The INSPIRE Journal

Volume 11 Number 1

November 2002

The VLF3 is (Almost) Here!

The design and development process for the new INSPIRE natural radio receiver, the VLF3, is now complete. VLF3 receivers will be ready to ship in 2-3 weeks. The price has been set at $80 plus shipping. The order form for the VLF3 can be found on the last two pages of the *Journal*. Please be patient since we cannot ship the kits until all components have been obtained and the assembly instructions have been written and tested.

In this issue:

1. A report from Bob Bennett comparing the performance of the VLF3 with the VLF2 and the RS4 models.
2. A description from Bill Pine of the VLF3.
3. A account from Shawn Korgan of how to use trees as antennas for natural radio receivers.
4. An invitation to record natural radio data any time and have the results published in the *Journal*.

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The INSPIRE Journal

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The INSPIRE Journal is a publication of The INSPIRE Project, Inc., a nonprofit educational/scientific corporation of the State of California. The purpose of the INSPIRE Project, Inc., is to promote and support the involvement of students in space science research. All officers and directors of the corporation serve as volunteers with no financial compensation. The INSPIRE Project, Inc., has received both federal and state tax-exempt status (FEIN 95-4418628). The *Journal* is published two times per year: November 1 and April 1. Submission deadlines: October 1 and March 1

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Field Observations are a Way to Participate!

Everyone is invited to participate in Field Observations. Field Observations offer an opportunity to record natural radio and have the results published in the *INSPIRE Journal*. The twice-yearly Coordinated Observations will still be held on the third weekend of November and the last weekend of April. Field observations may be made any time. All reports received by next March 1 will be included in the next *Journal*.

Subscription Information Included on the Address Label

You can determine the status of your subscription to *The INSPIRE Journal* by looking at the address label. In the upper right corner of the label is a 2-digit number that indicates the year your subscription will expire. All subscriptions expire with the November issue. If your label shows "02", then this issue will be the last under this subscription. If your label shows "03", then your subscription is good through the November 2003 issue. If you have any questions or if you feel that the information shown is incorrect, please contact the editor.

Write for *The INSPIRE Journal*

The procedure for contributing articles for *The INSPIRE Journal* could not be simpler! Just send it in! Any format is acceptable. Electronic format is easier to work with. A Word file on disk for either the PC or Mac platform is preferred. An email message will work, too. If that does not work for you, a paper copy will do. Any diagrams or figures can be scanned in.

What about topics? Anything that interests you will probably interest most INSPIRE participants. As long as the topic is related to natural radio or the equipment used, it will get printed. The deadlines for submissions are March 1 for the spring edition and October 1 for the fall edition. Don't worry about the deadlines, though. If you miss a deadline, you will just be very early for the next edition!

We at INSPIRE are looking forward to hearing from you.

TESTING OF THE VLF-3, BETA VERSION

Robert Bennett
Las Cruces, NM

1. BACKGROUND

In December 2001, I volunteered to help test the VLF-3 receiver prototype. I conducted a series of laboratory and field tests on the prototype during December 2001 and January 2002. I found that the VLF-3 prototype was substantially more sensitive than either of the previous INSPIRE receivers (the VLF-2 and the RS-4). My evaluation showed that the VLF-3 had the potential to be the best whistler receiver that I have experimented with. However, I noticed several things that I considered shortcomings in its design. The most serious being the receiver's sensitivity to LORAN interference and its undesired ability to pick up local AM broadcast stations. I also found the control and connector layout to be less than optimal.

I suggested several design changes to address these shortcomings. The most significant were the addition of a low pass filter between the first and second stages of the receiver to eliminate AM interference and addition of a switched low pass filter and attenuator between the antenna and input FET transistor to reduce LORAN. These suggestions were accepted by the design team and implemented. I also suggested several other design changes, some of which were implemented while others were not due to cost considerations.

2. VLF-3 BETA

In early July I received a "Beta" version of the VLF-3 for evaluation. I only received the circuit board and board components plus the connectors. The plastic case and front panel were not yet available. I assembled the board in about three hours and found assembly to be straightforward. The only problem I had was not realizing that the volume and gain controls were to be mounted on the reverse side of the board. I installed these controls on the component side of the board and realizing my error had to remove them and remount on the wiring side.

The intended mounting box for the receiver is a plastic box similar to the one used for the VLF-2. Not having a suitable plastic box, I mounted the receiver circuit board in a metal box. The fact that I used a metal box for the case means that my VLF-3 is better shielded than the final production units will be. This probably means that the susceptibility results described below are a little optimistic for the production units.

Note: I did NOT make the interstage coupling capacitor changes recommended by Shawn Korgan. I had already started testing when he suggested the changes and I wanted to maintain a stable receiver configuration. The changes he recommends will be useful in making the natural radio signals sound more "natural" by reducing the low frequency response of the receiver.

3. TESTING GOALS

After assembly and check out of the VLF-3, I conducted a series of field tests. I had three goals for the testing. First to measure the VLF-3 Beta's susceptibility to LORAN and AM broadcast interference. Second, take a look at the receiver's 60 Hz response. Finally, to conduct a comparison of the VLF-3 with the VLF-2 and RS-4 receivers.

4. TEST TIMING

I decided to conduct my tests during three time periods; early morning just before sunrise, midday just after noon, and late at night just before midnight. I selected the sunrise period to possibly monitor whistlers and also because 60 Hz hum is usually at its lowest this time of day (at least at my quiet site). I selected noon because AM broadcast, LORAN, 60 Hz interference, and other forms of man made noise are usually at their highest. Also, natural radio signals are at their weakest. I selected late night because LORAN is usually the predominant form of interference and also there is a possibility for some interesting natural radio signals. I was able to conduct tests on 15, 16 and 19 July.

5. WEATHER CONDITIONS

The weather did not cooperate during my testing. July and August are our "rainy season" and we get about 75% percent of our annual rainfall during these months. The desert around my quiet monitoring location was very wet and on some days had water standing. During one test we had light rain and for another test, it rained very hard and I had to make a hasty retreat from the desert. But, I didn't make a hasty enough retreat, the desert literally became a sea of mud before I could get back to the gravel road.

The wetness of the desert probably had an effect on my testing. The wet ground is more conductive by several orders of magnitude than the normally dry desert sand. Hence, the 60 Hz ground currents will be more concentrated around the power lines and will not spread out as far as they do in dry soil, resulting in less 60 Hz hum at my monitoring location. I have observed this effect several times over the last 10 years of monitoring. Also, the increased soil conductivity has an impact on propagation and the frequent thunderstorms caused the sferics and tweek levels to increase.

6. TEST SETUP

To conduct the tests, I decided to use field-testing instead of laboratory bench testing because I wanted to test under the most realistic conditions. I also decided to do comparative tests so that I would not have to worry about calibration and measurement of absolute levels. This means that I will not be able to determine the absolute gain of the VLF-3, its minimum detectable signal level, nor the levels of the various received signals. I will only be able to say that one receiver is so many DB better than another. For INSPIRE purposes, this should be more than adequate. I discovered during bench testing the VLF-3 prototype last January that the method of capturing the receiver's output has a profound effect on the final results. So, I decided to use the INSPIRE data collection techniques. Thus, I fed the outputs of both receivers into a Marantz stereo recorder.

My test set up is shown in Figure 1 below. The Figure shows that I connected the VLF-3 signal to the recorder's left channel. I used a switchbox in the recorder's right channel so I could select as input either the comparison receiver or a WWV receiver. I placed WWV timing marks on the tape every 5 minutes. I adjusted all the receivers to give a reading of 0.0 DB on the recorder's level meters. The data collection regime I followed was to collect 30 minutes of comparison data for each of the two comparison receivers (VLF-2 and RS-4) and then 30 minutes of VLF-3 data alone. I repeated this exercise three time, morning, midday and evening.

