Contents

June 2021

News and Reports

Annual RSGB Trophy Presentations	56
Around Your Region – Club events calendar	84
Around Your Region – Events roundup	88
New products	15
News	12
RSGB Matters	6
Special Interest Groups News	16

Regulars

Advertisers index	93
Antennas, Mike Parkin, G0JMI	18
Contesting, Steve White, G3ZVW	42
GHz bands, Dr John Worsnop, G4BAO	72
HF, Martin Atherton, G3ZAY	68
LF, Dave Pick, G3YXM	66
Members' ads	94
Propagation, Gwyn Williams, G4FKH	96
Rallies & events	95
Silent Keys	95
The Last Word	97
VHF / UHF, Paul Marks, G8FVK	70

Reviews

Alinco DM330MW PSU, James Stevens, M0JCQ	36
Book Review	79

56

68

Features

CQ Scouts worldwide, Antonino Spagnolo, IU3KIE	25

Technical Features

Data, Andy Talbot, G4JNT	80
Design Notes, Andy Talbot, G4JNT	60
EMC, Dr David Lauder, G0SNO	54
EMF: Your Questions Answered, John Rogers, M0JAV; Ian White, GM3SEK; Peter Zollman, G4DSE	76
n-Circle Antennas, Tony Preedy, G3LNP	44
Rotorua 2m linear repeater, Mike Pinfold, ZL1BTB	28
Secrets of the PL-259, Don Dorward, VA3DDN	82
Signal Strength and all that, Peter Duffett-Smith, G3XJE	22
Simple Morse keyer, Richard Tomlinson, G4TGJ	40
Surprising source of rechargeable batteries, Giles Read, G1MFG	53

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

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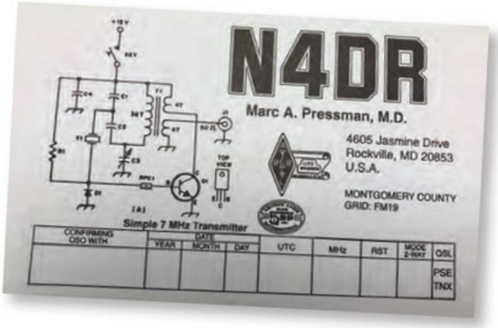
QSL Matters



Recycling QSLs: It's a fact that the RSGB QSL bureau simply could not provide this Membership benefit without the work of its sub-manager volunteers, some of whom have been volunteering for many years. They give freely of their time and when asked why they do it they usually reply, that they want to give something back to the hobby that's given them so much.

In a typical year, UK volunteers receive from us and process some 400-600,000 incoming cards, making it all the more disheartening if Members fail to collect them. Cards have to be sorted, recorded and stored for a minimum 90 days, much of the effort sadly going to waste when cards are recycled.

As an example, Cliff, G4MAR recently advised his current recycling totalled 1,325 cards for 45 calls in his G4M-S group. This included individual bundles of 70 for a G4N, 95 for a G4O, 60 for a G4P and 260 for a G4S, something he found very frustrating and disheartening. Cliff's experience is far from unique and sadly replicated across all groups.

Whilst in general some cards are unsolicited incoming or replies, by far the majority we see request a confirmation, many of which simply go unanswered. There's a phrase that we often see on QSL cards that says, *"The final courtesy of a QSO is a QSL card"*.

On behalf of all managers, please collect your cards even if you don't send cards. All it takes is a 2nd class stamp on a self-addressed envelope, with your callsign and Membership number in the top left-hand corner – see the *RSGB Yearbook* for all things to do with QSL cards.

N4DR: This month a card with a difference caught our eye. A good QSL card can say more than just a signal report, promote aspects of the hobby and this one certainly does. Obviously, Marc, N4DR has an interest in CW and in particular QRP. When we contacted him for permission to show his card, he told us that he often gets requests for the component values and build information. Nice one, Marc!

New call signs: It's a fact of life that at some point in the year there will be new callsigns that don't appear in the current *RSGB Yearbook*. Fortunately, QRZ.com can help us trace new calls and upgrades. If you have a newly issued call please help us to help you by registering a new entry, so that we don't reject cards. Remember to complete the QSL information entry and not to divert your call to any other additional or previous callsign.

SV-SZ: The national society in Greece has informed us that whilst their HQ is closed their bureau is not fully operating. For anyone QSLing direct to SV, cards can still be posted to: RAAG P.O.B. 42001121 01 PERISTERI-ATHENS, GREECE.

RSGB Radio Surfer Award

In March 2021, the RSGB Youth Team launched a new award aimed at inspiring young people to get involved in radio communications. Five youngsters have now gained the award, ranging in age from just six to 11 years old.

Ten-year-old John, MM7JGY was the first to achieve the award and he chose five activities that added up to the ten points required for his age: get involved in a contest, join a club, keep a log, use an internet-connected repeated to make a contact in another country and also design and send a QSL card.

Six-year-old Sophia Leviston isn't yet licensed but enjoys amateur radio with her dad Chris, M0KPW. Chris says, "Sophia has always shown interest in the hobby and has enjoyed sending greetings messages for a number of years, especially to female operators. She has accompanied me on a number of SOTAs over the last 12 months (when restrictions have allowed). She chose the two Radio Surfer Award activities herself as ones she could complete: she designed a QSL card for a greetings message she sent recently, and she also sent four greetings messages on a SOTA activation today as she knows you need four contacts to qualify a SOTA. Her QSL card reflects her love of fairy princesses!"

Milly McMahon, Caitlin O'Brien and Alice Ingoldsby have been learning about amateur radio and working through the award with John, G7OHO from Hilderstone RS. Two of the tasks they chose to do were to build something fun from an electronics kit and get a message from space by satellite. "We received a personal message from the FUNcube-1 satellite using a large (to us anyway!) antenna called a Yagi-Uda. We positioned ourselves on the Cliftonville promenade and pointed the antenna at the sky in a south easterly direction at an angle of 45 degrees. The satellite was over 800km away! We heard the beeps from the Dashboard software on the laptop. We had to change the position of the antenna as the satellite moved across the sky to a north easterly direction. The message was spelling out our names: Milly, Alice and Caitlin. Since November, when the satellite had started broadcasting our message, we calculated that it had sent the signal over two and a half million times!"

New RSGB video

2020 was a 'year like no other' for everyone around the world. In the UK, the Radio Society of Great Britain and radio amateurs rose to the challenge.

The Society has launched a new video, *2020 – a year like no other*, that looks back at the many fantastic activities and resources that helped to support radio amateurs through these difficult times. It also shows how existing radio amateurs 'got on the air to care' across the UK and thousands of people of all ages got involved in amateur radio for the first time. Take a look at www.youtube.com/theRSGB.

Correction

Last month's How the SWR Meter Works article by Tony Preedy, G3LNP contained an error in Formula 1. It should have been as shown below. We apologise for any inconvenience this may have caused.

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

New Products

Tiny SA Spectrum Analyser

Looking very similar to the popular nanoVNA, the TinySA spectrum analyser is a remarkably compact and economical spectrum analyser with primary frequency coverage from 100kHz to 350MHz and an extended range up to 960MHz. To add to its versatility, the TinySA also includes a useful signal generator. This provides an approximate sinewave output between 100kHz and 350MHz and a squarewave output from 240MHz to 960MHz. Supplied in an attractive presentation box with a USB-C cable, a pair of SMA leads, wrist strap, SMA female to female adapter and a telescopic whip antenna, the TinySA has all you need to get started. The internal Li-Ion battery keeps the TinySA going for around 2 hours of portable operation and is charged via the TinySA's USB-C socket. This USB connection provides a PC communications link for the control and display of measurements from the TinySA. The TinySA costs £69.95 including VAT and is available from Mirfield Electronics (www.mirfield-electronics.co.uk).

70MHz mast preamplifier

The SP 400 is a low-noise and large-signal-proof mast preamplifier for the 4m (70MHz) amateur band. It has a coax relay for transmit / receive switching. When using a sequence control, the maximum transmission power is 750W PEP and 400W CW / FM / WSJT.

This amplifier can be powered remotely via the coaxial cable through its output with supply voltage. Alternatively, local power supply can be provided via the UHF connector with a separate cable. When using the VOX switching, this amplifier must have a permanent power supply during operation. In VOX mode, the maximum transmission power may not exceed 200W PEP and 100W CW / FM / WSJT.

The input and output of this amplifier are protected with amplitude limiters to ensure a high level of operational reliability. The input and output circuits of the amplifier have an exact 50Ω impedance. This ensures that the antenna system is loaded with real 50Ω and that the parameters of the system are not changed.

With the highly optimised narrowband antennas that are popular, it is very important that they are terminated with real 50Ω. Mismatching at the input of the preamplifier used can lead to a change in the parameters of such antennas, which causes loss of gain and changes in the directional characteristic.

The SP 400 has a UV-resistant, weatherproof housing with N connector. Hot-dip galvanized clamps and mounting material made of stainless steel are included.

You can find out more about the 70MHz preamplifier at www.ssb-electronic.de/en.

Wide band preamplifier

The LNA 30 is a wide band preamplifier in the mast housing for applications from 5kHz up to 30MHz in the frequency ranges VLF, LF, MW and HF. Signals above 30MHz are strongly suppressed by a low-pass filter at the input of the amplifier. The used monolithic microwave integrated circuit (MMIC) has a low noise figure with high large signal strength. This amplifier is supplied with 12 to 24V voltage via the UHF socket. Alternatively, the device can be powered by a 24V battery. The highest large signal strength is achieved with a 24V voltage supply and the smallest noise figure at 12V. Only linear power supplies are recommended for the voltage supply of the LNA 30, since switching power supplies often generate too high interference level in the low frequency ranges. The mast preamplifier LNA 30 is is equipped with a UV-resistant, weatherproof housing. The product range of SBB-Electronic also includes coaxial cables, connectors, mounting tools and grounding kits. It costs EUR 179.00 and you can read more at www.ssb-electronic.de/en.

Antennas

End-Fed Wire Antenna Revisited: Part 1

Recently, some readers have asked what an end-fed wire antenna's length should be to maximise its multi-band capability. Therefore, this month we revisit the end-fed wire antenna.

The end-fed wire antenna

The end-fed wire antenna consists of a span of wire suspended as high as possible between two anchor points. This may seem a rather straightforward antenna, however it can achieve surprisingly good results and can be fairly inconspicuous compared to other types of antenna. With the antenna's wire span secured at height, the radio equipment is connected to the wire span's nearer end. However, one of the undesirable aspects of the end-fed wire antenna is that it can present a wide range of impedances at its feed point, which the antenna tuning unit (ATU) may not be capable of handling.

The length of the wire span determines the lowest band that is practical to use and several sources provide suitable guidance on wire lengths [1] [2]. The minimum practical length for an end-fed wire within the capability of most ATUs is about an eighth of a wavelength (λ/8). The same wire will also work as a quarter wavelength (λ/4) long antenna and still be within the ability of most ATUs to handle. However, as wire length becomes a half wavelength (λ/2), it presents a very high impedance and this can result in problems when matching the antenna to the transceiver using a conventional ATU. Similarly, when the wire is a full wavelength (λ) long then the impedance presented becomes high. As the wire length becomes two wavelengths (2λ) long, the impedance presented at its end tends to be reasonably low. An end-fed wire with a span of longer than a wavelength (λ) is often referred to as a long wire as well as an end-fed antenna.

Guidance for selecting an optimum length for an end-fed wire antenna was described by Alan Chester, G3CCB, based on matching an end-fed wire using conventional ATUs that use

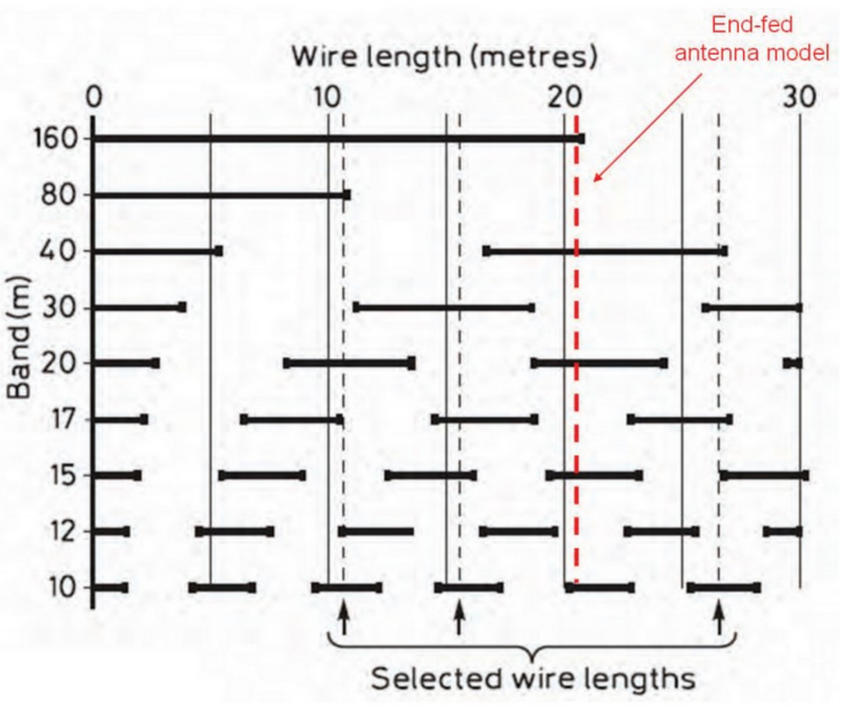


FIGURE 1: Antenna wire lengths, showing 'no-go' lengths for various bands. The model for the end-fed 20.12m long antenna is shown as the red dashed line.

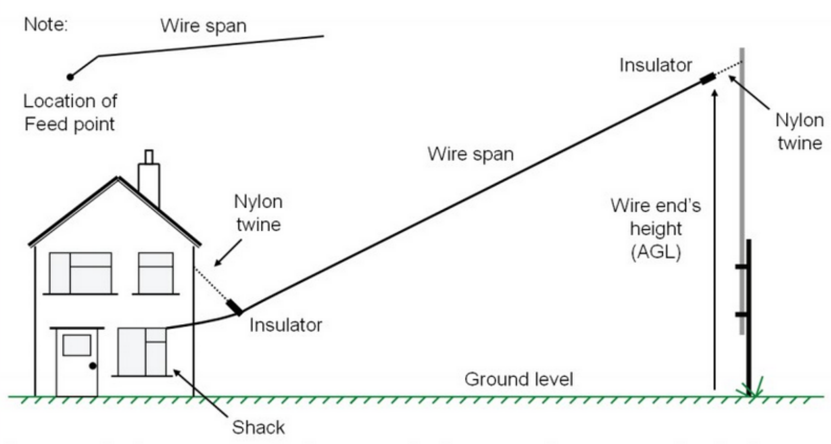


FIGURE 2: Concept of an end-fed wire antenna.

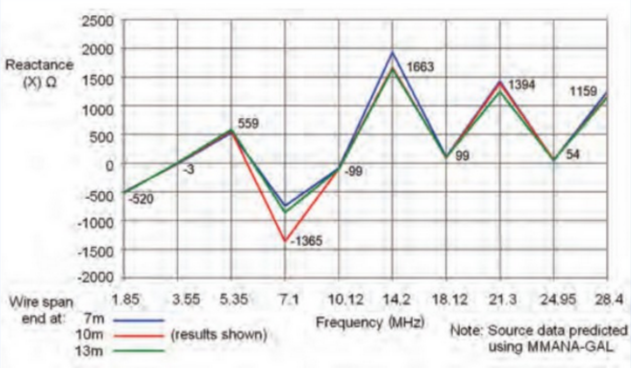


FIGURE 3: The predicted reactance (X) at the end-fed wire's feed point for a wire span of 20.12m with its end height at 7m, 10m and 13m AGL.

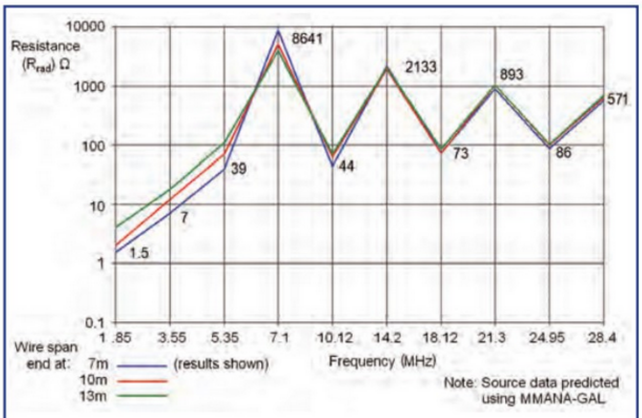


FIGURE 4: The predicted radiation resistance (R_{rad}) at the end-fed wire's feed point for a wire span of 20.12m with its end height at 7m, 10m and 13m AGL.

variable inductance/capacitance to tune out mismatches [2]. **Figure 1** illustrates the wire lengths covering nine HF bands, starting with 160m. The heavy lines running horizontally indicate areas where the impedance presented at the wire's end might exceed the matching capabilities of many ATUs. To assess if a particular length of wire is suitable, a vertical line is dropped down the diagram. Where the vertical line encounters a heavy line, then this wire length could be expected to be difficult to match using a conventional ATU. Within **Figure 1**, three black broken vertical lines have been included to indicate practical lengths that cover more than one band. As an example, using the broken line for a 26.5m wire length, this allows potentially five bands to be covered: 160m, 80m, 20m, 15m and 12m.

The efficiency of this type of antenna relies on how conductive the ground is below it. If this is poor, then arrangements may be needed to improve the antenna's performance **[3]**. Therefore, in the following summaries the ground has been considered as being reasonably conductive.

Example of an end-fed wire antenna

The concept of an end-fed wire antenna typically found in use at a domestic location is shown in **Figure 2**, where the antenna's feed point is within the shack (at a height of about 1m). As an indication of how an end-fed wire's length and its height above ground level (AGL) can affect the antenna's feed point characteristics, it is easier to consider this by using a representative example. Therefore, a 1.6mm diameter end-fed wire antenna with a span of 20.12m (66ft) was modelled from 1.85MHz to 28.4MHz using MMANA-GAL **[4]**. To examine the effect of height, the model was run with the wire span's end at 7m, 10m and 13m above ground level (AGL). A wire span of 20.16m was chosen because this is about a half wavelength (λ/2) on the 40m band.

Antenna model

The model predicted the wire span's end (feed point) as having a reactive impedance that changed between being inductive or capacitive depending on the frequency applied. **Figure 3** indicates how the reactance (X) varied at individual frequencies from 1.85MHz to 28.4MHz as the wire end's height was modelled at 7m AGL (shown as the blue line), 10m AGL (red line) and 13m AGL (green line). To give an indication of X at the feed point, the values when the antenna was at 10m AGL are shown.

To match the antenna to the transceiver, the ATU needs to introduce sufficient inductance or capacitance as appropriate to counteract the end-fed wire's reactance. This leaves the end-fed wire's radiation resistance (R_{rad}) for the ATU to match to the transceiver.

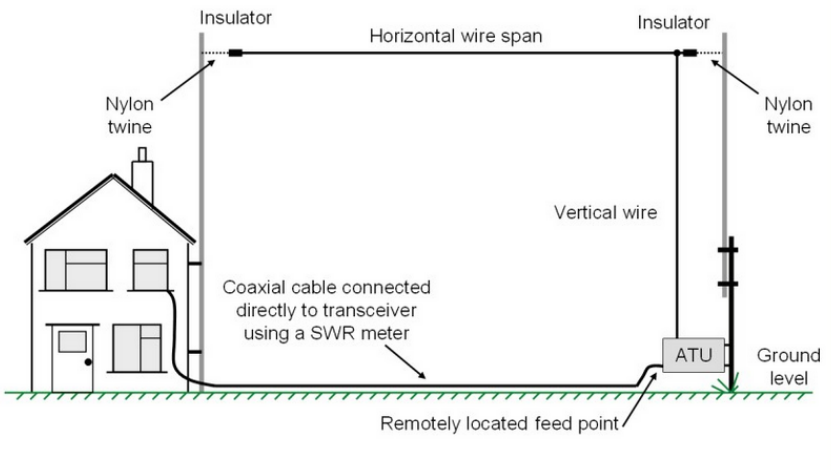


FIGURE 5: Concept of remotely matching an inverted-L antenna.

Mike Parkin, G0JMI
email2mikeparkin@gmail.com

The end-fed wire's predicted R_{rad} varied significantly with frequency as indicated in **Figure 4**, where a logarithmic axis has been used. Again the antenna was modelled at 7m AGL (blue line), 10m AGL (red line) and 13m AGL (green line). The difference in R_{rad} with frequency is evident as the wire's end height is decreased. To give an indication of R_{rad} at the feed point, the values when the antenna was at 7m AGL are shown.

Feasible band range and AGL

Comparing the predicted R_{rad} in **Figure 4** with **Figure 1** shows the actual antenna should be usable on the 80m, 30m, 17m and 12m bands, as shown by the dashed red vertical line on **Figure 1** (use on the 60m band is also feasible).

Interestingly, the prediction indicated the height of the antenna's wire end above the ground did not significantly affect which bands should be within the capabilities of a conventional ATU and so be feasible to use.

Undesirable aspects of an end-fed wire antenna

With the end-fed wire's feed point connected to the ATU in the shack, there can be a significant amount of the transmitted RF power radiated inside the room. This can result in various unwelcome effects including, for example, RF burns, electrical noise and interference with other equipment. Therefore, this arrangement for an end-fed wire is not advisable and tends to be infrequently used nowadays.

The inverted-L antenna

The concept of another configuration for an end-fed wire antenna often used by amateur radio stations [2] is shown in **Figure 5**. This type of end-fed wire is often referred to as an inverted-L antenna and is also known as a Marconi antenna. In this arrangement the ATU is connected to the wire span using a vertical wire run to the wire span's more remote end, resulting in the antenna's feed point now being distant from the shack. Remotely situating the antenna's feed point from the house/building avoids the undesirable effects associated with RF radiation in the shack, along with minimising electrical noise problems on both transmit and receive. In addition, the unpredictable effect on the antenna caused by metal conduits, wiring and water pipes associated with a house can be reduced.

The vertical wire will also radiate an RF field and this combines with the RF field radiated by the horizontal wire span. This has the effect of modifying the form of the inverted-L antenna's radiation pattern compared with a horizontal wire span directly fed at one end.

