THE POCKET-PORTABLE WR-3 NATURAL-VLF-RADIO PHENOMENA RECEIVER LISTENING GUIDE

By Stephen P. McGreevy

This WR-3 Listening Guide was first begun in mid-1991 and updated as of 29 March 2019

This WR-3 Receiver booklet/guide is also highly useful for all Natural Radio listeners due to its interesting information pertaining to Natural VLF Radio that I have been compiling since 1991. Information for recording using Sony Mini-Disc (MD) recorders and memory-chip-recorders (like my Zoom H2 employing an SD-card) has been added to the Recording section. Additionally, I am updating info. about how to interface the WR-3 output jack to the newer PC/phone 4-conductor jacks that combine stereo audio outputs with a monoural mic-level input (i.e. the lowest conductor closest to the "holder" of the plug (3.5 mm type/4-conductor) is the mic-level connection). One or two series 47 K resistors(s) plus a parallel termination-resistor of 1K suffices fine for interfacing the WR-3 joint 3.5mm audio-output jack (headphone level audio) of the WR-3 to the mic-level input of PCs and phones so you may employ their recording apps!(Stephen P. McGreevy, 12 February 2018)

Welcome to the realm of extreme and very-low-frequency (ELF/VLF) "Natural Radio!" The WR-3 is an electric-field ("E-field") type of "whistler receiver" specifically designed to monitor naturally-occurring VLF radio emissions of Earth **that occur in the 300-11,000 cycles-per-second (0.3-11 kHz) audio-frequency ELF/VLF radio spectrum**. It employs a telescoping whip antenna (BNC-mount) to receive VLF signals and requires stereo-mini headphones to be plugged into its output for listening.

(Older Photos of the WR-3):

May 2001 photo of the WR-3 shown with Superstick II BNC-base telescoping whip antenna

The original WR-3, in production since September 1991 has become one of the more popular VLF receivers to date due to its pocket portability, ease-of-operation, and high-sensitivity with a short antenna. It is the end-result of a third prototype version of a handheld VLF receiver developed by Frank Cathell and Steve McGreevy of Conversion Research in August 1991.

The original WR-3 which has an improved RC bandpass filter and input filter are now produced and distributed by S. P. McGreevy Productions as of November 1993. This receiver is currently in use in over 50 countries worldwide by individual listeners, aurora viewing tour groups, and science-research groups.

Earth-along with several other planets in the Solar System including Venus, Jupiter, Saturn, Uranus and Neptune - produces a variety of naturally occurring radio emissions at the lowest end of the radio spectrum (< 10 kHz), primarily in the form of electromagnetic (radio) impulses generated by ongoing lightning storms and also from the Sun's solar wind interacting with the magnetic envelope surrounding Earth, called the "magnetosphere." A large variety of unusual and beautiful Natural Radio sounds can be heard at ELF/VLF frequencies. These naturally-occurring radio signals are the subjects of ongoing scientific research by both amateur and professional groups, and are being monitored both on the ground by users of the WR-3, other ground-based VLF receiver systems, and by unmanned space probes and satellites.

It is at these lowest frequencies of the radio spectrum in which no man-made signals are assigned, that planet Earth's own mysterious radio emissions have been happening for eons. These fascinating "sounds" are "primal radio"-indifferent to the affairs of humankind-and insight into the causes of these ancient phenomena has only begun to be unraveled in the past 50 years, particularly commencing with the International Geophysical Year beginning in 1957.

LIGHTNING-STORM ATMOSPHERICS ("SFERICS") & TWEEKS: NOT JUST MERE "STATIC"

Besides 50 or 60 Hertz (and harmonics) alternating-current powerline "hum" from electric-utility power grids, the most noticeable sounds are going to be the snap, crackle and pop of lightning-stroke electromagnetic impulses (called "atmospherics" or "sferics" for short) from lightning storms within a couple thousand miles of the receiver--the more powerful the lightning stroke (or the closer it is your listening location), the louder the pops and crashes of sferics will sound in the WR-3 headphones. I should note here that some books and on-line texts use the term "sferics" to mean ALL natural radio phenomena, but more experienced listeners prefer to keep that term specifically for lightning-bolt (static) impulses (atmospherics).

Several million lightning strokes occur daily from an estimated 2000 storms worldwide, and the Earth is struck 100 times a second by lightning. The WR-3 makes quite an effective "lightning monitor"-at times the receiver's output is a cacophony of crackling and popping sferics in an ever-changing texture from lightning strokes originating in storms near and far.

These huge sparks of lightning strokes, whether from cloud to ground or within a lightning cloud cell, are tremendously powerful sources of electromagnetic (radio) emissions throughout the radio-frequency spectrum-from the very lowest of radio frequencies up to the microwave frequency ranges and the visible light spectrum. However, most of the emitted electromagnetic energy from lightning is in the very lowest part of the radio spectrum, from 0.1 to 10 kHz, which are the frequencies the WR-3 VLF receiver has been designed to monitor. The powerful electromagnetic radio pulses produced by lightning strokes travel enormous distances at these very-low radio frequencies, following the surface of the Earth as "groundwaves" or by other unusual propagation means.

It is quite interesting to note how generally quiet and lightning sferic free the hours are from just after sunrise to midmorning, when thunderstorms tend to be at their minimum. Later, the crackling and popping of lightning sferic activity picks up as afternoon thunderstorms build in numbers and intensity because of thermal heating and convection, especially in the summer and autumn months, when, by sunset, the sferics (snap, crackles and pops) are roaring in a varied and ever-changing texture as lightning storms rage on into the evening. Weather monitoring agencies employ special receivers that receive and direction find lightning sferics in order to determine where lightning strikes are occurring and the potential for wildfire ignition, hazards to aviation, and damage to electric power utilities from those lightning strikes.

While to some, the popping and crackling of lightning sferics may sound like just annoying "static," you should keep in mind that each click or pop is a lightning stroke flashing somewhere, and you also should note just how MUCH lightning is going on even though your local weather may be cloudless. Additionally, distinct seasonal variations in the density of moderate to strong lightning sferics are very noticeable with the WR-3. During the winter months in the mid-latitudes, when the electrical storm density is generally at its lowest, the amount of strong sferics are also at a minimum. Mid-winter, especially in the higher latitudes north of 40 degrees, can be very quiet with very little lightning sferic activity. However, a weak but continuous background level of lightning sferics may be audible between the few strong sferics--these are from the higher amounts of lightning storms occurring in the tropics and from the opposite hemisphere's summer lightning storms. Contrast that to local summer evenings, when there is a continuous "roar" of lightning sferics heard with the WR-3. The Earth is truly "awash" with lightning storm activity! Aesthetically, the random nature of lightning stroke sounds in the headphones can be soothing, much like the patter of rain drops on a roof.

TWEEKS:

At night, many of the popping and crackling sounds of sferics take on a pinging/dripping sound, called "tweeks," and can be quite musical sounding. Recordings of tweeks slowed down about 8 times sound vaguely like "Chinese Opera" gongs. Tweeks are a result of the impulse path from the lightning stroke to the receiver being influenced by the Earth surface-to-ionosphere (D and E-layers) region, which is about 45 and 75 miles (73 - 120 km.) respectively in height, measured vertically during the nighttime hours. This region between the lower ionosphere and surface of the Earth acts as a "duct" or "waveguide" at these VLF radio frequencies, which have wavelengths ranging from 18 miles/29 km. at 10 kHz to over 186 miles/289 km. @ 1 kHz, allowing lightning stroke impulse energy to travel considerably farther than during the daytime. As the lightning-stroke radio energy travels and is reflected within this Earth surface-ionosphere waveguide, the energy undergoes a slight "dispersion" effect whereby the higher frequencies of the lightning impulse arrive slightly before the lower ones within a fraction of a second. The 'waveguide dispersion effect' abruptly cuts off below about 1.5 to 2 kHz (1,500 to 1,900 Hz) in frequency (nominally 1,700 Hz or 1.7 kHz), resulting in the ringing/pinging "tweek" sound which is also centered around 1.5 up to about 1.9 kHz. Notably, on occasions there are tweek-harmonics at multiples of the fundamental frequency. This ringing/pinging "tweek" sound you hear is the lowest resonance frequency of the ionosphere-Earth surface waveguide and varies considerably depending upon the propagation-path location, path-length, height of the lower ionosphere, and other factors). This is similar effect to what sound waves experience in a pipeline. If you have ever clapped your hands inside a pipeline that was between about 1 meter/yd. in diameter, you will notice a sound somewhat similar to the radio sound of tweeks.

Because the Earth-surface to ionosphere waveguide cannot support radio energy below about the nominal frequency of 1.7 kHz, the dispersion effect is abruptly cutoff below that frequency, thus creating the resonance-like pinging and ringing sounds.

The sounds of tweeks can change on an hourly basis and from night to night, with the ringing and pinging effect very intense and musical at times, especially in the middle of the night in spring, summer and autumn when there is a higher density of relatively strong sferics. Only a few pops and crackles of sferics may be "tweeking," or all of them can be, and the tweeks may sound "crusty" (indicating harmonics) or be very clean/clear-sounding pings and rings that can be quite beautiful sounding. Tweeks can be indicators of the condition and height of the lower layers of the ionosphere to researchers as just described, but to many listeners to them including this writer, they also contribute to the aesthetic sounds of Natural Radio!

SAFELY DISTANT (over 30 mi./45 km away) but visible summer-time "heat-lightning" can make for a fascinating study of the nature of the electromagnetic sferics and their correlation with the visible characteristics of the lightning. The sounds of sferics from ground strikes compared to the sound of sferics from cloud-to-cloud/within cloud lightning strikes can be observed, and which of those lightning strikes are triggering whistlers, if they are at all. Please exercise caution when viewing distant lightning and be prepared to discontinue use of the WR-3 and seek safe shelter if lightning clouds approach your listening location.

The WR-3 can also be employed as a lightning detector, albeit a crude one, by detaching the telescoping whip antenna whereby the antenna screw post or BNC-connector base becomes the receiver's "antenna." Sensitivity can be raised by attaching a short length of wire or even a large size paper-clip stretched-out (couple of inches/a few cm in length), or a small alligator-clip to the antenna input if it is an older WR-3 employing the screw-mount.

Any invisible lightning strokes in suspect cloud formations will emit strong enough impulse sferics (pops/cracks) which will be audible in the WR-3's headphones. By de-sensitizing the receiver in this fashion, it will receive only lightning sferics that are very strong and hence emitted from close-by lightning (Alternatively, an AM/MW-band radio tuned to about 520 to 530 kHz - that is, toward to low-end of the band, works nicely in this fashion also.

This all should be done only in a safe location and not out in the open where any nearby lightning might strike. If out in the open and very strong lightning sferics are heard with suspected lightning clouds nearby, immediate lightning safety precautions should be instituted immediately. Never take shelter under trees during lightning - the induced ground currents from a nearby lightning strike to trees can kill! If you are ever caught outside while a lightning storm approaches, it is best to locate a low-spot that has flat, low rocks to crouch upon so as to further insulate your body from potentially lethal ground-currents induced by a nearby lightning strike.

