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SID: Study Cycle 24, Don't Just Use It

This VLF receiver system automatically logs received-signal data and displays it on your computer screen.

Hams are eagerly awaiting the arrival of sunspot Cycle 24 and the anticipated improvement in the marginal band conditions that we have endured the past few years. Instead of just using Cycle 24 and the improved ionospheric conditions, why not expand your knowledge of the ionosphere by joining a small group that is monitoring and studying the ionosphere through simple VLF receiver systems? Monitoring the ionosphere is also an excellent science activity for schools, and what is described below would make not only a novel conversation piece in your shack for eye-ball QSOs and stimulate conversations during your on-the-air QSOs, it also would make an excellent science fair project.

Background

The Earth's ionosphere refracts, or bends, radio waves and allows hams to talk over great distances well beyond the visible horizon. The ionosphere reacts strongly to the intense X-ray and ultraviolet radiation released by the Sun. This radiation strips the outer electrons away from their parent gas atoms, which make up the atmosphere, creating a region of ions that refract some radio waves while absorbing others depending on the wavelength and arrival angle of the wave. A somewhat more simplistic model of the ionosphere would be to consider that region of ions as forming a reflecting surface, or mirror, which returns some of the radio waves to Earth. Understanding the mechanics of the ionization of the ionosphere and how it affects the radio frequencies we use is part of the fun and mystique of the hobby. During significant solar events, where unusual radiation levels are released, however, there can be dramatic and sudden changes in the ionization of the ionosphere that disrupts radio communications. These significant and sudden solar events are called sudden ionospheric disturbances, or SIDs.

Very low frequency (VLF) radio waves are partially refracted and partially absorbed by the lowest region of the ionosphere (the D region), which begins approximately 40 km above the Earth's surface. Using a receiver to monitor the signal strength from distant VLF transmitters, and noting unusual changes as the waves return from the ionosphere, you can directly monitor and track SIDs. This method of observation takes advantage of signals from several powerful transmitters operating in the VLF band between 16 kHz and 24 kHz. These transmitters are used to communicate with submarines that are underway. Some of these sources operate more or less continuously and offer a good stable radio wave point source. A partial list of VLF stations and frequencies given are in Table 1.

The SID Receiver Station

The construction and operation of a SID receiver station is well documented by various groups engaged in monitoring the ionosphere.[1] In this article I will touch on the bits and pieces that I put together to make a SID receiver system and add to the discussion a unique interface that stores collected data (to preclude tying up a computer all day long) and then dumps the stored data to a computer running Microsoft *Excel* for display using a free software macro. This receiver can be easily and affordably duplicated so that you, or your local school, can begin monitoring Cycle 24.

Figure 1 is an overview of the SID receiver. A photo of the actual SID receiver set-up is show in Figure 2. The receiver is mounted on an interior wall of my house, like a picture. Follow along with the block diagram as the individual components of the receiver are described.

Antenna

The antenna is a capacitor tuned, inductively coupled loop antenna.[2] The sides of the loop antenna are approximately 18 inches. The capacitor tuner is made of a bank of 100 pF and 1000 pF capacitors connected in parallel or series. They are switch-selected and connected to the loop of 125 turns of no. 26 magnet wire. See Figure 3. The capacitor bank allows 50 pF capacitance steps between 50 pF to 4000 pF. This is more than enough range to tune the loop antenna to the desired receiving frequency. An inductive loop of approximately 25 turns of no. 26 magnet wire is connected to the receiver. As mentioned in the on-line documentation, I experienced some adverse detuning of the receiver while trying to tune the antenna, and the inductive loop took care of that problem.

VLF Receiver

The receiver design is called the Gyrator.[3] Far Circuits produces some circuit boards for the three variants of the Gyrator.[4] I used the Gyrator II variant because the circuit is improved over Gyrator I, but I didn't want the ADC features that were included in Gyrator III. I modified the board and circuit slightly. Figure 4 shows the receiver board. I drilled a hole in the board and installed a BNC connector for an antenna jack. I used multi-turn potentiometers for the tuning and volume

[1]Notes appear on page 00.

