30/20 GHz DEMONSTRATION SYSTEM
FOR IMPROVING ORBIT UTILIZATION

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ABSTRACT

The NASA LeRC 30/20 GHz Satellite Communications Program is developing a number of technologies to reduce satellite orbit/spectrum crowding and prevent saturation of our domestic United States Communications capabilities in the 1990 to 2000 decade. Developing the basic hardware technology to operate at 30 and 20 GHz provides 2.5 GHz of new communications bandwidth. This 2.5 GHz additional communications bandwidth is not the primary benefit of the program, however.

Rain losses are severe at 30 and 20 GHz, and innovative techniques are required for systems which are both reliable and economic. Techniques being developed include large satellite antennas with simultaneous multiple fixed and multiple scanning beam capabilities. These provide high antenna gain to increase communications margin and frequency reuse capability through beam isolation, while providing complete coverage of the United States. Effective communication bandwidths from a single satellite location can reach ten’s of gigahertz, with the communication capacity tailored to match the very nonuniform geographic demand pattern. Satellite onboard processing consisting of demodulation, adaptive forward-error-correction (FEC) decoding and coding, routing of hundreds of thousands of channels to thousands of terminals, and remodulation with independently optimized uplink and downlink modulation structures is being developed. The onboard processing reduces the scanning antenna requirements, allows more effective frequency reuse, and increases the rain margins by adoptively using system margins to support terminals currently experiencing rain. All of the functions described can be performed with reasonable satellite weight, thermal, and power impacts by using large scale integration (LSI) to implement the digital data processor. By designing the onboard processor with parallel internal structure, the hardware can be made extremely reliable (high level redundancy) and the number of LSI chip types required is relatively small.

The antenna and onboard processing techniques are readily adaptable to C-band and Ku-band, as well as Ka-band. Deployable antennas may be required at the lower bands, but

precision deployable antenna designs are available and the feed structures scale directly. Frequency reuse of all three commercial communication bands should greatly ease the orbit crowding problems now being experienced in C-band, and should allow United States domestic communications to accommodate any desired expansion in the next two decades.

*This paper reports work contracted under Contract NAS3-21933 sponsored by NASA Lewis Research Center.

INTRODUCTION

The 30/20 GHz Demonstration System designed by TRW for the NASA LeRC Satellite Communications Program utilizes three techniques to improve orbit utilization for United States Domestic Satellite Communications. These are: (1) opening a new satellite communications band with twice the bandwidth of all of the lower frequency bands together, (2) improving satellite communications efficiency in both frequency utilization and radio-frequency power utilization, and (3) providing rapid communication system adaptability for efficient demand-access system utilization and for rapid response to rain absorption of the communications signals.

This paper will briefly discuss the TRW recommendation for a 30/20 GHz demonstration system, capable of demonstrating reliable and economic 30/20 GHz communications to both large trunking terminals and small, low-cost customer premesis service (CPS) terminals. It will then describe the problems and problem solutions associated with the three orbit utilization techniques listed above.

Studies have indicated that the C and Ku band orbit/spectrum resource for domestic United States communications may saturate at some time between 1988 and 1992. The C-band orbit/spectrum resource seems to be at or near saturation now. Techniques being developed by the 30/20 GHz Satellite Communication Program will allow continued growth of this countries vital satellite communications capabilities, through the year 2000. This continued growth will result from increased communications efficiency at C and Ku band, as well as from the greatly increased bandwidth available.

SYSTEM DESCRIPTION

The 30/20 GHz Demonstration System consists of a satellite, trunking and CPS terminals, and a master control station. Figure 1 shows the satellite and Figures 2 and 3 show the trunking and CPS terminals.

