Chapter 9

Building a Very Low Frequency Solar Flare Monitor

This instrument is a SID detector. SID stands for solar ionospheric disturbance. The project is very easy, and remarkably effective, so it is recommended that beginners start here. The success you gain will provide you a boost and encourage you to continue in this fascinating hobby. In fact there is virtually no electronic construction involved! Apart from a suitable aerial, everything is off the shelf and you probably already own it – a PC with sound card!

Firstly let's introduce the science behind the telescope. In the strictest definition, the VLF (very low frequency) receiver is not a radio telescope. It can't detect radio waves directly from space. This is because Earth's Ionosphere is opaque to radio wavelengths longer than about 20 m most of the time. Propagation of manmade VLF radio signals over long distances depends on the electron density and particle collision rates in the lowest of the ionospheric regions, the D layer.

In daylight ultraviolet exposure causes ionization of nitrous oxide molecules in the D layer. However, there is a high rate of recombination, where the free electrons join once again with the molecules. The net effect is a relatively low level of ionization but a quite stable level during the day. At night, with the absence of solar UV, and X-ray the degree of ionization drops even lower, although it does not completely disappear. Galactic cosmic rays help to generate some free electrons, energetic particle collisions from the E layer above account for the rest. Therefore at night the state of ionization is much more random and variable, and where the region begins at a higher altitude.

Now for the useful bit. During solar flares, the Sun emits bursts of X-rays that significantly and rather quickly enhance the ionization of the D layer. This results in a measurable change in the strength of received VLF signals. Thus it is possible to use a VLF receiver as a solar flare monitor. Clearly it would be hard to distinguish between changes in output power of a VLF transmitter and a genuine SID. However, the characteristic patterns are different, and experience helps allow the observer to detect the difference. As a safeguard against manmade effects (some transmitters tend to go off periodically), this experiment is capable of monitoring several transmitters at the same time.

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Manmade VLF signals, for our purposes below 100 kHz, reflect from the D layer and back off the ground, making a series of hops over large distances. The D layer quite strongly absorbs higher frequencies until it once again becomes transparent in the VHF. The question is, what happens to the received signal when a SID occurs? This is more complex than you may think for short- to middle-range observations. If at your location you receive the signal directly (the ground wave) as well as receiving the signal by reflection (the sky wave), due to path length differences the two interfere to generate the result. This interference could be constructive, leading to enhanced strength, or destructive leading to weaker strength. So, during a solar flare the enhanced reflective properties of the ionosphere could result in slight change in the altitude at which the signal is reflected, also affecting the path length of the sky wave. The resultant interference pattern could then increase or decrease the received signal strength. It would be an interesting exercise to monitor as many VLF channels as you can to study the effects for yourself. For longer range stations, the ground wave will be weak or not present at all, and since it is only the sky wave that is affected by solar activity, these channels will often provide the greatest responses.

Construction of the Antenna

For this experiment, the antenna is the only item that requires construction. It is very easy to build, and so this device will provide fast results. You can have a working solar flare monitor in a single day.

The most suitable antenna at very low frequencies is a multi-turn loop. It does not matter whether the loop is round or square, in fact it is much easier to make it square. Fine-grained hardwoods offer better strength, but sections of knot free soft wood would also work.

Cut a piece of wood 57 cm long from a piece of 15 mm square wood. (The size is not critical, but keep it small and close to this size.) This will form the upright of a cross. Cut another piece to a length of 52 cm to form the horizontal section of the cross. The vertical section is longer to allow it to be mounted onto a baseboard.

Next cut four pieces of the same material to a length of 60 mm. Mark a line across each of them 1 cm from one end, and make a saw cut to a depth of half the thickness, completing the cut down from the end to remove the piece, leaving a tongue 1 cm long and half the thickness of the wood on all four short pieces.

Next mark the center of the 52-cm-long cross member, then make two more marks across the width of the material 7.5 mm (adjust accordingly to half the thickness, if you have chosen a different size stock) either side of the center line. Put two saw cuts down carefully to half the thickness of the wood, taking care to cut on the inside (towards the center) of your pencil lines. Using a small sharp wood chisel cut away the material between the saw cuts leaving a flat bottomed notch. Do the same on the longer upright, but don't forget it's not now in the center but offset 50 mm towards one end.

