Chapter 8

Introduction to RF Electronics

This chapter is a brief introduction to electronic components, to circuit building techniques, and to the tools you will need. The aim is to fill in a few gaps for those readers who may well be experienced amateur astronomers but to whom electronics is new. Many texts on amateur radio astronomy have assumed the reader already has skills in radio and electronics. It is not possible in such a small space to cover everything. Indeed, an entire book could be dedicated to this topic alone, so a reading list is included at the end of this book for further information.

The first section of this chapter looks at identifying components, understanding what they can do for us, and learning the symbols used in schematic drawings. More specific examples of using the devices will follow in the project chapters.

The next section discusses circuit building techniques, and the final section describes the essential tools, and some of more specialized but useful tools, for your birthday wish list.

Passive Electronic Components

The definition of a passive component either refers to a component that consumes (but does not produce) energy, or to a component that is incapable of power gain. The opposite is called an active component. So, a resistor that impedes the flow of current is passive, but a transistor which is capable of amplifying signals is active. So let's start with resistors.

The Resistor

See Fig. 8.1 for the possible circuit symbols used for various types of resistor. Note there are two forms, the box and the zigzag. These are interchangeable, but only one style should appear on a given schematic.

Resistor values can be identified by colored bands painted on their body. The majority have four bands, three together and the fourth spaced out. The group of three identify the value, and the fourth band the tolerance of the value. Precision

J. Lashley, *The Radio Sky and How to Observe It*, Astronomers' Observing Guides,
DOI 10.1007/978-1-4419-0883-4_8,

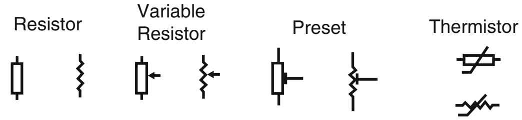

Fig. 8.1. Resistor circuit symbols.

Table 8.1. Resistor color codes

Color	Band 1	Band 2 and 3	Multiplier	Tolerance (%)
Black	0	0	1	
Brown	1	1	10	±1
Red	2	2	100	±2
Orange	3	3	1K	
Yellow	4	4	10K	
Green	5	5	100K	±0.5
Blue	6	6	1M	±0.25
Violet	7	7	10M	±0.1
Gray	8	8		±0.05
White	9	9		
Gold			0.1	±5
Silver			0.01	±10

resistors have five bands, the first four defining the value, and the fifth spaced out the tolerance. The table provides the key to determining their value (Table 8.1).

For example a 56 kΩ resistor with a 5% tolerance would have four bands colored Green, Blue, Orange, and Gold. A 4.7 kΩ 1% resistor would be Yellow, Violet, Red, and Brown. The colors can be surprisingly difficult to read when the body of the resistor is also colored. If in doubt measure it with a multimeter.

Resistors are used to limit the amount of current flowing in a circuit. They can also be used to divide voltages. Firstly consider the circuit in Fig. 8.2.

The important information we need to know about the circuit is how much current will flow. There is a simple formula known as Ohms law which is

$$V = IR$$

or, when transposed:

$$I = \frac{V}{R} \quad and \quad R = \frac{V}{I}$$

The current flow is calculated by dividing the voltage by the resistance, which in this case is:

$$I = \frac{9}{1000} = 0.009A\ (or\, 9mA)$$

Note that when calculating values using this formula, the current is in amperes, voltage in volts and resistance in ohms. However, we often deal with thousands of ohms, or thousandths of amps. Table 8.2 lists the nomenclature used as shorthand to write values that are very large or very small. It is important to understand these they will crop up all over the place.

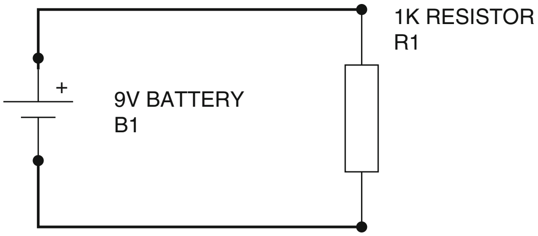

Fig. 8.2. Function of a resistor.

Table 8.2. Dealing with the large and small

Prefix	Scientific notation	Decimal
M – mega	10^6	1,000,000
k – kilo	10^3	1,000
C – centi	10^{-2}	0.01
m – milli	10^{-3}	0.001
μ – micro	10^{-6}	0.000001
n – nano	10^{-9}	0.000000001
p – pico	10^{-12}	0.000000000001

Examples of electronic component values:
10 kΩ = 10,000 Ω
2.7 μF could also appear as 2μ7 = 0.0000027 farads (see capacitors)

The other use for resistors is to split a voltage level. The circuit is known as a potential divider (see Fig. 8.3).

In the example the output voltage can be calculated from the ratio of R2 to the sum of R1 and R2:

$$V_{out} = V_s\left(\frac{R2}{R1 + R2}\right)$$

$$V_{out} = 10x\left(\frac{8000}{2000 + 8000}\right) = 8V$$

For the special case where R1 = R2 the voltage will be half the supply voltage (Vs).

Variable resistors come in two forms, potentiometers and presets. Potentiometers are larger and designed to provide an external control that will need regular adjustment by the user, for example, a volume control. Presets are smaller and usually mounted directly to a circuit board. They are designed to be adjusted infrequently, and possibly only one time, and are used to set up or calibrate a circuit after it is constructed. These devices have three pin and are variable potential dividers. The center pin is the same as the center point in Fig. 8.3.

When combining resistors together in series, their values are simply added together. However, when connected in parallel, the following formula is used (Fig. 8.4):

$$R = \frac{R1R2}{(R1 + R2)}$$

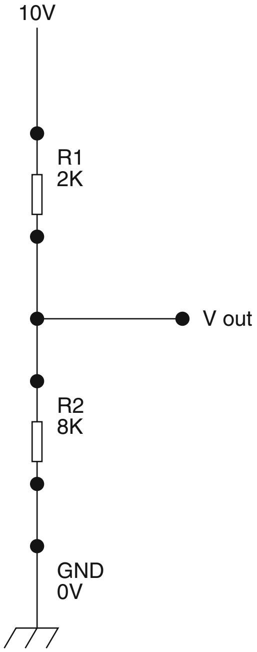

Fig. 8.3. Potential divider.

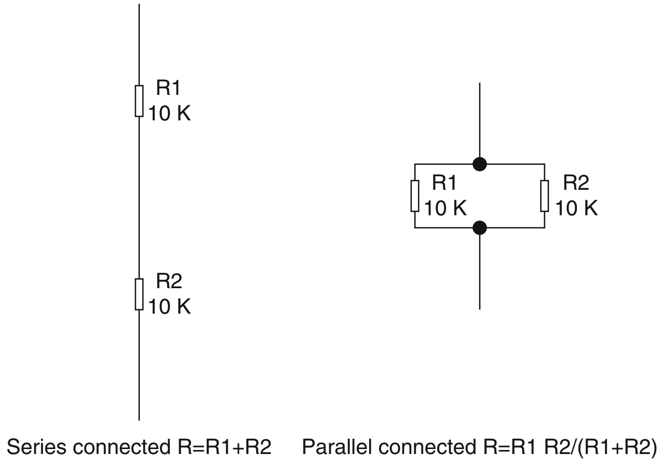

Fig. 8.4. Series and parallel.

Capacitors

Capacitors store energy in the form of an electric charge. In a DC circuit no current will flow through a capacitor, but it will charge up to the supplied voltage across it (Fig. 8.5).

As an experiment take a high value electrolytic capacitor, say about 1,000 μF, with a rating of 15 V or more. This type is polarized, and therefore has a positive

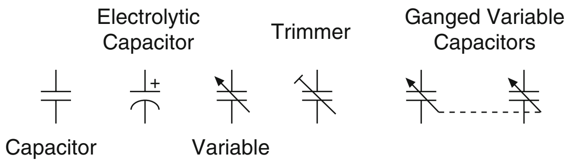

Fig. 8.5. Capacitor circuit symbols.

and negative lead. Connect it to a 9 V battery for a short time, and then as quickly as you can remove the battery and connect a 6 V lamp across the capacitor. Breifly the lamp will light and then fade, showing the capacitor had stored energy. If the capacitor is left for some time in a charged state, energy will slowly leak away due to imperfections. All capacitors leak charge, but some more than others.

In radio circuits it is much more important to understand their performance when subjected to alternating currents, especially sinusoidal radio frequency currents. At radio frequencies a capacitor can act like a resistor does in a DC circuit, that is, it has reactance that is also measured in ohms. Often in radio circuits there are points where it is necessary to block DC currents but allow RF signals to pass through, in which case a value is chosen that has a low reactance at the frequency involved. Devices that behave this way are referred to as bypass or coupling capacitors.

It is important to note here reactance varies with frequency. In general, reactance of capacitors falls linearly with increasing frequency, at least that is the ideal. The real world can be more complex than that! Capacitive reactance is calculated from the following formula:

$$Xc = \frac{1}{2\pi f C}$$

where f is the frequency in hertz and C is the capactitance in farads, and π is a constant of value approximately 3.1415. Xc is measured in ohms (Ω).

Unlike resistors, when capacitors are mounted in parallel, their values are added together. When they are mounted in a series the total value is given by:

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

where C_T is the combined capacitance, and C_1 and C_2 are mounted in a series.

There are many types of capacitors available, with their construction and appearance varying widely. They all consist of a pair of metal plates separated by an insulating material known as the dielectric. Their construction varies with dielectric type, capacitance, and voltage handling abilities. Therefore not all types are available in all values. Common types are electrolytic for high values and ceramic disc for small values. There are also various plastic film types. The photographs in Fig. 8.6 show what these look like.