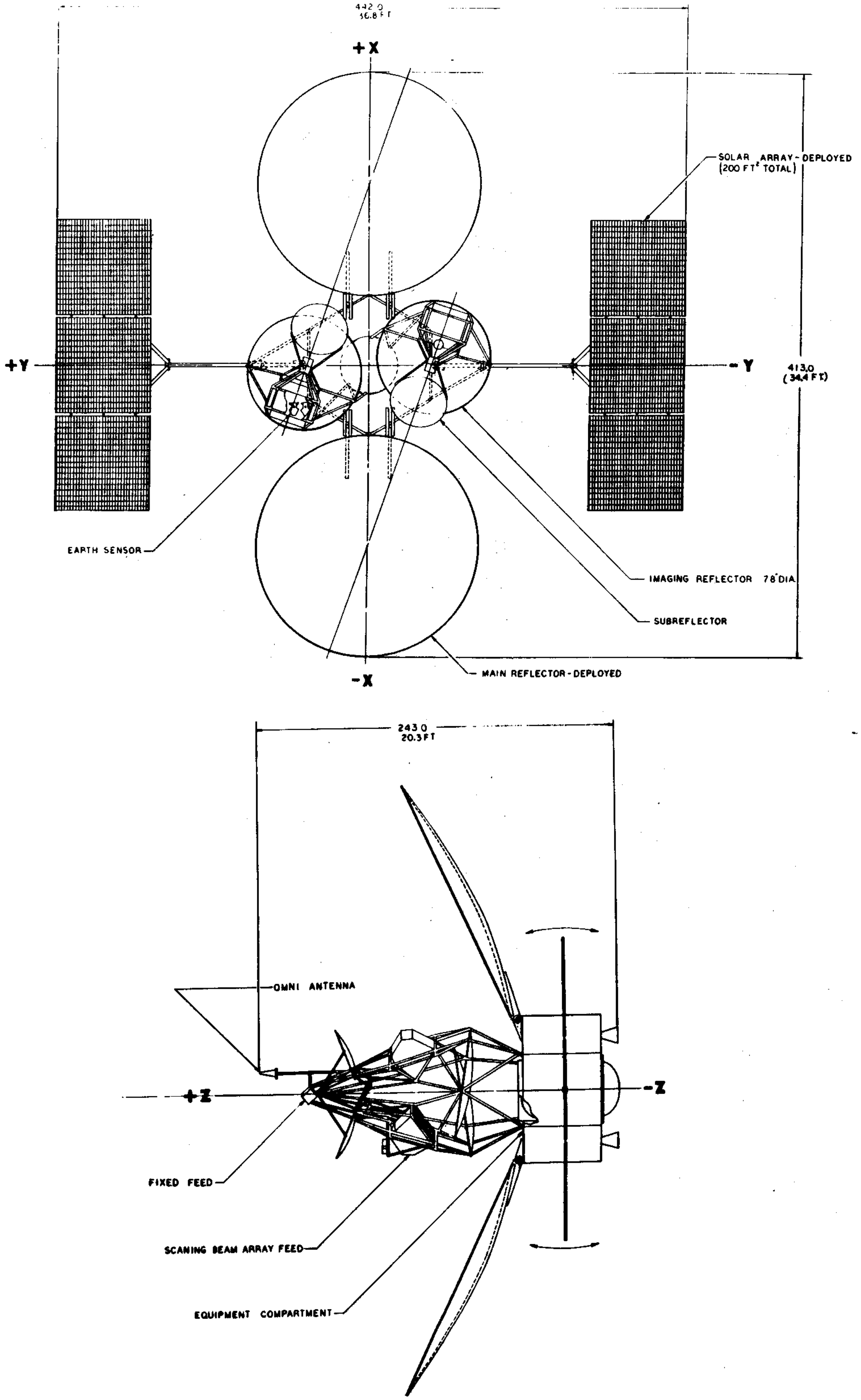

FIGURE 1. SATELLITE DESIGN

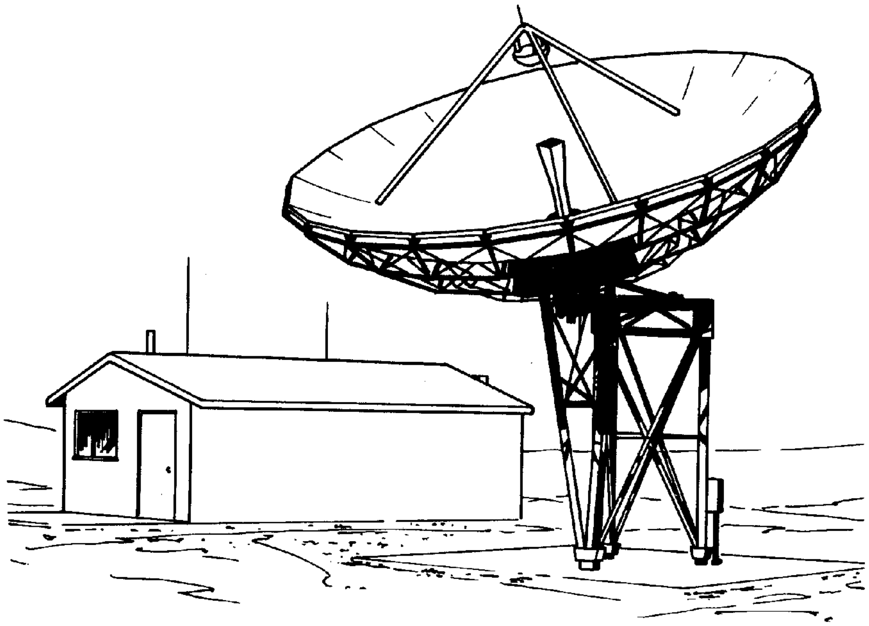

FIGURE 2. TRUNKING TERMINAL

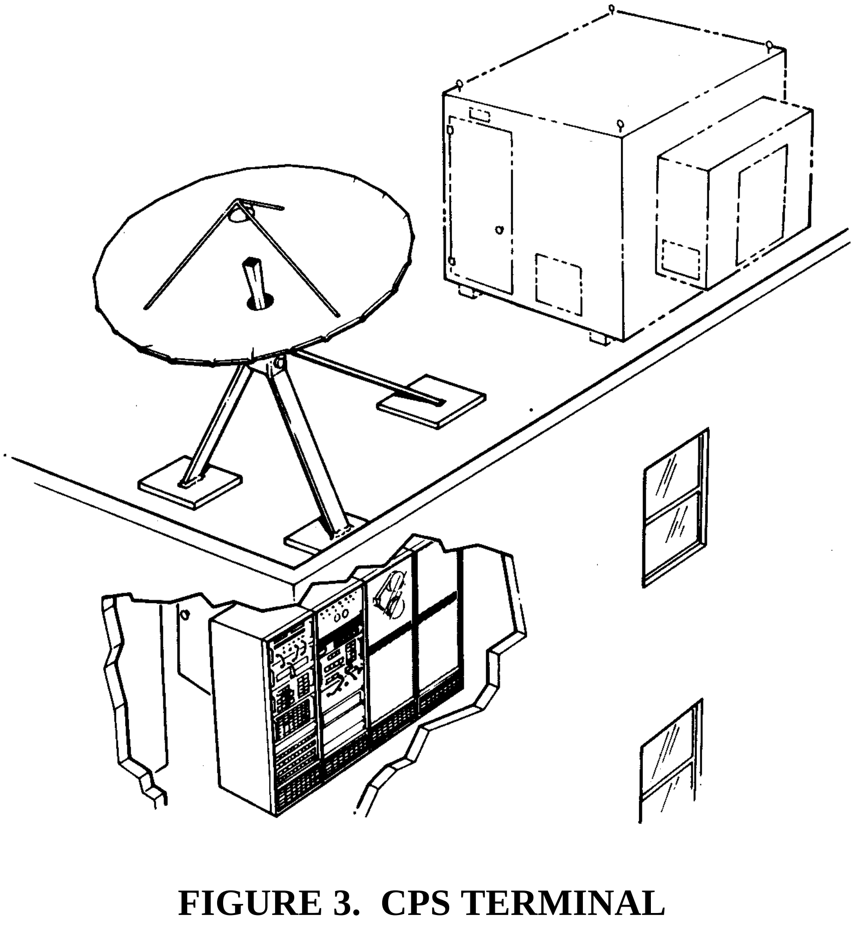

FIGURE 3. CPS TERMINAL

Two large (13-foot 8-inch) antennas are a major feature of the TRW 30/2O GHz Satellite. These provide narrow (0.3°) antenna beams both at fixed locations and scanning over the United States. By providing two antennas and pointing one at the east coast and one at the west coast, scan losses are reduced and the best system performance occurs in the coastal regions where most traffic is located and where rain losses are most severe.

The satellite also provides on-board processing for routing and adoptively forward-error-correction (FEC) coding signals to and from CPS terminals. On-board processing for trunking terminals is limited to and intermediate-frequency satellite-switched time-division multiple-access (SSTDMA) switch which allows each trunking terminal to access each other trunking terminal for appropriate periods during each TDMA frame. The satellite communication system block diagram is presented in Figure 4.

The 30/20 GHz Demonstration System Trunking Terminals use large (12 m.) antennas, relatively high power transmitters (100 to 250 watts), and reasonably sensitive low-noise receivers to provide large communications signal margins. Space diversity (about 10 Km between sites) and the large signal margins together provide high signal reliability despite the rain propagation effects. The relatively high-cost trunking terminal design does not degrade system economics because of the small number (about 18) large trunking terminals projected for operational use. Small trunking terminals will be mechanized by joining two CPS terminals with a fiber-optic link for space diversity operation.

