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TACIT EHF TT&C SPACE EXPERIMENT DESIGN

Research & Development Laboratories
5800 Uplander Way
Culver City, CA 90230

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Final Report

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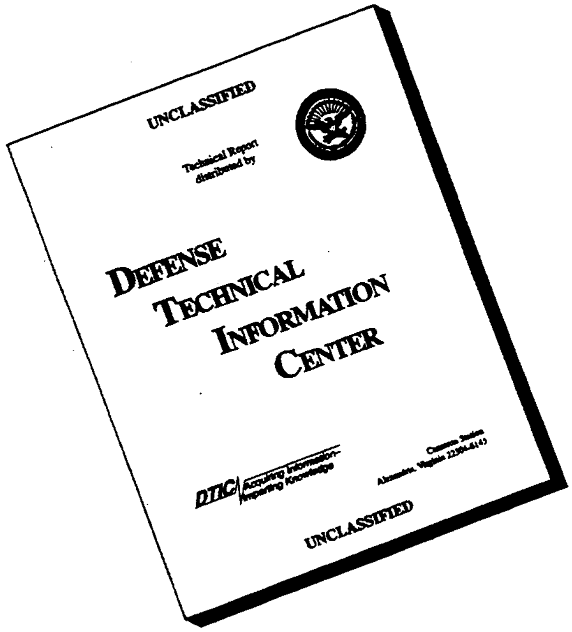

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14. Abstract. The original TACIT EXTREMELY HIGH FREQUENCY TELEMETRY, TRACKING, AND COMMAND (TACIT EHF TT&C) SPACE EXPERIMENT statement of work has been expanded in scope to include TACIT applications to remote transmit systems that are located on the ground. This report covers the application of TACIT EHF TT&C for use in remote ground terminals that are used for intelligence gathering purposes. Since TACIT utilized the emerging technologies that provide small size, low weight, and low power consumption, it is perfectly suited for remote application.

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1.0 SUMMARY

The original TACIT EXTREMELY HIGH FREQUENCY TELEMETRY, TRACKING, AND COMMAND (TACIT EHF TT&C) SPACE EXPERIMENT statement of work has been expanded in scope to include TACIT applications to remote transmit systems that are located on the ground. This report covers the application of TACIT EHF TT&C for use in remote ground terminals that are used for intelligence gathering purposes. Since TACIT utilizes the emerging technologies that provide small size, low weight, and low power consumption, it is perfectly suited for remote application.

The report has been structured to proceed logically from general requirements considerations through a description of operational modes, a survey of candidate satellite systems, and calculations of link budgets, to design of a remote transmit system (RTS).

Sections 2.0 and 3.0 provide basic and operational requirements that have been derived from the Statement of Work (SOW) and operational concepts that have been derived from the report entitled "Operational Constraints Influencing the Design of Special Purpose Unbalanced Meteor Burst Data Relays" (Ref. 1). They define satellite links, global RTS location, weather zones, RTS delivery modes, covertness, data rates, and operational modes.

Section 4.0, "Operational Concepts," describes satellite constellations, system architecture, earth coverage, and mission profile, and ends with mission constraints such as coverage, access, data rate, and rain-attenuation discussion.

Section 5.0, "Survey of Satellite Systems," contains a survey that is based upon the discussion in Section 4.0. It contains link descriptions -- such as frequency, bandwidth, effective isotropic radiated power (EIRP), and gain-to-noise-temperature ratio (G/T) -- that are used later on in this section for computation of link budgets. Other descriptions, such as satellite location and orbit history, are also included to establish windows of opportunity and availability time lines. The second part of Section 5.0 presents link budget calculations and tables. They establish signal-to-noise ratio (SNR) margins for each satellite-RTS link and various provided services.

Assumptions for the selection of ground terminal characteristics and/or selection of available ground terminals are given in Section 6.0, "Satellite - RTS Communications System."

Section 7.0, "The RTS Design," discusses the design. Since the previous sections have identified the substantial multiplicity of frequencies, bandwidths, modulation methods, multiplexing modes, and possible data rates, the design is given in terms of discussion rather than in specific design parameters. Modular construction is proposed to allow the greatest flexibility for module selection and the use of available ground terminals. The primary link parameters, EIRP and G/T, are given in terms of frequency and antenna diameter to allow matching of RTS with given satellite parameters. Also included are discussions of memory size, software, dc power, and security requirements. The section ends with a brief discussion of the available ground terminals.

From the survey of satellite systems, it is obvious that the most used and suitable satellites are INTELSAT and DSCS. Their frequency bands are 4/6, 11/14, and 7/8 GHz respectively and can be covered with a single antenna using FLAPS technology. This allows at least two levels of security, use of a common carrier, and instantaneous switching between frequency bands as well as satellites.

Sections 8.0 and 9.0, "Conclusions" and "Recommendations," discuss the conclusions that can be drawn from the material presented in Sections 4.0, 5.0, and 6.0. They also provide recommendations for the direction in which the RTS design should proceed in order to obtain the greatest flexibility and probability of success.

The final decision on satellite/frequency selection must be based upon signal format (modulation, comsec and transec), access protocols, priorities, and response time.

2.0 BASIC REQUIREMENTS

The following basic requirements were derived from the Statement of Work (SOW), Revision 1, Contract No. F29601-91-C-0111 dated 1-20-93 and entitled "TACIT EHF TT&C Space Experiment Design."

2.1 THE SATCOM PROPAGATION MEDIUM

Document a survey of the SATCOM propagation medium to support the operational requirements of an unattended RTS and communications between the unattended RTS and mobile command and control centers (C&CCs).

2.2 OPERATIONAL CONCEPT

2.2.1 Develop and Document an Operational Concept

Develop and document an operational concept for an RTS in terms of:

- Global locations of RTS and C&CC
- All terrain types
- All weather conditions
- All times of the year
- All times of the day and night

2.2.2 Operational Concept

The operational concept shall address the following:

- The RTS - COMSAT - C&CC network configuration
- Communication range limits
- Data throughout and speed of service
- Mission duration
- Size, weight, and system deployment
- Personnel
- Visual and electromagnetic covertness

2.3 THE SATCOM SYSTEM DESIGN

- For the identified SATCOM communication links, perform propagation loss computations in terms of link parameters and most constraining weather scenarios.
- Determine whether or not military or commercial satellite systems will be available and capable of performing the mission.

2.4 REMOTE TRANSMIT SYSTEM DESIGN

- Design a remote transmit system capable of operating within the operational concept and system constraints.

- Determine where new developments must occur to meet the system requirements.

3.0 OPERATIONAL REQUIREMENTS

The following operational requirements were derived from Reference 1.

3.1 AREAS OF ACTIVITIES AND INTEREST

3.1.1 Areas of Activities

The areas of activities lie mainly in Asia, South America, and Africa. Table 1 identifies the location of selected regional powers and Third World countries.

3.1.2 Activities of Interest

The main activities of interest to U.S. agencies are army movements, arms, and drug trafficking. These affect political, economic, and social stability and may lead to major unrest within one or several countries.

3.2 SURVEILLANCE

3.2.1 Surveillance Purpose

The purpose of surveillance is to provide the theater commander with observed and accurate information on enemy dispositions, movement activities, supply lines, and depot locations.

3.2.2 On-Site Support

On-site support will provide target designation and guidance support for weapons to aid theater forces in target neutralization.

Table 1. Location of selected regional powers and Third World countries.

SOUTH AMERICA		
Argentina	25-50 S	55-70 W
Brazil	00-25 S	35-75 W
Bolivia	10-23 S	57-69 W
Columbia	10-03-S	68-77 W
Peru	00-18 S	69-88 W
Suriname	02-05 N	53-57 W
ASIA		
Burma	12-29 N	91-100 E
India	09-35 N	70-89 E
Iran	25-40 N	45-62 E
Iraq	29-33 N	40-48 E
Israel	29-33 N	35-36 E
Korea, South	35-38 N	127-130 E
Korea, North	38-42 N	125-130 E
Laos	15-23 N	100-107 E
Pakistan	22-36 N	62-77 E
Phillippines	07-19 N	120-126 E
Saudi Arabia	16-32 N	35-55 E
Syria	32-37 N	36-42 E
Thailand	12-20 N	97-105 E
Taiwan	22-25 N	120-122 E
Turkey	36-41 N	27-44 E
AFRICA		
Algeria	20-37 N	09 W-10 E
Angola	06-17 S	12-23 E
Egypt	22-31 N	24-35 E
Libya	2 -32 N	10-24 E
South Africa	23-34 S	18-31 E

3.2.3 Sensor Complement

The sensor complement may include voice and acoustic (traffic and explosions) monitors, earth vibration (heavy motor traffic and explosions) monitors, radio traffic monitors, air chemical composition analyzers, and direction-finding (by sensor data correlation or by direction finding) capabilities.

3.3 EQUIPMENT LOCATION

3.3.1 Remote Transmit System

Remote transmit systems will be located deep within the denied and/or hostile territories.

3.3.2 Mobile Command and Control Center

Mobile CC&Cs will be located with military elements and in close proximity to the theater of operation.

3.4 The RTS

3.4.1 The RTS Deployment

System deployment will include vehicular transportation over rough terrain, airdrop, and amphibious access via unimproved landing sites, as well as use of the standard military rucksack.

