A Satellite Communications Controller

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A satellite communications controller, which is a component of satellite earth stations, establishes a time division multiple access structure that provides flexibility and efficiency in the use of satellite transmission capacity. The controller blends digital, computer, and communications technology to establish precise timings required for system synchronization. It also performs signal conversion and switching necessary to transmit voice and business machine traffic over the satellite. This paper discusses a particular satellite communications system and the architecture and implementation of the satellite communications controller.

The IBM Communication Products Division has developed a Satellite Communications Controller (SCC) for use in earth stations that communicate via geosynchronous satellites to provide integrated voice, data, and image communication services. The Satellite Communications Controller was developed under contract with Satellite Business Systems (SBS), which provides these communications services. (SBS is a partnership sponsored by subsidiaries of Aetna Life and Casualty Company, COMSAT General Corporation, and IBM.) The controller provides signal conversion, traffic switching, data multiplexing, and Time Division Multiple Access (TDMA) control. This paper begins with an introduction to satellite communications and a description of the SBS communications system and services. This discussion provides background for a detailed description of the Satellite Communications Controller.

Satellite communications

The launching of the Early Bird satellite in 1965 opened the era of geosynchronous satellites.[1] A satellite is said to be in a *geosynchronous orbit* when its angular velocity of revolution around the earth is the same as the earth's angular rotational velocity, and it is in the equatorial plane. Such a satellite thus appears to an earth viewer to hover in space above a point on the earth's surface. To achieve this orbit the satellite must be in a circular orbit 22 300 miles above the equator, traveling at about 6900 miles per hour in the same direction as the earth's rotation. Because of slight irregularities in the gravitational field acting on the satellite, occasional position adjustments are made to compensate for the resulting drift.

Typically, a *communication satellite* is used as an electronic relay station. An *earth station* beams radio signals to the satellite. The satellite receives the signals and retransmits them at a higher power level and at a different frequency back toward the earth where many earth stations can receive them.

There are trade-offs to be made in satellite communication system design and use. A geosynchronous satellite has the advantage that fixed antennas—which are simpler and cost less than tracking antennas used with non-geosynchronous satellites—can be used at earth stations. The radio signal propagation time from an earth station in North America up to a synchronous satellite and back to an earth station is about 260 milliseconds. (Propagation delay ranges from 240 to 280 milliseconds, depending on earth station location and satellite east-west position.) This propagation delay is an order of magnitude greater than the tens of milliseconds propagation delay that one might experience with a land-line telephone call. The long propagation delay aggravates the problem of echo, which occurs in a telephone system when a speaker's own voice is erroneously transmitted back by equipment at the remote end. The extent to which echo is noticed depends upon the loudness of the echo[2] and the delay that occurs before the echo is heard. An echo becomes distracting when the delay exceeds a few tens of milliseconds. Geosynchronous-satellite conversations, with round-trip delays of 500–600 milliseconds, can be subject to distracting echoes, unless control is applied. With digital data transmission, the additional delay can reduce potential data throughput if inappropriate control protocols are used.

To be economically practical, the bandwidth (information-carrying capacity) of a transponder should be wide enough to be shared by many earth stations.

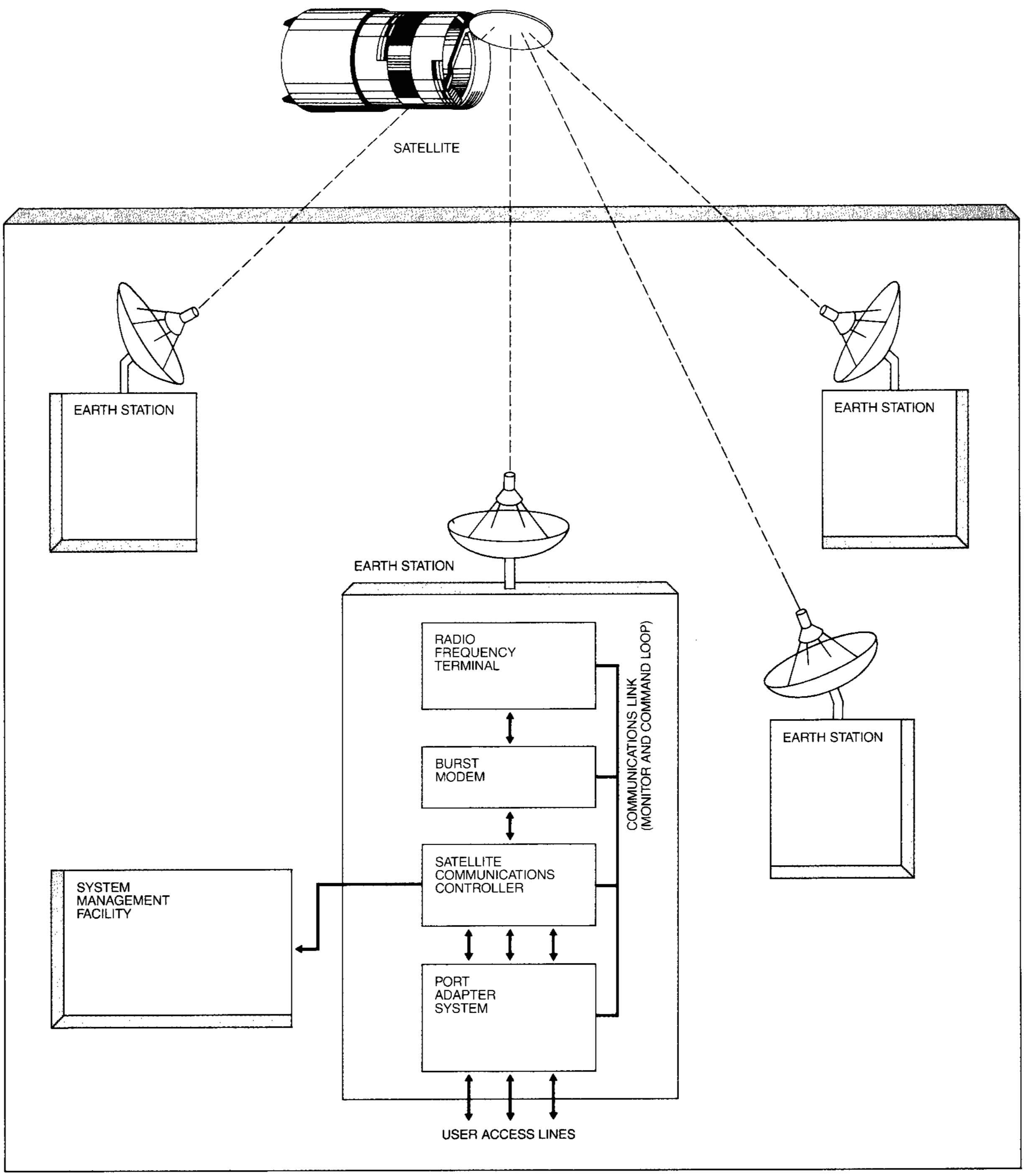
Weak radio signals are received from a geosynchronous satellite because radiated energy diminishes as the square of the distance traveled. Thus great care is required in the design of the receiving circuit and equipment. With proper design, the resulting communication link is very good in terms of error rate (less than one error in 10 million bits) under most conditions, but at certain frequencies the error rate can deteriorate to one error in 500 bits under heavy rain. Consequently, error detection and correction methods[3,4] are sometimes used to improve error-rate performance.

