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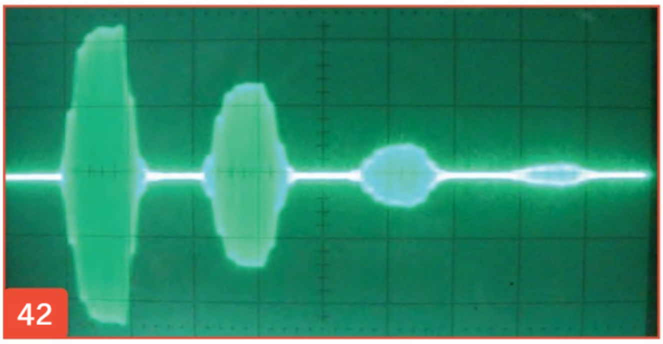

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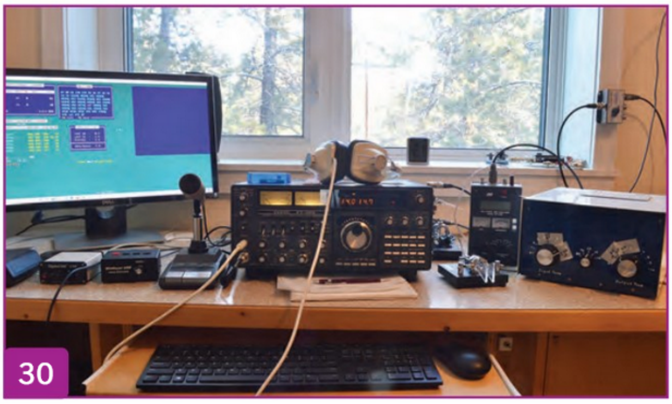

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Reviews

Technical Features

Cover image: Four shack essentials reviewed this month.
Design by Kevin Williams, M6CYB

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

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New Products

Z-mount for the IC-705

The MyDEL Z-Mount is suitable for mounting the IC-705 to create a more comfortable operation position. It folds away when not required and can be tilted to almost any possible angle. Retailing for £17.95 it is available from Martin Lynch and Sons. Go to www.hamradio.co.uk for more information.

New scheduler function

UK-based SDR receiver manufacturer, SDRplay, is close to releasing a new scheduler function. Available with upcoming release version 1.41 of SDRuno for Windows, the new scheduler software allows you to set up numerous recording events for your radio. As well as providing all the expected calendar options (time of day, date, start and stop times, repeating options and so on), you can also set the 'profile' for each recording – this allows you to pre-set frequencies, bandwidths, demodulator options (AM/FM/USB/LSB etc), choice of filters and antenna port selection. Additionally, you can choose the settings for connectivity to other third-party software or the running of a specific plugin. The graphic shows the scheduler in action.

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

Watch out for new demonstration videos on the SDRplay YouTube channel, which you can find at www.youtube.com/c/sdrplayrsp.

Watson tripod

A new WATSON tripod that can be used to support the Buddistick or the Alex Magnetic Loop is now available from Waters and Stanton. It has a standard camera male thread at the top, so anything else with a camera threaded socket can be attached to the top. It extends up to 1.5m with a collapsed height of 55cm. Once you have constructed the Alexloop Hampack, the vertical tube is dropped over the top of the tripod and the height can be adjusted as required. For Buddistick users, simply screw the Buddistick camera tripod adaptor (included with Buddistick kit) onto the tripod. It retails at £24.95 and is available from Waters and Stanton. Find out more at www.hamradiostore.co.uk.

New Sirio CX-4-68 antenna for 4m

With the explosion of 4m use now that several modern transceivers include 70MHz coverage, Nevada have in stock a new updated vertical from Sirio Italy, the CX4-68. The timing is perfect as we enter this summer's Sporadic-E season – amateurs will have already noticed that the 4m band has been open to the Mediterranean area.

The CX4-68 is a ¾ wave J pole type vertical that can cover from 63 to 73MHz, this giving full coverage of the 4m amateur band. The antenna is around 3 metres long, has 4.15dBi gain and 500 watt power handling. It is suitable for both local vertically polarised FM contacts and for use in Sporadic-E openings where it is omni-directional.

All parts are DC grounded to protect from static and constructed from high quality aluminium alloy 6063 T-832. This latest version has improved wet weather protection and performance.

The antenna sells for £69.95 and is available from the UK importers Nevada Radio. Go to www.nevadaradio.co.uk to find out more.

Fake RSP Alert

SDRplay Ltd has asked us to warn readers that there's an increase in the number of rogue traders and fake 'SDRplay' products out there on the internet. They urge everyone to double check they are only buying from SDRplay or their approved resellers. In the UK, genuine resellers include Martin Lynch & Sons, Moonraker, Nevada, Radioworld, SDR-Kits and Waters & Stanton. Some of the counterfeit devices appear cosmetically the same as the genuine SDRplay® devices. There is a high likelihood that these devices will not work as well as the proper receivers since the counterfeiters have no access to the rigorous production test solutions used by SDRplay. For more information, click on the "Fake Alert" button on the SDRplay home page: www.sdrplay.com.

Antennas

The end-fed wire antenna, part 2

Last month, the HF end-fed wire antenna was described that comprises a length of wire suspended as high as possible above the ground. This may seem a rather straightforward antenna, however an end-fed wire can achieve surprisingly good results. When the wire span is longer than a wavelength (λ), this antenna is often referred to as a long wire. The theme continues this month with an overview of other feeder arrangements and their effect on the antenna's performance.

The efficiency of this type of antenna relies on the conductive properties of the ground below it. If this is poor, then arrangements may be needed to improve the performance of the antenna **[1]**. Therefore, in the summaries to follow the ground has been considered as being reasonably conductive.

Modelling an inverted-L antenna

Last month's column described the concept of an end-fed wire configured as an inverted-L antenna (or Marconi antenna) and was shown there as Figure 5.

A MMANA-GAL **[2]** model was used to predict how an inverted-L antenna's feed point impedance changed as its height above the ground and frequency of operation were varied from 1.85 to 28.4MHz, with the application's default ground selected. The inverted-L model consisted of a length of 1.6mm diameter wire arranged to give a horizontal span of 20.12m (66ft), with one end was run vertically downwards with the feed point at its end. The antenna was modelled with its horizontal span at 7m, 10m and 13m above ground level (AGL), with the vertical wire's length altered to keep the feed point at 1m above the ground. The antenna modelled was based on an inverted-L antenna that could be found at a domestic location.

The model predicted the antenna as having a reactance (X) that swung between being inductive or capacitive depending on the frequency applied. **Figure 1** indicates how X changed from 1.85MHz to 28.4MHz, with the wire span's height modelled at AGLs of 7m (shown as the blue line), 10m (red line) and 13m (green line). To give an indication of the reactance at the feed point, the values when the antenna was at 7m AGL are shown. To match the antenna to the transceiver, the ATU needs to introduce sufficient inductance or capacitance as appropriate to counteract the inverted-L antenna's reactance. This leaves the antenna's radiation resistance (R_{rad}) for the ATU to match to the transceiver.

The inverted-L antenna's predicted R_{rad} varied significantly with frequency as indicated in **Figure 2** where a logarithmic axis has been used. Again the antenna was modelled at AGLs of 7m (blue line), 10m (red line) and 13m (green line). The difference in R_{rad} with frequency is evident as the wire span's height is increased. To give an indication of R_{rad} at the feed point, the values when the antenna was at 7m AGL are shown.

When R_{rad} is compared between the inverted-L antenna and the sloping end-fed wire (shown as Figure 2 last month), the influence of increasing the inverted-L antenna's overall length can be seen as a result the of adding the vertical wire, whose length also changes with increasing AGL. The range of the inverted-L antenna's R_{rad}, with frequency, now potentially extends the antenna's use from the 160m to 10m band, although matching the antenna on the 60m band may be a problem.

Comparison of radiation patterns

Using 10m AGL as a representative height for each antenna for comparison, **Figure 3** and **Figure 4** show the horizontal and vertical radiation patterns predicted by MMANA-GAL for the sloping end-fed wire and the inverted-L antenna respectfully. The antennas were modelled on the 80m (black curves), 40m (blue curves) and 15m (red curves) bands, with these bands chosen because they provided a reasonable indication of the radiation pattern as the band of operation was changed. Both of the antennas modelled had a horizontal wire span of 20.12m.

End-fed wire: Referring to Figure 3, the sloping end-fed wire's predicted horizontal radiation patterns on the 80m and 40m bands are similar, with the 40m pattern being the larger. Both these radiation patterns are slightly offset in the direction towards the feed point (ie along the Y axis). On the 15m band the antenna's horizontal radiation pattern has developed a lobe structure and indicates the antenna has some directivity in the direction towards the feed point.

The vertical radiation patterns for the 80m and 40m bands are similar, however the radiation pattern on 40m is larger compared to the pattern on 80m. A distinct change in the vertical pattern is evident on the 15m

PHOTO 1: Example of a 1:9 ratio unun auto-transformer using a T130-2 toroidal core used to match to an end-fed wire.

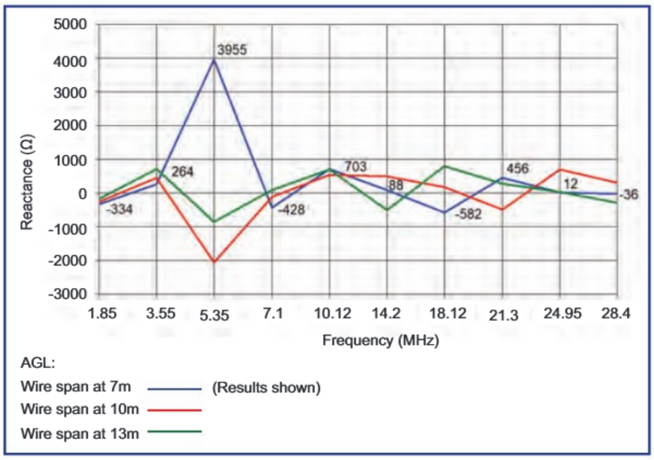

FIGURE 1: The predicted reactance (X) at the Inverted-L antenna's feed point with a horizontal wire span of 20.12m at 7m, 10m and 13m AGL.

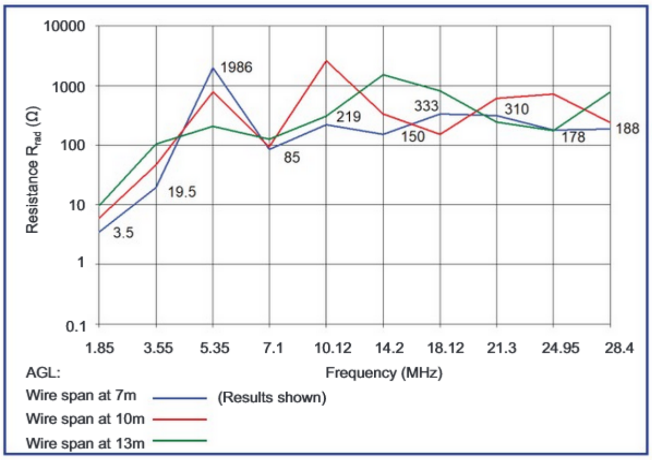

FIGURE 2: The predicted radiation resistance (R_{rad}) at the inverted-L antenna's feed point for a horizontal wire span of 20.12m at 7m, 10m and 13m AGL.

band, where a more lobed radiation pattern is predicted.

Inverted-L antenna: Figure 4 shows the inverted-L antenna's horizontal radiation patterns are similar when the antenna was modelled on the 80m and 40m bands, although the radiation pattern for 40m is larger, oval shaped and slightly offset away from the vertical wire compared to 80m. Again, on the 15m band the antenna has developed a lobe structure, which is more defined compared to the end-fed wire in Figure 3. However, the effect of the vertical wire can be seen where the antenna has developed directivity away from the vertical wire towards the other end of the antenna (ie along the Y axis). Comparing Figure 4 with Figure 3: on 15m the inverted-L antenna's directivity is now in the opposite direction to the sloping end-fed wire.

The vertical radiation patterns for the 80m and 40m bands are similar with, again, a distinct change on the 15m band.

For both antennas, their radiation patterns on the 15m band are representative of when either antenna is used on the bands between 20m and 10m, where a more lobed type radiation pattern can be expected.

Using an unun transformer with an end-fed wire antenna

A technique that can be used to handle the range of impedances that may be encountered with an end-fed wire is to use an unbalanced-to-unbalanced transformer (unun). The unun is connected to the nearer end of the wire span and a coaxial cable is run to the radio equipment as shown in **Figure 5**. The unun transforms the impedance seen at the wire span's end to an impedance range that can be accommodated by the ATU to match the antenna to the transceiver.

The unun transformer

An unun is an auto-transformer that can be constructed to cover frequencies from 2 to 40MHz using a powdered iron toroid core. To enable the transformer to work efficiently, the wires forming the windings are laid side-by-side to maximise the magnetic field coupling between them. There will always be some leakage inductance associated with a transformer and this increases in proportion to the transformer's self-inductance. Therefore, a transformer that works well at 3.5MHz may not work as well at 28.5MHz and this often manifests itself as a worsening of the SWR.

Figure 6 shows the concept of a 1:9 impedance ratio unun auto-transformer using a T130-2 core. If the end-fed wire is thought of as being connected to the transformer's secondary winding, then the ATU's unbalanced antenna socket is connected to the transformer's primary winding. The antenna's impedance presented at the transformer's secondary winding is transformed down to present a lower impedance at the primary winding, enabling it to be brought within the capabilities of most ATUs. If the third winding is omitted (ie C1c2) and the antenna is connected to point b2, the unun then has a 1:4 impedance ratio.

Peter Miles, VK6YSF and John Parfrey, M0UKD have published online several toroid core unun 1:9 impedance ratio designs for use with end-fed wires **[3] [4]**. These designs

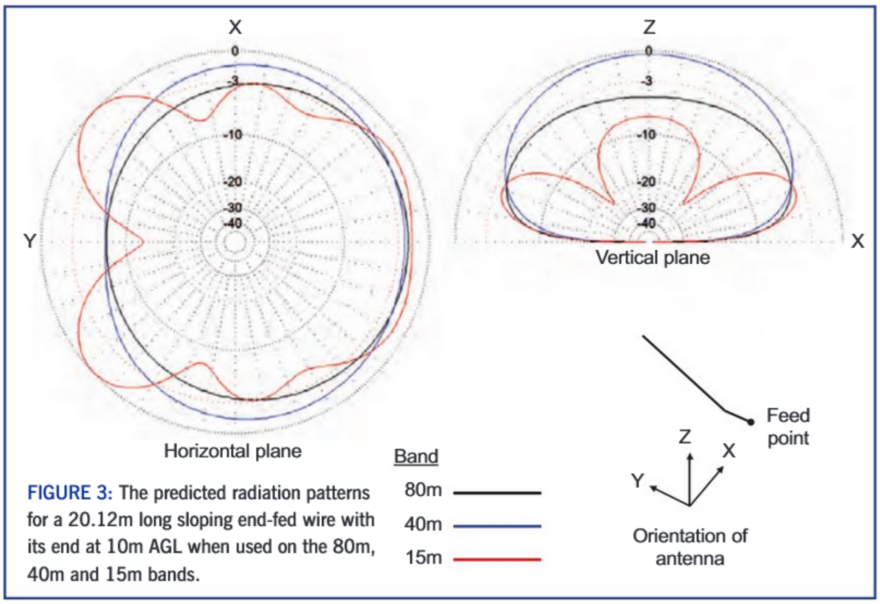

FIGURE 3: The predicted radiation patterns for a 20.12m long sloping end-fed wire with its end at 10m AGL when used on the 80m, 40m and 15m bands.

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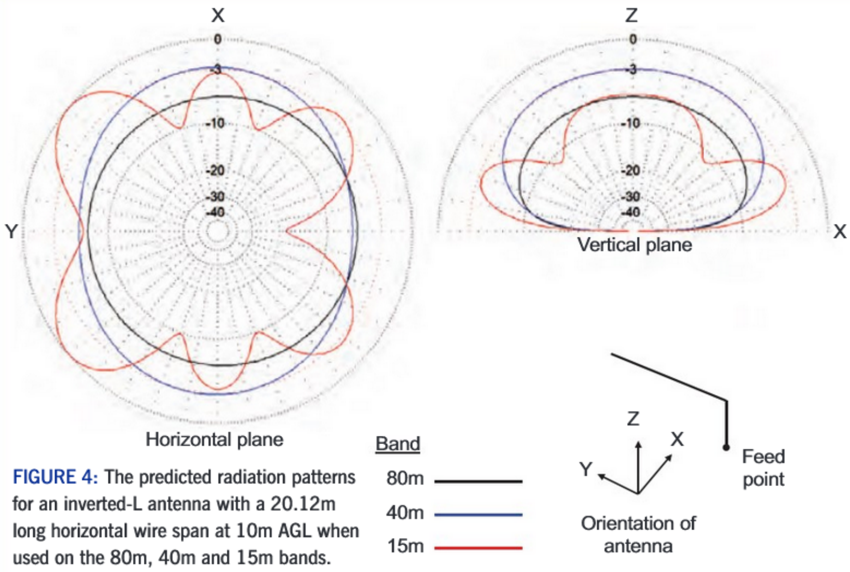

FIGURE 4: The predicted radiation patterns for an inverted-L antenna with a 20.12m long horizontal wire span at 10m AGL when used on the 80m, 40m and 15m bands.

