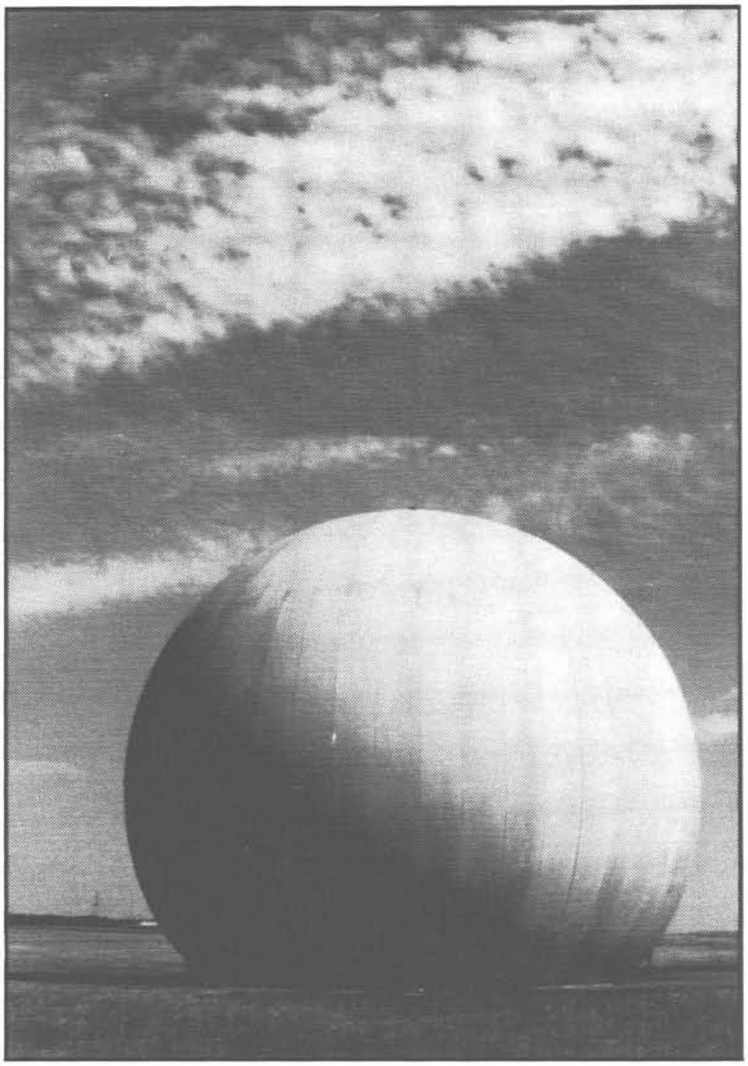
THE CHILL RADAR FACILITY:
A Description



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A DESCRIPTION

E. A. Mueller and J. L. Vogel
Climate and Meteorology Section
Illinois State Water Survey
2204 Griffith Drive
Champaign, Illinois 61820

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(The CHILL radar is a
National Science Foundation facility)

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INTRODUCTION

The CHILL radar system was designed and developed jointly by the University of CHicago and the ILLinois State Water Survey from 1968 to 1970. CHILL is a transportable, dual-wavelength (3 and 10 cm), dual polarization, Doppler radar. Between 1971 and 1983 the CHILL Radar Facility was used in many meteorological projects in East Central Illinois and in other locations in the United States. From 1971 though 1983 the CHILL radar had been moved 24 times and had taken data at 7 locations. By 1981 some of the components were becoming unreliable. In particular, the data processor was showing signs of wear and tear as a result of the many moves and the large number of weather-related projects which the CHILL had served. A Workshop was convened in 1983 by the National Science Foundation (NSF) to determine the desirability of refurbishing the CHILL. The feeling of the Workshop was that a need existed for a research radar like the CHILL. As a result, in 1984 the NSF awarded a 5-year Cooperative Agreement to the Illinois State Water Survey and the University of Illinois to refurbish, upgrade, and operate the CHILL radar as a National Facility.

The following is a description of the CHILL system as configured in 1988. The CHILL is designed so that the user can control the antenna scan mode and manage the displays. Some of the general operational characteristics of the CHILL are given in Table 1.