I used identical antennas for the INSPIRE receivers, a 6 foot whip mounted three feet above the ground and connected to the receiver with a 10 foot wire. The whips were placed on each side of the test station and were about twenty feet apart. Hopefully this is far enough apart to minimize mutual coupling.

I analyzed the collected data tapes with the computer program "SPECTRA-PLUS" which computes a time-averaged spectrum of the data. I also used GRAM to display some of the more interesting natural radio signals.

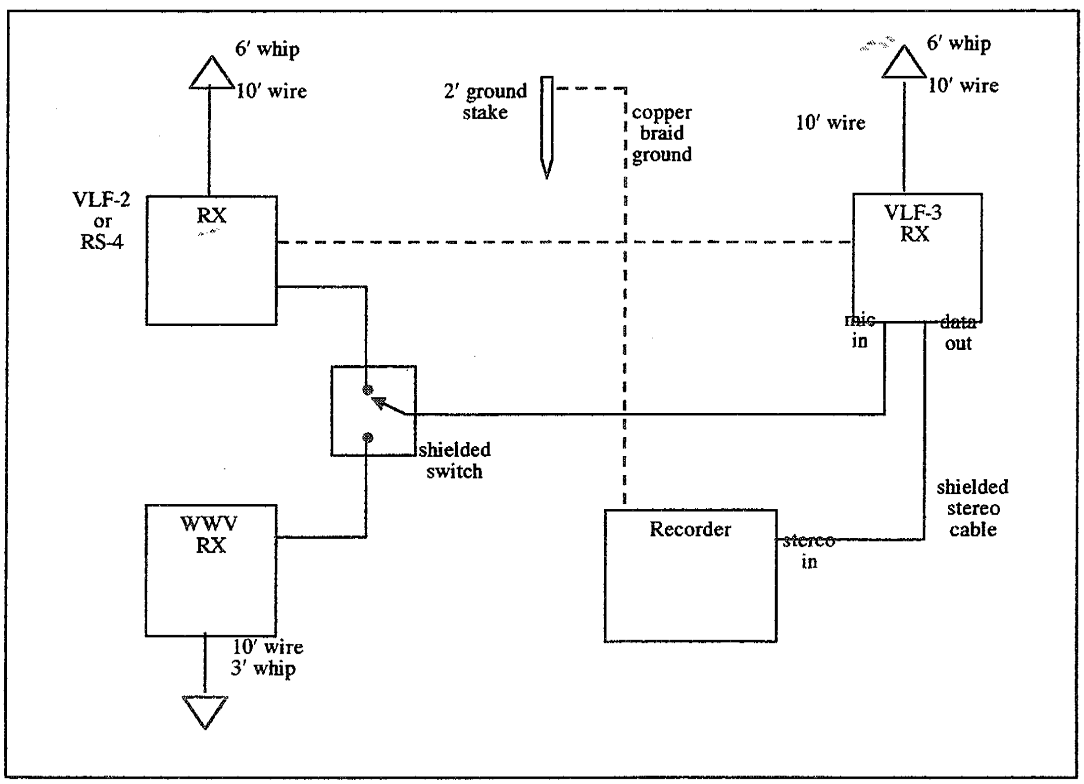

Figure 1. Test set up.

7. DATA ANALYSIS

The following paragraphs contain my analysis of the collected audio data. I have presented the analysis in four parts. First is the comparison of the VLF-3 with the VLF-2. Next is the comparison of the VLF-3 with the RS-4. Third is an analysis of the effect of VLF-3 settings, (the gain control and the antenna filter/attenuator) on LORAN interference. Finally, I present some miscellaneous items I found interesting.

When there is a marked difference in morning, day, night performance, I present all the data sets. If there is no significant difference, then only one set of data will be presented.

A. VLF-3 Versus the VLF-2.

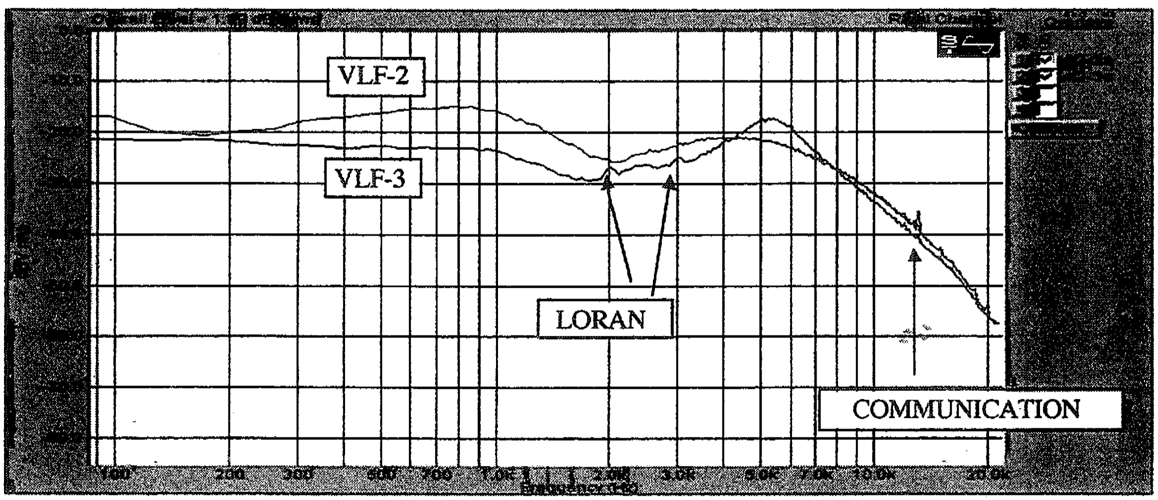

Figure 2. Morning comparison. Bottom trace is the VLF-3 and top trace is VLF-2.

This Figure shows typical results for early morning and daytime tests. LORAN Components are present in both receivers' output and are clearly visible at 2, 3 and 4 KHz in the lower trace. In this test, VLF-3 gain was set near Minimum, and VLF-2 gain near Maximum. Gains were set to give equal recorder level meter readings. Recorder gain was set at maximum. All filters are out and recorder limiter is in. By observing the recorder level meter readings, I was able to measure about a 10 dB gain advantage in favor of the VLF-3. In the Figure, note that the VLF-2 has more gain at low frequencies than does the VLF-3. However, the VLF-3 has enhanced gain at frequencies around 5 KHz. No 60 Hz interference was observed on either receiver. Also no AM broadcast station interference was observed.

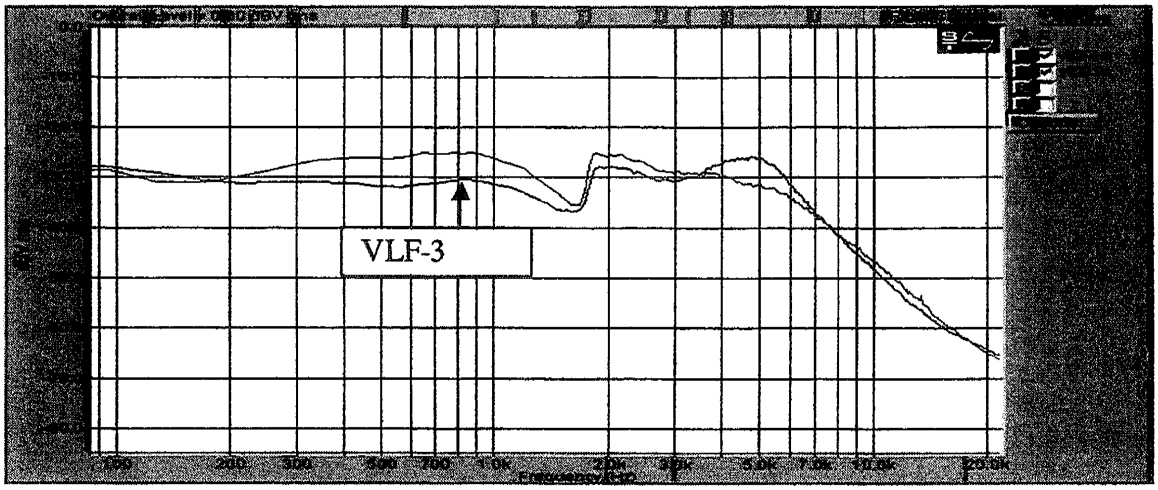

Figure 3. VLF-3 versus VLF-2 at night. VLF-2 is top trace and VLF-3 is bottom trace.

