Chapter 10

Microwave Radio Telescope Projects

The first project is a version of the Itty Bitty radio telescope designed originally by Chuck Forster of SARA (Society for Amateur Radio Astronomy) and outlined on the teacher's resource pages of the NRAO website.

This project will take the instrument to the next level. For example, we will add a computer interface for data logging. The heart of the telescope is a satellite finder and a universal satellite television LNB. The block diagram of the telescope is shown in Fig. 10.1.

The aims of the project are the following:

- To learn the basics of microwave radio receivers.
- To gain experience building real systems.
- To gain experience using a radio telescope.

Required Parts

The Dish

The dish can be any surplus or even a new satellite television dish. Even the smallest oval dish is capable of solar observation. Although a larger dish will improve signal strength, since the aims of this project is primarily educational, it is not recommended to use too large a dish at first. A 45 cm to 1 m size is best and is easy to handle and mount. If the dish is kept small the system can be made portable and used to demonstrate radio astronomy to friends, clubs, and at star parties.

Dishes come in two main types, offset and concentric. The offset type is very common in the small sizes, but poses more of a problem in accurately aligning the dish for practical observing sessions. The idea of an offset dish is to make it easier to fit to a house wall for use in a television receiving system. The dish sits nearly vertical against the wall but is receiving its signal from a satellite at an angle at about 20° to the horizontal. The LNB is also offset at an angle on the opposite side, so that the reflected signal is received. In radio astronomy we may want to point the dish to any arbitrary position, but it's always a bit tricky to know where it is

J. Lashley, *The Radio Sky and How to Observe It*, Astronomers' Observing Guides,
DOI 10.1007/978-1-4419-0883-4_10,

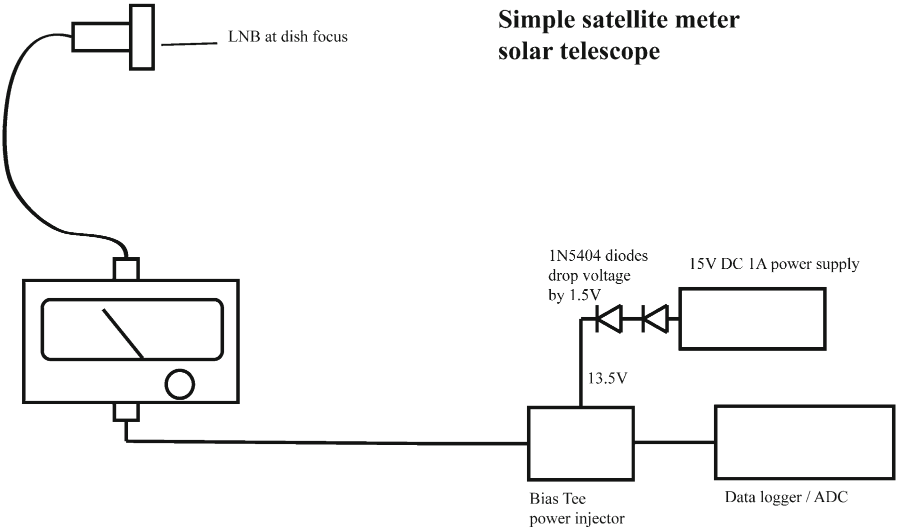

Fig. 10.1. Block diagram of the basic microwave telescope. The dish is not shown.

pointing. It's really worthwhile looking for a small concentric dish. Typically small concentric dishes are not used for television receiving but for microwave communication links or weather satellite receiving or such. These will probably need some conversion in order to mount a satellite television LNB, but more on this later.

The LNB

LNB stands for low noise block. The sky background is fairly quiet in the lower to middle microwave bands. It is therefore possible to utilize low-power satellite signals for direct reception of television in homes. Due to the weak signal strength at Earth's surface, a low noise amplifier is required to properly detect it. Remember that the most critical portion of a radio receiver that influences the overall noise performance the most is the first stage. LNB's are available with a noise figure as low as 0.3 dB. Many of the low cost units offered to the consumer market seem to be optimistic in the specifications. Although 0.3 dB may be the best a given LNB can provide, this may only be true at one small part of its receiving range. The average performance across its bandwidth may be closer to 0.6 dB. Many professional quality LNB's quote noise figures of 0.6–0.8 dB, probably a more realistic figure. Any of these would work well in this project. Note also, LNB's come in offset and concentric types and they should not be mixed.

To understand the workings of an LNB you need to understand some of the terms used in their specification. First, the term universal LNB may not be what you would expect. Universal does not refer to the way it is mounted, such as a universal bracket or clamp. It refers to the frequency coverage, the way that frequency tuning is achieved and in the way its polarity is controlled. Also, universal does not mean it is the same worldwide, either! The notes here refer to the European meaning of Universal LNB.

The frequency bandwidth – the coverage of the Ku band satellite TV allocation – is from 10.7 to 12.75 GHz. A universal LNB can cover this whole range but not

Fig. 10.2. (**a**) The LNB circuit. This kind of circuit is difficult to make at home. Note that the cover has built-in shielding walls to isolate various parts of the circuit. (**b**) LNB with a c120 feed horn used on concentric dishes. (**c**) A European Universal LNB used on offset dishes.

simultaneously. The bandwidth is broken down into two parts, 10.7–11.7 GHz and 11.7–12.75 GHz, sometimes referred to as low band and high band. Traditionally only low band was used, but to add extra space for more channels the TV allocation range was extended. Universal LNBs employ a 22 kHz tone signal to switch it to the high band. This is normally provided by a satellite TV tuner box. In this experiment the tuner is not present, and without a 22 kHz tone generator the LNB will default into operation in low band, providing our receiver with a 1 GHz bandwidth (Fig. 10.2).