A satellite receiver-transmitter pair is called a *transponder*. To be economically practical, the bandwidth (information-carrying capacity) of a transponder should be wide enough to be shared by many earth stations. One method of sharing transponder bandwidth is that of *frequency-division multiplexing*. By this method, earth stations are assigned different portions of the transponder frequency band, in a manner similar to the way FM radio stations in a large city share the FM radio frequency band.

Another method of sharing a transponder is that of *time-division multiplexing*, by which the entire bandwidth of a transponder is used by a number of earth stations for a short instant of time. If all user earth stations are accurately synchronized and managed, a time slot used by a single earth station may be as brief as a few microseconds. If the time slots are assigned to earth stations on an as-needed basis, and any time slot can be assigned to any earth station, the system is called *Time Division Multiple Access* (TDMA).[1,5] This method of transponder sharing lends itself to digital electronics in earth stations.

A satellite transponder operates at very high radio frequencies, that is, in the gigahertz (GHz) range, which is much higher than the frequencies we wish to transmit. For example, the telephone voice band is about 300 to 3500 Hz. To use the satellite radio link, an intermediate frequency, typically at 70 MHz, is modulated by the information to be sent. The signal is then used to modulate the transponder's GHz radio frequency. This intermediate process is carried out by a modem that converts a digital data bit stream (containing the information

Figure 1 The SBS system



to be sent) to a modulated 70-MHz intermediate frequency.

What remains now is to convert the original form of the information to be sent into the digital form used by the modem. For example, today's telephones typically convert the acoustical energy of speech into a continuous (analog) electrical signal. For transmission over the TDMA satellite link, the analog signal must be converted into a digital form. At the receiver, the digital signal must be reconverted to analog form to drive a conventional telephone. These conversions are done by a *coder-decoder* (CODEC).

Several types of CODECs are available. The most common type is *Pulse Code Modulation* (PCM), which takes an eight-bit sample of the analog signal eight thousand times a second, yielding a 64-kbps digital representation. *Delta modulation*[6] is another technique. By this method, the output data indicate the change between one sample and the next. In the simplest system, a "1" indicates an amplitude increase, and a "0" indicates an amplitude decrease. Many trade-offs are involved in determining which kind of CODEC to use. For example, circuit complexity, output bit rate, and quality of the final analog output at the receiver are of prime importance.

The SBS system

In 1981, SBS[7] began offering communications services to business and government via geosynchronous satellites and earth stations at user locations. Voice, digital, and image transmission services are provided. An SBS earth station can interconnect with PBXs, data terminals, and the facilities of other common carriers.

Each of the earth stations shown in Figure 1 transmits a traffic burst to the satellite at 14 GHz. The satellite functions as a repeater in that it retransmits (at 12 GHz) all traffic bursts back toward all earth stations. This transmission band (termed the Ku band) is relatively free of congestion. In addition, the Ku band allows the use of earth station antennas on user premises because it is out of the 4/6 GHz band (that is, the retransmit/transmit pair) in which terrestrial microwave operates. Further, a typical antenna for a 12/14 GHz system is smaller than one for a 4/6 GHz system. Time Division Multiple Access (TDMA) transmission techniques are employed. Voice signals are coded using Delta Modulation to produce 32 kpbs.

A *System Management Facility* (SMF) is maintained by SBS to monitor and collect statistical and accounting data from the earth stations, as well as to manage the network. SMF communicates with each earth station via a satellite connection or by a back-up Public Switched Network land line. A Satellite Control Facility monitors satellite performance and position and issues commands to make adjustments as needed.

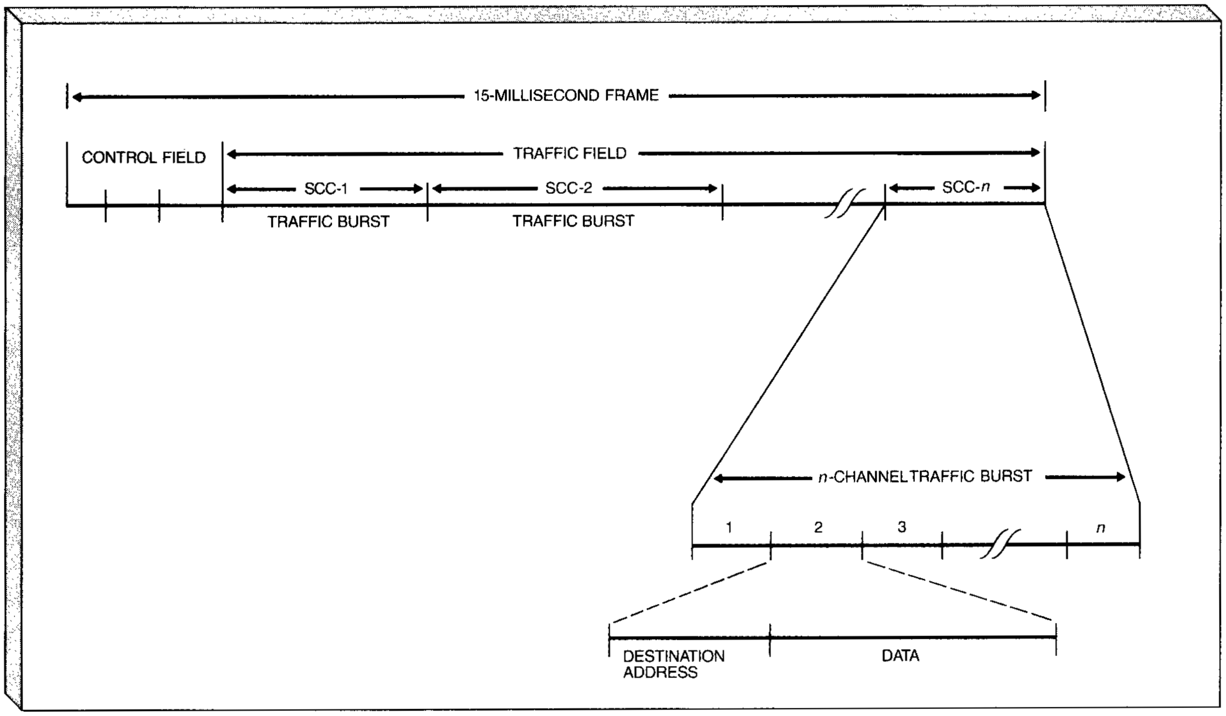
A user network can consist of as few as two or as many as one hundred Satellite Communications Controllers.