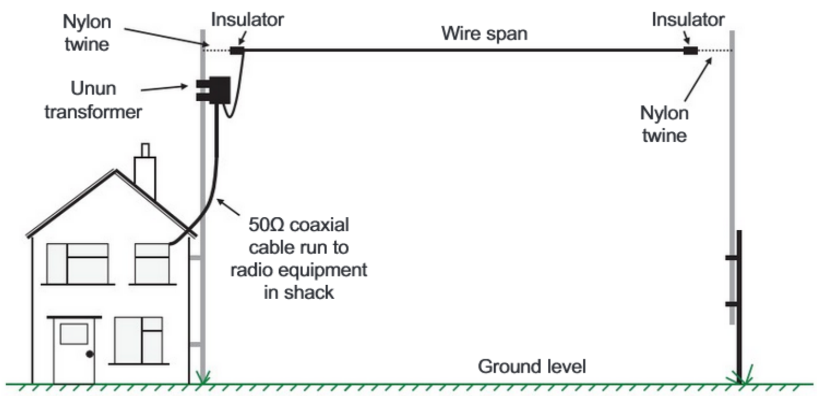

FIGURE 5: Concept of an end-fed antenna arrangement using an unun to interface the feeder cable to the antenna

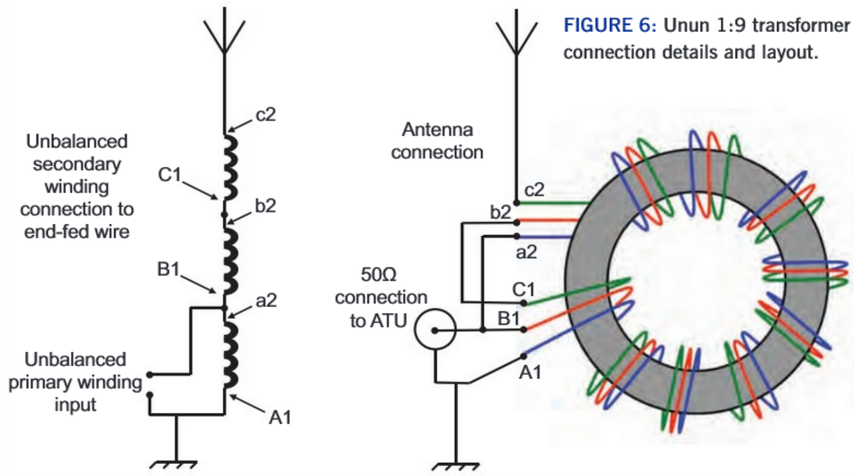

FIGURE 6: Unun 1:9 transformer connection details and layout.

used both the T130-2 and larger diameter T200-2 Micrometals iron powder toroid cores.

Example of a 1:9 unun transformer in use

Photo 1 illustrates an example of a 1:9 impedance ratio transformer using a Micrometals iron powder toroid T130-2 core that was used to match an end-fed wire covering the 80m to 10m bands. The antenna had a wire span of about 21m and was mounted at a height of around 7m. This transformer comprised 9 trifilar wound 3-wire turns with a small gap left between each turn, as shown. Photo 1 shows where the coaxial cable was connected to the primary winding and the antenna's connection to the secondary winding.

WR8RW's unun antenna

An example the end-fed wire design shown in Figure 5 is the antenna recently installed by Robert Webster, WR8RW, in his loft. Robert has provided the following summary:

"I have mounted a 'test' antenna in the loft of the house. The radiator is 15.7m of 26 AWG (0.4mm) wire connected to a 1:9 homebrew unun. The braid side of the feed line is connected, at the unun, to a 11.6m counterpoise (also of 26 AWG wire) pushed through a screen and gently draped onto the side lawn. Measurements taken with my nanoVNA show all bands from 80m to 10m are within the tuning range of my HF rig. An overnight run using WSPR at 5W produced results that were beyond expectations. On SSB I have made contacts into central Europe (during grey line periods) and all over North America during the evening."

Thanks to Robert for this information.

Note: another example of using an unun transformer to match an end-fed wire covering the 80m to 10m bands was by Jos van Helm, PA1ZP. This was published in the February 2016 *RadCom* and in the *Radio Communication Handbook* **[5]**.

Websearch

Radio Communication Handbook, 14th edition edited by Mike Browne, G3DIH. Section 15, Practical HF Antennas:
[1] Pages 15.36 to 15.37
[5] Pages 15.4 to 15.5
[2] 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
[3] http://vk6ysf.com/unun_9-1.htm
[4] https://m0ukd.com/homebrew/baluns-and-ununs/91-magnetic-longwire-balun-unun/

Review

Avair AV-201 SWR and power meter

The metal-boxed meter is capable of working in the range 1.8-160MHz.

Whether you have just obtained you Foundation licence or have moved on, allowing the use of more power, all shacks need a power meter.

The Avair AV-201 SWR and power meter is a small, compact device suitable for amateurs at all stages of their amateur career. I say this as it is capable of reading power in ranges of <5W, <20W and <200W. It also has a small push-button switch on the back that will allow it to read up to 1kW.

The metal-boxed meter, capable of working in the range 1.8-160MHz, measures 155mm wide by 103mm deep by 63mm tall and includes a 66mm-wide direct-reading power/SWR meter.

Out of the box

On the front panel is a small meter adjustment screw for zeroing the meter, a power range switch (200W, 20W and 5W), a function switch marked POWER, CAL, and SWR, plus a Power switch marked REF, FWD and OFF.

Also on the front is a switch that enables you to select peak (PEP) or average (AVG) power readings, plus a large knob marker "CAL", which is used for SWR calibration.

On the back is the aforementioned 1kW/200W switch, input and output SO-239 sockets, plus a socket for the supplied 13.8V power lead that enables the meter's LED illumination.

A sticker announces that caution should be taken to restrict usage to a maximum of 30 seconds for readings up to 1kW and 10 seconds for up to 3kW.

In use it is relatively easy to measure power – just switch to the appropriate power range and make sure "FWD" is selected on the power switch. Selecting FM and keying the microphone will give you a reading on the meter.

Power readings

If you wish to take a power reading in SSB mode, you have two choices. Either select "AVG" with the large blue button on the front, key the microphone and talk, or select PEP and do the same. The PEP setting dampens the meter's movement and allows a more accurate measurement when using SSB.

To take an SWR reading, it is easier to do this in CW or FM mode to give a constant carrier.

Again, selecting the appropriate power range, switch the function to "CAL", key the microphone or Morse key and adjust the meter until it reads full scale (marked by the letters "CAL" on the meter).

Then simply flick the function button to SWR, key the rig again, and read off the SWR. This process become second nature once you have done it a few times.

Conclusion

So all-in-all, the AV-201 is a classic, compact SWR/power meter for HF, 6m, 4m and 2m, that would fit into any shack. Its small size also makes it suitable for /P operation. Its 5W and 20W settings make it particularly suitable for Foundation licensees and QRP operators.

The AV-201 costs £59.95 and is available from Waters and Stanton in Portsmouth (https://hamradiostore.co.uk). Our thanks to Peter Waters, G3OJV for the loan of the meter.

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Plumber's Delight 13cm patch feed

This article describes the construction of a simple and cheap 13cm linearly polarised patch feed for a satellite TV dish, either for terrestrial use or as an uplink to QO-100. The method of construction is particularly suited for those without great metal-bashing skills or access to a lathe. Metal cutting is carried out using nothing more than a jigsaw with a fine metal blade using the method described in *Scatterpoint*, December 2019 (Poor Man's Dish Feed, G0FVI). This design is closely based on the well-known K3TZ left-hand circular polarisation (LHCP) patch feed.

Those who have built the excellent POTY dish feed designed by G0MJW *et al* for Es'Hail-2 (QO-100) use will no doubt notice the similarity. This feed differs in that it is solely for use on 13cm and is more easily adjustable for optimum tuning.

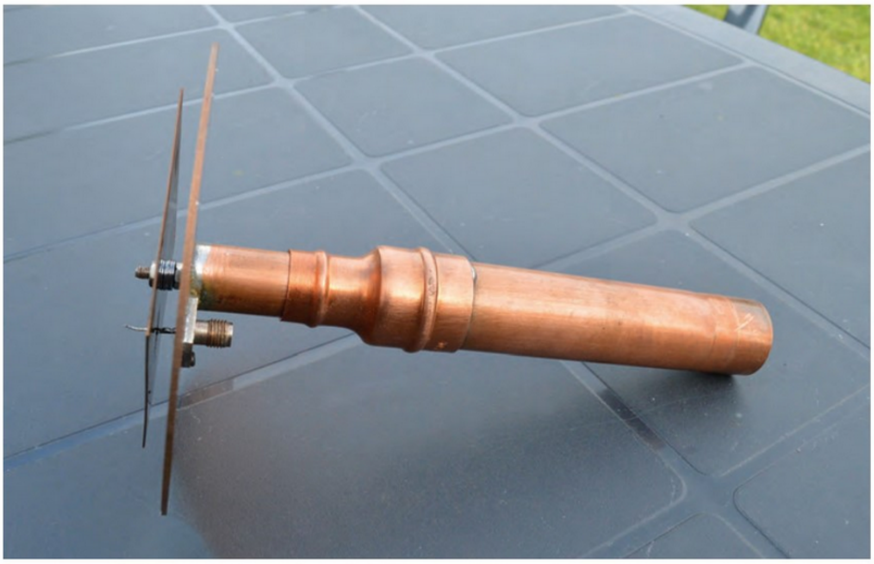

PHOTO 1: Completed 13cm 'Plumber's Delight' patch feed based on K3TZ design.

Description and construction

Dimensions of the patch and reflector are shown in **Figure 1**. The patch element is square and made from 0.5mm thick copper sheet. Unlike the original K3TZ feed, two opposing corners of the patch are not removed here so it is not LHCP (the POTY utilises a similar layout to achieve circular polarisation by patch corner removal). Use of 0.5mm copper for the patch allows for fine tuning after construction by slight bending of corners (as described by G0MJW *et al* in the POTY feed construction details), although this may not be necessary as construction allows for comprehensive tuning by altering distance between both plates before final soldering.

A centre support bolt of size M3 (see detail in **Photo 2**) allows alteration of plate separation by adding or removing 1mm (or 0.5mm) washers. Before placing patch and spacing washers onto the reflector, secure the centre support bolt with a locking nut.

An SMA socket is used to feed the patch. A short length of around 24 SWG wire is soldered to the centre pin. This protrudes through the patch plate to provide the connection. (An SMA socket with a long inner shaft is probably easier to use, as soldering the feed wire to the upper plate can cause it to detach from the SMA centre pin if you are not careful). The feed wire should protrude about 5-6mm above the patch so that it can be bent back to form electrical contact with the patch whilst tuning and prior to soldering. The exact dimensions of the patch can be scaled to whichever part of the band is required (those of the reflector are less critical).

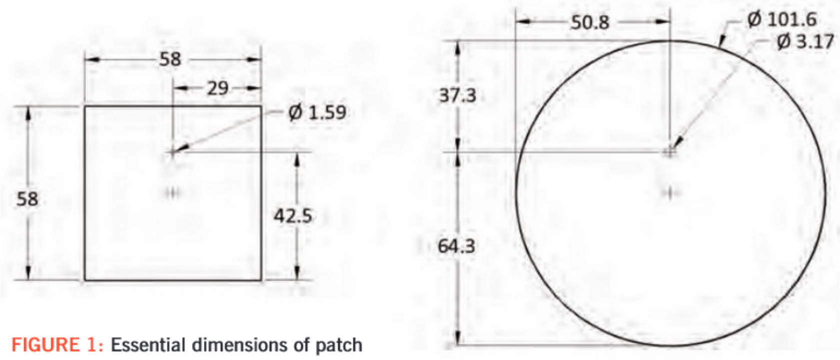

FIGURE 1: Essential dimensions of patch (left) and reflector (right), adapted from [1].

Note that placement of the SMA feed socket varies dependant upon the design and this will determine the rear mounting arrangement. With the POTY feed, for example, the SMA/N type socket is much further from the centre support.

The mounting tube at the rear of the patch consists of a short piece of copper plumbing pipe. This should be short enough to allow tooling to be inserted to tighten up/loosen the centre support bolt if required after soldering. 15mm diameter is used in this example. The location of the SMA feed – even if it is the elongated two-hole type – does not allow an SMA male connector to be easily attached if 22mm pipe was soldered directly to the rear plate (as in the POTY feed).

Solder the 15mm pipe to the back of the rear plate, taking care to keep it centred. I recommend you use a blowtorch rather than an electronics-size soldering iron, as there's

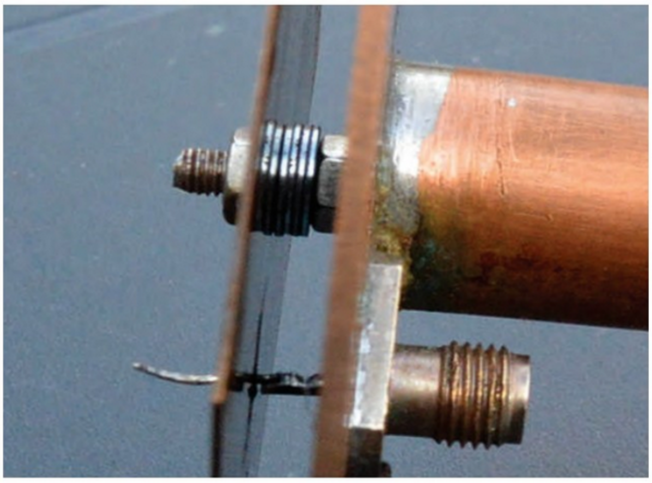

PHOTO 2: Detail of the M3 nut and washers spacing the feed from the reflector.

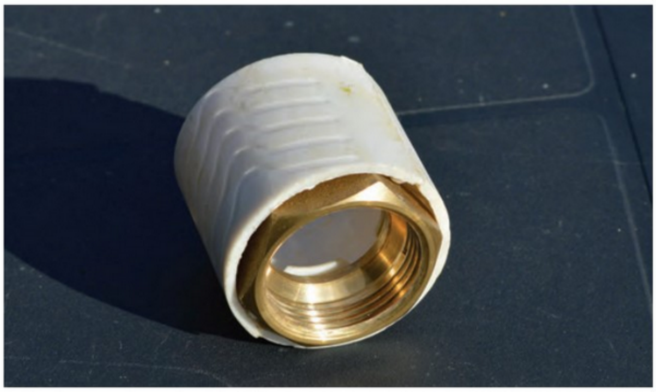

PHOTO 3: A simple mounting collar.

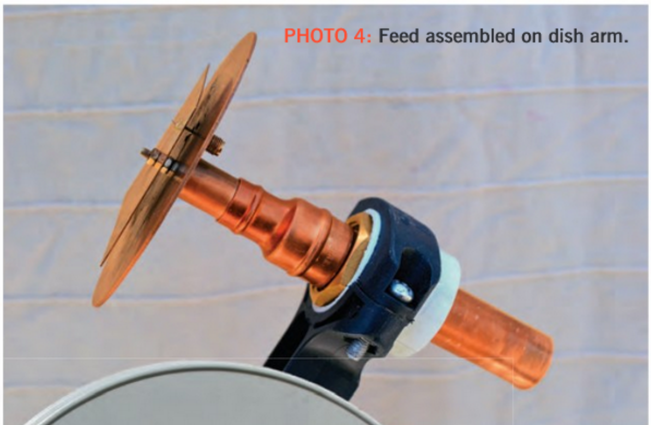

PHOTO 4: Feed assembled on dish arm.

