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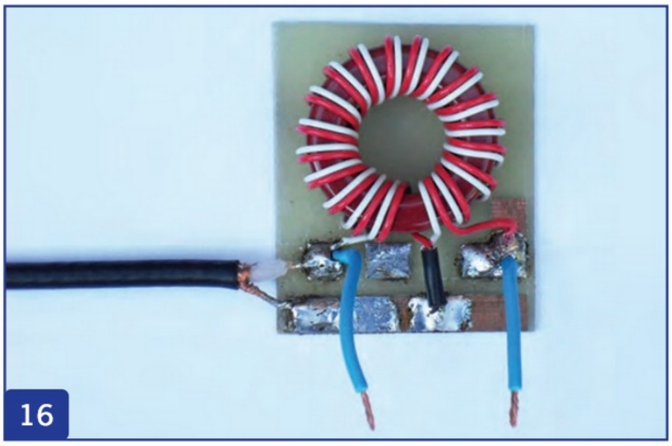

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Features

Technical Features

Cover image, LimeRFE front end and PA for LimeSDR. Design by Kevin Williams, M6CYB

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

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New Products

IC-T10 VHF/UHF dual-band FM transceiver

Icom has announced details of a new 5W VHF/UHF dual-band amateur handheld radio called the IC-T10. The IC-T10 has been built to the high-quality commercial specification that you would expect from Icom. The radio features a clear easy to use layout, rugged commercial build, IP67 dust-tight specification and waterproofing, 1500mW loud audio and long-lasting Li-Ion battery life all making it an ideal radio for beginners and seasoned amateur radio enthusiasts alike. Its strong mil-spec build and range of features will also make it a practical dual band radio for voluntary amateur radio emergency services such as RAYNET. Features include 5W RF output on 144 and 430MHz and up to 11 hours operating time with supplied 2400mAh Li-Ion battery pack. The IC-T10 will be available this summer. Cost and availability nearer the time. www.icomuk.co.uk.

Turbolog4.18 now available

During the pandemic, DX stations have been more rare than usual, so amateurs need to find them more effectively. Following user requests, Wanted Calls and Prefixes can now be specified by Band and DXCC-Mode. In addition, time intervals can be defined in which Alarms can be triggered. This avoids false alarms from spots for stations that cannot be worked at the time of the day due to propagation. Comfortable usage of FT8/FT4/etc was enhanced. It now just takes seconds to switch the transceiver's CAT link to applications like WSJTX or JTDX. Turbolog4 was updated to Network-Server NexusDB V4.5024 as well as databases for TelNet-Servers and the versatile Keyword facilities. Upon user request, new CAT-files were implemented for FLEX transceivers and other new hardware. The Turbolog4 website and all internal internet access was upgraded to the HTTPS-protocol. The overall view of new features is compiled in the Version-Information on the website (see below) and inside the HELP topic of the online help in the programme. Turbolog4 is a shareware project. www.turbolog.de.

The New 705 meter

The IC-705 has probably spawned more rig accessories than most radios in the last 20 years. This new 705 meter shows mode, filter settings, a real-time display of your operating frequency and SWR.
For more information see HamRadio.co.uk/705Meter

Geochron upgrades

You can now link your QRZ logbook to your digital geochron. If you have a Digital Geochron and are a subscriber to the Ham Radio Bundle, there is a new feature for you: QRZ logbook syncing. Following user requests, instead of manually uploading your ADIF logs via the website to your Geochron, you can now use your personal API key, and see your call logs on the Geochron. But you need to buy the Geochron Digital first. For full details, see www.geochron.co.uk.

MyDEL Ham Bag

The new MyDel Ham Bag is proving very popular with portable operators and can be used over the shoulder or round the waist. It has great storage capacity for such a small bag. The main compartment measures approximately; width 27cm, depth 13cm, height 18cm, with five secure zippered pockets and one drawstring pocket. Ideal for SOTA or POTA operations. It retails at £44.95. www.hamradio.co.uk.

Antennas

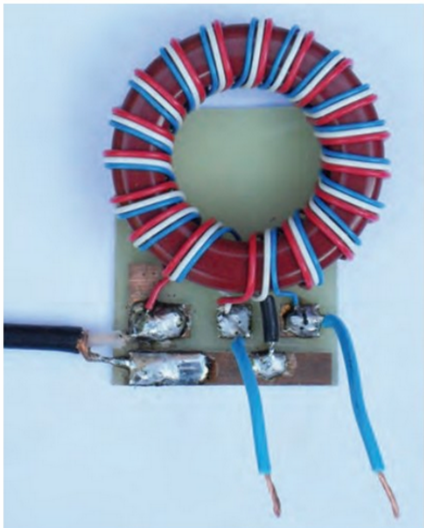


PHOTO 1: Example of a 1:1 balun, whose circuit is shown as Figure 1.

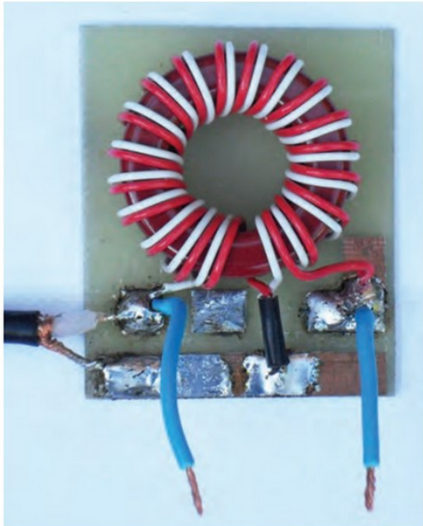


PHOTO 2: Example of a 4:1 balun, whose circuit is shown as Figure 2.

PHOTO 3: Example of a 1:1 choke balun for the HF bands.

Recently, several readers' emails have been received concerning HF baluns. It is some time since these have been the Antennas column's theme, so we revisit HF baluns this month.

Common mode currents

The majority of HF antennas in use tend to be balanced types that have equal, or near equal, voltages existing either side of the feed-point when referred to earth. However, when using an unbalanced coaxial cable to feed a balanced antenna this can result in undesirable common mode currents flowing along the outside surface of the coaxial cable's shield as a result of the imbalance between them. This occurs because skin-effect can make the outside of the coaxial cable's shield behave as if it is a separate conductor compared to its inner surface. As a result, this allows common mode currents to flow along the shield conductor's outside surface if its impedance is low enough. This is important because the flow of these undesirable currents results in the coaxial cable acting as an RF signal radiator that can distort the antenna's radiation pattern and so degrade its performance. Therefore, it is good practice to use an unbalanced-to-balanced transition (or balun) to minimise the flow of any common mode currents.

Detailed HF balun construction guidance is provided in the *RSGB Radio Communication Handbook* **[1]** and the following provides a guide to some of these techniques.

Transformer/voltage type baluns

Transformer-type (or voltage-type) baluns using iron powder toroid cores can be constructed to cover frequency ranges from about 3 to 30MHz. These are autotransformers that have their origins in the work performed by C.L. Ruthroff **[2]**.

The concept of two transformer baluns for impedance ratios of 1:1 and 4:1 are shown as **Figures 1** and **2**. To enable these baluns to work efficiently requires a high level of coupling between the windings. Therefore, bifilar or trifilar winding techniques are used where the turns are wound tightly together by laying the wires side-by-side in parallel. The trifilar 1:1 ratio arrangement (Figure 1) tends to increase the leakage inductance and this can limit its upper frequency range compared to the bifilar 4:1 ratio arrangement (Figure 2).

These transformers function in the same way as their lower-frequency counterparts, however the low magnetic permeability of the toroid core allows these transformers to operate at much higher frequencies. Efficient transformer action requires the primary winding's inductance to be sufficiently large to ensure that the transformer's connection has little overall effect, other than that due to the secondary winding's load. However, there will always be some leakage inductance that increases in proportion to the transformer's self-inductance and affects the transformer's higher frequency performance. Essentially, a transformer that works well at 3.5MHz may not work as well at 28.5MHz and this often shows as a worsening SWR as the frequency is increased.

Peter Miles, VK6YSF has published several toroid iron powder core balun designs, including 1:1 and 4:1 impedance ratio types with their details made available online **[3]**. **Photo 1** illustrates a 1:1 impedance ratio transformer balun using a Micrometals Iron Powder Toroid T200-2 core obtained from an online supplier. This balun comprised 17 trifilar wound 3-wire turns with a small gap left between each turn as shown. Plastic insulated 0.7mm diameter copper single core wire was used for the windings. In Photo 1, the stranded blue wires indicate the balanced connection to the transformer with the unbalanced connection shown terminated by coaxial cable. This 1:1 balun had a usable range from about 3 to 20MHz. Figure 1 shows the balun's circuit.

Photo 2 shows a 4:1 impedance ratio transformer balun using a Micrometals Iron Powder Toroid T130-2 core. This balun comprised 17 bifilar wound 2-wire turns with a small gap left between each turn as shown. In a similar way to the previous balun, plastic

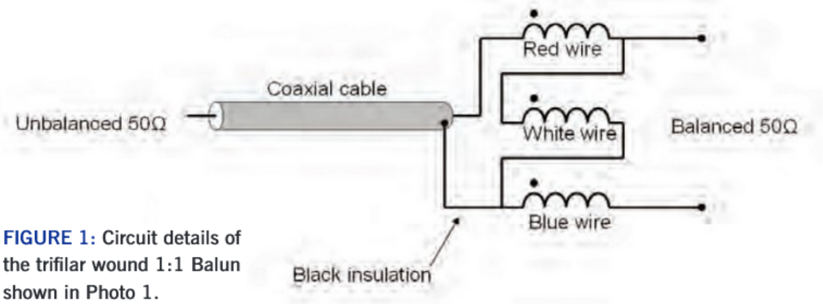


FIGURE 1: Circuit details of the trifilar wound 1:1 Balun shown in Photo 1.

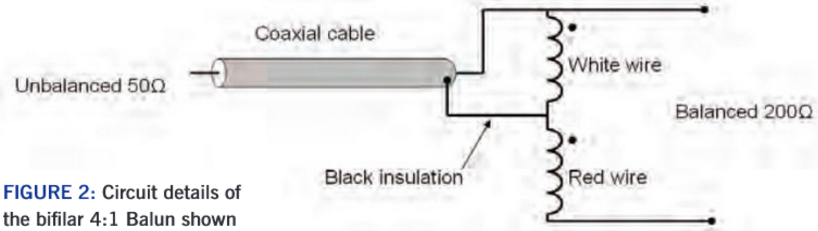
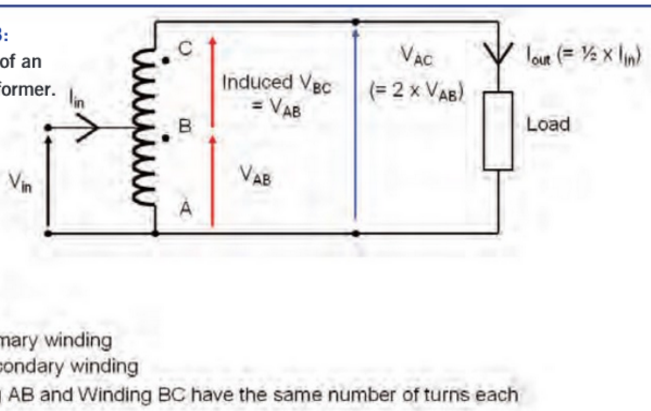


FIGURE 2: Circuit details of the bifilar 4:1 Balun shown in Photo 2.

FIGURE 3: Overview of an autotransformer.



insulated 0.7mm diameter copper single core wire was used for the windings. In Photo 2, the stranded blue wires indicate the balanced connection to the transformer with the unbalanced connection shown terminated by coaxial cable. This 4:1 balun had a usable range from about 3 to 30MHz and its circuit is shown in Figure 2.

Space has not allowed the inclusion of a detailed description of weatherproofing this type of balun. However, the balun could be housed in an ABS box, with the cables passing through suitably drilled holes and the arrangement waterproofed using an external grade sealant.

The 1:1 choke balun

Another technique used to minimise common mode currents from flowing down the outside of a coaxial cable's shield is to add sufficient inductance to increase the impedance of this path. This is the basis of the 1:1 choke balun where several turns of the coaxial cable are wound on a ferrite core to form an inductor. This type of 1:1 balun was developed by Joe Reisert, W1JR, and published in 1978 **[4] [5]**.

An example of a 1:1 choke balun is shown in **Photo 3** and was formed by passing 12 turns of the coaxial cable through a FT240-31 ferrite core, with cable ties used to hold the turns in place. This balun can be used from 3.5MHz to 30MHz for transmit powers up to 100W. However, higher transmit powers can cause the balun to heat up, leading to the possibility of the ferrite's magnetic permeability collapsing and the resulting failure of the balun.

When measured using an antenna analyser, the balun introduced an impedance of about 500Ω into the coaxial cable's outer shield, however above 30MHz the impedance decreased making its use unacceptable at 50MHz and above.

Note: This 1:1 choke balun design often appears in various publications as using only 6 turns of coaxial cable for ease of clarity, with the details of the balun's actual construction often omitted. This has resulted in many stations using only 6 turns of the coaxial cable and consequently experiencing problems. These 1:1 baluns should be wound with 12 to 14 turns of the coaxial cable as suggested by W1JR in his original article.

UnUn and Balun transformers

Several reader emails related to the operation of voltage unbalanced-to-unbalanced transformers (UnUn) and balanced-to-unbalanced transformers (balun). A search through various book and online sources indicated surprisingly little in the way of guidance on how either UnUn or balun transformers work; although many sources were found that provided guidance on how to build these transitions.

Particularly of interest to readers was the operation of the 4:1 ratio balun autotransformer in terms of a straightforward explanation of how it works without resorting to complex mathematics. Luckily, the *ARRL Antenna Book* **[6]** and a paper by Steve Hunt, G3TQX (SK) published online **[7]** provided background information.

Autotransformer: The 4:1 balun is an autotransformer whose concept is shown in **Figure 3**, where AB is the primary winding and AC is the secondary winding. As described previously and shown in Photo 2, this balun comprises two biflar windings, which are wound on a suitable magnetic core and both having the same number of turns each.

When an RF signal voltage V_{in} is applied to the primary winding, this develops voltage V_{AB} across points A and B (lower red arrow). V_{AB} causes a current to flow in the primary winding that energises the magnetic core and induces a voltage V_{BC} across points B and C (upper red arrow) as shown. The two windings are arranged so that V_{AB} and V_{BC} are additive and produce the secondary's output voltage V_{AC} across points A and C. V_{AC} is twice V_{AB} because the secondary to primary turns ratio is 2:1. The primary winding's current is I_{in}, while the secondary winding's

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current is I_{out} and will be half of I_{in} because the power transferred can not change (assuming minimal losses). For maximum power transfer, the secondary winding's load terminated across points A and C has to be four times the impedance connected to the primary winding. Therefore, if the primary's impedance is 50Ω, then the secondary winding's load needs to be 200Ω.

UnUn transition: Figure 4a shows the concept of a 4:1 ratio UnUn whose electrical operation is the same as described previously. The radio system's common potential is connected from the coaxial cable's outer shield to Point A, making the primary winding unbalanced. The output voltage V_{AC} is still formed from voltages V_{AC} and V_{BC}. However, V_{AB} is referred to the common potential at Point A, while V_{BC} is referred to Point B, which is not at the common potential and results in these voltages being out of balance. Consequently, the transformer's secondary winding presents V_{AC} as an unbalanced voltage to the load. This gives an unbalanced-to-unbalanced transition, giving the transformer its UnUn name. An UnUn is suitable for interfacing with unbalanced antennas, eg a end-fed long wire.

Balun transition: Figure 4b shows the concept of a 4:1 ratio balun whose electrical operation is same as described previously. However, the radio system's common potential is now connected from the coaxial cable's outer shield to Point B, with the primary winding still remaining unbalanced. With the common potential now at Point B, this has the effect that Points A and C are electrically equal because winding AB is same as winding BC. V_{AB} and V_{BC} still form the output voltage V_{AC} (= twice V_{AB}), however both these two voltages now develop referred to Point B, meaning these voltages are in balance. The transformer's secondary winding now presents V_{AC} as a balanced voltage to the load. This gives a balanced-to-unbalanced transition, giving the transformer its Balun name. A Balun is suitable for interfacing with balanced antennas, eg a doublet.

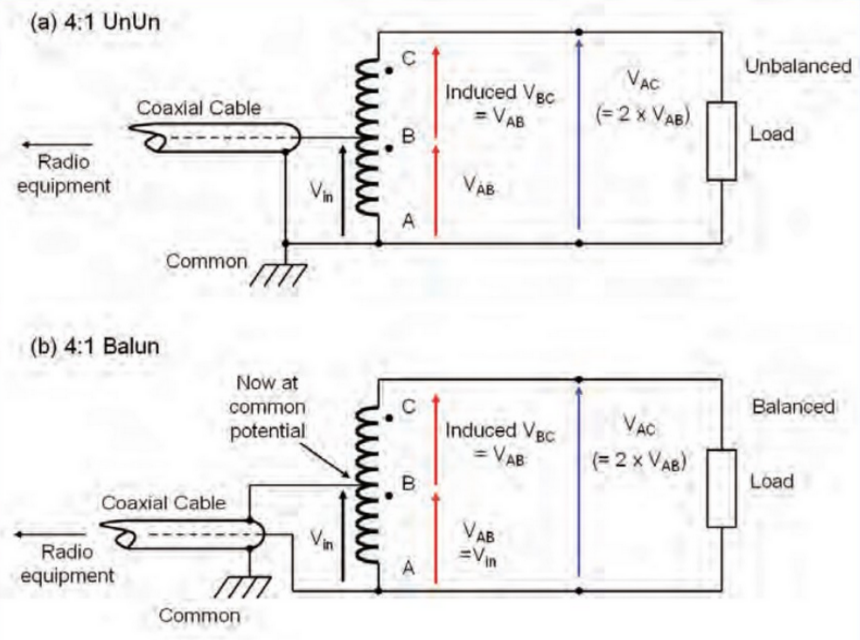

FIGURE 4: Overview of (a) 4:1 UnUn and (b) 4:1 balun.

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[1] *RSGB Radio Communication Handbook 14th edition*, edited Mike Browne G3DIH. Section 14 Transmission Lines, pages 14.11-14.15. Published 2020.

[2] *Some Broadband Transformers*, C.L. Ruthroff MIRE, published by the IRE, 1959.

[3] VK6YSF Projects, web link http://vk6ysf.com/projects.htm, July 2012.

[4] *Ham Radio Magazine*, September 1978, pages 12 to 15, published by Communications Technology Inc. A Simple and efficient Broadband Balun by Joe Reisert, W1JR.

[5] *Amateur Radio Techniques 7th edition*, 1991. Aerial Topics, Broadband balun, page 334. Pat Hawker, G3VA.

[6] *ARRL Antenna Book, 23rd edition*, edited by H. Ward Silver, N0AX. Section 24 Transmission Line Techniques, pages 24-42 to 24-44 and 24-54.

[7] *Basic baluns*, by Steve Hunt, G3TQX. http://www.karinya.net/g3txq/baluns/baluns.pdf

Input impedance of a feeder, and all that

$$Z_s = r + ix \qquad Z_p = \frac{RX^2}{R^2+X^2} + i\frac{R^2X}{R^2+X^2}$$

For equivalence: $R = r\left(1+\frac{x^2}{r^2}\right)$ and $X = x\left(1+\frac{r^2}{x^2}\right)$

FIGURE 1: Equivalent series and parallel combinations.

$$Z_{in} = Z_0\frac{Z_L + Z_0\tanh(\gamma l)}{Z_0 + Z_L\tanh(\gamma l)} = Z_0\frac{Z_L + Z_0\tanh(\alpha l + i\beta l)}{Z_0 + Z_L\tanh(\alpha l + i\beta l)}$$, which breaks down into

$$Z_{in} = Z_0\frac{(r+Z_0A)(Z_0+rA-xB)+(x+Z_0B)(xA+rB)}{(Z_0+rA-xB)^2+(xA+rB)^2}$$
$$+iZ_0\frac{(x+Z_0B)(Z_0+rA-xB)-(r+Z_0A)(xA+rB)}{(Z_0+rA-xB)^2+(xA+rB)^2}$$

where

Z_{in} is the input impedance, $Z_L = r + ix$ is the load impedance, and

Z_0 is the characteristic impedance of the cable (often 50Ω);

$A = \frac{\sinh(2\alpha l)}{\cosh(2\alpha l)+\cos(2\beta l)}$; $B = \frac{\sin(2\beta l)}{\cosh(2\alpha l)+\cos(2\beta l)}$,

and

$\alpha = \frac{1}{10}\log_e\left(10^{D/20}\right)$; D is the attenuation in 10m (dB); l is the feeder length (m),

and

$\beta = \frac{2\pi f}{\varepsilon c}$; f is the frequency (Hz); c is the speed of light (m/s); ε is the velocity factor.

