

Design of a low power, wireless, passive seismic monitoring instrument

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Introduction

A four-channel seismic digitizer was designed as part of a project to build battery operated wireless geophones. In the course of miniaturizing the circuitry for this application, the digitizing portion of the circuitry was identified as a useful component in building a continuously operating passive seismic recording instrument. The instrument consists of four functional blocks: the preamplifier, the A/D converter, the microcontroller, and the data transmission system.

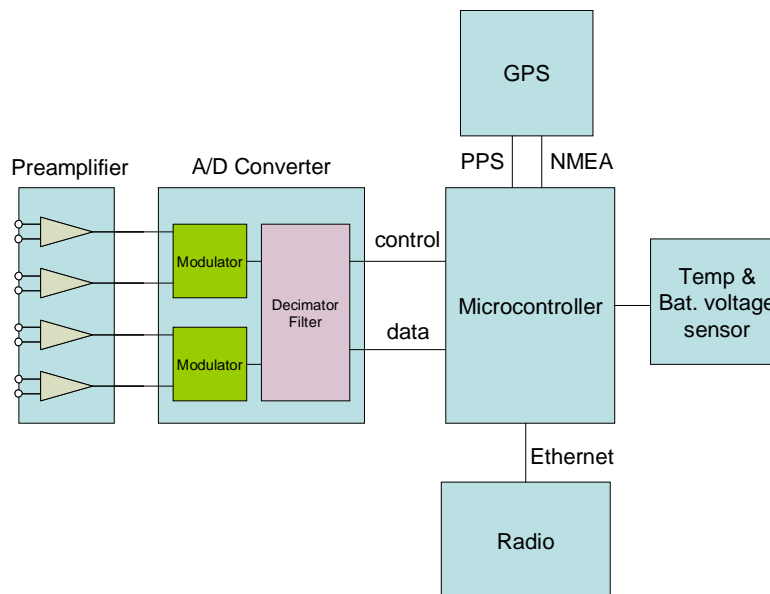


Figure 1. Block diagram of the passive seismic monitoring instrument

Preamplifier

The preamplifier handles a variety of sensing devices, such as geophone elements, accelerometers, or powered sensors. The initial design of the preamplifier used a two-stage differential instrumentation amplifier with a computer-selectable gain adjustment. Field testing of the first preamplifier design showed that it was susceptible to radio frequency interference. Since the instrument was designed for installation directly beside a wireless network radio, it needed to be tolerant of high levels of out-of-band radio frequency (RF) interference. The original preamplifier design was replaced with purposed-designed geophone preamplifier based on the CS3301 chip. These chips offer $8.5 \text{ nV}/\sqrt{\text{Hz}}$ noise floor between 0.1 Hz and 2 kHz and have a built-in programmable gain feature (Cirrus Logic, 2005). The new preamplifier has much better RF noise immunity than the original design. Because the preamplifier is based on a chopper-stabilizer design, the resulting output has very low

DC offset. This is of particular importance in passive seismic systems where STA/LTA¹ triggering algorithms require an input signal that is free of DC offset.

A feature of the preamplifier stage is a digitally-controlled geophone test circuit. Under software control, one can activate a small test current across the connected geophone. Observation of the signal during and after the application of the test pulse allows us to measure the geophone's resistance, natural frequency and damping factor. This feature is extremely helpful for periodic quality monitoring of any passive seismic systems – both for surface and down-hole installations.

A/D Converter

The A/D converter portion of the instrumentation is based on the Cirrus Logic CS5372/76 set of integrated circuits. The key components are the CS5372 two-channel delta-sigma modulator and the CS5376A four-channel decimation filter. Combination of two modulator chips and one decimation filter result in a four-channel A/D converter capable of sampling at rates of 1 to 4000 samples per second. At sample intervals above 2 ms, there are approximately 24 bits of effective resolution. Within the decimator filter chip are cascaded SINC, FIR and IIR filters. These provide a large variety of possible sample rate and filtering options.

The combination of one CS5376A and two CS5372 chips result in a monitoring instrument with four channels. Since most multicomponent sensors have three outputs for each of three axes, the fourth channel is left spare. Depending on the environment, the fourth channel might be used for record a hydrophone, auxiliary single-component geophone.

Microcontroller

Since the A/D converter's output is unsuitable for direct transmission over Internet Protocol networks, a microcontroller must be used to marshal the data stream and chop it into properly formatted data packets for transmission. In addition to data marshalling, the microcontroller also time-stamps the outgoing data, using a connected GPS-receiver as a time reference. The GPS receiver provides a pulse-per-second signal, detected by the microcontroller. The resulting data stream is therefore temporally accurate to one sample interval plus the GPS's pulse accuracy (typically 20 ns).

The Rabbit Semiconductor "Rabbit 3000" microprocessor forms the core of the microcontroller. With its software stored in flash memory, the unit may be reprogrammed as necessary over a remote network link. This allows changes to the sample rate, data format, or number of channels. Additional features, such as temperature monitoring and GPS health reporting have been added by remote programming and the addition of temperature sensors to the instrument package.

The Rabbit processor was selected because of its low power consumption, the availability of software libraries for Internet Protocol, and a large number of I/O ports. With support for multiple synchronous and asynchronous serial ports, the Rabbit processor was a well suited for the task. Though unable to perform complex mathematical tasks, the Rabbit processor excels at reliably moving data between its network and interface ports.

