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Spectrometer Technology Recommendations

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A typical heterodyne remote sensing system contains three major elements: the antenna, the radiometer, and the spectrometer. The radiometer consists of the local oscillator, the mixer, and the intermediate frequency amplifiers. This subsystem performs the function of down converting the high frequency incident thermal emission signal to a lower intermediate frequency. The spectrometer measures the power spectrum of the down-converted signal simultaneously in many contiguous frequency channels. Typical spectrum analysis requirements involve measurement of signal bandwidths of 100-1000 MHz with a channel resolution of 0.5-10 MHz.

Three general approaches are used for spectrometers: (1) filter banks, (2) Acousto-Optic Spectrometers (AOS's), and (3) digital autocorrelators. The filter banks are the most commonly used because of their simplicity; however, for spectrometers with greater than 100 channels, their size, weight, and power make their use for space instruments very undesirable. The AOS is an optical processing approach in which a laser beam is diffracted from acoustic waves in a piezo-electric crystal and detected on an optical array. The AOS has recently come into use in a few radio astronomy observatories. However, because of their temperature sensitivity, low dynamic range, laser reliability questions, size, weight and power requirements, the AOS appears to be a poor choice for a spaceborne spectrometer.

In contrast to the two frequency domain techniques described above, an autocorrelator works in the time domain. The auto-correlation function (ACF) of the incoming signal is computed and averaged over the integration time. The averaged ACF is then Fourier transformed to obtain the signal power spectrum; this needs to be done only once every several seconds. It should be noted that the averaged ACF has the same number of data points as the corresponding filter bank spectrum. The autocorrelator is very stable, has a large dynamic range, and has an effective filter response which is easy to characterize and is the same for each frequency channel.

The digital autocorrelator has been used in many radio astronomy observatories for many years and is a proven method for radiometer spectrometers. The disadvantage of considering present laboratory autocorrelators for space applications is that they have been constructed with medium scale digital integrated circuits and that they involve a large number of parts and consume considerable power. However, with the latest developments in supercomputers and VLSI, it is now possible to plan the technology development of a very low power and small digital autocorrelation spectrometer.

The digital approach with its inherent flexibility, stability, high speed, and low power make this an extremely attractive research area. Also there is the promise of further, very large scale integration to significantly reduce the size and weight. Another advantage is that digital circuits have very high reliability and can be radiation hardened to survive in space. It is important that research be started to establish a baseline so we can better judge the necessary directions for future developments to achieve the required high speed and low power for missions like LDR which will require 10^5 channels.

OAST funds an ambitious development program for applying heterodyne techniques to remote sensing in the millimeter and submillimeter wavelength regions. Astronomy and planetary programs fund airborne and ground-based mm and submm observations, and there are proposals to fly a Submillimeter Explorer Telescope and a Large Deployable Reflector (LDR). The program in Earth atmosphere observations using mm-wave spectral line radiometers is also active, involving balloon observations, the Upper Atmospheric Research Satellite (UARS), and a planned system for the Earth Observing System (EOS) polar platform.

Significant progress has been made in the development of submm antennas and radiometers. It is now time to begin research in the development of low power spaceborne spectrometers and to reduce their size and weight. The near-term research goal will be to develop a prototype digital autocorrelation spectrometer, using VLSI gate array technology, which will have a small size, low power requirements, and can be used in spacecraft mm and submm radiometer systems. The long-range objective of this technology development is to make extremely low power, <10 mW/channel, small and stable wideband spectrometers which can be used in future mm and submm wavelength space missions such as the Large Deployable Reflector.