A disadvantage of locating the ATU remotely from the transceiver is this can be inconvenient when it comes to tuning the ATU to operate on a band. A method to overcome this problem is to use an ATU that can be remotely controlled from the shack. There are a variety of ATUs commercially available from a number of suppliers (that tend to be of the auto-tuner type) that may be suitable as a remote ATU. When choosing an ATU for use as a remote tuner it is important to select one that is capable of handling the SWR range encountered with the station's antenna system for the amateur bands/powers that are intended to be used. A remote ATU will need to be protected from exposure to the weather and is ideally situated inside an out-building. If this is not possible, then a suitable arrangement to protect the remote ATU from the effects of the weather is required.

G8PJC end-fed wire horizontal-V antenna

John McDonald, G8PJC, sent in details of an 80m band end-fed wire that was intended for Near Vertical Incidence Skywave (NVIS) use. The antenna was devised to fit into a suburban garden and so took the form of a horizontal-V to accommodate it within the space available. The antenna was installed only at 2m AGL and its wire span was 20m long. The wire span was bent back on itself at about 11m from its nearer end at an angle of about 40°.

Figure 6 shows the concept of my version of John's horizontal-V antenna that was operated against a 10m long radial wire. The antenna was fed using a 1:2 turns ratio RF transformer with separate primary and secondary windings. The RF transformer had a primary winding of 9 turns and a secondary winding of 18 turns connected to the wire span and radial wire. The turns were wound side-by-side on a T130-2 toroidal core.

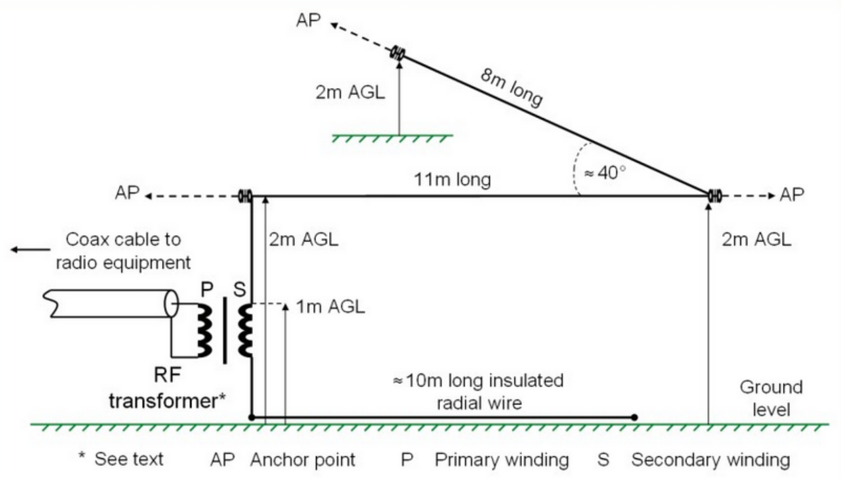


FIGURE 6: Concept of my version of G8PJC's 80m band end-fed wire horizontal-V antenna.

Using an MFJ269c antenna analyser connected to the RF transformer's primary winding; the measured SWR was 1.1:1 at 3.65MHz, rising to 1.6:1 at 3.5MHz and 3.75MHz. The radio equipment was connected to the antenna using a 50Ω coaxial cable and the results obtained using the horizontal-V were surprising.

When tested using SSB/CW, stations up to a radius of about 400km were worked with reasonable reports received.

Provided ICNIRP regulations are followed in full, this antenna could provide a solution to operating on the 80m band from a suburban environment and may suit FT8 use.

Websearch

[1] RSGB *HF Antennas for Everyone*, edited by Giles Read, G1MFG: Chapter 1, pages 1 to 3

RSGB *Radio Communication Handbook*, 14th edition edited by Mike Browne, G3DIH: Section 15, Practical HF Antennas,

[2] Pages 15.1 to 15.2

[3] Pages 15.36 to 15.37

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

Signal strength and all that

You often hear radio amateurs refer to their S-meters as 'signal strength meters'. Indeed, Wikipedia would agree **[1]**. But what does an S-meter actually measure? How does the reading of a properly-calibrated S-meter relate to the incoming radio waves and the noise in the pass band? Let's find out.

The intensity, I, of a radio wave is the power carried by the wave per unit area of the wave-front, usually expressed in watt per square metre (Wm^{-2}). (Some authors reserve the word intensity for watt per steradian (Wsr^{-1}) and use the term flux density instead for Wm^{-2}.) What we mean by this may best be understood if we imagine that we are in 'free space' (outer space perhaps, a very long way away from anything) observing the radio waves from a distant transmitter pass by. By the time the waves reach us, they appear as 'plane waves', in which the value of the electric field (or the magnetic field) at any moment is exactly the same over a plane that is perpendicular to the direction of travel of the waves. The oscillating electric and magnetic fields are in the plane and are perpendicular to each other. The waves carry power away from the transmitter, but as the waves travel further and further, that power spreads over the surface of an ever-increasing sphere, so the intensity of the radio wave decreases as the square of the distance from the transmitter. When we are sufficiently far from the transmitter, the spherical wave fronts appear to us locally to be almost flat, so we see plane waves passing by.

Some people prefer to define the intensity of the waves in terms of the electric field component, E volt per metre (Vm^{-1}), or the magnetic flux density of the magnetic component, B tesla (T), instead of the power. These three quantities, I, E and B, are related to each other by the equations

$$I = \varepsilon_o c E^2$$

and

$$I = \frac{cB^2}{\mu_0}$$

where ε_0 is a constant equal to 8.85 x 10^{-12} farad per metre (Fm^{-1}), μ_0 is another constant equal to 4 x π x 10^{-7} henry per metre (Hm^{-1}), and c is the speed of light in a vacuum, equal to 2.997 x $10^8 ms^{-1}$, also a constant. The I, E and B are instantaneous values, but we are dealing with sinusoidally-varying fields in amateur radio, so we are usually more interested in the average over one cycle. If ε_0 and B_0 are the amplitudes of the fields, averaging just introduces a factor of a half, so we have

$$I_{AV} = \frac{1}{2}\varepsilon_o c E_0^2$$

and

$$I_{AV} = \frac{1}{2}\frac{cB_0^2}{\mu_0}$$

Substituting values for the constants, we may write

$$I_{AV} = 1.326 \times 10^{-3} E_0^2 \ Wm^{-2}$$

and

$$I_{AV} = 1.192 \times 10^{14} B_0^2 \ Wm^{-2}$$

where E_0 is expressed in Vm^{-1} and B_0 in T.

How does the S-meter reading, S, relate to I_{AV}? Well, the relationship is quite complicated, as we shall see.

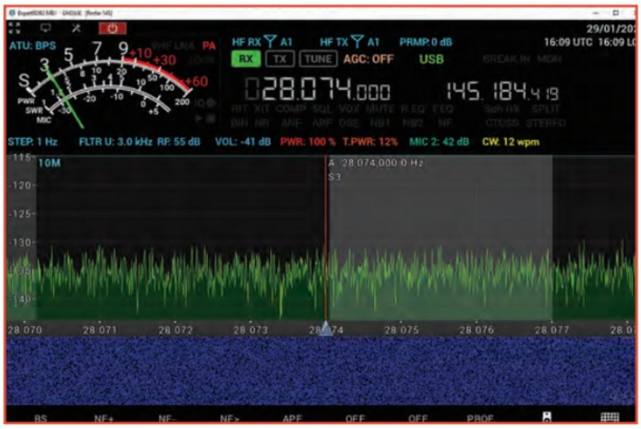


FIGURE 1: The user interface on an Expert Electronics MB1.

What does the S-meter actually measure?

A properly-calibrated S-meter measures the power in the signal applied to the antenna terminals of the receiver as a number in the range 1 to 9. (Signals stronger than S9 can be expressed as so many 'dB over 9'. Signals weaker than S1 are usually buried in noise of one sort or another.) The IARU Region 1 Technical Recommendation R1 for the HF bands defines S9 to be a power of -73dBm (dB relative to 1mW), ie about 50μV rms across an input resistance of 50Ω. For the VHF bands, these values are -93dBm and about 5μV rms respectively.

Each step in S is defined to be 6dB, ie a factor of four in power, or a factor of 2 in voltage. I have listed in **Table 1** the relationship between the power in dBm, the rms voltage, and the S-meter reading for both HF and VHF bands. Your S-meter is therefore acting as a kind of RF voltmeter, albeit with a non-linear scale.

The relationship between the S-meter reading and the intensity of the incoming radio waves obviously depends on the antenna. Very strong waves will register nothing if the antenna has fallen off; very weak waves could register S9+ if the radio's antenna terminals were connected to Jodrell Bank's big dish. So what is the relationship? To answer this question, we should first consider how an antenna works.

The effective area of an antenna

We imagine that the antenna can collect all the power incident on it over an area, A, which is the so-called effective area of the antenna. The power collected is dissipated in the matched load (the resistive impedance, usually 50Ω) across the receiver's antenna terminals. This power is equal to $I_{AV}A$. Note that we have assumed that losses in the antenna and feed system are taken into account through a reduced value of the effective area and that there are no further losses, eg from mismatches. Furthermore, the value of A is a function of direction for any given fixed antenna, being maximum along the main lobe, and reducing to near zero along nulls in the polar diagram.

A large dish antenna, like the Lovell telescope at Jodrell Bank, acts rather like a searchlight in reverse. Incoming radio waves along its beam are brought to a focus by the curved dish (which is very much larger than a wavelength) and 'collected' by a 'feed' at the focus. We can easily see how the effective area of this antenna, when optimally aligned, would be similar to the area of its aperture, ie $\pi \times R^2$, where R is the radius of the aperture of the dish. But what about a thin wire dipole? It has virtually no geometric area, yet it still possesses an effective area just like a big dish. It, too, dissipates incoming radio-wave power in the receiver impedance equal to $I_{AV}A$, but how do we understand the A part?

The answer to this question is rather subtle and has been discussed in several scientific papers. It is probably best understood by considering the Poynting vector at various points on the surface of an incoming plane wave front. The Poynting vector, aptly named after the English physicist John Henry Poynting who introduced it in 1884, is a vector which points in the direction of power flow. Mathematically, it is the vector product of the electric and magnetic fields, but we don't need to worry about that here. All we need to know is that the direction of the Poynting vector is perpendicular to both the E and B fields. In a plane wave, the Poynting vector at any point on a wavefront is perpendicular to the wavefront and pointing directly away from the transmitter. But now introduce a dipole antenna, aligned with the E field and connected to a matched resistive load. A current is induced in the antenna that therefore has a magnetic field associated with it, which adds to the field of the wave. The actual magnetic field around the antenna is no longer that of the plane wave passing by, but is distorted by the dipole field. If we calculate the Poynting vector at any point, we now find that it has turned in towards the dipole, so has a component pointing directly at the dipole. The effect of this is that the dipole 'collects' power from the radio waves over an area that is much larger than its negligible geometrical area.

Relationship between effective area and gain

Diffraction theory provides a relationship between the directivity of an antenna and its collecting area. If we include the losses associated with the antenna and its feeder, the collecting area becomes the effective area, A and we can substitute the gain, G, for the directivity. The relationship between them is given by the equation

$$A = \frac{G\lambda^2}{4\pi}$$

where λ is the wavelength. For a half-wave dipole, the gain in the broadside direction is 1.64 (2.15dBi). (Here, dBi refers to the gain in dB relative to a mythical perfect isotropic radiator that transmits equally in all directions.) Your half-wave wire dipole therefore has an effective area of about 59m² at 14.1MHz, equivalent to a square of side 25 feet! I have listed in **Table 2** some other indicative values of the relationship between the gain, frequency and collecting area.

Relationship between S-meter reading and wave intensity

We are now in a position to see how the S-meter reading, S, varies with the average intensity, I_{AV}, of the incoming radio waves. First we need to cast the S-meter reading in terms of the power, P, dissipated in the internal matched resistive load across the antenna terminals of your receiver. This relationship is shown in tabular form in Table 1, and is given by

$$S = \frac{10\log_{10} P + 157}{6}$$

where P is expressed in watts. Now P is the average power collected by your antenna, so is given by

$$P = I_{AV}A = I_{AV}\frac{G\lambda^2}{4\pi}$$

Collecting these two equations together, we can see that

$$S = \frac{10\log_{10}\left(\frac{I_{AV}G\lambda^2}{4\pi}\right) + 157}{6}$$

or

$$I_{AV} = \frac{4\pi f^2}{Gc^2}10^{\frac{6S-157}{10}}$$

where f is the frequency in Hz, and c is the speed of light. This is a messy relationship!

I have listed some illustrative values in **Table 3** for a half-wave dipole antenna receiving signals broadside on at several HF frequencies.

Looking at the values in Table 3, I am struck by how extraordinarily sensitive our receivers are, giving an S9 reading on 20m when the incoming radio wave intensity is less than a picowatt per square metre. This would be the intensity at a distance of nearly 4000km broadside on from a dipole driven with 100W in free space. (But many of us have experienced an S9 signal from transmitters many times that distance, illustrating the conductive and focussing properties of the ionosphere.) The second thing to note from the figures in Table 3 is how the sensitivity of your S-meter decreases with increasing frequency. For example, a signal of sufficient intensity to register S7 on the S-meter at 3.6MHz would register only about S4 at 28.2MHz. Another thing to note is that the range of S1 to S9 covers a variation of more than 60,000 times in the signal intensity. Such is the nature of a logarithmic relationship.

This is all rather academic perhaps, since radio amateurs are usually interested only in communicating with each other, rather than in measuring the actual intensity of the incoming radio waves. What matters for communicating is the signal-to-noise ratio (SNR), that is the power in the signal divided by the power in the noise. A signal, no matter how strong, cannot be heard if it is buried in noise. (I discussed this in another article, Signal and noise and all that, in the July 2020 *RadCom*.) So how is your S-meter affected by noise?

Noise and your S-meter

The S-meter on a software defined radio (SDR) can usually be trusted to within a few per cent. The user interface of such a radio often also provides a 'panoramic' display, both as a spectrum plot and as a waterfall display. The spectrum plot shows the power as a function of frequency. When there are no signals present, the spectrum plot indicates the noise level. The question is, what is the relationship between the noise level and the S-meter reading?

By way of illustration, I show in **Figure 1** the user interface on my Expert Electronics MB1 transceiver, in receive mode, with a 50Ω dummy load connected across its antenna terminals. You can see that no signals are being received, as expected, but that the S-meter gives a reading of just over S3. When I first noticed this, I wondered whether I needed to send my rig back to the supplier to have it repaired but, as I will show, all was in order.

The noise in my SDR comes from the combination of a very small amount generated by the 50Ω dummy load, a small contribution from the front end amplifiers and (mostly) from the sampling of the analogue signal inherent in an SDR. The amount of sampling noise decreases with the number of bits used in each digital sample (16 in my MB1). The noise is 'flat', ie it does not vary with frequency, so the spectrum plot is horizontal (albeit noisy), as seen in Figure 1.

The spectrum plot is constructed using a fast Fourier transform (FFT). This is the digital equivalent of the analogue Fourier transform that analyses a time-varying signal into its frequency components. (The 'fast' refers to the fact that the algorithm is based on a radix of 2 and some special properties of the intermediate products, to produce something that is efficient and uses the minimum number of steps.) We need not be

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worried by the details. All we need to know is that a standard FFT of total length *N* (16384 in the case of Figure 1) gives *N*/2 adjacent frequency 'bins', each of which measures the total power in the digitised waveform within the frequency range of that bin. The spectrum plot is constructed by joining adjacent values together, either with straight-line segments, or using an interpolation scheme.

The frequency range of each bin depends both on *N* and on the time interval over which the input signal is measured, which in turn is dependent on the sampling rate, *r*. In the case shown in Figure 1, the sampling rate was 39062.5 samples per second, giving the frequency range, *b*, of each bin equal to

$$b = \frac{2r}{N} = 4.768\text{Hz}$$

(This expression may be challenged in several ways as there are details of the algorithms implemented in the MB1 that can change things by a factor of two or so. However, we can get a good sense of what is gong on using this simple argument.)

The noise level indicated in Figure 1 was about -136dBm in each bin. If we had been able to use bins of just 1Hz width, the noise in each 1Hz bin would have been smaller by a factor of 4.768, or 6.8dB, so the receiver noise level was therefore N_0 = -142.8dBm WHz^{-1}.

The receiver bandwidth was set to 3kHz (the lighter shading in the spectrum plot area), so we expected to have a total noise power within the bandwidth 3000 times greater than N_0. Now 10log(3000)=34.8dB, so the total noise power within the pass band was -108dBm, or a little over S3 as seen.

I did not need to send my rig back for repair after all, but would all this noise affect my enjoyment of amateur radio? Well no, provided that the noise coming in from the antenna exceeded the radio noise by at least 10dB, thus making it negligible in comparison. At my QTH in Scotland, I see a noise level of between S4.5 and S5 in the 3kHz pass band with the antenna connected at this frequency, so that criterion is satisfied. (If it is not, the MB1 has a low noise 10dB preamplifier that can be switched in as needed.)

TABLE 1: IARU R1 relationship between S-meter reading, power and RMS voltage for HF and VHF.

	HF bands		VHF bands	
S-meter reading	Power (dBm)	Voltage across 50Ω (μV RMS)	Power (dBm)	Voltage across 50Ω (μV RMS)
9	-73	50.2	-93	5.0
8	-79	25.1	-99	2.5
7	-85	12.6	-105	1.3
6	-91	6.3	-111	0.63
5	-97	3.2	-117	0.32
4	-103	1.6	-123	0.16
3	-109	0.8	-129	0.08
2	-115	0.4	-135	0.04
1	-121	0.2	-141	0.02

TABLE 2: Antenna gain and effective area at various frequencies.

Gain		Effective area in m²				
dBi	Ratio	3.6MHz	7.1MHz	14.1MHz	21.2MHz	28.2MHz
2.15	1.6	905	233	59	26	15
3	2.0	1100	283	72	32	18
6	4.0	2200	564	143	63	36
10	10.0	5515	1418	360	159	90
15	31.6	17440	4484	1140	503	284

TABLE 3: S-meter readings and wave intensities at various frequencies.

S-meter	Average intensity in Wm^{-2}				
reading	3.6MHz	7.1MHz	14.1MHz	21.2MHz	28.2MHz
1	8.78×10^{-19}	3.42×10^{-18}	1.35×10^{-17}	3.05×10^{-17}	5.39×10^{-17}
2	3.50×10^{-18}	1.36×10^{-17}	5.36×10^{-17}	1.21×10^{-16}	2.15×10^{-16}
3	1.39×10^{-17}	5.41×10^{-17}	2.14×10^{-16}	4.83×10^{-16}	8.54×10^{-16}
4	5.54×10^{-17}	2.16×10^{-16}	8.50×10^{-16}	1.92×10^{-15}	3.40×10^{-15}
5	2.21×10^{-16}	8.58×10^{-16}	3.38×10^{-15}	7.65×10^{-15}	1.35×10^{-14}
6	8.78×10^{-16}	3.42×10^{-15}	1.35×10^{-14}	3.05×10^{-14}	5.39×10^{-14}
7	3.50×10^{-15}	1.36×10^{-14}	5.36×10^{-14}	1.21×10^{-13}	2.15×10^{-13}
8	1.39×10^{-14}	5.41×10^{-14}	2.14×10^{-13}	4.83×10^{-13}	8.54×10^{-13}
9	5.54×10^{-14}	2.16×10^{-13}	8.50×10^{-13}	1.92×10^{-12}	3.40×10^{-12}

S-meter readings in practice

The take-home message from all of this is that the actual S-meter reading really doesn't matter very much, provided that the signal gives a deflection that is 1 to 2 S-points greater than the indicated noise level, having taken account of the characteristics of the mode in use. For SSB reception, this means that you need a signal level which is at least 1 to 2 S-points more than the noise in the 2.5kHz bandwidth required. When I replace the dummy load with my antenna, the noise level in 2.5kHz rises to about S4.5 at 28MHz, so I would expect that I could copy stations coming in at S5.5 or higher using the MB1 in my shack. But what about other modes?

Table 1 of my July 2020 *RadCom* article lists the approximate overall gains relative to SSB that can be expected from various other modes. Taking FT8 as an example, this is around about 23dB. The additional gain comes from (a) the much smaller bandwidth used by FT8 (about 50Hz) and (b) the processing gain of the digital mode. You can understand the origin of the latter as arising from the fact that the small number of characters in a packet are sent at a much slower rate than they *could* have been sent, equivalent to the data being repeated many times. There are also other gains from clever error correction methods. The additional gain of FT8 is around 23dB, equivalent to about 4 S-points. I would therefore expect to be able to decode packets received at a level of S1.5 or higher, ie way below the noise level indicated by my S-meter in a 2.5kHz bandwidth.

Websearch
[1] https://en.wikipedia.org/wiki/S_meter

Rotorua 2m linear repeater rebuild

Introduction

Rotorua is a city of some 60,000, located on New Zealand's North Island. It is a major destination for domestic and international tourists. It also has a very active amateur radio community, who installed a 2m linear ('bent pipe') repeater some 20-plus years ago. Unfortunately, the original equipment was destroyed in a fire in 2015. A temporary replacement solution was soon up and running, though. The temporary system provided breathing space to design and construct the system described here. But rather than give a complete blow by blow description, I'm just going to highlight some of the parts I found most interesting to design, illustrated by circuit sketches from my notebook. I hope you find this an interesting insight.

Overview

Linear repeaters differ from FM systems in one important respect: they receive and re-transmit a chunk of spectrum, rather than demodulating a signal (FM or digital) to baseband and then applying that baseband (eg voice) signal to a fairly standard transmitter for re-broadcast. The Rotorua linear repeater uses a conventional front end and mixer down to a 10.7MHz intermediate frequency (IF) where the pass bandwidth (30kHz) is filtered. The resulting signal is then mixed back up to VHF, on a slightly different frequency from the receiver. Whatever you transmit on the input frequency – FM, AM, packet, digital voice etc – is simply re-transmitted in exactly the same form, just on a different frequency. The repeater simply doesn't care what modulation you're using, provided it fits within the 30kHz bandwidth.

The repeater input frequency is centred on 144.950MHz and the transmitter on 144.350MHz. There is also a control receiver on 145.000MHz. The two receivers share the same antenna, with the signal split after the front end preamplifier.