By now fitting the two long sections together in the center and gluing the joint you have a cross framework. The small pieces are now glued to the tips of the cross with the cutaway section on the inside forming a groove to carry the copper wire loop. The bottom piece needs to be carefully placed by measuring 52 cm from the top to the outside, not to the base of the notches. Once the glue is dry, the cross should have a 50-mm extension at the base, which can then be glued

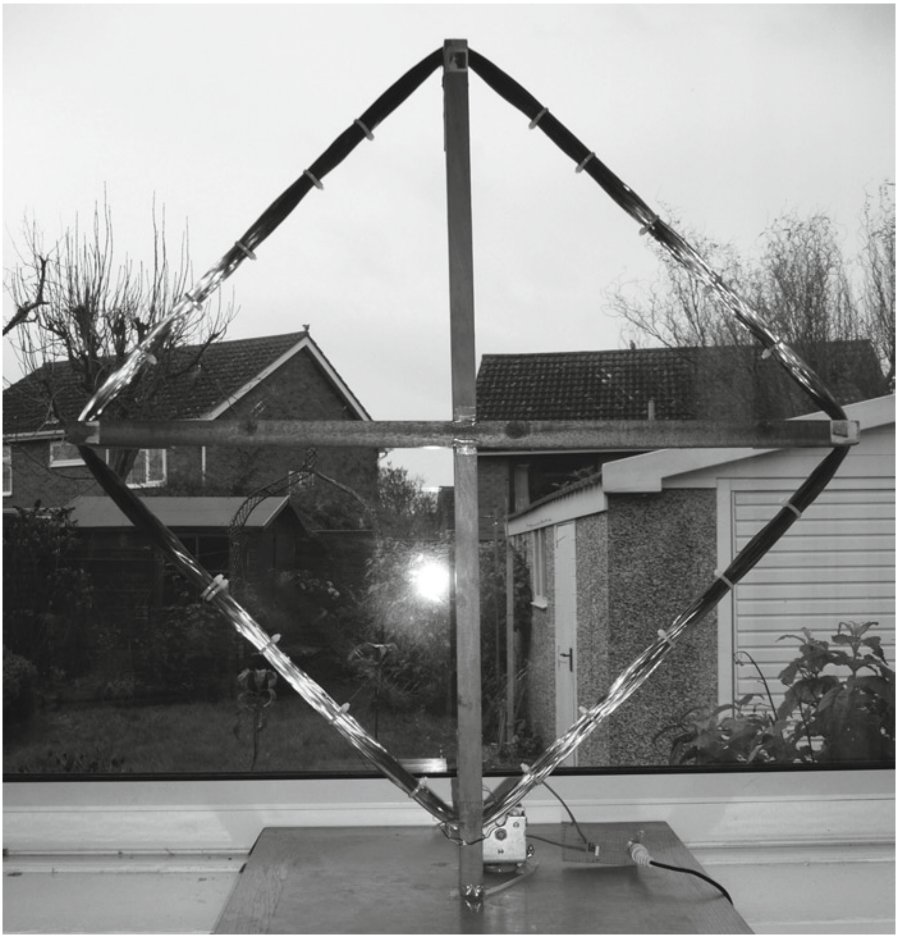


Fig. 9.1. The VLF loop antenna. It is a square with 400-mm-long sides and made up from 125 turns of enameled copper wire. There is a tuning capacitor on this one, which is not needed for this project.

into an appropriate hole in the center of a piece of 12- or 18-mm plywood approximately 30 cm^2.

The last stage in construction involves winding 125 turns of copper wire on the frame. Use enameled copper wire, of 24 or 26 swg and approximately 0.5 mm diameter, purchased from an electronics supplier. Try to get enough on a single roll to complete the job so you won't have to join it. You will need about 185 m. If you have to join two sections, be sure to remove a small amount of the insulating enamel from the ends to allow it to be soldered. You could paint a little enamel or varnish on the joint afterwards to ensure the turns remain insulated from each other.