The Universal LNB has two antenna probes mounted orthogonally, allowing it to switch between horizontal and vertically polarized radio channels. The way this is done is by switching its supply voltage between two states, 13 and 18 V. Actually the LNB will happily operate at any DC voltage between 12.5 and 18.5 V, although there is a gray area between 14.5 and 15.5 where you can't be quite sure what polarization it is using. The lower voltage makes it work in vertical mode, and the higher voltage in horizontal mode. Clearly horizontal and vertical refer to its primary role as a TV dish mounted vertically on its stand. In a radio astronomy function, the dish may well tilt at other angles if objects are tracked across the sky. In its simplest form the actual polarity used does not matter, as the Sun emits a random mix of polarities anyway.

Now, looking inside an LNB, we can see that it provides two functions for us. First it significantly amplifies the radio signals detected by the probe. Second it translates the frequency down from the Ku band to the L band, which is the first intermediate frequency of the system. This IF frequency is in the range 950–2,150 MHz.

Amplifying and reducing the frequency as close to the antenna as possible avoids most of the problems of loss of signal that would otherwise be present when sending a signal down a feeder to the receiver some distance away. There is a down side to this. The LNB is mounted via a short feed horn right at the focus of the dish. Normally this is no problem, but if we are to observe the Sun for any length of time, the reflected energy, particularly infrared and light, will cause significant heating of the electronics. This is not only detrimental to noise performance but could melt the plastic components of the LNB body and damage the electronics inside! It would be advisable to at least paint the dish with a matte black all-weather paint to reduce its reflective properties in the IR and visible wavebands. A better way to protect the electronics is to build an extended waveguide that curls around the back of the dish out of the way and mount the LNB there. This technique, however, will be left to the reader to think about.

A useful feature of the LNB is that it is powered by the same cable used to feed the radio signal, therefore saving the effort of routing extra power cables. This technique can of course be used for any mast head electronics. Normally the television receiver would power the LNB, but in our case we will have to construct what is known as a bias tee, a device for injecting power into the RF feeder.

In place of a conventional television receiver, we will use a modified satellite finder as our receiver. The basic satellite finder is a readymade signal strength meter. It could be used unmodified, but would then be a visual-only device. By modifying it we can connect a data logger to it to record signal changes. The beauty of the signal strength meter is that we have another layer of amplification, this time at the IF frequency, and a built-in detector and integrator. The output of the integrator is DC, which is normally used to feed the analog meter of the display.

Construction

The dish and LNB are best purchased together. Often the small dishes come as a package, such as the Sky mini dish in the UK and the Direct TV dish in the United States. As mentioned earlier LNB's come in concentric and offset varieties. It is important to match the LNB with the style and focal ratio of the dish being used. This ensures that the feed horn can make best use of the entire dish aperture. An offset LNB will have an oval beam pattern; if this is used in the center of a concentric dish it will prove inefficient, and the edges of the dish will be wasted.

If you are to use a concentric dish that needs modification to fit a TV LNB, it is first important to work out where the focus will be. Clearly this will be in the center, but the critical dimension is how far from the center of the dish is it. This boils down to working out what its focal ratio is. There is a simple formula you can use to calculate the focal length of a concentric dish:

$$f = \frac{D^2}{16d}$$

where f is the focal length, D is the diameter of the dish, and d is its depth. All these are measured in the same units.

D can be found by simply measuring the diameter with a tape measure, but depth needs a long-enough straight edge to cross the face of the dish. The depth is measured from the edge of the dish to the center point. Lay a good straight edge such as a length of metal box section across the center line, and measure down with a tape measure or use a thin rod and mark off the height with a felt pen so it can be measured. Plug the numbers into the formula and work out the focal length. The LNB is placed such that the focal length is a small distance inside the feed horn.

The face of the feed horn is sometimes invisible, as it is covered with a plastic cap. A little educated guesswork may be needed. If you need to know the focal ratio this is of course given by f/D.

The situation is completely different for an offset dish. An offset dish is a portion of a larger paraboloid, in effect a piece cut out of the edge of a larger dish. Therefore you don't know where the center of the dish lies. If you want to know how to work out the dimension of such a dish refer to the excellent article at http://www.qsl.net/n1bwt/chap5.pdf. For this exercise use a matching LNB with an offset dish – no modifications needed.

Next, before we do any changes to the satellite finder, we need to build the bias tee, so the system can be tested at this point. The circuit diagram is shown in Fig. 10.3.