Larger value capacitors in the μF range usually have clear values marked on the body. Small value capacitors often have a three-digit number representing the value in pico farads. So a number 103 means 10 with three zeros, or 10,000 pF, which is equal to 10 nF. The general rule is, if no clear range value is marked (such as nF or μF) then the marked value is in pF.

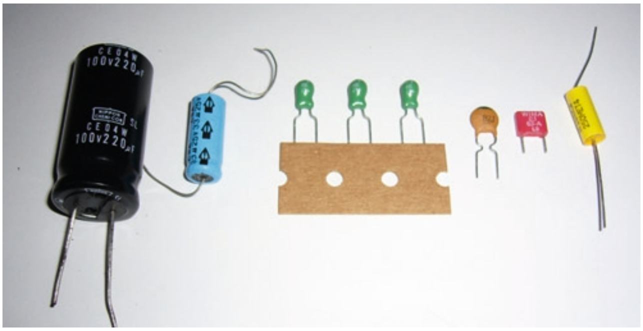

Fig. 8.6. Of all the common components, the capacitor appears in many different physical types. Some of the common ones are shown here. From *left* to *right*: radial electrolytic, axial electrolytic, three Tantalum beads, ceramic disc, plastic film, and high voltage non-polarized electrolytic. Most electrolytic capacitors and Tantalum types are polarized. The size of electrolytic types reflects their values and voltages. They are available in μF values. Disc types are found in pF and low nF values. Film capacitors are mostly available in nF ranges.

Capacitors also come in variable types. Although it used to be common that a variable capacitor was used to tune a radio circuit, such techniques have been largely superceded in modern times, and air-spaced variable models are now difficult to buy new. However, small value trimmer capacitors are still available. They can be used to tune the resonant frequency of a tank circuit (more on this later).

One farad is a very large value. All practical capacitors for our purposes hold very small values, so micro, nano, and pico farads are the values to be seen most often.

Inductors

Inductors are another important component used in radio frequency circuits. They are basically coils of wire wound onto a core, or even free-standing air-spaced if the wire is thick enough to support its own weight. Many types of inductors have a ferrite or powdered iron core that increases the coil's ability to store energy, this time in the form of a magnetic field (Fig. 8.7).

An inductor is the complement to a capacitor. It, too, has a reactance that varies with frequency, only this time the reactance increases with increasing frequency. The formula for inductive reactance is:

$$XL = 2\pi fL$$

where F is again frequency in hertz, $\pi = 3.1415$, and L is the inductance in henries.

Again like resistors, series-mounted inductors add up in value. And the value of two mounted in parallel is given by:

$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

where L_T is again the combined value, and L_1 and L_2 are parallel connected.

Like capacitance, 1 H is a very large value you will not encounter in practical circuits. Values of micro and nano henries are most commonly used.

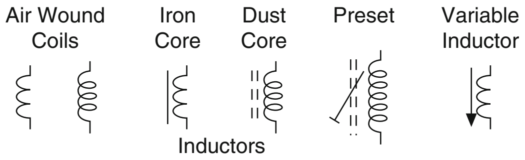

Fig. 8.7. Inductor circuit symbols.

Fig. 8.8. Toroidal inductor cores. Powdered iron types are usually color coded. Ferrites are normally *black*.

Traditional radio circuits employed a number of inductors or transformers usually screened inside a metal can. Valve cicuits employed some physically quite large coils of this type. Once again many of these components are obsolete in modern times. This often makes replicating published designs from the past very difficult.

For the simple circuits covered in this book one type of inductor is very useful, the toroidal inductor. Toroidal inductors can be constructed for most practical values of inductance using a single coil wound onto a ferrite or powdered iron core and can be made into RF transformers by winding a pair of coils onto the same core. Companies such as Micrometals and Amidon can supply a wide range of core types and sizes. It may prove useful to purchase a kit of the more common types (see Fig. 8.8).

The nomenclature used for iron cores follow a pattern such as T-37-2. The T stands for powdered iron toroids, whereas ferrites use the term FT. The middle section, in this case 37, refers to a size in millimeters of the torroid, and the final number, 2, is the mix type. For each core the manufacturer will supply a number referred to as the A_L value. This value varies from core to core and relates to the properties of the mix type and dimension of the torroid. Understanding its derivation is not required, but the following formulae allow the number of turns for a given value for inductance to be calculated.

Ferrite Materials (FT)

$$N = 1000\sqrt{\frac{L}{AL}}$$

where L is in mH (milli henries) and AL is in mH/ 1,000 turns.

Powered Iron Types (T)

$$N = 100\sqrt{\frac{L}{AL}}$$

where L is in μH and AL is in μH/ 100 turns.

In order to effectively use a toroidal core to make an inductor, you must know the mix type, which will tell you the AL value you need. It is pointless purchasing cores if the supplier can't tell you this information (which may be the case for surplus component sales). Tables 8.3–8.5 gives the properties for all types.

Another important form of inductor is the RF transformer. This is used to couple signals between different stages in a radio. Transformer coupling is important where there is a mismatched impedance between stages. It provides a means of transferring the maximum amount of power. In general, you will not be able to purchase readymade RF transformers; there are simply too many variations in their application. The exception is where common intermediate frequencies are used, such as 10.7 MHz. For many applications you will need to construct your own. The traditional way to do it used vertical coil formers with adjustable iron cores, surrounded by screened cans. These are getting more difficult to find now, so the following technique uses toroidal ferrite or powdered iron cores. The only drawback is they are not easily adjustable after construction.

A transformer contains a pair of coils wound onto the same core. The input coil is the primary, and the output coil is the secondary. When constructing use different colored enameled wires for each coil so they can be easily identified when you come to use them. The ratio of the number of turns in the tranformer is related to the ratio of the impedances by:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

where N_p and N_s are the number of coil turns on the primary and secondary, and Z_p and Z_s are the primary and secondary impedances, respectively.

The general rule in RF transformer design is that the reactance at the lowest frequency must be 4 times the impedance connected to the winding.

Here's an example. The ouput impedance of a tuner module must not exceed 500 Ω but needs to be down converted to a lower frequency by the next stage, which has an input impedance of 1,500 Ω. The IF output of the tuner is a range of frequencies from 33 to 39 MHz. So how do you design a transformer to match the system?

Table 8.3. Powdered iron toroid types

Mix	26	3	15	1	2	7	6	10	12	17	0
Color	Yellow/white	Gray	Red/white	Blue	Red	White	Yellow	Black	Green/white	Blue/yellow	Tan
Frequency (MHz)	DC-1	0.05–0.5	0.10–2	0.5–5	2–30	3–35	10–50	30–100	50–200	40–180	100–300
μ	75	35	25	20	10	9	8	6	4	4	1
Temp coef. (PPM/°)	825	370	190	280	95	30	35	150	170	50	0

Table 8.4. AL Values for powdered iron cores

Mix	26	3	15	1	2	7	6	10	12	17	0
T-12	–	60	50	48	20	18	17	12	7.5	7.5	3
T-16	145	61	55	44	22	–	19	13	8	8	3
T-20	180	76	65	52	27	24	22	16	10	10	3.5
T-25	235	100	85	70	34	29	27	19	12	12	4.5
T-30	325	140	93	85	43	37	36	25	16	16	6
T-37	275	120	90	80	40	32	30	25	15	15	4.9
T-44	360	180	160	105	52	46	42	33	18.5	18.5	6.5
T-50	320	175	135	100	49	43	40	31	18	18	6.4
T-68	420	195	180	115	57	52	47	32	21	21	7.5
T-80	450	180	170	115	55	50	45	32	22	22	8.5
T-94	590	248	200	160	84	–	70	58	32	–	10.6
T-106	900	450	345	325	135	133	116	–	–	–	19
T-130	785	350	250	200	110	103	96	–	–	–	15
T-157	870	420	360	320	140	–	115	–	–	–	–
T-184	1640	720	–	500	240	–	195	–	–	–	–
T-200	895	425	–	250	120	105	100	–	–	–	–

Table 8.5. AL Values for ferrite toroid cores

Type	43	61	63	67	68	72	75	77	F	J
FT-23	188	24.8	7.9	7.8	4	396	990	356	–	–
FT-37	420	55.3	17.7	17.7	8.8	884	2,210	796	–	–
FT-50	523	68	22	22	11	1,100	2,750	990	–	–
FT-50A	570	75	24	24	12	1,200	2,990	1,080	–	–
FT-50B	1140	150	48	48	12	2,400	–	2,160	–	–
FT-82	557	73.3	22.4	22.4	11.7	1,170	3,020	1,060	–	3,020
FT-87A	–	–	–	–	–	–	–	–	3,700	6,040
FT-114	603	79.3	25.4	25.4	–	1,270	3,170	1,140	1,902	3,170
FT-114A	–	146	–	–	–	2,340	–	–	–	–
FT-140	952	140	45	45	–	2,250	6,736	2,340	–	6,736
FT-150	–	–	–	–	–	–	–	–	2,640	4,400
FT-150A	–	–	–	–	–	–	–	–	5,020	8,370
FT-193A	–	–	–	–	–	–	–	–	4,460	7,435
FT-240	1240	173	53	53	–	3,130	6,845	3,130	–	6,845

The turns ratio of the transformer is given by:

$$\sqrt{\frac{500}{1500}} = 0.577$$

We require an reactance on the secondary side of 1,500 Ω × 4 = 6,000 Ω. The inductance in μH of the secondary winding can be found from:

$$L = \frac{6000\Omega}{2\pi f}10^{6}$$

$$\mathrm{L} = 28.9\mu\mathrm{H}$$

Using the earlier formula for calculating toroid inductance and choosing the ferrite core FT37-43 with an AL of 420:

$$L = 0.0289\text{mH}$$

$$N = 1000\sqrt{\frac{0.0289}{420}}$$

$$N_s \approx 8 \text{ turns}$$

Therefore

$$N_p = 8 \text{ x } 0.577 \approx 5 \text{ turns.}$$

Note here how to determine the number of turns in a toroid core. It is the number of times the wire passes through the center. If, for example, the wire was passed through wrapped around the core and passed through again this is two turns, not one.