TABLE 1. OPERATIONAL CHARACTERISTICS OF THE CHILL RADAR SYSTEM

Parameter	10-cm Channel	3-cm and 10-cm Channel	3-cm Channel
Antenna			
Shape	Parabolic		Polarization twist Cassegrain feed
Diameter	8.5 m		2.5 m
Half-Power Beamwidth	.96		1.0
Cain	43.3 dB		39 dB
First Side Lobe Level	-25 dB		-30
Polarization	Horizontal and vertical on pulse to pulse basis		Horizontal
Azimuthal Antenna Rotation Rate	30 °/s		Same
Antenna Controller			
PPI Capability		Yes	
Sector Scan with Variable Limits		Yes	
Azimuthal Sample Spacing		Unlimited	
Elevation Increment		Unlimited	
RHI		Yes	
Transmitter			
Wavelength	10.7 cm		3.2 cm
Frequency	2.73 GHz		9.375 GHz
Peak Power**	1 Mw		100 kw
Pulse Width	0.25, 0.5, or 1.0 µm		1 usec (150 m)
Pulse Repetition Time-Equispaced*	800-2500 µs		1056/1230 us
Maximum Unambiguous Range	375 Km		
Maximum Unambiguous Velocity	±36.4 m/s		
Receiver			
Noise Figure	4.0 dB		13 dB
Transfer Function	linear		logarithmic
Dynamic Range**	90 dB		55 dB
Band Width 3 dB	Varies with P.W		1.2 MHz
Min. Detectable Signal (SNR=1)**	-110		-98 dBm
Data Acquisition			
No. of Range Gates	1024-4096		1024-4096
Range Cate Spacing	0.25, 0.5, 1.0 µs		1 µs
Recorded Word Length			
Velocity	8 bits (2's comp)		
Width	8 bits (binary)		
Intensity	8 bits (binary)		8 bits (binary)
Ground Clutter Canceller	Not decided		No
Number of Samples in Estimate	Arbitrary		Arbitrary
Tape Recording			
Format		Almost Universal Recording	
Tape Density		6250 cpi	
Block Length		≤ 8192	
Initial Variables Available***			
Reflectivity	Yes		Yes
Horizontal Polarization	Yes		Yes
Vertical Polarization	Yes		No
Cross Polarization****	Yes		No
Differential	Yes		No
Velocity (from pulse pair algorithm)	Yes		No
Width (from 2nd lag pulse pair algorithm)	Yes		No
Correlation functions with lags of 1	Yes		No
Normalized Coherent power	Yes		No
Doppler Spectra from FFT processing	Yes		No

* A pulse repetition staggering is possible permitting larger unambigious ranges
** Representative value
*** Other variables or variants of these variables can be obtained by reprogramming of the preprocessor
**** With accuracy reservations

TRANSMITTER AND ANTENNA SYSTEM

The transmitter (figure 1) is essentially the same as the FPS-18 system obtained from the U. S. Air Force with some modernization. The original vacuum-tube, high-voltage rectifiers in the FPS-18 transmitter have been replaced by silicon rectifiers. Also, the rectifiers in the 5,000 volt power supply have been replaced by silicon rectifiers. These changes provide more reliable operations.

A charging diode has been added to the pulse forming network in the FPS-18 transmitter. This allows the pulse repetition time (PRT) to vary from 800 μs to 2500 μs, and the PRF from 1200 Hz to 400 Hz without large changes in the amplitude of the transmitting pulse. Software controls provide for a sequence of different PRT's which can vary from pulse to pulse. This feature allows multiple-PRT integration cycles which avoids range ambiguity, while maintaining a high Nyquist velocity. Changes in the PRT are made by the antenna-radar controller in steps of 16 μs.

The radio frequency chain preceding the transmitter tube (figure 2) is now controlled by a crystal. This provides a more stable local oscillator (STALO) than was possible in the original FPS-18 configuration. The new radio frequency chain allows pulse width to be variable, with sizes of 1/4, 1/2, and 1 μs. These intervals provide radial resolutions of 37.5, 75, or 150 m. A radial resolution of 37.5 m is obtainable if both the pulse width and receiver resolutions are set to 1/4 μs.

After the signal is transmitted, it passes through the waveguide and the switchable circulator. The transmission is through a Potter-type dual-polarization horn and is horizontal polarization, or when the polarization switch is activated alternates between horizontal and vertical polarization.

