REPORT ON PROJECT STEP 2011-2012 CONDUCTED AT MONMOUTH SCHOOL
SUPPORTED BY THE ROYAL SOCIETY
(Grant Project Reference R1/2011)

CONTENTS

1 Introduction

1.1 This report is written by the project tutor, Dr David Morgan[1], to summarise the conduct and results from project STEP (Solar Terrestrial Environment Physics). This project was devised by the author in 2010 and carried out at Monmouth School from September 2010 to May 2011. Eight students of both sexes from three schools in the Monmouth area took part under the auspices of the Monmouth Science Initiate (MSI).

The project was considered a success and gave the students an early experience of research physics that would be valuable in their future life, including applications for further study at University.

With this established background, it was possible to apply for a 'Partnership Grant' from the Royal Society to extend and develop project STEP to build more compact equipment that would be easier to set up and use in schools. One issue that had arisen in the 2010 – 2011 project was the difficulty some schools had in accommodating the 1 square meter loop antenna used to receive Very Low Frequency (VLF) signals that carry information on the state of the ionosphere.

The Royal Society supported project for 2011 – 2012 would enable the antenna to be reduced to the size of a 'milk bottle' whilst maintaining the performance of the previous equipment.

1.2 Four male students took part in the 2011 – 2012 project and each one built his own VLF receiver- giving him valuable experience in receiver design, circuit development and practical skills such as soldering. When the receivers were completed they were tested by plotting antenna response diagrams using a number of VLF transmitters around the world. The students then collaborated in setting up a receiver to monitor the state of the ionosphere twenty four hours a day for about a month. They recorded Sudden Ionospheric Disturbances (SIDs) that are caused by the impact on the Earth of Solar X rays produced by the Sun during X Ray flare and Coronal Mass Ejection (CME) events.

A number of such events were recorded and analysed during the project to understand the nature of the physics of the Solar-Terrestrial environment.

[1] A STEM Ambassador

2 Project Aims

2.1 As mentioned briefly in the introduction, the aim of the project was to give the students some experiences they would perhaps not have in the course of pursuing the normal school science curriculum. In recent years it appears that the time – and in some cases the laboratory and teaching resources needed to do extended laboratory work and practical measurements - has been diminishing. This project aimed to engage students in real electronic design tasks to build equipment to monitor remote physical processes in the Earth’s ionosphere that can tell us about Solar X Ray activity.

While the project required a careful approach and consistent application by the students over 7 months, it was also an opportunity to learn about the physics of the wider – non local - environment in which we live and where appropriate, working as a team to gather and analyse large amounts of digital data produced by the receivers.

2.2 In summary, the aim of the project was to involve and stimulate students to develop attitudes and skills in science theory, experimentation, observation and organisation. Furthermore, it would demonstrate the wonder of the physical environment in which we exist and show how we can observe and measure its properties to gain a wider view of our place in the universe. The aim was to do this in a friendly and supportive way and to have fun learning and acquiring a range of practical skills.

Figure 1 Students Building VLF Receivers

3 Project Structure

3.1 An outline of Project STEP is given below:

Equipment
Small loop or Ferrite Rod antenna to receive the magnetic field component of EM transmissions from VLF stations in Europe and the USA.
Build a suitably designed and fabricated low noise preamplifier to connect to the antenna.
Use of a PC or laptop computer with special Digital Signal Processing (DSP) analysis software package (free ware) to record and analyse the information.
Use of EXCEL to process data and produce overall results.

Project Elements
Simple Electromagnetic theory
Simplified wave propagation / reflection & refraction in plasmas
The ionosphere and magnetosphere morphology and behaviour
The sun and its behaviour, sun spots, flares, CMEs and X Ray emissions
The solar wind and its interaction with the magnetosphere & ionosphere
How to use VLF transmissions as an ionosphere probe tool
How UV, X rays and Gamma rays affect the ionosphere
Observations that can be made: natural ionospheric radio emissions, lightning tracking, Solar X ray flares – Sudden Ionospheric disturbances, magnetic storms, possibly even Gamma ray bursts
Accessing and understanding live satellite data on space environments.
Accessing world wide lightning activity data

Project Skills
Physics - electromagnetism, plasmas & geophysics
Electronics – operational amplifiers, computer interfaces
Practical instrument construction – circuit construction & testing
Using Internet to access relevant information and ideas
Project planning and log book keeping
Team working – interpersonal skills development
Observational techniques – planning & logging
Data base generation & manipulation
Data analysis
Using Digital Signal Processing software – Simplified mathematics – of Fourier Analysis

Organising data and forming conclusions
Preparation of presentation material
Presenting the project

Laboratory Requirements
A place to meet and work.
School lab technician support
Benches with soldering irons / fume control
A small set of tools, screwdrivers, wire cutters, pliers etc
A simple oscilloscope (10MHz)
Laptop or PC with sound card

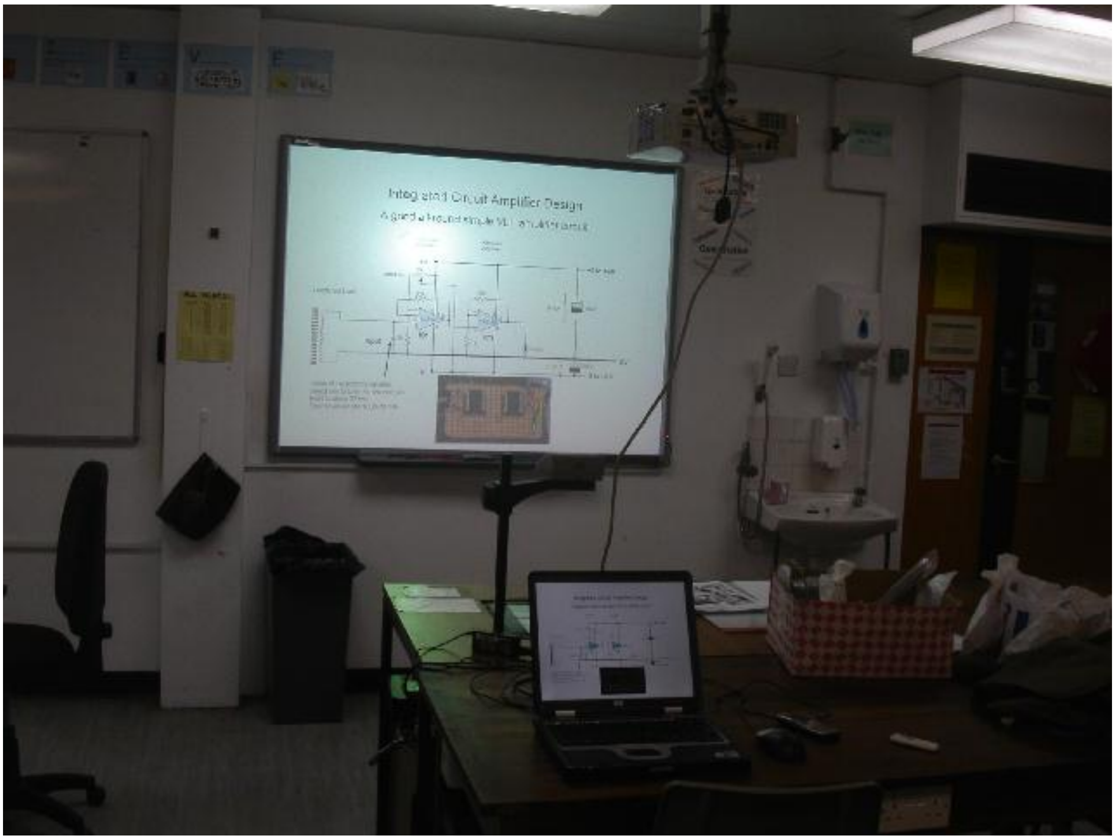


Figure 2 Laboratory Facilities

The facilities and support provided by Monmouth School were much appreciated by both students and the tutor and enable work to be carried out in a calm and safe environment.

3.2 PROPOSED WORK PLAN - Detailed activity plan

The project tutor and teacher agreed a work plan to cover the duration of the project. The plan prepared for Project STEP is given below:

The programme of work will be organised as follows:

Activity 1 Introduction

- Presentation by Project Tutor on aims of project, the VLF receiver, the software, the data that can be gathered, its organisation and analysis.
- Presentation on associated resources from satellites.
- Discussion with students to determine their capabilities & interests
- Allocation of teams
- Plan of next 5 weeks
- Preparation tasks – out of session work to prepare for next meeting

Activity 2 Antenna construction, amplifier design, analysis software

- Draw antenna construction, obtain parts, build frame /acquire ferrite rods
- Basic amplifier design knowledge, discuss options, draw layout
- Install & show Spectrum software, describe key features, experiment with configurations.
- Prep tasks for next session – coil induction, op amp characteristics, circuit design equations

Activity 3 Build & test antenna, populate circuit board, set up software with a VLF receiver.

- Wind antenna, measure ‘L’, calculate C for 5,10,15 kHz resonance
- Build one circuit board, physically check it; demonstrate software with borrowed VLF receiver, show spectrum, waterfall plot, oscilloscope & watch list.
- Work as a team to measure the antenna polar diagram, estimate receiver sensitivity and bearing to VLF transmitters.
- Use EXCEL to practise the analysis of real data from previous measurements made by the tutor.
- Prep tasks – find out about Fourier Transforms

Activity 4 Test amplifier, connect antenna, assess performance

- Connect circuit board to power supply & check current drain on both supply rails.
- Measure voltages at various points on the board & confirm they are as expected.
- Disconnect from PSU and put CA3140 ICs in holders.
- Connect output to oscilloscope with 100mV / div & 10ms / div
- Connect PSU & monitor oscilloscope for offsets, noise and oscillations
- Test temperature of ICs with finger to ensure they are not hot.
- Connect antenna to input & observe signal on oscilloscope
- Conclude performance of amplifier.

Activity 5 Build amplifier into casing and retest, connect amplifier to PC

- Prepare the metal box / compact antenna housing to accept input and output sockets & power cable
- Secure circuit board into box with nuts & bolts and stand-off spacers
- Retest circuit to ascertain functionality
- Connect amplifier to antenna and to PC and oscilloscope
- Operate Spectrum lab software and set up suitable configuration
- Record signal spectrum, waterfall plot and audio file
- Set the spectrum lab configuration for standard watch list
- Demonstrate how to save watch list as an exported CSV file

Activity 6 Use instrument to record data

- Run the unit for several days over a convenient time period (eg 09:00 – 16:00) before the session & store the data
- Recover the stored data and plot examples of signal strength for a number of stations using EXCEL
- Discuss and agree what measurements to make until the end of term
- Set up a preliminary measurement schedule with nominated operators

Activity 7 Discover how to obtain satellite data on solar and terrestrial magnetospheric activity

- Locate NOAA GOES web site and understand available data
- Locate SOHO web site & download images
- Locate SDO web site & gain access to data
- Locate near real time GRB web site and access data
- Locate world wide thunderstorm activity web site and download images
- Give suitable bibliography
- Discuss how all this data relates to VLF measurements

Activity 8 Set up observing schedule & log book

- Decide what the team wants to look for: X ray flares and SIDs, solar wind impacts, diurnal variations, seasonal variations, geomagnetic storms, magnetosperic and ionospheric natural radio emissions
- Develop a practical observing plan
- Prepare the outline of a final presentation and bring the project log book up to date.
- Present each team's Power Point presentation & discuss effectiveness (within groups)
- Revise presentation where necessary
- Give final presentation to wider audience

4 Introductory Presentation

4.1 At the initial meeting of the project group in September 2011 the tutor gave an introductory Power Point presentation explaining the nature of the project and what the students would learn during the next 7 months.

The presentation is supplied on the CD and can be found in the Tutor's section under 'presentations to students'. It is called 'Starter Presentation'.

A brief review of the key features of the initial presentation is given below. (Blue text is copied from the presentation)

4.2 Project Content

- We will build a radio receiver that can give us information on the X Rays emitted from the Sun

- We will learn about the Physics of the Sun, interplanetary space, and the impact of X rays and the Solar Wind on the earth.

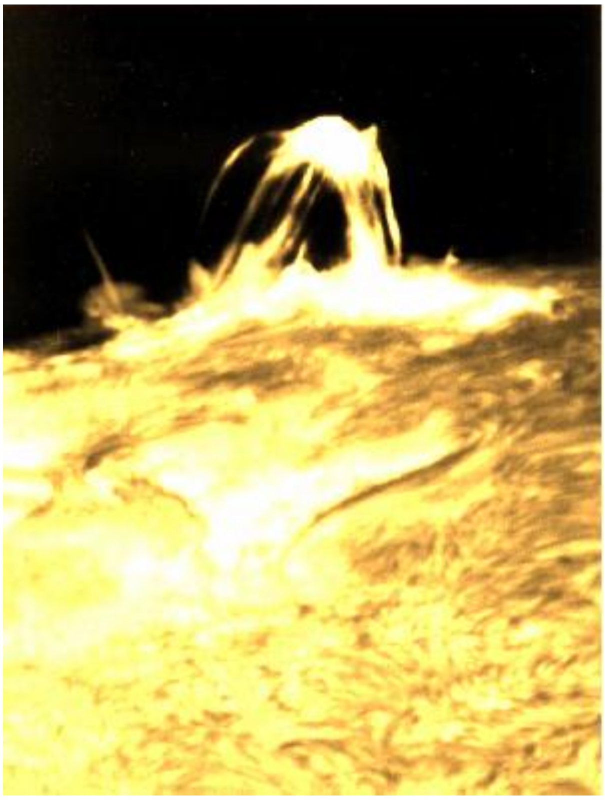
- We will set up a 24/7 observing programme and use software to analyse data

- The project will have a number of stages:
  - Introduction to Solar – Terrestrial Physics
  - Building a suitable radio receiver
  - Testing & calibrating the receiver
  - Monitoring & analysis software
  - Observing & logging data
  - Data analysis & physical insights
  - Comparing with Satellite data
  - Setting up an observing programme

4.3 The Sun

This section describes the nature of the Sun and indicates the importance of the solar magnetic field in the production of Sunspots, X ray Flares and CMEs.

