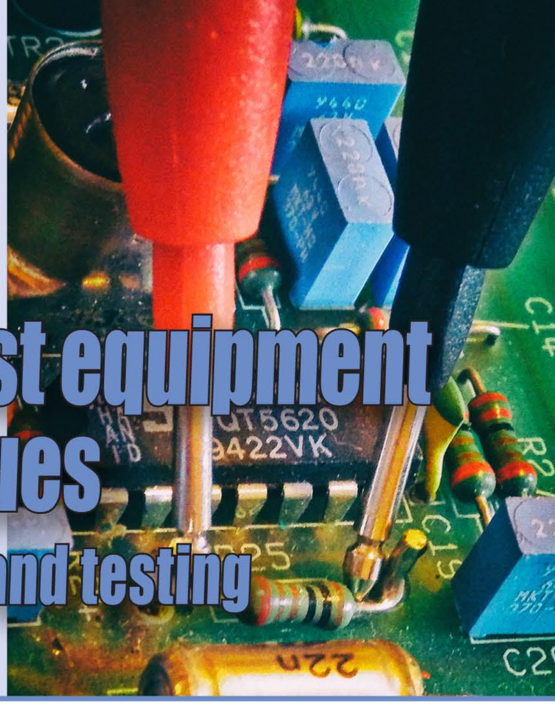

Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 7: Radio frequency measurement and testing

by Mike Tooley

Welcome to *Teach-In 2018: Get testing! – electronic test equipment and measurement techniques*. This *Teach-In* series will provide you with a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. We'll provide hints and tips on using, and – just as importantly – interpreting the results that you get. We will be dealing with familiar test gear as well as equipment designed for more specialised applications.

Our previous *Teach-In* series have dealt with specific aspects of electronics, such as PICs (*Teach-In 5*), Analogue Circuit Design (*Teach-In 6*) or popular low-cost microcontrollers (*Teach-In 7* and *8*). The current series is rather different because it has been designed to have the broadest possible appeal and is applicable to all branches of electronics. It crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone in this series!

Each part includes a simple but useful practical *Test gear project* that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible and most of them can be built for less than £10 (including components, enclosure and circuit board).

This month

In this seventh part, *In theory* will be looking at the principles and techniques that underpin a wide range of RF measurements, including voltage, power, modulation depth, and standing wave ratio (SWR). *Gearing up* introduces a variety of common items of RF test equipment while *Get it right!* helps you avoid some of the pitfalls and provides useful hints and tips that will help you to improve the accuracy and relevance of your measurements. Finally, our seventh *Test Gear Project* is a wide-band RF 'sniffer' that can also act as a useful relative field strength indicator.

In theory: RF measurement principles and techniques

In last month's *Teach-In 2018* we discussed audio frequency (AF) measurements. This month, we turn our attention to measurements that are made at much higher frequencies, extending from 30kHz to 30GHz (and beyond). They include the range of frequencies used for radio and TV broadcasting, as well as the 'wireless' and Wi-Fi networks that we use in our homes.

Measuring RF voltage

Provided that the frequency of a signal is within the measurement range of an instrument, the easiest method of measuring RF signals is with the aid of an oscilloscope. In conjunction with a ×10 probe, most oscilloscopes are capable of making measurements at frequencies of up to 30MHz or more depending on the upper frequency limit of the instrument used. An example is shown in Fig.7.1 where the sinusoidal output voltage of a low-power 7MHz transmitter is displayed.

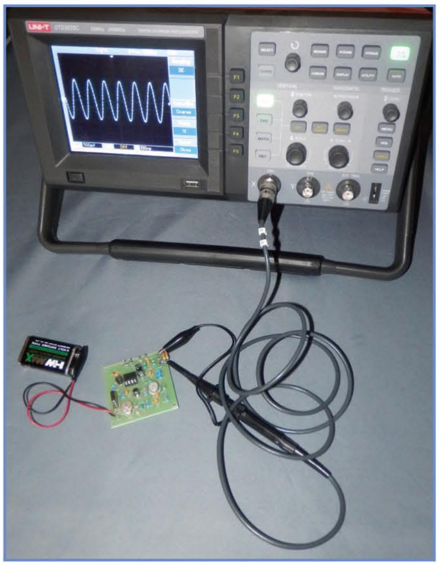

Fig.7.1. Using an oscilloscope and ×10 probe to measure the RF output of a low-power 7MHz transmitter

An alternative to using an oscilloscope for RF voltage measurements is a diode with a conventional analogue or digital meter, as shown in Fig.7.2(a). The probe will respond to the peak RF voltage but the meter can be calibrated in RMS volts. RF probes are often supplied with wideband voltmeters and they can extend the frequency range well beyond that which could be measured by an oscilloscope. To ensure the widest possible frequency range, the probe tip and ground connection need to be kept very short in order to minimise the stray reactance that would otherwise degrade the probe's performance.

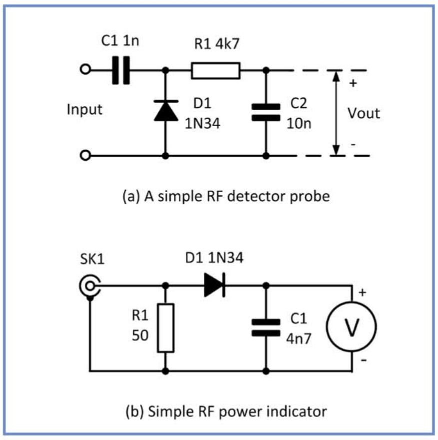

Fig.7.2. (a) A simple RF diode detector probe (b) A simple RF power indicator

A similar arrangement can be used to indicate RF power. In this case, the diode detector needs to be used in conjunction with a resistive load, as shown in Fig.7.2(b) and the meter needs to be scaled in mW or W. Since there is a square law relationship between power and RMS voltage, the instrument scale can be distinctly non-linear. Furthermore, the load resistor shown in Fig.7.2(b) must be appropriately rated in terms of power dissipation and it must be purely resistive (due to self-inductance, high-power wire-wound resistors must not be used). At frequencies above 30MHz, load resistors need to be specially constructed to minimize stray reactance and they should be fully screened in a metal enclosure and fitted with an appropriate coaxial input connector.

