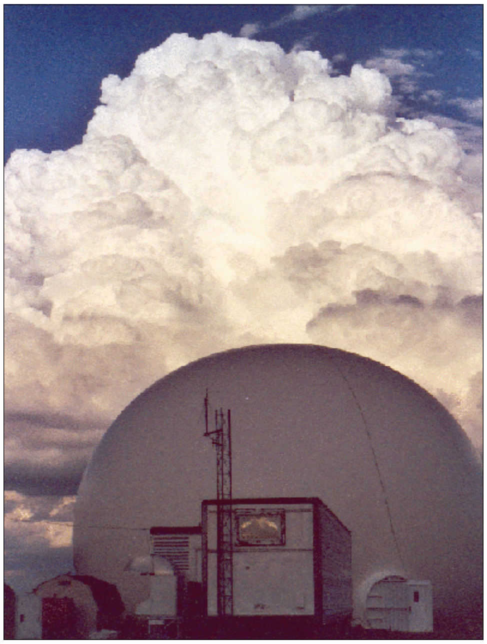
CHILL RADAR NEWS

2006 Fifteenth Edition

Overview (by Prof. Steven A. Rutledge, Scientific Director)

This is now the fifteenth edition of the CSU-CHILL newsletter. Our newsletters have been published every year but one, starting with the 1st Edition in 1991. The CHILL newsletters are widely circulated with the intent to inform the community about our developments and operations on an annual basis.

One of our main activities this past year has been to work towards installation of our new offset, Gregorian antenna. The antenna was delivered to the CHILL site in June 2006, and if all goes according to our latest plan, the antenna should be in operation by August 1st. The antenna project has become sort of a monster project mainly due to the fact that we need to construct a new antenna pad and purchase a new larger radome to accommodate the larger offset antenna. The antenna pad had to be shifted from its present location, as the new dome would have infringed on our existing property line. Surveyors, landowners, engineers, and for the last eight months, university Facilities, have all been involved in the project. Last week a contract was formally approved by Facilities to contract out the pad construction and other site improvements. We are pleased that we are making solid progress on this project. We will place a formal announcement to the community when the new antenna is operational. You will even be able to view realtime data on our V-CHILL web software.



Left: A developing thunderstorm just east of the CSU-CHILL radar site

CHILL supported three NSF funded projects this past year from its home base near Greeley, CO. Details on these projects are provided in the Operations Summary section. In the last few months, we have prepared and submitted a three-year continuation proposal to the NSF for operation of the CHILL facility. One of the major thrusts in the proposal is development of a dual frequency version of CHILL, realized by adding a fully coherent, dual-polarized X-band system. We propose to acquire a dual-wavelength feed for our new antenna, thereby obtaining a 0.3 degree beamwidth at X-band (of course, this would be co-staring with the S-band signal). We plan to work with the CASA (Collaborative Adaptive Sensing of the Atmosphere) Engineering Research Center, led by the University of Massachusetts for development of the RF portion of the X-band system. We are excited about this collaboration and the new measurements that this dual-frequency version of CHILL will provide for our community.

2006 Operations Summary (by Pat Kennedy, Facility Manager)

Inside this issue:

As outlined in the Engineering section of the Newsletter, the digital receiver and signal processing / data recording systems of the CSU-CHILL radar were completely replaced between October, 2005 and June, 2006. Once the radar became operational again, data was collected for three NSF-funded projects during the remainder of 2006.

The first NSF project supported during the summer of 2006 was REFRACTT (the **R**efractivity **E**xperiment **F**or H_2O **R**esearch **A**nd **C**ollaborative operational **T**echnology **T**ransfer). The Principle Investigators for this project were Rita Roberts (NCAR scientist) and Professor Frederic Fabry (McGill University faculty). The central objective of REFRACTT was the collection of detailed measurements of the distribution of atmospheric water vapor content, especially within the lower, boundary layer heights. (For additional information on the overall REFRACTT project, see: http://www.eol.ucar.edu/projects/refract.) A major component of REFRACTT's near-surface mois-

(Continued on page 2)

