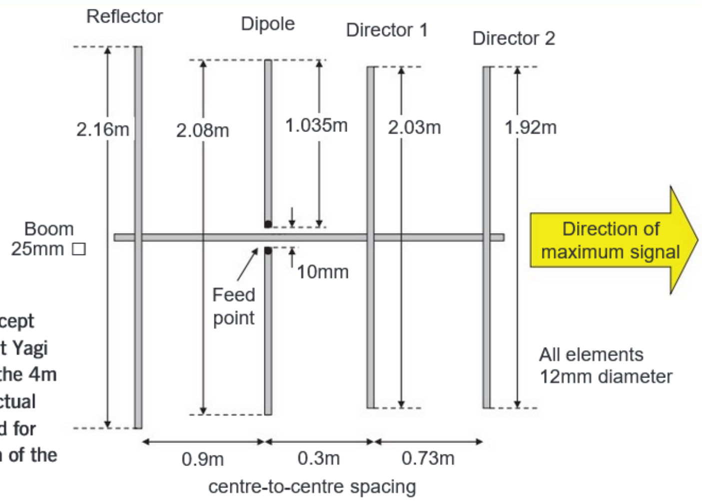

FIGURE 3: Concept of the 4-element Yagi beam array for the 4m band and the actual dimensions used for the construction of the antenna.

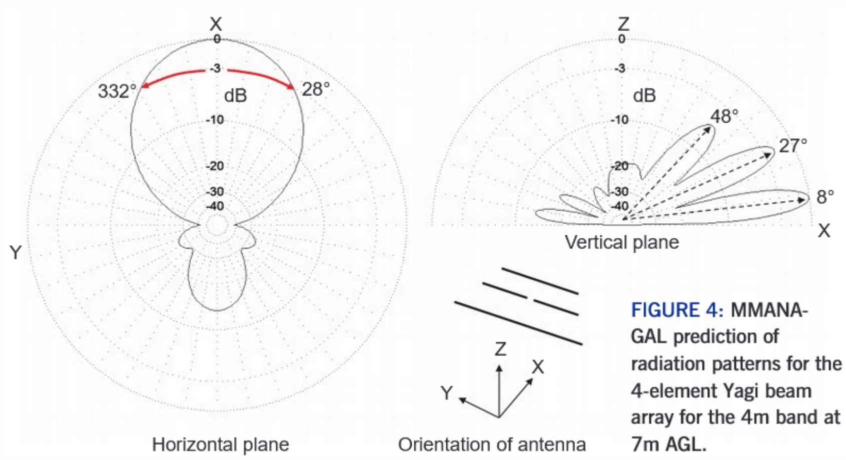

FIGURE 4: MMANA-GAL prediction of radiation patterns for the 4-element Yagi beam array for the 4m band at 7m AGL.

was completed and with the Yagi beam array at 5m AGL, the antenna was loaded with an initial power level of 10W which was increased to 25W with the SWR continuing to remain low. The directivity of the 4-ele Yagi beam array was monitored by tuning the transceiver to a beacon and turning the antenna to observe the change in level on the transceiver's S-meter.

Operation

The 3-ele Yagi beam array for 6m was constructed several years ago and has allowed many contacts to be made across Europe during Sporadic-E openings using both SSB and CW. Some surprising results have been obtained including contacts with South Africa, South America, the US East Coast and Canada. The 4-ele Yagi beam array for 4m has enabled many contacts to be made within the UK and occasionally into Europe.

References

[1] MMANA-GAL basic V3.0.0.31, freeware antenna analysing application. Original code by M Mori, JE3HHT. MMANA-GAL basic and MMANA-GAL Pro by A Schewelew, DL1PBD and I Gontcharenko, DL2KQ, 1999 onwards

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

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

[4] Radio Systems TECIII, D C Green, Section 5 Antennas, Pages 84-86. Pitman, 1979

TABLE 1: 6m band 3-element Yagi beam array boom and element actual lengths. Element centre-to-centre spacing is shown. All elements 12mm diameter. Boom length 1.9m, 25mm square section.

Element	Element length	Space between elements
Reflector	3.0m	-
Driven element		
(comprising 2 x 1.44m legs with 10mm gap)	2.89m	1.08m
Director	2.645m	0.72m

TABLE 2: 4m band 4-element Yagi beam array boom and element actual lengths. Element centre-to-centre spacing is shown. All elements 12mm diameter. Boom length 2.0m, 25mm square section.

Element	Element length	Space between elements
Reflector	2.16m	-
Driven element		
(comprising 2 x 1.035m legs with 10mm gap)	2.08m	0.9m
Director 1	2.03m	0.3m
Director 2	1.92m	0.73m

Technical

New licence regulations for RF electromagnetic fields

Part 1 of an ongoing series

In 2020, Ofcom published proposals to modify radio licences "to require compliance with international guidelines for limiting exposure to electromagnetic fields (EMF)".

These changes were triggered by the global deployment of new telecommunications infrastructure but will affect all radio licensees, including radio amateurs. Over the past year, the RSGB has responded to two Ofcom consultations **[1, 2]**, and is now meeting with Ofcom to clarify how these new requirements will apply to amateurs. The RSGB supports the safe and responsible use of RF communications but we are strongly urging Ofcom to minimise this new administrative burden.

Coincidentally, a similar process is underway in the USA between the FCC, the US regulator, and the American Radio Relay League (ARRL). A small team of RSGB and ARRL experts are cooperating on common technical areas, and sharing experience. In this introductory article, we cover the international background, and start to outline the approach that UK radio amateurs can take to comply with the new licence requirements. In 2021, Ofcom expects to finalise these requirements, and set an implementation time when they come into force. Future articles and support materials are planned by both the RSGB and ARRL to provide more detailed guidance for amateur operators, taking account of our respective national regulations as they are clarified.

PHOTO 1: **Common amateur activities should easily prove compliant.**

What is 'safe'?

Amateur radio is usually regarded as a 'safe' activity and for over 100 years people have enjoyed this hobby of using electromagnetic fields to communicate. However, for EMF exposure, like so many other things in life, there are differences between 'acceptably safe' levels and 'excessive' levels that might lead to health effects. Internationally, the World Health Organization (WHO) coordinates and evaluates the scientific investigation of all sorts of activities and agents that potentially might affect human health. Due to the widespread deployment of mobile telecommunications over the last 30 years, exposure to EMF has become commonplace and so has become a subject for special review by the WHO **[3]**. The WHO refers to expert groups such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) **[4]** and the IEEE **[5]** that provide guidance on limiting human exposure to EMF, including radio waves used by radio amateurs.

Both ICNIRP and IEEE review the extensive published research data relating to biological effects of exposure to EMF, irrespective of the mechanism or source. They then develop guidelines and recommended exposure limits to prevent potentially harmful effects from excessive exposure. These limits are set well below the levels at which any harmful effects have been detected. Because the work of ICNIRP and IEEE is based on the same underlying science, it is not surprising that they reach similar conclusions and recommend similar exposure limits.

At frequencies above 100kHz, it is generally understood that the most important effects to be avoided are due to excessive heating from too much RF energy being absorbed in body tissues. The human body has an exacting temperature regulation system that holds the normal core temperature close to 37°C, and a variation of just a few degrees can lead to cellular damage. Our bodies are efficient at removing excess heat energy by varying local blood flow, and then offloading the unwanted energy from the body by mechanisms such as sweating and faster breathing. But if the rate of heat generation exceeds the body's ability to remove it, prolonged over-exposure can then lead to harmful effects.

The exposure limits are designed to prevent those effects from occurring. Separate exposure limits are defined for averages over the whole body or for localised maximum values. The limits also recognise that the body can handle short bursts of higher exposure provided the longer-term average remains below the limit. Based on the body's available mechanisms for removing heat, the mandated averaging times are 30 minutes for whole-body exposure but only 6 minutes for local exposures.

In addition to thermal effects, currents and voltages induced in the body by strong external EMFs at frequencies below 10MHz may interact with the electrical nerve pathways and affect the body's 'internal signalling'. To protect against that, there are limits on peak (maximum) exposure that may be more restrictive below 10MHz than the more

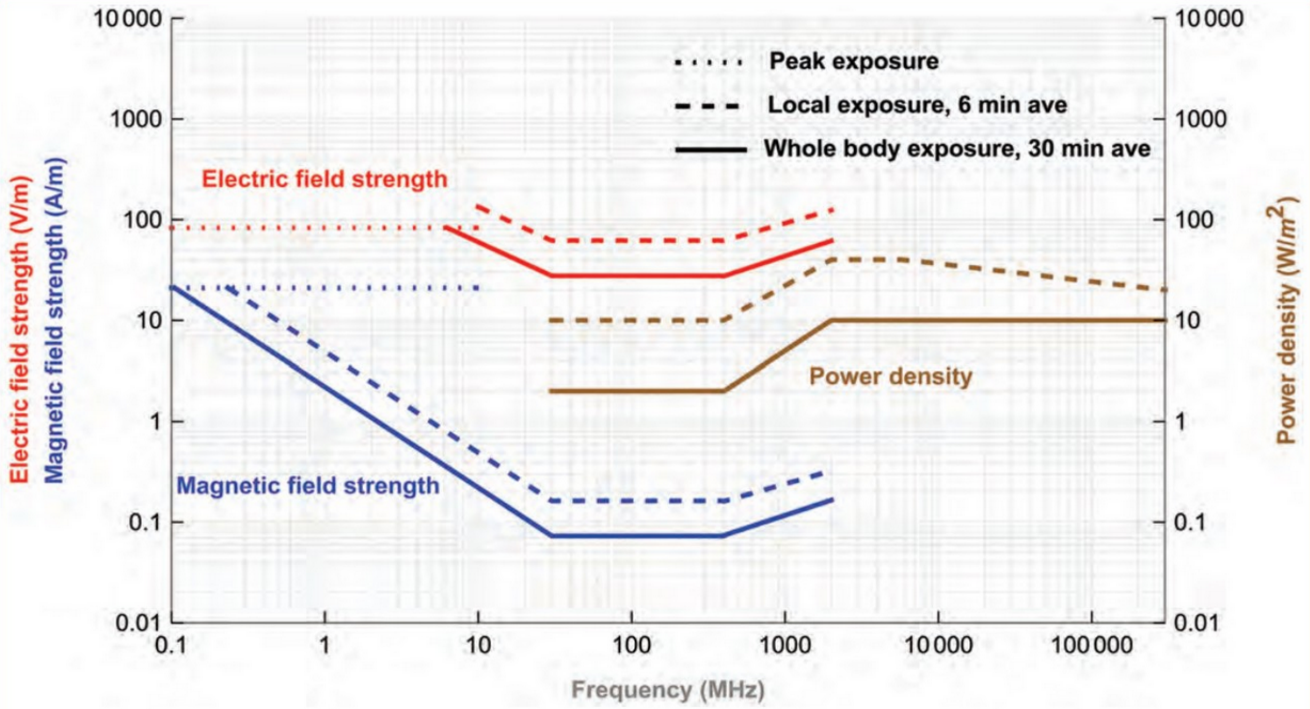

FIGURE 1: ICNIRP 2020 Reference Levels for General Public Exposures

familiar limits for thermal effects. Note that these exposure limits are expressed in terms of the field's peak (maximum) value at any point on the body, meaning that time and spatial averaging cannot be applied.

Why do exposure regulations exist?

Ofcom will require licensees to ensure that the RF energy used for communication does not cause harm to those exposed to it. Ofcom is not expert in the science that determines the safe levels of exposure, so it seeks advice from Public Health England (PHE). In turn PHE uses the ICNIRP guidelines on limiting human exposure as the basis to protect the population. The ICNIRP exposure limits deliberately include large safety margins which help greatly to ensure that, among other things, amateur radio transmissions do not harm the health of radio amateurs or any of the general public around us.

The scientific evidence demonstrates that the EMF exposure limits are not hard thresholds beyond which the situation suddenly becomes dangerous; they are more analogous to road speed limits. We all understand why speed limits exist – because at higher speeds the likelihood of an accident increases and also the consequences can be more serious. However, we are also aware that even though occasionally slightly exceeding the speed limit might not actually result in harm, it still could result in prosecution; and that in the event of an accident, the driver is likely to be considered at fault. Compliance with the ICNIRP exposure limits should be viewed in a similar way: minor excess exposures are unlikely to have caused actual harm; but failing to comply would be a breach of your licence.

The key to complying with the new licence condition is to be able to demonstrate that you have taken steps to ensure that your transmissions do not expose anyone to excessive levels of RF energy. In practical terms you need to be aware of the specific locations around your antennas where excess exposures *could* occur; and if people *could* access those areas, then ensure that you either reduce power or don't transmit while people are *actually present*.

There are also many areas where good RF engineering practice to reduce the risk of interference ('good RF housekeeping') and improve station performance will help to control RF exposure. We will show examples in later articles.

How is exposure specified?

Exposure refers to energy absorption in a person's body. This has a hugely important consequence: **If there is no-one present in an area then, by definition, no human exposure occurs.**

ICNIRP defines two types of exposure limit, termed "*basic restrictions*" and "*reference levels*".

Basic restrictions apply to people who are being exposed, and thus specify parameters within the body. For the thermally based effects, the ultimate definition of exposure – and hence the ICNIRP basic restriction – is the rate at which energy is absorbed by tissue. This is termed the Specific Absorption Rate (SAR), and is measured in watts per kilogram of tissue (W/kg). It is difficult to measure or compute the actual SAR in living people, so compliance with basic restrictions is commonly demonstrated using the more convenient reference levels.

Reference levels have been derived to provide a means of demonstrating compliance using quantities that are more easily assessed than basic restrictions, with an equivalent level of protection. Different reference levels are specified according to

For help and advice, contact m0jav@rsgb.org.uk

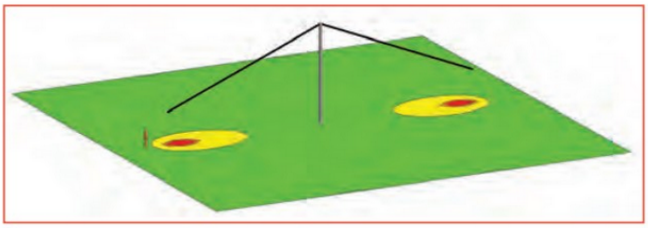

FIGURE 2: **Example exposure plot for people standing on the ground. For an 80m inverted-V dipole, the highest exposures occur below the ends of the antenna.**

the type of exposure that *could* take place if a person were to enter the EM field in that location:

- Whole-body exposure is averaged over time (30 minutes)
- Local exposure is the maximum time-averaged field (6 minutes) at any point
- Peak exposure is the maximum instantaneous field at any point.

There are three common reference level measures:

- Power density (*S*) measured in W/m²
- Electric field strength (*E*) measured in V/m
- Magnetic field strength (*H*) measured in A/m.

For more details about *E*, *H* and *S*, see *Electromagnetic Fields – What You Need to Know* on the RSGB website [2]. *E* and *H* are commonly used at lower frequencies, roughly below 1GHz and in the near field of antennas. *S* is the only applicable measure at frequencies above 2GHz but can optionally be applied in the far field at any frequencies above 30MHz. **Figure 1** outlines the defining aspects of ICNIRP 2020 reference levels **[6]** applicable to the general public. Note that we have not presented the local and whole-body exposures for frequencies where the peak value is most restrictive. For our own practical purposes, we can treat these ICNIRP reference levels as exposure limits (while also noting, as above, that minor excess exposures are unlikely to have caused actual harm).

Why are exposure limits so complicated?