Modulation

Different types of modulation (see Fig.7.3) can be applied to RF signals acting as 'carriers' to convey signals such as speech, music and data. The depth of amplitude modulation can be easily measured using an oscilloscope and calculated from the relationship:

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \times 100\%$$

where V_{max} and V_{min} are the maximum/minimum envelope voltages, see Fig.7.4.

RF power measurement

As mentioned previously, at low RF frequencies it is possible to use an oscilloscope to measure RF voltage and thus, provided that the load resistance into which the power is delivered is accurately known, it is possible to determine power from the peak-to-peak value of a waveform observed on an oscilloscope. The following relationship is used:

$$P_{out} = \frac{V_{out(pk\text{-}pk)}^{\ 2}}{8R_L}$$

Putting this into context, let's assume that the oscilloscope indicates a peak-peak voltage of 20V with a load having a resistance of 50Ω. The output power would be calculated as follows:

$$P_{out} = \frac{V_{out\ (pk\text{-}pk)}^{\ 2}}{8R_L} = \frac{20^2}{8 \times 50} = \frac{400}{400} = 1\text{W}$$

An alternative to using an oscilloscope is that of using a dedicated RF power meter, in which case the instrument scale will already be calibrated in mW or W – see Fig.7.5.

Instrument connection

When carrying out RF measurements it is usually important to ensure that input and output impedances (as well as all connecting cables) are correctly matched. When applied to cables, the term 'characteristic impedance' is the impedance that would be seen looking into an infinite length of the cable at the working frequency. Typical values are 50Ω, 75Ω and 90Ω for unbalanced (coaxial) cables, as well as 300Ω and 600Ω for balanced (twin) feeders.

Characteristic impedance is a function of the primary constants of the cable, the two most significant being the inductance (L) and capacitance (C) per unit length of the cable (note that L is measured with the far end of the cable shorted while C is measured with the far end open circuit). The value of characteristic impedance (Z_0) is approximately given by:

$$Z_0 = \sqrt{\frac{L}{C}}$$

Connectors

Different types of connector (see Fig.7.6) are used with coaxial cables, depending on the frequency range, power handling requirements and characteristic impedance required. The popular BNC connector is available in both 50Ω and 75Ω versions (note that the diameter of the centre pin is smaller for the 75Ω version). Conventional TV connectors (originated by Belling-Lee) are used with 75Ω systems. N-type and SMA connectors have a constant 50Ω impedance over a very wide frequency range.

Measuring low RF power

When low levels of power (less than 100mW) are to be measured, simple diode detectors are generally unsuitable due to their non-linearity and poor sensitivity. Sensitive power meters with separate power sensing elements are available but, in recent years, an alternative low-cost solution can be based around the use of a specialised logarithmic power detector chip, such as the AD8318 from Analog Devices (see Fig.7.7).

Designed for relative received signal strength indication (RSSI) and automatic power regulation, the AD8318 is a demodulating logarithmic amplifier that accurately converts an RF input to a corresponding dB-scaled output voltage. The device uses progressive compression over a nine-stage cascaded amplifier, and each amplifier stage has its own detector (see Fig.7.8). Detector outputs are then summed to provide an output voltage that varies between –2.1V with no input and –1.4V (with 10mW input into 50Ω). The useful measurement range (without external attenuation) is from +5dB to –55dBm (see Fig.7.9) with an error of less than ±1dB.

The logarithmic slope of the AD8318's transfer characteristic (see Fig.7.9) is nominally –25mV/dB but can be adjusted by scaling the feedback voltage from VOUT to the VSET input (see Fig.7.8).

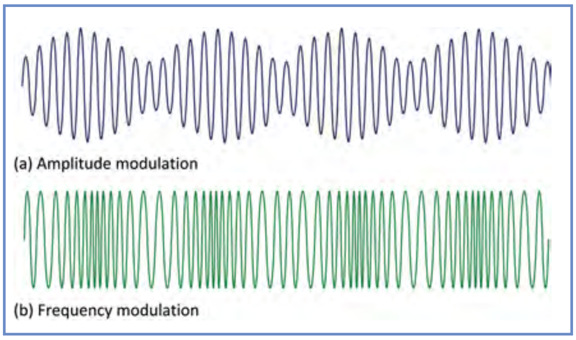

Fig.7.3. (a) Amplitude modulation (b) Frequency modulation

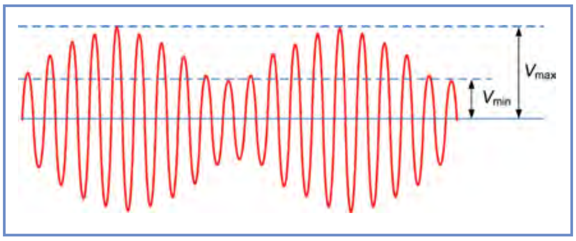

Fig.7.4. Measuring the depth of amplitude modulation

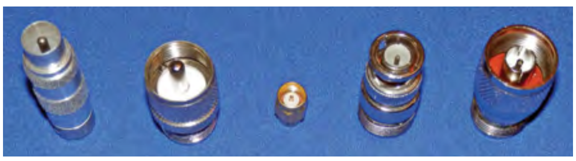

Fig.7.6. Common 75Ω and 50Ω RF connectors – (L-R) Belling Lee, PL-259, SMA, BNC, N-type

Table 7.1 Typical values of intercept (dBm) for the AD8318 logarithmic power detector