FIGURE 2: The equations needed to calculate the input impedance!

You probably already know that the input impedance of a feeder can depend on its length and characteristics such as its velocity factor, attenuation etc, as well as what is connected across its other end. But exactly how do these things depend upon each other, and can you measure the impedance at the transmitter end to calculate the impedance connected across the antenna end? Let's find out.

Serial or parallel?

An impedance generally consists of two parts: the resistive part and the reactive part. The resistive part is straightforward and is equivalent to having a resistor of so-many ohms. The reactive part is also measured in ohms, but it is equivalent to having an inductor or a capacitor. Mathematically, we can express the combination of the resistive part and the reactive part as a complex number, but we don't need to worry about the mathematical details here. All we need to understand is that, inevitably, are there these two parts.

The two components, the resistor and the capacitor/inductor, can be thought of as either connected in series, or in parallel, as shown in **Figure 1**.

I have used lower case r and x to represent the series combination of resistance and reactance, and upper case R and X to represent the parallel combination. The two impedances, Z_s and Z_p, are equal to each other when the components are related by the mathematical expressions shown. Again, we need not be troubled by the details. All we need to note is that we need to be clear about whether we are expressing our impedance as a series combination or a parallel combination, especially when it comes to interpreting measurements.

Calculating the input impedance

OK, so you have a feeder 4.5m long consisting of a 50Ω coaxial cable with a velocity factor of 0.8 and a loss of 0.1dB per ten metres. You have a parallel combination of 370Ω and 2.5μH connected across one end and are using a frequency of 21.2MHz. How can you determine the impedance presented at the other end of your feeder? You could, of course, measure it using a VNA. If you wanted to calculate it instead, you might use a Smith chart if you were familiar with such a thing, although I suspect that the inclusion of feeder loss would make matters more complicated. If you are mathematically minded, you could perhaps solve the equations for yourself, writing a computer program to help you. However, the equations are not straightforward and involve hyperbolic functions and complex numbers. For interest, I show them in **Figure 2**: I think many of us would be daunted when faced with the task of manipulating these equations but don't despair, help is at hand in the form of that often-forgotten, but powerful tool, the spreadsheet. There are several versions of spreadsheet programs, including Microsoft Excel and its free equivalent LibreOffice Calc. I have constructed a spreadsheet to carry out the above calculations and it is shown in **Figure 3.**

The spreadsheet in Figure 3 contains an array of individual cells, labelled A to P across the bottom and 1 to 27 down the side. Thus each cell carries a label such as D4 or M13 to identify it. The spreadsheet carries out its calculations by executing instructions contained in its cells. Some of these are simply numbers or text, such as the cell C4, which carries the number 50, representing the characteristic impedance of the feeder in the example shown. Other cells carry formulas, the results of which are shown in the cell concerned. These always begin with the equals sign, '='. Thus cell K3, which contains the formula '=B22', will always show the value of the cell B22. The real power of the spreadsheet is realised by using worksheet functions to carry out complex tasks. For example, cell C13 contains the formula

=IF(C13<0,"pF","uH")

using the worksheet function 'IF' to display something different depending on whether the value in cell C13 is negative or positive. We need not be concerned with all this, however, as I have dealt with the details and have already put the proper expressions into the cells.

The underlying formula in any cell is usually invisible because the cell displays the result of making that calculation. Therefore, in Figure 3, I have explicitly shown the underlying formula in blue text two columns to the right of the relevant cell. Thus cell D13 contains the formula (shown above), which is displayed in cell F13, and so on.

A	B	C	D	F	J	K	L	M	N	
Input impedance of a feeder										1
					Input impedance of the feeder :					2
Feeder:					Series resistance	13.2655	Ohms	=B22		3
	Z0	**50**	Ohms		Series reactance	47.4315	Ohms	=B23		4
	Attenuation (10 m)	**0.10**	dB		Equivalent component	0.3561	uH	=B26	=IF(I5<0,"pf","uH")	5
	Length	**4.5**	m							6
	Velocity factor	**0.8**			Parallel resistance	182.8595	Ohms	=B24		7
Operating:					Parallel reactance	51.1416	Ohms	=B25		8
	Frequency	**21.2**	MHz		Equivalent component	0.3839	uH	=B27	=IF(H9<0,"pF","uH")	9
Load:										10
	Series/parallel (S/P)	**p**		=IF(C11="S","",IF(C11="P","","error"))						11
	Resistance (Ohms)	**370.00**	Ohms							12
	Reactance (+uH or -pF)	**2.50**	uH	=IF(C13<0,"pF","uH")						13
										14
1	333.0088213	react	=IF(C13>=0,2*PI()*C9*C13,1/(2*PI()*C9*C13*0.000001))							15
2	165.5849572	r	=IF(C11="S",C12,C12*B15*B15/(C12*C12+B15*B15))							16
3	183.9784121	x	=IF(C11="S",B15,C12*C12*B15/(C12*C12+B15*B15))							17
4	0.010361633	2al	=0.2*LN(10^(C5/20))*C6							18
5	5.000132452	2bl	=(4*PI()*C9*1000000/(C7*299700000))*C6							19
6	0.00807094	A	=SINH(B18)/(COSH(B18)+COS(B19))							20
7	-0.746887888	B	=SIN(B19)/(COSH(B18)+COS(B19))							21
8	13.26551248	r in	=C4*((B16+C4*B20)*(C4+B16*B20-B17*B21)+(B17+C4*B21)*(B17*B20+B16*B21))/SUMSQ(C4+B16*B20-B17*B21,B17*B20+B16*B21)							22
9	47.43154732	x in	=C4*((B17+C4*B21)*(C4+B16*B20-B17*B21)-(B16+C4*B20)*(B17*B20+B16*B21))/SUMSQ(C4+B16*B20-B17*B21,B17*B20+B16*B21)							23
10	182.8595394	R in	=B22*(1+POWER(B23/B22,2))							24
11	51.14160595	X in	=B23*(1+POWER(B22/B23,2))							25
12	0.356083265	Ls/Cs	=IF(B23<0,-1000000/(2*PI()*C9*B23),B23/(2*PI()*C9))							26
13	0.38393582	Lp/Cp	=IF(B25<0,-1000000/(2*PI()*C9*B25),B25/(2*PI()*C9))							27
A	B	C	D E	F G H I	J	K	L	M	N O P	

FIGURE 3: Spreadsheet for calculating the input impedance of a feeder.

$$Z_L = Z_0\frac{(Z_0A-r_{in})(Ar_{in}-Z_0-Bx_{in})+(Z_0B-x_{in})(Ax_{in}+Br_{in})}{(Ar_{in}-Z_0-Bx_{in})^2+(Ax_{in}+Br_{in})^2} + iZ_0\frac{(Z_0B-x_{in})(Ar_{in}-Z_0-Bx_{in})-(Z_0A-r_{in})(Ax_{in}+Br_{in})}{(Ar_{in}-Z_0-Bx_{in})^2+(Ax_{in}+Br_{in})^2}$$

FIGURE 4: The equation for calculating the terminating impedance.

Some of these formulas are quite long, but if you have good eyesight and are of a patient disposition you can construct the spreadsheet for yourself from the information shown in Figure 3. Otherwise, just drop me an email and I will send you the spreadsheet.

To use the spreadsheet, first put in the characteristics of the feeder in cells C4 (the feeder impedance Z_0 in ohms), C5 (the attenuation in dB per ten-metre length), C6 (the physical length in metres of your feeder), and C7 (the velocity factor of your feeder). Insert the operating frequency in MHz into cell C9. Now put the resistive and reactive values of the impedance connected across the far end of your feeder into cells C12 (resistance in ohms) and C13 (the reactive element). If the reactive element is an inductor, enter its value as a positive number of microhenry (μH); if a capacitor, enter its value as a negative number of picofarad (pF). You will also need to specify whether these are connected in series (s) or parallel (p) in cell C11. The impedance presented at the other end of the feeder is then shown in the red box, both as series and parallel configurations.

Using the spreadsheet, you can test the effect of the feeder loss on various well-known configurations such as a quarter-wavelength transformer. For example, try this: put in a frequency of 29.97MHz and a velocity factor of 1. The cable wavelength is then exactly 10m, so a quarter wavelength is exactly 2.5m (entered in cell C6). Such a length should transform a short-circuit into an open-circuit at the other end. Enter a series configuration of zero ohms and zero μH in cells C11, C12 and C13, keeping the feeder loss in 10m as 0.1dB. The spreadsheet calculates the impedance at the other end to be 17.4kΩ resistive – quite large, but not infinite. Now change the loss to 0.01dB per 10m length. The spreadsheet calculates the input impedance to be 174kΩ resistive. Now try putting in zero for the loss. The spreadsheet throws a wobbly, giving errors of #DIV/0! from calculation step 6 onwards. This means that we are trying to divide by zero, the answer to which is so large that the calculator cannot handle it. Don't worry, just change the loss figure into something more realistic, and the errors all disappear.

The spreadsheet of Figure 3 cannot be used for the inverse problem of calculating the impedance connected across the far end of a feeder using a measurement of the input impedance of the feeder. For that we need to use a different equation for the impedance from that given in Figure 2 in which the terminating impedance (or load) is the subject of the formula rather than the input impedance. I show this in **Figure 4**, and have used it to construct the spreadsheet of **Figure 5**.

The spreadsheet shown over the page in Figure 5 has exactly the same form as that shown in Figure 3, except that the equation in Figure 4 has been used in place of the equation of Figure 2. You put your measurement of the impedance presented at the transmitter end into cells C11, C12, and C13, and the spreadsheet then shows you what is connected across the antenna end (usually the antenna itself) in the red box. We can test that it works by reversing the values of Figure 3. There, the parallel combination of 370Ω resistance and 2.5μH inductance gave an input impedance of 13.2655Ω in series with 0.3561μH. Put these values in cells C11, C12, and C13 of Figure 5 and the results are shown in the red box as 370.02Ω in parallel with 2.5004μH. These values are not precisely the same as those we started with, simply because of rounding errors. The spreadsheet of Figure 3 displayed the results of its calculation correct to just four decimal places, so we should not expect an exact match.

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Terminating impedance of a feeder									1
				The load connected at the far end of the feeder :					2
Feeder:				Series resistance	165.6114	Ohms	=B22		3
	Z0	50	Ohms	Series reactance	183.9902	Ohms	=B23		4
	Attenuation (10 m)	0.10	dB	Equivalent component	1.3813	uH	=B26	=IF(I5<0,"pf","uH")	5
	Length	4.5	m						6
	Velocity factor	0.8		Parallel resistance	370.0200	Ohms	=B24		7
Operating:				Parallel reactance	333.0586	Ohms	=B25		8
	Frequency	21.2	MHz	Equivalent component	2.5004	uH	=B27	=IF(H9<0,"pF","uH")	9
Measured input impedance:									10
	Series/parallel (S/P)	s	=IF(C11="S","",IF(C11="P","","error"))						11
	Resistance (Ohms)	13.27	Ohms						12
	Reactance (+uH or -pF)	0.36	uH =IF(C13<0,"pF","uH")						13
									14
1	47.4337765	react	=IF(C13>=0,2*PI()*C9*C13,1/(2*PI()*C9*C13*0.000001))						15
2	13.2655	r	=IF(C11="S",C12,C12*B15*B15/(C12*C12+B15*B15))						16
3	47.4337765	x	=IF(C11="S",B15,C12*C12*B15/(C12*C12+B15*B15))						17
4	0.010361633	2al	=0.2*LN(10^(C5/20))*C6						18
5	5.000132452	2bl	=(4*PI()*C9*1000000/(C7*299700000))*C6						19
6	0.00807094	A	=SINH(B18)/(COSH(B18)+COS(B19))						20
7	-0.746887888	B	=SIN(B19)/(COSH(B18)+COS(B19))						21
8	165.6113872	r load	=C4*((C4*B20-B16)*(B16*B20-C4-B17*B21)+(C4*B21-B17)*(B17*B20+B16*B21))/SUMSQ(B16*B20-C4-B17*B21,B17*B20+B16*B21)						22
9	183.9902012	x load	=C4*((C4*B21-B17)*(B16*B20-C4-B17*B21)-(C4*B20-B16)*(B17*B20+B16*B21))/SUMSQ(B16*B20-C4-B17*B21,B17*B20+B16*B21)						23
10	370.0200013	R load	=B22*(1+POWER(B23/B22,2))						24
11	333.0586374	X load	=B23*(1+POWER(B22/B23,2))						25
12	1.381271226	Ls/Cs	=IF(B23<0,-1000000/(2*PI()*C9*B23),B23/(2*PI()*C9))						26
13	2.500373985	Lp/Cp	=IF(B25<0,-1000000/(2*PI()*C9*B25),B25/(2*PI()*C9))						27
A	B	C	D E F G H I	J	K	L	M	N O	P

FIGURE 5: Spreadsheet for calculating the terminating impedance.

May 2022 — Ian Pawson, G0FCT

RSGB HF Events

Date	Event	Times (UTC)	Mode(s)	Band(s)	Exchange
Mon 9 May	80m Club Championship	1900-2030	SSB	3.5	RS + SN
Wed 18 May	80m Club Championship	1900-2030	DATA	3.5	RST + SN
Thu 26 May	80m Club Championship	1900-2030	CW	3.5	RST + SN
Mon 30 May	FT4 Series	1900-2030	FT4	3.5	4-character Locator

RSGB VHF Events

Date	Event	Times (UTC)	Mode(s)	Band(s)	Exchange
Tue 3 May	144MHz FMAC	1800-1855	FM	144	RS + SN + Locator
Tue 3 May	144MHz UKAC	1900-2130	All	144	RS(T) + SN + Locator
Wed 4 May	144MHz FT8 AC	1900-2100	FT8	144	Report + 4-character Locator
Sat 7-Sun 8 May	May 432MHz – 245GHz	1400-1400	All	432-245G	RS(T) + SN + Locator
Sat 7 May	432MHz Trophy	1400-2200	All	432	RS(T) + SN + Locator
Sun 8 May	10GHz Trophy	0800-1400	All	10G	RS(T) + SN + Locator
Tue 10 May	432MHz FMAC	1800-1855	FM	432	RS + SN + Locator
Tue 10 May	432MHz UKAC	1900-2130	All	432	RS(T) + SN + Locator
Wed 11 May	432MHz FT8 AC	1900-2100	FT8	432	Report + 4-character Locator
Thu 12 May	50MHz UKAC	1900-2130	All	50	RS(T) + SN + Locator
Sun 15 May	70MHz CW	0900-1200	CW	70	RST + SN + Locator (UK also sent Postcode)
Tue 17 May	1.3GHz UKAC	1900-2130	All	1.3G	RS(T) + SN + Locator
Thu 19 May	70MHz UKAC	1900-2130	All	70	RS(T) + SN + Locator
Sat 21-Sun 22 Apr	144MHz May	1400-1400	All	144	RS(T) + SN + Locator (UK also send Postcode)
Sun 22 May	1st 144MHz Backpackers	1100-1500	All	144	RS(T) + SN + Locator (UK also send Postcode)
Tue 24 May	SHF UKAC	1830-2130	All	2.3G & Up	RS(T) + SN + Locator
Sun 29 May	70MHz Cumulative	1400-1600	All	70	RS(T) + SN + Locator

Best of the Rest Events

Date	Event	Times (UTC)	Mode(s)	Band(s)	Exchange (Info)
Sat 30 Apr-Sun 1 May	UKEICC DX	1200-1200	CW	3.5-28	RST + SN (UK & EI also sent District code)
Sat 1 May-Sun 2 Aug	UKSMG Summer Marathon	0000-2359	All	50	4-character Locator
Sat 7-Sun 8 May	ARI International DX	1200-1200	CW, RTTY, SSB	3.5-28	RS(T) + SN (I give Province code)
Sun 8 May	UKuG Low Band	0800-1400	All	1.3-3.4G	RS(T) + SN + Locator
Sun 8 May	WAB 7MHz Phone	1000-1400	AM, FM, SSB	7	RST + SN + WAB
Sun 15 May	UKuG mm-wave	0900-1700	All	24G, 47G, 76G	RS(T) + SN + Locator
Sat 28-Sun 29 May	CQWW WPX CW	0000-2359	CW	1.8-28	RST + SN
Sun 29 May	UKuG High Band	0600-1800	All	5.7G, 10G	RS(T) + SN + Locator

For all the latest RSGB contest information and results, visit www.rsgbcc.org

Design Notes

This month I'm looking at Interfacing direct upconverter chips

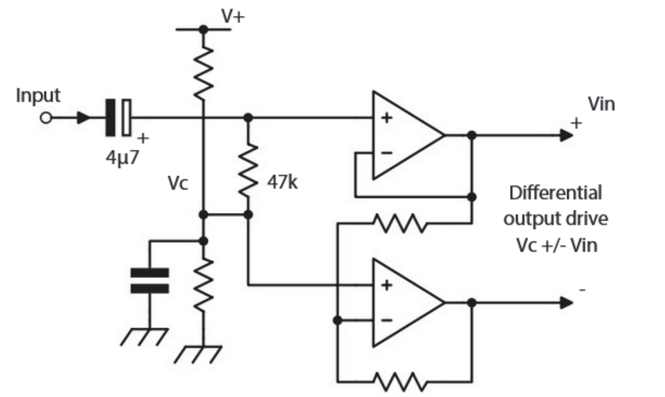

FIGURE 1: Generating a differential drive signal from a single ended input, using AC coupling. Vc is set by the potential divider from V+ to equal the common mode voltage needed by the upconverter chip. The low frequency cut off is defined by the 47k resistor and 4.7μF capacitor at around 0.7Hz.

Direct upconversion – taking a quadrature I/Q pair of signals and converting to RF in one go, cancelling out one of the frequency converted image products in the process – does away with the need for narrow band filtering that would otherwise be needed to remove the opposite sideband. In most cases the greatly attenuated unwanted image falls on top of the spectrum of the wanted waveform. The image only needs to be reduced by some 20dB to not cause problems with reception and, as it is co-channel, will not cause adjacent channel interference. 20dB image rejection, and in practice an awful lot more, is easily achieved with modern quadrature upconversion chips without any special tweaking or trimming of component values.

A few of these chips were studied in this column several years ago **[1]** and it can be seen they all have one factor in common in their circuitry; they all need differential drive. In other words, the I and Q baseband signals are each presented on two connections, with the input voltage being the difference between the two wires of each pair. Doing it this way means that it is easier for chip designers to get DC balance and accurate nulling at zero input (both wires the same voltage) than it would be if only a single input were adopted. It is the difference between the two differential lines that determines the output level, but there is another term that needs to be considered, that is the common mode voltage. This is the static level that the I or Q pair of inputs must sit at when the differential input is zero. It is not usually a critical parameter but the voltage does need to be close to the specified value to get best dynamic range and linearity. Each chip is different and the common mode or DC mean voltage is always specified in the data sheet, along with the maximum for peak to peak differential input for best linearity. **Table 1** lists peak-to-peak and common mode voltages for a number of direct upconversion chips; these cover the devices that were evaluated in [1].

If the baseband source waveform comes from a single ended source like a D/A converter or baseband Direct Digital Synthesiser, DDS, it has to be converted to a differential signal. If AC coupling can be used, then a relatively simple circuit such as that shown in **Figure 1** will suffice. An opamp unity gain buffer provides one channel (the +Ve) side of the differential input. An inverting unity gain buffer converts the polarity of this and drives the -Ve differential input. Both drives are raised to meet the common mode voltage by biassing the opamp inputs appropriately via a potential divider to give Vc. The input peak amplitude is set to be half the peak-to-peak required for the chip, which may require attenuating the output from the source driver hardware. The inverting stage driving the -Ve input causes an effective doubling of the peak input level. So there are two parts of the circuitry needing to be set. The values for the biassing potential divider have to be chosen to give the specified common mode voltage, and the input level has to be attenuated to meet the maximum specified drive levels. Both of these trimming processes can be done by calculation and appropriate choice of resistors. Provided the two resistors around the opamp forming the inverting stage are equal, DC balance will be maintained and there should be no need for trim pots for carrier suppression; 1% resistors will be good enough to get 30dB or more. The snag with this simple arrangement is that it is AC coupled.