3.4.2 The RTS Installation, Test, and Activation

The installation team will consist of military combat personnel who have received instructions and training regarding the procedures to be followed constrained by time, their educational level, and their ability to understand technical matters. Consequently, it is very important to design ease of equipment interconnection, antenna and sensor alignment, testing, and activation into the RTS.

The installation, test, and activation will be capable of operation in total darkness, with minimum use of external aids, and in adverse weather conditions, whether it be storm, rain, or extreme temperature.

3.4.3 Size, Weight, and Time Constraints

The RTS size and weight must be compatible with combat personnel that will carry it (in addition to carrying standard combat and survival equipment) to its final location. This limits the individual RTS to about rucksack size and 30- to 40-lb weight. The RTS may be broken down into several units but must limit the number and the cable lengths.

The RTS installation, test, and activation process must be performed in 5 minutes under nominal conditions and in 15 minutes maximum under the most difficult conditions.

3.5 MISSION PROFILE

3.5.1 Mission Duration

Mission duration is targeted at 10 days but is a direct function of activity intensity, mode of operation, and adverse weather conditions (extreme temperatures affect battery life). However, inclusion of a solar battery may increase mission duration indefinitely.

3.5.2 Operation Modes

There will be seven basic modes of operation: sleep, doze, search, copy, send, real-time communication, and CMD/STATUS. They will perform different surveillance functions and will be combined at different duty cycles to optimize surveillance functions to changing needs and to minimize battery energy use. Table 2 enumerates configurations and operating modes.

3.5.3 The RTS Control

The RTS control will be performed by the operator located in the transportable C&CC. He will examine the collected data and directly control (via a communication link) all the activities in the RTS. Software programs located in its memory will enable the RTS to operate in an autonomous mode. Software programs will be under the control of the operator and will be used to reduce his workload, to optimize data collection, and to assure proper system operation during high activity or adverse communications conditions.

3.6 COMMUNICATION LINK

3.6.1 Response Time

Command -	Instantaneous.
System reconfiguration -	Less than 1 minute.
Telemetry -	At scheduled intervals, upon command, and on a priority basis.
Sensor data -	At scheduled intervals, upon command, and on a priority basis. The actual data transfer time will depend upon both data rate and amount of data collected.

Table 2. Configuration and operating modes.

Mode	Function	Description
0	Sleep	All system power off except for timer clock
1	Doze	Periodically end sleep mode and listen on the command channel for instructions
2	Search	All systems powered down except for receiver (and DF) building signal data base
3	Copy	Receiver in directed search mode. When signal is present, audio is encoded into flash memory
4	Send	Stored data (either signal list or audio) is transmitted
5	Real Time Commo	Modes 3 and 4 combined; no flash memory
6	Cmd/Status	Various subgroups powered on for configuration change which could include GPS, receiver configuration, etc.

3.6.2 Data Rate

Command -	Low, 75 bps.
System reconfiguration -	Medium to high, to minimize reconfiguration time in response to changing activity. Dependent upon the size of program transferred.
Telemetry -	Low, 75 bps.
Sensor data -	High, to minimize response time and to reduce probability of detection.

3.6.3 Memory Capacity

Control software -	Low, sufficient to contain several control algorithms.
Sensor data	
Solid state -	Medium, < 5 Mbytes; required for priority sensor data recording and instantaneous transmission to the mobile C&CC.
Magnetic medium -	Large, 5 to 30 Mbytes; required for voice and acoustic data recording over long periods of time.

3.6.4 Precipitation

The communications link connectivity and quality are to be maintained under the most constraining scenarios. This requirement is to be met by providing sufficient rain margin and/or data rate reduction for most frequent precipitation rates and by time diversity (message repeat) for most violent tropical weather conditions.

Significant rain attenuations will occur in tropical zones at low elevation angles and at frequencies above 20 GHz.

3.7 VISUAL AND ELECTROMAGNETIC COVERTNESS

3.7.1 Visual Covertness

Visual covertness will require small and terrain-conforming units with nonreflecting and color-conforming surfaces. This can be achieved with low-profile units covered by camouflage materials and/or located in visually inaccessible locations, such as bushes and/or surrounding vegetation or soil.

3.7.2 Electromagnetic Covertness

Low Probability of Intercept

Low probability of intercept will be implemented by band spreading, frequency hopping or burst transmissions.

Low Probability of Detection

Low probability of detection will be implemented by any of the numerous encrypting and data interleaving techniques.

4.0 OPERATIONAL CONCEPT

The operational concept and intelligence-gathering architecture is depicted in Figure 1. The theater-located C&CCs control a group of RTSs via a communications satellite link whose earth coverage encompasses all the theater C&CCs and RTSs. Nominal earth coverages for geosynchronous earth orbit (GEO) satellites are 12,000 km for the entire earth, 1,500 km for a country, and 200 km for a large metropolitan area. For individual low-earth orbit (LEO) satellites, the coverage is based upon orbit height and periodic revisit times. For a constellation of LEO satellites such as the Iridium system, the coverage is based upon number of satellites, their orbits, and orbit synchronization.

The C&CC operator controls the assigned RTSs, displays and analyzes the received data, and passes the collected intelligence data to the area headquarters and/or commander. Since the satellite will cover many C&CCs and RTSs, the C&CC operators can share the RTS control and data transfer based upon the need and traffic intensity.

4.1 SATELLITE CONSTELLATIONS

Most of the present GEO communication satellites are dedicated to coverage of specific areas such as CONUS, central Europe, an individual country, or an ocean. In addition to area coverage beams, they usually have spot beams for coverage of high traffic density areas. Figure 2 is a world map which shows that most of the populated areas are located between 60° S and 60° N latitudes and that the selected regional powers and Third World countries are located between 40° S and 40° N latitudes. However, when coverage below 60° S and above 60° N latitude are included, ground-terminal-antenna elevation angles below 20° are required. This results in long paths through the atmosphere and the attendant increases in space loss due to atmospheric and rain attenuation.

To cover the polar regions, Molnya-type elliptic earth orbits or low-earth polar orbits are required. The 12-hour Molnya orbit requires two satellites for continuous coverage of

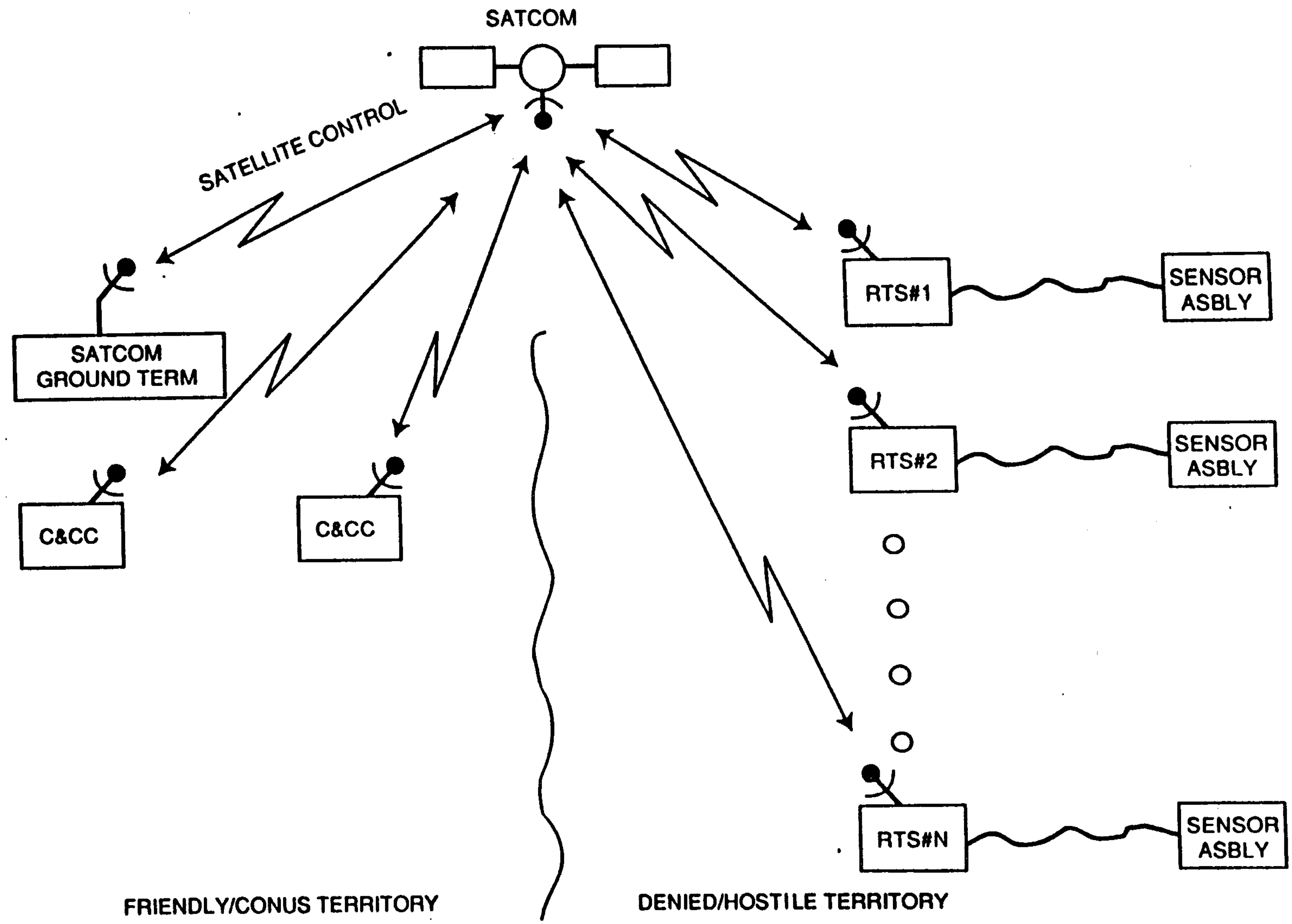


Figure 1. Intelligence-gathering system architecture.