- The Sun is a gravitationally bound nuclear reactor
- It is largely stable, but has some variability
- There is an 11 year sunspot cycle
- Strong magnetic fields 'wind up' as the Sun spins
- Eventually field lines 'snap' and trapped energy & particles are thrown into space



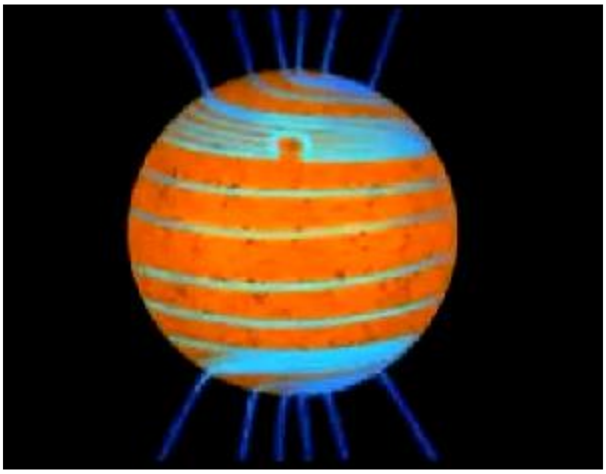


Figure 3 Solar Magnetic Field

Figure 4   Plasma ‘looping’ on Magnetic field lines

The Hard and Soft X rays are produced when magnetic field lines re-connect and accelerate charged particles to very high velocities. This process is shown in Figure 5.

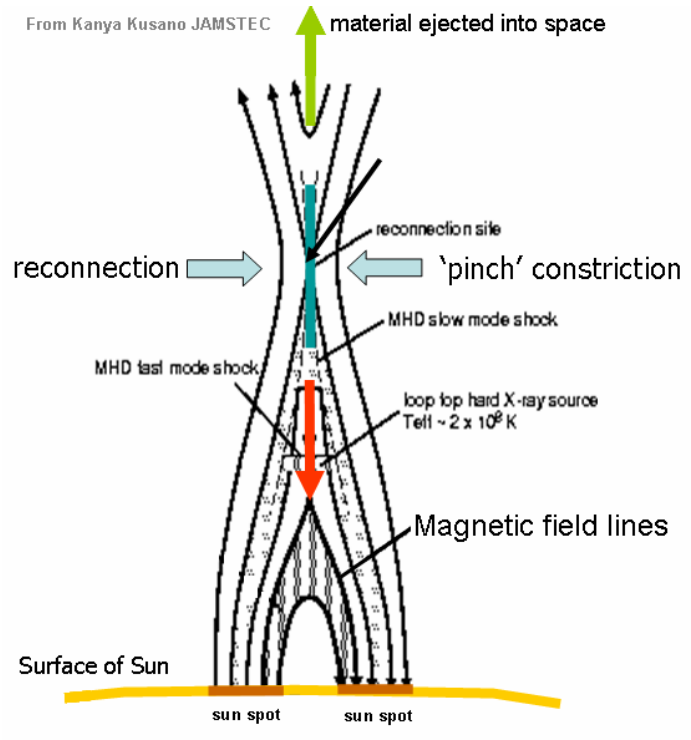


Figure 5   X Ray Production

4.4 **The Solar - Terrestrial Medium**

- The fast charged particles first encounter the Earth's Magnetosphere at up to 10x the radius of the Earth & form a shock wave boundary

- Charged particles cannot cross field lines – they must travel around & along them
- X rays are not charged particles, they are Photons – and can penetrate magnetic fields
- When they reach the Earth they pass through the Magnetosphere into the Ionosphere

- They only start to interact with the neutral atmosphere when it becomes dense enough at an altitude of ~ 100km in a layer known as the D region.

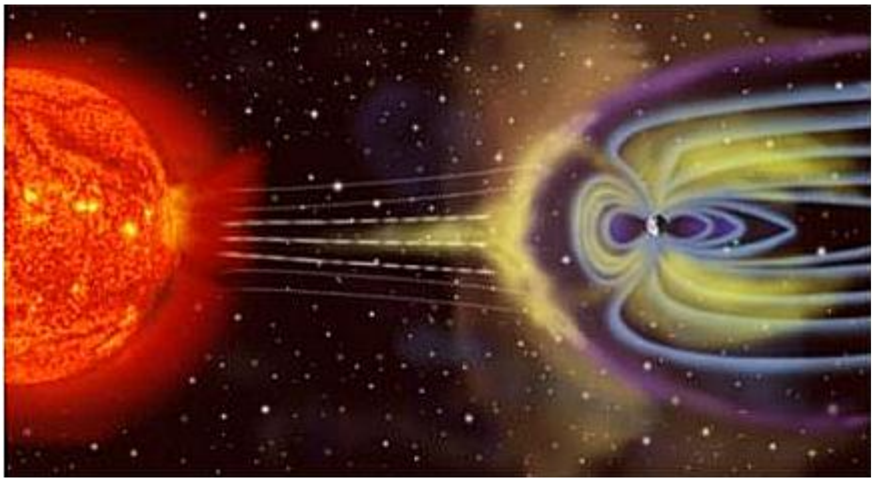


Figure 6 Solar –Terrestrial Medium

- UV and X rays ionise the day side of the ionosphere increasing the ionisation density
- When the X rays from a Solar Flare arrive they rapidly enhance the D Region ionisation levels, altering the way VLF radio signals are refracted back to Earth as shown in Figure 7.
- This is seen as a rapid onset of change in VLF signal strength, followed by a gradual return to normal.
- This is called a Sudden Ionospheric Disturbance SID and has the characteristic shape of a 'shark's fin'.
- This change in signal strength is detected by the VLF receivers to be built during the project and enables the Earth's ionosphere to be used as a very large detector of X Rays from the Sun.

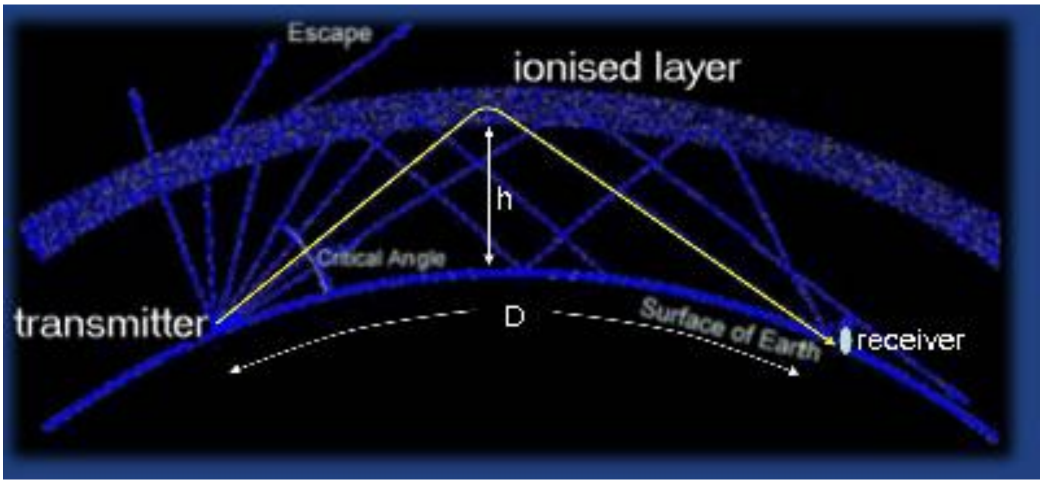


Figure 7 VLF signal refracted by Ionosphere

4.5 **VLF Radio Propagation**

VLF signals in the frequency range below 30kHz are transmitted from a number of military stations around the world to provide widespread communications capabilities to ships and submarines. The largest of these transmit up to 1 MW of power. The stations of use in Project STEP for monitoring the state of the ionosphere are shown in Figure 8.

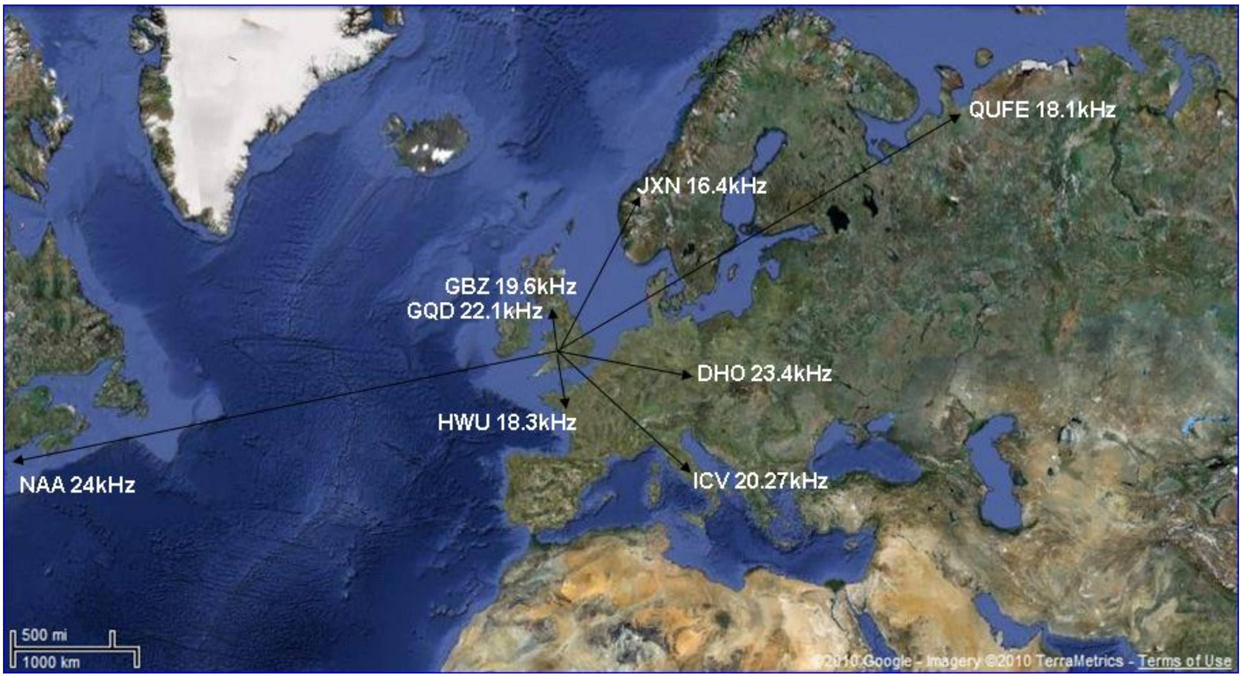


Figure 8 Military VLF Transmitters used in Project STEP

Evidence of X Ray impact generating a SID is shown in Figure 9

- Sudden Ionospheric Disturbance (SID) due to Solar X ray flares
- Normal diurnal variation shown in black is due to UV illumination
- Two SID events occur just after midday
- They have the characteristic ‘shark fin’ shape

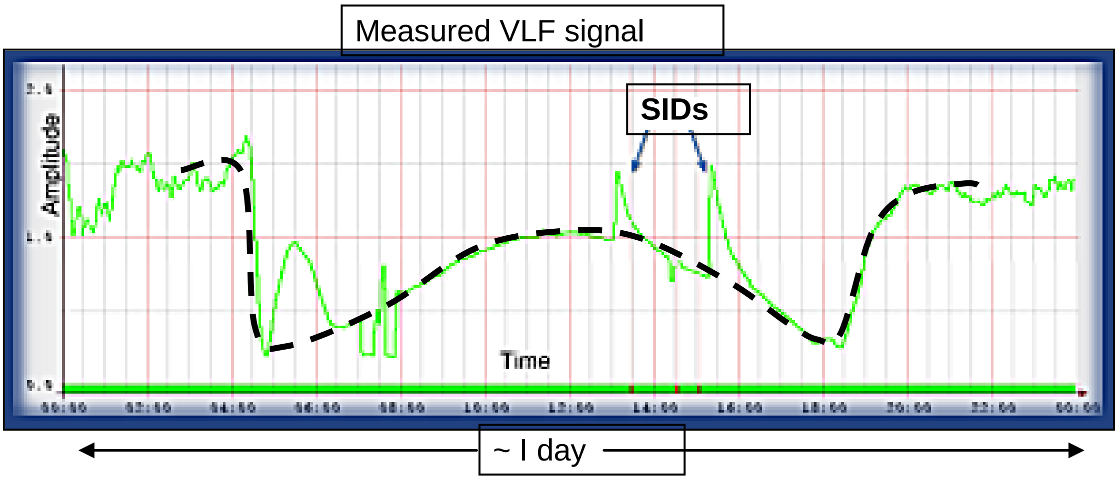


Figure 9   VLF Signal Strength showing Diurnal variation and two SIDs

4.6 **The Importance of Detecting X Ray Flares & CMEs**

- Solar generated Geomagnetic storms can damage sensitive satellites in Low Earth and Geostationary orbits
- Large scale power grids have been overloaded by surges on long power lines caused by geomagnetic storms