Frequency	900MHz	1.9GHz	2.2GHz	3.6GHz	5.8GHz	8.0GHz
Intercept	+22dBm	+20.4dBm	+19.6dBm	+19.8dBm	+25dBm	+37dBm

Fig.7.5. Measuring the output power from a hand-held digital transceiver (the power meter indicates an output of exactly 2W delivered to the 50Ω load attached to the power meter

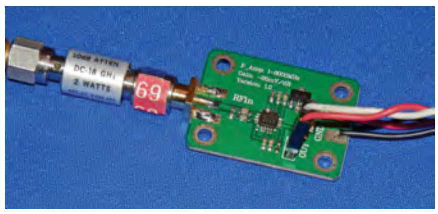

Fig.7.7. A logarithmic detector (the input on the left is fitted with a fixed 10dB attenuator rated at 2W from DC to 18GHz)

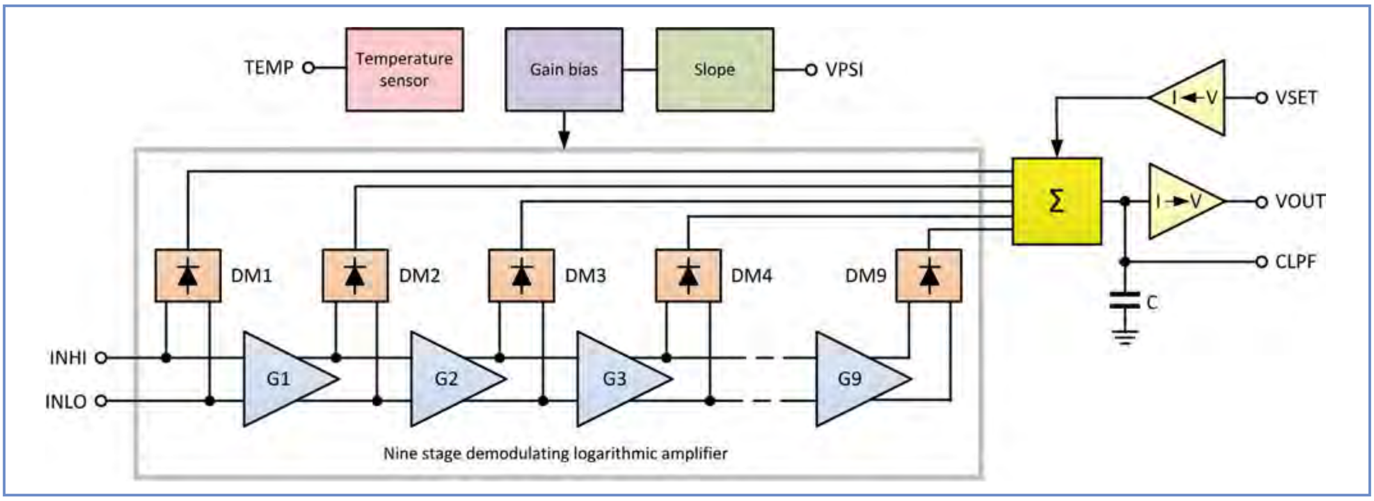

Fig.7.8. Simplified internal schematic of the AD8318 logarithmic detector

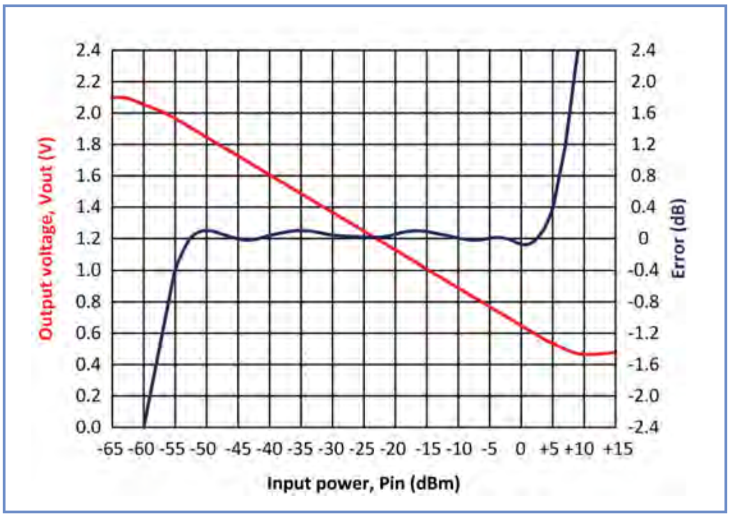

Fig.7.9. Output voltage (V) vs input power (dBm) at 2.2GHz

Input Data		
Enter slope in mV/db (e.g. -25)	-25	mV/dB
Enter intercept in dBm (e.g. +20)	25	dBm
Enter voltage indicated (e.g. -1.025)	-0.812	Volts
External attenuation (e.g. 40dB)	30	dB
Power at AD8318 input (into 50 ohm)		
Power (in dB ref: 1mW)	-7.48	dBm
Actual power	0.1786	mW
Input power (into 50 ohm attenuator)		
Input power	178.6488	mW

Fig.7.10. Using a spreadsheet to calculate the RF input power (see text)

The intercept (not shown in Fig.7.9) is nominally +20dBm (referenced to 50Ω but it varies somewhat with frequency, effectively shifting the transfer characteristic along the *x*-axis). Measured values of intercept at different frequencies are shown in Table 7.1 but to make life easier, we have made a spreadsheet calculator (see Fig.7.10) available for download from the *EPE* website. This allows you to calculate power levels at different frequencies with various amounts of external attenuation present.

