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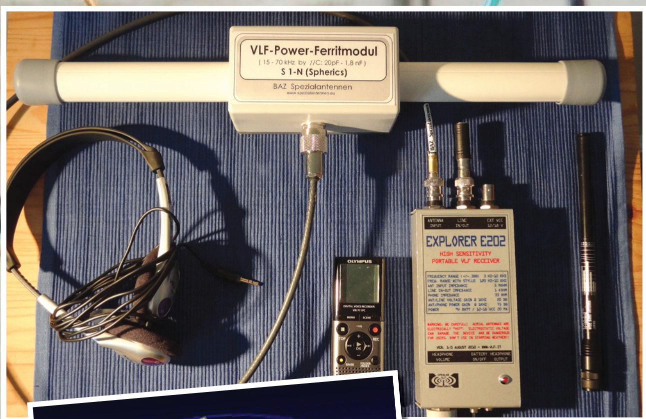

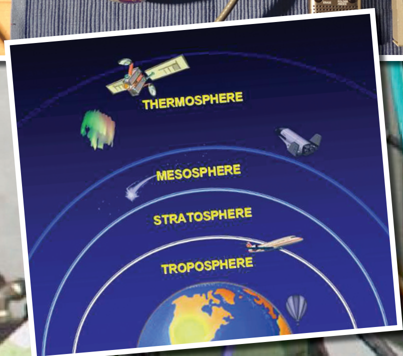

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Georg Wiessala looks at signals in the extremely low and very low frequency spectrum. He then investigates propagation of these signals, musing on the music of the magnetosphere.

Radio in Space and Time – Whistlers, Sferics and Tweeks

In the second part of my series on *Radio in Time and Space*, I am going to tell you about radio "…*but not as we know it.*" The electromagnetic phenomena and sounds in the extremely low and very low frequency (ELF and VLF) spectrum are sometimes described as 'natural' radio and are as fascinating as they are strange. Natural radio is a consequence of space weather.

For many years, I have been interested in space, astronomy and radio, so it seemed natural to seek out overlapping areas of these subjects. Weather forecasting is one such area (see *My Weather Day* in the May 2012 issue of *RadioUser*), as are natural radio and backyard radio astronomy (more on this topic in the future). Radio emissions from nature are an extension of my weather-related interest in space weather. The difference between weather and space weather is clear – our Sun is the source of ordinary, terrestrial, weather. It is also the principal (but not the only) source of space weather. Weather is everything that happens in the troposphere, up to approximately 10 kilometres above the surface of the Earth. According to *An Introduction to Space Weather* (2008: 2) by **Mark Moldwin**, space weather begins in the thermosphere – about 100 kilometres up – and extends all the way to the Sun. Scientists monitor it regularly, by means of the measurement of the number of sunspots, flare index, geomagnetic parameters, solar wind (particles) and solar flux (radiation).

Our Sun, which is one of 100 to 400 billion stars in the Milky Way, is the source of all natural elements on Earth and accounts for 99 per cent of the mass in the solar system – we too are stardust. Each year, in early January, the Earth is closest to our star (approximately 147 million kilometres) and in early July, the Earth is furthest away from the Sun (approximately 152 million kilometres). The empire of the Sun is the heliosphere. Moldwin (2008: 42) describes it as, "…*the vast bubble of magnetism, inflated by the solar wind, encircles our solar system beyond the orbit of Pluto into inter-stellar space*." At the time of writing, the two Voyager spacecraft are about to reach the end of it, leaving our solar system forever – quite a moment in human history.

Some natural radio signals are the sounds of electromagnetic phenomena, which can occur because of the sporadic interaction between the Earth and the Sun. This interaction comes in two forms since the Sun emits two kinds of radiation: corpuscular (consisting of small particles) and electromagnetic. On the other hand, the solar wind hurls particles towards Earth and brings with it the Sun's magnetic field. Solar flares and coronal mass ejections (CMEs) throw radiation at us. Both kinds of geomagnetic storm result in electromagnetic phenomena in our atmosphere. When we see the Sun's effect on our planet with our eyes, for example, we witness auroras – the aurora borealis in the northern hemisphere and the aurora australis in the southern hemisphere. In Greek mythology, **Boreas** carried the North Wind, while the Latin word australis simply means southern.

Other sounds, like whistlers, originate on Earth, for instance, in ordinary lightning discharges – on average about 44,000 per day.