Table 1
VLF Stations and Frequencies

Cutler, ME	24.0 kHz
Jim Creek, WA	24.8 kHz
LaMoure, ND	25.3 kHz

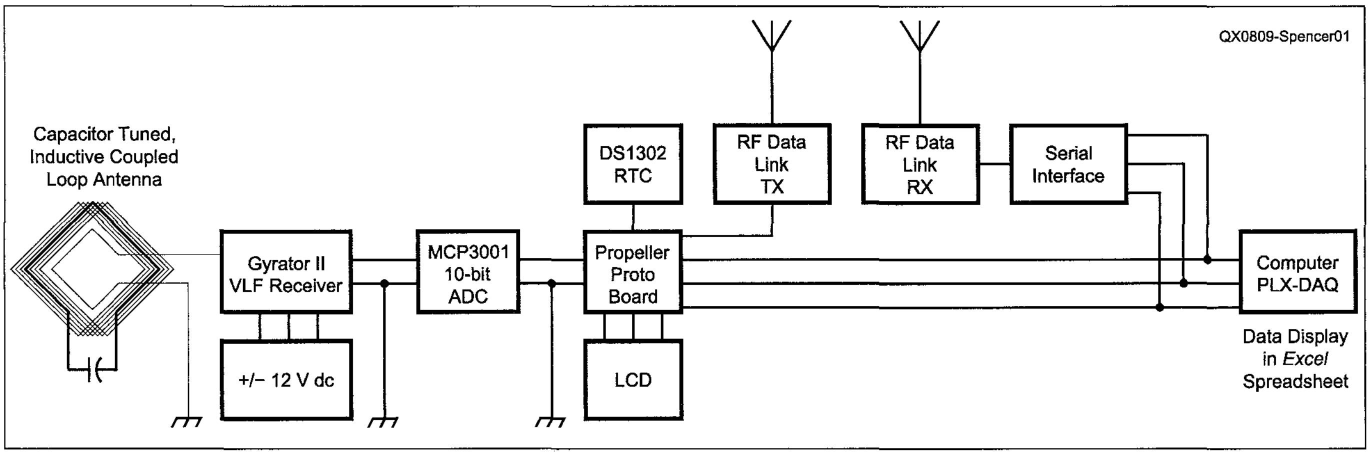

Figure 1 — This block diagram illustrates the operation of the SID VLF receiver, data collection and computer interface circuits.

controls. Tuning of the Gyrator receiver is very sensitive and the multi-turn potentiometer helped get accurate and stable reception on the desired frequency. Since the Gyrator II circuit is based on high gain op-amps, the circuit has a tendency to self oscillate. The volume control multi-turn potentiometer helped to keep the circuit under control. Finally, I changed the receiver output filter capacitor from the specified 10 pF to 100 pF to help alleviate the rapid amplitude changes that were caused by receiving weak signals. Amplitude changes caused by SIDs are not that rapid, and I found the higher capacitance made a better data plot, at the expense of making tuning the antenna, receiver, and aiming the loop a little more difficult because of the sluggish amplitude changes.

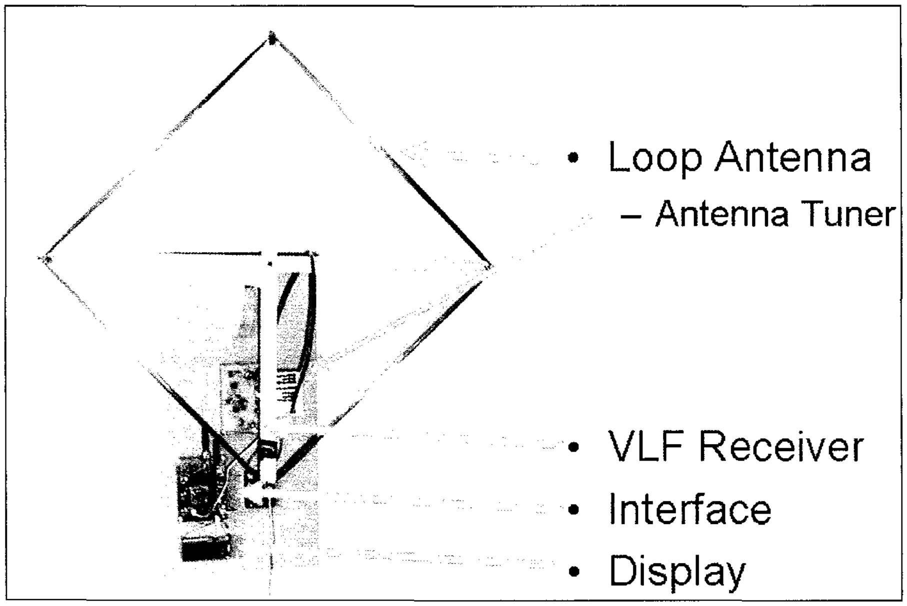

Figure 2 — This photo shows the loop antenna and receiver system mounted on the wall of the author's house.

SID Interface

The interface between the Gyrator II and the computer is unique to the designs published on the web. The center piece of the interface is the Parallax Propeller microcontroller and prototyping board shown in Figure 5. The Propeller has eight parallel programmable interface controllers (PIC) that share resources and 32 input/output (I/O) lines. The Propeller uses either the high level Spin language, assembly, or a combination of both. Parallax has a library of programming objects for various display, keyboard, and mouse devices just to name of few. This prototyping board is reasonably priced, and has a large prototyping area. It has all the voltage regulation and communication ports needed for the basic operation and programming of the Propeller.

