tories: The U.S. program in Antarctica. *Antarctic Journal of the U.S.*, 29(5).

Shafer, D.C., A.D. Brown, W.J. Trabucco, and U.S. Inan. 1994. A programmable and low-power ELF/VLF receiver for automatic geophysical observatories. *Antarctic Journal of the U.S.*, 29(5).

Weatherwax, A.T., J. LaBelle, and M.L. Trimpi. 1994. Auroral radio emissions observed at AGO-P2. *Antarctic Journal of the U.S.*, 29(5).

Weatherwax, A.T., J. LaBelle, and M.L. Trimpi. 1994. A comparison of electromagnetic noise at ground-based radio observing sites. *Antarctic Journal of the U.S.*, 29(5).

A programmable and low-power ELF/VLF receiver for automatic geophysical observatories

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Measurements of electromagnetic waves in the extremely-low-freqency and very-low-frequency (ELF/VLF) ranges [300 hertz (Hz) to 30 kilohertz (kHz)] have been carried out from various antarctic stations for the past 30 years. Waves in this frequency range play an important role in the acceleration, transport, and loss of ionospheric and magnetospheric plasmas, and their measurement provides a means of remotely sensing physical processes that occur in near-Earth space. Low-resolution data on overall ELF/VLF activity usually consist of the recordings of the detected-signal amplitude in selected bandwidths (channels), sampled relatively slowly (e.g., approximately 10 Hz). Since a diverse range of different types of waves are commonly observed, however, including discrete emissions such as chorus, steady, and structureless emissions (e.g., hiss and other signals originating in lightning discharges), wideband measurements of the signal waveform are necessary to identify the nature of the waves. At manned stations, such recordings are most compactly made in analog form (more recently also using video or digital-audio systems) on magnetic tape, which typically accommodates up to 30-kHz bandwidth in real-time.

The ELF/VLF receiver systems that have been used in Antarctica for the past 30 years have been based on highly optimized and robust designs, using large loop antennas (the most common IGY antenna is a 9-meter high triangular loop with a 15-meter base) to achieve high sensitivity (Paschal 1988). In view of the extremely low power and limited data-recording resources of the automatic geophysical observatories (AGOs), however, a completely new ELF/VLF receiver system and data-recording scheme needed to be designed for use with the AGOs. As part of the Stanford University participation in the polar experiment network for geophysical upper-atmosphere investigations (PENGUIN) program, a fully digital and programmable low-power ELF/VLF receiver system has been designed and built. In this article, we describe the basic properties of this new system and show sample data acquired at P2, Antarctica.

The Stanford University ELF/VLF receiver consists of one digital broadband snapshot (BBS) system, four narrowband channels referred to as *hiss filters*, and three additional narrowband channels tuned to the frequencies of powerful VLF transmitters (NAA/24.0-kHz at Cutler, Maine; NPM/23.4-kHz in Lualualei, Hawaii; and NLK/24.8-kHz at Jim Creek, Washington). The seven channels and the BBS share a common power system and line receiver, and the narrowband channels each have separate detector/integrators in a common module. A separate dual-channel low-noise preamplifier unit is deployed outside near the sensors, which consist of two 1.7×1.7-square-meter square-loop antennas deployed in orthogonal (magnetic north-south and east-west) configuration. The preamplifier is buried in the snow in its enclosure and is designed to operate at temperatures as low as –55°C.

Being much smaller in size than the ELF/VLF wavelengths, the loop antennas respond to the rate of change with time of the magnetic field of an incoming electromagnetic wave. The wideband voltage induced at the loop terminals is boosted by the preamplifier and transmitted along a 150-meter cable to the receiver in the AGO. The two channels of the line amplifier distribute these signals to the various broadband and narrowband receiver modules. The narrowband receivers connect to the detector/integrator unit, which outputs voltages representing signal level for each channel.