Crystals and Resonators

Crystals and ceramic resonators are very important to radio electronics in order to control the frequency of oscillators, for example.

Crystals operate by what is known as the piezo electric effect. If a oscillating signal is applied to the crystal, the device is induced into vibrating mechanically. Equally, if the crystal is mechanically vibrated, it will generate electricity (Fig. 8.9).

The first property is the most important to us in RF engineering. The crystal itself does not generate an oscillating electrical waveform; rather, it is used to regulate an existing oscillator and keep it accurately on frequency.

It is important to understand that all crystals are constructed to have a fundamental mode of vibration at a given frequency. Fundamental refers to the lowest frequency it will operate at. However, crystals will also oscillate at higher frequencies that are approximate multiples of the fundamental. These higher frequencies are referred to as overtone frequencies. Note that overtones are not exact multiples of the fundamental frequency. The term harmonic is used to mean exact multiples of a fundamental frequency.

In the construction of crystals, physically making them thin enough to vibrate at high frequencies becomes impossible for frequencies above about 20 MHz.

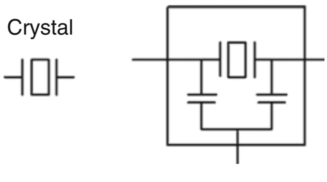

Fig. 8.9. Crystals and resonators

Higher frequency devices are known then as overtone crystals. The frequency marked on the crystal body is the frequency it was designed to operate on, but not necessarily the fundamental frequency. For example, a 27,000 MHz device will probably have a fundamental frequency of close to but not equal to 9 MHz. The device is therefore a third overtone crystal and was manufactured to work at precisely 27,000 MHz, the three zeroes indicating it is accurate within 1 kHz at least, whereas a crystal marked 9.4486 MHz is likely to be operating at its fundamental frequency.

Due to the properties of overtones, it is not recommended to use a crystal at different frequencies other than what is marked on the body. If only a number appears, the markings on the crystals will be in kHz, but high frequency crystals will more than likely show MHz after the number.

A crystal has two pins, but resonantors have three pins. Resonators can be crystal based or may be constructed of piezo electric ceramics. The reason for having three pins is because they contain a pair of internal capactitors. Resonators are usually used as filters, where the center pin is grounded and a signal applied between pin 1 and ground, and the filtered output taken from ground and pin 3. Resonators are not as accurate as crystals for controlling frequency and therefore are not suitable for making precision oscillators.

Diodes

Diodes are the simplest of the semiconductor devices. Most diodes are used to allow current to flow in one direction only, although there are some useful variants available.

Diodes may be found in power supplies, where they are used to rectify AC currents as a means to convert them to DC. They are also found in many radio detector and mixer circuits.

Silicon diodes are the most common general-pupose ones. In operation they do have some forward resistance (and of course a very high reverse resistance), so there is a small voltage drop across them. The voltage drop is typically 0.6 V for silicon devices but it can be as low as 0.15 V for schottky diodes (Fig. 8.10).

Special forms of diode include the varactor and the zenner. Varactors are effectively used in reverse. The function of the PN junction in reverse creates a region inside the diode that is an insulator preventing the flow of DC current, but it acts as a capacitor to AC current. By varying the DC voltage across the varactor, the insulating region will grow or reduce, thus varying the effective capacitance. Varactors can be used to control the frequency in variable oscillators.

The zenner diodes are used to provide a constant voltage to stabilize a power source. They are marked with the voltage at which they will operate.

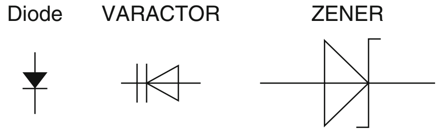

Fig. 8.10. Diode circuit symbols.

Active Components

Bipolar Transistors

The bipolar transistor is an example of an active component. So far we have only looked at passive components. An active component can amplify in some way – the output power is greater than that applied to it.

The BJT is the basis of most circuits. The modern IC chip is simply a miniaturized circuit of transistors and other components. BJT devices are available in two types, NPN and PNP. This refers to their construction, consisting of three layers of semiconductor, usually silicon these days. The N refers to the silicon, which is doped with an impurity that provides it with extra free electrons. P-type material is doped in such a way that the number of electrons are reduced, creating gaps in the crystalline structure known as holes. It is beyond the scope of this book to explain how a transistor functions internally, but there are many texts available that do this. It is only important that you can apply transistors to practical circuits. There are many instances in electronics where a chip or a readymade module is used effectively without the constructor knowing the internal workings of the devices. Not only is a transistor capable of amplifying signals, it can be useful as a solid state switch, too.

The symbols for transistors are shown in Fig. 8.11. The *arrows* in the symbols shows the direction of conventional current flow. Amplifying ability is achieved by applying a small current to the base pin, which allows a much greater current to flow across the collector and emitter pins, typically 50–250 times as much.

Although all transistors function in the same way, the selection of which type to use in a new design is largely based on the operating frequency and the power handling ability. The manufacturer describes in the datasheet what the design role is. For example, high current types may be for power amplifiers or power switching, while low power devices are more suited to small signal amplification and high speed switching in oscillators. While we are discussing datasheets, we should mention that the Internet is a very useful resource for information on active devices. Several websites are dedicated to offering free searchable access to them.

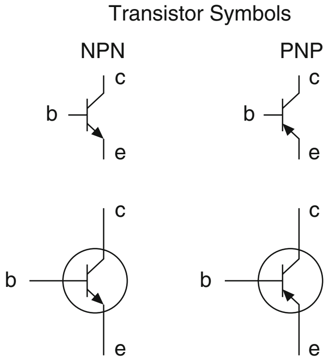

Fig. 8.11. Transistor circuit symbols.

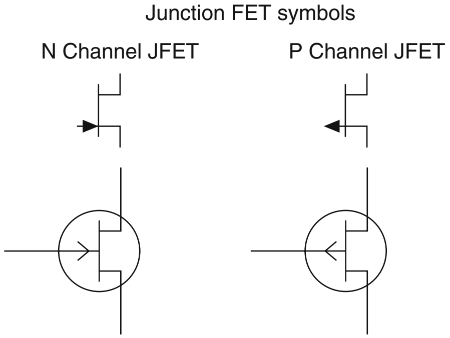

Fig. 8.12. Junction Field Effect Transistor symbols.

Field Effect Transistors (FETs)

The FET is similar to the transistor, in that it is also capable of amplifying signals, but this is a voltage-controlled device. Small devices are known as Junction Field Effect transistors. High power devices are constructed a little differently and are usually called MOSFETs (Metal Oxide Silicon Field Effect Transistors).

Junction FETs need to be handled with care. They have extremely high input impedance, which makes them sensitive to static electricity that can destroy them. Many IC chips that use FET inputs are similarly sensitive. It is therefore recommended to take precautions. MOSFETs are usually constructed with internal protection diodes, which make them easier to handle, but it is still recommended to use a static safe workbench.

Like BJTs they come in two types, N channel and P channel. However, P channel are very rare in JFET types. For the puposes of these projects only N channel devices will be considered (Fig. 8.12).

Power Supplies

Always use regulated power supplies in radio circuits. These can be purchased cheaply readymade. However, it is sometimes necessary to guarantee that a DC supply is stable, so you will also find a voltage regulator chip helpful. It is also useful in situations when more than one voltage is needed in a circuit. For example, the main circuits may have been designed to work on 12 V DC, but a particular IC chip will only work at 5 V. A 5 V regulator can be used to convert 12–5 at the point required.

Voltage regulators can be easily obtained for common voltages such as 6, 9, and 12 V and can handle currents up to 1.5 A in some cases. They are three-pin devices and usually only require a couple of capacitors to function at their best.

The circuit in Fig. 8.13 can supply up to 1.5 A. If a fixed value regulator is used, omit R1 and R2, and the center pin is connected to ground. The input voltage may be lower than 28 V, but it should be at least 3 V higher than the maximum output

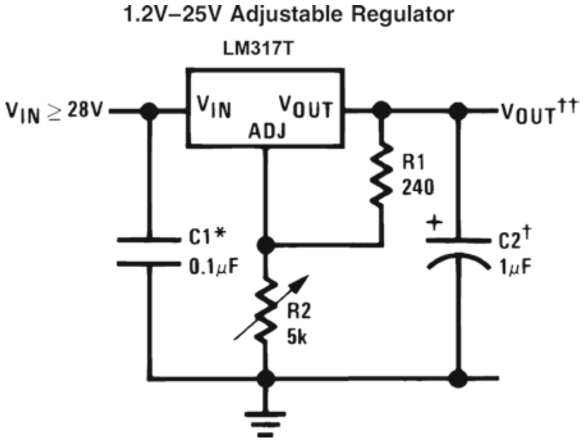

Fig. 8.13. Adjustable voltage regulator application circuit.

required. Note the application as displayed is used only to stabilize an existing DC power source. It is beyond the scope of this book to cover construction of mains AC/DC converters.

