CGMS-XXXI USA-WP31
Prepared by USA
Agenda Item: V.1

MULTI-CONSTELLATION USER TERMINAL (MCUT) DEVELOPMENT

USA-WP-31 discusses NOAA's development of the technical specifications for an affordable user station that can receive and display environmental data from meteorological satellites. NOAA is investigating technologies requires to receive and display signals from both polar and geostationary satellites.

NOAA has developed a prototype Multi-Constellation User Terminal (MCUT) to help facilitate, explore and promote technology that could enable the commercial development of Direct Readout user stations that would receive and process signals from multiple satellite constellations. This paper summarizes this effort including the advanced technologies employed by the prototype station.

The MCUT was projected to employ state-of-the-art technology, including: 1) digital processing software, and 2) Application Specific Integrated Circuits (ASICs). The program development investigated and demonstrated both technologies and logically left open the commercial issue as to which technology may prove more advantageous for various "markets" (e.g., high rate or low rate; high performance or low performance). Two MCUS systems are being developed: one for exploiting software hosted on common work stations (i.e., CPU's) and a second for exploiting ASICs technology. Both systems will share a common front-end receiver (i.e., tracking, acquisition, preselection, low-noise RF amplification and down conversion to a common intermediate frequency) to conserve project resources. This common front end was based on a previously developed DMSP front-end that demonstrated a potentially more cost-effective or efficient aperture.

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1. Introduction

The CGMS Task Force meeting to discuss coordination of data formats and frequency planning for all polar-orbiting satellites including their equator crossing times was held at the World Meteorological Organization (WMO) Headquarters in Geneva, Switzerland on 24 January 2001.

The Task Force suggested that the CGMS satellite operators investigate the possibility of establishing a global data dissemination service. The global service would be based on the already approved CGMS global specification for AHRPT. The global service should be provided by all satellite operators with near-polar-orbiting satellites. The global service should have a common frequency in the 1698-1710 MHz band and common bandwidth (3.5 MHz). Finally, the global service should have a comparable data content.

The Task Force also noted the intent by CGMS satellite operators to develop prototype user stations and that they would make the design available to all manufacturers in order to reduce the cost of user stations and provide for commonality of user stations. The USA is investigating the development of a multi-frequency, multi-constellation user terminal to acquire environmental data from various polar-orbiting and geostationary satellites.

2. NOAA Directive

NOAA funded a feasibility study to determine the feasibility of achieving reception of multiple satellite sources. The particular meteorological constellations and associated direct broadcast services being considered for this development are as follows:

Satellite	Service	Freq (MHz)	BW MHz	Data rate (Mb/s)
Metop	LRPT	137.9	.150	.072
Metop	AHRPT	1701.3	4.5	3.5
NPP	HRD	7812	30.0	15
NPOESS	LRD	1706	8.0	3.88
NPOESS	HRD	7812/7830	30.8	20
NOAA/POES	APT	137.5 – 137.62	.034	.017
NOAA/POES *	HRPT	1698 /1702.5	2.66	.665
FY-1 *	CHRPT	1698-1710	5.6	1.3308
FY-3A	AHRPT	1698-1710	5.6	4.2
Meteor 3M N2	LRPT	137.89 / 137.1	0.15	0.064
Meteor 3M N2	HRPT	1700	2	0.665
DMSP		??	??	
GOES *	LRIT	1691.2		.128
GOES	GVAR			2.2
MSG *	LRIT			.128
MTSAT	LRIT			.064

However, during the first phase of the development, only those constellations marked with an asterisk shall be operationally tested and demonstrated.

The MCUT configuration will consist of the following components:

1. A tracking antenna (includes positioned)
2. Pre-amplifier
3. Down-converter
4. Demodulator
5. Processor with basic data management and display capabilities

NOAA is developing two versions of the MCUT station, one using a receiver that is configured from Common O-the Shelf (COTS) Application Specific Integrated Circuit (ASIC) technology and the other equipped with state of the art demodulation software. The ASIC design option is a complete MCUT station consisting of the entire list of components above and the software design option uses the Intermediate Frequency (IF) output of the first to use for its implementation.

The ASIC design option will have L and S-band RF front ends that are designed with attention to potential interference from other microwave systems. Also, there is a VHF input for reception of APT like services.