It would certainly be simpler if there could be a single exposure limit for all frequencies! However, radio waves are not absorbed by the human body equally at all frequencies. Just as resonant antenna sizes differ for various frequency bands, structures in the body can be resonant at frequencies with wavelengths related to their sizes. For example, the whole body of a typical adult person is resonant in the lower VHF frequencies, meaning that the body absorbs energy from the RF field more readily, so the exposure limits at those frequencies are reduced. The lowest limits in Figure 1 are between 30MHz and 400MHz, where whole-body and organ structure absorption is the highest for both adults and children.

Local exposure deals with situations in which only part of the body is significantly exposed. A common example is the use of a VHF/UHF handheld radio because the attached antenna most strongly illuminates the head of the user. For such close proximity of the body to the RF source, local exposure limits based on SAR will then apply (see later articles in this series).

While heating is the main consideration, we have already noted that there are other ways that EMF can interact with the body. At frequencies below 10MHz, the potential effects on the nervous system are also important and can become the limiting factor as shown in Figure 1, the peak exposure as shown by a dotted line.

What will I be expected to do?

Compliance may be demonstrated in many ways. We suggest trying a series of stages of increasing complexity, any one of which would be valid. If you can demonstrate compliance simply, then that's fine.

Stage 1 – Screening by configuration: In an effort to make compliance simple for as many people as possible, RSGB and ARRL are developing guidance by identifying typical station configurations that will comply with exposure limits on each of the amateur bands. If you can match your station to one of these pre-assessed configurations on the amateur band in question, that will be the simplest way to demonstrate compliance. Little or no calculation will be required by the end user.

To make that possible, a wide range of different station configurations are being evaluated using advanced modelling techniques. An example for HF is shown in **Figure 2**. This is part of a programme to determine the minimum compliant height for various antennas, for a given transmitted power on each HF band. Similar work is underway for a range of VHF and UHF station configurations.

Stage 2 – Simple calculation: The next level of complexity involves some calculation by you. For example, Ofcom has developed a simple spreadsheet tool and RSGB is working with Ofcom to clarify and improve this method. The output from the Ofcom calculator is a so-called *"safe separation distance"* for the power level, antenna configuration, etc that you are using. If you can be sure that nobody is present within that zone while you are transmitting, then RSGB's understanding is that you will be deemed compliant.

Stage 3 – Further measures: If you cannot initially demonstrate compliance using these first two stages, then you will need to do some more work. You have considerable control over this – for example, you could revisit stages 1 and 2 and look at the effects of changing the antenna configuration, limiting transmit power and/or beam directions, taking measures to ensure that no-one is present in high-exposure locations when transmitting, and so on. If you then are able to demonstrate compliance, the problem is solved. Examples will be discussed in future articles.

Stage 4 – Advanced methods: If you are not able to work within such limitations, it may still be possible that more advanced assessment methods could be applied to your particular circumstances to provide a more accurate exposure estimation; and in some cases that might then demonstrate compliance. RSGB-ARRL team members are already developing advanced computation methods as part of the programme to define the pre-assessed configurations for Stage 1 (see above).

Next steps

The RSGB continues to liaise with Ofcom about the revised licence conditions and the implementation date, likely to be late 2021.

We anticipate that Ofcom will require you to keep records on how you have demonstrated compliance (eg Stage 1 to 4) for each case examined, and as a minimum this will include each amateur band on which you operate.

RSGB plans to provide more detailed advice when this series continues in a future *RadCom,* and on the RSGB website www.rsgb.org/emf.

Websearch

[1] Ofcom proposals: www.ofcom.org.uk/consultations-and-statements/category-1/limiting-exposure-to-emf

[2] RSGB: https://rsgb.org/emf/

[3] World Health Organization: www.who.int/peh-emf/project/en/

[4] ICNIRP: www.icnirp.org/

[5] IEEE: www.ices-emfsafety.org/

[6] From ICNIRP 2020 Table 5, Table 6, and Table 8.

The RSGB-ARRL EMF Team

This article was written by a team drawn from the UK and the USA, with professional backgrounds that together cover the disciplines of EM physics, RF engineering, computer modelling, radiation protection, and bioeffects. Current membership includes: Matt Butcher, KC3WD; Greg Lapin, N9GL; John Rogers, M0JAV; Kai Siwiak, KE4PT; Ric Tell, K5UJU; Ian White, GM3SEK; and Peter Zollman, G4DSE.

SOTA working via QO-100 /P

I've had an interest in microwaves and satellites since shortly after being licensed in 1981.

My first SOTA QO-100 experiments used a 25-ele Tonna Yagi and a Sky-type dish.

I dabbled with the old Radio Sputnik satellites that had downlinks on 10m and uplinks on 2m. I've used the weather satellites and received packet radio as well as slow scan TV (SSTV) from the International Space Station (ISS). I've also worked the FM satellites. For a while I had fully steerable 2m and 70cm beams up and worked some nice DX. But with QO-100 **[1]** coming on the scene things have changed. This satellite covers a large part of the globe and is in a geostationary orbit so there's no chasing around with aerials trying to find the 'Bird'.

I have done a bit on microwaves in the past, with simple wide band FM on 10GHz many years ago, then a small amount on 23cm more recently. The work of construction at these frequencies has always been a challenge for me. Things in recent times have got a whole lot easier, with cheap modules from the east and reasonably priced transverters from Bulgaria. You can now be more of a system builder than a constructor. I did a lot of 6cm FM ATV and wideband FM with Chris, M0KPW a couple of years back. This was using 'first person view' (FPV) drone modules; we both worked GI on simple kit, all available from eBay. Chris has posted his station info online **[2]**.

My QTH is pretty poor for VHF and up, with lots of Cumbrian fells obscuring my line of sight (LOS) in most directions. When I was first licensed, Class B callsigns did not have access to HF and most did their 'apprenticeship' on 2m. I continued in that vein and generally work from 6m (50MHz) and up. I've always done a fair amount of portable operating. This was a natural fit with the SOTA programme **[3]**, which I've participated in for around 20 years. So it all came together and I thought I would try to work through QO-100 from a SOTA summit. Repeater QSOs do not count for a SOTA activation, but satellite ones actually do.

Hardware

To work through QO-100, you uplink on 2.4GHz and downlink on 10GHz. There are many ways to go about building a QO-100 ground station. Mine may not be the most technical or efficient but it's worked for me.

I initially started out with kit I already had to hand, a bog standard LNB and a 60cm dish, a bias tee to inject the required 12V up the coax to power the LNB (the only purchase I needed to make and hardly worth making at the price from China) and a RSP SDR radio connected to my Android tablet, driven by the free SDR Touch **[4]** software. I do recommend paying the small fee for this software (about £6) as it allows the waterfall to work, which is a great help. I did find this software sometimes takes several attempts to load though and there may well be other suitable SDR software for the Android systems around now. If you're using a Windows laptop you're spoiled for choice, as all the regular SDR programs will work. Using just this tablet-based setup from my front garden I was thrilled to hear lots of stations using the narrow band part of the QO-100 spectrum.

I recently bought the excellent SG-Labs 13cm transverter **[5]**, which uses a 70cm radio as the driver and outputs about 2W at 2.4GHz. It's a simple matter to use the pin shunts provided on the transverter PCB to switch the local oscillator between the terrestrial frequencies and the satellite sub band. (I have since installed a panel switch to do this so I don't have to open it up; more on this later.) I used my 25-ele Tonna aerial with the transverter running its barefoot 2W. I managed to get into the satellite! I was not the strongest signal, *but I got in*.

To the hills!

The next fine day I was off to my Local SOTA summit Kirkby Moor G/LD-049 near to Ulverston in South Cumbria. I managed to carry all the kit up and was receiving QO-100 nicely, when I hit a snag. I plugged the power in to the transverter and it was dead. Oh no!

With dejection, I decamped and took it home. Right away I found that the inline fuse I had the forethought to fit had popped. The reason was that the centre pin of the DC connector supplied with the transverter is proud. If it touches the case as you plug it in, it shorts out. So fuses changed I was off again, remembering to plug in the DC connector before applying the power. One thing you learn on a fell top is that everything has to be simple and reliable. It's always compromise as to what you can take in the way of spares and the extra weight, so apart from the weather and terrain, equipment failures can stop a successful operation – but hopefully not too often. But it's all part of the challenge, fun and self-training.

Since that time I've changed the plug for one with a recessed centre pin and now also carry spare fuses. *[Inexpensive PTC self-resetting fuses can be very useful, though rather than fully disconnecting the DC supply they* limit *fault current, eg a 10A device might pass 150mA after tripping at, say, 12A – Ed].*

Once I'd applied the necessary First Aid to the equipment, off I went again and got to the summit. I set up and worked through

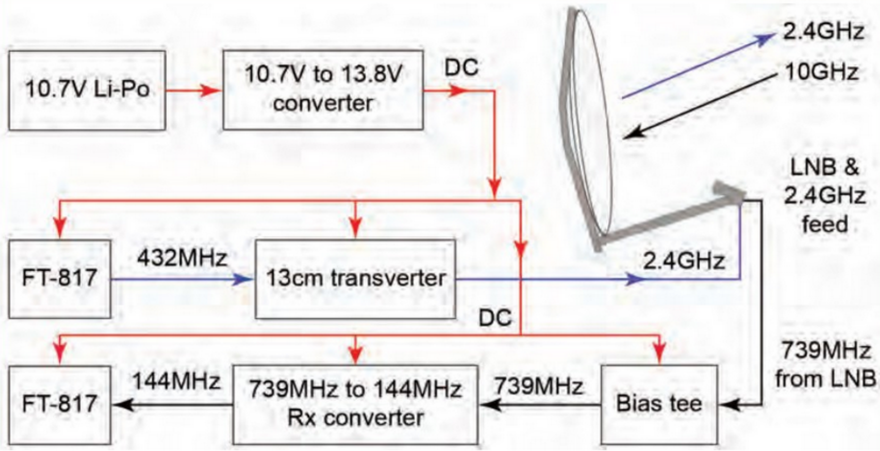

FIGURE 1: Block diagram of the most recent setup.

Everything packs up neatly for summit trips.

the satellite for my first SOTA activity – and it was the first time SOTA had been heard on QO-100!

Twice the fun

Shortly after that first contact I found out that Andrew, G4VFL was planning to operate SOTA though QO-100. I suggested that we should try a SOTA Summit to Summit (S2S) though QO-100.

Andrew had made what is called a POTY feed. This enables you to use the same dish for Rx and Tx, also creating the circular polarisation for the uplink signal. I had previously used horizontal polarisation, which incurs a 3dB loss, ie you need twice the transmit power. Andrew kindly offered to build a POTY feed for me, so of course I took him up on that! There is a lot of information on the internet to help you build the feed and several sources to buy one already assembled. Later I added the dielectric lens, which is meant to better focus the signal, but I must admit I did not notice any increase in the performance. But it does nicely cover the open end of the waveguide protecting it from the rain.

I also obtained a modified LNB, which had been fitted with a temperature controlled crystal oscillator (TCXO). Using this LNB, my receive setup drifts no more than 2kHz during a SOTA activation. It is off absolute frequency by about 45kHz, but it is stable, which makes life so much easier – a standard LNB can drift tens of kilohertz in response to even a small temperature change. I had also done away with the tablet and SDR, as I found it difficult to tune this setup whilst out portable. Instead, I had bought a converter **[6]** that takes the IF from the LNB and converts it to the 2m band. So I now ran two FT-817s; I am indebted to for the long term loan of the second FT-817 from a Furness Amateur Radio Society (FARS) club member.

Figure 1 shows the block diagram of the setup. Power is supplied by a 10.7V (three 3.7V cells in series, or '3S' as they're commonly known). Lithium-ion batteries are great but most of the common chemistries don't match the classic 13.8V we all know and love – you either have three 3.7V cells giving 10.7V or 4 cells giving 14.8V. That's not the whole story though, as the fully charged li-ion cell has a terminal voltage of 4.2V. This decays to a very steady 3.7V for the majority of the discharge cycle, but it does mean a 3S battery starts out at 12.6V and the 4S version starts at 16.8V, which few '13.8V' devices are likely to enjoy. The 10.7V nominal is fed to a DC-DC converter that provides a steady 13.8V output. Suitable converters are widely available for a few pounds on eBay; make sure the rating is adequate for the two transceivers (with one on Tx) plus the current draw of the other items. It's worth choosing a board with plenty of decoupling and suppression components and encasing the converter in a metal (screening) case.

The RF arrangement is fairly straightforward. An FT-817 transceiver feeds the SG-Labs 13cm transverter at 70cm, which is upconverted to 2.4GHz and connected to the 2.4GHz port of the POTY feed. On receive, the 10GHz signals from the satellite are downconverted to 739MHz by the LNB and fed via a bias tee to the input of the Rx converter, where it is downconverted again to 144MHz and received by the second FT-817. I recommend not connecting a mic to the second radio and/or disabling Tx, as receive converters don't like having several watts of RF fed into their output.

I now had a smaller, more effective station. I went off to Kirkby Moor again and Andrew went to Holme Fell, G/LD-051, north of Coniston. It's not a great distance and we easily communicated using 2m handhelds for our engineering talkback channel. Together, we made the first S2S via QO-100.

Even more fun with three

Carolyn, G6WRW had built a portable station by the next time we went out for a S2S contact, so we had a three way QSO via QO-100 with all of us on different Fells. Over the summer period my friend Chris, M0KPW was on furlough, so we took the opportunity to do as many Lake District Summits as possible.

I had also obtained another dish that I cut in half, making it much easier to backpack up a fell. Previously the alternatives were to carry a dish in hand or have it on my rucksack and look like a 'Hero in a Hardshell'. Though on some fells I was tempted to use the dish as a toboggan; a notable one being Harter Fell, which had quite a lot of shale and was so steep I saw myself going head over heels carrying my 15kg pack.

Over the weeks of summer Chris had a whale of a time on 2m and got quite a following. I persevered with QO-100 and worked from 20 Lake District summits, managing S2S from 12 of them, mainly with Andrew. I've worked 16 DXCCs so far in those activations including ZS, IT9 and VU.

Continued on p91

Nick Gregory, G0HIK
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Review

ZUMspot RPi Digital Voice Hotspot

How do you decide whether to follow the DMR, D-Star or Yaesu Fusion route for your handheld? You may not need to decide.

The 2m and 70cm bands used to be the lifeblood of local amateur radio clubs and the primary source of the local chatter. Over recent years, the previously analogue systems have been largely superseded by digital voice systems that offer many benefits, such as being able to use 70cm to communicate with fellow amateurs all over the world. However, new systems often mean new problems and, in the case of digital voice, it is the introduction of three similar but incompatible encoding systems, ie DMR, Yaesu Fusion and D-Star. Whilst DMR might seem the most logical way forward due to the commercial take-up and consequent opportunities for using surplus kit, all three systems have strong user bases, so are likely to remain with us. As you might expect, a few enthusiastic amateurs have tackled the compatibility problem, and one of the solutions is to use what's become known as a hotspot.

PHOTO 1: The ZUMSpot and handheld.

What is a hotspot

If you're a fan of the Douglas Adams' *Hitch-hikers Guide to the Galaxy*, you will have heard of the Babel Fish. It's a small, bright yellow fish that, when inserted in the ear, allows the user to understand any language. A hotspot is somewhat like that Babel Fish as it enables working other digital voice modes with your single-mode handheld. For example, with the ZumSpot, you can use your DMR rig to talk to a fellow amateur using a Yaesu Fusion rig, **Photo 1**. Impressive as that may seem, a hotspot takes the technology a bit further and uses its internet connectivity to route your call to any other network-connected repeater. That same link can also be used to connect to multi-mode servers that carry out the mode translation for you. This enables contacts with a wider range of digital modes such as D-Star, P25 and NXDN. The hotspot can therefore be thought of as your own private repeater that can be used for local calls or to link farther afield via the internet.

There are two main components to the ZUMSpot RPi; a single board computer (SBC) and a radio board. In the ZUMSpot RPi, the SBC is a Raspberry Pi Zero W, which is the Wi-Fi and Bluetooth enabled version of the single-core Pi Zero.