AC and Radio Frequency Signals

Before discussing some important information on how radio signals are affected by RF circuits, lets look at what a radio frequency of RF signal is.

A radio signal in its most pure form consists of a time-varying electric component and a time-varying magnetic component with sinusoidal profiles, which are at 90° to each other (Fig. 8.14).

However, for the most part in this book when we talk about an RF signal in a circuit it is in fact an AC electrical signal that was produced in the antenna and has the same frequency as the radio wave that was collected.

Real-world radio signals are made up from a collection of different frequency sinusoidal components, and all radio receivers collect at least a small range of them (narrow bandwidth). Radio astronomy receivers usually have much larger bandwidths than commonly found in communications receivers.

For the most part receivers are designed as though they are only receiving one pure sine wave signal, which is chosen to be the center frequency of a small range of interest. The bandwidth can be then designed to suit its function.

It should be noted at this point that it is not necessarily as easy as you think to measure the value of an RF signal. What value? Refer to Fig. 8.15. The parameters we need to know are amplitude (or peak to peak amplitude) and the frequency. The frequency determines how many full cycles occur in a second and is the reciprocal of the time it takes for one cycle to occur, i.e., $f = 1/t$.

When measuring the amplitude of an AC signal, you can't always rely on the AC range of a multimeter. Most multimeters are designed to test AC power circuits that have a low frequency of 50–60 Hz. They will prove inaccurate, and probably extremely inaccurate when the frequency is many megahertz. True, RMS meters

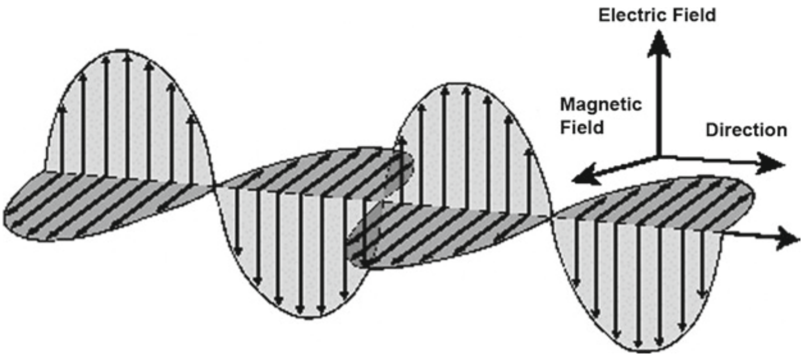

Fig. 8.14. Electromagnetic wave.

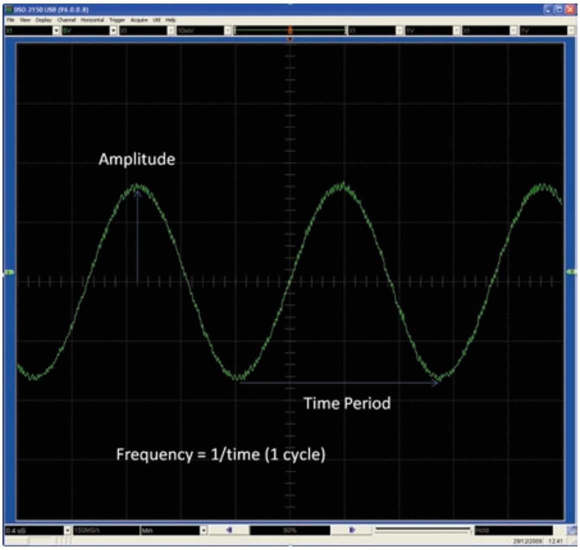

Fig. 8.15. Amplitude and frequency of a sine wave.

will work, but they are still likely to have an upper limit in their frequency response, which is provided in their specifications. Specialist RF voltmeters can be obtained, but these are rarer now than they used to be.

An oscilloscope (see later) can be used to view the signals on a screen, but most low cost units will only work well up to 20, 60, or even 100 MHz, which are useful but fall short in performance for many of the signals we deal with.

The best tool available for analyzing radio signals is the spectrum analyzer, which presents a graph of amplitude against frequency, rather than amplitude against time. High frequency units, though, are very expensive.

Finally, when we talk about the voltage of an AC or RF signal, it needs to be made clear what this represents. It is not the peak value. The voltage of an RF signal is known as the RMS, or root mean square value. It is a sort of an average value.

The RMS voltage can be found from the peak voltage (as seen on an oscilloscope screen) from:

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}}$$

The Tuned (Tank) Circuit

The tuned circuit is found in all radios and is a combination of an inductor and a capacitor. It is the basis of defining the frequency of response of an RF circuit. There are two forms, series connected and parallel connected. It is important to understand the differences.

Series Resonance

Consider the circuit in Fig. 8.16. The upper circuit is an example of series resonance, and the lower circuit parallel resonance.

The voltage in the inductor will lead the current flowing through it by 90°, and the voltage across the capacitor will lag the current by 90°. This means the two components oppose each other and tend to cancel out. However, the voltages across the components depend on their reactance. Reactance is a form of resistance but only applies to AC signals, not DC. As we saw earlier, reactance is calculated from the following:

$$X_L = 2\pi fL$$

$$X_C = \frac{1}{2\pi fC}$$

where X_L is the inductor reactance, X_C is the capacitor reactance measured in ohms, L in henries, and C in farads. The frequency in hertz is f.
From Ohms law:

$$V_L = IX_L$$

$$V_C = IX_C$$

where V_L and V_C are the voltages across the inductor and capacitor, respectively.

At a particular frequency, the reactance of the inductor and capacitor will be equal, and the voltages will exactly cancel out. This means:

$$2\pi fL = \frac{1}{2\pi fC}$$

Rearranging the formula we can solve it for f:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

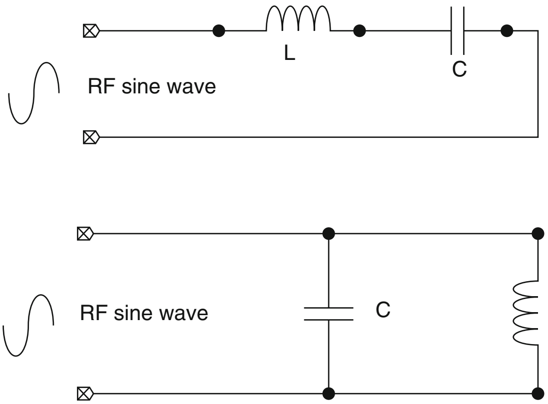

Fig. 8.16. Resonant circuits.

Although it is not necessary to remember the derivation of this formula, the result is extremely useful when designing radio circuits. In order to determine the values of L and C required for a given frequency, usually the value of C is preselected, and L is calculated. This way it is possible to build your own inductor to resonate at any reasonable frequency by using readily available capacitor values. When either L or C is preselected the other can be calculated eaily from:

$$C = \frac{1}{39.5 f^2 L}$$

or

$$L = \frac{1}{39.5 f^2 C}$$

where L is in henries, C is in farads, and f is in hertz.

The resulting values of L and C are very small numbers and need to be converted (usually) into micro henries and pico farads.

The important consequence of this for a series resonant circuit is that the impedance is at a minimum value at the point of resonance. Impedance will be theoretically zero, but in practice a small amount of pure resistance will be present, so a small loss is possible. Therefore a series tuned circuit will allow resonant frequency signals to pass through, but will impede (or reject) unwanted frequencies. This is sometimes known as an "acceptor" circuit. A practical use of this is found in chapter 12, see Fig. 12.3 for an oscillator circuit using series resonant components.

Parallel Resonance

In the case of parallel resonance it is the currents in the components that cancel out at resonance. The same formula applies to calulate the frequency at which this occurs, but now the impedance is at a maximum. This is a "rejector" circuit and will block the flow of RF signals at the resonant value.

Q Factor

The Q factor is a numerical representation of how sharply tuned a resonant circuit is. High Q is a sharp, small bandwidth response. The definition of Q is the ratio of the reactance to the pure resistance of the circuit. The resistance is mostly provided by the inductor. When an inductor and capacitor are used in a tuned circuit such as parallel tank circuit, the impedance at resonance is not infinite, due to the imperfections in the components, mostly the coil resistance. The resistance in this case is usually called dynamic resistance, or sometimes dynamic impedance, and is given by:

$$R_D = \frac{L}{CR}$$

where L is in henries, C in farads, and R in ohms. R_D is the effective resistance to rf signals in ohms.

The Q can then be found from:

$$Q = 2\pi fCR_D$$

or

$$Q = \frac{1}{2\pi fCR}$$

or

$$Q = \frac{2\pi fL}{R}$$

Q can also be found by dividing the center frequency f by the half power bandwidth. Q then is simply a figure of merit, or quality factor, of a tuned circuit.

Coupling Decoupling and Blocking

In radio circuits it is necessary to pass RF signals from one stage to another, but it is usually important to isolate DC volatge conditions between the two stages. The capacitor is used for this purpose. DC voltages are blocked by the capacitor, but so long as the reactance of it is low at the frequency involved the RF signal will pass through virtually unaffected. This is known as coupling. The values of capacitor for RF signals are usually a few pF up to about 0.01 μF.

Decoupling is essentially the opposite. It is the process of removing an RF signal and allowing the DC to pass. This can be done in two ways. A low reactance capacitor can be connected from a circuit point to Earth. RF signals will prefer to take the low impedance path to Earth, and very little will continue along the circuit path. The other way is to fit an inductor in series with the circuit. The value of L is chosen to be a high reactance at the operating frequency, therefore absorbing the RF signal but presenting a very low resistance to DC currents. The inductor approach is often used when feeding power into an RF feeder in order to power remote amplifiers. The capacitor technique is often used at points in an RF circuit.