The board is populated with a 10-bit analog to digital converter (ADC) that converts the signal strength output of the receiver into digital values between 0 and 1023 (equal to 0 and 5 V). A real-time-clock device with battery backup is also added to the board.

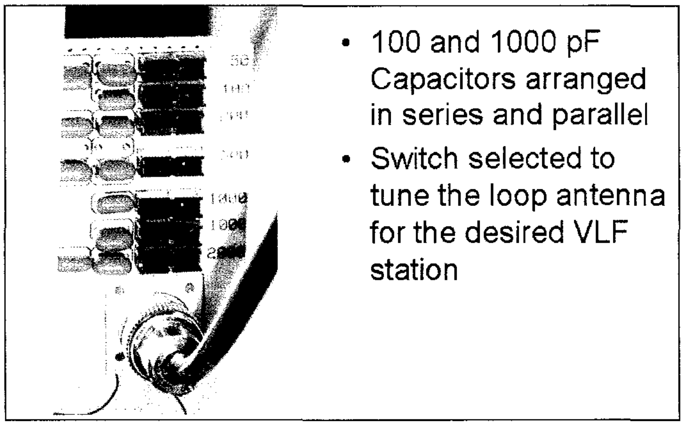

Figure 3 — Here is a close-up view of the antenna tuner. Various series and parallel capacitor combinations are switched in to tune the loop antenna for the desired VLF station.

The clock provides time-stamp data. A liquid crystal display (LCD) is connected to the board to display the time and the real-time ADC value. Though the LCD is not necessary for the operation of the SID receiver, it is a convenient way to monitor the station operation when not connected to the computer. To round out the interface board, a 70 cm data link transmitter module is connected to the serial port of the board to allow the collected data to be sent to the display computer without the need for a serial cable umbilical cord. This is a convenient feature if the receiver is not co-located with the display computer.

Push button switches and indicator LEDs allow the user to select various programmed features to operate the interface. One button allows the user to use the Microsoft *Hyper Terminal* program to set the real time clock. One button allows the user to start collecting and storing time and ADC data in the RAM that is part of the prototyping board and Propeller circuit. The final button allows the user to send the stored data either over a serial cable or over the data link to the display computer. If these were not enough options, the interface also sends the collected time and ADC data in real time to the display computer while it is simultaneously recording the data.

The circuit diagram of Figure 6 details the components added to the prototyping board and the connections between the individual components and the power and I/O pin numbers of the Propeller.

Interface Software

The software that is needed to program the Propeller for this interface is available from the author by e-mail request. A ZIP file containing the current software as of press time is also available for download from the ARRL Web site.[5] One each of the eight PICs in the Propeller are programmed to read the ADC, read the real time clock, display the time and ADC value on the LCD, and convert the time and ADC values and send them to the serial port. The program is set to begin storing data at 4 AM local time and record time and ADC value every 15 seconds until 9 PM local time. This interval covers sunrise to sunset. The collection period can be easily changed in software.

Datalink Receiver

The receive side of the data link includes a receiver module and a MAX232 based interface that converts the TTL output of the receiver module into RS232 voltage levels required by the computer's serial port. See Figure 7. The circuit diagram for the data link receiver interface is shown in Figure 8.

Display Software

On the display computer side of the system, download and install PLX-DAQ.[6] This