IF section

The IF was chosen as 10.7MHz, mainly because I had to hand suitable 30kHz-wide quartz filters for that frequency. Any IF would have been OK, even (in theory) 455kHz. But lots of receivers use a 10.7MHz first IF, so extracting this signal was convenient. 30kHz is a useful bandwidth, suitable for the great majority of analogue and digital voice modes. It's also a fairly easy bandwidth to achieve at 10.7MHz.

As this is a linear repeater able to pass any modulation type it is necessary for the IF section to have automatic gain control (AGC). I decided to base the IF on some old-favourite but now obsolete ICs that I had available, the Plessey 600 series. For SSB/AM Plessey produced a couple of workhorse ICs that used a minimum parts count and functioned extremely well. Most work with a 6-9V supply rail at some tens of mA.

I used the SL1612 IF amplifier and its RF-controlled AGC sibling the SL1623. There is a better, audio-derived AGC device for SSB, the SL1621, but since this repeater will be handling FM as well, a carrier derived AGC was a better compromise. The input to the IF amp board is 50Ω and feeds directly into a multi-pole 30kHz wide crystal filter, which is correctly matched via a simple L network to achieve an almost flat ripple free band pass characteristic.

The output of the filter is matched via a simple Pi network into the first AGC controlled SL1612 amplifier (with a gain of about 34dB). The output of the SL1612 feeds straight into a MPSH-10 transistor stage to drive the first 10.7MHz interstage transformer. Plessey advocated simple capacitive interstage coupling between ICs but I feel this generated too much broadband noise (which would translate to the 2m RF output stage) so I limit the RF band noise via a 10k dampened tuned 10.7MHz transformer.

The transformer link couples to the following SL1612 stage and also has a resistive tap off so RF can be removed from the IF amp unit and fed to a FM demodulator section or, if required, introduced from another front end source (eg 10m front end), into the second SL1612 and processed up to 2m. The AGC control range is much less via this connection. The second SL1612 is identical to the first, with a similar transformer coupling at the output. Link coupling off the second transformer carries amplified IF signal to the L matching circuit that connects to the second 30kHz wide 10.7MHz crystal filter. The second crystal filter limits the bandwidth of any noise generated in the 65dB gain IF strip to 30kHz as this IF noise will be translated up to the 144.350MHz repeater output frequency. Not only do we not want to waste RF spectrum on just broadband noise, but also need to keep potential upmixed broadband noise away from the receive frequency of 144.950MHz.

Our linear repeater sits in magnificent solar-powered isolation on a hilltop above the city of Rotorua.

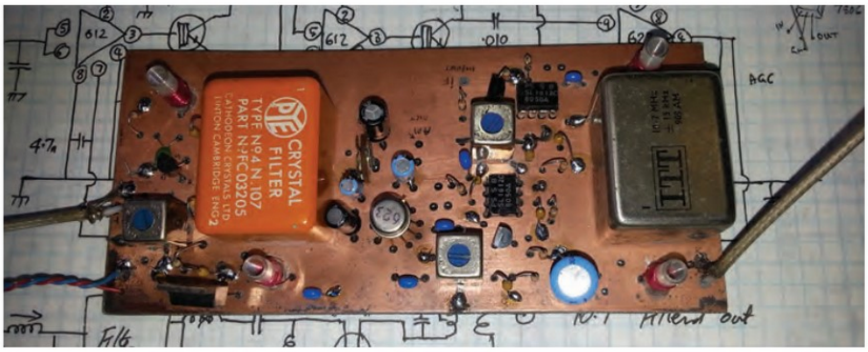
PHOTO 1: **Completed first version of the 10.7MHz IF board.**

The IF board was built on double sided fibreglass PC board for maximum screening and to minimise potential instability problems. But when first tested the board would break into oscillation at 10.7MHz whenever I removed my hand from the unit. The cause was found to be the very sharp tuning of the first IF transformer. This instability was eliminated by dampening the tuned circuit with a 10k resistor. Maybe I should have placed ferrite beads on the emitter leads of the MPSH-10 driver transistors; perhaps they are an overkill for use at 10.7MHz. Note that the driver transistors have un-bypassed emitter resistors. Bypassing would provide more gain if required (I measured 11dB) but you may run into instability problems.

The AGC is carrier derived and a tap from the collector of the final transformer drive transistor capacitively couples 10.7MHz signal into the SL623. The SL623 also contains a product detector and an AM demodulator but neither are used in this application. AGC voltage is fed to the appropriate pin of each of the SL1612s. When adjusted for 2V on the AGC rail with 125mV input the SL623 will hold the signal to within 4dB.

The two SL612 stages have a theoretical combined potential to provide 140dB of range but this will never be achieved in practice due to limiting performance of other components in the receiver. **Photo 1** shows the completed first version of the 10.7MHz IF board.

The second 10.7MHz crystal filter is L matched to a common gate JFET stage that provides a small amount of gain but whose very good return loss provides an easy 50Ω impedance with which to match to, thus maintaining the flat passband characteristics of the 'bandwidth tail noise limiting' crystal filter.

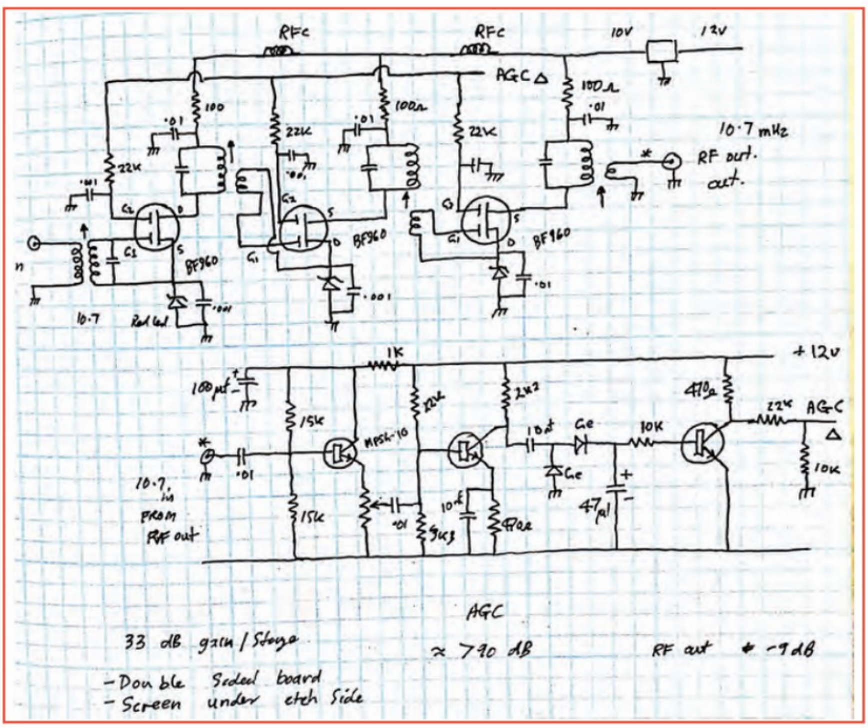

FIGURE 1: **Circuit notebook for the 10.7MHz IF amplifier.**

Faux pas

When designing the 10.7MHz to 144.350MHz up mixer it dawned on me I had made a blunder with the IF amp. The 10.7MHz IF amp in the destroyed repeater had three SL612 IF amp chips, giving a total stable IF gain of over 100dB, constructed on double side PCB without extensive shielding. Plessey knew how to make great RF stuff. This was a well thought out system with about 15dB of headroom, from broadband IF noise output and the start of full on AGC. This gave a 15dB range in the transmitted RF output from an input signal of less than –127dbm to -112dBm where the AGC now is fully on and controlling the receiver gain. I tried to close the AGC range into the upmixer with another outboard IF amp with its own extra AGC but ran into a mass of trouble with both interacting. In the end I gave up and redesigned the receiver IF board. I needed over 100dB so, as I had a small bucket of Siemens BF960 UHF dual gate MOSFETS available, I pressed them into action. Three stages gave a total of 104dB. Research on the internet found a lot of IF amps use almost direct broadband coupling from a RF choke in the drain, however I decided to use bandwidth limiting 10.7MHz interstage IF transformers to couple each stage and the output, then design my own RF derived AGC to control them. The circuit is shown in **Figure 1**.

One reason for this approach is that I am trying to minimise the amount of broadband IF noise generated in the amp so that the upmixed RF won't be drowned in the signal generated by the IF contribution. This will also cut down on the amount of unnecessary broadband RF output. After much further research and consulting *QST* articles, I decided to use red LEDs as reverse bias generators in the source of each BF960 stage. This trick enables you to apply more AGC control voltage than simple source resistor bias and achieve even greater AGC range, something I lacked in the previous amp.

10.7MHz IF amp, 2nd iteration

I built a standard three stage IF amp along the usual MOSFET amplifier designs on double sided PC board and used manual control of the IF to see if the amplifier was stable. Unfortunately, it was not: at high gain setting it was a reliable 10.7MHz oscillator. Some of the IF tuning was quite peaky, indicating some sort of regeneration was trying to take place. Stagger tuning helped stability but I did not want to use that as a control mechanism. Even after adding RF chokes in the B+ leads to each stage plus 10k damping resistors across tuned circuits, tuning was still very peaky. RF was still getting from the output to the input. 100dB is a lot of gain in a small area! Then I tried close shielding the printed circuit side of the board with some thin

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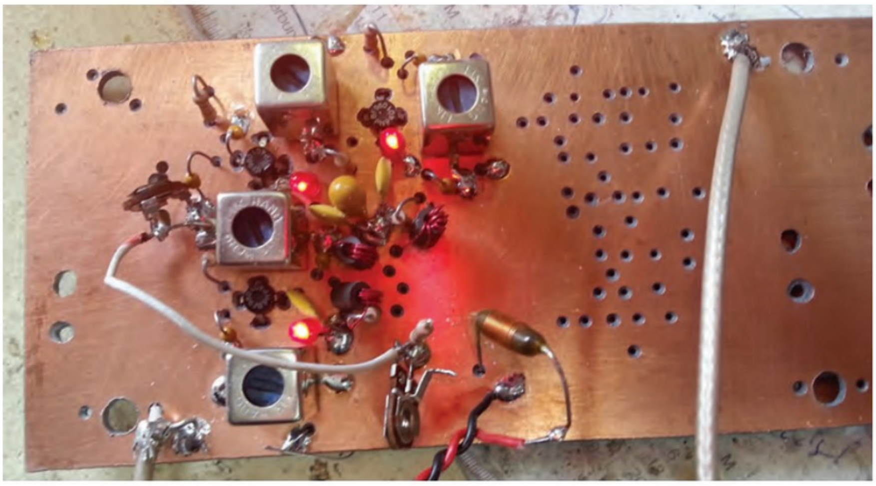

PHOTO 2: Second version of the 10.7MHz IF board.

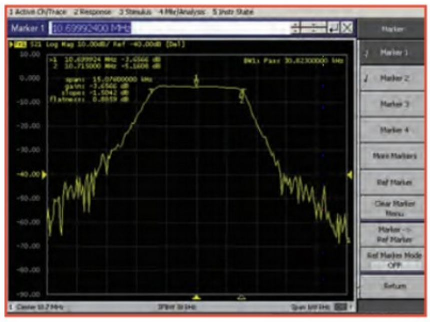

FIGURE 2: 10.7MHz IF filter response.

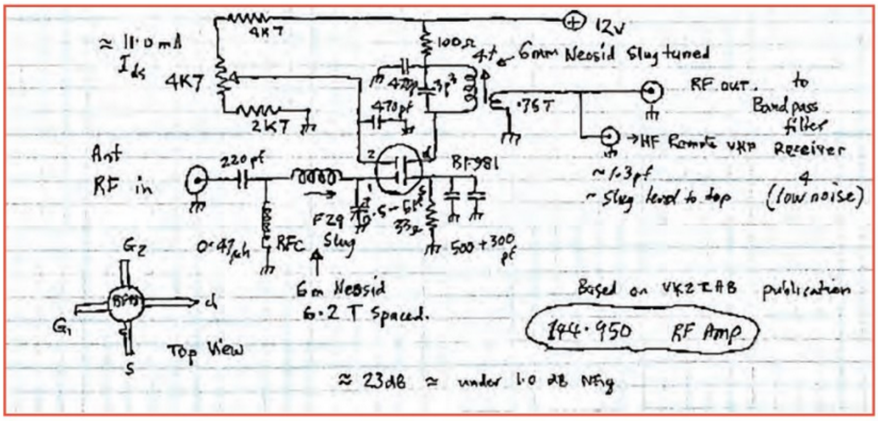

FIGURE 3: Low noise preamplifier circuit.

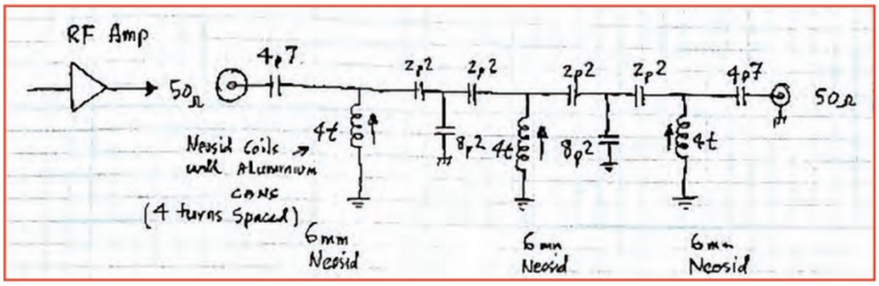

FIGURE 4: Three-pole 145MHz filter.

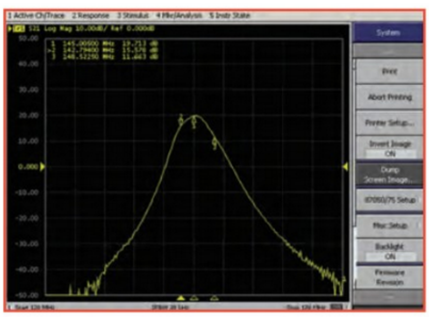

FIGURE 5: Response of the 145MHz post-RF amplifier bandpass filter.

shaped brass shim sheet soldered to the ground plane topside. That settled everything down. I then made up a simple RF-generated AGC control circuit with a load resistor on the AGC line and we were in business. The AGC could be made to kick in when the RF input was still quite low level, thus I had obtained my dynamic range of potential RF output from 100mW up to almost 10W at 144.350MHz. **Figure 2** shows the 10.7MHz IF filter response and the completed amplifier is seen in **Photo 2.**

The next thing was to redesign the L match to connect the two 30kHz IF filters to the input and output of the 10.7MHz IF. My only concern with these old wideband crystal filters is the overall stop band is not that good compared to narrower, more modern multipole filters. Using these wideband filters might make the system more susceptible to out of band interference, but in Rotorua we are a long way from such signals.

2m front end

The front end parts comprise a low noise amplifier based on a BF981, followed by a three-section bandpass filter. The filter output feeds the mixer.

RF input matching of the front end is configured for minimum noise (under 1dB) into the BF981 dual gate MOSFET. The circuit, shown in **Figure 3**, is based on a design by VK2TAB. I changed the output to a link coupled tuned circuit. The BF981 provides 23dB gain, which is more than enough. The output of the BF981 feeds a three section series filter with a loss of 3dB and good stop band performance to eliminate the image frequency. (The image frequency must be suppressed by at least 16dB or the presence of the image frequency will increase the noise figure of the RF amp by 3dB). **Figure 4** shows the filter circuit.

The RF output of the three-section bandpass filter has a tap off that provides the signal to the 145MHz command receiver. Tapping off here, after the preamp, means we don't incur the loss (and increase in noise figure) that would occur if a simple antenna splitter was used. There is also the added benefit that the 145MHz control signal passes through our 144.950MHz receive filters. **Figure 5** shows the frequency response of the filters and **Photo 3** shows the complete front end (with the RF cans removed).

Local oscillator

The LO circuit is shown in **Figure 6**. It is based on a 44.75MHz crystal oscillator. The third harmonic (134.25MHz) from the lightly biased multiplier stage is selected with dual tuned circuit output, producing around +2dBm at the link coupling that feeds a J310 in grounded gate configuration. The drain RF output is passed through two lightly coupled tuned circuits to achieve +8.5dBm as a drive level to a single 2N4427 class C stage which produces +23dBm into 50Ω. This signal is passed through a simple 3 pole low pass filter to clean the frequency then through a 6dB pad before it enters the double balanced mixer at +17dBm.

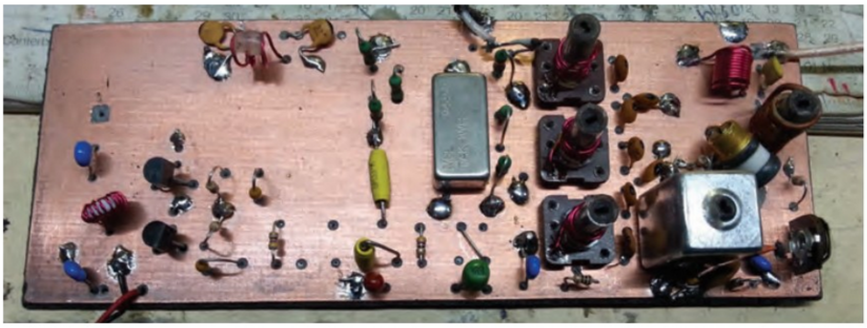

PHOTO 3: Front end, RF filter (with the RF cans removed), mixer and buffer amplifier.

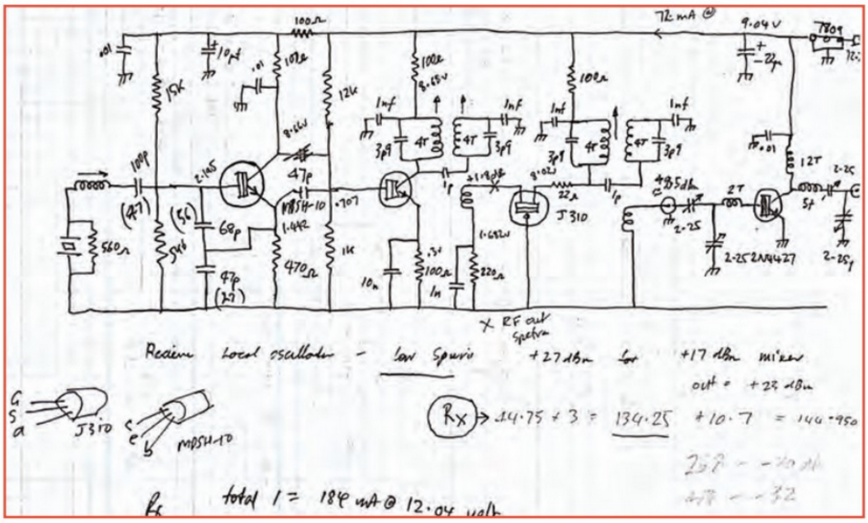

FIGURE 6: Local oscillator.

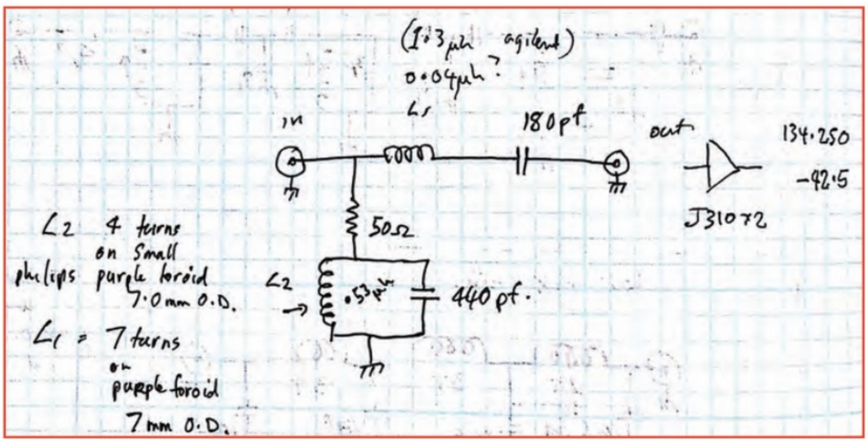

FIGURE 7: Frequency selective diplexer circuit for 10.7MHz IF.

Mixer

I decided to use a high level +17dBm passive double balanced mixer for good intermodulation performance. Another factor was that I had some MiniCircuits mixers available that have low noise and high third order intercept (subject to good matching). To guarantee this, 6dB pads were placed on the RF and local oscillator ports. The IF port was terminated with a 50Ω grounded gate j310 in a push pull amp. The IF output is terminated in 50Ω via a frequency selective diplexer circuit (**Figure 7**) that passes the 10.7MHz to the IF amplifier and diverts other mixing products to the 50Ω termination, thus keeping the mixer happy. The 10.7MHz output feeds the 30kHz wide crystal filters in the IF via a L matching circuit. The jFET amp provides a 50Ω buffer between the high level mixer and reactive 30kHz crystal filter via its matching network.

IF buffer

The IF output of the mixer passes through the diplexer to a dual J310 jFET grounded gate broad band amplifier (**Figure 8**). It has a gain of a few dB, but its main use is to isolate the mixer from the reactive components generated by the out of band frequencies reflected from the crystal filter. The 50Ω output of the jFET mixer connects to the L matching network at the input to the IF amplifier, described earlier.

One has to be a little careful to make sure the RF output of the oscillator multiplier chain is clean and free of spurii and noise as this will reflect on the RF performance of the 2m front end.

Photo 4 shows the completed receiver and IF section. On the left is the LO, which gives +23dBm RF output at 134.250MHz. The middle section is the BF981 RF amp with three section bandpass filter, high level mixer, post mixer diplexer and dual J310 jFET 50Ω post mixer amp. On the right is the BF960 MOSFET based IF amp.

RF upconverting mixer and amplifier

I decided to use an SBL-1 double balanced mixer in this section. With the SBL-1, RF losses are low and it has good strong signal handling ability, good balance to minimise LO feed through and an easily obtainable LO requirement at +7dBm. I chose the port that gave the greatest isolation for the 134.850MHz local oscillator as this enables me to relax the amount of 144.350MHz selectivity.

The up mixer linear amplifier chain consists of three stages of amplification. The first a common gate jFET amplifier (J310) with a 50Ω input impedance to match the output of the SBL-1, through two tuned circuits to enhance 144.350MHz and reject any residual LO leaked through the SBL-1. This feeds a BF960 dual gate MOSFET through more lightly coupled tuned circuits, for good selectivity, gain and linearity. The output of this stage feeds a 2N4427 bipolar linear stage for an output of up to +18dBm at 144.350MHz. The RF output drives a RA08H1317M 2m power 'brick' to achieve a nominal 8W peak RF output. The small RF power amp is attached to a very large heatsink to keep the electronics as heat-stress free as possible. The RF output of the power brick is filtered by a five pole filter to keep the radio inspectors from the door!

