Radio Effects of the 1999 Total Eclipse

By GH Grayer, BSc, PhD, G3NAQ*

THIS ARTICLE deals only with observing the eclipse by radio. If, however, you intend to observe the eclipse visually, act by the official advice given (references [1, 7]) otherwise your sight could be at risk.

THE ECLIPSE

FOR MOST PEOPLE the eclipse of 11 August will be a once-in-a-lifetime occasion. It will be the first time for 72 years that a total eclipse has been visible from mainland UK. The next will not occur until 2090. **Fig 1** shows superimposed on a map of Europe the *path of totality* [1] - where the sun is completely covered at some instant - while the rest is in the *region of partiality* where the sun will be seen to be partly obscured. **Fig 2** shows the geometry.

LINKS WITH THE EARTH

RADIATIONS FROM the sun are continuously bombarding the earth. Infra-red (heat), light, and ultra-violet originate mainly in the photosphere, and vary little in intensity. X-rays, gamma rays and radio waves emanate mainly from the outer regions, and vary enormously with solar activity. All these electromagnetic radiations travel in straight lines at the speed of light. In addition, charged particles flow out from its multiple poles ('coronal holes'), following the interplanetary magnetic field until they are deflected towards the polar regions by the earth's magnetic field.

*Bagatelle, 3 Southend, Brightwalton, Newbury RG20 7BE.

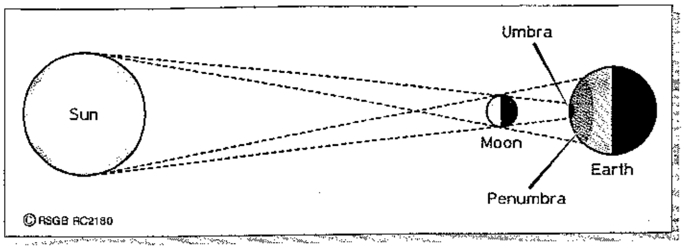

Fig 2: Geometry of the solar eclipse.

The ionosphere is formed by the interaction of these solar radiations with the earth's atmosphere, with the exception of the non-ionising radio, infra-red and light. Although these radiations disappear every night, they do so rather slowly, and only on the dark side of the earth. The effect of their sudden removal during an eclipse enables us to study the characteristic time with which the ions recombine, giving clues to the processes involved and ultimately leading to a better understanding of the ionosphere. But we can only observe these changes indirectly, by observing how the propagation of radio waves changes. To forecast what we will hear on a radio set covering the long, medium, and short wave bands during the eclipse requires an understanding of the basics of propagation.