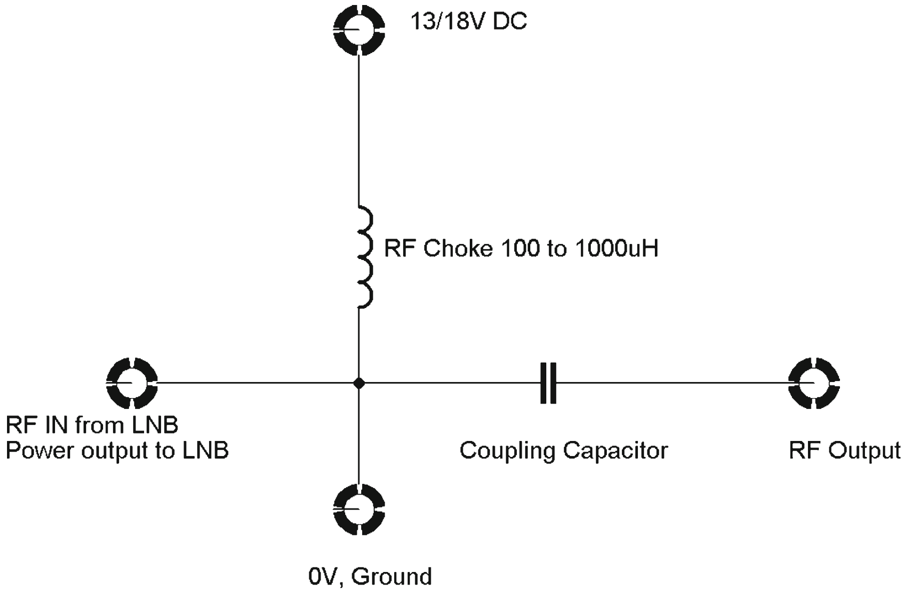

Fig. 10.3. Circuit diagram of a bias tee for TVRO. The ground connection is common to the shield of the RF in, RF out and the 0V from the power supply.

The most important consideration in making a bias tee is that the capacitor reactance should be very low and the inductor reactance very high at the frequency it is used. This allows the signal to pass via the capacitor with little attenuation, while blocking the DC power. The inductor prevents the signal from leaking into the power supply by virtue of its high impedance. The same technique is used inside the LNB and signal meter to separate power from signal again.

Note that the bias tee allows additional equipment to be connected to the RF out port for later expansion and experimentation. It is not strictly necessary to include the capacitor and RF out port for the simplest system.

Figure 10.4 shows the basis of the receiver detector system before any modifications were made. The connector on the right normally goes to a satellite TV receiver, and the connector on the left goes to the LNB.

First test the system in its basic form. Connect the bias tee to the receiver side of the meter, and the LNB to the dish side of the meter. Connect the power and turn on. By increasing the sensitivity control a whistling sound is generated, and the pitch increases with increasing signal strength. Setting the sensitivity somewhere in the lower part of the needle travel and pointing the dish at the Sun causes an increase in signal heard and seen on the meter. With small, careful movements various satellites will also be clearly found along the Clarke belt at zero declination.

Now for the interesting part. Break down the components again so that the meter can be taken apart. In the model of satellite finder illustrated in Fig. 10.4, there was no obvious way of opening the case. But the back panel was simply a press fit, and with a little work popped out. Since the circuit was soldered in situ to the F sockets, you needed cut away the plastic and remove three small screws so it could be withdrawn. Don't count on retaining the same box, however, as it is not shielded from stray RF. Figure 10.5 shows the circuit after removal from the box.

Fig. 10.4. The satellite finder as it came out of the box before any modifications were made.

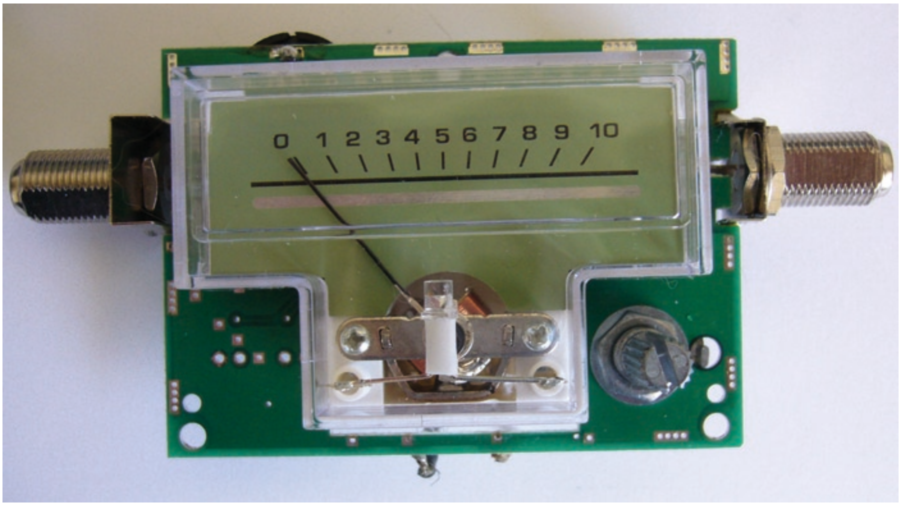

Fig. 10.5. The satellite finder with the box removed.

The first modification involves removing the meter. Simply de-solder the connections on the reverse side and pull it out. Solder a pair of wires to the same points, using the convention of red wire for the positive connection and black wire for the ground wire. Identify the ground wire, which is connected to a large area of copper surrounding all the places where there are no thin traces. If in doubt, connect the power and lnb again and turn up the sensitivity so that a buzz is heard, and use the multimeter to work out the positive and negative terminals.

