The Globalstar Cellular Satellite System

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***Abstract*—In this paper, the Globalstar cellular-telephone satellite system is described, including its use of code-division multiple access (CDMA) as the basic modulation scheme. Use of diversity for signal quality as well as power control is described. Development of the complex array antennas for L-band S-band communication with the hand-held radios is described in detail.**

***Index Terms*—Satellite mobile communication.**

I. INTRODUCTION

GLOBALSTAR is a satellite-based cellular telephone system that allows users to talk from anyplace in the world between 70 north and south latitudes. It provides clear communication thanks to code division multiple access (CDMA) transmission and avoids outages caused by blockage of signals by using diversity signals from two satellites.

The Globalstar system consists of a Walker 48-8-1 constellation; that is, 48 low-orbiting (1400-km altitude) satellites in eight orbits, inclined 52° with respect to the equator with six satellites in each orbital plane. They contact users on the 1.6-GHz L-band and 2.5-GHz S-band and communicate with the large Gateway ground antennas on the 5- and 7-GHz C-bands. CDMA provides for extensive frequency reuse through the use of orthogonal codes in the 1.23-MHz channels. Each large ground station (Gateway) has the capacity to connect up to 1000 users to the public switched telephone network (PSTN). The constellation has the capacity to serve up to 30 million subscribers (not simultaneously). Gateways will be distributed around the world in order to connect users with their local PSTN. A diagram showing the elements of the system may be seen in Fig. 1.

II. COMMUNICATION PERFORMANCE

A. RF Link Description

Globalstar contains a forward link, which consists of an uplink from a Gateway ground station and a downlink to a subscriber radio [or user terminal (UT)] and a return link, which consists of an uplink from the UT and a downlink to the Gateway. A typical forward link for a particular telephone conversation would have an effective isotropic radiated power (EIRP) from the Gateway of 41 dBW and the signal is received at the UT with an E_b/N_o of 3.9 dB with two circuits operating. For the return link, the UT typically has an EIRP of -9.2 dBW and the return link E_b/N_o is 5.7 dB, assuming satellite diversity. These values provide high-quality voice reception. Both the forward and return links use forward-error correction (FEC), rate $\frac{1}{2}, K = 7$ convolutional encoding, and Viterbi decoding to achieve good communication with these low E_b/N_o values. High-quality voice requires only 10^{-2} to 10^{-3} bit error rate, which these E_b/N_o's will deliver.

B. Description of Globalstar CDMA Operation

CDMA is a spread-spectrum technique that was developed for cellular applications and has now been standardized by the Telecommunications Industry Association (TIA) as IS-95. The basic concept of CDMA is shown in Fig. 2. With minor modifications, the technique is well suited to the mobile satellite applications [1].

The Globalstar air interface [(GAI)—the specification for the link operation] specifies a forward link CDMA waveform that uses a combination of frequency division, pseudorandom (Walsh) code division and orthogonal signal multiple access techniques. Frequency division is employed by dividing the available spectrum into nominal 1.23-MHz bandwidth channels. Normally, a mobile satellite service (MSS) Gateway would be implemented in a beam service area with the number of radio channels that demand requires. One Walsh circuit has a maximum usable data rate of 4.8 kb/s.

A Gateway with a single radio channel transmits on a single frequency. Pseudorandom noise (PN) binary codes are used to distinguish between the signals from different beams or satellites, with a different time offset to each beam of each satellite in its view. Since the correlation of the code with a time-shifted version results in a small random number relative to the peak correlation (unshifted version) when the average is done over many chips, signals from other beams of the same satellite or other satellites appear as noise. Time shifts are assigned to beams in a manner such that the codes do not overlap in the same coverage area. Two PN sequences are generated—one for each of two quadrature carriers, resulting in quadriphase PN modulation. The PN chip rate is 1.2288 megachips per second or exactly 256 times the peak 4800 bps information transmission rate. The quadrature (I&Q) spreading sequence is the modulo two sum of a quadrature inner PN sequence and a common outer PN sequence.

One important aspect of the forward link design is the use of the pilot channel that is transmitted by each Gateway to each beam. The pilot channel is a circuit that is unmodulated by information and is assigned the zero Walsh function (which consists of 128 zeros). Thus, the signal simply consists of a quadrature pair of PN codes. The UT obtains the first level of synchronization without prior knowledge of the Gateway's identity or the transmitting satellite's position by searching for this PN code. The UT performs a correlation to collect a sufficient amount of energy to detect the signal's presence.