Fig.7.11. Checking the output frequency of a dual-band FM transceiver. The digital frequency meter (shown on the right) indicates a frequency difference of 1kHz

Frequency measurement

Frequency is difficult to accurately measure using a conventional oscilloscope. Modern digital storage oscilloscopes (DSO) fare somewhat better in this respect as they can often display frequency values digitally. However, a digital frequency meter (DFM – see Fig.7.11) is a better solution and the desirable characteristics of such an instrument are high sensitivity, a high upper frequency limit as well as appropriate accuracy and resolution. A sensitivity of 100mV or less is suitable for most applications, and an upper frequency limit of 500MHz will be adequate for most measurements at HF and VHF.

Generating RF signals

An RF signal generator will be required for measuring the performance of radio receivers, amplifiers and filters. So that its output can be reduced to a suitably low level, such an instrument will need to be fitted with an accurate calibrated attenuator and the output level should be adjustable from a minimum of 1V RMS to less than 1μV. Precise frequency calibration is not essential if a DFM is available to monitor the output frequency (see Fig.7.12). The generator should have an output impedance of 50Ω and the output should be capable of being modulated in order to provide an AM or FM signal. Some instruments may also be supplied with internal calibration facilities, but this is no longer essential in the case of equipment that uses digital frequency synthesis where signals are derived from an accurate internal reference oscillator. Finally, to prevent leakage, adequate screening is required.

Fig.7.13 shows the complete circuit of

Fig.7.12. Bench test instruments: an RF signal generator used with a digital frequency meter (DFM)

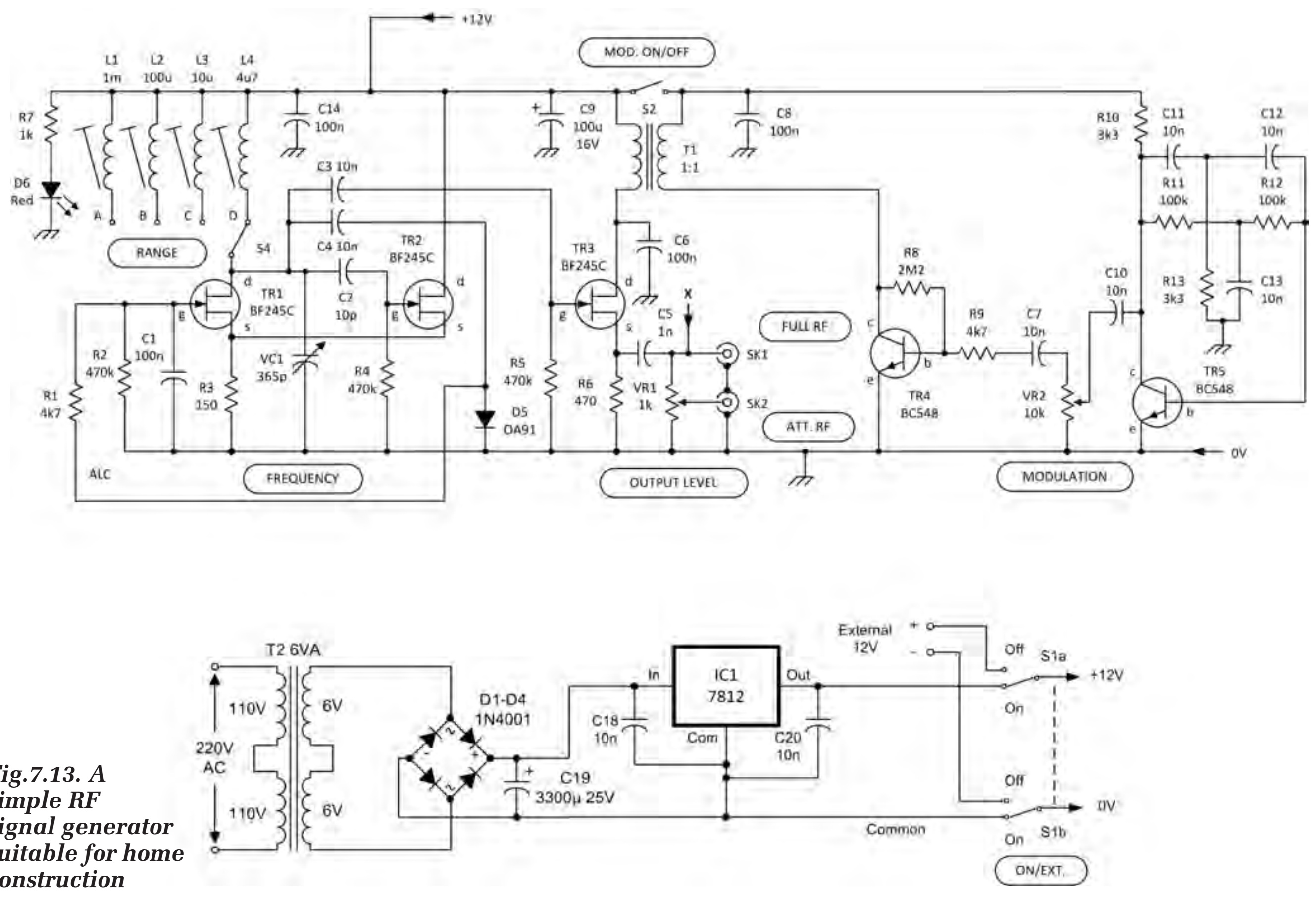

Fig.7.13. A simple RF signal generator suitable for home construction

a simple RF signal generator suitable for home construction. This instrument operates from a mains supply or 12V battery. It provides an amplitude modulated output from 250kHz to around 15MHz in four switched ranges.