For the recordings in Figure 3, the same gain and control settings were again used as in Figure 2. However, the levels from the receivers were great enough that I had to reduce the recorder gain by 40% to prevent overload. Note the absence of LORAN signal components in the Figure. LORAN was not audible on the tapes. No 60 Hz hum was observed. The tweek and sferic levels the night this recording was made were very dense and strong. It is likely that the natural radio signals were strong enough to mask any LORAN components that were present. I don't know what is causing the drop in signal levels between 1 and 2 KHz, but I suspect that it is propagation related.

B. VLF-3 Versus RS-4

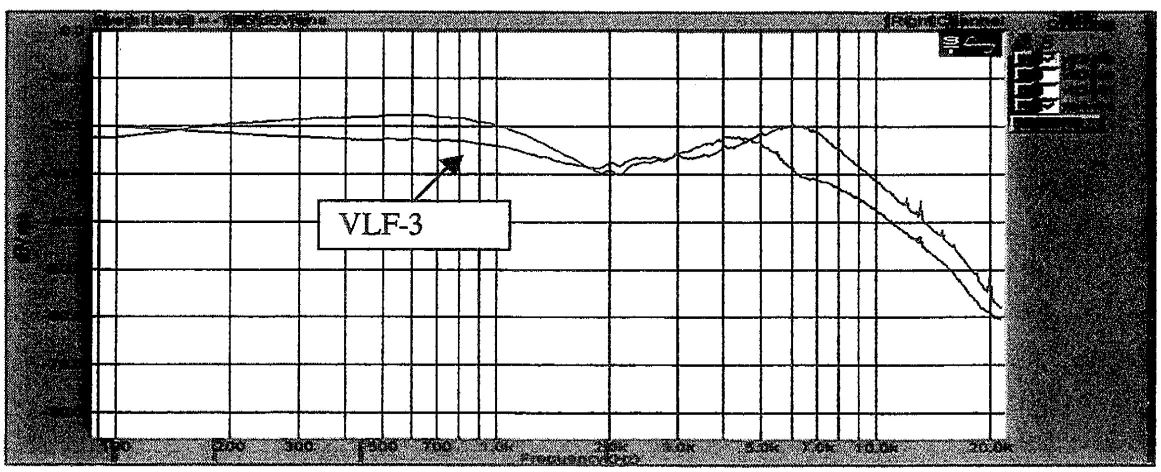

Figure 4. Morning comparison. The RS-4 is the top trace and the VLF-3 is the bottom trace.

In the above Figure, the LORAN components are present but hard to see at 2, 3, 4, and 5 KHz on the VLF-3 trace but only at 2 KHz in the RS-4 trace. Also note the communications signals between 10 and 20 KHz. The VLF-3 is much better at detecting them than is the RS-4. The receiver gain settings were adjusted to give the same recorder level meter readings. The gain of the RS-4 is near maximum while the VLF-3 is near minimum. The RS-4 has a peak in its response at about 3.5 KHz while the VLF-3 still shows a peak at about 6 KHz.

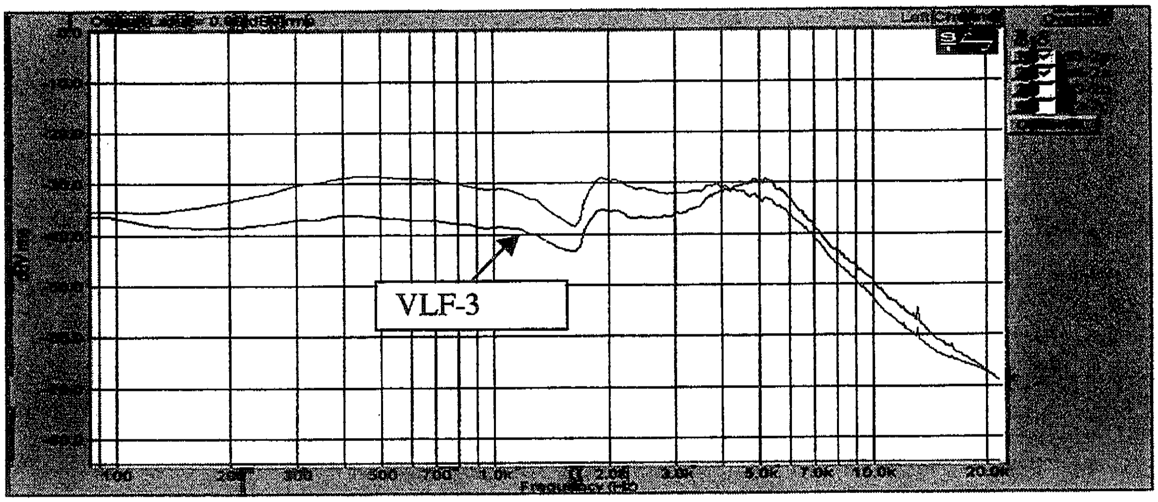

Figure 5. Night comparison of RS-4 versus VLF-3. The top trace is the RS-4 and the bottom trace is the VLF-3.

Again receiver gain settings were adjusted to give equal recorder meter level readings. The RS-4 was at maximum gain while the VLF-3 was at minimum gain. LORAN is not evident in either receiver's channels probably due to being masked by strong natural radio signals. Also, analysis of the recorder level meter readings indicate that the VLF-3 has 10-12 dB gain advantage over the RS-4.

C. Effect of VLF-3 Control Settings.

The VLF-3 has two controls that I wanted to gather some data concerning their effects on receiver performance. The first is the gain control for the data output and the second is the antenna filter/attenuator switch. I do not use the audio output of the VLF-3 when monitoring. Hence, I did not attempt to evaluate the effects of the receiver's audio volume control. My recorder has a "third" read head used to monitor the signals actually recorded on the tape while in the record mode. I prefer to listen to this audio output instead of the direct audio from the VLF-3. This way I can monitor the quality of the recordings in real time. The first results to be discussed will be the effects of the gain control.

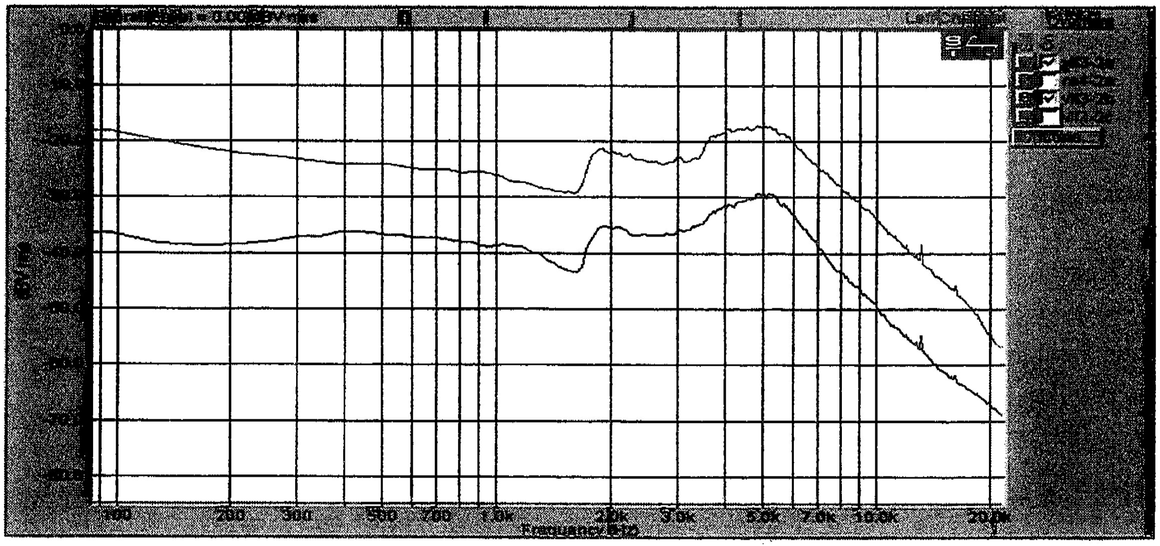

Figure 6. Effect of gain control on VLF-3.
Top trace is gain control set to maximum, bottom trace is gain set to minimum.