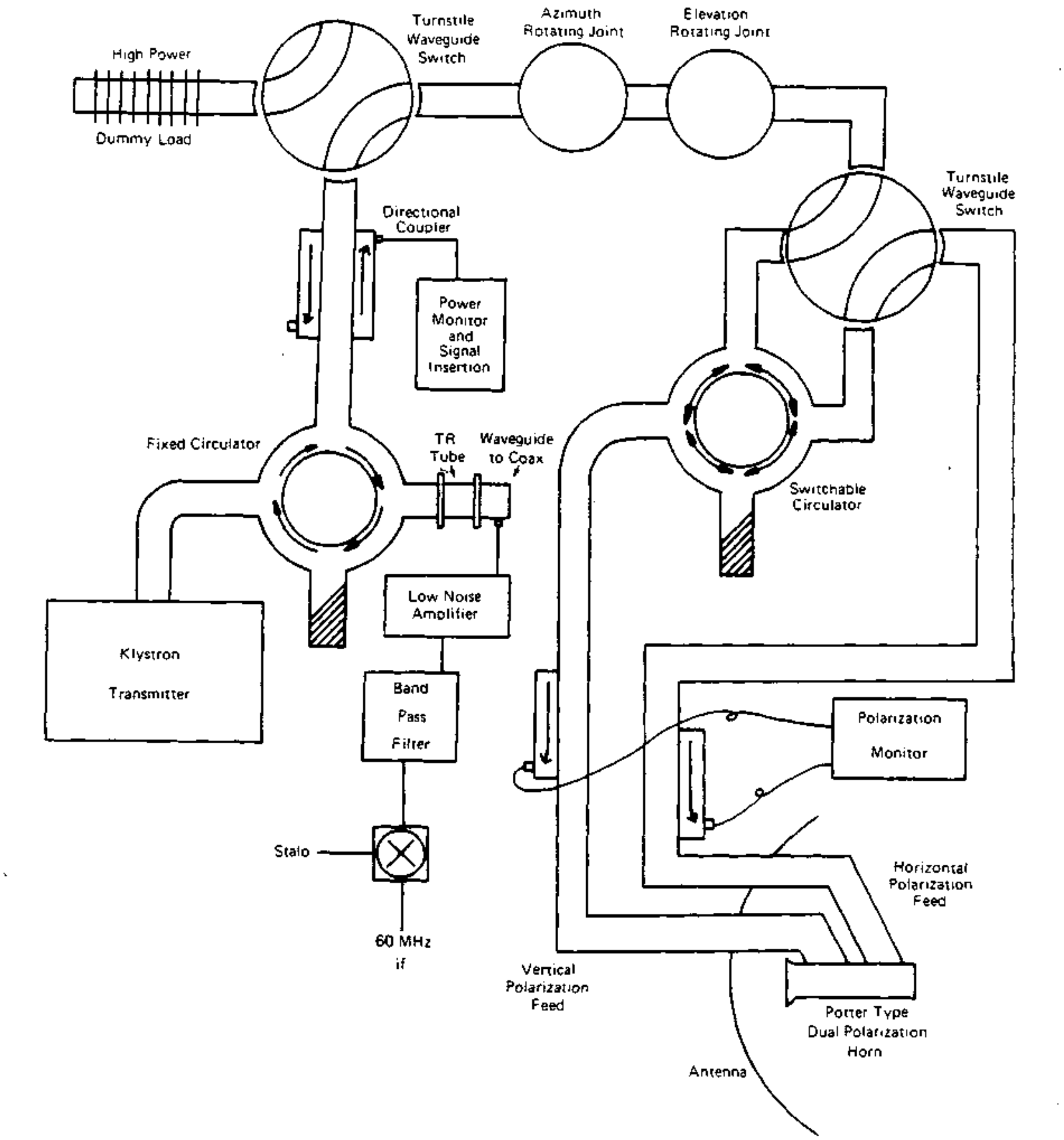
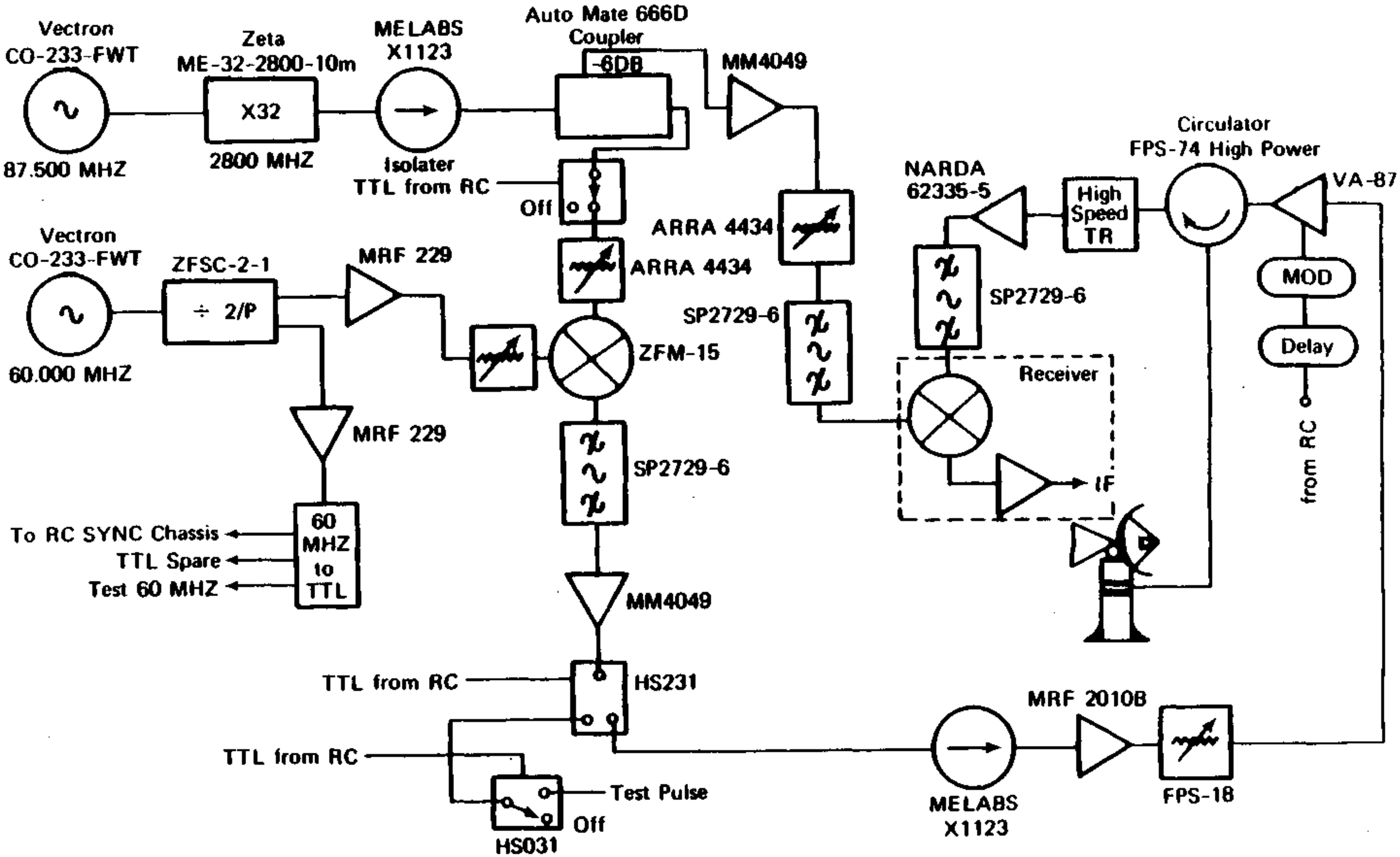