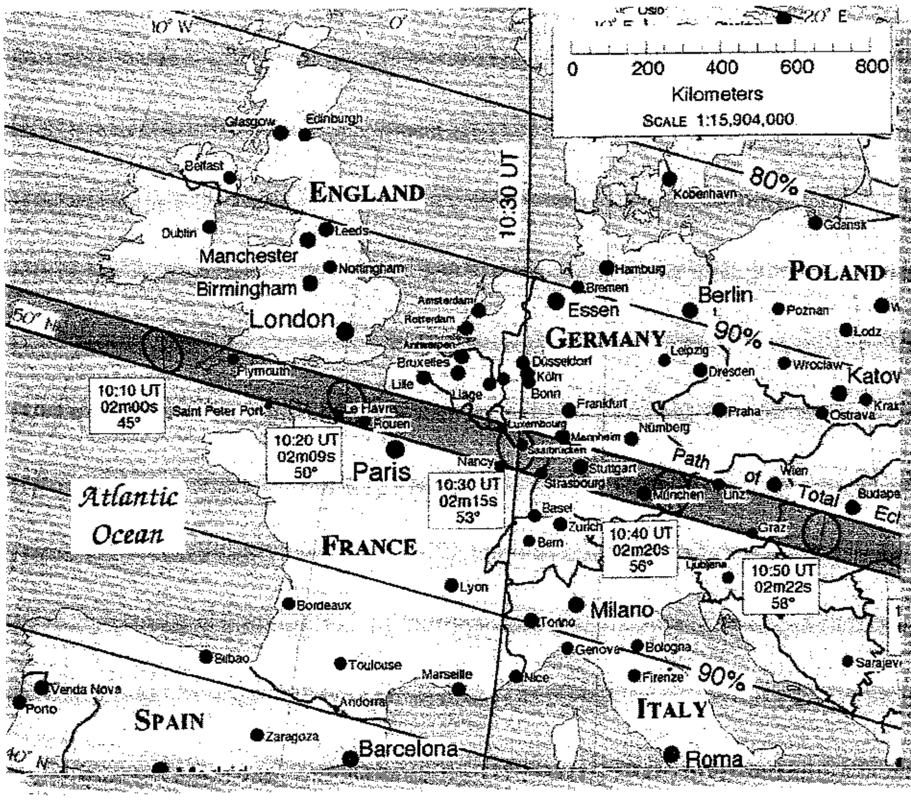

Fig 1: Path of the eclipse across the UK and Northern Europe. Lines either side of path of totality (dark grey) show the percentage of the sun eclipsed. Times are given at intervals along the path. Reproduced from [7] by permission of S Bell.

INTERPRETING PROPAGATION

IONOSPHERIC

Longer distance propagation requires a reflection off one or other layer of the ionosphere. This occurs due to the free electrons in the ionised gas ('*plasma*') which comprises the ionosphere. The energy which does not travel along the ground is known as the *sky wave*. **Fig 3** shows that, depending on the frequency of the wave and the state of ionisation characterised by f_{MUF} and f_0, several possibilities exist. **Fig 3a** shows that the sky wave may pass through the ionised layer completely ($f>f_{MUF}$); or (**Fig 3b** and **Fig 3c**) be returned to earth only above a certain minimum distance known as the *skip* ($f<f_{MUF}$, $f>f_0$); or (**Fig 3d**) the sky wave returned to earth at all angles ($f<f_0$). In this last case, the layer is said to be *blanketing*; ie no waves penetrate to reveal what is present higher up. Of course, at some higher frequency, the layer will no longer be blanketing.

Note the two parameters used to characterise the layer are f_{MUF}, the *maximum usable frequency*, ie the highest frequency just returned to earth; and f_0, the *critical frequency*, ie the highest frequency returned to earth at vertical incidence. This is the quantity measured by conventional ionospheric sounders (ionosondes).

FADING

If the receiving station is located within an area which receives ground wave and sky wave, they will not generally be in phase, so interference (ie vector addition of the two waves) takes place which can enhance or diminish the signal. The ionosphere is never completely stable, however, so neither are the signals. Fading can also be the result of interference between two sky waves reaching the receiver by different paths from one layer, or from different layers.

D REGION

The D Region (altitude 65-90km) is the lowest part of the atmosphere in which ionisation level is significant, but because collisions are frequent, absorption is high and free electrons are soon attached, so that reflection is unimportant. During daylight hours, the ionisation in the D Region results in absorption of Medium Frequencies and below (less than, say, 3MHz), so normal reception is confined to stations within a few hundred kilometres received via ground wave. During the eclipse, the re-combination of ions and electrons will take place rapidly, allowing E-layer propagation such as is heard at night on the medium and long wave bands. The 1.8MHz band should show such behaviour. The effects on the VLF bands are uncertain, and should be carefully observed.

E REGION

During the daytime, E-layer (altitude 90-120km) propagation dominates the lower end of the HF spectrum. A single reflection from the E Layer has a range up to about 2400km. The E Layer ionisation, similarly bereft of its source during the eclipse, will re-combine over a longer period - many minutes rather than seconds. The effect will be observed first on the higher frequencies - on 7MHz the skip will get longer; nearer stations will disappear. As the blanket E-layer disappears, longer distance F-layer propagation may take place. Similar effects should occur on 3.5MHz, only more slowly.