The radio board uses the same physical profile as the Pi and stacks neatly on the Pi's GPIO pins. Powered by an STM32 ARM microcontroller and running MMDVM firmware, the radio board provides the mode translation service and drives an ADF7021 RF transceiver chip to handle the RF link to your transceiver. The ZUMSpot also includes a small 1.3" OLED display that piggy-backs on the radio board and displays status information for the hotspot, see **Photo 2**. The Pi-Star software running on the Raspberry Pi provides the user interface for configuring the ZUMSpot RPi. This software is extremely powerful and versatile and can be used to power a full-blown repeater.

Getting started

The ZUMSpot from Martin Lynch and Sons comes with all the software and firmware pre-installed, which is very helpful. However, I still had to run through some basic configuration steps in Pi-Star to add my station specific details. Although the ZUMSpot RPi is supplied with very little paperwork, there was a link to the excellent Pi-Star guide by Toshen, KE0FHS. This guide provided a very clear path through the configuration steps with plenty of illustrations to help along the way.

The first step was to get the ZUMSpot RPi connected to my home Wi-Fi network. This turned out to be a simple operation thanks to Pi-Star's Auto AP(Access Point).

If, during startup, Pi-Star fails to find a network connection, it will automatically activate its local Wi-Fi AP. I was able to login to this AP using my smartphone and then follow the menus to enter the SSID (Service

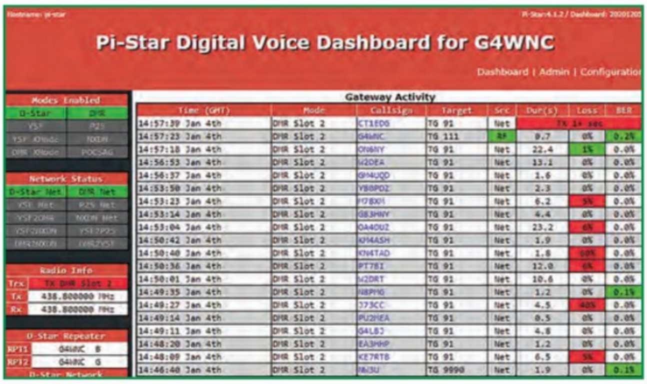

FIGURE 1: PiStar dashboard.

Set IDentifier) and password for my Home Wi-Fi network. Once the ZUMSpot RPi was rebooted, it found and connected to my local network. With the ZUMSpot RPi up and running, I could connect to the main Pi-Star interface simply by entering pi-star.local as the URL in my browser. This took me straight to the Pi-Star Dashboard, **Figure 1**, that provided a helpful status summary for the ZUMSpot RPi as well as giving access to the configuration menus.

Before I could start operating, I had to add a few personal details in Pi-Star, such as my name, callsign, DMR ID, location, etc. As you would expect, the Pi-Star configuration menus are password protected and have a default username/password combination. One important point here is that you **must** change the default password. As the ZUMSpot RPi is connected to the internet, running with the default password is a security risk. Once you've made the change to a strong password, the ZUMSpot RPi becomes very secure.

Once I had access to the configuration menu, the first task was to enable the appropriate digital radio modes in the MMDVM Host Configuration section, **Figure 2**. Pi-Star includes all the popular digital voice modes such as DMR, D-Star, Yaesu Fusion, P25 and NXDN plus conversions between some modes. For most users, it's generally best to set Pi-Star to match your handheld, which in my case, was DMR. I say this because the online cross-mode servers do a very good job of mode conversion so you get a slicker changeover between overs than when working cross-mode locally. If you are planning to do cross-mode scanning on the ZUMSpot RPi, you may need to adjust the hang time settings. The hang time is the length of time Pi-Star will remain in the current digital mode after a transmission ceases. It's important to get this right because, if it's too short, Pi-Star will revert to mode scanning between overs. Pi-Star then requires around 1.5 seconds of audio to identify the mode before continuing the QSO. When the hang time is correctly set, Pi-Star should remain in the selected mode in between overs, thus giving a smoother exchange and making it easier to follow QSOs.

On completion of this section, I had to click the Apply Changes button to save the changes and add the DMR configuration panel. This also applies to all the other modes, as you won't see the relevant configuration screen until you've set the mode and applied the changes.

Another step that may be necessary is to adjust the Tx and Rx offset. This is used to compensate for small frequency errors in the reference clock that drives the transceiver chip. Any error here shows up as an increased bit error rate (BER) that you can see reported in the Pi-Star dashboard, **Figure 3**. The review model was spot-on frequency and returned a BER of 0.1% or better, which is good for a DMR link. I experimented with the offsets to see if I could make any further improvements. To access the clock offsets, I opened the Configuration menu and chose Expert followed by MMDVMHost and then altered the RXOffset and TXOffset in the Modem section. I tried

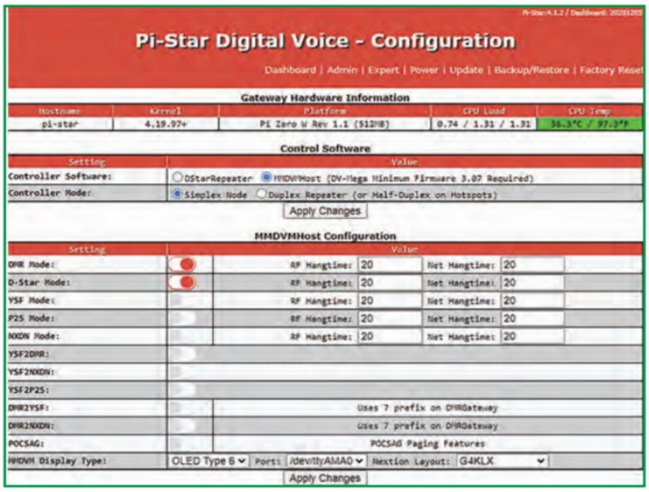

FIGURE 2: MMDVM Host configuration.

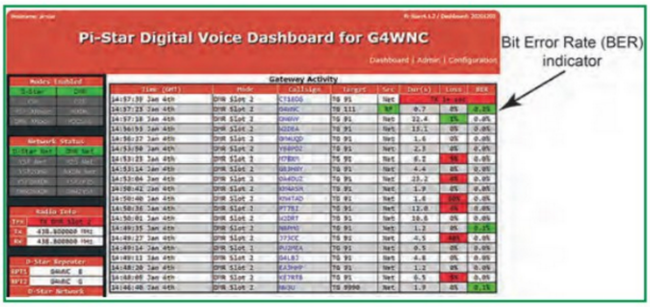

FIGURE 3: BER display on the dashboard.

positive and negative offset values and found a useful starting point was to adjust both offsets in 100Hz steps. After each adjustment, I hit the Apply Changes button and returned to the dashboard. I could get an updated BER reading by keying the handheld and checking the BER column of the Gateway Activity monitor. I found this to be an effective way to adjust the offsets.

Next I proceeded to complete the DMR configuration by selecting the BrandMiester network.

Using the ZUMSpot

For most users, the simplest way to use the ZUMSpot RPi is to configure it to match the digital mode of your handheld, ie DMR, D-Star or Yaesu Fusion. You will still be able to work crossmode, but the mode conversion will be done by the online servers rather than in the ZUMSpot RPi. This generally allows for a faster exchange of overs and greatly simplifies setup.

Before I could use the ZUMSpot RPi I had to configure my radio with the operating frequency and the talkgroups, reflectors, etc that I wanted to use. As I was using a DMR rig, I started by creating a new Zone for the ZUMSpot RPi and then added channels for each of the popular talkgroups such as Worldwide (91), Europe, UK, etc. It's also important to remember to set your rig to low power for all the programmed channels as you won't ever need to use a higher power

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PHOTO 2: ZUMSpot status screen.

with a hotspot. From this point on, using the hotspot was extremely simple. I just selected the talkgroup on the rig, keyed up for about a second and the ZUMSpot RPi would switch to monitoring that talkgroup and I could listen on my rig. To make a call I simply keyed up on the desired Talkgroup. At this point I was free to roam the house and garden whilst in QSO. I tested the range with the AnyTone AT-D868UV set to its low power setting of 1 watt. I was able to operate successfully anywhere in the house and also at the extremities of the property, which were about 35 metres from the ZUMspot RPi.

Summary

The ZUMSpot worked very well during the review and transformed the capabilities of a handheld rig. It literally provides a gateway to the world from any location that has Internet connectivity and is an ideal partner for most digital handheld rigs. To make the most of the ZUMspot RPi, you do need to have a good working knowledge of your rig, so you can program the appropriate talkgroups, reflectors or rooms, depending on the technology you're using. With ZUMspot RPi, I could always find someone to talk to.

The ZUMSpot RPi costs £159.95 and is available from Martin Lynch and Sons (www.hamradio.co.uk).

My thanks to Martin Lynch and Sons for the loan of the ZUMSpot, AnyTone AT-D868UV (£129.95) and TYT MD-UV380 (£84.95) DMR radios.

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Although initial draft and discussion material can be accepted in most common formats, we will need to receive the final material in a suitable form for reproduction. Usually this means text in a Word file with the minimum possible of formatting, and photos as per [1].

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[1] www.rsgb.org/radcompix
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A brief look at NEC-5

Introduction

Version 5 of the Numerical Electromagnetic Code (NEC-5) is now available **[1]** and seems to have been released without much fanfare. Indeed, I only came across it by chance. For those of us familiar with the ubiquitous NEC-2 antenna modelling software, a new version that claims improvements over NEC-4 is a very exciting development, particularly as the one-off licence fee for an 'individual' is US$110 (approachable if you are seriously interested in antenna simulations and much less than the cost of a NEC-4 licence, although fees for academics and businesses are somewhat higher).

This article provides a short review of NEC-5, looking at some aspects of the software, as well as providing some example models and simulation results.

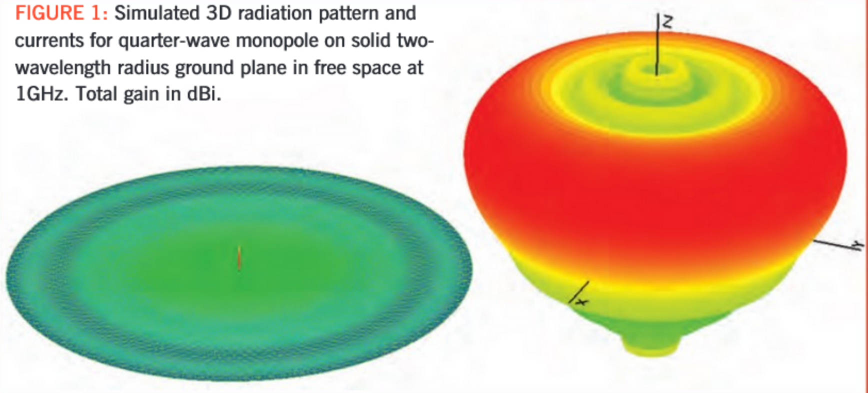

FIGURE 1: Simulated 3D radiation pattern and currents for quarter-wave monopole on solid two-wavelength radius ground plane in free space at 1GHz. Total gain in dBi.

A concise history of NEC

NEC was developed at the Lawrence Livermore National Laboratory (LLNL), with NEC-1 released in 1977 **[2] [3] [4]** . NEC-2 followed in 1980 and is the most widely used public-domain code based on the Method of Moments (MoM). NEC-3 came out in 1983 to limited distribution and was capable of modelling buried wires, something that NEC-2 cannot do. NEC-4 was released in 1992 and, until recently, was the last major release of NEC. As well as buried wires, NEC-4 can model stepped-radius wires and junctions of closely spaced wires, again something that NEC-2 cannot do.

About NEC-5

The User Manual for NEC-5 was published [1] in 2017. According to the *Validation Manual* **[5]**, "NEC-5 is essentially a complete rewrite of NEC" owing to the different methods used within the software. With NEC-5, voltage sources are placed at the ends of wire segments, whereas they are placed in the centre in NEC-4 (and also NEC-2). NEC-5 can also model surfaces as rectangular or triangular patches. With NEC-2, a surface can be approximated by a grid of wires (eg equal-area rule **[6]**) but this can lead to simulation problems if not used carefully. "NEC-2 survives because it is free software in the public domain and NEC-4 is licensed software that costs at least several hundred dollars" [4].

As with other versions of NEC, NEC-5 is based on 'cards', a term dating back to an era where a deck of punched cards were used to run the antenna simulation. The user is required to create an input text file of cards (commands) and, assuming a successful simulation, the output is a formatted text file of data. Where possible, the input and output format has been kept the same as previous versions of NEC but some differences have been unavoidable. Because of these differences, it is more difficult to build models and so NEC-5 comes with graphic assistance; an optional interactive mode while running the code (which I have not evaluated) and a graphical user interface (GUI), NEC5GI, which is used to build models and also view the simulation results **[7]**. With NEC-2 and NEC-4, third-party GUIs (eg EZNEC, 4NEC2) simplified the modelling process and removed many of the challenges and frustrations with working with NEC cards and processing the text output. NEC-5 can also be used from the command prompt (NEC5CL). Thus, it can be called from other software, for example, as part of an optimisation routine.

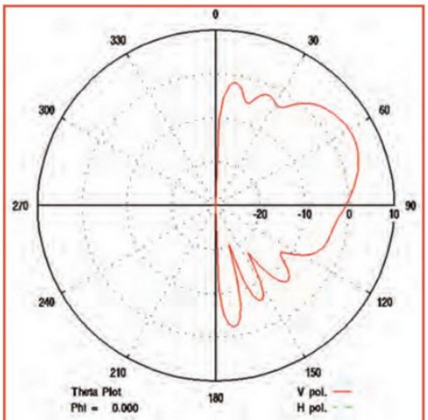

FIGURE 2: Simulated 2D elevation pattern (gain vs theta) for quarter-wave monopole on solid two-wavelength radius ground plane in free space at 1GHz. Gain in dBi.

NEC-5 in use

It pays to read the NEC-5 user manual [1] and also that for the GUI [7]. Many of the writings on NEC-2 and NEC-4 by L B Cebik, W4RNL (SK) **[8]** will also help with becoming familiar with NEC cards and building viable NEC-5 models.

Whilst many amateurs will be familiar with azimuth and elevation for describing antenna characteristics, NEC-5 uses a spherical coordinate system (ie phi and theta), as is commonly used in the academic and professional antenna world. Antenna gain is given in units of dBi. NEC-5 can also be used for radar cross-section (RCS) simulations, in which case the units are dB square metres per wavelength squared. If you are working with other dimensions (eg feet, mm etc) it

TABLE 1: Demonstration NEC-5 cards for a simple inverted-V dipole.

```
CE 5 MHz inverted-vee dipole above
    'average' ground
PA H_TOP 6
PA H_LOW 1
PA X_LEN 12.5
GW 1 11 0 0 H_TOP X_LEN 0 H_LOW
    0.001
GW 2 11 0 0 H_TOP -X_LEN 0 H_LOW
    0.001
GE -1 0 0
FR 0 1 0 0 5.3 0.
GN 0 0 0 0 13 0.005 1 0
EX 0 1 1 1 1 0
RP 0 19 73 1001 0 0 5 5 0. 0.
XQ
EN
```

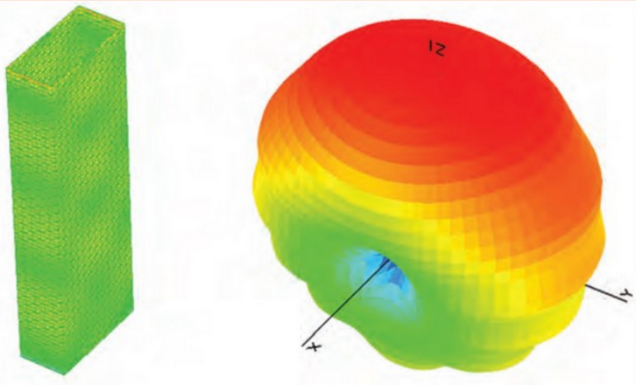

FIGURE 3: Simulated surface currents and 3D radiation pattern for probe-fed open waveguide at 10GHz. Total gain in dBi.

