A LOW-COST PORTABLE FAST SAMPLING SYSTEM FOR ASTRONOMICAL APPLICATIONS

Jean-Luc Margot[(1)]
[(1)]***California Institute of Technology, MC 150-21, Pasadena, CA 91125, USA***
(margot@gps.caltech.edu)

Radio and radar astronomical observations frequently involve the sampling of wide-bandwidth signals at coarse quantizations. Hagen and Farley (1973) have shown that autocorrelation spectroscopy can be carried out effectively with two-, three-, and four-level sampling and minimal impact on signal-to-noise ratio compared to a finely quantized signal. If one is concerned with real-time processing, the sampling at one- or two-bit quantization simplifies the required multiplications. If one is concerned with a limited data rate to a storage device, the small number of digital bits maximizes the bandwidth that can be Nyquist sampled. In planetary radar imaging applications, the ability to sample a waveform encoding the largest possible bandwidth is required to obtain fine range resolution. Because the range compression operation is a digital correlation, Hagen and Farley's result also applies, and coarsely quantized signals are highly desirable.

The requirements of radio and radar astronomers -sampling a wide bandwidth signal at coarse quantization- are unlike those seen in most scientific or industrial applications. They are not accommodated effectively by commercial data acquisition products which generally offer a sampling resolution of at least 8 bits and no provision for discarding the least significant bits. In addition, commercial devices normally sustain their highest advertised data rates in burst-mode only, while astronomical applications typically require continuous recording. These difficulties prompted the development of a low-cost portable fast sampling system at Arecibo Observatory in 1999. The science drivers at the time were the need to support radar imaging at the highest range resolution available with the post-upgrade radar, and the need to record Arecibo-transmitted radar waveforms at remote antennas (Margot and Nolan, 1999).

The design philosophy for the Arecibo portable fast sampler (PFS) was inspired by existing pulsar machines such as the Penn State Pulsar Machine (Alex Wolszczan, personal communication) and the Caltech Baseband Recorder (Shri Kulkarni and Stuart Anderson, personal communication). It consisted of using a programmable logic device (PLD) to handle bit selection and packing, effectively circumventing the limitations of commercially available products. After the signal has been sampled and digitized at high resolution, a PLD selects the most significant bits and packs the consecutive samples in a 2- or 4-byte word. This data stream is then transferred to an interface card connected to a computer for data storage. The PFS differed from the existing pulsar machines in two fundamental ways. First, the circuitry was built with off-the-shelf digitizer evaluation boards and wire-wrap circuitry rather than by laying out a printed circuit board. Second, the PFS relied on mass-produced personal computer technology and its fast PCI bus rather than on slower, more expensive workstations. These features allowed for fast development and low cost.

The current configuration includes two dual-channel 8-bit Analog-to-Digital boards with maximum conversion rates of 60 million samples per second. These samples are handled by a programmable logic device to emulate 2, 4 or 8 bit sampling and to pack successive samples in 16-bit words. A parallel interface card then transfers the data to computer memory at rates of up to 20 MB/s, with a straightforward upgrade path to 60 MB/s. A PCI-bus computer is used to store the data onto SCSI hard drives which currently allow sustained transfer rates of over 20 MB/s per disk. A computer program controls the operation of the samplers such as desired quantization, sampling duration, and start times. The start of a data recording sequence is always referenced to a one pulse-per-second (PPS) signal from an observatory clock. In addition to the 1 PPS signal, the data taking system requires a +13 dBm sinewave at the desired sampling frequency and up to four input channels. All signals are terminated into 50 Ohms.

These sampling systems have been installed at Arecibo Observatory and the Green Bank Telescope (GBT). Four units have been replicated at JPL for installation at the NASA tracking stations in Goldstone, California. The PFS was also used for observations at NASA's 70 meter antenna in Madrid and at NRAO's VLBA antenna in St-Croix. In a bistatic mode with the GBT, it recorded Arecibo radar echoes from slowly rotating asteroid 2001 EC16 (Margot et al., in preparation) and Venus (Campbell et al., in preparation). The PFS has been used to provide radar images of the first binary asteroid detected in the near-Earth population (Margot et al., 2002), of near-Earth asteroid 1999 KW4 at 8 meter resolution (Ostro et al., in preparation) and of the rings of Saturn (Nicholson et al., in preparation). Multi-station radar observations of Mars (Slade et al., 2002) and Venus (Jurgens et al., 2002) have been carried out at Goldstone. Other observations included OH masers and pulsars, the Earth's ionosphere, Saturn's largest moon Titan, and numerous near-Earth asteroids.

ACKNOWLEDGEMENTS

Jeff Hagen (NAIC) and Joseph Jao (JPL) provided excellent software contributions and suggestions.

REFERENCES

J. B. Hagen and D. T. Farley (1973), Digital-correlation techniques in radio science, Radio Science, vol. 8, pp. 775-784.

R. F. Jurgens et al. (2002), Geological interpretations of the topography of selected regions of Venus from Arecibo to Goldstone radar interferometry, Lunar and Planetary Science Conference XXXIII, submitted.

J. L. Margot and M. C. Nolan (1999), Radar Interferometric Imaging of Near-Earth Asteroids, BAAS 31.

J. L. Margot, M. C. Nolan, L. A. M. Benner, S. J. Ostro, R. F. Jurgens, J. D. Giorgini, M. A. Slade, D. B. Campbell (2002), Science 11 April 2002 (10.1126/science.1072094).

M. A. Slade et al. (2002), Four-station interferometric radar observations of Mars Exploration Rover landing sites, this meeting.