Because of the many years I have had listening to lightning sferics, I have come to know quite alot about lightning and its effects upon the Magnetosphere as well as the general nature of electromagnetic-pulse (EMP) emissions. Besides Gamma Ray Bursts, Sprites and Jets in addition to upward-lightning striking the ionosphere (creating or contributing to sporadic-E-ionization? whistlers at ELF-VLF?); lightning strokes produce gobs of radio energy that I have studied for decades, especially at ELF and low-VLF radio frequencies. Your WR-3 opens up a door into observing and the subsequent understanding of the various types of EM-emissions from lightning strokes at ELF-VLF (audio-band) radio frequencies.

WHISTLERS: Endless varieties...

In addition to the musical pinging, dripping, popping, and crashing sounds of lightning sferics and tweeks, you may be rewarded by hearing downward falling musical notes ranging from nearly pure to "swishy" or "breathy" sounding tones from 1/2 second to over 4 seconds in duration. These are the aforementioned "whistlers," and they may sometimes happen a couple of seconds after some of the static crashes and pops of sferics from lightning strokes, although quite often no preceeding lightning static sound is heard.

One of the best known natural radio phenomena, Whistlers generally sweep downward in frequency from about 6 kHz to around 0.5 kHz, but the lower cutoff frequency does vary markedly as conditions change, and the upper frequency of whistlers can sometimes start higher than 10 kHz. Whistlers sound quite fascinating - sort of like some "science-fiction" sound effects - and besides lightning sferic "static" are one of the more common Natural Radio sounds you can hear with your WR-3. They occur in many varieties and characteristics.

In September 1989 I discovered the phenomenon of "tweek echoes" or tweek reverb" upon taking some natural radio recordings I made of tweeks from the Big Island of Hawaii in the middle of the night, at the times of night lightning bolt radio energy propagation at ELF frequencies is most intense (the space between the ionosphere and Earth's surface, especially the Oceans(!) create an efficient type of "waveguide" that propagates the lightning EMP emissions for very long distances, but the cut-off at about 1600 to 1700 Hz of this pseudo-waveguide creates the ringing/pinging sounds of tweeks, and out in Hawaii they are beautiful due to long oceanic paths to storm sources.

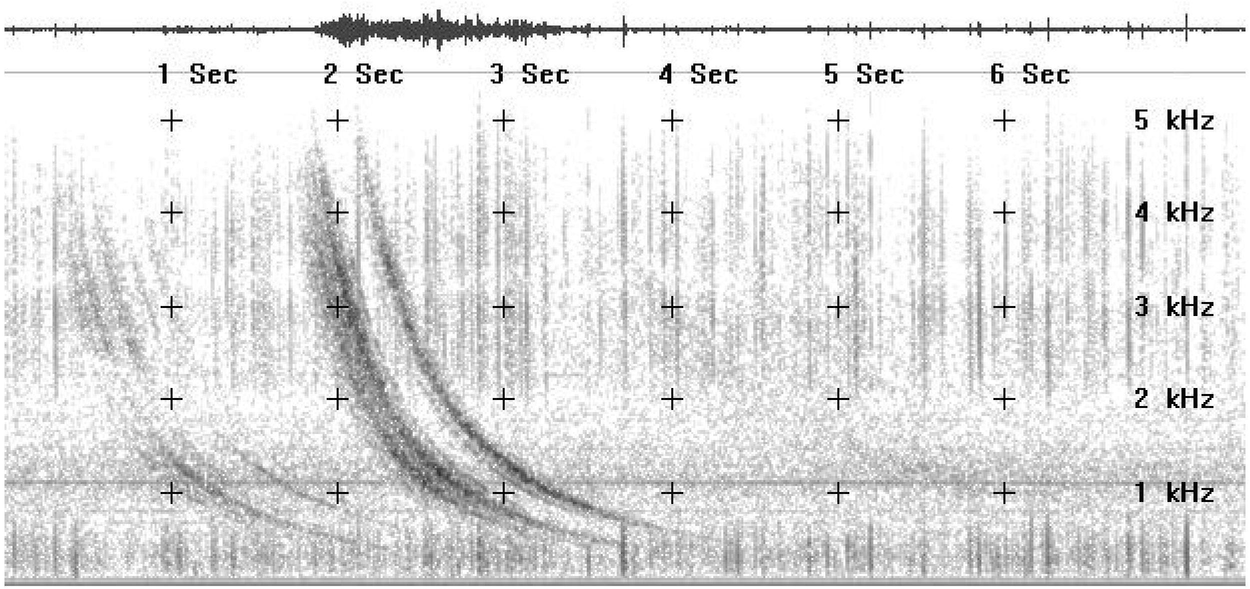
Returning home to Marin County after my stay on Hawaii Island, I slowed-down the tape recordings up to 16 times, and noted that a substantial amount of the deep-tweeking sferics had two or three "echoes" or "reverbs" at identical intervals occurring after the initiating (or first) tweek-sferic, owing likely to varying propagation paths within the waveguide (at varying ray-path-angles).

The Magnetosphere

The Earth's outer magnetic field (the "magnetosphere") envelopes the Earth in an elongated doughnut shape with its "hole" at the north and south magnetic poles. The magnetosphere is compressed on the side facing the Sun and trails into a comet-like "tail" (the "magnetotail" which exetends well beyond the orbit of the Moon) on the side away from the Sun because of the "Solar Wind," which consists of energy and particles (plasma) emitted from the Sun and "blown" toward Earth and the other planets via the Solar Wind. Earth's magnetosphere catches harmful electrically charged particles and cosmic rays from the Sun and protects life on Earth's surface from this lethal radiation. Amongst the charged particles caught in the magnetosphere are ions (electrically charged particles), which collect and align along the magnetic field "lines" stretching between the north and south magnetic poles.

These magnetic-field aligned ions bombarding Earth's magnetosphere form "ducts" which can channel lightning-stroke electromagnetic impulse energy. Whistlers result when an electromagnetic impulse (sferic) from a lightning-stroke enters into one of these ion-ducts formed along the magnetic lines of force, and is arced out into space and then to the far-end of the magnetoionic duct channel in the opposite hemisphere (called the opposite "magnetic conjugate"), where it is heard as a quick falling/descending emission of pure note tone or maybe as a brief "swish" sound. Whistlers sound the way they do because the higher frequencies of the lightning-stroke radio energy travel faster in the duct/waveguide channel and thus arrive before the lower frequencies in a process researchers call "dispersion." A person listening with a VLF receiver like the WR-3 in the opposite hemisphere to the lightning stroke (at the far end of the Magnetospheric duct path) will hear this "1-hop" falling note whistler. One-hop whistlers are generally about 1/3 to 1 second in duration.

If the energy of the initial "1-hop" whistler gets reflected back into the magneto-ionic duct to return near the point of the originating lightning impulse, a listener there with a VLF receiver will hear a "pop" from the lighting stroke impulse, then roughly 1 to 2 seconds later, the falling note sound of a whistler, now called a "2-hop" whistler. Two-hop whistlers are generally about 1 to 4 seconds in duration depending on the distance the whistler energy has traveled within the magnetosphere. One-hop whistlers are usually higher pitched sounding than 2-hop whistlers - another sound illusion we hear with our ears but when displayed in a spectrogram we can see that they are fast versions of 2-hop whistlers.



Spectrogram of strong 2-hop whistler (and a weaker one) recorded in northern Nevada on 19 April 1996 at 2358 UTC - S. McGreevy

The energy of the originating lightning stroke may make several "hops" back and forth between the northern and southern hemispheres during its travel along the Earth's magnetic field lines-of-force in the magnetosphere. Researchers of whistlers have also observed that the magnetosphere seems to amplify and sustain the initial lightning impulse energy, enabling such "multi-hop" whistlers to occur, creating long "echo trains" in the receiver output which sound spectacular! Each echo is proportionally longer and slower in its downward sweeping pitch and is also progressively weaker. Conditions in the magnetosphere must be favorable for multi-hop whistler echoes to be heard. Using special receiving equipment and spectrograms, whistler researchers have documented over 100 echoes from particularly strong whistlers - imagine how much distance the energy from the 100th echo has traveled - certainly millions of miles/Km! Generally, only 1 to 2 echoes are heard if they are occurring, but under exceptional conditions, several echoes will blend into a collage of slowly descending notes and can even merge into coherent tones on a single frequency -- hard to describe here, but quite unlike any familiar sounds usually heard outside of a science-fiction movie!

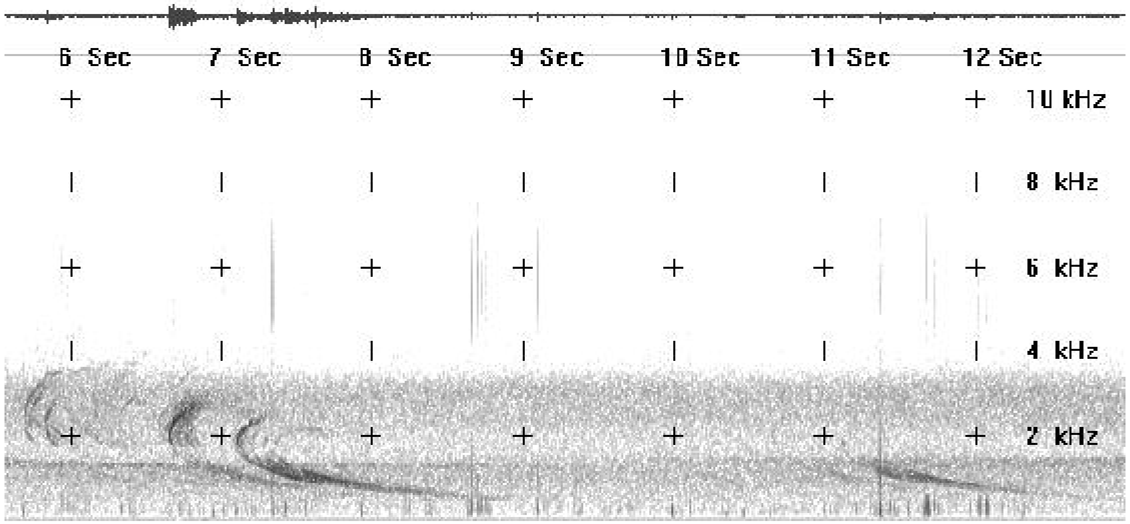
It should be reiterated that strong 2-hop (and echoes) can occur from lightning that is not necessarily close to the listener or even within a couple of hundred miles from the your listening location, but perhaps from lightning that is over 1000 miles distant. Magnetic field conjugate points are not fixed but always in flux as is Earth's magnetosphere.

COnjugate Region 1-hop whistlers: If you know the exact or nearby "conjugate region" - this is, where the opposite-end of the magnetic-field line in the opposite hemisphere from your own, it is possible to determine via global weather maps and lightning-stroke maps where lightning is happening, and if lightning storms are near the conjugate region (such as New Zealand for the Pacific Northwest of North America for one example, strong one-hop whistlers might occur). Periods just after magnetic storms and periods of fast solar-wind streams coming from the Sun through coronal-holes (should be above 500 km/sec. speed) can create ideal magnetospheric conditions to spawn whistlers of this kind.

You may notice that "louder" sferics (i.e. closer lightning strokes) often do not trigger the loudest whistlers, if they do so at all, but then a loud whistler may come howling through from a relatively weak sferic from quite distant lightning. This is because the lightning impulse sferic energy may propagate within the earth-ionosphere region for considerable distance before entering a magnetospheric "duct." A vast majority of fine whistlers are heard during periods of locally fair weather - lightning need not be within visible distance. In fact, many extremely loud "big whistlers" are heard WITHOUT ANY preceding lightning sferic audible whatsoever, indicating the initiating lightning-strokes of those strong whistlers are very far away - possibly over 3000 miles!