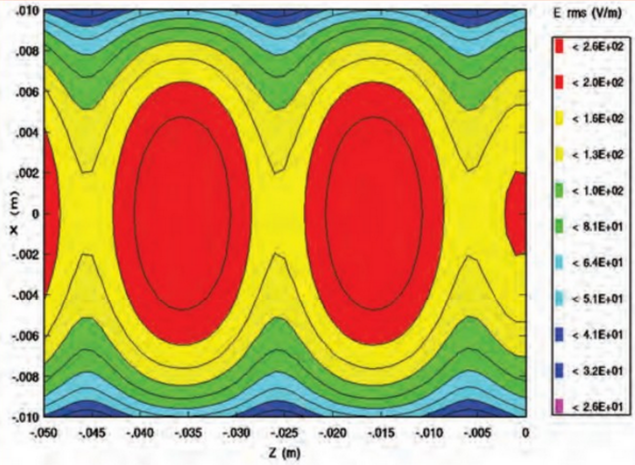

FIGURE 4: Simulated electric field strength inside probe-fed open waveguide at 10GHz. E field (V/m) at Y=0.0000E+00.

is essential to include the scaling command. Frustratingly, simulations still run without it but odd and obviously incorrect results will have you puzzling until you realise the scale command is missing.

Centre-fed antennas, such as a half-wave dipole, require an even number of segments because the source is now at a segment end and not at the centre (in previous NEC versions, these antennas required an odd number).

Wires can join a surface but must be connected to the corner of a triangular patch (not a rectangular patch). Where adjacent surfaces join, the patches must align. The NEC5GI GUI helps with creating valid models and appears to catch most build errors, but some still get through. With antenna modelling and electromagnetic simulation in general, it is essential that effort is put into validating the model and the simulation results. Sanity checks at the start, finish and throughout the process help to get good results. NEC-5 users will still have to work a bit to validate models and results. That's where third-party GUIs for earlier versions of NEC have been so valuable. Indeed, it may only be a matter of time before others provide GUIs to run NEC-5.

The use of symmetry in NEC-5 models can greatly reduce the PC memory requirements and speed up simulation runs. Simulations of a quarter-monopole with 120 x 0.4 wavelength radials is substantially faster **[9]** with NEC-5 compared with NEC-2 and NEC-4.

A current limitation with NEC5GI is that antenna impedance data cannot be viewed graphically as a VSWR or return loss chart, or on a Smith chart. However, it is understood that Gerald Burke, one of the authors of NEC, is developing appropriate software (ZPLOT) to provide this functionality.

NEC-5 validation

The NEC-5 *Validation Manual* [5] presents numerous examples where NEC-5 is compared with NEC-4 and/or published results for scenarios where NEC-4 has known limitations (eg monopole on a box, half-loop on a box). It is recommended that the *Validation Manual* is reviewed to confirm whether or not NEC-5 is likely to meet your own antenna modelling needs.

NEC-5 is seen to be more accurate than NEC-4 in most situations, although for thick wire dipoles, NEC-4 converges much more rapidly than NEC-5. Testing for convergence is an important aspect of antenna modelling and involves adding more segments and patches to the model until the simulated impedance does not change much for further additions (ie the solution has converged). With previous versions of NEC, there needs to be a sufficient number of segments on a wire to get meaningful results but not too many that the solution is in error. In this regard, NEC-5 copes better with smaller segment sizes on thin wires.

The 'average gain test' is another important test with lossless antenna models, ie a lossless antenna in free space or above a perfect electrical conductor (PEC) ground plane. In this case, the average gain should be close to one (ie 0dB). Any large deviations from one indicate the likelihood of numerical problems with the model.

Example models

The following examples aim to show the use of cards in NEC-5 and then to test it with scenarios that would have been impossible using NEC-2.

To demonstrate the use of cards with NEC-5, the commands I used for a simple inverted-V dipole at 5MHz are provided in **Table 1**. The simulated impedance, average gain, peak gain and 3D radiation pattern using NEC-5 are very similar to those simulated using NEC-2, which is to be expected for this simple example (for reasons of space, the results are not shown).

Figure 1 shows the model for a quarter-wave monopole on a solid circular ground plane (radius two wavelengths) with simulated currents and corresponding 3D radiation pattern at 1GHz in free space. Peak gain is close to 4.6dBi at approximately 28° above horizontal (see 2D elevation pattern cut in **Figure 2**), which is comparable with results for similar types of monopoles, eg **[10]**. **Figure 3** shows the model with surface currents for a probe-fed open waveguide at 10GHz together with its 3D radiation pattern (peak gain approximately 6.1dBi). Although the use of a 'thin' wire probe at such a high frequency will make the simulated feedpoint impedance doubtful, the purpose of this model was to look at the reflection coefficient at the waveguide aperture for comparison with published work by others. NEC-5 does not provide waveguide reflection coefficients but this can be calculated from the simulated electric and magnetic fields inside the waveguide, which NEC-5 can provide. **Figure 4** shows the magnitude of the simulated electric field strength inside the waveguide up to its opening (region at probe feed not included). A standing wave is clearly evident inside the waveguide. The simulated gain (6.1 dBi) and calculated magnitude and phase of the reflection coefficient (about 0.26 and -104° respectively) are comparable to calculations and measurements by Yaghjian **[11]**. The small differences may be due to the use of a thin-walled waveguide in NEC-5, whereas measurements will have been carried out using practical waveguide with a 'thick' wall.

Continued on p57

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Technical

Audio DSP processor

Introduction

I've recently retired from a long career as an embedded firmware engineer and re-awoken my early interest in amateur radio from my childhood now we are in lockdown. This has provided me the 'perfect storm' to get my hands back into some embedded software and minor hardware construction.

Back in July 2020 I passed my Foundation exam. To ease myself into the arena I plumbed for a well featured, but relatively cheap, Chinese SDR HF transceiver. Whilst I learn Morse code I am using the transceiver as a SWL station to get familiar with the bands and to test out various antenna setups at my QTH. The transceiver is good – I like it – but it does have some 'missing' features. In particular it does not include any noise reduction. Now, whether it is because of my QTH and antenna setup (in suburbia, in a geek's house full of gadgets, not to mention the local broadband telegraph post right outside my shack window), or inherent in the bands, time of day and the transceiver, the audio output from the transceiver for SSB is somewhat noisy, particularly on weaker signals. The developers have been quite good at updating and releasing firmware updates and adding/fixing features for the radio, but it is unclear if noise reduction will make it into the unit in a future upgrade, or if the hardware even has enough processing headroom left to achieve that. Thus, I decided to look into homebrew external noise reduction projects and to build myself something.

PHOTO 1: **The completed unit provides filtering and many other features.**

The project

The general idea is to take the audio output of my receiver, process it, then pass it on to an amplified speaker. (My receiver also provide I/Q outputs; processing these rather than the audio domain may give some advantages but would also be inherently more complex so I chose to go the audio-only route, at least as an entrée.)

Existing solutions

Before diving in to build my own solution from scratch, I had a quick look at the existing commercial and homebrew noise reduction systems to help crystallise my ideas. SOTABEAMS, bhi and West Mountain Radio are the main commercial suppliers I found, with all of them offering good products in a range of form factors. On the homebrew side - which I found more interesting - there were several alternatives. .

The *$19 DSP Filter* **[1]** is an interesting project. It's based on a small but powerful Arduino-like board and designed to be wired inside a Yaesu FT-817. It provides a range of functions including audio filters, a USB interface (for CAT and as a sound card), Morse decoding (output via USB or synthesised voice, which also announces settings).

The *Teensy-ConvolutionSDR* **[2]** is a complete SDR DSP based HF receiver, fed from an I/Q signal. It has a number of advanced features including a number of noise reduction algorithms, noise blankers, notch filters and general filters. The audio processing features looked great, but I could not see an easy way of feeding in line level audio for processing.

Cute and cheap, the *RadioDSP-Stm32f103* **[3]** implements various filters and a couple of noise reduction algorithms. It's built around a $2 board. Its noise reduction algorithms are very simple, possibly restricted by the limited computing power of the module it's based on.

Choosing the hardware

Initially I considered doing the audio processing on my Linux desktop station machine (I am

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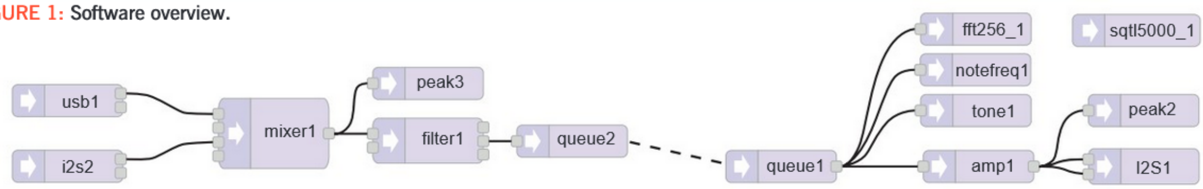
FIGURE 1: **Software overview.**



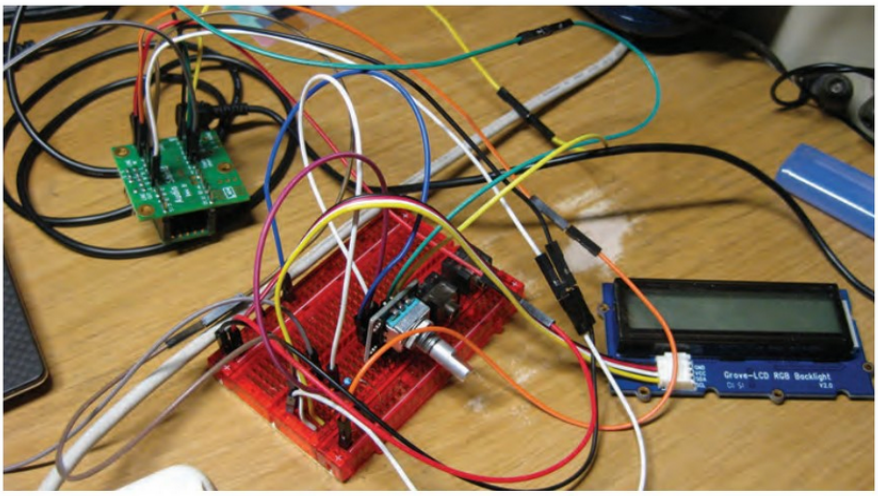


PHOTO 2: **Breadboarding the design meant I could make any hardware changes very easily.**

a Linux person at heart). I considered using GNUradio **[4]**, but didn't find any existing noise reduction examples. I was also put off by the learning curve and effort that would have been required for me to construct the filters from scratch.

My second choice of hardware would be something based around a Raspberry Pi **[5]**. I expected not to need network or screen output, so the inexpensive Pi Zero **[6]** would probably be suitable. But there is a wrinkle in all the Pi boards: although it is fairly easy to get audio out, getting audio *in* to a Pi is much harder. The few reasonably priced audio analogue to digital boards seem to have gone out of production; the others that *are* available are quite high-end and aimed more towards commercial or studio projects and are thus expensive.

So, taking inspiration from some of the existing homebrew projects, I chose the PJRC range of Teensy boards **[7]**. A number of their features appealed to me. They are Arduino 'compatible', which provides a simple programming environment, widely used in the amateur radio community, include some powerful processors with inbuilt digital signal processing and floating point instructions, and perhaps most importantly there are cheap audio daughterboards available that provide line level input and output and come with a powerful Arduino audio library **[8]**. And so the project was born. I ordered a Teensy 4.0 **[9]** and matching audio board **[10]**, and started to mock up on a breadboard development system.

On the shoulders of giants

Here I must say that this project is built by 'standing on the shoulders of giants'. All the technically challenging 'hard maths' innards of the code has been derived and extracted from other projects. My task was merely researching, collating and knitting together all the relevant parts into one functional unit that implemented the features I was looking for. I was particularly helped by the hard work by the authors and contributors to the Teensy-ConvolutionSDR project, along with the closely related UHSDR **[11]** and wdsp **[12]** projects, from which much of the noise reduction and other code has been derived; GI1MIC and the $19 DSP Filter project [2], for inspiration, showing the use of a Teensy, and for Morse decoder and filter code; PJRC **[13]**, Paul Stoffregen **[14]** and the Teensy community for creating a fantastically usable powerful Arduino-like board along with documentation, examples and excellent supporting libraries; K4ICY **[15]** and TF3LJ **[16]** for alternative Morse decoders; and many others. Without the work of these people this project would have been orders of magnitudes more difficult and taken significantly longer to put together.

Project definition

Having researched the 'competition', had a good long think, checked out the available hardware and software, I decided on the set of features I wanted. These were

- A selection of noise reduction algorithms, including Least Means Square, Exponential smoothing moving filter, Average smoothing moving filter, plus Spectral noise reduction, with a choice of algorithms
- Noise blanker
- Auto-notch filter for tone/whistle removal
- Configurable band pass filtering, with presets for SSB, CW, AM and FM
- A selection of CW decoders including the GI1MIC/WB7FHC 'Morseduino' decoder; the K4ICY decoder using geometric mean for pulse categorisation; and the TF3LJ Bayesian-based decoder
- Hardware AGC or software volume tracking
- Ability to bypass all features (to aid comparison)
- Line and USB audio in; line and headphone out

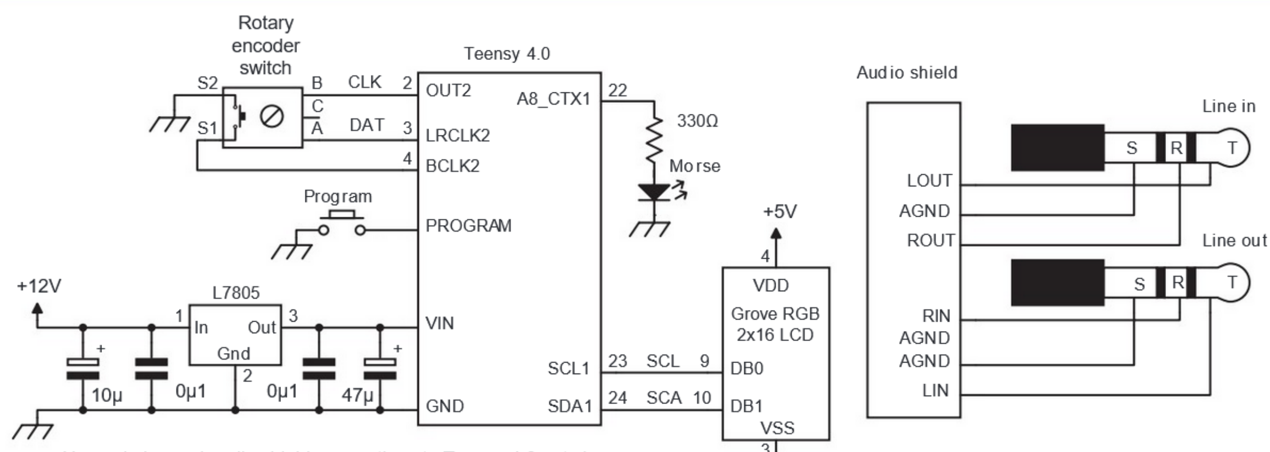


FIGURE 2: **Circuit diagram.**

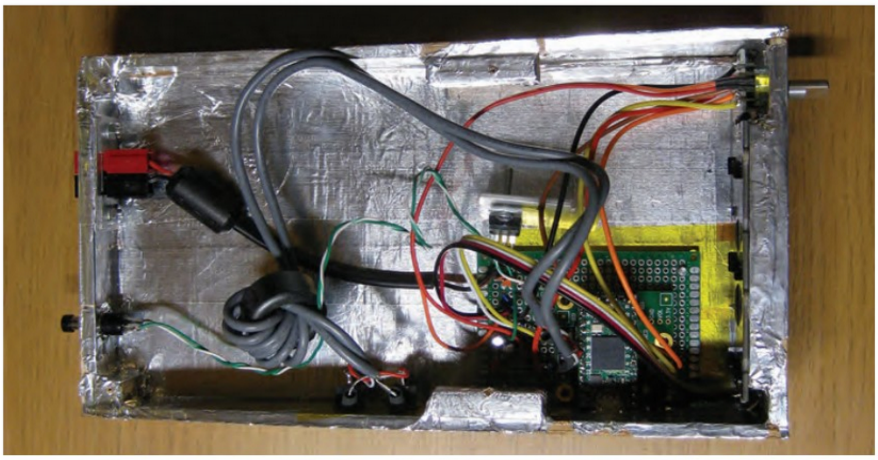


PHOTO 3: **It was necessary to line the plywood box with aluminium tape in order to reduce radiated birdies (see text).**

I also decided I'd use a rotary click encoder and 2x16 LCD for the menu-driven user interface and Morse decode output, a LED to confirm Morse decoding and a decent number of setup memories so that favourite arrangements could be saved and recalled with ease.