The next modification is to remove the sensitivity potentiometer. Carefully de-solder it, and use a solder removal tool, such as a vacuum sucker, which can be purchased from electronic component supplier. Get as much of the solder off as you can. Then reheat the terminals and slowly remove the potentiometer. It is very easy to damage the fine copper tracks if you are too abrupt with it. Even trying to be careful, you can still slightly damage a track. To fix it any damage carefully remove a little of the green lacquer insulation, which allows you to solder a fine wire to it. Alternatively follow the trace until the nearest component connection is found, and solder the wire to end of the component. The aim after removal of the potentiometer is to solder in three wires that can be later soldered onto the potentiometer after moving it and mounting it on the outside of a new metal box.

The F connectors need to be removed. Heat the solder points and use the vacuum tool to suck away the excess. Retain them for installation on the new metal case. You can also replace them with N-connectors (if you already have them). Using some short lengths of thin diameter coaxial cable, take off a short length of insulation at the ends and solder into place where the F connectors were. Always keep short lengths of useful cable like this in your "scrap box" from dismantled surplus or dead equipment. Don't worry too much about the cable impedance. The lengths are so short it hardly matters.

Next you can de-solder the buzzer and turn it around 180° and solder it back into the circuit. A fine wire is then soldered onto the board where the second buzzer pin used to be. Another wire, perhaps yellow, can be soldered to the now free-floating buzzer pin, the junction being insulated with heat shrink or electrical tape. The pair will later be soldered to a panel switch so the buzzer can be disabled for long-term observation runs.

A suitable metal enclosure should be purchased, large enough to take the circuit board of the meter and deep enough to allow the board to stand off the metal base and clear the electrical connections in the top. The F connectors (or N's, if you prefer) should be installed into the case lid. The bodies will make an electrical ground connection to the box. Then mount a miniature SPST toggle switch and solder to the buzzer wires. Make a paper template of the circuit board mounting holes, and stick that to the base of the box with tape. Drill the relevant holes to take stand offs. Stand offs can be purchased from electronic component suppliers and consist of a rod which is drilled and tapped with a thread at both ends. This allows the base of the stand off to be screwed to the case, and the circuit board to be screwed to the tops of the stand offs. These ensure the board connections do not come into contact with the box and short out. The mounting holes in a meter can be through the ground plane areas. This means that by using metal stand offs a ground connection is made to the body of the box. If plastic standoffs are used or if you need to insulate the mounts from nearby tracks, then a ground wire will need to be soldered from the board and bolted to the box somewhere to ensure good shielding properties.

A socket of some kind is needed for the output signal (formerly the meter connections). You can use a phono socket. It's not very critical what type is used since the output is a DC voltage.

Now the power feed. While you could use the previous technique of injecting power via an external bias tee, you should think of potential future experiments of placing extra electronics on the output side. So you can remake a bias tee internally, by soldering it directly to the output coaxial socket. A small piece of circuit board can be used to install the capacitor and inductor. This way the capacitor blocks the DC power supply from entering the output coaxial line. This method means that a power socket needs to be installed in the case of an external DC power supply. You can use a pair of banana sockets or a 3.5 mm power-type jack socket.

Once all the connections have been made, recheck everything, and use a multimeter on continuity test or a low resistance range to confirm basic things, like the power connections are not shorted and that the power ground is connected to the metal case. Check that the ground plane (the large area copper pads) of the circuit is also connected to the metal body. Check that the RF connectors are properly grounded to the box, and that the center pins are not.

The only remaining task is to connect the output socket to a suitable data logger. Refer to the last chapter for details on making or buying suitable data loggers and how to use to them. In the example given the maximum output voltage encountered was 7.8 V; you may want to measure yours, as it may influence what data logger you build or buy.

Once everything is connected up, apply power and confirm that the buzzer still operates by turning up the sensitivity. Then connect it to an LNB on a television dish and confirm the system still works as it did before, by making sure the pitch of the buzzer is still changed, and by connecting a multimeter on the DC voltage scale to the phono output socket. If you do not have satellite TV then use the dish to point at the Sun; it does not have to be a clear sky, although you will have to guess where the Sun is in cloudy conditions! Operationally it should be noted there is a jump in output voltage when the buzzer is disconnected. This should not pose any really problems. The absolute voltage reading is not important. It is only the changes in voltage with received signal that is important. Once set up the buzzer plays no further role in an observational run.

The photos in Fig. 10.6 show various stages of the modification process.

To complete the telescope a data logger was built from a kit. The kit is still available from Magenta Electronics from their website, www.magenta2000.co.uk and it is KIT877. The design was published in EPE magazine in August and September of 1999. The heart of the logger is a PIC 16f877 microcontroller. The CPU comes already programmed with the software. The advantage of this kit is that it has eight channels and so can log data from multiple devices simultaneously. The disadvantage is that there is no real time clock on board, so careful note of the starting time is needed. It will happily run for hours on batteries, logging data to flash memory chips. There is not a great deal of memory, but with samples taken every 5–10 s it will record for a day. The data can be downloaded via serial cable to a PC (Fig. 10.7).

Observing Projects

Drift Scan Solar Transit

The Sun at Ku band frequencies has a diameter of half a degree, the same as the visual diameter. This means the radio emissions are emanating from the low regions of the solar atmosphere, just above the photosphere. At this frequency with this simple radiometer the solar output will appear to be fairly constant. Unlike UHF and VHF rapid changes in the solar output due to flares will not be visible.