The two ends of the loop can now be soldered to a Phono or a 3.5-mm jack socket mounted into the baseboard. For the purposes of this experiment, the loop works very well untuned, so no capacitors are needed. Although in the prototype antenna shown there were fitted some fixed capacitors and a variable air spaced capacitor to allow the aerial to be tuned to the frequency of the channel, the main reason for them was to connect to a borrowed hardware receiver. In practice there is no difference in this experiment if there were no capacitors. Although a dedicated tuned receiver can give excellent results, it means you need several receivers, and a multichannel data logger to monitor more than one channel at a time. Read on and find out an easier way to monitor multichannels.

The Computer as a Receiver

Now for the clever part – using an appropriate sound cable, which connects the antenna to the microphone port on your computer sound card. Download and install a piece of software called *Spectrum Lab* from the following website: http://freenet-homepage.de/dl4yhf/spectra1.html.

The software was written by Wolfgang Buescher, whose amateur radio call sign is DL4YHF. It is free to use and is an extremely useful piece of software for many radio projects.

Setting Up Spectrum Lab

When you first run *Spectrum Lab*, the window will appear as in Fig. 9.2. First go to the Start/Stop menu and click on "Start Sound Thread." The items "Spectrum Analyser #1" and "Audio Input: from ADC, active" should already be ticked.

With the antenna connected to the microphone port of your PC, and with the sound card recording control set to microphone, you should see a plot that looks something like Fig. 9.2.

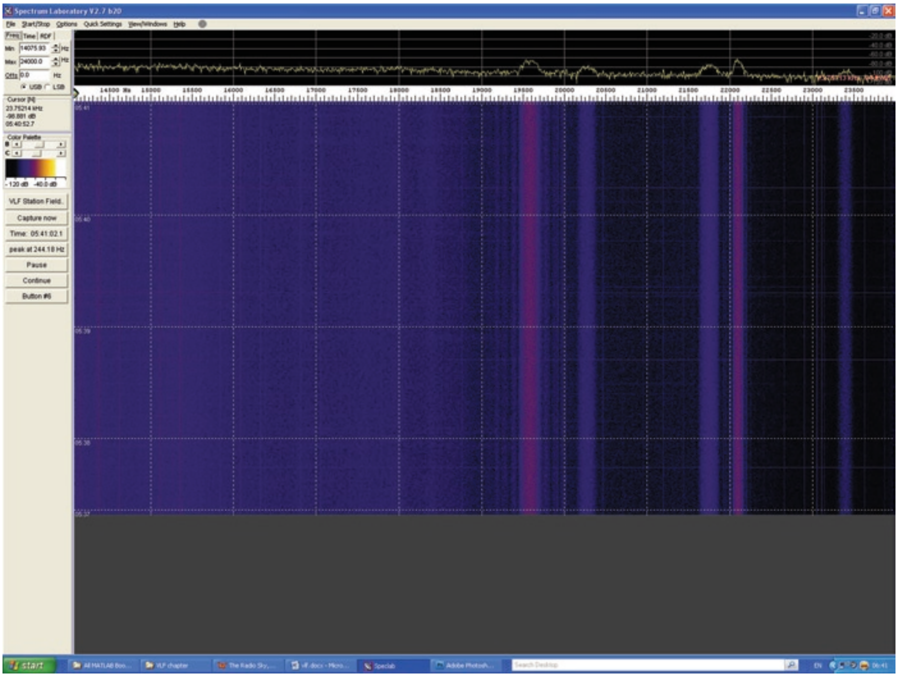


Fig. 9.2. *Spectrum Lab* in action, showing five VLF channels.

The upper graph is the audio spectrum. The lower graph is referred to as the waterfall. The broad vertical lines on the waterfall and the corresponding peaks in the spectrum plot should be VLF radio stations. However, some care needs to be taken before you jump to that conclusion. Some interference looks exactly the same as a VLF channel, especially that of the old CRT tube televisions at a frequency of 15,625 Hz. The plot in Fig. 9.2 does not show this; it was taken at 6:45 a.m., when few people watch TV!

Ok, now we want to tweak the display to suit our needs. A larger spectrum display is best. Go to the options menu and click on the Spectrum display settings item, which will bring up a window as in Fig. 9.3.

On the right hand edge half way down is an item Spectrum graph area (pix), which refers to the height in pixels of the spectrum plot, next on the left side of the main window you will find a color palette with two sliders for B, brightness, and C, contrast. By adjusting these you can enhance the visual appearance of the waterfall. This is merely a preference feature that has no effect on the values of the signal strength.