Whistlers are best heard in latitudes between 30 and 60 degrees north latitude in North America, with the prime latitude being 30-45 degrees north. I have heard strong whistlers in Hawaii in October 1991, during that time when it was near solar-maximum. (More on this under the "WHERE TO LISTEN" section further on).

At higher latitudes such as in Canada, Alaska or Scandinavia , a type of whistler called "nose whistlers" can be easily heard when they are occurring. These are named for the way they appear in spectrograms, and often occur in clusters. They are quite spectacular sounding. Nose whistlers have both rising and falling frequency components. Compare the nose whistler spectrogram below to the one of the whistlers recorded in Nevada above.



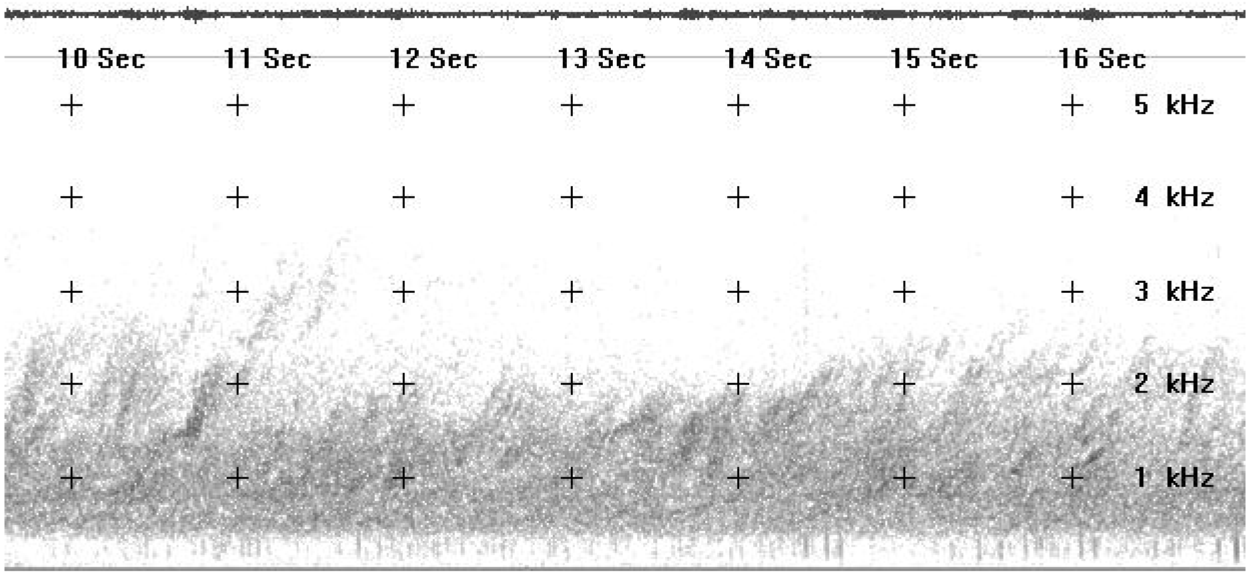
Spectrogram of nose whistlers accompanied by hissband recorded in northern Alberta 02 June 1996 at approximately 1430 UT - S. McGreevy

Every whistler is triggered by a lightning stroke, and lightning that is DISTANT enough away not to pose a danger to a listener with the WR-3 but which is also **visible** (especially at night) can sometimes trigger whistlers (very weak to very loud) shortly following the simultaneous visible flash and loud radio static "pop"/"crack" of the local lightning sferic in the WR-3 receiver's headphones. If the whistlers you hear coming from the visible lightning strikes are very loud, this indicates a magnetospheric duct happens to terminate relatively close to your location. Because the sferics from lightning strokes within 50 miles to your listening location will sound EXTREMELY LOUD in the headphones, keep the audio gain setting **low** to protect your hearing.

Don't confuse the sounds of tweeks with the longer duration whistlers, which many newcomers to Natural Radio monitoring tend to do at first. Tweeks, as explained above, have a similar sound to water dripping into a bucket of water or gravel hitting metal sheeting, are of roughly the same duration as a "drip," and generally are accompanied with the "click" or "pop" sound of the lightning stroke impulse. Whistlers on the other hand are much longer in duration than a tweek - anywhere from 1/2 second to as long as 4 seconds in duration as I have previously mentioned above.

MAGNETIC STORMS, AURORA, & THE BEAUTIFUL SOUNDS OF "CHORUS"

Occasionally, shortly after sunrise and occasionally extending into the midmorning, a phenomenon called "Dawn Chorus" may occur. Dawn chorus can resemble the sound of a flock of birds singing and squawking, dogs barking, or sound like whistlers raining down seemingly by the hundreds-per-minute (called a "whistler storm"). Dawn Chorus generally results from hundreds of overlapping, rapidly upward rising tones that can be continuous or appear in bursts, called "chorus trains." These chorus trains sound very fascinating -- the bursts of chirps and squawks (risers) seem to suddenly commence, and over the course of 2 to 5 seconds, weaken and fade away, then repeat over again, often in different pitches. During a chorus train, the sounds sometimes seem to be echoing or reverberating back and forth until fewer and fewer risers happen, then there may be a brief pause before the next chorus train commences. Chorus trains also seem to be harmonically related-a chorus train's center audio frequency may alternate randomly, first centered on about 1 kHz, then another chorus train will suddenly start up one octave higher at around 2 kHz, or maybe 4 kHz. Bursts of chorus trains happening at different octaves can overlap in a truly beautiful sounding cacophony.



Spectrogram of strong daytime chorus taped in central Alaska by Stephen McGreevy on 06 Sept. 1995 via WR-3E

Dawn chorus can occur several times a month for listeners in middle latitudes during years of high sunspot and solar activity (years 1989 to 1993 and 2000 to 2004) after solar flares and/or coronal mass ejections on the Sun send a barrage of charged particles into the Earth's magnetic field, causing a geomagnetic storm and also producing Aurora (the Northern and Southern Lights). In years of low-sunspot counts and few solar flares (1994-1997), coronal mass ejections from the Sun can still cause magnetic storms once or twice a month. Check out www.spaceweather.com for predictions of heightened geo-magnetic activity.

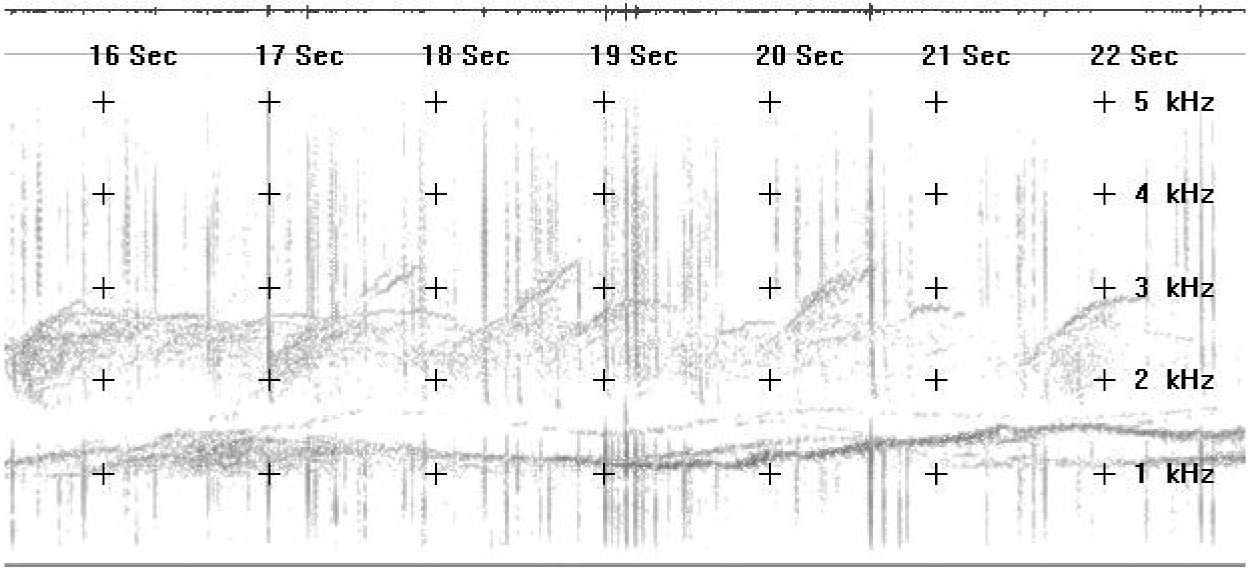
Chorus doesn't always only occur at dawn, especially for listeners who are located at higher latitudes, particularly in southern and central Canada (50-55 degrees north latitude), Alaska, and in northern Europe. At these higher latitudes closer to the auroral zone, which is a ring (oval) surrounding the magnetic pole and usually passing through central Alaska and through Canada at about 57-62 degrees north latitude, as well as northern Europe (Iceland, northern Scotland & the Hebrides Islands, Scandinavia, etc.). The auroral zone is source to a vast amount of natural VLF phenomena. When a solar disturbance on the Sun (such as the aforementioned solar flare or coronal hole mass ejection) sends highly charged and high-speed particles and ions towards Earth via the Solar Wind, Auroral displays often occur, and are visible to people near the auroral zone oval. Earth's magnetic field also undergoes a "storming" process as well, called a "magnetic storm." During auroral displays, chorus is often heard, as well as "hiss" of various pitches, "sliding-tone emissions" which very eerily and weirdly rise in pitch slowly over one to several seconds' duration. The chorus that occurs during displays of Aurora or during the daytime within auroral-zone regions is called "Auroral Chorus" or "Auroral-zone Chorus."

As such, both Auroral chorus and dawn chorus are related in that they occur during magnetic storms. The more severe the magnetic storm, the farther south away from the auroral zone and the louder the chorus will be heard with the WR-3. It is known that the Auroral Zone "oval" surrounding the magnetic poles expands during magnetic storms and reaches farther southward (and the southern Auroral Zone "oval" in the southern hemisphere expands farther northward). It has also been discovered that aurora is a daytime phenomenon but is not visible to the naked eye due to daylight illumination of the sky. Particularly intense events of nighttime and dawn chorus can get very loud even for listeners below 40 degrees north latitude (in the U.S.), and point to the evidence that aurora can reach considerably southward into the middle latitudes despite it not being visible.

The maximum intensity region of chorus emissions, like aurora, can spread southward during magnetically disturbed periods. Daytime aurora can sometimes be more intense than nighttime Aurora, and events of auroral and dawn chorus can reveal quite an array of information about the nature of aurora.

Nighttime auroral hiss (in at least a weak form) can be heard well over half the nights a year for listeners in Alaska and central and northern Canada along with a plethora of other phenomena, particularly during active auroral displays around 10 p.m. to 2 a.m. local time. And these same locations good for auroral viewing will also often experience wonderful dawn and daytime chorus **that will carry-on the entire day**, peaking around noon local time and gradually tapering off in the late afternoon. (If you want to hear fabulous daytime chorus of infinite variety, take a trip to central Canada or northern Scandanavia during the summertime. If a magnetic storm occurrs during your trip to those auroral-zone regions, you'll be astounded at the loud chorus events you'll hear!)