The CPS terminals are small (3.5m) and are inexpensive in quantity. The design approach utilizes sophisticated communications techniques, digitally mechanized in large scale integrated circuits (LSI), to reduce the requirements on transmitter power and receiver sensitivity. The RF performance parameter requirements are minimized by this approach, since the cost of the RF components cannot be reduced by integrated circuit and batch-production techniques. Minimization of CPS terminal cost is critical since there will be a very large number of these units providing small-user communications and, as mentioned above, thin route trunking with a diversity fiber-optic link.

The master control station will be colocated with trunking terminal at Cleveland, Ohio for the demonstration system. It will control the satellite, communication subsystem routing and adaptive FEC, telemetry and control for the CPS terminals, and several toher system functions. For operational use two such stations will be required. These will share control functions normally with one assuming all critical control functions should a failure occur at the other station.

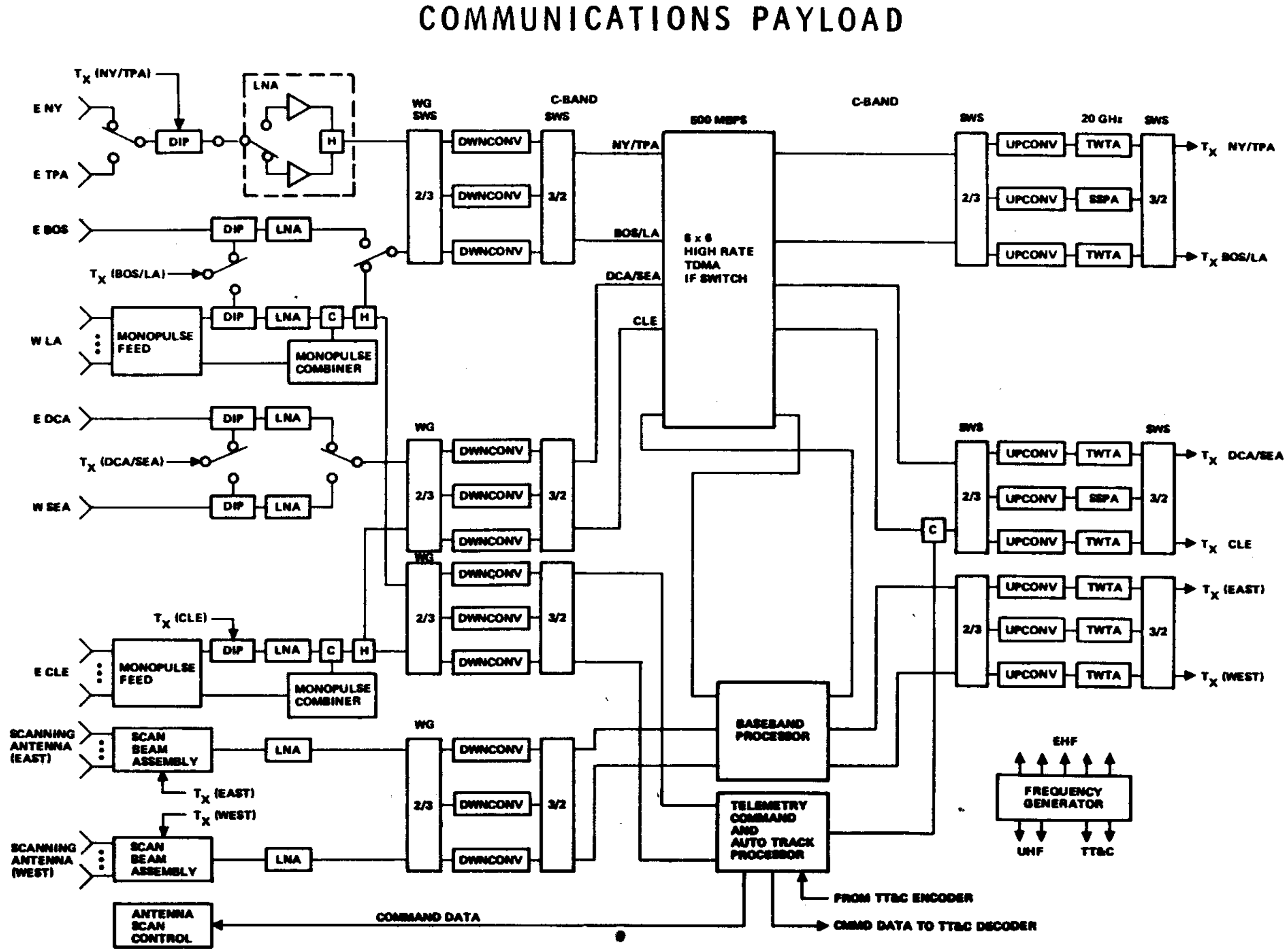

FIGURE 4. COMMUNICATIONS SUBSYSTEM BLOCK DIAGRAM

OPENING A NEW SATELLITE COMMUNICATIONS BAND

The basic components, transmitters receivers and antennas, must be available before one can design an economic commercial communication system. A significant portion of the 30/20 GHz program must address this problem. The unique characteristics of the 30/20 GHz band make it necessary to address technologies that go beyond the techniques used at lower frequencies. A general listing of technologies addressed and their applicability to the orbit utilization problem is provided in Table 1.

TABLE 1: 30/20 GHz TECHNOLOGIES

TECHNOLOGY	EFFECT ON ORBIT UTILIZATION
Solid-state and TWTA transmitters	Opens up 2.5 GHz of new comsat bandwidth at 30/20 Ghz
FET LNA Receivers	Opens up 2.5 GHz of new comsat bandwidth at 30/20 Ghz
Fixed 0.3° Beam Antennas	Provides theoretical reuse factors of 25 to 50. Provides practical reuse factors of 10 to 20. Increases satellite EIRP and G/T to reduce terminal costs.
Scanning 0.3° Beam Antennas	Covers thin-route areas with same EIRP and G/T advantages of fixed-beams, but at lower satellite complexity and cost.
Onboard Demod/Remod	Provides small increase in communications efficiency. Reduces terminal costs by allowing routing, adaptive FEC, and coherent single-carrier down links.
On-board Routing	Allows terminals to receive data with a simple single-burst-per-TDMA-frame receiver. Avoids wasting satellite downlink transmitter power in areas where signals are not required.
On-board Adaptive FEC	FEC provides 5 dB of coding gain. Adaptive FEC provides 3 dB more (R½ code) by avoiding signal-rate increases except where needed. 8 dB of adaptive margin is made available to combat rain losses when needed.