AC coupling

All the initial testing in [1] was done with stereo I/Q output from a PC soundcard. A soundcard cannot have a DC component and usually has a lower frequency response of a few Hertz, so the use of AC coupling was perfectly OK for these tests. The simple voice storage described in March's Design Notes worked fine, as did some tests using the JT4G data mode from a quadrature baseband DDS. All these were happy with AC coupling of the I/Q baseband input, but during the recent rebuild of the GB3SCS beacon **[2]** to add the Q65 data mode (one of the more recent modes added to the WSJT-X suite), the disadvantages of AC coupling came to the fore and showed that DC coupling should ideally be used from the D/A converter used to generate the baseband tone waveforms for upconversion to RF. To see why, we need to look again at the conversion of I/Q baseband waveform to RF.

The I and Q drive signals each contain essentially identical waveforms, except that they are separated by 90° in phase at all frequencies. The direction of the phase shift between I and Q determines whether the RF is converted up or down in frequency. This is why it is perfectly reasonable to talk about negative frequencies when we have dual I/Q drive. A negative frequency is one where the phase between I and Q drive is swapped from that for the positive case. An I/Q baseband drive waveform that contains components from zero up to 1500Hz can, when converted by a local oscillator at 14.0015MHz, give an RF output that spans 14.000 to 14.003MHz. A DC level, zero frequency, on I and Q results in an output mid band at the LO frequency. And this is where AC coupling causes a problem.

AC coupling means a high pass response, so very low frequencies are attenuated. In the circuit of Figure 1, this high pass response

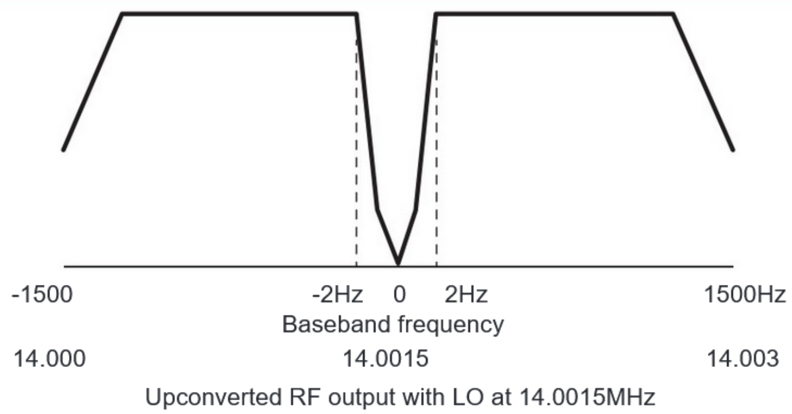

FIGURE 2: The resulting output spectrum when AC coupling is used in a direct quadrature upconverter. A narrow 'hole' is created in the middle of the passband due to the low frequency roll-off.

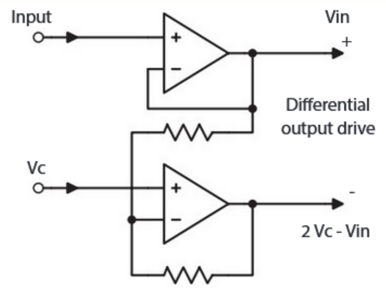

FIGURE 3: Producing a differential drive signal from a single ended input, for example a D/A converter. Vc is set to be equal to the mid-point voltage of the input waveform. This circuit is duplicated for I and Q channels.

comes from the 4.7μF input capacitor and the 47kΩ bias resistor, giving a roll-off below about 0.7Hz. A zero frequency baseband term translates to the middle of the RF output spectrum so these missing low frequency components now cause a small band of frequencies to disappear just above and below the middle of the RF passband. There is a hole in the spectrum, equal in width to twice the high pass cut off frequency of the AC coupling components, shown in **Figure 2**.

Missing tones

A hole a couple of Hertz wide will go unnoticed in an SSB voice signal, especially as it is in a part of the voice band where there is little energy. Datamodes such as JT4G, consisting of four tones 315Hz apart, will pass though uncorrupted provided the two centre tones straddle this hole. The baseband drive just consists of two absolute values of frequency for this four-tone mode, ±157.5Hz and ±472.5Hz. Well away from the hole at zero frequency, centre band. The real problem came when Q65-D modulation was tried. This consists of 65 tones, spaced 13.333Hz apart, so the total span is 853.3Hz. The obvious way to generate the baseband waveform would be to generate the tones equally about the centre, using a drive from -426.67Hz corresponding to the lowest tone-zero (T0) to +426.67Hz for tone 64 (T64). But there's a snag here, T32 would then correspond to zero frequency and this won't get through the AC coupling.

The first attempt to mitigate this involved shifting the offset by half a tone spacing, making the zero frequency baseband drive correspond to tone 31.5, mid-way between T31 and T32. Now, the lowest frequency that could appear in the baseband would be equal to half the tone spacing, or ±6.67Hz. Surely this would pass unmolested through the AC coupling. But, on final test, monitoring the output from the beacon on a power meter, several significant dips in power were seen when tones 31 and 32 were being generated. The assumption wasn't valid and the high pass response was affecting things.

A quick fix for GB3SCS was made by looking at the actual tones being generated for the particular beacon identification message "GB3SCS IO80UU". It was observed that Tone-30 did not appear in the sequence, so the RF source and baseband tones were adjusted to set this 'missing' tone at the zero frequency point.

This worked, with now barely a flicker on the power meter as the Q65 sequence keyed and was adopted for the final GB3SCS hardware, now in service at its remote site. But hardly a satisfactory solution, having to customise the frequency plan depending on the tones that appear in any particular multi-tone message! The solution is to do away with AC coupling.

DC coupling

It is not essential that the opamp bias, Vc of Figure 1, is used to define the common mode voltage on the upconverter chip – the level shifting can be applied elsewhere. The solution is to go to a two-stage approach. **Figure 3** shows the first part of the process, with two opamps in a simpler design of buffer to convert to a differential drive, this time DC coupled with bias adjusted to be the mid-point of the drive signal, irrespective of what the upconverter chip wants. The two resulting outputs from the opamps are now Vin, and 2.Vc – Vin, which can be thought of as a differential waveform of peak-to-peak value equal to 2.Vin centred on the mean, Vc.

The resistor network of **Figure 4** is then used on each of the opamp outputs, on each side of the I and Q channels, four identical networks in all, to attenuate and level shift the opamp output voltages to those needed for the upconverter chip. Vref can conveniently be the +5V supply. By specifying any arbitrary two input voltages delivered from the opamp buffer, such as the maximum and minimum peaks, and the corresponding pair of output voltages, the calculation of the values for the resistors R1, R2 and R3 looks at first sight to be a straightforward process. It turned out to be anything but.

Using superposition to calculate Vout for any given Vin and Vref is straightforward, but the calculation then has to be turned around to obtain valid values for R1 and R2 given a pair of Vin/Vout values and Vref. R3 can be fixed at some arbitrary value and R1/R2 then calculated relative to it. Deriving R1 and R2 by specifying two spot values for Vin and two for Vout proved quite a challenge, involving solving simultaneous equations with a quadratic in there somewhere, too. A request on the RSGBTech Group for a bit of help with the algebraic manipulation after I'd got lost in seven pages of A4 scribble resulted in several replies and sets of working that are encapsulated into a spreadsheet that can be downloaded from **[4]**. Once resistor values could be calculated, a breadboard was made up for the AD8346 upconverter chip. A test was made using an identical DDS as that used for GB3SCS generating Q65-D at two different LO input frequencies, 1296 and 2320MHz. This showed a completely flat response over the tone spread, whatever RF offset and centre tone was selected. Sideband rejection was excellent at -40dBc and carrier rejection without any trimming was 26 – 31dB depending on frequency of operation. This could probably be improved by fine tuning the two 'nominally equal' resistors in the inverting buffers, but anything better than 20dB is acceptable for data usage. Upconverting speech may be a bit more fussy as carrier leakage appears as a whistle in the middle of the audio at around 1.7kHz.

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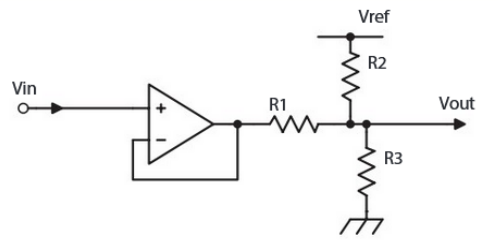

FIGURE 4: Level shifting the output from Figure 3 to match the input voltage needs of the Direct Upconverter chip. Four of these networks are needed, +I, -I, +Q and -Q.

TABLE 1: Common mode and differential drive levels for some Quadrature Upconverter chips.

Type	Freq Range	V_{PK-PK} DIFF	DC MEAN
AD8345	140– 1000 MHz	1.2	0.7
AD8346	800 – 2500 MHz	2.0	1.2
U2790	100- 1000MHz	1.0	2.5
U2793	30 – 300MHz	1.0	2.5
ADL5375-05	400 – 6000MHz	1.0	0.5
ADL5375-15	400 – 6000MHz	1.0	1.5

Being able to now send all frequencies of the baseband signal, including DC, now allows on-off keying to be included as an option via the direct upconversion process, something that wasn't possible using AC coupling.

PIC Programming

One member wrote in to say:

"DSPics are powerful processors chips but (relatively) hard to write code for. It may not be news to you but I have today learned of a resource that supports programming the devices in compiled BASIC – see [3].

"I have used the unrelated PICbasicPRO for many years, mainly because it made code development a doddle in the simple stuff I was working on, and I'd never really got my head round any assembler (except for the occasional, speed-critical or interrupt-driven bits).

"The list of devices supported by the paid-for version of the software is impressive, but the list of those supported by the free version appears useful too:

"The Trial compilers support a few popular devices and are *absolutely free!* to use and have no limitations. The full compilers support a whole bunch of PIC, PIC24, and dsPIC33 microcontrollers for a small fee to help its support and improvements. Also, remember, the Positron16 compiler comes with the Positron8 compiler, so it's a single installation for a huge catalogue of devices.

"FREE" 14-bit core Devices:
PIC16F84, PIC16F628, PIC16F628A, PIC16F877, PIC16F877A, PIC12F1552, PIC16F1614, and PIC16F1937

"FREE" 18F devices:
PIC18F13K50, PIC18F25K20, PIC18F25K22 PIC18F452, PIC18F45K20, and PIC18F46K20

"FREE" 16-bit devices:
PIC24EP128MC202, PIC24FJ64GA002, PIC24FJ64GA004, and dsPIC33FJ128GP802"

References

[1] 'Integrated Quadrature Up and Downconverters' Design Notes February 2012 and April 2017
[2] http://g4jnt.com/DirectUpconversionBeaconSource.pdf
[3] https://sites.google.com/view/rosetta-tech/an-introduction-to-the-positron-basic-compilers
[4] http://g4jnt.com/ResistorVoltageLevelShifting.zip

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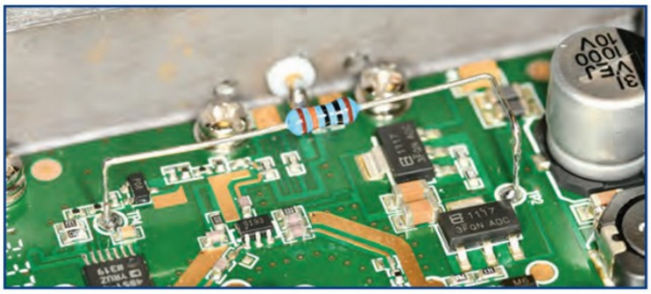
Big or small, as long as it's something to do with amateur radio, we're interested. There is great demand for constructional projects, ranging from simple to complex. Aerial projects and any sort of buildable electronic widget are favourites. The most complex projects go into *RadCom Plus* but the majority will appear here in *RadCom*.



What to do

The first step is get in touch with the editorial team via email to radcom@rsgb.org.uk and simply tell us what you have in mind.

It doesn't matter if you have never written before – we can provide as much or as little editorial support as you require. We'll need good quality photos to accompany your article **[1]** but line drawings (circuits and other diagrams) can be a simple sketch. We re-draw the majority of diagrams to give a consistent style across all articles. There is rarely any time pressure, so you can work at your own pace.

Acceptance procedure

Our acceptance procedure for technical articles **[2]** involves an independent review by a member of the Technical Panel, whose members are always willing to work with authors if there's something that needs more explanation or would benefit from clarifying.

Feature articles aren't assessed in that way, but most of the info in [2] still applies: it's well worth reading that page before you send any articles to *RadCom*.

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].

[1] www.rsgb.org/radcompix
[2] https://tinyurl.com/RC-guidance

Technical

HF Noise Case Study

If you're lucky, the depressing tale that follows won't apply to you but I suspect that many radio amateurs now have their operation severely restricted by man-made RF noise (QRM), whether they fully realise it or not.

I never imagined that I'd ever get to the point of being nostalgic about the good old days in the 1960s when as a schoolboy with an ex-WWII R107 receiver I had low enough QRM to be able to hear QRN (natural noise) such as distant lightning crashes or 'rain static' on Top Band and the 80m band!

My garden measures about 29m by 22m and my bungalow is plonked roughly in the centre of it. It's a corner plot and therefore rather exposed to the gaze of neighbours. See **Figure 1** for the general layout of the neighbourhood. Consequently I try to arrange my antennas to have a reasonably low visual impact.

Unfortunately, there are no convenient tall trees that I can use to hide things or act as antenna supports. The G5RV-look-a-bit-alike that I put up recently has the centre section slung between the aerial poles at either end of the bungalow. One pole carries two TV antennas and the other carries a VHF/UHF triple band collinear plus a 4m dipole. So the G5RV is only 8 or 9m above the ground in the centre and is even lower at the ends, nowhere near as high as I'd like it to be but I'm stuck with it until a winning lottery ticket comes my way...

Tests with a VNA showed that despite the G5RV low height and the ends being twisted about to fit the garden, the VSWR was sensibly low on 80m, 40m and 20m. As expected it was not really usable for transmission purposes in dipole form on 160m, and needed quite a lot of help from an ATU to bring down the VSWR to something more sensible on the other bands.

A quick listen around with my old Yaesu FT-747GX confirmed that some signals were being received but they were drowning in a deep sea of wideband noise on the lower bands. From what has been published in *RadCom* over the last few years I suspected that the bulk of the noise was almost certainly due to broadband DSL interference escaping from the surrounding telephone network. In my area both the electricity supply and the telephone network is carried overhead on poles. There's even an electricity pole in one corner of my back garden. This means that there is a very limited choice when it comes to the location for big things like HF antennas.

The PA0RDT 'mini whip' active receive antenna that I built and placed well away from the house a couple of years ago was never successful because it too was swamped by noise.

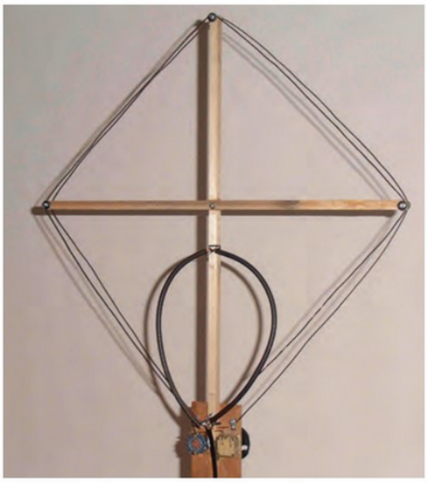


PHOTO 1: Portable loop antenna.

Investigation Starts

The RSGB EMC Committee has called upon the amateur community to complain to Ofcom and MPs etc about the scourge of interference escaping from DSL networks. I was quite prepared to do this but held back because I felt that I ought to do some thorough homework first, particularly with regard to putting my own house in order. When I moved to this QTH several years ago I noticed that the internal telephone extension wiring was rather a mess, although it worked and my broadband speed was not too bad. Now, after comprehensively reworking the wiring in an attempt to reduce the DSL racket, I've ended up with only a few inches of the external BT cable entering the house before it terminates in the master socket. Following that the internal cable drops straight down to floor level and then travels along 3 or 4m to the broadband router. The 'bell wire' is no longer connected in order to reduce any potential wiring imbalance, so only a single twisted, and hopefully balanced, pair is in use. There is no other telephone extension wiring connected now so it's as short and direct as it can be.

Sadly noise measurements made both with the G5RV and with a portable receiver at various locations in the garden showed that my phone rewiring efforts had not made a scrap of difference to the noise!

The next blind alley that I ventured up involved 'QRM Eliminators'. To cut a very long and convoluted story short, I designed and built a signal phase cancellation unit loosely based upon an old design by Lloyd Butler, VK5BR. When tested with signals from signal generators on the bench it worked splendidly well. It would also cancel off-air interference very well, but only if it was from a single discrete interference source. The best it would do with DSL was to knock off 2dB, or maybe 2.5dB if you were really careful and held your breath to the point of nearly passing out while adjusting it for phase and amplitude. However the very high DSL noise level meant that a reduction of a couple of dB didn't make much of a dent in it. It gradually started to dawn on me that the DSL racket was arriving from multiple sources, each one having a different phase relationship and so unless I assembled a dozen or so QRM eliminators in series I was never going to make any headway with this approach!

Time perhaps to take a closer look at the 'enemy', ie the suspected DSL noise. So I downloaded the Lelantos software created by some very brainy people in the RSGB EMC Committee. This software is used in conjunction with an SDR receiver such as one of the 'RSPs' from SDRPlay. Incidentally

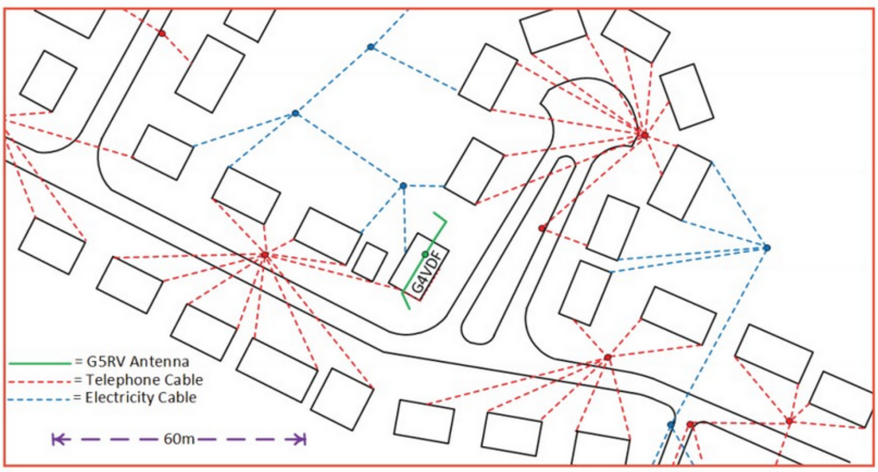


FIGURE 1: QTH and surrounding overhead cables.

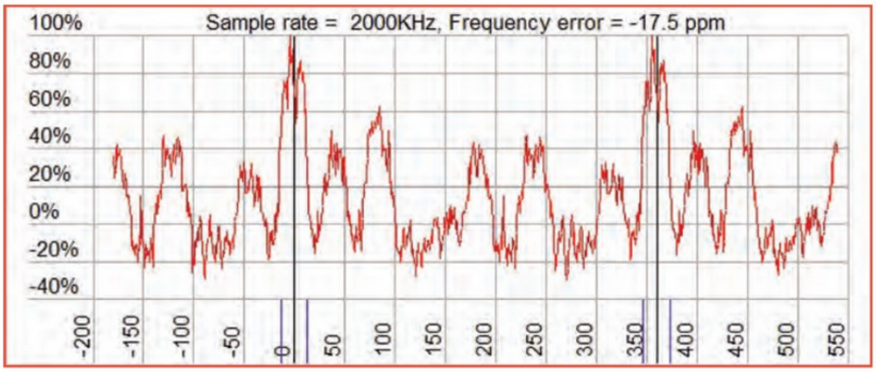


FIGURE 2: Lelantos DSL Timing Signature.

