

Stephen P. McGreevy's BBB-4 (Bare Bones Basic) Natural VLF Radio Receiver Schematic

REVISED RELEASE COPYRIGHT 1996 to 1998 S. P. MCGREEVY. BBB-4 VLF Receiver for broadband 0.1 to 11 kHz reception of naturally-occurring ELF-VLF radio phenomena. This schematic is being offered as-is. Please see notes at the bottom of this sheet before contacting me about this unit. If all instructions and notes are followed, there should be no problem with it whatsoever. Also, this unit will not receive ULF earthquake signals, nor am I very knowledgeable about such phenomena except for the very basics (I say this to reduce the number of inquiries I receive about such phenomena).

BBB-4 receiver notes and other information:

The "BBB-4" is a broadband 0.2 to 12+ kHz V.L.F. receiver with a passband peak at approximately 1.5 - 2 kHz, and is designed to receive naturally-occurring V.L.F. phenomena (such as "whistlers") that occur as electromagnetic (radio) waves at audio-frequencies. This receiver was designed to be hand-held or tripod mounted, and its output patched to a MICROPHONE-LEVEL input such as a tape-recorder or speaker-amplifier (such as the one available at Radio Shack ("Mini Audio Amplifier/Speaker" cat. # 277-1008). "Radio Shack" in the US and Canada is also known as "Tandy" overseas, such as in the U.K.

It is similar to the ready-made WR-3 and WR-3E that I used to sell (but no longer as I am concentrating on the development of three compact disc audio albums of natural radio) in its employment of a whip antenna to successfully and with sensitivity monitor audio frequency VLF Natural Radio. The differences between the BBB-4 and WR-3/3E units are that the BBB-4 does not have a headphone amplifier like the WR-3/3E units nor a switchable audio-filter. This BBB-4 receiver can only be patched either to an outboard speaker/headphone-amplifier or a microphone-level tape recorder input.

Dissatisfied with more complicated and cumbersome multi-turn loop receiver schemes back in 1991, I opted to design a whistler receiver that was simple to build and use by newcomers to this realm of radio. I also desired the BBB-4 to be as sensitive and low-noise as possible using a small whip antenna while being highly immune to broadcast and utility station overload.

The BBB-4 V.L.F. receiver circuit ("BBB-4" standing for a fourth version of my "Bare-Bones-Basic" designs) is remarkably sensitive and works very well with short whip antennas between 1-3 metres in length, since it operates on the same principle as high-impedance "active antennas" designed for other frequency ranges (such as long, medium or shortwaves).

The BBB-4, due to its F.E.T. "front-end" being a high-performance J-FET, has an input impedance of about 10 megohms, which is why the short whip antenna--more correctly called an "electrical-field probe"--works fantastically for being such a tiny fraction of the received-frequencies' wavelengths in size (the ultimate isotropic antenna). R1 and C2 act as a roll-off to frequencies above about 20-30 kHz, efficiently eliminating potential receiver overload/intermod from Loran-C (100 kHz), strong AM-BCB signals or SWBC signals, and frequencies up into the VHF ranges. R2 sets the gate impedance for the J-FET. R4 and R3 set the optimum bias on the FET for maximum dynamic range and minimum susceptibility to overload and intermod. C3 and C6 slightly helps roll-off low-frequencies such as powerline "hum."

The "pi-filter" consisting of C4, L1 and C5 roll-off frequencies beginning at about 7 kHz, so there are not excessive levels of 10.2 - 13.6 kHz "Omega" signals or higher frequency signals, which can create problems with the recording system connected to the output of the receiver. R5 to R8, Q2 and C7 form a fairly low-noise Class-A audio amplifier which boosts the output from Q1 to a level plenty for all microphone-level recorder inputs and even some more "sensitive" line-level inputs. Bypassing R3 (1K) with a 2.2 uF cap will boost FET gain somewhat, esp. the higher frequencies--depending on your location and listening conditions, this may or may not be desirable.

The circuit can be built on perfboard such as IC-LSI boards or even wired point-to-point, as layout is not very critical. However, the parts' values ARE critical for optimum passband shape and sensitivity. It is recommended that this circuit be installed into a metal enclosure for maximum RF shielding.

L1, the inductor, can either be a 160-200 milliHenry choke or the Radio-Shack 1K to 8 ohm audio transformer available at Radio-Shack (cat. # 273-1380). Use the black and green or black and blue wires (the center-tap and one end of the primary winding).

AUDIO FILTER L1 (A PI-FILTER USING A COMMON AUDIO XFMR AS INDUCTOR)

(From FET drain coupling cap C3) L1 (1KCT xfmr primary) OR 160-200 milliHenry choke (Approx. 160 milli-Henries)

***L1 is a 1 KCT pri. to 8 ohm sec. audio xfmr. using one half of primary winding and the center-tap as a series inductor equalling approx. 160 milliHenry. C4 and C5 range from 0.0033 microFarads to 0.0047 microFarads regardless of J-FET used.**

The audio transformer was used since it is easily available at Radio Shack stores. In fact, ALL the parts are available at Radio Shack. Capacitors C4 and C5 work with L1 to reduce Omega to tolerable levels. Solder the J-FET into the circuit LAST, and take measures to protect the FET from static electricity. The total cost for parts (not including an enclosure) for the BBB-4 are in the neighbourhood of \$15-20 U.S.

A rugged telescoping-whip antenna is the GROVE ENTERPRISES "ANT-8" 7-46-inch telescoping whip with a BNC connector. This is available for \$16.95 from Grove Enterprises, P.O. Box 98, Brasstown, NC 28902-0098, U.S.A. (Order Line 1 (800) 438-8155. They send out a free catalog. Another telescoping whip antenna of like design is available from C. CRANE RADIO CO. in Fortuna, CA in Fortuna, California (800) 522-TUNE (522-8863). E-field-probe receivers of this type need to be operated at locations away from trees, buildings, or other obstacles by about 100 feet/30 metres. This is because received signal levels (due to E-field attenuation) will be poor if the receiver is operated too near (or under) such obstructions.

The greatest nemesis to monitoring and recording naturally occurring VLF phenomena are electric AC powerlines, which emit annoying hum at 50/60 Hertz and also harmonics beyond 1 or 2 kHz. The only cure for this "hum" problem is to locate monitoring sites well away from AC powerlines. Locations at least 1 km/0.6 mi. or so away from a.c. powerlines will begin to be acceptable, though the farther you can get from powerlines, the better. Hilly or mountainous terrain (with open areas free of trees) offer larger areas away from powerlines, though large fields and meadows where the powerlines are shielded by trees, etc. may be surprisingly hum-free. (On the other hand, "low-hum" areas can exist remarkably close to or within towns and cities if most AC lines are below ground.)

Remote locations such as deep into desert and wilderness regions offer the most rewarding locations, both aesthetically and electrically, to listen, and you may be able to get over 10 miles from the nearest powerline. If so, you can make the receiver's antenna several metres in length (keeping it vertical) for maximum sensitivity. Longer vertical antennas or horizontal wires may either overload the receiver, or in the case of long/low wires, will create a mismatch which will actually reduce output. Experiment here.

NOTE: A 100 milliHenry choke across C5 (the second .0047 cap in the audio filter) will greatly reduce the below 1 kHz frequencies, including pesky power-line hum. This may enable you to listen far closer to AC power-lines including even some backyard locations! Grounding is non-critical. High-impedance FET receivers of this type need only minimal grounding to work well--even just the body of the listener holding the metal enclosure of the receiver will be adequate in most cases. If you wish for really low noise performance in the input stage, replace R1 with a 100 milliHenry choke.

If recording, it is best to stick a 8-10 inch ground rod into the soil to reduce the possibility of feedback with some tape recorders. Also, a small ground-rod (8-10 inches long) will cut noise from body or foot movements (due to capacitive interaction with the ground). If you ground the receiver to objects such as fences, beware that certain grounds may couple AC powerline noise to the receiver, which is why I recommend a simple Earth ground. Better quality tape recorders, with adjustable input level controls, are desirable, as "cheapie" portable recorders with auto-level control will often have annoying variations in record level due to lightning-sferics. And, these cheap recorders also put noise of their own onto the tape.