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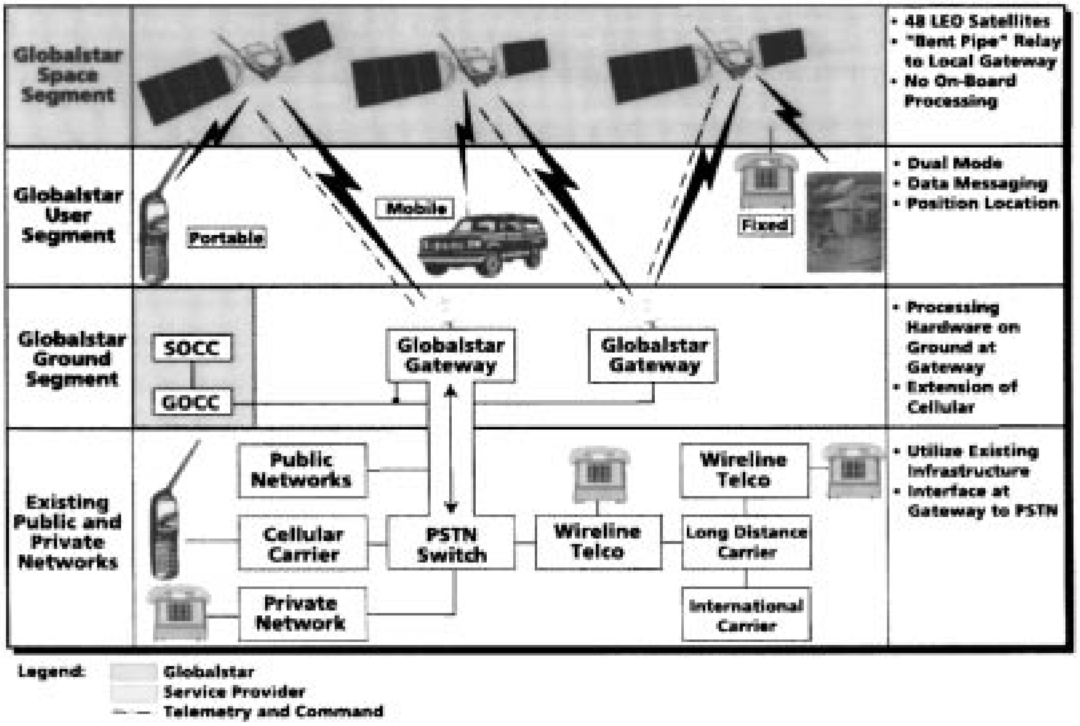


Fig. 1. Globalstar system.

The UT also acquires a synchronization channel and a paging channel in order to complete its log-on process.

The Globalstar return CDMA channel also employs PN spreading using a quadrature spreading code of length 215.. Here, however, a fixed code time offset is used. Signals from different handsets (UT's) are distinguished by the use of a very long (242-1) PN sequence whose time offset is determined by the user address. Because every possible time offset is a valid address, an extremely large address space is provided. This also provides a high level of privacy.

The transmitted digital information is convolutionally encoded using a rate 1/2 code of constraint length nine. The encoded information is grouped in six symbol groups or code words. These code words are used to select one of 64 different orthogonal Walsh functions for transmission. The Walsh function chips are combined with the long and short PN codes. Note that this use of the Walsh function is different than on the forward CDMA channel. On the forward CDMA channel, the Walsh function is determined by the UT's assigned code channel, while on the return CDMA channel the Walsh function is determined by the information being transmitted. The employment of the Walsh function modulation on the return channels is a simple method of obtaining 64 symbol orthogonal modulation, which can be demodulated by a fast Hadamard transform. The fast Hadamard transform is similar to a fast Fourier transform except that it requires only additions and subtractions and thus simplifies demodulator implementation. Also note that on the forward channel, the pilot channel signal is shared among all the handsets and is used as a reference for coherent demodulation of essentially a BPSK signal. The return channel uses orthogonal modulation with noncoherent demodulation.

A return "channel" consists of a signal centered on an assigned frequency, offset quadriphase modulated by a pair of PN codes, biphase modulated by a long PN code with address determined by code phase, and biphase modulated by the Walsh encoded and convolutionally encoded digital information signal.

The Globalstar UT and the Gateway utilize rake receivers to process multiple received components of the transmitted signal. The rake receiver has the property of combining several digital signals digitally. These different signals can be either multipath reflections or intentionally created diversity paths through alternate beams or satellites. Each received component can be differentiated by its time offset from the others as well as its Doppler offset. The UT utilizes a single RF front end, but multiple rake fingers in the digital hardware. In addition to combining two or three signals, still another "finger" continuously searches for additional signal paths. After the demodulation process, the output signals are coherently combined and aligned in delay and frequency (doppler is taken out) to achieve the maximum signal-to-noise ratio (SNR).

To maximize capacity, CDMA requires that the Eb/No received from all UT's is at a similar level at the Gateway. UT's transmitting more power than normal create more interference, which reduces the system capacity. To resolve this problem, Globalstar uses dynamic power control on the return traffic channel to command UT power output and on the forward traffic channel to command Gateway power output.

Closed-loop power control is used. For the return link, the Gateway compares the SNR from the UT to a threshold and sends out a command to have the UT increase or decrease its transmitted power until the ratio corresponds to the threshold in the Gateway. The power control-loop update period is