This Figure shows that the gain control has about a 20 dB control range and that its effect is almost constant across the receiver's frequency pass band as expected. Also, I observed that decreasing the gain reduced the overall output level without changing the signals present. This was a surprise and unexpected outcome. One would expect, given the VLF-3 circuitry, that reducing the gain to zero would totally eliminate all signals except recorder noise. This did not happen and to me implies that there is sufficient stray coupling to allow enough of the signal to bypass the control to activate the recorder.

The next Figures, Figures 7, 8 and 9 show the effect of the antenna filter and attenuator. The attenuator switch on the VLF-3 actually accomplishes two functions when placed in the "in" position. First it places a resistive voltage divider network between the antenna and the gate of the input FET transistor. This will attenuate all signals entering the VLF-3 by about 10 dB. Second, the switch places an additional capacitor to ground across the FET gate. This in effect forms a low pass filter and reduces the high frequency response of the receiver. These features were added specifically to reduce LORAN interference.

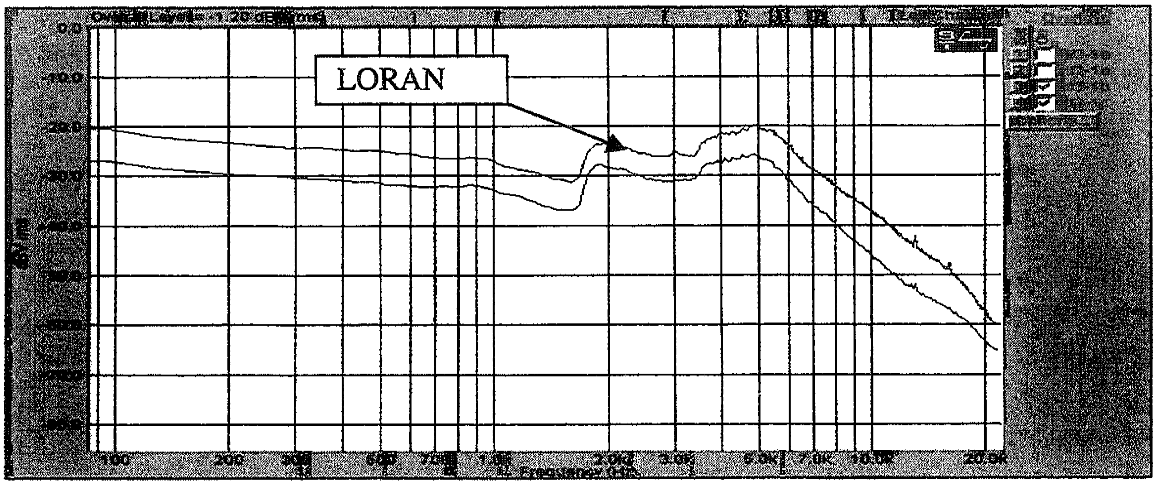

Figure 7. Morning and daytime results. Top trace is with the antenna filter "out". The bottom trace is with the antenna filter "in". Receiver gain controls were set to maximum for the above tests.

Note that LORAN components are present in the "attenuator out" position but are hard to see on the above chart. The 3 KHz component is the easiest to see on the top trace. They can be clearly heard on the tape. Also, note that the switch reduces the receiver gain almost uniformly across the pass band by about 8 dB.

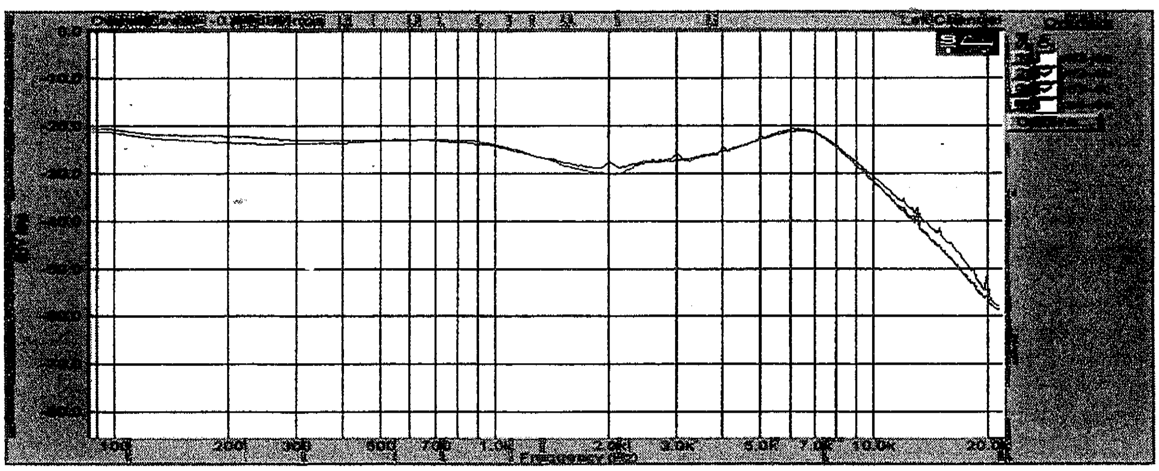

Figure 8, Effect of the antenna filter/attenuator on the VLF-3 Nighttime data.

The top trace is with the filter "out" and LORAN is present on the recording. The bottom trace is with the filter "in" and there is no LORAN audible on the tape nor is any evident on the spectrogram. Note that the drop in signal levels across the pass band observed in the morning and daytime tests are not evident here. This seems to be an artifact of the very strong natural radio signals present during the night monitoring session. I suspected that the VLF-3 was driving the recorder into overload and adding 10 dB of attenuation didn't stop the overload. The following figure shows an attempt to test for overload by reducing the receiver's gain.

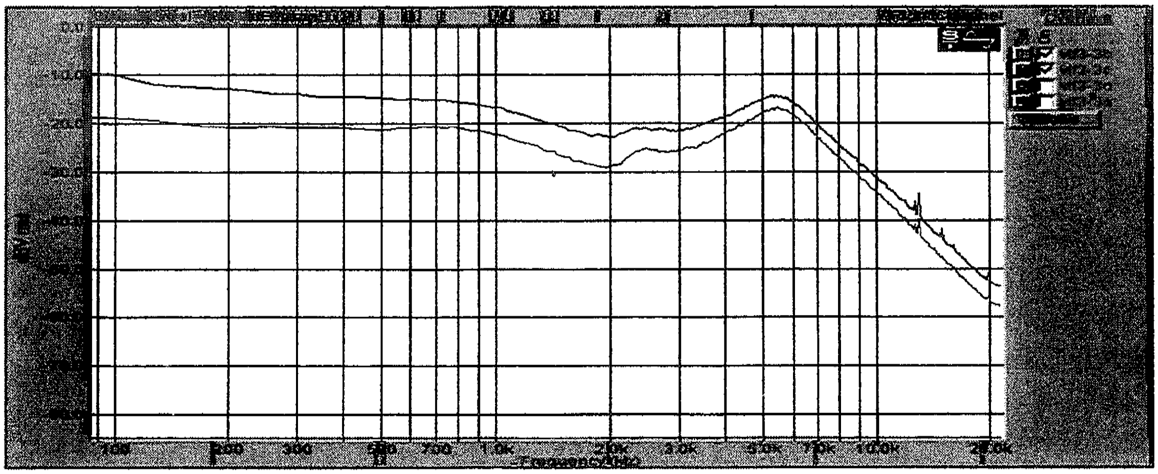

Figure 9. This plot shows the effect that the VLF-3 Antenna filter/attenuator has on the received spectra when the gain control is set to 1/3 of Maximum. The top curve is for maximum gain. The bottom trace shows is for 1/3 gain. Note that LORAN is suppressed in both traces. Unfortunately, the communications and navigation signals above about 10 KHz are also suppressed. Note that the response curves have started to separate and this implies that the recorder is indeed in or near saturation at maximum receiver gain.