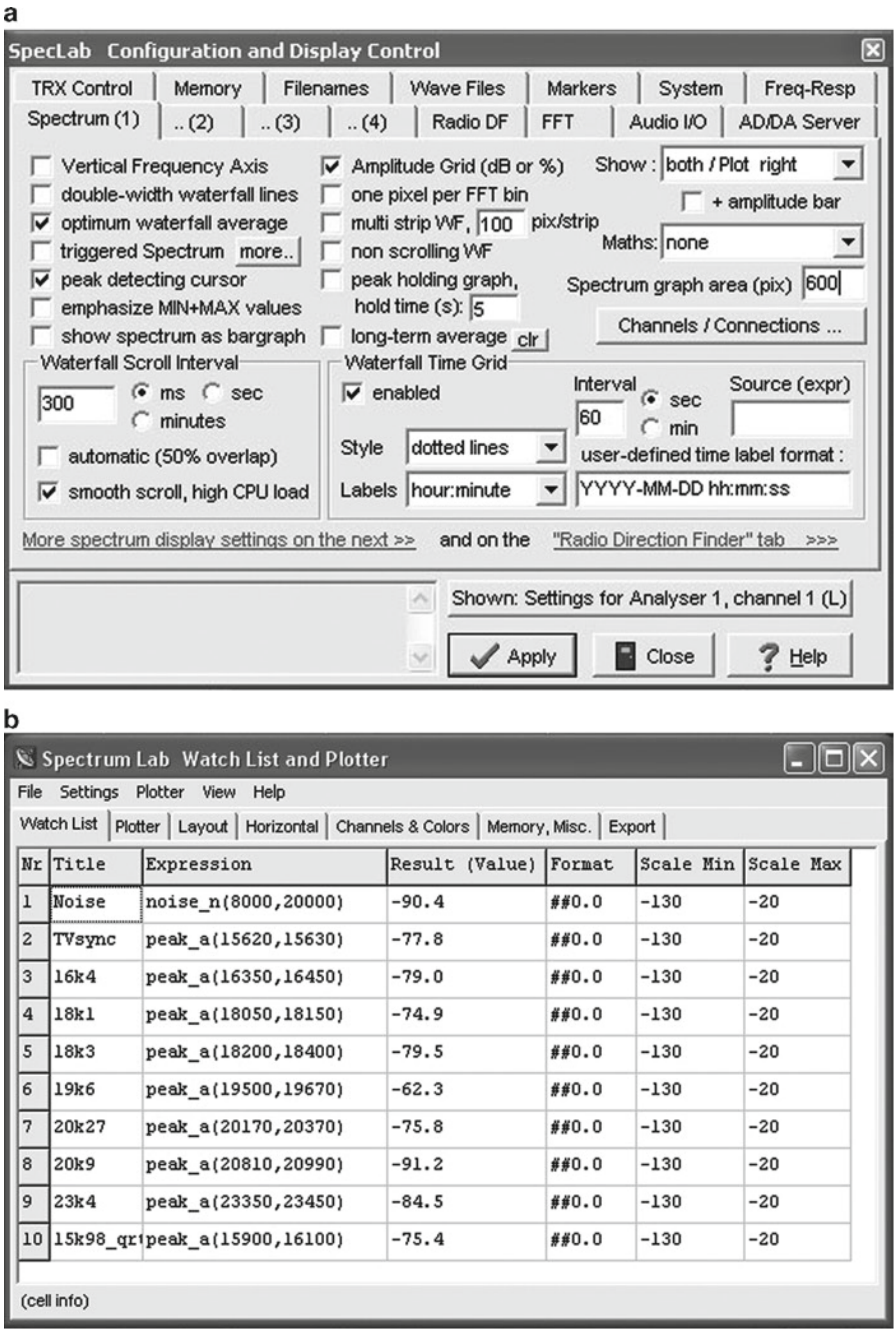
The most important feature of *Spectrum Lab* for our purposes is setting it up to log data of the signal strength to a file for long-term monitoring. There is a neat built-in plotter for that purpose. Before you configure the plot window you need to set the sampling rate for the sound card to as high a value as your card will support. Most built-in sound cards will have a maximum sampling rate around 48,000; some may be 96,000. Whatever sampling rate you choose, the Spectrum plot window will show frequencies up to half that value. So for a 48 K/bit sampling rate the plot window can show up to 24 kHz radio channels. Set the sampling rate by going to the Options/Audio settings menu item, and under the audio processing section there is a drop down box for setting it.