There are four major components in each earth station, as shown in Figure 1. The *Radio Frequency Terminal* (RFT) includes a five- or seven-meter parabolic antenna, a transmitter, and a receiver. There is a 70-MHz connection between the RFT and a modulator-demodulator that is termed the *burst modem*. The burst modem receives a digital 48-Mbps signal (million bits per second) from the Satellite Communications Controller (SCC). The fourth component is the *Port Adapter System*, which provides interconnection for telephone equipment and presents a standard interface to the SCC. These earth station components are linked together for maintenance purposes by a communication link that starts and terminates at the SCC. This linkage permits communication between the earth station components and the System Management Facility (SMF) via the SCC.

A user network can consist of as few as two or as many as one hundred Satellite Communications Controllers. A network is allocated a portion of a satellite transponder's capacity. This capacity is dynamically allocated among network SCCs to meet changing traffic requirements.

An SBS satellite has ten active transponders, each of which has a 43-MHz bandwidth that is capable of carrying 48 Mbps. The satellite's orbit is precisely

Figure 2 Time Division Multiple Access (TDMA) structure



maintained to minimize drift, and thereby to permit the use of non-tracking earth station antennas. The satellite antennas are arranged to maximize radiated energy in the more highly populated areas of the contiguous forty-eight United States. One SCC per transponder is designated a *reference station*, and it transmits timing signals to the other earth stations, so that precise Time Division Multiple Access synchronization can be maintained. In addition, the reference station assigns TDMA time slots on an as-needed basis to user stations.

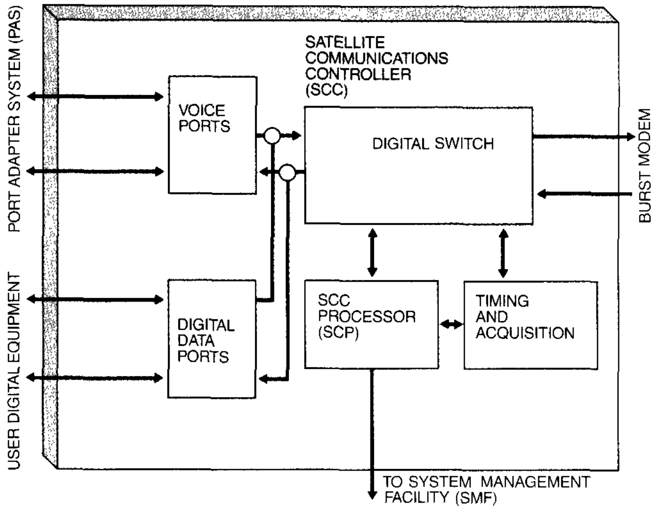
In operation, the SBS satellite radiates energy over the entire continental United States, thus rendering it susceptible to unauthorized reception. In the future, SBS will offer an encryption system for security. This system is based on the federal Data Encryption Standard[8] for the protection of both data and voice traffic.

TDMA structure

The TDMA structure is based upon the 15-millisecond *time frame* illustrated in Figure 2. A *reference SCC* (REF) transmits a frame synchronization signal to all other SCCs via the satellite. To achieve synchronization, the SCCs receive and track this signal. In addition, once every 20 frames, the REF transmits an assignment set for all SCCs that are using the transponder. This assignment set specifies the capacity and position of each SCC's traffic burst. Assignments are made in response to requests received in earlier frames. The remainder of the control field contains the capacity request messages and status information from other SCCs to the REF. Using this information, the REF can compute the best set of channel allocations to transmit. The critical information of the control field is protected from transmission errors by error detection and correction codes.

The remainder of the frame is the *traffic field* containing a traffic burst from each SCC in the system in the position assigned by the REF. Traffic is packed in 512-bit *channels*, which have a 32-bit destination address and 480 bits of data. One channel per frame (480 bits in 0.015 seconds) is equivalent to 32 kbps, the rate at which voice traffic is

Figure 3 Satellite Communications Controller (SCC) functional areas



coded. A high-speed digital connection (greater than 32 kbps) requires multiple channels per frame. Channels contain voice or digital traffic for user or SMF communications.

Timing and acquisition

System timing requires the establishment of a precise time base in each SCC so that traffic can be transmitted and received within the TDMA structure.

Receive synchronization. An atomic oscillator provides the REF with a very accurate clock frequency. The control field, transmitted by the REF once every frame and received by all other SCCs in the transponder, contains a frame synchronization signal that is the input signal for a receive phase-lock loop in each SCC. This loop establishes a precise internal receive time base that is identical in frequency to that in the REF. With the channel assignment set—also from the REF—each SCC can identify traffic bursts from other SCCs using the transponder. Receive synchronization is the first step in SCC synchronization.

Transmit synchronization. Transmit synchronization is the process by which a user SCC determines the precise time-range to the satellite, so that its transmitted burst occurs in the proper position of the receive TDMA frame. First, the software computes an approximate range using the geographic location of that particular SCC. Next, a short trial burst is transmitted using the approximate time-range. The trial burst is received within a trial transmission target area of the TDMA receive frame. The actual receive burst position is compared to the target position in order to adjust the transmit time base. Timing is maintained by another phase-lock loop. Completion of transmit synchronization enables an SCC to transmit a burst such that it arrives at the satellite at the proper position within the TDMA frame.

The synchronization process is accomplished one step at a time, as directed by software. Once complete synchronization is established, no further software intervention is required, unless an exceptional condition occurs.

