SATELLITE PAYLOAD CONTROL AND MONITORING USING PERSONAL COMPUTERS

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ABSTRACT

Universal acceptance of the Windows NT operating system has made utilization of the personal computer (PC) platform for critical space operations a reality. The software attributes of the operating system allow PC products to attain the reliability necessary for secure control of on-orbit assets. Not only is the software more reliable, it supports better networking interfaces at higher speeds.

The software upgrades that the Microsoft Corporation generates on a regular basis allow PCs to offer capabilities previously available only with UNIX-based solutions. As technology matures, PCs will operate faster, offer more graphical user interfaces, and give customers a lower cost versus performance choice.

These reasons, and others to be discussed further, clearly demonstrate that PCs will soon take their place at the forefront of mission-critical ground station applications.

KEY WORDS

Personal Computers (PCs), Windows NT, Ground Stations, Mission Control Center (MCC), Satellite Command and Control, Remote Tracking, Uplink/Downlink, On-Orbit Operations, RF, IF, GEO, MEO

INTRODUCTION

The advancement of PC technology brings with it the utilization of digital design approaches for modems, up/downconverters, and other components of ground systems that communicate with spacecraft in orbit. The digitization of filters, correlators, oscillators, and the like allows complex analog circuits to be “cloned” on a silicon chip.

When chips replace analog circuits, miniaturization is possible, enabling whole receivers, modems, and modulators to be contained within a single PC chassis. This trend is accelerating, and we are beginning to see functions that once took several discrete chassis appearing on one integrated module.

Many, if not all, of the satellite up/downlink processes (commanding, ranging, telemetry, time correlation, etc.) can be modularized for utilization in a commercial personal computing environment. Adding software that is easy to use, universally understood, and maintainable results in a technology platform that can be utilized by the space industry at a much lower cost than any product previously offered.

EASE OF USE

One of the problems that occurs with any new product introduction is the ability of the user to comprehend the operation and maintenance functions necessary to fully exploit the product's capabilities. This scenario is especially true when users are of various national origins. Operation of the product can require extensive training in a user's second language, and often something is lost in the translation of highly technical subjects.

Deploying the Windows operating system goes a long way toward meeting the goal of having a universal operator interface or language that can speed up use of the product, reduce expensive training, and shorten repair cycles. Using the PC for controlling satellite payloads thus gives users a much needed universal and easy-to-use operator interface. Ironically, the notion of a universal interface is often overlooked by the "would be" purchaser, but in the international community, using such an interface becomes a major attribute toward overcoming initial barriers in understanding and using technical complex systems for satellite communications.

For example, using PCs, complex front panel functions that were normally found in discrete chassis are replaced by a familiar point-and-click command environment. As shown in Figure 1, information appears in a graphical format on the PC's screen so that it can be understood by customers who don't have a complete understanding of the native language of the product manufacturer. Complex messages, operating system nuances, and incomprehensible system conditions are eliminated using an easy-to-use Windows environment.

Figure 1. PCs are an Affordable, Accessible Platform for On-Orbit Operations

THE BUILDING BLOCKS OF A PC-BASED CONTROL AND MONITORING SYSTEM

The PC industry is progressing at a rapid rate with new higher speed chips appearing on the market every six months. The Pentium processor and all of its derivations are industry standard. Higher clock speeds and more memory (cache and RAM) make the PC system run faster. PC platforms with multiple processor systems are not unusual. In fact, dual Pentium processors are offered by all the leading PC manufacturers, and the new quad models will be commonplace by the time this paper is presented.

In terms of the basic PC chassis, users can choose anything from common commercial desktop units to ruggedized industrial units that are very robust and moderately priced. PC disk space is growing without impacting cost, and multi-gigabyte drives are standard on most large personal computers.

The core chassis is a “commodity,” making it viable for fabrication by national manufacturers. That is, a basic platform can take on a country’s name, which will make it more acceptable to the customer base that overall product is sold into. PC chassis have embedded CRTs or flat panel displays as well as rack- mounted keyboards, etc. Almost any configuration can be purchased for a reasonable price.