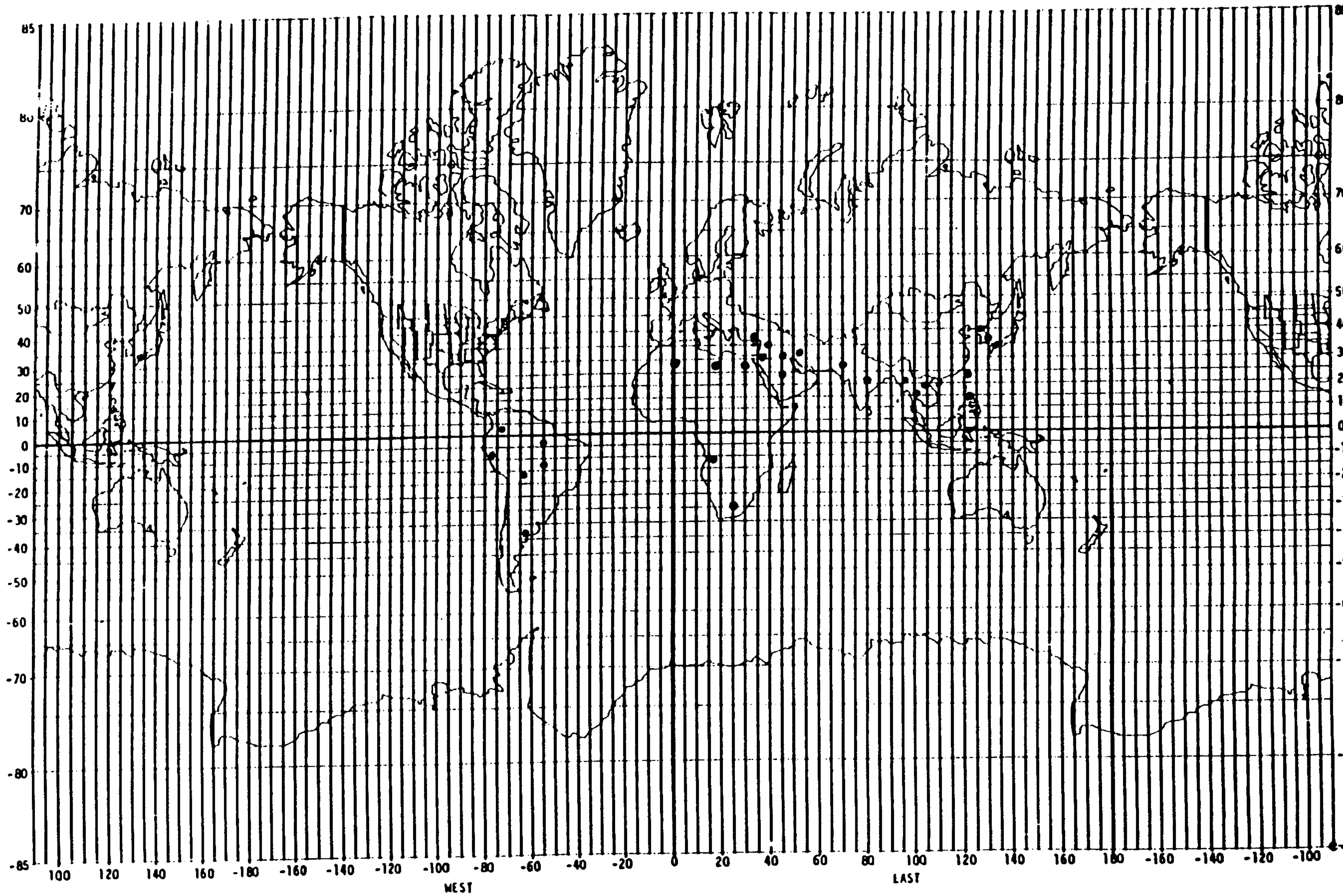


Figure 2. Map of selected regional powers and Third World countries.

the northern polar region and two satellites for continuous coverage of the southern polar region. The RTSs for these satellites would use low-gain, wide-beam antennas (e.g., 15 dB and 30°) to avoid the need for satellite spatial tracking. Figures 3 and 4 show LEO, medium earth orbit (MEO), highly eloptical orbit (HEO), and GEO satellite orbits (planar and elevation views) to delineate the type of coverage each orbit is suitable for. Each coverage can be transcribed onto the world map, shown in Figure 2.

In the case of LEO satellites, the coverage is a circular footprint whose diameter is a function of satellite height and ground-terminal-antenna elevation angle. Figure 5 shows the LEO satellite earth coverage footprint diameter versus the minimum ground-terminal-antenna elevation angle for 200-km, 500-km, 1,000-km and 3,000-km orbits. It can be seen that for RTS application, the LEO satellite coverage is more than required, but it suffers from short visit and long revisit times. Since the LEO satellite orbit time is much shorter than the GEO satellite earth orbit time (24 hours), the LEO satellite visibility time can be calculated approximately for an arbitrary-direction orbit. Figure 6 gives approximate LEO satellite visibility times for a given satellite altitude and ground-terminal antenna elevation angle. For a minimum antenna elevation angle of 5°, satellite visibility time can be as low as 5 minutes and as high as 35 minutes for satellite-orbit heights of 200 km and 3,000 km respectively.

The LEO satellite revisit time is a complex function of altitude, orbit precession, and number of satellites and their relative positions. For the simple case of a single satellite traveling in the same orbit relative to earth, the revisit time is 88 minutes and 105 minutes for 200-km and 1,000-km orbits respectively.

Thus, LEO satellite revisit time is 90 minutes at best, unless accompanied by a large constellation such as the 66-satellite Iridium system.

The proposed commercial direct-satellite communications systems such as Iridium (66 satellites), Globestar (48 satellites), and Odyssey (12 satellites) will provide almost full

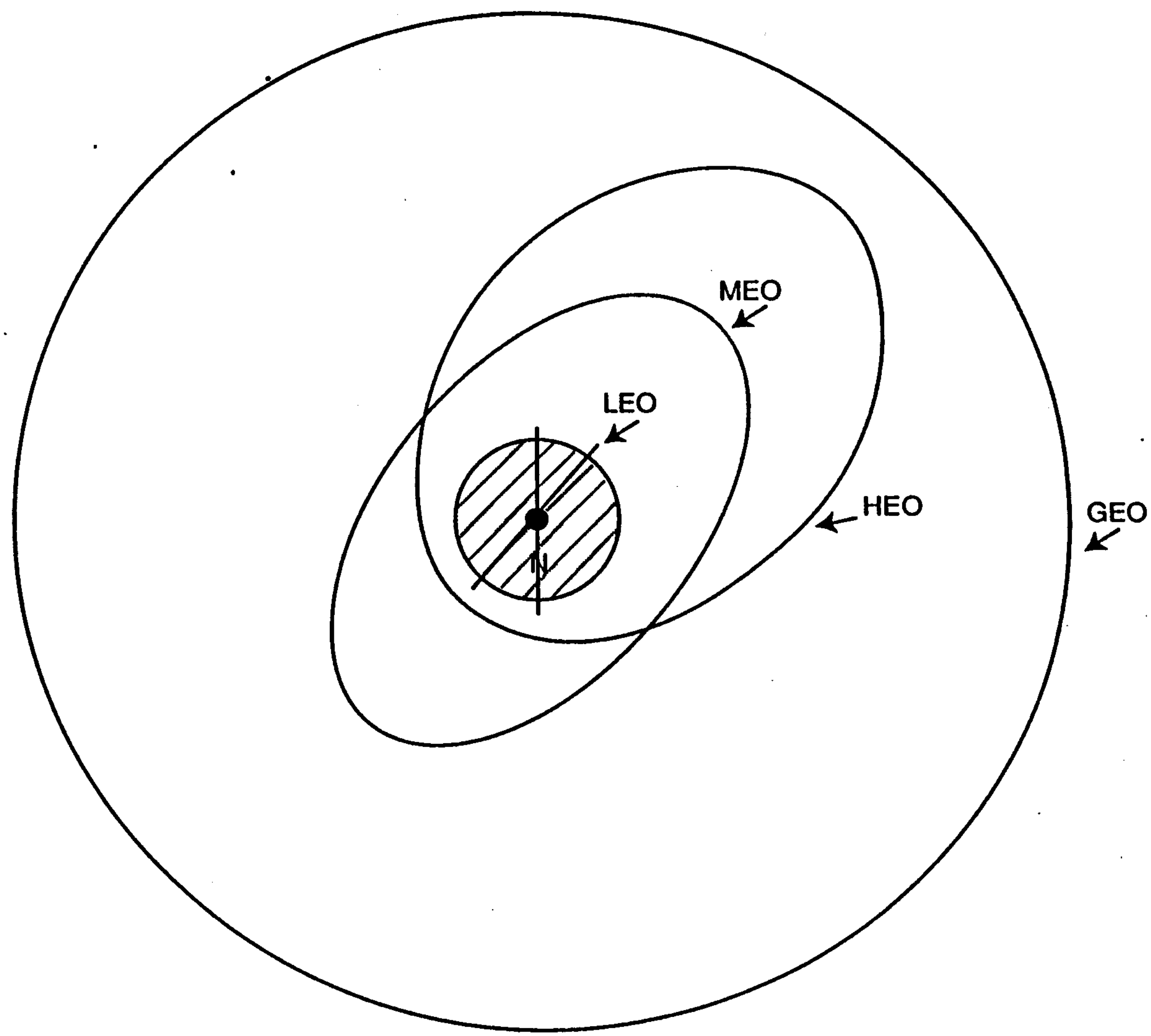


Figure 3. Planar view of LEO, MEO, HEO, and GEO satellite orbits.