To open the plotter function go to the View/Windows menu item and select the watch list and plot window lower down in the list. Next open the file menu on the main window, and select "load settings"; it should then list a variety of configuration files in the configurations subfolder, one of which is "VLF_Station_Plotter.usr." This will bring up a box similar to Fig. 9.3.

This shows a list of VLF stations currently found in Europe; for other regions the plot can be modified easily to suit.

The first tab is the watch list, which defines the frequency and the range over which it will display. By double clicking on each item it can be edited. The Title is simply a useful text string. The expression column defines what is going to be measured. Here peak refers to the peak amplitude, and in the parentheses is the range of frequency it will monitor – low first, high second. When changing the frequency to suit your application, use the cursor to determine the start and the end frequency to monitor in the main window. As you point the cursor to the spectrum the frequency value appears beside the cursor. These values can then be typed into the expression. The software will automatically determine the peak value between these two frequencies. Be warned if no transmission is active in the range; it will still record something, the peak noise!

The result column is generated by the software; the format column should not need to be changed. The scale maximum and minimum refer to the decibel range of the vertical axis. You may ultimately want to lower the max level, depending on the peak strength of the signals you receive. You might want to lower it by 50 dB, for example. By properly scaling the plots to fit your screen window you can maximize the ability to spot changes in signal strength that could be due to solar flare activity.



☐ Vertical Frequency Axis
☐ double-width waterfall lines
☑ optimum waterfall average
☐ triggered Spectrum
☑ peak detecting cursor
☐ emphasize MIN+MAX values
☐ show spectrum as bargraph
☑ Amplitude Grid (dB or %)
☐ one pixel per FFT bin
☐ multi strip WF, 100 pix/strip
☐ non scrolling WF
☐ peak holding graph, hold time (s): 5
☐ long-term average
Show : both / Plot right
☐ + amplitude bar
Maths: none
Spectrum graph area (pix) 600

Waterfall Scroll Interval
300 ● ms ○ sec ○ minutes
☐ automatic (50% overlap)
☑ smooth scroll, high CPU load

Waterfall Time Grid
☑ enabled
Interval 60 ● sec ○ min
Source (expr)
Style dotted lines
Labels hour:minute
user-defined time label format : YYYY-MM-DD hh:mm:ss

Shown: Settings for Analyser 1, channel 1 (L)

Nr	Title	Expression	Result (Value)	Format	Scale Min	Scale Max
1	Noise	noise_n(8000,20000)	-90.4	##0.0	-130	-20
2	TVsync	peak_a(15620,15630)	-77.8	##0.0	-130	-20
3	16k4	peak_a(16350,16450)	-79.0	##0.0	-130	-20
4	18k1	peak_a(18050,18150)	-74.9	##0.0	-130	-20
5	18k3	peak_a(18200,18400)	-79.5	##0.0	-130	-20
6	19k6	peak_a(19500,19670)	-62.3	##0.0	-130	-20
7	20k27	peak_a(20170,20370)	-75.8	##0.0	-130	-20
8	20k9	peak_a(20810,20990)	-91.2	##0.0	-130	-20
9	23k4	peak_a(23350,23450)	-84.5	##0.0	-130	-20
10	15k98_qr	peak_a(15900,16100)	-75.4	##0.0	-130	-20

Fig. 9.3. (**a**) Spectrum options. (**b**) Spectrum watch list.

