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Amateur Radio Astronomy Projects—A Whistler Radio

The author takes us for a ride into the amazing world of natural radio signals!

[In the author's Jan/Feb 2010 *QEX* article, there was an error in Figure 5, the schematic diagram of the Gyrator II VLF receiver. When our Graphics Department created the schematic, a 0.001 µF capacitor, C4, was omitted between sections U1A and U1B of the op amp. When I reviewed the schematic for accuracy, I failed to notice that missing capacitor, and I apologize for the error. Several readers wrote to point out the omission, and we thank them. A corrected version of that schematic diagram is reproduced here. — Ed.]

I wanted to continue my project articles with my favorite, a "whistler" radio.[1] "Whistler" radios (named for the whistle-like sound heard when radio signals from lightning travel along magnetic field lines and disperse) detect the electromagnetic radiation at about 10 Hz to 20 kHz from lightning, aurora, solar flares and other effects on the Earth as they react with the atmosphere. These signals are easily detected and create a variety of sounds, which I will discuss in this article. This gives the "whistler" radio data a distinctive sound quality that no other radio astronomy project has, and makes them much more enjoyable to use and share with others.

[1]Jon Wallace, "Amateur Radio Astronomy Projects," *QEX*, Jan/Feb 2010, pp 3-8.

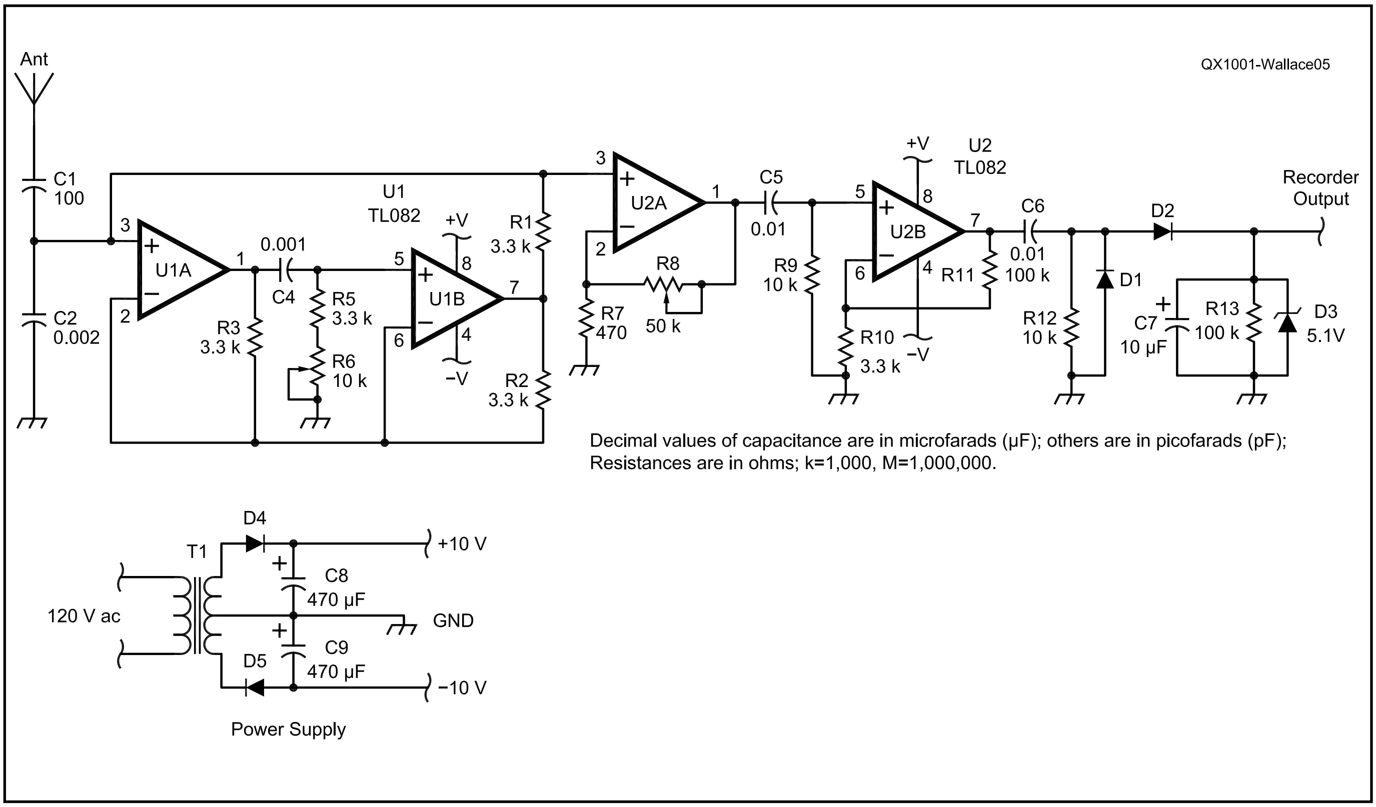

Figure 5 from Jan/Feb 2010 *QEX*, p 5 — This corrected schematic diagram shows the Gyrator II VLF receiver. (Capacitor C4 was omitted.) There is more information, including a complete parts list at www.aavso.org/images/fullgyrator.gif.

Background

VLF and the Ionosphere

The ionosphere is the region of the atmosphere which is ionized by solar and cosmic radiation. It ranges from 70 to 500 km (about 40 to 300 miles) above the surface of the Earth, and is generally considered to be made up of three regions, or layers D, E, and F. Some also include a C region and most experts split the F region into two (F1 and F2) during the daylight hours. Ionization is strongest in the upper F region and weakest in the lower D region, which basically exists only during daylight hours. As I mentioned in the Jan/Feb *QEX* article, solar flare and coronal mass ejection events can strengthen the Ionopsheric regions and they then act as a wave guide for VLF. This is due to the fact that the wavelengths of the signals we are monitoring are a significant part of the height of these regions. (Remember that $\lambda = c / f$ thus (300,000 km/s) / (2000 Hz) = 150 km). This allows signals from lightning to be heard from nearly half way around the Earth.