Some of the ions formed from metallic atoms end up in states where capture of an electron is 'forbidden', and can survive for hours. Thus they are unlikely to be affected by the eclipse. It is these ions which are believed to make up the thin, high density patches of ionisation which appear from time to time known as Sporadic-E. These produce reflections back to earth from the upper end of the HF spectrum to as high as 200MHz. However, Es layers are so thin that they are penetrated by the longer wavelengths and can thus be ignored on the 3.5 and 7MHz bands.

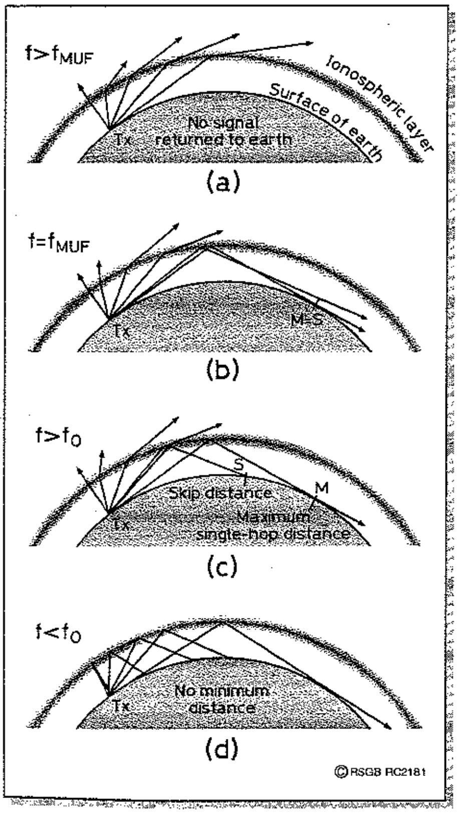

Fig 3: A simplified picture of ionospheric reflection as the transmitted signal is reduced in frequency, (a) to (d). The relation to the Maximum Usable Frequency (f_{MUF}) and the critical frequency (f_0). M denotes the maximum single hop distance, and S the minimum skip distance. The ground wave is not shown.

F REGION

The F Region (altitude 120-300km) extends from the top of the E Region (where there is a minimum in the ionisation) and essentially merges with the solar wind. Under normal conditions, the ionisation of this region is the highest, but the particle density is extremely low. As a result, the recombination rate is also very low. Hence the eclipse is likely to have little effect at the upper end of the HF range.

73kHz
128kHz
1.933 or 1.937MHz*
3.760MHz
7.060MHz
(14.265 or 14.359MHz*)
if there is sufficient interest.

Table 1: Eclipse SSB net frequencies. *At the discretion of the Net Controller; depending on QRM; please check both frequencies. Actual frequencies used will depend on QRM.

SOLAR OBSERVATIONS

SO FAR WE HAVE dealt only with the effect of the eclipse on the earth. However, there is another completely different field of study which the solar eclipse enables. This is the study of the sun itself. The possibility is to use the passage of the moon across the sun to determine the precise position of radio sources on the sun itself. This is called *occultation*; the moon acts as a huge shield, cutting off the radiating source as it passes in front. A unique position can be determined for discrete sources by observing their disappearance and re-appearance; while the general solar radiation decreases continuously as the moon covers the sun, then re-appears in the same way.

This type of experiment is described by Emerson [2], in which observations were made of the solar noise at 144MHz during two partial solar eclipses. The eclipse of May 1994 occurred near a minimum in the solar cycle and showed only normal solar noise spread across the solar disc. The other took place near solar maximum (July 1991); in this case discrete sources were found, and their positions and radio brightness (source temperature) determined. In the case of position, this was within 3 arc-minutes (1/20 degree). By comparing with a photograph made at the same time, the sources were determined as being close to, but not co-sited, with a sunspot cluster.

OBSERVING THE ECLIPSE

YOU HAVE A wide choice of possibilities how to optimise your eclipse experience. This will depend on your level of commitment and confidence, whether you act alone or as a member of a group, and, of course, whether you want to join the lemmings in the rush to the south-west, or are content to collect data from home. However you do your radio observations, you will have a smug sense of your time not having been wasted if the skies are cloudy!