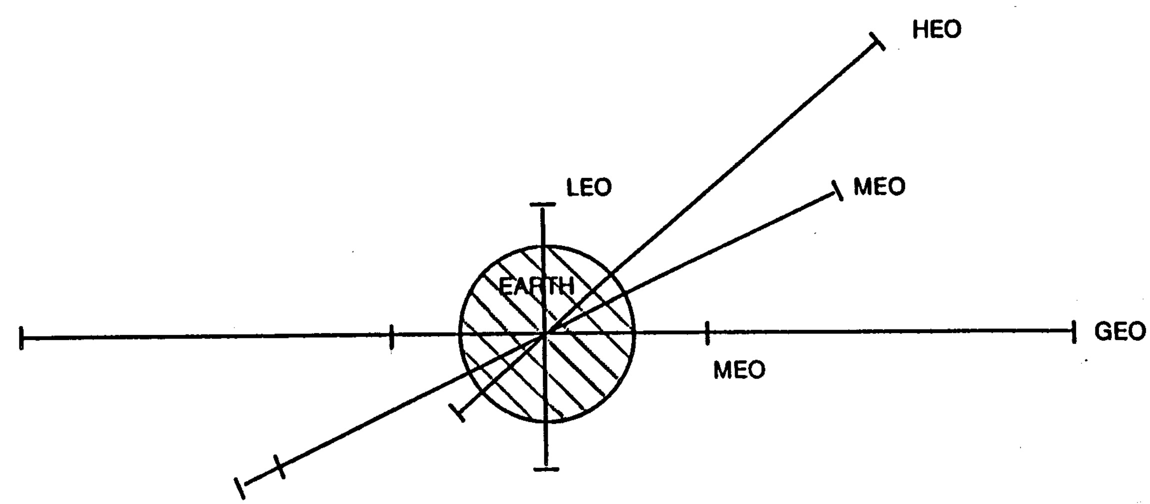


Figure 4. Elevation view of LEO, MEO, HEO, and GEO satellite orbits.

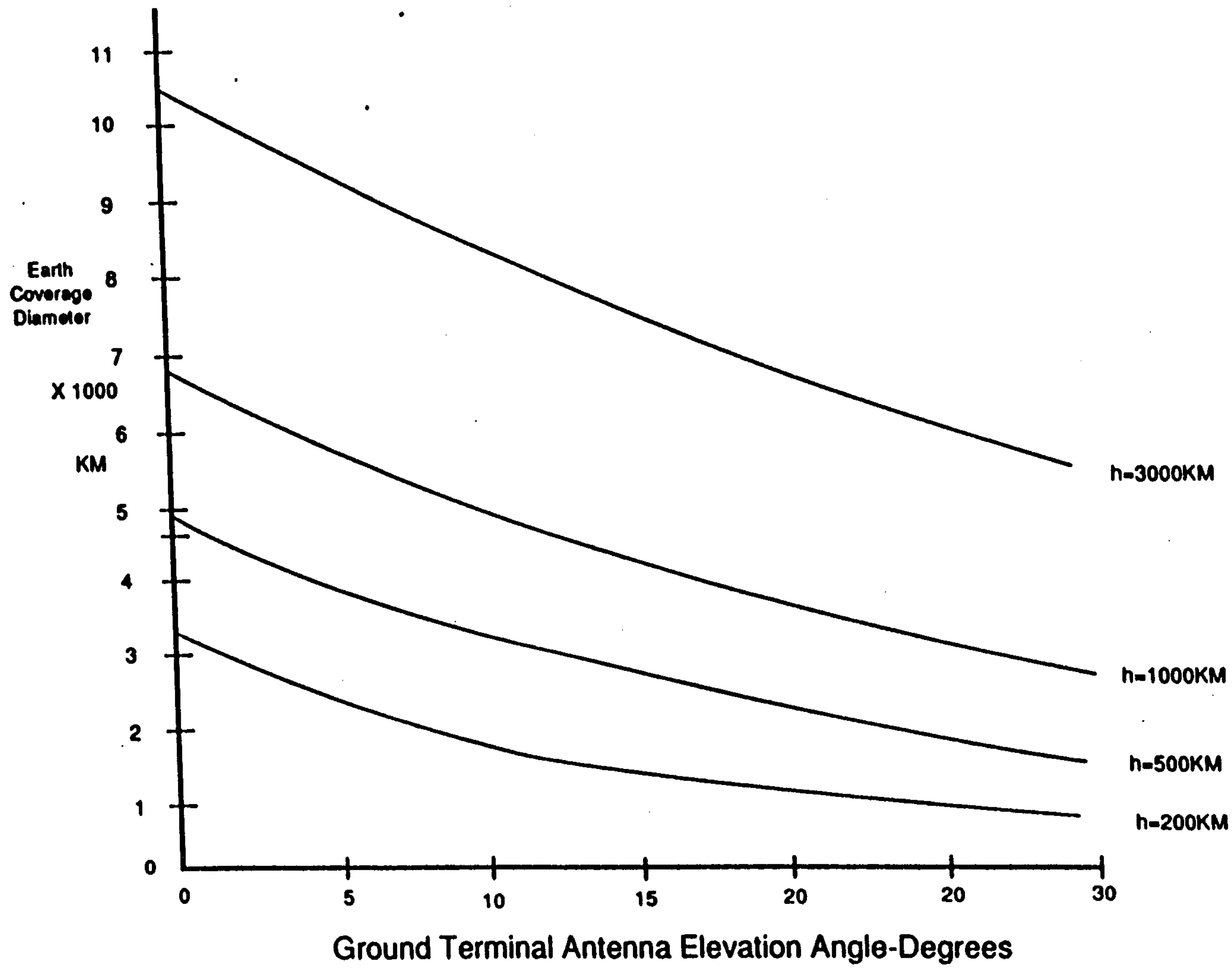


Figure 5. The LEO satellite earth coverage.

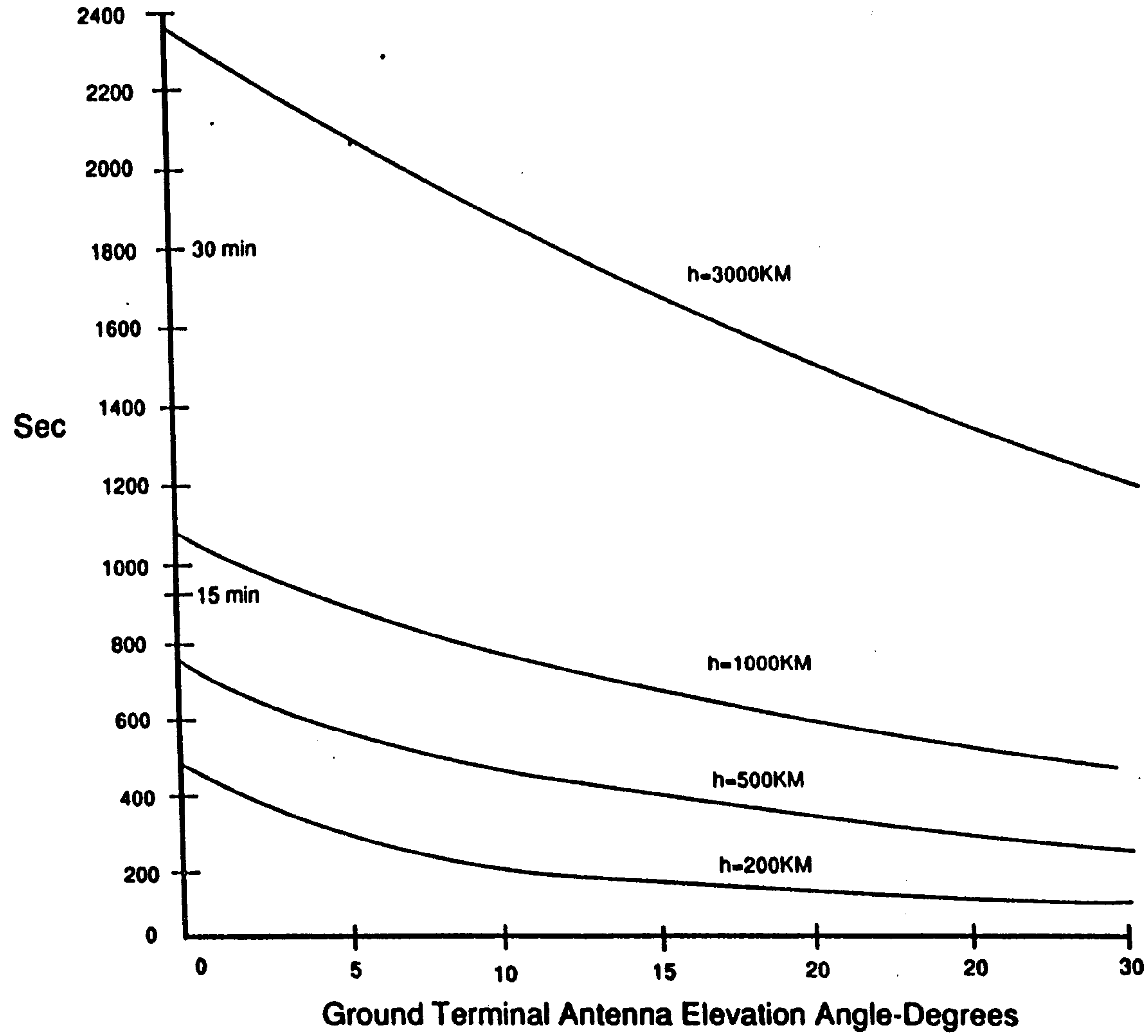


Figure 6. The LEO satellite visibility time.

earth coverage but at the price of specialized and complex user equipment. However, due to the extremely large quantities of ground terminals involved, the projected unit cost will be low.