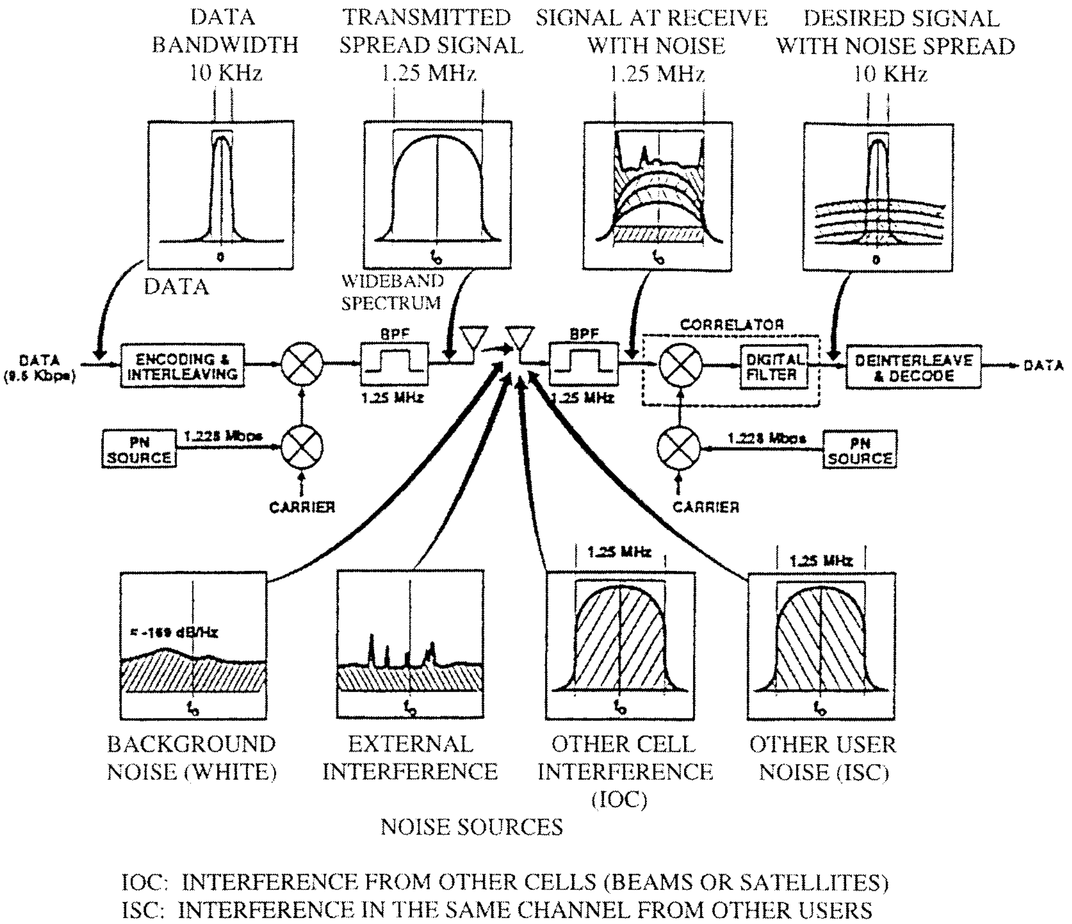


Fig. 2. The CDMA concept.

typically 200 ms, meaning it does not compensate for very fast fades such as those experienced in the vehicular environment.

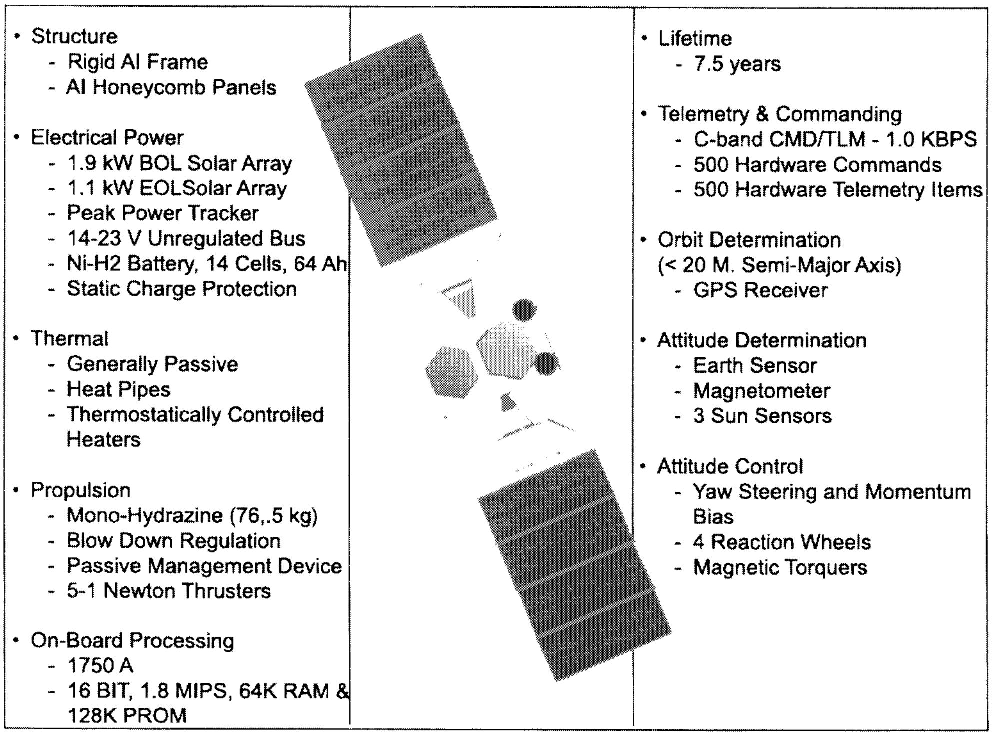
In the Globalstar system, the same frequency assignment is used in an adjacent beam or overlapping satellite for diversity. When a UT is covered by another beam or satellite, the UT detects the pilot channel of the overlapping beam or satellite and reports that to the Gateway. The system assigns a modulator and demodulator at the Gateway and notifies the UT that a soft handoff is in progress. The Gateway transmits the same information to both beams or satellites on the code channels assigned to the call. The UT combines the transmitted signals in its rake receiver. Likewise, the signals that are demodulated at the Gateway are combined. Both the UT and the Gateway are using diversity reception. When the UT is fully in the coverage area of the new beam or satellite, it reports that the old satellite's pilot channel has dropped below some level. The system then tears down what has been a soft handoff by discontinuing the beam to the departed beam or satellite.