The software design option will supply compatible frequency conversion components, to interface with the IF signal frequency of the ASIC option and will employ two high-end standard PC compatible processors, which will perform the Demodulation, Bit-Synchronization, Viterbi Decoding, Frame Synchronization, Reed-Solomon Decoding, and any government supplied application layer processing.

3. Multi-Constellation User Terminal Development

3.1 Hardware Development Using Application Specific Integrated Circuit (ASIC) Technology

The development of user terminals capable of data readout from several meteorological services in different constellations is described. This development pursues user terminals that could be manufactured at a low cost. The cost can be controlled if common components can be combined to accommodate different applications. This development pursues user terminal designs comprised of an integrated antenna and receiver and a laptop computer that provides hardware operation commanding, received data processing and display, and received image storage.

The heritage and future meteorological satellites provide direct broadcast services from satellites in both polar and geosynchronous orbits. These meteorological services differ in frequency band, data rates, modulation and data formats. However, an examination of the terminal resources needed for data reception reveals that today's technology has the flexibility to accommodate both the heritage and future services. For example, existing ASIC technology developed for the wireless community includes digital tuner and demodulator chip sets that can be commanded to apply to different carrier frequencies, data rates, and modulation formats that envelope those used by the meteorological satellites. This technology has been developed for wireless applications and consequently is available at low cost without the software development needs of other digital approaches. The available meteorological services operate in different frequency bands. The receiver can command voltage controlled oscillators (VCO's) for the different frequency bands as well as select appropriate front end RF filters and preamplifiers to accommodate the different services. Potentially cost effective antenna designs capable of multiple frequency operation have been developed and demonstrated. The largest cost element for user terminal hardware is found in the positioners required to track polar satellites. The fixed position geosynchronous satellites need only a suitable fixed mount, whereas polar satellites require a positioner capable of following the orbital dynamics. While a positioner is required for polar satellite, the positioner can be pointed at geosynchronous satellites when polar satellites are not in view. Thus, a single user terminal can be timeshared between polar and geosynchronous providing meteorologists with the benefits of more detailed resolution of weather features provided by polar satellites and the rapid refresh capability afforded by geosynchronous satellites. The above lines of reasoning were followed in developing this prototype terminal.

User terminals for different applications are configured using the following components. The ASIC-based receiver is capable of operating at VHF, UHF, L-, and S-band frequencies, and the principal cost impacts for these four frequency bands are the modest VCO, filter, and LNA costs. In operation, the receiver is commanded to a carrier frequency, data rate, modulation format, and error correcting coding. This receiver thus serves the heritage and future meteorological services with a single hardware component avoiding the cost of different hardware for different applications and the software development costs for each service inherent in other digital receiver approaches. The appropriate antenna and RF front end is connected to the receiver. A simple VHF/UHF antenna (Ref. 1) was developed earlier for receiving those services. This simple antenna design requires no beam pointing. A wider variety of services exist at L- and S-band frequencies, and an examination of antenna requirements for these services reveals the need for a common antenna size. Suitable dual frequency feed designs have been developed as will be described further. If L-band services are required, a suitable L-band RF filter and preamplifier having a modest cost would be used with the receiver. Similarly, if the S-band services are required, an S-band filter and preamplifier would be used. The prototype described here is capable of both L- and S-band operation with a cost comparable to that for a single frequency. The VSAT development results in a wide variety of vendors capable of supplying inexpensive antenna reflectors. A more significant cost impact results when a positioner to track polar satellites is required. A survey of available COTS positioners revealed that designs capable of the required performance are expensive. Accordingly, a positioner was developed with the potential of low cost manufacture, e.g., single item prices for the basic positioner components are less than $3K. Simple program track techniques are appropriate for these antenna beamwidths.

The MCUT prototype development includes dual frequency L/S band feeds, and two distinct implementations have been pursued. The first design uses a crossed dipole located in a cavity terminated with a rolled edge as shown in Fig. 1. The dipole is loaded to produce a wide bandwidth response from 1.5 to 2.5 GHz. The rolled edge provides effective aperture illumination of the reflector by reducing feed backlobe levels that do not contribute to the main beam antenna gain. A second design has been pursued with microstrip patch technology that could be produced with a potentially lower cost. This design stacks an S-band patch atop an L-band patch. To improve the illumination efficiency, a series of chokes surround the stacked patches. The analytic projection of its performance is promising and the prototype design in Fig. 2 has been constructed for validation. The choke assembly is machined from plastic and metalized with paint having a silver pigment. It is believed that both feed designs could be inexpensively manufactured at a low cost by employing, for example, injection molding techniques. Both feed designs produce orthogonal linearly polarized outputs and have rotationally symmetric patterns with low sidelobes. The orthogonal linear polarization is used since both linear and circular polarization is required.