Some of the problems, and perhaps the solutions, of operating a satellite communication system at 30 and 20 GHz are illustrated in Figure 6. (Picture of rain, diversity, CPS terminals) Rain can strongly absorb the radio signal energy. Different approaches are used to avoid loss of communications during rain for two different types of earth terminals. A list of techniques to combat rain loss and the usage and effect of these techniques is provided in Table 2.

Small customer premesis services (CPS) terminals use adaptive forward-error-correction (FEC) to operate through uplink and downlink rain losses of 15 to 25 db). The adaptive coding and decoding is accomplished in the satellite, and is used only on those links currently being affected by rain. Since only a few terminals will be in heavy rain at any one time, the average communication rate is not affected significantly by those terminals using rate one-half coding. By shifting TDMA assignments, the terminals experiencing rain are allowed to double the length of their uplink and downlink bursts to accommodate the rate 1/2 FEC. The rain margin available is then 3 dB for burst duration increase, 5 dB for FEC coding gain, plus whatever clear weather margin is available to a terminal. TDMA burst rate selections of 128 MBPS or 32 MBPS are also available for another 6 dB of adaptive rain margin on the 30 GHz uplink (30 GHz rain losses are more severe than the 20 GHz downlink losses, and the terminal transmitter power is a system cost driver).

The adaptive coding and rate changes complicate the earth terminal but, the complication is restricted to the digital data-processing terminal hardware. This hardware will be implemented in large-scale-integration (LSI) microcircuits which will be inexpensive after the circuit development is completed. In return for this increased digital hardware complexity, transmitter power requirements can be reduced by 14 dB (a factor of 25) and receiver sensitivity can be reduced by 8 dB (a factor of 6).

Large trunking terminals use large transmit effective-isotropic radiated power (EIRP) levels and receive gain-to-temperature (G/T) ratios to establish large transmit and receive signal margins. When space diversity is added to allow the signal to “go around” the worst heavy rain storms, acceptable communication reliability is achieved. Small trunking terminals can use all of the techniques available to CPS terminals, plus space diversity to meet trunking availability requirements. No small trunking terminals are currently planned as part of the demonstration system, but all of the hardware, software, techniques, and rain statistics necessary to implement them will be developed.