A shielded 600 ohm patch-cord will suffice between the output of the BBB-4 and microphone input of a tape recorder or speaker amplifier.

The most common naturally occurring V.L.F. emissions to be heard are the myriad "crackling and popping" sounds of lightning-stroke electromagnetic impulses (static/sferics) from lightning storms within a couple thousand-km/mile radius of the listener. Since there are nearly 100 lightning storms in progress anywhere on the Earth at any given time, and that millions of lightning strokes happen daily, there is NEVER a moment when these lightning "sferics" will not be heard. However, the density and strength of lightning sferics can vary day-to-day and hour-to-hour. Mid-winter offers the lowest density of sferics, and summer evenings can be full of a dense barrage of strong sferics masking everything else.

The other most common (and most awesome) sounds are "whistlers"--eerie descending tones caused when the lightning electromagnetic energy gets "ducted" along Earth's magnetic lines-of-force (magnetosphere) to the opposite polar hemisphere, then gets rebounded back to the vicinity of the originating lightning stroke impulse. However, there doesn't have to be lightning within sight or even a few hundred miles of your listening location--lightning from storms up to thousands of km/miles away, particularly if more to the north of your location, can generate large whistlers which are heard continent-wide.

On the other hand, it's quite spectacular to watch safely distant lightning storms generate whistlers in the receiver's output--you hear the huge "crack" of the lightning impulse sferic, then, if the conditions to support whistlers are occurring, a whistler may follow from 1 to 2 seconds after the lightning stroke.

Optimum times to listen for natural V.L.F. phenomena, such as whistlers, are between sunset and sunrise, with the midnight to sunrise period generally being the best.

Statistically, the greatest activity to be heard is around dawn and sunrise (4-7 a.m. local time)_sferics tend to be fairly low as compared to the sunset period. Dawn Chorus can occur during magnetic- storms, and will peak anywhere from an hour before sunrise to 2 hours past sunrise.

Whistlers can occur at anytime, but the period of minimum frequency is midday. Sometimes, activity can also occur just after sunset, but sferics will be fiercer. Lightning sferics will be most fierce during summer afternoons and minimum (generally) an hour or so after sunrise until thunderstorm activity picks up later on. Winter can present delightfully low lightning sferics_other activity will be more "in the clear."

Weeks, the "ringing/pinging" sounds of sferics caused by the Earth- surface/ionosphere "waveguide," will be best from an hour after sunset to 2-3 a.m. local time, gradually tapering off toward sunrise. Their number and intensity of "pinginess" can vary from night to night_some nights they can sound rather "pale," but other nights they can ring in a variety of beautiful mixtures and pitches. Whistlers, which may or may not be heard on some days or even weeks, can range in sound from quite pure notes to very diffuse "breathy" sounds. They can swoop in frequency from very high to low, or abruptly cut-off as they descend in pitch.

If you live north of the about latitude 45 in the US and Canada, or in northern Europe, or extreme southern Australia and New Zealand (closer to the auroral zones), you will likely be able to hear interesting natural radio activity about 50% of the time, especially during magnetically disturbed/storming periods. For those farther south, don't be discouraged if you listen for several hours, or several sessions on different days, without hearing whistlers or other natural radio phenomena. When you DO hear them, it will make up for the "dry" times, as there is nothing like "live" listening! Listeners located north between 40-55 degrees north or south latitude are in the optimum latitudes for monitoring natural V.L.F. phenomena.

If you can see visible Aurora (Northern/Southern Lights) from your location, you are at a great location for natural V.L.F. phenomena monitoring! Latitudes between 20-30 degrees north and south will hear less, but at times, still loud phenomena. I've heard whistlers just fine in Hawaii_presumably those whistlers were louder farther north, but still, they were heard! DO NOT operate this receiver (or any other) when nearby lightning threatens! Take appropriate lightning precautions when lightning is occurring nearby (within 5-10 miles).

Nearby lightning will cause excessively loud sferics in the receiver's output, and whistlers will not be louder just because lightning is close-by. Reserve listening for fair weather periods_most often, the best and loudest natural V.L.F. phenomena will happen during clear weather, since lightning can be quite distant, as mentioned above, and still spawn loud whistlers.

Coordinated monitoring of naturally occurring V.L.F. phenomena among individuals and groups has a strong potential to uncover new and previously unknown characteristics of these phenomena, particularly if those monitoring simultaneously are located hundreds and thousands of miles apart. Research and understanding of V.L.F. phenomena has been hindered by a lack of listeners, which is something a few research groups, both amateur and professional, are attempting to alleviate.

I hope you enjoy this receiver and are interested in monitoring and studying naturally occurring VLF radio phenomena for yourself. It is quite fascinating, especially when one ponders the fact that Earth's natural radio emissions have been "sounding-off" way before we Humans came into existence and started making radio waves of our own!

Happy Listening!

Stephen P. McGreevy

Text and schematic originally released November 1993, updated November 1995, January 1996 with thanks to many rec.radio.shortwave readers!!!

Additional Tips:

- 1) A 100-200 milliHenry inductor connected across C5 will act as a high-pass filter, nicely attenuating 60-360 Hz powerline emissions (hum).
- 2) If you want less gain from the Q2 stage (and slightly lower noise), reduce R8 to 4.7K.
- 3) Listen to WWV-shortwave (2.5, 5, 10, 15, 20 MHz) for geo- magnetic indices at 18 min. past each hour (WWVH-Hawaii at :45). A K- index at or above 3 indicates enhanced conditions for natural phenomena, especially chorus.
- 4) The U.S. NOAA/USAF/Space Environment Center (SEC) runs a fantastic Website with geomagnetic indices and other information available at:<http://sec.noaa.gov>. Lists the past 30+ days' geomagnetic conditions, proton and electron fluences, and so forth. There seems a rough correlation between high electron fluences and louder whistlers at middle latitudes-- look for fluences at 1.0E + 07 or higher. Periods when the solar flux is rising also seem to be times when whistlers occur more often. Nights of fabulous whistlers can be unpredictable and can't be reliably predicted via "indices," so if you have a chance to listen, do so! Again, high K-indices over 3-4 mean probable chorus (auroral chorus at higher latitudes and dawn chorus at mid. latitudes near or just after your local sunrise. Conditions which hinder HF propagation make Natural Radio come alive!

Stephen P. McGreevy, N6NKS

FINAL NOTE: This E-field VLF receiver schematic and instructions are being offered "as-is." It performs very well as described and in its form shown. Experiment at your own risk and enjoyment. It is made for a 1-3 metre whip (vertical) antenna only. It will not work with ham or SWL antennas, nor loop antennas, nor longwires. It is designed for approx. **300 Hz to 11 kHz** reception--not lower nor higher frequencies. As it is presented herein, it will not receive man-made broadcasts/transmissions such as military VLF stations in the 16-25 kHz spectrum, nor earthquake (ULF) signals below 5 Hz, as some have previously asked me.

It is strictly a 0.4 - 11 kHz receiver for Natural Radio phenomena listening. I tend to lack time to answer questions about it other than what is presented here. Other than that, have fun with it!!! Commercial-use strictly prohibited without consent of Stephen McGreevy (ask and you may/shall receive...).