PHOTO 5: Completed feed with dish.

a *lot* of metal to heat. The centre support bolt may be put in place before or after soldering, although it is easier to do it beforehand and secure it with a locking nut. A 15mm to 22mm standard plumbing coupler allows transition to a piece of 22mm copper plumbing pipe, which lends itself fairly well to easy mounting on a standard offset-type dish (I have an 85cm satellite TV dish that will eventually be used portable). The length of the 22mm pipe will depend on how much focal travel is required but is unlikely to exceed 150mm at most. It is suggested that only the 22mm pipe is soldered to the coupler, with the 15mm pipe inserted and held in place with a toluene-based contact adhesive. The reason for this is that it facilitates future disassembly, should this become required, without desoldering the coupler.

A mounting collar of some description will be needed for clamping the 22mm pipe of the finished assembly to the dish arm. If you are using a standard satellite TV dish, a simple solution (seen in **Photo 3**) is two 22mm brass plumbing nuts and an olive glued into the sawn-off neck of a surplus LNB. **Photo 4** shows the feed mounted on the dish arm and **Photo 5** the complete assembly with the dish.

Tuning and adjustment

Tuning is perhaps best accomplished with an inexpensive vector network analyser (such as the Nano VNA2) or some more elaborate setup. Adjust the spacing between the patch and the reflector, adding or removing washers as required to get the best SWR across the required operating band. (VNAs often give you a 'return loss' rather than specific SWR: you're looking for the *highest* return loss, as this means the smallest amount is being reflected back along the coax).

You will need to determine the optimum focal point after fitting to your dish, after which you are ready to go. Polarisation (horizontal or vertical) will depend on orientation of the feed point to the mount axis.

Acknowledgements

This project would not have been possible without the work of K3TZ **[1]** and the POTY ('Patch of the Year') dual band dish feed designed by Mike Willis, G0MJW, Remco den Besten, PA3FYM and Paul Marsh, M0EYT. I am also grateful to Derek, M0WGD, who provided assistance during the construction of this project.

Websearch

[1] https://www.qsl.net/k3tz/k3tz.html

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Hybrid loop antennas

Lower bands from littler gardens

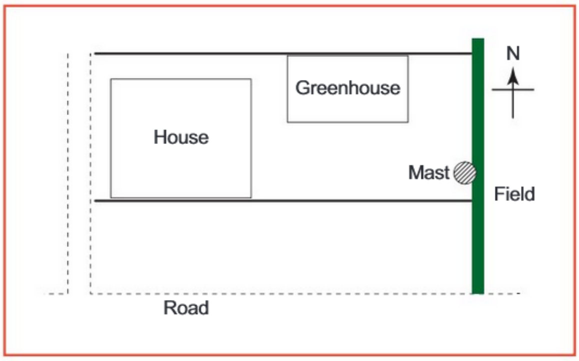

FIGURE 1: General survey of my plot.

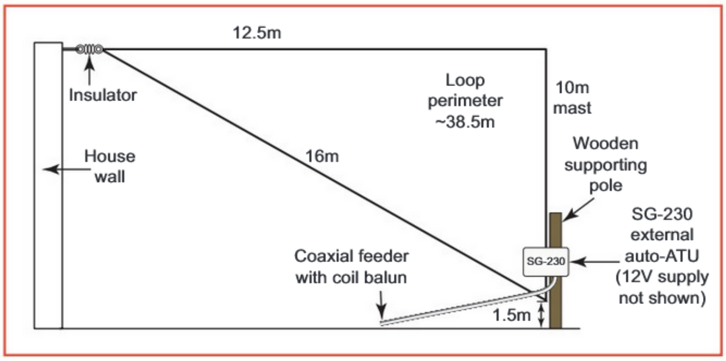

FIGURE 2: Side view of the 40m loop arrangement. The perimeter is about 38.5m. The top of the mast is about 11.5m above ground level; the horizontal part of the loop is about 12.5m and the diagonal is roughly 16m.

The curse of the small garden

If you think that the low bands are off limits to you because you have a small garden then please think again. My back garden is about 7m by 11m and it includes a large green house, many shrubs and some small fruit trees – lovely but cluttered. The house has a path accessible on one side only and also 8m in length but with a dormer it gives me 8.5m of usable height. A simplified view of the layout is shown in **Figure 1**. My shack is based at the top of the house in the dormer. There is a mast on the garden side of the house for an HF beam and my 40m inverted dipole, aligned E-W. But note this is not used in antenna details described below. There is only a good take off to the West, North West and South West. Being Sheffield, there are hills everywhere. I am located at 130m elevation below a steep hill to the South with maximum elevation 170m.

For years I have struggled to get a decent inter-G signal out on 80m – let alone working DX. I have tried using 40m Inverted Vs with traps for 80m in a dog leg arrangement, an 80m horizontal loop with many coils and stubs for resonance, loaded verticals with a few radials, Inverted Ls and more. They worked to a point, but only a very small point. But Top Band? Only in my dreams.

Time for a new approach

With the onset of all the Covid-19 lockdowns in the autumn and the HF bands such as 20m often being dead just after sunset, I decided I needed some fresh thinking for using the lower bands. My goal was to design a multiband antenna suitable for 160 to 40m. Multiband that is without using traps or being dependant on the ATU in the shack for tuning. Using that ATU would be a very inefficient way to give a tuned system. So my design would have to give a tuned match at the antenna feed point.

Starting with 40m

I chose 40m as the easiest starting point and decided I would build a loop. I rejected the G7FEK **[1]** because the layout and dimensions would not work well and even my long-suffering neighbours and partner would not like a feeder hanging down in the middle of our little lawn.

So, the feed point would be the furthest point from the house, which electrically is less noisy than near the dwelling's walls. I would use a 10m extendable aluminium mast (mine was from Sandpiper; a Spiderpole or similar would also work) and, mostly importantly, an SGC 230 external ATU, with a rating of 200W. For wire, I used green-covered lightweight multi-stranded wire that I sourced from SOTABeams.

Despite the long drop of over 18m from the shack, I used standard 50Ω RG-213 coaxial cable. I calculated the losses at the low frequencies used would be less than 0.5dB (0.55dB at 10MHz and 0.17dB per 30m).

The SGC-230 was fed by a separate 12V PSU that I located in the greenhouse. An alternative would have been a 12V battery with a solar panel trickle charger – the ATU only requires 900mA for 2 seconds or so, and only when it tunes. A DC feed from the shack would also have been OK.

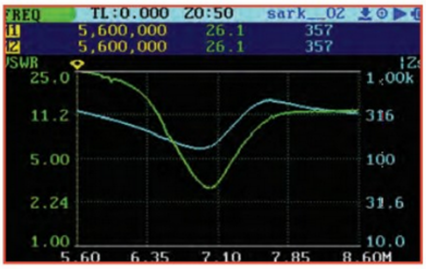

FIGURE 3: Response of the 40m triangular loop.

A simple coaxial balun was made at the feed point to minimise any earth return currents. I used 4 turns in a 25cm diameter loop. **Figure 2** shows the general setup.

Based around what was most practical, I used a triangle design with a right angle at the apex of the mast. Although it bears a passing resemblance, it is not a delta loop. As seen in **Figure 3**, resonance around 7.1MHz was obtained with only a 38.5m perimeter.

The results in the winter on 40m using FT8 enabled 2-way world QSOs but in particular I was receiving requests from JA morning noon and early evening. The North South loop alignment must have helped.

Figure 4 shows an example of 40m FT8 reports at 0815UTC on 22 December 2020.

FIGURE 4: Example FT8 reports on 40m at 0815UTC on 22 December 2020.

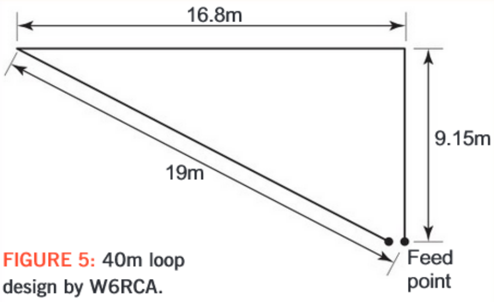

FIGURE 5: 40m loop design by W6RCA.

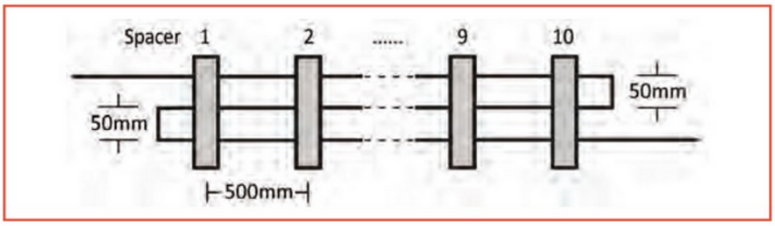

FIGURE 6: The 'Cobra' arrangement. Only four of ten spacers are shown; the overall length is ~5m. Dimensions are approximate and not critical.

But if it's not a delta loop, what *is* it? After some searching for right-angled HF loops I came across a talk given at Four Days In May Symposium 2000 by L B Cebik, W4RNL. Entitled 'Do the VOMBA', the presentation discussed Vertically Orientated Multi-Band Antennas, including 'my' type, which was identified as a form of hybrid or right angled loop first described by Cecil Moore, W6RCA. W6RNL stated that the hybrid is a variation of SCVs – self contained (no radials) vertical 1-wavelength loops. As a group, SCVs are normally relatively poor performers as multi-band antennas, though they do give low angle radiation that's good for DX. But the Hybrid gives some low and some high-angle radiation. I would recommend reading the whole of his presentation **[2]**, which gives a detailed analysis of all types of loops and includes polar diagrams.

The overall loop perimeter of the 40m design by W6RCA, shown in **Figure 5**, is approximately 45m, rather more than mine. So why the difference in perimeters? I assume that his loop was mounted at 10m above the ground, which is about ¼ of a wavelength. My loop is virtually at ground level, which will mean it has a strong capacitive effect from the ground.

80m loop

Extending the M0GDX loop so that the furthest point from the feed was fixed to the top of my dormer gave me a loop perimeter of approximately 60m. A full-size rectangular loop for 80m would be around 84m. A usual rule of thumb says that to avoid a serious loss of efficiency the physical length of antenna should not be less than ⅔ of the wavelength. I decided that my 60m perimeter should be sufficient, possibly with suitable loading. Nearly half the loop would be close to house and this would likely have some (small) impact on dimensions.

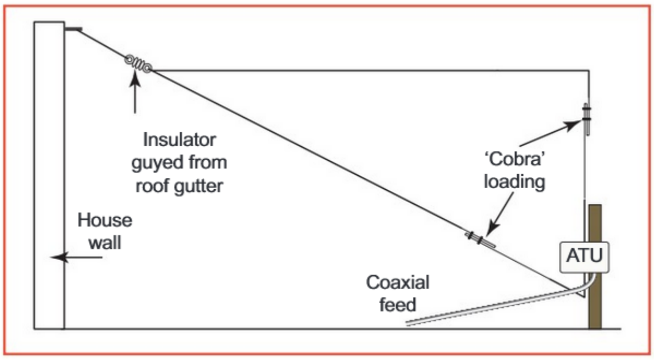

FIGURE 7: Two sections of 'Cobra' loading on the loop.

To obtain the desired 3.7MHz resonance I made three coils, each of six turns of RG-213 wound on a plastic former. Published literature suggests that loading should be placed at mid points in a loop but mine were placed in series with the loop at convenient (but not ideal) points. Resonance around 3.7MHz was difficult to obtain without raising the SWR to over 5:1. But then I decided to use a different approach: 'Cobra' linear loading.

In 2020 Frank Dörenberg, N4SPP published **[3]** an article on a 40-10m 'Cobra' dipole, in which he suggests folding a radiator into a zig-zag arrangement of three or four parallel wires. My arrangement

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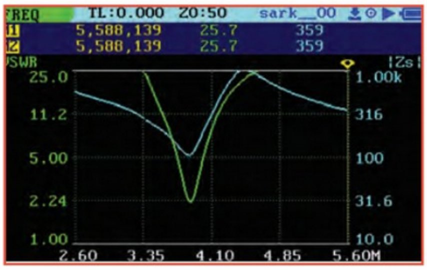

FIGURE 8: Loop with 'Cobra' sections resonating on 80m.

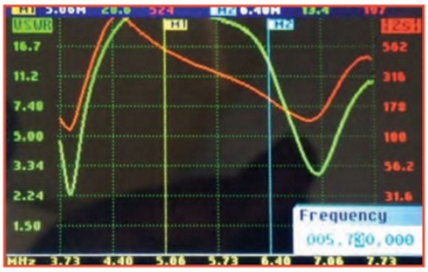

FIGURE 9: Loop with 'Cobra' sections swept across 80m and 40m.

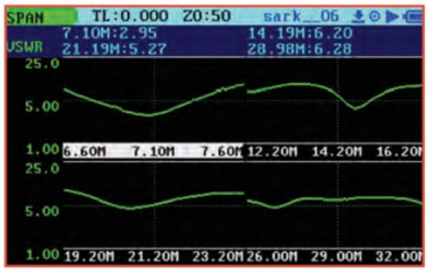

FIGURE 10: SWR on higher bands.

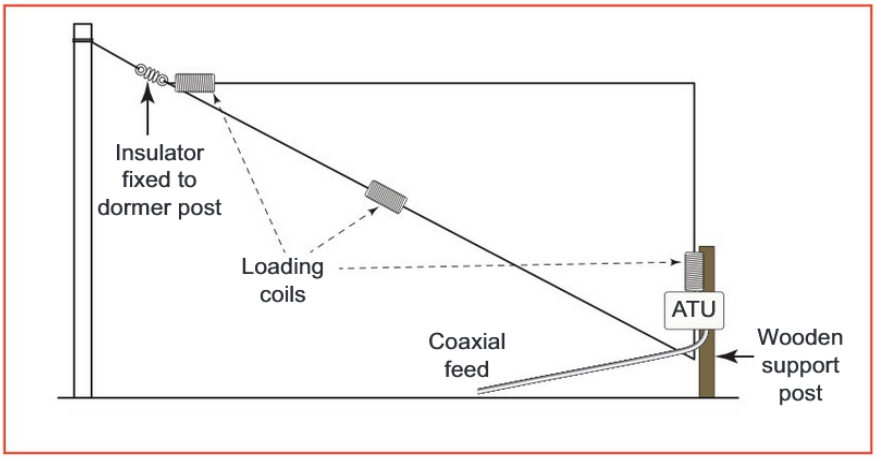

FIGURE 11: Adding extra coaxial loading coils to Figure 7.

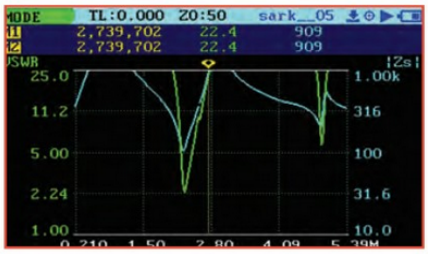

FIGURE 12: Resonance around 1.8MHz.

used three wires spaced 5cm apart on plastic formers. Ten formers were spaced 50cm apart on the lower 5m half of the mast; a further ten were employed on the lower 5m part of the mast. **Figure 6** shows the general arrangement of the spaced wires and **Figure 7** shows how these were arranged on the loop.

Figure 8 shows that I achieved good resonance around 3.7MHz. I increased the sweep to cover 80m and 40m and was rewarded with the result in **Figure 9** – most definitely usable on both bands. Use on higher bands was also possible but the SWR was poor. **Figure 10** shows the SWR response on the 7, 14, 21 and 28MHz bands.

Rick Littlefield, K1BQT has analysed **[4]** a cobra-style arrangement using close spacing multi-core cable instead of the much wider spacing I employed. His experiments were very interesting and showed that this would work, but was rather lossy.

160m operation

Top Band is my final challenge. Extending a 60m perimeter loop to operate efficiently on Top Band would seem quite a tall order. However, I found even with the 40m loop I could still obtain good FT8 reports within Europe on 1.874MHz – but there was obviously power inefficiency as the external tuner was doing a lot of the 'heavy lifting' to match the antenna to 50Ω. So the object remained to get a resonance around 1.8MHz.

The solution was to include the previously made loading coils as well as the Cobra loading. **Figure 11** shows where the loading coils were added (Cobra wires omitted for clarity; they are as per Figure 7).

Goal achieved! **Figure 12** shows the measured LF response, with a rather nice resonance around 1.8MHz.

Summary of Top Band results

Despite the onset of increasing daylight hours I have had 2 way FT8 QSOs with numerous Europeans as far as UA6 and UA9, plus 2 East Coast Ws, A65 and 5N5. I am getting good reception reports from VE and V01, 5B4 and a 4X4 and a JA but as yet no 2 way QSOs. Reports from VK and ZL still escape me! One problem I have is around a local noise level of S7-8, which doesn't help.