Architectural overview

The architectural flow is somewhat influenced by the excellent Teensy audio library **[17]**. **Figure 1**, which comes from its web based audio system design tool, shows the general arrangement of the system. Audio data comes in via both the line-in (via 'inter-IC sound', I^2S **[18]**) and the USB port. Only a single channel is taken from each, as all processing is currently done in mono. The two inputs are equally mixed into a single mono channel. It should be noted that they are not scaled down in the mix, so if you input two full scale signals at the same time, the audio will get clipped.

The finite impulse response (FIR) filter **[19]** block is configured as a bandpass. The high and low clips are dynamically configured depending on the user's choice. The resulting data is passed into a data queue. This is a very powerful aspect of the Teensy audio library that allows the data flow to be extracted and further processed with other code and tools before being re-injected back into the library flow. In this case we use a mixture of open coded and the ARM CMSIS DSP library functions **[20]**. During that processing we handle all the noise reduction, blanking and auto notch filtering functions.

After processing the tone, fft256 and note frequency detectors are used to feed the Morse decoders and present a Morse tone tuning guide.

The combination of the amplification and the two peak detectors can be used to provide a rudimentary form of automatic gain control (AGC), whereby the peak value of the outputs after processing are adjusted to try and match the peaks of the original inputs. This evens out any volume level changes invoked when switching between different processing methods, which may either attenuate or boost the original signal.

Ultimately the final signal is passed out to the I^2S bus and thence to the digital to analogue converter (DAC). This output ends up at the line-out and headphone sockets. The sgtl5000 block is used to control the audio CODEC chip, including optionally enabling a hardware AGC block.

Circuit diagram

Figure 2 shows the remarkably straightforward circuit diagram. The main elements are a simple power supply, the Teensy board with the associated LCD and rotary switch, plus the audio 'shield' (daughterboard) that contains the ADC and DAC. For clarity, unused pins are not shown; neither are the connections between the Teensy and the audio shield (largely because it's a simple plug-in job and we simply don't need to know about those internal signals).

Construction

The Teensy PCBs were mounted onto a protoboard, which simplifies interwiring. This serves two main functions. First, it provides a convenient way of mounting the boards so that the assembly can be bolted to the case. Second, the board houses the 7805 voltage regulator and associated parts that allow the unit to be powered from 12V (nominal) via Anderson PowerPole connectors I mounted on the rear panel.

I should mention here there are a couple of, errm, 'borderline' choices on the current setup. They are working, in my *particular* setup, but if you are constructing from scratch you may want to bear the following points in mind and make some different choices from me. First, the Teensy 4.0 board is not 5V tolerant (it has an onboard 3.3V regulator), but the Grove I^2C 2x16 LCD is a 5V part. In my prototype the I^2C bus seems to be working fine but, if starting from scratch, you might want to ensure you get a 3.3V (tolerant) display or perhaps incorporate some level translators. You may even want to move to the more normal 4 or 8-bit 2x16 LCD interface. I only used the I^2C display as that is what I already had to hand.

Driving the Morse LED direct from the Teensy pin is not ideal because the output current from Teensy 4.0 pins is pretty low. It would be better to drive the LED through a transistor if you can, or at least use a high-efficiency LED so you get decent brightness.

The code was developed using the Teensyduino plugin to the Arduino IDE. The integration is as good as you would hope and things 'just work'. One interesting thing to note is that during development the ability to stream audio into the Teensy over USB was a godsend. It means you don't have to have your rig powered up and you can feed recorded samples through over and over again to compare changes. You can also tune into a WebSDR on your host system and listen to that through the device, which was a boon for me at times. At the same time you can have a USB serial port enabled and use that for debug messages back to your host. I believe you could also stream audio out of the device and back to the host in parallel to playing it out of the line-out and headphone socket but I did not investigate that, as it was not a feature I was looking for.

I won't go into the code in any detail here, other than to mention that it is documented within itself and can be found on my Github page for the project **[21]**. The code is wholly open source. All new code is licensed under GPL Version 3. All imported code is under open source and permissive licences, including a mixture of MIT and GPL licenses.

With a 2x16 character display, there was a limit to the amount of information I could show. **Figure 3** shows a typical display, annotated to identify the significance of the various parts. The top line shows the currently selected 'settings slot' number, along with its name. Rotating the encoder, when not in the menu system, moves between the setting slots. The menu system is entered by clicking the encoder. If the CW decoder is active, the decoded characters scroll across the top line of the display. The bottom line shows the status of the various functions. I had to convey a lot of information in a very limited number of characters!

After initial evaluation on the breadboard, the unit was boxed up. The case is constructed out of thin plywood. This was easier for me to source and work than doing a bent metal case, but the downside is it has no inherent RF shielding. The case shape is designed to match the size of my transceiver, and tilt the transceiver up to allow easier viewing and access of the front panel. I didn't search to see if there were any pre-made cases of the correct size with a slope to them - I suspect not.

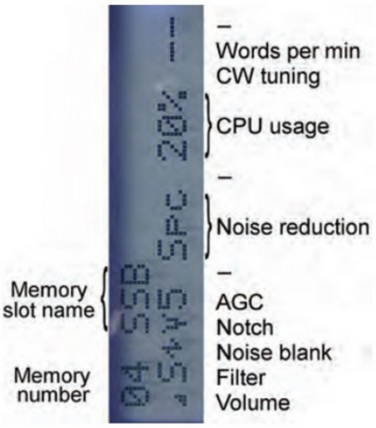


FIGURE 3: LCD details.

Birdies abound

After construction and testing and once I'd got the line in/out connectors wired up, I connected the unit to my transceiver for a test. It worked, but... on some bands there were some new interference noise peaks. Birdies! Some bands were worse than others. Tuning around, I found that the peaks were just under 100KHz apart.

Fixing the birdies turned out to be perhaps the hardest part of the project. How to identify what was causing the birdies - and what to do about it? Well, the circuitry has a number of clocking items. The Teensy itself is clocked at 600MHz, driven by a 24MHz crystal. It also has a 32.768kHz crystal for the real-time clock (RTC). The audio board is clocked from the Teensy at 11.29MHz, 1.41MHz and 44.1kHz. Then there are peripheral clocks (I^2C, SPI etc) and the display probably also has its own clock. That's a lot of clocks!

The original case was unshielded, made simply from plywood. So I lined the case with aluminium foil tape of the type used for sealing ducting and insulation joints. I also put ferrites on all the incoming and outgoing cables. At least temporarily, I disconnected the USB cable in case that was a source of (additional) noise. After all, I wasn't planning to have the USB cable hooked up during normal operation. I also used an audio line level isolator on the line in connection, as that is the primary direct connection between the transceiver and the processor. These precautions and actions did reduce the noise across the bands somewhat, but certainly didn't eliminate the birdies. Somewhat in desperation, I tried running the unit from a separate power supply - a battery. Voila! Most of the birdies vanished. Here was a clue.

I put more capacitors around the 7805, bringing it to the version shown in the circuit diagram. I also added an internal ferrite to the power cord and replaced the debatable ribbon cable I'd used to hook up the line in/out with some shielded audio cable, wrapped heavily through a ferrite ring. These additional actions 'killed off' almost all of the residual birdies. If I go looking I can still just find some very small peaks, for instance on the 5MHz band, but they are now so small and few and far between that they are not interfering with my operation. I'm glad I've added the shielding and the ferrites anyway; it will reduce the chance of problems cropping up 'the other way' when I eventually start transmitting.

The lesson here was not to go skimping on decoupling capacitors, connecting leads, screening, or ferrites.

Performance

Results when using the DSP filter are positive: some functions perform remarkably well. Notably, the Morse decoder works better than the one built into my transceiver. It's more sensitive and better at auto-detecting and tracking the Morse speed. The auto-notch filter is amazingly effective, pretty much completely removing any constant tones and whistles whilst having no detectable impact on the remaining audio.

Noise reduction is also pretty good. Noise reduction is a hard computational problem and is generally a compromise between how much noise you remove and how much 'distortion' you introduce or what parts of the actual signal you inadvertently remove. The best noise reduction algorithm in the unit is probably the Spectral noise reduction from the Teensy-ConvolutionSDR/UHSDR project, but it can leave the sound with a 'watery' effect. Overall though I find having the noise reduction enabled makes my transceiver much more listenable to and less fatiguing than without the noise processing. Noise (impulse) blanking appears to work, but it is very subtle. Generally I don't suffer from a lot of impulse noise, so it is hard for me to judge. At least it seems to have no negative effects when not actively removing impulses. The band pass filters work as expected. Enabling the SSB filter for instance can improve SSB signals coming out of the transceiver. The CW filter can isolate and improve the Morse decoders.

Possible future developments

My plan has always been to have a 'Version 2' that utilises a 1.8" 160x128 TFT screen and multiple rotary encoders so that several parameters can be varied without recourse to the menu system. I'd really like to show the original and resulting audio overlaid on the screen in real time. I have a second set of development boards just for this reason, so I can actively use the V1 setup whilst tinkering on the next version.

I'd also like to investigate some other features such as binaural/stereo processing, particularly for multiple CW tones, further 'tuning' the noise reduction algorithms, enabling the 7-band parametric equaliser in the sgtl5000 chip for noise shaping, hearing correction etc and maybe adding more soft decoders such as RTTY and possibly others. The Teensy 4.0 has lots of space and processing power left for more crunching. If it is found to be running out of processing power then a leaf could be taken out of the Teensy-ConvolutionSDR book, which downsamples the incoming audio before processing. Presently I run the complete chain at the full 44.1kHz sample rate. Even for SSB audio, that is quite over the top. The Teensy-Convolution SDR samples at 96kHz and downsamples by 8 to 12kHz, which should be plenty for processing a ~3.5kHz wide signal. I could for instance downsample the 44.1kHz by a factor of 4 to around 11kHz. In fact I did experiment with this in early development (and it worked fine) but found that the Teensy had more than enough processing power to run everything at the full 44.1kHz sample rate so that's how I left it.

Costs

This was not an expensive project. The Teensy boards are powerful and relatively cheap (£20), which contributes massively to keeping the costs down. The audio board was £15 and when I totted up all the other bits and pieces, the total came to about £50. This compares very favourably with many of the alternatives I investigated at the start of this project. And I had a lot of fun and gained a lot of features I was looking for to boot.

Summary

Overall, I'm glad I undertook the project. It was fun and functional, and provides extra capabilities to and makes my transceiver more pleasant to use. I'm looking forwards to see what I can achieve in the 'Version 2' system, whilst actively using my 'Version 1' on a daily basis.

Websearch

[1] https://gi1mic.github.io/
[2] https://github.com/DD4WH/Teensy-ConvolutionSDR
[3] https://github.com/gcallipo/RadioDSP-Stm32f103
[4] https://www.gnuradio.org/
[5] https://www.raspberrypi.org/
[6] https://www.raspberrypi.org/products/raspberry-pi-zero/
[7] https://www.pjrc.com/teensy/
[8] https://www.pjrc.com/store/audio_tutorial_kit.html
[9] https://www.pjrc.com/store/teensy40.html
[10] https://www.pjrc.com/store/teensy3_audio.html
[11] https://github.com/df8oe/UHSDR
[12] https://github.com/NR0V/wdsp
[13] https://www.pjrc.com/
[14] https://github.com/PaulStoffregen/Audio
[15] http://k4icy.com/cw_decoder.html
[16] https://sites.google.com/site/lofturj/cwreceive
[17] https://www.pjrc.com/teensy/gui/index.html
[18] https://en.wikipedia.org/wiki/I%C2%B2S
[19] https://en.wikipedia.org/wiki/Finite_impulse_response
[20] https://developer.arm.com/tools-and-software/embedded/cmsis
[21] https://github.com/grahamwhaley/DSPham

10 metre band medium-distance propagation via FT8

FT8 has proved to be a very robust tool, enabling contacts around the world for stations running poor antennas and/or low power.

However, it has also thrown up some anomalies. For example, I started to notice FT8 contacts on 10 metres that appeared to defy propagation lore as we know it. These contacts were often in excess of 160km. In fact, they were a bit like Goldilocks contacts – thought of as possibly too far for conventional ground wave, but not far enough for F2 layer or Sporadic-E (Es) contacts.

As such they warranted closer attention and I put a request out in *RadCom* for other amateurs to report if they were also seeing them. The result was that a number of UK amateurs regularly sent me details of stations heard or worked on 10 metres.

For example, Andy, G0SFJ (Market Harborough), and later GB9XMS, supplied reports from PSK reporter that showed signals being received from David, MM0AMW (Campbeltown, Argyll) at a distance of 443km. Or from PA3ECU (Gildenburg, Netherlands) at a distance of 490km.

So what was the mode of propagation?

Looking at the 10m band

Any study had to wait until the end of the main Sporadic-E season in September in order to reduce the possibility of Es propagation being a factor. There is still the possibility of Es, after September but it is less likely.

But firstly, just how far is ground wave propagation on 10m FT8? My experience with 10m is that CW signals can often be heard out to about 100-120km.

An informal test with fellow Propagation Studies Committee member John, G4BAO showed that FT8 signals could be reliably decoded over the 72.36km path between my QTH in Wymondham, Norfolk (JO02NO) and John's Waterbeach QTH (JO02CG).

From the *Radio Communications Handbook* (page 12.4) a formula (neglecting cable/connector losses) gives:

Pr (dBm) = Pt (dBm) + Gt (dBi) + Gr (dBi) – PL (dB)

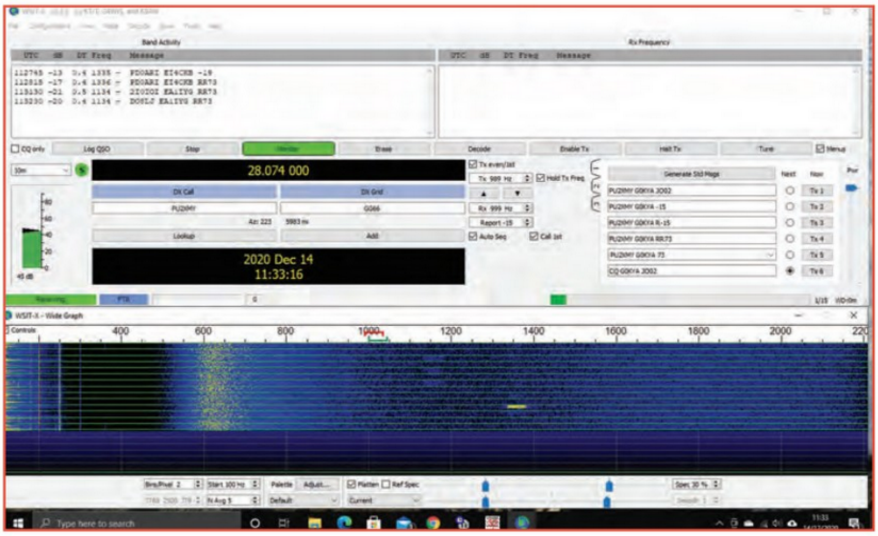


FIGURE 1: **A screenshot of WSJT receiving FT8 signals from Spain and Ireland on 10 metres.**

where:

Pr = Received signal strength
Pt = Transmitted power
Gt = Transmitter antenna gain
Gr = Receiver antenna gain
PL = Path loss

You can use ITU-R Rec. P.368 **[1]** for estimating ground-wave losses. Or you can download the GRWAVE ground wave propagation program from the ITU (https://www.itu.int/en/ITU-R/study-groups/rsg3/Pages/iono-tropo-spheric.aspx).