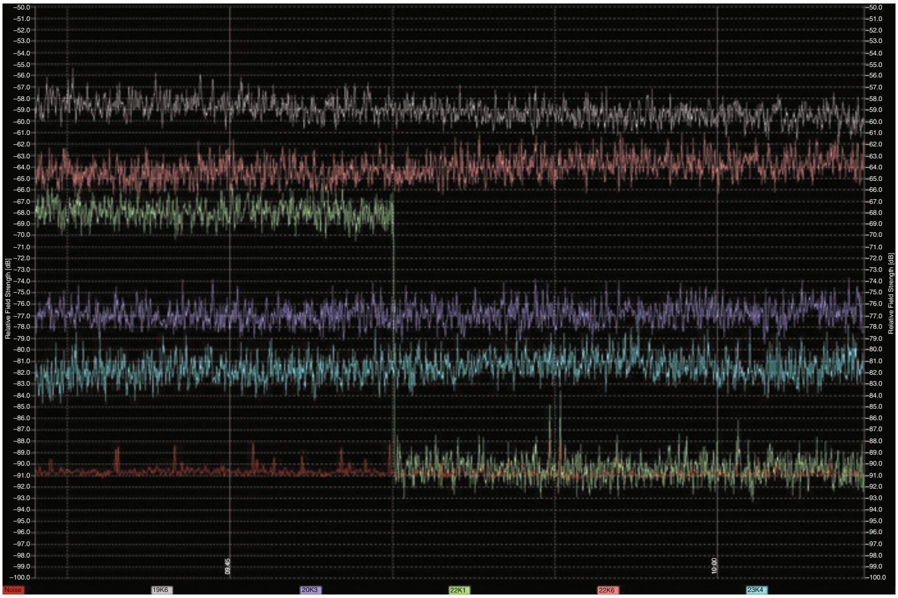


Fig. 9.4. VLF plot window from *Spectrum Lab.* Note how the 22.1 kHz (*green*) channel was turned off at 09:50, and the signal dropped to the noise floor (*red trace*) at −91 dB.

Once you are happy with the definition of the channels you want to watch, go to the "Channels & Colors" tab and turn off any channels not required. To do so select the channel number, and go to "graph styles" and select off.

Finally go to the export tab, and set a filename for the log followed by selecting the check box "periodically export the plotted data." Finally select the radio button "comma as column separator."

Go to the file menu of the watch list window and select save settings, and save it. To operate the plotter, from the plotter menu, click on "Run (now stopped)." It will change to "Stop (now running)" with a tick beside it. When you select the plot window you will see a slow-moving graph start to develop. You should now be observing and recording your observations! Daily data can be exported as a text file for later processing if needed.

Figure 9.4 shows a plot screen obtained from *Spectrum Lab.* It covers about 20 min of time and was a series of 1-s samples. In practice samples should be every 15–30 s. Note how noisy the trace is on a short time scale. Should a particular plot contain useful information, such as a solar event, the data can be smoothed by later processing.

Figure 9.5 shows raw data exported via a text file to Microsoft Excel and plotted. This is data that was gathered on July 17, 2009. The raw data is very noisy and confused. Figure 9.6 shows the result of averaging samples over a 5-min period.

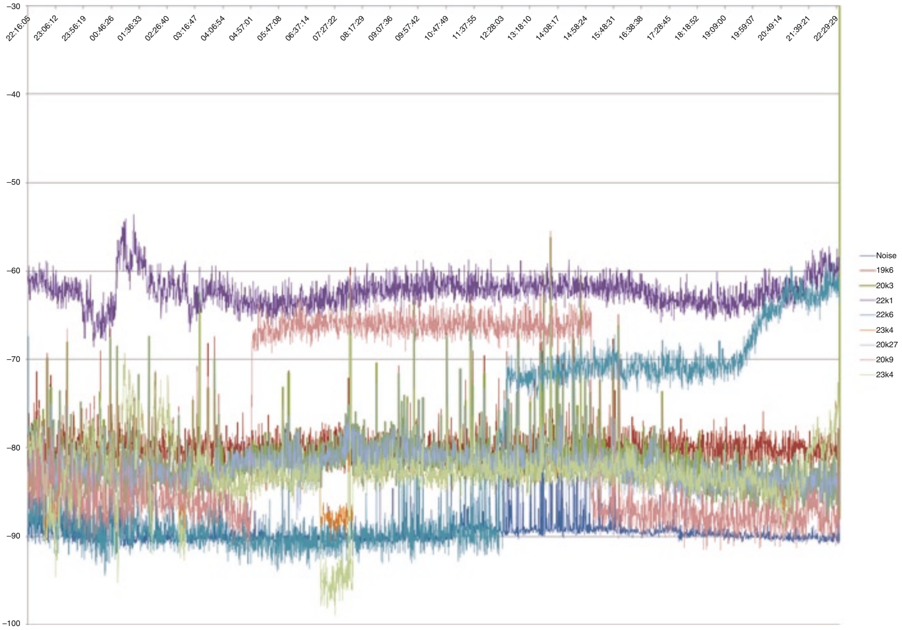


Fig. 9.5. VLF plot of five stations plus the noise background for July 17, 2009. This is the raw data showing lots of short period noise in the traces.