The PC itself is the “shell” of the real ground system designed to process satellite up/downlinks. The hardware modules that comprise the internals of the product are modular cards, with often several functions existing on one printed circuit board. With the advent of the digital signal processor (DSP) and the use of reconfigurable gate array technology, the functions that used to require independent chassis can be significantly miniaturized (see Figure 2). Even RF circuitry can be accommodated on circuit boards that fit into a PC chassis.

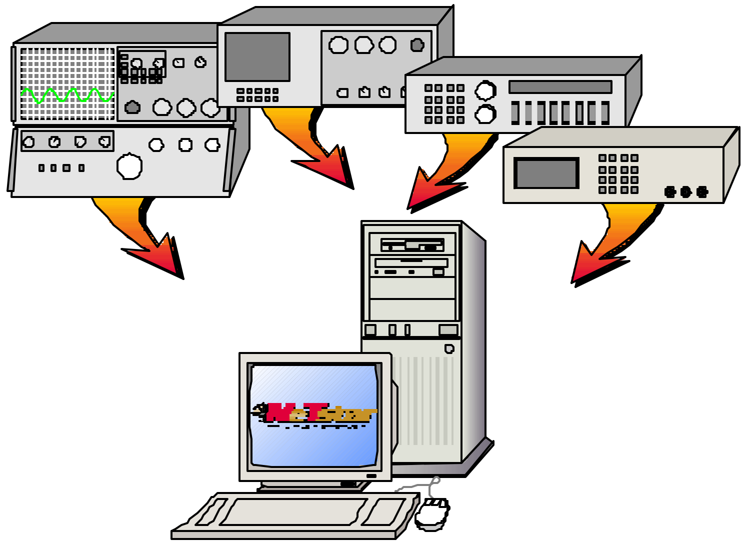

Figure 2. PC Systems Collapse Racks of Ground Station Equipment into a Single Chassis

Most of these modules are designed to plug into the ISA bus, which is standard throughout the PC world. The utilization of this bus is usually minimized to communication with the CPUs for initialization instructions and status monitoring functions. Very little real-time data flows over this bus as it can become a bottleneck for any high-speed transactions with the CPU. The normal signal flow is direct from one module to another or one part of the circuit board to a different location within the same element. Signals often require shielding of one type or another, and modules processing gigacycle signals usually require elaborate metal "honeycomb" structures to ensure isolation between the basic PC bus and these signals. Internal noise and cross-coupling of signals must be carefully controlled so as not to degrade the performance of the overall system.

In addition to RF miniaturization, technology has allowed the design of printed circuit modules that contain IF filtering, demodulation, bit synchronization, frame synchronization, and status reporting functions. These modules are fully programmable and allow for rapid configuration changes to support different satellite characteristics in just a matter of seconds.

REMOTE CONTROL ISSUES FOR SATELLITES IN DIFFERENT ORBIT PLANES

Geosynchronous Earth Orbit (GEO) stationary satellites are usually in constant contact with the ground station or mission control center (MCC) and therefore do not require real-time responses. Data and command rates are slow and the demand for attention to satellite conditions is low. But there are exceptions to this scenario in both the military and commercial arenas. A new breed of GEO satellite is on the horizon (see Figure 3). It supports direct contact to portable telephone environments from orbit. This kind of satellite emulates a telephone switching system in GEO. Local and long distance services require near real-time switching in the satellite payload. Command rates are much higher than traditional GEO satellites in this orbit and real-time monitoring and responses are necessary at the ground station.

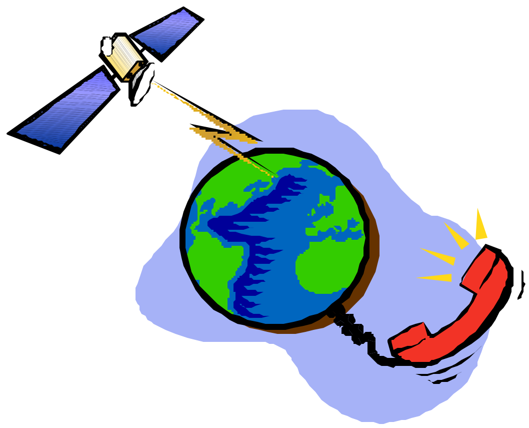

Figure 3. New GEO Satellites Switch Telephone Conversations from Orbit

Satellites that change their position relative to their earth stations are in mid- or low-earth orbit and require tracking stations at remote locations. These tracking sites have antennae, RF equipment, and some type of front-end processor, like Telemetry & Instrumentation's NeTstar system shown in Figure 4, which formats commands and telemetry data. This front end is usually connected to the mission control center via some type of local or wide area network.