Transistors as Amplifiers

The circuit in the diagram is the general form of an transistor amplifier using an NPN transistor (Fig. 8.17).

Consider what happens when a small AC or RF current is applied to the input. As the current rises, the current flowing through the transistor from collector to emitter rises, too. Ignoring the presence of C3 for the moment, R3 and R4 form a potential divider. The amount of voltage dropped across R3 increases, so the collector voltage falls. As the input current drops again and turns negative the current flowing decreases, and the voltage at the collector increases. Therefore the output is phase-shifted 90° with respect to the input.

The input current only has to be small to turn on the transistor, but the current flowing through it will be defined by R3 and R4 and can be many times the input current so amplification takes place.

The configuration in the diagram is known as the common emitter, since the emitter pin is common to both the input and output. The transistor will present about 1K of input impedance, and 5K output impedance, but the values of the resistors in the circuit will modify that. Note that sometimes R2 is ommitted, and R1 is connected between the collector and the base. Also, sometimes R4 is omitted.

There are other forms of layout known as the common collector or common base and the emitter follower where the output is taken from the emitter pin rather than the collector. For a more in-depth discussion of amplifiers see the reading list at the end of this book.

In order to function correctly, the transistor needs to be biased. This is where the DC voltage conditions are set up to enable the transistor to work within its dynamic range. If the DC voltage at the base pin is too low, then the positive peaks will "clip" or saturate at the positive supply voltage. If the biasing is too high, then the signal will clip at the minima and distortion also occurs.

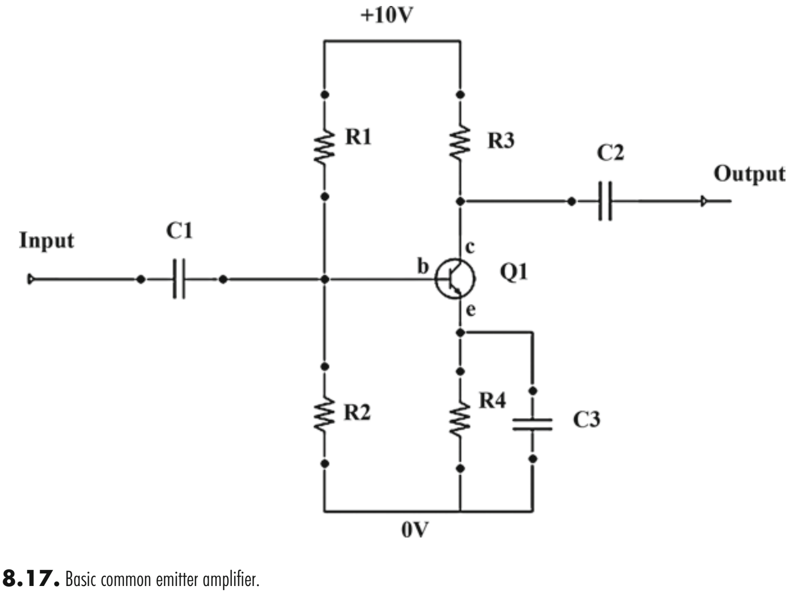

Fig. 8.17. Basic common emitter amplifier.

The resistors R1 and R2 form a fixed potential divider setting up the DC voltage at the base for best operation. R4 is usually small compared with R3, and a typical emitter voltage would be 1.5 V. The voltage at the collector needs in general to be centrally placed between the 10 V supply and ground at, say 5, volts to allow the output to swing either way without distortion.

If the design current through the transistor is to be 1 mA then R4 is 1.5 V/1 mA or 1,500 Ω and R3 = 5 V/1 mA or 5,000 Ω.

There is a voltage drop across a PN junction, i.e., between emitter and base of 0.6 V, so that would place the base voltage at 2.1 V. The actual current drawn by the transistor will be about 10 μA, but to avoid the base current variations upsetting the voltages, we will allow for 100 μA. Therefore from ohms law, R1 = (10 − 2.1 V)/100 μA = 79 kΩ and R2 = 2.1/100 μA or 21 kΩ.

Capacitors C1 and C2 block the DC voltages from affecting the operation of circuits either side, but allow RF signals to pass; they are therefore coupling capacitors. C3 is a bypass capacitor and is chosen because it has a low reactance at the operating frequency. Without C3 the gain of the amplifier will be lower, as R4 will reduce both DC and RF currents.

Circuit Construction

When you think of an electronic circuit you probably picture the PCB, or printed circuit board, used in most modern commercially built instruments. You may think, how am I ever going to be able to build something like that? The answer is, you may not have to.

Constructing simple PCB's is not that hard. You start with a blank board that will have copper deposited on one side, or maybe on both sides. If the circuit has only a few components, and small size is not important, you can draw the layout with a special etch resist pen purchased from an electronics supplier. Even nail varnish will work if you cannot get an etch resist pen quickly enough.

Once you are happy with the layout and the copper is adequately protected where you want tracks to exist, the board is submerged in a bath of ferric chloride. Ferric chloride is purchased, as mentioned earlier, from electronic suppliers as a dry powder and mixed with water according to the instructions. It will keep for a long time in a storage jar. One thing, however, is that you need to be careful with it, as it will stain clothes, fingers, and lots of other things badly and should not come into contact with skin or eyes. So wear protective gloves and glasses. The fluid will dissolve bare copper on contact but will take 5 or 10 min, so just let it work, but don't leave it too long, as it will undercut the resist eventually. Once completed wash down the board with clean water and dry it. The resist can be removed with a solvent such as acetone. Once again protect skin and eyes from the acetone, and don't let it come into contact with any plastics, as it may well dissolve them!

Where more complicated circuits are needed, especially those containing IC's, a different technique is required. Where one-off or small hobby production is concerned, you can buy transfer sheets that are designed to take the print from a laser printer. Laser printer toner is a thermoplastic and melts when heated. It acts as a kind of glue that sticks to the copper. The printed sheet is placed face down on the copper and heated with a domestic clothes iron. When cool, peel off to reveal the protected tracks of your design. Check to make sure there are no missing bits, and touch it up with a resist pen if there are.

For simple single-sided boards where the copper tracks are on the bottom, the print is not mirror imaged, but when transferred to the copper it is reversed when you look at the copper side. The board is best drilled first and then etched as before. Special small electric drills can be purchased for the task and small drill bits obtained from good electronics stores. It is best to use a drill stand, or you will forever be breaking off the tiny bits that are typically less than 1 mm diameter. Figure 8.18 shows the transfer process.

Another popular method for PCB manufacture is to have it made for you by specialist manufacturers. The cost of one-off's is relatively high. You need to prepare the artwork for the layout and send it off; a few days later you get your board. The cost falls with quantity, so it would be an idea to use these services if a club were to build several circuits of the same type for members.

For small prototype and one-off construction it is easier to use the dead bug style of construction, also known as ugly style. Dead bug technique works remarkably well for the kind of radio frequency circuits we will deal with in these projects. Figure 12.4 shows a picture of a mixer-built ugly style.

Dead bug refers to the components being mounted often upside down onto a copper-clad board with their legs in the air. Metal can-style transistors can be soldered directly to a copper board; plastic-bodied variants will need a dab of glue to hold them. The copper board is not etched at all this time, because the copper surface acts as a grounding plane, which helps to keep high frequency circuits stable. After all an oscillator, which is inherently unstable by design, is simply an amplifier with a feedback loop. If high frequency amplifiers are badly constructed, accidental feedback through poor grounding could make them oscillate nicely. This is one reason why strip board is not suitable for RF circuits. The longitudinal copper strips can act like capacitors or inductors at high radio frequencies. Also prototyping breadboard is useless for testing high frequency RF boards. This author tried building a 27 MHz oscillator on breadboard once, but it really wanted to oscillate at 87 MHz and there was nothing that could be done about it!

Most metal can transistors have one of the legs attached to the case internally for NPN types; this is usually the collector. It may well be necessary to attach an "island" first. Cut small pieces of double-sided copper board, and solder one face onto the main board. The upper surface of the island can then be used to solder items such as a transistor, or the positive voltage feed. Once you have mounted the main items, the pins can then support interconnecting components such as resistors, capacitors, etc. Try to keep the construction neat, folding component legs with small pliers. In many cases it is convenient to lay out the circuit as it appears in the circuit diagram to make it easier to understand later. The photograph of an RF mixer shows a completed working converter used by the author for testing.

When constructing RF circuits it is often best to separate circuits into modules, built on different PCBs, and possibly housed in separate, metal screened boxes, the interconnections being made by coaxial patch cables for the signals. A complete radio may be broken down into maybe four or five modules. By making each module independently you can test them as you go, making sure each works as it should, so the final design should operate as expected when all hooked up. This method also makes it easy to convert the receiver later to, say, operate on a different frequency just by changing one or two modules, or by making multiband radios by switching in alternative "front ends."