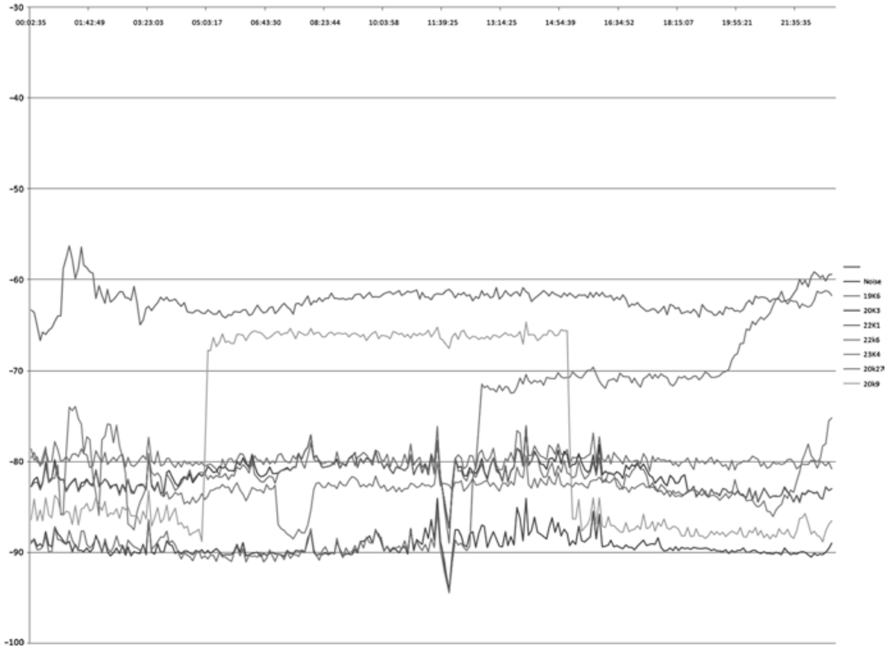


Fig. 9.6. The same data as Fig. 9.5 but averaged over 5-min intervals. Note the two channels that switch on and off during this period. There is a significant dip in one trace, but this is not seen on the others, so it is not likely to be a solar event.

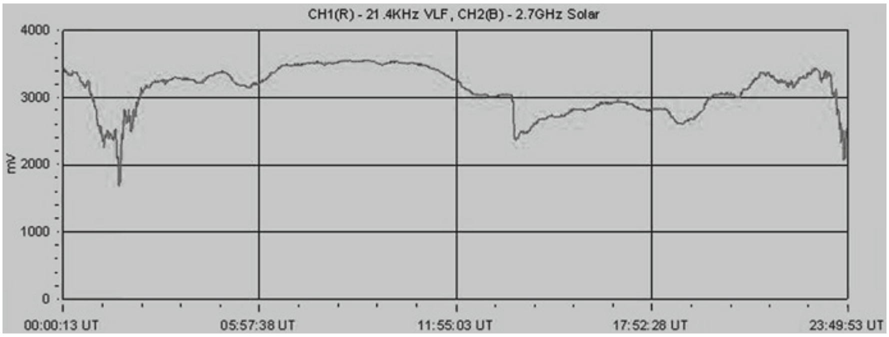


Fig. 9.7. VLF channel plot dated July 9, 2007, showing a significant SID event at around 13:00 UT. Note only channel 1 (VLF) is shown in this graph. (Image courtesy of Martyn Kinder.) Note also the wide variations in signal at night. There are always characteristic dips in the signal at both sunrise and sunset daily.

Figure 9.7 shows a VLF plot taken with a hardware receiver now available ready built or as a Kit from UKRAA, an offshoot of the British Astronomical Association Radio Astronomy Group. This was taken on July 9, 2007, and shows a SID event at about 13:00 UT. The data was captured using a homemade data logging interface based on the Maxim MAX186 chip (see Chap. 13) and *Radio Skypipe* software.