Figure 1. S-Band System for CHILL Radar.



Note: All connections SMA(50)
Type N connectors with
0.141" semi-rigid coax cable

Figure 2. Block Diagram of Radio Frequency Source Redesign for CHILL Radar.

The switchable circulator is really a fast polarization switch which conceptually can be visualized as a circular track with four outlets. Energy can be made to propagate around the track in either a clockwise or a counter-clockwise direction depending on the direction of a residual magnetic field. Two of the inlet/outlets are used to direct the signal to the horizontal or vertical polarization feeds, one transmits or receives the signal, and the fourth carries a dummy load.

The polarization switch must reverse direction between the transmission and collection of data if copolarization of the receiver is being used. Since this takes time, there is a loss in the minimum range for which data can be obtained when the fast polarization switch is utilized. If only a single polarization is required (e.g. always horizontal) another reversal occurs before transmission, and this time loss, which occurs just before transmission, is not usually important. The switching time is less than 14 microseconds, so that no target inside 2.1 km can be observed with the polarization switch in use. If the polarization switch is bypassed by the turnstile waveguide switch (figure 1), then horizontal-only reflectivity can be obtained without any range penalty.

Differential reflectivity measurements require that the polarization switch be transferred from horizontal to vertical polarization. Thus, two separate channels of incoherent integration are used to keep the horizontal and vertical measurements separate. The same receiver and analog to digital (A/D) converters are used for both channels.

Two turnstile waveguide switches allow 1) for rapid testing of the radar using the dummy load, and 2) for bypassing the polarization switch rapidly if it becomes inoperative, or in situations where the minimum range is important.