When we just listen, we might hear the music of the spheres – the radio waves, natural radio or VLF sounds this article is all about. The strength and whereabouts of all of this geomagnetic activity are dependent upon a number of factors, including the 11-year sunspot cycle and your location. We are currently in Sunspot Cycle 24, which started in January 2008 – the recording of solar sunspot activity, now referred to as Sunspot Cycle 1, started in 1755.

People have observed both the visual and acoustic effects of space weather for millennia. These phenomena led **Pythagoras** and later philosophers to invent the concept of a *musica universalis* or harmony of the spheres: a perfectly harmonious music, inaudible on Earth. Many believed then that it came from the movement of the planets – each at a different ratio and audio pitch. **Galileo Galilei** famously drew the spots on an imperfect and revolving Sun as early as 1610. **Captain James Cook** recorded in his diary on February 17th 1773, "*Last night lights were seen in the heavens similar to those in the Northern Hemisphere, commonly called the Northern lights, I do not remember of any voyagers making mention of them being seen in the South before.*" However, Greek, Babylonian and Chinese records back to around 500 BCE show that people noticed sunspots much earlier than previously thought.

The music of the Earth's magnetosphere, the sounds of the spheres, was much slower to be understood because the magnetosphere is invisible. In *Whistlers and Related Ionospheric Phenomena* (2006: 11/12), **Robert A Helliwell** reported the anecdotes of soldiers in WWI, who heard strange whistling sounds on long wire telephone lines laid out in the trenches. Some first-time witnesses of these phenomena (at the beginning of the 20th Century) even believed that what they

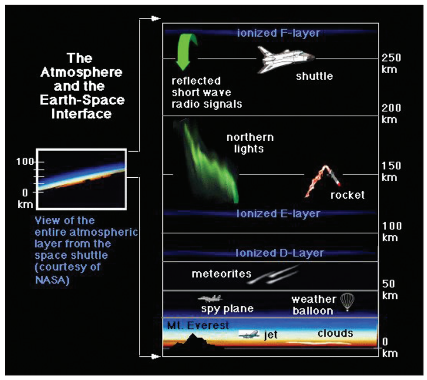
were 'voices from space', the Martians or flying saucers. Now we know that the Martians are only talking to NASA's Curiosity Rover! Check out more on the fascinating history of natural radio on the Natural Radio Lab website.
http://naturalradiolab.com

Table 1 contains a list of significant discoveries in the history of natural radio.

Space Weather and Propagation

Many short wave listeners (SWL) are concerned with the properties of the atmosphere, especially the ionosphere. This is the lower part of the magnetosphere, encompassed by the mesosphere and the thermosphere. If you are a radio amateur, you might have tried meteor scatter communication, which occurs because passing meteors leave reflecting 'tunnels' of briefly ionised particles behind them. Moreover, radio hobbyists know that natural radio and space weather are all indicators of propagation (as well as sources of disruption) which can affect satellite communications, spacecraft and their occupants, aircraft, power lines, pipeline and railway operations and many other aspects of modern life – see **David Smith's** *Airband News* in the August issue of *RadioUser* (2012: 38).

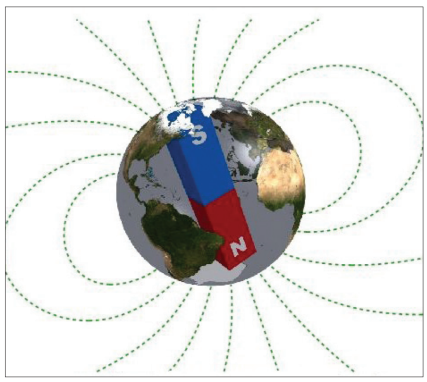
Governments were slow to realise this but there are now documents like the UK House of Commons report on electromagnetic pulses and their impact (*HC 1552 Developing Threats to Electronic Infrastructure*) published



S.Rowland/LPI

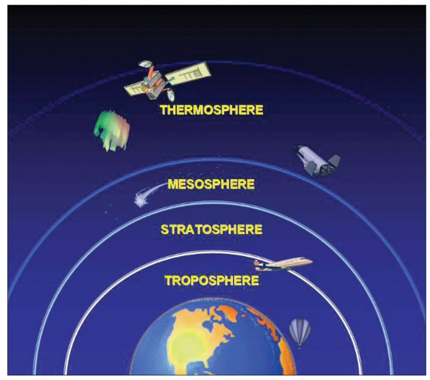
in 2012 and the Parliamentary Office of Science and Technology (POST) *POSTNOTE Number 361 July 2010* on space weather. An example from 'down under' is the Australian Government's Bureau for Radio and Space Weather Services. The Bureau's two-part report, *Space Weather and Radio Communications*, makes interesting reading. For aviation, Eurocontrol now offers material on space weather on its website.