Activity sense and switching

Repeaters normally require a mute circuit to gate the Tx on receipt of a signal. This was important for our repeater as it relies exclusively on solar power (backed with batteries of course). The local oscillators remain on all the time to minimise drift.

I based the mute circuit on a SL6600 dual conversion PLL based FM detector IC. I etched up a small board, populated it and tested the performance of the chip at 10.7MHz and I was impressed. The mute action was very decisive even under the high level of broadband noise that came in along with the wanted signal from the 30kHz wide 10.7MHz IF.

PHOTO 4: Completed receiver for 144.950MHz with 30kHz IF filters.

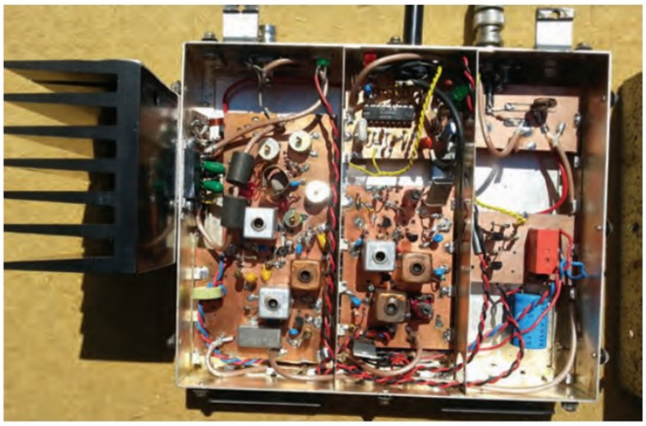

PHOTO 5: Completed transmitter section.

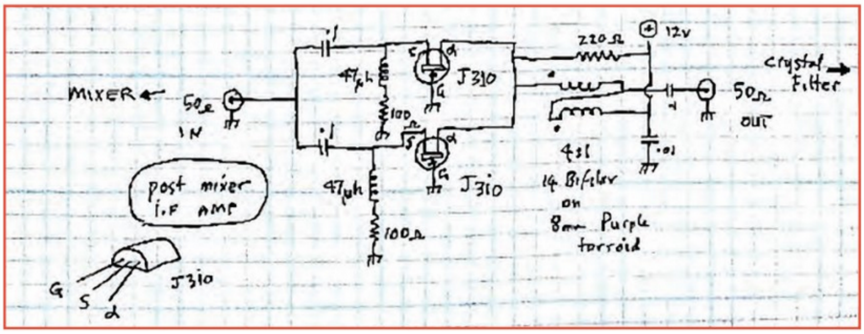

FIGURE 8: IF buffer amplifier.

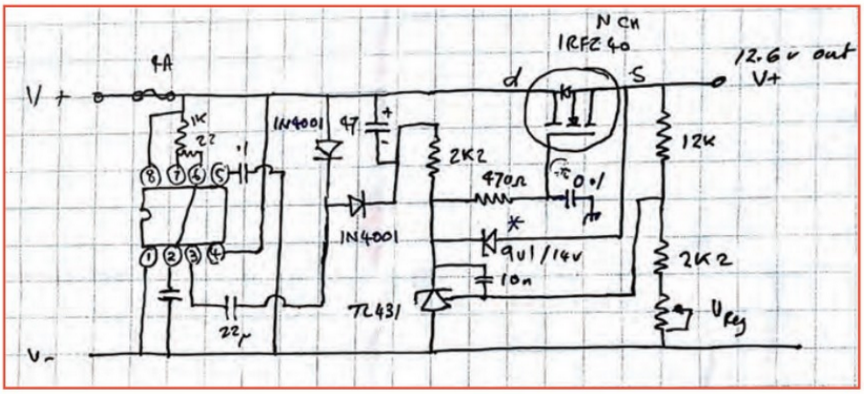

FIGURE 9: Low dropout regulator circuit by Serge Patrishin. *=optional part.

The squelch output was taken through two transistor stages to drive a small relay. I settled on a –124dBm mute open signal as this is the border of readability of a NBFM signal. I put a 1000μF electrolytic across the Tx relay coil to reduce the 'mute chatter' on weak signals and place a small tail on the signals to hold the repeater open voice peaks in SSB contacts between. The relay contacts were paralleled to increase current capability. A power MOSFET would be a good substitute, but I didn't have any to hand. All of the RF circuits in the transmitter operate in Class A for reasons of linearity; the squelch relay is used to switch the +12V supply from which the bias to all the stages is derived, including the RA08H1317M linear amplifier (which actually runs in Class AB).

Photo 5 shows the completed transmitter section. On the right is the power supplies and mute relay. The centre section houses the SL6600-based squelch circuit and the local oscillator board. On the left is the mixer, filtering and power amplifier.

Aerials

We use two vertically stacked 2x5/8 collinear antennas about 3m apart, one each for transmit and receive. These give a low angle of radiation and a gain of some 6dBd. They are robust and low maintenance. The isolation between the antennas is about 40dB – but not enough to operate a repeater without a further 80dB of cavity filtering.

DC power supply

I made extensive use of three terminal regulators in the various receiver and transmitter modules. However, being a solar-powered site our battery voltage can be from 12 to almost 15 volts. I had a small problem with the RF power module in that it was recommended not to exceed a supply of 12.6V. Standard regulator circuits require 2 or 3V drop over the pass transistor to perform well (be they three terminal or discrete). This is too much for our application; I had to explore alternatives.

Many manufacturers produce low dropout regulators. These are better than the standard regulators but a lot drop at least one volt when powering a 3A load. After a web search I found a very good circuit by Serge Patrishin (**Figure 9**). It is based on a TL431 adjustable Zener controlling the gate voltage of a series fed power MOSFET. The drop is as low as tens of millivolts at 2A. In order for this elegant circuit to function, a low current higher voltage supply is required. I used a NE555 timer in a voltage doubler configuration, seen on the left of the circuit, which works fine. The TL431 monitors the regulated output voltage and adjusts voltage by robbing the gate bias to control conduction hence regulate.

Conclusion

NBFM contacts through a linear repeater sound so much clearer than your standard FM repeater as there is no audio processing to distort and modify the voice. Digital modes cause no problems: they pass straight through. We don't need a power-hungry PC at the repeater generating all sorts of noise to interfere with our low background noise receiving site! Any required processing can all be done at users' residence.

So far the repeater has been working well and I am satisfied with its performance. You may well ask, why build a linear repeater? Well it is an RF challenge to start with, something to get the brain going. The fire-destroyed predecessor was also a linear repeater, but 16kHz wide. The increased bandwidth should provide more room to experiment, particularly with digital modes.

Review

Alinco DM330MW UK MKII power supply

The front panel of the Alinco DM330MW UK MkII, a well-built power supply.

Power supplies, while not the most exciting piece of equipment, are essential and we all need one (or two) in the shack.

This review is for those who are new to the hobby and will help introduce the types and the different connectors you may come across. I will also review the new Alinco DM330MW UK MKII power supply.

I remember when I first came into the hobby being somewhat surprised that I needed to buy a separate power supply for my transceiver – shouldn't the rig just come with one? Unlike regular consumer equipment, the majority of transceivers and their accessories rely on a separate power supply.

So why exactly do we need a power supply? We need to convert the high voltage mains alternating current (AC) into low voltage direct current (DC). Transceivers are typically designed to work with 13.8V of DC, so clearly, we need to do something to convert the ~230V of mains supplied AC.

A primer on power supplies

The first choice you must make when choosing a power supply, is whether you want a linear power supply or switch mode power supply (SMPS)? Both have advantages and disadvantages.

Linear power supplies convert high voltage AC into low voltage AC using a transformer, and then convert this into DC voltage. Switch mode power supplies convert AC into DC first, then convert this into the desired voltage.

You have probably already got several SMPS in your house; your mobile phone and laptop chargers use this type. Linear power supplies, however, are a bit more specialist these days and tend to be used specifically for audio and RF applications.

The major advantage a linear supply has is that, unlike a SMPS, it produces little to no noise, which is great for our RF needs. An SMPS on the other hand creates noise interference, due to switching, that can create electromagnetic and RF interference.

So, with this in mind, you might ask why would we consider a SMPS? Well, there are several disadvantages with linear power supplies:

- Heat dissipation – they are much less efficient, so therefore produce a lot more heat.
- Bulky heat sink – As a result of the extra heat, they need a big heat sink to keep cool.
- Step-down transformer – Again, this is bulky and heavy.

You might be able to see where this is going; in conclusion, linear supplies are bulky and weigh a lot!

So, while a SMPS produces more noise; it has the following key advantages:

- Efficiency – they are a lot more efficient, therefore generate less heat.
- Low heat – Because they are efficient, they do not need such a bulky heatsink.
- Lightweight – The step-down transformer is smaller and lighter, add to this the reduced need for a heavy heatsink and the result is that SMPS are much lighter and smaller than linear supplies.

Because of these convincing advantages, you will mostly come across the SMPS types. If they are produced for amateur radio, then they tend to already have good EMI filters and RF shielding to minimise the noise/interference they can produce. Couple this with the much smaller size and weight and most amateurs are happy to use them in the shack – plus they are much more portable for travel use too.

Different types of connectors

Now that we understand the two types of power supplies, we should consider some of the key types of connectors we will use to connect our equipment's power cables to the power supply unit.

The back panel of the Alinco power supply.

Fork and Ring terminal connectors are very popular, I tend to prefer the Fork type, because they are easier to connect and remove, the ring type however require you to fully unscrew the thumbscrews on the power supply. If you do not intend to change your shack equipment much, then go for the ring type, otherwise choose the fork type.

Anderson PowerPole connectors are frankly excellent, they make it difficult to mistake the connector polarity, due to their design. I personally love Anderson PowerPoles on all my equipment where possible.

Banana connectors are quite common too. These have a push connector, so no need to use thumbscrews, just push the connector into the power supply.

There are other types of connectors, but these are the main types you will come across.

The Alinco DM-330MW UK MKII

The Alinco DM330MW UK MKII is a 30 amp switch mode power supply offering a number of useful functions for the shack. It is advertised as a 'high efficiency, compact, lightweight and high-performance switching mode power supply'. It is offered for sale by Nevada Radio and comes with a generous two-year warranty. This model is specifically designed for the UK market and conforms with UK safety regulations specifications and is CE approved.

It can provide a variable voltage from 5V up to 15V DC, delivering up to 25 amps (30A peak). It comes with a large, illuminated combination volt/amp meter, a front panel voltage adjustment and customer-defined output voltage preset. The ripple is rated at less than 15mVp-p and has three in-built circuit protection functions for short-circuit, over temperature, and current limiting.

This model is the deluxe version of the Alinco DM330FXE, the main difference being that this model has improved filtering, for even better performance when used with transceivers and receivers.

Out of the box

My initial impression during unboxing was positive, it is supplied in a well packaged and branded box, complete with an instruction booklet. The instruction booklet is written in good English and covers everything you need to know about this relatively uncomplicated power supply.

A frequent problem with switch mode power supplies that are not designed for our hobby is that they can generate noise and interference. During a field day, I once witnessed a laptop charger wipe out the whole of the 80m band, producing S9 of noise upon plugging it in. Suffice to say we turned it off and logged using paper!

This Alinco power supply is different, it has been specifically designed for radio use and has low noise and a noise offset circuit. A noise offset function is always useful with switch mode power supplies. You will sometimes find they can cause noise at a certain frequency, the noise offset adjustment allows you to shift the noise to another frequency. The Alinco has a dual control knob on the front to control both the voltage and noise offset. I would prefer two separate knobs here for safety, it would be easy to mistake one for the other. Either way, I did not encounter any noise from the Alinco power supply, but it is nice to know it is there if you need it.

Regarding the voltage adjustment knob, this has been designed with a notch at 13.8V, which is likely to be the voltage you will want to run your transceiver and most other shack equipment from.

The power supply weighs in at 2.5kg (with the UK mains lead), so it is lightweight enough to take out of the shack for field days. The build quality is robust, and it feels well made, the heatsink is integrated with the case. Its dimensions are 190mm wide, 69mm high and 181mm deep. I have seen smaller supplies that would be more useful if you had to travel a lot or were going on DXpeditions, but really it is small enough otherwise.

A word about connectors

The Alinco power supply does come with a wide range of power connectors, which gives you some good options for connecting your equipment.

On the back panel, you will find the ubiquitous binding posts, supplying up to

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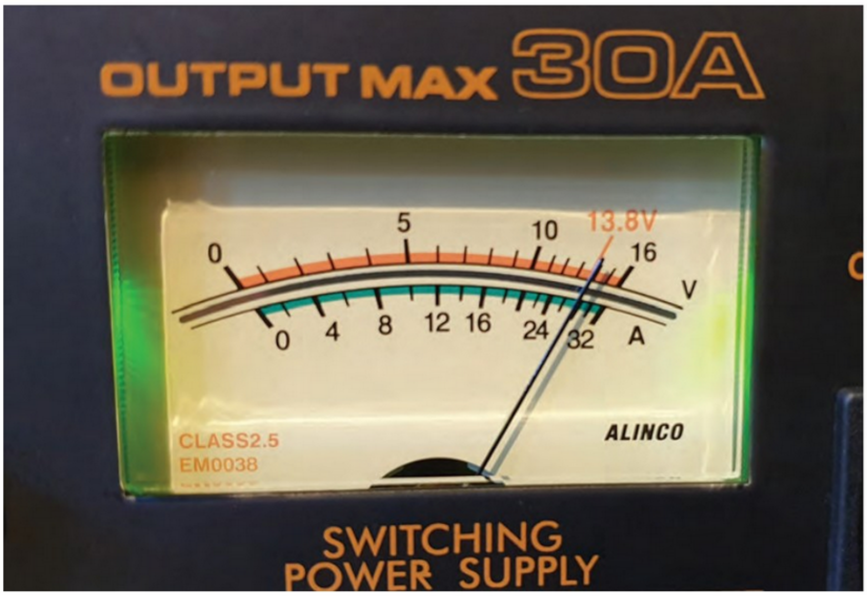

Front panel meter showing the supplied voltage and current.

30A at peak. Due to the 25A limit (and 30A at peak), this is where you would connect your transceiver.

On the front panel, you will find two pairs of snap-in terminals supplying 5A each. These would be particularly useful for shack accessories like an antenna tuning unit (ATU), power meter, etc.

On the front panel you will also find a cigar outlet supplying 10A. This is a bit less common on shack power supplies but could be useful for powering a receiver or handheld with a cigarette power adaptor. You could even add USB connections by sticking a car USB charger in it!

Even though the Alinco comes with a wide range of common connectors, I would have liked to have seen Anderson PowerPole connectors included and even a few USB charging points. Apart from this, it has everything you would expect.

Other features

Another nice feature is the ability to set a voltage preset. Using the Preset switch and Preset Adjust dial on the back of the unit, you can effectively fix the voltage for the unit to supply. Enabling this deactivates the manual voltage adjustment control on the front panel, possibly saving you from any nasty mishaps.

The illuminated analogue meter on the front is pleasant to use. It is a dual-purpose meter displaying either the voltage or the current being delivered. You need to press a switch on the front to change between the two – I would have preferred two separate meters here instead but cost then becomes a factor. The backlight illumination is sufficient but could be brighter, it seems to be provided by two dim green LEDs either side.

Drawing 23 amps on transmit resulted in no discernible noise from the power supply, in fact I was hard pushed to even tell if the fan was on. It is one of the quieter power supplies I have used. It got a little bit warm to the touch, so I imagine the passive heatsink on top of the case is sufficient to dissipate the heat under normal use.

Conclusion

The UK model on review here retails for £149.95 from Nevada. The Alinco DM330MW UK MKII is a well-made and thought-out power supply dedicated for radio use and the UK market. The build quality is good and it feels like a quality item. Attention has clearly been spent on the design and functionality. It has several useful features, not seen on all power supplies. Thanks to Nevada (www.nevadaradio.co.uk) for supplying the review model.

Websearch

[1] www.nevadaradio.co.uk/product/alinco-dm330mw-uk-mkii/

Technical

Simple Morse keyer

Introduction

I passed the 12wpm Morse test as a teenager to get my A licence in 1983 and was on the air with CW using an old Heathkit valve transceiver for a few years from my parents' house. But then university, work and starting a home took over and I left amateur radio. I came back to the hobby in 2017 (after the RSGB sent me a free copy of *RadCom*) and, after a short dalliance with FT8, reignited my love of the Code. I hadn't touched a straight key in almost 30 years so it was a relief to find that all modern transceivers contain a Morse keyer, meaning I could send with a paddle.

My interests then moved towards constructing my own equipment. I've worked as a software engineer for over 30 years so it was natural that anything I designed would be computer controlled. I started with an Arduino-based CW transceiver and, since I wanted to use my paddle with this, I included software for a Morse keyer. At the beginning of the first lockdown in 2020 I decided to change tack slightly and have a play with some simple transmitter circuits from the G-QRP Club journal *Sprat*. To ensure I could continue to send with the paddle, my first project was a simple Morse keyer.

The transceiver's Arduino uses a 28-pin ATmega328 microcontroller, which is overkill for this simple application. I looked for a smaller device from the same family to minimise the amount of work required for porting the software. It would also mean I could use the same development tools.

I chose the ATtiny85-20PU, which is an 8-pin DIP part. It has 8K of flash and a clock speed of up to 20MHz but it isn't necessary to use exactly this chip. The software uses the default internal 1MHz RC clock, so a slower version would be fine. The code is just under 2K so you could use the 4K or 2K versions. However, in small purchase quantities there is hardly any difference in price, so I used the larger device for maximum flexibility.

The keyer supports Iambic A and B and Ultimatic modes. For simplicity, it uses a switch to select one of two possible speeds. I tend to use 16wpm for rubber-stamp and rag chew QSOs and 20wpm for DX/special event/contest stations. If I call someone working at a lower speed I just increase the gaps between characters.

The mode and speeds are configured within the microcontroller's internal EEPROM in a simple file that can be changed using the method described later.

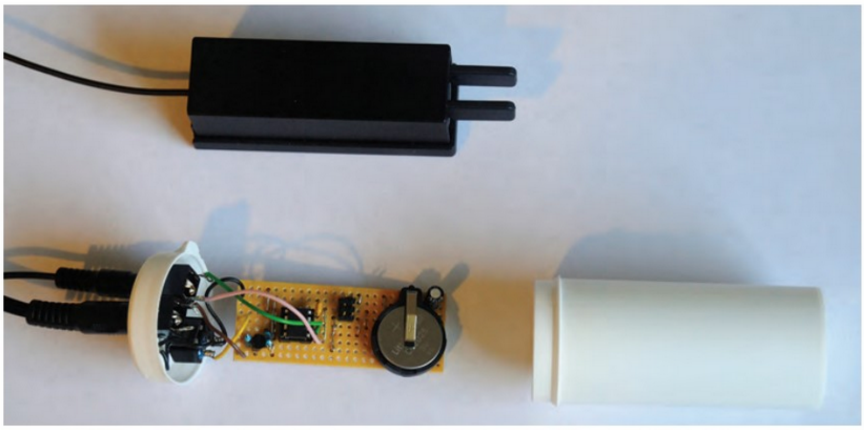

PHOTO 1: General view of the keyer, its pill-box case and my paddle.

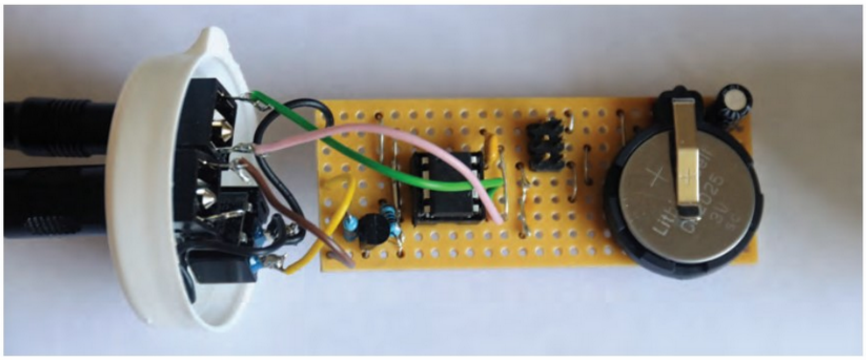

PHOTO 2: Closer view of board.

Circuit description

The circuit diagram is shown in **Figure 1**. U1 is the ATtiny microcontroller. It is powered by BT1, a 3V coin cell. The hardware and software are designed to use as little power as possible and there is no need for an on/off switch.

C1 and C2 are decoupling and reservoir capacitors. Although the power consumption is very low, U1 – like all digital circuits – will draw its current in bursts; these capacitors help ensure the supply voltage doesn't dip. This will become particularly important as the battery discharges and its internal resistance rises. C1 should be placed close to U1. These capacitors should be low leakage types (any leakage will directly shorten battery life) although I found no excess current draw with the two I found in my junkbox.

J1 is the header for in-system programming (ISP). This is needed to program the ATtiny. If you have the means to program the chip externally you could omit this, although including it does make changing the keyer mode or speeds easier.

J2 is a 3.5mm stereo jack socket for the paddle, with the standard wiring of tip for dot and ring for dash. Sleeve is ground.

J3 is a 3.5mm stereo jack socket for keying the transmitter, with tip for key and sleeve for ground. Ring is not connected. Using a stereo connector ensures the keyer is compatible with transmitters using mono or stereo jacks.

SW1 selects the speed from the two choices defined in the EEPROM.

R1, R2 and Q1 form a switch to ground the key out line and hence key the transmitter. Q1 is shown as a 2N7000 MOSFET but almost any N-channel device with a gate threshold voltage below 3V could be used here. If you are using the keyer with an old valve transmitter you will need to choose a device that can handle the voltage on the key line. R1 and R2 are not strictly necessary but R1 limits the current if there is a fault in Q1 and protects U1. R2 guarantees that Q1 is off if the power is disconnected (a MOSFET's gate will hold its charge otherwise).