Reducing Top Band noise levels

Many of us suffer from high noise levels, particularly on Top Band. I sometimes get an extra dose of noise around sunrise, just in time to wipe out possible 2 way USA QSOs. I am investigating a number of possibilities.

The simplest is a rectangular receiving loop running along two walls of the garden. Each loop is 8m long by 3m height with 2 or 3 turns. Such loops are bi-directional and mine give East/West and North/South reception. I use a commercial antenna relay to switch between antennas on changeover from Tx to Rx.

Another approach is the so-called 'loop on ground' antenna. There are many variants; I followed in the footsteps of Matt Roberts, KK4JY **[5]** by laying out on the ground a square of wire about 4.5m on a side, as per Matt's diagram (**Figure 13**).

As a student I made a unidirectional receiving loop arrangement using a frame antenna for MW with an inductively linked vertical wire acting as a sensing antenna. Such systems were developed in WW2 and are in common use today by ARDF enthusiasts (in modified form, with a ferrite rod rather than a loop). I experimented along the lines seen in **[6]**.

Cardioid loop

A bidirectional receiving loop can converted into a unidirectional one without using additional antennas. Chris Moulding, G4HYG of CrossCountryWireless has described how a circular or rectangular loop can be constructed by using a suitable resistor to break the loop opposite the feed point. Quoting a paper by C & S Antennas in 1974, he states: "Their idea was to insert a resistor in the loop directly opposite the feed point. This still allowed the loop to act as a magnetic loop but also as two monopoles as an electric field antenna. This had exactly the same effect as using separate loop and sense antennas and using modern antenna modelling software can be optimised

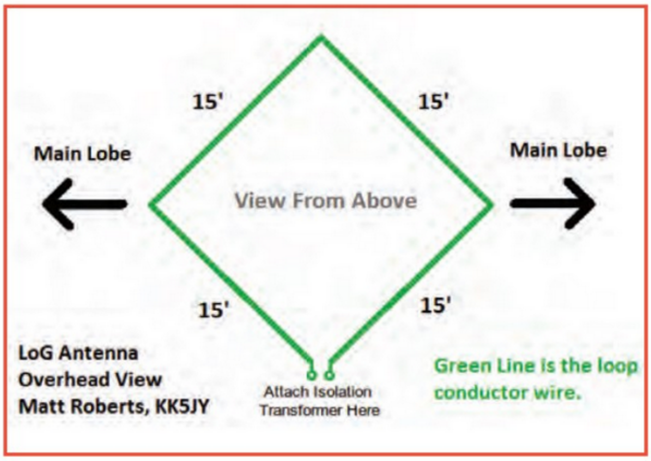

FIGURE 13: Loop on Ground antenna, from work by Matt Roberts, KK5JY.

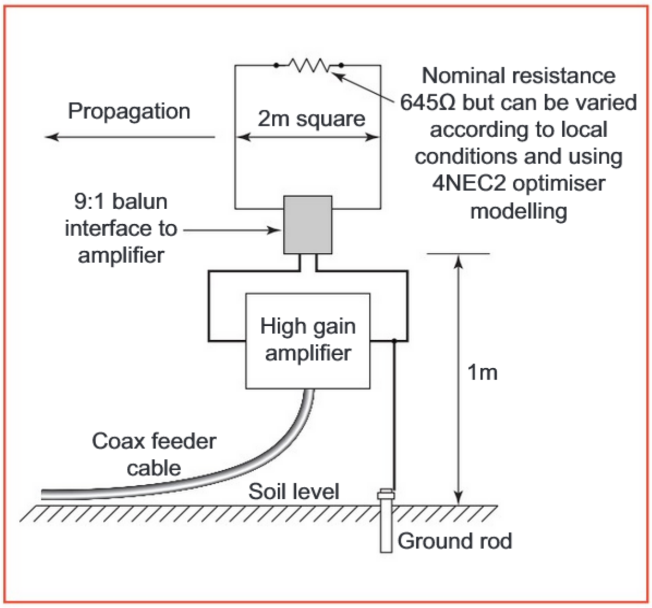

FIGURE 14: Cardioid loop antenna.

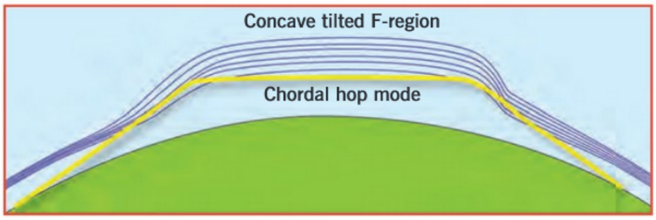

FIGURE 15: Principle of chordal hop propagation.

to give a good cardioid pattern. It's of interest to note that I came up with exactly the same values they did so the modeling tool they used was probably an earlier version of the NEC 2 tool I used." The general arrangement is shown in **Figure 14**. See **[7]** for Chris' research, which includes polar diagrams. Do note that a high gain broadband amplifier is essential with this kind of antenna (a suitable type is available from CrossCountryWireless, among other sources).

Top Band propagation

There is a reason why HF propagation charts usually stop at 80m. As the frequency approaches 1.8MHz, our radio wave electrons will be affected by the Earth's upper electrons gyro frequency, which appear to resonate around that frequency. This rotational movement introduces another variable into ionospheric variations (which are, otherwise, better understood).

My understanding is that Top Band DX is better during years of sunspot minima; for best results the path should be mostly in darkness. DX signals are also given a boost by using the so-called grey line – the line that separates day from night and whose shape varies with the time of year. But – and a big but – this is all a generalisation.

Writing in *CQ*, December 2005, Carl Luetzelschwab, K9LA said, "A signification number of Top Band openings over 4000km may be caused by signal ducting". The article went on to give a significant overview of ducting, which was originally described in the 1950s. You can read what he wrote at **[8]**.

In his seminal work *HF Antennas For All Locations*, Les Moxon, G6XN discusses chordal hop (tilt mode) and bemoans the fact commercial operators were ignoring the work of amateurs in achieving S9+ reports over 12,000 miles.

With chordal hop propagation you have much less attenuation due to the fact the signals remains within the ionosphere for long distances rather than bouncing back down to earth and up again (as in classic multi-hop propagation). **Figure 15** illustrates how this works.

Ducting means that the signal does not always return back to Earth (causing a signal loss) but remains in the ionosphere for maybe another thousand or so km.

Conclusion

One constant issue over the many years that I have been a member of the Sheffield radio club has been to persuade fellow amateurs to experiment with HF antennas. Nowadays it is easier than ever to do meaningful antenna experiments. Modelling programs are available for free and help one examine 'what-if' scenarios; remarkably accurate antenna analysers (and network analysers) are available at low cost and make it very convenient to check performance across a range of frequencies – one is no longer limited to a SWR meter and amateur-band-only testing.

Newer on-air test methods (including the likes of FT8 and PSK Reporter) make it easier for anyone to have a go and try out practical solutions for their own QTH. So what are you waiting for?

Acknowledgements

My thanks to Peter Day, G3PHO for general support and inspiring me to get active on Top Band; also to Graham Coyne, G3YJR for information on low noise counterpoises and other references.

I'd also like to express my appreciation of the members of Sheffield & District Wireless Society for their encouragement in preparing this article.

Websearch

[1] http://www.g7fek.co.uk/software/G7FEK%20antenna.pdf
[2] http://on5au.be/content/fdim/fdim5.html
[3] https://www.nonstopsystems.com/radio/frank_radio_antenna_cobra.htm
[4] https://www.nonstopsystems.com/radio/pdf-ant/cobra-1.pdf
[5] http://www.kk5jy.net/LoG/
[6] https://web.archive.org/web/20180327100558/http://www.mwcircle.org/mw_antenna.htm
[7] http://www.crosscountrywireless.net/cardioid_loop_antenna.htm
[8] http://myplace.frontier.com/~k9la/160m_Ducting_and_Spotlight_Propagation.pdf

Daiwa CN-901HP cross-needle SWR and power meter

An SWR and power meter is a must-have in almost every shack, whether your interest lies in the HF or VHF bands.

The Daiwa CN-901HP cross-needle SWR and power meter is described in its literature as a “high-quality instrument with unique features which make tedious measurement of SWR and Power during antenna tests, matching and tuning of transmitters a very easy task”. It certainly looks the part, being dark blue in colour with a 9cm-wide cream meter face.

The meter reads the SWR at the point the meter needles cross.

Out of the box

The Japanese-made unit is quite large, measuring 17cm wide x 12cm high x 12.5cm deep. It weighs in at one kilogram and has removable black rubber bumpers on its ends to protect it from bumps and scrapes.

Its frequency range is 1.8-220MHz, so covers everything from Top Band to two metres in one box. It is designed for 50Ω systems and, if connected to a suitably-designed antenna, will read the SWR at the point the meter needles cross.

On the right are four push-buttons, which allow you to select (from top to bottom) a two-kilowatt range, 200-watt range and 20-watt range. The bottom button allows you to select average or PEP readings.

The meter’s tolerance is quoted as being ±10% and the instructions say that the power rating on 144MHz is 1kW and to “add 15% of full scale at 160-200MHz”.

The meter, therefore, appeals to everyone, from Foundation licence holders to high-power DXers. One point to note is that the meter dials are logarithmic. That is, on the 20-watt range, the 10-watt position reads a little higher than the halfway point. This means that it is very easy to read powers of five watts or less for QRP fans.

On the back are SO-239 sockets for both input and output, along with switches for the PEP hold function and a light, which can be powered by a 13.8V (70mA) supply. A one-metre-long cable with an appropriate connector is provided with the meter. Note that this isn’t fused.

The light comprises two blue LEDs at the bottom of the meter and is quite pleasant.

Note that a power supply is required to make PEP meter readings. You also have to switch it on at the back of the meter, which confused me at first!

In use

In use then, once the meter is connected to your antenna and the radio it is just a case of selecting the appropriate power range button and pressing the PTT, or keying the radio with a Morse key.

The meter proved accurate and has a nice dampened movement. This means that it takes a fraction of a second to settle.

One quick tip – make sure you have selected a range that can accommodate the power you are running. That is, it is not a good idea to run 200W into it when you have selected the 20W range. This would almost certainly damage the meter.

Conclusion

In conclusion, the Daiwa meter makes a delightful addition to your shack. It is both stylish and effective with large clear readings of power and SWR. The CN-901HP costs £139.95 plus P&P and there is also a CN901HP3 variant, which can handle up to 3kW, for £179.95. My thanks to Mike Devereux at Nevada in Portsmouth for the loan of the meter (www.nevada.co.uk).

Further information

On the RSGB website is a very useful section on setting up your station (https://rsgb.org/main/get-started-in-amateur-radio/setting-up-your-shack/). Here you will find descriptions of commonly-used equipment, its function and uses.

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Impedances and reflections on transmission lines

Introduction

The recent article 'SWR and all that' by G3XJE seems clear and correct to me, but subsequently there seems to have been some confusion over the reflected power on feeders.

From recent correspondence in these pages, it has become clear that some people are frustrated by the terminology of others and ways of expressing the behaviour of transmission lines – and especially mismatch. I know many radio amateurs clearly understand this subject, but some of the comments show a lack of understanding of what is a universally-accepted industry-wide model of transmission lines, which has been stable at least since the Smith Chart was devised around 1939. This has always been a subject that has been inclined to cause confusion in the amateur world and I think there may be a significant number of *RadCom* readers, especially newcomers, who would like the situation made a little clearer.

All the information about this is freely available in RSGB books and on the net. The aim here is to collate information and test results to present a clear picture. Because we are trying to look at basic circuit principles, some of the circuit configurations we use are simple textbook ways to do things rather than the more complex, less easily-understood situations that are likely to exist in a radio station. In particular, in all of the examples here the signal source end of the transmission line is terminated with its characteristic impedance (Z_0) unless stated otherwise. The reason for this is to make understanding the theory as easy as possible. We are looking at the general characteristics of transmission lines; when using a signal generator with a well-defined output impedance, it is relatively easy to understand how they behave in specific applications. It is not really possible to give a complete proof from first principles here, but these are basic principles accepted by all who work in RF engineering. If you *would* like further information, there are some references at the end of this article that you could look at or, if still unclear, please email me.

Superposition

There is an important principle, which is fundamental to electronics theory, known as the Superposition Principle. It applies to all linear electronic systems and states that if a system is stimulated by more than one signal, then the response of the system to the multiple stimuli is equal to the sum of the responses to the individual stimuli. (Resistors, capacitors and inductors are linear devices, but diodes for example are not.) What this is saying is that a linear system, such as a transmission line, will respond to a signal applied to it in the same way regardless of whether or not there are other signals applied to it at the same time. This is just saying formally something we all know: multiple signals in the band pass through the aerial feeder without interfering with each other. Also, one feeder allows us to transmit and receive *at the same time*, as is done in some situations. Note that the superposition principle does *not* apply to power. Voltages and currents add linearly, but powers are proportional to the squares of those quantities.

Forward and reverse waves

The reason for considering superposition is just to understand clearly that we can apply a signal at one end of a transmission line and absorb this signal in a correct termination of the line at the other end; simultaneously, we can send a signal down the transmission line in the reverse direction. These two signals will behave completely independently of each other.

Let's begin with the simple situation in which the signals are DC voltages (see **Figure 1**). If Vg1 is equal to 2V, and Vg2 is equal to 0V, then 1V appears across the left-hand (sending) end of the line (1 volt is dropped across the 50Ω source resistance), and when the signal arrives at the right-hand end, 1V will be across the 50Ω load resistance (assuming that there is no resistance in the line).

We could also send a signal down the line in the reverse direction from Vg2, exactly the opposite of what we have just done. If, with Vg1 equal to 2V, we make Vg2 also equal to 2V with the polarity shown in Figure 1, then we are sending a signal down the line from right to left while there is already a signal on the line from left to right.

From the superposition principle we know that when sufficient time has elapsed for the signals to travel down the line (in the region of 1μs per 300m) then the voltages due to the Vg2 source will be superimposed on the voltages already present due to the Vg1 source. If the voltages are applied in the relative polarity shown in Figure 1 then the voltages will oppose from each other. Clearly, no current will flow. Now this might seem a bit confusing at first sight; it fits with the superposition principle, but there is no power flowing in either direction in the circuit. What happened to the original left to right signal on the line that was being dissipated in the right hand load? The answer is that, although the superposition principle means that voltage and current signals caused by each of the voltage sources are independent of each other, the addition of a new source, Vg2 in this case, causes the effective value of the load resistance connected across the right-hand end of the line (the ratio of voltage to current) to change, even though the actual resistor value has not changed. This analysis provides a bit of insight into what happens with a mis-termination at the load end of a feeder. When we switched on Vg2, we can explain what happened in two ways. We can say that we have sent a signal back down the line towards the sending end of the same magnitude as the original incident signal. We could alternatively say that, in effect, we have changed the resistance at the load end from 50Ω to infinity (the load has 2 volts across it and no current flows). Because the load is infinite, there is no power dissipated in it.

Now suppose we have the original left to right signal and then we switch on Vg2 in the reverse polarity so that the voltages around the circuit add. In the earlier case we considered, there was a voltage on the line with no current; now we have a situation of current with no voltage (at either end of the line there is no voltage across it). We are applying exactly the same voltage signal in the right to left direction as in the earlier example but in the opposite polarity and this makes the apparent value of the termination across the right-hand end of the line zero (current with no voltage). We have done this with DC for simplicity, but the same principles would apply with RF signals: it is the phase of the reverse-direction signal that makes the apparent value of the terminating resistance oscillate between zero and infinity. The two conditions of zero resistance and infinite resistance are in some ways the similar to each other and they have a certain symmetry.

We can extend our discussion with the help of a certain passive RF device, only used at fairly high frequencies, known as three-port circulator. These

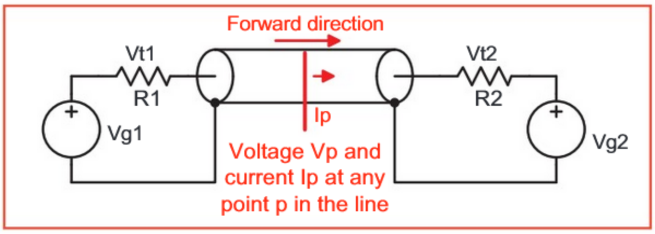

FIGURE 1: Simple situation using DC voltages.

devices have three ports, labelled 1, 2, and 3, which enable RF signals to be coupled from 1 to 2, or 2 to 3, or 3 to 1, with low loss as shown by the arrows in **Figure 2**, but isolate couplings between 1 and 3, or 2 and 1, or 3 and 2. For this discussion it is only important to see that it is possible to make a system such as shown in Figure 2 where the forward and reverse signals on the transmission line can be separated from each other and, as far as the theory is concerned, the open circuit and short circuit cases are equivalent to each other except for the relative phases of the reflected signals. **Figure 2(A)** shows the case in which 1W of power is delivered by the signal generator (connected to port 1 of the circulator) and this is sent down the line (attached to port 2) and is dissipated in the 50Ω load at the right-hand end. There is no reflected wave – the line is matched – so there is no power dissipated in the 50Ω load connected to port 3. **Figure 2(B)** shows what happens when the right-hand end of the line is open circuit. Now all the power in the wave is reflected at the right-hand end, flows back down the line towards port 2 of the circulator, and is dissipated in the load connected to port 3. **Figure 2(C)** shows the same thing happening with the right-hand end of the line short circuited.