Provision is made to recognize quickly and replace a failing REF with a back-up REF to avoid system interruption. This process is termed "baton pass." A software algorithm is used to effect a baton pass. The algorithm takes into account two kinds of variables. One is the channel error rate, and the other is the number of SCCs reporting valid reception of frame reference bursts. The former is derived from a count of errors detected by the forward error correction code. The latter is accomplished by having each SCC place a symbol in the status portion of the control field indicating whether the SCC heard the REF and the backup REF transmissions.

SCC functional areas

The SCC is a software-controlled unit that consolidates the functions of control timing, switching, and call processing. The SCC is the heart of the SBS system in that it is the point at which all traffic is merged into a single digital stream. It is composed of standard IBM hardware, augmented by a large complement of special hardware and software built by IBM to SBS specifications.

Major SCC functional areas and interfaces to other earth station equipment are shown in Figure 3. Voice ports convert analog voice or modem signals to a 32-kbps digital representation. With each voice port is a pair of signaling wires that provide call signaling information, such as offhook. Digital data ports provide a broad range of data services at speeds from 2.4 kbps to 1.544 Mbps.

The *SCC Processor* (SCP) executes SCC software. The SCP has both main and auxiliary storage and an I/O bus to which various adapters are connected. Connections to the System Management Facility (SMF), monitor and command loop, and operator panel are provided.

The digital switch in Figure 3 transfers data between ports and the burst modem, and converts continuous data from the ports to high-speed bursts at 48 Mbps, as required by the burst modem. In addition, the digital switch compensates for timing variations caused by satellite movement.

Synchronization with the reference SCC is done by timing and acquisition. The TDMA frame and the precise timings required for its operation are established here.

Call processing

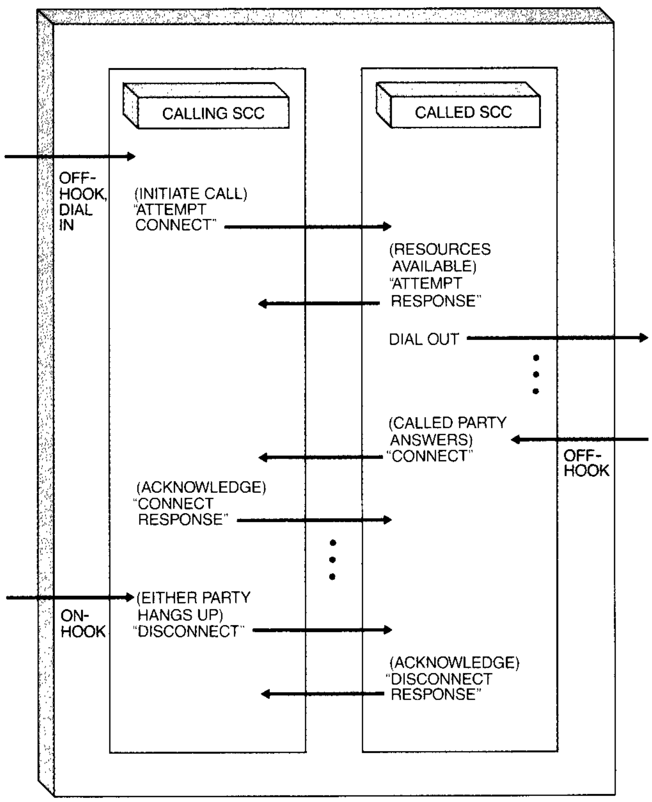
Call processing establishes both local and remote calls. Hardware associated with voice ports (call processor) interprets supervisory signals such as onhook, offhook, and dial pulses, and passes the information to software.

A normal sequence of events for a voice call starts when the calling party picks up the telephone. When a voice port is observed to be offhook, the software sets up control blocks to record connection status. The software also causes the appropriate tone (dial tone, fast busy, etc.) to be sent to the calling voice port. At call completion, when a disconnect indication (onhook) is received, the control blocks and port are released. Accounting and statistical information is accumulated on each call and passed to the System Management Facility (SMF) periodically.

The software is interrupted each time an incoming digit is received and transfers each digit to the connection control block. The software transfers outgoing digits to the call processor one digit at a time to complete the call.

Space signaling messages (transmitted via the satellite) initiate connections to remote SCCs by the procedure illustrated in Figure 4. An initial message is sent by the software when all dial digits have been received. A message is returned when the called party goes offhook, and a disconnect message is sent when either party hangs up. A request-response protocol is utilized for all messages. Space signaling

Figure 4 Space signaling

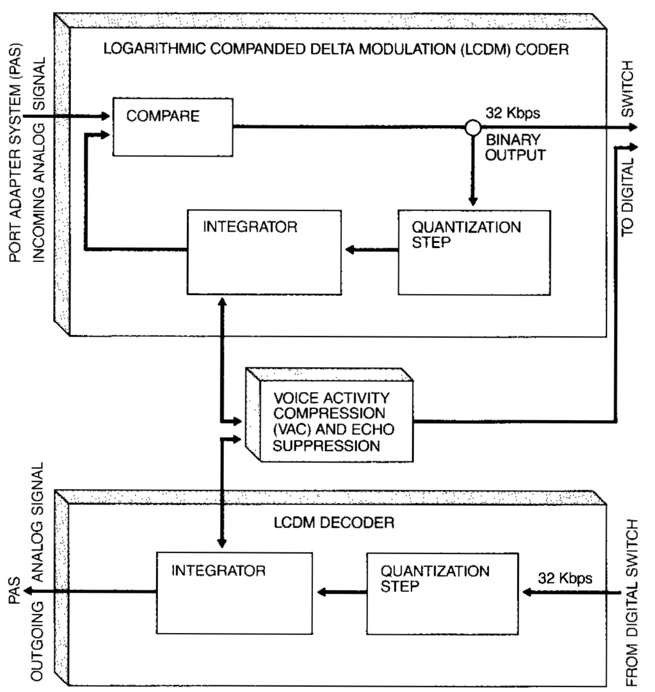


messages may be retransmitted a number of times if no acknowledgment is received and may be either single- or multi-segment in nature. Calls completed within an SCC are handled in a similar manner, but no messages are sent via the satellite.