The L/S-band RF front ends are designed with attention to potential interference from other microwave systems. With the increased use of the lower microwave frequencies and the impact of future cellular services in adjacent frequency allocations, design attention to interference susceptibility was a development requirement. In this design, a low pass filter and preamplifier follows each of two orthogonal linearly polarized antenna feed outputs to attenuate high power systems at frequencies above the requirements. High power pulsed emitters below the required frequencies are attenuated by the feed cutoff frequencies. The initial preamplification has a modest gain to avoid compression and is followed by a quadrature hybrid to produce circular polarization. Amplitude and phase matched preamplifiers maintain good axial ratio performance. When linear polarization is required, one preamplifier is simply turned off. These components are shown in Fig. 3. The signal output from the hybrid is then routed to the receiver where the desired frequency band is selected and separate L- and S-band filters are provided. In this way, a high dynamic range and protection from RF interference is achieved. The system loss that impacts the total system noise temperature is confined to the low pass filters between the feed and the LNAs. Design attention to minimizing the system noise temperature allows the use of small antenna reflectors. While the cost of a large antenna reflector is modest, the cost of a positioner to maintain antenna pointing with wind loading increases rapidly with antenna diameter.

The receiver developed in this program follows the design previously demonstrated (Ref. 2) and the functional diagram in Fig. 4. Increased flexibility in RF coverage provides the capability for heritage and future meteorological services at VHF, UHF, L-band and S-band. The prototype receiver is believed capable of operating at future LRD data rates. This same technology with increased filter bandwidths and upgrades to data transfer rates is also believed to apply to future HRD services with the appropriate RF front end. Design attention within the receiver is paid to filtering to isolate the desired signals and provide protection from compression and anti-aliasing caused by out-of-band interference. After conversion to a 70 MHz IF frequency, an A/D converter, a digital chip set comprising a tuner and demodulator, and a Viterbi decoder follow. This initial development concentrated on the existing L-band services, with demonstration of other services to be performed subsequently. The receiver is configured in the compact package shown in Fig. 5. The receiver and antenna control system are integrated within the antenna pedestal with the only connections being prime power (110 V) and a USB interconnect to the laptop computer.