NASA's tracking data relay satellite system (TDRSS) consists of three geosynchronous satellites that provide overlapping coverage of the Pacific Ocean, North America, South America, and the Atlantic Ocean at the S and K bands. The low data rate (50-kHz) multiple access (MA) S-band link operates with a phased array that can point multiple beams at any earth spot or LEO satellite.

The high data rate (20-MHz SSA-FWD, 10 MHz SSA-RET, 50-MHz KSA-FWD, and 225-MHz KSA-RET) S- and K-band links operate with two steerable high-gain antennas that can point at any earth spot. The disadvantage of the TDRSS system is that all the communications must be looped back via the TDRSS ground terminal.

The general advantage of military satellite systems is the inclusion of COMSEC and TRANSEC requirements, but it is offset by the requirement for strict waveform compatibility. The processing complexity drives the size, weight, power consumption, and cost. Recent developments such as the Advanced Scamp ground terminal use advanced technologies to reduce size, weight, and power consumption -- which make them truly portable. Commercial, international, government, and military satellite systems are described in Section 5.0, "Survey of Satellite Systems."

4.2 SYSTEM CONFIGURATION/ARCHITECTURE

The intelligence-gathering system architecture is depicted in Figure 1. The RTSs are deployed in the denied and/or hostile areas and collect information needed by the theater commander for his decision-making process. The RTSs modes of operation are controlled by C&CCs collocated with the friendly forces. The control is direct, positive, and timely to provide meaningful data to the theater commander.

Based upon the need of the theater commander, the C&CC controller collects, prioritizes, and reduces the received data to a format that is compatible with the friendly forces requirements. This may be event history, correlation with other events, quantitative data, time tags, and/or geographical location.

The command and data flow between the RTSs and the C&CCs is via a satellite and/or the satellite constellation whose footprint covers the theater of operation. The C&CC operator controls the RTS modes and its associated sensors via the forward satellite link commands and algorithms located in the memory, formats the operational profile, and controls the data received. System status provides self test, status, and communications-link quality information.

These data will be displayed and recorded at the mobile C&CCs, and the return communications link will have low probability of detection and low probability of intercept. The low probability of detection will be implemented by data encryption and the low probability of intercept by appropriate band spreading, frequency hopping, or data bursting.

Communication between ground terminal and satellite requires a clear line-of-sight propagation condition. For the GEO satellite, this requirement determines maximum elevation angle for an RTS antenna as a function of location latitude. Figure 7 gives ground terminal elevation angle and shows that for latitude and longitude differences $>60°$ from zenith, the maximum antenna elevation angle is $>20°$. At these angles, the nearby buildings and hills could pose a problem.

4.3 SYSTEM CONTROL AND DATA FLOW

The system control is implemented via the forward communications link. There are three types of controls: 1) direct command to implement a specific control, 2) software selection to implement algorithms-controlled activity, and 3) request for status data. Both the direct

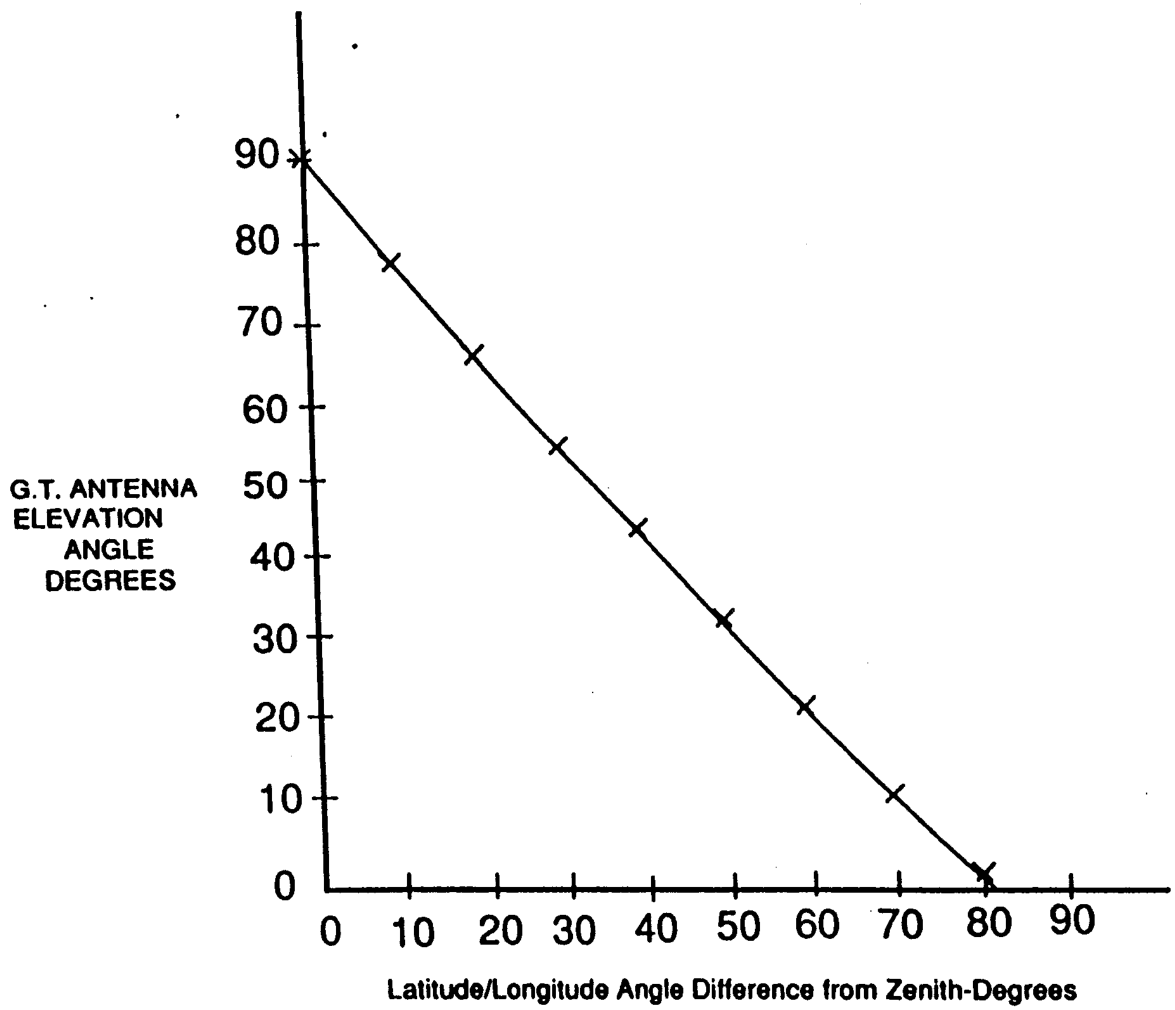


Figure 7. Ground terminal antenna elevation angle.

command and status request require a low data rate, but the RTS memory loading may require either a longer transmit time or a higher data rate. This, of course, will depend upon the size of the algorithm. In general, the control link data rate will be much lower than the RTS transmit data rate.

The RTS transmit data rate will be substantial and will depend upon area activity, monitored parameter type, and the RTS operational mode. The received sensor data will be digitized and loaded into memory for storage, formatting, and transmission upon command generated remotely by the C&CC or locally by the RTS. Figure 8 provides a parametric graph of RTS memory size versus data rates and transmission times. For a given data size, we can trade off data rate against transmission time. Similarly, the data rate, for a given link frequency, range, and satellite G/T, will be directly proportional to RTS EIRP and inversely proportional to the link SNR. This, in turn, will determine RTS transmitter power and antenna gain product and power consumption.