The BBS consists of a single-board computer (SBC) buscard cage, two custom circuit boards, an embedded V-40 SBC, front panel liquid crystal display and pushbuttons, and an RS-232 serial communications port. The microcomputer program is stored on EPROM and can be replaced annually as requirements (frequency range, snapshot times, north-south or east-west channels, or goniometer mode) change. The wideband signals from the line receiver are sampled at 25 kHz with 12-bit resolution; the processor can sample/record the north-south or the east-west channel or simulate a goniometer. In the first deployments (1993, 1994), the BBS was programmed to record 6 seconds of north-south data every hour, covering the time period XX05:30–36, which is in the middle of the established synoptic recording minute. The sampled signal is processed further by downshifting the frequency spectrum (presently programmed to be down to 3 kHz), generating a complex signal (in-phase and quadrature components). This complex signal is passed through a low-pass FIR filter with a corner frequency of 2 kHz. Next, the samples are decimated in time (by a factor of 10, resulting in a data rate of 2.5 kHz) and then serially communicated (RS-232) to the AGO data processing unit. The stored information is sufficient to reconstruct the original signal filtered through a 2–4 kHz bandpass filter.

The system has two sets of narrowband receivers: those tuned to the frequencies of operational VLF transmitters and the hiss filters, which provide a summary of magnetospheric wave activity in selected channels in the 1–30-kHz range as shown in figure 1. The transmitter channels (located in individual modules) are designed to measure signals from powerful VLF transmitters in North America, to deduce the characteristics of the Earth-ionosphere waveguide along or near their paths of propagation to the AGO sites. These channels measure predetermined frequencies and use passive (RLC) filters to achieve low-power operation and 3-decibel (dB) filter bandwidths of 500 Hz with sharp edges (6-pole elliptic filters) to eliminate other transmitter signals nearby. The wideband signal from the line receiver is mixed with an appropriate local oscillator signal to shift the spectra so that the transmitter frequency is centered around 3 kHz and then passed through a bandpass filter. The hiss filters (all located in a single module) do not use any mixing; rather, these channels simply amplify and pass the signal through a bandpass filter. All of the narrowband receivers can have their gains modified through knobs on the front panel. Two of the hiss filters cover the same frequency range (1–2 kHz) with two different antennas (north-south and east-west) to allow the extraction of direction of arrival information during postprocessing.

The outputs of both types of narrowband units are fed into the detector/integrator unit. Each detector-integrator channel rectifies the incoming signal and passes it through a lowpass filter. The filter is designed to have a slower risetime than falltime to minimize the effects of impulsive radio atmospherics originating in lightning discharges. The final signal changes slowly enough to be sampled at 1 Hz.

The power supply of the ELF/VLF receiver unit is fairly complex. It converts the 27-volt (v) direct-current input into +5-v, ±12-v, and ±15-v lines that are distributed throughout the system. Because the analog/digital sampling and processing by the SBC consumes significant (approximately 5 watts) power, an important feature of the BBS system is its use of battery power. The three

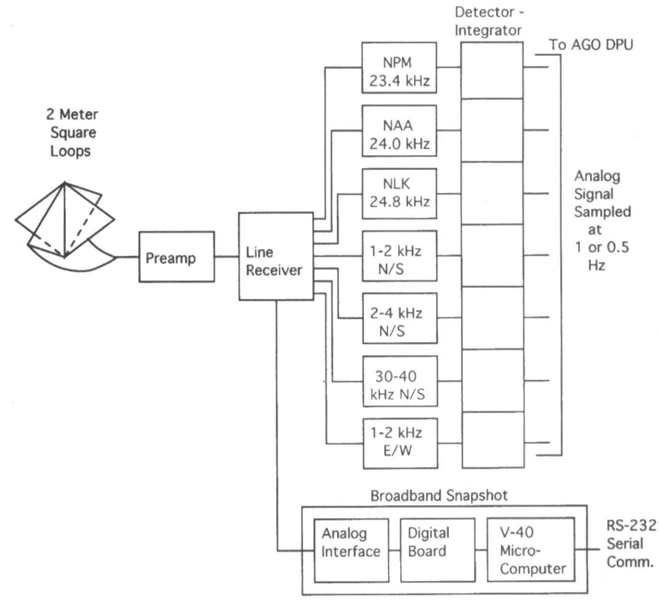

Figure 1. Block diagram description of the Stanford University ELF/VLF receiver system. (N/S denotes north/south; E/W denotes east/west.)