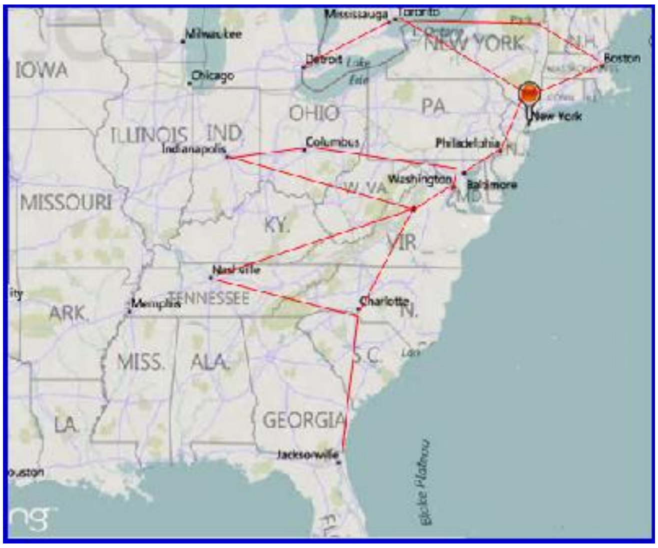


Figure 10   US East Coast Power Grid failure as a result of a CME

4.7 **Building a VLF Receiver**

The key components of a suitable VLF receiver are shown below:

- Requires an antenna - a Loop or Ferrite aerial
- An amplifier - high gain & wide band
- A waveform digitiser - computer sound card
- Spectrum analyser - Fourier software
- Data logger - data file software
- Graph plotter - graphing software
- Data analysis - Microsoft XL

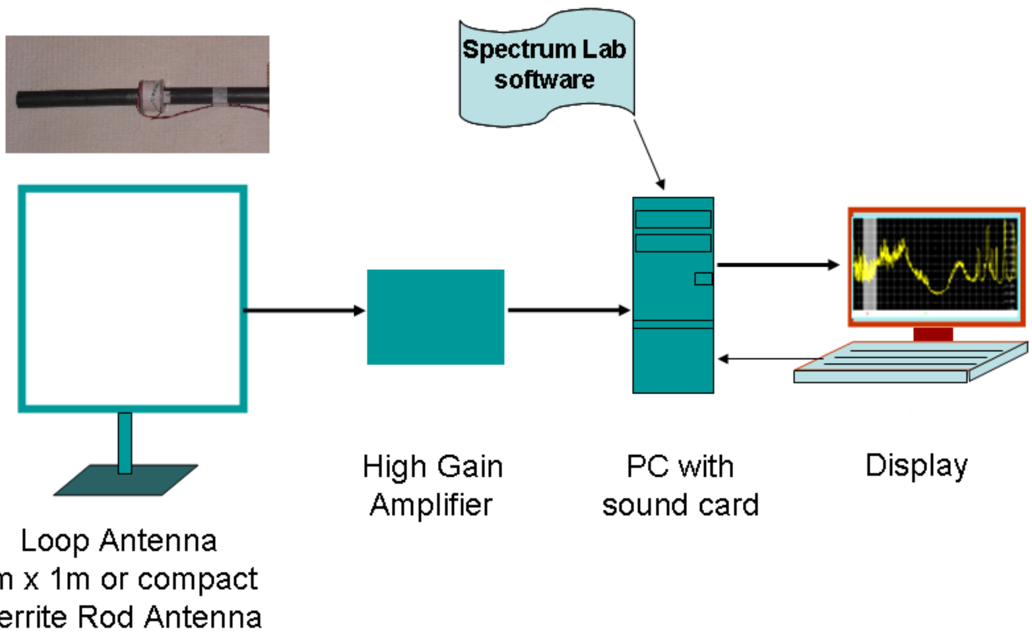


Figure 11 VLF Receiver Components

The loop antenna was used in Project STEP 2010 – 2011 and the Royal Society supported project in 2011- 2012 used the new Ferrite Road antenna.

4.8 Compact Ferrite Rod Antenna 2011-2012

- We will develop a new compact antenna based on a high magnetic permeability ferrite material

Small hand held unit

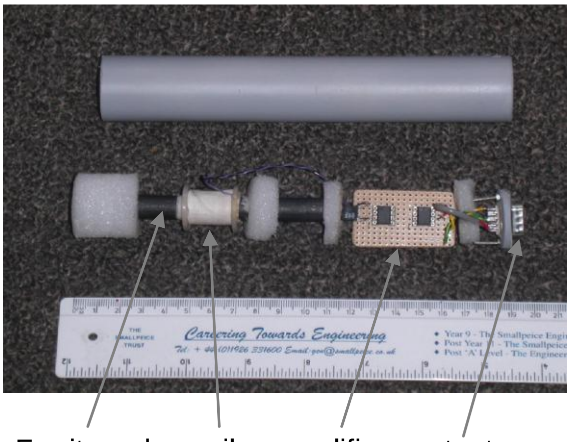


Figure 12 Developing the Small Ferrite Rod VLF Receiver

- We will each build the antenna and electronics shown below in Figure 13

Integrated Circuit Amplifier Design

A good all-round simple VLF amplifier circuit

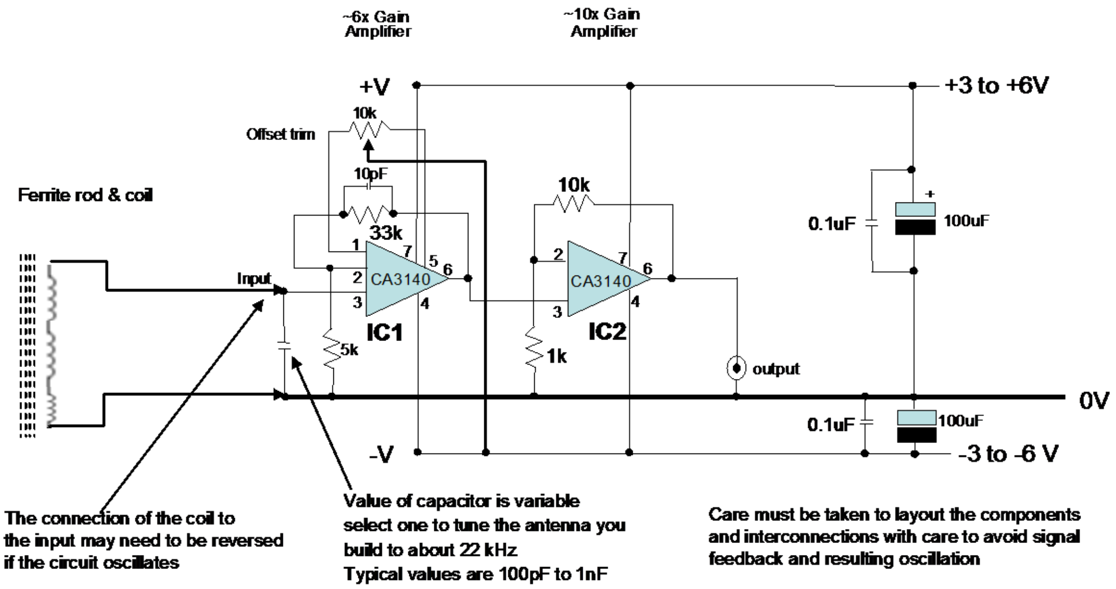


Figure 13 The Receiver Design

4.9 Planning the Circuit Board layout

- What size of circuit board do we have to work with?
- Where will the power and output connections be?
- Where will the decoupling / filtering capacitors go?
- Where will the input be?
- How far apart should the Op Amps be?
- Where should the high gain amp be sited?
- Will I have enough room for all the components?
- How can I minimise the number of interconnecting wires?
- How do I avoid feedback?

4.10 Conditions for success

- Plan with care - think things through
- Develop soldering skills – avoid 'dry joints', solder blobs & short circuits
- Test ALL circuit connections on the board - verify layout with ohm-meter
- CHECK AGAIN
- Avoid Electro-Static discharge (ESD) on Integrated Circuits (ICs)
- Put ICs on board
- Test with low voltage (3V rails) - measure amplification, check for hot components
- Look for instability - oscillation, variation in gain, excessive current drain

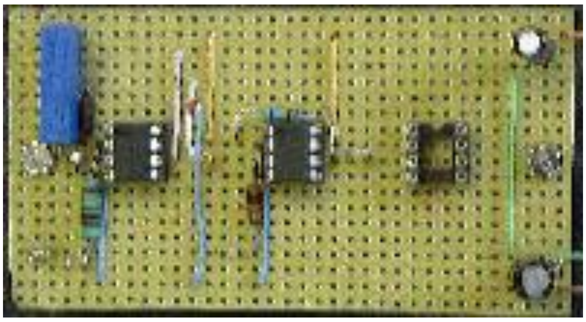


Figure 14 The Circuit Board

4.11 Assembly of Antenna Components

The antenna is integrated with the amplifier in a single weatherproof tube as shown in Figure 15.

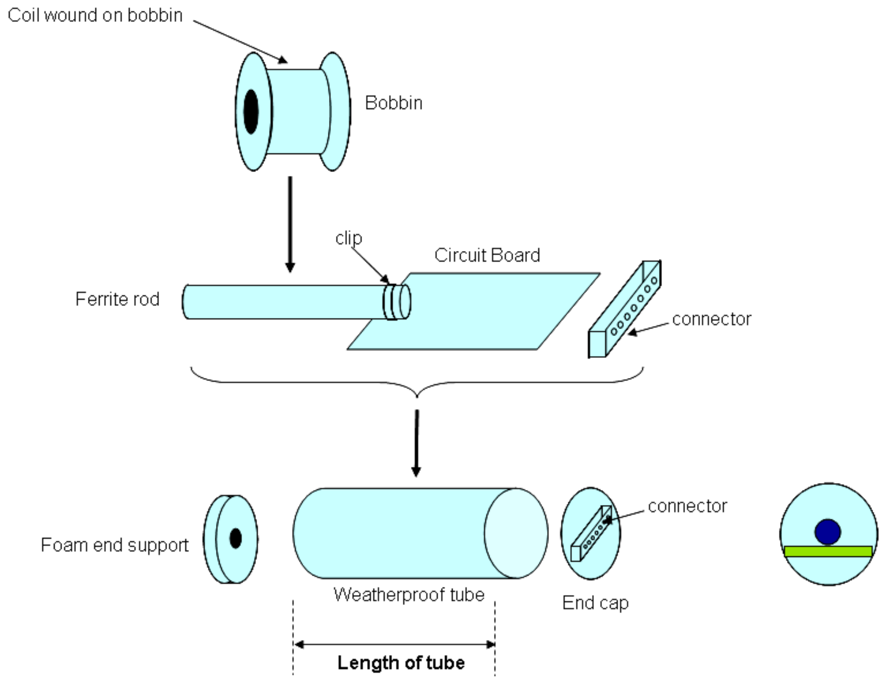


Figure 15 The Antenna / Receiver Assembly

4.12 Spectral Analysis of the Signals

This is done with free software called ‘Spectrum Lab’. It is a sophisticated fast Fourier analyser and students will require some time to become competent at using it.

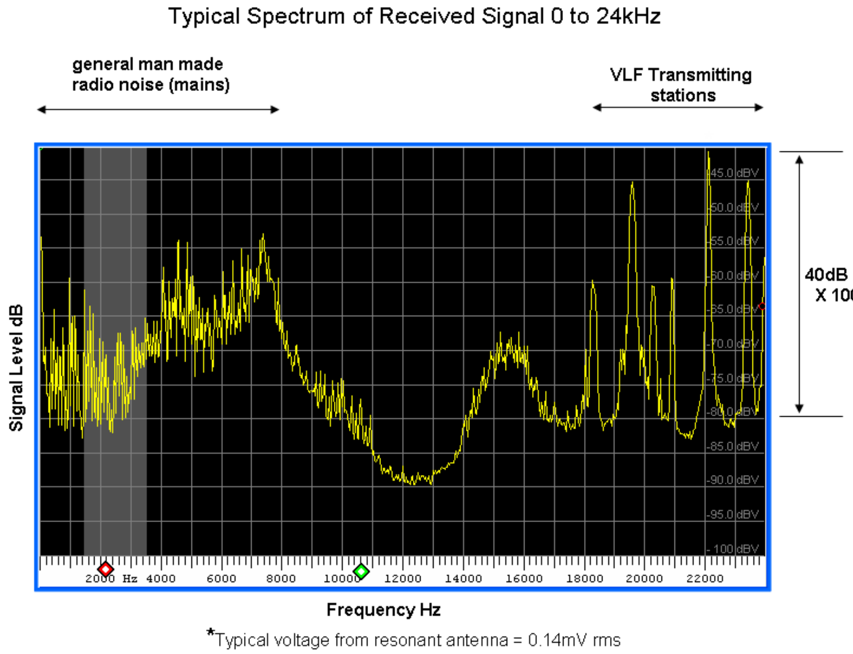
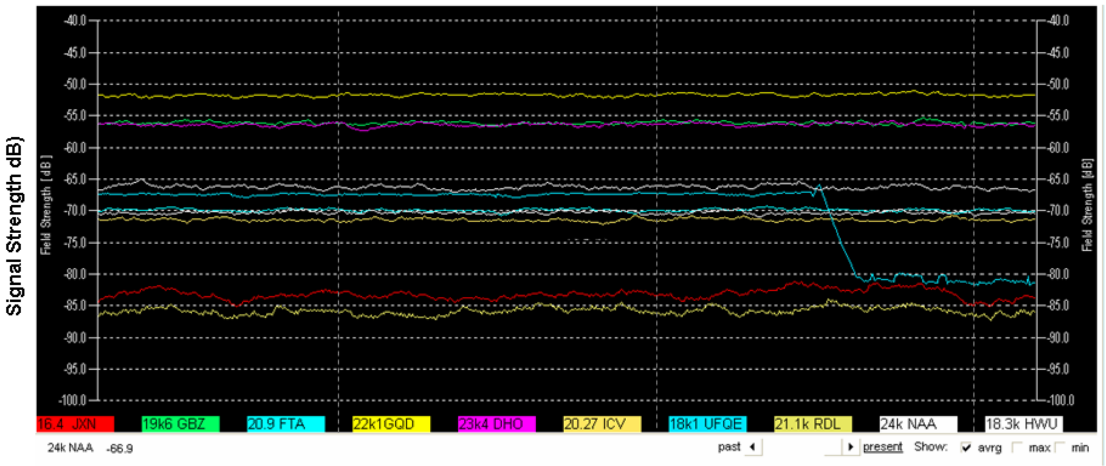


Figure 16 A Typical Received Signal Spectrum

The software will record a time history of the strength of each VLF station nominated in a list. Such a record is shown in Figure 17.The data can be retrieved for further analysis as a text file.