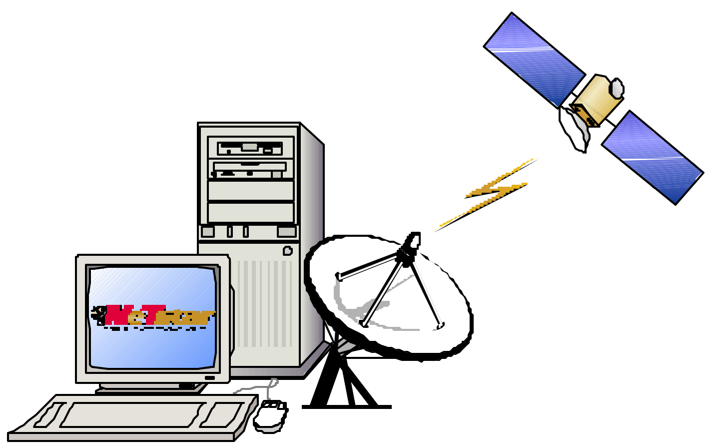

Figure 4. NeTstar Front-End Processor Formats Satellite Commands and Telemetry Data

Unlike GEO satellite systems, Mid Earth Orbit (MEO) satellite systems require 6 to 12 stations for worldwide coverage depending on the frequency of contact required. Stations are usually positioned to track the satellites in approximately 8-hour orbits with at least two satellites in view at any one time. Commands are sent to the tracking site and formatted for direct uplink to the satellite. Simultaneously, the health and welfare telemetry is received and decommutated by the PC front end and sent back to the MCC for viewing. Again, rates are low and urgency of action by the operator/software monitor is relatively long.

Status of the entire front end can be sent back to the MCC to determine link quality, health of the front end, commands sent, etc. Lower orbiting satellites have a greater urgency factor because each tracking site has very short periods (usually minutes) where communication with the satellite is guaranteed. Sending commands from the MCC may require an intermediate storage facility at the tracking site to ensure that commands are executed in a timely manner.

Once the satellite is in view and the time of day is correct, the command is sent directly from the PC front end without MCC intervention. This strategy adds requirements to the PC in that additional disk storage must be online and intelligent commanding software must be resident to ensure that proper conditions exist before the command “strings” are executed. If the command software is compute-intensive, it may require its own CPU to ensure uninhibited operation.

Such a scenario is easily accommodated with multi-Pentium processors and the NT operating system, which supports multi-threaded operations. Either store-and-forward or real-time commanding strategies can be accommodated to ensure that payload control criteria are met. Figure 5 shows a PC system currently being used to perform commanding of communications payloads for GEO and MEO satellites.