Space weather (photons from the Sun)



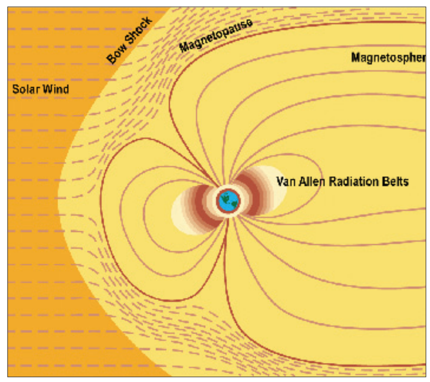
CARISMA

The Earth is like a dipole magnet.



Mr Gardner

modifies the density of the layers of the ionosphere and sub-ionospheric radio reception fluctuates, depending on the degree of ionisation, which occurs due to solar storms, X-rays and cosmic rays. Who has not waited for the (daytime only) D-layer to disperse, so that that elusive DX catch can be logged? The layers of the ionosphere have been compared to a mesh wire fence that reflects radio waves but constantly changes the width of the mesh and thus its reflective capacity (Klawitter 2008: 12). Other propagation



www.centennialofflight.gov

The Earth's magnetosphere showing the location of the Van Allen radiation belts.

variables are time of day, seasons, your geographical location, the Sun's position and the Earth's magnetic field. For the visual side of natural radio, it is the E-layer and Sporadic-E, 90 to 170 kilometres above Earth's surface, which we need to be aware of. Here, we often find the aurorae – as oval shapes around the poles (Moldwin, 2008: 7, 75).

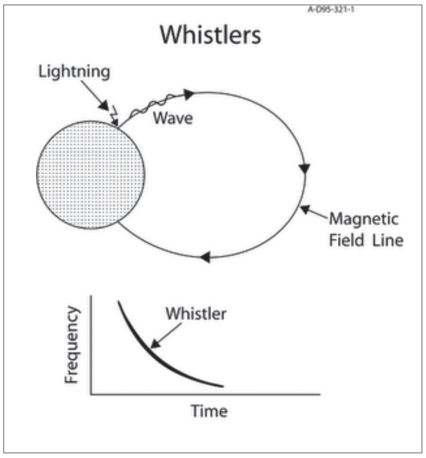
Audible Natural Radio

For the audible side of ELF and VLF natural radio we need to travel beyond the ionosphere, into the magnetosphere. The magnetosphere affects our climate and produces some of the sights and sounds of space weather and natural radio. The movement of molten iron in the Earth's core is responsible for Earth's magnetic field. Our globe is a dipole magnet – something that was first realised by **William Gilbert** (1544-1603),

Table 1: Natural Radio: A History of Discovery, Awe and Wonder

(Sources: Lutz, 2004) and:
www.albany.edu/faculty/rgk/atm101/magneto.htm
http://naturalradiolab.com/a-brief-history-of-natural-radio

1701 **Edmund Halley** (of comet fame) produces first map of variations in the Earth's magnetic field
1852 **Sir Edward Sabine** shows that what happens on the Sun contributes to the Earth's magnetic field
1886 **Robert Helliwell** mentions that the first reports of whistlers came from a 22 kilometre telegraph line in Austria
1894 British observers connected telephone receivers to telegraph lines and heard tweeks, whistlers and chorus
1895 **Alexander Popov** demonstrates that lightning generates some of the natural radio waves (sferics)
1903 **Kristian Birkeland** proposes idea to explain aurora as 'polar rain'
1915 Whistler radio waves detected
1925-1929 **Eckersley, Barkhausen** and other researchers identify magnetic storms and the dispersive medium
1931 **Sydney Chapman and Vincent Ferraro** develop theory for Earth's magnetic cavity
1953 **Owen Storey** proves inter-hemispheric propagation of "whistler" radio waves from lightning
1957 The International Geophysical Year (IGY) was a pivotal event for Natural Radio and geomagnetic research
1959 **Thomas Gold** coins word 'magnetosphere'
1961 **James Dungey** proposes 'magnetic reconnection', transferring solar wind energy into Earth's magnetosphere
1961 Explorer 12 detects the magnetopause (the boundary between the magnetosphere and surrounding plasma
1963 Equatorial plasma-pause identified by **D.L. Carpenter**, through the analysis of "whistler" radio waves
1963 **Hannes Alfvén** describes theory of magneto-hydro-dynamic (MHD) waves and existence of bow shock
1964 IMP-1 (Interplanetary Monitoring Platform) probe detects bow shock and existence of magneto-tail
1976 **Ed Shelley** and others find evidence for polar wind
2001 Four Cluster spacecraft detect rippling of the magnetopause
2006 **Robert Helliwell's** *Whistlers and Related Ionospheric Phenomena* is re-released as a paperback