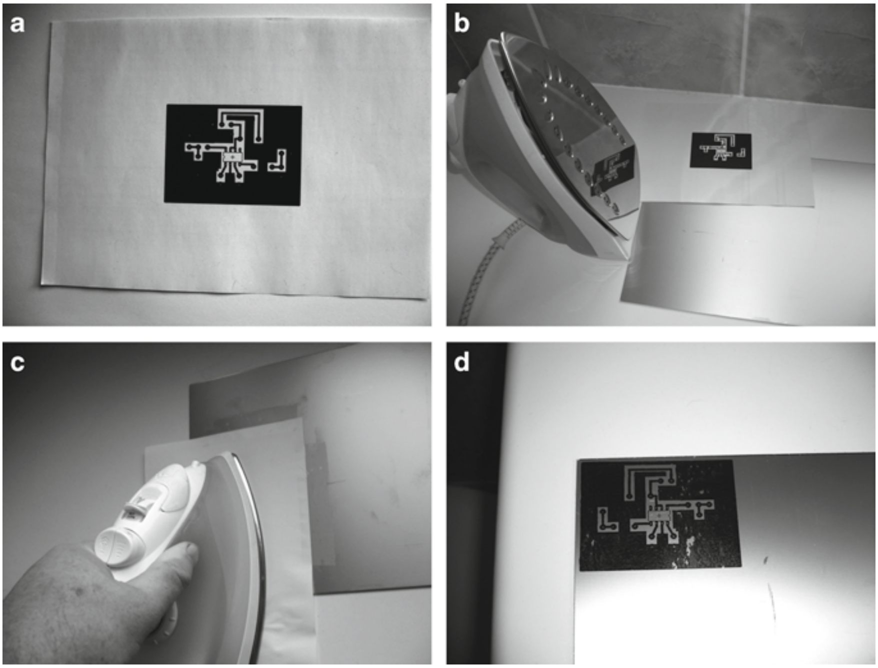

Fig. 8.18. (**a–d**) Using a laser-printed transfer for PCB construction. Note that when the image was transferred to the copper lots of missing patches existed. These were touched up with lacquer from an etch resist pen. None of the important tracks were damaged. Also, an outline of the IC had been left in the print by mistake. This was scratched off with a fine screwdriver before etching.

Screening

Careful thought needs to go into the layout of RF circuits. It is important to isolate stages from each other to avoid RF coupling interfering with the operation of the circuits. For example, the magnetic field from a tank circuit may be coupled through free air to a neighboring element of the circuit. An oscillator will radiate a low power RF signal, which may then be picked up elswhere in the circuit, causing self interference.

Screening is the process whereby possible sources of RF coupling are blocked by mounting them inside metal enclosures that are earthed. Sometimes all it takes is to fit a metal wall between two sections, which could be a piece of copper clad circuit board soldered to a grounded part of the circuit. Cylindrical coils may need screening in a can, but toroidal coils are self screening, which means the field is contained within the iron ring, and only a small separation is needed to avoid problems.

Test Instruments and Tools

Basic Tool Kit

The beginner has to start somewhere. You will probably build up an extensive tool kit in time if the bug really bites. To start off with the following list is essential:

- Soldering iron and stand. Temperature control workstation soldering irons are available at fairly low cost and have the advantage of a good weighted stand/power supply. Small hand held ones are a little cheaper. For PCB work a pointed tip rather than chisel tip unit is best. If the heat is not variable, then a 15–20 W iron is better than high power ones for electronics.
- Side cutters. The smallest side cutters are best for close cropping component legs, but a larger pair is useful for cutting wires. Don't abuse side cutters by trying to snip hard metal items or even circuit boards – you may well break them!
- Small screw drivers, a mixed set of flat and cross head types.
- Needle nose pliers, with or without cutting blades.
- Magnifier, used mostly as a head shield magnifier, especially if you intend to work with surface mount components.
- Multimeter. Most multimeters are digital these days, which is certainly recommended if you only have one. The cheapest ones are not good value, because they have limited ranges and are not as accurate as you may think. It is worth investing in a good brand and model. Research the market, or ask your local amateur radio society for recommendations. The basic ranges are DC and AC volts and amps, resistance, and diode test. A capacitance and frequency range is useful, but it would be better to get a quality meter without these than a poor one with them.
- Drill and drill bits. Useful when constructing antennae, mounting components in boxes, etc. A PCB drill and drill stand will be needed if you choose to etch your own circuit boards.
- Hack saw, not only for cutting the obvious things but for cutting small circuit board pieces, too.

In order to properly test electronic circuits you build, the following items are really useful to have. Although you may be able to get by with the basic kit at first, you will need some or all of these instruments at some point. By joining a local amateur radio club you may be able to get access to these tools at club meetings or even borrow from your friends until you can source your own.

- RF signal generator. The RF generator is used to simulate real radio signals when testing RF amplifiers, mixers, etc. RF signal generators can be very expensive in wide band high frequency models, even on the surplus market, but they are always useful to have and should be part of your test bench.
- Oscilloscope. These days it is easy to pick up a useful working oscilloscope on the surplus market reasonably cheaply. Oscilloscopes are very useful at visualizing what is going on inside circuits. Low-cost units can be purchased from eBay to connect to a PC via USB. The computer then acts as the display. Often they have a bonus feature of a spectrum analyzer, too. Their advantage is the ability to store traces on the PC.
- Frequency counter. A digital frequency counter is handy to confirm the operation of oscillators, or the output frequencies of mixers when used with care. Surplus units that operate to UHF frequencies can be found at reasonable cost. However, as with all surplus or used test equipment, their accuracy can suffer with age. It is not worth buying an old tired inaccurate instrument for a low price and then spending hard-earned money having it calibrated or repaired. Buy the best one you can up front – better if it comes with a dealer's warranty if you are not sure of its quality.

- Step attenuator, which can be bought or made at home, as we shall see. Step attenuators are useful in controlling the output of test oscillators, or the noise source we will construct.
- Noise source. Good calibrated noise sources can be expensive, but later we will see how you can make one. A noise source is handy to simulate the kind of signal we see from space, as well as in testing the performance of amplifiers.
- Impedance bridge. Impedance bridges were once a common tool in the workshop and have been largely superceded by digital instrumentation. However, they can be really useful in testing antenna impedances. Home construction is simple.

Finally, in any RF engineer's wish list is the following instrument:

- Spectrum analyzer. This is a great tool for testing radio circuits. An oscilloscope measures how a signal varies with time; a spectrum analyzer measures how signals vary with frequency. Spectrum analyzers can help you sort out the function of filters, mixers, RF amplifiers, and do many other tasks. However, good ones are seriously expensive new, and even pretty expensive used. However there are some useful if limited performance options available. There are a number of USB computer-based oscilloscopes on the market with useful bandwidths. As a bonus with certain models you can get spectrum analysis, too, which use FFT mathematics to generate the spectrum. The bandwidths are limited on the low-cost models to around 250 MHz or less, but that is still useful. A spectrum analyzer can be obtained for setting up television systems. It has many limitations, but it is still useful for examining the output of RF circuits in the range of 45–2,150 MHz. This can be augmented with a USB oscilloscope/analyzer to fill the gap below 45 MHz.

Most of the tools listed here should be purchased either new or from a surplus source. Online auctions can be a useful source of used test equipment, but it is a minefield out there, and the equipment functions should be established first, unless you need lots of interesting door stops.

Three useful tools are easily constructed that will prove very useful in setting up a radio telescope. The step attenuator, the noise source, and the impedance bridge.

Building the Impedance Bridge

The bridge circuit is a valuable tool to use in testing antenna impedance. It will take out a lot of the guesswork when setting up. Where an antenna has some adjustment, such as the gamma match, or where we make up a one quarter wavelength matching section, the bridge will allow us to tune it correctly.

To understand how a bridge works first consider the circuit in Fig. 8.19. We have seen a similar circuit earlier, the potential divider. This circuit is a pair of potential dividers. If R1 to R4 resistors are all of equal value, say 50 Ω, then the voltage across the output will be half the input voltage, in this case 6 V. Let's now keep R1 and R2 at 50 Ω but make R3 and R4 75 Ω; the output voltage is still half of the input, or 6 V.

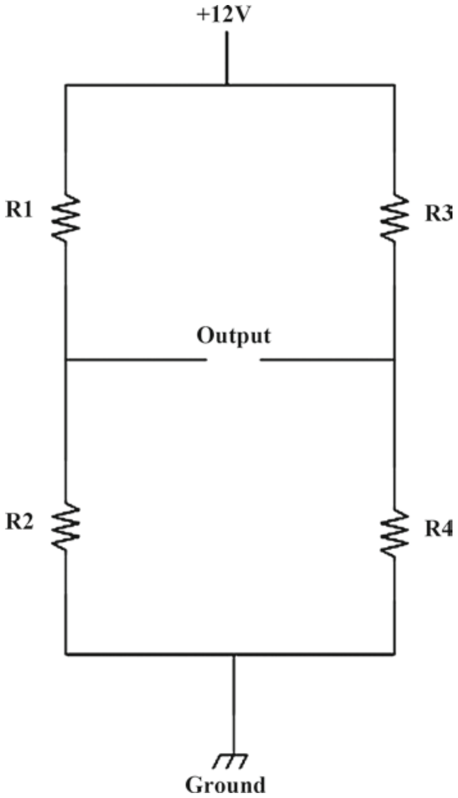

Fig. 8.19. The basic layout of a bridge circuit.

Consider now the current flowing through the output. The voltage at the center of R1 and R2 is 6 V, and the voltage at the center of R3 and R4 is 6 V. Without a difference in potential here, no current will flow. If we place a current meter here, we can detect this null condition when the meter reads zero.

Now consider replacing R4 with an unknown resistor that we think is about 75 Ω, but let's say it is actually 95 Ω. R3 is set to be 75 Ω, the value we want R4 to be, and R1 and R2 are equal, say 50 Ω. Now the voltage between R1 and R2 is 6 V, but the voltage between R3 and R4 is given by:

$$V_{out} = V_{supply}\left(\frac{R_4}{R_3 + R_4}\right)$$

which is

$$V_{out} = 12\left(\frac{95}{75+95}\right)$$

which makes

$$V_{out} = 6.7 volts$$

Therefore a small current will now flow through the output from the high voltage side to the low voltage side. Note here the value of the current is not important; any current flowing means the unknown value of R4 does not match the known value of R3. If R4 is adjustable, it can be set to provide a zero current in the output, and we know it now matches R3.