Spectrum analysis

It is often useful to be able to display the frequency spectrum of an RF signal. This will allow you to identify unwanted harmonic components as well as those resulting from noise, spurious oscillation and unwanted mixing of signals. A dedicated RF spectrum analyser can be prohibitively expensive, but a low-cost solution can be based on a simple DVB-T tuner 'dongle', as shown in Fig.7.14. Such devices are widely available, and they are usually marketed as USB 'digital TV sticks'. Used in conjunction with suitable software running on a desktop PC, laptop or tablet, they will allow you to receive signals over a frequency range extending from around 25MHz to 1.5GHz. If desired, the frequency range can be extended down to around 150kHz by modifying the device, bypassing the front-end tuner/frequency changer and feeding the input signals direct to the I and Q inputs on the SDR decoder, as shown in Fig.7.15. Alternatively, a ready-made RF up-converter (such as the NooElec Ham it Up) can be fitted. A typical spectrum display is shown in Fig.7.16. This shows a 2MHz frequency range that extends from 104MHz to 106MHz in which signal levels range from –20dBm to –40dBm. The strong signal at 104.6MHz is a local FM broadcast station.

Fig.7.14. A low-cost DVB-T tuner 'dongle' can make the basis of a simple RF spectrum analyser

Noise sources

A wideband noise source can be used to carry out various RF measurements and is a low-cost alternative to using more sophisticated equipment such as tracking spectrum analysers. The inexpensive noise source shown in Fig.7.17 can be useful for testing amplifiers and filters.

The output of a noise source is normally specified in terms of Excess Noise Ratio (ENR). This is a normalised measure of how much noise is generated when the noise source is switched on compared with the noise that would be thermally generated with the noise source switched off.

$$\mathrm{ENR} = 10\log_{10}\left(\frac{T_h - 290}{290}\right) = 10\log_{10}\left(\frac{T_h}{T_c} - 1\right)$$

where $T_h > T_c$ (290K), T_h is the temperature 'hot', and T_c is the temperature 'cold'. (Note temperatures are measured in kelvin, not Celcius.)

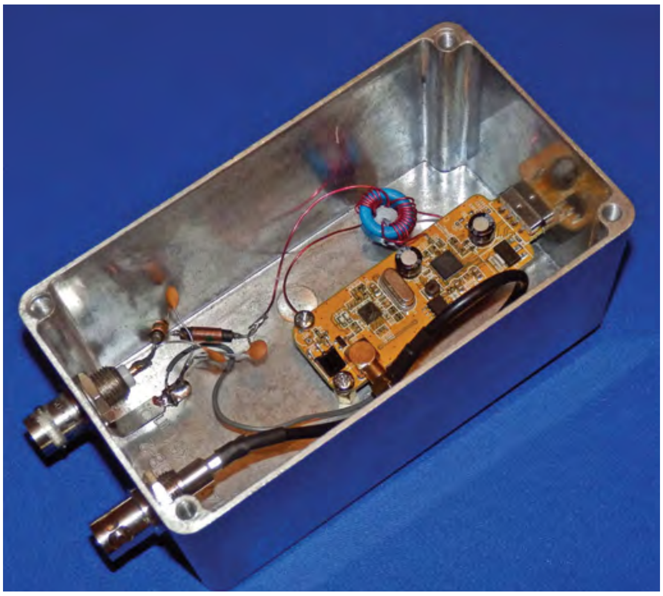

Fig.7.15. A DVB-T tuner 'dongle' modified to support MF/HF as well as VHF/UHF inputs. This permits operation over a frequency range extending from around 100kHz to well over 1GHz

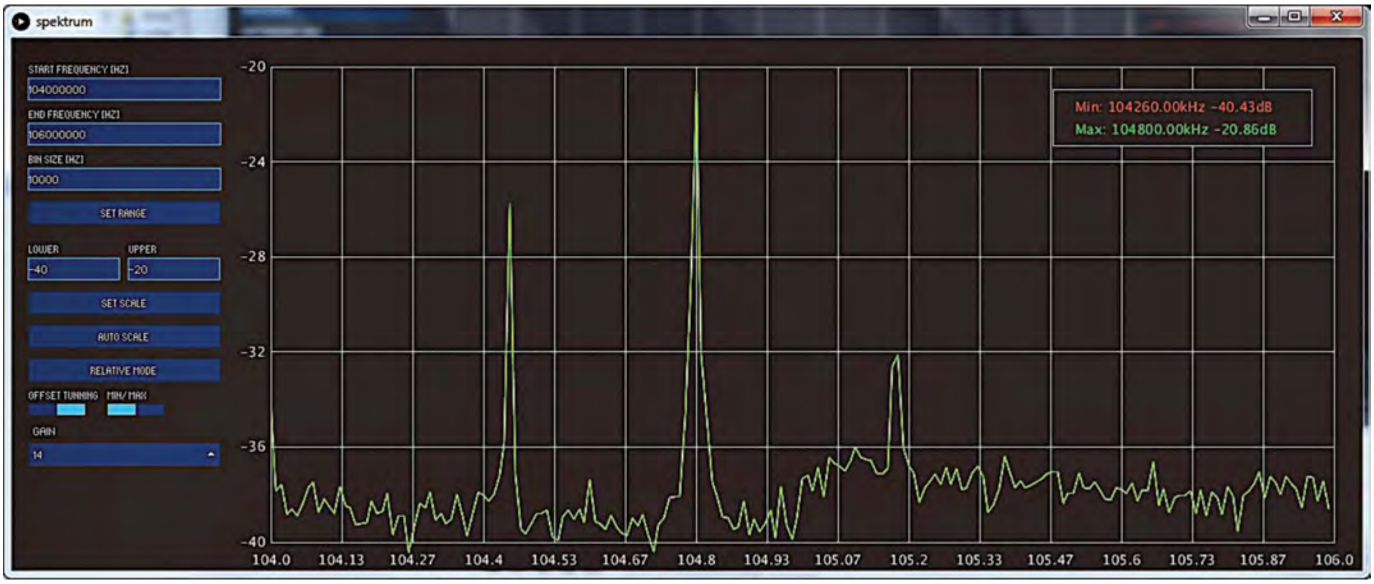

Fig.7.16. A typical spectrum display obtained from a DVB-T tuner 'dongle' and appropriate SDR software. The strong signal at 104.6MHz is a local FM broadcast station