Springer

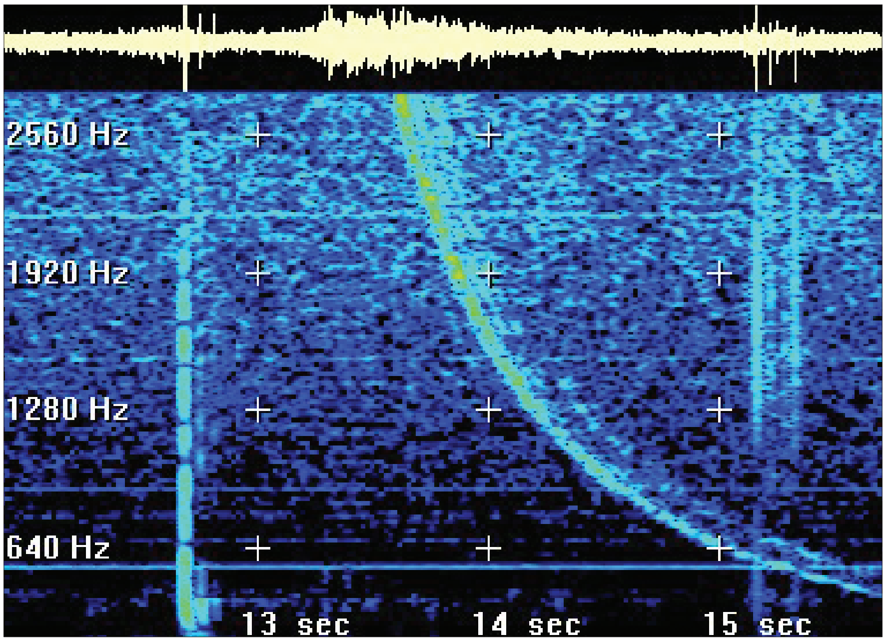
Queen Elisabeth's personal physician, in 1600 in his book *De Magnete*. **www.lancs.ac.uk/fass/projects/gilbert/works/demagnete.htm**

The orientation of this terrestrial magnetic field is northward. This means the field points outwards from the South Pole (off the coast of Antarctica, south of Australia) and inwards at the North Pole (in the Canadian Arctic).

It is principally the electrical currents generated by the movement of molten iron through the Earth's (liquid) outer core, circling the (solid) inner core, which are responsible for Earth's magnetic field. According to the **British Geological Survey** the field, "…*is generated in the fluid outer core by a self-exciting dynamo process. Electrical currents flowing in the slowly moving molten iron generate the magnetic field. In addition to sources in the Earth's core the magnetic field observable at the Earth's surface has sources in the crust and in the ionosphere and magnetosphere*." Blundell (2012: 106) explains further, *'"…the idea is that there is a circulation of hot, conducting, fluid in the Earth's core, driven by thermal effects. As the conducting fluid moves through the magnetic field of the Earth, electrical currents are generated. It is these currents that produce the magnetic field of the Earth".* **www.geomag.bgs.ac.uk/education/earthmag.html**

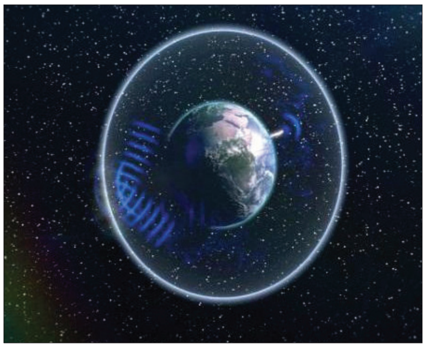
The point where the magnetic field leaves the Earth is the south magnetic pole and the area where it re-enters the north magnetic pole. This is the reverse of the standard definition of a magnet. Solar magnetic interaction of a polarity opposite to the Earth's is most effective at producing the mystifying sounds of natural radio in ELF and VLF.