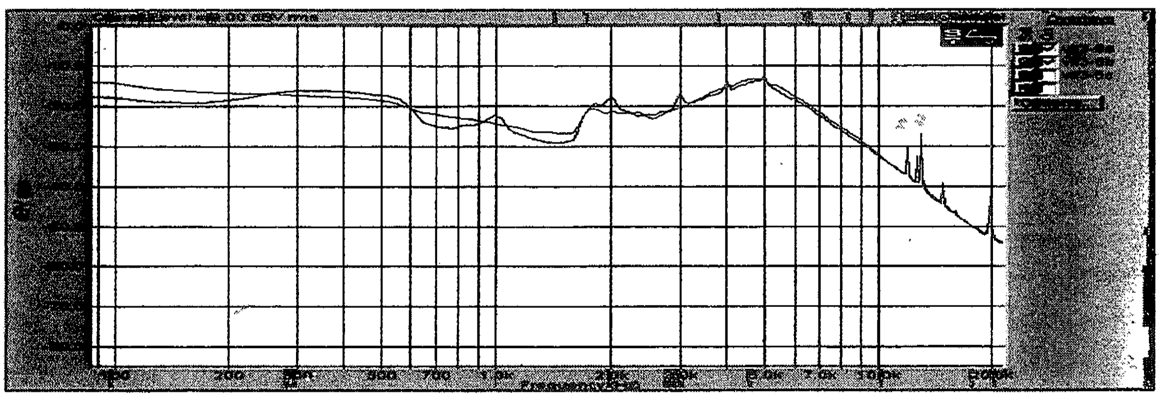

Figure 10. This chart shows the VLF-3 with and with the antenna filter. The lower trace is without the filter. The upper trace is with the antenna filter "IN".

This chart shows data from the early morning test on 19 July. The LORAN components are very clear at 1, 2, 3, 4, and 5 KHz with the antenna attenuator in the "out" position. Note the absence of LORAN when the attenuator is placed "in". Also, note how strong the communications signals between 10 and 20 KHz are compared with other days.

The next Figure (11) is a spectrum from the GRAM program. The filter is "in" in this data. Two things are worthy of note in the Figure. First is the absence of LORAN. The second is the presence of a "Hiss" band around 6 KHZ. This corresponds to the 6 KHZ hump in the Spectra-Plus plots. Compare this to Figure 12, which is a GRAM spectrogram with the filter "out".

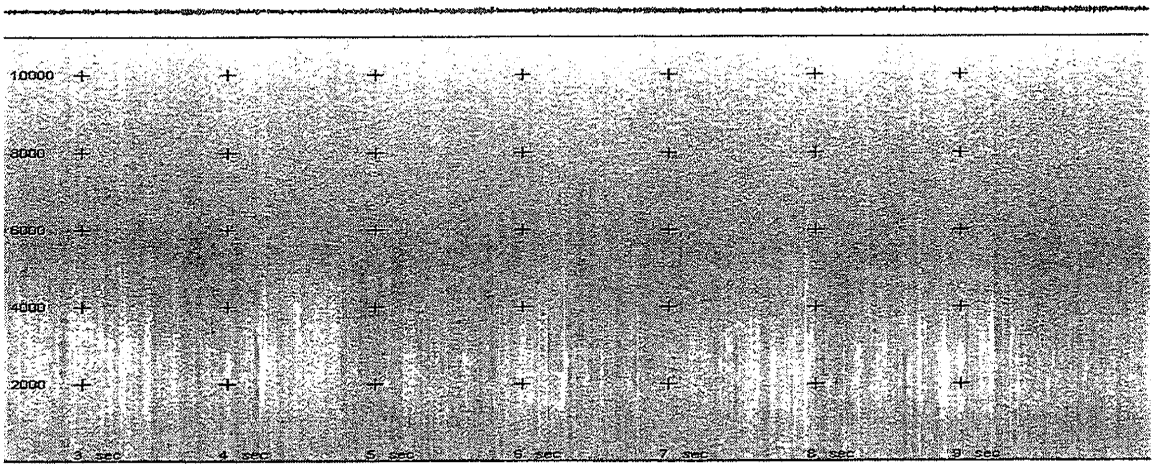

Figure 11, GRAM spectrograms with antenna filter "in".

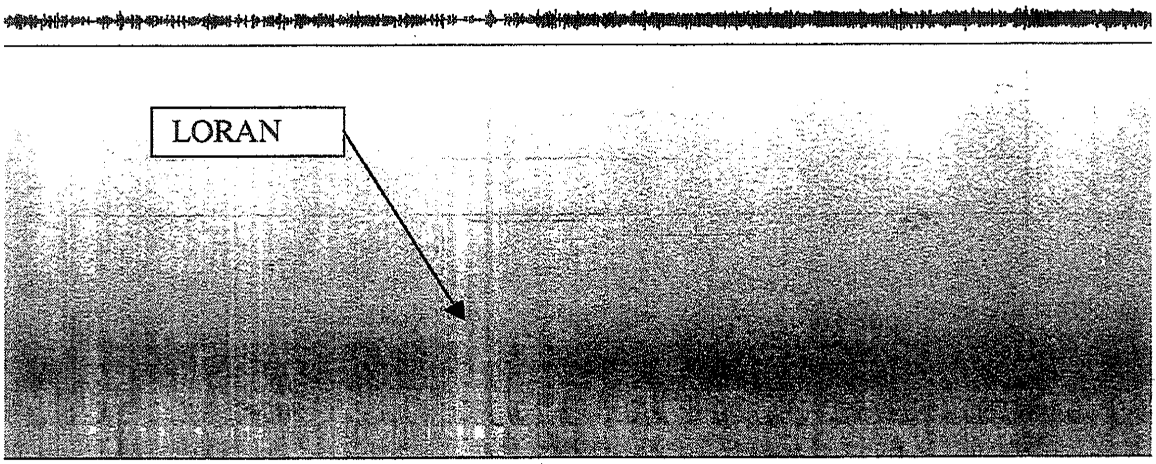

Figure 12. Spectrograms with the antenna filter "out".
Note the LORAN interference in the Figure (the small vertical dashes spaced about 1 KHz apart).

D. Other Items of Interest Observed.

During the field-testing, I recorded many whistlers in the early morning sessions and a few during the night sessions. Some examples follow.

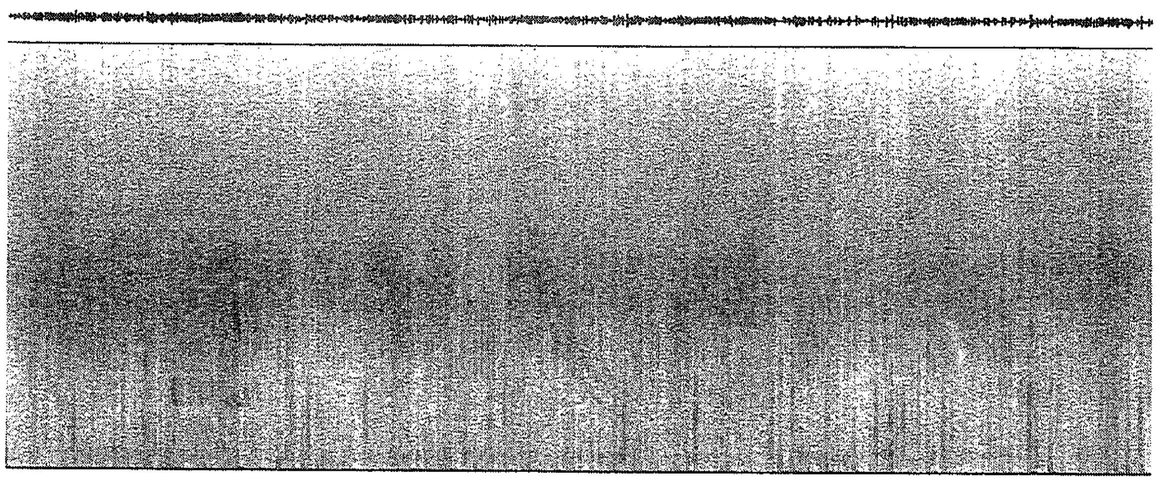

Figure 13. Whistlers recorded evening of 15 July. The antenna filter was "in" and there is no LORAN interference present. The whistlers occurred immediately after the 0357Z WWV marker.