NEW!: Dave in north-eastern Holland (Gronigen) sent me this e-mail, saying how well his build of the BBB-4 works. He has a fantastic web site showing photos of his finished receiver and antenna to BNC jack adaptations for use with his own BBB-4. The URL of his web site with this information is: <http://www.da4e.nl/elfspecial.html>

He also has some .wav recordings of his reception at this site. The text of his e-mail is as follows:

Message-ID: <001401bdd387\$568a6cc0\$b40e86c2@do42>
From: "Dave"
To:
Subject: Whistlers and chorus
Date: Sat, 29 Aug 1998 21:58:05 +0200

Hi Stephen

I am impressed with the performance of the BBB-4 receiver, I have now built 2 and am avidly busy day and night recording in the very north east of the Netherlands in the polder areas where there are no cables and trees. So far I have captured both chorus and whistlers, and am using Gram to spectrums the recordings. We had great trouble trying to get the transformers, **so used 2 82 millih chokes** instead. Great stuff. I have been a radio freak for years, from UHF to LW and now to ELF. I intend to set up a page(s) on this area with spectrograms and sound bits, I would like to have the E-mail address of the designer of the Gram program, I could not find his address anywhere. Also if you have any more details of filtering in progress.

Thanks so much for the turn on in this region of the atmosphere, as I was and am busy with the magnetic end of this for some time now.

If you have time, like to hear from you..

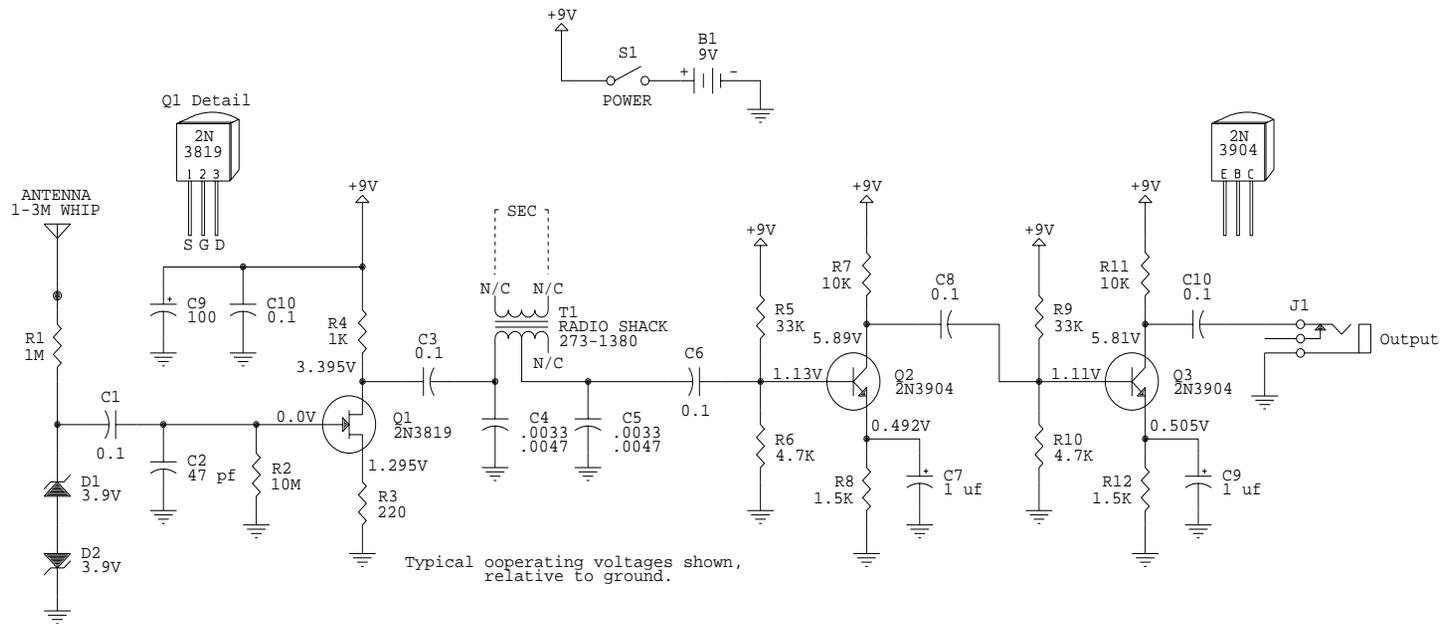
best wishes from Holland..

Dave. <http://www.rcg.nl/~dave/elfspecial.html>

<http://www.rcg.nl/~dave/index.html>

McGreevy VLF Radio Receiver

RX Frequency Range: 100 Hz - 11 kHz



This version sports a 2nd audio amplifier stage at Q3. The output level with this version is sufficient to drive a crystal headphone to a comfortable volume.

The "crystal" headphone is like those used on ye olde crystal radios. A "Walkman" type headphone is NOT the same thing! Check out Mouser #25CR060. Or use as input to your amplifier.

D1/D2 Optional - protects Q1 from nearby lightning

Schematic From: www.auroralchorus.com/bbb4b.htm
C4/C5 values: See text on above web reference

See also: www.auroralchorus.com home page
See also: www-pw.physics.uiowa.edu/mcgreevy/

NOTE: Output is microphone level audio.

T1 is a Radio Shack 1K CT primary to 8 ohm secondary
Only 1/2 of primary is used. Secondary is not used.
Rat Shack part number is 273-1380

VLF RECEIVER

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B	Documented by	Tom Farrand	0
Date:	July 29, 2002	Sheet	1 of 1

BBB-4 E-Field VLF-Receiver Project

Now I have been using and testing my first BBB-4 E-Field VLF receiver for about a year and liked to rebuilt all the receiver for some modifications of my own, here are two pictures one of my old and one of my new receiver.



(Old receiver)



(New receiver)

First I would like to tell a little about the BBB-4 E-Field VLF receiver made by Stephen P McGreevy, the BBB-4 stands for "Bare bone basic version 4" and is a kind of "keep it simple VLF receiver" for the beginner.

The BBB-4 receiver are made for receiving naturally occurring radio phenomena's in the frequency area 200 Hz. to 11000 Hz. The receiver are a high impedance FET E-Field receiver for small antennas size 1-3 meters.

The technical data for my new built VLF receiver are like this:

Input Lowpass filter stops about 23 KHz.

PI Filter stops about 6 KHz.

Current about 8,4 V / 25 mA.

When I prepare to built my new receiver, I had some wishes I like to do better in this version:

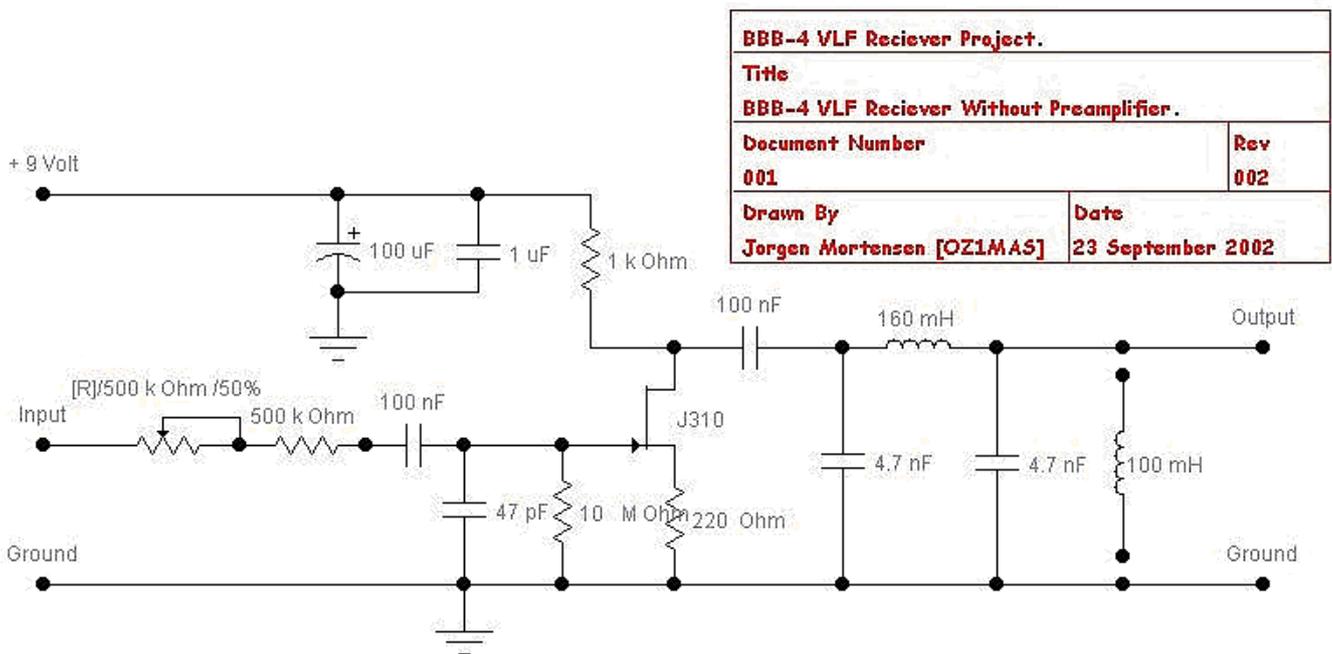
Better antenna connection.