A unique capability of direct sequence CDMA is to provide path diversity. The wide bandwidth PN modulation allows different propagation paths to be separated when the difference in path delays for the various paths exceeds the PN chip duration. This is because the PN sequence has essentially zero correlation for time offsets greater than one chip time. If two or more paths exist with greater than one chip differential path delay, as may be the case with low-elevation angle satellites, multiple PN receivers can be employed to separately receive the multiple path signals. The number of signal paths that can be received is equal to the number of PN receivers (rake receiver fingers) that are used. For Globalstar, a one-chip path delay corresponds to a differential path distance of 250 m. Signals arriving with larger than a chip-delay spread will likely also arrive from different directions and will be affected differently by obstructions in the immediate vicinity of the UT. Multipaths caused by reflections near the UT will typically have much less than 250 m of differential length compared to the primary path and will, therefore, not be accommodated by the fingers on the rake receiver.

III. SYSTEM DESIGN

A. Satellite Design

Fig. 3 shows a drawing of the satellite with callouts. The satellite is three-axis stabilized with the earth facing panel always parallel to the orbit tangent. A global positioning system (GPS) receiver is used to accurately determine the orbit parameters and also to supply accurate time and frequency to the satellite systems. Solar panels and a large nickel-hydrogen battery provide power for all phases of the mission. Battery recharge takes place over the oceans, where there is less traffic. The attitude control system uses small (one Newton) thrusters for attitude control. Yaw steering is employed to provide



- Structure
  - Rigid Al Frame
  - Al Honeycomb Panels
- Electrical Power
  - 1.9 kW BOL Solar Array
  - 1.1 kW EOLSolar Array
  - Peak Power Tracker
  - 14-23 V Unregulated Bus
  - Ni-H2 Battery, 14 Cells, 64 Ah
  - Static Charge Protection
- Thermal
  - Generally Passive
  - Heat Pipes
  - Thermostatically Controlled Heaters
- Propulsion
  - Mono-Hydrazine (76,.5 kg)
  - Blow Down Regulation
  - Passive Management Device
  - 5-1 Newton Thrusters
- On-Board Processing
  - 1750 A
  - 16 BIT, 1.8 MIPS, 64K RAM & 128K PROM

- Lifetime
  - 7.5 years
- Telemetry & Commanding
  - C-band CMD/TLM - 1.0 KBPS
  - 500 Hardware Commands
  - 500 Hardware Telemetry Items
- Orbit Determination (< 20 M. Semi-Major Axis)
  - GPS Receiver
- Attitude Determination
  - Earth Sensor
  - Magnetometer
  - 3 Sun Sensors
- Attitude Control
  - Yaw Steering and Momentum Bias
  - 4 Reaction Wheels
  - Magnetic Torquers

Fig. 3. Globalstar satellite characteristics.

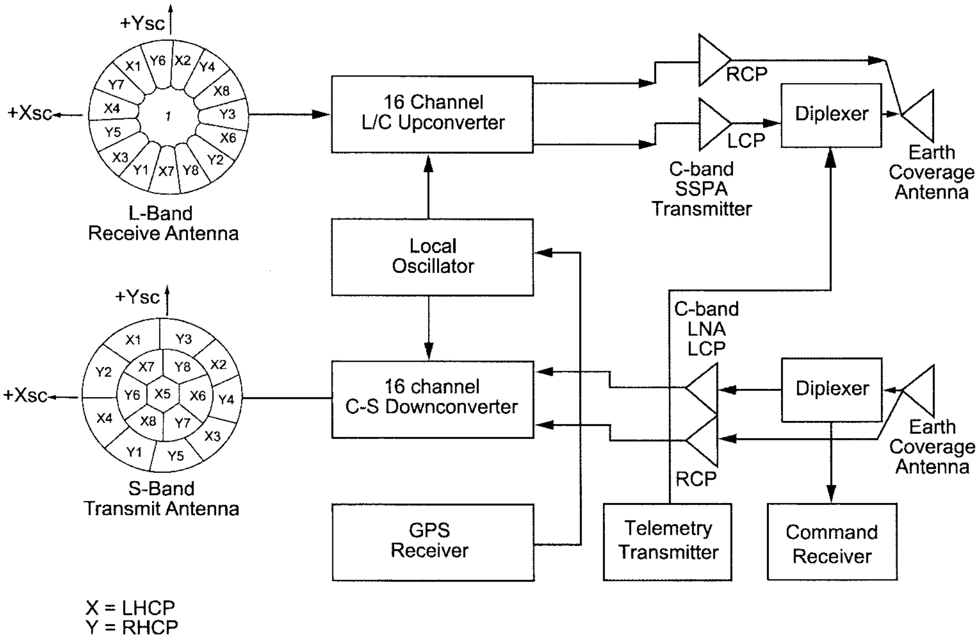


Fig. 4. Satellite payload block diagram.

sufficient solar array power during all phases of the mission. Fig. 4 shows a block diagram of the communication subsystem payload.

B. Gateway Design

A block diagram of the Gateway may be seen in Fig. 5. The antennas are approximately 6 m in diameter. The Gateway contains all the electronics to perform the CDMA communication, including rake receivers, in addition to having a home location register (HLR) and visitor location register (VLR) for security, access, and roaming and billing for all those using the system. It also connects to the PSTN through a switch and also provides a global system for mobile (GSM) interface, the interface of the European cellular standard.