CHANGES IN MUF

The simplest exercise, which we recommend for schools and young people without special equipment or a source of cash, is to monitor the Long and Medium wave bands and note the stations audible at any one time. Apart from a suitable radio covering these bands, a cassette recorder would be useful to record stations heard for later identification. This would be facilitated by the *World Radio TV Handbook* [3].

Most broadcast sets have a very poor frequency readout. A communications receiver, if available, would be much better. Failing this, a crystal calibrator giving marker pips at 1MHz, 100kHz, or 10kHz intervals would be extremely valuable - see [4] pp.2-10,11 for constructional details. Chasing the identification of stations with exotic languages is a lot of fun, as well as educational! Finally, the distance and direction of these stations could be plotted against the progress of the eclipse.

We would expect the majority of radio amateurs and serious short wave listeners, however, to join in our LF/HF eclipse nets and send us copies of their observations. These will be most valuable if you take the trouble to calibrate your S-meter in dB beforehand (or even after!). This programme could give useful scientific information, and your reports will be analysed at the Rutherford Appleton Laboratory. Everyone submitting reports will be eligible to receive a special certificate commemorating the 1999 eclipse.

Finally, for those who hate nets, prefer VHF, or have some other reason not to participate so far, you might like to consider carrying out the solar noise experiment previously described [2]. If you want to be really ambitious, you could try to observe on more than one VHF/UHF frequency at once, giving some spectral information on the solar emissions. This would be an interesting summer vacation project for a school science group or university students.

REPORTING NETWORKS

As part of an RSGB/RAL (Rutherford Appleton Laboratory) collaboration, it is our aim to form SSB nets on the frequencies given in **Table 1**, normally used by the Worked All Britain awards group, who have kindly agreed to co-operate. We would also like to encourage CW nets for those who prefer Morse, especially on 73 and 128kHz, where the effects could be surprising.

DATES AND TIMES

The official observational period of the nets will be 0830 to 1230UT, though there is no

1999 ECLIPSE - RADIO REPORT FORM

CALLSIGN/BRS:			NAME:		LOC/WAB:				
DATE:	FREQ:		ADDRESS:						
TIME UTC	STATION	POSITION	SIGNAL	NOISE	TIME UTC	STATION	POSITION	SIGNAL	NOISE

Fig 4: Format of the report form for net participants and listeners. Use this as a template for generating your own forms, or as a basis for a PC spreadsheet (in this case do not double-up the reporting columns).

objection to operation outside this period for discussions and exchange of information. Those intending to participate are asked, if possible, to register the day before and the day after, between the same times, and fill in the same report forms. This will enable the controllers to establish the level of activity, locations, names, etc, and for participants to get used to the procedure, to minimise time lost during the observation period. The day after will offer the opportunity for a post-mortem and de-briefing; stations might like to compare their results, and establish any missed data.

As far as the experiment is concerned, *it is essential to have a record of the normal signal strength between stations* at the same time of day in the absence of an eclipse. If there is significant geomagnetic activity on one of these control days, the nets may be re-formed; we can of course do nothing if there is activity during the eclipse itself! Stations must attempt to maintain the performance of their equipment constant during this period, and not to change power output.

OPERATING PROCEDURES

During your period of participation in the net, you are asked to record the signal strength *for each transmission made by other members in the net*, even if not audible. Transmit only your call and location (eg G3NAQ IO91HL), using phonetics for the letters, and then a carrier or SSB tone for 15-20 seconds. This allows an accurate signal strength assessment, remembering that it may be necessary to adjust the RIT for maximum reading. The net controller will then leave several seconds for a measurement of the background noise before announcing the callsign of the next station.

You may, of course, join or leave the net at any point, but the most valuable observations will be those made throughout the observing period. To join the net, just announce your callsign between overs. To leave the net, just say '73' clearly after giving your call and locator.

REPORT SHEETS

Fig 4 gives the format of a report sheet. These can be used for sending-in your observations, though we would prefer your observations via e-mail or on a PC compatible disk. We can accept the spreadsheet programs EXCEL, LOTUS or QUATTRO-PRO, using a similar layout. An Internet address is given at the end of this article.