Speaker amplifier.

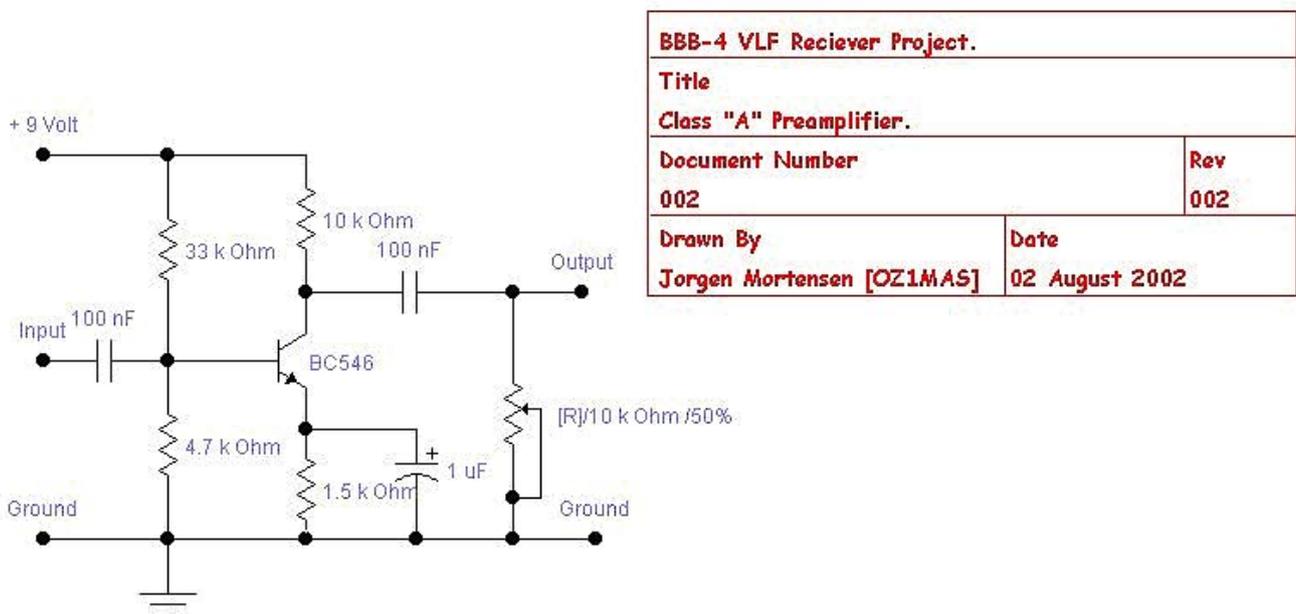
Control of input level at every single stage.

Led for On/Off (And finding the receiver at night).

Here is the schema for the original BBB-4 receiver and the class "A" preamplifier, the two 100mH coils in the input and in the PI filter are modifications and not a must.

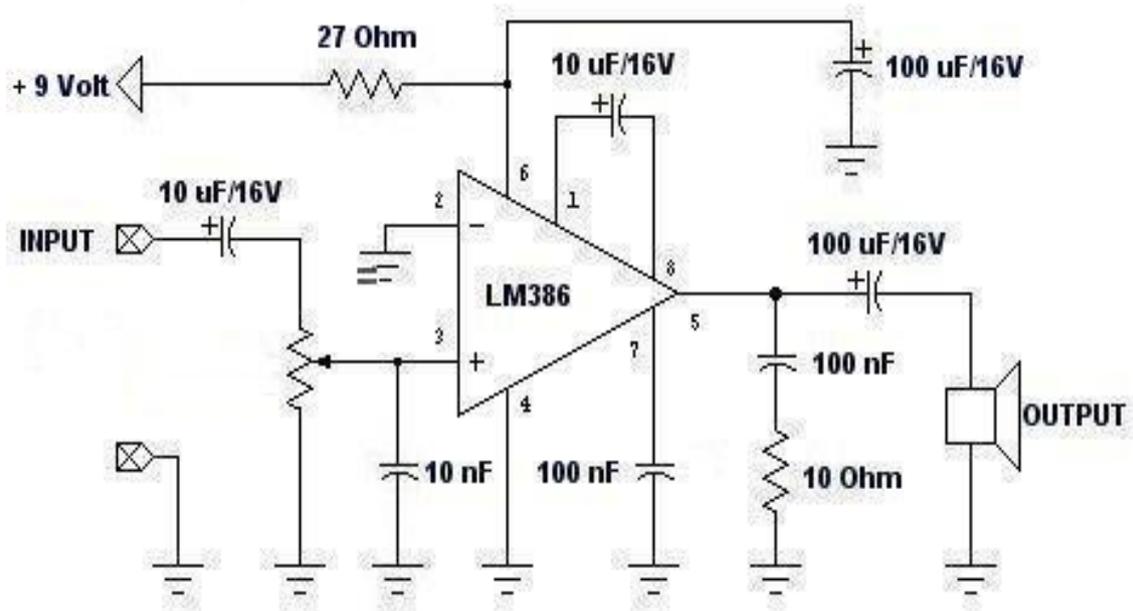


(The schema for the receiver unit using a J310 FET transistor)



(The schema for the class "A" Preamplifier using a BC548 or BC546 transistor)

This is the schema for the LM386 AF amplifier.



(The 0.5 Watt audio amplifier with a LM386 IC)

Here there are some pictures of the 3 PCB I made for the receiver.



(500mWatt LM386 Amplifier)



(BC546 Preamplifier)



(VLF receiver with J310 FET)

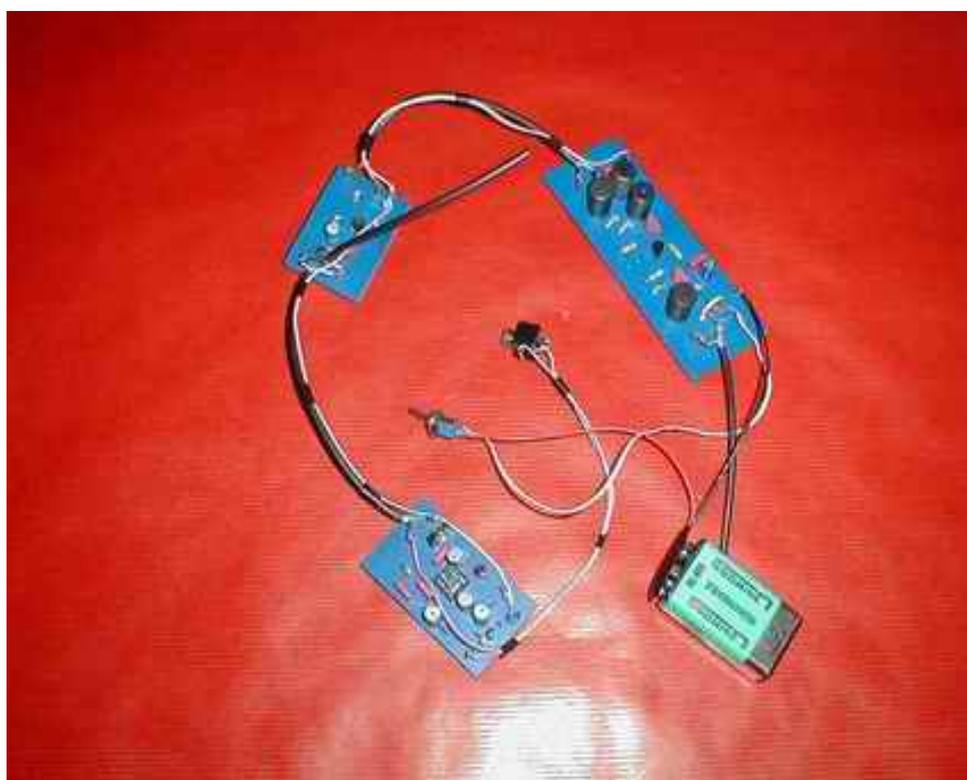
The LM386 AF amplifier is a for me well known and simple amplifier used for many projects, this version are made for 200 times gain, that's lot of power for a small speaker or headphones.