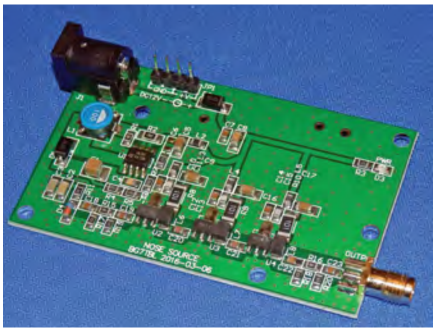

Fig.7.17. A low-cost wideband RF noise source can be useful for testing amplifiers and filters up to about 1GHz

When a spectrum analyser is used for testing a filter in conjunction with a noise source, the ENR of the noise source must be significantly greater than the spectrum analyser's noise floor. An ideal value would be 60dB but, for testing an RF amplifier the ENR should be very much smaller and 6dB to 10dB would usually be more appropriate. Thus, an RF noise source should normally be used in conjunction with an attenuator. Without an external attenuator, the measured broadband power output of the noise source shown in Fig.7.17 is around 10dBm (10mW) and so an external attenuator will invariably be required when using it with a spectrum analyser.

Measuring standing wave ratio (SWR)

Before describing instruments that can be used to measure SWR it is important to understand what we are trying to measure. In radio equipment an antenna is connected to a source of RF (eg, a transmitter or transceiver) by means of a feeder. This feeder (usually a length of coaxial cable) forms a transmission line, along which the RF energy is conveyed. The line is said to be correctly 'matched' when the impedance of the source, line, and load are all *identical*. The source is the sender or transmitter, while the load is the antenna.

If the system is perfectly matched and the line is loss-free, the voltage will be the same at all points along the line. If the system is perfectly matched and the line is 'lossy', there will be a linear reduction in voltage along the line. If, however, the system is not correctly matched, which would be the case if the antenna had a different impedance from the source and line, part of the energy will be reflected back from the load to the source. This results in standing waves of voltage and current along the line. The presence of standing waves is undesirable for various reasons, including additional power loss along the feeder. This can be very important when a long run of poor quality feeder is used. In summary:

- The SWR of a feeder or transmission line is an indication of the effectiveness of the impedance match between the transmission line and the antenna
- SWR is the ratio of the maximum to the minimum current or voltage along the length of the transmission line, or the ratio of the maximum to the minimum voltage
- When the line is correctly matched the SWR is unity. In other words, we have unity SWR when there is no variation in voltage or current along the transmission line
- The greater the number representing SWR, the larger is the mismatch and the greater is the loss due to an imperfect feeder.

SWR is easily measured using an instrument known variously as an SWR bridge, SWR meter, or combined power/SWR meter (see Fig.7.18). Despite the different appearance of these instruments they are all based on the same operating principle; sensing the forward and reflected power and displaying the difference between them using a meter scale or digital display. Fig.7.19 shows the internal construction of a low-cost SWR bridge for operation at up to 30MHz. This shows the main transmission line in the centre and the two coupled transmission lines either side of it feed

Fig.7.18. Typical low-cost combined RF power meters and SWR bridges

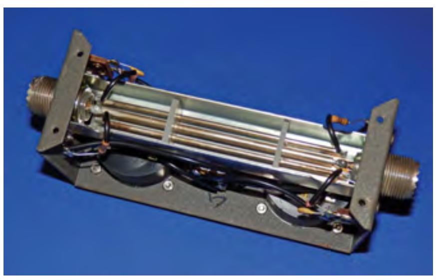

Fig.7.19. The interior of an HF SWR bridge showing the main transmission line and the two coupled transmission lines that feed the forward and reverse detectors

Fig.7.20. Checking output power and antenna SWR with a dual-band VHF/UHF base station transceiver

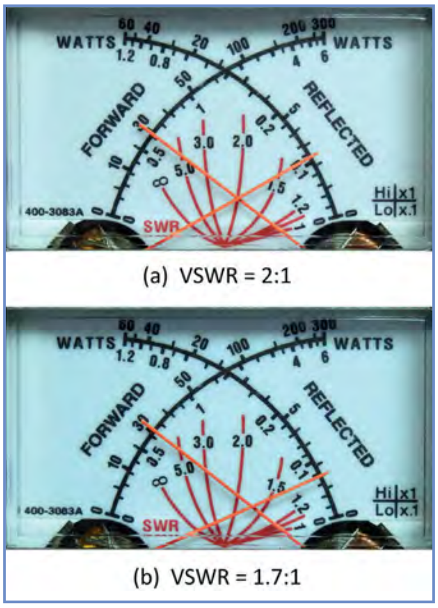

Fig.7.21. Reading a cross-needle SWR indicator

Fig.7.22. HF/VHF antenna analyser for operation between 1.8MHz and 170MHz. The instrument can display resistance, reactance, impedance, reflection coefficient and SWR

the forward and reverse diode detectors. Fig.7.20 shows a combined HF and VHF power/SWR meter being used to check the output from a dual-band VHF/UHF base station transceiver. The instrument has two separate sensing heads (one for HF and one for VHF) and measures power from 5W to 400W in four ranges at frequencies from 1.8MHz to 525MHz.

Instead of using a single meter with forward/reverse switching (or two separate meter movements) to indicate forward and reverse power, some SWR bridges make use of cross-needle indicators. These comprise two separate moving coil movements each with its own needle pointer. One needle indicates forward power while the other (simultaneously) indicates reflected power. The corresponding SWR is read along a line marked in the centre of the display, as shown in Fig.7.21.