Be careful with GRWAVE as it uses defaults with settings for sea paths. You will need to change "EPSLON" – note GRWAVE drops the "I" from EPSILON (the relative permittivity of the Earth) to a more suitable figure, such as "15" from the default "70". And SIGMA (the conductivity of the Earth) to "0.005" from the default "5" **[2]**.

Putting these values into GRWAVE, we find the ground-wave loss for 28MHz at 70km is ~185dB.

For 160km it is ~215dB.

So, assuming 50W Tx (+47dBm) and a dipole-to-dipole link, plugging the numbers in we get:

Pr= 47+2.15+2.15-185

Pr~-134dBm over a 70km path

and Pr=47+2.15+2.15-215

Pr ~ -164dBm over a 160km path.

My noise level on 28.074MHz is about -129dBm in a 2.4kHz bandwidth, therefore FT8 signals may be 5dB below the noise at 70km with 50W Tx and zero gain antennas (dipoles) at each end.

At 160km this would be -35dB below the noise level. Or below the minimum required for an FT8 contact.

So we could argue that 10m FT8 ground wave contacts could be reliably made over distances of more than 70km, but not as much as 160km, perhaps longer over sea paths.

Obviously, if you run more than 50W or have an antenna with gain your distances will increase. I regularly decode Gary, G0FWX in Bromsgrove, Worcestershire at about 0dB to -7dB at a distance of 219.7km, but Gary runs 100 watts into a 10-element band optimised log periodic at 60 feet. He is also on top of a 198m hill.

At these lower frequencies, vertical polarisation propagates via ground wave more efficiently than horizontal polarisation. So, if you are trying for record-breaking FT8 ground-wave distances on 10m, vertically-polarised antennas are probably the way to go.

Note that while an antenna may be oriented horizontally (eg horizontal dipole), there may be vertical polarisation along the axis of the antenna (ie off the ends if mounted as an inverted V). This is, in fact,

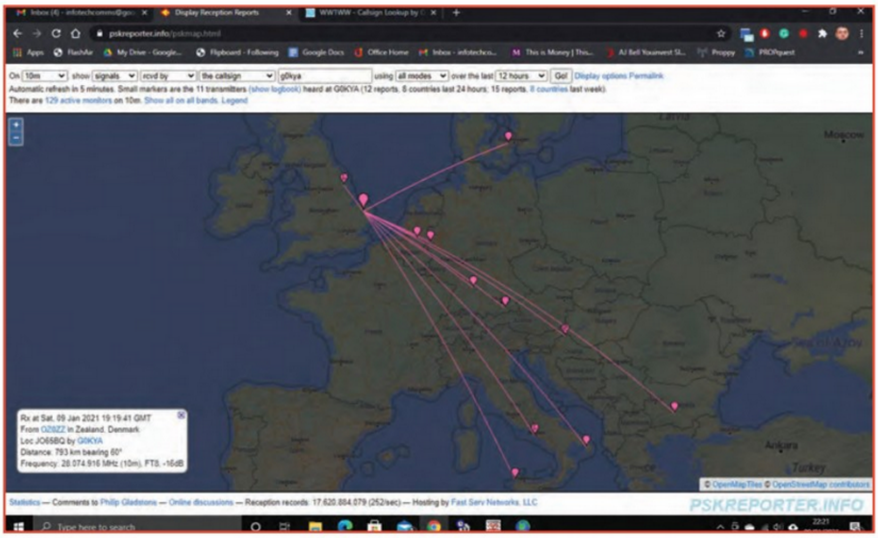


FIGURE 2: A typical mid-Winter 10m Sporadic-E opening with signals from Italy and Bulgaria, but also closer signals from Denmark, the Netherlands and Germany.

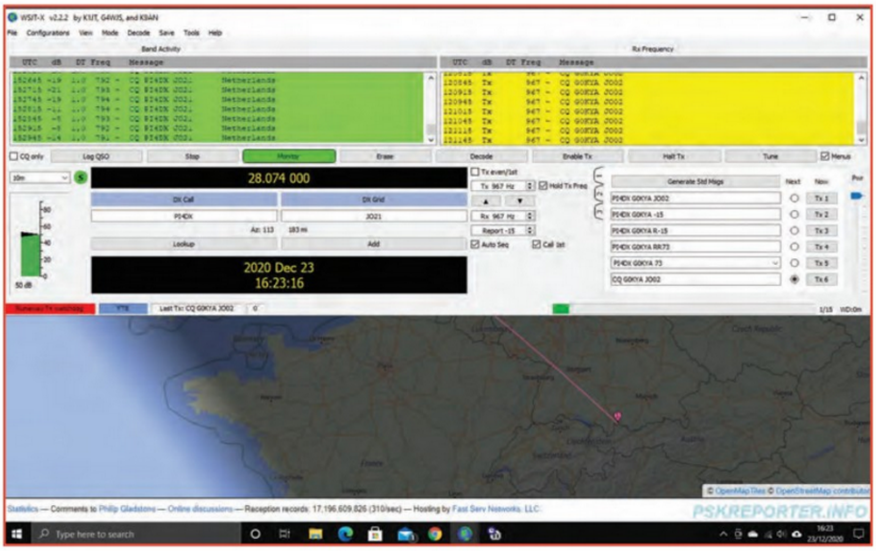


FIGURE 3: 10m FT8 Signals being received from PI4DX in the Netherlands.

roughly how my 132ft EFHW antenna works on 10 metres, exhibiting roughly –9dBi gain in the south-westerly direction towards G4BAO at low angles. But what about those FT8 contacts in excess of 160km?

Troposcatter

I think the answer is troposcatter, ionoscatter or Sporadic-E. I discounted aircraft scatter as there were plenty of days when there were aircraft flying, but no signs of any FT8 activity at distances between 100km and 500km. Meteor scatter was ruled out as the contacts were often seen outside of the times of major meteor showers.

But as a warning, there have been times when I have seen an FT8 signal rise out of the noise for just a few seconds, which rather suggests that meteor scatter is a possibility.

Troposcatter is a method of communicating with radio signals over considerable distances, depending on terrain and climate factors. More common at microwave frequencies, it has also been reported at 50MHz, which was the topic of a talk by Palle Hansen, OZ1RH **[3]** at the 2018 RSGB Convention (Palle also gave a talk on ionoscatter at the 2020 online convention **[4]**).

This method of propagation uses the tropospheric scatter phenomenon, where radio waves are randomly scattered as they pass through the upper layers of the troposphere. Because the troposphere is turbulent and has a high proportion of moisture the tropospheric scatter radio signals are refracted and consequently only a tiny proportion of the radio energy is collected by the receiving antennas.

Troposcatter was used by commercial services and the military in 1950-80 and, for many years, Palle says radio amateurs have worked many 700-800km QSOs any day at higher frequencies, so why not troposcatter on 10 metres?

If the mode of propagation was troposcatter, received signal strengths on 10 metres would generally be quite low [tick] and distances up to 800km might be possible [tick].

In 1960, L P Yeh **[5]** wrote a paper entitled "Simple Methods for Designing Troposcatter Circuits" in *IRE Transactions on Communications Systems*. In it he said that troposcatter losses boiled down to:

- Free space path loss
- Scattering loss
- A loss factor dependent on the refractive index of the air
- Aperture-to-medium coupling loss, which is a function of the scattering angle and the antenna beam widths used.

We will ignore the last aperture-to-medium coupling loss for the purposes of this exercise as his paper dealt with VHF and above links. But we will deal with the other factors. The free space path loss can be calculated using a tool such as that found at https://www.everythingrf.com/rf-calculators/free-space-path-loss-calculator

Based on $L_{fs} = 32.5 + 20\log10(d) + 20\log10(f)$

where d is the (great circle) distance in km and f is the frequency in MHz.

At a distance of 160km the free space loss on 10m is therefore about 105.5dB.

Yeh [5] determined the scattering loss empirically based on two sets of experimental observations. The first was that scattering loss was proportional both to frequency and to the scattering angle (10dB per degree). The second was that the scatter loss at a one-degree scattering angle (about a 144km path) was 57dB at 400MHz. These observations were combined to yield the relationship:

$L_s = 57 + 10(\theta-1) + 10\log(f/400)$

Where θ is the scattering angle in degrees and f is the frequency in MHz.

This can be simplified to:

$L_s = 21 + 10(\theta) + 10\log(f)$

So on a typical probable scatter path on 10m:

L_s could be $21 + 10(1) + 10\log28$

$L_s = 21+10+14.47$

$L_s = 45.47\text{dB}$

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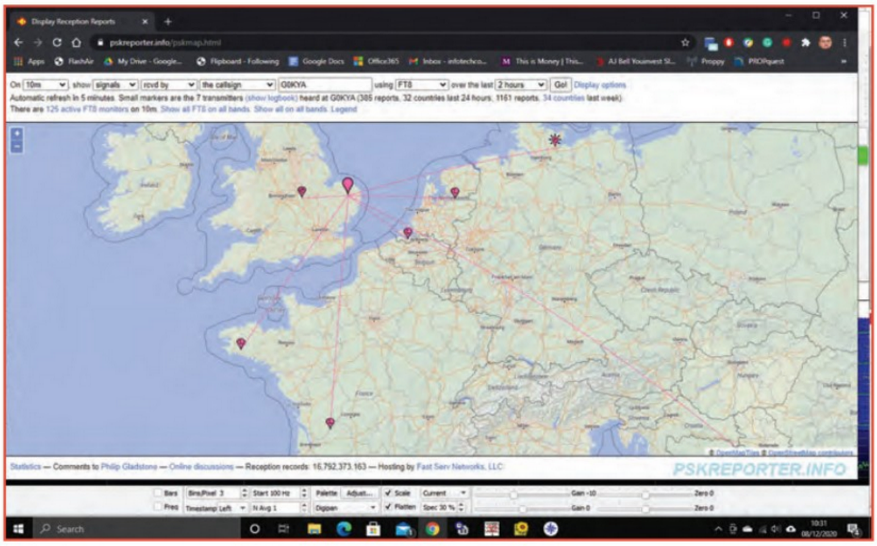

FIGURE 4: A mix of 10m FT8 signals from the UK, France, the Netherlands and further afield.

The loss factor due to the refractive index of the air rests on a number of variables, the most important of which are air temperature and humidity.

The surface refractivity, Ns, is the refractive index expressed in millionths above unity. For example, if the refractive index is its nominal value of 1.000310, the value of N = 310. The value and range of variability of Ns is a function of geographical location and season. It's highest in the summer in tropical coastal regions, and lowest in the winter in the mountains.

Because Ns is dependent on atmospheric pressure, it follows that it's also a function of altitude. The actual surface refractivity will be lower and can be approximated by the formula

$N_s = N_0 e^{-0.1057h}$

where h is the elevation above sea level in km.

The importance of the radio refractive index lies in the fact that a higher value of Ns causes radio waves to bend back towards the Earth to a greater extent. More accurately, it's the change in refractive index with height which results in this effect which can be likened to the bending of light rays passing through a graded index lens.

Thus radio waves don't travel in a straight line when passing through the atmosphere, but tend to bend back slightly towards the Earth. An alternative way of looking at the same phenomenon is to regard the radio waves as travelling in straight lines above an Earth whose radius is larger than the true radius. The increase in path loss as a function of Ns is approximated by Yeh as

$L_n = 0.2(310 - N_s)$ (dB)

So we see that troposcatter relies on the refractive index of the air, just as tropospheric enhancements do.

Ionoscatter and Sporadic-E

And lastly, what about contacts in excess of 800km? The most likely explanation would appear to be ionoscatter or Sporadic-E (Es). Taking Es first, although we normally associate Es with the May to September period in the Northern hemisphere, with a smaller peak in mid-winter, there is evidence that Es can occur all year round.

The openings may not be as strong or long-lived as summer Es openings, but there is often enough to support 10m FT8 propagation for a few seconds or even minutes. The openings may be hard to predict, but there is ongoing work looking at how the jet stream may contribute to Es by moving across mountainous areas and the subsequent deflection resulting in "gravity waves" that propagate upwards, compressing ions in the E region.

These ions may come from meteoric debris and there are plenty of showers in the winter, including the Leonids, Geminids, Ursids and Quadrantids. However, a paper entitled "An explanation for the seasonal dependence of midlatitude Sporadic-E layers" **[6]** shows that the occurrence of Sporadic-E is linked more to the variations in the arrival rates of sporadic meteors than it is to meteors from showers.

Jim, G3YLA introduced his Es probability index (EPI) to Propquest.co.uk last year and this shows the jet stream's path over Europe and the UK.

Our last mode is ionoscatter, which is possibly responsible for FT8 contacts in the range 1,000-2,000km **[7]**.

According to Palle OZ1RH, ionoscatter is most often caused by scattering from irregularities in the ionosphere at 70-90km height. You may recognise this as the D layer, which we normally associate with absorption on the lower HF bands.

The military discovered ionoscatter in the 1950s and 60s, but the mode was not normally open to radio amateurs due to the high powers and high-gain antennas normally required. 40kW and 20dB antenna gain were not unheard of for ionoscatter stations. But fast forward to the 21st Century and the reduced signal-to-noise ratios needed by modes like FT8 means anyone can now take part.

A typical scenario

An example of a 10m FT8 contact that could have been ground wave was logged between me (G0KYA) and PI4DX at 1335UTC on 22 December 2020. PI4DX had been spotted earlier that morning and later came up to -1dB at 1339UTC (although the station was actually worked at -6dB). They remained workable for almost two hours.

The path from my QTH to the Netherlands is well known for 2m openings when conditions are good as it is mostly over the North Sea. A subsequent email to PI4DX revealed it is a contest station and Erik said they were running 25W to two six-over-six element Yagis at 36 metre height.

So let's do some sums. The distance between my station in Wymondham, Norfolk (JO02NO) and PI4DX in Walsoorden (JO21AJ) in the Netherlands is 237km.

Their antenna gain is probably in the region of 19.4dBi including ground gain. The relative permittivity (Epsilon) and conductivity (Sigma) along that path is a tough one. The figures for sea water are 70 and 5, the figures for average ground are 15 and 0.005, so what figures do you use?

Rec. ITU-R P.368-9 Annex 2 [1] suggests using the 'Millington Method' for mixed paths. That is, you break the path down into land and sea segments. So 237km became 35km land, 164km sea and 40km land. Millington then suggests some maths to combine the three paths. This gave a result of 202dB.

Plugging the figures back into Pr (dBm) = Pt (dBm) + Gt (dBi) + Gr (dBi) - PL (dB)
we get Pt (43.98dBm) + Gt (19.4dBi) + Gr (2.15dBi) – PL 202dB
= -136.47 dBm

As I said earlier, my noise level on 28.074MHz is about -129dBm in a 2.4KHz bandwidth, therefore PI4DX's FT8 signals were calculated to be 7.5dB below the noise at my QTH assuming my antenna gain of 2.15dBi. I copied them between -1 and -6dB.