The Preamplifier are nearly the original from BBB-4 but in this version I control the output with a 10k Ohm variable resistor, it was not possible for me to get a 2N3904 but a BC546/BC548 transistor can do the same job, the reason for making a control of the output is that I would like to control the recording level to the tape recorder.

The VLF receiver & PI filter are also nearly the original BBB-4 with all modifications included, I use a 500k Ohm variable resistor for control of the input, it was not possible for me to get a 2N3819 but a J310 FET transistor work as well.

The idea with a LED to indicate On/Off is good idea, you remember to turn the receiver off and one early morning some time ago, I had some problems to find the receiver in the dark, it's easy to see a LED in a dark night.

After testing the PCB's I wired them like this for the last test.



(Test of the receiver)

The loose shielded wires are for tape output and antenna connection. I choose a waterproof solid-state moulded Aluminium box for safety of the PCB and for good RF shield.

Now it was time to make holes in the moulded aluminium box, I choose to make it like this.



(Holes drilled in the box)



(PCB's placed in the box)

Now it was time to mount screws and PCB's into the box.



(Inside look in the Receiver)

Finally some pictures of the VLF receiver box, when it's ready for field test.



The two screw's at the back is for mounting a aluminium tube to set into the ground and the screw at the left side are for ground cable if used, antenna are a one/two meter 8 mm aluminium tube. mounted in a PL 259 male connector with some 10 mm air hose as isolator and some crimp flex to complete the finish, I have made two antennas the first at one meter and the other at two meter to use at more silent areas.



After the first field-test of my new BBB-4 VLF receiver I was very happy for the new design and modifications I have made in this version. It have really boosted the receiver sensibility and made the receiver better to use in the field.

Modification: Instead for the 1M Ohm resistor / 100uH coil in the input stage, use a 500K Ohm resistor and a 500k Ohm variable resistor, now there will be much more input to adjust, my BBB-4 receiver works now just as good with 1 meter antenna as with 1,5 meter before the mod, off cause the hum also get's stronger.

Modification: Instead of the 100uH coil in the input stage you can use first a 200k Ohm resistor second a 150uH coil, it would make the noise temperature lower for the FET transistor.

Here is a picture of the receiver in the field at Knudskov and one of my daughters with the receiver as portable.



(550502N 0114865E)



(Susan with the receiver as portable)

Natural Radio

A journey to the music of the nature

What is it?

Natural radio is a term given to very low frequency (VLF), ultra low frequency (ULF), and extremely low frequency (ELF) radio waves emitted by charged particles in Earth's atmosphere and magnetosphere. These emissions can have frequencies in the range of tens to thousands of hertz, as opposed to the megahertz and gigahertz frequencies we normally associate with man-made broadcasts. Because of its low frequencies, natural radio can be translated directly into sound, revealing its complex and beautiful nature. Natural radio signals are being generated all the time, but go unnoticed because they are difficult to detect. They are frequently overwhelmed by man-made VLF noise sources, primarily the noise from alternating current power lines. Detection of natural radio signals requires special electronic equipment capable of detecting VLF signals.

Despite the term natural radio has been used to describe VLF/ULF/ELF radio emissions, electromagnetic waves produced by natural sources in our universe, do not only occur in this region but in almost every frequency in the electromagnetic spectrum. In this case, these frequencies cannot be translated directly into sound and other means of equipment is needed to listen to them. But they are also parts of the natural radio.

What can you hear out there?

From Plate Tectonics to Particle Physics, Natural Radio is any electromagnetic energy which occurs in Nature. Such phenomena have been around since before we had the technology to detect them, before life existed in earth or even before our solar system was born. Here are some examples:

Sferics - Mainly the ubiquitous snap, crackle and pop of lightning all over the earth, this can be heard anytime, anywhere, on frequencies from 1 Hz to beyond 100 MHz. Just tune your AM radio to an empty frequency. Sferics below deserve special mention.

Tweaks - A modified form of lightning sferic where the electromagnetic impulse undergoes a process of dispersion, and its frequency components become 'smeared out' in time. Commonly sounds like a 'chirp' or 'tweak'. Dispersion results from interaction between the energy wave, the magnetic field of the earth, and the ionosphere (ozone layer). Can be received from 100 Hz to 30 kHz with homebuilt gear, best in an electrically quiet location.

Whistlers - A sferic which has become dispersed in time to the point of becoming a descending tone. Whistlers are less common, and may be only associated with recently discovered 'upward lightning'. Whistlers can 'echo' back and forth between the northern and southern hemispheres of the earth between magnetic conjugate points, sometimes blending into an eerie and beautiful harmony. Receive techniques same as tweaks.

Chorus - A sferic normally associated with dawn or aurora especially during magnetic storms. Chorus can sound like whispery voices, or like distant singing of birds, barking animals, surf crashing on a shore, or almost anything. Receive techniques same as tweaks.

Earthquake waves and precursors - Not sferics, occur at lower frequencies. Gaining credibility in mainstream science as a possible early warning for major earthquakes since the landmark work of Antony Fraser-Smith. Equipment, which can be home built, usually includes a computer to record signals 0.001 to 10 Hz, below human hearing. In the range of 0 to 10 Hz, we 'hear' or sense waves from the internal groans and creaks of the Earth, the solar wind howling around the Earth's magnetosphere, magnetic storms, and a host of unknown phenomena. Although these are infrasonic, below human hearing, you can speed up a recording to bring them within range of human hearing. One of the hottest research topics in this part of the electromagnetic spectrum is the possibility of earthquake precursors that could provide an early warning and save lives. The National Earthquake Information Center at the United States Geological Survey provides this and other near-real time maps, maintains searchable databases and other resources, a veritable Mecca of seismology.

Fields and Waves in this region of the spectrum include magnetometers and electrometers for magnetic and electric fields to DC, and seismographs and gravimeters for mechanical and gravity waves.

Schumann resonance - A resonant cavity is formed between the ionosphere and the earth. Energy from sferics or other sources may excite this natural resonator to ring at about 8 Hz. Special purpose receiver, can be home built.

Other Planetary sources - Earth is not the only planet to exhibit a radio personality. Venus is quite similar to Earth, and the four gas giants, Jupiter, Saturn, Uranus and Neptune are natural emitters of HF radio signals. Jupiter's powerful voice may be received on Earth using simple hobby equipment on frequencies around 10 to 40 MHz. The FCC has set aside a 'quiet zone' from 25.55 to 25.67 MHz as one of the radio astronomy listening windows.

Solar phenomena - The sun is by far the most powerful electromagnetic emitter in our solar system, generating broadband radio emissions, flares, magnetic waves, and storms of electrically charged nuclear particles and ions. These directly cause and/or influence the propagation of electromagnetic waves throughout the known spectrum. The lowest documented electromagnetic solar cycle is about 22 years, or 0.000000014 Hz. High end frequencies above 100000000000000000000 Hz have been detected.