Geomagnetic Storms

A geomagnetic storm is a disturbance created by a coupling of the Earth's magnetic field with the magnetic field of the solar wind, caused by solar flares, coronal mass ejections, coronal holes, and so on. They can induce large currents into Earth's magnetosphere and as a result can induce currents into long wire antennas and power lines, leading to damaged equipment and blackouts. Given a powerful storm, these events often generate beautiful auroral displays, which can be seen as far south as Florida. Geomagnetic storms have been linked to many VLF emissions such as *chorus* and *risers* (described in more detail below).

Signals Detected

Lightning Induced Signals: Sferics

Sferics is short for "atmospherics" and these signals are caused by the burst of radio energy emitted by lightning strikes. They cover the entire range of frequencies we are monitoring and are by far the easiest signals to detect. They sound like cracks, pops, and snaps, and are characterized by vertical lines on a spectrogram (see Figure 1). Sferics from lightning can be heard from as far as a thousand miles because of the ionospheric ducting mentioned earlier.

Tweeks

Tweeks are generated when lightning occurs at greater distances from the receiver than those of sferics. Distances can be as great as half way around the Earth. While traveling through the ionospheric duct from these distances, the signal experiences dispersion — a process in which higher frequencies travel faster than lower frequencies. This yields a sound for tweeks like a musical saw being plucked, or a musical "twang." They are characterized by vertical lines with "hooks" on their bases, around 2 kHz on a spectrogram (see Figure 1).

Whistlers

Whistlers are created when energy generated by lightning travels away from Earth along magnetic field lines, toward conjugate areas on the Earth. They can sometimes travel back and forth several times between conjugate areas. Since the path along magnetic field lines is very long (as much as three Earth diameters) the dispersive effects are great and the signal sounds like a descending whistle or a bomb dropping. The whistler sound can last for as long as a couple of seconds because of the great dispersion experienced. They are characterized by long descending arcs on a spectrogram (see Figure 1). Whistlers can consist of pure tones if they travel along single paths or be much more diffuse if they travel more complex paths. As mentioned earlier, they can sometimes travel between conjugate areas on Earth, so more than one whistler can be heard from the same lightning event, each experiencing more and more dispersion and therefore spread out more with each trip.