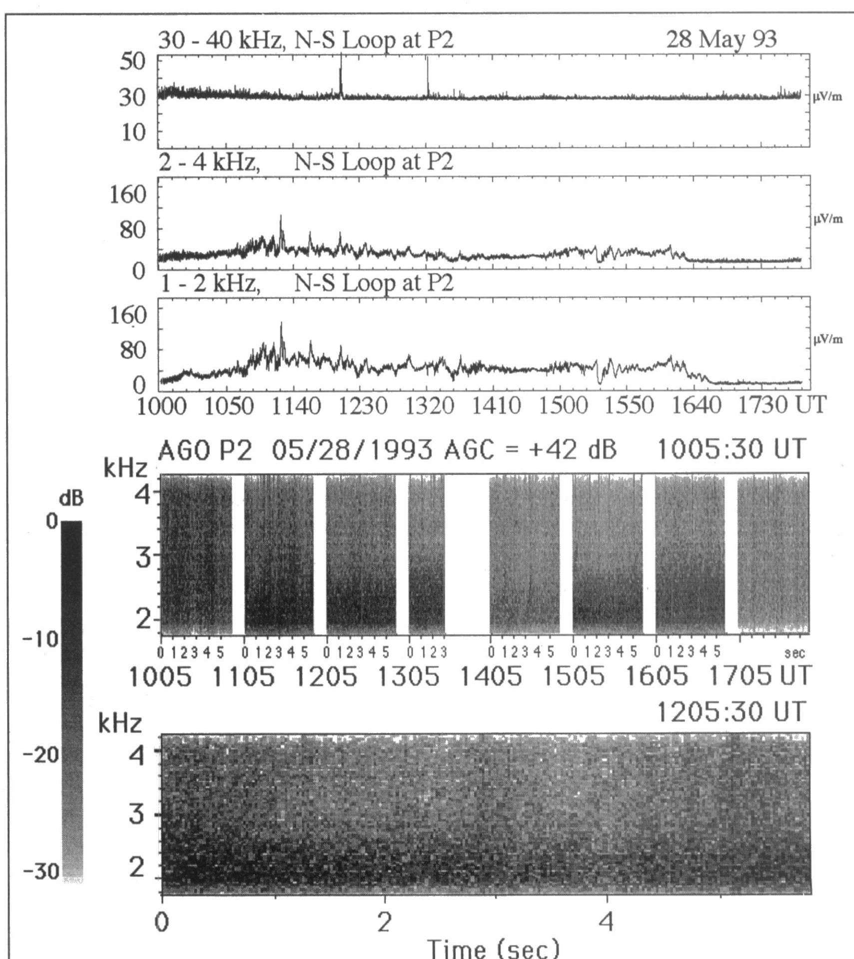

Figure 2. Sample data recorded by Stanford University ELF/VLF receiver system at P2, Antarctica. The top panels show the outputs of three narrowband hiss filters for the 8-hour period. The second panel from the bottom shows the hourly 6-second broadband snapshots in concatenated fashion. Each snapshot starts at XX05:30. The snapshot at 1305:30 was only 3 seconds long due to a data recording gap. The lowest panel shows an expanded display of the snapshot starting at 1205:30 UT. The various data products allow the determination of the long timescale evolution of the phenomena as well as its detailed characteristics. (N-S denotes north-south.)

sealed gelled lead acid batteries are slowly charged during the times when the BBS system is idle (i.e., for about 1 hour in presently programmed configuration of taking 6-second snapshots every hour) and fully used during the snapshot period (currently 6 seconds), providing the necessary power for the BBS. The preamplifier system draws less than 300 milliwatts, which is provided over the 150-meter cable that transmits the signal from the antennas to the AGO. The entire ELF/VLF receiver unit is designed to run on approximately 7 watts of continuous power. To the degree possible, CMOS technology was used in all electronics to achieve the goal of low-power operation as required by the limited AGO power resources.