In other words, ground wave may appear to be the mode of propagation for 10m FT8 between G0KYA and PI4DX over this 238km path.

Ionoscatter is a forward scatter mode like troposcatter, and is likely to peak around midday at mid latitudes. You can expect fast fading and path losses are reportedly lower for horizontal polarisation – the opposite of ground wave.

In his RSGB lecture [4], Palle Hansen, OZ1RH showed that the ionoscatter loss will be 10dB less at 30MHz than at 50MHz.

If ionoscatter is a mode for 10m FT8 we might expect signals to increase during HF blackouts after a sudden ionospheric disturbance – there is room for experimentation here. There is also the possibility of F-layer scattering at about 250-300km height, which could give distances of 2500-2800km.

Conclusions

So in summary, 10m FT8 paths out to around 100-250km are likely to be ground wave, especially if antenna height/gain and power are factored in; from 275-1300km troposcatter or Sporadic-E (probably 550km to 1300km for Es); and from 1000km upwards ionoscatter, Sporadic-E or F2 layer. The latter two modes depend upon whether the solar flux index is high enough to support ionospheric propagation or if there are likely to be Es clouds around, such as in the summer months or during the mid-winter Es peak.

As both scatter modes probably need high gain antennas and high power I think the most likely explanation for longer distance contacts is Sporadic-E, unless you know exactly what the station is at both ends. A good way of watching for long-distance 10m modes, is Gabriel Sampol, EA6VQ's DXmaps.com.

Just when we thought we knew everything about HF propagation, a new mode (FT8) comes along and challenges what we thought we understood! I hope this feature will encourage you to look for longer-distance contacts on 10m when the band seems otherwise closed.

Acknowledgements

My thanks go to the many radio amateurs who contributed logs and to fellow Propagation Studies Committee members Marcus, G0IJZ, Chris, G4IFX and Jim, G3YLA for their help.

Websearch

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The RSGB Propagation Studies Committee promotes interest in radio propagation amongst radio amateurs and shortwave listeners, to enable them to make informed use of the amateur bands and develop a research interest into the subject. See www.rsgb.org/psc for details.

A brief look at NEC-5 – continued from p35

Obtaining NEC-5

Details for obtaining NEC-5 software can be found on the LLNL website **[12]**. The NEC-5 *Validation Manual* [5] can be downloaded before purchasing the software, so prospective buyers can decide for themselves whether NEC-5 is likely to give the modelling results they need. Note that the NEC-5 *User Manual* [1] is only available with the software.

Prospective buyers must complete an End User License agreement with LLNL, a Licensee Information Form (and additionally a Customer Screening Form if you are not a US entity).

Don't expect to immediately pay online and have instant download of the NEC-5 software. It can take a few days for processing at the LLNL side and for a bank transfer to be confirmed by LLNL Accounts. But once complete, you'll be informed of the download process, which is fairly straightforward.

It's worth noting that "LLNS is under no obligation to provide maintenance or support for the Software; or to notify End User of Software Updates (if any) (including without limitation bug fixes, patches and upgrades)." However, updates have been made available at the download site, so it is recommended that users check every now and then for updates.

Summary

NEC-5 is an exciting development in the story of NEC. If you're interested in antenna modelling, then NEC-5 may offer you simulation capabilities that you didn't have previously with NEC-2 or even NEC-4. Antenna designs with buried wires, tapered-diameter wires and multiple wires at a junction can be conveniently modelled with greater confidence. Furthermore, NEC-5 enables antennas on surfaces to be simulated more accurately, something that could only be approximated with wire grids in NEC-2.

Whilst not free like NEC-2, the NEC-5 'Individual' license fee of $110 is much lower than the cost of NEC-4. If your antenna modelling needs are not met with NEC-2, then NEC-5 may be for you.

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Tilt-over modification
for vertical antennas

I live in a small three bedroomed bungalow in a semi rural part of Cheshire and have a small, low maintenance garden to match my advancing years. It isn't the best location for HF reception. My usual antennas are a mixture of dipoles and long wires strategically placed to avoid attracting problems with neighbours. Although vertical antennas have a reputation for being noisy **[1]** I decided to try a Hustler 4BTV (four band tuneable vertical), ground mounted with radials (because of the location constraints). In view of lockdown difficulties I needed either to be able to safely erect and adjust the antenna single-handed, or wait until the world gets back to normal. I decided to go ahead and get it assembled and erected, which I felt ruled out the manufacturer's pole mount method using U bolts. It would be impossible for me to hold the antenna and fit the U bolts without the possibility of an injury to myself or an accident damaging the antenna, particularly the connection terminals on the bottom of the mounting bracket. Other than the mounting method, I intended to follow the manufacturer's instructions closely as possible in all other aspects.

My plan was mount the antenna bracket on a swivel so I could walk it up into the vertical position, then secure it with clamp plates. I chose to use 50mm square heavy duty rectangular hollow section steel mounting post in place of the 1¼" (32mm) ID steel water pipe suggested in the instructions. I pulled a rag soaked in anirust compound through the post before setting it on top of a few stones to act as a soakaway and prevent water from filling up the post. I also made and fitted a blanking cap for the top of the post. There is much more than just a bit of rust at stake here: if your mounting post fills with water that then freezes, it could easily be split by the expanding ice. Such damage may not be immediately obvious (out of sight, out of mind) but will certainly rob the support of much of its strength, greatly increasing the likelihood of catastrophic failure.

PHOTO 1: Antenna mount in upright position.

I modified the antenna mounting bracket by fitting a 6mm thick spacer to the back of the bracket with cutouts to accommodate the pole mount protrusions and bolt heads, and to give a flat swivelling mounting surface. **Figure 1** shows the general arrangement.

The swivel mount consisted of an 8mm bolt on the vertical centreline of both the antenna mounting bracket and the 50mm square mounting post. The vertical position of the swivel was set at 75mm down from the top of the bracket. It is important that the swivel mount is on the centreline otherwise there may be difficulty on final assembly. Also, do make sure you use a nylon locking nut on the swivel bolt. The chances of it coming undone in use are small, but could be devastating.

The U bolts of the original design were replaced by two heavy duty clamp plates and four 6mm x 90mm bolts with nuts and washers. The holes in the clamp plates were pitched to match the U bolt mounting holes (being from the Us and using imperial measurements, it was 2.25 inches between centres), making it a snug fit around the square post. The assembled antenna was bolted to the post with the 8mm bolt as a swivel mounting. The clamping plates were loosely fitted with one bolt on the open side of the upper and lower clamp to act a stop once in the upright position and allowing the whole assembly to be walked up to the vertical. Once the antenna was vertical the remaining bolts were fitted and tightened, properly securing the antenna to the pole. The method proved to be a great success allowing the antenna to be handled, tuned and serviced with ease.

Although I used this mount with a Hustler 4BTV vertical

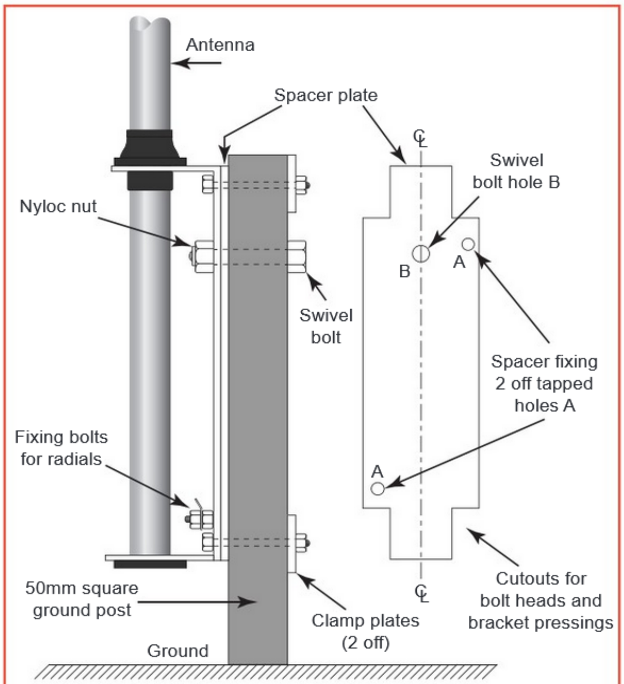

FIGURE 1: General mechanical arrangement of the tilt bracket.

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Continued on page 82

Book Review

The Radio Today guide to the Icom IC-705

by Andrew Barron, ZL3DW

Andrew Barron is one of the ascending stars of amateur radio writing. His titles feature fairly frequently in *RadCom* book reviews – and deservedly so, because he really does have the all-too-rare knack of explaining things clearly, concisely, and at just the right level. It's like having what Americans would call an 'Elmer' on your bookshelf.

This book on the new Icom IC-705 joins ZL3DW's other *Radio Today Guide* books on the IC-7300, IC-7610 and IC-9700 as the go-to learning, reference and *enjoyment* aid for these fine new radios.

Once *I* get a shiny new toy home I tend to dive straight in to see what it can do, usually without reference to the manual. Why? Well, most radio manuals do a fine job of documenting the functions, one by one, and often in isolation. Great if you can't quite remember what Scan Mode 47 does, but not so useful if you want to, say, set up a memory for the CW net with particular bandwidth, noise blanker and notch filter options.

What Andrew does in this book is concentrate much more on the IC-705 *from the point of view of the amateur who's trying to use it*. He generally takes what I'd call a 'task-oriented' approach – if you want to do *this*, you'll need to do *this*, *this* and *this* – and you may want to read up on *that* (for example a detailed discussion of D-Star parameters or perhaps computer-to-radio communication). He really does lay out the IC-705 from the user's point of view. I was also pleased to see judicious use of things like high quality screendumps and other images used where they illustrated a point better than words might. And if anything seems to go wrong, there's even a Troubleshooting section at the end of the book with loads of useful info, including a section entitled "HELP, I SET MY RADIO TO JAPANESE TEXT MODE"!

My appreciation of *The Radio Today guide to the Icom IC-705* should not be taken as a criticism of Icom's documentation. The point is that ZL3DW is writing from a different perspective, one that many people will find more accessible and intuitive. If you have an IC-705 – or even if you're *thinking* about getting one – then I wholeheartedly recommend you get a copy of this book. You'll learn a lot, possibly without even realising it, and be able to master the functions of one of today's excellent radios.

Size 174x240mm, 224 pages, ISBN 9781 9139 9505 8
Non Members' Price £15.99, RSGB Members' Price £13.59

Microcontroller Projects for Amateur Radio

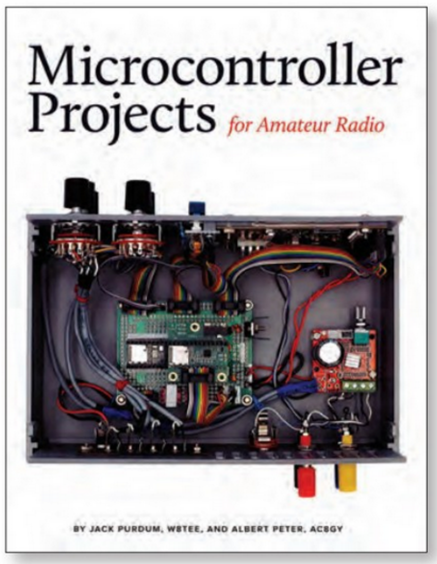
by Jack Purdum, W8TEE, and Albert Peter, AC8GY

Microcontrollers run everything from your TV remote to your washing machine. This mass production has reduced the prices to just a few pounds for complete development boards. This book shows you how to harness the power of these useful devices for amateur radio applications. The choice of components and detailed physical construction is covered along with full details of the program that supports the project. Key parts of the program are fully explained, and the source code is fully documented.

The book begins with a description of the processor models used in the projects. These include the Arduinos, Teensy 4.0, STM32F103 ('Blue Pill') and the ESP-32. These can all be programmed using the free Arduino Integrated Development Environment (IDE). Although not mentioned in the book, much of the information should be adaptable for the new Raspberry Pi Pico microcontroller as that can also be programmed via the Arduino IDE. The book provides some especially useful programming tuition with an overview of the C language as well as an introduction to the more advanced C++. One chapter is dedicated to displays but the main part of the book covers 11 projects including a dummy load power meter, Morse tutor, bench power supply, and a graphical SWR display antenna tuner (amongst others).

This is an excellent educational resource and provides a solid grounding with good programming practices. The excellent project descriptions make it relatively easy to adapt the designs for other projects.

Size: 208x276mm, 400 pages, ISBN 9781 6259 5128 1
Non Members' Price £39.95, RSGB Members' Price £33.95



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Meteor trails can sometimes be incredibly bright. ***Image: Ultra Mendoza.***

auroral scatter) occur at similar heights of 80 to 120km in the ionosphere.

Looking for work covering such interactions, I found some interesting research on sounds produced during an aurora **[5, 6, 7]**. In these reports, Laine (Aalto University, Finland) writes: "Eerie sounds associated with bright and lively moving aurora borealis have surprised and even frightened observers for thousands of years. Since the 17th century their existence and cause have been at the centre of many speculations and hypotheses. These have ranged from a totally sceptical view of their existence to some possible physical or physiological explanation". He continues [6] "Strange sounds that sometimes accompany bright northern lights have been difficult to study and even more difficult to explain since the light phenomenon occurs at such a high altitude. Due to the strong atmospheric attenuation of sound waves, no audible components remain after their long travel time from the ionosphere to ground level. Only infra sounds (<20Hz) are able to survive the long journey. Another strange aspect is connected to this phenomenon: the sounds are observed sometimes *simultaneously* with movements or intensity modulations of the lights. This should not happen if the sound source is located close to the light source (at the ionosphere level). These two facts have caused many physicists to be deeply sceptical about the existence of these sounds entirely. According to them the sound observations must be illusions or a kind of malfunction of our senses or our cognitive system."

The research addressed these issues by installing a microphone array and recording equipment to monitor sounds and a VLF antenna to measure electric field fluctuations during auroral activity. Measurements taken during the event of 17-18 March 2013 detected some sixty loud sound events, and they all had a counterpart event in the magnetic field signal. The time difference between the electrical and acoustic events indicated that the altitude of the sound sources were on average 75 metres above ground.

In **[7]** Laine expands on this: "Rank correlation between the RMS values of the magnetic pulses and the sounds showed a 99.9% probability that the sounds had a causal relation to discharging currents (possibly corona) about 75 meters above the ground. Concurrent atmospheric measurement data also show that a temperature inversion layer was located at the same altitude."

Laine's research thus postulates that the noises are caused by charged particles in an inversion layer of the atmosphere formed during a cold night. The charged particles discharge when particles from the Sun hit the inversion layer, creating the noise.

In a more general sense, acoustic effects can be created by illumination with light or other radiation. This photoacoustic effect (sometimes called electrophonic sounds) was discovered by Alexander Graham Bell in 1880 **[8]**. He observed that when a beam of sunlight is focussed on a dark sample and rapidly interrupted with a rotating disk, sound is produced. This observation led him to the invention of the 'Photophone' for transmitting the human voice. More recently the effect is used in medical imaging, and a historical review can be found at **[9]**. Put very simply, the incident radiation causes an increase in temperature of (for example) the gas. This causes a very brief thermal expansion, which generates a pressure wave that propagates through the gas and can be detected as a sound. It's evident that solids and liquids can exhibit the effect also.