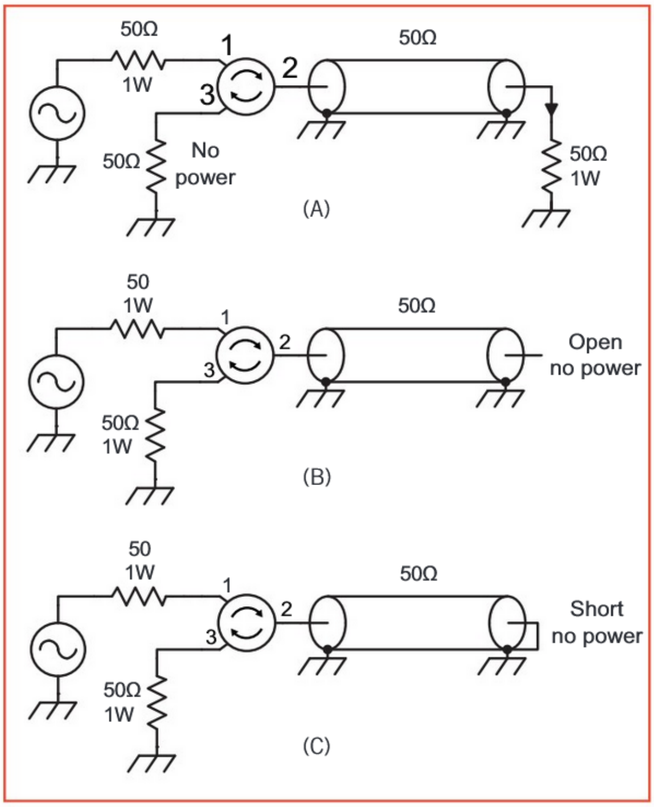

FIGURE 2: Effects of three-port circulators.

The Smith Chart

Our discussion so far has been based on the assumption that the terminating impedances have been purely resistive. In practice, the terminating impedances can be complex – that is, they have both a resistive and a reactive part. Mathematically, we need two numbers to describe an impedance, and this is usually done using complex numbers with real and imaginary parts. This all gets rather messy, but Smith invented his chart in 1939 to provide us with a graphical way of working out what is going on.

It is not necessary to fully understand the Smith Chart here. We will not concern ourselves with all the impedance contours normally seen inside the chart, but just consider the basic descriptions shown in **Figure 3**. The chart also shows a relationship between the forward and reverse vectors and the effect that they have on the impedance seen at the end of a line. If you are not familiar with the detailed working of the chart, I would recommend (perhaps later on) looking into it because you will find it fascinating. The chart provides an area within the main circle that covers all possible impedances from zero to infinity combining R, L, and C. The scales are not linear and they are normally calibrated in impedances scaled relative to Z_0. The centre point of the chart is Z_0 (50Ω resistive in a normal case), and the outer circle traces all the passive impedances that are as dissimilar as it is possible to get from Z_0. The far left end of centre line, where it meets the circle, is zero impedance, the far right of the centre line, where it meets the circle, is infinite impedance. The top centre of the circle is a purely inductive impedance of magnitude Z_0, and the bottom centre is the capacitive mirror of the top.

Any point on the chart, representing the impedance at the open end of a cable (connected to whatever you like at the other end) will move at constant radius from the centre in a clockwise direction if the cable is lengthened, and anticlockwise if the cable is shortened. Each quarter wave moves an angle of 180° on the chart.

Although the chart is calibrated in impedance and also electrical length along the transmission line, the chart is actually a vector diagram (as shown by the red arrows in Figure 3). The forward voltage vector sent to the load (the voltage that would be present on a correctly terminated load) is always by definition a vector from the left hand side edge of the impedance chart to the centre. Any voltage vector reflected from the load towards the source starts from the centre and its length and angle are plotted on the chart in the normal way for a vector relative to the forward vector (an arbitrary case is shown). It is easy enough to see that a perfectly matched cable, when driven from a source of equal impedance, will have a certain voltage at its terminals, which we will scale as V_f on the chart. There is no reflection because the cable is correctly matched and the voltage is just V_f. This is half the voltage that would appear at the source if there was no load, because the source impedance is equal to the load. Now if something happens to the cable to change its perfectly matched impedance to an open circuit, then the voltage would be doubled (as we have just said). You can see this new open circuit impedance on the chart as a V_r vector that goes from the centre to the far right hand side. What has happened here is that in the representation of impedance as a reflection vector: power is still flowing from the source to the cable input (which is an open circuit) and also a reflection vector is coming out of the cable and returning the power back to the source. If you look at a proper Smith Chart with all the impedance lines drawn in you can directly see how a particular reflection vector relates to the impedance, to which it is equivalent. We have considered the open circuit case – now think about the short circuit case.

The distance of any impedance point from the centre of the chart, divided by the radius of the chart, is the reflection coefficient (Γ) of that impedance point. The reflection coefficient can be converted into VSWR – it is a measure of the same parameter, just on a different scale. The centre of the chart is 1:1 VSWR and the outer circle is an infinite VSWR, covering all the possible impedances (purely capacitive, purely inductive, zero resistance, infinite resistance). The ratio of reflected power to forward power is the square of the reflection coefficient Γ. All three quantities are giving the same information,

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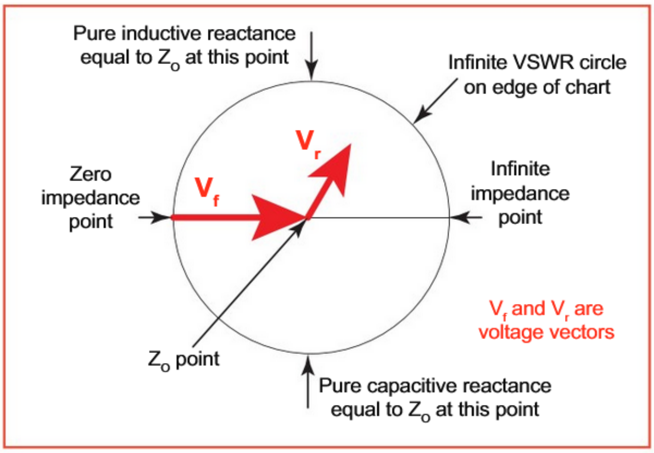

FIGURE 3: The impedance Smith Chart. The horizontal line covers all purely resistive impedances. The upper half of the diagram covers all inductive complex impedances and the lower half covers all capacitive complex impedances.

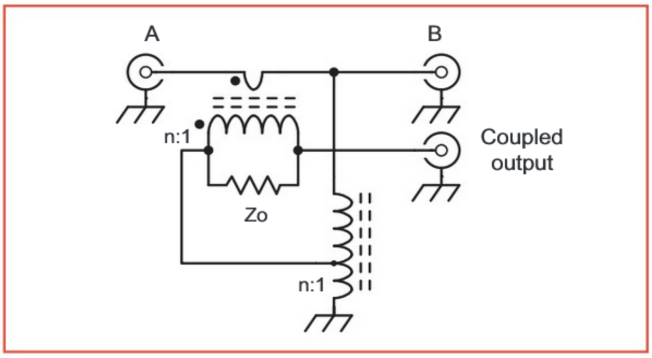

FIGURE 4: Basic concept of the directional coupler in a VSWR meter.

how good or bad the match is. The reflection coefficient sometimes has a phase angle associated with it; if the angle is given it just enables the actual impedance to be specified, as opposed to just how far out the match is.

The main signal on a transmission line, the forward wave, is a normal RF alternating current signal, which is carried along the line to the load. Any mismatch at the load causes a second signal, known as the reflected wave, to be sent back down the line in the reverse direction, but superimposed on the forward wave. The reflected wave is phase-coherent with the forward wave and, since it is travelling in the opposite direction, its phase relation to the forward wave changes with position on the line. This causes the effect that, at some specific points, the current of the reflected wave is in opposite phase to the forward wave current and subtracts from it, giving a current minimum, and at these points the voltages add. A quarter of a wavelength either side of these points will be points where the voltage of the reflected wave will be in opposite phase to the forward wave voltage and so will cause a voltage minimum and current maximum. This effect of the RF voltage or current envelope changing in amplitude along the transmission line is called a standing wave, but it is not a wave in the same sense as the forward and reflected waves since the points of maximum and minimum amplitude are at a fixed position on the line. The ratio of the standing wave voltage maximum to standing wave voltage minimum is called the VSWR.

Because the chart represents a vector diagram, we can see what happens to the standing wave as we move along the line and go angularly round the chart. For a perfect match at the centre, there is no change as we move round the chart, each 180° represents a quarter wave. If the reflected wave takes us from the centre to the far right hand side, this represents an open circuit

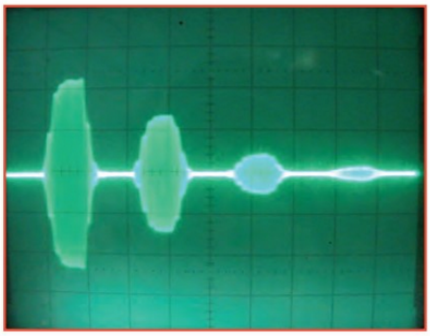

PHOTO 1: RF pulse into a length of coax (see text). Timebase is 100ns per division in all images.

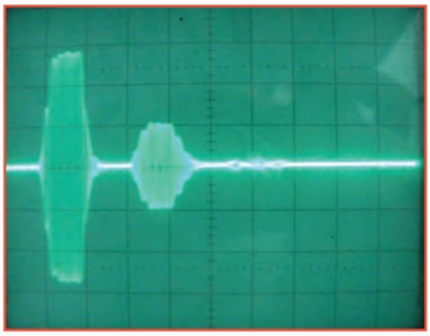

PHOTO 2: Same pulse as Photo 1 but with the cable properly terminated at the source end.

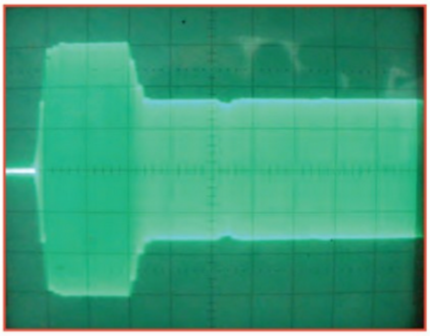

PHOTO 3: A much longer pulse (see text).

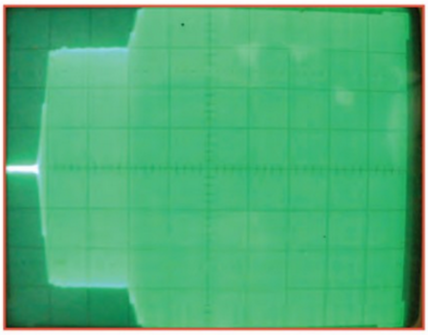

PHOTO 4: As per Photo 3 but on a slightly different frequency.

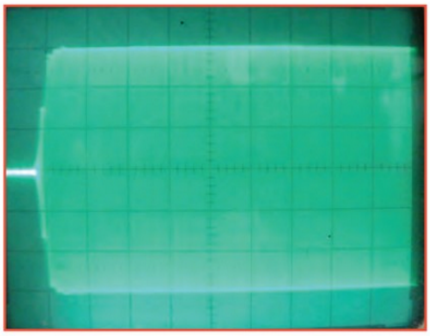

PHOTO 5: Correct cable termination prevents reflection.

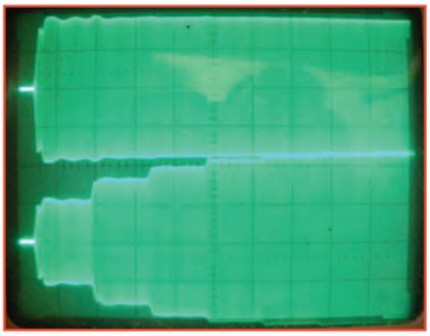

PHOTO 6: Observed voltages from the setup in Figure 7. Upper trace shows Tx forward wave, lower trace shows the feeder forward wave.

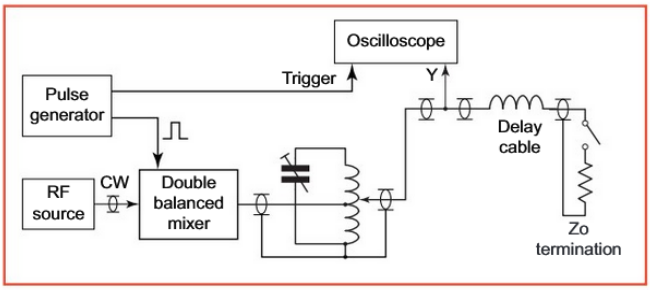

FIGURE 5: Test arrangement to show how forward and reflected waves determine the impedance looking into the sending end of the cable.

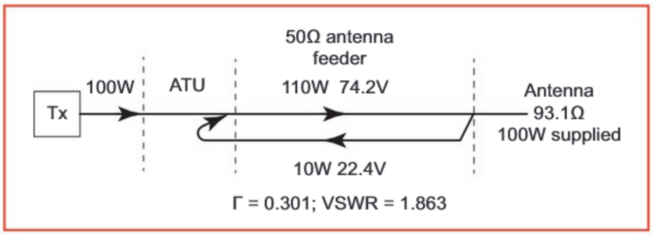

FIGURE 6: Power flow diagram for an antenna feeder having a standing wave ratio that is matched to a transmitter using an ATU. This diagram shows the power flow in the hypothetical case of no feeder or ATU loss.

termination (or twice the terminated voltage). As we move round the chart angularly, the radius (or magnitude) stays on the outer circle of the chart and after a quarter-wave (180° on the chart) we have come to the far left hand side and have a short circuit, or zero voltage where the V_f and V_r vectors cancel.

Directional measurements

So if a transmission line is terminated by an impedance that is not equal to Z_0, this situation is equivalent to saying that the transmission line is terminated in Z_0, and in addition to this some power is thrown back down the line in the reverse direction which is a fraction of the forward power. How can the load match be measured? There is no direct way to measure VSWR on a line without being invasive and sniffing the voltage or current along its length. However, provided we know the Z_0, of the line then we can determine the value of the VSWR by measuring the impedance looking into the line. To put it another way we measure the ratio of reverse to forward power (but we can only do this if we know the Z_0 of the line).

Since the current and voltage in a resistor are proportional to each other it is possible to measure instantaneous values, scale them for R and subtract one from the other such that the result is zero. This is the basic principle on which directional couplers work. In Figure 1, at a particular point on the line P, V_p is the sum of V_r and V_f, while $I_p = I_f - I_r$. What we want is V_f and V_r in isolation. It is a trivial matter to obtain a voltage proportional to a signal of interest in a circuit (V_r), the tricky bit is to balance out the contribution from an unwanted signal, V_f. If we provide an output equal to $V_p - I_p \times Z_0$ we can see that the contributions from the V1 source due to its components in V_p and I_p will cancel out. However the contributions from the V2 source due to its components in V_p and I_p will add: this is a directional coupler. It enables us to measure V_f and V_r independently. The types of practical circuit for such a coupler are fairly well known; **Figure 4** shows the basic idea. The directional coupler and an RF detector are the important components of a VSWR meter. We will not go into this in detail as this is a common topic in *RadCom* and shown in references. Now remembering that we concluded that measuring impedance and referring to reflected signal (reflection coefficient) are actually an indication of the same parameter, an alternative way to look at this is to say that the device in Figure 4 is an impedance bridge that gives no coupling between port A and the coupled output when the impedance on port B is Z_0. This means that the device can measure the signal flowing from B to A, with no contribution from the signal from A to B.

A practical experiment

Figure 5 shows a circuit that was set up to try to show how forward and reflected waves determine the impedance looking into the sending end of the cable. We can see a fairly crude indication of the impedance looking into the cable by the voltage at the source end. I used a reel of 75Ω coax I retrieved from a skip: it was unmarked but you can see from **Photo 1** that the one-way delay time is about 110ns. The time scale is 100ns per division in all of the oscilloscope plots in this article. The experiment was done at approximately 30MHz. The RF cycles would just about be visible on this time scale, but they are not seen because they are not synchronous with the timebase.