The sensitivity of the ELF/VLF receiver system is 1.89×10^{-4} μV m^{-1} Hz$^{-1/2}$ and is determined by the relatively small loop antenna used to provide ruggedness and ease of deployment (compared to IGY-type loops).

Typical data from the ELF/VLF receiver system is shown in figure 2. Data acquired at P2, Antarctica, during an 8-hour period between 1000–1800 universal time (UT) on 28 May 1993 is shown, illustrating both the hiss filters and broadband snapshot data. The lower narrowband channels (1–2- and 2–4-kHz) show an increase in activity starting shortly before 1100 UT and lasting until just before 1700 UT. The 30–40-kHz channel shows no activity during this same period. The broadband snapshot data show the activity to be limited to frequencies less than 2.5 kHz, and the expanded record (lowest panel) indicates that the signal consists of a superposition of many discrete chorus elements. The latter aspect is not easily visible on the black-and-white spectrogram but was confirmed on a color version of figure 2, which has better resolution.

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Reference

Paschal, E.W. 1988. The design of broad-band VLF receivers with air-core loop antennas. Stanford, California: Stanford Electronics Laboratories. [Internal report]

Auroral radio emissions observed at AGO-P2

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The automatic geophysical observatories (AGOs) on the antarctic polar plateau provide an excellent platform from which to study high-latitude ionospheric processes. In particular, the AGOs provide an exceptionally quiet electromagnetic environment for the operation of radio receivers in the low-frequency/medium-frequency/high-frequency (LF/MF/HF) bands, as documented in a companion paper (Weatherwax, LaBelle, and Trimpi, *Antarctic Journal*, in this issue). During the 1992–1993 austral summer, this type of radio receiver was incorporated into the first of six proposed AGOs (AGO-P2). A list of the experiments aboard AGO-P2 (85.7°N 313.6°E, L ≈ 8.3) is given in the table. Preliminary data taken from only 1 week of operation at AGO-P2 have already proved to be interesting.

Narrowband emissions at frequencies near twice the ionospheric electron cyclotron frequency ($2f_{ce}$) have been observed by the LF/MF/HF radio receiver located at AGO-P2. The emissions appear similar in frequency, intensity, and temporal structure to auroral roar events previously observed at Northern Hemisphere observing sites (Kellogg and Monson 1979; Weatherwax et al. 1993).

Block *A* in the figure shows an example of a $2f_{ce}$ auroral roar event detected by the LF/MF/HF receiver on 28 May 1993. The horizontal axis panel represents universal time (UT), and the vertical axis represents frequency. The logarithm of the intensity of the received signals is represented by a 16-level grayscale, with white pixels corresponding to 5×10^{-9} volts per meter per root hertz (V/m Hz$^{1/2}$) or less, and black pixels corresponding to at least 5×10^{-8} V/m Hz$^{1/2}$. Each frequency sweep [50 kilohertz (kHz) to 4,850 kHz] takes 10 seconds. An interference line at 2,400 kHz appears as a black horizontal line, and a calibration signal appears as a striped vertical line right after 0516 UT. Between 0530 UT and 0600 UT, a $2f_{ce}$ auroral roar event appears between 2,450 and 2,650 kHz. Using the International Geomagnetic Reference Field (IGRF) model, this frequency range maps to an altitude range

Experiments at AGO-P2

Instrument	Institution
All-sky camera	Lockheed Research Laboratory
Imaging riometer	University of Maryland
LF/MF/HF receiver	Dartmouth College
VLF receiver	Stanford University
Search-coil magnetometer	Tohoku University
Fluxgate magnetometer	AT&T Bell Laboratories