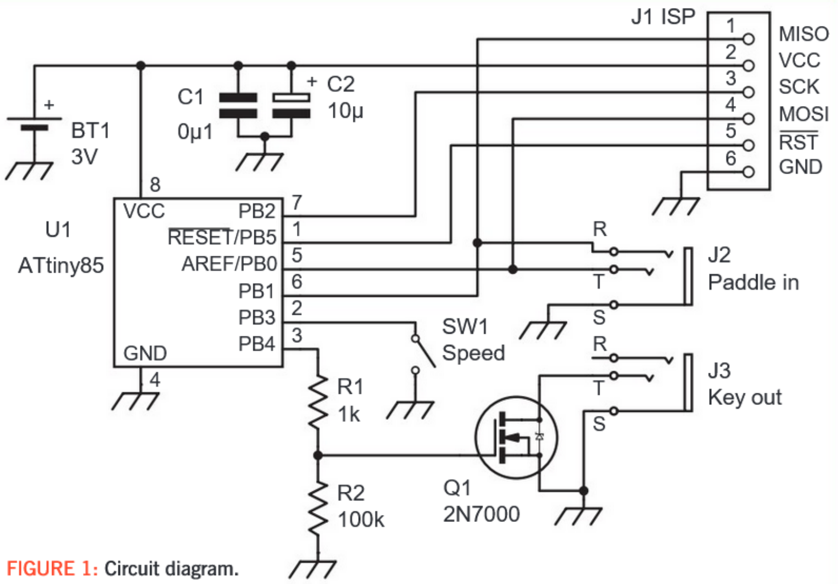

FIGURE 1: Circuit diagram.

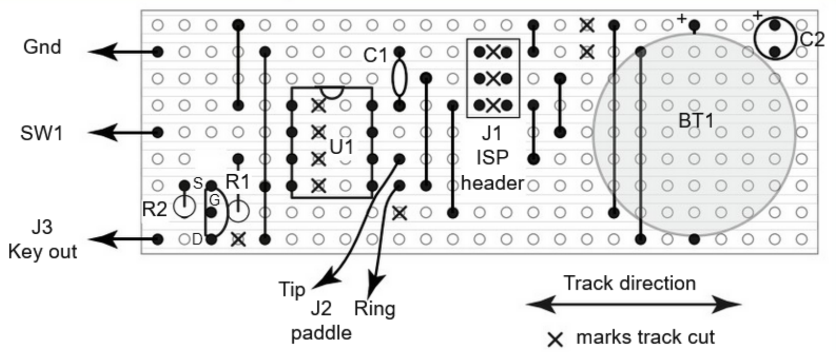

FIGURE 2: Layout on stripboard. Note breaks between pins of ISP header.

Power consumption

There is no on/off switch so it is important that the design draws as little current as possible. My measurements are 800μA while sending and less than 2μA while idle. A CR2032 lithium coin cell is about 200mAh so in idle it should last around 100,000 hours, which is over 11 years. In constant 24 hour per day use the battery should last some ten days, more than enough for even the *most* demanding contest!

To achieve this low power consumption, the software puts the ATtiny into power down mode shortly after the last dot or dash is sent. This shuts down almost everything on the chip. It is woken by a pin-change interrupt on the dot and dash paddle pins.

One enhancement would be to use a potentiometer connected to an analogue input pin as a speed control. This could allow any speed to be set between, say, 10 and 30wpm. But this has two power problems:

- The A/D converter uses around 400μA so it considerably increases the consumption during use, although it's possible to switch this off in power down mode.
- A pot across the 3V battery will continuously draw current. The largest value I had to hand was 47k so the additional 64μA would flatten the battery in just a few months. I could have used a 1M pot for a reasonable battery life but as I didn't have one to hand I decided, for simplicity, to just provide two speeds.

Other possible approaches might include running the pot from the keying output pin (PB4) and sampling while 'key down' (pin high), but I did not explore this as the two-speed approach met my needs.

Software

The software is written in C and built using Atmel Studio 7, which is a free download for Windows. It can also be built using avr-gcc on Linux. The software is open source and hosted at GitHub **[1]**. There are also ready-built hex files here that you can program without having to build the software yourself. Instructions for programming the device and building the software are on the website.

The keyer engine is part of TARL ('TGJ AVR Radio Library) **[2]**, a collection of source files that can be used for a number of radio projects. This library is also used in my frequency generator (*RadCom* November 2020).

In System Programming

The software and EEPROM image need to be programmed into the ATtiny. There are a number of cheap tools available for this such as USBasp or you can use an Arduino. Instructions are provided with the software at GitHub. Alternatively, if the ATtiny is socketed, you could program it off board (if you have a suitable programmer).

Before programming, make sure that you remove the battery cell so that the circuit is supplied only by the programmer. It is fine to use a 5V programmer.

EEPROM format

By default the keyer is in Iambic A mode with a slow speed of 16wpm and a fast speed of 20wpm, but these can be overridden by writing to the EEPROM. The file can be created in any text editor. Its format is `TMK x yy zz`
It always starts with the letters TMK.
x is A for Iambic A, B for Iambic B or U for Ultimatic; yy is the slow Morse speed in wpm, eg 16; zz is the fast Morse speed in wpm, eg 20
For example, `TMK U 14 28` would set Ultimatic, 14wpm slow and 28wpm fast.

If the format is incorrect or the slow and fast speeds are outside the program's minimum (10wpm) or maximum (30wpm) limits then the default values (Iambic A, 16/20wpm) are used.

Construction

Circuit layout is not at all critical and you're free to do whatever you're comfortable with. I built the prototype on stripboard (9 strips by 25 holes). **Figure 2** shows how I laid out the components. X is used to show where track breaks are required. Note that the tracks under the 6 pin ISP header must be cut *between* the holes. I used a small pill tub as the enclosure.

After construction but before inserting the coin cell, use the external programmer to program the microcontroller's flash and EEPROM (if you want to override the defaults) via the 6-pin ISP header.

Websearch

[1] https://github.com/G4TGJ/MorseKeyer
[2] https://github.com/G4TGJ/TARL

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How to build n-circle antenna arrays

I have been experimenting with HF circle antenna arrays since 1997 [1]. All of the earlier designs required miles of ground wire, 90° phasing lines, complex phasing circuits and multiple relays for direction switching. **Photo 1** shows the phasing and switching unit for a 6-circle array that could fire in 12 directions. In an effort to reduce the component count, I built an eight-circle with mixed driven and parasitic elements that relied on a single capacitor for phasing. This was described in the ARRL publication *QEX* several years ago.

The antenna designs described here are relatively easy to duplicate as no special components are required. They are intended for DX working on the 40m and 80m bands where they form a switchable beam array that performs like the popular 4-square but they do not require the associated phasing lines, phasing networks, hybrid couplers, complex tuning or extensive multiple radial ground systems. Whilst maintaining the same performance in a selected direction of radiation, the orientation and quantity of elements may be adapted to fit the available land area that, in many cases, may be less than the footprint of a comparable conventional 4-square array. They require only a single mast and may, therefore, be more acceptable to neighbours and planning authorities.

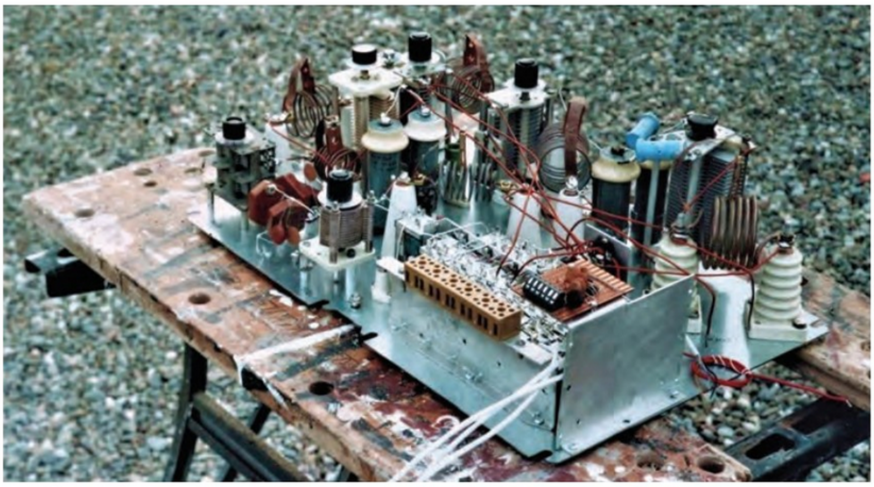

PHOTO 1: **The complex phasing network for a six-circle, 12 direction all-driven phased array.**

Performance

As with other arrays of vertical elements, best performance requires local ground of good conductivity (otherwise they may be outperformed by a high horizontal dipole). In this case, EZNEC shows the gain to be up to 7dBi with 15-20dB front-to-back radiation ratio and 90-100° horizontal beamwidth. There is a null near 50° elevation in the reverse direction rather than that at 90° from a 4-square. Net gain may be somewhat more than that achievable from a conventional 4-square at the same site because of lower ground connection loss together with increased radiation at a lower vertical angle of 15-20° due to the longer elements. Further gain of up to 3dB (an S-point on many radios) may be achieved in directions between the radiation lobes from a 4-square by employing six parasitic elements of which two are active. This may be seen in the lower plot of **Figure 1** that shows relative VRPs towards the Caribbean of a conventional UK based 4-square, blue trace, and the 7-element version of this antenna. This was confirmed on many occasions when signals from New Zealand and Pacific islands were propagated over this path.

Design philosophy

The basic 5-circle array consists of a central driven element surrounded by four evenly spaced bent wire parasitic elements. Parasitic reflector elements are formed by switching extra length on to director elements near ground level. In each radiation direction, two of the wire elements are active and the remaining unused elements are connected to ground by relays. This makes them transparent because at a half-wave wire a low resistance ground connection is transformed to the centre of the wire as an open circuit. Consequently, little current can be induced into the wire, therefore, there is negligible power dissipated at the ground connection. The array then consists of three active elements, like a 4-square except that the mast replaces the pair of centre elements. This direction switching technique, applicable to half-wave sized elements, may be employed with alternative element shapes to suit available mast and site limitations.

Because they are sloping, the parasitic element wires naturally produce a mixture of horizontal and vertical polarised radiation. The horizontal components in upper and lower parts of the bent wires oppose each other, while the vertical components reinforce each other. Undesirable horizontally polarised components, from a DX viewpoint, cause skyward or zenith radiation that effectively reduces the front to back radiation ratio at high take-off angles, although it has little effect at low angles of radiation. This is a mixed blessing as it allows local high angle contacts without resort to a separate antenna but provides less protection from EU co-frequency QRM. The ratio of the lengths of upper to lower parts of a single bent wire and, to a lesser extent ground conductivity, determines how much residual radiation is horizontally polarised. This may be seen in **Figure 2**. Except when the whole of the element is vertical or nearly so there is an optimum position for the bend in half-wave wires that results in minimum zenith radiation. This is when typically 48% of the wire is above the bend. Other lengths and bend angles will have different optimum bend locations but,

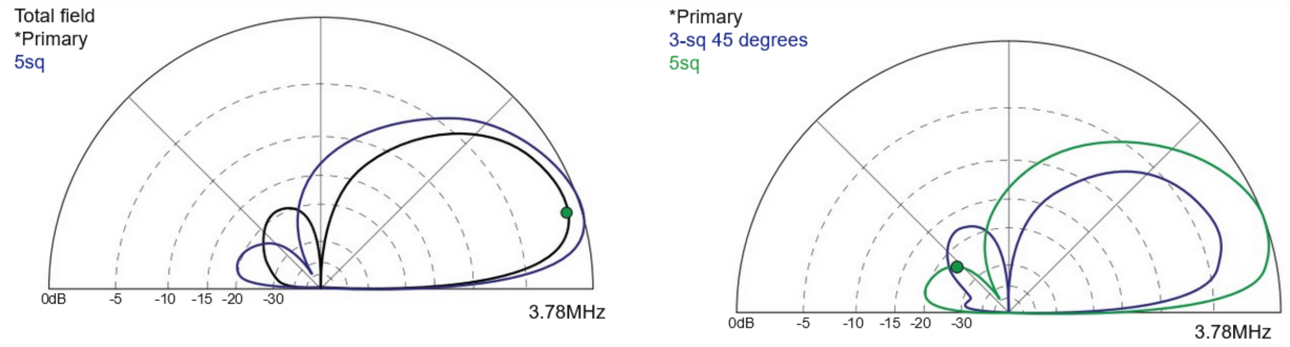

FIGURE 1: The left plot compares the VRPs of a standard ARRL 4-square and the 3 or 5-circle arrays, blue trace, over ground of good conductivity. The plot on the right is a comparison between a conventional 4-square, blue trace, and the 7-circle array towards a westerly direction from the UK.

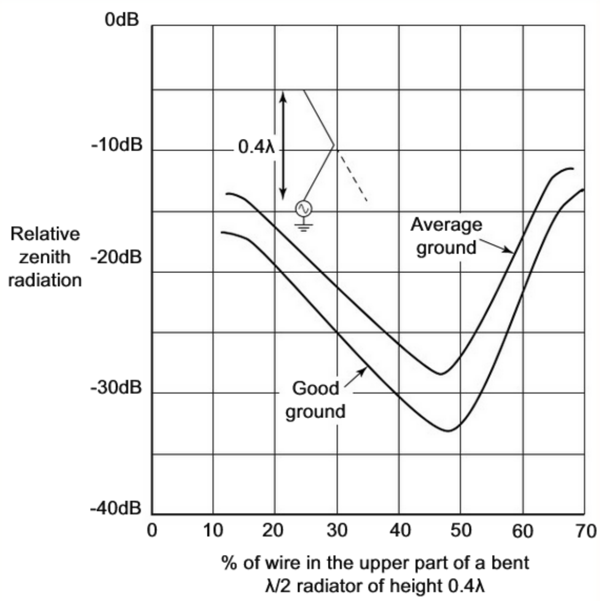

FIGURE 2: How horizontally polarised radiation relative to major lobe vertically polarised radiation depends on the location of the bend in a half-wave element.

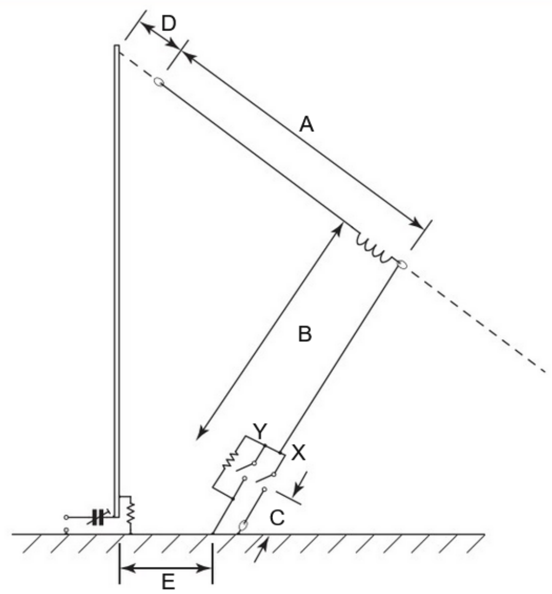

FIGURE 3: The general arrangement of one of the bent elements in the array with dimensions of the wires. The inductor is required only in the wires of the 80m array.

for 90° bends and a variety of ground types, the calculated range is 55-45% for wires of 0.25 to 0.5λ respectively. Unfortunately, these result in a wide radius for the ropes that are required to pull the wires away from the mast.

A compromise has, therefore, to be accepted unless a large site area is available. A 60/40 split between respective upper and lower parts makes the pulling radius more acceptable with typically 20dB attenuation of radiation to the zenith relative to the main lobe for a single wire. However, when two active bent elements are involved with different current phases as in these designs, the zenith radiation is increased to about -15dB. This may be seen in the upper plot of Figure 2 where the black trace is the VRP of a conventional 4-square array.

Originally, when I experimented with this design I did not have loading inductors in the arrays but these are now added to make mast dimensions and site requirements for the 80m array more acceptable. (I had conveniently located trees to which I could attach the pulling ropes). General dimensions in terms of wavelength λ for an array of this type without loading are included in **Table 1**. The changes necessary to construct the '7-circle' version are straightforward with just two extra elements, identical to those in the table, each with their relays, ground pipes and control cables as with the 5-circle. Where there is insufficient space for a 5 or 7 element array, a 3-element version with just two bent elements firing say east and west in a suitably oriented linear garden may be appropriate. A 4-element version with three bent elements spaced 120° is also practicable. This was the arrangement that I first experimented with on the 40m band. In both of these arrays only the X relays, described later, are required.

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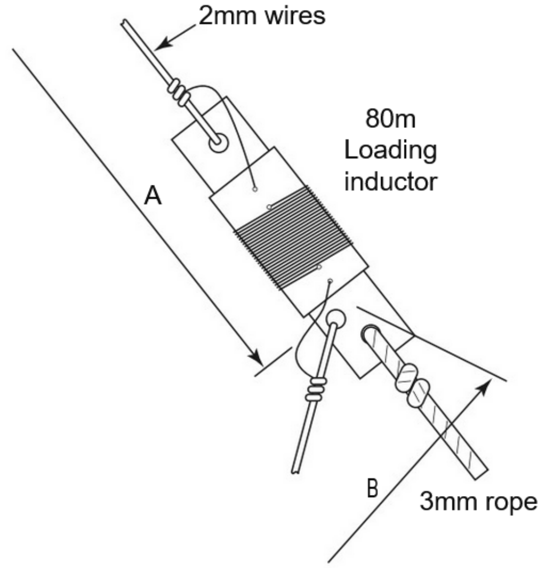

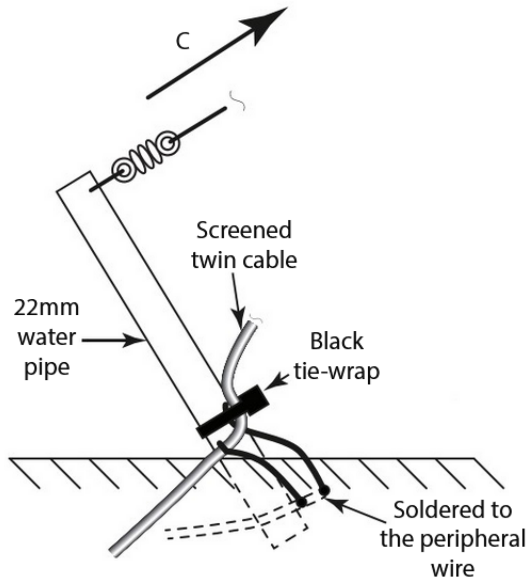

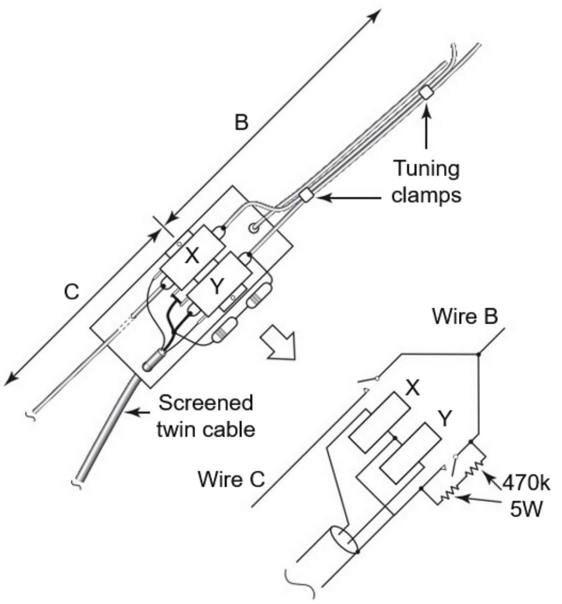

FIGURE 4: **Suggested construction details for the arrays.**

Construction

Figure 3 shows one of the identical bent nominally half-wave parasitic elements supported by a guyed mast that itself forms the driven element. This may be 48mm steel scaffolding or 2 inch aluminium tube with insulated base and guys of low-stretch rope. The parasitic elements of the basic array are pulled away from the mast at NW, NE, SW, and SE directions (in UK) by ropes that terminate on a radius that is roughly equal to the height of the mast. Each of the wire elements in the 80m array is loaded near its centre by an inductor to make it half-wave resonant a few percent above the design frequency. This makes them all into parasitic directors as with those that are not loaded in the 40m array. High voltage reed relays, X, connect the wire, lengths C, when necessary to convert either one of them into a reflector.

Figure 4 shows how the lower ends of the element wires are terminated, how the relays are mounted on insulation board and how the 80m inductors are rigged. In my situation, I had to protect the lower ends of the elements from sheep by enclosing an area around each termination with a fence. If reed relays having encapsulated coils are employed, they may not require further weather protection. Those that I used were rated at 10kV and 3A and are the only costly items required **[2]**. However, the important parameters are low capacitance and high voltage handling as current is negligible and live switching is not a requirement in this application.

A tuning facility is shown in Figure 4 where the B wires are made longer than specified and the extra wire is folded back to be clamped to the standing part. Suitable clamps for 2mm copper wires may be obtained by removing the brass parts from a round 30A electrical junction box. For galvanised or stainless steel wires use compatible wire rope clamps. When joining the inductors and relays to galvanised wires or stainless steel wires, we must tin the ends of copper connecting wires first and protect the joint from moisture or a corrosion problem is likely to develop quite quickly. There are several possibilities for attaching the elements to the head of the mast.

Individual halyards or a lesser number supporting several elements will simplify maintenance but my preference was to permanently attach them to serve as the upper set of guys for the mast. During the five years that the six-wire array was in service I only needed to drop the mast for repairs once, and that was after a tractor tangled with one of the pulling ropes.