In Photo 1 a short RF pulse is sent into the line with a mismatch present at both ends. The pulse arrives at the load end, which is open circuit, and is reflected. After a delay the reflected pulse reappears at the sending end. The sending end is also not terminated properly and so some of the original reflected pulse is reflected at the sending end and goes down the cable towards the load for a second time. This process theoretically goes on forever, but of course the pulse is getting weaker all the time because of attenuation in the cable.

Photo 2 shows the same situation with a correct line termination at the source end. The pulse is reflected at the load end by the mismatch and appears at the source end, but all the reflected pulse is now absorbed at the source end so it does not appear at the load end for a second time.

Photo 3 shows the pulse lengthened so that it is longer than the oscilloscope time frame and does not stop until after the end of the trace. The cable is terminated in an open circuit at the load end. The frequency has been adjusted so that the reflected pulse is in the optimum phase to reduce the impedance at the sending end. We see the voltage at the source end is 3 divisions peak at the start of the sending pulse and then drops to about 1.7 divisions peak when the reflected pulse arrives at the source end. So the impedance at the load mismatch does not have an effect on the impedance at the source end until a delay of twice the cable length has elapsed.

Photo 4 shows the same long pulse and amplitude levels, but the RF frequency has been adjusted slightly so that phase of the reflected pulse is in the optimum phase to increase the impedance at the source end.

Photo 5 shows the same pulse and amplitude levels as Photo 3 and 4, but the cable is correctly terminated. You can see that, because there is no reflection, there is no impedance jump.

The standing wave that results from an imperfect match is a change in RF amplitude along the cable length. The amplitude will always be at the same level at a particular point on the cable for given power, frequency, and termination. So the wave can't be seen on an oscilloscope. In Photo 3 and 4 you can see the maximum effect of the reflected wave in both reducing (Photo 3) and increasing (Photo 4) the RF voltage.

Mode of propagation of a travelling wave on coax cable

We have discussed impedances and reflections. It would help to further clarify the matter if we are clear about the mode in which a travelling wave is propagated on the line. This is something that has caused confusion. We do not need to look into the electromagnetic fields (although I acknowledge there are complex effects at the frequency limits of coaxial cable) but for normal use we can consider that the cable just has uniformly-distributed inductance and capacitance. You can look at this in the references if you want to see this mathematically, but a simple explanation will help to clarify the situation. We can see from the symmetry in Figure 1 that the forward and reverse waves will be the same apart from direction of travel and magnitude. We know from the superposition principle that we can consider the forward and reflected waves completely separately as they do not affect each other. The voltage or current is measured at any point on the line it is

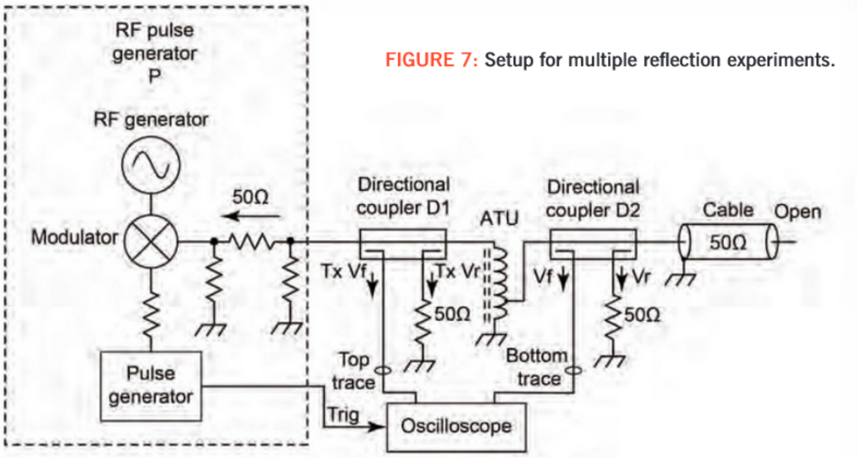

FIGURE 7: Setup for multiple reflection experiments.

the sum of the two (or current difference depending on convention). If we have a terminated line with just a forward wave, then the current is in phase with the voltage, and related by Ohm's law and Z_0, which is always purely resistive. (We are ignoring pedantic considerations which are not relevant to the feeders usually used in amateur radio and are outside the scope of this article.) So it would appear that the travelling wave inherently travels with I and V related by the pure resistance Z_0. Another indicator of this is that we saw from the experiment in Photo 5 (crudely) that the input impedance appears to be equal Z_0 right at the start of the pulse where the wave has no information about the termination – it is only the line that determines the input impedance here. We know that real power is flowing into the line for 110ns before it reaches the termination, because this energy is needed to make up that power which flows out of the line for 110ns into the load after the input is switched off. So it appears that the only way a wave can propagate along a transmission line (in either the forward or reverse direction) is in a mode where I and V are related by Z_0, with a phase angle zero. The theory says exactly these things that we have observed, simplified relationships from references (instantaneous quantities, any waveform type):

$V_f = I_f \times Z_0$ and $Vr = I_r \times Z_0$

At any point on the line, $V_p = V_f + V_r$ and $I_p = I_f - I_r$.

An important thing to note is that for a travelling wave the voltage, current, and power are all related by Ohm's law and Z_0 so any one will imply the other two. Also, the voltage and current will always be in phase. So the corollary to this, is that whenever the voltage and current looking into a line are not related by Ohm's law and Z_0, and are in phase, then this can only be due to a reflected wave. It is the movement of the reflected wave relative to the forward wave (because they are travelling in opposite directions) that causes the impedance to change with position on the line and the standing wave (which are different ways of describing the same thing). If it was possible for a travelling wave to have a mode of propagation on the line with a voltage to current relationship that was different to the line Z_0, then it would be possible for a line to exhibit an input impedance different from Z_0 that does not change with position on the line; this is never seen in practice.

Multiple reflections

We have seen from some practical experiments how reflections influence the impedance at the input of a miss-terminated line. A very important topic to the radio amateur is what happens when an ATU is used to tune out this mismatch at the radio end of a feeder having a VSWR significantly above 1:1. This situation involves a reflection at the ATU in addition to a reflection at the antenna.

We have been through the theory; if we apply it to the ATU case we see something like that shown **Figure 6**. We know that the reflected signal causes an impedance away from the line Z_0 at the shack end, and the ATU converts this impedance to what we need the transmitter to see, normally 50Ω. Figure 6 takes the case of no losses to avoid complication with details not of primary importance to understand the situation. Since there are no losses, all power not absorbed by the antenna is returned as a reflection. This causes some arbitrary impedance to be presented to the ATU. Provided the ATU can convert the impedance seen looking into the line to 50Ω, then the transmitter operates into 50Ω and all the power delivered by the transmitter to its load appears at the antenna.

Figure 6 shows the effect G3XJE mentioned in his earlier article, that the forward (and also possibly the reverse) power in the feeder can be above the transmitter power when there is a mismatch at the load. This may seem a little strange if you have not considered this before, but from a logical point of view this is the only solution that fits with the known characteristics of the various components we are now putting together. This behaviour of RF circuits is well known by people working in this field. The components have no loss, so provided a match condition can be found it will be possible to transfer 100% of the input power to the output. Because of the termination on the feeder there will be a reverse power that is some fraction of the forward power. The net power conveyed to the antenna is the difference in the forward and reverse power, so this must be equal to the transmitter power. At low frequencies, the mismatched antenna feeder with an ATU at the source end to provide a good match to the radio is quite common. Figure 6 does not consider losses. When these are taken into consideration, a poor antenna match will increase losses due to the increased feeder and possibly ATU loss. What is going to be good enough depends very much on the situation. The higher the frequency, the higher the cable loss and generally achieving a low loss is more important at high frequency. The earlier G3XJE and also the ARRL reference are good at explaining the practical significance of feeder loss.

Multiple reflection experiments

An experiment was done to demonstrate what happens in the situation shown in Figure 6. Actually, a cable that had significant loss was used because it needed to be fairly long to conveniently show the effects in the time domain. **Figure 7** shows the equipment setup, and **Photo 6** shows the result of the experiment.

At the input to the line there is a significant VSWR. Both directional couplers are the same and have negligible effect on the through path. A normal LC ATU could not be used because the bandwidth would not be wide enough to cover the bandwidth needed to look at signals with features in the time domain that are associated with practical cable lengths, so the ATU was replaced with a ferrite transformer. The frequency was adjusted to a point where the V_r vector at the input to the line was in anti-phase with the V_f vector, the lowest impedance possible (but not zero because of line loss). The 'ATU' was then adjusted to give a good match at the input. A pulsed RF source P supplied a signal at the input to the first coupler D1. The pulse was longer than the time frame on the oscilloscope so the place where the pulse stopped was off screen. It is important to note that P has a matched output impedance, and this means that the forward power in D1 is constant regardless of the load impedance. If the output of D1 is perfectly matched by the 'ATU', all power is absorbed in the load. If the output of D1 is not perfectly matched, some or possibly all the power is reflected back towards P. Since P has a matched output impedance all power reflected back into it is absorbed and this does not change the forward power from it. Photo 6 shows the observed voltages of the Tx forward wave, top trace, and the feeder forward wave, bottom trace. The powers are proportional to the squares of these traces and both traces are to the same scale.

A thing we are expecting from the similar previous experiments is that the impedance looking into the feeder is changed by reflections. This is an important reason why a matched output impedance is used on the pulsed RF source. Notice that, within the measurement accuracy of this experiment, the Tx signal level is constant from the start of the pulse (at about ½ division into the trace). Notice also that the forward voltage on the feeder at the start of the pulse is about 1.1 division peak, while the Tx voltage is about 1.8 divisions peak. This is because the feeder is a good match at the input before any reflections return, and so the 'ATU' is introducing an unwanted impedance change, which causes some of the Tx power to be sent back into the Tx and the feeder V_f to be reduced from what it would be with no ATU. Only about 40% of the Tx power is in the line forward power. At approximately 2 divisions into the trace the first reflection from the load arrives back at the line input end This has the effect of lowering the line input impedance. The effect of the reflection arriving is twofold:

a) lowering the impedance increases the proportion of the Tx power that is matched into the feeder and reduces the proportion of the Tx power reflected back to the Tx;

b) some of the power that was returned in the feeder reflection will be mismatched at the 'ATU' interface and reflected back along the feeder towards the open end.

Both a) and b) have the effect of increasing the feeder forward power. Because at this point an increase has been made to the feeder forward power, after a second 'there and back' delay there will be a further increase in the feeder reflection and this causes a second, slightly smaller increase in the feeder forward wave, at approximately 3.4 divisions into the trace.

This process of settling down carries on for several cycles, each taking twice the feeder delay. Eventually the match conditions converge to the situation that I had tuned up under static CW conditions where the ATU matches the feeder to the Tx. The time necessary for the feeder standing wave to settle down is tied to two physics fundamentals: a) there is a delay in signals propagating along the feeder, and these cause the steps in the trace; b) there is stored energy in the forward and reverse power of the traveling waves that make up the standing wave. This can't be supplied instantaneously from the finite input power of the Tx signal. Increasing the feeder delay would increase the stored energy, also increasing the VSWR would increase the stored energy. Higher stored energy requires a longer time for a given degree of settling.

When the energy store has been pumped up, the feeder forward and reverse powers, which are largely circulating, can be *higher than the Tx input power*. We can see that these travelling waves carry real power by the way that the voltages get pumped up by each new contribution step. The voltage and power going into a load, if there was one, would follow similar steps. The Tx reverse power (not shown) starts out high and goes down towards zero with each step, converging towards the good match under static conditions.

In this example at the start of the pulse the 'ATU' was introducing a mismatch that reduced the feeder forward power; after the circulating forward and reflected signals had settled down, the feeder input impedance had changed to the value I tuned up under static conditions, V_f / Vtx = 2.3/1.8 and so the forward power was about 1.6 times the Tx power. This situation is similar to the more familiar case of a high Q LC resonator that, when resonant, can transfer more stored energy between the L and C in each cycle than is supplied in energy each cycle to keep the resonator running.

Conclusions

Transmission lines have many applications in electronics. They are not only used as interconnect they are also used for interesting circuit functions. It is interesting to look at alternative perspectives on things to gain fresh insight; it may be worth looking at topics such as microstrip and distributed amplifiers and of course the basic theory if you are interested in transmission lines. There is often more than one way to look at things, and there is nothing wrong with looking at transmission lines as matching networks and not thinking too much about forward and reflected waves; but the forward and reflected waves are the most complete way to visualise what goes on, due to time effects etc. It can be seen from the experiments that *real power does flow in both directions simultaneously on the line and the standing wave and impedance changes results from this.*

The discussions around Figure 1, Figure 2, and Figure 3 are really showing the same thing in different ways. If you understand one of them, the other two are just helping to expose the significance of what you already know.

The Smith Chart is a clear way to relate the magnitude of the reflection to impedance.

In the situations we have been discussing, Z_0 is a parameter that has real meaning in the circuit, and hence the reflected power has a real meaning: it does actually flow on the line. However in some situations, Z_0 is an arbitrary choice as far as the circuit is concerned; for example when semiconductor devices have their impedance parameters specified by way of reflection coefficient, the common reference impedance of 50Ω is of no significance to the device, it is used because it is an RF measurement standard.

If 80% of the power is thrown back out of a matching circuit that we intend to feed our new expensive PA transistor into, this may be exactly what we are aiming for. The reflection coefficient magnitude and angle are used to represent circuit impedances, but the magnitude of the reflected power alone does not really mean anything that relates to the circuit in an example like this. If the device was characterised in 75Ω, its parameters expressed as reflection coefficients would be different, though the device would be unchanged. It is possible that some misunderstood comments in a context different to where reflected power has a real meaning, caused a misconception that reflected power on a transmission line is not real. It is also of course true that on the radio side of a properly-matched ATU there should be no reflected power.

Long mismatched cables as aerial feeders can be a cause of loss, but mismatched cables can also be intentionally used for impedance transformation. Thinking more of the general use of cables than the particular case of aerial feeders, the reflections on mismatched cables can cause loss of frequency 'flatness' in wide-band systems, but this is not normally of significance amateur radio systems. Mismatched cables can also cause problems with fast modulation if the cable delay becomes comparable with the shortest time elements involved in the modulation, but for most amateur radio applications this is not an issue. The problems in frequency and time at the load end in fast and wideband systems due to mismatch are theoretically not seen provided the cable is correctly terminated at one end at least. Terminating both ends gives better performance if the terminations are not perfect. An example where these issues of fast signals and wide bandwidths are relevant is analogue TV signals and homebrew microwave test equipment if frequencies span a wide range and frequency flatness is needed. Multi-band radio systems are usually tuned for each band so this is not an issue.

The question now arises; since we have generally considered cases where the source impedance is equal to Z_0, how does this relate to a typical radio installation? A high power amplifier has the output matched for considerations of efficiency and other issues; the impedance looking back into the amplifier is not normally a consideration. If the feeder has a VSWR greater than 1:1 then an ATU should be used between the power amplifier and the feeder and in this case there is no reverse power at the amplifier. The VSWR is only of significance to feeder loss in this case. In the case of a valve amplifier and pi tank, the tank is in effect an ATU of limited tuning range, so provided the VSWR is within its range an external ATU is not needed (harmonic suppression is poorer if the loading capacitor is reduced towards zero). Usually at HF precise matching of the Rx to the antenna is not so important. At higher frequencies the feeder loss becomes significant both for Rx and Tx and so while the theory is still valid, at VHF the antenna should be a good match to the feeder and the aim is to minimise feeder loss rather than tune out mismatch. If a solid state amplifier is connected to a feeder with VSWR greater than 1:1 without an ATU (ie the wrong impedance load) and the full drive level is used, then this will have an adverse effect on things such as linearity, amplifier stress and output power; either automatically or by manual adjustment the drive (and hence output power) must be reduced. So to summarise, provided an ATU is used VSWR is only a feeder-loss issue. The time taken for the reflections to settle in the experiment, less than 1μs, is of no significance to a radio system using a 3kHz bandwidth where the rise time is in the region of 100μs.

Continued on page 73

Sharman multiCOM SM-30II switch mode power supply

There was a brief primer on power supplies in the June *RadCom*, (page 36) that will give you the basics on the different types of power supply available.

The Sharman multiCOM SM-30II is a 30 amp switch mode power supply offered by Moonraker. As a recap, switch mode power supplies work by converting AC into DC first, and then transforming this into the desired voltage that will run much of our radio equipment.