Good chorus events are sometimes accompanied by whistlers that have an extraordinary amount of "echoing"-10 or more echoes may be noted on some whistlers and the echoes may blend into a coherent tone or band of "hiss" which seems to be very slowly descending in pitch. Other sounds such as "wavering-tone" or "whispering wind" sounds may also be heard in addition to the phenomena described above.



Spectrogram of wavering-tone emissions taped in northern Alberta by Stephen McGreevy on 02 June 1996 via WR-4b

If you can see Aurora (Northern or Southern Lights) or the news media is mentioning them, by all means listen for possibly interesting and unusual whistler and/or hiss activity, which is likely occurring along with the auroral displays - with great Chorus events to follow the following morning and into the day - as is common at higher latitudes.

Even if geo-magnetic conditions seem "quiet" and no chorus events seem likely, conditions may still be very good for whistlers to occur-determining when whistlers are going to happen is still a rather unpredictable affair. More on this topic in the following sections...

GEO-MAGNETIC STORM, AURORAL & SOLAR ACTIVITY REPORTS

Geomagnetic storms (which result from solar flares and particularly coronal-hole mass ejections, causing Aurora and VLF radio Chorus as described earlier) are announced on short-wave time-standard stations WWV in Colorado and WWVH in Kauai, Hawaii at 18 minutes past each hour on WWV and 45 minutes past each hour on WWVH. Both stations can be heard on 2.5, 5, 10, 15 MHz. WWV additionally is on 20 MHz but is very subject to propagation variations. During these "geo-alert" notices, the A and K-indices are announced. These indicate the amount of planetary (as differing from localized) magnetic disturbance as follows: K of 0-1 = quiet, K of 2-3 = unsettled, K of 3-4 = minor storm, K of 5-6 minor-major storm, K above 6 = major-severe geo-magnetic storm. If the K-index is above 3, the A-index above 25, and they are saying the geomagnetic field is at "active," "minor storm" or "major storm" levels, odds are that some form of natural emission is likely to be occurring besides the ubiquitous sferics and tweeks.

Dawn chorus may also occur on mornings that seem to be having only "active" or "unsettled" geo-magnetic field conditions (K-indices from 2-3) according to WWV/WWVH, because at higher latitudes the magnetic field may be more stormy than at middle and low latitudes, so don't rule out times when the magnetic field is not "storming" according to WWV/WWVH, since it MAY be storming at very high latitudes and producing fine chorus emissions which propagate southward (in the northern hemisphere). Also, regarding whistlers, they can be howling by the dozens-per-minute even though the A & K-indices are seemingly "bottomed out" (say, A = 7 and K = 0 or 1 which indicate "quiet" geo-magnetic conditions), so the geo-magnetic indices give a **far less clear** of an indication that whistlers may occur than of potential dawn chorus or daytime chorus events and other related VLF emissions to chorus.

Whistlers DO seem to be more far common a few weeks surrounding the equinoxes of March 21 and September 21 - good whistler months tend to be late February to mid-April, and then again from late August to mid-October.

INTERNET WEB-SITES: As an alternative to the WWV and WWVH geo-alerts at 18 or 45 minutes past each hour, you can get information via the Internet. a couple of computer bulletin boards (BBS's) and Internet sites exist which supply detailed information on solar activity and related phenomena. The "Solar-Terrestrial Dispatch" (based in Stirling, Alberta, Canada) has aurora and magnetic storm announcements, as well as weekly and monthly reports of past activity, weekly predictions of future magnetic conditions, and Aurora reports sent in by observers - Their Internet World-Wide Web site at this URL: **http://solar.uleth.ca/solar/www/hourly.html**.

Another popular Internet site is www.spaceweather.com and has many links to other very fascinating and useful solar-terrestrial related websites. The Space Environment Center office in Boulder, Colorado, U.S.A., has a great website (also linked to from the spaceweather.com site) where you can obtain a considerable amount of information pertaining to Geo-magnetic and solar/space-weather related phenomena. The address is: www.sec.noaa.gov. This site's text-only menu system can be viewed with any Web browser, is fairly easy to navigate, fast access and loading, and has loads of information albeit possibly too technical in nature for many newcomers to natural VLF radio listening and "space weather" studies. There are also URL's given to get to additional text and graphical information via the Web.

Another fine NOAA-based web site is: **http://www.ngdc.noaa.gov/stp/stp.htm** This is the Solar-Terrestrial Physics Division Home Page

In addition to the NOAA and Canadian STD sites is the IPS Space and Radio Services out of Australia. They maintainn another fabulous web site at: **http://www.ips.oz.au/** - IPS Australia Home Page (Solar-Terrestrial Research)

Still another great Swedish site for real-time magnetometer images is: **http://www.irf.se/mag/**

These sites, and the WWV/WWVH reports, should give you all the information you would require to understand and be aware of magnetic conditions for optimum planning of your listening sessions.

WHEN TO LISTEN FOR NATURAL RADIO PHENOMENA AND WHERE IN THE WORLD THEY OCCUR:

(Much of the information following should be used concurrently with the above sources of geo-magnetic information for best listening results.)

Statistically, the time between local midnight and an hour after sunrise is when the greatest amounts of whistlers are heard, although dusk to midnight may reveal substantial whistler activity, and even (though not very often) loud whistlers may be heard a couple of hours before sunset. Over the long term, the period from two hours before sunrise until an hour after sunrise is the optimum time to listen for natural VLF phenomena of all sorts, as the amount of sferics (lightning stroke pops and crackling) are less -- natural VLF radio phenomena are not as "buried" under the sferics as in the evening when lightning storms are more numerous. Also, magnetospheric conditions are optimum around morning twilight time and an hour before for best whistler listening.

Interestingly, between April 1996 and March 1997, I had been hearing good whistler events during the DAYTIME and particularly late afternoon before sunset! Many times, these whistler events die out after sunset and are not heard at sunrise. But, after that through December 1997, whistlers were once again more frequently heard between 2 - 6 a.m. local time.

In early March 1997, whistlers started up around 4 p.m. local time and were going in earnest (several-per-minute) between 8 p.m. and 11 p.m. PST. This may be a solar-minimum phenomenon, but it points out the need to listen as much as one can for whistlers and at ANY time, as they occur when least expected. This recent late-afternoon trend has not always been the usual case a few years ago and many listeners got used to listening only after midnight to dawn, as did I. In early 1998 from near Death Valley, California, I caught the first " whistler storm" heard since 1992.

In early to mid-1999, especially in March and April 1999 (equinoctal periods), whistlers were frequently heard in great variety near Death Valley by myself during the midnight to 7 a.m. local-time period. Weak Dawn Chorus has been occurring about 2 times a month in eastern California in early 1999 - and much more frequently farther northward toward the auroral-zone regions.

During the Solar-Maximum period between 2000 and 2002, VLF events became frequent and widespread, especially during equinoctal periods (several weeks surrounding the spring and autumn equinoxes. I myself saw three spectacular auroral displays in the eastern California desert and also in eastern Utah in 2001, accompanied by a torrent of whistlers and chorus and hissband during and after the auroral displays faded away.

Therefore, whenever I am out hiking in areas even just a bit away from powerlines, I bring along my WR-3 and am sometimes plesantly surprised with nice whistlers to enjoy! (S .P. McGreevy)

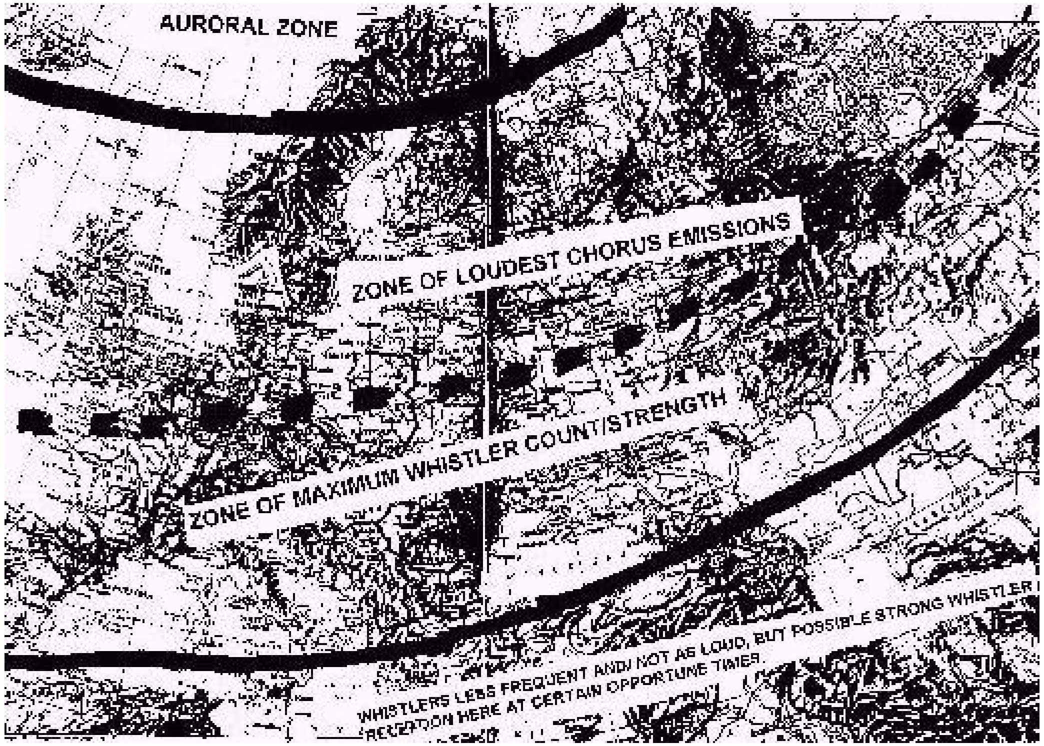
So, in summary, while the pre-sunrise hours are generally the best time to listen for whistlers and other phenomena, intense whistler events of short duration can occur at any time between just before local sunset through 1 to 2 hours after sunrise. A good whistler event that is happening at 10 p.m. or even at SUNSET may not be occurring later on that night at the usually optimal sunrise period, so don't rule out the evening hours to listen, especially during geo-magnetic storms.

On several mornings a month, one whistler a minute may be heard on average, but as is often the case, whistlers will not be heard at all. Occasionally during a geomagnetic storm caused by a solar flare, over 100 whistlers a minute or more may be heard - called a "whistler storm!" Whistlers may or may not have echoes and they may be few and far between and very loud, or may occur often but be quite weak. The sound characteristics, intensity, and number of whistlers can change rapidly hour to hour. Everything depends upon the sensitivity and conditions of Earth's magnetosphere and the location of lightning storms and magnetospheric ducts in relation to the WR-3 VLF Receiver user.

Whistlers are seldom heard midday at mid-latitudes, except during unusual conditions occurring with a severe geo-magnetic storm or unusually strong electron and proton output from the Sun impinging upon Earth's magnetosphere. Unfortunately, on a good number of days during the year there will not be any whistlers audible even though there is plenty of lightning activity and sferics within a few hundred to few thousand miles miles of your listening location. Often elusive, whistlers may not be heard for days or weeks at a time. Again, it is hard to predict when whistlers are going to occur based on the geo-magnetic indices, but they are generally more common in the spring and the fall surrounding the equinoxes, and at sunrise, or less frequently, at sunset.