Set up the dish fixed onto to something solid, such as a building wall or a heavy tripod, and aim it at an altitude where the Sun will drift through its beam. This is

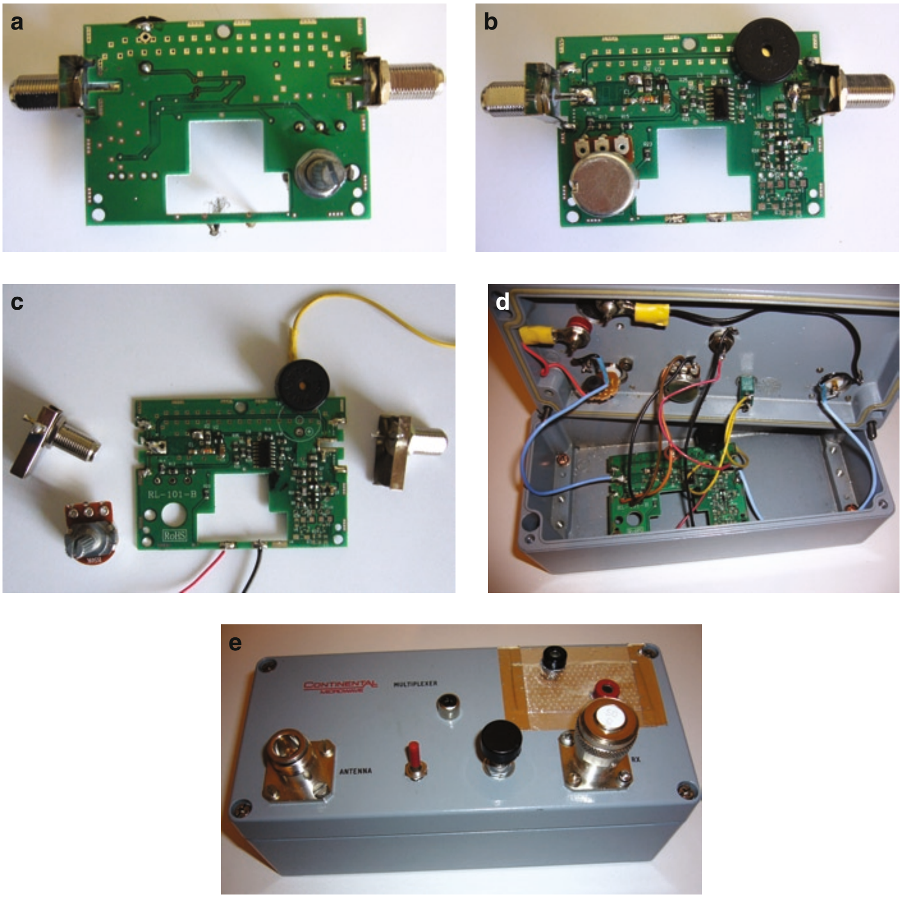

Fig. 10.6. (**a**) The circuit after removal of the meter looking from the front. (**b**) The view from the back showing the electronics; the buzzer is the black disc, and the potentiometer the silver disc. (**c**) This shows the removal of the RF connectors, the potentiometer, and the reversal of the buzzer. The wires for the potentiometer and the second wire for the buzzer have not yet been installed. (**d**) The finished receiver viewed from inside. Note on the left of the lid a small circuit board is soldered to the RF connector center pin containing a bias tee network. (**e**) The finished receiver viewed from the outside. The *top right hand corner* has some metal foil tape applied to cover a hole left by a redundant N connector. The case was "rescued" from a surplus sale, hence the engraved writing. The RF connectors are marked as suitable by accident! There is a 50 Ω terminator fitted to the output socket that is not being used at present. This should be a 75 Ω terminator in reality.

Fig. 10.7. Data logger, this one is based on a kit supplied by Magenta Electronics. There is more on data logging in a later chapter.

easier said than done with an offset dish. One method of aiming is to mount a flat metal bar about 150 mm long to the top edge of the dish so it overhangs at the rear. Determine the offset angle of the dish; this may be supplied with the dish, or it may be marked somewhere on it. It can be estimated from the angle between the center point and the center of the lnb feed, with respect to the normal at the center of the dish. Adjust the mounting bracket of the flat bar to the same offset angle so it effectively points in the direction the dish is looking, and ensure it is perpendicular to the rear face of the dish in the horizontal central position. Using a protractor with a plumb bob attached to its origin, hold the protractor against the underside of the bar; the plumb bob can be used to measure the altitude.

Allow the Sun to drift through the beam of the dish. The result can be used to measure the beamwidth of the antenna. Strictly speaking the beamwidth is measured between the 3 dB points, in other words, when the received power is half of the peak value. By measuring the time interval on the graph between the points where the signal is half its full value, the beamwidth can be estimated from the angular drift rate of the Sun (approximately 15°/h). For a Sky mini dish of 45 cm across, the beamwidth will be in the order of 4°.

The above argument relies on the assumption that the satellite signal strength meter is providing a measure of the received power and not something like the amplitude of the signal; after all, the system is completely uncalibrated.

Detecting the Moon

The Moon reflects solar energy towards us and is therefore theoretically observable. However the signal strength is much less than for the Sun. It is not easily detectable with a dish as small as 45 cm, so it may be a real challenge. You could try the same experiment with an 80 cm or 1 m dish. The signal will be close to the noise floor of the instrument.

Determination of the Equation of Time

By accurately setting up the dish to point due south, and maintaining its altitude to ensure the Sun always passes through the beam pattern, using the logger the time of solar transit can be determined. This will differ from midday clock time by the value of the equation of time. It will take a year of observations to achieve this, and the dish should be rigidly mounted in azimuth and smoothly adjustable in altitude.