Meteors

I guess it was in August in about the year 2000 when my wife and I joined our then neighbours for a walk on the downs to watch the Perseid meteor shower. The meteor shower is a stream of debris that stretches along the orbit of the comet Swift-Tuttle **[10]**. There were about six of us and it was very amusing as someone would say "There's one!" and point to it, but of course by the time we all looked in that direction it was gone. We all had a good time and saw plenty of meteors, but it was a comment by our neighbour Chris that I found curious – she said that on a previous occasion she had seen meteors *and heard them*, roughly simultaneously. I pointed out that meteors burn up at around 100km altitude and the time for the sound of that to reach the ground would be several minutes. But Chris seemed sure that she had indeed heard them. I gave this no further thought until recently.

Reading of the sounds heard during an aurora and outlined here, I wondered if meteors really *could* be heard. Can the radiated heat and light from a meteor really be significant? Perhaps the most extreme recent answer to this was the fireball created by the meteor that passed close to Chelyabinsk on 15 February 2013. The video evidence from CCTV and dash-cams was dramatic, and the pressure wave that struck the town after a few minutes caused many injuries and significant damage **[11, 12]**. Sounds *simultaneous* with the visible fireball were widely reported by eyewitnesses. Reports indicate that such sounds were heard at ranges to at least ~100 km from the fireball's path.

But for a less extreme example, is it really possible to hear a meteor more or less simultaneously with seeing it? Many people have reported hearing a swishing or hissing sound, but the difficulty of recording such events has been an obstacle to a convincing explanation. It appears that only a minority of meteors – probably the largest and brightest – are heard.

It's worth mentioning that scepticism about this has bedevilled research for decades. Many respected astronomers have expressed the opinion that the sounds are psychological or imagined by the observer. But as more reports were made, researchers came to the view that the cause was physical rather than psychological. Reports by respected observers who heard a sound *before* seeing the meteor helped to show that this was a real phenomenon.

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Auroras and meteors sometimes combine to make fabulous night skies. ***Photo: Noel Bauza.***

How might the sound be created? One theory suggested that the meteor or its trail emitted strong radio waves and that these were then transduced into acoustic energy and detected close to the ground. However, measurements showed that very little energy was radiated in the HF and VHF spectrum. In 1993 Keay **[13]** suggested that the meteor or its trail might be radiating in the ELF/VLF range, even down to ~40Hz. In 2011, Rault **[14]** conducted experiments to measure ELF/VLF signals coincident with meteor reflections of the Graves 143MHz radar. There did seem to be evidence supporting the ELF/VLF theory, although the paper noted that more data are needed to confirm such a conclusion. (For those wishing to pursue this themselves, the paper includes details of circuitry for the ELF/VLF receiver used).

An alternative theory was examined in a 2017 research paper by Spalding **[15]**, which describes experiments to evaluate the magnitude of sounds produced by irradiation with modulated light. Note that the light from a meteor will fluctuate, with significant energy below 100Hz.

The paper contains the following abstract: "Concurrent sound associated with very bright meteors manifests as popping, hissing, and faint rustling sounds occurring simultaneously with the arrival of light from meteors.

"Numerous instances have been documented with [Magnitude] −11 to −13 brightness. These sounds cannot be attributed to direct acoustic propagation from the upper atmosphere for which travel time would be several minutes. Concurrent sounds must be associated with some form of electromagnetic energy generated by the meteor, propagated to the vicinity of the observer, and transduced into acoustic waves. Previously, energy propagated from meteors was assumed to be RF emissions. This has not been well validated experimentally. Herein we describe experimental results and numerical models in support of photoacoustic coupling as the mechanism. Recent photometric measurements of fireballs reveal strong millisecond flares and significant brightness oscillations at frequencies ≥40Hz. Strongly modulated light at these frequencies with sufficient intensity can create concurrent sounds through radiative heating of common dielectric materials like hair, clothing, and leaves.

"This heating produces small pressure oscillations in the air contacting the absorbers. Calculations show that −12 brightness meteors can generate audible sound at ~25dB sound pressure level (SPL). The photoacoustic hypothesis provides an alternative explanation for this longstanding mystery about generation of concurrent sounds by fireballs."

A brightness magnitude of -12 is a little less than the full moon **[16]**. A 25dB SPL is very quiet, but audible **[17]**. A fireball of brightness -11 can weigh from a few kg up to several tens of kg. It follows that such events are rather unusual.

So whether the significant EM energy from the meteor is in the ELF/VLF range or infrared/visible, it may be capable of causing heating effects in local materials, which then create the sound. It seems that my neighbour was right, she had indeed heard meteors. And the likely cause relates to Bell's discovery of the photoacoustic effect.

There are indeed a number of interactions between the ionosphere and the lower atmosphere, even down to ground level. Or as Dirk Gently [1] in a different context puts it: "What we are concerned with here is the fundamental interconnectedness of all things".

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Design Notes

Noise and dynamic range

Martin, G8JNJ stated in a post to the RSGB-Technical Group, "I have a theory, based on observation, that typical wire (or even simple beam) antennas in an urban environment can't deliver more than about 70 to 80dB worth of dynamic range at most (noise floor to maximum level of any received signal) to the receiver." When we talk about noise at the same time as power level, we MUST always specify a bandwidth, so I enquired of Martin what bandwidth he was referring to. He said it was using a normal SSB filter. So let's look at a few figures and get this into perspective.

The standard S-meter calibration at HF is 50µV (or -73dBm) for S9, at 6dB per S-point. In a typical urban environment noise may sit at something like S5 when a normal antenna is connected to the radio. Mine is showing -93dBm on 7.2MHz, or around S6, as I write this in the middle of the day. The maximum input to my Elad-FDM Duo before input saturation occurs is -20dBm. This is 73dB above the background noise and in S-point terms 53dB above S9. If we take the absolute worst case situation of the loudest signal in the entire band being the one we are listening to, it can take on a maximum of -20dBm before overload sets in. The difference between that level and antenna noise is 73dB, at the lower end of Martin's quoted range. Quieter locations and higher frequencies may offer an improvement, but it does look as if a dynamic range much exceeding 80dB in an SSB bandwidth isn't going to be observed in any practical scenario.

Spikes and voltage regulators

In another post Kent, G8ENY / WA5VJB gave a warning about the damage over-voltage spikes can cause with voltage regulators. He states that "…the usual failure mode [of voltage regulators] is voltage spikes on the Vcc line. I NEVER use a 3-terminal regulator in a GaAsFET preamp. They work nicely until they see a 40-50V pulse, then the pulse passes right though them. A 2W resistor and a Zener diode may not be as sexy, but they take abuse. I have also seen remote mounted preamps blown when the ham fired up a high power HF rig. That long DC wire can make a nice HF antenna. When remote mounting it's a good idea to use a shielded wire when practical."

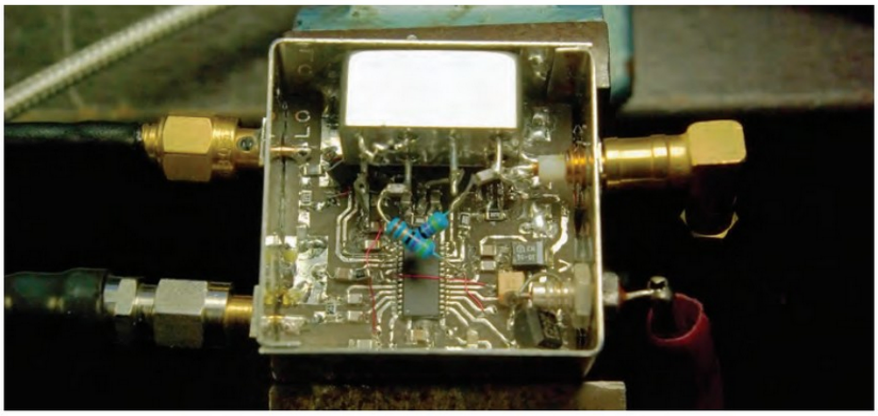

PHOTO 1: Breadboard of the AD8347 quadrature downconverter.

To test this I took two regulators, an LM7805 and an LM317 set to deliver +5V. The variable input of up to 90V came from three adjustable lab power supplies in series. A 680Ω resistor was used as a load on each regulator to give a few mA of working current. The LM317 is rated for up to 40V across the device, so when delivering +5V a maximum input of 45V is permitted by the specification. The LM7805 is specified for a maximum of 35V input; as it has a ground connection, this is an absolute value.

The results were interesting, to say the least. The LM317 was quite happy at up to 60V input (55V across it) which was appreciably above its rating, but at 74V the output dropped to 4.3V, after which it rose to 11V output at 80V input, gave 18V out at 85V in and 22V at 90V. Since there is no ground connection to the device, the chip could not draw excessive current, but devices inside were clearly breaking down and the output voltage going up alarmingly. Because of this, the device did survive and reducing input to below 50V restored normal operation. Even though it appeared to be still operational, not knowing if components inside had been permanently degraded I felt it safest to consign to the rubbish bin.

The 7805 was a different matter altogether. It behaved itself up to 35V input (as it should!) but at 40V, the output dropped to 4.3V. At around 50 – 60V input the output wobbled a bit in an unpredictable way between three-point-something and 5V. Above 60V input, the output shot up to 7 to 8V, then suddenly jumped to 58V and the device was permanently destroyed. It hadn't drawn too much excessive current up to this point, but the over-voltage was enough to destroy something inside the regulator.

So, if you use a voltage regulator in any situation where voltage spikes can appear on its input, beware. Filter these out using a bit of series R and/or inductance and a shunt capacitor. Use a clamp, such as a transorb **[1]** or Zener diode to keep spikes to below the maximum permitted. And, from the results of my quick test, use an LM317 type device in preference to a 78xx.

Running regulators from a high voltage input

It is sometimes the case that a voltage regulator needs to be fed from a voltage higher than its ratings allow – one used in a high power amplifier running on 50V rails would be a typical modern situation. A high voltage version, the LM317HV is available for use up to 60V input; other regulators such as the TL783 allowing up to 125V input do exist. An alternative is to add additional circuitry to share the voltage drop. Two cascaded LM317 devices could be used with up to 40V across each, or a separate bipolar device used to share out the voltage drop as shown in **Figure 1**. In all cases, take care to consider the situation if the output is shorted, even briefly, as for example when a decoupling capacitor charges up. Perhaps a simple Zener in series with the input to drop a fixed voltage may be the safest way to go,

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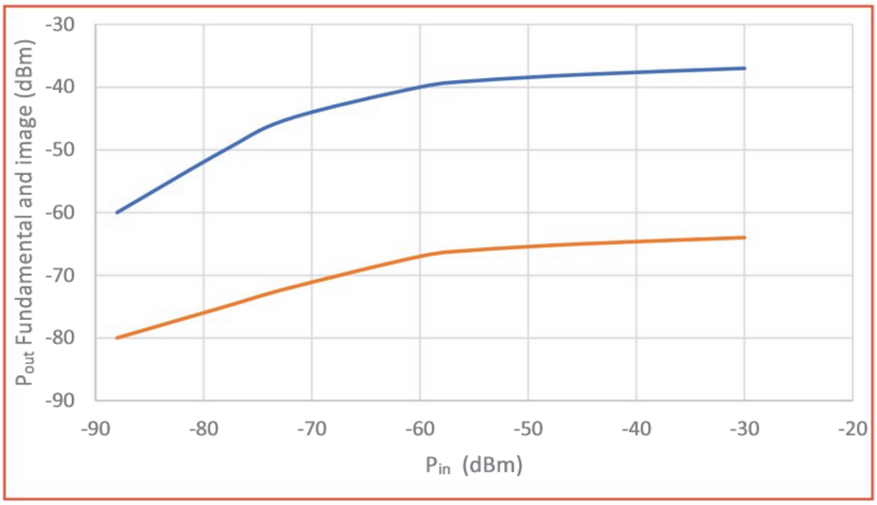

FIGURE 3: **Input / output power of the AD8347 showing AGC operation and image rejection.**

will increase output and reduce device dissipation by 75W. Another, more effective way to improve efficiency is harmonic tuning, but that is a different topic for another time."

AD8347 quadrature downconverter with RF output

In the March 2012 Design Notes we looked at several direct quadrature downconverter chips, all tested with baseband I/Q output into a stereo soundcard. In the July 2019 column we saw the 50 – 1000MHz AD8348 device used with RF output at 50MHz and the U2794 covering a similar input frequency range with 28MHz output. More recently, when I needed a receiver to monitor a test signal on 2.4GHz, it became the turn of the AD8347 integrated quadrature downconverter designed for the input range 800 – 2700MHz to be used with an I/Q combiner hybrid and RF output. This chip has a variable gain input RF amplifier, quadrature mixers and further gain stages in the I/Q demodulated paths. The output amplifiers are designed primarily for driving A/D converters, are differential output and require a relatively high output load resistance – not ideal for connecting to the 50Ω of a quadrature hybrid. Further examination of the data sheet revealed that the outputs from the mixers, which come out to external pins to allow users to insert filtering before passing back into the IF amplifiers, are at a low source impedance at a level up to 65mV / -20dBm. So by using a series resistor to bring the source impedance up to 50Ω, along with DC blocking capacitors, direct connection to a quad-hybrid can be achieved. **Figure 2** shows the circuit configuration for operation with an RF band output.

Automatic gain control

The original breadboard module built for the test back in 2012 was modified by removing the baseband opamps and squeezing in a Mini-Circuits PSCQ-2-70 quadrature hybrid for use with a 40 to 70MHz IF. There is no reason why one of the discrete designs, described in this column in April 2020 as part of a quadrature upconverter, could not be used here, but I already had several of the Mini-Circuits components and they are a bit smaller than my low frequency design. **Photo 1** shows the final result.

Because the modified PCB still incorporated all the connections to the inputs of the now unused IF amplifier stages and AGC detection circuitry, as well as the DC level setting, it soon became apparent that AGC operation was still available even with output being taken direct from the mixers. Varying the input power showed there was more than 35dB of automatic gain control, starting off with +28dB gain at low input level, falling to -7dB before saturation was reached. **Figure 3** shows a plot of input versus output power, along with the opposite sideband rejection. No attempt was made to optimise image cancellation and it can be seen that over 25dB of rejection is achieved. While this is not really a lot compared with that from a proper filter in any typical transverter for the band, it is more than enough to remove image noise, allowing this chip to be used in an S-band receiver where strong image-band signals are not likely to be present **[4]**.

Websearch

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[2] https://web.ece.ucsb.edu/Faculty/rodwell/Classes/ece218c/notes/Lecture9_SwitchingPAs.pdf
[3] https://www.silabs.com/documents/public/application-notes/AN435.pdf
[4] Strong signals in the image band of a 2.3 or 2.4GHz receiver can be a very big problem indeed if the IF frequency is not chosen carefully. 3G mobile phone base stations transmit in the range 2110 to 2170MHz, so any IF greater than 65MHz gives the possibility of the image response falling in this band. In this instance, the use of a low IF of just a few MHz could well be advantageous to keep the image well away from 3G. Base stations for 4G transmit in the 2.5 to 2.6GHz range and would only be a direct image issue if a high-side LO were to be employed.

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PHOTO 2: **Antenna mount in luffed (down) position.**

antenna, there is no reason why the design should not be adapted for use with any other similar-size vertical. Provided the clamps are properly tightened on my design there is no day-to-day strain on the swivel bolt, as it only ever sees any load when the antenna is being lowered or raised. *[It is perhaps worth noting that DX Engineering (and possibly others) offer a luffing plate arrangement for verticals, which work on a slightly different principle and may be better-suited for heavier antennas, though cost may also be a consideration – Ed]*

Reference

[1] Noise at lower frequencies (including HF) is predominantly vertically polarised because typical grounds can be described as 'quasi-conductors' at these frequencies. Boundary conditions require an electric field to be perpendicular to a conductor at the interface (ie horizontal ground, vertical E field). Horizontally polarised ground-wave signals are heavily attenuated in comparison, which explains why a vertical antenna might be perceived as noisy compared with a horizontal dipole (although 'vertical' polarisation is received off the ends of a horizontal dipole).