Choices

When buying a power supply for the shack, you have two main choices to make: switch mode or linear. Linear power supplies produce no noise on our bands but are typically much bigger and heavier than the smaller switch mode power supplies. Switch mode power supplies (SMPS) sometimes get a bad reputation for generating noise. Sometimes this is justified and sometimes not. A well-designed one for amateur radio use should come with good EMI filtering, RF shielding and the function to move the noise to another frequency.

So, while a SMPS produces more noise than a linear supply; it has some considerable benefits too, enabling the average amateur to compromise. They are a lot more efficient, generating less heat, requiring less of a heatsink and therefore resulting in smaller and much lighter form factor than a linear supply.

The front of the Sharman mutliCOM SM-30II switch-mode power supply unit.

Out of the box

The Sharman multiCOM SM-30 switch mode power supply can provide a variable voltage from 9V up to 15V DC, delivering 20 amps continuously and up to 30 amps at peak. The unit is supplied with a simple user manual that covers everything you need to know about the power supply; most amateurs probably won't need it anyway.

The unit comes with attractive analogue meters to monitor both the amps and volts; these are both brightly illuminated and are easy to read. After using power supplies with mostly digital meters, I found the analogue meters a refreshing change.

The power supply includes a noise offset control to eliminate the pulse noise of the switching circuit. This is a patent-pending function and is specially designed for communication equipment use. Additionally, it has built in protection for short circuits and automatic current limiting (over 30A).

The Sharman power supply comes with the typical range of connectors. On the back of the unit, you will find two binding posts, supplying up to 30A for your transceiver. These will allow you to use fork and ring terminals and banana plugs. On the front of the unit, you will find two pairs of snap-in terminals supplying a maximum of 3A each. These would be handy for quickly connecting shack accessories like an ATU, power meter etc. Confusingly, the two positive/negative terminals are not consistent, with the two negative terminals appearing next to each other. As always, look and check twice before connecting any equipment to ensure the correct polarity!

On the front panel you will also find a cigar outlet supplying up to 10A. This could be useful for powering a receiver or a handheld with a cigarette power adaptor. It is also a straightforward way to add USB charging capability by plugging in a car USB adaptor.

In use

Setting the required voltage using the front knob is easy, once you remember there is a switch on the back of the unit, which either keeps the voltage locked at 13.8V or allows it to be variable from 9V up to 15V! Leaving the switch set to 13.8V effectively disables the voltage adjustment knob on the front, which is a neat safety feature if you only plan to power equipment requiring 13.8V (ie most commercial transceivers).

Flicking this switch to the ADJUST position enables the front knob and allows you to select your desired voltage. Two things to note here, if I were being picky on the voltage adjustment knob; it does not have a notch to let you easily know when

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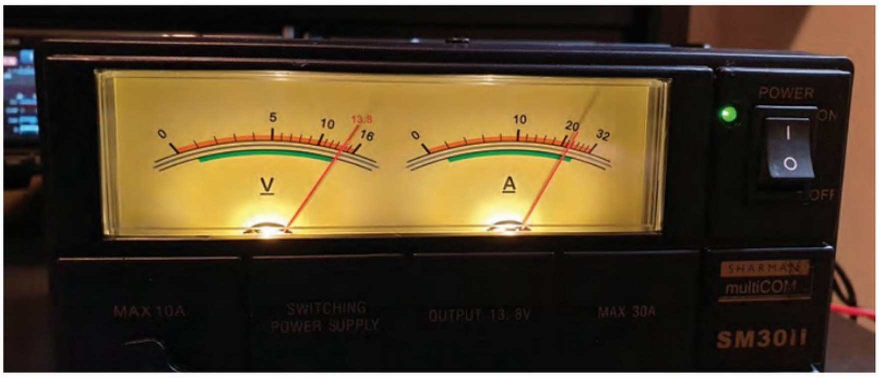

The power supply features two attractive backlit analogue displays.

The back of the Sharman multiCOM SM-30II switch-mode power supply unit.

it is set to 13.8V and, it is labelled as "VOL ADJUST". This label could be misconstrued as a volume adjustment, possibly!

Drawing 20 amps on transmit resulted in little discernible noise from the power supply, despite the seemingly oversized fan in the unit. You could hear the fan spinning during use, but it was noticeably quiet and certainly quieter than the fan on another PSU I have on transmit. I did not notice any switching noise on HF while using the power supply, but should you notice any on a frequency of interest, you can use the NOISE OFFSET knob on the front unit to shift it to another frequency.

Conclusion

The model on review here currently has a special offer price of £69.95 (regular price is £79.99) from Moonraker. The price is good for a power supply unit like this. The power supply is lightweight, but quite big for a 30A power supply, this would not be a problem if you just intend to use it in the shack but might be a little large for travel use. Moonraker also offer the SM-50II model, which is the same as the SM-30II, except it supplies up to 50 amps.

Thanks to Moonraker for supplying the review model (www.moonraker.eu).

Websearch

https://moonrakeronline.com/sharman-sm-30ii-30-amp-switch-mode-dc-power-supply

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

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[1] www.rsgb.org/radcompix
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Downtown Georgetown shopping area – Cross Hill in background, photo courtesy M0BLF.

Ascension Island Government Office in Georgetown – where amateur radio licences are issued, photo courtesy G3ZAY.

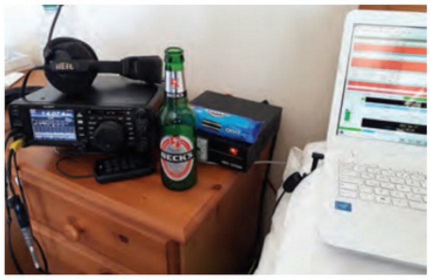
Operating

As the Club Log Most Wanted 110th entity ranking for digital, I made this mode my priority. As I was sharing my room with a colleague, my on-the-air hours had to be limited, but in just six weeks I was able to reach the DXCC award. I also participated in the REF SSB and ARRL DX SSB contests working only Sundays on SSB.

During the month of March, I took part in the Russian DX and CQ WPX SSB contests. Unfortunately, plans for the departure changed and I left the island on 8 April, before I could setup an antenna for 30m; so there was no activity on the 10MHz band.

Altogether I managed to log 10,516 QSOs on seven bands, 139 different DXCC entities and 174 QSOs were with G stations. My QSL policy has been immediate confirmation on LoTW, eqsl and qrz.com. With the Covid-19 pandemic, many people have started to use these methods and I reached my target of the DXCC Award with 129 confirmed. The ranking of ZD8 for data is now 141 at Clublog; so it seems like I have made some guys happy. It is always very enjoyable to be on the other side of the pile-up.

BBC Atlantic Relay antennas at English Bay, courtesy G3ZAY.



The rig and the cooler!

What's next?

Looking forward to Covid-free days, I am now in the planning phase for the next one. D6? A2? or 9H? Who knows?

See you further down the log...

Impedances and reflections on transmission lines – continued from page 48

I have read three articles suggested by others in The Last Word to support the myth that reflected power does not actually exist on a transmission line. Here are my findings.

1 – an article on the Bruene Directional Coupler by Gary Bold: This appears to explain the directional coupler in a normal way. It refers to forward and reverse power, and I do not see any reason to think it is suggesting that the reverse power on an antenna feeder is not a real power which may be measured.

2 – The Myth of Reflected Power by IZ2UU: This article, despite the title, does not suggest that reflected power is bogus. Rather, it describes forward and reflected power in what I would consider a normal way. The aim of the article is to bust a myth surrounding the reflected power, but there is not a suggestion that reflected power does not exist.

3 – Power in Reflected Waves, Ham Radio, *Oct 1971*: This article clearly is claiming that reverse power does not exist on feeders. Unfortunately, this article appears to have been published at the wrong time in the year. It should have been either six months earlier or six months later *[ie April – Ed]*. There is a confusion over the matching of the transmitter PA into the feeder having a VSWR greater than 1:1, and an idea that this means that reverse power on the feeder will be directly coupled into the amplifier. If an amplifier output is coupled into a feeder having a VSWR greater than 1:1 using the normal type of tank, and the tank is capable of being correctly adjusted, then any reverse power will be reflected back along the feeder in the forward direction by the tank and not appear in the amplifier as suggested in the article. We have already discussed this. The conclusion made in the article that reverse power does not exist is not correct.

References

On the effect of VSWR:

SWR and all that, G3XJE, *RadCom* September 2020

Understanding SWR by example, Darren Walraven, K5DVW, *QST* November 2006, viewable at www.arrl.org/files/file/Technology/tis/info/pdf/q1106037.pdf

On transmission lines:

Transmission Line Theory, Dr M A Motawea, https://deltauniv.edu.eg/new/engineering/wp-content/uploads/chap.3.pdf

Introduction to Transmission Lines, Dr Farid Farahmand, http://122.physics.ucdavis.edu/sites/default/files/files/Electronics/TransmissionLinesPart_II.pdf

On SWR meter theory:

Notes on Directional Couplers for HF, K6JCA, http://k6jca.blogspot.com/2015/01/notes-on-directional-couplers-for-hf.html

Design Notes

A big attenuator

Once in a while we may want to test a source, a transmitter driver or a beacon driver for example, by feeding it into a receiver antenna input. It is usually desirable that the signal into the receiver is not too strong – and we may even want to reduce it down to the receiver noise threshold if we're doing tests at low S/N ratios. The attenuation needed will often be in excess of 100dB, possibly as much as 160dB for weak signal testing. It may be tempting to just let a bit of signal 'leak across the room' from a bit of wire shoved the RF ports on the receiver or the source, but the unpredictability and changing level soon leads to annoyance with this crude attempt at getting a large amount of attenuation. And if either end is running unshielded, this is a route to nowhere. If we have a sufficient number of coaxial attenuators these *could* be strung together in a long chain, but who has six or more 20dB attenuators to hand?

I do have the switched attenuator shown in **Photo 1**, which is useable up to a few tens of MHz, but it does only go to 100dB maximum. Clearly some extra attenuation was needed, so how about making a 100dB attenuator?

Deriving the resistor values for making matched attenuators using a Pi or Tee configuration is straightforward. First, obtain the attenuation as a voltage ratio using the equation $A = 10^{(-dB/20)}$ to convert decibels to a voltage ratio less than one. For a system impedance of 50Ω, the value of the two shunt resistors in a Pi network are then given by $R_{SHUNT} = 50 \times (1+A)/(1-A)$. The single series resistor in the Pi design is then $R_{TOP} = 50 \times (1-A^2)/2A$.

If a Tee network is preferred, the two series resistors are $R_{SERIES} = 50 \times (1-A)/(1+A)$ and the single shunt resistor in the middle becomes $R_{MID} = 50 \times 2A/(1-A^2)$.

Returning to the 100dB attenuator, any attempt to do it in a single stage would be ridiculous – the series resistor for the Pi would have to be 2.5MΩ and just a fraction of a pF of stray capacitance would make a mockery of this value at frequencies above a few MHz. However, by cascading four 25dB stages, the values become more realistic (at $R_{SHUNT} = 56Ω$ and $R_{TOP} = 443Ω$).

A design to the circuit of **Figure 1** was built using microstrip on 1.6mm PCB material. The PCB was made using a scalpel to mark out the track and its gaps, then a hot soldering iron used to peel away unwanted copper areas. 0805 SMT resistors were used and, as I only had values in the E24 series, an approximation to the 443Ω was needed. Three stages using 430Ω in this position and one of 470Ω were calculated to give the overall value of 100dB. To attempt to increase power rating a bit at the input, where all the incident power would be dissipated, two resistors were used in parallel at each end of the attenuator. The PCB has a continuous copper underside. Copper foil wrapping the edge on each side gives a low impedance ground for the shunt resistors. The finished 100dB attenuator can be seen in **Photo 2**. I only wanted operation to a few MHz so BNC connectors were quite satisfactory. It behaved as expected at the test frequencies of 475kHz and 2MHz and did indeed present 100dB insertion loss on testing. All testing of my signal source then proceeded as expected.

PHOTO 1: Switched attenuator – these can often be found as surplus at rallies and from some of the second hand equipment suppliers. The one shown is good up into the VHF region.

Bit of a puzzler

Sometime later I thought I'd see what sort of frequency response this unit was good for. I'm fortunate in having a digital radio test set – purchased at a Microwave Roundtable – that amongst other dubious tasks works as an excellent narrow band spectrum analyser from near DC to 6GHz. It is completely digital and if a narrow-enough resolution bandwidth is selected can measure the level of a stable carrier over more than 100dB dynamic range. The same sort of capability any modern SDR with FFT and display software can offer, but over a wider tuning range. In conjunction with an RF synthesiser with a calibrated and known output level (of +10dBm) the frequency response of the attenuator was plotted at a number of frequencies from 10MHz to 1GHz. BNC connectors do not behave too well when you go over about 1GHz, so I

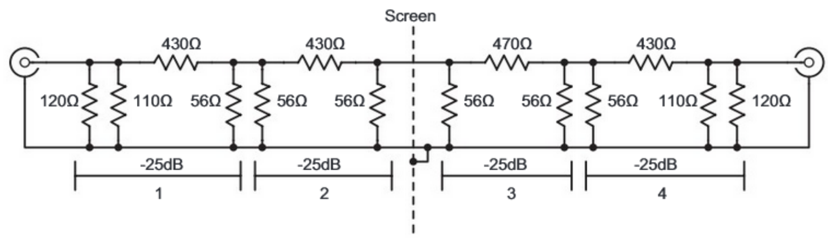


FIGURE 1: Circuit of a 100dB attenuator made from cascading four 25dB sections.

PHOTO 2: Practical implementation of Figure 1. Constructed using 0805 SMT resistors on microstrip. There is a continuous ground plane on the rear with copper foil wrapped round the long edges connecting the top grounding area to this.

decided to stop there. The graph shown in **Figure 2** was the result and it threw up a big surprise. Up to around 20MHz the measured attenuation was within 1dB of the design value. Above 30MHz, something appeared to be degrading performance quite fast, so that by the time 145MHz was reached, attenuation was down to 86dB. I'd hoped for a response a fair bit better than that and for a more gradual degradation – after all, the construction of the PCB really ought to be good for use up to at least low UHF.

What came as a real surprise, though, was that from 150MHz up to 200MHz the attenuation started to increase again, so that at 200MHz it was nearly back to 100dB. It then steadily degraded, but more slowly, dropping to 87dB when testing stopped at 1GHz. The puzzle is, why the abrupt drop in performance at a relatively low VHF frequency then recovery as frequency then rises further? The behaviour is as if some low-Q resonance is taking place in the 140MHz region that causes coupling between the ports. The PCB and casing would appear to be too small to contribute any resonances, so it is difficult to envisage it being a layout or construction issue. And then why is performance so smooth from 200MHz to 1GHz? There must be some resonance in the low VHF region in there. A measurement using completely different test equipment (not nearly so precise) also confirmed the value around 145MHz, so I can't blame the test set.

I wondered if the resistors themselves were misbehaving at VHF. Design Notes October 2013 described how 0805 sized thermistors were tried in an attempt to build a thermal balancing type power meter. They were found to be useless above 10MHz, appearing inductive. To test this hypothesis, a single stage attenuator using identical resistor types and values was built rats-nest style and tested on one of the ever-popular VNWAs covering DC to 900MHz. A flat response to within 1dB of the expected value (of 25dB) was observed. So, as Sherlock Holmes said, "Once you have eliminated the impossible, whatever remains, however improbable, must be so". Perhaps there is something in a double-sided PCB, 17mm wide and 80mm long with top to bottom connection via foil wrapped around the edges that causes a resonance or stray coupling at low VHF frequencies. Is the diecast box doing something it shouldn't? Perhaps something to watch out for in future breadboards. At some point in the future it may be worth rebuilding in a tinplate box with the PCB connected on all sides, top and bottom, to the walls.

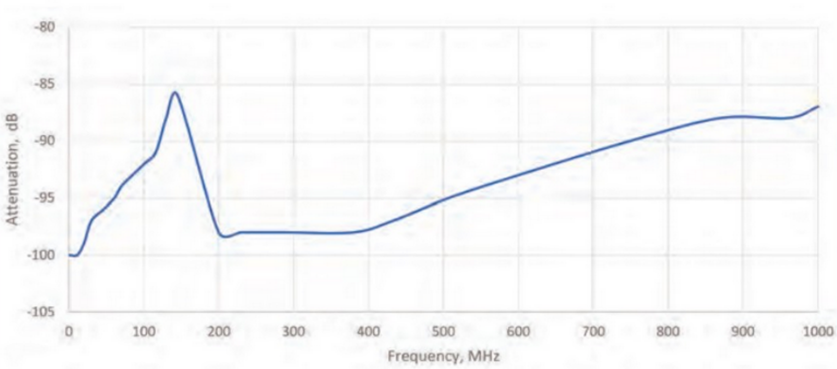


FIGURE 2: Measured frequency versus amplitude response of the homebrew attenuator shown in Photo 2. Note the unexpected poor performance in the 20 – 200MHz region, then a recovery followed by the more expected slower degradation up to 1GHz.