Band	160m	80m	60m	40m	30m	20m	17m	
Freq MHz	1.900	3.755	5.317	7.100	10.125	14.200	18.100	
Unmodulated Sig Gen Level								
-73dBm	-73.0	-73.0	-73.0	-72.9	-72.9	-73.1	-73.3	dBm
-83dBm	-82.9	-82.9	-82.9	-82.8	-82.8	-83.1	-83.2	dBm
-93dBm	-93.0	-93.0	-92.9	-92.9	-92.9	-93.1	-93.2	dBm
-103dBm	-102.9	-102.8	-102.8	-102.7	-102.7	-102.9	-103.1	dBm
-113dBm	-112.8	-112.8	-112.8	-112.7	-112.7	-112.9	-113.1	dBm
-123dBm	-122.1	-122.2	-122.0	-121.9	-121.7	-122.0	-122.3	dBm
Sig Gen Off	-130.3	-130.3	-130.2	-130.0	-129.5	-130.0	-130.6	dBm
TranZmatch Noise Gen:								
10dB Attenuator	-60.0	-64.8	-63.0	-66.4	-71.8	-71.7	-77.9	dBm
20dB Attenuator	-69.5	-74.6	-73.7	-76.2	-81.6	-81.8	-87.8	dBm
30dB Attenuator	-79.4	-84.6	-82.6	-86.1	-91.6	-91.8	-97.8	dBm
40dB Attenuator	-89.5	-94.8	-92.9	-96.4	-101.7	-101.9	-107.8	dBm
50dB Attenuator	-99.3	-104.4	-102.6	-106.1	-111.4	111.6	-117.3	dBm
60dB Attenuator	-109.4	-114.5	-112.7	-116.0	-120.9	-121.3	-125.9	dBm
70dB Attenuator	-119.1	-123.4	-122.0	-124.5	-127.3	-127.9	-129.9	dBm
80dB Attenuator	-126.0	-128.1	-128.4	-129.1	-129.2	-129.6	-130.4	dBm

FIGURE 3: RSP1 signal and noise measurement checks.

my SDRPlay RSP1 is one of the most useful radio things that I've ever bought but I find I use it mostly as a piece of test equipment rather than a general purpose 1kHz to 2GHz receiver. Lelantos decodes a 0.5 second recording of the IQ stream from the SDR sufficiently to identify the presence of DSL timing signals.

I connected the RSP1 to the G5RV via an ATU. After making short WAV file recordings with SDRUNO on various frequencies the graphs produced by Lelantos at once confirmed suspicions of the presence of DSL interference. On some frequencies it was possible to clearly see six different timing signals indicating that I was receiving strong DSL interference from at least six different networks. See **Figure 2** for the Lelantos Graph. One complete timing cycle runs from '0' to about '350' on the X axis.

Now that I had confirmed the presence of DSL interference I needed to try and quantify how much of it there was. With the RSP1 I could measure the noise power in any suitable bandwidth. I was hopeful that, with a bit of mathematical jiggery-pokery, I would be able to relate that measurement to the reference man made noise figures (in dB above thermal noise) published by the ITU in their document "Recommendation ITU-R P.372 Radio Noise" **[1]**. The ITU noise measurement method is described in ITU-R SM.1753, "Methods for Measurements of Radio Noise" **[2]**.

The RSGB has helpfully produced a short downloadable leaflet about the subject entitled "The Background Noise on the HF Amateur Bands" (EMC Leaflet 16) **[3]**. It uses as a reference the ITU Man Made Noise Figures from an earlier revision of P372, i.e. P.372-13 (see Figure 10 in P.372-13 or Figure 39 in the later revision P.372-15 that shows the same levels). The RSGB leaflet translates the ITU noise figures (F_{am} dB) into RMS electrical field strengths in terms of dBμV/m as would be received by a reference very short vertical antenna above a perfectly conducting ground plane. The RSGB leaflet shows the noise field strengths for 'Residential', 'Rural' and 'Quiet Rural' portrayed on a graph against frequency from 1MHz to 100MHz. The graph also shows the expected UK day time and night time atmospheric noise levels, not that I stand a chance of hearing any of that until DSL goes away…

An isotropic antenna in free space would produce field strengths 1.3dB lower than the short vertical so initially I thought if I know my antenna gain in terms of dBi, which is the common way of expressing antenna performance, I can relate that to the noise levels shown on the graph in the RSGB leaflet. However after much calculation and head scratching it became clear that it wasn't going to be easy to make a direct comparison because my G5RV and loop antennas had very different gains and radiation patterns compared with the ITU test antenna setup which was a short vertical monopole less than 1/10th λ long over a perfectly conducting ground plane. So hopes of making something like 'absolute' noise measurements or comparisons with ITU figures gradually fizzled out. All I could really hope to do was make comparisons of noise on different frequencies and in different locations.

Preparation for Noise Measurements

The RSP1 SDR controlled by SDRUNO software would be used for most measurements so I needed to thoroughly check and understand its performance for my own peace of mind. Incidentally if you're thinking of carrying out similar measurements yourself but using the S-meter of an HF transceiver instead, it would be worth reading an article on the website of VU2NSB first **[4]**. He has carried a large number of tests on the accuracy, or lack of it, of the S meters of many popular HF transceivers and the results are rather disappointing to say the least!

First I carried out a set of signal level measurements on the RSP1 with plain unmodulated carrier from my old Stabilock 4018 Radio Telephony test set. Its synthesised signal generator certainly isn't the cleanest in terms of phase noise but it was adequate for confirming that the RSP1 still responded to signal levels sensibly. I had confidence in the accuracy of the signal levels produced by the 4018 because, although no longer formally calibrated, it had been checked against three other signal generators recently. The RSP1's readings were recorded on various frequencies for levels from -73dBm (= 'S9' on HF radios = 50μV PD = 100μV EMF) down to -123dBm in 10dB steps. The RSP1's readings were very accurate, even down to inputs of -123dBm. However at the lowest levels the accuracy begins to tail off because

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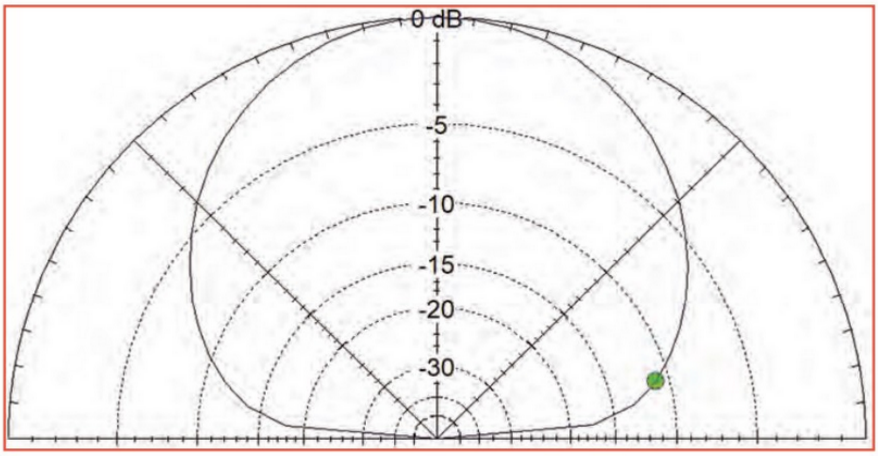

FIGURE 4: **G5RV elevation radiation pattern for 80m.**

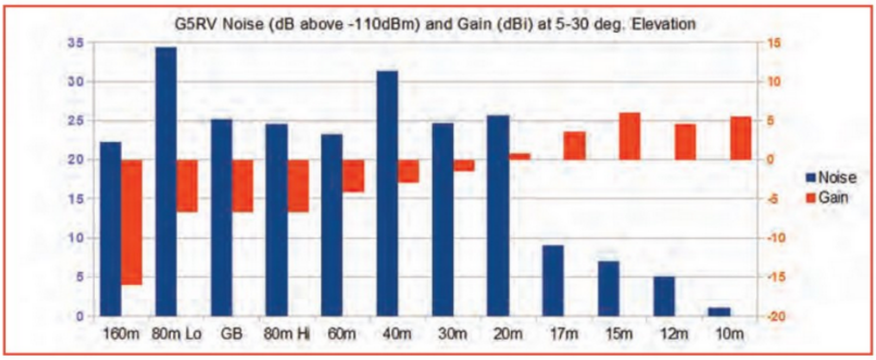

FIGURE 5: **G5RV noise levels and low angle gains.**

the internally generated noise within the RSP1 becomes more significant in relation to the external signal or noise that's being measured and adds to it.

In the past I've successfully used the RSP1 for measuring the signal power of wide bandwidth transmissions such as those employed for digital terrestrial TV and DAB. It has always given sensible results, eg if you halve the measurement bandwidth you then see half (-3dB) the signal power on the display of the SDRUNO software. So I'm happy that it's genuinely measuring power in terms of 'watts per Hz', or at least watts per whatever its minimum 'measurement bin' width is. What I wasn't so sure about was what happened when measuring noise at various levels and how linear its response would be.

So I wanted to set up a quick test, but where can I get some nice predictable noise from? Well fortunately I have an ancient SEM TranZmatch ATU that has a built-in thing called 'Ezitune' which is basically a noise generator feeding an RF bridge circuit. When the TranZmatch is correctly tuned the antenna's impedance will be transformed to 50Ω so the bridge will be balanced and the noise shown by the S-meter of the attached receiver will be at a minimum. That's the theory but with high external noise from the antenna nowadays sadly it's difficult to spot a null in Ezitune noise at the correct tuning point! However with no antenna attached to the TranZmatch and the bridge hopelessly unbalanced the Ezitune produced lots of useful noise for my RSP1 checks.

Whereas the traditional bandwidth used for noise measurements such as those carried out by the ITU is 9000Hz, that was a bit too wide for measurements on some of the crowded amateur bands. So I opted to universally use the 2800Hz LSB bandwidth setting on the SDRUNO software.

It wasn't until a fair way into my measurements that I noticed that SDRUNO's idea of 2800Hz in LSB or USB mode is actually 2700Hz! The software sneaks in a little 'dead zone' between the frequency where the carrier would be if there was one, and 100Hz up or down from that point depending on whether you've selected USB or LSB respectively. However in the great scheme of things it's hardly worth worrying about the missing 100Hz because it only makes -0.16dB difference. I also made a series of noise measurements in AM mode with a genuine 8000Hz bandwidth and found only around an average of 0.1dB discrepancy after the power difference in bandwidth between 2700Hz and 8000Hz had been taken into account.

The noise output of the TranZmatch was attenuated in 10dB steps until a total of 80dB was connected in line and I'd run out of attenuators / enthusiasm. I found that the RSP1 readings were consistent with the amount of attenuation in each case. The noise output from the TranZmatch was greater on the lower frequencies.

After all the plain signal and noise level checks I was happy that the RSP1 was giving reliable measurements. The test results are shown in **Figure 3**. The '-60' noise figure in red on the 1.9MHz column signifies that the RSP1 was complaining about 'overload' even though there was a 10dB attenuator in line. I really ought to have backed off its LNA (Low Noise Amplifier) gain when that noise reading was taken.

Noise measurements from the G5RV

I made a series of noise level measurements on the G5RV antenna using the RSP1 on each of the HF bands. An ATU was used to match the antenna to the RSP1 at each frequency. The SDRUNO measurement mode was set to LSB with a 2800Hz bandwidth, so actually 2700Hz bandwidth as mentioned above. What was immediately apparent was that the bands from 160m to 20m indicated a noise level at least 16dB greater than the bands from 17m to 10m. This is consistent with DSL being the primary cause of noise because the highest DSL frequency is 17.664MHz and the 17m band starts just above that at 18.068MHz.

There is another factor that will be influencing measurements from the G5RV and that is the shape of its radiation pattern at various elevations above the ground. My antenna is very close to the ground compared to wavelength on the lower frequency bands and so I would be expect it to have a very high 'take off' angle, therefore favouring NVIS working. This means that its response to signals arriving from low angles, say 5 to 30 degrees above the horizon, would be poor so I would not expect it to favour receiving noise from adjacent telephone cables etc.

I used EZNEC software to model the antenna and I threw in some additional conductors underneath it to represent various lengths of wiring and pipes inside the house because they were quite close to the antenna in terms of wavelength and could therefore influence the radiation pattern. As an example **Figure 4** shows the EZNEC modelled vertical radiation pattern on 3.7MHz. The green blob is a cursor at 15° elevation and it indicates a 'gain' of -7.56dBi, or to put it another way, -9.71dBd,

Frequency	1.900	3.755	5.317	7.100	8.475	10.125	12.000	14.200	18.100	MHz
BW	14.7	60.0	88.0	129.0	159.0	252.0	424.0	316.0	480.0	kHz
Q	129.3	62.5	60.4	55.0	53.3	40.2	28.4	45.0	37.7	
Rrad	11.8	180.0	723.7	2301.0	4671.3	9516.2	18776.2	36816.0	97184.5	μ Ohms
Rloss	0.397	1.623	2.378	3.486	4.290	6.788	11.401	8.492	12.886	Ohms
Efficiency	-45.3	-39.6	-35.2	-31.8	-29.6	-28.5	-27.8	-23.6	-21.3	dB
Efficiency	0.003	0.011	0.030	0.066	0.109	0.140	0.164	0.432	0.749	%

FIGURE 6: Characteristics of test loop antenna.

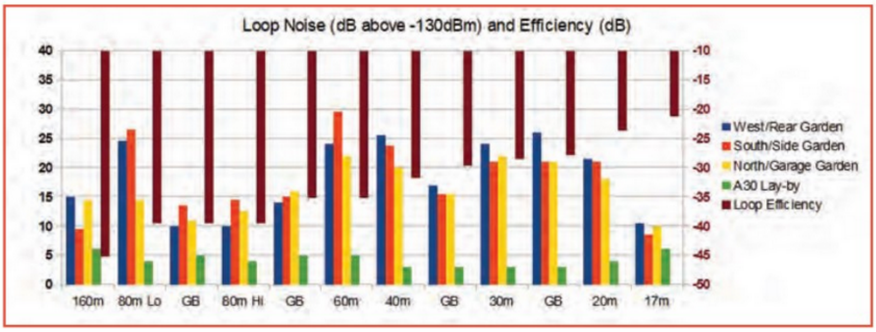

FIGURE 7: Loop noise levels and efficiencies.

ie almost 10dB less than a ½ wave dipole in free space. The average gain from 5 to 30° elevation works out to -7.52dBi, and the antenna has a maximum gain of 3.43dBi directly overhead at the '0 dB' scale mark.

However I now realise that I was pushing my luck a bit with this modelling exercise because EZNEC can only be expected to model the 'far field'. The radius to the boundary between near and far fields, R, is generally taken as $R = 2L^2/\lambda$ where L is the maximum dimension of the antenna and λ is the wavelength, both in the same units. For example, R would be 96m on the 20m band or 128m on the 15m band, assuming a G5RV with a 31m top. Some of the nearby cables suspected of radiating noise would be less than than 'R' away on the higher frequencies and so within the 'near field' region, or perhaps in the twilight zone of what you might call 'electromagnetic no man's land' where modelling becomes rather complex.

The results of the G5RV noise measurements are shown in **Figure 5** along with the predicted average gain of the antenna at low angles from 5 to 30° elevation, for what it's worth… On 80m you will see that there are three measurements, '80m Lo', 'GB' and '80m Hi'. This is because 80m encompasses a transition point in DSL spectrum usage. '80m Lo' is within DSL Downstream 1, 'GB' is within the Guard Band between Downstream 1 and Upstream 1, and '80m Hi' is within Upstream 1. The '80m Lo' reading from emissions in Downstream 1 exceeded the 'GB' reading by 9.2dB but the hoped for really large drop within the Guard Band was not evident. Also the noise in the Upstream 1 band ('80m Hi') was actually marginally lower than in the supposed Guard Band.

Maybe some DSL network providers don't bother to fully attenuate in the Guard Bands or use those bands for some other signalling? Or maybe the noise is not actually DSL data but other spurious noise from all the broadband routers and their switch mode power supplies being radiated by the telephone cables? I suspect the 'CE' mark on some poorly designed equipment stands for 'could explode' or 'causes ear-ache'!

Noise in different locations

The next step I decided to take was to get a feel for how the noise in my location compared with somewhere that wasn't surrounded by overhead cables and other houses. Obviously it wasn't practical to carry around a G5RV so I needed a portable antenna. Some early tests with a couple of setups consisting of whip antennas and tuned matching circuits looked like the way to go initially but unfortunately proved to be susceptible to the noise radiated by the old HP laptop that I was using with the RSP1.

With a whip antenna arrangement the RSP1, the USB cable and the laptop itself all form a sort of ground plane or the other element of the dipole against which the signals from the whip are referenced, and so they are actually part of the complete antenna. Although I couldn't see the laptop noise when testing at home due to the very high DSL noise level, when I ventured to a quieter location it quickly became evident that on some bands the noise results were being obscured by close-spaced spurs from the laptop.

Some research on the web turned up an interesting IARU document by Koos Fockens, PA0KDF, who is a member of the EMC/EMF committee of the Netherlands Amateur Radio society, VERON. Document number VIE19 C7-008 **[5]** discusses in detail various methods for the measurement of radio noise and concludes by favouring the use of tuned 'magnetic' loop antennas.

So I did a bit more reading and calculation regarding balanced magnetic loop antennas and noise. I found a BBC Research & Development White Paper WHP 091 by R. H. M. Poole very helpful. It is entitled *Ferrite Rod Antennas for HF?* and can be found online at **[6]**. The author runs through the theory and calculation of both ferrite rod and 'frame' / loop antennas to assess their feasibility for use in HF DRM (Digital Radio Mondiale) receivers with regard to environmental noise levels. Incidentally the BBC R & D website is crammed full of interesting stuff and so is well worth a visit.

I needed a loop antenna of sufficient efficiency to be able to 'see' noise down to at least the ITU man made noise levels. Loop efficiency increases with size and number of turns. However if the antenna was too big or had too many turns it would have too much inductance and it wouldn't be possible to tune it to at least 18.1MHz / 17m band, ie just above the highest DSL band. Ideally it also needed to fit through a car side window during my noise DXpedition! The loop was modelled at each test frequency by using 'RJELOOP3' software created by Reg, G4FGQ (SK). It is part of a very useful suite of DOS RF programs **[7]** that run happily in Windows 10 via 'DOSBOX' **[8]**.

Another source of information on loop antennas that I found very helpful was *The LF Experimenter's Source Book* **[9]** that was published in the 1990s when radio amateurs were first given access to the VLF bands.

Eventually I settled on a square loop with 343mm sides and two turns spaced about 20mm apart. I used some ancient enamelled copper strip which, according to the faded label on the wooden reel, was 0.1 by 0.05 inch. This gives a cross sectional area of about 3.2mm² but more importantly from the 'skin effect' losses point of view, a reasonable circumference of about 7.6mm. The loop was tuned by a dual gang 232 + 232pF variable capacitor, this being the only mortal remains of a 1960s Russian transistor radio that I mauled to death in my quest to understand how radio things worked as a schoolboy! A rotary switch was fitted so I could connect an additional 1500pF capacitor across the loop so that it would resonate on 160m. The main loop was matched to 50Ω feeder by a smaller coupling loop. This consisted of a 540mm length of 75Ω TV coax, the shield being cut at the halfway point, the inner conductor then being soldered to the shield of the remaining half. The shield at the bottom of the coupling loop was soldered to the mid-point of the main loop. When its shape and position was wiggled about optimally the coupling loop provided a 1:1 VSWR on 80m and was no worse than 3 or 4 to one on any of the other bands up to 17m. The measured inductance of the main loop was 4.3μH.

If you calculate the radiation resistance of a small loop antenna you come up with some incredibly small numbers in the $\mu\Omega$ range, especially at the lower frequencies.

Radiation Resistance Rrad

$$= 320 \times \pi^4 \times (N \times A / \lambda^2)^2 \ \Omega$$

where N is the number of turns and A is the area of the loop in m² if λ is also expressed in metres.

On the lower frequencies the loss resistance, Rloss, will often be much greater than Rrad so efficiency will be very poor. The Rloss figure for each frequency, F, can be calculated by measuring the -3dB bandwidth to derive the 'Q'

(Q = F / BW)

and then Rloss = (XL / Q) – Rrad

where XL is the inductive reactance of the loop (XL = 2 x π x F x L in Ω)

The efficiency of the loop is then:

10 x LOG_{10} (Rrad / (Rrad + Rloss)) dB. 'Efficiency' should not be confused with 'gain' because it only indicates what proportion of the RF energy applied to a loop would be usefully radiated compared with that which is lost by heating up the loop itself and surrounding objects. Obviously my loop is only being used for receive purposes but the same efficiency, or lack of it, applies in receive mode.

The measured bandwidth and Q characteristics of the loop when loaded by the RSP1 are listed in **Figure 6**. Don't ask me why the bandwidth at 12MHz is greater than the bandwidth at 14.2MHz. I suspected I'd messed up the measurements somehow so I repeated them four times but it always came out the same!

The appearance of the somewhat shambolic loop contraption is shown in **Photo 1.** I won't be entering it in any 'construction competitions'!

As had been hoped, the balanced nature of the loop and its preference for magnetic field reception as opposed to the electric field favoured by the whip antenna, alleviated the problem of picking up noise from the laptop.

Noise Comparisons using the loop

I decided to measure the noise levels at three different locations in my garden where it would be possible to mount a permanent receiving antenna if any of them proved to be advantageous due to lower noise levels. For want of better descriptions these were the west/rear garden, the south/side garden and the north/garage garden. However after my casual noise checks a few months earlier with a whip antenna and a scanning receiver I rather doubted that I would find any really quiet spots.