TABLE 2: TECHNIQUES TO COMBAT RAIN LOSS

TECHNIQUE	USE	EFFECT
Adaptive FEC	CPS terminals uplink and downlink	Reduces rain margin requirements by 8 dB • can be used only for small percentage of system comm load at any instant • requires rapid system response • not applicable to trunking
Variable TDMA	CPS terminals	Reduces rain margin requirement by 6 dB
Burst Rate	uplink only	• 128 MBPS to 32 MBPS rate change for 6 dB • requires rapid system response since average data rate unchanged
Clear Weather Margin	All terminals	As much as 30-40 dB required without adaptive response technique • cannot design economic system with such margins • about 5 dB margin required with adaptive techniques to provide system stability
Space Diversity	All Trunking Terminals	Increases 0.999 single terminal availability to • .9999 • valid technique for high rain-rates only • Low rain-rate storms have larger geographic extent

COMMUNICATIONS EFFICIENCY IMPROVEMENTS

Communications efficiency improvements affecting orbit utilization include greatly increased satellite antenna directivity allowing frequency reuse, increased satellite antenna gain, and on-board processing to reduce uplink and downlink transmit power levels. All of these improvements can be used at C and KU-BAnd as well as 30/20 GHz with appropriate scaling of antennas. The antenna gain and reduced transmit levels are especially needed at 30/20 GHz, however, because of the need to combat rain loss and the lower transmitter powers available due to technology limitations.

Frequency reuse available with narrowbeam (0.3°) low-sidelobe antennas provides the most dramatic orbit utilization improvements. A triangular grid pattern with 4.0 dB 3-way crossover points, fits about 200 beams within the lower 48 continental United States (CONUS). Using low side lobe antenna beams with two frequencies and two polarizations to achieve a "four color map", we can reuse the 2.5 GHz spectrum 50 times. If we do not use polarization, but get our "four color map" with four frequencies, we still get a frequency reuse factor of 25.

Much of the communications capability made available by the frequency reuse described above is only available in relatively unpopulated parts of the country. Communications traffic in he United States is extremely nonuniform in geographic distribution. Matching the capability to geographic requirements reduces the effective improvement to the range of of 10 to 20. This is still a very impressive capability, considering the 2.5 GHz bandwidth available before applying the reuse capability.

In addition to the frequency reuse capability as seen from the satellite, there is a frequency reuse capability as seen from the territorial terminals. C-Band satellites are spaced about five degrees apart in the orbital arc, allowing the entire C-band spectrum to be used approximately 14 times. If the terminal antenna sizes are held constant we can space satellites 4 to 5 times closer. Communications with smaller terminals is desirable to reduce terminal cost, but we should be able to still place twice as many 20/30 GHz satellites in the orbital arc.

We can get about 28 reuses at the orbit/spectrum by using different orbital locations. Combining this with the satellite reuse factor of 10 and the 2.5 GHz spectrum available, there is about 140 GHz of communications bandwidth available to United States Domestic Communications by using the 30/20 GHz band. If the cost of video terminal hardware drops significantly, the resulting communications market demand might saturate even this.

Increased satellite antenna gain results from the 200:1 ratio of areas covered by 0.3° antenna beam and by a traditional "CONUS-coverage" antenna. Several 0.3° coverage circles are plotted on a map of CONUS, as seen from synchronass orbit, in Figure 5. This results in 23 dB greater EIRP and G/T in the satellite for the same transmitter and receiver performance. A large portion of this improvement goes to compensate for the rain losses and poorer transmitter and receiver performance available at 30/20 GHz, however.

Fixed beam coverage of the entire United States is inefficient since too much satellite hardware is used to cover areas with little or no communications traffic. Scanning beams provide a solution to covering the sparsely populated areas. Communications to and from these areas is not large in volume, but is if anything more important than in areas where alternate communications are available. The particular technique chosen for scanning beam mechanization uses “tracks” shown in Figure 5. The beam is switched between tracks, and phased-array techniques form the beam in the east/west dimension.

Combining a scanning beam with on-board processing reduces the scanning beam speed requirement by about an order of magnitude. This results from sorting all the communications traffic to and from a particular area into a single TDMA burst per frame. Without a processor the antenna must establish connectivities between each pair of communicating terminals by scanning the uplink and downlink beams at differing rates.

On-board processors provide some communications efficiency improvement by demodulation and remodulation, but unless uplinks and downlinks are balanced (have the same SNR) the improvement is small. The primary advantages of on-board processing are:

- reducing antenna scanning speed requirements
- simplifing small terminals by concentrating all data on to one
- implementing FEC coding

RAPID COMMUNICATIONS SYSTEM ADAPTABILITY

Satellite communications systems are unique in providing communications capacity that can be utilized anywhere over a wide geographic area. It is extremely wasteful to utilize such a capability with the same system orinization as terrestrial communications links that do not have the ability to shift their capacity to the area where the need exists.