So far we have been discussing the bridge performance with a DC power supply. An antenna operates in AC conditions, with radio frequency signals. Let's suppose we now connect our antenna in place of R4 but still use a pure resistor as R3. True, R4 will be a reactive impedance this time, and R3 is pure resistance, but it does not matter. It will work adequately well for our purposes. However, this time we must replace the DC power supply with a radio frequency signal from an RF signal generator.

In building a practical test instrument, we can't be sure which way the current will flow through the output or meter contacts. So now consider the circuit in Fig. 8.20. The addition of a series of small signal diodes will ensure the current will always flow through the meter the same way. The connections for R3 and R4 can be fed to chassis-mounted RF sockets, for easy access to hook up the antenna and a reference impedance. If the R3 reference was made to be a variable resistor using a 250 Ω potentiometer, then we could balance the bridge and measure the resistance of the potentiometer to find our antenna impedance. Better still fit a calibrated scale to the potentiometer so resistance could be read directly. The meter is better built in, or you may use a multimeter if suitable connection points are built into it. It will need a reading scale of 50–100 μA. All resistors should be of composition or metal film type and not wire-wound. In practice it is easier to obtain 51 Ω resistor values for R1 and R2.

When constructing the bridge, mount it inside a metal box, with the ground points connected to the case and to the bodies of the RF connectors. Keep all component leads as short as possible. It will certainly work well enough up to VHF frequencies.

The photograph in Fig. 8.21 shows a variable "standard" resistor mounted in a small hand held metal box and connected to the main bridge via a coaxial cable. This version used a 50 μA meter. The lower connector is for inserting an RF signal, the upper two for connecting the standard impedance and the unknown impedance. The pictures were taken before the variable standard was calibrated, and labels fitted. The control knob was taken from a surplus faulty power meter. From start to finish, including cutting the holes in the box, it took a morning's work to build. Not only can it be used to measure antenna impedance, but it can also be used the same way to measure unknown inductor or capacitor values, if a series of known standard inductors and capacitors are available. All in all a low cost but very useful tool for the workshop!

When you come to calibrate the variable standard impedance, use the bridge to do it, and fit known values to the other connector port. Try to have a precision resistance decade box to set it up.

The picture of the circuit is a little hard to follow, but it was constructed using the dead bug style. Note that there are five island pads soldered to the base. The islands are double-sided copper board; the lower side is first tinned with solder and then held onto the base with a small screwdriver while a "wave" of solder is run down the sides, which creeps under and sticks the island to the base. The baseboard is the ground plane. The board is held down by a mounting stud from one corner of the meter and ensures the case is also earthed. The bodies of the RF connectors also reinforce the ground connections to the box. Small coaxial cables

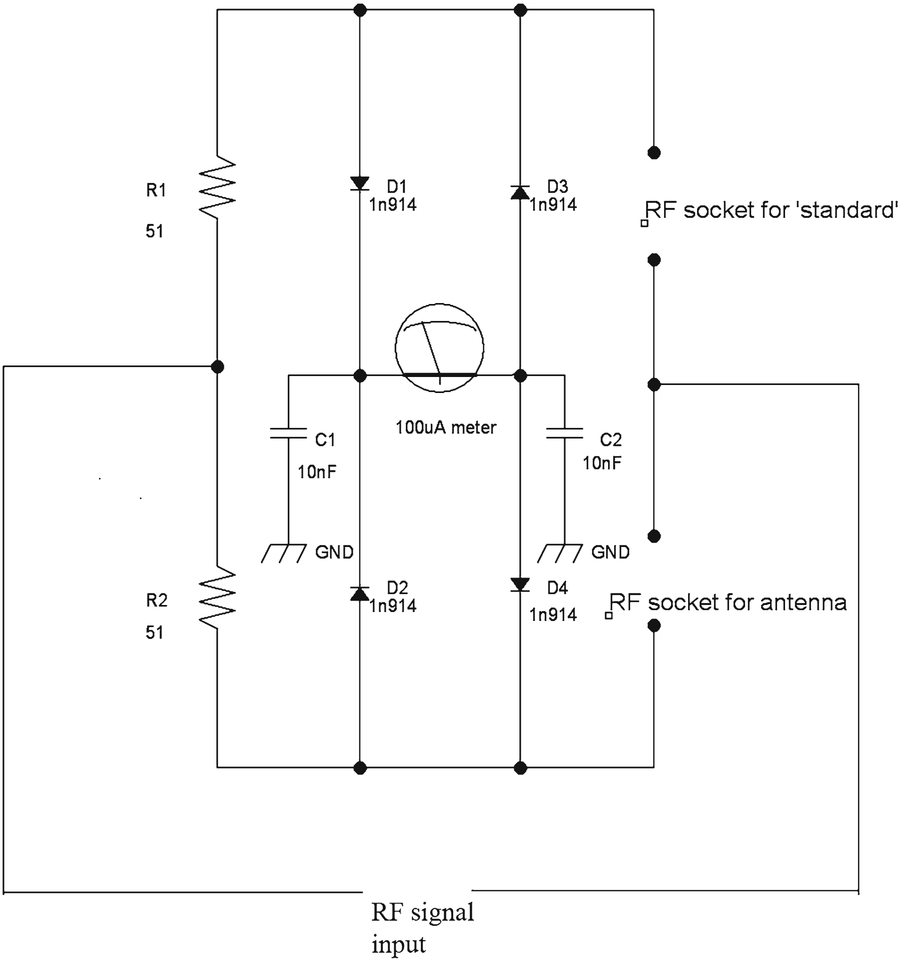

Fig. 8.20. Impedance bridge.

connect the circuit to the meter and the RF connectors. Don't worry about how your circuit looks, so long as you follow the simple guidelines and connect everything the right way.

Constructing the Noise Source

Calibrated noise sources are expensive bits of test equipment. Even surplus equipment units can fetch a high price. Untested surplus units may not even work, or may need repair and recalibration which further bumps up the price.

Following is an interesting way of constructing a noise source, based on articles written by G. W. Swenson years ago in *Sky & Telescope* magazine. It uses a light bulb as a source. The filament of a light bulb is essentialy a resistor, and a hot resistor makes a good approximation to the sort of noise received from space. The fact that

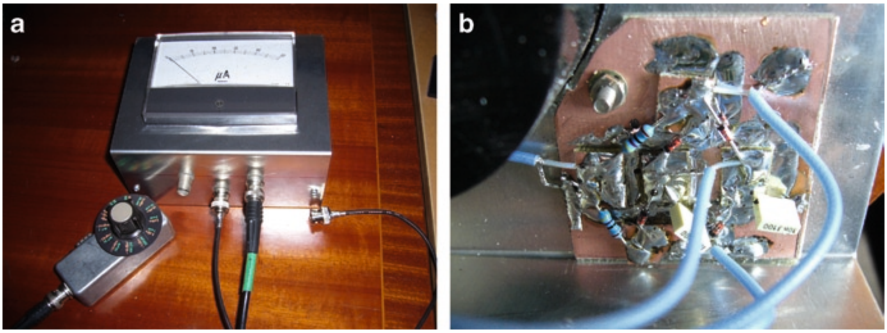

Fig. 8.21. (**a**, **b**) A basic but practical impedance bridge.

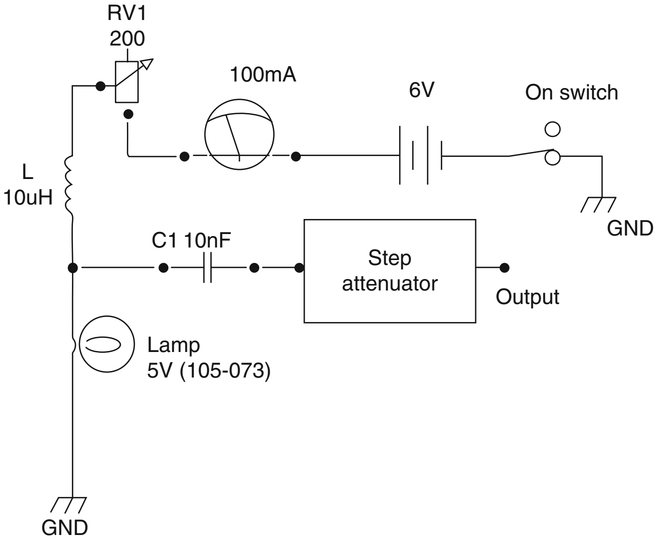

Fig. 8.22. Noise source.

the light bulb filament is hot by virtue of its function saves us the trouble of heating a normal resistor and maintaining its temperature.

In theory, by varying the current through the lamp, its noise temperature will also vary. However, it turns out the response is non-linear, and different between different bulbs. What G. W. Swenson found out was that at rated current, all tested lamps had a noise temperature of 1,300 K. So if the bulb was run at constant current, and an attenuator used to vary the output, we could provide a variable noise source from low temperature up to 1,300 K. Swenson used a 3 V pilot lamp with a rated current of 60 mA. However it is hard to find one of these now, so in chosing a lamp for the job, find one that has about a 50 Ω resistance. This can be worked out from Ohm's law, in that if the rated current is 90 mA and the operating voltage is 5 V then the filament resistance will be around 55 Ω – close enough. At the time of writing the RS components part number 105-073 seemed suitable.