2006 Operations Summary (continued)

ture field measurements involved the application of Fabry's method of relating the absolute phase of ground targets observed by a Doppler weather radar to the moisture content in the beam path between the radar and the target (Fabry et al. J. Atmos. and Oceanic. Tech, 1997, 987 - 987). The phase of the return signal measured from a stationary ground target by a perfectly coherent radar is determined by the microwave frequency refractive index properties along the beam propagation path. At typical summer season temperatures, variations in atmospheric water vapor concentration appreciably affect the microwave refractive index value. In practice, a reference phase data base is constructed by making repeated low elevation angle PPI scans of the general ground clutter scene surrounding the radar site; the best reference data are obtained when the low level temperature and moisture fields are fairly uniform in soace and steady state in time over periods of approximately an hour. Once the reference phase data base has been obtained, differences between the observed and reference ground target phase values can be used to develop horizontal mappings of water vapor concentration.

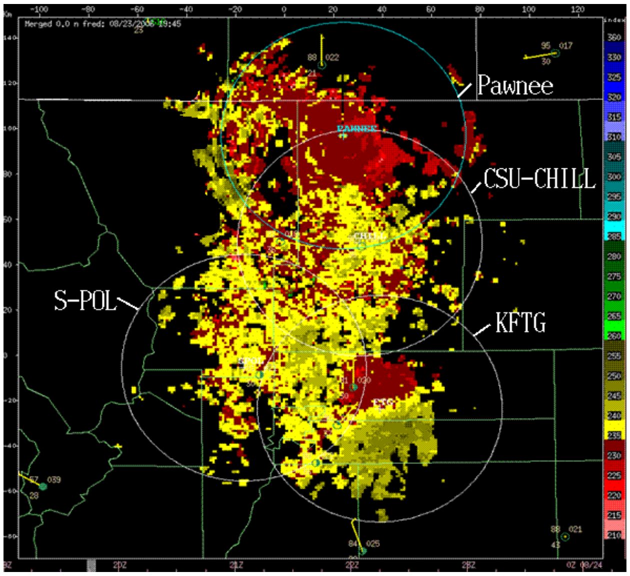


Figure 1: Composite refractivity map from the afternoon of 23 August 2006 during the REFRACTT project. Color scale values are N (10^6 (n-1), where n is atmospheric refractive index). The cooler colors at the top of the scale are generally associated with higher concentrations of water vapor. (Plot provided by Rita Roberts, NCAR).

During the REFRACTT 2006 field project, ground target phase data (expressed by in-phase and quadrature (I and Q) voltage values averaged over an integration cycle) were collected by the NCAR S-POL, CSU-CHILL and Pawnee research radars. Additionally, specialized equipment was installed on the Denver / Front Range WSR - 88D radar (KFTG) to extract the I, Q data stream from its data system. These phase measurements were transmitted to NCAR in real time where they were assembled into a composite map of the refractivity field over the four radar network (Fig. 1). These regional refractivity maps were updated on a four minute cycle and made available via the internet to the NWS forecase office in Boulder. Post analysis case studies are currently underway to explore applications of the water vapor mappings provided by refractivity measurements to various nowcasting and mesoscale numerical weather forecasting problems.

A byproduct of support of CSU's support of the REFRACTT project was a complete upgrade of the receiver and signal processing systems at the Pawnee radar. The new data system installed at the Pawnee radar in August of 2006 was clone of the FPGA - based equipment developed in-house for the CSU-CHILL radar (See the Engineering section of this Newsletter). The FPGA signal processor has the capability of applying a digital clutter filter to the time series data stream. (The limited computational power of the 1980's era SP20 signal processor that was installed at Pawnee prevented the implementation of a ground clutter filter in the past). Figure 2a shows clutter filtered reflectivity data in a 0.9° elevation angle PPI Pawnee radar scan on 14 August 2006. At the time of this scan, a marginally severe thunderstorm was approaching the radar site from the northwest (Fig 2b). The PPI plot domain only extends +/- 15 km from the radar; it is within this short-range environment that ground clutter contamination is the most significant. The clean depiction of the approaching thunderstorm at the short ranges plotted in Fig. 2a attests to the effectiveness of the clutter filtering in the Pawnee's new FPGA signal processor.

