

The New Meteor Radar at Penn State

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Abstract

In order to provide new and improved meteor radar sensing capabilities, Penn State has been developing advanced instruments and technologies for future meteor radars, with primary objectives of making such instruments more capable and cost effective to study basic properties of the global meteor flux, such as average mass, velocity, and chemical composition. Using low-cost field programmable gate arrays (FPGAs) and open source software tools, we describe a state-of-the art radar system that is both cost-effective and efficient, optimized to collect and display instantaneous profiles of atmospheric parameters and climatology on a daily basis throughout the year. An overview of the system and some of the emerging technologies developed for this meteor radar are presented.

1 Introduction

Meteoroids impact and disintegrate in the Earth's atmosphere daily. Current estimates for this global meteor flux vary from 2,000-200,000 tons per year, and estimates for the average velocity range between 10 km/s and 70 km/s [1,2]. The understanding of the properties of the meteor flux is important for several fields of study which range from solar system evolution to imaging of gravity waves in the mesosphere. Yet, the basic properties of this global meteor flux, such as average mass, velocity, and chemical composition remain poorly understood [1]. It is still unknown how the changes in the meteor flux will influence these phenomena, because current modeling efforts of the physics and chemistry of meteor atmospheric entry and ablation require better observational constraints [3,4]. In an effort to provide new and improved meteor radar sensing capabilities, Penn State has been developing advanced instruments and technologies for future meteor radars, with primary objectives of making such instruments more capable and more cost effective in order to study the basic properties of the global meteor flux. We describe in this paper the current implementation of an open source VHF software radar system as a first step towards developing a new generation of radar systems for meteor and aeronautical science.

2 System Description

The current system utilizes an linear array of four 5-element Yagi antennas for transmission and five 5-element Yagi antennas in a cross configuration for reception. The system carrier frequency is 49.8 MHz and peak power during transmission is approximately 20 KW. During reception, incoming signals are conditioned using a series of amplifier stages and bandpass filters to minimize undesired signals. Additionally, limiter and blanker stages are used to protect the system from spurious noise as well as artifacts from the transmission phase. After the signal is conditioned, it is sampled, base-banded and further processed by a custom-designed digital receiver. The digital receiver is a customized form of the popular Universal Software Radio Peripheral (USRP), modified for use with pulsed radars and optimized for use with meteor observations. A single receiver can process up to 4 RF/IF channels using 12-bit samplers and a combined instantaneous bandwidth of up to 4 MHz. Each receiver channel is comprised of a down-converter stage followed by a decimating filter stage. Down-conversion is performed using a 12-stage CORDIC filter with a 16-bit data and performance variable paths. Internal stages utilize 2 guard bits on both data and performance variable paths to increase/preserve precision. Additionally, the performance variable is bit-pruned to reduce logic usage, reducing the variable's width by 1 bit with each successive stage in the design. After base-banding is

performed, the signal is filtered, decimated, and gain-compensated using a 5-stage variable decimation CIC filter utilizing the Hogenauer bit-pruning technique [5]. Processed data from the digital receiver is output to a general-purpose computer (GPC) where further processing is performed, including: 1) advanced buffering and data synchronization techniques, 2) CIC droop compensation, 3) phase decoding, 4) and optionally additional filtering.

The USRP, originally designed for Software Defined Radio (SDR) applications, is not well suited for pulsed radar applications where sampling is triggered for pre-defined range windows, requiring accurate ranging for proper analysis. To overcome this limitation, modifications were made to provide gated sampling through the use of an external TTL-level gating signal. Additionally, to ensure proper phasing, the first sample of each channel is encoded with a unique data tag that can be retrieved by downstream (i.e. GPC processing) operations. This data tag is also used as part of the validation process when designing a new configuration. Sophisticated application software was designed, using several modern languages and techniques, in an effort to provide maximum flexibility with respect to configuration, while keeping the setup simple and intuitive.

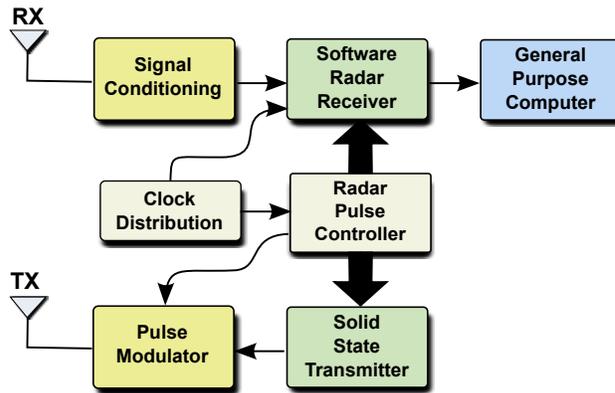


Figure 1: Block diagram of the radar system's configuration.

Currently system configuration is managed using a combination of XML and the Java programming language, thus providing an easily expandable frame work that functions on most popular computing platforms. To maximize performance, all data stream processing routines are coded in C++, utilizing modern object-oriented techniques, promoting robustness and re-use. Additionally, low-level C++ routines to control data collection and provide system status have been designed to operate over a network (i.e. UDP packets), allowing the user to manage observations remotely using Java-based applications which provide benefits discussed earlier. To provide diagnostics and data visualization, incoming data from the USRP is buffered using the GPC's RAM in such a way that external processes can be connect, read, and process buffered data without affecting the primary data stream. In this application, real-time data visualization was produced using open-source Python libraries. After completion of GPC-based processing, the data stream is encoded with metadata and formatted using the HDF5 format, which provides a large number of freely available tools in several languages (e.g. C++, Python, MATLAB, etc...) for visualization and post-processing of archived data.

3 First Radar Observations

We have conducted first radar observations with the software radar system in conjunction with four 5-element Yagi antennas for transmission and a 50-MHz transmitter with peak power of 20 kW. On reception, we used five 5-element Yagi antennas in a cross configuration. The experiment was carried out with an inter-pulse period (IPP) of 1 ms and pulse width of 1 km range resolution. After a quick analysis of the meteor trails of the received data, the first results of the new system look promising. Figure 2 shows In-Phase and Quadrature raw voltages of an underdense meteor trail. Clearly present in the signal is the attenuation or classical exponential decay of these type of reflections.

4 Conclusion

We have presented an overview of the implementation of a new meteor system based on open source hardware and software tools. This system will be used by Communication and Space Sciences Laboratory at Penn State University to conduct meteor research. The acquisition system enables the operation of the radar with bandwidths approaching 4 MHz and data throughput greater than 32 MBPS. The system is flexible and is easily reconfigurable, allowing the user to concentrate on the experimental setup. All presented software freely available under the GPLv3 license at: [<http://github.com/rseal/GnuRadar>].

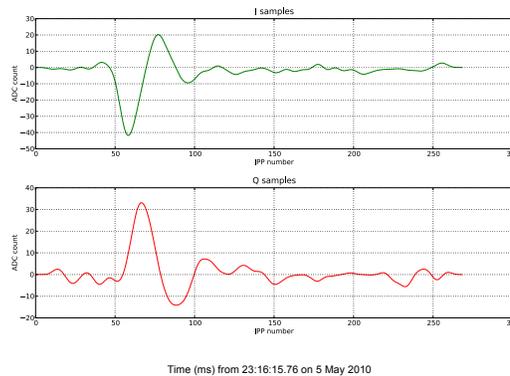


Figure 2: Typical In-Phase and Quadrature raw voltages of an underdense meteor trail detected with the Penn State Meteor Radar.

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5 References

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