It has been said that the interaction of the Earth's magnetic field with the magnetised solar wind and solar flux is



NASA

A big whistler.



NASA

The Schumann Resonances.

similar to a rock in a stream – hence the 'elongated' shape of the magnetosphere and the geomagnetic 'tail'. The solar wind is supersonic, so a 'shock wave' (the bow shock) lies on the 'dayside' of the magnetosphere – the whole thing looks a bit like a comet, compressed on the 'day' side and elongated on the 'night' side. Many charged solar wind particles get 'stuck', in the Earth's doughnut-shaped Van Allen belts.

The field is not even in strength and there is a weak patch called the South Atlantic anomaly. This is caused by the 'tilting' of the Earth's rotational axis, compared to its magnetic axis. This 'tilt', amounting to 11 degrees, means the (inner) Van Allen belt comes quite close to the Earth in this area. This phenomenon has repeatedly played havoc with satellites and the Hubble Space Telescope passing over South America. Over the last 40 years or so, the Earth's magnetic field has actually been getting weaker. Blundell (2012: 104) reports a 10 per cent decline since the 19th Century. The field can also 'flip' over – reverse polarity – over time. Geologists have found the evidence of long-term magnetic field reversals encoded in the rocks and lava they have studied through radiometric dating (Blundell, 2012: 114).

Finally, let us bear in mind two things: first, the solar flux consists of radiation (optical, infrared (IR), ultraviolet (UV), radio signals and X-rays). It arrives at our magnetosphere after about eight minutes travel time from the Sun, at the speed of light. The solar wind, by contrast, carries particles (electrons, protons, helium nuclei) travelling, supersonically, away from the Sun at about 400 kilometres per second and meeting our magnetosphere after a journey of four and a half days. The latter pushes the shock wave ahead of it, carrying with it the Sun's magnetic field (Moldwin, 2008: 38).

Renato Romero explains in *Radio Nature: The Reception and Study of Naturally Originating Radio Signals* (2008: 91/2) that the solar wind helps create the field lines, ducts and channels of the Earth's magnetosphere. In addition, the (invisible) channels of geomagnetic field lines surrounding our planet are the superhighways for the first group of signals of natural radio – energy resulting from lightning strikes (tweeks and whistlers). Solar wind and solar flux produce another group of signals (hiss, chorus, auroral chorus, dawn chorus) through interaction with the magnetosphere.

Some listeners like to distinguish between terrestrial and extra-terrestrial origins of these signals (not ET) and between weather sferics and geomagnetic sferics, where (confusingly)

Table 2: Earth Song: Definitions of some 'Natural Radio' Sounds

Chorus: Multitude of rising tones, sounds like birdsong; originates in ionosphere, due to interaction with solar flux, solar wind and CMEs. There is a correlation between auroras and VLF sounds (auroral chorus).
Sferics (Statics): terrestrial; from atmospherics, non-dispersive static interference (radio noise) received from a lightning strike or strikes, via ground wave. Most medium and high band (AM broadcast through short wave) radio receivers can receive them. A dedicated VLF receiver picks up sferics originating thousands of miles away.
Tweeks: terrestrial; dispersive (distorted) statics; the sounds of lightning strikes reflected via sky wave, by the Earth's ionosphere – often heard in the evenings.
Whistlers: extra-terrestrial; sound of the remnants of a lightning strike, after travelling through Earth's magnetic field (magnetosphere). No two are identical, there lots of types and they are strongly dispersive.

'sferics' has become an umbrella term for all those signals.

Music of the Magnetosphere

Spherics are the electromagnetic waves produced by lightning discharges.
The lightning 'canals' act like very tall antennas, creating short duration, broad band, electromagnetic impulses. Some of this 'static' dissipates, via ground waves, some through the conducting boundary of the Earth-ionosphere gap (the waveguide).

These are (weather) sferics, sounding just like 'snap, crackle and pop'. Others, as sky waves, bounce off the (night-time) ionosphere layer and show dispersion (the so-called tweeks). They 'chirp', slightly more tunefully, at around the 1.5 to 2kHz mark. In addition to this, some of it escapes into space and travels back half way around the globe, guided along the field lines of the magnetosphere (whistlers). These signals arrive back to Earth at the 'geomagnetic conjugate point' of where they started, at frequencies between 100Hz and 10kHz.