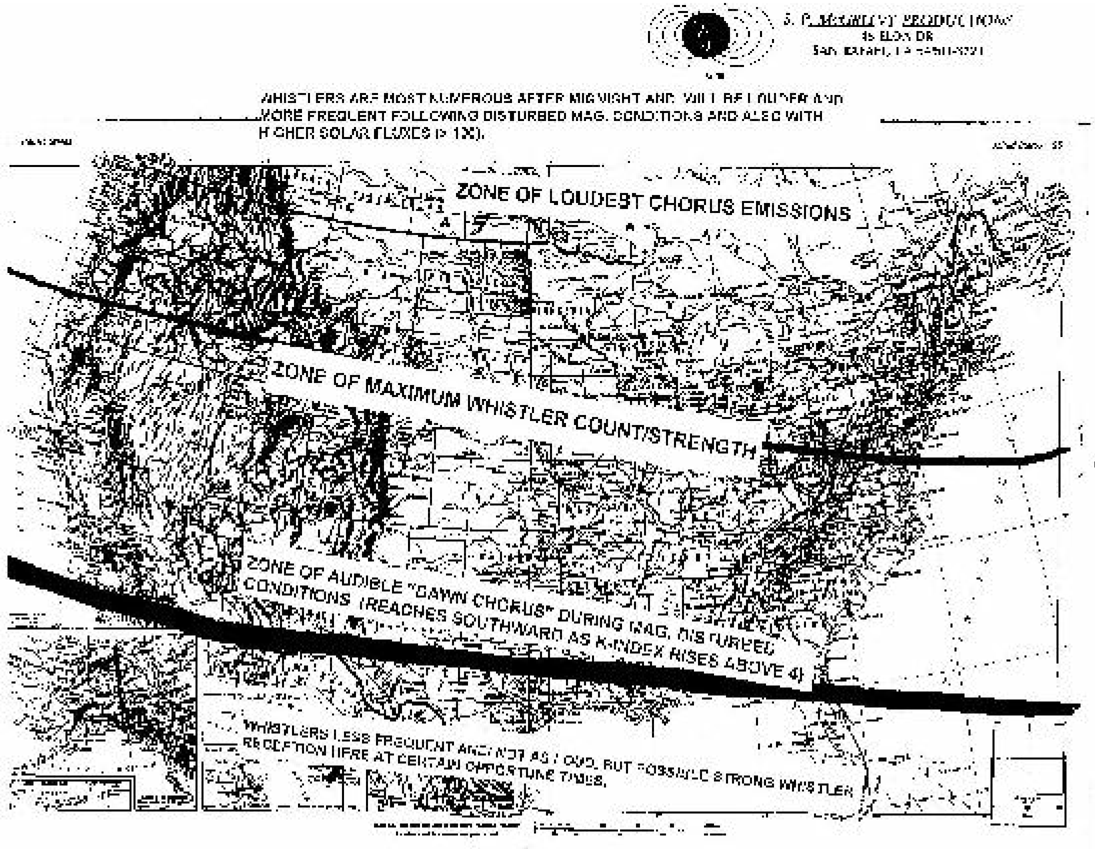
In North America, higher latitudes where the Northern Lights (Aurora Borealis) are visible are excellent locations to hear whistlers, and particularly, very loud Auroral and Dawn chorus, and a myriad of other bizzare-sounding Natural Radio emissions when they are occurring. (This is the reason I make recording expeditions into northern Canada to capture all the lovely VLF activity up north). For instance, in the center of the Canadian Provinces of Alberta through Ontario, chorus of infinite variety is an almost daily occurrence, even when geo-magnetic indices would seem to indicate listening would otherwise be "dead" farther south! Spend a week or two in August, say, in central Alberta and/or Manitoba, Canada (as I did in 1996) or in central Alaska, and you too would be delighted and in awe of the Natural Radio sounds heard each day and the gorgeous auroral viewing at night if the sky is clear...

For those in Europe and the British Isles, similar fabulous chorus listening locations would be northern Norway and Finland; Iceland, and the extreme northernmost parts of the British Isles.

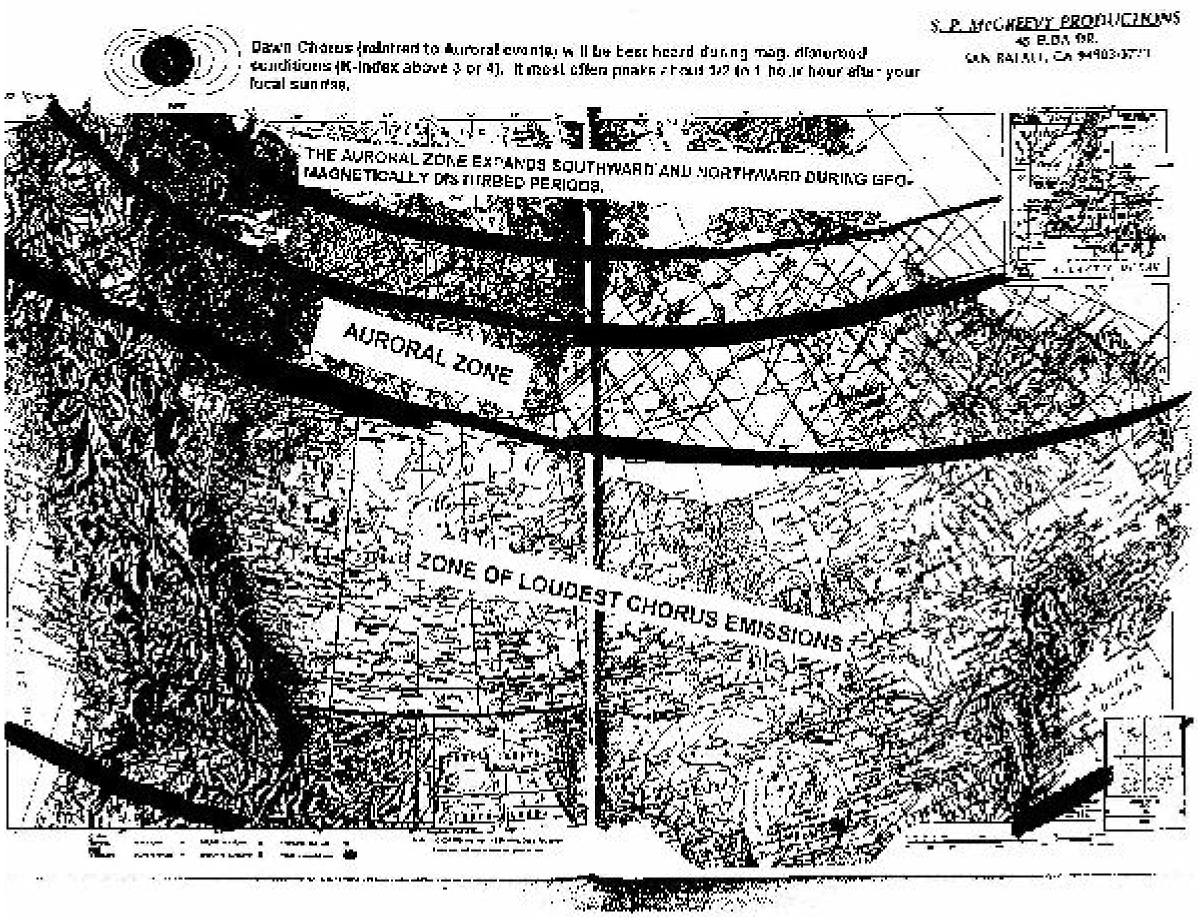


For middle-latitude listeners, Dawn Chorus (as previously mentioned) tends to peak in intensity between sunrise and one hour afterward, but at high latitudes, can peak as late as noon or even in the mid-afternoon, particularly if there is any geo-magnetic activity (Kp index > 2) and can take on incredibly beautiful sounds.

Whistlers of intense strength can sometimes be heard across the middle and southern-most United States and southern Europe and North Africa. The latitudinal zone where the loudest whistlers are heard falls roughly between 30-55 degrees north for North American listeners. In the United States, statistically, the "northern tier states" region is blessed with the highest number of whistlers and chorus occurrences (Washington State, northern Idaho, Montana, North Dakota, Minnesota, Wisconsin, Michigan, Pennsylvania, New York, and New England. In Canada, the southern parts of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec and the Atlantic Maritime Provinces hear large amounts of whistlers and chorus. Throughout central Canada and Alaska, wonderfully strong chorus events lasting from morning to evening can occur, particularly in Feb. April and August - early October.



Strong events of chorus occurring at higher latitudes can be heard into more southern latitudes too, albeit somewhat weaker and less often. Southern Canada, all of Europe, especially northern Europe and the British Isles, are good locations to listen for both whistlers and chorus. Everywhere, the lightning impulse "static" sounds of sferics and tweeks from Earth's great number of electrical storms abound.



In the Southern Hemisphere, New Zealand, the Australian states of Tasmania, Victoria, South Australia and parts of Antarctica are also prime whistler monitoring regions, as would be locations along a radius of about 3,000 mi./4800 km. radius around the southern magnetic pole. Note that both the north and south magnetic poles don't fall on the true geographic poles of the Earth but are several hundred miles offset. The geographic coordinates of the north magnetic pole is approx. 75 degrees north latitude by 100 degrees west longitude. The south magnetic pole is approx. 67 degrees south latitude by 155 degrees east longitude. Whistlers have been reported in Saudi Arabia despite its southern geographic latitude. In rare cases and very strong whistler events, whistlers can be heard even at the Equator.

Whistlers have also been observed by unmanned spacecraft passing by the planets Jupiter and Saturn which also have considerable electrical storm activity and very powerful magnetospheres.

In summary, the zone where the loudest chorus events occur is higher in latitude than whistlers (please refer to the maps), and for North American listeners it is between 45-60 degrees north latitude. In some locations, such as northern British Columbia or in Alaska, the whistler rate is slightly lower than in places such as Washington state, Minnesota or Maine, but Chorus will occur far more often in Alaska and in central Canada than farther south.

Nothing but static: You shouldn't be discouraged if after several listening sessions, whistlers, chorus, or other VLF phenomena sounds (besides lightning sferics "static") are not immediately heard. Perhaps 25 - 33% of days in a month result in nothing of interest being heard, especially below 35 north latutude, however, sooner or later, you will be rewarded with a variety of fascinating sounds from whatever VLF phenomena is occurring at the time you listen - as though the times of not hearing anything are suddenly "made up for" by a listening session filled with all types of beautiful natural VLF radio sounds! As a reminder, weather and outside temperature permitting, the period from about 0430 local time to around local sunrise will be the most rewarding time to listen - requiring you to be an early riser! Natural VLF Radio signals can sound truly eerie and awe-inspiring, especially when one realizes it is all naturally occurring - not man made, and that these radio emissions have been occurring for millennia.

ALPHA:

Other manmade signals within the WR-3 VLF Receiver's passband that are heard besides 50/60 Hz and harmonics A.C. powerline hum are shrill dashes of a brief 0.4 second duration on 14.881, 12.649, and 11.905 kHz in frequency. These emanate from 3 transmitters across Russia and compose a radio-navigational system called "Alpha." or "RSDN-20 Hyperbolic Radionavigation System".;

The OLD format (it has now changed as of 2000) is as follows:

Stations:

1) **KO** - Komosomolskamur (north of Khaborovsk), 50N/137E

2) **NO** - Novosibirsk (master station, Central Russia), 54N/83E

3) **KR** - Krasnodar (Black Sea), 45N/38E

Time Schedule: Cycle period 3.6 seconds, 6 time slots at 0.4 sec. duration, 0.2 sec. spacing

Estimated radiated power in wattage 50 kW to 100 kW. The table reads left-to-right and repeats every 3.6 seconds per Time Schedule above.