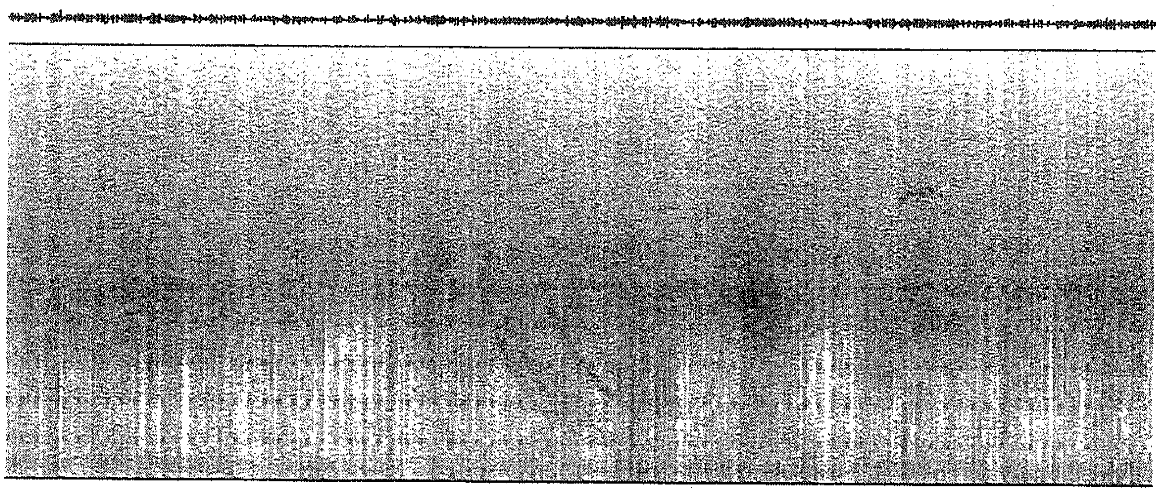

Figure 14. Whistlers and echoes recorded 19 July in the morning at about 1100Z. This recording did not have the antenna filter engaged so LORAN is present.

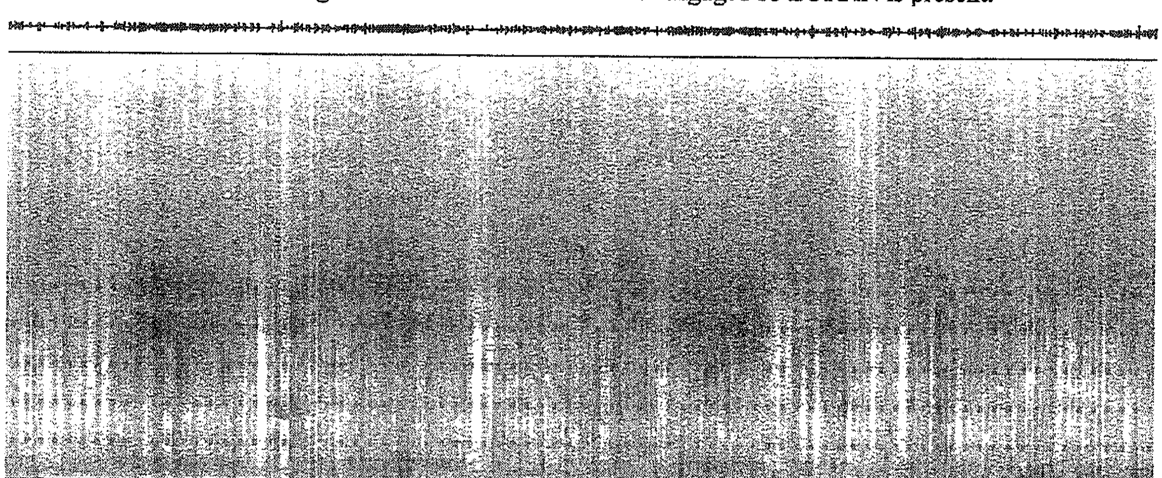

Figure 15. A rare (for me) daytime whistler recorded in the afternoon on 16 July. The antenna filter is "out" and LORAN is present. The whistler occurred just after a local light rain shower started.

As discussed in an earlier paragraph, I got caught in the desert in a very heavy rain shower about 0600 MDT on 19 July. I continued monitoring until water started to flow in an arroyo that is near my site. When the water level became about a foot deep, I made a hasty exit from the area. Just before I secured my equipment, I started getting some very strange signals on the VLF-3. They sounded like some kind of audio feedback (possibly caused by rain hitting the antenna). The following GRAM plot shows the signals. Figure 18 shows a spectra-plus plot of the same data.

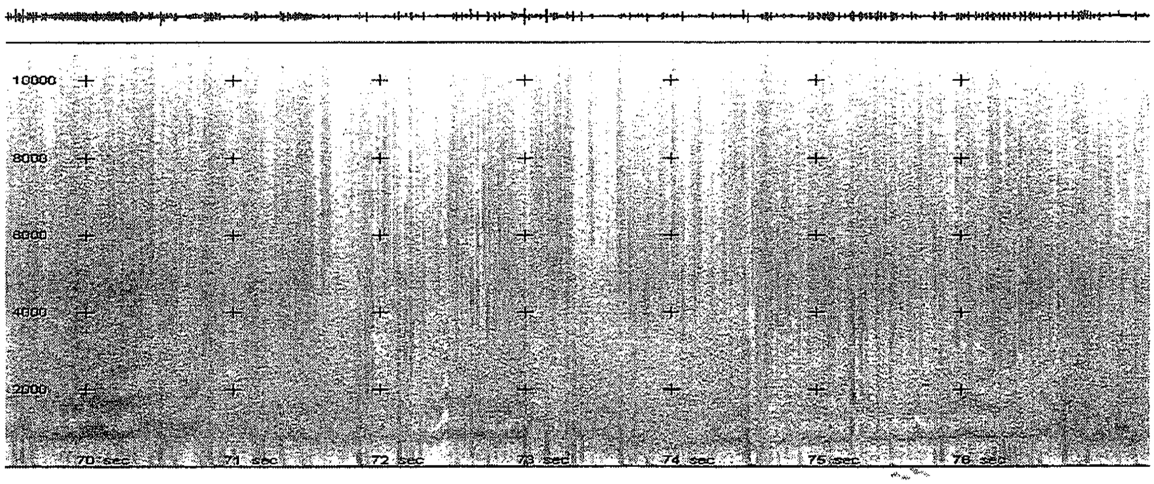

Figure 16. Strange signals detected during a rainstorm on 19 July.
Notice the near horizontal lines between 1 and 2 KHz.