Pulsars - Some stars collapse into rapidly spinning cores of extremely dense matter, their intense magnetic fields sweep out charged particles forming an electromagnetic pulse. Typical pulsars rotate about once per second, compared to the earth's rotation of once per 24 hours. A faster spinning pulsar is PSR J0835-4510 (psrb 0833-45) is a remnant of the Vela supernova, and rotates at about 11 Hz (period=0.089308556629 s) and sounds to me like something getting slapped by a ceiling fan. The fastest spinning pulsar PSR J1939+2134 (psrb 1937+21) rotates at 642 Hz, (period=0.001557806468819794 s) and its surface at the equator is moving about 14% of the speed of light.

Gamma Ray Bursts - Satellites designed to monitor nuclear tests received unexpected gamma ray bursts (GRBs) not of earthly origin. In average week, several of these distant, mysterious cosmic events will occur, which for a few seconds will illuminate our planet with gamma rays brighter than our own sun. At such great distances the energy at the source must be immense, the entire energy output of our sun over its 10 billion year lifetime is emitted in a few seconds. Even more surprising, the pulse time indicates these distant sources are also much smaller than our solar system.

Other Cosmic sources - Our universe is filled with many other strange and mysterious electromagnetic voices. Main sequence stars, neutron stars, pulsars, quasars, novae, gas clouds, and even the afterglow of the birth of the universe itself all have their part in the electromagnetic music of the spheres. We don't really know the full range of frequencies, but two high energy (high frequency) events above 10^{20} eV have been recorded so far, and the lowest frequency cycles are so slow our technology has not been around long enough to see a complete cycle.

Human biological sources - The human nervous system uses electricity, and thus creates electromagnetic waves. These waves are usually very weak, but researchers are exploring possible connections with parapsychology in humans, and effects of external sources on living beings. Brainwave radiation can be recorded by instruments at close range in a shielded room between 0 Hz and 100 Hz.

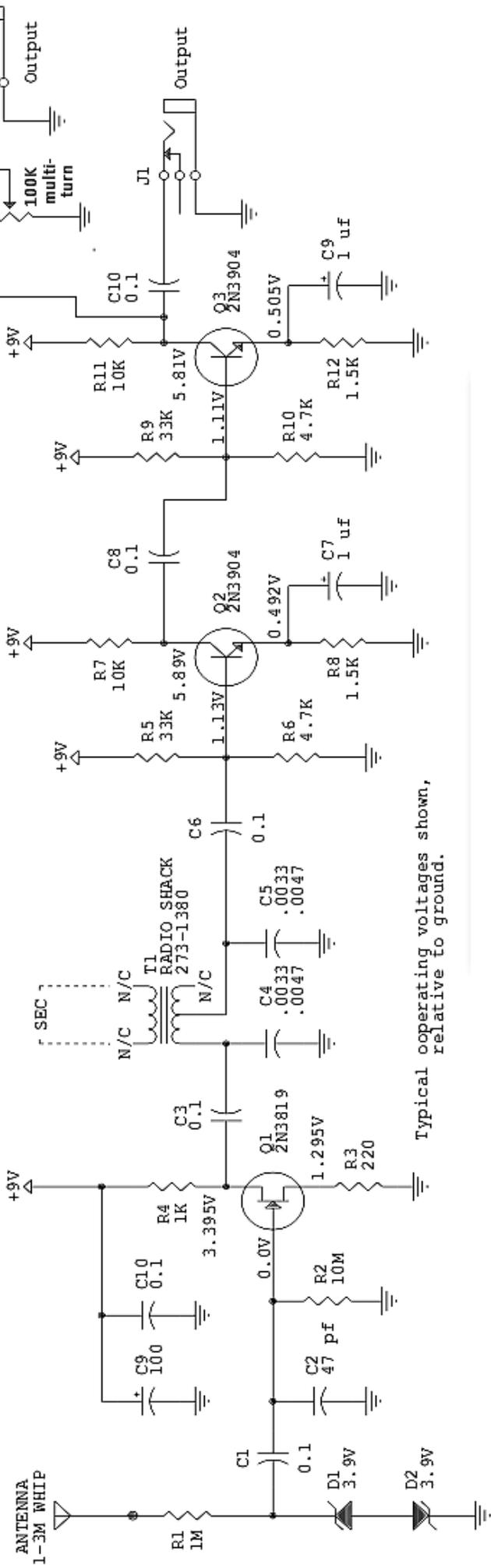
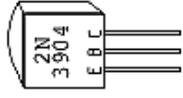
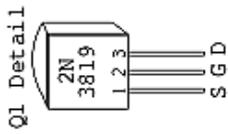
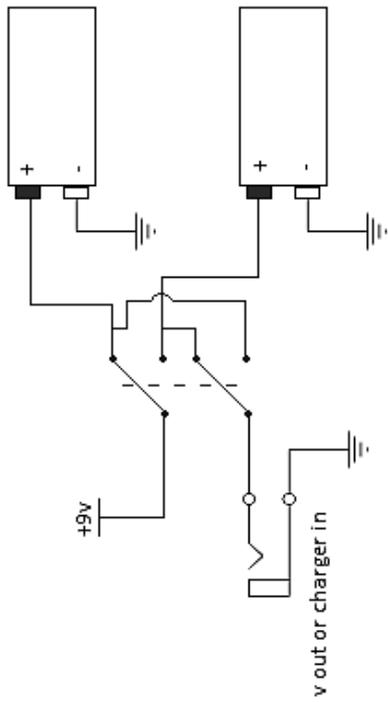
Marine biological sources - Many species of marine life form use high levels of electricity and electromagnetic waves for sensing, location, communication and defense. Electroreceptive life can sense but not create electromagnetic energy. Dogfish and sharks have receptors called ampullae of Lorenzini, small innervated bulbs attached to a long jelly-filled canal running to an opening in the skin. Detection threshold is only 0.005 microvolt/cm = may detect a flounder at 30 cm, even if buried in the sand. They do not recognize cut up fish buried in sand but will attack a buried cable or electrode. Electrogenic life can generate electromagnetic energy, generally in the frequency band of 1 Hz to 10 kHz. Most Electrogenic fish generate up to 1 volt or so for sensing, location and communication. Here is an Electrical Organ Discharge (EOD) of the Elephant-Nose fish (Gnathonemus Petersi). Jamming of the signal appears when several species of weakly electric fish coexist in the same area, or individuals of the same species. Eigenmannia produces pulses at the frequency 250 - 700 Hz, when another fish interferes, it shifts their frequency (jamming-avoidance reflex). Each fish then has its own private

channel. Individuals may be recognized.

Strongly Electrogenic fish such as Torpedo, Astroscopus, and Electrophorus (electric eel) can generate 10 to 500 volts for defense or to stun their prey.

Equipment

In this section, we will focus on the equipment that is needed in order to listen natural radio in audio frequencies. Below, such a receiver is presented (click the image for a clearer version). Its frequency range is about 100Hz - 11kHz. In fact the receiver can receive from 50Hz at least. This is a variation of the famous BBB-4 VLF receiver that is easy to construct, it has been constructed and it works perfectly ok for this range of audio frequencies. This version sports a 2nd audio amplifier stage at Q3. The output level with this version is sufficient to drive a crystal headphone to a comfortable volume. The "crystal" headphone is like those used on the old crystal radios. A "Walkman" type headphone is NOT the same thing! Check out Mouser #25CR060. Or use as input to your amplifier. This simple receiver works so well that it remains a basis for a good VLF receiver for audio-frequency natural radio phenomena listening in a simple, straightforward design!