A plot of 10 VLF transmitter signal strengths as a function of time



Time (hours)

Each of these traces is the signal strength from a different VLF transmitter plotted as a function of time

Figure 17 Time histories of VLF Signals

The raw data in Figure 17 can be manipulated using Microsoft EXCEL to produce signal graphs shown in Figure 18

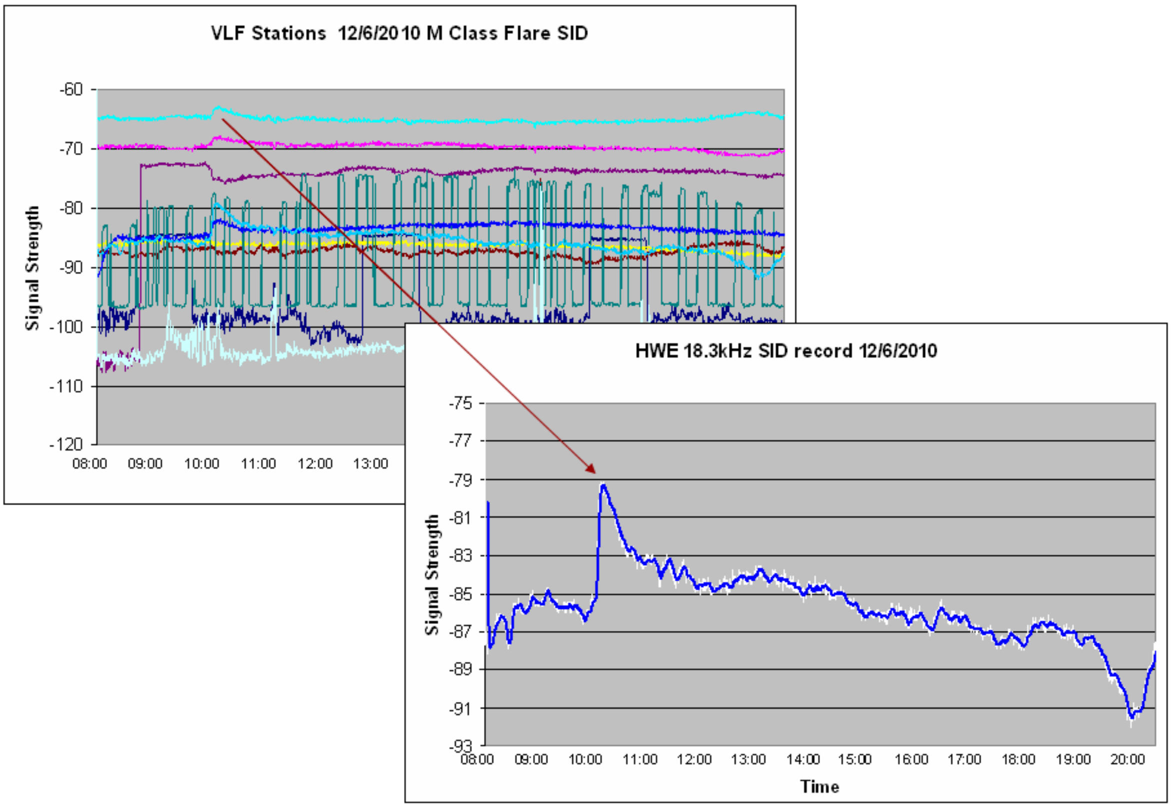


Figure 18 The extraction of a SID from Raw Data

4.13 **Comparison of Results with other Observations**

- To confirm a true SID we need X Ray flux data
- This can be obtained from the GOES satellite
- Near real time download via the internet

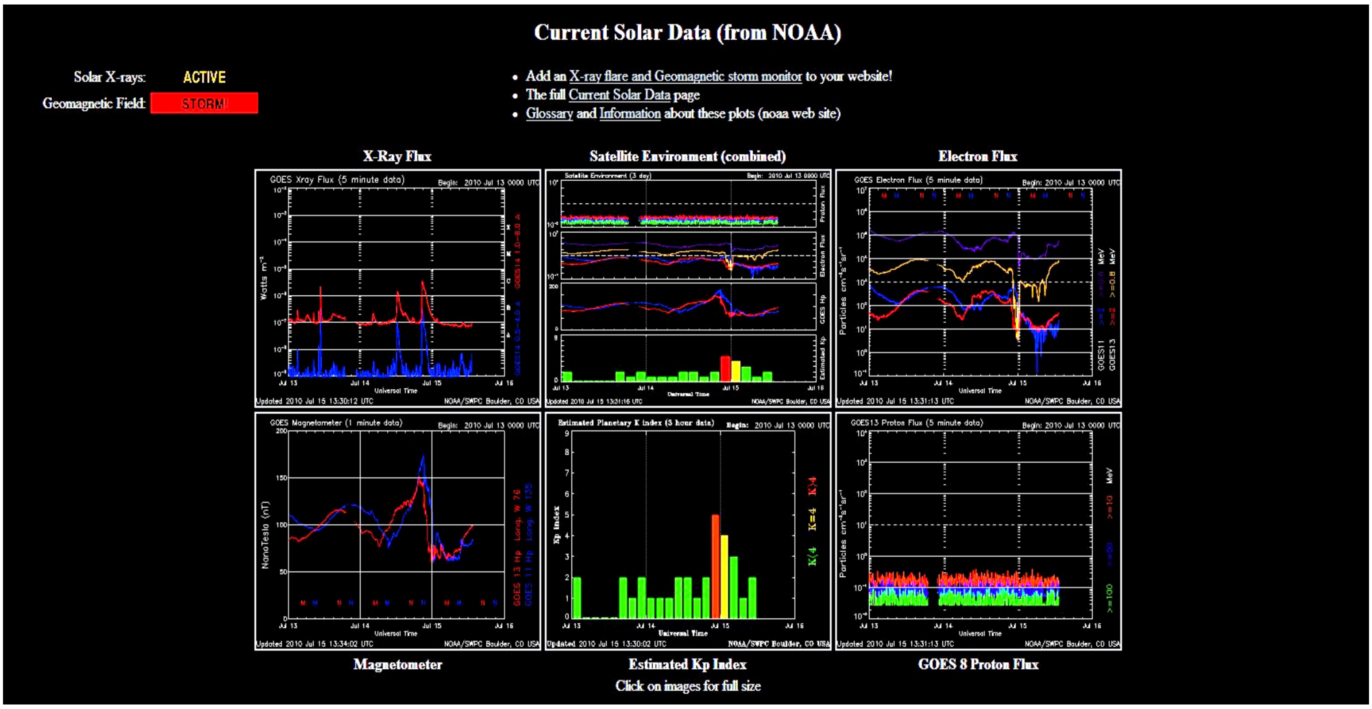


Figure 19 X Ray flux and other pertinent data from the GOES Satellite

Figure 20 shows the detail of a Solar X Ray burst from the GOES Satellite

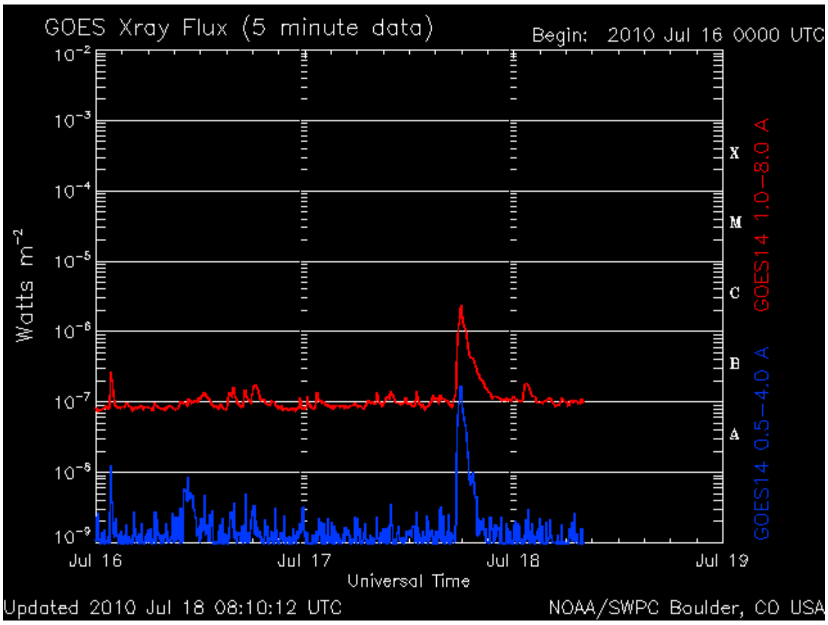
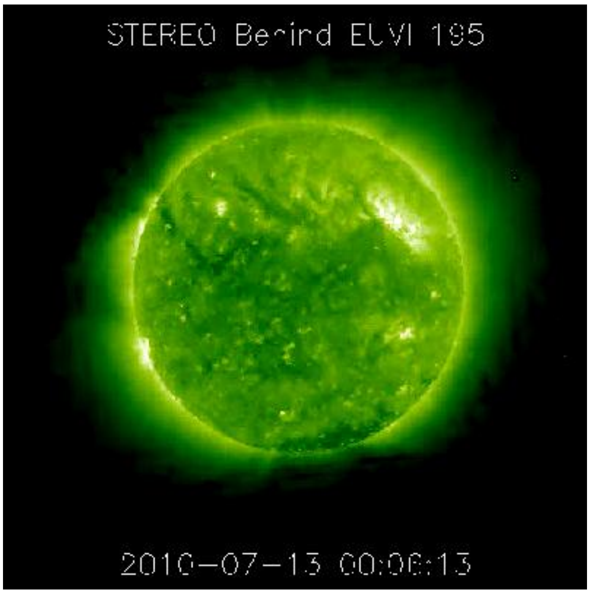


Figure 20 X Ray Flux data from GOES Satellite

Time lapse movies of the Solar disc at many wavelengths, including Extreme UV, are taken by orbiting satellites and are available on the internet.

Students are asked to locate and download relevant images that correspond to the timing of SIDs they have observed with the VLF sensor.



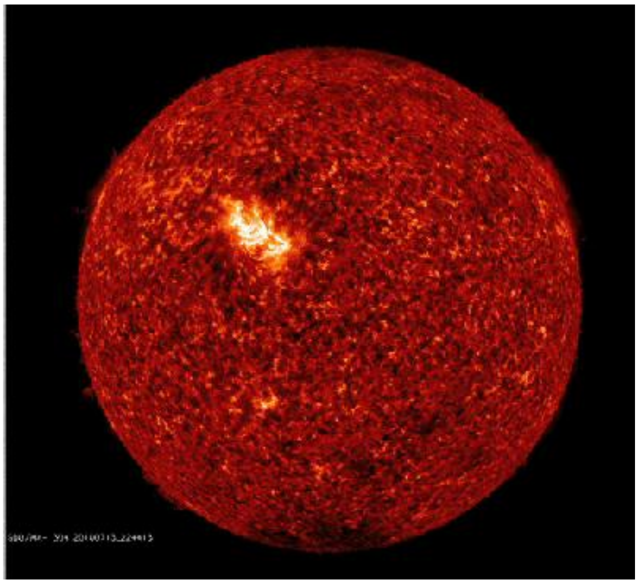


Figure 21 Stereo Spacecraft

Figure 22 Solar Dynamic Observatory

In addition to satellite data there are other VLF receiving stations in Europe recording SIDs

- SID monitoring site in France
- Enables us to compare our results
- We need to collect data every day and log all results

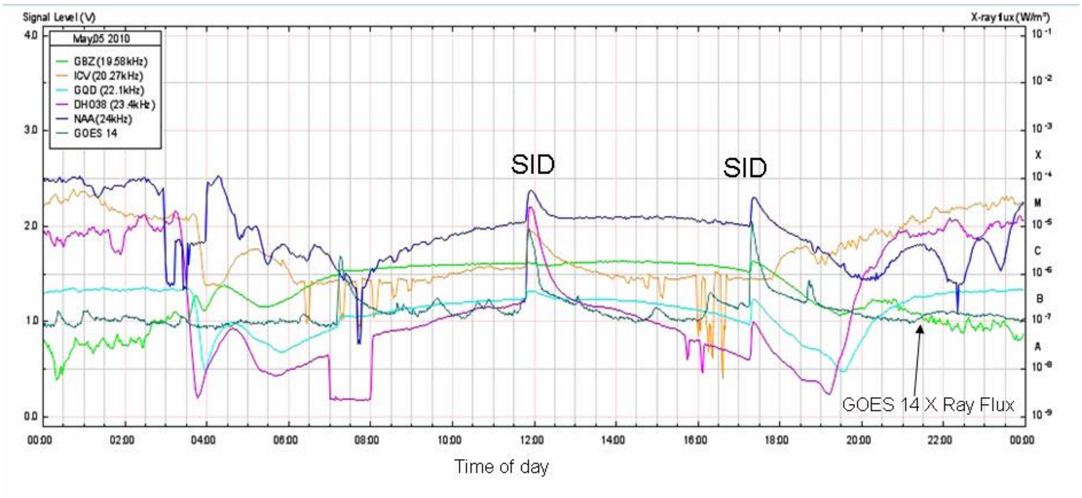


Figure 23 Lionel Loudet's VLF signal results from Southern France

5 Building Receivers

5.1 For the students this was the most interesting part of the project. Most had never constructed any electronics before and were unfamiliar with the skill of soldering small components onto circuit boards. Indeed, time was spent enabling them to practise soldering wires to blank boards before they attempted to solder expensive components to the receiver circuit board. It took some time for a few students to get out of the notion that solder could be treated as ‘glue’ and to allow the solder to flow onto the joint and so avoid ‘dry joints’ which can plague the reliability of experimental circuit boards.
To explain the design features of the receivers the students were given the presentation called “ Electronics Information” [found in the Detailed Information Modules section on the CD].
The building phase of the project took 6 to 8 weeks, with some students more adept than others at the construction task. Some students took note of the guidance given on board layout and wiring routes. Others did their ‘own thing’ – these often got into trouble with poor layout and many more wiring connections than were necessary in order to compensate for the poor lay out and lack of forward planning.