The most interesting thing to me would be the comparison between my QTH and somewhere remote and well away from any telephone lines. A look on the map suggested that a lay-by on the nearby A30 road was worth a try. It was only a couple of kilometres from home, about 670m from a pub, 500m from a military camp, 460m from a farm, and there were no overhead cables anywhere to be seen. The lay-by was also near the crest of a hill and 30m higher above sea level than my own QTH so theoretically a bit more exposed to noise coming from afar. The loop was vertically polarised for all measurements and it was tuned for peak response at each test frequency. **Figure 7** shows the results obtained. Again 'GB' refers to a test in one of the DSL Guard Bands.

A look at the results

At a first glance the results from the loop antenna tests in Figure 7 do not show quite such a dramatic interference level on all the lower bands as those in Figure 5 with the G5RV. This may be due to the loop being less responsive to the electric field than the G5RV, but it must also be noted that the efficiency of the loop was 24dB lower on 160m compared with 17m so the levels are skewed. It later occurred to me that wave polarity was probably playing a part in this as well so perhaps I should have also carried out tests with the loop laying horizontal?

Despite all my careful playing about with the loop antenna I think the real evidence of a serious DSL interference problem is shown by the measurements taken from the G5RV.

You only need a cursory glance at the measurements in Figure 5 to see that the noise level in the bands from 160m up to 20m is significantly higher than in the DSL-free 17m to 10m bands where the noise drops to below -100dBm, despite the G5RV 'sideways' gain increasing at the higher frequencies. So, in round numbers, I'm suffering around 15 or 20dB penalty due to what seems to be largely DSL interference.

For those unfamiliar with dB quantities, 20dB is the difference between running 1W and 100W. Unfortunately, the ATU that I used was unable to tune the G5RV at the higher Guard Band frequencies that I chose that were at 5.2MHz, 8.475MHz and 12MHz, so I was only able to test these frequencies with the loop antenna. These may not be optimum Guard Band test frequencies but at least they were clear of obvious interference spikes.

Looking at Figure 7 for the loop results, the 3.72MHz test frequency in the 80m band was lower in noise than the Downstream test at 3.65MHz but it showed roughly the same noise level as the Upstream test at 3.755MHz. Maybe there was very little Upstream activity at that time? The next GB up at 5.2MHz had around 10dB lower noise than the 60m test at 5.317MHz, which is in a DSL Downstream band. The GB test at 8.475MHz, ie between the 40m and 30m results, showed a dip in noise but not more than about 7dB or so. The highest GB at 12MHz, ie between the 30m and 20m results, didn't show any dip at all.

Conclusions

This was an interesting but ultimately frustrating exercise and all it has done is convince me that operation on the lower HF bands at this QTH will be a struggle and is probably not worth the effort. It could be worse, I could have just shelled out £4k+ for the latest top of the range HF wonder-wireless! I might try a better shielded loop antenna in the north / garage area of the garden but loops add the complication of needing to be rotated and possibly tuned.

Of course there are some 'Web SDRs' available that provide useful receive facilities on some bands but to me they seem a bit like cheating if they are used during a QSO. Unless they are located nearby, Web SDRs give a distorted impression of one's communications capability.

References

[1] Recommendation ITU-R P.372 Radio Noise

[2] Recommendation ITU-R SM.1753, Methods for Measurements of Radio Noise

[3] EMC Leaflet 16: https://rsgb.org/main/technical/emc/emc-publications-and-leaflets/

[4] S Meter Tests: https://vu2nsb.com/radio-systems/amateur-radio-station-ham-shack/radio-transceiver-s-meter/

[5] International Amateur Radio Region 1 Interim Meeting - Vienna Austria 27-28 April 2019, document number VIE19 C7-008. A web search of "VIE19-C7-008-VERON-Noise-Floor-Measurements-Issues" will find it.

[6] *Ferrite Rod Antennas for HF?* https://www.bbc.co.uk/rd/publications/whitepaper091

[7] G4FGQ RF software http://www.zerobeat.net/G4FGQ/

[8] DOSBOX to run DOS programs in Windows https://www.dosbox.com/

[9] *The LF Experimenter's Source Book* edited by George Dobbs, G3LDO, and published by the RSGB.

There is much more information on the EMC pages of the RSGB website that you may find helpful. Go to www.rsgb.org/emc

LimeRFE front end and PA for LimeSDR

Introduction

The LimeRFE is a low noise front end and power amplifier add-on for the Lime series of SDR hardware from Lime Microsystems **[1]** and is available through Mouser and other distributors **[2]**. This review will focus on the RF performance of the unit on the European Amateur bands, as much is already available about configuring and programming the unit on the internet (see references). All the details of the hardware are on the MyriadRF GitHub pages **[3]**.

Like most open source equipment, documentation is developed by users and evolves as more people use the device. A good place to start is the MyriadRF Quick Starter manual at **[4]**. Most of the tests here were run using the Lime Suite GUI application **[5]** to control the unit and make changes to the settings. Some tests were done configuring the unit in combination with a LimeSDR using GNU Radio Companion running on a Raspberry Pi 4, and also with the SDR-Console software **[6]** just to find how easy it is to use it with little or no programming experience. The LimeRFE control GUI in Lime suite is very intuitive, with drop down boxes to set up the parameters and a configure button to send settings to the LimeSDR via USB, or via GPIO using a 10-way IDC cable.

PHOTO 1: The LimeRFE.

Features and functions

While originally designed as a module for inexpensive cellular base stations, the version under review has the cellular band hardware removed and is aimed at the amateur radio and 'maker' market at even lower cost. The unit covers all the amateur bands within the full frequency range of the LimeSDR (1-4000MHz). Each 'HAM' band (to use the supplier's nomenclature) has appropriate filtering both for Rx and Tx as well as wideband modes covering 1-1000MHz and 1000-4000MHz, with a selectable AM/FM notch filter on receive. The low noise receive section also supports a fully software configurable attenuator, to allow receive level setting.

The RF amplifiers produce an output power at 1dB compression of around 1.5 to 3W from HF through to 23cm as well as around 1W on 23 and 13cm plus around 300mW on 9cm.

When combined with the Lime or other SDR and suitable software, this makes it a low-cost proposition if you consider the cost of individual transverters or transceivers for all the bands it covers. Add this to the support in the LimeSDR for DATV and other wideband modes, it really does look attractive as the heart of a modern amateur radio station.

Software support

The unit is fully integrated in to the LimeSuite and has a full range of open source software and firmware including an application programming interface (API). It is supported by GNU Radio Companion's gr-limesdr module, allowing you to add and control it from your GNU Radio programs. The BATC Portsdown 2020 transceiver **[7]** has support for the LimeRFE, allowing its use as a DATV driver or PA.

Control & configuration

The host serial connection is via a standard USB mini Type B connector and uses a FT232RL USB-to-serial converter. The onboard controller uses an ATmega328 Arduino Nano-compatible microcontroller, making it programmable via the Arduino IDE software.

Interfacing

The unit is shown in **Photo 1** and its block diagram is shown in **Figure 1**. I refer you to the Quick Start manual for details as there are a LOT of interconnect available on this board!

For RF it has a number of SMA I/O

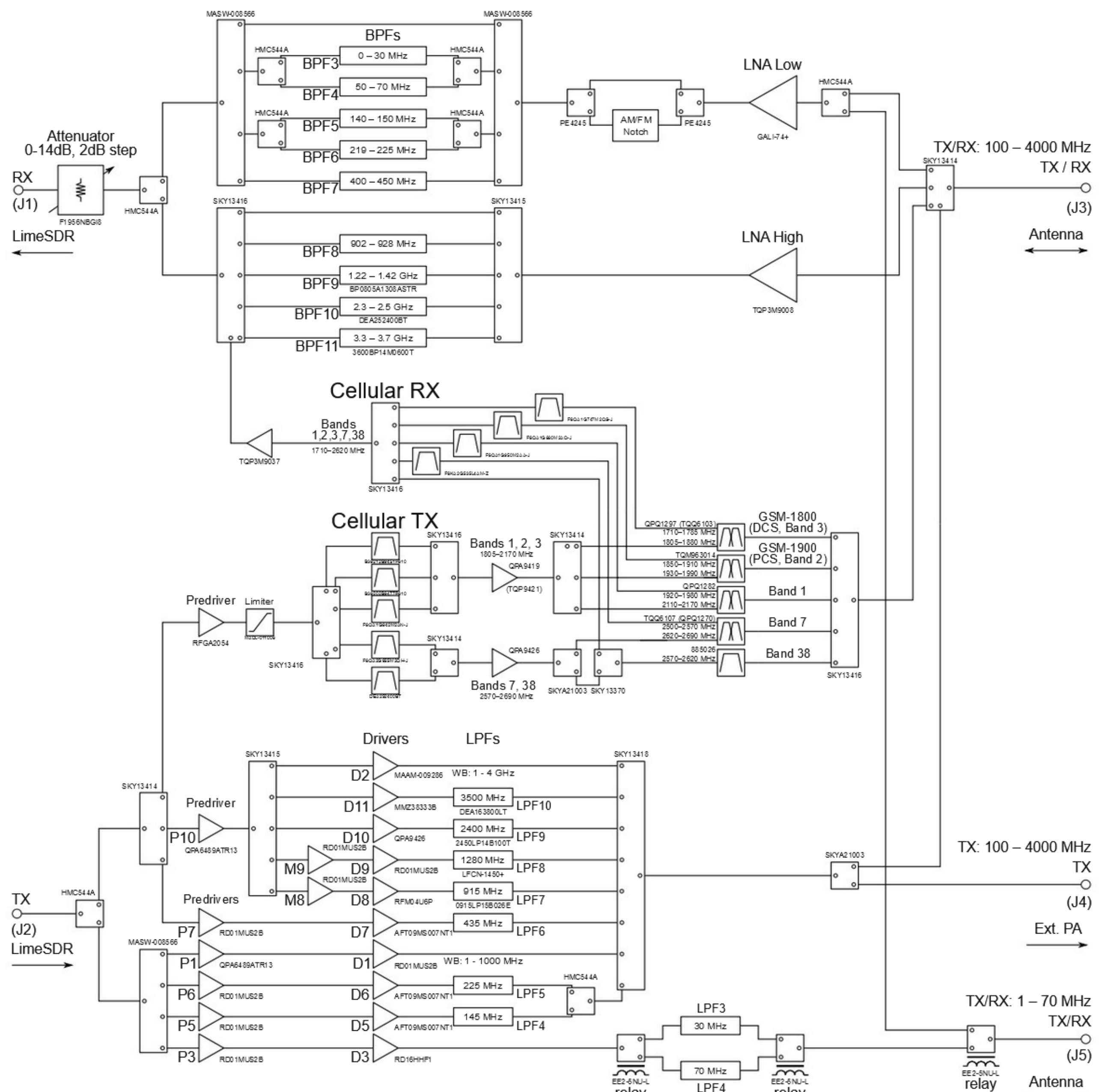

FIGURE 1: Block diagram of the LimeRFE.

connectors. A pair to the Tx and Rx ports on the LimeSDR and a number of outputs configured as either Tx or Tx/Rx and dependent on band. It also has connectors to an external directional coupler to enable a power and SWR meter for 1 to 4000MHz to be implemented.

As well as USB control, the board can be controlled directly from the GPIO port of a LimeSDR; other SDR GPIO interfaces are being developed. The unit has a 10-pin interface to the LimeSDR consisting of power and ground, I²C (SDA and SCL), 2x GPIO (connected to on-board microcontroller), 4x bi-directional level shifted I/O and 1.2 – 5.5 V supplies. Each I/O has individually switchable direction (input/output) and a high voltage and power Darlington drive stage for inductive loads such as coaxial relays, so things like sequencing of antennas can be done easily in software.

Performance testing

In all these tests I used a Windows computer running the LimeSuite GUI program via USB to manually configure the unit for each test, apart from transmit linearity where I used a custom two-tone generator based on the LimeSDR USB and GNU Radio, as described in the January 2022 GHz Bands column.

Noise figure

Single sideband noise figure and gain were measured in the amateur bands above 30MHz and up to 1296MHz with the HAM filters selected, using an HP

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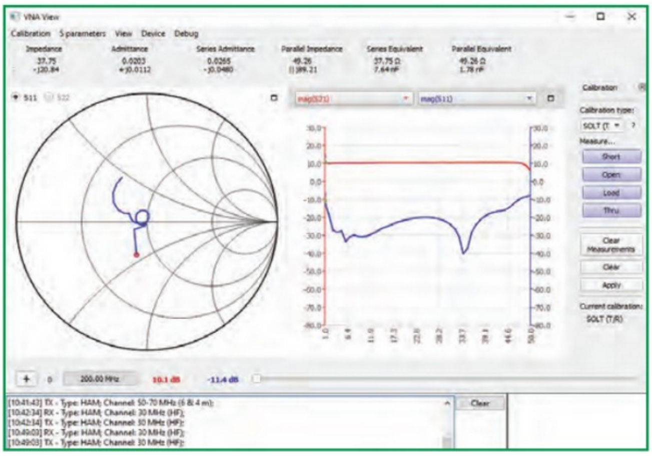


FIGURE 2: Rx filter HF.

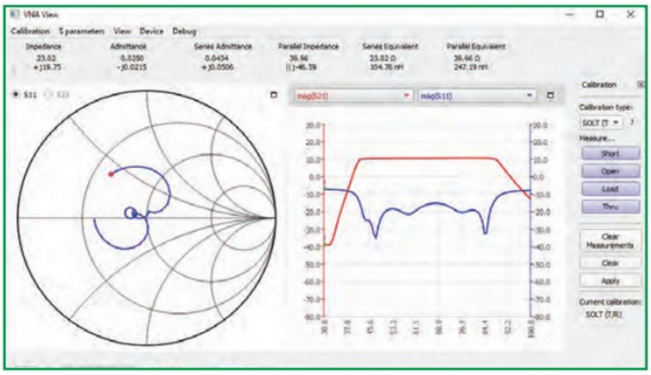


FIGURE 3: Rx filter 50-70MHz.

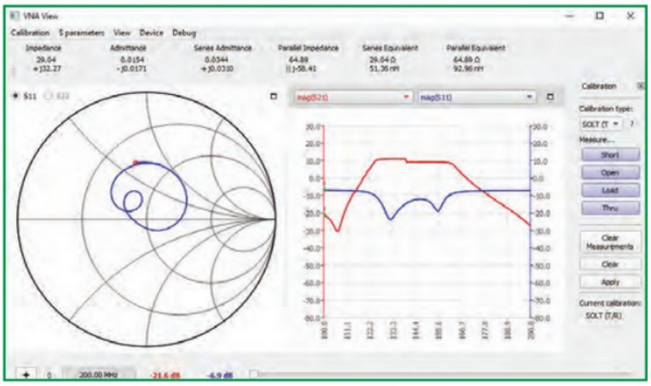


FIGURE 4: Rx filter 144MHz.

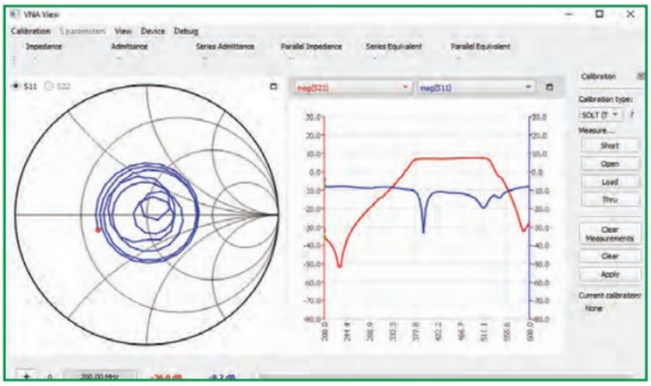


FIGURE 5: Rx filter 432MHz.

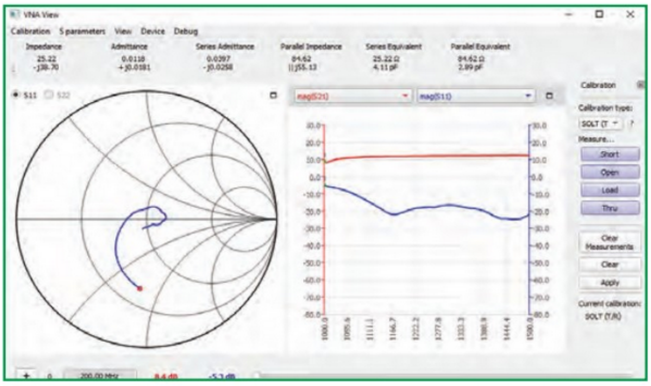


FIGURE 6: Rx filter 1296MHz.

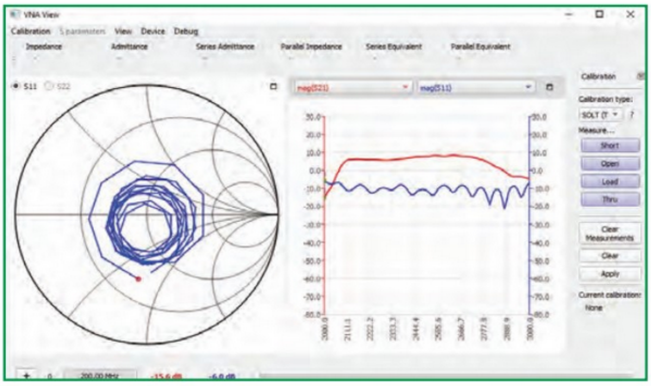


FIGURE 7: Rx filter 2320MHz.

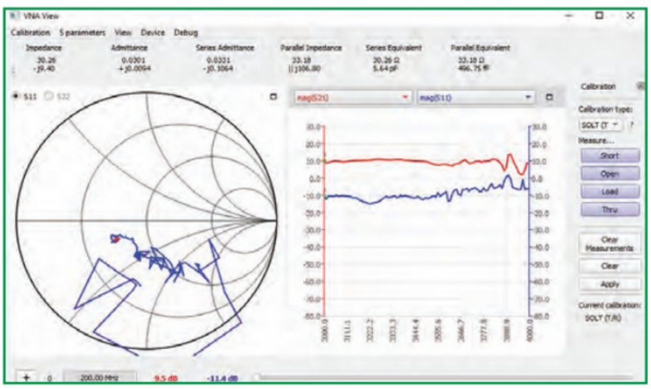


FIGURE 8: Rx filter 3400MHz.

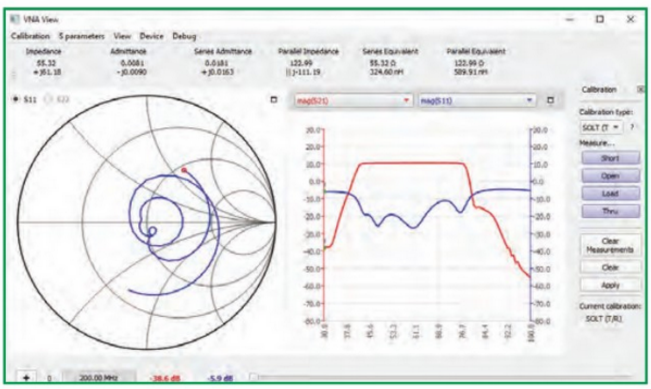


FIGURE 9: Rx filter 50-70MHz with FM Notch.

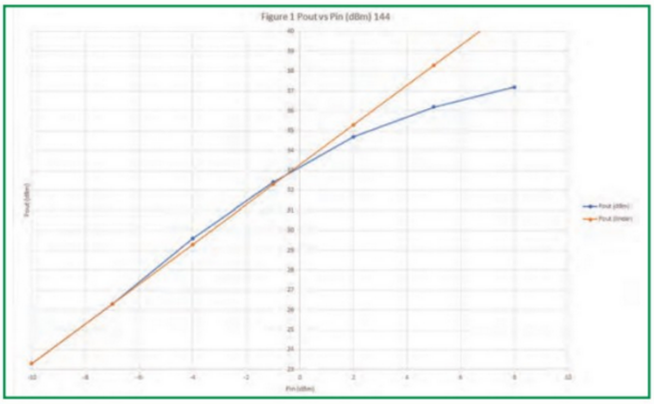


FIGURE 10: **Power out v power in at 144MHz.**

8970A noise figure analyser with a 15dB ENR noise source. At 2320 and 3400MHz, external mixers were used in front of the noise figure analyser. Gain measurements with a noise figure analyser are notoriously unreliable and Lime Micro's own results indicate somewhat better results for gain, for all bands except the last one, HAM3500, where my measurements obtained better results.

The test results are shown in **Table 1**. These results are quite respectable and compare well with many VHF/UHF transceivers available today, but not to a decent microwave transverter on the top three bands. For serious low noise operation an additional masthead preamp is always recommended above 144MHz.