C. User Terminal (UT)

The UT will typically be a dual-mode unit, although a variety of one-, two-, and three-mode units will be available, operating on both the Globalstar system and one or more of several terrestrial cellular systems. In Globalstar operation it

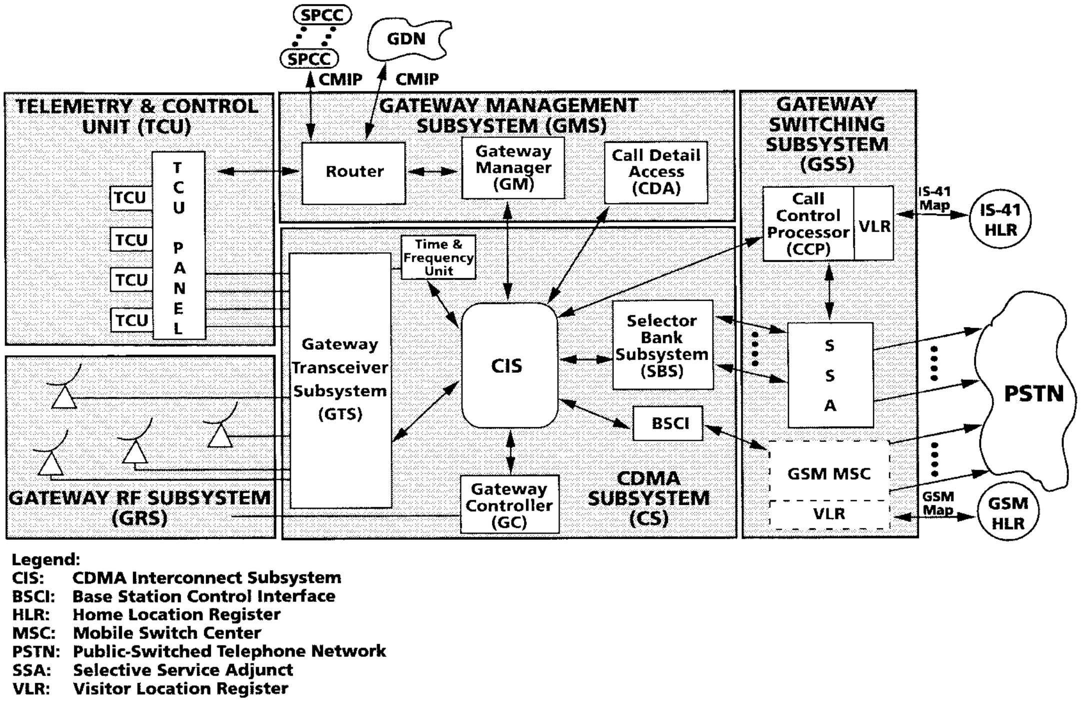


Fig. 5. Globalstar gateway diagram.

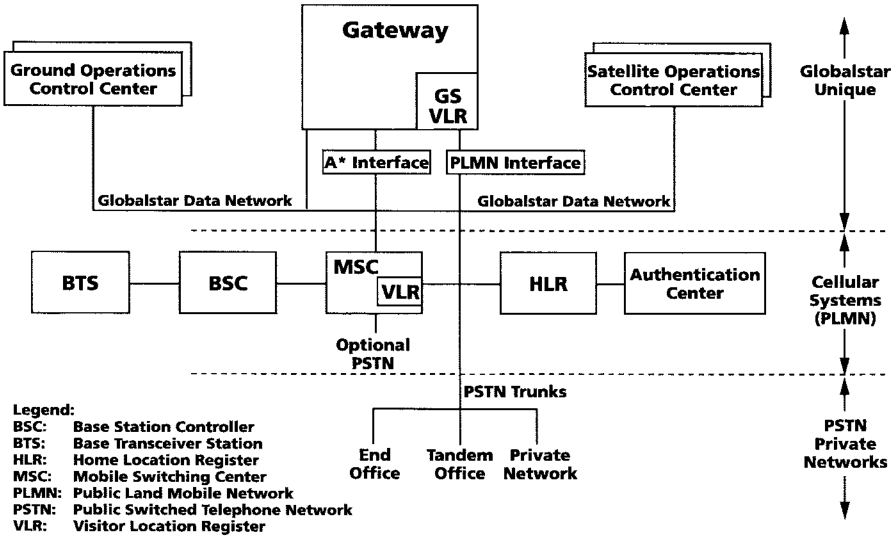


Fig. 6. Globalstar world-wide network.

will transmit an average EIRP of about −10 dBW (maximum −4 dBW) and contains a three-channel rake receiver so that it can receive signals from more than one satellite simultaneously.

The basic UT is a hand-held unit that looks like a cellular phone with a longer and thicker antenna. Automobiles will be supplied with a kit with a higher gain antenna and power amplifier that will adapt the hand-held unit for mobile use. Globalstar will also employ fixed user terminals, which will typically be a solar-powered phone booth in a village.

D. World-Wide Network

Fig. 6 shows a diagram of the entire ground system for Globalstar. It shows the interconnection of the Gateways to the Globalstar Operations Control Center (GOCC), and to the Satellite Operations Control Center (SOCC) via the Globalstar Data Network (GDN). This will be a network of links connecting the various sites, including all the Gateways. The GOCC and SOCC are located in the Globalstar facility in San Jose, with an alternate site near Sacramento.