4.4 MISSION PROFILE

There are five distinct phases that describe the mission profile from information request to mission termination. They are:

1. Mission requirements analysis and planning,

2. System setup and test,

3. RTS equipment deployment,

4. System operation, and

5. Mission termination.

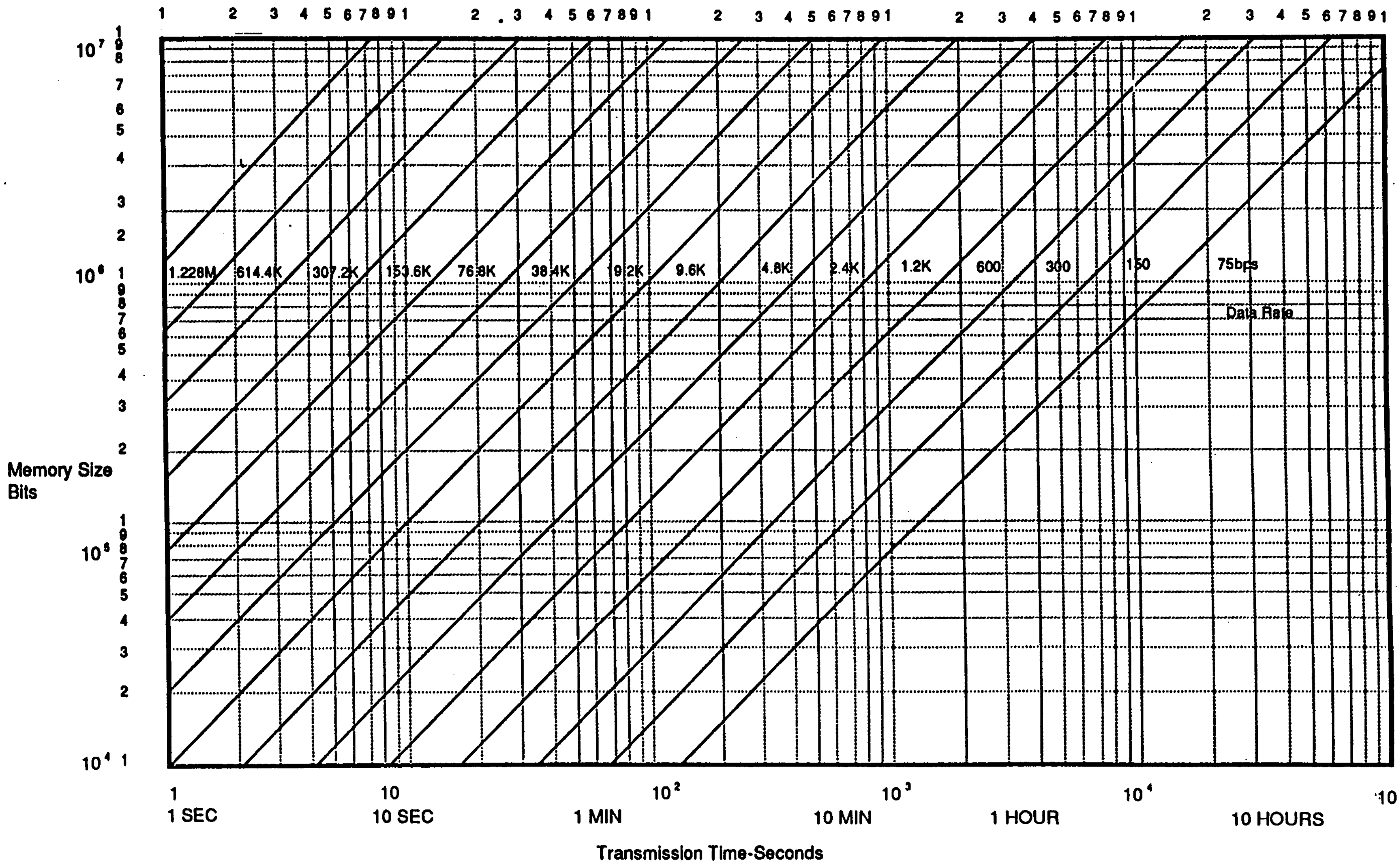


Figure 8. Memory size as a function of data rate and transmission time.

4.4.1 Mission Requirements, Analysis, and Planning

Intelligence information requests from the theater commander will establish mission priority and duration, support required, type of data requested, and response time.

The C&CC controller will translate these requirements into sensor types, memory size, operational modes, data processing, antenna size/type, and battery size. He will also select the satellite, reserve the communication channel, and establish access protocols and priorities. Further, he will establish visual- and electromagnetic-covertness requirements, onsite setup and testing, military personnel training and will perform mission success risk assessment. He will coordinate deployment methods with military personnel and establish any special equipment packaging, handling, deployment and camouflage requirements.

4.4.2 System Setup and Test

The C&CC controller will assemble and set up the RTS and sensor equipment and establish a satellite link between the C&CC and the RTS. He will perform RTS equipment checkout, verify whole-system operation, and train the deployment personnel in equipment assembly, setup, and checkout.

4.4.3 The RTS Equipment Deployment

The RTS equipment deployment will be performed by military personnel who have been given basic equipment handling, setup, and testing training. The actual deployment mode will be established by the military. This may be by land, air, water-borne vehicle, or parachute drop. The deployment will be performed, most probably, under cover of darkness and/or under hostile environment. Therefore, it is imperative to mission success that assembly, setup, and checkout be as simple as possible, be performed without complex additional equipment, and in total darkness.

Since the carried RTS equipment will be in addition to the standard military gear and survival equipment, it must be compatible with deployment unit capabilities.

4.4.4 System Operation

The mission system operation will start with RTS unit checkout and establishment of RTS-satellite-C&CC link connectivity. The C&CC controller will have the RTS under direct control via the satellite link. He will display the sensor data, command the appropriate modes, record and reduce the data to the format required by the military, and interface with the theater commander, who will assess the usefulness of the data contents. The controller will also modify the system operation modes to reflect both the changing environment and the needs of the theater commander.

4.4.5 Mission Termination

Mission termination will occur upon battery discharge or upon deliberate termination of transmission. The mission termination decision may include an RTS-destruct command to prevent equipment use for counterintelligence purposes. The satellite link will be disabled and assigned for other purposes. The collected data will be archived for postmission analysis, system effectiveness analysis, and C&CC personnel training.

4.5 OPERATIONAL CONSTRAINTS

4.5.1 Earth Coverage (Satellite Access by RTS)

Geostationary satellites provide near-vertical access to ground terminals in near-equator regions. This minimizes subsatellite position atmospheric and rain losses as well as receiving system noise. However, as the latitude increases from the equator, the RTS antenna elevation angle decreases to 10° above latitudes of 70°. The same occurs as the RTS longitudinal location departs from the GEO satellite radar position. However, the GEO satellites are usually spaced with a substantial overlap in longitudinal direction. Figure 7 shows the RTS antenna elevation angle as a function of latitude for a GEO satellite.

For polar region coverage, Molnya or LEO polar satellite orbits are required. They offer polar coverage at the expense of the noncontinuous coverage and wide-antenna pointing (horizon-to-horizon) requirements. While the 12-hour Molnya orbit offers repeated and extensive coverage, the LEO polar orbit offers limited-area and time-duration coverage at revisit times determined by orbit precession with respect to the earth's rotation. Figures 5 and 6 show a LEO satellite's earth coverage and visibility time.

4.5.2 Terrain, Access, and Site Location

A satellite communications link requires clear line-of-sight propagation conditions. Consequently, a mountainous terrain will impose an RTS location constraint, and the higher the latitude, the lower the antenna elevation angle for a GEO satellite. However, all areas of interest lie within ± 40° of latitude.

Dense foliage canopy, especially in tropical regions, can produce substantial signal attenuation. To avoid this, the antenna will have to be located high on a tree or in a reasonably wide forest clearance.

The last stage of equipment delivery will be performed manually by a combat crew with limited installation training. Reasonably uneven terrain with foliage and soft ground is preferable for implementation of visual covertness. Camouflage nets, color matching, and use of nonreflecting surfaces will aid in visual covertness.

4.5.3 Mission Duration

Temperature extremes can seriously effect battery discharge efficiency. To avoid this, the battery should be encased in a good thermal blanket and, if possible, located several feet underground. A dry, 5-ft deep hole covered with loose soil is usually sufficient to isolate the battery from the most severe temperature extremes.

Since the transmit data rate is directly proportional to the dc power consumed, data reduction and prioritization will extend mission duration. Further, use of solar batteries will permit battery recharge and extend mission duration indefinitely.

4.5.4 Climate and Weather

The basic parameters of climate and weather are temperature, wind, cloud coverage, and precipitation. They are functions of geographical location, season, and difficult-to-estimate statistical distribution.

The main effects of low temperature and cloud coverage are reduction in battery discharge efficiency and reduction in charging by solar battery respectively. Both of them reduce mission duration. Use of a Ni-Cd battery will reduce the battery operating temperature to -10°C, and insulating the battery from environment, as mentioned above, will alleviate the problem. There is also an attendant propagation attenuation with cloud coverage, but it occurs only at the higher frequencies, above 20 GHz.

The main effect of wind is upon the antenna pointing accuracy. This may be a major problem in high-gain narrow-beam parabolic antennas requiring solid anchorage and reflector rigidity. This effect can be substantially reduced by using newly-developing technologies that allow transformation of physically flat surfaces into electrically parabolic surfaces. Physical surfaces are shaped electronically by an array of passive dipoles suspended above a conductive ground surface. The dipoles are sized and spaced for the particular frequency and the physical shape to be obtained. The physically flat surface can be made of strings on which the phase shifting dipoles and ground plane can be mounted. Such an antenna will exhibit very low wind resistance.

Precipitation has a major effect upon communications. It changes the polarization and increases signal attenuation. Temperate zone rain introduces link attenuation that is of medium intensity and static over hours/days, covers large areas, and follows slowly varying patterns. On the other hand, tropical zone rain introduces attenuation that is high, very dynamic over short periods of time, and covers small areas. The details of rain attenuation are given in the next section, entitled "Rain Attenuation."