The first two lines are for details of the reporting station. Listeners may use BRS, ISWL, or any other identification in place of callsign. Your position should be given in the LOC/WAB slot. The preferred position indicator is the six-character IARU Locator known as LOC [6]. We will also accept WAB area from UK operators. Both are acceptable from the point of view of resolution. Listeners may give geographic latitude and longitude if they are unaware of the other two. Name and address are optional, though the address is a useful cross-check of the position information. DATE is obvious, FREQ should be the net frequency in MHz for HF or kHz for VLF. Please concentrate on one band only.

The columns below are for your reports. TIME (note UTC = 'GMT' is used - subtract one hour from British Summer Time); STATION (callsign), and POSITION (LOC or WAB) refer to the station being reported. The report, given preferably in dB above intrinsic receiver noise, is entered in the SIGNAL column. If you are unable to calibrate in dB, then use whatever units your S-meter provides. If there is rapid fading, include details, eg '23-28dB'. The S-meter reading in the absence of a net station, ie between overs, should be noted in the NOISE column.

WHAT YOU CAN DO NOW

IT IS CERTAINLY not too early to start preparing for the eclipse.

Firstly, we need net controllers. Volunteers should be experienced in net control and confident that they understand what is required in this case. They need a high performance antenna and equipment. They should state the bands they could operate, in order of choice. We will choose for each band, on the basis of experience, a *net co-ordinator*, and give him details of all other volunteers assigned to that band. It is up to him to organise the nets; these should be set up the day prior to the eclipse. Stations who register on the frequencies listed will be assigned a net controller and frequency. The starting size of a net should not exceed 15 stations; this allows up to 5 more to join in, as it is hoped that overseas stations will join during the eclipse, when propagation changes (we are making our European friends aware of this project). A net occupancy of 20 at one minute per over implies one transmission per 20 min from each station; any larger interval would be unacceptable.

Secondly, if your S-meter is not calibrated accurately in dB (and even if it was once), you should calibrate it as described later.

Finally, make report forms using Fig 4.

REDUCTION OF DATA

YOU WILL PROBABLY want to plot your data in a meaningful manner. For this, a personal computer with a spreadsheet or plotting program will save a lot of effort, but it is equally valid to plot by hand. You will need a map of Western Europe. Since you will need to write on it, you may prefer to cover it with a transparent sheet and use marker pens. Alternatively, use a soft pencil which can later be erased.

We suggest you do the following. First, plot the position of all other net stations. Draw lines between your location and the others. Mark the path of totality; this will tell you which paths should show the most effect, ie those which lie along the path of totality first, then those which cross the line of totality, finally those increasingly distant from the line of totality.

Now plot for each path the signal strength (vertical axis) against time (horizontal axis). Estimate the difference in signal strength between the lowest and highest point for each trace; mark this figure on the appropriate path line on the map. These should fall into a pattern. See if you can interpret them with the information given in this article. We will be doing the same!

LUNAR OCCULTATION

WE DESCRIBED EARLIER how AA7FV/G3SYS identified the exact position of the origin of radio noise on the surface of the sun, by means of the occultation method. Darrel's *QST* article is very readable and informative, so if you are interested in this slightly more challenging project, I suggest that you get a copy of his reference and read it.

Any modern DX station should have no trouble detecting solar noise on the VHF/UHF/microwave bands; comparative observations on the different bands (144MHz - 47GHz) could give useful information about the mechanism involved in its production. This reference is also useful for showing a simple receiver noise detector and integrator with variable time steps, which can be used as an interface to a meter, chart recorder, or computer.

You could try measuring the percentage polarisation of the solar radiation on the VHF and UHF bands. The Faraday effect ([5], p.2-62) rotates the direction of polarisation as it passes through the ionosphere, so that the direction of polarisation will be lost; however, the direction will be continuously changing due to the disturbed state of the ionosphere caused by the eclipse. If a linear polarised antenna is used, plotting the signal as a function of time should show a sinusoidal curve, the difference between minima and maxima indicating the degree of polarisation. This could give useful information regarding the mechanism of generation.