Geomagnetic Signals:

Geomagnetic effects can induce large amounts of energy into the Earth's magnetosphere and generate a number of signals that we can detect. Monitoring the Space Weather Web site (**www.swpc.noaa.gov/today.html**) and looking for a planetary K index over 5 gives you warning of a geomagnetic storm. The planetary K index is a weighted average of the maximum deviations on magnetometers compared to a "quiet day" in several locations worldwide. It is calculated every three hours from near-real-time data from these geomagnetic observatories. It ranges from 0 — very quiet to 9 — very large geomagnetic storm. Any K index over 5 is considered a geomagnetic storm and may generate signals we can detect (see Table 1).

Chorus

Chorus seem to be associated with auroral activity caused by geomagnetic storms (there is more study being done on this effect). Chorus signals have a very distinctive sound, which sounds like crickets or birds chirping, many times sounding like a tropical rainforest soundtrack. The signals are characterized by quick rising arcs of less than a second each in duration on a spectrogram, and they tend to be more prevalent during the early morning hours (see Figure 2).

Triggered Emissions

Other signals can be detected and are lumped together here. They include single

Table 1
Planetary K index, Geomagnetic Index and Magnetic Field Intensity in nT

K	*nT*	*G*
0	0 - 5	0
1	5 - 10	0
2	10 - 20	0
3	20 - 40	0
4	40 - 70	0
5	70 - 120	1
6	120 - 200	2
7	200 - 330	3
8	330 - 500	4
9	>500	5

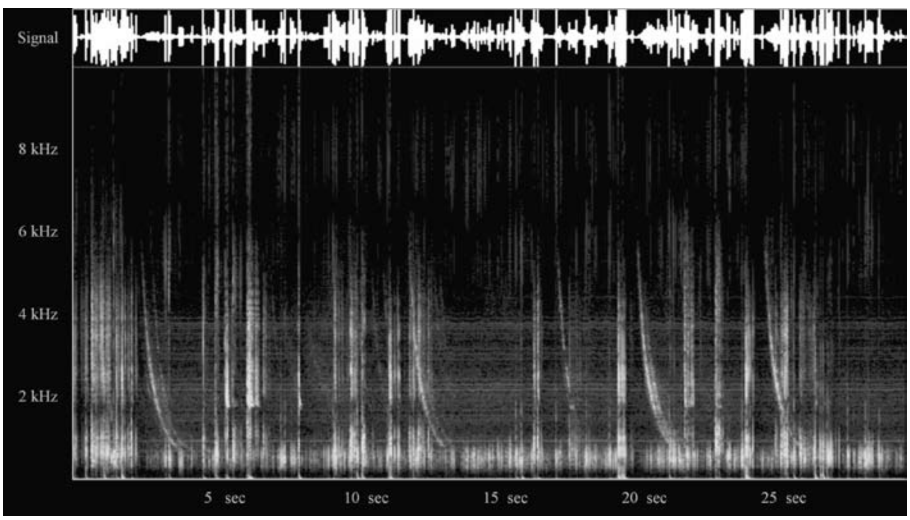

Figure 1 — A sample spectrogram display of natural radio signals. In this display you can see sferics (vertical lines), tweeks (vertical lines with hooks at 2 kHz) and whistlers (download arcs). Original sound file from NASA INSPIRE: www.theinspireproject.org/index.php?page=types_vlf_signals.