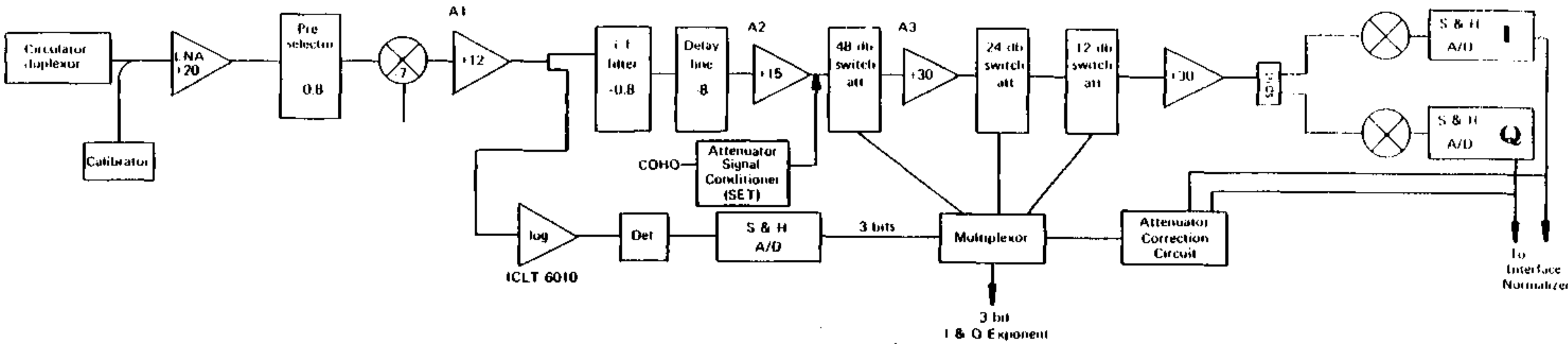
RECEIVER

The rebuilt receiver for the CHILL (figure 3) includes the low noise amplifier (LNA), previously in the CHILL (a better solid-state LNA was not available), and a balanced mixer with a wider dynamic range. The dynamic range of the linear receiver is about 80 db. Semi-rigid coaxial cable is utilized wherever possible to reduce noise and prevent changing attenuation through flexing.

After the coherent quadrature detection, the numbers from the in-phase (I) and quadrature (Q) channels are both fed to the interface unit and then to the preprocessor. The integer numbers from the receiver are transformed into floating point numbers for the I and Q channels with 5 exponent bits, a sign, and 12 mantissa bits, a standard IEEE format. The interface unit also provides for three different resolutions, which is accomplished by always sampling the I and Q channels at 1/4 μs intervals. If the desired resolution time is 1/4 μs, the samples are normalized and passed on. If a resolution of 1/2 μs is required, two adjacent values of I and Q are averaged. Finally, a 1 μs resolution is obtained by averaging two adjacent 1/2 μs samples. Control of the receiver resolution is by a Z8 microprocessor, which also serves as the controlling processor for the modulator control. The Z8 is in turn under the control of the antenna-radar controller.

ANTENNA-RADAR CONTROLLER

Control of the antenna and the operational characteristics of the radar is provided by software on a combination of a MicroVax I, satellite Z8 microprocessors, and two custom circuit boards. A key feature of the antenna-



LEVELS IN RECEIVER

Circulator output	LNA out +20	A1 out +4	Delay line -9	A2 out +15	48 db sw -2 -50	A3 +30	24 db sw -2 -26	12 db sw -2 -14	A4	Exp
-112	-92	-88	-97	-82	-84	-54	-56	-58		0 0
-92	-72 -72	-68 -68	-77 -77	-62 -62	-64 64	34 -34	-36 -36	-38 -50		0 1
80	-60	-56	-65	-50	-52	22	-24 -48	-38 -50		1 2
68	-48	-44	-53	-38	-40	-10 -10	-36 -36	-38 -50		2 3
56	-36	-32	-41	-26	-28 -76	+2 -46	-24 -48	-38 -50		3 4
-44	-24	-20	-29	-14	-64	-34	-36 -36	-38 -50		4 5
32	12	-8	-17	-2	-52	-22	-24 -48	-38 -50		5 6
20	0	+4	-5	+10	-40	-10	-36 -36	-38 -50		6 7
8	+12	+16	+7	+22	-28	+2	-24	-38		7
Required Dynamics	104 db	104	104	104	56	56	30	20		

LNA 1 db compression +12 dbm
A1 1 db compression ≥ +22 dbm
A3 1 db compression ≠ 2

ATTENUATOR CONTROL

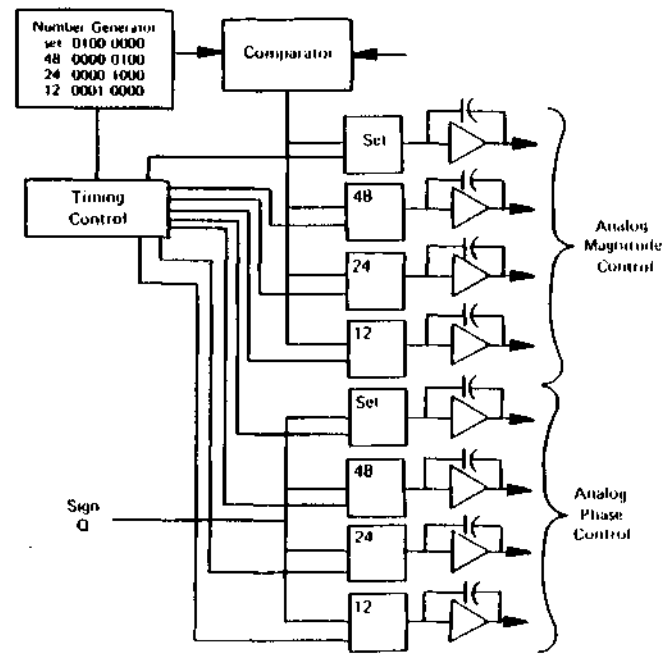


Figure 3. Block Diagram of Receiver System for CHILL Radar.

radar controller is the ability for the operator to interact and control the operation of the radar. The antenna-radar controller performs many tasks, some of the key ones are:

1. Sets the operational mode of the transmitter (pulse width and repetition frequency);
2. Sets the antenna scan sequence;
3. Downloads and controls the signal processor (begins the integration sequence and receives data from the SP20);
4. Coordinates and assembles housekeeping data;
5. Controls the antenna drive system, and
6. Assigns the parameters to be received and recorded (reflectivity, radial velocity, differential reflectivity, or others).