The second NSF-funded project supported during 2006 involved Professor V. N. Bringi and Dr. M. Thurai on drop oscillation and mean shape studies under different rainfall types/rates as measured by a two dimensional video disdrometer (2DVD). The 2DVD uses two single-line scan video cameras with orthogonal viewing directions. These cameras observe light sources whose beams are momentarily blocked when hydrometeors fall through the illumination plane. The two camera planes are vertically seperated by ~6mm; as hydrometeors fall through the optical planes, the cameras obtain two orthogonal "shadow" images as well as a measurement of the particle's vertical velocity. The camera data are stored as digital files that can be

Figure 2b: Leading edge of the thunderstorm approaching the Pawnee radar at approximately the same time as Figure 2a. View is towards the North.

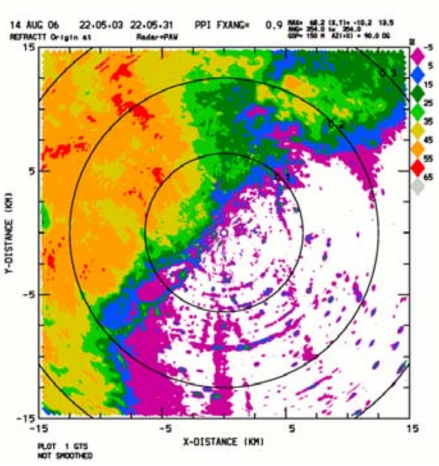


Figure 2a: Pawnee radar reflectivity in 0.9° elevation PPI scan with clutter filtering applied in the signal processor. Color scale is reflectivity in dBZ.

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2006 Operations Summary (continued)

processed into particle size and axis ratio distributions, scatter plots of mean axis ratio vs. diameter, etc. During the summer months of 2006 the 2DVD was installed at NOAA's field site near Platteville, Colorado (approximately 30 km south-southwest of the CSU-CHILL radar).

To obtain high time resolution polarimetric radar observations, the CSU-CHILL radar conducted dedicated scans over the 2DVD when >25 dBZ precipitation echoes were observed in the Platteville area. On several occasions, a fixed pointing scan mode was used that parked the CHILL radar beam over the 2DVD site an elevation angle of 0.5°. Figure 3 shows a comparison of the CSU-CHILL observations obtained in this fixed pointing mode with the corresponding 2DVD data collected around 0130 UTC on 26 July 2006 during a period of stratiform rain. In this plot, the reflectivity and differential reflectivity values were computed from the power spectra developed from the separate H and V polarization time series recordings. This spectral domain processing allows the removal artifacts such as ground clutter returns, etc. before the meteorological moments are calculated. (The spectral processing was done by Dr. Dmitri Moisseev of the CSU ECE Department). Figure 4a shows additional precipitation characteristics calculated from drop size distributions collected over one minute periods by the 2DVD during the 26 July precipitation event. Drop spectra that extend to relatively large diameters are indicated by greater spectral line lengths in the positive Y direction. The color shading along each one minute spectral line represents the drop concentrations per diameter interval according to the scale shown along the top of the figure. The open dots show the median volume diameter obtained from normalized gamma fitting of the DVD's. The line traces in Fig 4b show the reflectivity and rain rate calculated from the 2DVD observations. Of particular note in these graphs are the two dashed reference lines. These indicate times when similar reflectivity values were associated with rain rates that differed by approximately a factor of two. The additional drop size distribution information available in polarimetric radar data can be used to reduce this inherent uncertainty in rain rate characterizations made using reflectivity data alone. Combined analyses of the CSU-CHILL polarimetric data and the detailed 2DVD precipitation particle spectra collected during the 2006 season are continuing.

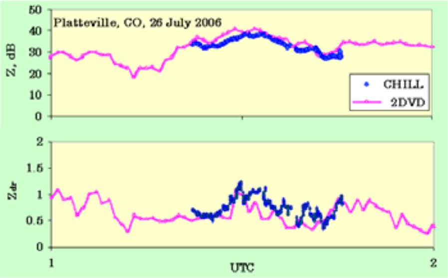

Figure 3: Comparison of reflectivity and differential reflectivity values computer from 2DVD drop size spectra with the values observed by the CSU-CHILL radar during a stratiform rain event on 26 July 2006. (Plot prepared by Drs. Thurai and Huang of the CSU ECE Dept.)