The grounding system

As the ground connections are made where the element impedance is high, the ground system requirement is not as stringent as that for conventional 4-square arrays that use quarter-wave or loaded shorter elements. These arrays will work with no other ground system than that provided by the control cables, copper pipes and 16 buried bare wires extending from the mast to a peripheral wire as shown in **Figure 5**. For symmetry, 18 radials should be used at the 4-circle and 7-circle arrays. However, more and longer radials

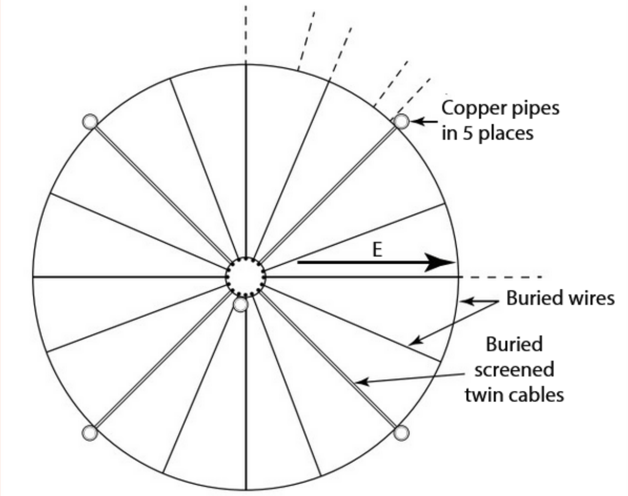

FIGURE 5: **Arrangement of the ground system of the 3- and 5-circle arrays. The system for the 4- and 7-circle arrays differs by having 18 radial wires. Two extra ground pipes are required by the 7-circle.**

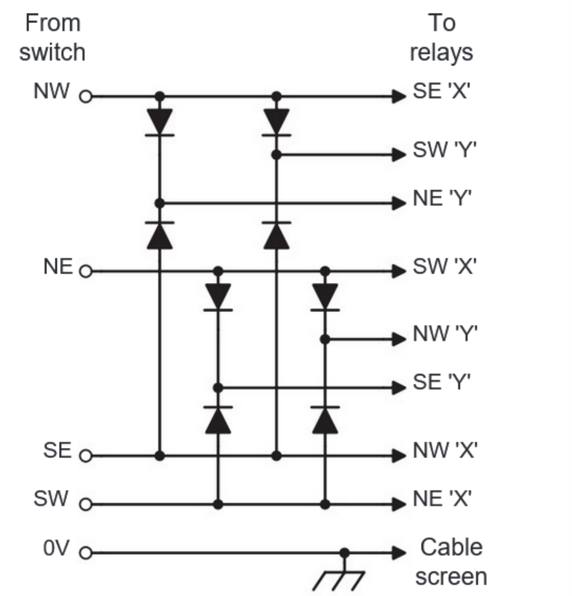

FIGURE 6: **The circuit of a diode matrix for controlling the relays of the 5-circle array from a remote heading switch.**

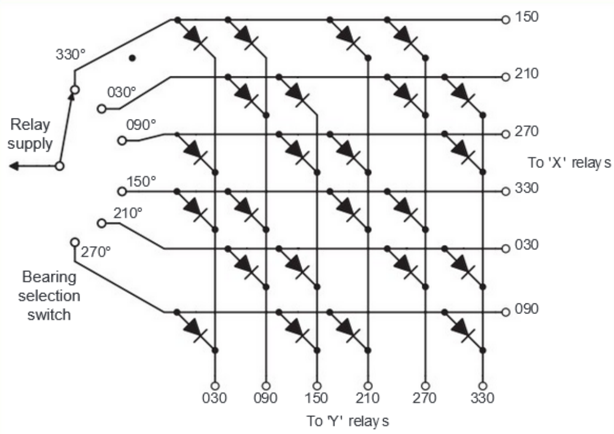

FIGURE 7: **The circuit of a diode matrix for controlling the relays of the 7-circle array from a remote heading switch.**

extending within and beyond the peripheral wire are expected to improve driven element transmitting efficiency, but are unlikely to improve directivity unless they extend for many wavelengths. The 22mm copper ground pipes should have 1m of their length driven into the ground at 45° and have 30cm or more projecting above. The slope is specified to ensure that the reflector extension and element grounding cables are about the same length. The reflector extension wires, C, are attached via insulators to the top of the pipe. The unused parasitic elements are attached via their Y relays near ground level to the copper pipes and to the peripheral wire that is joined to the radial wires. I soldered the peripheral wire connections and coated the joints with roofing mastic before burying them at 5cm below ground. A similar ground pipe near the mast base is used for connection of the radials and is somewhere to mount a weather-proof box containing the diode matrix, terminals for control cables and feeder connections. The screen of the relay control cables provides a return for relay coil current and forms part of the mast's basic radial ground system. The sheath of the screened cables is removed where necessary to make a weatherproof connection at the mast ground pipe, element ground pipes and relays.

Direction switching

Many 4-sqares employ direction switching systems having a pair of relays to perform 'rotate' and 'reverse' functions over three wires between the control position and their phasing/impedance matching unit at the centre of the array. Instead, for simplicity and reliability, I used a matrix of diodes for the 5-circle array as in **Figure 6**. Relay control voltages are directed to the buried twin wire screened cables that are routed radially from the mast to the parasitic elements. The diodes, located near the mast will require a 5 wire cable from the direction switch. Inexpensive 6 core alarm type cable was used here in which two wires were paralleled for the ground side of the relay supply. The switch was a modified wafer type with 90° click stops at 45, 135, 215 and 315° to correspond with the beam headings.

Figure 7 shows the necessary switching matrix circuit for the 7-circle. Here it is assumed that the six parasitic elements are terminated on ground pipes placed at 60° intervals at 030, 090 etc around the peripheral wire. The 7-circle needs a control cable with 7 cores and a switch with 60° indexing. Simpler direction switching may be employed at the 3 element and 4 element versions as there are now no unused elements to be connected to ground. Any two elements must be switched to perform as reflectors in the 4 element three direction array for which **Figure 8** shows the diode configuration.

Loading inductors

The four inductors must be matched as precisely as possible. Their inductance will be critical to performance and should be obtained with a measuring instrument or by dipping when resonated with a constant value of capacitance at the design frequency. Failure to match the inductors will make subsequent optimisation of performance in all four directions frustrating because of the mutual

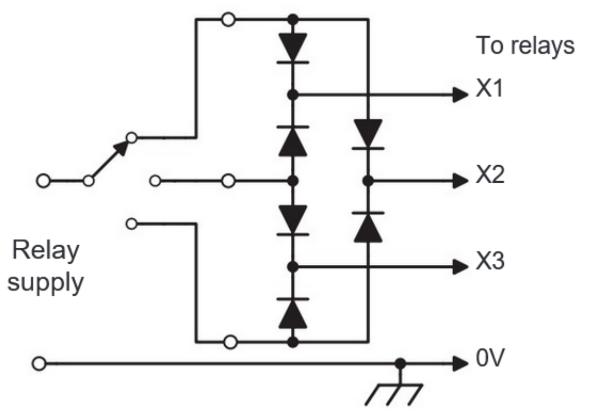

FIGURE 8: The circuit of a diode matrix for controlling the relays of the 4-circle array from a remote heading switch.

impedance between elements. The inductors have to withstand about 2kV at 4A with 400W CW input power. Ideally, inductors of greater diameter and fewer turns of thicker wire offering a higher Q would be advantageous but to be able to accept the high voltage between turns they would need to have the turns spaced apart. Those described here are easily reproduced. They are wound with 1.5mm enamelled wire on 34mm OD black plastic sink waste pipe. They are close wound with 39 turns. I recommend trying to keep the wire warm whilst winding to make it tighten as it cools. Space the end turns for adjustment to the specified inductance and fix them with silicone bathroom sealant. When complete, cover the winding with black insulation tape or heat shrink cable sleeve to protect the enamel from ultraviolet light. Mount the coils over a strip of 6mm x 30mm insulation board. This will form an insulator on which the element wires and tensioning ropes may be terminated, as in Figure 4.

Fine tuning of the parasitic elements

Roughly tune the mast so that some power can be put into the antenna. Unless the ground slopes or there are conducting structures nearby, SWR should not alter as the radiation direction is switched. If it does, check that the relay's contacts are closing and that the corresponding wire lengths are all the same. Confirm that the antenna has some differential front to back sensitivity on the ground-wave signal from a local station. Fine adjustment for the best font to back at ground level may now be made by simultaneously trimming the lower end of all four wires, B. Reflectors and directors are then simultaneously adjusted.

Tuning the mast

Final tuning of the mast should follow fine tuning of the wires. The mast of the 80m array is resonated for minimum SWR only by the series capacitor, which should be protected from static charge by a series pair of 470kΩ 5W resistors between mast and ground. A similar pair of resistors is required across the contacts of the Y relays to prevent build-up of static electricity across the relay contacts. The capacitor value in **Table 1** is only a guide as it will be influenced by diameter and base insulation of the mast. A wide-spaced variable capacitor is recommended as it must withstand about 1,500V at 400W input power. A simple and inexpensive alternative is to strap to the mast a 2.5m (250pF) length of RG213 cable with, at the lower end, outer conductor connected to the base of the mast and inner conductor connected to the feeder. Cut pieces off the upper end until the SWR passes through minimum, then seal the cut end. The feed resistance will be in the region of 50Ω after tuning with the series capacitor. The mast of the 40m array with series capacitor looks like 100Ω but this may be transformed to 50Ω by adding a shunt inductor of 30μH on the mast side instead of the resistors. This may be made like the loading inductor but with about 6 extra turns. In this case about 60cm of RG213 cable will be required for the series capacitor.

Bandwidth

Dimensions are given in Table 1 for elements of 2mm copper, galvanised fence, copper plated steel or stainless steel wire (no-one will be able to tell the difference when in use). The design frequencies are 3.78 MHz and 7.15MHz. I used copper plated steel wire because it was less likely to stretch when serving as the top set of mast guys. As the parasitic elements are relatively thin the array will not cover the whole of the 80m band and must be tuned for the segment of interest. The usable bandwidth limited by SWR of 2:1 and front-to-back ratio of 10dB is about 80kHz. Bandwidth for the 40m array is about 200kHz. Other 80m band segments will require adjustment of the wire dimensions. As a guide, increasing wires A or B by 0.04λ, 3.1m, should shift the working frequency of the 80m array to the CW sector. Although wire B is more accessible, an increase in the length of wire A will require less of a compensating increase to the pulling radius.

Websearch

[1] Single support directional wires, G3LNP, *RadCom* August and September 1997

[2] Suitable relays are Cynergy3 type DAT 2415 and Meder Electronics type H12-1A69

TABLE 1: Dimensions in metres and nominal component values.

Frequency	Mast	A	B	C	D	E	Inductors	Capacitors
7.15MHz	16m	11.64	8.18	0.80	7.0	6	none	60pF
3.78MHz	24m	12.93	12.50	0.82	14.0	12	23.9μH (j568)	200pF
General λ	0.4	—— 0.472(A+B) ——		0.02	0.175	0.15	none	-j400*

* with shunt inductance of j1400Ω for a match to 50Ω feeder.

An unexpected source of rechargeable batteries

We've all had an occasion, perhaps on a day out, when our phone hasn't had quite as much charge as we'd like – but we're nowhere near a charging point. Several retailers would like us to think that they have the ultimate answer to this calamity, in the form of a disposable phone charger that sells from around £1 to £3. Versions exist with micro-USB or Apple-specific connectors.

Leaving aside the inexpensive availability of fully rechargeable 'power banks', I purchased a couple of 'Power Pod' disposable chargers via eBay (though I discovered from the packaging they were originally made for Poundland). Other brands are available, including 'Power Hit' and 'Hero'.

What's in the box?

Inside the snazzy foil pouch was a sturdy plastic box roughly 60 x 50 x 10mm. It featured a prominent micro-USB connector and a small on-off switch. In the interests of testing I connected it to a phone, switched it on and it started charging.

'Disposable' implied to me that there was probably a primary cell of some sort inside. Although well-constructed, a few moments of careful work with a thin screwdriver popped the case open. This revealed a small PCB containing a switch mode PSU and – to my surprise – what looked very much like a rechargeable lithium-ion cell! Indeed, although the cell was stuck to the inside of the case with a bit of double sided foam adhesive, it was soon prised free and printing on the formerly hidden side revealed that the cell was rated at 3.7V, 650mAh, or roughly 2.4Wh.

Non-rechargeable rechargeable?

Using a proper lithium-ion battery charger/discharger I tested the cell and confirmed that yes indeed, it is rechargeable and yes, it will happily take a (re)charge. So it seems there's nothing to stop you carefully 'harvesting' the cell and using it in your own projects – or perhaps to replace a similar, failing one in another piece of equipment.

Safety warning

Be very careful if you try to open anything containing a lithium-ion cell. Do not under any circumstances cut or pierce the fragile foil packaging of the cell, as this may cause the cell to catch fire or even explode.

Note too that the inductor on the PCB is fragile and it's easy to chip off part of the ferrite as you open the case. The secret seems to be to 'go in' carefully from the corner with the cutout. But if you're planning just to re-use the cell, you may not be worried about damaging the boost converter.

There is one other important point to note. An X-ray clearly showed that there is no protection circuit inside the cell's pouch. That's fine in its intended use, but it does mean that it should only be connected via an intelligent charging (and discharge protection) circuit. Fortunately, the chips that do this are as cheap as, well, chips – and any project or product that's intended to use a li-ion cell will almost certainly include a suitable circuit.

Power Pod is one of several disposable charger brands available.

An X-ray of the PowerPod is revealing.

Conclusion

Precisely why it was decided to use a rechargeable li-ion cell in a non-rechargeable application remains a mystery to me. Maybe the cells – which are doubtless made in their tens of millions – are just so cheap that it's less expensive than using a primary (non-rechargeable) cell. Or perhaps it's simply that there aren't any readily-available and inexpensive primary cells with the required two-and-a-bit watt-hour capacity.

Whatever the reason, we can benefit – not just from a compact emergency power source for your phone, but also knowing that even once 'used' it retains great potential for upcycling.

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EMC

PHOTO 1: 12V pulse repair charger for car batteries.

PHOTO 2: Smart Fast Charger for car batteries.

More battery chargers

The RSGB EMC Committee is concerned about the increasing number of reports of electrical equipment such as car battery chargers that are CE marked but appear to have no RF interference filtering. The resulting interference not only affects amateur radio bands up to 50MHz and beyond but it could also affect FM broadcast reception.

Following the item about the RF Noisy Battery Chargers in April 2021 *RadCom* EMC column, RSGB Member Phil reports that he purchased a similar battery charger in February for £24.59 from a major online retailer. The brand name was 'Buddygo' (see **Photo 1**). Phil reports strong RF interference through HF and up to and above 50MHz, despite being around 60 feet from his antennas.

Rather than opening the unit with a screwdriver to check for missing components, Phil contacted the retailer to tell them about the radio interference and claimed that the product was not fit for purpose because of this. Despite being more than one month outside the normal 30 day return period for unwanted items, the retailer provided a return paid postage label, accepted the charger as a return and gave a refund. The 30 day return period is for customers who change their mind but if the item is not fit for purpose or if it contains a defect that the purchaser was not aware of at the time of purchase then the purchaser may have rights under the Consumer Rights Act 2015, see **[1]**.

Externally this looks exactly like the battery charger that was featured in April 2021 EMC column but a significant difference is that it is being sold by a major international online retailer, who would appear to be responsible for the CE marking. If you Google BUDDYGO FBC12050 you should find the supplier. It claims to be the #1 best seller in car battery charging units and, at the time of writing, it has 3651 ratings. It is not known whether these units comply with the Essential Requirements of the EMC Regulations, ie whether the CE mark is valid.

Another Member, Chris, writes that the EMC column in *RadCom* is one of the first that he reads, with great interest, so he thought I would be interested in the following info. During the recent COVID-19 pandemic, Chris decided to lay up one of his vehicles but he needed to keep the battery well charged for when he needed the car again. He purchased via the web a KMW-1210D Smart Fast Charger that was manufactured in China (see **Photo 2** and **Photo 3**). Chris reports that it works fine charging the car battery but he was suffering from wide band nose spikes on all HF bands which trolled across his radio's display from LF to HF. He turned the charger off and suddenly the bands were relatively clear.

Chris sent screen shots of some of the affected bands, including **Photo 4**. He tried to open the unit but it was welded shut, so he couldn't see if it was missing any RF interference filter components. The label clearly shows a CE mark on the back of the unit. As far as Chris could tell the noise was radiated at RF, as he has mains filtering for his rigs.

He suggests a warning in an EMC column. Chris sent **Table 1**, a list of noise band by band from his rig's S-meter. All measurements were carried out with a narrow bandwidth suitable for RTTY, during daylight at around 1700BST. The antenna for 160m to 40m was a Butternut 3 band vertical mounted on a metal clad roof, some 3m above the charger. The antenna for 30m to 10m was a 4-ele SteppIR at 10m AGL, at 20m from the charger.

Chris comments that it is not clear why 15m was not showing noise as the spikes were definitely there. He states that these measurements are by no means definitive but they show what he was up against in a recent RTTY contest.

LTE/4G and Freeview interference

Although this item is not directly related to amateur radio, we have heard of cases where radio amateurs have been asked by neighbours for technical advice about why their Digital Terrestrial TV (DTTV) or 'Freeview' reception has stopped working. In some rare cases, it has been claimed that radio amateurs were causing interference to Freeview TV reception that was actually caused by a new LTE/4G mobile phone base station nearby. This item gives some background information that may be useful to radio amateurs when dealing with any such enquiries.

The UHF TV broadcast band was originally 470 – 860MHz, but the portion from 800 – 860MHz has been cleared of TV signals and it has been reallocated to LTE/4G mobile phone base stations. Existing TV aerials, amplifiers and receivers were designed to receive the whole 470 – 860MHz band so they also pick up the new LTE/4G signals. For TV viewers close to a new LTE/4G mobile phone base station, for example perhaps within 100 metres, the LTE/4G signals are likely to be much stronger than the TV signal – particularly if the TV aerial is pointing towards the LTE/4G base station.

Figure 1 shows the problem at a location 100m from a 4G base station. The peaks on the left hand side of the screen are DTTV signals from the London Crystal Palace transmitter. Those in the centre are from a local TV relay station, though

PHOTO 3: Smart Fast Charger label.

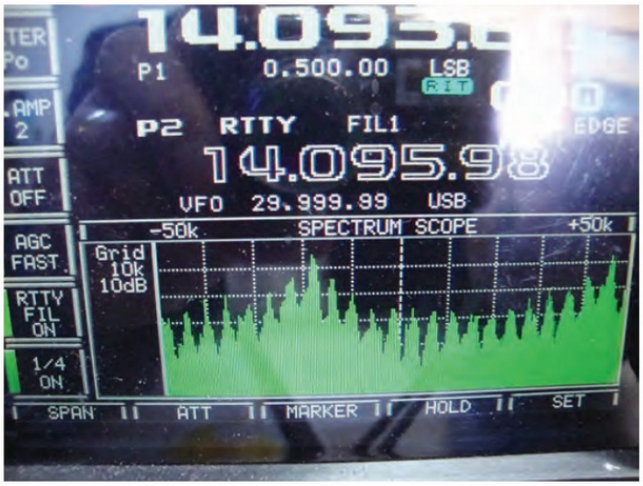

PHOTO 4: RFI radiated by battery charger in the 14MHz amateur band.

FIGURE 1: Spectrum plot of UHF TV band near a 4G base station.

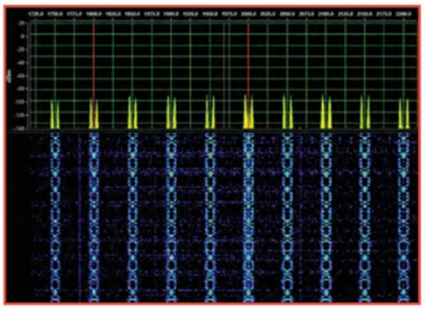

FIGURE 2: RFI radiated by a solar PV installation.

this does not carry all channels. The peaks on the right are not TV signals; they are from a LTE/4G base station. The amplitude units are dB relative to 1μV in 300kHz resolution bandwidth (RBW) and the vertical scale is 10dB per division. It can be seen that the power of the LTE/4G signals is about 30dB (or 1000 times) higher than the TV signals. This can cause overloading or blocking of TV receivers (and TV aerial amplifiers if fitted).

Many LTE/4G base station started operating around 2013 and at that time postcards were sent to householders who might be affected. Filters were issued free of charge where required but then, in 2021, the power of some 4G base stations was increased and we have heard of cases where installations that had been working with a filter since 2013 stopped working in 2021. **Photo 5** shows the type of consumer filter that is sent out **[2]**. This is a low pass filter that cuts off above Channel 59. This filter only works if it is connected between the TV aerial and the first amplifier. That means that it won't prevent overloading or blocking of an active TV aerial that has a built-in amplifier. If the amplifier is up a mast, that is difficult! The next stage is to clear the frequencies from 700MHz – 800MHz, so that filters will again be required.

TABLE 1: List of noise band by band (see text).

Band	Unit on	Unit off
10m	S1	S0
12m	S6	S1
15m	S1	S1
18m	S7	S2
20m	S9+20	S8
30m	S8	S2
40m	S9+20	S7
80m	S9+10	S8
160m	S9+20	S9

Solar PV

Various reports have been received of RF interference from solar PV systems that consists of harmonics at intervals of 200kHz across HF radio spectrum and beyond. According to a post by W6HDG on a forum on qrz.com **[3]**, this can be caused by optimisers made by SolarEdge. These optimisers are DC/DC converters that are connected by installers to each solar panel. The purpose is to minimise losses due to mismatch when there is partial shading of the panels. The optimisers are connected together via a large wire loop, which can radiate RFI.

W6HDG recommends tuning to 14.198MHz during daylight hours. He reports that if you tune from 14.198 to 14.199 and hear a whooshing noise, it may be coming from a SolarEdge installation up to a mile away! If you can rotate your antenna then you may find signals from various directions, as he did. He reports that in general, even distant solar PV installations can be heard every 200kHz from 10 – 30MHz. If this noise disappears at night, then the source may be a solar PV installation. We understand that ARRL is aware of this and have been working with the company concerned.

We also have a report from the Isle of Man about two systems fitted by Manx Energy. One has a SolarEdge SE8000H-RWR00BNN4 inverter with 28 x JA solar 320W PV panels and a neighbour has a SolarEdge SE3000H-RW000BNN4 inverter with 15 x JA 320W PV panels. The RF interference generated by these systems is shown in **Figure 2**. It can be seen that in this case there are harmonics at intervals of 50kHz. These appear to be modulated by data transmission and the resulting waterfall display looks like chains or twisted pair cables!