The two custom circuit boards provide 1) digital to analog (D/A) converters to drive the antenna control system; 2) analog to digital (A/D) converters for sensing the antenna velocity; 3) high speed interfaces for receiving the digital antenna position and time information; and 4) circuitry for counting transmitter pulses used to synchronize the MicroVax I with the remainder of the data system.

The operator can control, through software, the radar parameters (PRT, pulse length, and others) and the antenna scan parameters. Sector or continuous PPI scans with fixed elevations scans can be set by the operator and obtained within the same volume scan. RHI and time synchronized volume scans can also be acquired. The rate at which the antenna scans can be controlled by the user, but the maximum antenna acceleration is limited by the software so that smoother scan reversals and initiations are provided. Control of the polarization mode is also managed by the antenna-radar controller. The antenna position is transmitted to the data system via a fibre-optic link. This fibre-optic link also provides lightning protection and isolation between the antenna pedestal and the control area. The operational procedures can also be preprogrammed and stored in the disk memory and called upon when needed. During radar operations communications with the antenna-radar controller can be made from separate terminals in the User and Radar Vans.

DATA PROCESSING AND RECORDING

An overview of the new data processing and recording system is shown in figure 4. Among the key features are a wide dynamic range floating point A/D converter and the use of floating point arithmetic throughout the signal processor. The input normalizer accepts complex floating point samples from the 10-cm receiver every 250 ns and a sample from the 3-cm log receiver every microsecond. The input normalizer may optionally block average two or four 10-cm samples together to effectively match the receiver bandwidth with the transmitter pulse width (1/4, 1/2, or 1 μs). The normalizer converts the numbers to standard IEEE floating point format, and sequences them onto the SP20 input bus, which is divided conceptually into 1 μs frames of ten complex samples each. Even with the 10-cm radar sampling at 1/4 μs intervals, and the 3-cm radar sampling at 1 μs intervals, there are still five unused slots in each frame available for expansion. The data flows from the SP20 to the SKY320, where the data are compressed and housekeeping information is added. From the SKY320 the data are transferred to the MicroVax II where the data are buffered for recording and sent forward to the two display systems.