The circuit for the noise source is simple and shown in Fig. 8.22. The lamp should be soldered directly into the circuit and not fitted to a holder, to avoid extra attenuation.

Table 8.6. Calibration table for the noise source.

Attenuation (dB)	Noise output (K)
0	1,300
3	800
10	390
30	290

By adjusting the 200 Ω potentiometer RV1 until the meter reads 90 mA the lamp will be operating at its rated current. If you chose another lamp, the current may be slightly different but should be the rated current. The actual value required for the resistance of RV1 is about 83 Ω, so in fact a 100 Ω pot may be used. However, the low value potentiometers can be a little hard to find, so you can scale a higher value pot down by adding a parallel resistor, so a 500 Ω potentiometer in parallel with a 330 Ω resistor will give you about a 200 Ω pot. As for power, either a 6 V battery or a 5 V external power supply could be used. Once again build it in a metal box, where the ground points are connected to the case, the component wires are kept very short, and the output fed to a coaxial socket whose body is also grounded to the case.

The output of the noise source is varied by using a step attenuator of the type described next. Varying the current is not a reliable way of adjusting the noise level. Remember the lamp will show a 1,300 K noise level at its rated current into a 50 Ω load. Table 8.6 gives the values expected by adding attenuation factors to the output.

It should be noted the lamp characteristics will likely change with usage. Atlhough it is not going to be used for extended hours, the lamp should be periodically replaced after say 100 h of use.

The Step Attenuator

I was lucky to find a good used step attenuator on eBay a while back for £40. I remember thinking it was expensive at the time, but it probably wasn't that bad. Recently I have seen similar ones for £100, and one item brand-new that would operate at up to 40 GHz was £2,400 – ouch!

My own example is good up to 1 GHz, and that is enough for me anyway. However, you can build your own from a few DPDT switches and a set of precision 1% resistors.

The resistors are laid out as a pie network, as illustrated in Fig. 8.23. Each step of the attenuator contains a unit like that; the resistors required for several common attenuation values is given in Table 8.7.

The circuit showing the first three sections of the attenuator with switch contacts is shown in Fig. 8.24.

The switches are DPDT (Double Pole Double Throw) toggle switches. Each switch has two independent contacts or poles, and the double throw is acting as a changeover switch. The RF lines are connected to the common center pins. One side of the switch is shorted with a wire between the pins, and the pie networks are connected to the other side of the switch. In this way each attenuator can be switched in or out without breaking the continuity of the chain. The value of total attenuation obtained is the sum of the individual attenuators. Mount a chassis RF socket at each end for easy connection to equipment.

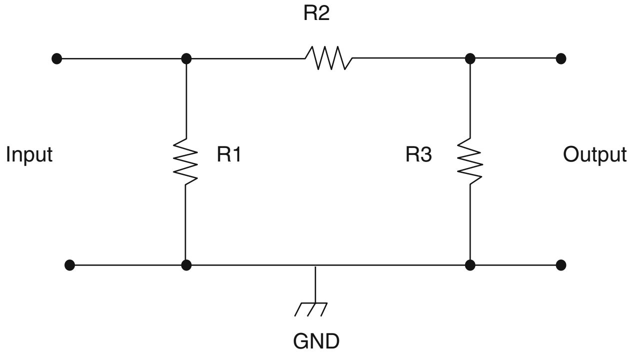

Fig. 8.23. The general form of each stage of a step attenuator. Refer to Table 8.7 for the resistor values.

Table 8.7. Resistor values in ohms for different attenuation steps

Attenuation (dB)	R1	R2	R3
1	866	5.6	866
2	432	11.5	432
3	294	17.4	294
5	178	30.1	178
10	95.3	71.5	95.3
20	60.4	249	60.4
30	53.6	787	53.6

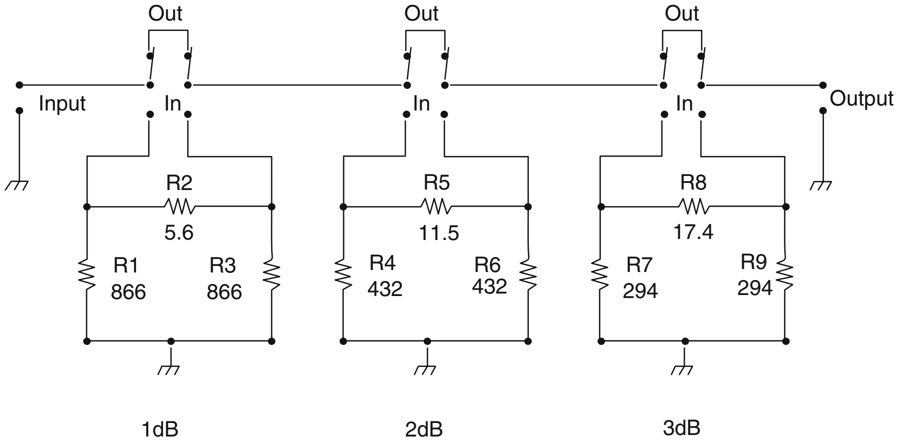

Fig. 8.24. The step attenuator circuit diagram.

Note that a grounded screen should be installed between each attenuator. Pieces of plain copper clad circuit board could be used and soldered together to form an array of boxes within a box.

The values of resistors shown are available in precision ranges; some will cost more than others, depending on their precision and rarity. All leads must be kept short. A resistor will work adequately well up to UHF frequencies of around

450 MHz or maybe more with reduced accuracy. At 450 MHz it would be expected to be within 2 or 3 dB of the maximum attenuation value of 71 dB. At zero attenuation, it may have a stray value of something like 0.4 dB.

Using Your Newly Built Test Equipment

Measuring Antenna Impedance

In order to use the impedance bridge, a signal generator is required that will operate at the frequency for which the antenna was designed. If that is below 200 MHz then it would be fairly straightforward to build an oscillator along the lines of circuits outlined elswhere in this book. However, constructing oscillators for higher frequencies becomes quite difficult, and some experience will be required. If you browse the web pages of Minicircuits at http://www.minicircuits.com/ you will see readymade oscillators covering a wide range of useful frequencies. It is far easier and not too expensive to find a suitable unit for any frequency under 1 GHz (construction at higher microwave frequencies does require some considerable skill). Their range of VCOs is very useful. VCO stands for voltage-controlled oscillator. All VCOs require is a low-voltage fixed power supply and a low variable DC voltage to control the output frequency.

An alternative to this would be to buy a good RF signal generator. You might want to have several, covering frequencies up to 250, 500, and 2 GHz, all generally available from various surplus sources relatively cheaply. They are always useful to have in the workshop. However you chose to generate your RF signal you will probably have to turn up the output power to its highest level (this will not be much, as many tests use milliwatts of power or less).

Note that when using the impedance bridge to test an antenna using a balanced feed (twin line), a balun such as the coaxial balun will be needed to attach it to the bridge. You will therefore need to account for the 4:1 impedance ratio of the balun. The actual impedance of the balanced antenna will be 4 times that obtained from the bridge.

When you connect the antenna to the bridge, say via the coaxial balun, and if you expect the impedance to be 75 Ω (which is confirmed by the bridge with a good deep null reading of close to or equal to zero at 75 Ω), then all is probably well and the antenna is an excellent match. In fact if the impedance is within even 20% of the expected value this would be considered a good match.

If the reading is more than 20% off target, first check that the balun is good by removing it and soldering a 300 Ω resistor across the antenna terminals, testing the balun on its own to confirm that it is indeed 75 Ω. If not then there will be either bad solder joints or the length of the coaxial cable is wrong for the frequency used. Don't forget to account for the velocity factor of the line in determining its length. If all is well with the balun, then work systematically up the line, moving the balun up each section as you go, testing each section.

Once everything has been checked, if no faults were found (such as bad joints), and the impedance is still off, then it comes time to adjust where necessary until the impedance is correct (such as gamma match adjustments and correcting impedance matching sections to suit).

Using the Noise Source to Test Amplifier Performance

Earlier we discussed the importance of the noise characteristic of the first stage of a radio receiver. It is this first stage that contributes the greatest proportion of the overall noise. The test instruments described here are likely to be only useful from mid-UHF frequencies or lower. The procedure and the crude instrumentation will only give us a rough and ready answer, but firstly it will be very instructive to the beginner, and secondly it should be good enough to highlight major faults, or give some confidence in the proper function of the devices.

Set the noise source to a low setting via the attenuator and connect it to the receiver being tested. Assuming a reading is achieved on the output make a note of the value and the temeparture setting of the source. If no output is obtained, increase the noise level slowly until it reads something like mid-scale, or a decent level anyway. Now add a 3 dB attenuator between the noise source and the receiver (this is an additional attenuator, not a step of the step attenuator in the noise source). Adjust the noise source to achieve the same output level as before. The difference in the two temperature settings is then a measure of the noise performance of the receiver.

An additional check can be done. Take a short piece of coaxial cable of the type used to feed the receiver, solder a resistor whose value is the same as the impedance of the cable across the end of the cable (keeping the leads short), and fit a suitable coaxial connector to the other end. Seal the resistor with silicone sealant and let it dry.

When ready, fit the resulting "probe" to the receiver, and dip the sealed resistor end into a bowl of ice water that has a lot of ice cubes in it and which has been stabilized to 0°C. Take a reading from the output of the reciever. Now dip the resistor into a pan of boiling water that is at 100°C. The output of the receiver should increase noticeably. If it does it should have sufficent sensitivity to do some useful astronomy.