The Slowly Varying Component of the Sun

At the operating frequency of around 12 GHz the instrument is able to observe the chromosphere of the Sun up a maximum altitude of 70,000 km above the photosphere. The radiation detected is largely thermal Bremsstrahlung from hot gases present in that region. The temperature of the gas varies over the solar cycle from a minimum at solar minimum to a higher level around solar maximum. The changes are slow and gradual rather than sharp and burst like. The enhancement in the solar output is due to the effects of sunspots.

At solar minimum the flux density observed is around 275 sfu (solar flux units), which is 275×10^{-22} $\mathrm{Wm^{-2}\,Hz^{-1}}$ so 1 sfu is 10,000 Jansky. Although no professional studies of the slowly varying solar output are being done now, the value of the solar flux density observed at solar minimum is considered to be constant enough that it is often used as a calibration source.

For a minute let's step back and look at what this output means for our telescope. Our lnb has a bandwidth of about 1 GHz, and a collecting area of 0.15 $\mathrm{m^{-2}}$. The efficiency of the dish is estimated at 56%. Therefore the amount of power it receives from the quiet Sun is $275 \times 10^{-22} \times 1 \times 10^{9} \times 0.15 \times 0.56 = 2.3 \times 10^{-12}$ or 2 pW! Not only that, but the Sun gives a clear, strong signal, too.

Anyway, at solar maximum the overall output at 12 GHz will increase by a factor of about 1.37 over the value at solar minimum. A long-term project that would be interesting is to log the received signal power daily over the solar cycle to try and observe this slowly varying component. An observation period of 3–6 years should reveal a change. However it would be best if the instrument were calibrated against a known source to try and remove temperature effects from badly affecting the results. Don't forget if the dish is pointed at the Sun for extended periods the lnb could suffer significant heating, which will change the gain of the unit quite a lot. However alongside the previous experiment to determine the equation of time the transit instrument can be used to measure the solar flux density at noon by drift scanning. The Sun will only take 2 or 3 min to pass through the dish beam, so it will not cause overheating of the lnb, especially if the dish is a matte black color.

As for a calibration source use a compact fluorescent lamp (this is not an absolute calibration method – it is relative to the output of the lamp). Get one of the more powerful types around 26 W. These are usually constructed from coiled tubes. The lamp should be pointed into the dish beam end at a range of at least 0.6 m, but always the same distance each time. A power reading should be logged along with the Sun. The calibration measurement needs to be taken as close as possible in time to the solar reading so the lnb temperature is the same for both measurements. In practice you can't be there every day to take a calibration reading, but weekly measurements of solar flux would be sufficient to study the long-term changes. Note that the lamp should be retained for use only in this project and used for as short a duration as possible. These lamps age with use and their output changes. Also they take a short while to reach full output, so allow it stabilize for at least a few minutes before taking a reading.

When processing the results take the difference between the reading from the lamp and the reading from the Sun. This should remove receiver temperature effects sufficiently. In practice the brightness temperature of a compact fluorescent is going to be around 5,000 K and the Sun about 12,000 K.

A Low Cost Microwave Interferometer

This project is similar to the satellite finder telescope in that it uses low-cost satellite television components, but it contains some innovative trick concepts that make this one stand out. The idea was created by Dr. Alan E. E. Rogers of the MIT Haystack Observatory and is known as the VSRT (science loves its acronyms!), standing for the Very Small Radio Telescope. The project was funded by the U. S. National Science Foundation.

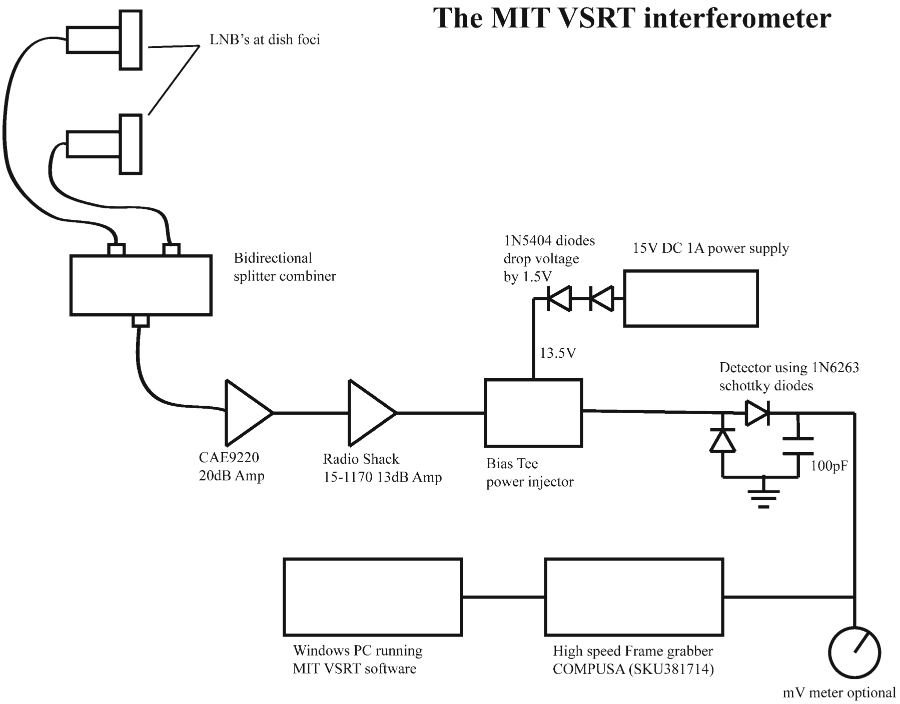

Fig. 10.8. The VSRT block diagram.