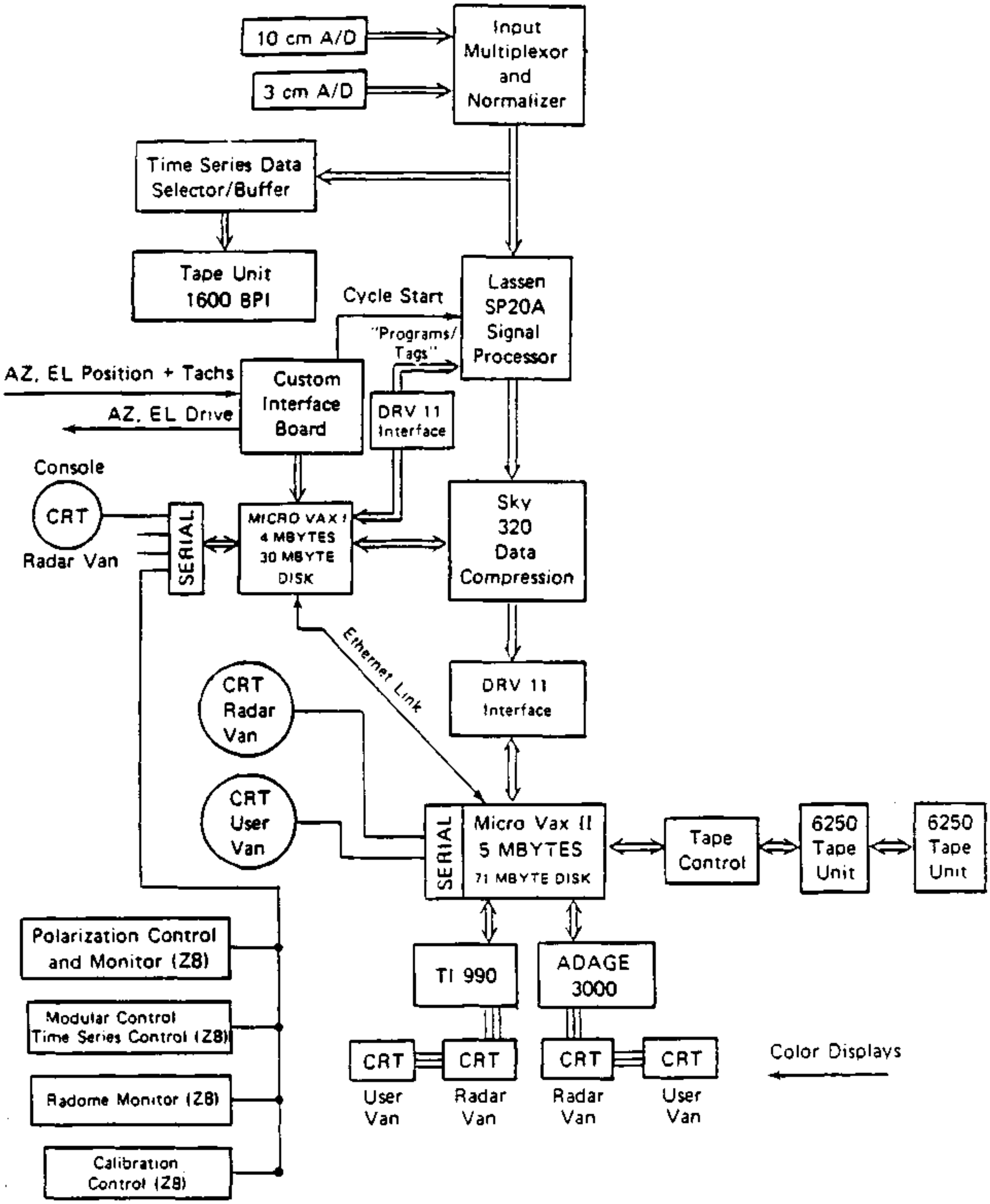


Figure 4. Block Diagram of Data Systems for CHILL Radar.

SP20 Signal Processor

Central to the design of the data processing and recording system is the SP20 Signal Processor manufactured by Lassen Research. The SP20 Signal Processor is a modular array processor which emphasizes flexibility, rapid data handling, computational capability, and is fully programmable using assembler language. The main function of the SP20 is to perform the first computation of the radar data to obtain the base data (reflectivity, differential reflectivity, radial velocity, and spectral width) to be transferred to the SKY320 computer. The processor is composed of an input/output module and can support from 1 to 20 identical computational modules. A set of three busses having a total bandwidth of 240 Mbytes per second provides fully general inter-module communication. The control/input module can accept data at rates up to 80 Mbytes per second. Each computational module has an output port of similar bandwidth and is capable of 20 million floating-point operations per second (20 Mflops). The CHILL processor has 4 computational modules with a computational capability of 80 Mflops. The microcode for each module can run an independent program if desired, though in many instances the modules will be running similar programs, operating on different parts of the data set. Since each module can communicate with all other modules, sequential operations can be efficiently partitioned. The MicroVax I, the host computer, communicates with the control/input module via a DRV11-W type interface.

The programming capability of the SP20 makes it a general purpose processor and allows it to replace special-purpose hardware. When changes in algorithms are required because of a shift in operating location or because different information is required, it is no longer necessary to rewire the processor only the coding of the algorithm needs to be changed.

SKY320 and MicroVax I

After data has been preprocessed in the SP20, they are routed though the output port from one of the computational modules into the input port of a SKY320 board. The SKY320 is an "off-the-shelf" 16-bit integer signal processor consisting of a Texas Instrument TMS32010 chip supported by 64 k-words of memory, direct memory access input and output ports, and Q-Bus host computer interface. The two main functions of the SKY320 are 1) to merge housekeeping data (date, time, antenna position, volume number, and other identifying information) with the high-speed data stream, and 2) to (optionally) apply a bit-mapped data compression algorithm. The SKY320 resides on a Q-Bus card, and like the SP20 is hosted by the MicroVax I.

The MicroVax I, the host computer, interacts directly with the SP20 by downloading programs to the input and computational modules of the SP20, and by exerting some control on the execution of programs in the SP20 by enabling interrupts. While the data from the receiver are being processed by the SP20, the MicroVax I samples the azimuth and elevation at the end of the integration cycle and passes these values along with other housekeeping data to the SKY320. This information is then merged by the SKY320 with the high speed data stream from the SP20.