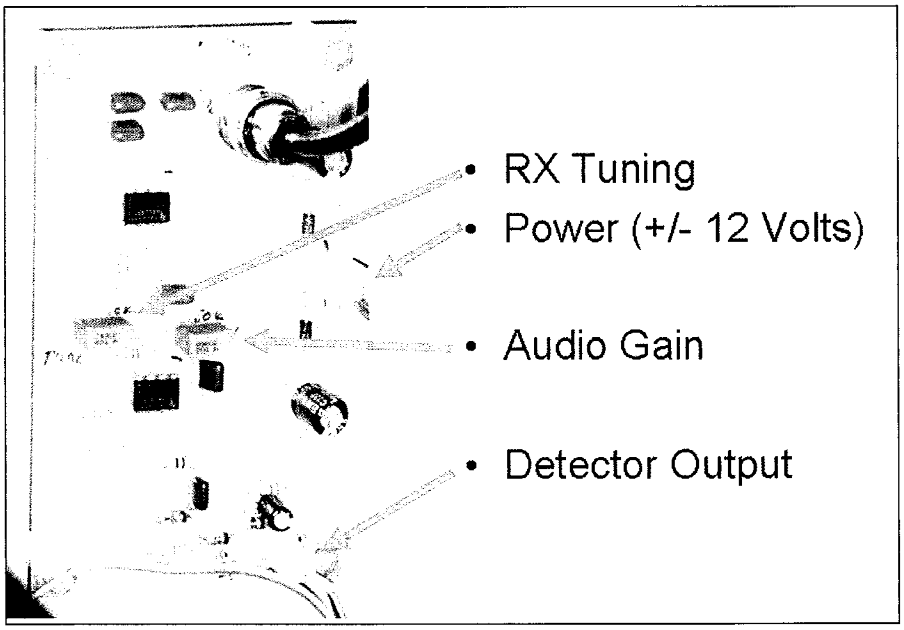

Figure 4 — This photo shows the Gyrator II receiver circuit board.

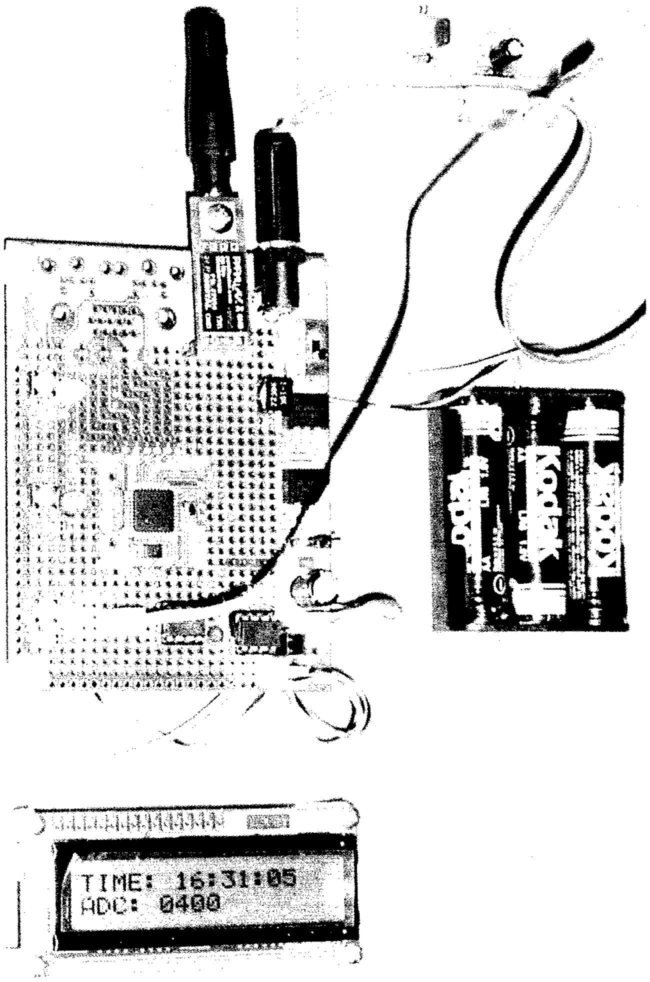

Figure 5 — Here is the Parallax Propeller microcontroller and prototyping board with an LCD and RF datalink transmitter.