All the receiver amplifiers worked, although some faultfinding was required in some cases. This too was valuable for the students to understand what could go wrong, how to carry out step-by-step tests and how to remedy problems found.

5.2 A selection of photographs of the equipment being constructed is given below: grouped under the heading of Figure 24.

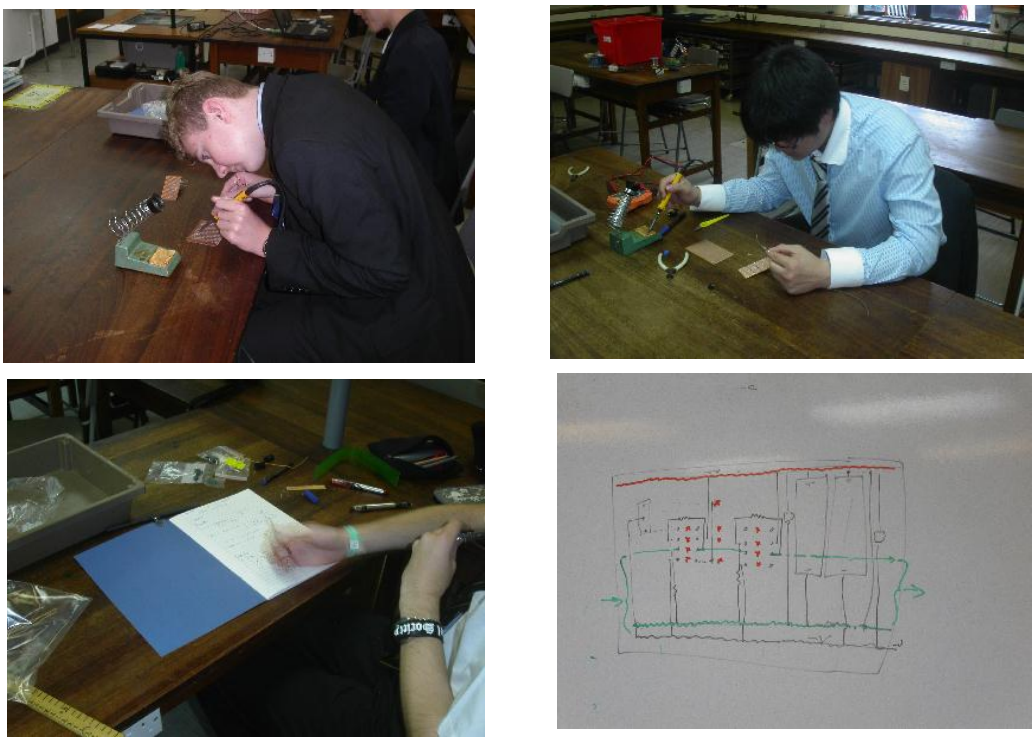


Figure 24 Students Building Receivers

6 Antenna Design

6.1 Once the receiver amplifiers were finalised and tested, the pick up coils to be placed on the ferrite rods were constructed. In preparation for this, two of the theory modules were presented to the students. [To be found in the Detailed Information Modules section / Theory Modules on the CD].

- AC Circuit Theory Module
- EM Induction Module

It was known that most of this material was unlikely to have been covered in the normal school curriculum but was thought necessary for the students to grasp how the ferrite rod antenna was able to generate signals from the VLF wavefields returned from the ionosphere.

Such modules might stretch the students somewhat, but the whole project was pitched to do that. Evidence gathered from the students' views of the 2010-2011 project, was that they started out a bit baffled. Fortunately, by the end of the project they felt comfortable that they had grasped all the key ideas and were able to see how they could be used to understand the project.

6.2 AC Circuit theory

The aim of this module was to explain the properties of resonant circuits and how they arose. This was necessary to understand how the tuned ferrite rod antenna was to be constructed.

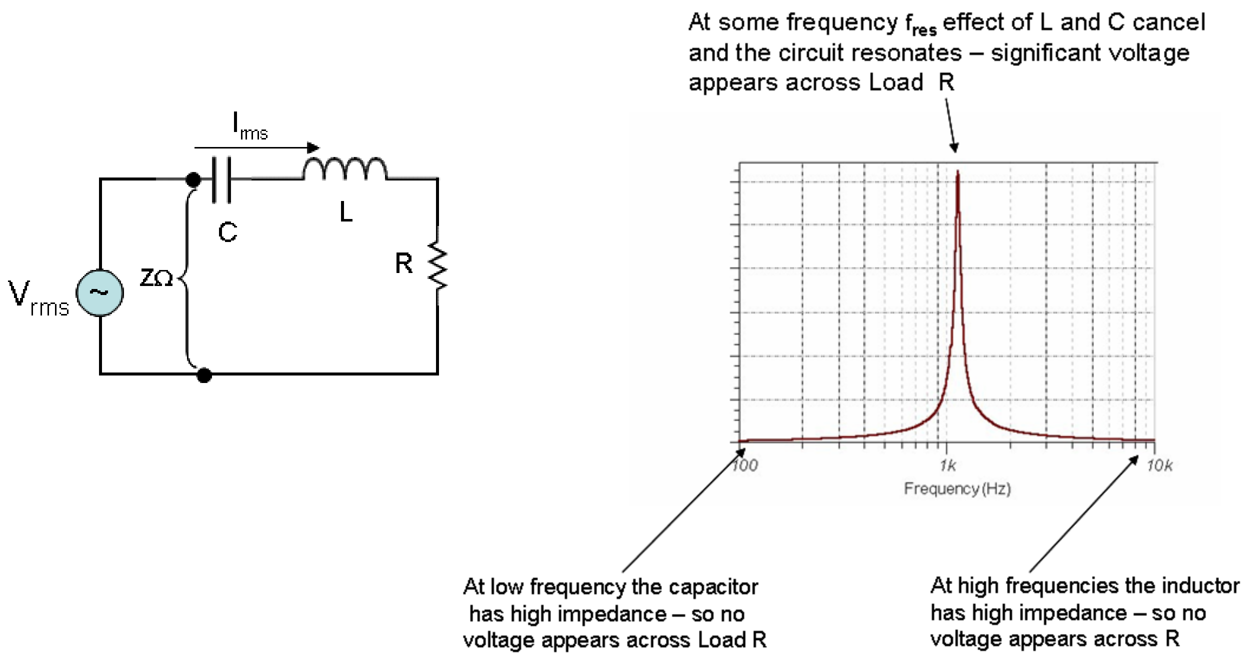


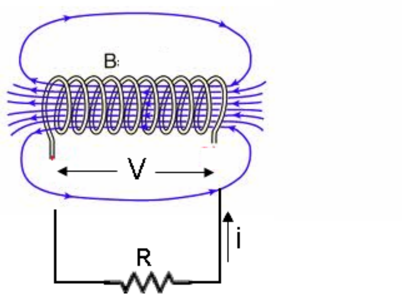
Figure 25 AC Circuit Theory Module

6.3 Electro-Magnetic Induction Module

This module conveyed the basic ideas of EM induction and how they could be applied to a loop antenna. The idea of Inductance was introduced and the concept of a transverse electromagnetic wave was explored.

The ideas were combined to show that a wire loop would have a dipolar angular response in respect of the magnetic field component of the wave and that this could be measured in a simple experiment.

If a magnetic field threads a coil, it sets up a current into a load – and produces an open circuit voltage of V



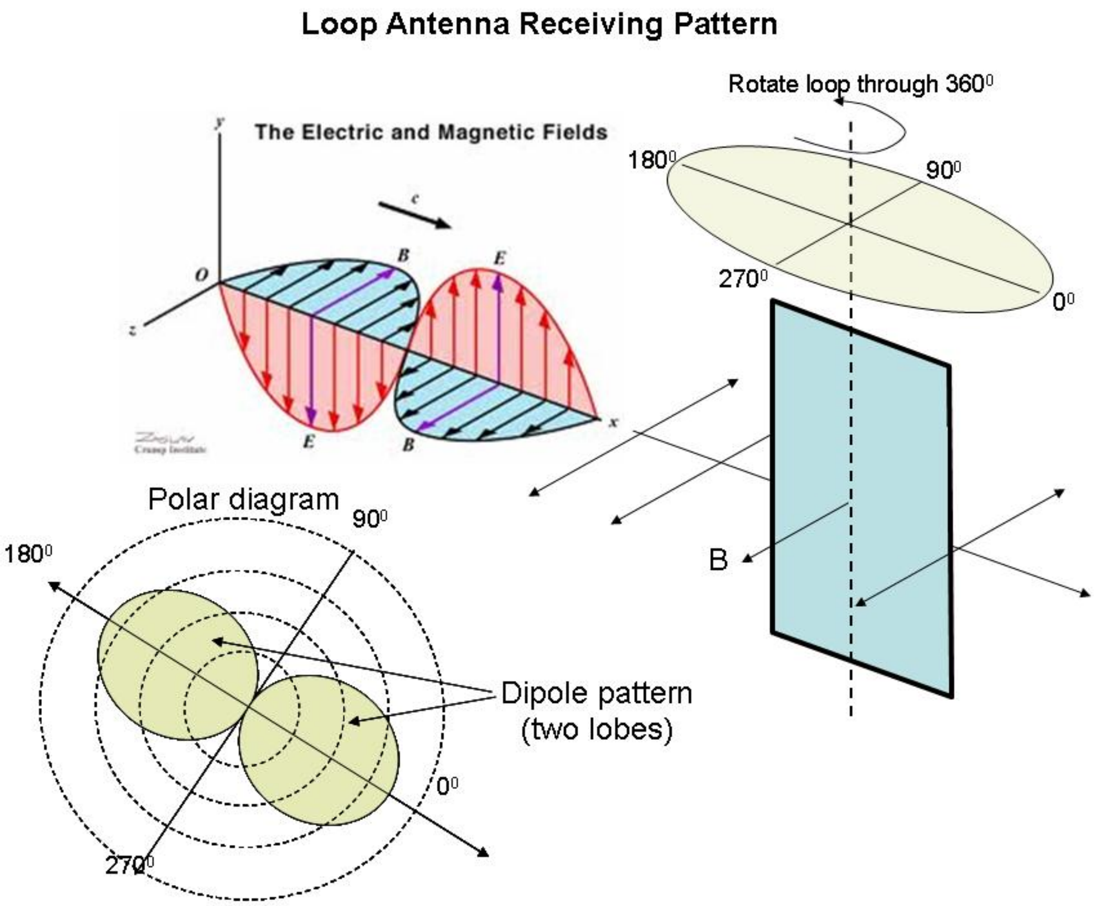


Figure 26 Diagrams from the EM Induction Module

6.4 Antenna Construction

Having understood the role of the loop or coil of wire in the design of the antenna, the students wound small coils with the aim of achieving the required inductance of 42mH when placed in the centre of the ferrite rod. This had been previously determined by the tutor to be the inductance needed to resonate VLF frequencies in the coil with a small capacitor across the input to the amplifier.

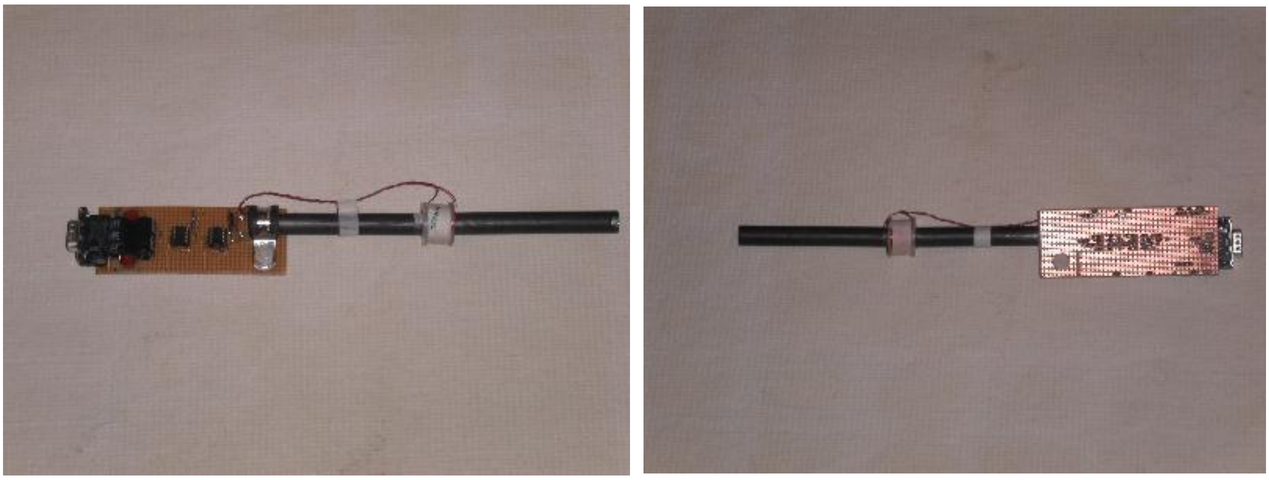


Figure 27 Views of the Ferrite Rod Antenna, Coil and Circuit Board

The final configuration of the compact VLF receiver is shown in Figure 28. Each student constructed his own receiver and was encouraged to take it to his school or home and use it to monitor VLF SIDs after the formal project closed at the end of May 2012.