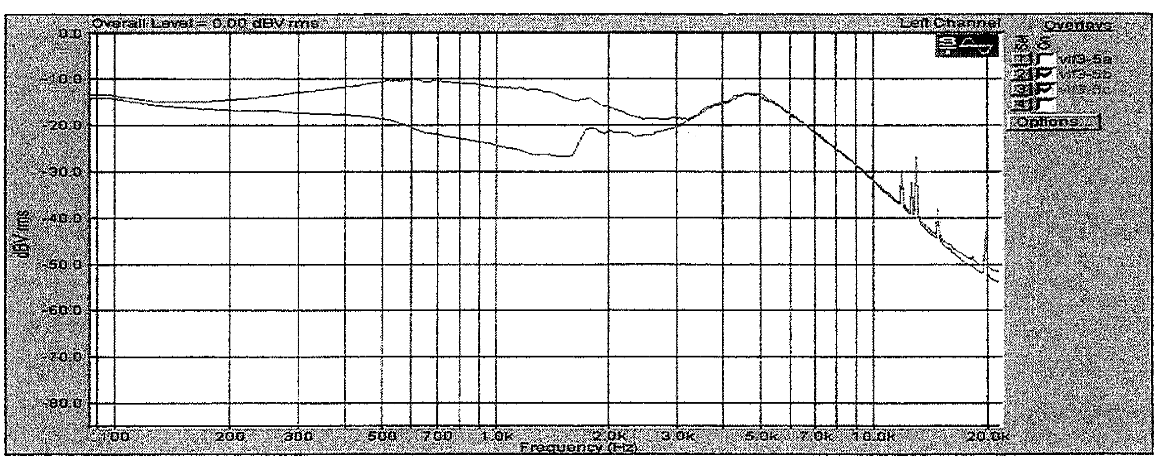

Figure 17, This chart shows possible feedback oscillation induced by rain. The upper trace was taken during the feedback. The lower trace is before the rain storm. Note the increase in broadband levels between 300 Hz and 2 KHz.

8. FINDINGS

A. The VLF-3 receiver has 10-12 dB more gain than the previous INSPIRE receivers. This additional gain permits the VLF-3 to be used with a short whip antenna (e-field probe) and provide about the same performance as the VLF-2 and RS-4 when used with a long wire antenna.

B. The antenna filter/attenuator effectively eliminates LORAN interference at my location without significantly degrading the natural radio signals.

C. The VLF-3 is basically a linear receiver and the data gain control can be used to adjust levels to prevent recorder overload without degrading output signal-to-noise ratios.

D. The VLF-3 did not exhibit any signs of AM broadcast station overload or bleed through.

E. I did not observe any signs of 60 Hz interference. However, I believe this is due to the remoteness of my monitoring site and the local weather conditions. Earlier testing last January with the VLF-3 prototype showed that the VLF-3, VLF-2 and the RS-4 all performed about the same in the presence of power line interference.

F. The VLF-3 is more complicated to assemble than were the VLF-2 and RS-4. However, I believe VLF-3 assembly is well within the skill levels of High School students.

9. ACKNOWLEDGEMENT

I would like to thank Mr. Pine and Dr. Taylor for their review of this article and the many useful comments they provided.

Introducing the INSPIRE VLF3 Natural Radio Receiver

Bill Pine
Ontario, CA

INSPIRE is proud to announce the introduction of the INSPIRE VLF3 Natural Radio Receiver. The VLF3 is a redesign of the VLF2, the receiver INSPRE has sold for the past few years. Participating in the development process were: Dr. Bill Taylor, President of The INSPIRE project, Inc.; John Kohus, owner of Laboratory Services, South Barre, MA, who is the designer of the VLF2 and the provider of the INSPIRE kits; Shawn Korgan of Gilcrest, CO, a veteran VLF observer and radio designer and builder; Robert Bennett of Las Cruces, NM, a veteran VLF observer with extensive electronic experience and Bill Pine of Ontario, CA, secretary/treasurer of The INSPIRE project, Inc.

The development process began in 2001 with an exchange of ideas and suggestions for improvement of the VLF2 receiver. John Kohus then incorporated these ideas into a new design, built a prototype and circulated the prototype for further input from the development team.

When consensus was reached, John produced 5 beta kits and these were distributed to the development team. These kits were assembled and field-tested. Some of the team members tried changing he values of some of the components and tested and reported on the results. The beta phase resulted in several suggestions for component values and circuit layout. These suggestions were then incorporated into the final design that is now available in kit form from INSPIRE.

The VLF3 has retained many of the features of the VLF2 that have proved valuable. These include: two outputs (one to headphones and one to a recorder), the ability to switch a microphone input on one track of the stereo recording, diode protection against reverse connection of the battery and LED power lights. Added features of the VLF3 include:

1. improved filtering to exclude AM radio stations,
2. improved filtering to exclude power line (60 Hz) hum,
3. improved sensitivity and signal-to-noise performance,
4. an external power jack for use with a battery pack,

and 5. a BNC jack input into the receiver for ease in bench testing.

Improvements in circuit layout have reduced the number of wires needed to connect the receiver to the various inputs and outputs. The new printed circuit board (PCB) consists of two fiberglass boards with the circuit traces on one board sandwiched between the two. This allows some control components to be mounted on the side opposite the circuit components. On the following page is the schematic for the VLF3 receiver.

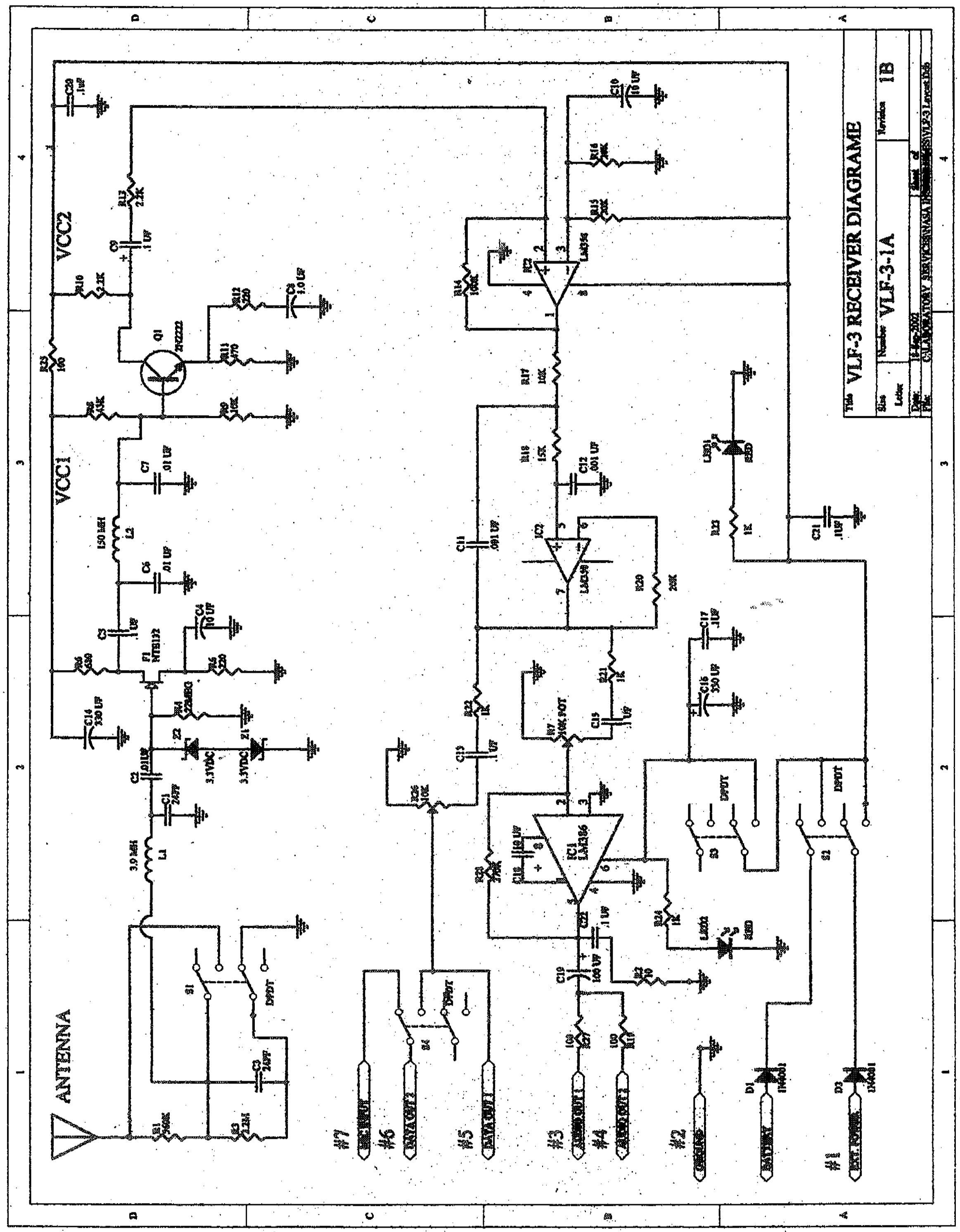

Figure 1. The VLF3 schematic.