Voice digitization

Coder. Illustrated in Figure 5 is the digitization of analog signals (speech or modem) at an SCC voice port. This is accomplished by a CODEC using 32-kbps *Logarithmic Companded Delta Modulation* (LCDM). LCDM is a refinement of Delta Modulation, which increases the dynamic range of the coding by a logarithmic scaling of the input amplitude. LCDM has the effect of compressing higher signal levels and expanding lower signal levels (i.e., *companding*). (An analogous technique is used in making conventional phonograph records.) LCDM provides a low data rate, good tolerance to transmis-

Figure 5 Voice port



sion channel errors, and good performance over a wide range of input signal levels. The LCDM coder compares the present input signal with the value of the input signal at the previous sample time, from an integrator circuit. Comparisons are made 32 000 times per second. The binary output reflects the result of the comparison. The previous value is then updated by the quantization step (a logarithmic scaling) and is passed through the integrator.

Decoder. The decoder is similar to the coder, in that incoming bits contain the information needed to calculate the quantization step, which is integrated to produce the outgoing analog signal.

Voice Activity Compression. An SCC voice port performs both *Voice Activity Compression* (VAC) and echo control. VAC allows more efficient use of TDMA channels. Only data from the coder corresponding to signals exceeding a minimum energy level—the VAC threshold—are transmitted. Since a person conversing over a telephone tends to alternate between speaking and listening, it is possible with Voice Activity Compression (VAC) to share satellite channels. Thus only persons who are speaking require channels. If the decoder receives no data during a particular frame it sends quiet background noise to the listener. The shortness of the 15-millisecond frame allows the system to identify pauses in conversation more accurately than would be possible using a longer frame. The VAC threshold is set just above the noise level on the attached telephone line and is recomputed frequently to adjust for gradual changes in the noise level.

Echo control. Telephone circuits outside an SCC sometimes return an echo of the received speech. The SCC controls this echo by means of an echo suppressor in the voice port. Simply stated, the suppressor prevents transmission if the magnitude of the signal received via the space link is greater than the incoming analog signal. Refinements to the magnitude comparison based on an *a priori* expectation of echo strength minimize the suppressor's effect on simultaneous speech. SBS also offers equipment external to the SCC to further enhance echo control.

***Data Activity Compression* (DAC) saves bandwidth by not transmitting all characters in a sequence of repetitive characters.**

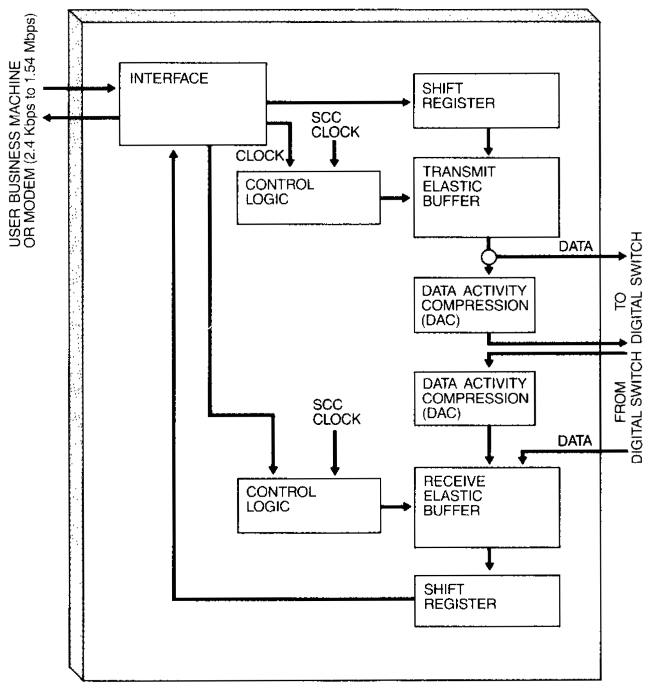
Digital data port

SCC data ports provide digital connections for business machines and modems, with data rates ranging from 2.4 kbps to 1.544 Mbps. A port can appear either as a modem or as a terminal to the customer. A data port block diagram is shown in Figure 6. Data are received from a user in a serial stream and assembled into bytes. An elastic buffer in the port compensates for variations between SCC clocks and the clock accompanying user data. As the input data rate slowly varies around its nominal value, the fullness of the buffer varies. The receive side of the data port contains logic that complements the transmit side. A separate elastic buffer compensates for clock differences. Finally, a shift register converts data bytes into a serial bit stream for transmission to customer equipment. The transfer of data between the port and the digital switch is regulated in such a way that the number of channels transferred is equivalent to the port speed divided by 32 kbps.

Data Activity Compression (DAC) saves bandwidth by not transmitting all characters in a sequence of repetitive characters. DAC operates on a channel-by-channel basis. When an entire 480-bit channel contains a string of identical characters that are the same as the last character of the previous channel, that channel is not transmitted. A receiving port recognizes that DAC has occurred and reconstructs the original data stream. The port uses the last channel received from the port and repeats the last character to reconstruct channels that are not transmitted.

As previously mentioned, rain at an earth station can affect the quality of the satellite radio link. To compensate for this, error correction codes are provided for digital data as an option. A forward error correction code corrects errors, without having to retransmit the data, by the injection into the data stream of additional error correction bits that enable the receiver to recognize and correct a limited number of errors. This, of course, requires additional bandwidth.