Websearch

[1] Citizens Advice, Consumer Rights Act 2015: https://tinyurl.com/yz9dfwbm

[2] 4G rollout and Freeview: https://at800.tv/

[3] QRZ forum, Solar Power and RFI: https://tinyurl.com/256w4ekz

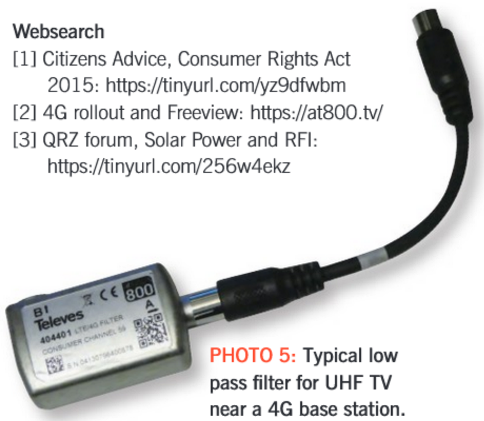

PHOTO 5: Typical low pass filter for UHF TV near a 4G base station.

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Design Notes

Transmitters, antennas and field strength

With all the recent discussion over the new licence requirement for us to analyse our local field strengths, it may be opportune to go back to the basic theory and see just how you go from a transmitted power, via an antenna, to a field strength at any specified distance. We start with the basic physics and a simple scenario. A transmitter radiates P watts uniformly in all directions – it has an isotropic antenna and behaves as a point source. For now, don't worry about the practicalities; it's floating in space and such an antenna is possible. At a distance R the radiated power has spread out uniformly in all three dimensions and forms a sphere with radius R. We know the surface area of any sphere is a function of its radius, equal to $4 \bullet \pi \bullet R^2$, so at a distance R metres from our transmitter the power flux density PFD (or just 'power density') = $P / (4 \bullet \pi \bullet R^2)$ watts per square metre, or W/m^2.

Now we replace our isotropic antenna with one that concentrates that RF power into a beam going off in one direction, typically a cone spreading out. The total RF power is now concentrated onto just a small portion of the surface of the sphere and here we need to introduce the concept of antenna gain, G. If the antenna is so designed such that it concentrates all the power onto a fraction of the sphere's surface that is one-hundredth of the total area, the power density in that small part of the total area is going to be 100 times larger than it would be in the uniform case. The gain, G, in this case is 100. (We're sticking with linear units for everything for now as using decibels at this stage will just confuse things. Purely for information only, that 100 times antenna has a gain of 20dBi).

So the PFD in the direction of the main beam at a distance R is now $P * G / (4 \bullet \pi \bullet R^2)$ watts per square metre. Everywhere else, since the power has been concentrated into the main beam, power density is lower than it was with an isotropic antenna so it can be said the antenna gain in other directions is less than one. In these directions. Any value used for antenna gain always needs to be in the direction of interest. Obviously, in normal circumstances, this is the main lobe but for calculations of levels off to the side of the antenna the pattern needs to be considered to get a value for the gain in that direction.

So now we know how to calculate power flux density, PFD, but the EMF requirements in the licence are specified as an electric field strength E in volts per metre, or a magnetic field strength H in amps per metre. Fortunately, in the far field radiation pattern (we'll come to near and far field definitions shortly) E and H are intimately connected via Ohm's law and the impedance of free space, which is $120 \bullet \pi$ or 377Ω. So E/H = 377Ω. Again, from Ohm's law we know Power $P = V^2 / R$ and $P = I^2 \bullet R$. Here,

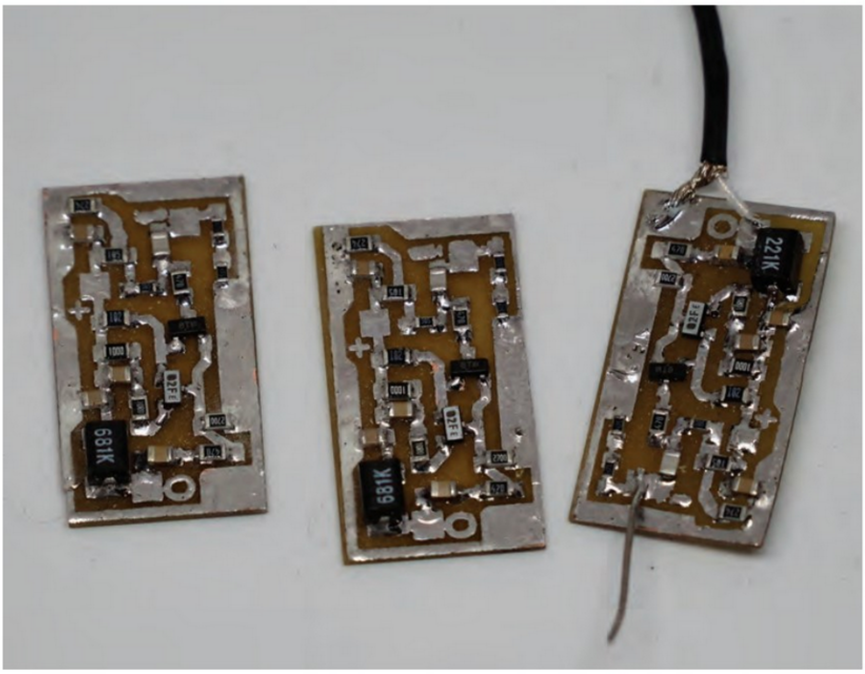

PHOTO 1: Feedback gain-stabilised high input impedance amplifier for E-probes.

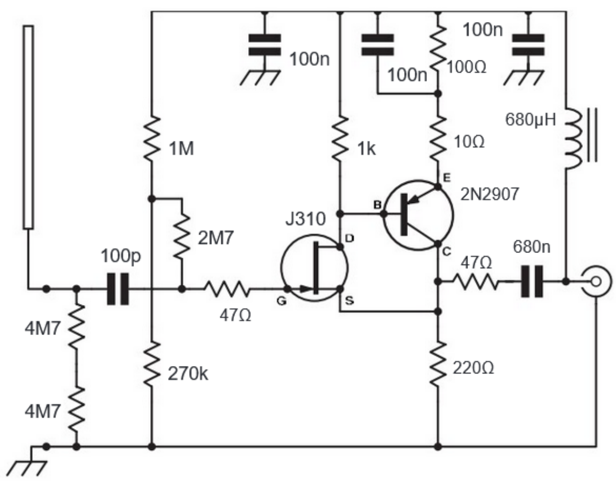

FIGURE 1: Unity gain high impedance input amplifier using a feedback arrangement to ensure gain flatness and precise gain control.

V and I can be directly replaced with E volts per metre and I amps per metre, and with a bit of rearrangement we get

$E = \sqrt{(PFD \bullet 377\Omega)}$ and

$H = \sqrt{(PFD / 377\Omega)}$.

EIRP and ERP – and confusion

That's all there is to it, but you will note that so far there has been no mention of ERP or EIRP which, unfortunately, is one parameter that is required to be input to the Ofcom and RSGB spreadsheets. Effective Isotropic Radiated Power, EIRP, is a convenient concept in many cases and is given by multiplying power into the antenna by its gain in the direction of interest. As such, EIRP just replaces the term 'P x G' in the equation for calculating power density at a distance R. But as we saw earlier, gain is different in any direction around the antenna away from the main beam, so EIRP is different. It is always EIRP in the direction of interest that has to be considered.

Now, what about that other oft-quoted value, ERP, and its equivalent in antenna gain terms, the gain expressed in dBd. (Yes, I know I wasn't going to bring decibels in, but there really is no equivalent official term for linear antenna gain equivalent to dBd). Back in days of yore, and at frequencies where dipoles in free space are practical for real measurements, mainly at VHF and UHF, the gain of an antenna was measured by swapping the antenna under test with a half-wave dipole and measuring the two relative received power levels. The resulting increase (or decrease when measuring off to the sides) of the antenna under test was taken to be the gain. As the comparison antenna was a dipole, the gain was oft-specified in relation to a dipole – so let's call it Gd (as I still refuse to talk in decibels here). But a dipole itself has gain – the radiation is forced into a doughnut pattern, omni around the elements, but zero off the ends. It can be shown mathematically that a half-wave dipole has a gain of 1.64 times over isotropic, so any antenna gain quoted or measured with respect to a

PHOTO 2: E-Probe testing underway at G0API.

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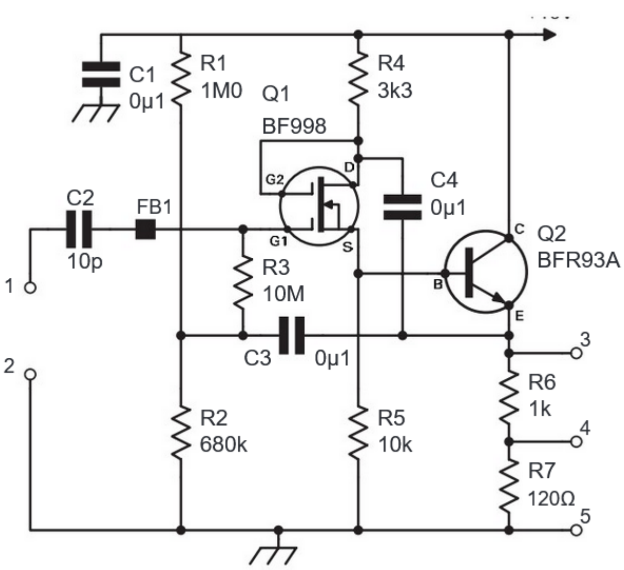

FIGURE 2: **Another design of high input impedance buffer amplifier using a bootstrapped MOSFET input stage.**

dipole needs to be multiplied by 1.64 to get the isotropic gain.

To really, really, really, really confuse matters, Effective Radiated Power, that product of Tx power and antenna gain, is given the abbreviation ERP when it is calculated using gain with respect to a dipole, Gd, and EIRP when isotropic gain is used. 1 watt into an isotropic antenna gives 1 watt EIRP. Into a dipole it gives 1 watt EDRP in the direction of the main lobe, and is higher than 1W EIRP because some of the RF power is concentrated away from the full surface of the sphere. 1 watt into a dipole generates 1.64 watts EIRP in the main lobe.

In normal usage I'm not prepared to use the generic term ERP and will always quote either EIRP (or EDRP if the latter really has to be stated). Needless to say, 'EDRP' appearing in texts usually causes questions to be asked and proof-readers and editors insisting it is changed to 'ERP' – but then it becomes their choice, not mine! IARU, ITU etc. all accept 'ERP' is radiated power referred to gain with respect to a dipole, and 'EIRP' is the term for the true, mathematically correct, meaningful value. Even the amateur licence terms and conditions gets this mixed up. Maximum power for 137kHz is specified in 1 watt EDRP, but that for 475kHz as 5 watts EIRP. Daft – but, whatever…

Near and Far Field of a big antenna

There are two subsets to the subject and meaning of near and far fields of an antenna, and they are very different. Near field of a large antenna, usually at high frequencies; and near field of a small antenna, usually at low frequencies. They come about due to very different reasons.

If we have a large antenna, several wavelengths in size, it is totally unrealistic to consider it as a point source with its gain concentrating the energy into a tight cone when we are only a few wavelengths away from the antenna, possibly closer even than the maximum dimension of said antenna. Now there are no rules, and every case needs to be considered on its merits. But we are talking about short distances here – a few wavelengths, except perhaps in the case of ultra-high gain antennas where this could be many wavelengths.

For antenna measurement purposes, where accuracy is needed, there is a boundary beyond which far field calculations are considered accurate. The distance of this boundary is $R = 2 \cdot D^2 / \lambda$. D is the maximum dimension of the antenna and λ the wavelength. For a 3 metre long Yagi operating at a wavelength of 2 metres, the far field boundary is taken as 9 metres. At distances less than this from the feed point, simple calculation of field strength is impossible. In practice, for rule of thumb estimation, probably half this distance could be used.

As another somewhat extreme example, take the 3.2 metre dish used at G4RFR for Moon bounce on 10GHz (λ = 0.03m). The theoretical far field boundary is $2 * 3.2^2 / 0.03 = 680$ metres, but this is only in the very narrow 0.6° beamwidth where, due to the way the dish is mounted, few people could ever be exposed to the main beam. A much easier calculation is possible for local exposure levels close to the antenna. The dish is fed from a small horn designed to properly illuminate the surface, with perhaps no more than 10% spill over at the edge. So for close-in EMF assessment, that feed antenna can be assumed to be what matters, and will therefore have a gain of 0.1 at the rim of the dish (and significantly less further away from the edge of the dish). It is by such applications of practicalities, common sense and stopping-to-think that a value delivered by a spreadsheet can be treated as if it means something or is meaningless in its own right.

Small antennas

If we have an electrically small antenna, one very much less than a wavelength in size, there are local E and H fields that are different from those forming the radiation and out of phase with each other, so don't contribute to the radiation of power. These fields fall off more rapidly with distance than the radiation field, but nonetheless are still there when you get close. For small mono/dipoles the E field dominates; for small loops the H field dominates. The guideline boundary for this zone is typically taken as $\lambda/(2 \cdot \pi)$, inside of which normal EIRP calculations cannot accurately give exposure levels. The only solution is modelling and common sense with regard to the (usually high) voltages present on small wire antennas.

We still haven't used dB, dBi or dBd, but if you insist:

gain in dBi is $10 \cdot \log(G)$;
gain in dBd is $10 \cdot \log(GD)$.

So the gain of a dipole is 0dBd and $10 \cdot \log(1.64) = 2.15$dBi.

EIRP = $10 \cdot \log(P)$ + antenna gain in dBi
EDRP = $10 \cdot \log(P)$ + antenna gain in dBd

E-Probe amplifier with feedback

Last month we saw the circuit of the PA0RDT Miniwhip amplifier, consisting of a high impedance FET source follower followed by an emitter follower (with or without its output resistor). This amplifier operates open loop, with no feedback and its gain is a bit uncertain, being simply two cascaded source and emitter followers. On the RSGB-Technical Forum group someone posted a link to an *Electronics* magazine design from 1975 that showed a high impedance input amplifier using an N-channel FET and PNP bipolar transistor with 100% negative feedback, giving exactly unity voltage gain from antenna probe to output. A series resistor of Zo is used to define the output impedance, so the overall voltage gain is now exactly 0.5. That design used now-obsolete devices but a version with more modern transistors is shown in **Figure 1**. The N-Channel / PNP pair operate with full feedback; the high gain inverting common emitter output amplifier feeds back via the source -drain of the FET, which for this part of the circuit, the feedback, acts a non-inverting common gate stage. The result is complete negative feedback giving unity voltage gain from the antenna probe on the FET's high impedance gate, via source-follower action and the unity gain of the feedback pair to the output terminal.

I constructed several of these on a small PCB (**Photo 1**) and sent one to John, G0API to test alongside his well-tested PA0RDT design. He writes: "I did a comparison with the permanently installed Miniwhip using a similar sized antenna plate. It [the new design] seems to have a slightly better performance at the HF end. LF signal to noise ratio seems to worsen at a higher [LF] frequency, but that may well be because the test antenna did not have the mass of ferrite coupling in use here on the PA0RDT normal one.

"The new one was mounted onto a 5m carbon fibre fishing pole supported by a heavy duty tripod base that added another 1m to the total height of the probe. Tests were conducted using the normal earthing at G0API, the new probe feeder being 7m of UR43, with the remaining 20m using UR67. The G0API E-probe (G4HUP kit) was in the top of a pine tree at 5m.

"The earthing consists of a 25mm galvanised steel pipe inserted 1m into the ground and a 1/2" copper earth rod driven down the inside the pipe. A circular 120ft diameter steel, 5" railway track is within 2m of the earth stake and the two are bonded via 25x3mm aluminium strip. The ground is underlaid with solid concrete and under that is sand and gravel shoals. Not perfect by any means…

"At 17.2kHz the noise floor of the new design was -96dBm in 6Hz resolution bandwidth. The G0API probe was 2dB higher at -94dBm. Note that for LF use, the G0API feeder is decoupled with a stack of toroids wrapped around the miniature coaxial feeder, which decouples external noise from the feeder up to at least 100kHz. At the bottom of HF the G0API probe had initially 2dB better S/N, with the difference diminishing as the frequency increased.

"At 21MHz the noise floor was identical for both designs, at -140dBm. A PY2 was audible and decoded in FT8 on the new design but was only just audible and failed to decode on the G0API. Probably at least 2dB better S/N for the new version.

"At 28MHz the new one was at least 2dB better S/N than the G0API one. All testing was done in daylight at around 1400UTC. The probes used were 0.5mm tin plate, approximately standard postcard size. 13.2V DC was supplied by the same PSU via the coaxial feeder. Measurements were made using a Toshiba Satellite Pro laptop and SDR-IQ SDR Rx with a visible span of 10kHz. Noise floor with 50Ω terminated input on the SDR-IQ was -140dBm at 137kHz and -142dBm at 28MHz. **Photo 2** shows the testing underway at G0API."

Ultra-high input impedance unity gain RF amplifier

Quite independently, and purely by coincidence at this time, Peter Swallow, G8EZE wrote in to describe his design for yet another high impedance buffer stage. "I needed to measure the performance of a number of small inductors of uncertain provenance. The shunt capacitance of a x10 oscilloscope probe is 14-15pF and offers less than ideal control of stray capacitance for repeatable measurements. I don't think the circuit (shown in **Figure 2**) is readily applicable to EMF measurements with a short dipole as aired in recent RSGB Technical Group discussions because of its input voltage limitations, but is applicable to measurement of lower levels.

"This bootstrapped non-inverting amplifier can handle at least 4Vpp input with near unity gain and better than 0.2dB amplitude flatness between 50kHz and 50MHz. On paper, the input impedance is more than 30kΩ at 50MHz and several MΩ at lower frequencies. The shunt capacitance of a few tenths of a pF has been verified, but measurement of the real part of the input impedance has not been possible.

"The external load at Q2 emitter should be at least 3kΩ and have low shunt capacitance, but is less critical if tapped down the emitter resistor. The prototype amplifier was built using 0805 surface mount devices on 1.6mm double sided copper clad FR4 board. Careful layout and additional decoupling may be necessary to ensure stability, and screening may be needed to avoid stray signal pickup dependent on application. The ferrite bead to suppress parasitic oscillation at UHF has negligible impact on the input impedance.

"R1 and R2 set Q1 DC bias through R3. The in-phase RF signal at Q2 emitter is fed back to gate1 of Q1 by C3 at a level that, if equal to the input signal, would result in infinite input impedance. In practice it is lower because the overall amplifier gain is slightly less than unity. The input shunt capacitance of Q1 due to the Miller effect is neutralised by feeding an anti-phase signal from Q2 emitter back to Q1 drain via C4."

Even more on voltage regulator protection

After reading recent comments Ulrich, HB9AIK / VK2ANI, wrote in to say: "Reading the text covering the voltage regulators and their reaction to overvoltage and spikes, I felt it could be useful to add a few notes from my professional experience. It might be worthwhile reminding our friends that what is called 'maximum ratings' or even 'absolute maximum ratings' in datasheets is meant to be just that. Beyond these values, unforeseeable events – such as high voltages on the output etc – might occur and the structure of the chip potentially be permanently damaged. The regulator has to be protected from any such condition existing, even when of a very short duration, no matter whether it's a 78xx or 117/317 type of chip.

"Spikes caused by switching or other sources are a very well known problem in DC applications eg. in vehicles and aircraft. One will therefore find a wide selection of items often called 'Transient Absorption Zener' which are Zener diodes specifically designed to be capable of absorbing a large amount of energy and react in a very short time. Such a device will protect any chips on a local power rail effectively. Microsemi, as one supplier, has many components such as the small P6KE series (600W) **[1]**, which would probably protect an antenna mast preamp from spikes on the supply line. Larger, more powerful devices also exist. Whether a current limiting device or a fuse needs to be included depends on the power source used. I have used such devices with good results, eg in Land Rover Defenders to protect radio and control electronics from spikes.

"Using such a protection device at an input to anything connected to 13.5VDC in the shack would, suitably protected by a fuse, also protect the device from reversed polarity, without a voltage drop as would be incurred with a series diode. Obviously, to protect a radio with a 25A fuse a more powerful element than that previously mentioned would need to be selected.

"Apart from protecting the input of the regulator another such element could be used to protect the regulator output voltage from ever being able to damage the GaAsFETs. In my case I have used many 1N5908 absorption Zeners to protect valuable microprocessor circuits from failing 7805 type on-board regulators. I hope that these tips perhaps help to save some valuable items from destruction."

Websearch

[1] Microsemi Voltage Transient Suppressors.
https://www.microsemi.com/product-directory/discretes/682-transient-voltage-suppressors

EMF –Your questions answered

Questions have been written to The Last Word as well as sent directly to the EMC Committee regarding the new EMF regulations for the amateur licence.

The RSGB has received many comments on the new Ofcom EMF licence condition, we are sorry that it is not possible to answer all of the points raised individually. We have therefore prepared responses to the frequently asked questions as well as taking many of the points raised in letters to The Last Word. The aim is to cover the main aspects of comments received and you can read these letters in the RadCom section of the RSGB website.

The RSGB and many UK amateurs have responded robustly in engagement with Ofcom. Over the consultation period, Ofcom has implemented some critical amendments that are helpful. This process continues and we hope that once a number of issues have been resolved we will be able to proceed more confidently in preparing additional support materials. The next 12 months will prove challenging but let's try and meet it positively. Follow developments at www.rsgb.org/emf.

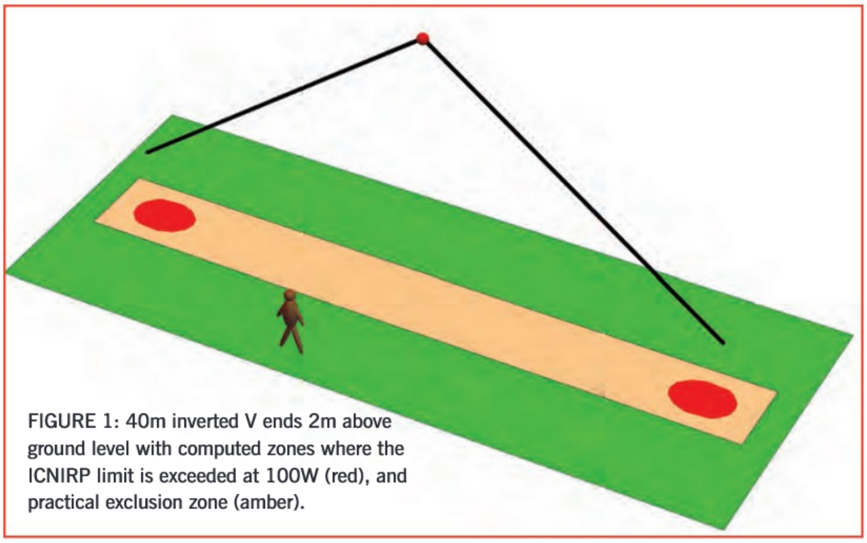

FIGURE 1: 40m inverted V ends 2m above ground level with computed zones where the ICNIRP limit is exceeded at 100W (red), and practical exclusion zone (amber).

