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Subject: Plan for upgrading C-Band radiometer to polarimetric operation

References: "Polarimetric Radiometer Configurations:…" by Skou et. al., September 1999

Foreword

The Microwave Geophysics Group's current C-band radiometer is not capable of full polarimetry, which is needed for the 2004 arctic tundra experiments in Alaska. I have been assigned to investigate the available options for upgrading the current radiometer, as well as start the preliminary design. This report identifies the best plan for upgrading the radiometer given our current constraints.

Summary

One of the requirements of our grant from the National Science Foundation for the 2004 arctic tundra experiment is the conversion of our C-band radiometer to fully-polarimetric operation. The upgrade must be completed by summer of 2004, when the arctic tundra experiment is to take place as directed by the NSF. The upgrade must also fit within our current budget and time constraints while meeting the technical specifications required.

A number of tested polarimetric radiometer configurations exist, all of which trade off complexity for stability and precision. Radiometer requires high precision due to the low signal levels involved. The best configuration is called a Correlation Radiometer. However, complex microwave electronics are extremely expensive and have long lead times for delivery. It would be very difficult to meet any of our constraints if we built this system directly.

A solution is to use digital signal processing to replace a large portion of the complex microwave electronics. With today's electronics, this is a relatively easy task that would be an order of magnitude cheaper and easier to build. In order to implement a digital correlating system, the input is sampled at a high speed without the need for complex microwave electronics. This also eliminates the need to modify any of the microwave electronics. I should note that the Microwave Geophysics Group (MWGP) has had experience with direct sampling digital radiometers before.

Given the options available and the constraints, I fully recommend upgrading the C-band radiometer by using a digital sampling Switching Correlation Radiometer. This system gives the best stability and precision while keeping costs and time to build low.

Technical Discussion

This section provides an overview of the design choices made behind the recommendation of digital Switching Correlation Radiometer. The background of radiometry is introduced, followed by the layout of the basic radiometer types for polarimetric studies. Digital sampling and processing methods are discussed. Finally, the immediate integration and design tasks are explicitly defined.

Background

The Microwave Geophysics Group (MWGP) studies Earth surface hydrology. This is an important research area because, for example, latent energy transport associated with soil moisture is a dominant summer time land-atmosphere process governing weather and climate. MWGP uses microwave radiometers to measure various land surface characteristics used to create and verify land surface processes models and to calibrate airborne and satellite radiometer instruments.

Where radiometry studies the "radio-brightness" of radiation emitted from bodies of matter such as the earth, polarimetry studies the difference in radio-brightness between the horizontal and vertical polarization of that radiation. Polarimetry has been used for a long time in ocean surface measurements, but has not been used for land surface hydrology. It is the goal of this NSF directed research to investigate the importance of polarimetry to land surface hydrology.

Microwave Systems for Polarimetry

The microwave electronics for a simple radiometer are very straightforward. After the antenna that collects microwave radiation, a number of amplifiers and filters are used raise the signal to an appreciable level and to define the frequency bandwidth of interest. A detector diode is used to convert the input signal to a power level signal. The power level signal is measured usually with an analog to digital converter. Because of the total amplifier gain is on the order of one million or more, frequency conversion is used to prevent the output signal from coupling to the input of the amplifier. This arrangement is called heterodyning. In essence, a heterodyning radiometer operates exactly like AM radio.

A polarimetric radiometer, or polarimeter, is a further advancement to a standard radiometer. In addition to measuring radio-brightness, it also must determine the complex relationships between two antenna inputs, the horizontal and vertical polarizations. There are four brightness parameters that need to be generated, called the Stokes parameters. Functionally, the polarimeter uses complex additions, subtractions, and phase shifts between the inputs to generate a number of output signals that can be detected and used to compute the Stokes parameters.

The simplest configuration, called the Multiplex Polarization Combining radiometer uses a number of microwave switches to channel the signal through the electronics and generate the output signals one at a time through just one power detector. It works well but has low sensitivity and poor time-resolution due to all the complex switching required. A similar configuration, the Parallel Receiver Polarization Combining radiometer works fundamentally the same way but has six separate power detectors to compute the Stokes parameters directly. The detrimental effects switching are eliminated at a great increase in system complexity and cost. Furthermore, precision is impaired by variation between the power detectors.

The best configuration is the Correlating radiometer. This configuration eliminates much of the complex addition, subtraction and phase shift hardware in favor of a "complex correlator". The complex correlator takes the signal that would go to the power detectors and determines the Stokes parameters directly. It basically moves the complexity from the microwave domain to mathematics.

Further information on polarimetric radiometer configurations can be found in a paper by Niels Skou, et. al. "Polarimetric Radiometer Configurations: Potential Accuracy and Sensitivity." By using the Correlating radiometer, the only added hardware needed for our radiometer would be a complex correlator.

Direct Digital Sampling

Complex correlation is a rather difficult task to carry out in the analog domain. Therefore almost all correlators work by digitizing the signal and computing the correlation results with a digital signal processor. This is not only easier, but it immune to temperature drift and noise that are inherent in analog systems. Most systems however, digitize the signal very late in the chain after the microwave electronics.

Instead of doing this, the signal should be digitized immediately after amplification and filtering. Doing so is called direct digital sampling. With our C-band radiometer, after heterodyning down from 6.9GHz the frequency is 1.4GHz. This would be sampled and then all further operations would be carried out in the digital domain, including more filtering, the complex correlation, and the power detection.

By allowing the digital signal processor to perform all the calculations of the parameters, costs are significantly reduced. The programmable nature of the processor allows for future upgrades and changes to the code without any financial burden other than time to write code. The Stokes parameters would be available numerically ready for storage on the control system.

Integration Tasks

From a design standpoint, a suitable analog to digital converter needs to be selected and installed in each channel of the current radiometer. These must be tied to a digital signal processor that has enough power to perform all the desired computations. That completes the hardware upgrade requirements. While the hardware upgrade is taking place, the coding of the signal processor can take place. A set of desired functions and an operating protocol also needs to be determined for this project to go forward.