Frequency response of the 'HAM' Rx filters

The LimeRFE has software- selectable filters for the amateur bands and the unit was swept with each filter selected in turn, using a generic NanoVNA. The plots of the seven UK bands are shown in **Figures 2 to 9**. Commenting on them, Figure 2 shows the unit in HF (30MHz) mode and it is clear that this is actually a 48MHz low pass filter on receive.

Figure 3 is the '50-70MHz' filter and again seems somewhat wider, at around 36 to 83MHz. Figure 4 is the '144-146MHz' filter and again seems somewhat wider, at around 123 to 150MHz. Looking at Figures 5 to 8 we see this pattern repeat, with filters somewhat wider than the specification would indicate. Above 1GHz there seems to be little roll off with any of the filters until well outside the amateur band edges, so be aware of this – especially on 23cm (Figure 6) where it seems just flat from 1 to 1.5GHz.

The FM notch filter does seem particularly effective though and comparing Figure 9 (notch on) to Figure 3 with the 50-70MHz 'HAM' band filter selected, clearly shows a sharp roll off above 77MHz.

Test equipment used in this review

RF power meter: HP 436A with 8484A diode power sensor
HP 8498A 30W 18GHz 30dB power attenuator
Assorted attenuators
Noise figure meter: HP 8970A with 346B 15dB ENR noise source
Generic NanoVNA
Sweep generator: HP 8350B plus 86290A 2-18GHz plug in
Spectrum analyser:HP 8592B
RF signal generator: Marconi 2024
Note that all measurements in this review were made using 'good' surplus, amateur radio standard test equipment that does not necessarily carry a current professional calibration certificate, so measurements should be taken as a guide only.

Performance as a transmit amplifier

Linearity was measured by inserting two closely spaced RF carriers in to the amplifier and measuring the amount of 3rd order intermodulation on the output. This test signal was produced by resistively combining two RF carriers generated from a LimeUSB using a custom GNU Radio script. Before that, some measure of linearity was made at 144MHz by measuring the amplifier's output power versus input power curve and measuring the 1dB compression point P1dB. The higher the P1dB the more linear the amplifier.

As an example, of the unit's compression curve, **Table 2** and **Figure 10** show the results, with a saturated CW power output from the amplifier at 144MHz of around 36dBm and a P1dB of around +35dBm (3 watts).

Two tone intermodulation tests tor transmit linearity using two RF carriers spaced by 10kHz were carried out on various amateur bands and the PEP output measured (+6dB above tone levels) at the point where the 3rd order intermodulation products were 30dB below the PEP. **Table 3** shows the -30dB IP3 PEP powers by band.

Photo 2 shows the 2-tone spectrum at 5W PEP at 432MHz. 3rd order products are some 28dB below PEP and higher order some 40dB below PEP.

Using a spectrum analyser (but no fundamental notch filter) and carefully controlling the fundamental level to the analyser, I looked for harmonics up to 24GHz with an input level to produce the P1dB power for each band. **Table 4** shows the results: nothing beyond 3rd harmonic was visible above -65dBc.

The manufacturer notes that, depending upon the application and overall system configuration, "additional filtering may be required for use on the HF bands". As HF is not one, but ten bands, starting at 1.8MHz and moving upward incrementally to 28.0MHz, measurements were made on six of the main bands. On-board filtering will attenuate signals greater than 30MHz, but not Tx harmonics or out-of-band Rx signals below this. You may need additional filtering, depending on the environment, especially if there are nearby stations operating on other HF bands, and on whether or not you are using external power amplifiers with integrated filters, antenna tuning units, etc. **Table 5** shows the harmonic levels on the six main HF bands.

On-air testing

Testing was carried out by driving the LimeRFE with a LimeSDR using SDR Console version 3.1. SDR Console is my own personal choice for the LimeSDR as it supports LimeRFE control directly. The LimeSDR is supported by a number of other SDR programs, but many at the moment do not support the LimeRFE. One exception I know of is SDRAngel. As I was air-testing the LimeRFE, not a particular SDR or SDR program, this setup gave an easy 'configure and go' option, not requiring any code to be written by the user.

I set up the SDRconsole program for the narrowband transponder for the QO-100 satellite and enabled LimeRFE support as described on the SDR console site [6]. On transmission, I found could easily hit the 'LEILA' signal limit warning on the satellite with the LimeRFE to a 1.2m dish with a POTY feed. The LimeRFE was configured to use the 13cm HAM band filter on transmit and the wideband 1000-4000MHz filter on receive. This allowed for the locked LNB's IF range around 740MHz to the LimeSDR via the LimeRFE. As expected, it just worked. Signal reports were good and no issues were noted on either transmit or receive.

Daniel, EA4GPZ has also used his LimeRFE with WSPR on HF and on QO-100 to good effect, see **[8]** and **[9]**.

Conclusions

The LimeRFE is a viable option for a multiband SDR station when combined with a decent SDR program like SDRconsole and a Lime Mini. At under £600 for the pair, you get a multimode QRP rig that you can use from 160m to 9cm (but see notes on filtering). The LimeRFE will support any mode that the SDR software writers can conceive of, including all the analogue modes (SSB/FM/AM/CW) plus DATV and wideband modes such as DAB and wideband high-speed data. There is already digital voice support in the form of FreeDV **[10]**.

Be aware though that the harmonic performance of the PA is totally inadequate on the HF bands. Separate low pass filters should be used for each band before an antenna or linear amplifier, but as the power is just a few watts, these can be made from standard leaded or SMD components.

If you already have different SDR such as the Pluto, the Lime RFE's Open-Source Application Programming Interface and GnuRadio support means that you can add LimeRFE support to many systems. You can also write your own control applications for any SDR.

Now, I'm not a programmer, so I had to rely on other people's software and the GNU Radio Companion to do the coding for me. Controlling the LimeRFE via GNU Radio is very simple if you make the effort to learn the basics and experiment.

The buffered GPIO interfaces on the LimeRFE allow you to (for instance) do your own antenna changeover sequencing and masthead preamp and/or high-power PA control in software, making the unit a system designer's dream.

I have only scratched the surface of what can be done with the LimeRFE and an SDR, but I'm looking forward to doing much more!

Acknowledgements

My thanks to Andrew Back and the teams at Myriad RF and Lime Micro for the loan of the unit tested and for their feedback on the first draft, plus Simon Brown, G4ELI for his work integrating it into SDR-Console and Dave Crump, G8GKQ for integrating it into the Portsdown DATV system

Websearch

[1] https://limemicro.com/
[2] https://www.mouser.co.uk/c/?q=LimeRFE
[3] https://github.com/myriadrf/LimeRFE
[4] https://bit.ly/3F4e6lw
[5] https://wiki.myriadrf.org/Lime_Suite
[6] https://www.sdr-radio.com/lime-rfe
[7] https://bit.ly/3qltOLn
[8] https://bit.ly/3qlUf3D
[9] https://www.rtl-sdr.com/tag/limerfe/
[10] https://bit.ly/3mYDXeS

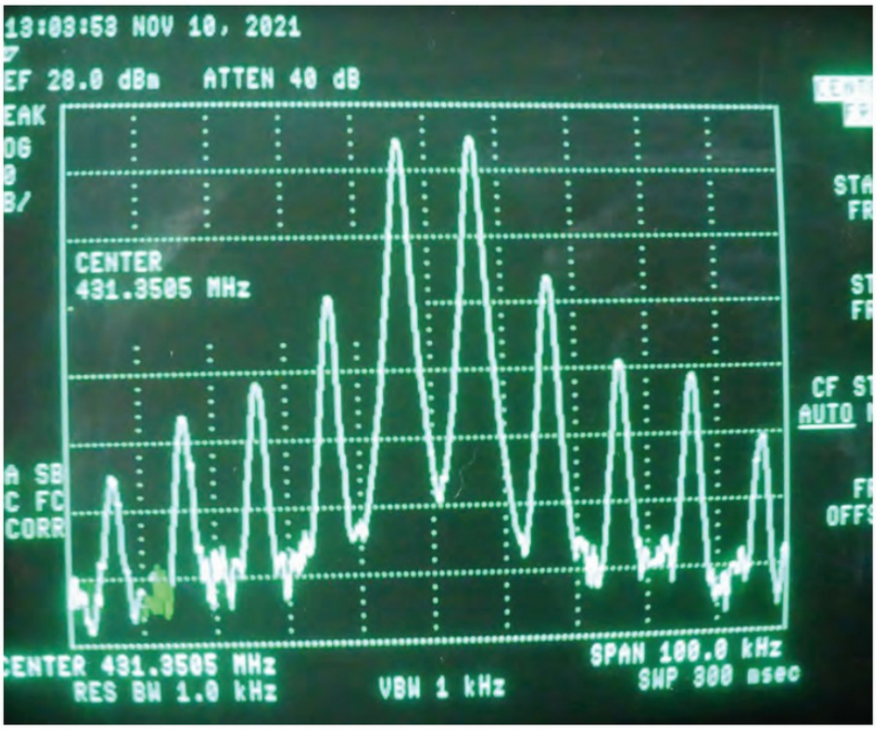


PHOTO 2: Tx spectrum at 432MHz.

TABLE 1: Gain and noise figure for selected bands.

Frequency	Gain	Noise figure
50MHz	16.3dB	3.8dB
70MHz	16.3dB	3.4dB
144MHz	15dB	3.8dB
432MHz	12dB	4.0dB
1296MHz	15.3dB	2.7dB
2320MHz	11.4dB	3.96dB
3400MHz	10.5dB	4.7dB

TABLE 2: Power in vs power out at 144MHz.

P_{in}	P_{out}	P_{out}	Gain
-10.3dBm	23.3dBm	0.21W	33.3dB
-7.3dBm	26.33dBm	0.43W	33.3dB
-4.3dBm	29.63dBm	0.91W	33.6dB
-1.3dBm	32.43dBm	1.74W	33.4dB
+2.3dBm	34.73dBm	2.95W	32.7dB
+5.3dBm	36.23dBm	4.17W	31.2dB

TABLE 3: PEP output at -30dB IP3.

TX frequency	PEP at -30dB IP3	
30MHz	+35dBm	3W
70MHz	+33dBm	2W
144MHz	+36dBm	4W
432MHz	+37dBm	5W
1296MHz	+32dBm	1.6W
2320MHz	+30dBm	1.0W

TABLE 4: Harmonic levels above 30MHz.

TX frequency	2nd harmonic	3rd harmonic
50MHz	-55dBc	>-65dBc
70MHz	-60dBc	>-65dBc
144MHz	-50dBc	-51dBc
432MHz	-60dBc	-53dBc
1296MHz	>-65dBc	>-65dBc
2320MHz	-43dBc	>-65dBc
3400MHz	-44dBc	>-65dBc

TABLE 5: Harmonics on the HF bands.

TX frequency	2nd harmonic	3rd harmonic	4th harmonic	5th harmonic	6th harmonic
1.9MHz	-20dB	-30	-45dB	-60dB	>-65dB
3.6MHz	-22dB	-30dB	-46dB	-60dB	>-65dB
7.1MHz	-22dB	-30dB	-45dB	-60dB	-65dB
14.1MHz	-24dB	-30dB	-40dB	-48dB	>-65dB
21.1MHz	-22dB	-30dB	-50dB	>-65dB	>-65dB
28.5MHz	-24dB	-42dB	>-65dB	>-65dB	>-65dB

Anytone AT-779 70MHz

FM mobile transceiver

The Anytone AT-779 is a 70MHz FM transceiver, suitable for mobile use.

The 4m can be a very useful band and this small mobile transceiver reminded me just how useful.

A couple of months ago, I had a chance to look at the Wouxun dual band handheld for 70 and 144MHz and, in the course of carrying out that review, I was reminded of what a useful band 4m can be. I was delighted to then get the chance of having a look at the Anytone AT-779 low band VHF mobile transceiver. The coverage of the rig is from 66 to 88MHz, but of course, the useful frequency range for us is the 70MHz band. The advertising for the rig lists the following as the key features:

- Frequency range: TX /RX : 66-88MHz
- Number of memory channels: 199
- Step sizes: 12.5/15/20/25/30/50kHz
- Squelch: CTCSS/DCS
- Hard wired microphone
- Power levels 5/10 & 15 watts
- Clone-by-cable software is free download

First impressions

The first impression on taking the rig out of the box is of the size – or rather the lack of it! The rig is tiny. It's barely bigger than my iPhone. That's immediately good news if you are thinking about fitting the rig in a car where space is at a premium. Similarly, it won't take up much space in the shack.

The microphone is hard-wired into the rig, which is not so good news if you were thinking about using it with a hands-free kit in the car. The rig is easy to operate and has some very basic controls.

The knob on the right of the rig serves not as a channel change control, as you might think, but as an on/off switch and a volume control. Channel change is achieved by using the up/down keys on the microphone. The 'Fun' key serves as the Function key to get into the menu, which allows you, amongst other things, to change the power level.

RF output on the review rig was High (17W), Medium (8W) and Low (4W). It would be good if the medium power level was 10W as that would then enable Foundation Licence holders to use their maximum licenced power.

In use

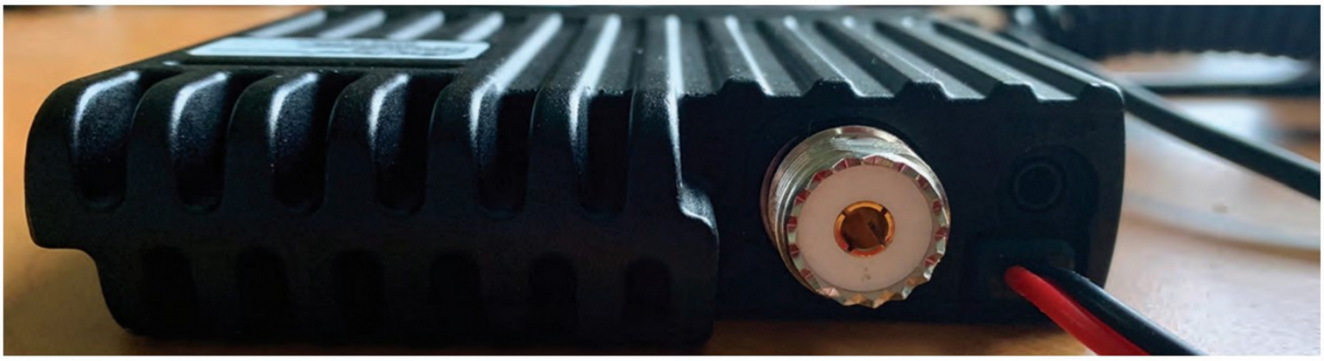
I quickly found my way around the controls of the rig and had a listen to it on the monitor receiver – the transmitted audio sounded good quality as was confirmed later in contacts on the air. A quick check with the signal generator showed that the rig is not particularly sensitive. This is quite normal for low band VHF FM sets where the noise level can be quite high – so a very sensitive set might be rather counterproductive. In practise, the sensitivity of the AT-779 was good in both fixed and mobile situations. Driving past a petrol station, I noticed that even a very strong signal was wiped out. I suspect that in a very dense urban area, then the AT-779 might struggle with a high ambient noise level.

The squelch is easily adjusted from the menu and seemed nicely balanced.

People always ask me about the spurious signals produced by the transmitter on low-priced sets. I do not have laboratory quality equipment to make these tests; but I do have some simple equipment that allows me to get a feel for the quality of the output. Initial tests of the 2^{nd} and 3^{rd} harmonics based on a transmission on 70.450MHz showed that these harmonics were not as low as I would have liked. Discussion with other users (including someone with some very decent test equipment) showed that other units were much better than the review model, so it may be that I was unlucky with the review model, although Martin Lynch & Sons were able to reproduce the issue on another model, from the same batch. As soon as I raised this with Martin Lynch & Sons, they took the matter up with Anytone to see if improvements can be made.

The rig comes with a PC programming cable (USB). However, given the nature of operation on 70MHz, this is probably largely unnecessary, as there is no repeater operation requiring repeater shifts, CTCSS tones and the like. Operation is simplex, so you will probably be quite happy, as I was, to move between the different channels

The clear front panel of the Anytone AT-779 shows the rig is easy to operate and has some very basic controls.



I connected a quarter wave magmount on the car, connected it to the radio and placed the AT-779 in the centre console of the car.

using the up/down keys on the microphone. The AT-779 does support the use of CTCSS tones, should you require it.

On the air

So, how did the rig work on air? I wanted to find out. Not having a 70MHz aerial on the house, I popped a quarter wave magmount on the car and placed the AT-779 in the centre console of the car. It fitted easily! The only snag was that the rig's speaker is downward facing, so the audio is not as strong as it might be if you use the rig in this way. There is an extension speaker socket, so this is easily remedied if you need to.

With the rig all connected up and the car parked in the yard, I tried a CQ call on 70.450MHz. I was, if I'm honest, totally surprised to be called straightway by Luke, 2W0LXT about 7 miles from me in Letterston. Luke's signal was strong and I was delighted to find that he was receiving me well. It's an obstructed path, so I felt that was very promising. On finishing the contact with Luke, I was then called by Richard, GW1JFV in Haverfordwest, some 15 miles away. Signals to and from Richard were a little weaker with some noise, but the path is much more obstructed, particularly as both our aerials were quite low.

A few days later, I asked Richard if he would help do some tests as I drove around. He kindly agreed. Richard runs 25W to a Sandpiper 'Ringo-Ranger style' aerial at 12 feet above ground. For much of our test, the signal path was obstructed. Nevertheless, as I drove around the North Pembrokeshire countryside, stopping at various spots to check signals – including the bottom of some valleys, we were amazed at the coverage that we got over distances of 20 or so miles in very undulating terrain. I found that 70MHz FM does a remarkable job of covering areas that 144 or 430MHz FM would struggle with, given a similar power level and antenna. We were both very excited and enthused with the results of this test.

After an extended QSO of about 30-40 minutes on the rig's high power setting, the AT-779 was rather hot! There is no fan to cool the heat sink, so do be aware that the rig will get hot – be careful where you place it. The downward facing speaker meant that I had the volume on maximum as I was driving around and the audio level was still a little on the low side. I also noticed that the up/down buttons on the microphone are very sensitive, so it is easy to change channel inadvertently (if you are not going to QSY – the lock feature might be worth using).

Overall

The AT-779 is a simple, easy to use 4m FM radio with a tiny form-factor. The power levels are useful for both fixed and mobile users. The rig does get very hot after a reasonable length QSO on the high power setting – please be careful. The levels of the 2nd and 3rd harmonics of the review radio gave cause for concern, but I am happy that not all radios are affected. Transmitted and received audio is good. An extension speaker may be useful when using the rig in a noisy mobile environment. The hard-wired microphone reduces the flexibility of the rig – more difficult to use a hands-free kit, which is needed if you want to operate when actually mobile.

Importantly, the AT-779 reminded me how good 4m FM operation can be. I know many people have 4m FM capability but perhaps have not used it in some time. With better weather and hopefully, more freedom to travel to mobile/portable locations on the horizon, the AT-779 combined with a simple vertical antenna could make for lots of fun.

The Anytone AT-779 costs £79.95 and is available from Martin Lynch & Sons (www.hamradio.co.uk). Very many thanks to Martin himself and Gary Spiers at ML&S for their help and support in producing this review.

Tim Kirby, GW4VXE
longworthtim@gmail.com

GHz Bands

Plenty of activity and records to report this month, including two new World DX records and Gibraltar on the QO-100 satellite.

PHOTO 1: DB6NT's 134 and 241GHz systems. Courtesy DB6NT.

New 134 & 241GHz World records

High mountains, cold dry Winter weather and excellent engineering enables our German colleagues to keep ahead in the world of upper GHz distance records.

On Tuesday, 1 March 2022, DK5NJ went to the Leipigerturm (797m ASL) near Schmiedefeld (JO50ON60BJ) and DB6NT to the Aschberg (913m ASL) near Klingenthal (JO60GJ03RO) to set new world 134GHz and 241GHz records on CW. A distance of 92.8km. Air temperature was 6°C at Aschberg and relative humidity 29%. The QSO on 134GHz was at 1503UTC with 599 reports, and on 241GHz at 1538UTC with 559 reports. Both stations used the same DB6NT transverter equipment. On 134GHz running 100mW, and 241GHz, 50mW to 40cm parabolic dishes made by OE5VRL. **Photo 1** shows DB6NT's setup. The equipment was loaded on to sleds to get it from the car park! **Photo 2** shows them loading up. A full report and more photos and videos can be found at **[1]**.

Another new UK 122GHz record

On 25 February, John, G8ACE, Dave, G1EHF and Noel, G8GTZ achieved a new UK distance record for the 122GHz band. The path was 36.44km from IO91KF42 to IO91EE26. Dave and Noel made a two-way contact using VK3CV units and John, whilst much stronger on transmit, did not receive G8GTZ. A full report is in *Scatterpoint*, and some pictures are on Twitter at **[2]**.