Antenna and virtual network analysers (VNA)

If you are making regular measurements at RF (and particularly if you are working with antennas) you will find an antenna or virtual network analyser invaluable. A basic antenna analyser is shown in Fig.7.22. This popular instrument is capable of measuring SWR, impedance (resistance and reactance), and reflection coefficient over a frequency range extending from 1.8MHz to 170MHz. For automated measurements in conjunction with a desktop PC, laptop or tablet, virtual network analysers are available from several RF test equipment manufacturers.

Gearing up: RF test equipment

In addition to an oscilloscope for general RF measurements, you will need an RF signal generator and a digital frequency meter. Both are available at reasonable cost, new and second hand. For a basic RF signal generator, you can expect to pay around £100, but instruments are regularly available from on-line auction sites at bargain prices. Typical examples are shown in Fig.7.23 and 7.24. When choosing an RF signal generator, it is important to select an instrument with sufficiently wide frequency coverage and also with a calibrated attenuator. For basic radio and TV servicing such instruments are often designed to work with 75Ω systems, but for most professional applications a 50Ω output is more common. For AM measurements, depth of modulation can be measured using an oscilloscope, but dedicated modulation meters capable of measuring both AM and FM signals are available (see Fig.7.25).

SWR bridges are available at various prices and quality levels but it is advisable to avoid the cheaper instruments that invariably have cramped displays, limited frequency response and poor accuracy. A good quality cross-needle instrument from Avair is shown in Fig.7.26. This instrument covers the range 1.8MHz to 200MHz in two ranges; 30W and 300W full-scale and is available at around £50. Directional power meters from Bird (the 'Thruline' series of wattmeters) are highly recommended, but you may require a selection of different plug-in sensing elements in order to cover the required range of frequency and power. Following the purchase of a basic instrument these can represent a significant additional outlay.

Fig.7.23. AM/FM RF signal generator

Fig.7.24. A highly accurate RF signal generator that incorporates phase locked digital frequency entry

Fig.7.25. FM/AM modulation meter

Fig.7.26. A cross-needle SWR meter (like this instrument from Avair) can be a useful investment if you need to measure RF power or adjust antennas at HF and VHF

Other RF instruments and accessories

In addition to the instruments listed above, several other useful items of test gear can be acquired from second-hand and on-line sources. They include:

- RF voltmeters and AC meters with diode probes (see Fig.7.27)
- RF power meters with internal loads (see Fig.7.28)
- RF spectrum analysers (see Fig.7.29)
- Calibrated RF attenuators (see Fig.7.30)
- RF connectors, inter-series adapters, patch leads and probes (see Fig.7.31).

Fig.7.27. Part of the author's RF test bench showing a variety of RF voltage and power meters purchased from second-hand dealers and from on-line auction sites

Fig.7.28. A Marconi TF1152 power meter suitable for continuous power of up to 25W with an internal load rated for use up to 500MHz. Instruments like this can make an excellent second-hand purchase

Fig.7.29. A Farnell 352C spectrum analyser suitable for use from 300kHz to 1GHz

Fig.7.30. A Marconi switched attenuator suitable for use from DC to 1GHz with attenuation of up to 142dB in steps of 1dB

Fig.7.31. A variety of connectors, adapters and other accessories can be extremely useful when carrying out RF measurements

Get it right when carrying out RF measurements

- Always ensure that test leads and cables carrying RF signals are properly screened and fitted with appropriate connectors
- When using an RF probe always ensure that the ground connection is as short and direct as possible
- Avoid over-driving amplifiers, filters and attenuators and always keep input signals within the working range for the equipment on-test
- When carrying out measurements of RF power, use a matched and fully screened resistive load that is appropriately rated in terms of impedance and frequency range
- When in doubt about signal and power levels it is wise to use an attenuator ahead of the measuring instrument and then progressively reduce the attenuation as required
- When carrying out tests and adjustment on antennas, avoid physical contact with the antenna and maintain a safe working distance from it
- Don't rely on measurements of RF voltage, power and SWR when an instrument is working towards the end of its measuring range (accuracy will invariably be impaired as an instrument's limits are approached).

Test Gear Project: A handy RF 'sniffer'

Our handy RF 'sniffer' will provide you with a useful device for detecting RF energy. It operates over a wide range of frequency extending from around 3MHz to over 500MHz (with reduced sensitivity). The presence of RF is indicated using an LED with brightness depending on the level detected, but the instrument can be used with an external voltmeter as a sensitive field strength indicator.

The complete circuit of our *Test Gear Project* is shown in Fig.7.32. The circuit comprises a diode detector followed by TR1 and TR2 acting as a high-gain DC amplifier. To improve sensitivity, the diode detector is biased to the edge of conduction by means of a constant voltage source formed by D2 and adjustable via RV1. The input of the circuit is applied by means of a BNC connector that permits the connection of a measuring probe or short antenna.

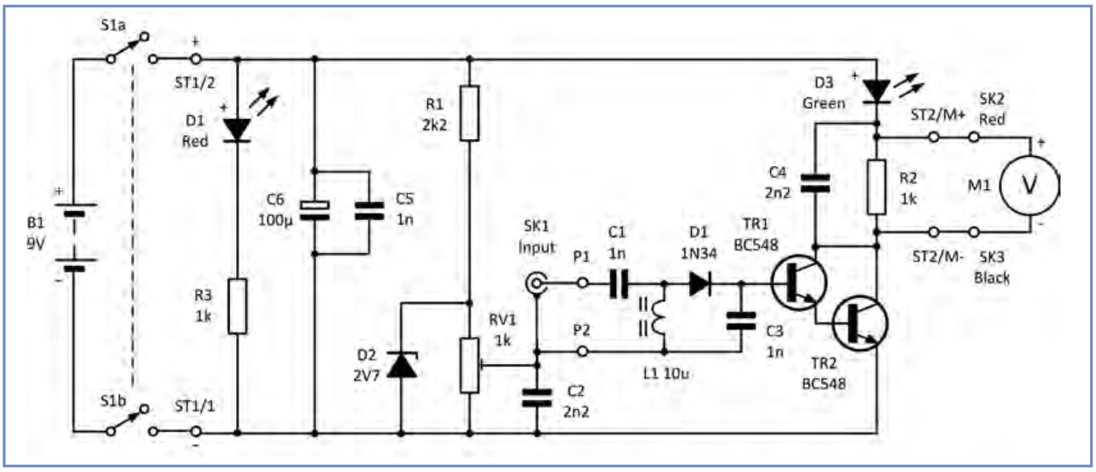

Fig.7.32. Complete circuit of the handy RF 'sniffer'