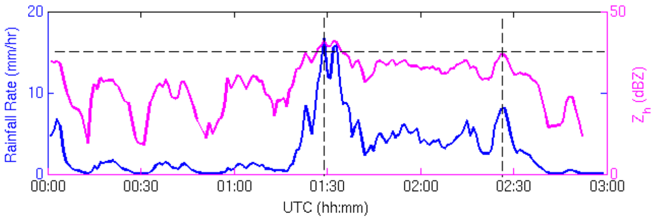

Figure 4b: Reflectivity and rain rate values calculated from the 2DVD spectra. (Plot prepared by Drs Thurai and Huang of the CSU ECE Dept.)

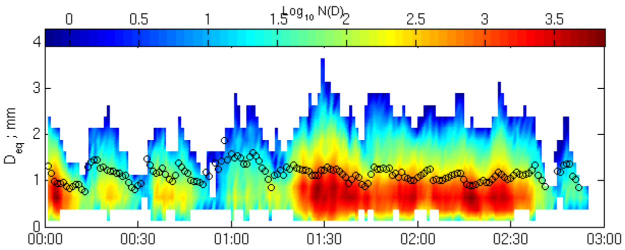

Figure 4a: One minute drop size distribution spectra from the 2DVD data collected in a stratiform rain event during the early hours of 26 July 2006 (UTC). Open circles mark the medium drop diameter in each size

The third NSF project of 2006 was a Research Experience for Undergraduates (REU) program conducted by Prof. V. Chandrasekar of the CSU Department of Electrical and Computer Engineering. The 2006 REU class was composed of six students from five institutions. The entire REU group received several introductory lectures at and tours of the CSU-CHILL radar facility. These lectures provided an overview of weather radar system design considerations, fundamentals of radar signal reception and processing, and meteorological applications of polarimetric radar data. Under the direction of mentors, the students then completed individual radar-related research projects over the course of the summer. (For example, one REU student worked under Professor Bringi in an examination of the calibration stability of the 2DVD at Platteville).

In addition to data collection in support of formal, NSF-funded projects, the CSU-CHILL radar also collected data on a "target of opportunity" basis when suitable interesting precipitation was expected in the radar coverage area. One such interesting precipitation episode occurred on 20-21 December 2006 when blizzard con-

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2006 Operations Summary (continued)

ditions developed over a wide area of northeastern Colorado. This precipitation event took place under a synoptic circulation pattern that contained a general upslope wind flow pattern through much of the troposphere. Under this flow pattern, a mesoscale barrier jet of northerly winds typically flows immediately east of the foothills of the Rocky Mountains where the terrain blocks the general westward synoptic flow. Figure 5 shows a 279^{O} azimuth RHI scan taken by the CSU-CHILL radar at 2126:34 UTC. The sloping depth of the barrier jet (i.e., increasing depth towards the higher terrain) is illustrated by zero radial velocity color band that separates the north-northwesterly barrier jet flow from the synoptic scale upslope flow at higher altitudes. The vertical organization of the polarimetric data fields observed in these RHI scans is also currently being analyzed.

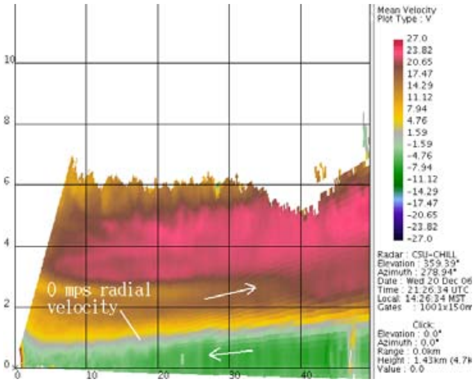


Figure 5: CSU-CHILL radar velocity data (ms^{-1}) in an RHI scan on an azimuth of 279° at 2126 UTC during a blizzard on 20 Dec 2006. Positive velocities indicate motion away from the radar. Range and height axes are in km. The surface-based negative radial velocity layer that deepens with range from the radar is associated with barrier jet flow. (The velocity perturbation at low heights near 47km range is ground return from the foothills of the Rocky Mountains.

2006 CHILL Facility Developments (by Pat Kennedy, V. Chandrasekar & V.N. Bringi)

New Antenna Status:

The components of the new data dual offset Gregorian antenna for the CSU-CHILL radar arrived at the radar site during the summer of 2006. Figure 6 shows the first two trailer loads after their arrival from the VertexRSI manufacturing plant in Kilgore, Texas. The back of the subreflector and its mounting boom can be seen on the trailer on the left in this figure. The trailer on the right is carrying the center section of the main refllector. On 20 September, 2006, the final shipments of the antenna components arrived at the CSU-CHILL stie in Greeley.