IV. SATELLITE ANTENNAS

The function of the L- and S-band array antennas is to communicate with the UT's. Both the transmit and receive antennas produce 16 independent fixed beams covering the visible earth. Frequency reuse of the beams allows the narrow spectrum (16.5 MHz) at L and S band to be used 16 times by each satellite. Each beam has a separate satellite transponder [2]–[4].

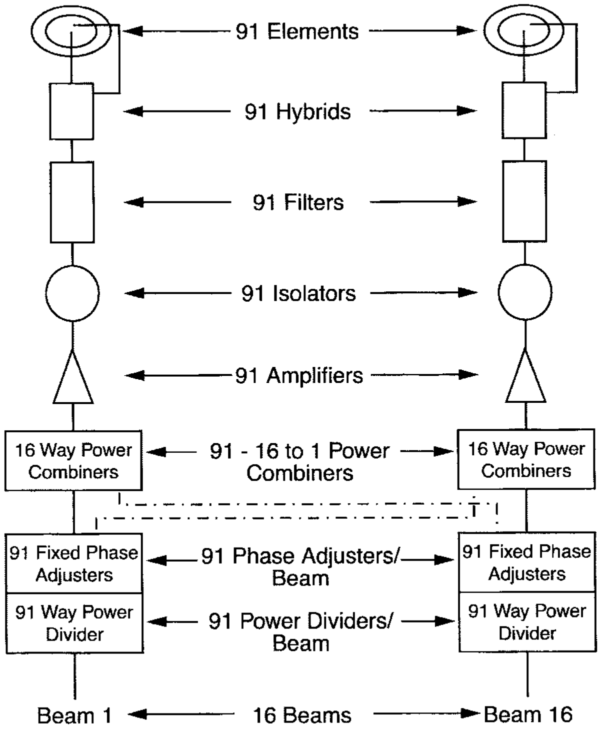


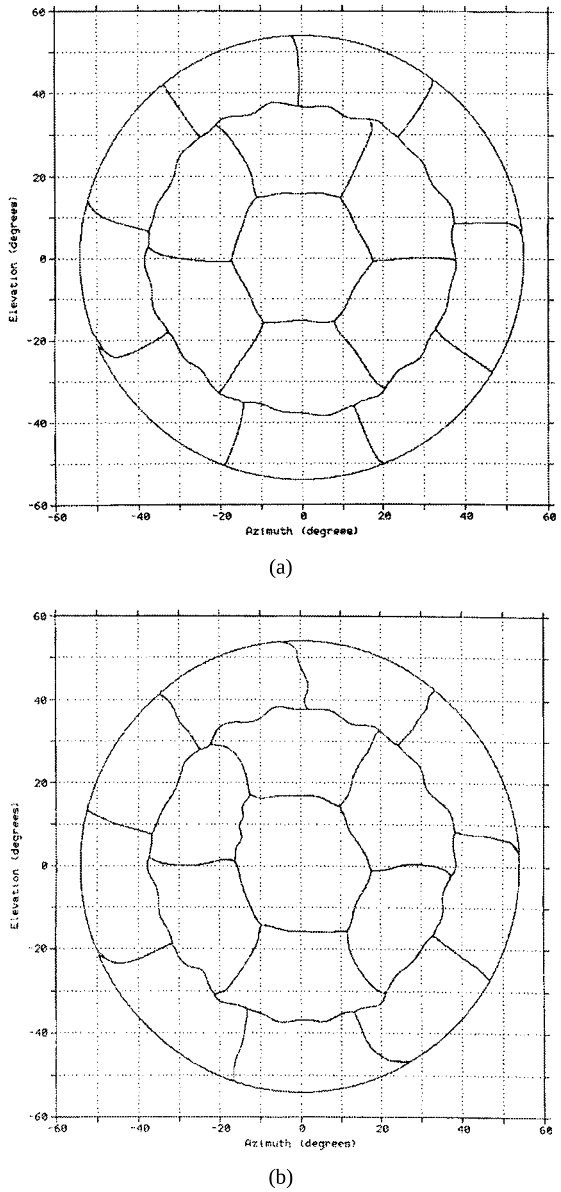
Fig. 7. Block diagram of S-band antenna.

The beamforming approach used to form the beams utilizes separate power divider networks for each of the beams to shape and position them on the earth's surface. Combiner networks are used to share the beams among the 91 transmit (or 61 receive) elements. The antennas contain integral active modules (power amplifiers (PA's), low-noise amplifiers (LNA's), and bandpass filters). Fig. 7 presents a block diagram of the S-band antenna showing the signal path from the beam inputs to the radiating elements. The L-band antenna block diagram is the same, but with 61 radiating elements and LNA's. The operation of both antenna can be understood from this diagram.

A. S-Band Antenna Design

Fig. 8(a) presents the predicted 16 simultaneous beam circularly polarized receive-array antenna pattern coverage, and Fig. 8(b) presents the corresponding measured beams. It should be noted that these are not normal gain contours; instead, the lines represent the locus of points of equal gain between the two adjacent beams the line divides. A particular loop does not necessarily represent constant gain around the loop. The contour gains are typically 2–4 dB below peak gain, but they vary from loop to loop.

Fig. 9 presents a photograph of the antenna. The size and hexagonal shape of the antenna results from the use of a 0.6 wavelength, equally spaced triangular lattice array structure containing 91 radiating elements. Each radiating element is connected to a PA module and the modules are mounted on a solid beryllium heat sink for heat storage. Heat pipes integral to the heat sink conduct the heat to thermal radiating panels.