Figure 1. Rolled Edge Cavity Feed

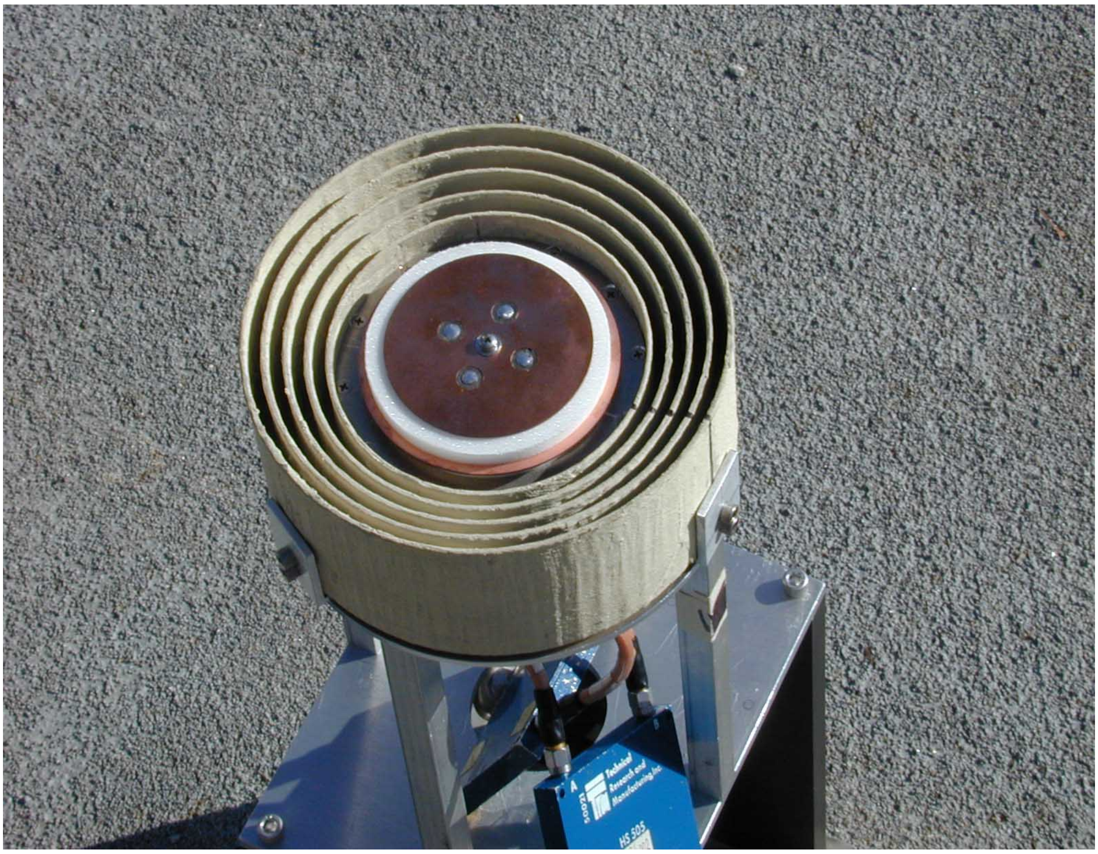

Figure 2. Dual Frequency Microstrip Patch Feed

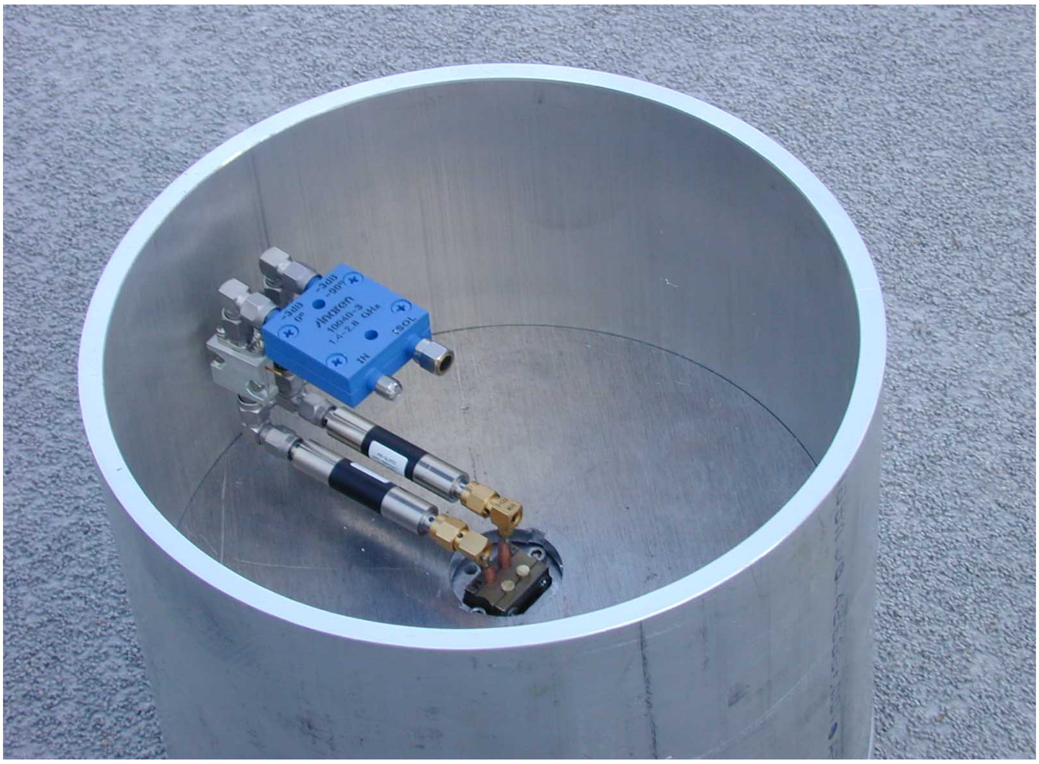

Figure 3. Dual Band Feed LNA Assembly

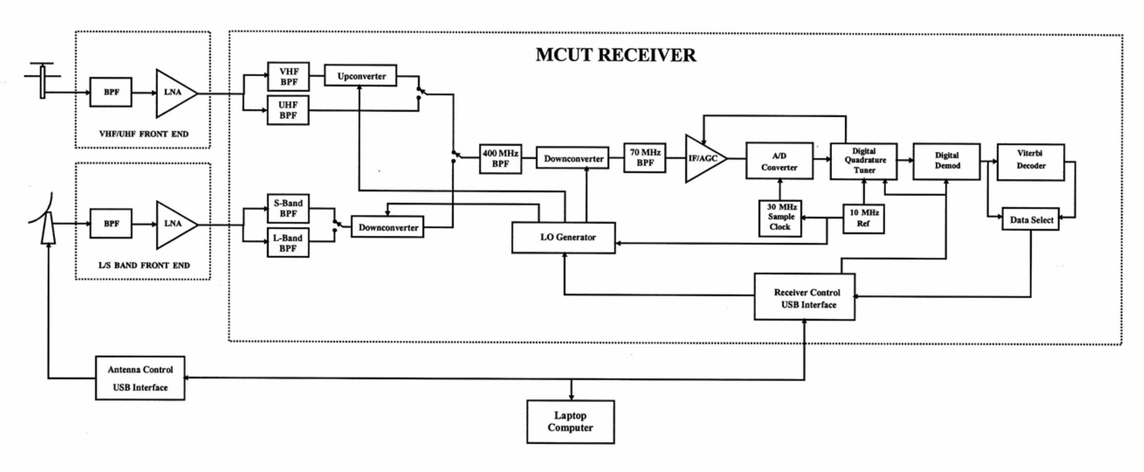

Figure 4.   Receiver Block Diagram

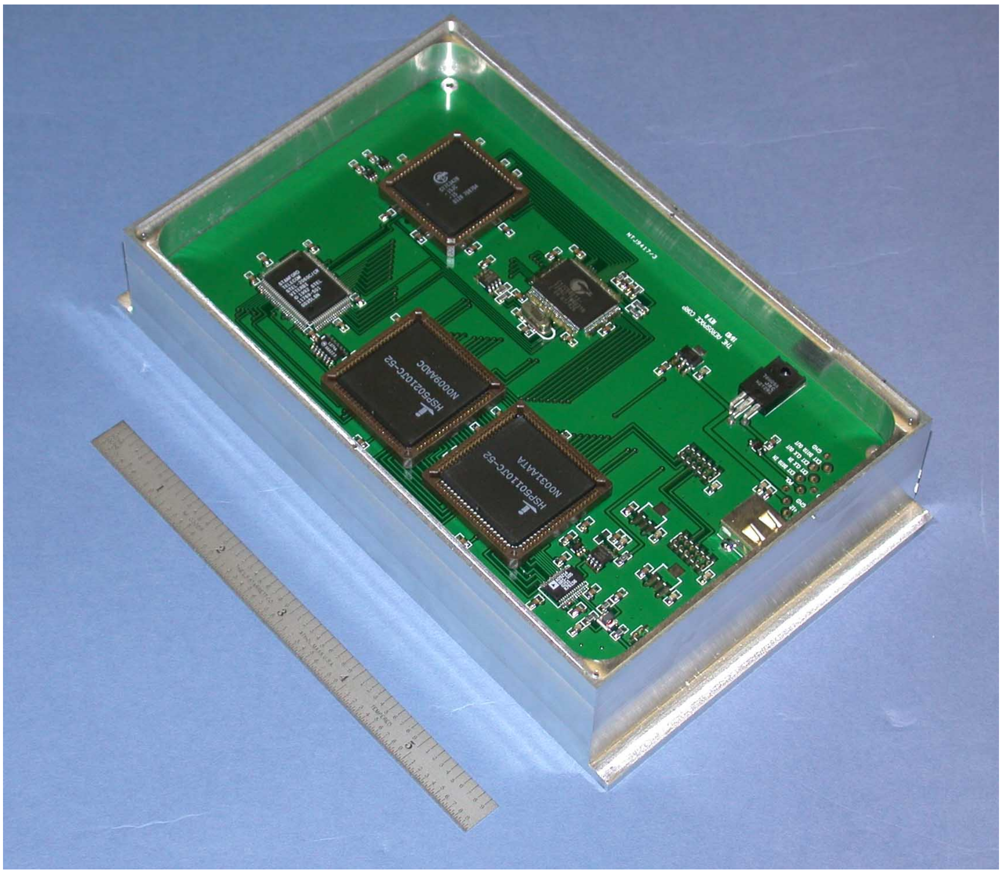

Figure 5. MCUT Receiver

3.2 High Performance Low Cost Software Receivers

With the development of fast general purpose processors, it has become possible to directly demodulate information carrying signals using the increased computing power of these new CPU's. Significant cost benefits are also obtained through the use of high volume low cost parts as part of the receiver chain. It is now possible to directly demodulate the IF frequency from a LNB (Low Noise Block down converter), after an appropriate adapter to convert frequency and signals levels required by the A/D card. The performance and associated costs of this down A/D card can be adjusted to match the requirements for specific applications or users.