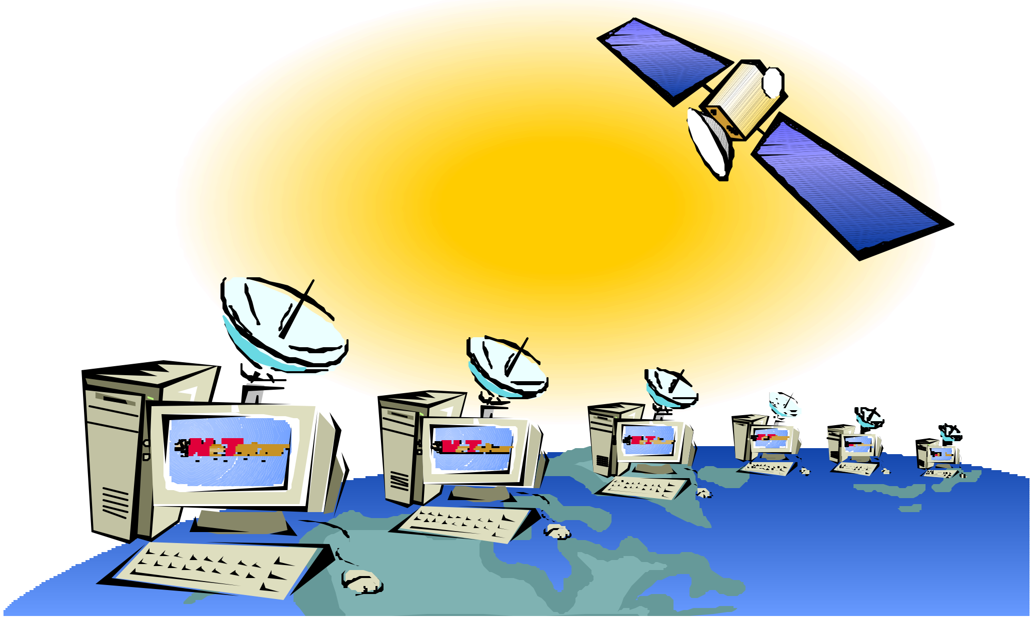

Figure 5. NeTstar Ground Stations Provide Remote Tracking Capabilities for GEO/MEO Satellites

REDUNDANCY AND RELIABILITY TRADE-OFFS

When controlling payload systems, reliable operation of the ground system is mandatory. The payload is the way in which satellite owners earn revenue. Anything that disrupts the payload links to the ground will cause a loss of capital and seriously upset the customer. Since the satellite builders, service providers, and ground station operators are all in a highly competitive environment, systems must be designed to eliminate the disruption scenario.

One of the bigger issues in selecting PC products for critical control functions is system reliability. Anyone with a PC has, at some point, experienced a system crash that resulted in the interruption of a process and usually a computer restart. Such an occurrence begs the question, Is a PC reliable enough to control payloads? The answer is a conditional *yes*. The condition is that the PC system must be designed with reliability as a primary attribute and that all failure modes of operation are accounted for.

Redundancy is the answer, coupled with smart software that can detect failures and take corrective action with or without human intervention (see Figure 6). Since PCs and their software are far less expensive than older box-type solutions, redundant systems using PC chassis can be designed at a lower cost and with a smaller footprint. If a mission is to support two satellites simultaneously, one can have a "hot" backup unit waiting to be called into action should a failure of one of the primary units occur. Depending on the number of simultaneous support activities occurring, a formula of N+1 units will normally be sufficient.

What has improved reliability immensely is the utilization of the Windows NT operating system software. This Microsoft product was designed to support networks far more reliably. What's more, as the operating system matures, so does its performance.

Figure 6. Built-In Redundancy Ensures the Reliability of PC Ground Stations

Another factor that makes the PC the right choice for control is the wide variety of PC chassis available at a low cost in the general market. PC chassis can be "industrialized" to increase performance in a tracking station environment. Most of these chassis are designed to handle more shock, maintain a more consistent operating temperature, and accommodate additional modules. The common PC "tower" or desktop version is not recommended for tracking station environments.

Ultimately, the case for PC reliability is easily won with ruggedized chassis, a more robust software operating system, and additional hardware dedicated to backing up the primary satellite links.

A DISCUSSION OF AN EXAMPLE SYSTEM

To illustrate a typical payload control system for a MEO satellite constellation, we will use an existing system that has been delivered to a customer. This system illustrates how straightforward a telemetry and command system can be (see Figure 7).