First QO-100 Gibraltar activation

QO-100 continues to function perfectly, and activity can be intense when there's a new DXCC on the satellite. Kev, ZB2GI sent in a QO-100 report via James, M0JCQ. Kev operated from the Gibraltar ARS club station as ZB2GI, the first activation from Gibraltar on the satellite. He made 228 SSB QSOs and worked 36 DXCCs. Equipment was provided by DL4EA and consisted of a DX Patrol up-convertor and power amplifier connected to POTY mounted on a 60cm dish, with an Icom FT-705 or a FT-817 as the exciter. On Rx, they used a LNB fed via a basis tee, connected to an RTL_SDR dongle running on SDR Console with Beacon lock activated.

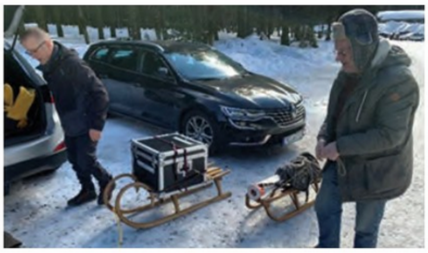


PHOTO 2 Sled transport! Courtesy DB6NT.

Next operation as ZB2BU the group made 147 SSB QSOs, and John, ZB2JK also operated and logged 84 SSB QSOs.

Activity Reports

G4DBN continues his experiments on 10GHz. In mid-March he reported very low absorption across the North Sea in the evening, but no sign of tropo into PA/ON/F/DL. However, he received a seventy-five second aircraft reflection from a 777 flying almost exactly along the path between his QTH and PA3GCO/B in JO21EU (410km), with a solid decode at -18dB of the PI4 signal despite a bit of doppler. More planes a few minutes later resulted in another good decode and two minutes copy. Earlier he had a reflection from GB3KBQ in IO80 (342km) apparently off a General Atomics Reaper Drone somewhere over Gloucester. Neil said he was "mildly surprised" that those little things are so reflective! Later in the month, he reports a super signal from DB0GHZ from the island of Heligoland, JO34WE, some 570km across the North Sea and over a 150m hill between him and the coast on 10368.810MHz. He also had his regular QSO with Adrian, G4UVZ on 10GHz SSB in IO80 earlier the evening. This was a 340km path under flat conditions.

Beacon Update

The GB3CSB beacon is now up and running on 6cm from IO75XX on 5760.985MHz with 25W EIRP. Mark, GM4ISM (IO85AR) is hearing it on a tiny patch antenna behind trees at 559 so all indications are that it is getting out as expected.

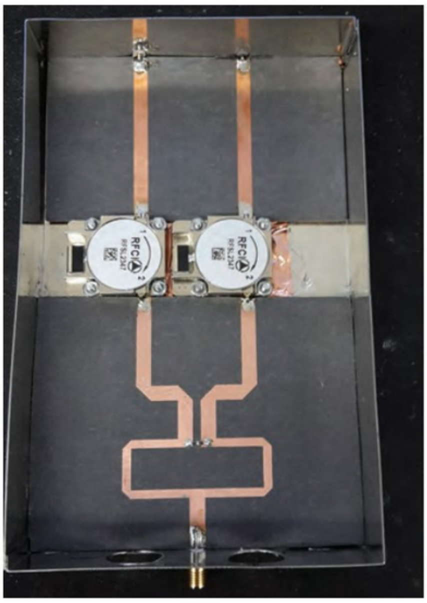


PHOTO 3 1.3GHz Wilkinson Combiner designed using free CAD software. Courtesy G4BAO.

Coverage is expected to be similar to the other beacons on the site. Modulation is identical to the other microwave beacons from site, CW and JT4. Many thanks to David, GM6BIG for the bulk of the work in building and commissioning the beacon. Antennas are centred on a bearing of 150°, and beamwidth is no more than 180° due to the local terrain. The beacon is on the side of a hill, giving it an excellent take-off South, "OK" E/W but terrible to the North! Over a two-minute sequence it sends JT4g, Morse id, 30 second plain carrier, 20 second of alternating 1 second duration tones (easy to hear and spot on a waterfall). The Morse id also contains beacon status info. An "L" after the callsign means the GPS reference is locked

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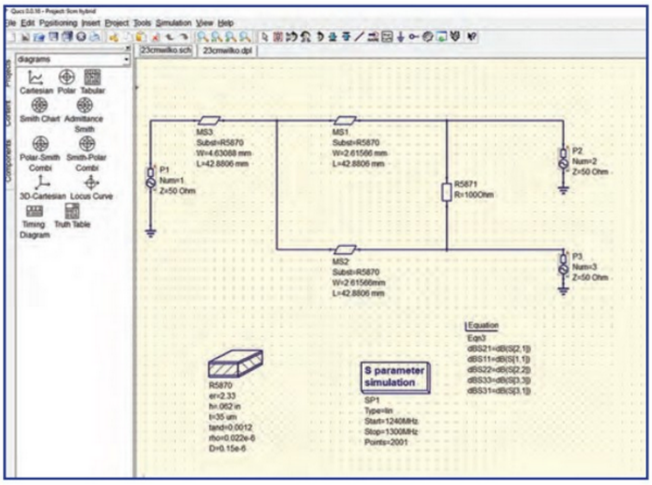

FIGURE 1: QUCS screen showing the 1.3GHz combiner design.

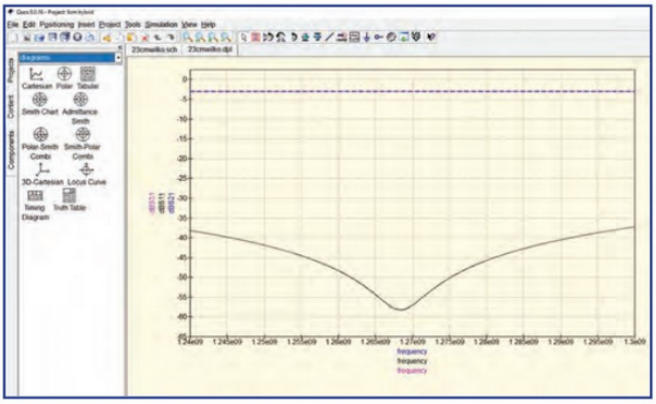

FIGURE 2: QUCS screen showing the1.3GHz combiner analysis.

reference and a "U" means Unlocked.

The GB3CAM beacons in IO92WI have a new site owner due to Paul, G4AJE retiring and selling the water tower (his pension!) to a commercial provider. We thank Paul for his support over the last ten years or so and thank him for clearing the way to allow beacon keeper, Bernie, G4HJW to agree very favourable terms for continued use and access. The 24GHz beacon has been off the air for a while, as this agreement was being set up, but as I write this, we are going to site this week and hopefully I can get it back on air.

Technology Update

Lime Mini 2.0: Many of you will be familiar with the Lime Microsystems LimeSDR USB and LimeSDR Mini. I've covered the use of these units for a number of applications such as ATV and QO-100 in this column in the past, and they are at the heart of a number of Amateur Projects. In March, Lime announced that they are preparing to launch a LimeSDR Mini 2.0 **[3]** that includes a larger field-programmable gate array (FPGA) allowing more functions to run on the device and ease the load on the host processor. Mini 2.0 will boast a Lattice Semiconductor ECP5 **[4]** with 44k logic gates; more even than the LimeSDR USB, and compared to the 16k on the original Mini. The new FPGA has an extensive set of open source tools and a great community of developers **[5]**. The RF specification of the new board remains the same. More information can be found at the Crowd Supply site **[6]** where you can also sign up to be notified on news and stock updates.

Free RF Design software: While some RF CAD software is just 'out of the question' for amateurs due to the high cost of ownership, there are plenty of free tools out there that can help your circuit and system designs. The ever-useful Microwaves 101 website **[7]** list quite a few that are worth looking at.

My 'go to' packages for general circuit design are QUCs **[8]** for general analogue design, filters, S parameter analysis and the like, and LTSpice **[9]** from Analog Devices for general circuit design with active devices. The latter includes a comprehensive library of Analog Devices ICs plus many others as well as the standard Spice models. For system design I use Appcad **[10]** and for EM modelling of circuit boards for filters and couplers etc, Sonnet lite **[11]** works for me.

To show an example of the design and build process, using QUCs I modelled the layout for a 1.3GHz Wilkinson input combiner that I now use to allow me to drive my PA from the narrowband transverter and the ATV system without any need for switching. **Figure 1** shows the QUCs model that I started with, just based on microstrip lines from the QUCs line synthesis tool. **Figure 2** shows the response plot from the QUCs analysis after I manually 'tweaked' the dimensions. I transferred the dimensions to Sonnet and again tweaked it to come up with an optimised real-world layout that included the tinplate box. Finally, I moved the dimensions for the Rogers substrate PCB to EaglePCB, (my preferred PCB layout program) printed it out on Press'n Peel film **[12]**, ironed it on to the substrate etched the board. **Photo 3** shows the finished item. This is a good example of what can be achieved with free software tools.

Martlesham Round table

As most UK readers will receive this issue in mid-April, I can report that the Microwave Round Table at Martlesham will go ahead as a one-day event on Sunday 24 April. It will be in a slightly different part of the BT complex at Adastral Park, but the organisers think it will prove as good or better than the previous accommodation used. Car parking will be on site in the same car park as in previous years, with the new venue signposted for visitors. A flea market area will be available, the usual snack bar and test gear available for checking your equipment, including noise figure and network analysis.

As usual the event will be free to attend, but for security purposes the organisers require registration beforehand. Google should find you the registration site. The UKuG AGM is planned to be on Zoom the following weekend, as this offers more members the opportunity to join the AGM without travelling.

Finally

If you have any comments on this or anything else to add to the GHz discussion, email me or Tweet @g4bao and @ukghz using the hashtag #GHz_bands.

Websearch

1: 134/241GHz world record: https://bit.ly/3D1vs9a

2: 122GHz record: https://twitter.com/G8GTZ and https://twitter.com/G1EHF

3: LimeSDR Mini 2.0: https://bit.ly/3twHZP2

4: Lattice ECP-5: https://www.latticesemi.com/Products/FPGAandCPLD/ECP5

5: ECP-5 support: https://www.latticesemi.com/en/Support

6: LimeMini 2.0: https://www.crowdsupply.com/lime-micro/limesdr-mini-2-0

7: https://www.microwaves101.com/encyclopedias/free-eda-software

8: Qucs: https://sourceforge.net/projects/qucs/

9: LTSpice: https://bit.ly/3wykW8p

10: Appcad: https://www.broadcom.com/appcad

11: Sonnet lite https://www.sonnetsoftware.com/products/lite/download.html

12: Press'n Peel: https://amzn.to/3iJKkQt

For the first time since I started writing this column, I did not submit this draft to Giles Read, G1MFG. His contributions to GHz bands as Technical Editor generally went unnoticed and unacknowledged and his sudden and untimely death was a shock to us all. As Mark Twain put it, "Do not complain about growing old, it is a privilege denied to many".

American wiring

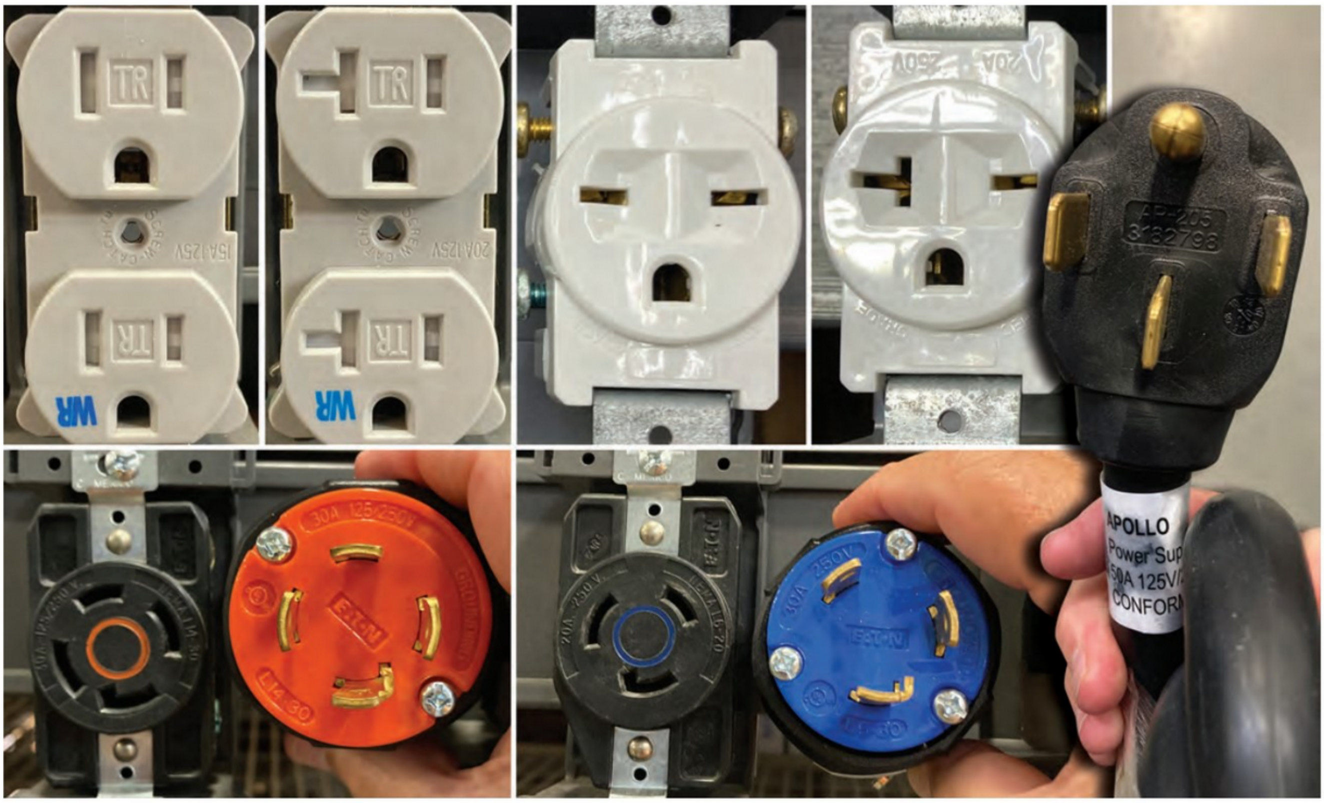

PHOTO 1: **Various electrical connectors used in the US. Clockwise from top left: 15A/125V, 20A/125V, 20A/125V *or* 250V, 15A/250V, 50A 125V / 250V 'RV' plug, 3-prong 20A/240V, 4-prong 30A/120 + 240V split phase.**

The US isn't *just* 115V

Growing up in the United States, all things electrical fascinated me. I learned lots about radios and electronics and valves (we call them tubes) and even high voltage. But growing up in the US I never gave mains voltage a single thought. It was always 115 volts, 60 cycles per second, period. When we got an electric clothes dryer, I was astonished to find that it worked off a dangerously high voltage – 230V. Later, when I got to inspect various pieces of real electronic test gear I noticed the 110/220 switch that many had on the rear of their chassis. It was about then that I finally became acquainted with the fact that much of the rest of the world did not share our lower voltage and still seemed to get along just fine. And still further along my career I had to design equipment that had to be adaptable to anything the customer's mains could offer and still work properly. This small article may help to explain in general terms the US electrical mains system in case you come across equipment designed for it.

Three key points

There are, generally speaking, three things that anyone must know to adapt between mains voltages. First is *how* the equipment adjusts for different voltages. We've become way too comfortable with so-called 'universal' switch mode power supplies. Typically they'll take anything from under 100V to well over 240V and anything from 40-90Hz. Supply the correct cable and plug and you're set… almost. But having caused smoke to exit a few pieces of equipment in my 72 years, my level of comfort has been replaced by the need the use a Rosetta Stone to compare the equipment's operation to my expectations. More on that in a bit.

Second is the choice of *connectors*. The world requires a dizzying array of different types. Here in the US, a trip down the aisles of the local hardware store makes a confusing situation even worse. Why? Well, a big limitation is our 120V AC (which has now pretty much replaced 115V across the country – and is often really 125V). Most house circuits are limited to about 15 amps before the lights go out. And even a dedicated 15 amp circuit is limited to 120V x 15A = 1800 watts (*one reason you rarely see electric kettles in the US with as much power as we're used to in the UK - Ed*). When your rig and linear are collectively pulling about that much, the circuit breaker is so close to blowing that anything can shut you down. One seldom-used solution for American amateurs is to wire up 20 amp circuits with heftier wire, requiring a distinctively different connector (though it isn't always used, but it should be). That gets your 1500W PEP linear on the air… maybe.

Third is circuit *protection*: fusing. Double the mains voltage requires – generally – half the current. That is, after all, the whole idea of increasing the mains voltage. Demands on the wiring lessen with higher voltage, after all. But when you squint at the fine print on small cartridge fuses there's much to learn. Is it slow-blow or fast? Rated for only 125V, or more… or *less*? How much surge can it take? In the end, flea-market fuses are fine, up to a point, but it's always a good idea to purchase fuses from suppliers that give you all the info. "Looks like Slow-Blow to me" is seldom the right way to go.

So the Rosetta Stone? Well, let me give you our version of the mains, in **Figure 1**. This is how one handles 240V AC home wiring in the US (for clarity, omitting fuses, Ground Fault Interrupters and all other protection

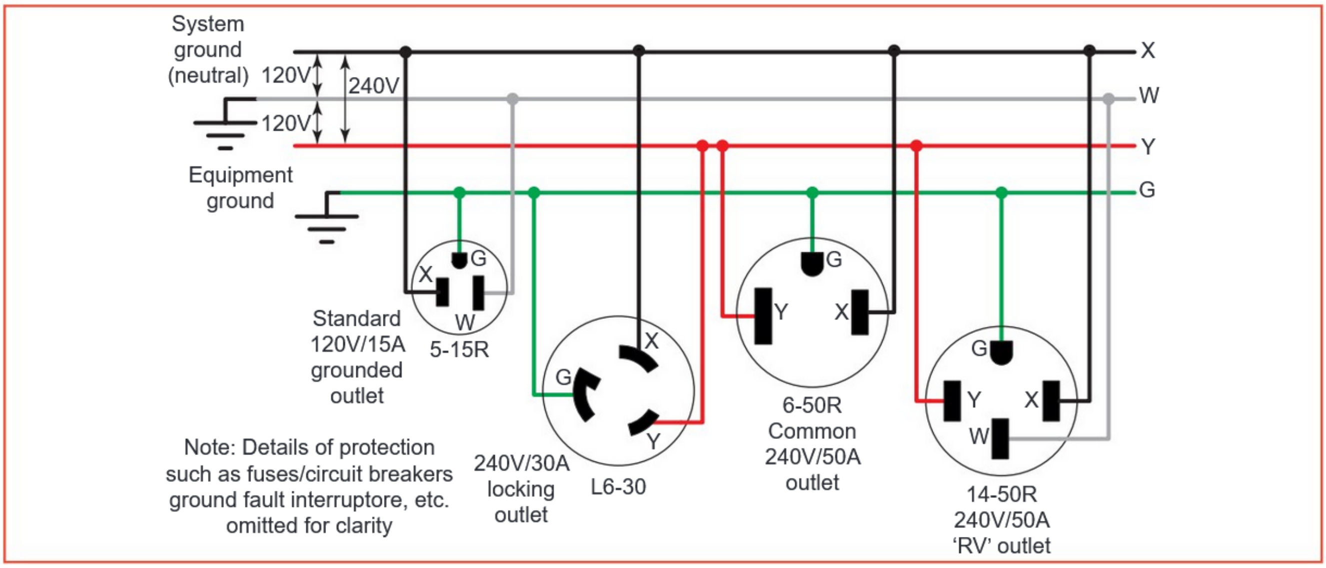

FIGURE 1: **Basic US house wiring (fuse/breaker arrangements not shown).**

devices). Hopefully it offers insight for anyone elsewhere trying to adapt US equipment for other mains systems. Here, unless you've wired in a special 240V line to your shack, or have an electric clothes dryer or a new electric car charger, we never see the red wires.

While most of the rest of the world has adopted single-phase circuits with
Line = Brown
Neutral = Blue
Protective Earth = Green/Yellow,
most circuits in the US still use
Line ('Hot') = Black
Neutral = White
Protective Earth ('Ground') = Green.