(a)

(b)

Fig. 8 . Transmit array pattern. (a) Predicted. (b) Measured.

The transmit beamforming network (BFN) forms each of the 16 individual beams using an equal-amplitude phase-control-only distribution at the radiating elements. An equal amplitude distribution is used to reduce the phase error contribution of the PA's. The BFN is a solid bonded strip transmission line (STL) package containing 16 power divider/power combiner layers and one distribution layer to route each of the 91 individual BFN outputs to the designated PA module. A layout of one particular power divider board is presented in Fig. 10. It is a STL circuit containing a 1 : 91 power divider network with a phase-shifting line length at each of the 91 outputs. The line lengths are selected to form one of the 16 required beams. Also at each of the 91 outputs is an input to one of the 91, 16 : 1 combiner networks. The combining networks are located around the outside of the round STL layers and extend vertically through all layers.

The complete bonded BFN consists of 17 interconnected STL layers composed of 68 copper layers and 34 dielectric layers resulting in a rigid assembly 24.9-mm-(0.98 in) thick containing a 559-mm-(22 in) diameter central cylinder composed of 32 0.508-mm-(0.020 in) thick dielectric layers

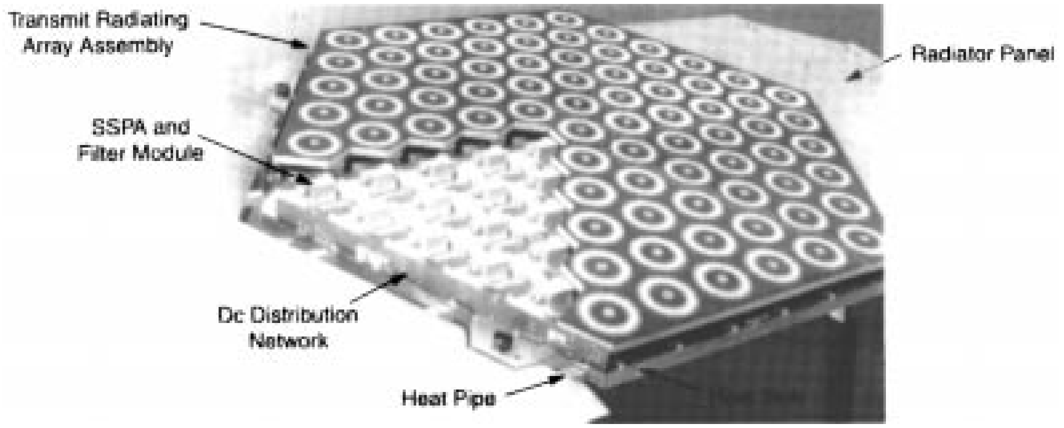


Fig. 9. Photograph of S-band array.

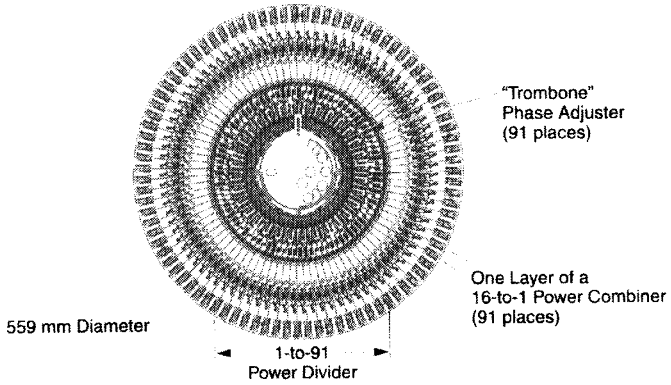
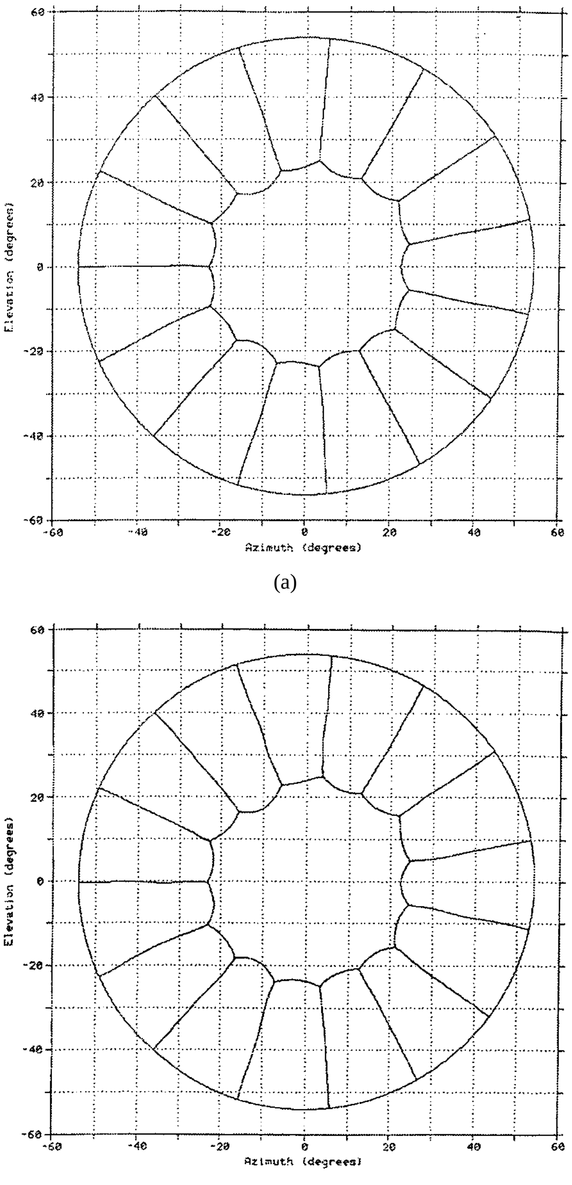


Fig. 10. Layout of a beamforming network.