The software demodulator algorithms developed have demonstrated that the software based demodulation can perform better than traditional hardware approaches, since the software can be tuned to a particular signal in a manner that is not generally practical using a traditional hardware demodulator approaches. For instance, performance tests show the software demod-bitsync can acquire and track signals down to -4 EbN0, and has performed within 1 dB of Theoretical over -4 to 12 dB EbN0 range. Typical hardware approaches are unable to acquire signals below approximately 1-2 dB EbN0. Since the demodulation routines are contained in software, any changes to the modulated signal over time (through deployment of new systems) can be handled.

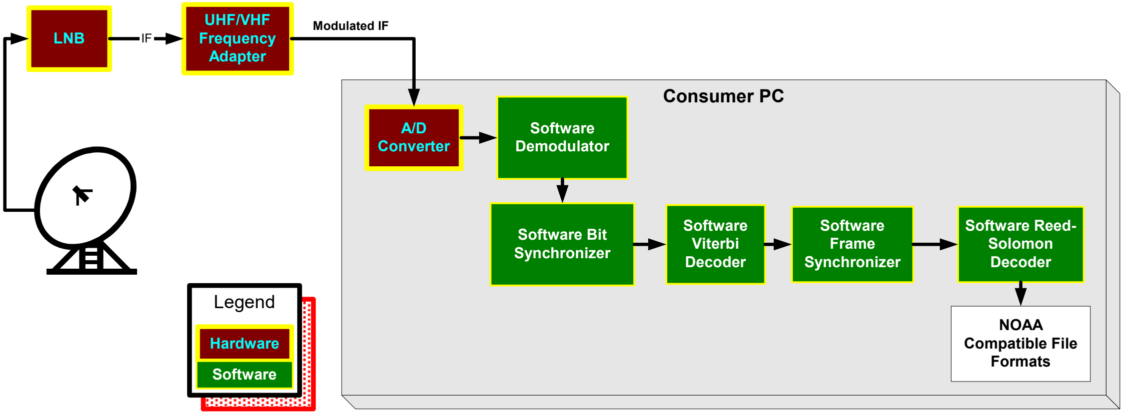

Figure 6.Components

3.2.1 Background/Current Software Receiver Implementation

A software (S/W) Multi-Modulation receiver for both the EMWIN and LRIT services was developed under specific NOAA programs. These developments took advantage of commercial IR&D efforts that demonstrated the ability to fully decode BSPK signals at a rate of 293 k symbols per second. Also NOAA developed internal testing environments to speed the development process and verify performance. The demodulation routines developed, to date, support BPSK, QPSK, and OQPSK modulation formats.

AS shown in figure 6, a commercial off the shelf (COTS) antenna and Low Noise Block (LNB) down converter is used to receive the signal and down convert it to a compatible frequency for A/D sampling. The samples are then input into the S/W receiver running on a PC for FSK or BPSK demodulation.

The Software Demodulator architecture shown in the figure 7, above, is the heart of the FSK & BPSK receiver. It takes the input digitized bit stream, demodulates, bit synchronizes and optionally Viterbi decodes it. The output of the PC demodulator goes to the frame synchronizer to start the process of decoding.

The software was developed to run on consumer PC hardware. It is coded in C++ and uses mostly 32 bit integers. Occasionally, 16 bit integers and 32 bit accumulators are used where applicable. The containers and algorithms provided by the C++ standard library will be exploited where possible.