You might also like to consider imitating another of Darell's achievements; the second eclipse was observed completely automatically from his home, while Darrel was many miles away observing the eclipse visually!

Further information on making solar noise measurements near the 144MHz band is given in [8].

FURTHER INFORMATION

See references [1] and [7] for easy reading and practical advice. For those wishing to learn more about the sun and its effect on planet earth, reference [9] is highly recommended. For a modern, authoritative, but highly readable book on the sun itself, see [10].

For those with Internet access, the prime eclipse website is: http://www.hermit.org/Eclipse1999/

This has a connection to the main UK website via links: http://www.eclipse.org.uk/

Adding 'radio' to the end of this address brings you to the Rutherford Appleton Laboratory (RAL) site, co-ordinating amateur involvement in the ionospheric experiments. http://www.eclipse. org.uk/radio

This will link with the RSGB Propagation Studies Committee site, where you can expect to find the latest updates on the projects suggested in these pages, copies of this and relevant material, and any information you send us which we think will be useful to others. The direct address is: http://www.keele.ac.uk/depts/por/eclipse.htm

If you have questions which cannot be answered on the Internet, you can contact us by e-mail: radio.eclipse@rl.ac.uk or by post at: Radio Eclipse, RAL, Chilton, Didcot, OX11 0QX, enclosing a self-addressed stamped envelope (SASE) for your reply. Single copies of 'How to calibrate your S-meter', 'The Amateur Radio Eclipse Network', and reference [2] may also be obtained from this address on receipt of an SASE. Your results should also be sent to either of these addresses. If you would also like a handsome Certificate of Participation, please send us an A4 size SASE along with your results.

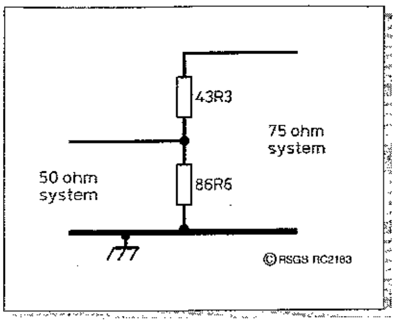

Fig 5: Pad for matching 50 and 75Ω systems. Suggestions for practical values: 43.3R is made up from series 33R and 10R; 86.6R is made up from series 69R and 18R. In either direction, the insertion loss is 4.6dB.

S-METER CALIBRATION

WHY CALIBRATE?

Measurements have units; the recognised unit of relative signal strength being the decibel (dB). In order to compare the measurements from different observers they must be given in dB. In addition, the calibration of your equipment is a good exercise in the art of experimental science, and can be useful for giving objective reports of QSB, antenna comparisons, processor compression, etc. The guy at the other end will be impressed!

WHAT IS AN S-POINT?

Most S-meters are marked in 'S-points' (1 to 9) and then numbers of dB above S9. In my experience, very few are meaningful in having a consistent value of the S-point. One exception is my Kenwood-Trio TS-820S, which follows very linearly a calibration of one S-point = 6dB, the original definition. You could however just ignore S-points and calibrate directly in dB.

THE SIGNAL SOURCE

You will need a stable signal source within the range of the receiver. This could be a signal generator, a crystal calibrator, or a transmitter run at very low power. An off-air signal is the last thing to consider, because propagation is never stable, certainly not to a few dBs. A simple two-transistor HF source is given in [4], p. 8-2. The source must be well screened if you are to successfully calibrate down to the bottom end of the range, as there must be no leakage of signal around the attenuator.