Figure 28 The Compact VLF Receiver

7 Measuring Performance

7.1 Measuring Antenna Polar Diagrams

The students undertook, as a team, the simple experiment of rotating the receiver through 360^0 in azimuth as shown in Figure 29 and recording the output signal at a frequency of one of the VLF transmitters. This showed the dipolar response, the sensitivity of the receiver and the bearing (direction) of the selected transmitter.

The spectrum of signals received by the antenna is shown in Figure 30. With the Spectrum Lab software the polar responses to multiple VLF transmitter signals can be measured simultaneously.

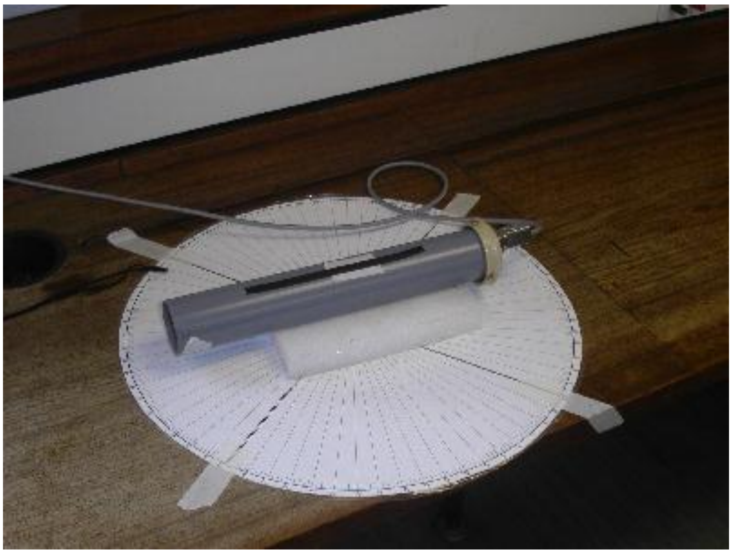


Figure 29 Measuring Antenna Polar Diagram

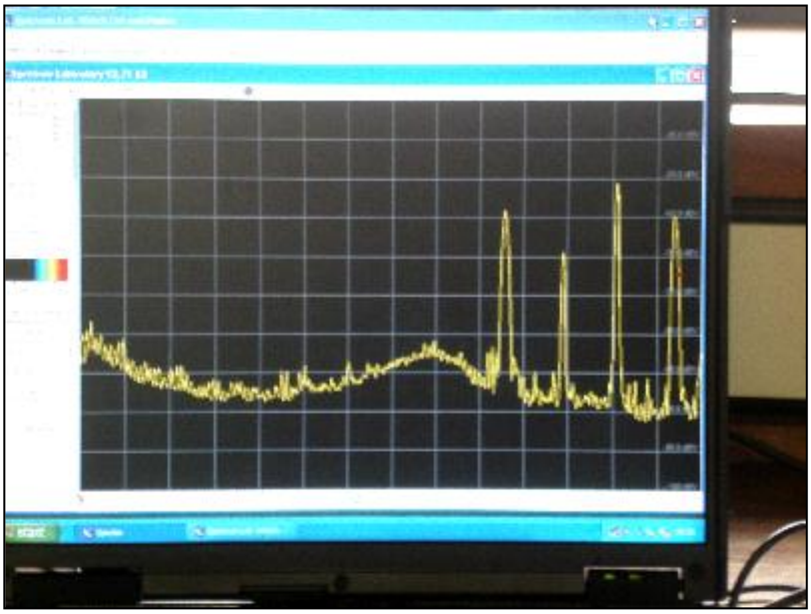


Figure 30 Spectrum showing four VLF signals

The students collaborated on setting the antenna position, recording the signal strengths of the VLF stations and using Microsoft Excel to plot the polar responses.

Figure 31 Recording the Signal Strengths

The resulting polar responses are shown in Figure 32

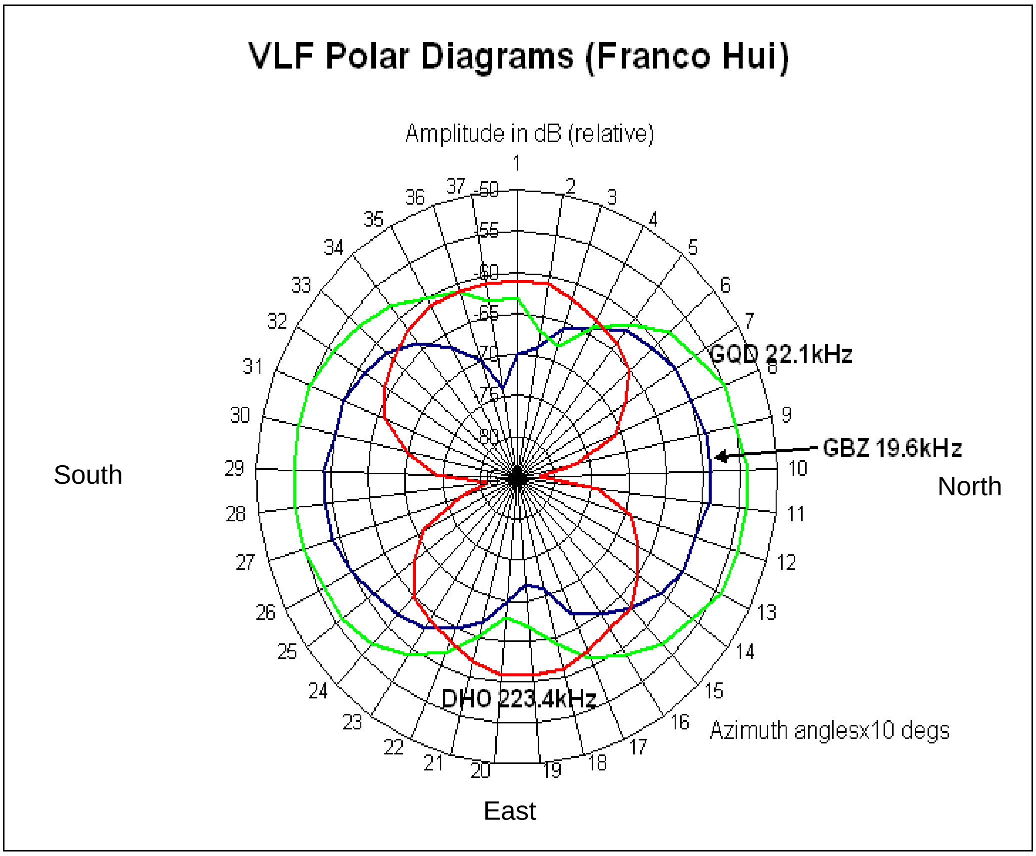


Figure 32 VLF Polar Responses

7.2 Interpretation of Polar Diagrams

The students were able to see from Figure 32 that the theory of EM induction and the resulting dipolar antenna response was confirmed. It was possible for them to determine the direction of the transmitter from the shape of the lobes. The best way to do this is to draw a line normal to one passing through the polar response nulls, as this is more accurate than judging the position of maxima.

The two UK transmitters GBZ and GQD are located in northern England and the DHO signal is transmitted from northern Germany.

8 SID Monitoring Program

8.1 The VLF receiver was set up close to an outside wall in a small room that was allocated for the project in the school. The VLF sensor was orientated NW to SE in order that all the signals on the polar plots could be received reasonably well.

The main problem in positioning and orientating the receiver was to achieve the best compromise between signal reception and the minimisation of mains and other interference from computers, air conditioning / heating plant etc.

The students experimented with antenna positioning until a useful compromise was achieved that enabled the signals from the VLF transmitters to be recorded without jumps or breaks due to interference.

8.2 The VLF receiver was connected to a desktop computer located in the small room. The Spectrum Lab software was installed by the students and after some familiarisation they were able to load a predefined configuration supplied by the tutor that set up the software to monitor 12 VLF transmitters located in the UK, Germany, France, Italy, Russia, Norway and the USA. As the signal from each transmitter travels over a different path to reach the receiver, the probability of detecting a SID is considerably increased over monitoring just one station.

It is interesting to note that these different paths can lead to different shapes for the VLF signature of a SID. In some cases the ‘shark fin’ may be inverted due to different combinations of the phases of direct and reflected ‘rays’.

The students agreed a 24 hour a day, 7 days a week monitoring program starting in February 2012 where they would periodically download data from the computer and, using Microsoft Excel, examine it for characteristic SID profiles on any of the 12 VLF transmitter traces. Relevant sections of the data were filed for further analysis,

9 Experimental Results

9.1 Data Accumulated

The VLF receivers operated for almost 2 months producing a continuous stream of data, some of which was selected for further analysis. Each day a student would archive the data recorded over the last 24 hours. This was done by saving the entire ‘Watch List’ in Spectrum Lab as a text file. Each file was about 1MB in size and contained the signal strength of up to 12 specified VLF transmitter frequencies, with a measurement being made every 5 seconds. This resulted in a data table with up to 13 headings and 17280 measurement points over the 24 hour period.

An example of a small section of a data file is shown in Table 1.

YYYY-MM-DD hh:mm:ss	16.4kk	19k6 GBZ	20.3	22k1GQD	23k4 DHO	20k9 FTA	18k3 UFQE	24k NAA
07/05/2012 10:29	-96.2	-70.7	-97.7	-74.7	-113.9	-101.4	-97.4	-104.1
07/05/2012 10:29	-94.3	-68.3	-95.1	-71.8	-111.3	-99.1	-94.4	-100.8
07/05/2012 10:29	-94	-67.6	-92.6	-71	-110.3	-98.4	-93.3	-99.9
07/05/2012 10:29	-93.7	-67.5	-92	-70.5	-110.3	-97.8	-93.4	-100
07/05/2012 10:29	-93.8	-67.4	-91.6	-70.3	-110.5	-98.1	-93.2	-100.4
07/05/2012 10:29	-93.7	-67.3	-92	-70.3	-110.5	-98.4	-92.9	-100.1
07/05/2012 10:29	-93.8	-67.4	-91.3	-70	-110.2	-97.5	-93.1	-100
07/05/2012 10:30	-94.1	-67.5	-92.4	-70.2	-110.5	-98.1	-93.4	-99.7
07/05/2012 10:30	-93.7	-67.3	-91.6	-70.3	-110.3	-97.9	-93.6	-100.1
07/05/2012 10:30	-93.6	-67.4	-92.3	-70.4	-109.7	-98	-92.9	-100.3
07/05/2012 10:30	-93.8	-67.5	-91.4	-70.2	-109.8	-98.3	-93	-100.4
07/05/2012 10:30	-93.5	-67.5	-92.2	-70.4	-109.9	-98	-93.1	-100.5
07/05/2012 10:30	-93.5	-67.5	-91.5	-70.6	-110	-97.7	-93.3	-100.5
07/05/2012 10:30	-93.8	-67.6	-92.3	-70.5	-110.2	-97.8	-93.3	-100.6
07/05/2012 10:30	-93.6	-67.7	-91.7	-70.5	-110.3	-97.8	-93.6	-100.3
07/05/2012 10:30	-93.2	-67.4	-92.1	-70.3	-110.3	-97.9	-92.9	-100.3
07/05/2012 10:30	-93	-67.5	-92	-70.1	-110.3	-97.7	-93.1	-100.5
07/05/2012 10:30	-93.1	-67.6	-92.6	-70.2	-110	-97.3	-93.1	-100.5
07/05/2012 10:30	-93.4	-67.7	-93.1	-70.4	-109.8	-97.2	-92.5	-100.5
07/05/2012 10:31	-93.4	-67.7	-92.2	-70.2	-110.2	-97.9	-92.8	-100.5
07/05/2012 10:31	-93.3	-67.7	-91.8	-70.3	-109.8	-98.1	-92.9	-100.3
07/05/2012 10:31	-93.5	-67.6	-91.6	-70.1	-109.9	-98.2	-93.1	-100.3
07/05/2012 10:31	-93.3	-67.4	-92.1	-70.2	-110.3	-98	-93.2	-99.9
07/05/2012 10:31	-93.1	-67.3	-91	-70.3	-109.7	-97.8	-93.4	-100.4
07/05/2012 10:31	-93.3	-67.4	-91.8	-70.1	-109.9	-97.2	-92.4	-100.3
07/05/2012 10:31	-94.1	-67.4	-91.3	-70.2	-110.2	-97.4	-93.1	-100.6
07/05/2012 10:31	-93.9	-67.6	-92.3	-70.1	-110.4	-97.9	-93.6	-100.5
07/05/2012 10:31	-93.3	-67.5	-91.5	-69.9	-109.9	-98.1	-93.2	-99.7
07/05/2012 10:31	-93.3	-67.6	-92.7	-70.2	-110.3	-98	-93.4	-99.9
07/05/2012 10:31	-93.5	-67.6	-92.6	-70.5	-110.3	-98.1	-93.2	-100
07/05/2012 10:31	-93.8	-67.4	-92.5	-70.4	-110.2	-98.1	-93	-100.1
07/05/2012 10:32	-94	-67.7	-91.6	-70.3	-109.9	-97.7	-92.8	-100
07/05/2012 10:32	-94.5	-67.8	-91.7	-70.7	-110.2	-97.7	-93.2	-100.2
07/05/2012 10:32	-94	-67.7	-92.1	-70.4	-110.3	-97.8	-93.6	-100.2
07/05/2012 10:32	-93.8	-67.5	-91.8	-70	-110.3	-98.2	-93.3	-100.3
07/05/2012 10:32	-94.1	-67.3	-92.4	-70.4	-110.2	-97.7	-93.3	-99.9
07/05/2012 10:32	-93.8	-67.2	-93.8	-70.7	-110.2	-97.5	-93.1	-99.9
07/05/2012 10:32	-93.5	-67.4	-93	-70.6	-110.2	-97.8	-92.9	-100.5
07/05/2012 10:32	-93.4	-67.1	-91.7	-70.4	-110.1	-97.6	-92.9	-100.2
07/05/2012 10:32	-93.5	-67.3	-92.4	-70.3	-110.2	-97.7	-93.2	-100.1
07/05/2012 10:32	-93.9	-67.4	-92.4	-70.5	-109.9	-97.3	-92.7	-100
07/05/2012 10:32	-94	-67.2	-94.5	-70.9	-109.8	-97.1	-93.1	-99.8
07/05/2012 10:32	-93.5	-67.3	-94.3	-70.9	-109.6	-97.2	-92.9	-99.5

Table 1 The data from the ‘Watch List’ file in the Spectrum Lab Software

The Spectrum Lab software is a comprehensive digital spectrum analyser and can act as a multi-channel software defined VLF radio receiver. The students were familiarised with part of its functionality to enable them to produce the necessary data files.