Later generation PIC micros

Strictly speaking, this is being written ten years too late. 'JNT Labs is quite slow off the mark when it comes to adopting later digital technologies and devices, but at least when a new something has at last been taken up, there is plenty of information out there about its idiosyncrasies. A recent case is a move from the old tried and trusted PIC16F628A PIC microcontroller to the later generation 16F1827. I originally moved to the '628 from one of the very first workhorse PICs, the 16F84, around 15 years ago after the '628 had itself been around for a few years. Until recently the '628 served in my applications in all but a few cases, mainly those where an A/D conversion was essential. If more memory was needed, its larger brother the 16F648 served. For analogue conversion projects, the 16F819 did the job. Other PICs of a similar vintage were used when smaller or larger pin counts were needed: all had much the same complexity and used the same command set – so JNT Labs became very familiar indeed with programming PIC 16F devices in assembler. Some while ago I had purchased a few of the (then) new and enhanced 16F1827 devices, as these offered four separate pulse-width modulators that I had hoped to use in a single-chip quadrature tone generator to be used for creating baseband modulation for direct I/Q upconversion. To use the 16F1827 would have needed an upgrade in both assembler

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software and programmer hardware *and* a learning curve, so that never happened at the time – the I/Q source went ahead with a separate A/D converter chip instead. Now (complete with new assembler software and upgraded programmer that had been forced for other reasons) I wanted some code for generating the new FST4 WSJT mode in a single PIC device. FST4 encoding makes use of a large parity lookup table to generate the error correction bits and that would use up most of the memory of a '628 just for the table itself. So it was time to re-investigate those later generation chips sitting in the junk box.

The 16F1827 has been around for about 8 years now and really offers an extraordinary lot of peripherals and useful capability in a single chip costing less than £2 – cheaper than a 16F628A. With 4K of memory, twice as much as the 16F628A, it includes an A/D converter with multiple input channels, four pulse width modulators with improved capabilities over the single one in the '628, plus assorted timers and all the other peripherals that the earlier device already carried. There are a few other peripherals also perhaps worthy of a look later. The 4K of memory meant room for my parity matrix, but on reading the datasheet **[1]** I saw it also had better memory reading capabilities. Those who use the 16F family of PIC devices will be familiar with the original rather clumsy procedure for lookup tables, a process returning a single 8-bit value via a RETLW command. Now these later generation processors include new registers that allow program memory to be read directly, making large tables easier to implement. The full 14-bit wide memory can now be used for tables, so the 101 bit x 139 parity matrix needed for FST4 code generation can be stored as 139 x 8 fourteen-bit words, for a total program memory usage of 1.1K.

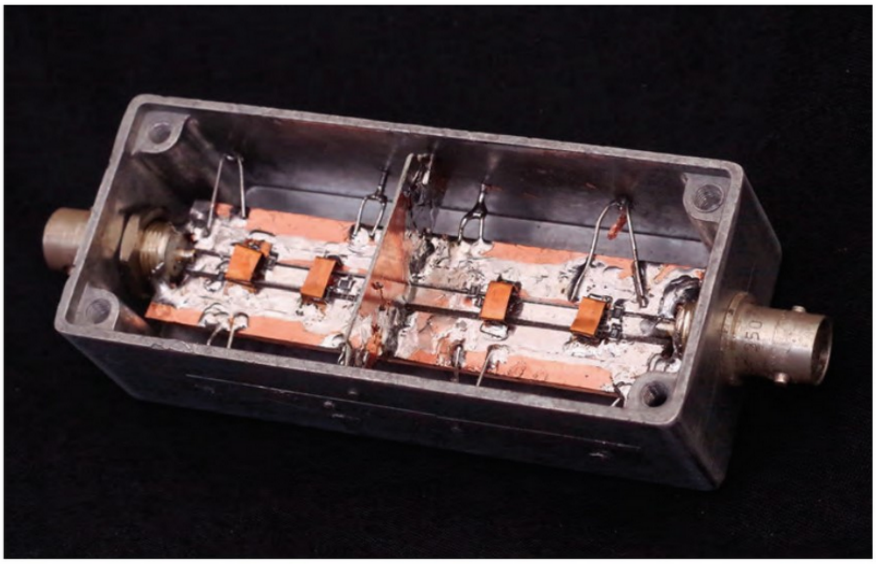


PHOTO 3: **Modifications to the 100dB attenuator to remove the unwanted leakage that degraded its attenuation around the 150MHz mark as seen in Figure 2. PCB pins in the wall of the diecast box allow the PCB to be connected to the sides, making the attenuator useable now up to at least 500MHz.**

Diodes as temperature sensors

One peripheral embedded inside the 16F1827 is a temperature sensor, configured as one channel of the A/D converter. It is quite simple, merely measuring the voltage drop across a few diodes. It is uncalibrated from device to device, so is only any good to get a rough idea of temperature – and even then the chips need to be individually calibrated.

The thermal resolution, in terms of A/D output count versus temperature, is between 0.5 to 1 degree per A/D count, depending on supply voltage – but at least it is linear!

Quite often we need to read a temperature, if only to turn on fans or show a warning or reduce power when heatsinks become too warm. Thermistors are often called into use here and, when used just to trigger at particular thresholds, work very well. But things are different if an actual temperature measurement is needed. Thermistors are far from linear, so they are difficult to use as thermometer sense elements with any degree of accuracy.

One low-cost solution is to simply to drive a constant forward current of a mA or so through a few diodes in series and then measure the voltage drop across them **[2]**. At constant current, the voltage across each diode is linearly proportional to temperature, dropping by about 1.8mV per degree C. The actual voltage across the diode at any particular temperature varies from device to device, but the roughly -1.8mV/°C is reasonably uniform across diodes of similar type and batch. It may be a convenient solution to a quick and cheerful temperature indication. As the temperature response is linear, all that is needed to get an absolute calibration is a measurement at just two known spot temperatures. From this is it straightforward to construct the calibration chart.

1.8mV/°C may not sound like a lot but four diodes in series gives a total swing of about 720mV over a 100°C range. Even the naïve approach of feeding this straight into the input of an 8-bit 0-5V ADC will give you a working range of about 36 counts, or an increase / decrease of roughly one count per 3°C temperature change. Raising the reference voltage to 2V and reducing full scale to 3V – often quite easily done with little more than a couple of resistors – gives a resolution better than 1/3°C per count.

STOP PRESS: Latest news on the 100dB attenuator

After originally writing the attenuator section earlier in this month's column, I reasoned that the leakage must be due, somehow, to the non-grounding of the sides of the PCB to the diecast box. So in an attempt to cure it, I drilled several 1mm holes through the sides of the box and inserted PCB pins, connecting these to the top copper grounding plane as shown in **Photo 3** above. This not-pretty modification resulted in the sharp reduction in attenuation around 150MHz being completely eliminated, with 100dB overall attenuation maintained up to around 500MHz. Above that frequency the attenuation falls gracefully, exactly in line with the curve shown in Figure 2. This isn't exactly the complete rebuild into a tinplate box I was musing about earlier, but it does suggest that I might be onto the right track.

So, the leakage was solved, but why was this occurring in the first place? What resonance element or effect could be happening in the mid VHF region in such a configuration?

Answers on a postcard please.

Websearch

[1] Microchip PIC 16F1827 (series) datasheed: http://ww1.microchip.com/downloads/en/devicedoc/41391d.pdf

[2] Texas Instruments paper on using diodes as temperature sensors: https://www.ti.com/lit/an/sboa277a/sboa277a.pdf?ts=1622545013723

Review

Comet CAA-500 Mark II standing wave analyser

The CAA500 Mark II came in handy for adjusting the reviewer's 80m dipole. The lead image shows the readings in SSB part of the band, with SWR around 2:1, whilst the right image shows the antenna almost resonant on the CW part of the band.

What's the purpose of an antenna analyser and why would you need one?

Simply, it tells you the resonant frequency of a particular antenna, allowing you to trim the antenna to the frequency you want to use it. It'll give you the SWR and impedance of the antenna at that frequency and perhaps show you a SWR curve of the antenna, allowing you to see the SWR at different frequencies in the band.

Background

Antenna or Standing Wave Analysers are a comparatively new thing. As a young G4, they weren't about at all. We'd measure the SWR using a SWR bridge, first at the top of the band, and then at the bottom of the band. If you were lucky, they were the same, meaning that the SWR was flat across the band. Otherwise, it was a case of measuring the SWR at various points in the band, deciding where you wanted the antenna to be resonant and trimming the antenna accordingly to achieve this. Did you need to bring the resonant frequency up a little, by shortening the antenna, or bring it down, by lengthening the antenna? Perfectly do-able with a transmitter and an SWR bridge, but not the quickest of processes and one potentially involving a bit of shoe leather between the shack and the garden.

Then, I became aware of people turning up on contests or DXpeditions with these little boxes, with a display, generally two meters, showing SWR and impedance and a couple of controls – a band switch and a 'tune' control with one or more antenna inputs. The great thing about these units was that they could be taken out into the field and the adjustments made without needing someone at the transmitter end, someone in the garden and all that back and forth!

Early antenna analysers were quite expensive and I did not have one! Over the years though, the price has come down and many amateurs find them invaluable in their station, especially if a lot of antenna experimentation and work is done.

That's a little bit about what an antenna analyser does and why you might want one. More specifically, what about the Comet CAA-500 Mark II? What does the manufacturer say about the unit?

The NEW CAA-500 MKII version SWR/ Impedance Analyser now adds a full colour TFT LCD display to the original model whilst *still featuring an analogue cross needles display for SWR and impedance.*

Auto Sweep Mode: Automatically graphs the SWR on the LCD display. Choose any one of the pre-set amateur band frequency ranges and press the sweep button in for about 30 seconds the SWR graph is completed and displayed.

Manual Sweep Mode: Choose the band and manually set the band-width and manually sweep the chosen frequency range.

Multiple Manual Sweeps: Should you want to make an adjustment to the antenna length, to the position, height above ground, a gamma match adjustment, etc – you can overlay 5 manual sweep results in different colors! Instantly graph and see exactly what happened after each adjustment!

- Range: 1.8 - 500MHz
- RF output level: 0dBm 1mW
- Measured SWR Range: Analogue meter 1.0 6.0:1 , LCD display 1.0 9.9:1
- Impedance measurements: 12.5-300Ω
- Reactance range: 0 - 500Ω Oms (absolute value) 1.8 -190MHz
- Battery indicator and selectable Auto-Power-Off timer
- Operates up to 9 hours continuous using six AA Alkaline or NiMH cells (not included) or use an external 8-16VDC 200mA power source (DC cable included)
- Internal trickle charger option when using NiMH batteries
- Size: 3.5 x 7.75 x 2.65 inches (overall)
- Weight: 2lbs 2oz with alkaline batteries installed.

In the box

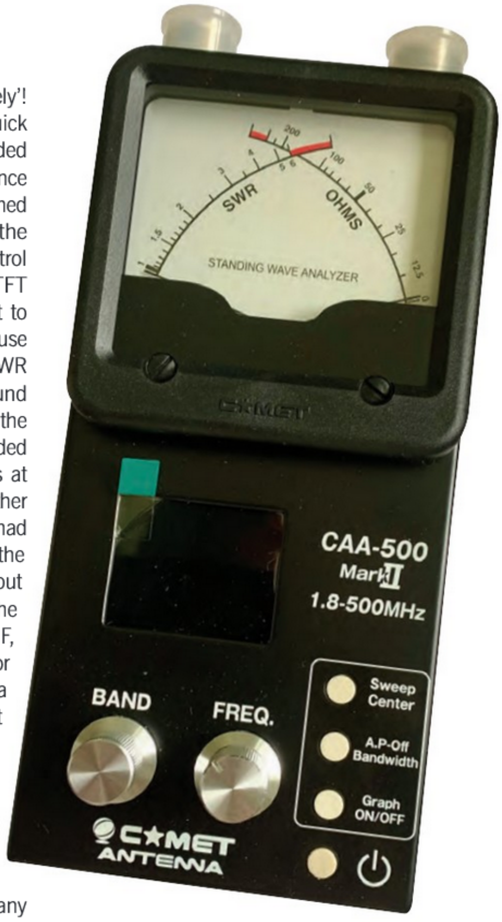
On opening up the box, the first impression is of a chunky, substantial unit. The analogue display, displaying SWR and impedance is nice and large and easy to read, especially when out in the field. There's a colour TFT display, two controls for 'Band' and 'Frequency' as well as On/Off, Sweep Centre, AP-Off Bandwidth and Graph On/Off switches.

The unit takes six AA alkaline on NiMH rechargeable cells, a source of some dismay initially to your reviewer who didn't have that many batteries in the house! Fortunately, a 12V power cable is supplied which, of course, is fine for using the analyser in the shack, but for work in the field, you'll want to use batteries. There's a trickle-charger built into the unit for use with NiMH cells (a Charge switch is located in the battery compartment to enable this function). There are two antenna inputs on the unit, an SO-239 socket for 1.8-300MHz and an N-socket covering 300-500MHz.

In use

As it turned out, the antenna analyser had arrived at a very useful time. A few weeks ago, I'd quickly put up an 80m dipole, measured 'approximately'! Its SWR was a little high in the band, but a quick tune on the ATU and all was good. I decided though, I would take advantage on the presence of the analyser and do a proper job. I switched on the analyser, connected the dipole to the 1.8-300MHz port, switched the band control to 80m (just rotate the control until the TFT displays a frequency in the band you want to use). Then, using the Freq control, you can use the big analogue meter to see where the SWR dips at resonance. In my case, it was around 3.3MHz – rather low in frequency, so to bring the antenna to resonance around 3.5MHz, I needed to shorten the aerial a little bit. Wire cutters at the ready, I trimmed off an inch or two off either end and re-tested. This time, the frequency had come into the 80m amateur band, making the dipole easily usable in the CW segment without an ATU – perfect. Up at 3675kHz though, the frequency of my weekly SSB sked with GW5NF, the SWR is 2:1. As I'm happy to use an ATU for the sked, that's fine – but I could easily trim a little more off the dipole ends and try and get resonance somewhere in the middle so that I can work CW and SSB without an ATU. With the analyser, it's a simple process, as you can see.

Something else that is quite fun and instructive to do is to run the analyser across some of the other bands and see if there are any useful looking resonance dips. For example, my 80m dipole shows an interesting resonance around 17m – I'll have to see if it works!



The CAA-500 is simple to use and both the analogue meter and the TFT colour display are nice and easy to read quickly.

Functions

That's the basic use of the analyser covered, which the instruction leaflet (that is quite well written) terms as 'Normal mode', and the procedure I went through is termed as 'Manual Plot Mode'. Manual Plot mode allows you to set the centre frequency and the bandwidth of the plot. In this mode, if you press the AP-Off button, during the sweep, this changes the colour of the plot and allows you to have multiple sweep traces on the screen. Useful, as the instruction manual mentions, if you're trying to adjust a gamma match on a Yagi and are trying to gauge what effect you have made.

There's an 'Auto Sweep Mode', which allows you to display an SWR curve on the unit. The SWR curve is nicely displayed on the TFT screen. If you want to record it, you'll probably need to take a photo of it on your smartphone – as there's no means of transferring this data, or any other from the unit, onto a computer.

Up until now, I've only talked about using the unit on HF frequencies, but with a range up to 500MHz, it will be handy on the VHF/UHF bands too. I tried it on some of the VHF/UHF aerials here where it worked well and correlated well with other measurements I had made using my VHF/UHF equipment. I had wondered how accurate the frequency would be on the higher bands, but did not see any problems.

Conclusion

Overall, I was impressed with the CAA-500 Mark II. It's not cheap at £499.95 but performance is very good and the unit is very portable, which will be ideal if you want to use it out in the field (or in the garden). Cheaper units such as a nanoVNA can yield the same sort of information, albeit presented in a different way, work well but do not necessarily lend themselves to being used in the field, especially if they are connected to a computer, whereas the CAA-500 Mark II is entirely standalone.

I hope you have enjoyed this look at the Comet CAA-500 Mark II as well as a slightly more general discussion as to why you might find an antenna analyser useful. My thanks to Nevada Radio (www.nevadaradio.co.uk) for the loan of the CAA-500 Mark II.

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