A *much better* and more detailed article on Alpha/RSDN-20 (with maps) by Trond Jacobsen in Halden, Norway, is at: http://www.vlf.it/alphatrond/alpha.htm.

Russian ALPHA Radio Navigation Format

Frequency (kHz)	time slot 1	time slot 2	time slot 3	time slot 4	time slot 5	time slot 6

11.905	KR	KO	NO	NO	NO	--
12.649	KO	KR	--	--	--	NO
14.881	NO	NO	--	--	KR	KO

Sources:

Beukers Laboratories, Inc.: VLF and LF for Navigation, Summer 1974, Vol. 21, No. 2

Kerckhoff, Manfred; Bremen, Germany - narrow-band and wide-band receiving observations (Manfred also supplied the article above)

The nearest Alpha transmitter to North American listeners is near Khaborovsk, Far eastern Russia, and is likely the loudest Alpha signal that will be heard with the WR-3 VLF Receiver for most listeners throughout North America, except for the eastern part of North America, where Alpha station near Krasnodar (Black Sea) will be the strongest Alpha signal. The same goes for listeners in the British Isles and Europe, with Novosibirsk the next strongest station.

SUGGESTIONS ON FINDING A GOOD PLACE TO LISTEN:

The WR-3 VLF receiver should be operated well away-at the very least 1/8 to 1/4 mile (300-600 metres)-from any 50/60 Hz A.C. powerlines or structures that contain them, such as houses and buildings, or else a "hum" sound from the A.C. powerline frequency (and harmonics to well above 1 kHz) will dominate the WR-3 receiver's output. This is because the alternating current frequency of 60 Hz (50 Hz outside of North America, Hawaii, and most of South America) carried by power lines also puts out harmonic emissions every multiple of 50 or 60 Hz, and these power-line harmonics can be easily received by the WR-3. Locating a listening spot 1/2 to 1 mile (800-1600 meters) away from power lines if possible will probably eliminate most if not all "hum" interference. The farther away you can locate away from electric power lines, the less "hum" will cover the desired VLF Natural Radio phenomena, especially the weaker and more subtle ones.

Lower voltage underground power lines such as those within newer residential neighborhoods may not be an annoyance at 1/4 mile/1000 metres away from them, however, high-tension/high-voltage power lines in "utility corridors" can cause some hum even 2 to 3 mi./3 to 5 km distant in worst case situations. Powerline buzz and hum presents the greatest obstacle to Natural Radio listening for most listeners, and more-or-less eliminates "backyard" listening, thus requiring some sort of "expedition" to an electrically quiet location, which can often be quite challenging but fun! The WR-3 is a great receiver to take with you on wilderness trips or long walks on the beach, whether via car, boat or on foot.

It's also important to be in a clear, open place away from trees by at least 50 yards/meters - a meadow, field, or open hilltop is best. Trees act as electrical-field "short circuits" at these low frequencies - the WR-3 VLF Receiver will lose sensitivity as you get closer to trees and other obstacles. All VLF signals will be attenuated almost completely if the WR-3 is operated under trees, no matter how few of them are around due to e-field dampening and absorbtion.

Standing under a lone tree surrounded by miles of open space will be little better than being deep in the woods - relocate away from trees and be in the open. In short, AC power lines cause annoying "hum" that masks all other signals and trees reduce all the signals there are to hear, so it is best to locate a listening site away from both of them. You need not seek the highest location around to listen with the WR-3, but if you listen in deep valleys and canyons, signals will also be reduced a bit.

When using the WR-3 VLF Receiver, hold the whip antenna as vertically as possible while grasping the aluminum enclosure, whereby your body will act as a "ground." Additional grounding can be accomplished by clip lead attached to one of the screws on the aluminum enclosure of the WR-3 and to a 6-8 inch nail, or rod stuck into the soil where you use the WR-3, but this will not be necessary unless you tape record the output of the WR-3 or wish to eliminate capacitive "foot" noise caused when shoes are rubbed on the ground or when dry grass or shrubs touch your clothing or shoes.

CAUTION: DO NOT OPERATE THE WR-3 WHEN NEARBY LIGHTNING STORMS THREATEN AND TAKE APPROPRIATE LIGHTNING PRECAUTIONS!

Most of the time, better whistlers will be heard when their sources of lightning are not close to your listening location anyway (and as far away as 2,000 miles). **Many listeners have the mistaken impression that they will only hear whistlers when lightning is close-by, but this is not true for the most part**. When lightning flashes nearby, put away your WR-3 and wait until the storm passes.

OTHER INTERESTING EFFECTS: INSECT WING SOUNDS

A very interesting electrical effect easily observed with the WR-3 are insect wing sounds caused when insects such as bees, flies, and mosquitoes fly within a couple of feet of the WR-3 whip antenna. The resulting sound is a buzzing sound very similar to what can be heard by ear, however, this effect is caused by electrostatic discharges each time the insect's wings flap. It is thought that electrostatic charges (static electricity) are collected on the insect's wings and then and dumped during each wing beat, creating a "modulated" electrical field around the insect at the same frequency as the wings beat. Large insects, such as wasps, Yellowjackets, Bumblebees and honeybees, make particularly strong buzzing sounds in the WR-3 headphones-easily heard when those insect fly within 3-4 feet (1 meter) of the WR-3 antenna. High-pitched Mosquito wing beat sounds can be heard the small insects fly within a few inches of the WR-3 Receiver's whip antenna.

Certain kinds of flies and other insects have much more electrostatic "buzz" from them than other kinds - Bees and Horse Flies, in our observations, have the loudest "buzz" in the headphones! This may also have something to do with the composition of the insect's wing, with certain type of insect wings more prone to static electricity accumulation and subsequent discharge. There may also be insect bodily electrical discharges generated within the insect's wing muscles that contribute to this effect, and a some believe that the insect's carapace (outer body shell) has a piezo-electric effect similar to quartz crystals, but not much is understood about this phenomenon yet and further studies are encouraged.

ABOUT HEADPHONES: The WR-3's output jack requires a pair of STEREO headphones (for dual-ear monaural sound). The most convenient and portable kind are the lightweight "personal-stereo" type of stereo headphones that have a 3-conductor 1/8 inch (3.5 mm) plug. These kinds of headphones have an impedance of 8 or 16 ohms, are widely available, lightweight, match very well with the WR-3 and are highly recommended. While the output of the receiver is not true "stereo" but "dual-ear monaural" sound, we designed the WR-3 to match with these very commonly available headphones.

Not all stereo headphones work the same with the WR-3, and ones with 32 ohms impedance or those that are rather "cheap" may have too low of a volume to be very satisfactory. It is highly recommended that you try out several pairs of good quality for greatest volume level output and sound quality.

Beware of the kind of headphones which are small, "plug"-like types designed for bass-boost listening -- these can emit excessive/harmful audio output from sferics and other sounds and they may also cause deafening audio feedback. Some of these kind, however, work fantastically with the WR-3 when used properly. But...these are the words of one regular WR-3 listener of natural VLF radio and is very good advice: Do not use "earplug" phones with soft, flexible seals that fit tightly within the ear to improve "bass" audio effects, which might inflict serious hearing damage on very powerful, sharp "cracks" due to strong, local discharges. The cheap kind of phones with the openly vented foam pads are acoustically perfect and pretty safe.

Other kinds of headphones such as full-size 8-16 Ohm stereo headphones designed for use with stereo component systems will work very well, though you may need an adapter to convert their 1/4 inch plug (7 mm) to the 1/8 inch (3.5 mm) plug. The audio volume from the WR-3 may be considerably louder with full-size headphones compared to some mini-stereo style headphones - plenty for most listeners-especially if their impedance is 8 or 16 ohms. Full-size headphones also give you the advantage of enclosing your ears better than mini-headphones,thus shutting out exterior noises and enabling you to hear natural VLF phenomena better.

High-impedance (600 to 1000 ohm) audiophile headphones will not work with the WR-3 because the volume is too low and inadequate due to mismatch with the WR-3's headphone amplifier. However, you could employ an audio transformer to convert the 8-ohm output of the WR-3 to 1000 ohms for far better results with high-impedance headphones if you're willing.

Whatever headphones you choose to use, they MUST have a 3-conductor (stereo) plug. Two-conductor (monaural) plugs will not work conveniently without an adapter to convert the 2 conductor (mono) plug to the 3-conductor (stereo) plug, although in a pinch you can use headphones with a mono plug (or patch-cord) by plugging them in about half way into the WR-3 headphone jack, perhaps with the assistance of a non-metallic washer and tape to hold the mono plug out at the proper distance for it to make good contact with the WR-3's headphone jack. If in doubt about the type of plug on the headphones, it should have three metal bands separated by two thin black plastic insulators. If it only has two metal bands separated by one plastic insulator (mono plug), it won't work without an adapter unless you plug it in only half way-enough to make contact.

BATTERY POWER: A 9-volt (rectangular snap-type) PP9 ALKALINE or LITHIUM battery is best recommended for use with the WR-3. An alkaline battery will last from 20 to 30 hours of use depending on the audio gain level, with a lithium battery lasting about 3 times longer than an alkaline battery (and which also costs about twice the price of an alkaline battery). Other types of 9 volt batteries such as "General Purpose" types will not have as long a life as Alkaline types but will last quite a long time anyway (about 10-15 hours of listening).

Rechargeable Ni-Cad 9-volt batteries can be used, but are not recommended because of their limited discharge life-which is shorter than an alkaline battery, and also due to their lower voltage (8.4 volts). Battery replacement is achieved by removing the four screws that secure the receiver's top cover and snapping on a new battery to the battery clip and carefully re-fitting the cover. Be sure the WR-3 is switched off to avoid circuit damage if you accidentally connect the battery backwards, ESPECIALLY is you are using a Ni-Cad or other newer rechargeable types which have high current.

TAPE/DISC/CHIP RECORDING:

WR-3: A tape/disc/chip recorder with an aux./line-level input can be used to record directly from the WR-3 headphone jack (the only output jack on the WR-3 to keep it simple and which is line-level output at the lowest-gain setting and low-headphone-level at its highest-gain setting level).

For MICROPHONE inputs (~10 mV), an attenuating patch cord with the appropriate connectors will be required, as the audio level present in the headphone jack (line-level to headphone-level) is not matched for microphone inputs on most audio recorders.

Use an attenuating patch cord ***and adapters which will convert a stereo (3-conductor - 3.5 mm) (1/8 inch) mini-phone jack to the input jack style your audio-recorder requires***. Failure to use an attenuating patch-cord will result in recorder input overload and terrible audio quality to mic.-level inputs. Most audio recorders of any quality employ standard line-level (100mv) inputs. Check the operating manual of your recorder. Again, I highly recommend Sony Mini-Disc recorders (a lot on used market now!) because they don't emit hardly any RFI at VLF frequencies from LCD displays, etc., compared to some units.