Due to its increased size, the offset feed antenna requries the use of new, larger diameter inflatable radome. (The dome currently in use is well past its design lifetime and was ready for replacement.) To accommodate the larger radome within the CSU property limits, a new concrete foundation for the combined antenna and radome installation will be poured during the late spring of 2007. Test operations with the new antenna should begin during the summer of 2007.

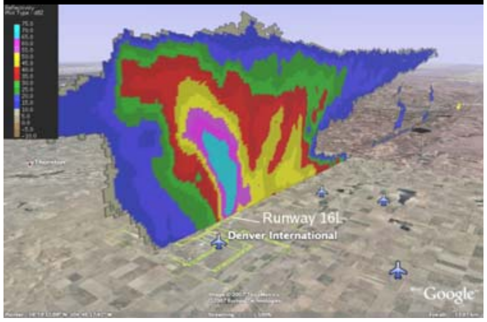
Figure 6: Feed boom and center main reflector section of the new antenna.

Advances to the VCHILL System:

The popular VCHILL system has evolved into a robust operational system that continues to get used by a variety of users of CSU-CHILL. One of the important applications of radar data is geo-location with auxiliary measurements such as rain gages, damage survey sites, and geographical maps. Several systems have used radar data in a GIS framework. During the past year, the CSU-CHILL Facility has developed the capability to export VCHILL data display images in a data file format that can be directly ingested into the popular Google Earth software. The new feature enables Google Earth's highly flexible image rotation, zoom and eye-point relocation features to be applied to the combined radar data from VCHILL and the terrestrial image.

An example of such an application is shown in Figure 7a. The CSU-CHILL data were collected in an RHI scan through a severe hailstorm that affected the Denver International Airport during the early evening hours of 20 June 2001. The RHI scan has been plotted as a properly scaled vertical plan extending upwards from the terrestrial surface view provided by Google Earth. Using Google Earth's display capabilities, the eyepoint has been moved to a location that clearly displays the location of the high intensity (>65dBZ) echo core over the approach end of runway 16L (Figure 7a). In

Figure 7a: Combined CSU-CHILL RHI scan and Google Earth image. Radar data is reflectivity observed at 0126 UTC on 21 June 2001 as a severe hailstorm began to affect Denver International Airport. Color scale is in dBz.



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2006 CHILL Facility Developments (continued)

Figure 7b, VCHILL has calculated the Hail Differential Reflectivity (H_{DR}) values from the basic reflectivity and differential reflectivity values. Large positive H_{DR} values (> ~ +31 dB) are often associated with damaging hail; Figure 7b depicts these large positive HDR values in the echo core. Surface observations confirmed the existence of significant hail from this storm: Hail damage to both vehicles and structures took place as the storm crossed Denver International Airport (KDEN). The storm also affected Front Range airport (KFTG; located just southeast of KDEN). The damage inflicted on a general aviation aircraft parked at KFTG attests to the severity of the hail. (Figure 8).

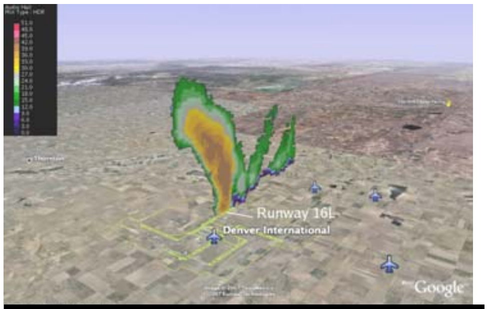


Figure 7b: As in figure 7a except radar data is Hail Differential Reflectivity (H_{DR}). Color scale in in dB

Figure 8: Hail damage to wing skin of a general aviation aircraft parked at the Front Range Airport (KFTG).

In addition, we have embarked on providing the CSU-CHILL educational bookmark sections as Podcasts. These Podcasts are a part of the broader effort of educational outreach, providing resources for students and educa-

2006 CSU-CHILL System Upgrades & New Capabilities (by D. Brunkow, J. George, and V. Chandrasekar)

Recent advances in signal processing and handling capabilities are revolutionizing the communication and computing landscape. The new signal processor and data system upgrades at CSU-CHILL have taken advantage of state of the art capabilities in computing and communication technology. These innovative technologies have simplified the complexities associated with radar signal processing, while improving the overall performance of the system.