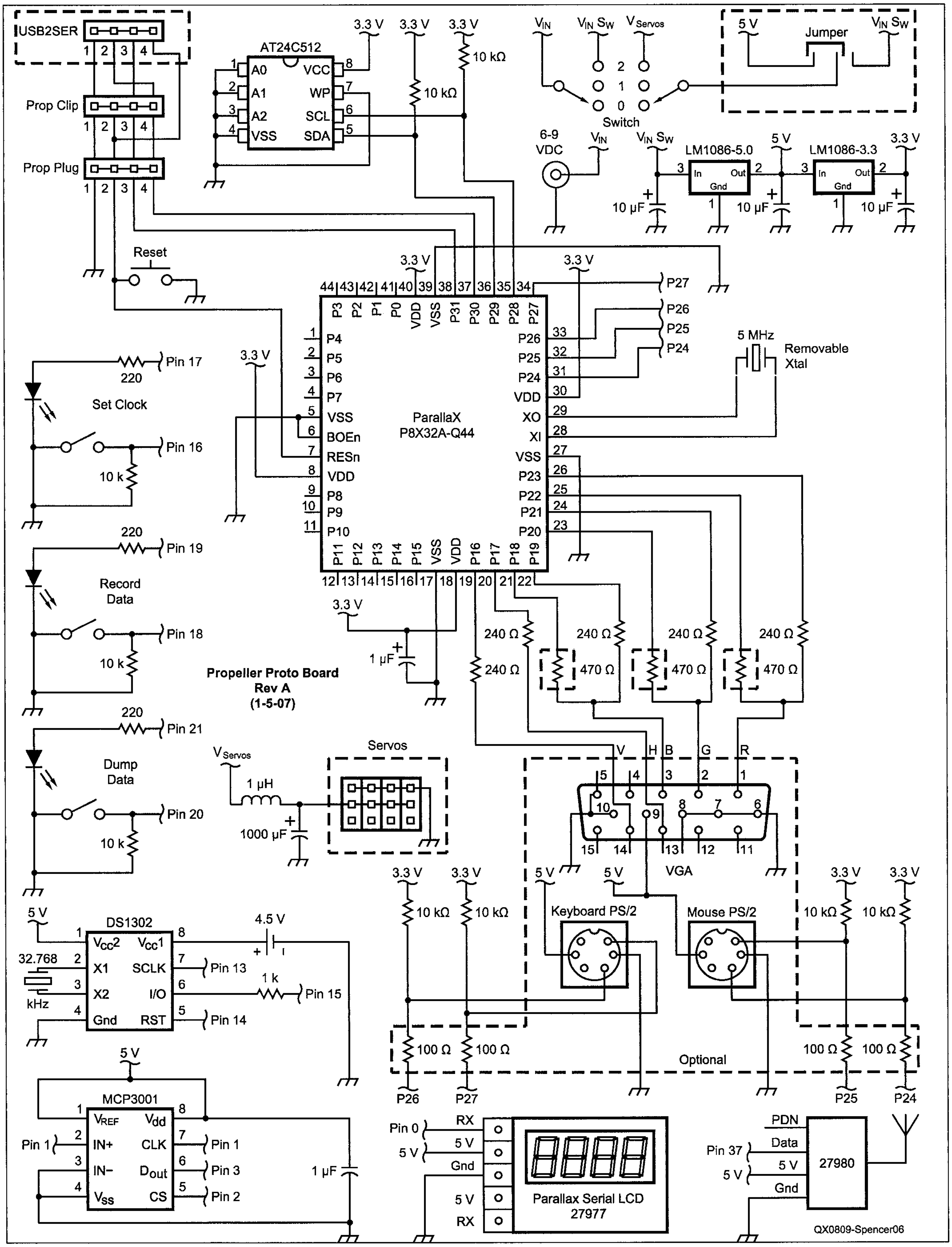

Figure 6 — This schematic diagram shows the SID interface circuit, including the Parallax Propeller prototyping board.

is a macro that is designed for use with *Excel*. The PLX-DAQ will capture the data collected and sent by the SID receiver and interface, and put the data values into the cells of an *Excel* spreadsheet. The math and graphic capabilities of *Excel* are then used to graphically display the data. The *Excel* template that is used to produce the following graphics is available from the author upon e-mail request. (This file is also included in the ZIP file available for download from the ARRL Web site. See Note 5.)

Data Interpretation

The real value of the SID receiver system is the interpretation of the graphic displays produced, and many times, more questions are raised than answered. Figure 9 is a typical collection from a quiet 24-hour period. The most obvious signal variations are those caused by the Sun's radiation. During daylight, the Sun's ionizing radiation penetrates deep into the ionosphere, producing enough free electrons at altitudes down to the D-region to allow radio waves to refract and return to Earth from that region. The air density is still relatively high at that height, though, so the electrons soon lose energy through collisions with air molecules, and consequently there is a lot of absorption too.

At night, the electrons in the lowest regions dissipate by recombination, and thus the region becomes transparent to radio waves. Refraction then takes place from regions at 80 km altitude and above, and with lower absorption due to the longer mean free path of electrons in the lower air density. Long distance paths improve, while signals from closer transmitters may reduce.

The Sun's elevation is added to this plot. You can see that in the mornings, the ionosphere becomes illuminated when the sun is still some 10 degrees below the horizon as seen from ground level. While the sun is above the horizon, signal levels vary roughly in proportion to the sun elevation. After sunset, it takes the ionosphere nearly until midnight to recover. This pattern repeats from day to day.

The graphic in Figure 10 shows the data collection from just before sunrise until sunset. Notice the apparent noisy signal between 1330 Z and 1530 Z (0630 and 0930 local time). This is called scintillation. The cause of this scintillation is thought to be because the "reflecting under-surface" of the ionosphere is uneven, which means that the signal arrives at the receiver via multiple paths, each of which is continually varying in amplitude and phase due to the constant fluctuation of the ionosphere. The result is chaotic random interference, and the received signal amplitude therefore constantly varies around its mean level, producing the slow