4.5.5 Rain Attenuation

Ground terminal-to-satellite signal rain attenuation can be estimated using techniques based upon the modified Global Prediction model, which is an extension of the Crane model. This model is based upon the geographical distribution of earth surface rainfall statistics. Further, the model uses a rain layer of 0° C isotherm height in terms of latitude and probability of occurrence, as well as the antenna elevation angle to compute the rain path length. The end result is rain attenuation given in terms of rain statistics, climate zones, 0° C isotherm layer height and satellite, rain cloud, and ground terminal geometrical configuration.

Weather bureau rainfall predictions are usually given in cummulative annual and seasonal statistics that are averaged over long periods of time. This is of limited use in propagation attenuation prediction in temperate climate zones and even of more limited use in tropical climate zones.

Rain rate statistics show that rain rate increases very rapidly as we move from the temperate to tropical climate zones. Further, the rain rate also increases rapidly as the rain rate measurement averaging time is reduced from the usual year to days, hours, and minutes to expose the finer structure of seasonal, daily, hourly, and minute interval dynamics.

There is also a further refinement in rain characterization. Two extreme examples are the steady and moderate rain rates that are characteristic of parts of Europe and the USA and the dynamic and extreme (very low to very high) rain rates that are characteristic of near-equatorial locations in Latin America, Africa, and the island parts of Asia. While the moderately steady stable rain falls from hours to days and covers areas in excess of 100 km, the dynamic tropical rain falls from tens of minutes to 1 or 2 hours and covers areas of 3 to 5 km.

This is exactly the information that the propagation attenuation model requires to account for instantaneous link SNR, attenuation dynamics, and time profile. These data can be used for the selection of preventive measures, such as variable output power, message repeat, and space, angle, and frequency diversities.

This shows that excessive rain margins are required for a very low probability of outages in tropical regions. However, when moderate annual outages are acceptable, very reasonable rain attenuation margins result. Consequently, low power outputs, low antenna gains, low dc power consumption, and lightweight primary-power batteries are possible. Thus, for reasonable link outages and frequencies below 15 to 20 GHz, rain attenuation does not pose serious problems.

The methodology and an example of rain attenuation has been extracted from a NASA document entitled "A Propagation Effects Handbook for Satellite System Design," ORI TR 1979.

5.0 SURVEY OF SATELLITE SYSTEMS

5.1 INTRODUCTION

A survey of satcom systems was performed using published data, government and commercial documents, and vendor literature. The data used included:

- *Communications Satellite Handbook* (Ref.3)
- *World Satellite Communications and Earth Station Design* (Ref.4)
- *Jane's Military Communications, 1992* (Ref.5)
- *Jane's Space Flight Directory, 1992* (Ref.6)
- MIL-STD-1582 (unclassified) (Ref.7)
- *Space News*
- Commercial advertising literature

The criteria used for selection of candidate satellite systems for system analysis were:

- Coverage of areas of interest
- Waveform compatibility requirements
- Satellite system availability

- RTS EIRP and G/T requirements

- Availability of portable ground terminals

It soon became obvious that the usual GEO satellite locations above the Atlantic, Indian, and Pacific Oceans give very good coverage of the areas of interest. As stated above, Table 1 lists countries of interest and their geographical locations, and Figure 2 shows a map of the world with each country's location superimposed on it. Out of a total of 26 locations, 20 lie in Africa and Asia, and can be covered by a single satellite located over the Indian Ocean. The remaining six locations in South America can be covered by a satellite located over the Atlantic Ocean. Furthermore, all the locations lie within 40° of south and north latitudes, which translates into a ground terminal antenna elevation angle restriction to above 45° in the latitude direction from subsatellite position. Figure 7 shows the ground terminal antenna elevation angle as a function of latitude or longitude departure from subsatellite position.

Each selected satellite system's global coverage is superimposed upon a world map to show coverage by individual satellites and overlap between two adjacent satellites. Note that the new and replacement satellites reflect upgrades in transponder design and changes in satellite positions which will affect coverage of locations that lie on coverage fringes.

5.2 SATELLITE SYSTEM CHARACTERISTICS

The following satellite systems were surveyed and analyzed for compatibility with RTS requirements:

- INTELSAT V, VA, VI, VII

- INMARSAT II

- IRIDIUM

- TDRSS
- DSCS II, III
- MILSTAR
- FLTSATCOM/AFSATCOM
- UFO

Sections 5.2.1 through 5.2.8 provide summaries of satellites, frequencies, transmit and receive characteristics, antenna characteristics, launch history, locations, and earth coverage.

5.2.1 International Telecommunications Satellite Organization (INTELSAT)

General Description

INTELSAT is an international organization that controls the international traffic via satellites. The satellites are owned and operated by the organization, and the ground terminals by member countries. The satellites are located over the Atlantic region to carry the USA–Europe traffic, over the Pacific region to carry the Asia–USA traffic, and over the Indian region to carry the Asian traffic.

The system handles telephone, telegraph, data, and television traffic, with the telephone taking a major proportion of the total volume. The initial multiplexing and modulation format was frequency division multiplexing/frequency modulation (FDM/FM). However, in the eighties, a transition was begun to satellite-switched/time division multiple access (SS/TDMA) and code division multiple access (CDMA) multiplexing and phase shift keying (PSK) modulation. This has improved bandwidth efficiency and has allowed dynamic sharing of resources.

Detailed Description

The INTELSAT satellite system consists of three satellites positioned over the Atlantic, Indian, and Pacific regions. Earth coverage by each satellite for 10° RTS antenna elevation angle is given on the map in Figure 9. All areas of interest are well inside the RTS antenna elevation angle of 10°. The RTS can communicate with the INTELSAT satellite, but due to the small size antenna and low RF output power it has to utilize a substantial part of the channel resources to obtain a positive SNR. Tables 3 a and b through 6 a and b give details of satellite system characteristics.

5.2.2 Intergovernmental Maritime Organizations (INMARSAT)

General Description

INMARSAT is an international organization that controls the satellite communications between shore and shipborne terminals. The system consists of four segments. The space segment consists of satellites owned or leased by the INMARSAT organization. The network control segment is controlled from the INMARSAT operations control center in London. The coastal earth stations' segment stations are owned and operated by INMARSAT members. And the mobile segments' ship earth stations are owned/leased by the ship owners.

Initially, the INMARSAT used leased satellites but since 1990 it has had four satellites to cover the east Atlantic, west Atlantic, east Pacific, west Pacific, and Indian Oceans regions. The services include voice, telex, and data at 2,400 bps. However, data rates of up to 10 Mbps are possible with large antennas.

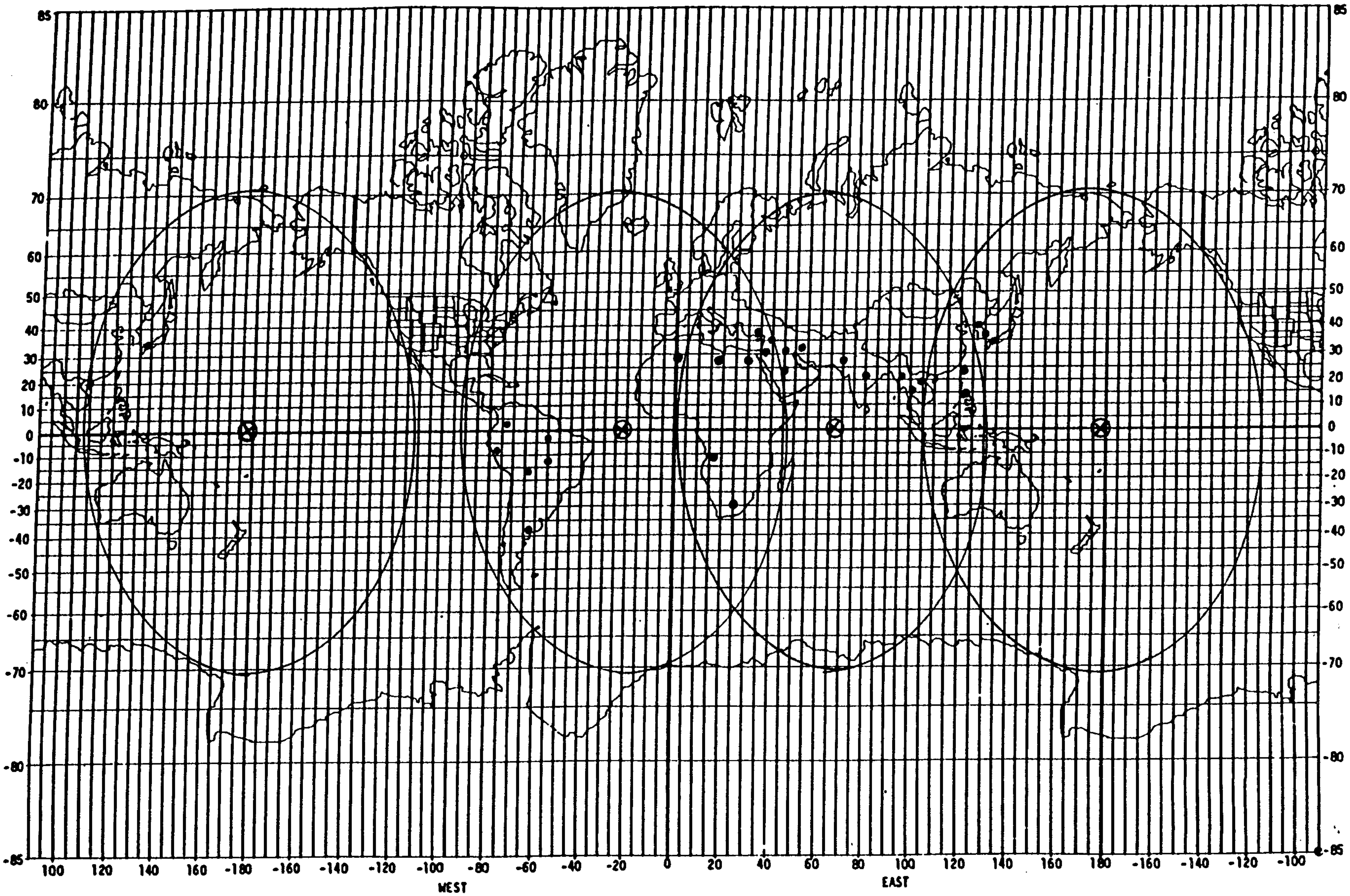


Figure 9. INTELSAT -- map of earth coverage.