Advanced signal processing, high quality transmitter pulse control, as well as novel waveform design capabilities have been part of the long term strategy for the CSU-CHILL system. During the last 2 years with support from the ITR program, the CSU-CHILL hardware and software architecture have been significantly modified and upgraded to ensure full flexibility to enable the complex tasks discussed above. These upgrades have been made maintaining the VCHILL philosophy of full remote control of all the features of the CSU-CHILL system. Among the numerous upgrades that have been made, the significant ones are:

a. Transmitter Waveform Generator and RF Chain
b. Digital Receiver
c. Distributed Signal Processing
d. Data Display and Archiving

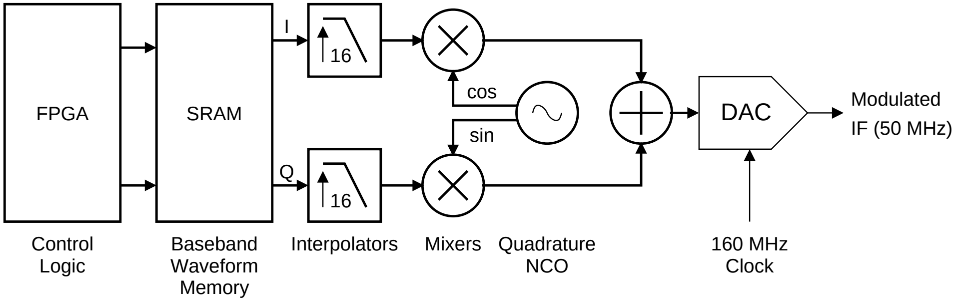
Transmit Waveform Generator and RF Chain

The CSU CHILL uses two independent klystron transmitters in order to achieve maximum polarization flexibility and channel isolation. The klystrons are driven by a digital modulator/waveform generator, which under software control can generate a variety of modulated RF pulses from a base band pulse definition. Each klystron develops approximately 1 MW/Channel output power. The transmitter output is sample to monitor the spectral purity and the transmitted power.

The transmit waveform generator allows precise control of the drive signals supplied to the final power amplifiers in the two transmitters that are used to deliver power to the horizontal and vertical polarization ports on the CSU-CHILL antenna (Figure 9). The basic transmitter pulse timing is derived from an external GPS-stabilized crystal oscillator. The GPS stabilization allows long-term drifts to be corrected, while preserving the excellent phase noise performance of the crystal oscillator.

Modulation of the transmitter drive pulses is obtained using complex baseband waveforms that are pre-loaded into the waveform generator memory. This capability supports a variety of applications such as pulse tapering to limit the transmit bandwidth and inter-pulse phase coding for a variety of applications including second trip echo suppression. The drive pulse modulations applied to the H and V channel

Figure 9:Transmit Waveform Generator Block Diagram (only one channel shown)



2006 CSU-CHILL System Upgrades & New Capabilities

Klystrons can also be separately specified to compensate for differences in the transmitter characteristics, yielding final H an V transmitter ouputs that are well matched. By applying different pahse codes to each channel, LDR measurements have been implemented in simultaneous transmission mode.

Digtial Receiver

Digitization of the received signals is now being done with a commercial board that uses field-programmable gate array (FPGA) technology. A customized wideband digital downconverter is implemented on the FPGA, which allows the receiver bandwidth to be digitally controlled (Figure 10). The basic digitizer output is combined with the relevant radar housekeeping information (such as GPS pulse time and antenna pointing angles) into a time series data stream of the in-phase (I) and quadrature (Q) voltage component representations of the signal received at each sampling time (range gate).