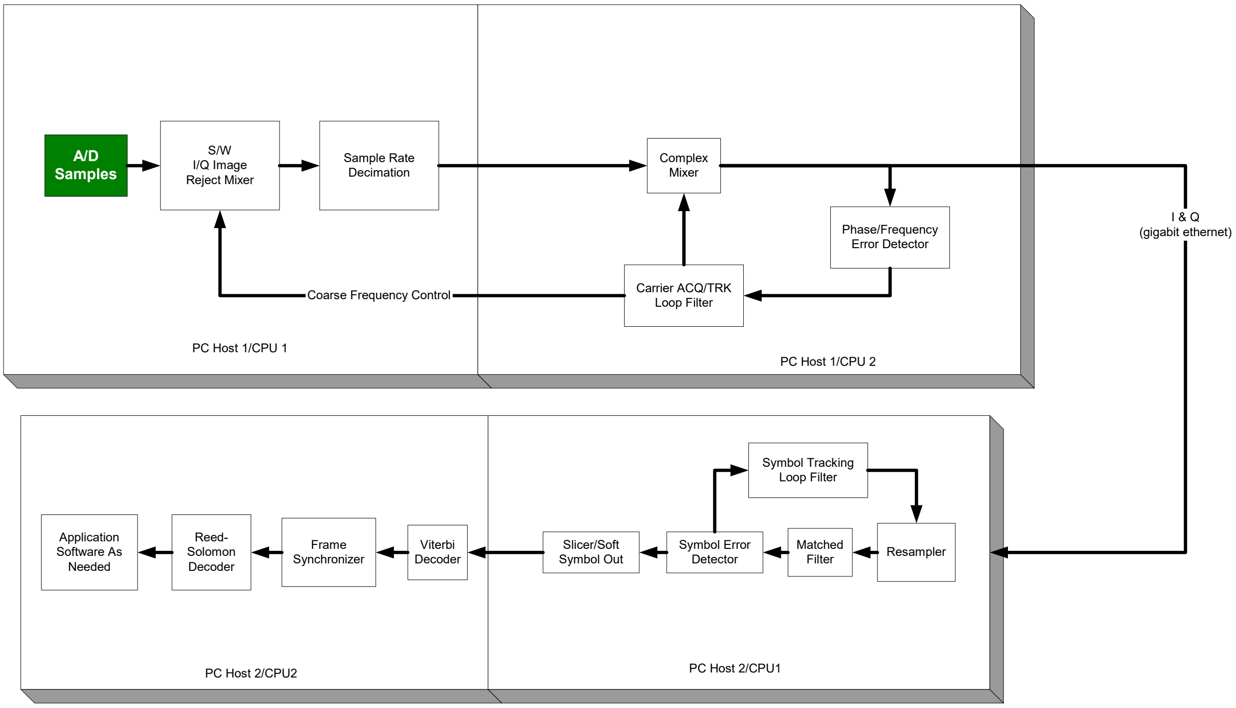

Figure 7. High Performance Software receiver architecture for parallel processor

3.2.2 Benefits of Software Receivers

Software receivers can be readily adapted to new signal environments or communication scenarios including different coding and modulation schemes.

Capacity and performance are readily scaleable to satisfy CPU or platform cost constraints.

Capability inherently improves as general purpose CPU’s improve.

Generally lower recurring implementation cost

Provides nearly theoretical performance

3.2.3 Meeting Future Higher Capacity and Performance Requirements

3.2.3.1 Field Programmable Gate Arrays (FPGA)

For very high rate signals, it may not be possible in current implementations to use standard general purpose hardware to process signals. One technology which has nearly all of the benefits of the CPU is the FPGA. Currently, FPGA have been enjoying the same performance and cost improvements over time as the general purpose CPU's. Many of the same benefits derived from the software demodulator can be realized in the FPGA.

The algorithms developed for the software demodulator have been crafted in such a way as to allow their migration to an FPGA based implementation.

FPGA are quickly reprogrammable such that they can be reconfigured in real time to adapt to new demodulation requirements as warranted. FPGA have nearly the same level of performance as the general purpose CPU's.

4. References

1. J. T. Shaffer and R. B. Dybdal, "Dual Frequency Tactical Antenna," 1998 IEEE AP-S Symposium Digest, Atlanta GA, pp 58-61, June 21-26, 1998.
2. J. D. Michaelson and R. B. Dybdal, "Development/Demonstration of a Tactical RDS Terminal," 2003 MAXI Symposium.