"Why are these new conditions being imposed on our licences?"

Since Ofcom is the UK amateur licence regulator, we as spectrum users have to comply with whatever regulations and licence conditions are in force at any given time. Ofcom have responded to public worries about Health Effects from radio waves by applying EMF limits on all radio users who are permitted to transmit above 10W EIRP.

Why has the RSGB not stopped Ofcom doing this?

Ofcom is the regulator! We, the RSGB, and individual amateurs have raised many significant points during the consultations, in an attempt to reduce the impact of these new conditions, and to provide simple means for amateurs to demonstrate compliance.

Some of the important changes that were made as a result:

- Recognition that compliance limits only apply if there is someone actually present in the exclusion zone
- Recognition of RSGB as a competent organisation to give advice on pre-assessed configurations
- ICNIRP 2020 limits can be used as an alternative to ICNIRP 1998 limits
- Examples of types of records to be kept, to demonstrate compliance are given - including not using more than 10W EIRP
- Limits for exposure are relaxed for licensee and visiting amateur licence holders
- Only required to re-assess when changes are likely to increase EMF levels.

Why have amateurs been required to do assessments and yet CB operators who can use up to 12W PEP are not covered?

Ofcom says that it does intend to apply similar conditions for equipment that is currently licence-exempt. "We are proposing to include the new condition in new licences and vary existing licences to include the new condition. We propose to apply a similar approach for equipment that is currently licence-exempt (or may be exempt in the future)"

Is there a sound scientific basis behind the ICNIRP limits?

Yes. The interpretation of science by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) needs to be viewed in the wider context of the EMF safety management structure.

At the base is the extensive set of published scientific papers that report experimental and theoretical data for the range of disciplines such as physics, biology and medicine needed to understand the potential for EMF to impact human health. ICNIRP (and other health agencies) then assess this evidence considering its quality and consistency and, based on the "balance of evidence", make appropriate recommendations.

ICNIRP recommendations are adopted by 135 countries, including the whole of Western Europe, China and Japan, and most of Africa and South America. A similar review process by the Institute of Electrical and Electronics Engineers gives rise to the IEEE standards, which are similar in content and are adopted by 11 countries, notably the USA and Canada.

The present understanding of science, built up over many decades of research, shows that the body reacts differently to EMF at different frequencies and with different characteristics (eg, short pulse v sinewave). ICNIRP therefore have identified for each frequency the range of potential effects that demonstrably could occur, and the EMF exposure levels at which they may become harmful. From these data, reduction factors are applied to the lowest harmful exposure to define their exposure limits at that frequency.

These exposure limits (ICNIRP term 'basic restrictions', IEEE term 'dosimetric reference level') are usually expressed as values inside the human body – which makes them impractical or impossible to measure directly, and requires specialist techniques to compute. To get around this, a second set of exposure limits is defined in terms of EMF levels outside of the human body, in the environment. (ICNIRP calls these 'reference levels', IEEE C95.1 calls them 'exposure reference levels'.) By measuring or computing these external EMF parameters (typically measured in units of V/m, A/m, W/m^2) at a location *without* the human present, dosimetry studies show that the basic restrictions would not be exceeded if a person were actually present.

Taking the process further, standards bodies such as the International Electrotechnical Commission (IEC) and the IEEE establish standards to interpret the exposure guidelines for specific situations or products and to define methods of assessment.

Based on all of that international work, national agencies such as Public Health England (PHE, which advises Ofcom on these matters) and Ofcom then establish policies for the actual regulations.

From this complicated background it can be seen that the exposure limits reflect a complex interaction between how the body reacts biologically to EMF, how EMF propagates into the body, how the body absorbs energy, how the body conducts induced currents, how the body reacts to internal potential differences, and how all of these are affected by the frequency and other detailed characteristics of the EM field itself. This results a whole lot of unavoidable complexity!

Are there significant differences between ICNIRP 1998 and ICNIRP 2020 guidelines?

There are a number of differences, but so far the RSGB has identified two major differences that can have a significant effect on EMF compliance assessments in the amateur bands below 10MHz.

Above 10MHz, ICNIRP 1998 and 2020 guidelines have similar Reference Levels based on "thermal" effects or body heating. However, for frequencies below 10MHz ICNIRP now considers the dominant health effect to be 'electrostimulation', the direct effect of the EM field on electrical nerve activity. This was introduced in an interim release, ICNIRP 2010, that looked at shock effects mainly below 100kHz but extending to 10MHz and the limiting Reference Levels in ICNIRP 2020 now reflect this change. Reference levels for thermal effects are based on field values averaged over several minutes, which can be very useful in achieving compliance; but those for electrostimulation are based on peak values (a similar concept to Peak Envelope Power) with no further time averaging allowed.

There are significant differences between ICNIRP and the IEEE in the exposure limits in this frequency range and the RSGB/ARRL team has identified significant debate amongst experts on what limits are justified. These differences have been communicated to PHE and Ofcom for urgent consideration since the peak limits seriously impact the maximum power that may be radiated at frequencies below 10MHz while remaining in compliance with ICNIRP 2020. This affects not only radio amateurs but also broadcast and industrial users of this spectrum, so we hope for an early resolution. In the meantime, Ofcom has allowed a six-month extension for demonstration of compliance at frequencies below 10MHz until May 2022 to give some time to resolve these differences.

The second major issue is that ICNIRP2020 also include a 'limb current' limit that is intended to protect against localised thermal effects in the ankles of people in contact with ground. This issue is likely to be the most significant in the assessment of ground-mounted vertically-polarised antennas in the frequency range 7MHz to 30MHz (and in principle up to 70MHz). Clarification on this reference level has been sought from Ofcom. In the meantime, work continues in the ARRL/RSGB EMF team to better understand limb currents and how to determine compliance with the Reference Levels.

This current uncertainty is also the answer to another FAQ: "Why hasn't RSGB published information on HF vertical antennas?"

"Why are the ICNIRP 1998 and 2020 Guidelines different?"

Over the last 20 years, the global increase in use of radio communications has stimulated further scientific and engineering studies relating to exposure assessment and potential health effects. Naturally, such recent studies were not considered by ICNIRP in their 1998 guidelines. In order to provide the best advice, these data have now been considered and the ICNIRP guidelines updated accordingly.

Incorporation of new guidelines into national regulations follows much more slowly, on its own timetable. (See also the question at the top right of this page.)

If ICNIRP 2020 is more onerous than ICNIRP 1998, why is RSGB recommending compliance with ICNIRP 2020?

The main reason is to be future proof. Ofcom have indicated that they intend to move to ICNIRP 2020 as a basis when professional assessment standards have caught up. However, for the amateur service, no such standards have ever existed. Standards bodies often take several years to prepare a new standard because the process requires significant resources from industry, regulators, and research communities.

In the absence of standardised assessment methods specific to amateur radio, a small team of UK and US EMF experts has been assembled to establish protocols for radio amateurs. This is a considerable effort and so we don't want to have to repeat it when Ofcom finally decides to change its regulatory basis from ICNIRP 1998 to ICNIRP 2020.

Will RSGB publish guidelines for the types of antennas used by people with small gardens?

Yes – but antennas for small gardens are often more difficult to assess. The RSGB/ARRL team is first establishing robust assessment methods that can be applied to a very wide range of antennas. Inevitably the first data to emerge will address situations that are simpler to assess. Over time the content will be extended to cover a wider range of typical amateur configurations including those installed in a small plot such as verticals, inverted L's, longwires, bent dipoles, G5RV types etc.

Will we need EMF detectors calibrated to measure the E and H fields near our antennas?

No. Direct EMF measurements are not as easy as they look, and RSGB is not recommending them for the first rollout of compliance assessments. EMF measurements are subject to compliance standards of their own, to ensure

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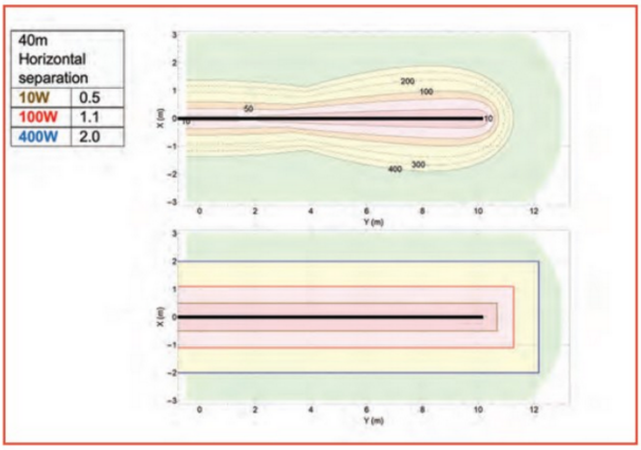

FIGURE 2: Compliance boundary at ground level for 40m dipole from PAC-1.

that the test equipment and methods used will give a reliable result. Professional EMF test equipment costs £000's. EMF detectors aimed at the amateur market are most unlikely to give results that would stand up to critical review. However, this is an area for investigation and perhaps innovation will lead to suitable methods being defined in the future.

Will guidance be published for people in the near field of large antennas for the LF bands?

Yes. Pre-Assessed Configuration report PAC-1 is already published for half-wave dipoles for the 160, 80, 60 and 40m bands (www.rsgb.org/emf and look for PAC-1). This report covers exposure within distances as short as 2 metres.

What about roof mounted antennas, chimney mounted collinears and/or folded antennas in the loft which may be close to occupied bedrooms?

The latest version of the RSGB Calculator can be found at www.rsgb.org/emf and may already enable you to demonstrate compliance in many of these cases. Other cases can go "on the list" for more detailed assessment by the RSGB/ARRL team in due course.

> "Do Maxwell's equations apply for fields in the human body?"
>
> Maxwell's equations do apply everywhere – no doubt about that. However, when the electric field is rapidly absorbed on entering the body, that does not require the magnetic field component to immediately follow suit. Instead, what does change immediately is the ratio of E/H at any given location. As the modified EM wave progresses, Maxwell's equations predict that the ratio of E/H would gradually change towards a new value that is applicable to that medium; but in practice the human body is not large enough for that change to be complete before the modified EM wave emerges from the body and is re-radiated. That re-radiation would then constitute a new 'near field' with a modified E/H ratio... which then will tend towards far-field conditions at greater distances in the usual way.

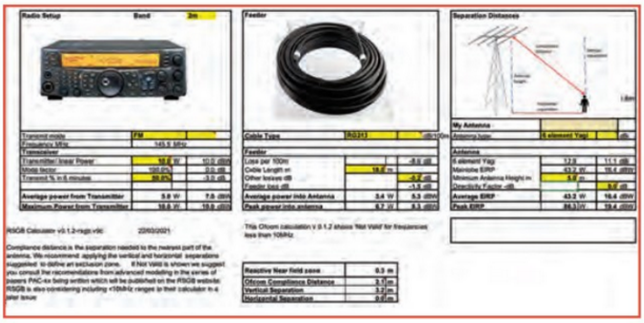

FIGURE 3: RSGB calculator showing compliance distance (2.1m) for a 2m 6 element Yagi.

Can I check that exclusion zones are not occupied by using PIR detectors or CCTV?

Ofcom does not attempt to regulate the practical means by which you avoid transmitting when people are present within an exclusion zone. If you can demonstrate that your chosen method is effective in establishing that no-one is present in a potential high exposure area when you transmit, and you also make sure that the detector is routinely used, it seems unlikely that Ofcom would object. (But note that CCTV may raise other issues that a simple PIR movement detector would not.)

How have the FCC recently changed the requirements for US amateurs?

On 3 May 2021 the FCC announced a number of changes for US amateurs. They abolished "Categorical Exclusions to Evaluation" which had previously applied to stations with power below band dependent limits and all mobile / portable transmitters. Instead, an exposure analysis is now required. For stations that fall within new exemptions (which are dependent on frequency, maximum ERP, separation distance and staying out of reactive near fields), a reduced analysis requiring fewer calculations is permitted. This reduced analysis is equivalent to using a simple calculator (like the RSGB one) but FCC Maximum Permitted Exposures are based on Occupational levels so cannot be read across to Ofcom general public requirements. FCC now also require radios used closer than 20cm to a person to be measured or modelled for SAR, a complicated process to undertake. US stations have until 3 May 2023 to comply.

The RSGB calculator includes a Directivity Factor. What is this?

The antenna gain used to calculate compliance distance in the RSGB calculator is in the direction of maximum signal. The gain in the direction of people standing below an elevated antenna will often be significantly lower, so the field strength at ground level will be less than the value calculated. The RSGB calculator therefore allows input of a "gain reduction factor", although an appropriate value may be difficult to estimate. Do not assume that deep nulls in the far field radiation pattern will still be present at close distances.

We would like to thank all those who have asked questions, in particular those who have written to The Last Word. Please continue to ask questions. You may also find the lecture given by John Rogers, M0JAV after the 2021 RSGB AGM useful. This can be viewed on the RSGB YouTube channel at www.youtube.com/theRSGB.

Secrets of the ubiquitous PL-259/SO-239

Sooner rather than later most amateur radio operators will come across the ubiquitous PL-259 male coaxial plug for coaxial cable and/or its equally ubiquitous female version, dubbed the SO-239 socket (or jack). There is also the female-to-female 'barrel' joiner, technically dubbed the SO-238, but that designation is never used. They are collectively referred to as 'UHF' connectors, named at a time when 'UHF' was synonymous with 'everything above 30MHz'.

Photo 1 shows some typical 'UHF' connectors. I have shown the common name for the various pieces that I will use in the text.

If you have an HF transceiver, or a 2m/70cm transceiver, the antenna jacks on the back are likely to be SO-239. Unlike antenna connectors on small handhelds, these rugged RF connectors can be required to handle serious power. You will even find them used on linear HF amplifiers where they will sometimes be used for 1000 watts or more.

My purpose in this article is not to cover old ground about origins of the connector, as you can do that yourself, by searching online (start at **[1]**) or picking up almost any edition of the RSGB *Radio Communication Handbook*. Rather, I hope to pass on to you some lesser known characteristics learned by personal experiences over the years. Hopefully you may find some to be of use or at least find they help explain to you why something is not working.

The bottom line is that this remains a very popular connector, used in many pieces of amateur radio equipment. This is surprising, because it can have serious limitations – most of which are due to its relatively uncontrolled manufacturing history. You need to understand that, unlike what you might reasonably expect, *none of the male & female connectors of this type offered for sale these days are made to a common global or even national standard*.

Various names

'UHF connector' is a popular name, in spite of the fact that it performs poorly at what we now call UHF frequencies today. The original name, from the US Army Signal Corps, is PL-259/SO-239 and this remains probably the most-used designation. They're also (uncommonly, now) known as Navy #49190/49194, but I include this only for the record.

PHOTO 1: Some typical 'UHF' connectors.

Manufacturers

There are many fabrication sources for these connectors, particularly in the Far East. It sometimes seems to me that everybody is out there trying to make their own version of these connectors, which results in some really poorly-made clones. Inconsistencies and variations may be present in the dimensions and/or the materials used. You'll even find different threads on the shell, which can lead to connections that *appear* to do up 'tight' but that are in fact loose or intermittent. The only thing that seem to be consistently right is the centre pin size – and that's because it's based on a 4mm 'banana' plug. It is definitely a buyer beware scenario and a good example of where getting what you pay for applies.

Standard or base specification

Amphenol **[2]** publishes a few outline drawings of their own versions of these connectors and I think these are likely the most consistent relative to the original. However, world-wide, there is no single accepted standard that governs the mechanical (let alone electrical) performance of these connectors. There are a whole host of problems and potential issues to be aware of; I can only highlight the most common ones here.

Common problems

The centre contact of the SO-239 socket is supposed to stay fixed in place but may, sometimes, rotate when you insert the PL-259 plug and twist it. This can be caused by lack of effective 'staking' of the centre contact in the insulator when it is made, or overheating during soldering, or simply because of a very tight fitting plug. When the male plug is inserted, it is you will almost always have to rotate the plug body a few degrees, to get the anti-rotation pips to line up with corresponding serrated detents on the female connector edge. Some of the poorly made female connectors may only have two or four

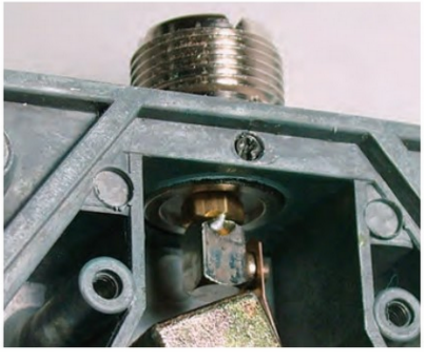
PHOTO 2: Coax switch with rotated contact.

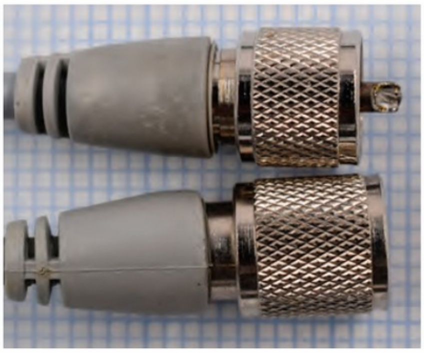
PHOTO 3: PL-259 shells different lengths.

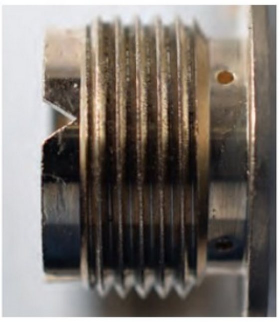
PHOTO 4: 'Short' SO-239.


PHOTO 5: 'Honeycomb' type SO-239.


PHOTO 6: SO-239 female with 'cored-out' dielectric.

serrated detents, guaranteeing you will have to twist the plug – and thereby increase the risk of rotating the SO-239 centre connector. Why is this a problem? Simple: if the solder connection on the other side of the SO-239 is connected to something flimsy, like a component or wire lead, then you may actually break it off, or cause other problems due to the rotation of the centre connector. This happened on one of my antenna analysers and even on a coaxial switch (**Photo 2**) that had gone intermittent. In the coaxial switch, the SO-239 has a silver contact that has rotated, causing it to make intermittent contact. (The set screw on top only assures that the main body of the SO-239 cannot move.)

PL-259/SO-239 connectors have no resistance to weather or moisture. If used outside, they will readily admit the damp and must be weatherproofed in some way, such as by wrapping with self-amalgamating tape etc. Otherwise they will quickly fail. And, perhaps worse, they will allow moisture into the coaxial cable, likely ruining that too.

The insulation of older, early 'UHF' connectors, both male and female, used a version of Bakelite, a thermosetting phenol formaldehyde resin, sometimes called phenolic. Usually brown or dark yellow, these insulators seem quite resistant to melting from soldering heat and the centre contact seems to be tightly held in place. Newer, better quality connectors use PTFE (Teflon) for the insulators. However, there is no telling what other plastic materials may be used by low-cost manufacturers, such as acetal or nylon.

Depending on who made the connector, the overall length of the threaded shell can vary, as seen in **Photo 3**. In my experience crimp versions tend to have shorter barrels and threads. Problems can occur if you try to use a PL-259 with a long shell and mate it with a very short SO-239. **Photo 4** shows an SO-239 jack on the rear of a popular SWR/wattmeter. It is rather short, having only about 6 threads. I know someone who had this style of socket and had an issue with low power out and high SWR – it was down to poor contact on this socket.

The function of the shell of a PL-259 is to pull the two main connector parts together (the plug and the jack) and thus establish a low resistance butt contact between the body of the plug and the body of the socket. In this case that won't happen, because the leading edge of the shell 'bottoms out' on the jack before the trailing edge can pull the plug into close contact. In fact the plug may actually remain physically loose, resulting in an intermittent or no connection.

Better quality connectors are machined from solid brass and use silver plating for the shell, plug body and centre pin. Don't be fooled by fake gold centre pins or bodies. You may also encounter some shiny nickel plated versions that are made from die cast zinc. I have heard it said that the nickel plated types are not suitable for high power use at VHF or higher, due to high skin effect increasing losses. If you *must* use 'UHF' connectors for more than a few watts, and/or at VHF and above, it is well worth spending the small extra amount for decent quality connectors. Or maybe just upgrade, eg to 'N' connectors, but that's outside the scope of this article.

Though nominally 50Ω, the impedance of the PL-259/SO-239 connectors is non-constant with frequency. The main issue is with the SO-239 female, which presents an impedance of only 35Ω over a length of about 12mm, depending on type. This isn't so much of a problem at lower frequencies, but as you get to VHF and above the effect of the discontinuity is to cause mismatches and signal reflections.

In some areas, crimp-on versions seem to have taken over the market. They are reckoned to be much easier to install as the only thing needing soldering is the centre connector pin. But all the issues already mentioned can affect crimp versions just as much as other types.

I have seen several SO239s that try to mitigate the impedance bump. One was on a Daiwa wattmeter, seen in **Photo 5**. Notice how the previously solid plastic dielectric has been 'honeycombed' in the area of the centre conductor. **Photo 6** shows a similar approach on a short female to female SO-239 I recently purchased. Here the dielectric is 'cored-out' away from the centre pin. The object is to trade plastic dielectric for air.

The last 'issue' on my list occurs due to a loose fit between the male PL-259 plug and the quadfurcated female centre connector SO-239 socket. Some amateurs have reported intermittent or even completely open connections, usually due to worn or damaged female contacts. The often-used female to female 'barrel' joiner (SO-238) seems particularly prone to this. I have found that a simple test is to fit a 5/32" (0.156") diameter drill bit into the female contact. If it's loose, then you may have found your problem.

Conclusion

The 'UHF' series connector is basically fine for HF and low VHF but becomes less appropriate the higher up you go. Many engineers would say that the connector is well past its best by 430MHz. I have never seen it used at 23cm or above – it's just too lossy and the impedance mismatch problems are too significant. But for most amateur purposes – certainly on HF up to the UK legal limit – a good quality PL-259 connector, paired with good coax, will do everything you need, and do it reliably.

Websearch

[1] https://en.wikipedia.org/wiki/UHF_connector
[2] www.amphenolrf.com/connectors/uhf.html

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