D1/D2 Optional - protects Q1 from nearby lightning. A second plug has been added to give the ability to connect the recording equipment and the phones at the same time. One of the two levels can be precisely adjusted using a multi-turn potentiometer. The main reason I used the multi-turn potentiometer was its resistance to humidity. Most carbon potentiometers will induce noise to the audio signal due to humidity after a long period of being unused, but wire potentiometers will not. Output on both output plugs is microphone level audio. I tried to cascade another 2n3904 class-A amplifier section but it gave me more microphonics rather than audio amplification, so I used only what is displayed in the schematic above. T1 is a Radio Shack 1K CT primary to 8 ohm secondary. Only 1/2 of primary is used, secondary is not used.

The receiver has been designed for high mobility. If you are far away from home you may not be able to find batteries. The consumption of the receiver is very low and the receiver will operate for months before the battery gets consumed. The battery configuration was chosen so that this will be a highly portable receiver. If you switch to battery 1, the receiver will operate from battery 1 and you can charge battery 2, without affecting the operation of the receiver. Also, if battery 2 is charged you can use its power to power other devices external to the receiver too, without affecting the operation of the receiver. If you switch to battery 2 the opposite scenario is taking place. I used two 9v rechargeable batteries and I embedded them into the receiver, to create a high mobility device.

BBB-4 receiver notes and other information

The "BBB-4" is a broadband 0.2 to 12+ kHz V.L.F. receiver with a passband peak at approximately 1.5 - 2 kHz, and is designed to receive naturally-occurring V.L.F. phenomena (such as "whistlers") that occur as electromagnetic (radio) waves at audio-frequencies. This receiver was designed to be hand-held or tripod mounted, and its output patched to a MICROPHONE-LEVEL input such as a tape-recorder or speaker-amplifier (such as the one available at Radio Shack ("Mini Audio Amplifier/Speaker" cat. # 277-1008). "Radio Shack" in the US and Canada is also known as "Tandy" overseas, such as in the U.K.

Dissatisfied with more complicated and cumbersome multi-turn loop receiver schemes back in 1991, the designer of the BBB-4 receiver opted to design a whistler receiver that was simple to build and use by newcomers to this realm of radio. He also desired the BBB-4 to be as sensitive and low-noise as possible using a small whip antenna while being highly immune to broadcast and utility station overload.

The BBB-4 V.L.F. receiver circuit ("BBB-4" standing for a fourth version of my "Bare-Bones-Basic" designs) is remarkably sensitive and works very well with short whip antennas between 1-3 metres in length, since it operates on the same principle as high-impedance "active antennas" designed for other frequency ranges (such as long, medium or shortwaves).

The BBB-4, due to its F.E.T. "front-end" being a high-performance J-FET, has an input impedance of about 10 megohms, which is why the short whip antenna--more correctly called an "electrical-field probe"--works fantastically for being such a tiny fraction of the received-frequencies' wavelengths in size (the ultimate isotropic antenna). R1 and C2 act as a roll-off to frequencies above about 20-30 kHz, efficiently eliminating potential receiver overload/intermod from Loran-C (100 kHz), strong AM-BCB signals or SWBC signals, and frequencies up into the VHF ranges. R2 sets the gate impedance for the J-FET. R4 and R3 set the optimum bias on the FET for maximum dynamic range and minimum susceptibility to overload and intermod. C3 and C6 slightly helps roll-off low-frequencies such as powerline "hum."

The "pi-filter" consisting of C4, L1 and C5 roll-off frequencies beginning at about 7 kHz, so there are not excessive levels of 10.2 - 13.6 kHz "Omega" signals (AND Russian "ALPHA" in the Eastern hemisphere) or military communication signals in the 18 to 25 kHz range, which can create problems with the recording system (particularly cassette-type recorders) connected to the output of the receiver. Mini-Disc or other recording systems capable of broadband recording past 20 kHz will suffer far less problems from ALPHA and mil. comms., and the pi-filter caps can be further reduced to .002 uF - experiment here if you like. R5 to R8, Q2 and C7 form a fairly low-noise Class-A audio amplifier which boosts the output from Q1 to a level plenty for all microphone-level recorder inputs and even some more "sensitive" line-level inputs. Bypassing R3 (220 ohm) with a 2.2 uF cap will boost FET gain somewhat, esp. the higher frequencies--depending on your location and listening conditions, this may or may not be desirable.

The circuit can be built on perfboard such as IC-LSI boards or even wired point-to-point, as layout is not very critical. However, the parts' values ARE critical for optimum passband shape and sensitivity. It is recommended that this circuit be installed into a metal enclosure for maximum RF shielding.

A note about R1: experiments in early 2001 have shown that lower receiver J-FET temp. noise results with the substitution of the 1 megohm resistor with (first) a 200K followed by a 150 milliHenry inductor (choke) in series.

L1, the inductor, can either be a 160-200 milliHenry choke or the Radio-Shack 1K to 8 ohm audio transformer available at Radio-Shack (cat. # 273-1380). Use the black and green or black and blue wires (the center-tap and one end of the primary winding).

The audio transformer was used as an inductor, since it is easily available at Radio Shack stores. In fact, ALL the parts are available at Radio Shack. Capacitors C4 and C5 work with L1 to reduce Omega to tolerable levels. Solder the J-FET into the circuit LAST, and take measures to protect the FET from static electricity. The total cost for parts (not including an enclosure) for the BBB-4 are in the neighbourhood of \$15-20 U.S.

E-field-probe receivers of this type need to be operated at locations away from trees, buildings, or other obstacles by about 100 feet/30 metres. This is because received signal levels (due to E-field attenuation) will be poor if the receiver is operated too near (or under) such obstructions.

The greatest nemesis to monitoring and recording naturally occurring VLF phenomena are electric AC powerlines, which emit annoying hum at 50/60 Hertz and also harmonics beyond 1 or 2 kHz. The only cure for this "hum" problem is to locate monitoring sites well away from AC powerlines. Locations at least 1 km/0.6 mi. or so away from a.c. powerlines will begin to be acceptable, though the farther you can get from powerlines, the better. Hilly or mountainous terrain (with open areas free of trees) offer larger areas away from powerlines, though large fields and meadows where the powerlines are shielded by trees, etc. may be surprisingly hum-free. (On the other hand, "low-hum" areas can exist remarkably close to or within towns and cities if most AC lines are below ground.)

Remote locations such as deep into desert and wilderness regions offer the most rewarding locations, both aesthetically and electrically, to listen, and you may be able to get over 10 miles from the nearest powerline. If so, you can make the receiver's antenna several metres in length (keeping it vertical) for maximum sensitivity. Longer vertical antennas or horizontal wires may either overload the receiver, or in the case of long/low wires, will create a mismatch which will actually reduce output. Experiment here.

NOTE: A 100 milliHenry choke across C5 (the second .0047 cap in the audio filter) will greatly reduce the below 1 kHz frequencies, including pesky power-line hum. This may enable you to listen far closer to AC power-lines including even some backyard locations! Grounding is non-critical. High-impedance FET receivers of this type need only minimal grounding to work well--even just the body of the listener holding the metal enclosure of the receiver will be adequate in most cases. If you wish for really low noise performance in the input stage, replace R1 with a 100 milliHenry choke.

If recording, it is best to stick a 8-10 inch ground rod into the soil to reduce the possibility of feedback with some tape recorders. Also, a small ground-rod (8-10 inches long) will cut noise from body or foot movements (due to capacitive interaction with the ground). If you ground the receiver to objects such as fences, beware that certain grounds may couple AC powerline noise to the receiver, which is why I recommend a simple Earth ground. Better quality tape recorders, with adjustable input level controls, are desirable, as "cheapie" portable recorders with auto-level control will often have annoying variations in record level due to lightning-sferics. And, these cheap recorders also put noise of their own onto the tape. A shielded 600 ohm patch-cord will suffice between the output of the BBB-4 and microphone input of a tape recorder or speaker amplifier.

The most common naturally occurring V.L.F. emissions to be heard are the myriad "crackling and popping" sounds of lightning-stroke electromagnetic impulses (static/sferics) from lightning storms within a couple thousand-km/mile radius of the listener.