ADJUSTING THE LEVEL

If you are using a commercial signal generator, this may have its output already calibrated in dB relative to some fixed level, eg 1μW. It may be calibrated in power level, normally microwatts (mW), in which case these must be converted to dBs by the formula $10\log_{10}(P2/P1)$, where P1 is an arbitrary power level. Sometimes the output of a generator is marked in volts, millivolts (mV) or microvolts (mV). These may be converted to a dB power ratio, remembering that power is proportional to V^2, so $dB=20\log_{10}(V2/V1)$. Again, V1 may be chosen arbitrarily. For those not mathematically inclined, many electronic reference books give tables of linear ratios of power and voltage corresponding to a range of dB values, eg [4] p.11-6. Any outside this range can be derived by adding dB and multiplying the corresponding ratios. Thus, 23dB = 10dB + 10dB + 3dB = 10 x 10 x 2 = x 200 (power), or x 14.2 (voltage).

If your signal source does not include a calibrated output, you will need a variable attenuator. Generally these are switched, and should have a minimum step of 1 or 2dB. You will need in addition fixed attenuators to add up to about 100 dB.

It is important to note that attenuators only give the correct value when the input and output are correctly terminated by the impedance for which they are designed. You cannot rely on the impedance at the antenna socket to be its nominal value. The same is true of many signal sources. We overcome this by using fixed attenuators either side of the variable attenuator, to 'isolate' it from any incorrect impedance. The larger the attenuators, the better the isolation, but the signal source has to be beefy enough to be able to supply full scale deflection on the S-meter with these attenuators in line. At least 6dB attenuators are recommended, though 3dB can be used if signal strength is a problem.

IMPEDANCE MATCHING

Most of the amateur radio equipment today matches a nominal 50Ω impedance, though older equipment (and many signal generators) will be 75Ω. You may well find surplus 75Ω attenuators much cheaper than their 50Ω counterpart.

You can use either 50 or 75Ω attenuators (but not in combination). Where the nominal impedance of either the receiver or the generator differ from the impedance of the attenuators, you need a matching unit. **Fig 5** shows a circuit designed to match 50Ω to 75Ω and vice versa. It consists merely of two resistors, which should be mounted using the connectors as supports in a small metal box (soldered-up tin is ideal), the leads being kept as short as possible. Take care not to overheat the resistors when soldering them in position.

CONNECTIONS

Connect your signal source to the input of your variable attenuator via a fixed attenuator, and the output of the attenuator again via a fixed attenuator to the receiver, using good quality coaxial cable of the correct impedance. If you are using a calibrated generator, the variable attenuator and one fixed attenuator are omitted. It is best if you place the receiver and

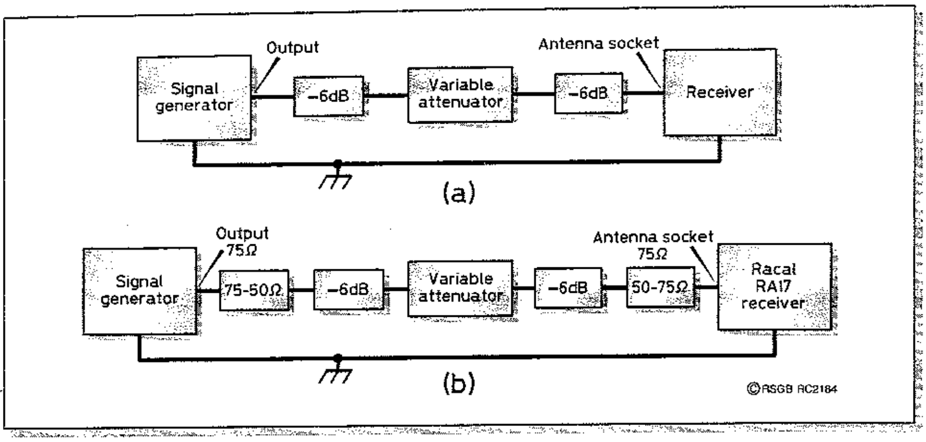

Fig 6: (a) The simplest set-up for S-meter calibration. Each unit must match the same impedance, and connections are made using co-ax cable of the same impedance. The 6dB attenuators are to isolate any impedance mismatch at the receiver or generator from the variable attenuator. Earth connections are made with heavy copper braid. (b) A more complicated set-up with generator and receiver being matched to 75Ω, while the available attenuators are 50Ω. Two pads as shown in Fig 5 have been used.

source some distance apart, to minimise direct pick-up. Make sure also that any units supplied with an earth connection (usually the signal generator and receiver, but also possibly the variable attenuator) are electrically joined together, preferably with thick braid, and then to a good earth connection.