(a)

(b)

Fig. 11. Receive array pattern. (a) Predicted. (b) Measured.

with a hexagonal-shaped 635 mm (25.0 in) flat to flat section composed of two, 1.5-mm (0.060 in) dielectric layers.

The PA modules are mounted to the top of the heat sink and the BFN assembly is mounted to the bottom. This was shown in Fig. 9. The array assemblies fasten to the top of the PA modules with quarter-turn fasteners. All module input and output RF connections are made using GPO brand-name blind-mate interconnect coaxial "bullets." The dc distribution network carries up to 180 amps and is made of multilayer rigid flex boards with printed circuit conductors and supplies the variable drain voltage for the PA.

For reliability, the BFN contains no internal solder joints and no signal via passing through more than two dielectric layers. Quarter-wave couplers pass signals. The Wilkinson-type isolated power dividers and combiners use etched Ω-ply resistors. The 16-input and 91-output connectors are blind-mate GPO type and are soldered in place.

B. *L*-Band Antenna Design

The block diagram for the L-band antenna is the same as the S-band presented in Fig. 7 except the amplifiers are LNA's not PA's, are reversed, and there are only 61 radiating elements and amplifiers. Also, since the LNA's do not produce as much heat as the PA's, an aluminum honeycomb structural panel with graphite faceskins is used to support the modules and the BFN instead of a heat sink. Furthermore, the receive BFN uses $1:61$ power dividing networks in its construction and each of the 16 individual beams are formed using both phase

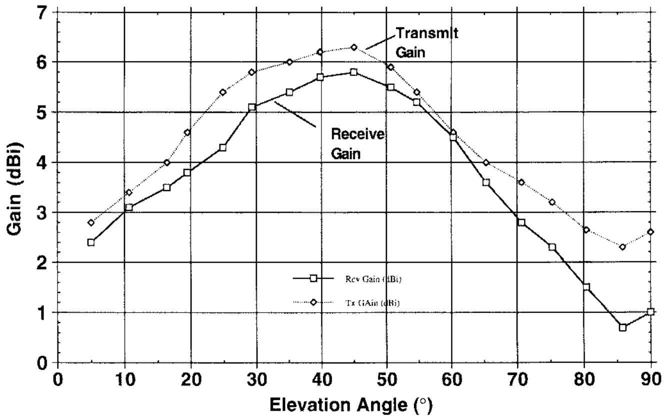


Fig. 12. Measured pattern of C-band scalar horn.

and amplitude distribution control in the BFN.

Fig. 11(a) presents the predicted 16 simultaneous beam circular polarized receive array antenna coverage and Fig. 11(b) shows the corresponding measured beams. The receive antenna's contour edges are much smoother than those of the transmit antenna's contour edges presented in Fig. 8(a) and (b) since both amplitude and phase-controlled distributions were used to form the receive beams.

The Globalstar predicted pattern contours are loci of equal-power crossover points between adjacent beams. Each beam is calculated using the appropriate amplitude and phase distributions from the superposition of 61 (L-band) or 91 (S-band) element patterns using a $\cos^N$ approximation to the measured embedded element pattern. Radial cuts are extended outward from the center of each beam until the crossover with the adjacent beam is located. The curve joining these crossover points forms the portion of the predicted pattern contour for that beam. The complete predicted pattern contour consists of the superposition of these contour lines for the 16 coverage beams.

C. C-Band Horn Design

The C-band scalar horn antennas are designed to communicate with the Gateway antennas with an earth coverage pattern that compensates for radial space loss variation from Nadir to the edge of the earth. This "near isoflux" pattern provides nearly constant sensitivity for received signal and flux density at the earth surface for any Gateway antenna elevation angle. Measured C-band receive and transmit engineering model antenna patterns are presented in Fig. 12. Near isoflux type pattern performance is achieved from nadir to 40° off of nadir.

V. SUMMARY

The Globalstar system described above is well on its way toward reality. The first launch is scheduled for February 1998. Satellites are being manufactured, user terminals are being manufactured and Gateways are being installed.

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Since 1985, he has worked in telecommunications. He is currently the Manager of system architecture at Globalstar/Limited Partnership, San Jose, CA, working on open-system engineering issues regarding the current Globalstar system and designing the next generation of Globalstar. He was part of the original three-member team that designed Globalstar withan emphasis on the RF requirements, system capacity, user availability, constellation coverage, and definition of the overall system architecture.

Phil Monte received the B.S.E.E. degree from California State University at Long Beach and the M.S.E.E. degree from the University of California at Santa Barbara, in 1969 and 1973, respectively.

He has 28 years of experience in the design of antennas and is presently the Antenna/Microwave Director at Space Systems/Loral in Palo Alto, CA. He and his organization are responsible for the design and development of the Globalstar satellite antennas.