Demand assignment with rapid reassignment of unused capacity is vital to a system serving many small users. In particular, telephone voice channels should be assigned in a period of time comparable with normal telephone dialup procedures. Figure 6 shows a time line for such rapid assignment in the 30/20 GHz Demonstration System.

Rapid modification of assignments meets another need in the 30/20 GHz system. Adaptive error correction coding doubles the TDMA burst period required for any link. Implementation of coding and modification of TDMA assignments to allow the additional required time must be accomplished rapidly enough to avoid outages. A decrease in system performance must be detected and corrective action must be complete before the rain loss causes an outage. Statistical data on the rate of increase of rain loss is not currently available, but response time should be less than one second if possible.

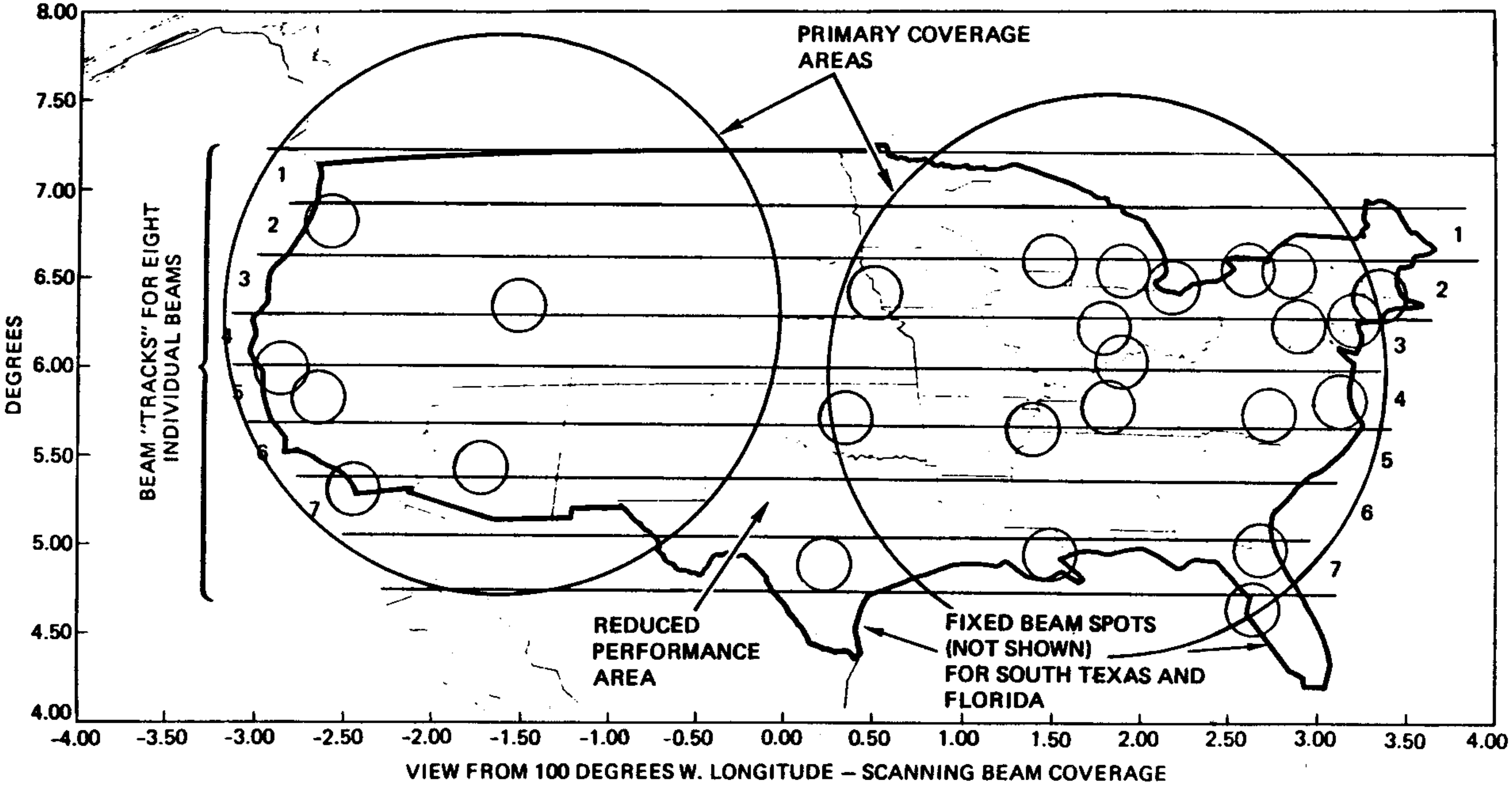

FIGURE 5. CONUS FROM SYNCHRONUS ORBIT (100° LONGITUDE)