Additionally, to interface the WR-3 output jack to the newer PC/phone 4-conductor jacks that combine stereo audio outputs with a monoural mic-level input (i.e. the lowest conductor closest to the "holder" of the plug (3.5 mm type/4-conductor) is the mic-level connection). Use one or two series 47 K resistors(s) plus a parallel termination-resistor of 1K suffices fine for interfacing the WR-3 joint 3.5mm audio-output jack (headphone level audio) of the WR-3 to the mic-level input of PCs and phones so you may employ their recording apps!(Stephen P. McGreevy, 12 February 2018)

With regards to using newer digital audio-recorders (SD-card, etc.), noise (usually a buzzing/whining sound) in the ELF-VLF audio frequency-band can be substantial compared to back in the days when I was recording natural-radio to a Marantz PMD-221 three-head cassette recorder that almost completely lacked any noise on ELF-VLF, but nowadays modern digital-audio recorders are noise-plagued via their LCD screens and microprocessors, and devices such as smart-phones and portable computers can be similarly very noisy at ELF-VLF frequencies. (My Sony Mini-Disc (MD) recorder only emitted a tiny amount of digital noise to my WR-3s also, but when I went to using a Zoom H2 audio-recorder I had to take the following steps.)

Therefore I offer tips to keep most if not all digital-noise from getting into the input of the WR-3 and as such your recording:

1) when recording it is best to clamp the WR-3 to a camera-tripod to keep its antenna erect vertically and your hand free to operate the audio recording device.

2) clip a small battery-post clip/clamp to the (base) bottom-connector (silver section) of the BNC-based whip antenna where it attaches to the WR-3's male BNC connector - this is part of the WR-3 enclosure/case negative-ground. An insulated wire of any size (even thin enamel wire has been used!) then goes to another clip or electrical attachment to a short 20 to 30 cm / 1-foot length of steel or copper rod or thick length of wire such as a coathangar wire sanded-clean, and this is then a kind of "ground-rod" that is then pushed or poked into Earth/soil nearby the tripod with the WR-3. "Earthing" or "grounding" the WR-3 to Earth in this fashion will improve sensitivity and eliminate a lot of ESD-noise problems and noise from audio recorders too.

3) Use a very LONG (up to perhaps 20 feet / 5 to 10 metres) shielded audio patch-cord with a stereo/3-conductor 3.5 mm/ 1/8-inch plug on one end and whatever plug works for the LINE-level/AUX. input of your recorder but NOT to the microphone input as the audio output of the WR-3 is only compatible with line-level inputs to recorders. Locate the digital recorder as far from the WR-3 as is possible via the long audio patch-cord and monitor the quality of the recording/recorder input via headphones that are plugged into the headphone-jack of the audio recorder.

Hopefully these tips will make your recording efforts successful, too!

MINI-DISC RECORDER users: The output level of the WR-3 from its headphone jack is fully compatible with the LINE-IN inputs on the Sony Mini-Disc recorder which is a remarkably low-emitter of noise in the ELF-VLF bands - I have used a Sony MZ-R70 portable MD unit since the summer of 2000 and 2001 with wonderful results and as just said I like the unit because it emits very-low levels of noise in the ELF-VLF band, also. Keep the WR-3 audio gain control at the mid-to-lowest setting, and adjust the audio-level setting on the MD recorder in Manual Record Mode for about 2/3 scale on the bar-graph and record in MONO Record Mode for 148 minutes total on a 74-minute mini-dis or 160 minutes on newer 80-minute discs.

ZOOM H2 RECORDER users: (Also please refer to the tips above) The output level of the WR-3 from its headphone jack is fully compatible with the LINE-IN inputs on the Zoom H2 recorder to its 3.5 mm stereo input-jack (line level input!) - I have used a Zoom H2 since about 2008 with fine results, however the LCD display can induce some buzzing noise into the WR-3 input if not carefully situated some distance from the receiver (2 to 3 meters/10-15 feet-plus best - usa a long shielded patch-cord for optimum results).

A very commonly available 3-conductor mini-stereo plug (1/8 inch/3.5 mm) patch cord is ideal between the WR-3 headphone jack and the MD/chip recorder's line-in jack. The audio from the WR-3's headphone jack can be patched directly into the "auxiliary" or line-level input of other types of recorders having this input option, using appropriate adapters.

Use quality SHIELDED coaxial-style audio patch cords only, whether standard or attenuating type for the finest results.


Sony-Mini-Disc MZ-R70 shown connected to WR-3 headphone jack which is compatible with the Sony MD unit's line-in jack, using a stereo (3-wire) 1/8-inch/3.5mm patch-cord.

Additional receiver grounding (see grounding section) will usually be needed if an audio-recorder (any kind: from cassette to memory-chip) is used to prevent audio feedback from the recorder into the WR-3 whip antenna and to reduce static-electricity noises from your clothing and hair from impeding upon the recording.

When I record with my own batch of WR-3s, I clip (using a small battery-post clamp) a 2-meter-length length of insulated wire to the clip attached to the silver-section at the base of the WR-3s whip-antenna, and the other end of the wire is attached to a 1-foot (about 20 to 30 cm) length of rod or sanded-clean coat-hanger wire poked into soil/Earth. This simple Earthing/grounding method really cleans-up my own recordings of noise from electrostatic effects and recorder noise, and so is highly recommended!

Better results are obtained if the WR-3 audio gain is kept at lower levels and not at full gain. Feedback problems are non-existent with the Sony MD Recorder if used correctly and wisely - I use the Sony MZ-R70 MD recorder with excellent results all the time and sometimes w/o extra grounding other than my hand/body, usually. This is my audio-recording unit of choice

I've also been using my WR-3 and several personal variations of it with a Zoom H2 (SD-chip) recorder that has a line-level jack. It works great, except be aware that display noise from the Zoom (and similar units) might feed-back into the WR-3 (creating a buzzing noise), and any type of e-field VLF receiver for that matter - one solution is a long patch-cord of a couple of meters / 6-10 feet in length might help, as it has with me, and I locate the recorder away from the WR-3's antenna as far as possible. Sometimes simply re-positioning the WR-3 and recorder helps tremendously. Experimentation is required when using any kind of e-field receiver with an audio recorder! Earth-ground your WR-3 per further above, for optimum results.

ANTENNA:

WR-3s work best and with the highest sensitivity with the Smiley-Antenna Inc. "Superstick II" telescoping-whip (2-meter OR the aero-band unit - the latter is a tad longer) with a base male-BNC connector OR the also-excellent Diamond RH205 VHF-HT telescoping-whip antenna also with a male BNC-base.

Normally, the telescoping whip antenna should be used fully extended for maximum receiver sensitivity and held vertically at at a half-arm's-length away from you, with the receiver at chest or shoulder level (whatever is most comfortable). Tripod-mounting the WR-3 saves you from tiring out your arm while holding the WR-3, especially for longer listening sessions!

The WR-3 will not match as well (or can overload) with longer wires or with ones laid out on the ground, on bushes or in trees, as its antenna input circuit has been optimized for a 3-10 foot (1-3 meter) vertical "whip" antennae. Feeding the WR-3 with COAXIAL cable to an outside or vehicle-mounted antenna will not work very satisfactorily due to the high-impedance of the WR-3's antenna input and the capacitive loading problems with coaxial cable - the antenna must be right at the BNC antenna connector. Exceptions to this caveat exist such as using just a very short (less than 2 feet or maybe about 500 mm) length of coax feed to a long vertical whip antenna (2 to 3m tall) has been tried by some listeners successfully, so experimentation can be undertaken here, also.

SAVE YOUR EARS!: Please avoid turning on the WR-3 VLF Receiver indoors with the headphones on your ears because this will result in a loud "hum" or "buzz" being heard in the headphones due to close proximity to 50/60 Hz AC lines, and this loud volume can be harmful to hearing. (Again, it's best to operate the WR-3 at least 1/4 mile/500 meters from AC power poles to avoid excessive hum pickup). The difference in sound level of the loudest lightning sferics to the most subtle Natural Radio sounds can be substantial. Resist the temptation to "crank up" the volume level. Excessive headphone volume, whether from the WR-3 VLF Receiver or other audio devices, can result in eventual hearing loss.

Enjoy your WR-3 and the sounds of VLF "Natural Radio." Listening to the sounds of whistlers, tweeks, chorus, and other Natural Radio sounds under a star filled sky or while watching aurora or sunsets and sunrises increase one's wonder and appreciation of the natural beauty of Earth -- the WR-3 is simply a tool to enhance sensory awareness of Earth's natural beauty further and into another "realm," whether for research purposes or aesthetic enjoyment. Awareness of WHY these VLF radio sounds happen and their origin, much of it gained through scientific study and learning, helps to satisfy our curiosity about them. The necessity of taking the WR-3 out of the electrically "polluted" urbanized areas and into more open areas further into nature adds GREATLY to the enjoyment and appreciation of the natural environment and the beauty of Natural Radio. Happy Listening!

WR-3 VLF RECEIVER SPECIFICATIONS:

Receive frequency range: 0.1-14 kHz (100 - 14,000 Hz), peaking in the 1.5 to 3 KHz range

WR-3: peak frequency approx. 1.5 kHz with roll-off below 200 Hz and above 3 kHz. RFI protected to reduce LF-VHF broadcast and utility station overload and IMD. Audio Output: Maximum 100 mW into 16-Ohm stereo headphones

Headphone jack: 1/8 inch (3.5 mm) stereo (3-conductor) audio jack

Size: H: 110 mm (4 7/16 in.) W: 60 mm (2 3/8 in.) D: 31 mm (1 3/16 in.) not including antenna length

Weight: Approx. 300 gm (11 oz.) with battery **Antenna:** accepts BNC-base telescoping whip up to 1.5 meters in length

Antenna input impedance: Approx. 10 Megohms.

Power: Use a 9 volt battery for 20-40 hours of listening time depending on type (@7-20 mA current consumption). Alkaline or Lithium types preferred

Acceptable Headphone Impedance: 8-32 Ohms (common 16 Ohm mini-stereo type recommended)

Additional References and recommended reading for those interested in additional information about natural VLF phenomena:

The Lowdown, published by the Longwave Club of America (LWCA), is a monthly publication for people interested in this part of the radio spectrum. In addition to articles on Natural Radio sounds including writings by Mike Mideke, the publication covers lowpower Low and Medium Frequency experimental transmitting of voice and data, receiving techniques, radio wave propagation, and articles about controversial topics such as military radio transmissions, etc. Membership is $18.00 per year ($26.00 U.S. Overseas) from: LWCA, 45 Wildflower Road, Levittown, PA 19057. Website: www.lwca.org

Ionospheric Radio Propagation, by Kenneth Davies, National Bureau of Standards, Monograph 80 (1965/1990). Excellent text on radio propagation including verylowfrequencies. The old 1965 edition is nearly impossible to find but a new 1990 edition (priced at about $65.00) is available. Write to: Space Environment Services Center, NOAA R/E/SE2, 325 Broadway, Boulder, CO 80303-3328. Phone (303) 4975127.

Robert A. Helliwell ("Father" of VLF research), Whistlers and Related Ionospheric Phenomena, Stanford University Press, 1965. A very comprehensive introduction to whistler research before space flight plus the beginnings of "spaceage" research documenting early satellite data. It is accurate and concise with numerous diagrams and illustrations. The book has more information than a beginner would likely immediately use or pursue, but is fascinating nonetheless. ***RARE BOOK*** It is difficult to find copies of this book. Check large libraries. They may be able to obtain the book using the interlibrary loan system.