Figure 2 below shows the silk screen for the printed circuit board.

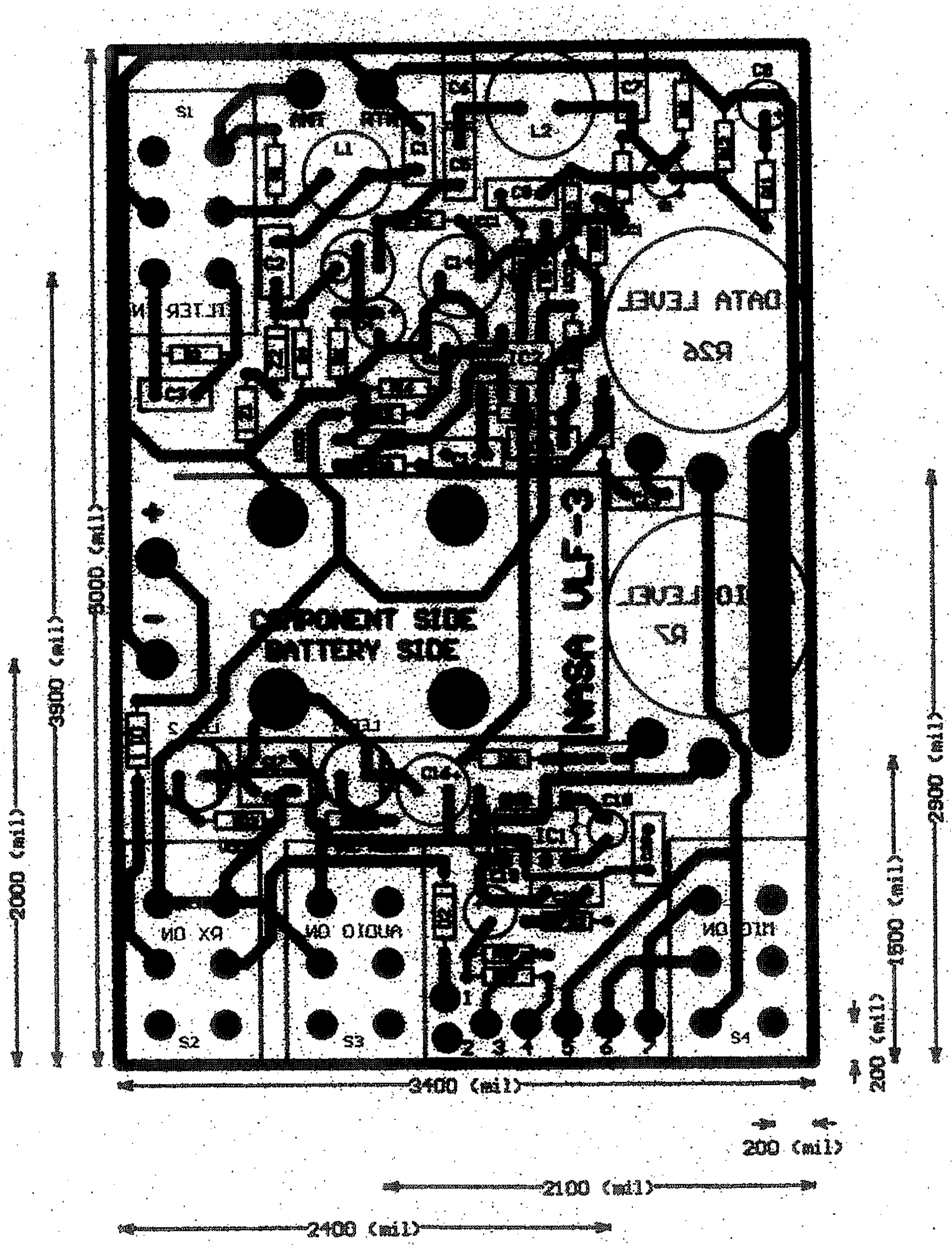

Figure 2. PCB silkscreen

The new faceplate will be black with white print.

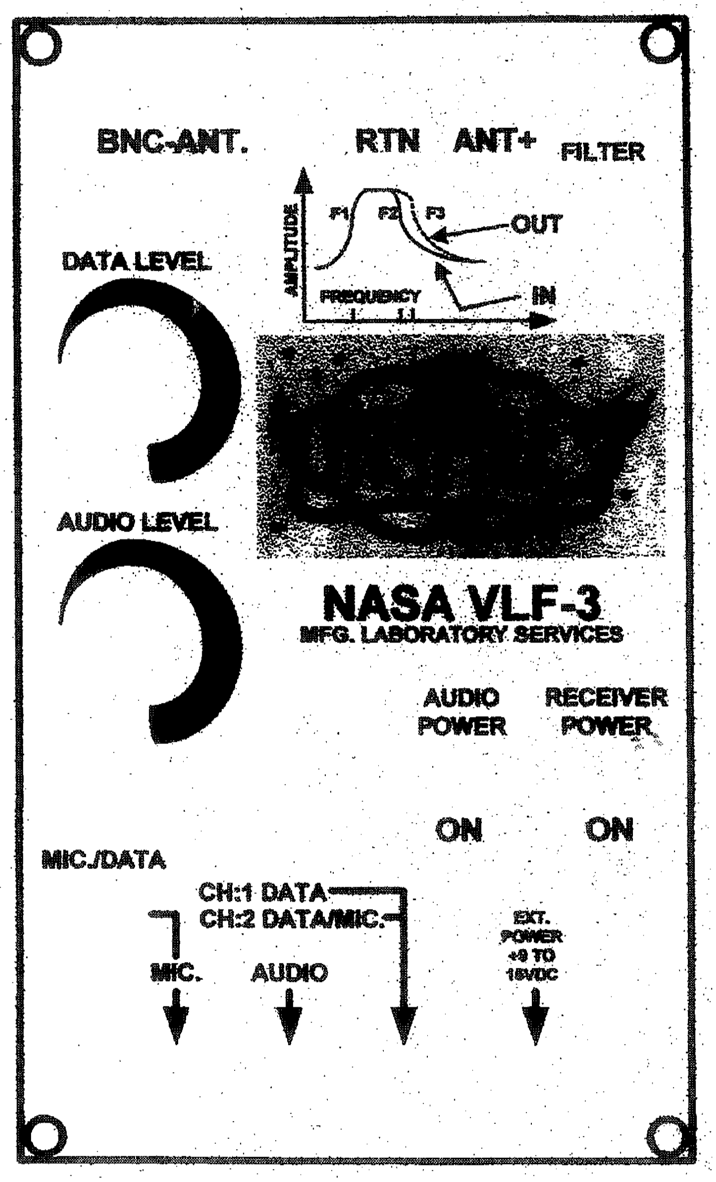

Figure 3. VLF3 Face Plate

At the top are connections for the antenna: a BNC jack and a two-screw antenna terminal. Across the bottom are 3.5 mm jacks for the microphone, audio output to headphones and output to the recorder. The external power jack is in the lower right corner. Above the external power jack are slide switches for audio power and receiver power with their LED power lights.