The simplest set-up using an uncalibrated signal source is shown in **Fig 6a**. An example using a signal source and receiver designed to match 75Ω, but retaining the 50Ω attenuators, is shown in **Fig 6b**.

SET-UP AND CHECK

Leave your signal source and receiver switched on for at least half an hour before calibration, to let them reach a stable temperature. During this time you can do the following:

Tune your receiver to the frequency of the signal source, choosing a quiet frequency if the source is tuneable. With the variable attenuator set to zero, turn up the output of the signal generator to ensure you reach full scale deflection of the S-meter. If not, you need a stronger signal source. Now unplug the output of the variable attenuator, moving the cable well away. Check that there is no deflection of the S-meter when you tune the receiver through the generator frequency. If there is, you have leakage of the RF past the attenuator circuit. Eliminate this before proceeding, by improving your screening or increasing the distance between generator and receiver. If all else fails, it may be necessary to wind each end of the coax on ferrite toroids to eliminate currents on the outer of the coax.

PRELIMINARY ADJUSTMENTS

Most S-meters have provision for adjusting the zero reading and the sensitivity. Look in the handbook, if you have one, otherwise look for two adjustable potentiometers in the meter circuit. If you have any doubt about the function of any adjustable, *do not move it*. Instead, calibrate the S-meter as it is, skipping the next two paragraphs.

ZERO ADJUSTMENT

With the receiver connected to an attenuator (so that the antenna socket is correctly terminated), but with the signal source off, you should hear only receiver noise. Adjust the zero setting so the S-meter reads S1. The reason I prefer my S-meter reading S1 on noise is that I can often read signals which do not move the S-meter, but cannot give a report of R3 or R4 and S0!

SENSITIVITY ADJUSTMENT

First, work out the dynamic range of the scale. There are eight S-points between S1 and S9, spanning a range of 8 x 6dB = 48dB. Add the 'dBs over S9' (my S-meter reads up to S9 + 40dB, making a total of 48 + 40 = 88dB). Subtract 6dB (one S-point) from the value calculated. You now need to adjust the S-meter sensitivity such that a change of attenuation equal to this value produces a change from S2 to full scale. If the adjustment does not cover this, set it as close as you can. You will need to vary the level of the source to achieve this, or use a combination of attenuators if the output is not adjustable.

CALIBRATION

Next, adjust the output of your signal generator or attenuation to produce full scale deflection of the S-meter (S9+40dB in my case). Now increase the attenuation (or reduce the calibrated output) until the next division is reached (S9+20 dB in my case). Make a note of this value. Repeat for each subsequent meter division. If you are using a variable attenuator, you will eventually run out of range. You must either add fixed attenuators or, if these are not available, re-set the output of your generator. To do this, note the position of the S-meter, reset the variable attenuator to zero, and reduce the generator output to get to the same point on the scale. You must now add to subsequent values the change of dBs in the system - because it was necessary either to add attenuators or reduce generator output.

PLOT THE RESULTS

You are now able to plot a graph of S-meter reading along one axis against added dBs. You should be able to draw a smooth line through the points. If a straight line suffices, the meter is linear in dB; if it is curved, you may want to use a flexi-curve or French curve to obtain a smooth fit. If you have a computer with a curve fitting program, try a polynomial with increasing powers until the fit is satisfactory. Now measure the difference in dB between each point and the line (positive one side, negative the other). If it is a good fit, these differences should add up to near zero. If one of these values is very large (that is, the point is a long way from the smooth line), go back and check this point and if necessary the values of the attenuators.

The so-called 'standard' or RMS deviation of the points from the curve is a measure of its accuracy. If you used a computer fit, the program should give you this value. If not, square the differences you have calculated (they are now all positive), add them, divide the sum by the number of points less one, and take the square root of this number. If your calibration was properly done, this number should be between 1 and 3dB.

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