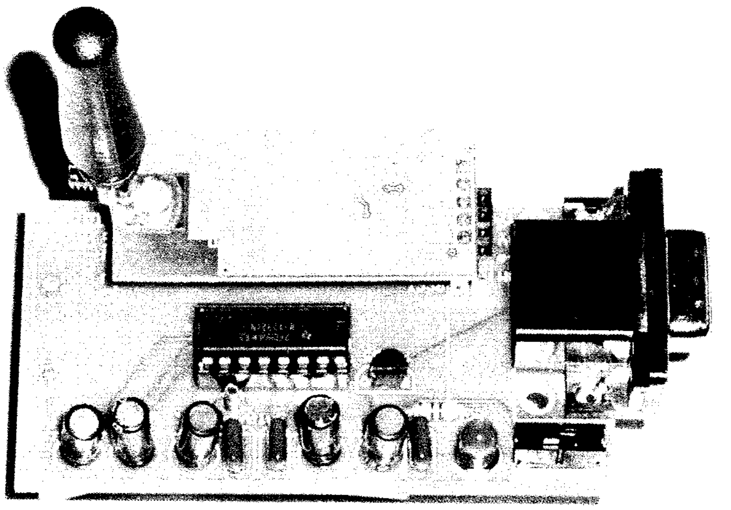

Figure 7 — The datalink receiver and serial interface connects to the display computer to feed the collected data into the computer for display in an *Excel* spreadsheet.

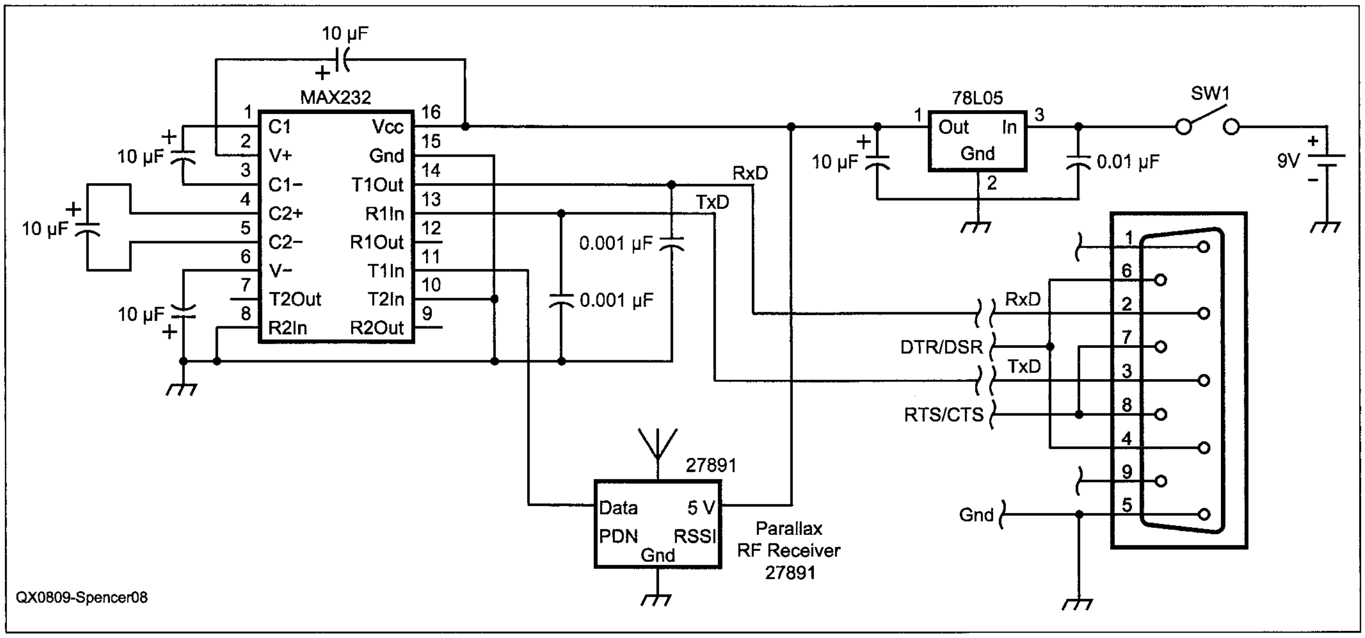

Figure 8 — This schematic diagram shows the schematic diagram of the datalink receive module and serial interface.

fading well known to HF operators, as well as more rapid variations which can readily be observed when the signal amplitude is sampled more rapidly as is done with the SID receiver.

The amount of scintillation is portrayed by the thickness of the signal trace, and varies constantly — slowly waxing and waning, presumably as patches of turbulent ionosphere drift across the path of the signal. This variation of scintillation does not repeat from one day to the next.