Figure 6 Digital data port



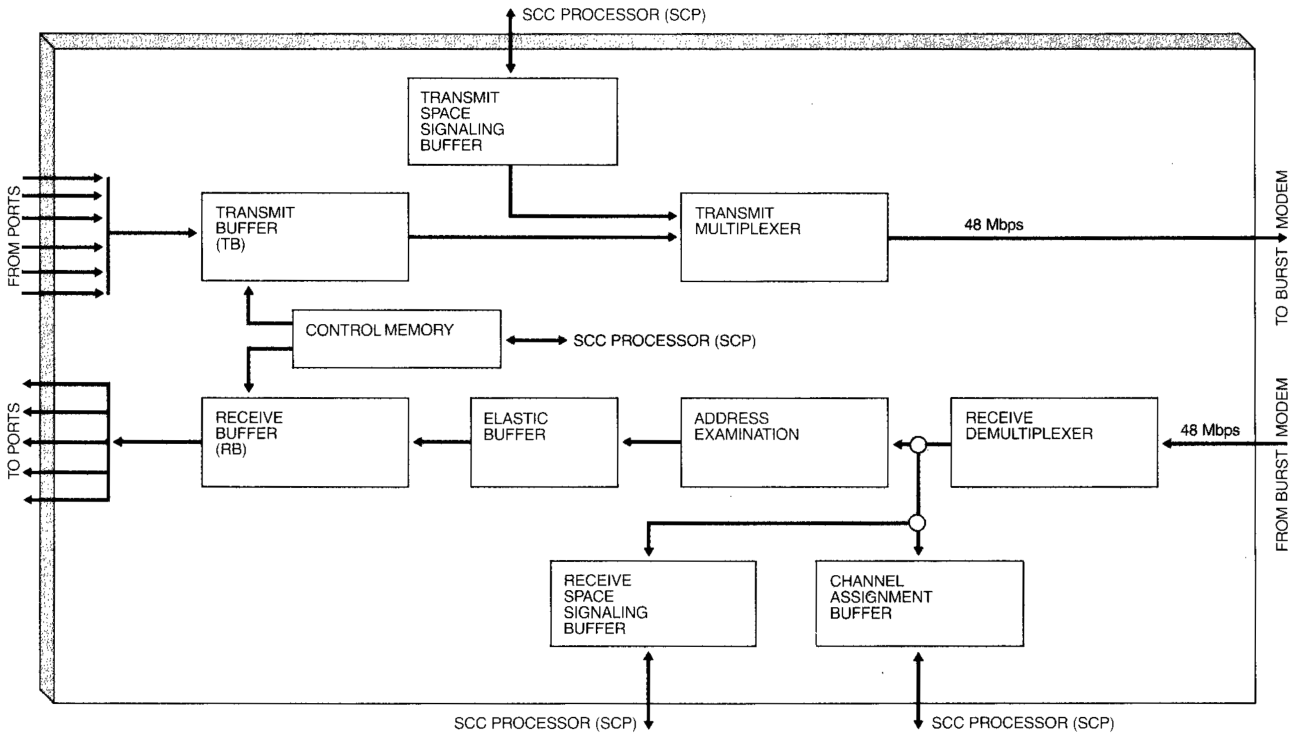
Digital switch

The digital switch shown in Figure 7 moves data between ports and the burst modem. All port-generated data to be sent to the satellite are accumulated in a two-sided Transmit Buffer (TB). During a frame, one side is loaded with port data while the other side is supplying data for transmission to the satellite. The data are loaded continuously at a rate of 12 Mbps. The transmission rate is 48 Mbps. After each frame time, the roles of buffer sides are interchanged. Information received from the satellite is held in a Receive Buffer (RB) until it can be sent to the ports. The RB is also a two-sided buffer, similar in structure and operation to the TB. Associated with the RB is a bit for each partition that is set whenever data from the satellite are received. This bit is used for voice and data activity compression. If no data for a voice port are received, the port sends quiet background noise to the listener. A separate buffer for local traffic serves to connect ports that are attached to the same SCC without using the space link.

Ports are connected to the digital switch buffers via a time division bus. Each port can send and receive 60 bytes per frame on this bus. A source for audible tones, including dial tone, ringing tone, busy signal, and quiet background noise, is provided for receiving ports.

Software manages the flow of data between ports and digital switch buffers by storing connection parameters in the control memory. Entries for each port are set up when a port is engaged in a call. Entries specify the port number, type, and digital switch buffer locations. A single entry is used for voice transmission. Digital data calls may use multiple entries in which one entry is used for each 32 kbps of transmission bandwidth. A software algorithm assigns slots in the control memory.

Figure 7 Digital switch



Once per frame in the proper TDMA time slots, the transmit multiplexer logic sends a burst of channels to the burst modem at 48 Mbps. The maximum duration of the traffic burst is limited to the number of traffic channels assigned by the reference SCC. In some cases, the number of channels ready for transmission exceeds this assignment. For each frame, priority logic determines which traffic channels to send, based on a measure of importance of the traffic. Data traffic is not lost by this process, and voice traffic losses are not perceptible. Signaling messages from the transmit space signaling buffer are transmitted in the same burst as port traffic.

Demultiplexer logic receives the complete TDMA frame from the burst modem and identifies control and traffic field portions. Error correction coding on received data is examined and processed. Channel assignment information is directed to an assignment buffer, which is read to determine the traffic burst position of this SCC. Signaling messages used in call processing are identified and routed to the receive space signaling buffer.

An SCC receives all traffic transmitted in the TDMA frame. Clearly, only certain traffic is addressed to a particular SCC. Logic examines the destination address appended to each traffic channel and determines whether a given channel should be accepted. The 32-bit address is composed of 16 actual address bits protected by 16 bits of error correction code. An indirect addressing table is used for conference and broadcast connections. The indirect address specifies the group of SCCs that should accept the received channel.

Typical propagation delay of a radio signal from a sender to a receiver via the satellite is about 260 milliseconds, with about one-half millisecond daily variation due to satellite movement. An elastic buffer absorbs this variation, so that the propagation delay is constant.

TDMA channel assignment

The TDMA frame structure provides approximately 1400 32-kbps channels for use by SCCs in a transponder. Within a transponder, SCCs are grouped into user networks. Assignments from the REF allocate channels for SCCs within the user network. Requests for channels originate at user SCCs and are transmitted in the control field of the TDMA frame to the REF.

A user SCC calculates channel requirements, based upon the number of connected voice and data ports and queued data connection requests. Voice channel use is shared by means of Voice Activity Compression (VAC). Voice channel requirements are determined statistically, taking into account the frequent pauses in normal conversation. Thus, fifty conversations might require only thirty shared channels, as opposed to fifty channels without sharing. A user SCC must manage its assigned channels to effectively serve connected calls. The SCC must also limit call connections to the number that its channel allocation can support. Digital data connections of less than 32 kbps also share channels to conserve capacity. Data connections greater than 32 kbps request the number of channels required for their speed. If a digital call cannot be connected within the channel allocation of the SCC, the request is queued until capacity is available. The REF can free-up channels from user SCCs to accommodate a request for a queued digital data call.

SCC processor

The *SCC Processor* (SCP) is an interrupt-driven CPU, with 0.5M bytes of main storage, disk storage, operator panel, and various I/O adapters. A schematic diagram of the SCP is shown in Figure 8. The SCP executes the SCC operational software and diagnostics. I/O adapters detect interrupts and collect status information from the hardware. Diskette storage provides a method of updating software. A hard disk is used for the permanent storage of code and data. An operator panel and adapter provide communication between the software and operator. (This adapter includes a timer.) Another adapter is also provided to permit the attachment of a portable maintenance computer.