The SKY320 ingests the data fields produced by the SP20 software, reformats them, and passes them on to the MicroVax II Display Controller along with the current housekeeping data. The SP20 outputs a 16-bit number which is generally the upper half of the IEEE floating point number. For reflectivity and differential reflectivity the SKY320 converts these numbers to 8-bit integers. Additionally, range bins beyond the last discernable echo are suppressed, providing a blue-sky eliminator. The lag-one and lag-two correlation fields are currently left as 16-bit floating point complex numbers. The antenna-radar control program on the MicroVax I indicates to the SKY320 which fields are to be retained on tape and which may be omitted. The SKY320 also keeps track of the noise level by averaging the returned power from distant range bins when the antenna is above 10 degrees elevation. This number is used 1) in the spectral width algorithm, 2) to check receiver drift, and 3) to determine when the "last discernable echo" has occurred. Output from the SKY320 is in the format that goes on the archived magnetic tape. In brief, the major role of the SKY320 is reformat the data from the SP20, to link the radar data with the housekeeping data, and compress the data for recording.

MicroVax II Display Controller

After receiving the data from the SKY320, the MicroVax II performs the following key functions: 1) buffers the data from the SKY320 into larger blocks for recording on 6250 bits-per-inch tape; 2) passes data to and drives the display systems (ADAGE 3000 and TI-990 computers); and 3) passes control information from the operators back to the MicroVax I radar controller. Data are recorded by two Kennedy 9400 tape units capable of accepting data at rates up to about 200 kbytes per second. During radar operations, magnetic tapes are sequenced so that as the tape on one unit finishes, the recording on the second tape unit begins. Thus, no data are lost during tape changes.

Recording Format

Currently data are recorded in the CHILL Modular (CM) format, which is similar to the Universal Recording (UR) format. The CM format is more efficiently generated on the CHILL recording system than the UR format, and has been designed to facilitate conversion to either the Universal Exchange Format

(UF) or the UR format. In the future, the UR format may be adopted for recording data, but it would impact the real-time capabilities of the recording system. Until this impact can be determined the CM format will be used.

The CM format consists of three different types of logical records. They are 1) CC or comment records, 2) CD or data records, and 3) CU or supplementary housekeeping records. CC records allow for the inclusion of operator comments into the data stream. These records are also used to include calibration information on the data tapes. The format of the calibration data has been coordinated with NCAR/FOF so that both groups can adopt the same usage wherever possible. CD records contain a short non-universal housekeeping region followed by the data fields. CU records consist of UR data records with the data removed and "UR" ASCII tag replaced with "CU". These records contain complete data headers, but the pointers to the actual data are set to zero. CU records are inserted into the data stream by the data buffering program at the start of each sweep, or whenever a significant change in the housekeeping data occurs.

DISPLAY SYSTEMS

Two different displays systems are available for the CHILL Radar Facility. The primary system is built around a new ADAGE 3000 computer. The TI-990 display system which was developed by ISWS personnel in 1979 has been retained as a second or backup system. In addition an analog video recorder (VHS format) is available to record data in real time, or after the fact from magnetic tape. The primary use of the latter is to allow researchers to review data quickly, and to identify those data that will be used in subsequent analysis.

ADAGE 3000 Display System

This computer has a very flexible and expandable frame buffer with a 1024x1024 array of 24-bit pixels. The visible display area of 512x512 pixels is produced by three (red/green/blue) 10-bit D/A converters. A cross-bar switch allows any of the 24-image memory bits to be connected to any of the D/A converter input bits, permitting the subdivision of the display memory into a number of channels. For the CHILL display system, the image memory has been divided into four 16-color channels, with 8 bits free for overlays and annotation. The user can assign one channel to display one radar field such as radial velocity, reflectivity or differential reflectivity. A high-speed, micro-programmable computer in the ADAGE is used to unpack the radar data and perform the required conversion from polar to cartesian coordinates. An ICROSS compiler allows the translation of C source language into ADAGE microcode.

Software has been written which allows the ADAGE to read the same data packets that go onto the archive and produce real-time displays. Part of the software which allows the operation to interact with and control the display system is run from the MicroVax II. Much of this interaction takes place through the use of a three-button mouse. A custom interface board allows for mouse controls to be used in the radar and user van at the same time.

TI-990 Display System

The TI-990 display system is the secondary or the backup display system. A custom interface board between the MicroVax II and the TI-990 transforms the data from the MicroVax II so that it looks like the output from the old signal processor system. The TI-990 provides four 16-color display channels with a 240x256 pixel resolution. Normally, the fourth channel is used as an overlay channel for range rings or geographic displays.

USER VAN AND RADAR TRAILER

The radar trailer contains all the radar, processing and control equipment, and provides a work area for acquiring and monitoring data and for developing software. All processor equipment and hardware for the FPS-18 are installed in this trailer. This trailer and operating equipment are intended for use by the CHILL Facility personnel only.

The user van is designed to be primarily an operational center for the scientists. Access to both displays systems (ADAGE and TI-990), terminals to control the display systems, and the scanning mode of the radar are located in the user van. Voice communications between the radar trailer and the user van are available. There is also space for a limited amount of user provided hardware (Personal Computers, radios, and other small equipment). Tables and chairs are available and can be arranged by the user in the field to fit the needs of the project.