It isn't until you require 240V in the US that you'll encounter red wires seen in Figure 1. And ordinarily in the US we use both sides of the 240V two-phase line to double the number of outlets that can be attached. But when one wires up any 120V line, say, to an outlet, it's still the same old black, white and green. Some of the black wires get connected to the 'red wire' bus, sometime with a wrapping of red electrical tape to indicate its source, but it's still black-equals-hot at the outlets.

Where to start?

When one acquires some piece of (probably used) equipment from the US, the place to begin your campaign of worrying and adaptation is the connector. **Photo 1** shows the bewildering variety of mains outlets used in the US. The most common are the two pairs top-left. To the left is the 15A/120V version. The taller (or wider) blade socket is always the neutral and the D-shape at the bottom is ground. Next to it, with the T-shaped neutral, is for 120V circuits wired to supply up to 20A. The difference will be the gauge of wire leading to the outlets and the capacity of the breaker at the input ('fuse') box.

Moving clockwise, we see two more similar sockets, except that the prongs are horizontal rather than vertical. On the left is the 20A 125V or 250V type and on the right is the much-less-used 15A 240V type. They look alike, but the extra horizontal slot is the clue that someone's possibly using double the 'normal' 120V! The one on the left 'can' be used as a 15A 250V OR a 20A 120V connector. But here's a word of caution… *EXTREME* caution. Connectors with one or both slots horizontally fitted (or blades on the plug end) are not commonly used in the US, and so have been routinely used improperly by folks to keep unauthorised users from turning on the equipment just by plugging it into the normal wall socket. They keep a home-made extension cord hidden somewhere that can be used to make the connection to the wall outlet. The warning is that, when you see an unexpected connector, you must NEVER assume that it was installed for the correct reasons. Your next task is to go spelunking into the works to trace the mains paths to ascertain what voltage is actually expected. Sometimes wiring and fusing can help decipher the correct answers.

US amateurs who live in more modern houses (say, 1970 onwards) are more likely to have access to a 240V line that was installed by a *bona fide* electrician. Such an installation would terminate in a connector similar to one on the bottom row. Of the two types, the 240V 20A 3-prong (blue) is more common for things like linear amplifiers. The 30A 4-prong 120/240V (orange) type tends to be used primarily for industrial equipment, but 'can' be used on circuits requiring less current. Again, the 30A rating is tied to the wire gauge feeding the outlet.

Lastly to the right is a large a connector still widely used in the US. It's sometimes referred to as a 'kitchen' or 'dryer' or even 'RV' (Recreational Vehicle, motor caravan) connector. It commonly uses very heavy-gauge wire and can handle 50A easily. It's possible to see how a ham might just adapt such a connector to mate to an old circuit via some ungodly extension to their station, unplugging the dryer to make way for a *big* linear when chasing DX contacts. In the RV application it is a common hookup to the RV from a campsite and that's where one might encounter such connectors, even for hooking up mobile gear.

Bewildered?

If all this seems a tad bewildering, that's because it *IS*, even to amateurs in the US. And, believe me, over the years amateurs have made do with even the most outrageous AC mains connections, just to get on the air. Don't know the electrical codes or don't have the right connector? Find the selection at the hardware store overwhelming? People simply resolve to use whatever they can find. The next owner will just have to deal with that trip down the rabbit hole to make things safe again. Most amateurs are NOT like that! But in my years I've seen too much to take anything for granted – and neither should you.

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N6JJA@ARRL.net

AR88 radio simulator

Introduction

It was suggested that we might build a simulator showing the path that an encrypted radio message would take during the Second World War, from reception to decryption. This project is now complete and it was brought to our attention that it was also of interest to radio amateurs. Some of our group in the Tunny Gallery at the National Museum of Computing are licenced amateurs.

The idea was for the museum visitor to sit at what looks like an RCA AR88 radio receiver and 'tune' it across its range, looking for the characteristic two-tone audio of a radio-teleprinter transmission. At first we thought about using an actual AR88. But how would the 'stations' be found reliably? And where can some good audio frequency shift keyed (AFSK) signals to be found these days? As a museum, we try to involve our visitors in our exhibits wherever possible but operating our vintage AR88s (**Photo 2**) was not feasible.

So we built our own 'pseudo radio receiver'. We already have machines that can generate real AFSK data signals so we recorded one of these and put the audio on a microSD card. Many other radio stations were recorded as individual audio tracks until we had a total of more than 40 tracks. This microSD card sits in an MP3 player module, more on this later. As the tuning knob is turned, the gearing turns a quadrature encoder which is connected to the control PCB. This is powered by a Microchip micro-controller chip 18F26K22 which then commands the mp3 player to play a certain track.

The software is written in the Positron language (nee Proton). It does feel as though you are tuning across the dial of a real radio. We added recordings of broadcast stations, music, noise, clicks, pops, bangs and whistles – everything you would hear on a real receiver.

PHOTO 1: The completed AR88 radio simulator.

Background history

Bletchley Park played an important role during World War 2. The science of cryptography took several leaps forward during that time. Part of Bletchley Park now houses the National Museum of Computing with exhibits of computing machines from nearly all periods of their history. The machine that spawned this museum now stands proudly at its centre: Colossus, the world's first electronic digital computer. It was designed in great secrecy by Tommy Flowers and his team at the GPO Research Establishment at Dollis Hill. Colossus helped to decode messages which were part of an unknown encrypted radio message system.

These messages had in fact been sent by radio teleprinter (RTTY) and had been encrypted through a Lorenz Schlüssel-Zusatz 40/42 cipher machine (Schlüssel-Zusatz = Key (or Cipher) Attachment). The Lorenz 40/42 were a series of cipher machines used with standard teleprinters and could be switched in or out of the circuit as required. Although Bletchley Park knew that the German military were using RTTY they had no idea what cipher system was being used. In fact they did not see a Lorenz machine until right at the end of the war.

The Germans had established a large RTTY network so the high commands in the occupied and Axis countries could maintain secure contact with Berlin. By the end of the war there were over 30 RTTY links. This was referred to as 'Fish' traffic at Bletchley Park and each individual link was given the name of a fish. Different encryption settings were used for each link.

German teleprinter apparatus used the International Telegraph Alphabet No 2 (ITA2) at the standard speed of 50 baud, the same as British machines. (The USA used a slightly slower speed of 45.5 baud and this speed is still commonly used by radio amateurs today.)

Early on in the war, messages were encrypted locally on a teleprinter/Lorenz closed loop and then sent in five-letter groups by Hellschreiber (which basically sends images of the characters). Eventually, after experimenting with various ways of keying, the Germans adopted a modified 3 channel multi-channel voice frequency (MCVF) telegraph system for amplitude modulating the transmitters. With the teleprinter and Lorenz connected to all three channels in parallel, there were three tones for mark and three for space: 540Hz mark / 900Hz space, 1260Hz mark / 1620Hz space, 1980 cycles mark / 2340Hz space. Doing this gave a degree of protection against selective fading over the radio link. It can be appreciated that only one mark and one space tone need be received successfully for the message not to corrupt.

One important section of our museum is devoted to the radio reception of the Lorenz encrypted messages. These communications were of the highest military intelligence value to the allies, even higher level than Enigma.

We won't go into the details of how Bletchley Park broke into this cipher or how the Lorenz works, other than to note that the big break for Bletchley Park came in August 1941 when operators on a Link between Vienna and Athens (Tunny) sent very nearly the same message twice using the same settings on their Lorenz machines, a fatal mistake in cryptography terms.

Much of the RTTY traffic that Bletchley Park handled during the second world war was received on RCA AR88 communications radio receivers. However, the interception of encrypted RTTY traffic was not straightforward. The Metropolitan Police had became involved in 'Y Intercept' work around the time of the General Strike in 1926, initially at Scotland Yard and later in 1932 at their new communications HQ at Denmark Hill in London. During that time they had become experts at intercepting and analysing high speed non-Morse (ie RTTY) transmissions. It is highly likely that the transmissions in August 1941, leading to the big break, were intercepted there.

Initially, standard teleprinters could not be used to copy the intercepted messages, due to the fact that the Lorenz cipher machine encrypts the five function keys on the keyboard as well (specifically, figure shift, letter shift,

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National Museum of Computing, Bletchley Park

PHOTO 2: **Rack of vintage AR88s (with Undulators in front) at The National Museum of Computing.**

space bar, carriage return and line feed). For example, a line feed is sent on the teleprinter but once it has been processed through the Lorenz it could appear over the radio link as, for example, a letter B. Even the spare 'All Space' combination could appear in the cipher stream.

To enable an accurate copy of the encrypted message at Denmark Hill, Marconi high speed telegraph recorders (more commonly referred to as Undulators) were employed, two of which can be seen in front of the receivers in Photo 2. The Undulators were connected to the receivers via terminal units that converted the received tones back into a DC signal to operate the magnet in the Undulators, which traced out the signals in ink on a narrow paper tape known as 'slip'. The resulting traces appeared as lines of ups and downs corresponded to the marks and spaces.

The resulting slips were read by eye, usually by women whose job title was Slip Reader. Slip Readers sat at perforating machines. The slip was passed across the front of the perforating machine on a motorised transport mechanism so the slip could be read and the cipher stream punched onto 5 hole perforated tape. The speed of the slip tape could be controlled means of a foot pedal.

Due to the amount of RTTY traffic being generated by the Germans it became apparent that a new purpose built intercept station (Y Station) was needed. As a result, in May 1942, the Foreign Office opened a new station at Ivy Farm, Knockholt, Kent. Henceforth, Knockholt became the main Y Station for the interception of German RTTY traffic. Due to propagation and skip distances small outstations were established at existing Y Stations, enabling the reception of signals throughout a 24 hour period.

If the reception of signals was good, it was possible to connect reperforators to the terminal units as well as the undulators. This enabled a perforated tape to be produced (known as 'raw tape') without the need for slip reading. However, any poor copy meant that the undulator slip would have to be used. The latter always gave the most accurate copy of the message.

Later, the GPO modified Creed 7B teleprinters to become what were termed 'shiftless' teleprinters. These modified machines could be connected to the terminal units as well, producing a printed copy of the cipher text. The modification involved adapting the type head of the teleprinter to print figure shift characters for Letter Shift, Figure Shift, Carriage Return, Line Feed, Space Bar and All Space. The machines were then fitted with a tape printing carriage rather than the standard page printing carriage.

Our pseudo receiver

The front panel of our 'AR88 radio receiver' is actually a photographic print, glued onto a 3mm thick aluminium panel. Three of the control knobs, plus the tuning dials, S meter and frequency display are real. A sheet of clear acrylic covers and protects the photograph.

Photo 3 shows what's behind the panel. The tuning gearbox was salvaged from an AR88 that had seen better days. We fitted a nylon gearwheel on the output shaft and found a matching gear to fit on the encoder. A little imaginative engineering was needed at times.

The old AR88 gearbox has a flywheel and spinning the tuning knob gives just the right amount of run-on when you spin the wheel with a bit of gusto. It feels just right. Holes were cut in the aluminium panel so the original tuning dials could be seen and these were lit from behind with a strip of LEDs. The rest of the components are fairly new. The printed circuit board (**Photo 4**) was designed by us. It enables reading the encoder, which determines which 'station' is being received, controls the MP3 module that generates the audio, drives the SH1106 OLED frequency display via an I²C interface, drives an S-meter (using PWM, with the 'signal strength' varying randomly under program control), and an audio amplifier that drives a small speaker. The board has provision for some other features (eg the push button) that are used in this implementation.

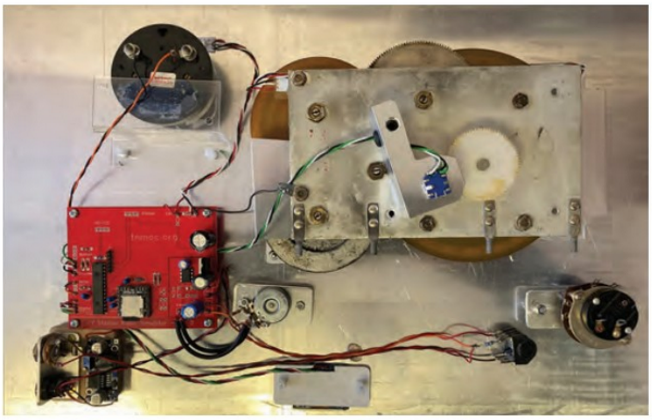

PHOTO 3: **The 'works' behind the front panel.**

The encoder drives two signals to the microcontroller. There is a fast software timer in the microcontroller that examines the encoder signals about 1000 times per second. If it detects a change, then the direction that the tuning knob is turning is determined and a string of data is sent to the MP3 player module to play the requested track. The progress of the audio is followed by the microcontroller and as soon as the track has finished it is played again. This avoids the radio 'going silent. The tracks have been edited to sound feasible and are at least 30 seconds long each. If the encoder isn't moved for 5 minutes then the radio does goes idle, and silent.

The mp3 player is a DF-Player module, which are available inexpensively via the usual online sites. You drive it with an RS232 stream at 9600 baud and it has stereo outputs, which we merge with a couple of resistors. There are a few variations with these devices: some need a 1k resistor in series with the RS232 data line and others don't. Experimentation is the answer.

The audio from the MP3 player goes via a volume control to an LM386 single chip audio amplifier and on to a loudspeaker. An LM386 can produce a surprising level of sound and we had to slug its input to avoid making visitors jump if the volume was turned up too far and the radio suddenly started playing.

An SH1106 OLED display shows the frequency being 'received'. This is driven from the microcontroller using I²C. The backlighting on the original AR88 dials is a warm orange colour, which came from filament lamps. We tried orange LEDs but they didn't look right. The answer was to use a strip of RGB LEDs called WS2812B. These come as a flexible strip-PCB and you cut off as many as you need. Each LED can have any mix of the three primary colours and we use a software routine to set the colour and brightness to suit the unit.

Unexpected problems

When the encoder was turned very slowly through the gearbox of the tuning system, it sometimes changed from one state to another then reverted to its original state. This caused confusion in the software

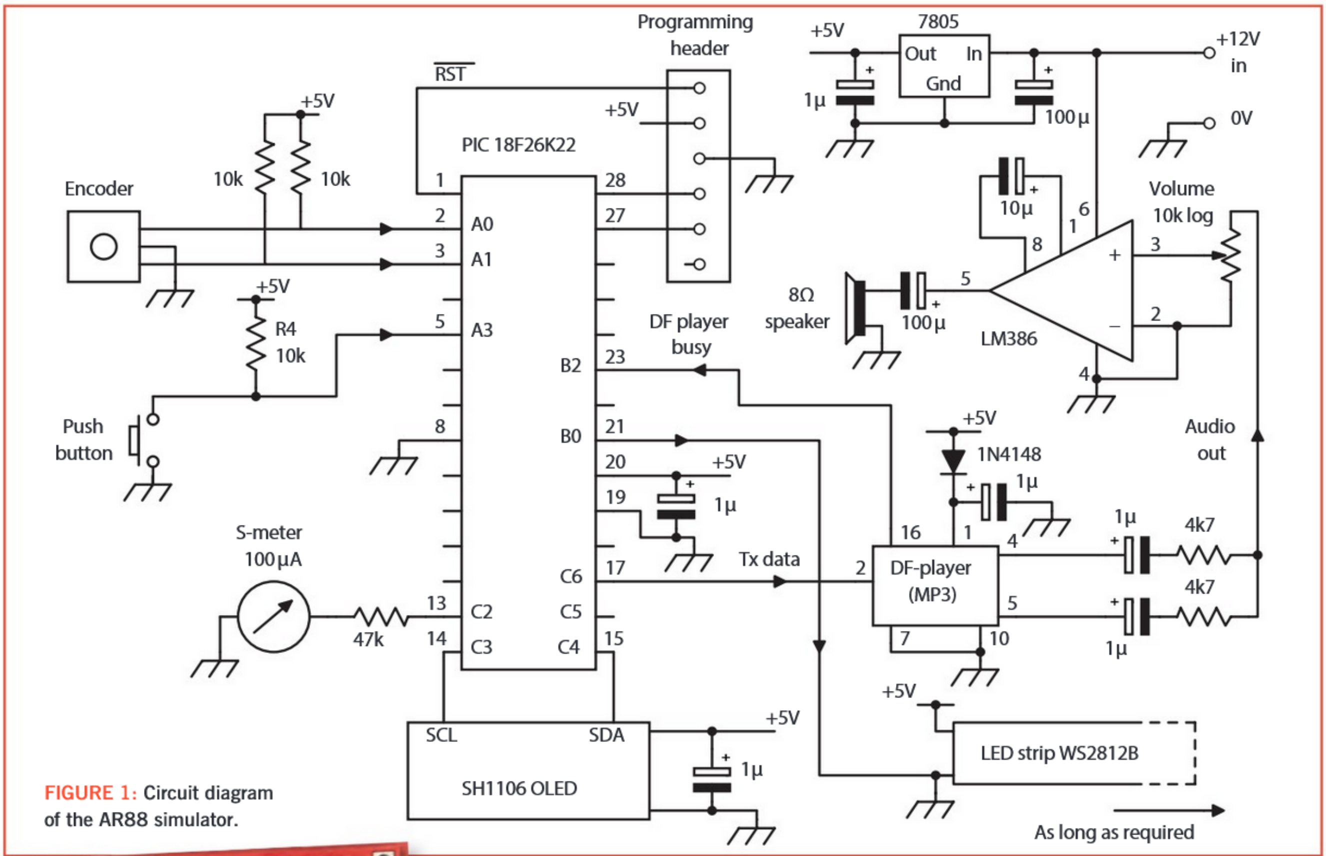

FIGURE 1: Circuit diagram of the AR88 simulator.

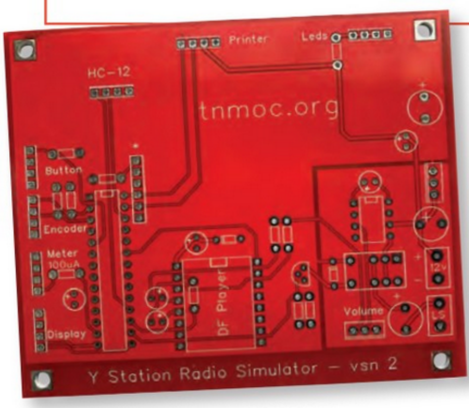

PHOTO 4: Closeup of the custom PCB.

and the same track was repeated. It was solved in the code that reads the encoder: the value of the encoder before the move is stored, then compared with the value after the apparent move. If it is the same then the move is ignored. A fast timer strobes the encoder states, which allows this very slow movement to be detected reliably.

Once we got the basic 'radio' working we found it was necessarily to ensure there were no gaps (silences) at the start or end of the audio tracks in order to avoid brief silences, which would harm the illusion. When controlled by the microprocessor the MP3 player switches between tracks fast enough not to cause any silences.

The one thing that a real radio receiver does is to gradually leave one station and then slowly merge into the next. We couldn't find a way of doing this. But our visitors haven't commented on that – yet!

Two of our members set about making a wooden enclosure for the unit, suitably arranged so that curious visitors couldn't get inside and fiddle about. The DC power (12V) comes from a switch mode wall transformer. It was noticed that there were some birdie-type noises on the audio, caused by the SMPSU. A few capacitors across the rails cured this to a large extent.

Success

So successful was our project that the Museum's management asked if we could make another unit for a different gallery. We were delighted of course. We then had a visit from the RSGB's Martyn Baker, G0GMB, who was so impressed that he asked if we could make a third unit, for the RSGB National Radio Centre. The main difficulty was finding a second and then a third gearbox from defunct AR88 receivers!. We considered making a gearbox from Meccano parts but we managed to salvage two from RCA AR88 receivers that were in a very sorry state. This third simulator is now installed and is part of the magnificent display of hands-on radio equipment in the RSGB National Radio Centre at Bletchley Park. If you haven't been there yet then it's well worth a visit.

If you take the idea of a radio that you can program the 'stations' it receives, a little imagination leads to the thought that this would be an ideal addition to an Escape Room. Food for thought…

Further reading and references

The National Museum of Computing at Bletchley Park: www.tnmoc.org

Positron Compiler: https://sites.google.com/view/rosetta-tech/home

Positron compiler forum: http://protoncompilers.com/index.php

In the Tunny section of the TNMOC website there is a paper called *Breaking Lorenz*. Go to www.tnmoc.org, Explore, Galleries, Tunny and Lorenz: the article is near the end of the Lorenz section.

The National Archives at Kew holds three very interesting documents:

HW3/81 *A brief history of events relating to the growth of the Y service*, H C Kenworthy

HW3/163 *The interception of German teleprinter communications by Foreign Office Station, Knockholt*, H C Kenworthy

HW50/63 *History of the FISH subsection of the German military section*

A very comprehensive hardback book, involving lots of complicated mathematics, is *Breaking Teleprinter Ciphers at Bletchley Park*, ISBN 978-0-470-46589-9