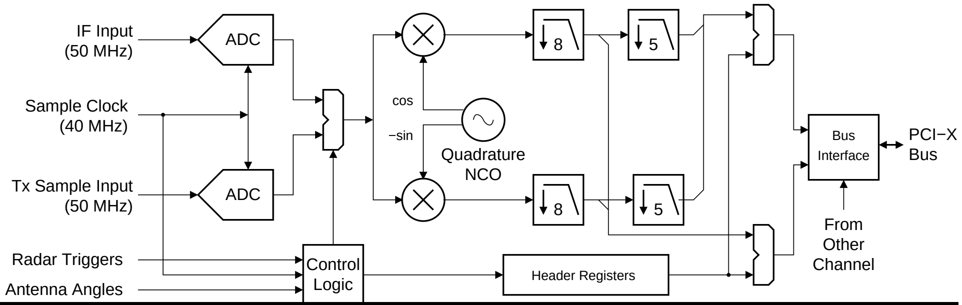


Figure 10: Digiitizer and Digital Downconverter Block Diagram (only one channel shown)

Distributed Signal Processing

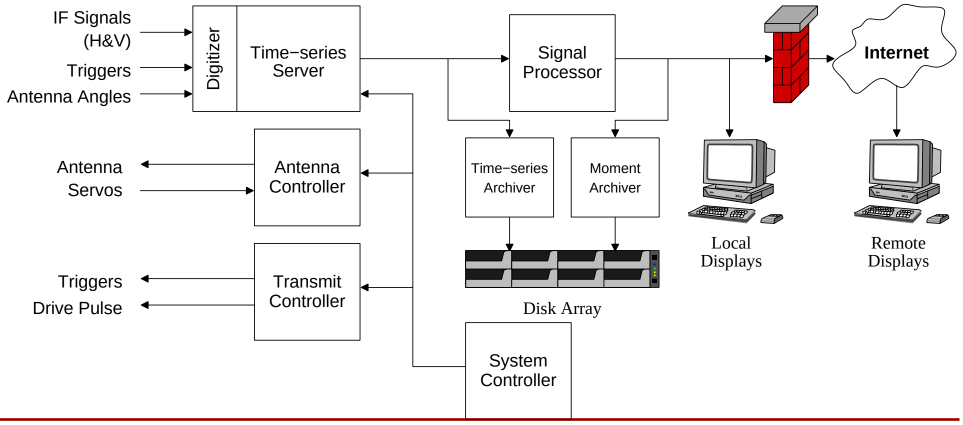
To support distributed processing, the radar's basic time series data stream is made available to multiple processing nodes over a local area network (Figure 11). Nodes on this network ingest the time series data, calculate various meteorological moments (such as reflectivity, radial velocity, and differential reflectivity), and make the moment data stream available for real time display and disk archival. The flexibility of the CSU-CHILL radar data system allows many types of processing to be done in the distributed processing branches. For example, ground clutter filtered data could be presented to the radar operator in real time while unfiltered data is being archived. The data system also supports the archival of complete volumes of raw time series data, permitting maximum flexibility in post– analysis.

Archival and Display

The CSU-CHILL data archiver, routinely writes the computed products to a local disk array. In addition, the data may be remotely archived in a variety of common data exchange formats such as netCDF. The real-time display and the Java V-CHILL display are two data visualization tools developed at CSU-CHILL. They obtain streaming from the signal processor through the VCHILL protocol. The real-time display is designed for use during routine operations, and features high-speed rasterization of the polar radar data, with geographic base maps and overlays. Multiple data products may be observed simultaneously, with selectable color tables. The Java VCHILL display is a cross-platform program designed for remote viewing of real-time data as well as browsing archived data. The VCHILL bookmark feature presents a catalog of selected radar data examples and associated descriptions for educational purposes.

An initial test of the new data system took place during the REFRACTT field project during the summer of 2006. (see operations summary section of this newsletter for additional information on the REFRACTT project.) In REFRACTT, one data processing branch generated and archived data files containing the data fields necessary for real time generation of refractivity fields (reflectivity, radial velocity, velocity spectrum width, and integration time averaged I and Q components). A separate processing branch computed and archived complete polarimetric data sets (i.e., including differential propogation phase, differential reflectivity, etc.). In addition, clutter filtering was applied to the time series data based on the PPI elevation angle: in REFRACTT, no filtering was applied to the lowest two elevation angles where the ground target echoes were necessary to develop the refractivity observations. Filtering was applied at the higher elevation angles to provide cleaner depictions of the atmospheric echo. The computed netCDF data files were seamlessly archived in real-tiome at the NCAR REFRACTT operations center in Boulder.

Figure 11: Signal Processor Block Diagram



With these upgrades, CSU-CHILL stays in the forefront of the advances in RF, digital and computing technology, while maintaining its philosophy of easy network access for advanced research and education.

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