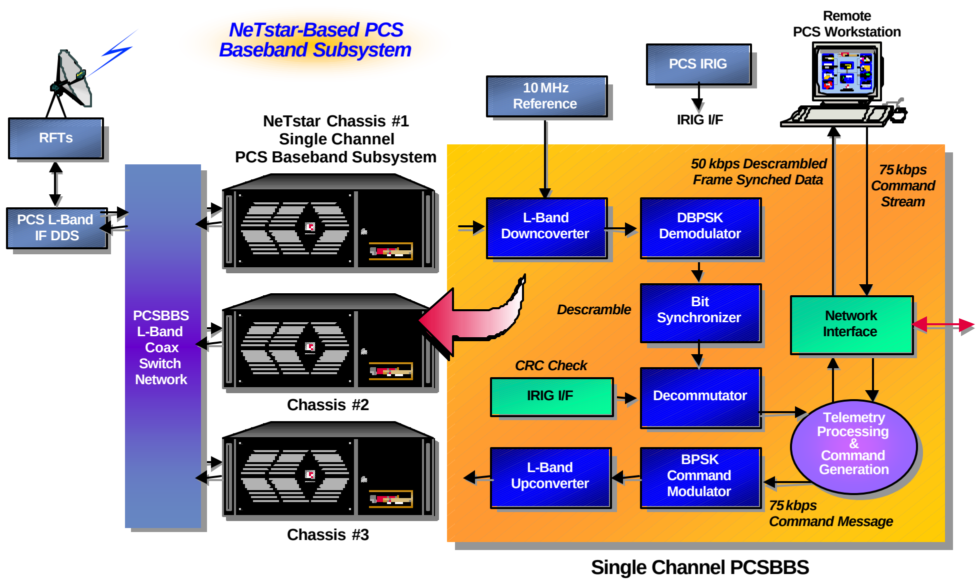

Figure 7. Typical Payload Control System for a MEO Satellite Constellation

At each tracking facility, the PC is interfaced to the RF subsystem at S-Band frequencies. Each system is configured to support one contact with a hot backup. The PC is configured with an S-Band receiver, a 70 MHz modem, a bit synchronizer, a PCM decommutator, a time correlator, a command formatter, a modulator, and an upconverter. All of these components reside inside a PC chassis that is rack-mounted, as shown in Figure 8. Three separate PC chassis are used, and the standard complement of dual Pentium processors, gigabyte disk drives, and Ethernet interfaces are included in the configuration. All three PCs have access to a single monitor/keyboard combination for local control and troubleshooting system problems. Each unit is connected to a master workstation via Ethernet. This workstation contains the interface software to manage the PC front ends and provide selected data parameters to the payload control center located at a distant facility. Ranging equipment is not required as payload systems do not use these types of systems (they are on the satellite bus).

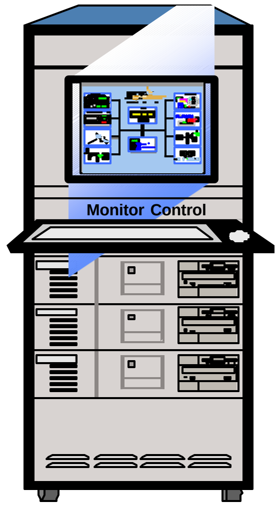

Figure 8. Fully Integrated PC-Based Payload Control System

The downlink is received from the RF front end, downconverted from S-Band to 70 MHz, demodulated to extract the serial PCM signal, filtered, and presented to the PCM decommutator. The “decom” synchronizes the frame structure and routes frames to the Ethernet interface. The data is routed to the workstation software where parameters of interest are extracted for algorithmic processes and sent back to the payload control center. Status data from each of the three PCs is also sent to the workstation and is analyzed to ensure that link integrity is maintained. If a failure of any of the units is detected, the software switches the backup unit to the primary position and reports the failure to the center. Maintenance of the system that failed is performed using the local display and keyboard coupled with software diagnostics.

Commands are received from the payload control center by the workstation, subjected to rule-based software programs to ensure all necessary conditions are met before transmission, and routed to the PC front end for formatting. After the formatting process is completed, the signal is sent to the modulator for uplinking to the satellite. The footprint of the entire system is very small and all the equipment can fit into a single 2-meter rack with room to spare.

CONCLUSION

As illustrated by this paper, a PC system is not only viable for today's payload control applications, it is the best solution for attaining lower system cost, a dramatically smaller footprint, and ease of operation. Indeed, current trends show that future ground station systems will have to incorporate PC systems if they are going to succeed in the highly competitive marketplace of spacecraft control.