Notice the rapid increase in signal strength at around 0100 Z (1800 local time). I have observed similar increases over a number of days, with some minor variations in the time of occurrence. I am not sure what is causing this; if the occurrences were more random in time I would suspect the cause of the step change is the direct effect of an electromagnetic pulse associated with a strong sferic (lightening strike), which causes a localized upset in the D-region ionization, but I am not confident that this is the reason.

The graphic in Figure 11 shows another dawn to dusk collection. Notice there is scintillation just after sunrise, and a similar step change just before sunset. The numerous spikes in the late afternoon are cause by lightning strikes in the area (not necessarily in the immediate area, the storms could be hundreds of miles away).

The collection depicted in Figure 12 gave me some concern. I had made some changes to the system and it appeared to suddenly stop working! It turns out that the VLF transmitters are periodically turned off for maintenance. This was the case here.

I have not had the opportunity to witness an actual SID event, but I am ready when one occurs. Now that I have a good collection of graphics that represent quiet times, I will have a baseline for comparison when a SID occurs. A SID would cause a major disruption in the ionosphere that would show up as a major deviation from the normal curve. For instance, a solar flare would cause extra ionization in the upper regions of the ionosphere that are bathed with intense X-rays, and causing changes in radio wave propagation. This increase in ionization would penetrate down to the D-region and in turn cause an observable deviation in the measured signal strength of VLF signals as indicated by the collected data graph. The Web documentation has numerous examples of what a SID event would look like on the graphics and how to correlate the data to other sensors monitoring the Sun.[7,8]

Conclusion

The SID receiver will give you an opportunity to explore VLF techniques as well as learn more about the ionosphere that we

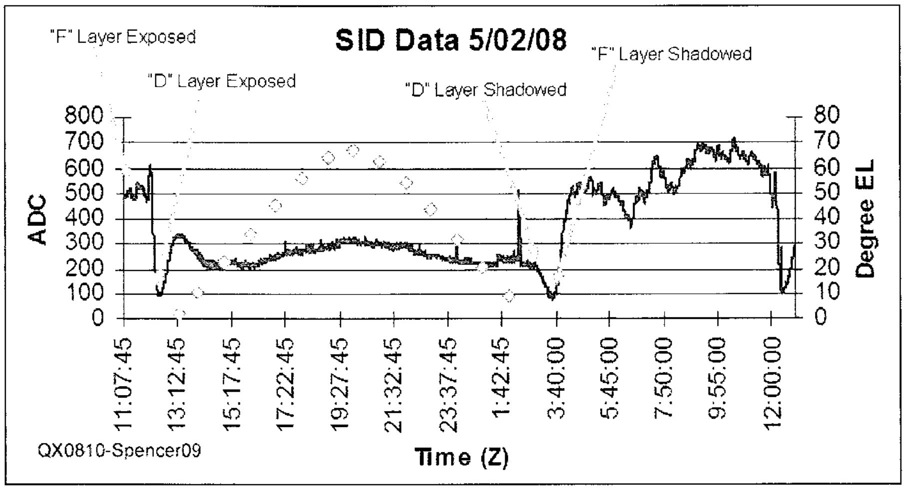

Figure 9 — A graph showing one 24 hour data collection period. You can see the propagation changes that result from sunrise and sunset, as well as the sun elevation throughout the daylight hours.

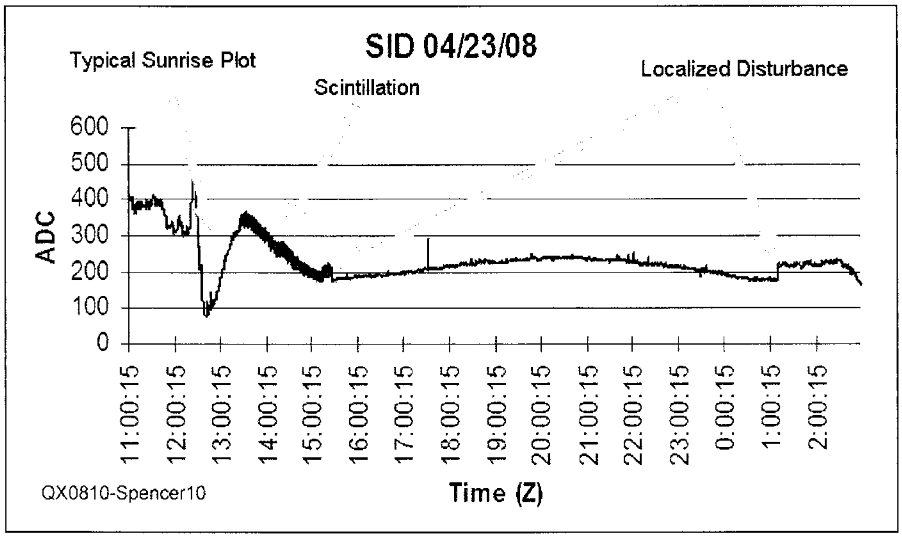

Figure 10 — This graph shows an approximately 2 hour scintillation pattern just after sunrise.