The main operating window is shown in Figure 33. Here the signal spectrum is displayed on the right side of the screen (frequency 0-24kHz) and the 'spectrum waterfall plot' in the centre section, with time running from right to left spanning about 20 seconds.

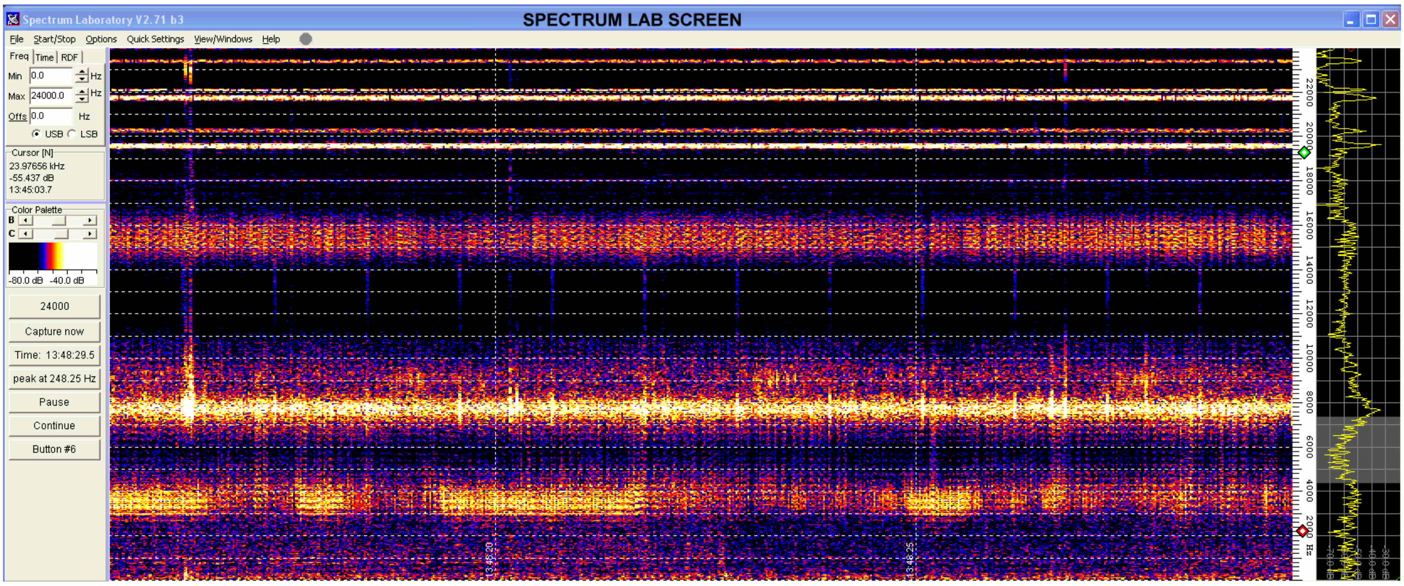


Figure 33 The Spectrum Lab Main Window

The 'Watch List' is a record of the amplitude of the signal at nominated frequencies of VLF transmitter stations. The plot can show the time history of the signal strength over the whole 24 hours for each VLF station.
See Figure 34 for an example over a 3 hour period.

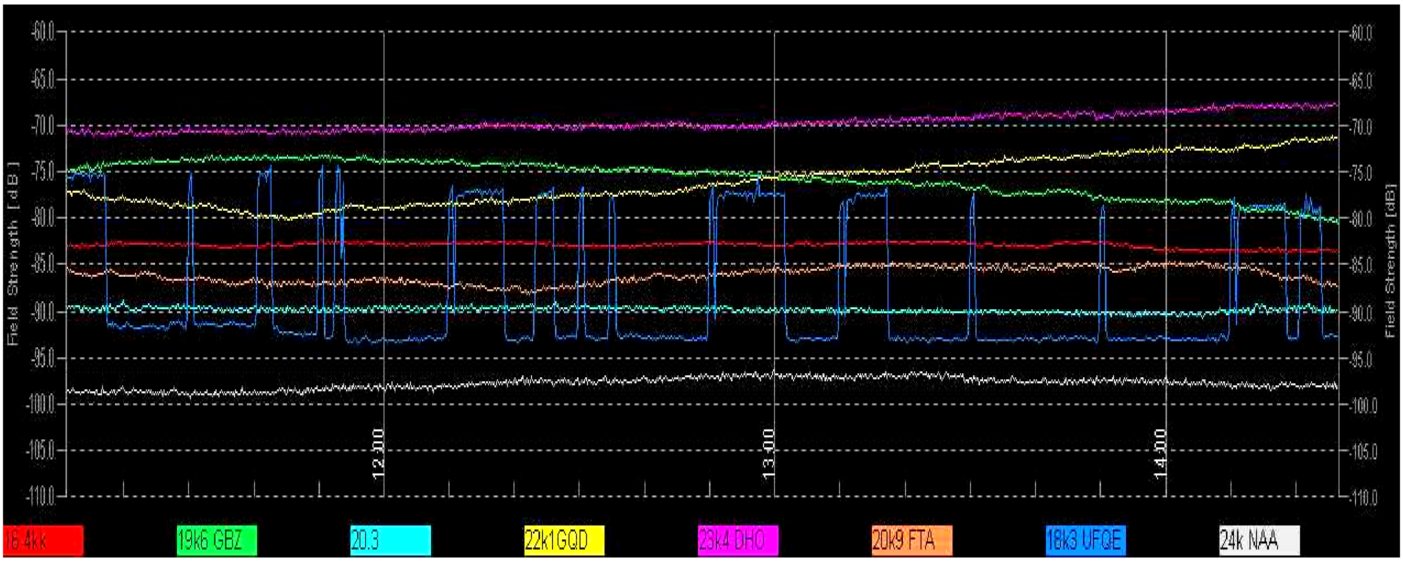


Figure 34 Spectrum Lab Watch List

From all the data collected on each day, the most interesting were selected on the basis of SID activity and are listed in Table 2 below.

Date (DD/MM/YY)	Analysis	Loupe I	SDO		Stereo		GOES X-Ray
			Video	Still	Video	Still	
01/02/2012 - 02/02/2012							
02/02/2012 - 03/02/2012							
03/02/2012 - 04/02/2012							
04/02/2012 - 05/02/2012							
05/02/2012 - 06/02/2012							
06/02/2012 - 07/02/2012							
07/02/2012 - 08/02/2012							
09/02/2012 - 10/02/2012							
10/02/2012 - 11/02/2012	x	x	x				
11/02/2012 - 12/02/2012							
12/02/2012 - 13/02/2012							
13/02/2012 - 14/02/2012							
14/02/2012 - 15 /02/2012							
15/02/2012 - 16/02/2012							
27/02/2012 - 28/02/2012							
28/02/2012 - 29/02/2012							
29/02/2012 - 01/03/2012							
01/03/2012 - 02/03/2012							
02/03/2012 - 03/03/2012							
03/03/2012 - 04/03/2012	x						
04/03/2012 - 05/03/2012							
05/03/2012 - 06/03/2012	x	x	x				
06/03/2012 - 07/03/2012							
07/03/2012 - 08/03/2012							
08/03/2012 - 09/03/2012							
09/03/2012 - 10/03/2012							
10/03/2012 - 11/03/2012							
11/03/2012 - 12/03/2012							
12/03/2012 - 13/03/2012							
13/03/2012 - 14/03/2012							
14/03/2012 - 15/03/2012							
15/03/2012 - 16/03/2012							
16/03/2012 - 17/03/2012							
17/03/2012 - 18/03/2012							
18/03/2012 - 19/03/2012							
19/03/2012 - 20/03/2012							

Table 2 Selected data from measurement program

After inspection, the students selected the most interesting SID events for further analysis. The strongest SID events occurred on three days - and these are marked with a red cross in the table.

The table heading shows the sources of information that the students could access to build up a full picture of the X Ray flare / CME event. The red crosses indicate where they had obtained data.

They include:

- Their own VLF analysis
- VLF data from the SID station in France (Lionel Loudet)
- Solar Dynamic Observatory SDO
- The STEREO spacecraft
- The GOES spacecraft

In the tutor's opinion the students did not access all the sources they should have – this is indicated by the lack of red crosses for the three days they selected for detailed study. Despite the web site information (See Table 3) and the encouragement to access this useful data the students failed to take full advantage of these sources of information.

IMPORTANT WEB SITES FROM WHICH TO DOWNLOAD INFORMATION RELATING TO SIDs

http://www.swpc.noaa.gov/today.html	
http://www.n3kl.org/sun/noaa.html	Space Weather including X Rays
http://sidstation.loudet.org/data-en.xhtml	SID monitor in France
http://stereo-ssc.nascom.nasa.gov/browse/2010/05/05/index.shtml	Stereo spacecraft
http://sdo.gsfc.nasa.gov/	SDO Solar Dynamic Observatory
http://sohowww.nascom.nasa.gov/data/realtime-images.html	SOHO Solar & Heliospheric
http://www.n3kl.org/sun/index.html	Current Solar Data
http://www.srl.caltech.edu/ace/	ACE Advanced composition explorer
http://www.blitzortung.org/Webpages/index.php?mode=0&map=0&lang=en	Lightning in Europe
http://webflash.ess.washington.edu/	Global lightning
http://www.backyardastronomy.net/sid_receiver.html	SID observatory
http://grb.sonoma.edu/index.php	Gamma Ray Burster alert
http://flux.phys.uit.no/cgi-bin/geodata.cgi?site=tro2a	Tromso Geomagnetic Fields
http://geomag.nrcan.gc.ca/common_apps/plt/mp-eng.php?ref=data&plot_type=b_plot	Canada Geo Fields
http://kogma.nict.go.jp/cgi-bin/geomag-interface	Geomagnetic fields

Table 3 Web sites relating to X Ray Flares, CMEs and SIDs

9.2 Typical Data Selected for Analysis

A small section of VLF signal strength data for 11/2/2012 is shown in Figure 35. Here we see the time histories of 8 VLF signals around 10:00hrs GMT. The SID responses are clear on 20.9kHz FTA (France) and 23.4kHz DHO (Germany). A smaller and inverted response can be seen for NAA 24.0 kHz (USA). Note that the path of the NAA signal crosses the Atlantic Ocean, a very different path from those of the European transmitters.

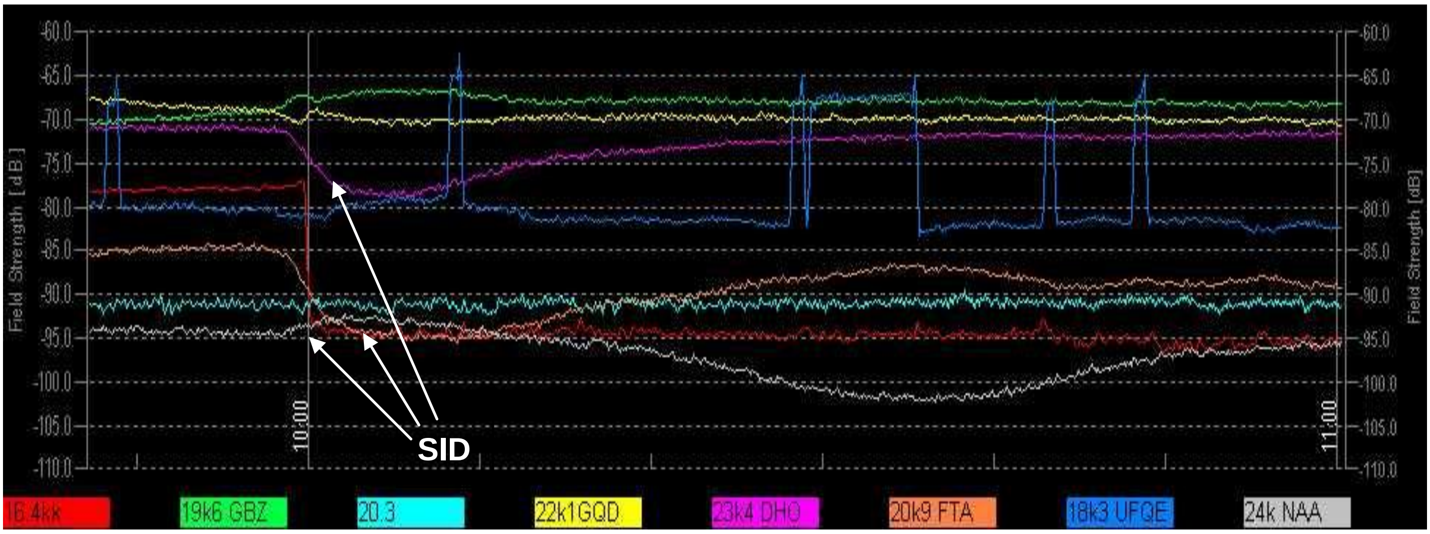


Figure 35 A Typical Raw Data Record – Showing a SID Event

The data for the VLF stations showing the SID are extracted and manipulated in Microsoft Excel to reveal the details of the event. Figure 36 shows 11 hours of data for the three chosen signals. The SID is marked with a dotted line.