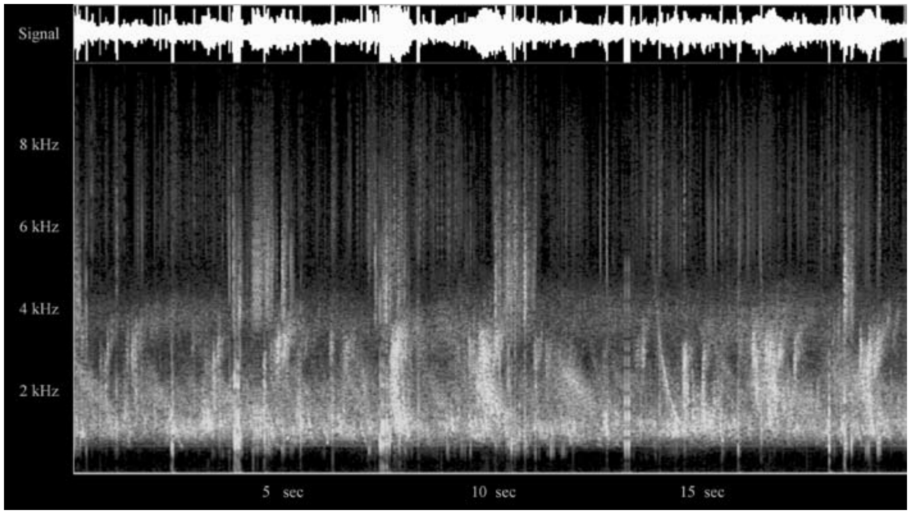

Figure 2 — In this sample spectrogram display you can see chorus signals. Original sound file from NASA INSPIRE: www.theinspireproject.org/index.php?page=types_vlf_signals.

rising tones, hissing, periodic emissions (non-whistler related), and short tonal signals (non-whistler related).

Man-Made Signals:

60 Hz Hum

By far the most readily heard signal and the curse of natural radio listeners is 60 Hz hum. The power lines in the US radiate radio energy at 60 Hz and many harmonics above this, which make it particularly difficult to filter out. This is why you must find a location that is about ¼ mile from normal power lines and at least a mile from major lines to begin to hear the much weaker signals from natural radio sources. On a spectrogram you will notice horizontal rows on your chart, which represent the hum and its harmonics.

Other Electrical Noise

Devices such as electronic ballasts for fluorescent lighting and computer monitors generate distinctive sounds as well. Again, try to get far away from these signal sources so you can detect the weaker natural radio signals.

Loran

LORAN navigation signals can be detected and appear as horizontal dots on a spectrogram. [Recent news stories indicate that the US Coast Guard will stop transmitting US LORAN-C signals as of 2000 UTC on 8 February 2010. See, for example, **www.navcen.uscg.gov/loran/default.htm**. — Ed.]

Russian Alpha and Coast Guard Omega Navigational Signals

Alpha and the now inactive Omega signals can/could also be detected at the upper range of our receiver. They appear on a spectrogram as horizontal rows of dashes.

Other Signals:

Tire Noise

Tire noise can be detected whenever a car drives by. A brief signal is heard, which appears to be generated by static charge on the tire. These signals can only be detected within about a hundred feet or less of the vehicle. It sounds like a short swish or buzzing.

Flying Insects

Apparently, the flapping of insect wings near an antenna can disrupt the signals detected. It is a very distinctive signal and sounds like … an insect flying. Normally it is not a problem unless there are swarming insects or an insect that remains close to the antenna for extended periods of time.

Equipment Needed

The Receiver

Whistler radios operate at the ELF and VLF range (typically 10 Hz to 20 kHz). This band of frequencies is known as the audible band, not because you can hear them (you can't hear radio frequencies directly) but because you can feed them into an amplified speaker with a long wire antenna input and hear them. This explains how people in the 19th century knew about some of these phenomena; they were heard on telegraph lines. Unfortunately, due to the ac power grid and other modern innovations, you now need a receiver that has filtering and more sensitivity than just an amplified speaker. Several sources are available for these radios, all of which work well. Links are included at the end of this article. I currently use the Kiwa Earth Monitor and a small portable unit built by Brian Lucas in England. The Lucas receiver has a ferrite loop antenna that cancels most 60 Hz electrical interference but at a cost to sensitivity (few whistlers will ever be heard with this radio). See Figure

Figure 3 — This photo shows the Kiwa Earth Monitor (left) and Brian Lucas' ATMOSS (right) VLF receivers. (Photo by author.)