The digital switch adapter is the means by which software controls and monitors the digital switch,

Figure 8 SCC Processor (SCP)

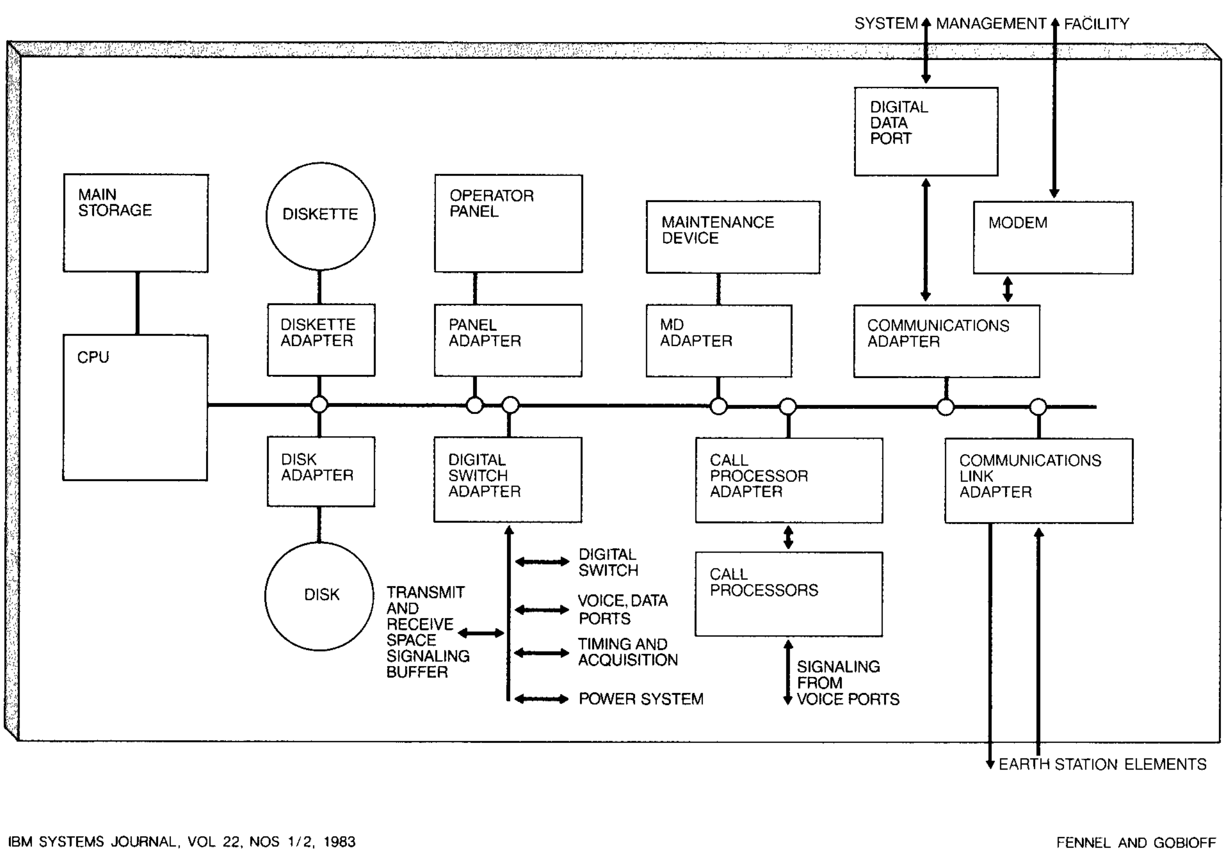
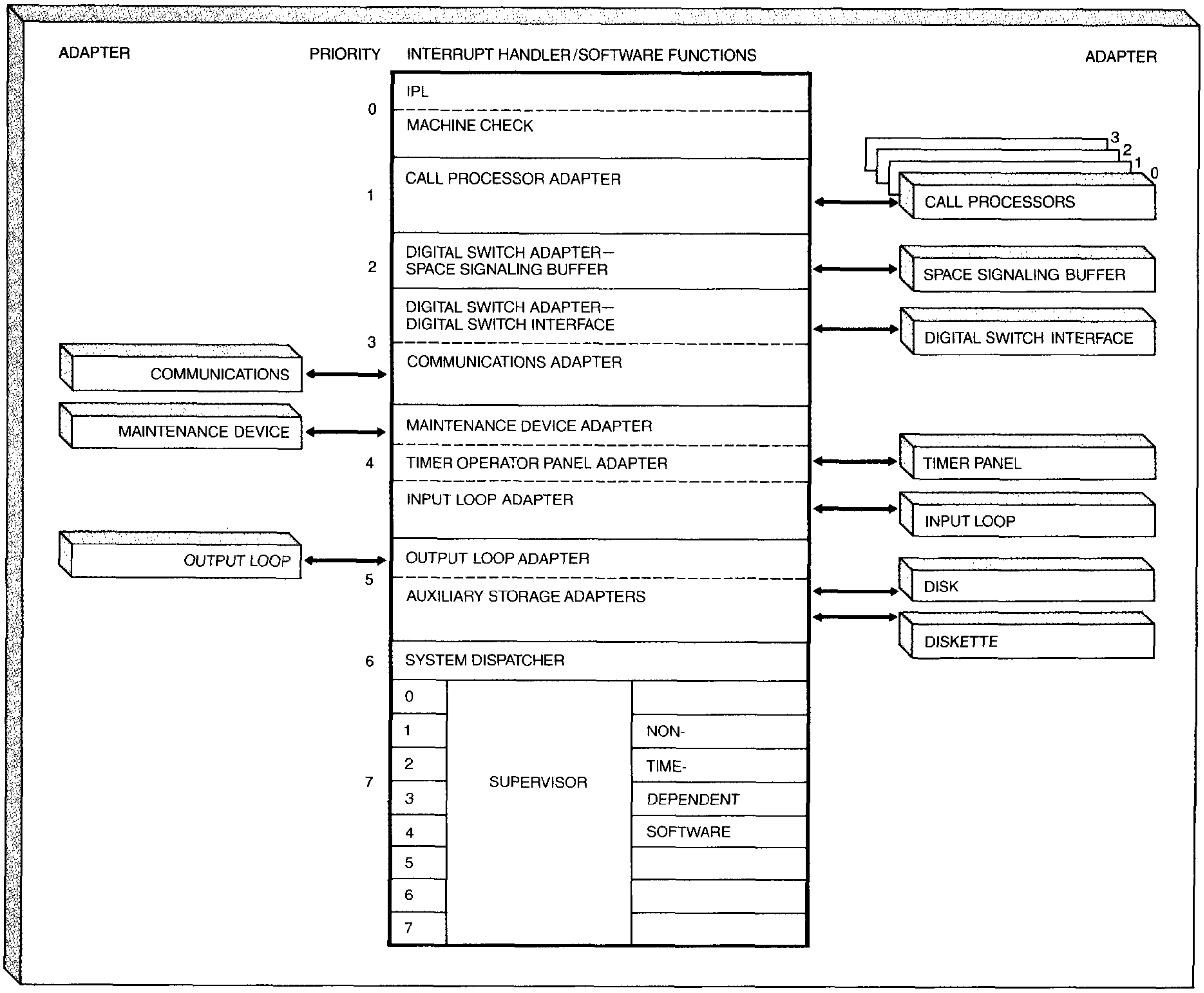