You will need

1 Perforated copper stripboard (9 strips, each with 25 holes)
2 2-way miniature terminal blocks (ST1 and ST2)
1 ABS case with integral battery compartment
1 9V PP3 battery clip
1 9V PP3 battery
1 Miniature DPDT toggle switch (S1)
1 chassis mounting female 50Ω BNC connector
1 red 2mm panel mounting socket (SK2)
1 black 2mm panel mounting socket (SK3)
2 BC548 transistors (TR1 and TR2)
1 5mm red LED (D1)
1 5mm green LED (D3)
1 2.2kΩ resistor (R1)
2 1kΩ resistor (R2 and R3)
1 miniature axial lead 10µH inductor (L1)
1 1kΩ miniature multi-turn pre-set resistor (RV1)
3 1nF disk ceramic capacitors (C1, C3 and C5)
2 2.2nF disk ceramic capacitors (C2 and C4)
1 100µF 16V radial electrolytic (C5)

Assembly is straightforward and should follow the component layout shown in Fig.7.33. Note that the '+' symbol shown on D1 indicates the more positive (anode) terminal of the LED. The pin connections for the LED and transistor are shown in Fig.7.34. The reverse side of the board (NOT an X-ray view) is also shown in Fig.7.34. Note that there's a total of 23 track breaks to be made. These can be made either with a purpose-designed spot-face cutter or using a small drill bit of appropriate size. There are also nine links that can be made with tinned copper wire of a suitable diameter or gauge (eg, 0.6mm/24SWG). When soldering has been completed it is very important to carry out a careful visual check of the board as well as an examination of the track side of the board looking for solder splashes and unwanted links between tracks. The internal and rear panel wiring of the test signal source is shown in Fig.7.35.

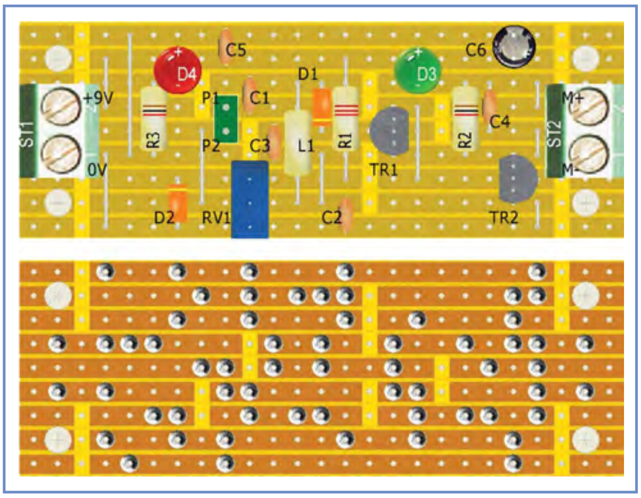

Fig.7.33. Stripboard layout of the handy RF 'sniffer'

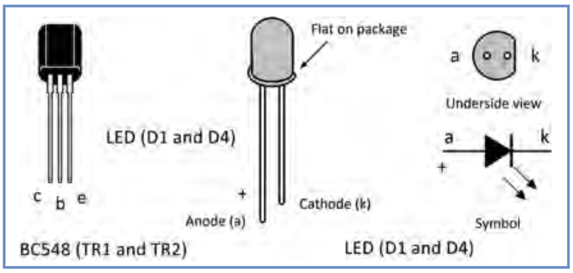

Fig.7.34. LED and transistor pin connections

Setting up

Setting up is reasonably straightforward. Switch 'on' and with no input connected to SK1, set RV1 to minimum position. Then slowly increase the bias voltage at P2 by advancing the setting of RV1 until the green LED (D3) just starts to become illuminated. Back off the setting of VR1 slightly until the LED turns 'off'. Next, connect a short antenna or pick-up loop to SK1 and, with the aid of an RF source, such as a wireless key-fob or other 430MHz remote control device, placed close to the antenna, check that the green LED becomes illuminated. If desired, connect a DC voltmeter on the 10V or 20V DC range to SK2 and SK3 and check that a reading is obtained. Note that a PMR handy talkie, or other transceiver with an output of between 1W and 5W, should typically produce an indication of between 250mV and 1.5V when positioned at distances of between 8m and 2m respectively.

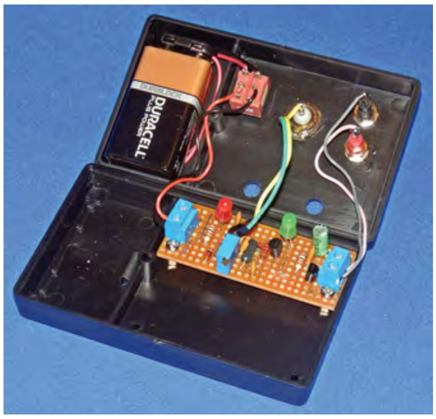

Fig.7.35. Internal wiring of the handy RF 'sniffer'

Fig.7.36. External appearance of the handy RF 'sniffer'

Fig.7.37. Using the handy RF 'sniffer' as a relative field strength indicator

Next month

In next month's *Teach-In 2018* we will be looking at digital measurements and associated test equipment. Our practical project will feature a simple logic probe.