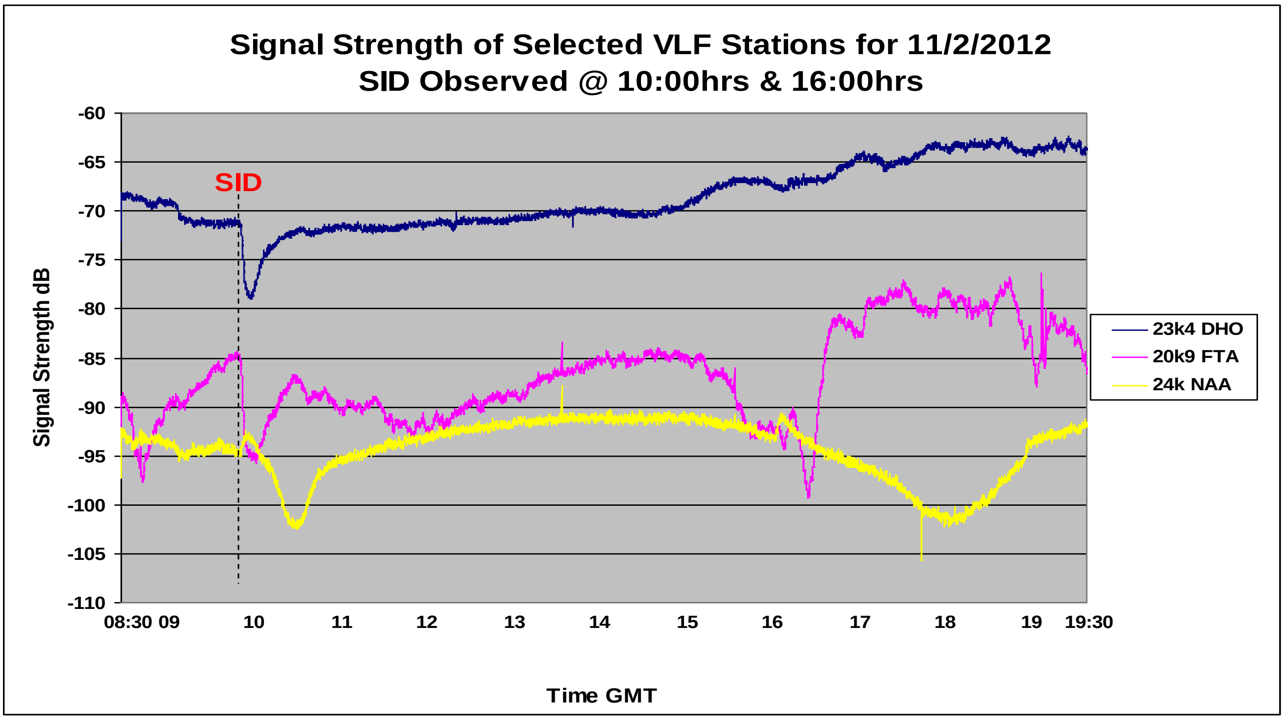


Figure 36 11 Hours of Signal Data Showing a SID Event

9.3 Comparison with GOES X Ray Data

The students were encouraged to correlate their VLF records with X Ray flare data from the GOES Spacecraft to confirm their findings. The GOES records for 11/2/2012 are shown below.

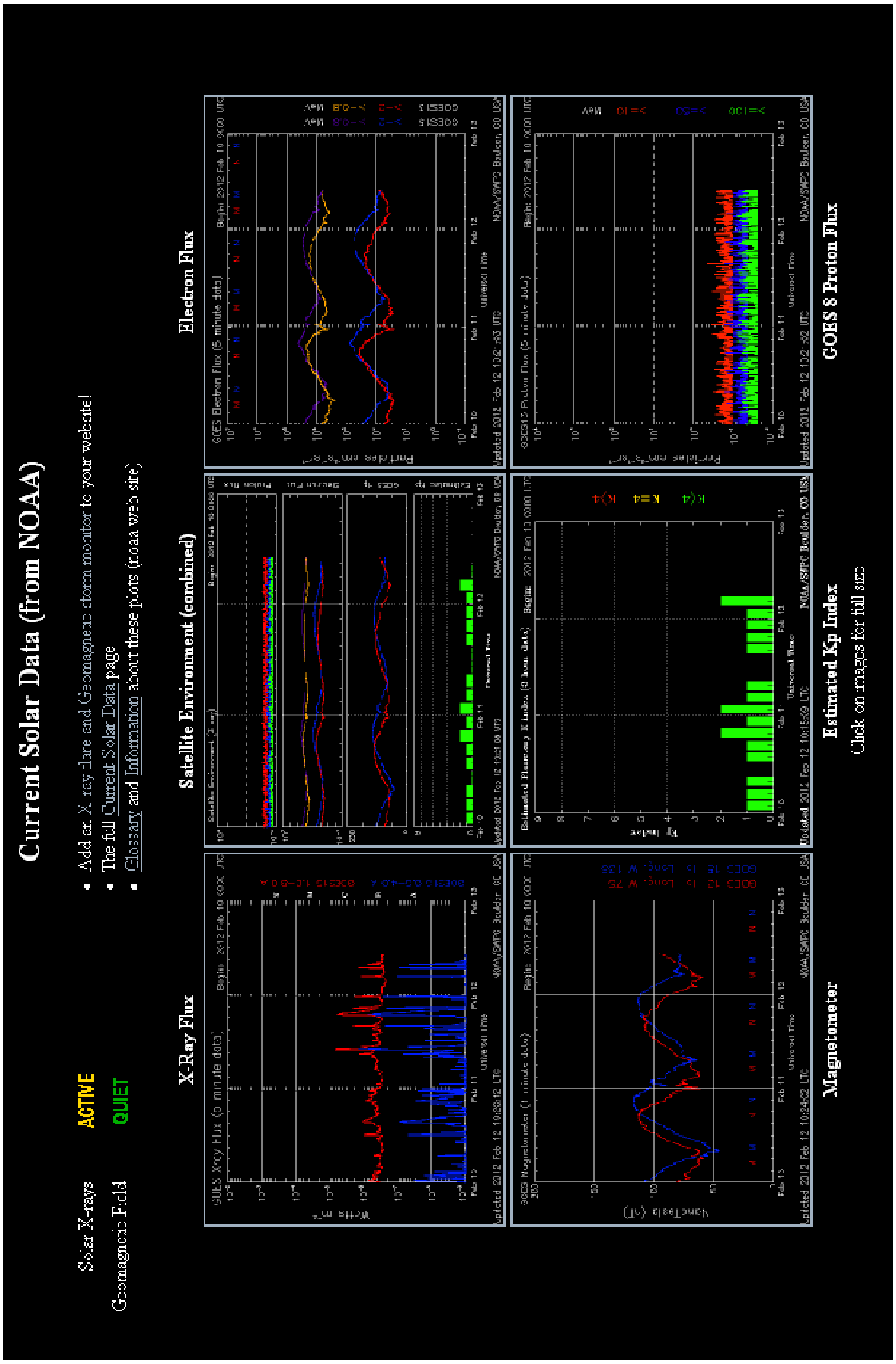


Figure 37 GOES Space Weather Data Showing Solar X Ray Flares

Figure 38 shows the particular X Ray flare that gives rise to the SID observed at the three VLF frequencies.

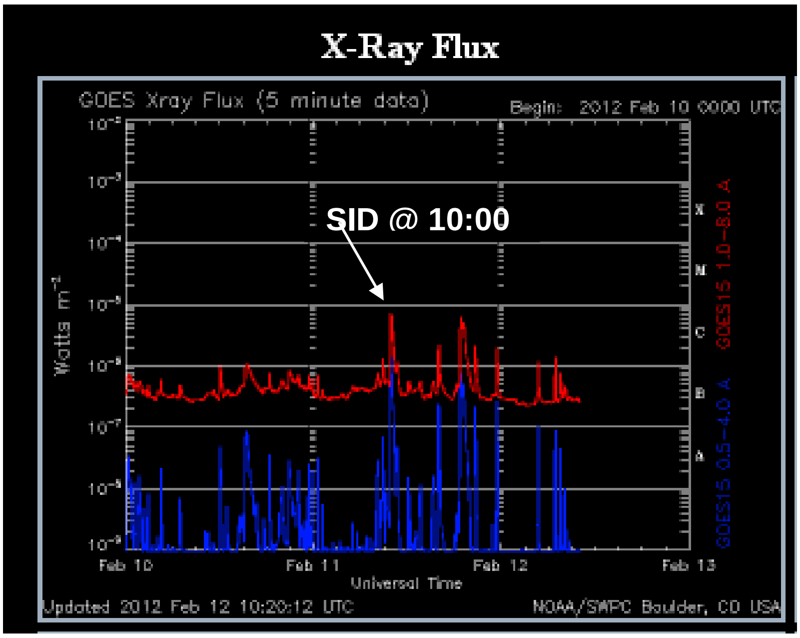


Figure 38 GOES X Ray Data showing the Flare that resulted in the observed SID

The data the students selected and their analysis can be seen in their final presentations on the CD under - Students Section / Final Presentations / 2011-2012 Presentations.

Some students did access the SDO spacecraft site to retrieve relevant Extreme UV Mpeg time lapse pictures of the Sun. One such picture shows the flare responsible for the SID on the 6th of March 2012.

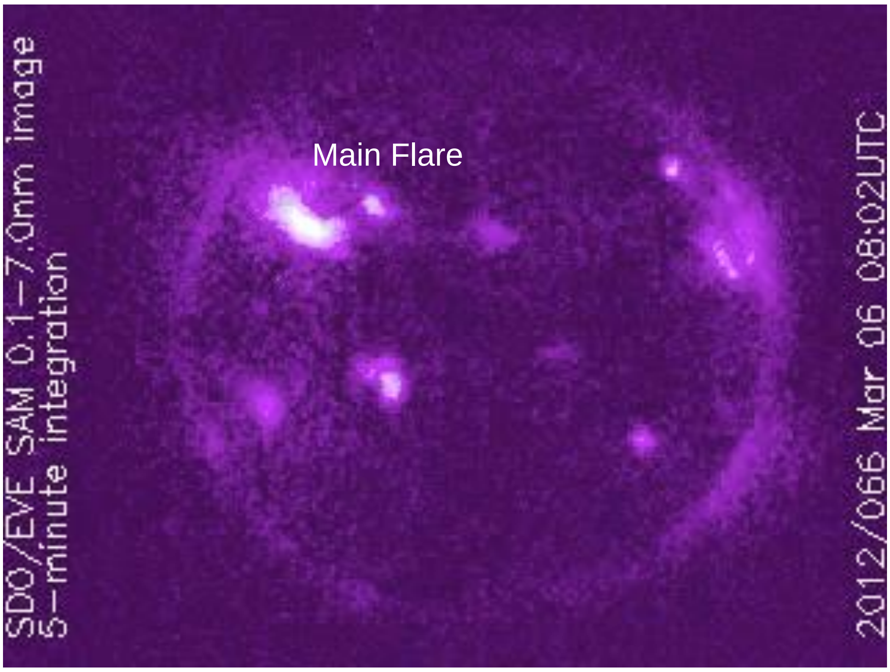


Figure 39 SDO Spacecraft EVE image of X Ray flare on 6/3/2012

10 Student experience of the Project

The students completed the Royal Society Project Evaluation form (except for one) and these can be found on the CD under – Students Section / Evaluation forms.

11 Tutors Experience of the Project

All the students found building the receiver interesting. However there were very different approaches to this task, with some students calmly setting out the circuitry and making neat and careful soldered connections. Some were almost ‘artistic’ in their layouts and regularly encountered spacing problems with components and wiring.

In the 2011-2012 project group there were no female students and this may have led to a less ‘workmanlike’ approach. There had been two female student in the previous year and the atmosphere was more conducive to study and attention to detail.

The number of students taking part in the project was lower than expected. Only four attended, but they did attend almost all the sessions. There were eight students in the previous year and this was more satisfactory as they were able to work in groups of two.

It was something of a disappointment that despite continuing efforts by the tutor, the students did not take advantage of accessing all the sources of scientific data that they could have to support and confirm their VLF SID results.

The students did not seem enthusiastic about preparing their final presentations. It took repeated reminders from the tutor to get most of them to complete this aspect of the project.

12 Acknowledgements

The tutor wishes to acknowledge the support of the following bodies and people involved in this project:

The Royal Society for the allocation of grant funding to enable the purchase of components to build the receivers.

Monmouth Science Initiative (MSI) for providing the framework within which the project is undertaken

The STEM organization for providing liability insurance cover.

Dr Keith Moseley (Head of Physics at Monmouth School) for his personal support.