Figure 9 Software priority structure



timing and acquisition, voice and data ports, and the power supply system. The digital switch adapter also connects to the transmit and receive space signaling buffers. These buffers are used by software to send and receive space signaling messages via the satellite.

Call processor adapters provide an interface between call processor hardware and software. A call processor monitors the status of voice signaling lines and determines when signaling information should be presented to the software.

A communications adapter connects the SCP to an SCC data port, which communicates with the System Management Facility (SMF) via the satellite. A backup path is provided through an internal modem to a Public Switched Network connection. The SCC monitors earth station equipment through the monitor and command loop.

Software system structure

Software execution is based on the inherent priority structure of the SCP. As shown in Figure 9, the software system is divided into the following eight interrupt levels: six levels (i.e., 0 through 5) for hardware adapters, a system dispatch level (level 6), and the lowest level (level 7), where non-time-dependent software is executed. Hardware adapters that initiate software tasks are assigned to interrupt levels that are based upon their response time requirement. Thus a task running in the SCP can be preempted by a task initiated by an interrupt from a higher-priority hardware adapter. Among the six hardware interrupt levels, for example, interrupt level 1 is assigned to call processing, since quick response is required to avoid overrun of incoming dial digits. A lower priority is assigned to the disk adapter, since its response time is not critical. Other hardware adapters are assigned to interrupt levels 2 through 5. The lowest priority level (level 7) is further subdivided into eight software-managed levels.

A software system dispatcher operating on interrupt level 6 controls interrupt level 7. A supervisor manages the execution of software in the SCP and controls the use of such processor resources as time, interrupt levels, register pages, and storage. The supervisor schedules and dispatches tasks, manages main and disk storage, handles initial I/O interrupts, and supports intertask communication. In addition, the supervisor provides linkage management services. System macro services support the above facilities.

Software execution is based on the inherent priority structure of the SCP.

Initial Program Load (IPL)—priority level 0—procedures load SCC software into storage. The procedure begins with the execution of software from Read-Only Storage (ROS) to initiate the loading of software from the disk. Multiple copies of IPL configuration data are maintained on the disk. System changes can be installed by using the multiple-IPL facility, without destroying the current IPL. The multiple-IPL facility also provides a backup IPL for recovery. There are three types of IPL procedures. A cold IPL resets SCC hardware and runs CPU tests before loading the software. A warm IPL loads the software while maintaining established call connections. A maintenance IPL is a cold IPL that initiates extensive diagnostic routines.

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Maintenance

An important requirement for communications systems is that they continue to operate in the presence of faults. In Reference 9, the authors contrast the fault-tolerance requirement in communications systems with that of a data processing system. When a data processing system is down, it is an inconvenience; when the system drops a bit, it is a disaster. In a communications system, the reverse is true. When a communication system drops a bit, it is an inconvenience; when the system goes down, it is a disaster.

The SCC is designed to be tolerant of faults. When an SCC begins to make errors, it is imperative that the condition be quickly detected and analyzed. Then corrective action is taken to protect the TDMA frame. Accordingly, the SCC is designed with on-line error detection and fault isolation circuitry. Errors are captured and checked against a threshold. The error detection and fault isolation hardware and the on-line error handling software provide fast and accurate isolation of permanent and intermittent faults. On-line detection, analysis, and logging of intermittent faults allow replacement of marginal hardware and failed noncritical hardware during off hours.

Error source identification requires the capture of precise hardware status. SCC hardware is segmented into error domains, which have the effect of allowing only the first state to be captured. Error domain states are analyzed and a list is produced that identifies the most likely failed unit. The first unit identified has a greater than ninety percent probability of being the failing unit.

On-site maintenance is done with a maintenance device, which is a plug-in, microprocessor-based maintenance tool. With the maintenance device, one can run diagnostics and control the SCP. Tests include the use of a microprocessor-based test card, which generates data patterns through SCC hardware for analysis.

Concluding remarks

This paper has described the present design and implementation of the Satellite Communications Controller and its role in the SBS system. The SCC represents a major step in the realization of efficient, integrated digital satellite communication systems. The SBS system had over ninety earth stations operating in the U.S.A. at the end of 1982. Each of these earth stations contains one or more SCCs. With these earth stations and three satellites in orbit, SBS has demonstrated the feasibility of transmitting voice, data (up to 1.544 Mbps), and teleconferences in a TDMA stream formed and controlled by the SCCs.

Future trends in satellite controller design are expected to respond to growth in user applications and progress in technology. User applications will dictate bandwidth and connectivity requirements. Growth in application will necessitate means for communication across several transponders. SBS is effecting this by means of a device called a Data Aggregator, a device that allows communication across four transponders. Improved modulation techniques are being studied with the objective of expanding the information-carrying capacity of communication channels. More efficient methods for bandwidth compression, including new sophisticated algorithms for voice encoding, will reduce the bit-rate requirements for voice transmission. New high-data-rate applications, such as facsimile and teleconferencing, are becoming increasingly important. The ability of satellite systems to assign bandwidth dynamically will become essential as bandwidth utilization grows.[10]

Technological developments are driving satellite controllers toward microprocessor-based architectures. This trend is becoming evident in increased functional capability of system components (e.g., more intelligent digital ports) as well as in increased hardware redundancy.

Acknowledgment

SCC development and follow-on enhancements required the dedicated efforts of a large group of persons over a seven-year period. The authors point out that they are only reporters of this significant accomplishment. Writing this paper has also been a team effort. Many written contributions were received from the development team, which we gratefully acknowledge.

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