Syun-Ichi-Akasofu, The Dynamic Aurora, Scientific American, May 1989, pp. 90-94. Describes the functioning and structure of the magnetosphere and causative factors in the generation of Aurora. Examines the magnetosphere as an electrical "generator," field-aligned currents, electrojets and substorms, why Aurora are "curtain" shaped. While not directly examining VLF natural emissions, the article helps in understanding the magnetosphere and lends insight into its role in naturally occurring VLF emissions.

Jeremy Bloxham and David Gubbins, The Evolution of the Earth's Magnetic Field, Scientific American, December 1989, pp. 68-75. Examines geologic processes which generate Earth's magnetic field, describes the shape and functioning of the geo-magnetic field, magnetic field drift, magnetic lines-of-force, magnetic field polarity shifts, and so on.

George John Drobnock, Radio Waves from a Meteor?, Sky & Telescope, March 1992, pp. 329-330. Reports on the author's experiences with a homemade H-field "loop" VLF receiver and a noted "hiccup in the background noise" as well as a "swoosh" sound correlating with the sighting of a meteor on two separate occasions. Examines the possibility that large meteors may disrupt the magnetic field because of their ionized "wakes" created by swift passages into the upper atmosphere, causing VLF radio emissions. An under-researched and still-controversial premise demanding further attention.

Russ Sampson, Fire in the Sky, Astromony, March 1992, pp. 38-43. Beautifully illustrated article about the phenomenon of Aurora and the geo-physical processes responsible. Written more for the layman than the Syun-Ichi-Akasofu article above, but essentially covers the same topics including the influence of solar activity on the magnetosphere. The article is replete with excellent amateur photographs of various colors of aurora. Since Natural Radio emissions arise from the same processes, this is also recommended reading to gain understanding about the magnetosphere.

Donald Herzog (U.S. Geological Survey, Golden, Colarado), Hazards of Geomagnetic Storms, Earthquakes & Volcanoes, Fall 1991

David Schneider (Assistant Professor of Physics, Northern Kentucky University), Mother Nature's Radio, QST, January 1994, pp. 49-51. Discusses basic theory about VLF whistlers and the VLF frequencies of 0.1-10 kHz, Earth's magnetosphere, whistler VLF experiments, whistler sonograms, whistler recording and analysis setup, basic definition of Natural Radio terms, and how to get involved in whistler monitoring and research.

Tom Kneitel (editor of Popular Communications Magazine), Radio's Incredible Rock Bottom!, Popular Communications, September, 1992, pp.9-13. Introductory article on the amazing variety of "Earth Sounds" to be heard in radio's "Basement Band."

Don't Blame Solar Flares, Sky & Telescope, June 1994, page 12 (News Notes). Explains how sceintists have been mistakenly explaining solar flares as the causes of geo-magnetic storms rather than coronal mass ejections (CME's), which now appear to be the cause of many, if not most geo-magnetic storms. A CME injests plasma into the solar wind as speeds of 2,000 km/sec., often faster than the solar wind, causing a shock front which impacts Earth's magnetic field, triggering magnetic disturbances (and aurora along with natural radio emissions). With 4 photographs showing an expanding CME of 18 Aug. 1980, 1004-1310 UT. Syun-Ichi Akasofu, The Shape of the Solar Corona, Sky & Telescope, November 1994, pp. 24-27. Modern astronomical research has found the Sun's corona (outer atmosphere) to have the same structure throughout a Solar Cycle (from solar minimum to solar maximum), and that the apparent visual shape variances during a solar cycle are caused by polarity reversals of Sun's magnetic field during a solar cycle. Conventional solar photography has created the "myth" that the Sun's corona is uniform at solar maximum and non-uniform at solar minimum, due to over exposure of photographic film. (The sun's magnetic field can interact with Earth's in ways which enhance or suppress geo-magnetic storms and their accompanying auroral displays and natural ELF/VLF radio "chorus" emissions).

Neil Davis, The Aurora Watchers Handbook, University of Alaska Press, 1992 Fantastic book and a must for those interested in observing auroral displays visible in the far northern tier of the U.S. "Lower 48" states, Canada, or Alaska. Chapeters include: Cause of the Aurora, basic facts and definitions, such as the auroral zone, auroral forms, etc., kinds of auroras, variations in the aurora, control of the aurora by Earth's magbnetic field, aurorally-related phenomena (such as auroral sound/VLF radio, folklore and legends about aurora and auroral mysteries. I used this book and it was a VERY useful guide during my 2-week Manotoba VLF recording and auroral-viewing expedition to central Manitoba, Canada in August 1996.

QUICK TIPS FOR MAXIMUM ENJOYMENT OF YOUR WR-3 NATURAL VLF PHENOMENA RECEIVER

This is a summary of what you can do to maximize your enjoyment of your WR-3 VLF Receiver and your success at hearing Earth's VLF radio emissions:

Listen for Natural VLF Radio sounds in locations as far as possible from above-ground electric utility power lines (A.C. power-lines). A minimum distance of ¼ - ½ mile (400-800 meters) away from power-lines is recommended. This is because the alternating-current frequency is 50/60 Hz (cycles-per-second or "Hertz") and this frequency is within the WR-3's receive frequency range. Plus, there are "harmonics" in the power-line frequencies well past 2-3 kilo-Hertz (kHz), often resulting in an annoying mix of "humming and buzzing" which masks Natural Radio sounds if you are too close to power lines. Good locations for you to listen might be large school playing fields away from nearby electric power lines, farmlands, large parks, empty lots not surrounded by buildings and power-lines, golf courses, etc.

If you have access to open-space areas such as meadows, hilltops, beaches, etc., that's all the better! If you can listen at remote locations such as rangelands, deserts, hills or mountains many miles from electric lines, you may not hear ANY background "hum," and thus, you'll hear even the most subtle Natural Radio phenomena. And, just being in a beautiful and remote location will enhance your enjoyment and awe at Natural Radio phenomena-it IS a part of Nature. NOTE: Motor Vehicles with their engines OFF usually do not create interference to Natural Radio, but many newer models like my 2000 Toyota $Runner produce clicking noises from clocks and micro-processors with about 4-5 metres of the vehicle, so beware!.

Second to listening to Natural Radio away from electric power-lines is to locate yourself away from nearby obstructions such as trees and large bushes as these tend to dampen the "E-field" that the WR-3 is sensitive to. The WR-3 will be essentially useless even if you try to listen while next to or under even ONE tree even though that tree may be located in an otherwise open area. Locate meadows and fields if possible, in locations which have many trees. Listening at "high ground" locations is better than listening in deep valleys, gorges, and canyons, as the VLF "E-field" is also reduced by being near steep terrain if it is above you.

Listen from 1 hour before sunrise (beginning of morning twilight) if possible, as the vast majority of times you will hear Natural Radio sounds, especially whistlers and "The Dawn Chorus" will be at dawn and shortly after. 2 hours before sunrise up to 9 a.m. local time is the best. If you like the ringing/pinging sounds of "Tweeks" and the popping and crashing sounds of lightning "Sferics," you may want to listen just after local sunset up to midnight, when Tweeks are at their best. Whistlers may also happen beginning late afternoon and peak in activity between 8 p.m. and midnight your local time, particularly in late winter and early spring.

The ferocious sounds of lightning-storm "Sferics" are also best in the evening hours of the Summer and Fall when lightning storms are at their greatest number and intensity, though the amount of whistlers and chorus will generally be far less than on towards sunrise.

If you have limited time to listen and want the greatest chances to hear interesting Natural VLF Radio Sounds, 5-7 a.m. local time would be the best period to do your listening sessions. The period of day when you are generally LEAST likely to hear any Natural Radio sounds other than the popping and crackling of lightning storms is between 11 a.m. to 2 p.m. local time. However, midday activity DOES occur, especially at higher latitudes, and these events should be considered extraordinary. We urge you to avoid listening when lightning is nearby (within 5 miles/8 Km) as you run the risk of being struck by lightning if out in the open with your WR-3 (The receiver doesn't attract lightning, but your body CAN, just like trees and other objects).

Resist the temptation to listen when lightning is nearby as the impulses in the headphones will be VERY loud. Watching lightning flash while listening to the static impulses with the WR-3 can be exciting, but S. P. McGREEVY PRODUCTIONS can not be held responsible for injury or death due to misuse of equipment or by being struck by lightning.

If you have a World Band (Shortwave Radio), listen to WWV Colorado, USA on 2.5, 5, 10, 15 & 20 MHz at 18 minutes past the hour (or WWVH Kauai, Hawaii on 2.5, 5, 10 & 15 MHz at 45 min. past the hour) for "Geo-Alert" indices-if they say the "K-index" is at 3 or higher, conditions are enhanced for Natural VLF phenomena to occur. If the K-index is 4 or higher, and they say there is a "minor geo-magnetic storm" or "major geo-magnetic storm" in progress or forecasted for the next 24 hours, by all means listen the following morning at dawn for eerie and beautiful "Dawn Chorus," which is likely to occur.

If you live far enough north to see the Northern Lights (Aurora), try to listen when they are happening or on toward sunrise after nights of good displays-you will very definitely hear some intriguing VLF radio sounds off of the Aurora such as Auroral Chorus! Geo-magnetic storms cause Aurora, and reported WWV/WWVH K-indices of 4 or higher greatly increase your chances of seeing Auroral Lights and hearing Auroral Chorus or Dawn Chorus with the WR-3. Northern listeners will probably hear chorus last past local noon during magnetic-storm periods. Surprisingly, active auroral displays at night may not produce much VLF radio sounds other than "hiss," but loud chorus surely will start up before local dawn and sunrise, and go on many hours into daylight with exciting variety. Strange sounding whistlers with sustained echoing may also occur.

HEADPHONES

Not all headphones are created equal--if the volume from the WR-3 seems too low with your headphones, you may wish to try another pair of different make or model. 8 ohm and 16 ohm mini-stereo headphones will be louder sounding than 32 ohm models-check your headphones' specifications for their "impedance" in "ohms." Full-size stereo 'phones are fine, though you may need an adapter plug.

SAVE YOUR HEARING! - FINAL CAVEATS ABOUT WR-3 LISTENING:

As with usage of any audio device (portable MP3 players, radios, etc.) capable of delivering strong audio volume-levels to a listener's ears, whether via a speaker or headphones, please begin your WR-3 listening sessions with the audio gain control fully minimum, and establish comfortable listening levels that are safe for your ears. The audio-levels from lightning "sferics" can be loud and quite intense, being "impulse noise" that can damage hearing if excessive volume levels are employed. As such, please protect your hearing by using headphones of external speakers in a manner safe for your hearing, that is, keep listening volume-levels low. If you experience disturbing or uncomfortable hearing sensations while using your WR-3 (hearing-loss or tinnitus), please immediately discontinue WR-3 usage and take measures to find a more suitable listening device (another, different pair of headphones. I prefer using headphones that do not have excessive/deep bass-response such as ear-buds that are placed within a listener's ear-canals - those I consider inappropriate. Open-style headphones and/or external-speakers are vastly preferable.

It is my hope that these tips will enhance your enjoyment of Natural VLF Radio listening and helps you increase the amount of fascinating naturally occurring VLF phenomena heard with your WR-3!

(THE END)

Large repository of Natural ELF/VLF Radio audio-files available at:
Natural Radio Audio Albums Page
-And-:

Download and read more about Natural Radio Listening in-the-field: THE VLF STORY (Updated November 2016) by Stephen P. McGreevy

---

WR-3 Listening Guide updated November 2016, Stephen P McGreevy - Good Listening!