Since there are nearly 100 lightning storms in progress anywhere on the Earth at any given time, and that millions of lightning strokes happen daily, there is NEVER a moment when these lightning "sferics" will not be heard. However, the density and strength of lightning sferics can vary day-to-day and hour-to-hour. Mid-winter offers the lowest density of sferics, and summer evenings can be full of a dense barrage of strong sferics masking everything else.

The other most common (and most awesome) sounds are "whistlers"--eerie descending tones caused when the lightning electromagnetic energy gets "ducted" along Earth's magnetic lines-of-force (magnetosphere) to the opposite polar hemisphere, then gets rebounded back to the vicinity of the originating lightning stroke impulse. However, there doesn't have to be lightning within sight or even a few hundred miles of your listening location--lightning from storms up to thousands of km/miles away, particularly if more to the north of your location, can generate large whistlers which are heard continent-wide.

On the other hand, it's quite spectacular to watch safely distant lightning storms generate whistlers in the receiver's output--you hear the huge "crack" of the lightning impulse sferic, then, if the conditions to support whistlers are occurring, a whistler may follow from 1 to 2 seconds after the lightning stroke. Optimum times to listen for natural V.L.F. phenomena, such as whistlers, are between sunset and sunrise, with the midnight to sunrise period generally being the best.

Statistically, the greatest activity to be heard is from 2 a.m. to first-light (dawn) - sferics tend to be fairly low as compared to the sunset period. Dawn Chorus can occur during magnetic- storms, and will peak anywhere from an hour before sunrise to 2 hours past sunrise.

Whistlers can occur at anytime, but the period of minimum frequency is midday. Sometimes, activity can also occur just before and after sunset, but sferics will be fiercer. Lightning sferics will be most fierce during summer afternoons and minimum (generally) an hour or so after sunrise until thunderstorm activity picks up later on. Winter can present delightfully low lightning sferics_other activity will be more "in the clear."

Tweeks, the "ringing/pinging" sounds of sferics caused by the Earth- surface/ionosphere "waveguide," will be best from an hour after sunset to 2-3 a.m. local time, gradually tapering off toward sunrise. Their number and intensity of "pinginess" can vary from night to night_some nights they can sound rather "pale," but other nights they can ring in a variety of beautiful mixtures and pitches. Whistlers, which may or may not be heard on some days or even weeks, can range in sound from quite pure notes to very diffuse "breathy" sounds. They can swoop in frequency from very high to low, or abruptly cut-off as they descend in pitch.

If you live north of the about latitude 45 in the US and Canada, or in northern Europe, or extreme southern Australia and New Zealand (closer to the auroral zones), you will likely be able to hear interesting natural radio activity about 50% of the time, especially during magnetically disturbed/storming periods. For those farther south, don't be discouraged if you listen for several hours, or several sessions on different days, without hearing whistlers or other natural radio phenomena. When you DO hear them, it will make up for the "dry" times, as there is nothing like "live" listening! Listeners located north between 40-55 degrees north or south latitude are in the optimum latitudes for monitoring natural V.L.F. phenomena.

If you can see visible Aurora (Northern/Southern Lights) from your location, you are at a great location for natural V.L.F. phenomena monitoring! Latitudes between 20-30 degrees north and south will hear less, but at times, still loud phenomena. I've heard whistlers just fine in Hawaii_presumably those whistlers were louder farther north, but still, they were heard! DO NOT operate this receiver (or any other) when nearby lightning threatens! Take appropriate lightning precautions when lightning is occurring nearby (within 5-10 miles).

Nearby lightning will cause excessively loud sferics in the receiver's output, and whistlers will not be louder just because lightning is close-by. Reserve listening for fair weather periods_most often, the best and loudest natural V.L.F. phenomena will happen during clear weather, since lightning can be quite distant, as mentioned above, and still spawn loud whistlers.

Additional Tips

1) A 100-200 milliHenry inductor connected across C5 will act as a high-pass filter, nicely attenuating 60-360 Hz powerline emissions (hum). Experiment here.

2) If you want less gain from the Q2 stage (and slightly lower noise), reduce R8 to 4.7K.

3) Listen to WWV-shortwave (2.5, 5, 10, 15, 20 MHz) for geo- magnetic indices at 18 min. past each hour (WWVH-Hawaii at :45). A K- index at or above 3 indicates enhanced conditions for natural phenomena, especially chorus.

4) The U.S. NOAA/USAF/Space Environment Center (SEC) runs a fantastic Website with geomagnetic indices and other information available at:<http://sec.noaa.gov>. Lists the past 30+ days' geomagnetic conditions, proton and electron fluences, and so forth. There seems a rough correlation between high electron fluences, low K-indices (especially following a magnetic-storm period) and louder whistlers at middle latitudes-- look for fluences at $1.0E + 07$ or higher. This seems to follow best during equinoctial periods (autumn, spring). Periods when the solar flux is rising also seem to be times when whistlers occur more often. Nights of fabulous whistlers can be unpredictable and can't be reliably predicted via "indices," (but it seems lower K indices are better if following a period of higher K indices) so if you have a chance to listen and it's past sunset, do so! Again, high K-indices over 3-4 mean probable chorus (auroral chorus at higher latitudes and dawn chorus at mid. latitudes around dawn and local sunrise. Conditions which hinder HF propagation make Natural Radio come alive!

FINAL NOTE: This E-field VLF receiver will not work with ham or SWL antennas, nor loop antennas, nor longwires. As it is presented herein, it will not receive man-made broadcasts/transmissions such as military VLF stations in the 16-25 kHz spectrum, nor earthquake (ULF) signals below 5 Hz, as some have previously asked me.

Recording Equipment

If you want to record your samples and process them on the computer, the recording equipment and software is as important as the receiver itself. Depending on the frequency spectrum you want to receive and the quality of recording, you have to choose the appropriate recorder. Battery life is important for mobile applications too. Have in mind that tape recorders may induce their own noise into the recording in such low signal levels, so it is better to choose a better quality recorder.

Mini Disk is one of the best quality recorders, if you record without compression. It can record signals beyond the human hearing (you cannot listen to them but you can see them on the computer spectrogram). Even when using some sort of low compression it will be ok, since the bandwidth of the receiver is not beyond the human hearing. The only problem with mini disk is that it has mechanical moving parts (motor), so the battery life is limited and that it can record for a limited time. Also, the medium allows for limited recording time. By using a mini disk, you cannot leave your equipment outside in the night recording for more than 1 - 2 hours (stereo/mono rec)

To overcome this problem in my approach, I used a digital dictation recorder, the cheaper that I could find, the Olympus VN-5500. These recorders consume very little power they are easy to operate and they can quickly erase and write tracks. You can use any digital recorder you can find but take care of the recording qualities. My recorder has 3 recording qualities. This basically specifies the bandwidth of the recording. This bandwidth must not be too narrower than the bandwidth of the receiver because you could lose valuable audio signals. In fact you will find the best recording quality by trial and error. For example my recorder has three recording qualities (the finest has 300Hz - 7KHz bandwidth) but I found in many cases the medium quality better for tweaks, as it induces less noise from the background.



Specifications of the VN-5500:

512Mb built-in memory, 300 hours recording time in LP mode, about 22 hours in HQ mode, 4 folders, Voice activated, Scheduling function, LCD display, Headphone and microphone sockets, Built-in microphone and speaker, Requires 2 x AAA batteries, Size (H)10.2, (W)3.6, (D)2.05cm, Weight 63g, 512Mb built-in memory.

The only drawback of this recorder is that it has not got a USB port to write the samples directly to the computer, so you need to connect it to the line input of your sound blaster and re-record the samples using an appropriate recording software. USB connectivity is available in more expensive recorders.

Software

There are a lot of software packages which will help you record your samples in your computer. I have found a freeware program that lets you record samples from your recording equipment to your computer, edit them and convert them to mp3.