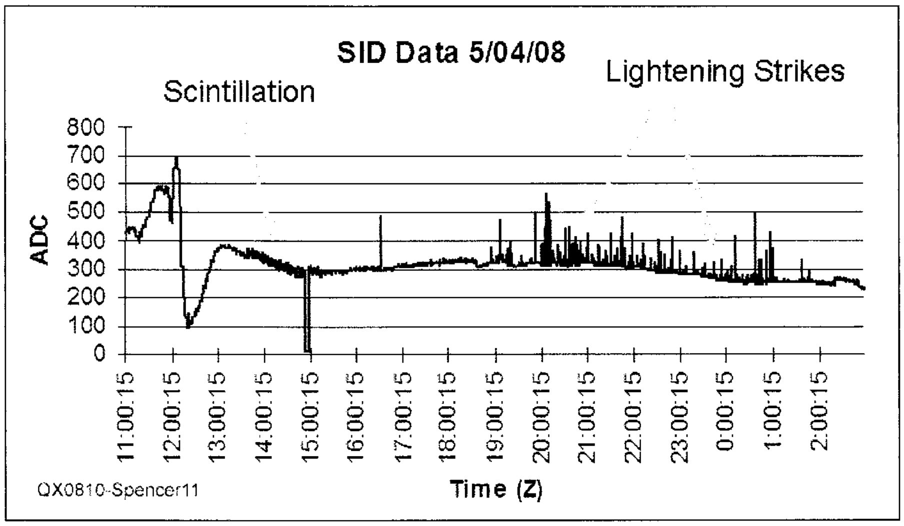

Figure 11 — Multiple lightning strikes were plotted during the afternoon, local time on this day.

depend on so much for our communications. Why not give it a try? Happy graphing.

Notes

[1]Selected SID Information: **www.aavso.org/observing/programs/solar/sid.shtml, solar-center.stanford.edu/SID/AWESOME/Goddard.pdf**

[2]Antenna notes: **www.aavso.org/observing/programs/solar/antenna.shtml**

[3]RX notes: **www.aavso.org/observing/programs/solar/minimalVLF.shtml**

[4]Circuti Board Source: **www.farcircuits.net/**

[5]A ZIP file of the software files associated with this article are available on the ARRL Web site. These files were current as of the to-printer date. Go to **www.arrl.org/qexfiles** and look for the file **9x08_Spencer.zip**.

[6]PLX-DAQ software download: **www.parallax.com/tabid/441/Default.aspx**

[7]Interpreting Collected Data: **http://www.dcs.lancs.ac.uk/iono/data/summary/interpret/**

[8]Government reports of SID events for correlation: **www.swpc.noaa.gov/Data/goes.html** and **www.swpc.noaa.gov/ftpmenu/indices/events.html**

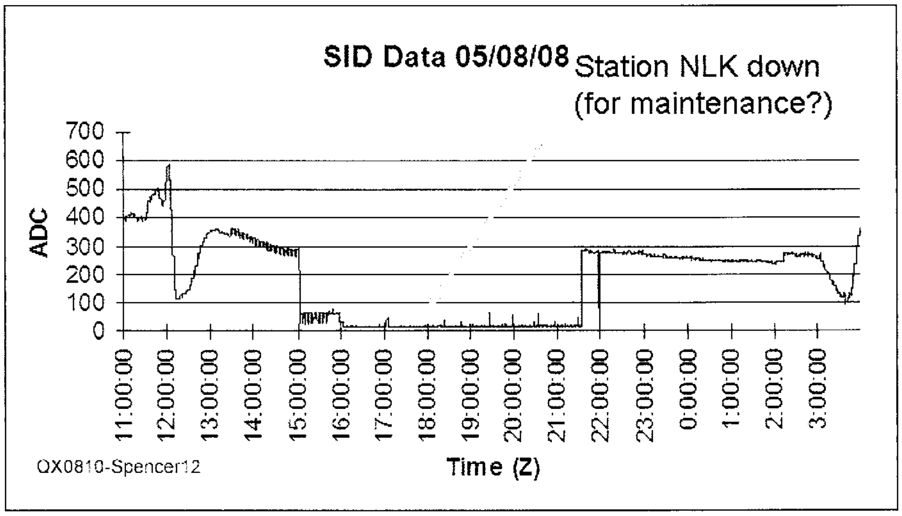

Figure 12 — If the signals seem to totally disappear, it may be because the station was shut down for maintenance, as was later confirmed to be the case on this day.

QEX