There are lots of notes, instructions, and downloadable software available from their website at http://www.haystack.mit.edu/edu/undergrad/VSRT/index.html. The memos section outlines a lot of the theory behind the instrument, which can be quite mathematical, but it is not necessary to understand all the theory to be able to build it, use it, and appreciate the basics of its function.

At the time of writing it's a new design and will probably be developed further, so keep an eye on the website. Figure 10.8 shows a block diagram of the telescope.

Let's look at the components in more detail. The LNB's are attached to dishes not shown in the diagram. In the United States small Direct TV dishes are suitable, in the UK and Europe Sky mini dishes are more readily available. Note, however, that Direct TV uses circular polarized LNB's and Sky mini dishes use linear polarized ones. But this does not affect the design or performance. Any dish, including larger ones, can be used with universal LNB's. Note that modern low-cost LNB's can have a significant drift in their local oscillators, which will affect overall performance. It may well be necessary to try several LNB's to find a good pair. Note also LNB feed horns for Sky mini dishes are not interchangeable with larger dishes that are more round in profile. The type of LNB should be matched to the type of dish used (ask your supplier if in doubt).

The LNB feeds are taken to a power splitter/combiner using patch leads with F connectors attached. The splitter combiner should have DC pass on all ports. This device is low cost and easily available on eBay, or via satellite TV specialists. A picture of one is shown in Fig. 10.9. The example illustrated shows a single in

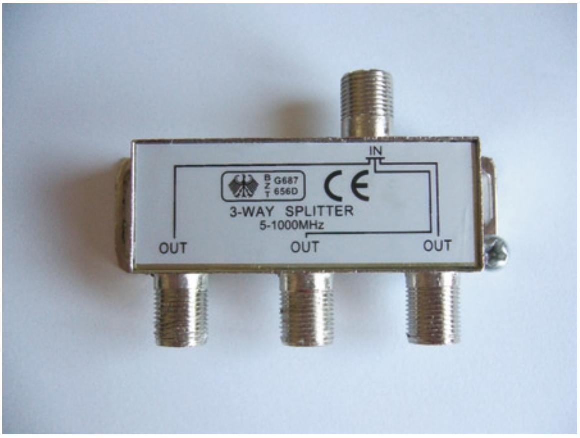

Fig. 10.9. Power splitter combiner.

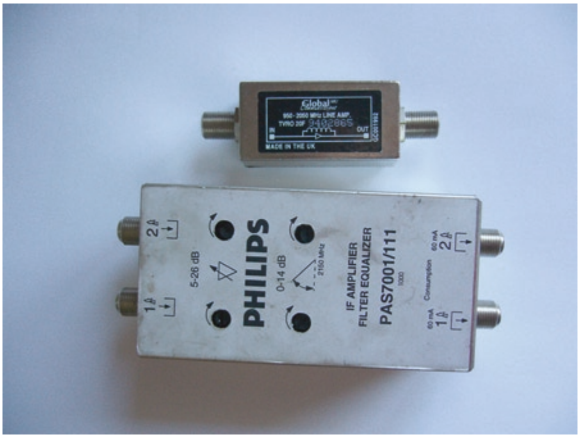

Fig. 10.10. VSRT in line amplifiers.

port, and three out ports, which are in fact reversible, and although not marked this one will pass DC power on all ports. You can confirm this with a multimeter set to measure continuity or resistance.

All ports on the splitter are matched to 75 Ω impedance, so all connecting feeders can be 75 Ω types. Use good quality double-shielded satellite TV feeders throughout.

Following the splitter the VSRT design calls for 40 dB of amplification, which is achieved using a pair of amplifiers in line on the output of the combiner (remember this is marked IN on the model illustrated because we are using it as a combiner rather than a splitter). A specific pair of amplifiers is detailed in the MIT documentation, but you can use a pair of surplus units you might have in your spares box. These are illustrated in Fig. 10.10. The larger amplifier is itself a dual unit, but you can use only one channel; this has variable gain of from 5 to 26 dB. The smaller amplifier has a gain of 14 dB. The combination of both units provides a range of amplification from 19 to 40 dB. Adjustability is not essential, but it is a

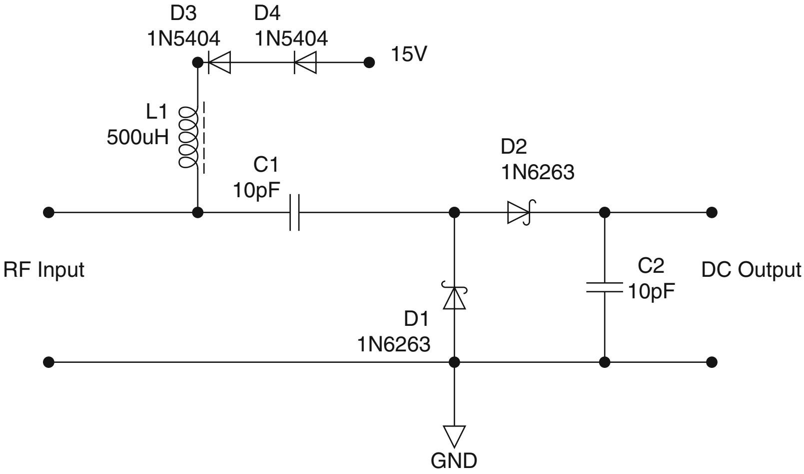

Fig. 10.11. Bias tee power injector (*left*), including a square law detector (*right*).

nice feature. The amplifiers need to be the wideband variety designed for cable, TV, and satellite TV use. If in doubt, obtain the models recommended in the MIT VSRT documentation. Some amplifiers will not work well if the input signal is too strong already (in a chain of amplifiers) and may oscillate, in which case you should try alternatives.