Table 2
Sample INSPIRE Data Form

INSPIRE Data

INSPIRE Observer Team ______________________________ Team Number: __________

Coordinated Observation Date: ______________Receiver ____________________

Tape/Recording Start Time (UT) ________Tape/Recording Start Time (Local) ____________

****

Local Weather: ____

Codes: M – Mark (WWV or Voice), S – sferics, T – tweek, W – whistler, A – Alpha, C – chorus

Sferic density: D: ______ Scale of 1-5 (1 – Very Low, 3 – Medium, 5 – Very High)

Time (UTC)	Entry	Observer
_________ M – WWV or V	S T W C A _____________________	D: ___ ______________
_________ M – WWV or V	S T W C A _____________________	D: ___ ______________
_________ M – WWV or V	S T W C A _____________________	D: ___ ______________
_________ M – WWV or V	S T W C A _____________________	D: ___ ______________

3. I've also built an INSPIRE (Interactive NASA Space Physics Ionosphere Radio Experiments) VLF radio (though not the newest version, which is available as a kit from INSPIRE at: **http://theinspireproject.org/**). The receivers are quite simple to build and operate, usually with just some simple filtering options and antenna and headphone inputs. I have tried a bunch of antennas and find that the longer the antenna, the better the signal. There is a trade-off, though, since it is difficult to travel with and erect a long wire antenna (I've been stopped by police officers and people driving by and asked what I was doing), so I've settled for a long whip antenna mounted to a tripod and find this satisfactory for most observing sessions. Grounding is also a necessity. Lastly, be aware that signals can range from barely audible to extremely loud crashes of lightning. Adjust your headphones appropriately so you don't damage your hearing.

Data Recording

I have used cassette tape for years, but with the advent of portable digital recorders I hope to transfer to this type of recording. Be sure the device you use doesn't have an automatic level control, or has one that can be turned off, since this will limit your ability to hear weak signals over loud lightning crashes.

Data Analysis

There are many spectrogram programs available on the web. I currently use the program *Spectrogram 12* by Richard Horne (**www.brothersoft.com/publisher/richard-horne.html**) to view sonograms of my data and visualize natural radio signals. It is a freeware program and is easy to use. Simply input the file you recorded using the function/scan file options and then choose your file. The scan file screen then appears and allows you to adjust all aspects of your sound file. Once you've chosen your preferences for this file, it creates the spectrogram with the sound file shown on top. Of course, what you hear is much better than anything you will be able to create with a spectrogram, so be sure to listen to the recorded data, preferably as you record it, and make notes about what you hear for later analysis. INSPIRE has a format they recommend. Table 2 shows a sample of this form.

When and How to Listen

Generally, whistler activity seems greatest late at night, and the hours from midnight to dawn seem best. I've found my best activity near dawn, and sunrise can be a great time to observe. I've also found that winter and spring are the best times for activity. The INSPIRE program used to schedule coordinated observations during the spring. For geomagnetic activity, you must check the planetary K index and see when it rises above 5. This will give you the best chance to hear chorus and other geomagnetic emissions. These rules aren't written in stone, and some great observing can be had at any time. My suggestion is: if you have the time and the inclination, observe.

I hope you will enjoy listening to natural radio signals as much as I have.

Sources for VLF Whistler Radios and Additional Information

NASA INSPIRE Radio Kits: **http://theinspireproject.org/index.php?page=order_vlf_receiver_kits**

Kiwa Earth Monitor: **www.kiwa.com/ethmon.html**

LF Engineering Co.: **www.lfengineering.com/products.htm**

Steve Mc Greevy's Web site: **http://n6gkj.blackpage.net/vlf/mcgreevy/VLFRadio.htm**

The Society of Amateur Radio Astronomy (SARA): **www.radio-astronomy.org/**

Jon Wallace has been a high school science teacher in Meriden, Connecticut for over 28 years. He is past president of the Connecticut Association of Physics Teachers and was an instructor in Wesleyan University's Project ASTRO program. He has managed the Naugatuck Valley Community College observatory and run many astronomy classes and training sessions throughout Connecticut. Jon has had an interest in 'non-visual' astronomy for over twenty-five years and has built or purchased various receivers as well as building over 30 demonstration devices for class use and public displays. He is currently on the Board of the Society of Amateur Radio Astronomers (SARA) and developed teaching materials for SARA and the National Radio Astronomy Observatory (NRAO) for use with their Itty-Bitty radio Telescope (IBT) educational project. Other interests include collecting meteorites, raising arthropods ("bugs") and insectivorous plants. Jon has a BS in Geology from the University of Connecticut; a Master's Degree in Environmental Education from Southern Connecticut State University and a Certificate of Advanced Study (Sixth Year) in Science from Wesleyan University. He has been a member of ARRL for many years but is not a licensed Amateur Radio operator.