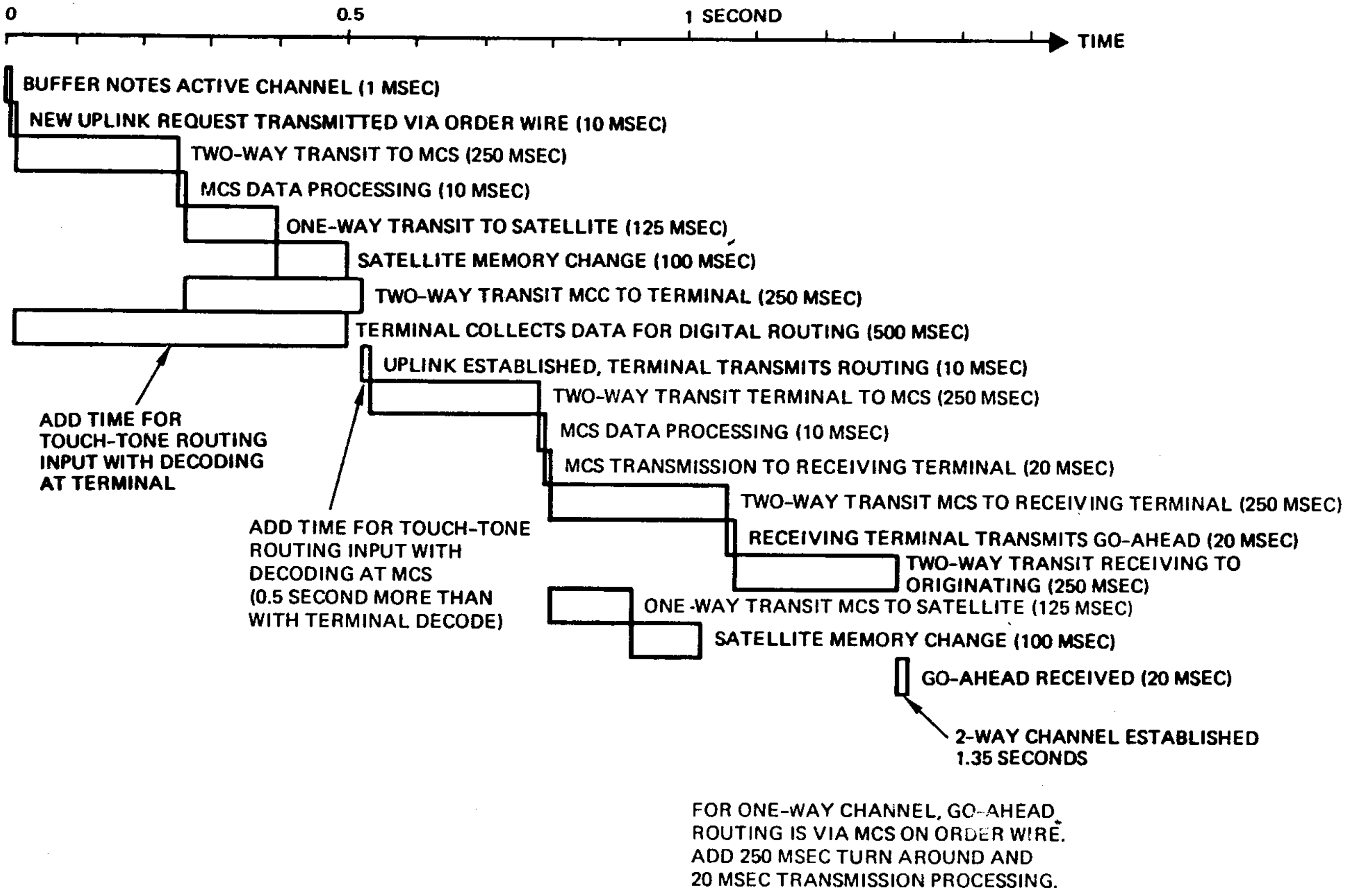

FIGURE 6. TELEPHONE DIAL-UP TONE LINE