The next two modules in the chain are the only parts you need to construct, although you can buy the bias tee (sometimes called power injector). This method was used in the previous single-dish telescope. The circuit layout is given in Fig. 10.11, along with the circuit layout for the integrator. This integrator is of a square law configuration. The output is in proportion to the square of the input amplitude and is therefore proportional to the power of the input signal. This is only true if the device is driven with a signal of a suitable level. If the input signal is in the order of 30–250 mV it's about right.

The detector and power injector can be mounted in the same box. Use a die cast metal box as small as possible. If the box is small enough the components can be soldered directly to the connectors without the use of a circuit board. Try to keep the leads as short as possible. Use a power jack socket for the DC supply, a chassis F connector socket for the RF, and a phono socket for the DC output. Note the purpose of diodes D3 and D4 are to drop the voltage of the 15 V power supply to about 13.5 V. A 13.5 V power supply is not a common type, but a 15 V supply in the 1–2 A range will be easy to source. The diodes exhibit a voltage drop of about 0.7 V each, so the supply to the LNB's and amplifiers will be about 13.6 V. It is important to include these components because at 15 V it is not possible to know for sure what polarization mode the LNB's are in. At 13.5 V they are guaranteed to be the same. The chosen power supply should be of a regulated type. The diodes used in the square law detector are the Schottky variety, which have a low forward voltage drop.

The final hardware element is a video frame grabber, a particular USB-connected device manufactured by CompUSA, and its part number is SKU381714. This is the only one currently known to work with the software for the VSRT, distributed via the MIT Haystack website. The software package requires the Java runtime environment and has MS Windows drivers included geared especially for the CompUSA video capture device chipset. Follow their instructions for its installation.

How does the VSRT work? There are some clever ideas used in the design of the VSRT, which at first sight seem unlikely to work. The concept is quite straightforward. The LNB's are working in the 11–12 GHz frequency range, but the signals are internally down converted to a range of 1–2 GHz. These are then combined in the splitter/combiner, which is acting as a crude resistive mixer. The signals mix together. If the local oscillators of the LNB's were identical then the output of the combiner would be zero. But manufacturing tolerances mean the LNB local oscillators will probably differ by an amount up to 1 MHz. In fact we rely on the oscillators being different; in this way when the signals mix we get an output (the difference output) of up to 1 MHz. This is low enough to be manageable. The video frame grabber is used as a high-speed analog to digital interface, the second of the VSRT's clever design ideas. The bandwidth of a video capture unit is typically 4.5 MHz or better. The interference fringes generated and captured via USB are then integrated further in software and a power spectrum is displayed on screen.

What kind of observing projects are there for the VSRT?

Once again this instrument is a learning tool, its goal being to teach aspects of radio theory and design. It is capable of detecting the Sun, and it also could be used to record solar flux levels, but calibration is once again a major hurdle for its use as a scientific instrument. As in the previous receiver, relative calibration against a known source is a possibility. Again a compact fluorescent lamp of about 26 W could be used; however their microwave output can vary over a period of 10–20 s, and this output will change with lamp age and may vary between different lamps of the same type. Some experimentation will be needed to establish a suitable calibration. The comparison of the Sun signal with the lamp has got to be better than nothing at all. The team at Haystack are also working on calibration ideas for this project.

While observing the signal strength from the Sun changes in the Sun will be very hard to detect. The strength of the signal will depend on an amplifier gain, which itself will be influenced by ambient temperature. It will be affected by the variable attenuation in our Earth's atmosphere and will be dependent upon antenna pointing accuracy. This is also true for the single-dish telescope. This should not be an excuse to give up. Amplifier gain variation can be adjusted for by comparing signals with known sources. Not just the lamp method but the cold sky background at 12 GHz will show a figure about 8 K (3 K background plus a contribution from the atmosphere), although this will increase with lower altitude to about 35 K at 8° above the horizon. A hand placed in front of an LNB in "room temperature" conditions will show about 300 K. Take readings of all of these as a comparison along with the Sun. Record also the weather conditions at the time of observation, such things as air temperature, pressure, cloud cover, rain, etc. As for pointing accuracy mark the central point of the LNB's with a permanent felt marker pen. Attach a small piece of flat mirror to the dish face and carefully align it so that when it is pointing at the Sun the light reflection can be centered on the LNB. This offers the best chance of repeatability for each observation.

Radio signals from the Sun can twinkle like stars at night do in the visible band. This twinkling or scintillation is caused by the variable refractive properties in the radio band of our ionosphere. The VSRT could be used to investigate these phenomena.

A rather more advanced observing project, capable of resolving active regions on the Sun, is known as the closure phase method. This uses three dishes instead of two. The full description of this method is beyond the scope of this text, but you can read more about it in the memos section of the VSRT website.