Therefore, you can hear lightning strikes in South Africa as 'whistlers' in Europe. Whistlers are dispersive, their higher frequency components arrive before their lower ones (Romero, 2008: 36/7). Some of them travel back and forth along the magnetic lines and there is a whole 'zoo' full of varieties of whistlers you can hear: one-hop, two-hop, chains, echo-trains, multi-path and more (Helliwell, 2006: 84/5; Romero, 2008: 38). Most of them sound like musically descending tones ('pioouuu') and Jupiter has them too!

These sound messengers allow us to draw conclusions about the state and electron content of the atmospheric regions through which they travel. This can make very useful additions to the data gathered by ionosondes.

Table 2 contains a list of some natural radio sounds as defined by Robert A Helliwell in 1965 and Renato Romero in 2008. You will also find many 'nature' sounds described as hooks, risers, hiss, insects, buzzers, flying saucers and under many other names. There is a large onomatopoeic (relating to sounds) vocabulary in this field.

Schuman Resonances

Outside the range of this article and outside of the human hearing range (approximately 20 to 20,000Hz) are the spectrum peaks of the Schuman resonances, which also originate in lightning. The resulting phenomenon produces a standing wave in the Earth–ionosphere cavity with a wavelength equal to the circumference of the Earth. It was named after German physicist **Winfried Otto Schumann** (1888 to 1974) who found that the space between the surface of the Earth and the conductive ionosphere acts as a closed waveguide. Schumann resonances appear as distinct peaks in the ELF spectrum, at 7.83 to 8.50Hz and its rough multiples (around 14.3, 20.8, 27.3 and 33.8Hz; figures are slightly variable). Recording them has applications in global earthquake prediction, lightning triangulation, the detection of space weather effects and the study of global climate variations. Just don't believe any of the 'psycho-babble' out there, in regard to brain-waves, the Earth, your health and the Schuman resonances.

Radio Nature Band

Space weather – and many of the sounds of natural radio – are closely linked to the interaction of the solar wind with the magnetosphere of the earth. The second variety of natural radio, closer to Earth, consist of strong electromagnetic impulses and large electrical currents along the 'paths', sketched out by the Earth's magnetic field lines. Both varieties are audible in the ELF and VLF part of the spectrum, the 'radio nature band'.

Outside of the scope of this article are the man-made signals in this band, for example, the hum of the alternating current (AC) power grid (50 or 60Hz) and interference from engines, televisions or machinery. You can find some definitions of radio nature sounds in Table 2.

In Practice

Natural radio – by which I mean phenomena like whistlers, chorus, sferics and tweeks – is relatively easy to receive with the simplest of equipment and there are many sound files readily available on the internet.

Natural radio listening might well appeal to the Summits On The Air (SOTA) and Islands on the Air (IOTA) communities and everyone who likes getting out and about, since the 'urban jungle' with all its electric interference is not an environment conducive to this aspect of the radio hobby.

Physical obstacles can also be a problem. The Natural Radio Lab website, lists three rules for natural radio success. First, listen when you are likely to hear something; second, get away from power lines, trees, houses and other obstructions; and third, check your equipment and plan ahead. I would add a fourth rule – don't be a 'shack sloth'.
http://naturalradiolab.com

Hardware

What you need for baseband signals (approximately 0 to 10kHz) is an electric field receiver, wideband and without frequency conversion – in other words, a low noise audio amplifier with high input impedance (Romero, 2008: 59).

There are diagrams and plans for homebrew receivers on the internet, especially on the websites of Renato Romero and **Steve McGreevy** (see *Websites*). The latter's websites have a link to the WR-3 Receiver.

If you can read German, **Wolfgang Friese** has construction plans, books and antenna tips.

BAZ Spezialantennen offers a ferrite rod antenna (LFM/S2) for VLF which has received favourable reviews in the German (hobby) press.

If you fancy building a kit, then have a look at the INSPIRE Project VLF-3 radio receiver.
http://theinspireproject.org/default.asp?contentID=3

If you prefer ready built equipment, then the Italian firm SISTEL offers the E202 receiver.
www.comsistel.com

Software

Alternatively, you can adjust your computer's soundcard and thus have a software receiver for VLF use. Since most computer soundcards have a maximum sample rate of 48kHz, your PC soundcard will best enable you to receive signals with frequencies under 24kHz (Lutz, 2004: 9). In addition, instructions

can be found online at the following websites.
www.vlf.it/trond2/softreceiver.html
www.vlf.it/harald/strangerec.htm
http://naturalradiolab.com/PDF/NR2010_12.pdf
www.qsl.net/dl4yhf/vlf_rcvr.html

There are other, dedicated, VLF software defined radio (SDR) receivers. The two I have looked at come as software by **KB0KBJ** and **SM6LKM** – they work well on the computer in my shack.
http://kb0kbj.com/ham-radio/vlf-receiver
https://sites.google.com/site/sm6lkm/saqrx

Spectrum Lab, which is in widespread use in the radio hobby community, has an inbuilt VLF setting. Choose from the menu under 'Quick Settings' – 'Natural Radio'.
http://www.ab9il.net/vlf

For signal analysis, I find the Spectrum Lab, Spectran and SFS/RTGRAM software offerings extremely useful.