¹ The ratio of short-term-average to long-term-average is severely affected by large DC components.

Data transmission

Data from the microcontroller is transmitted via an Ethernet network interface using Internet Protocol encoding. In cases where the passive seismic system is hardwired to the data recording computer, regular cable or a fiber-optic media converter may be used to connect to the instrument. At remote sites, commodity wireless network radios have been used to transmit data over long distances. A wide variety of network radios have been tested with the instrument. Radios from vendors such as Wi-Lan, SmartBridges, Engenius, DLink and Linksys have all be used successfully. Most of these radios have no difficulty in transmitting over 1-5 km distances in rural locations using high-gain antennas. One 26km link was established using a pair of Wi-Lan AWE 120-58 radios operating at 5.8 GHz. For this to work, greatly elevated 1 m dish antennas were used.

Software

Data from the remote digitizer is received by software running on a conventional desktop or rack-mount computer. Software was developed to combine data from multiple 4-channel units and gather them into a combined multi-channel data stream. Additional software stores the continuous data in either a database or a series of data files. Finally, event detection software combs the data for signs of seismicity using a STA/LTA trigger algorithm.

Results

Combination of the components into a completed system allowed us to verify the design by running a series of instrument tests. Tests indicate that the instrument operates as expected based on the electrical components used. Total power consumption for the finished instrument is 1.4 W. When coupled with a low-power wireless radio, the entire system consumes under 4 W.

Several monitoring stations were deployed using the newly designed instrument. One instrument is located in a seismic monitoring vault near Priddis, Alberta, Canada. This instrument is connected to a Kinometrics Wideband Ranger seismometer and operates at a sample interval of 8 ms. This device has operated continuously four years without any intervention.

A number of other instruments are installed at the Frank Slide site in Crowsnest Pass, Alberta, Canada. This field site is very harsh, with instruments operating at temperatures ranging from 32 C down to -40 C.

Discussion

The passive seismic instrument was successfully designed and deployed. Given the equipment's early stage of development, the first set of field deployed units have performed very well. The greatest challenge to operation of the units remotely is an adequate supply of power – some sites receive prolonged periods of shade due to local topography and foliage. Another issue which has caused the failure of some units is nearby lightning strikes. Since many of the instruments are deployed along the ridge of a 2000m mountain, lightning has proven to be problem during the rainy periods. Installation of gas-discharge tubes on the preamplifier-inputs has helped reduce the frequency of lightning-induced damage.

The remoteness of the initial test site has helped underline the importance of reliability in passive seismic monitoring instrumentation. To prevent costly repair missions, simple systems with few user-selectable adjustments seem to work best. Remote diagnostic facilities such as geophone pulse test circuits, temperature and power monitoring have proven extremely valuable – particularly when attempting to remotely diagnose system failures and plan repair missions.

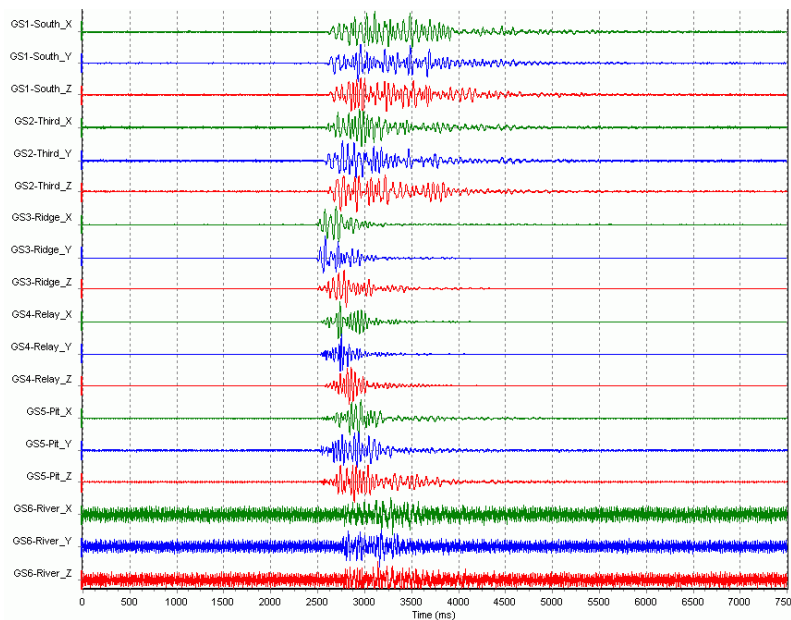


Figure 2. Sample of data acquired by six passive seismic monitoring instruments at the Turtle Mountain site in Crowsnest Pass, Alberta, Canada. Traces are ordered in X, Y and Z components for each station. Stations are ordered according to their surface elevation. Data at this site are recorded to disk and plotted by software from Terrascience Systems Ltd.

Future work

Having completed a set of four-channel passive seismic instruments, work continues on increasing the channel count to make an instrument that is suitable for multi-level borehole recording. A system with on-board event detection and storage is also in development.

Acknowledgement

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References

- Cirrus Logic (2005) CS5371/72/76A Product Bulletin, www.cirrus.com.
- Cirrus Logic (2005) CS3301/02 Product Bulletin, www.cirrus.com.