Online VLF Receivers

Finally, there are streaming online VLF receivers, for example, the 13 feeds available via the website created by **AB9IL**.
www.ab9il.net/vlf/vlf1.html

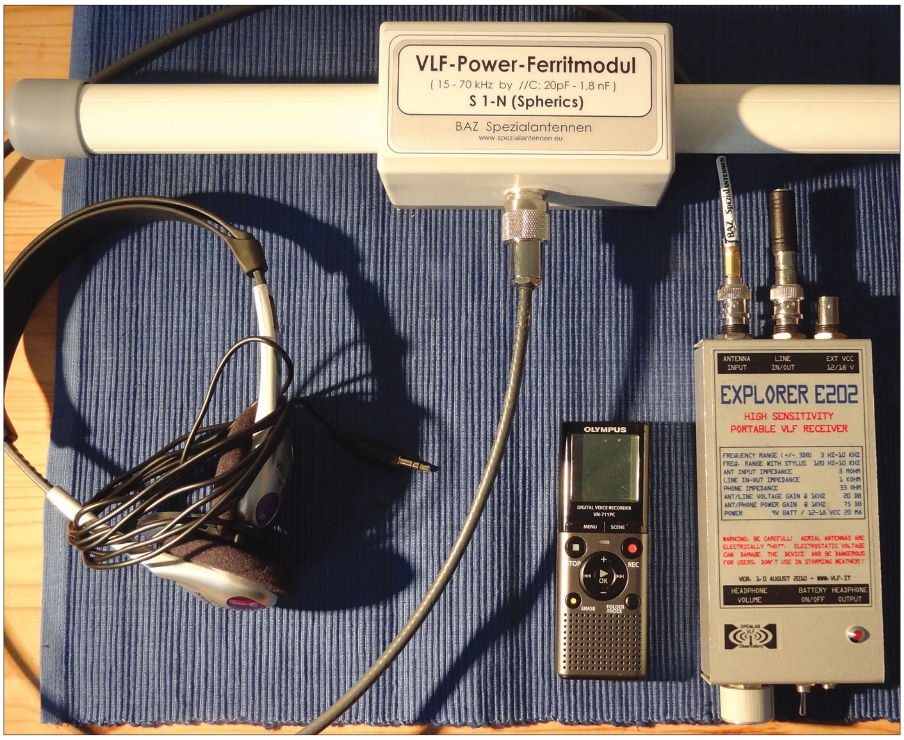
There is also the very engaging NASA Inspire Project radio.
http://theinspireproject.org/default.asp?contentID=3

Online Audio Files

If you would like to get a taste of what VLF Natural Radio sounds like without going to the trouble and expense of new software and equipment and without accessing streaming audio VLF, then you can find plenty of websites on the internet, containing sample audio files of whistlers, tweeks and many other sounds from the magnetosphere (and from space). Have a look at the list of suggested websites at the end of this article. Top of my list would without doubt be Steven McGreevy's (now) five CD compilations, which you can freely download from his two main websites.

These recordings are a real '*labour of love*'. Produced and archived continuously since the middle of the 1990s, they are, no doubt, the fruit of countless trips to the wilds of North America, Canada and elsewhere. The last instalment came out in August 2012.

You do need to try and get away as far as possible from civilisation for this pursuit and possibly quite a way up north but many places in the UK afford good reception. Seek out the places that are known as 'dark sky' locations in amateur-astronomy circles. For an initial listen, the University of Iowa and NASA sound file collections are also a very good starting point, as is the Luxorion website.
www.astrosurf.com/luxorion/audiofiles-geomagnetosphere.htm



My Explorer E202 receiver, whip antenna, BAZ LFM/S1-N antenna and Olympus digital voice recorder.

G Wiessala

SISTEL Explorer E202

When my new SISTEL Explorer E202 arrived from Italy in September 2012, I began reception experiments with both the supplied telescopic whip antenna (RH795, 70 to 1000MHz) and with the tree outside my shack as an antenna. Yes, a tree can act as an excellent antenna in this low frequency area and you will easily find several designs on the internet for tree antennas, as well as ground rod antennas.
www.vlf.it/romero2/explorer-e202.html

In the end, I decided I was interested enough in this aspect of the hobby to invest in some more specialised kit and I sent for a magnetic ferrite rod antenna from BAZ Spezialantennen in Germany. The model in question was the BAZ LFM/S1-N, covering 15 to 70kHz. It is available with an N-Type connector and BNC adaptor cable, for direct connection to your receiver. Alternatively, you can opt to order the antenna with a special connector for a matching amplifier unit that BAZ also provide. At the time of writing, this antenna has delivered by far the best results, both indoors and out.

Having used the receiver with a combination of antennas nearer home, I started exploring the Lancashire countryside around Beacon Fell and Cumbria. From November 2012, I began to receive sferics and tweeks on an almost daily basis but I am still waiting for that elusive whistler and might have to travel further North to catch one!

For the time being, I am recording my reception catches onto an Olympus digital voice recorder (VN-711-PC) as separate MP3 files but I am planning to experiment with other recording equipment in the future. I am also beginning to archive recordings onto DVDs and a separate, dedicated, MP3 player.

Sonograms

I thought I'd also include a few sonograms of pre-recorded natural radio sounds, having used the SFS/RTGRAM software to make these.
www.phon.ucl.ac.uk/resource/sfs/rtgram

Starting with the most recent development in natural radio, Earth chorus recording made in September 2012 by NASA's two Van Allen Probe spacecraft – formerly known as the Radiation Belt Storm Probes (RBSP) – are a remarkable sound testimony, since these were captured from outside of Earth's lower atmosphere – see **Fig. 1.** **http://science.nasa.gov/science-news/science-at-nasa/2012/28sep_earthsong**

Note the succession of rising tones at the bottom of the sonogram, read from left to right.

Fig. 2 shows a sonogram taken from some beautiful whistlers. You can clearly see the 'dispersion-effect' at work here – a range of falling tones.

Finally, for something more 'exotic', **Fig. 3** shows a sonogram of lightning-charge induced whistlers on Jupiter, (Jovian Whistlers) recorded by Voyager a while ago. The (fainter) recording reveals that the laws and phenomena of nature are the same across our galaxy.

See you again soon for more on how I am getting on with this exciting part of the hobby and for some practical insight into reception, logging, signal analysis and antennas. ●

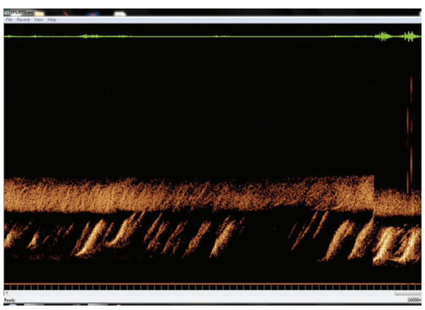


Fig. 1: A sonogram of Earth chorus from a recording by NASA's two Van Allen Probe spacecraft.

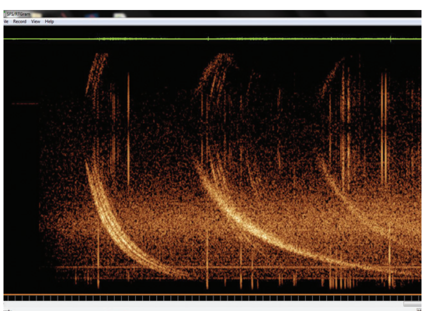


Fig. 2: A sonogram of some beautiful whistlers.

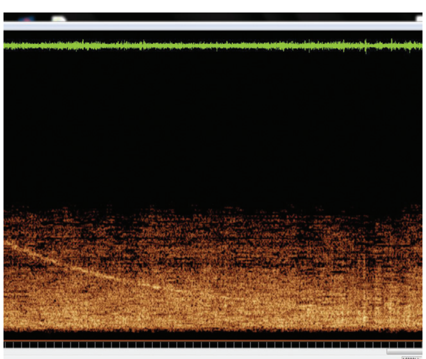


Fig. 3: A sonogram of a Jovian whistler.

Further Reading

Alexander, David (2009) *The Sun* (Oxford: Greenwood Press)
Blundell, Stephen (2012) *Magnetism – A Very Short Introduction* (Oxford: Oxford University Press)
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