Table 3. INTELSAT V system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq.MHz	G/TE dB/°K	Freq. MHz	EIRP dBW
INTELSAT V	3	GEO	177°W Pacific 22°W Atlantic 66°E Indian	5,929-6,423	-18.6 Global -11.6 Hemi. -8.6 Zone	3,707-4,198	23.5 Global 26.0 Zone 29.0 Zone
				14,004-14,498	0.0 E-Spot +3.3 W-Spot	10,945-11,191 11,459-11,698	41.1 E-Spot 44.4 W-Spot
				1,636.5-1,644.5	-15.0	1,535-1,542.5	32.6
				6,417.5-6,425	-17.5	4,192.5-4,200.5	20.0

Table 3 (concluded). **INTELSAT V system characteristics (b) antenna and orbit.**

Antenna		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
6 GHz Horn Earth Cov. Gain 14.5 dB BW 22 deg. Dish 61" dia.	4 GHz Horn Earth Cov. Gain 16.5 dB BW 18 deg. Dish 96" dia. Hemi. Cov. Gain 21.5	F 2	12-11-80		22°W Atlantic
		F 1	5-23-81		177°E Pacific
		F 3	12-81		177°E Pacific
		F 4	3-5-82		34.5°W Atlantic
		F 5	9-28-82		66° E Indian
		F 6	5-19-83		18.5°W Atlantic
		F 7	10-19-83	Retired	
14 GHz Narrow West Gain 36 dB BW 1.6 deg. East Gain 33 dB BW 1.8x3.3 deg. Maritime Communication 1.6 GHz Gain 14.0 dB BW 18.0 deg. 6 GHz Horn Global Cov.	11 GHz Narrow West Gain 36 dB BW 1.6 deg. East Gain 33 dB BW 1.8x3.3 deg. 1.5 GHz Gain 14.0 dB BW 18.0 deg 4 GHz Horn Global Cov.	F 8	3-4-84		180°W Pacific
		F 9	6-85	Failure	

Table 4. INTELSAT VA system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq.MHz	G/TE dB/°K	Freq. MHz	Eirp dBW
INTELSAT VA	3	GEO		5,929-6,423	-16.0 Global -9.0 ZONE	3,704-4,198	23.5 Global 26.0 Zone 29.0 Zone 32.5 Spot
				14,004-14,498	+1.0 E-SPOT		
					+4.3 W-SPOT	10,945-11,191	41.1 E-Spot
						11,495-11,698	44.4 W-Spot

Table 4 (concluded). INTELSAT VA system characteristics (b) antenna and orbit.

Antenna		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
4 GHz	6 GHz	F 1	3-85		174° E Pacific
Horn	Horn				
Earth Cov.	Earth Cov.	F 2	6-85		63° E Indian
Gain 14.5 dB	Gain 16.5 dB				
BW 22 deg.	BW 18 deg.	F 3	9-29-85		1° W Atlantic
Dish	Dish				
61" dia.	96" dia.	F 5	5-86	Failure	
Hemi. Cov.	Hemi. Cov.				
Gain 21.5 dB	Gain 21.5 dB	F 4	5-17-88		53° W Atlantic
Zone Cov.	Zone Cov.				
Gain 24.5 dB	Gain 24.5 dB	F 6	1-89		60° E Indian
14 GHz	11 GHz				
Dish-Narrow B	Dish-Narrow B				
West	West				
Gain 36 dB.	Gain 36 dB				
BW 1.6 deg.	BW 1.6 deg.				
East	East				
Gain 33 dB	Gain 33 dB				
BW 1.8x3.2 deg.	BW 1.8x3.2 deg.				

Table 5. INTELSAT VI system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
INTELSAT VI	4	GEO		5,854,-6,423	-16.0 Global	3,629-4,198	26 Global
					-9.0 Hemi.		34-37 Hemi.
					-6.0 Zone		31 Zone
				14,004-14,498	+1.0 E-Spot	10,954-11,191	41 E-Spot
					+4.0 W-Spot	11,459-11,698	44 W-Spot

Table 5 (concluded). INTELSAT VI system characteristics (b) antenna and orbit.

Antenna		Orbital history			
Receive	**Transmit**	**Sat**	**Launch**	**Status**	**Longitude**
6 GHz	4 GHz	F 2	10-27-89		24.5° W Atlantic
Horn	Horn				
Earth Cov.	Earth Cov.	F 3	3-14-90	Low Orbit	
Dish	Dish				
79" dia.	126" dia.	F 4	6-23-90		27.5° W Atlantic
Hemi. and Zone Cov.	Hemi. and Zone Cov.				
		F 5	8-19-91	In test	
14 GHz	11 GHz				
Dish	Dish	F 1	10-29-91	In test	
39" dia.	43" dia.				
W-Spot	W-Spot				
Gain 36 dB	gain 36 dB				
BW 1.6 deg.	BW 1.6 deg.				
E-Spot	E-Spot				
Gain 33 dB	Gain 33 dB				
BW 1.8x3.2 deg.	BW 1.8x3.2 deg.				

Table 6. INTELSAT VII system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/Te dB/°K	Freq. MHz	EIRP dBW
INTELSAT VII	3	GEO		5,929-6,423	-11.5 Global	3,704-4,198	26 to 29 Global 33 to 36 Spot 33 Zone
					-3.0 Spot		
					-8.5 Hemi. 1		
					-7.5 Hemi. 2	11,945-11,191	43.4 to 46.7 Spot 1
					-6 to 9 Zone B1	11,458-11,694	41.4 to 45.8 Spot 2
					-4 to -7.5 Zone B2	11,704-11,941	41.2 to 44.1 Spot 2 & 2A
				14,004-14,494	+1.5 to +4.5 Spot 1	12,504-12,741	4.30 to 47.5 Spot 3
					-1.0 to 2.5 Spot 2 & 2A		
					+0.8 to +3.8 Spot 3		

Table 6 (concluded). **INTELSAT VI system characteristics (b) antenna and orbit.**

Antenna		Orbital History			
Receive	**Transmit**	**Sat**	**Launch**	**Status**	**Longitude**
6 Hz	4 GHz	F 1	1993		
Horn	Horn				
Global Cov.	Global Cov.	F 2	1993		
Gain 16.8 dB	Gain 16.8 dB				
BW 18 deg.	BW 18 deg.	F 3	Uncertain		
Dish	Dish				
28" dia.	28" dia.	F 4	Uncertain		
Spot	Spot				
Gain 24.8 dB	Gain 24.5 dB	F 5	Uncertain		
BW 6 deg.	BW 6 deg.				
62" dia.	96" Dia.				
Hemi. and Zone Cov.	Hemi. and Zone Cov.				
14 GHz	11/12 GHz				

Three types of ship earth stations are available to serve the ships. In 1989, a small mobile terminal (type C) was introduced for use by the smaller ships, trucks and aircraft. Due to the small antenna size, the service includes only low data rate (1,000 bps) messages.

Detailed Description

The INMARSAT satellite constellation consists of four geostationary satellites positioned over the east Atlantic, west Atlantic, Indian, and Pacific Oceans. As in the case of the INTELSAT system, all the identified areas of interest lie within an RTS antenna elevation angle of 10° in the longitude direction and within 45° in the latitude direction. Earth coverage for each satellite is displayed on the world map shown in Figure 10.

An RTS can communicate with the INMARSAT satellite. The B-type ship earth station with 1.5-ft diameter antenna, 26-dBW EIRP, and -12 dB/°K G/T will provide one voice or a 2,400-bps data channel. Tables 7 a and b give details of satellite system characteristics.

5.2.3 <u>IRIDIUM</u>

General Description

The IRIDIUM system was designed for round-the-world voice communication. Since the phone set had to be small, low power, and use a low-gain antenna, the system was designed to use low-earth orbit (778 km) satellites. The satellite constellation consists of 66 satellites flying in polar orbits, shown in Figure 11.

Due to rapidly changing satellite positions with respect to the user, the system requires rapid and complex satellite position determination, frequency and range tracking, satellite-to-satellite handover, monitoring, and control. The system will support duplex voice, paging, facsimile, and data transmissions.

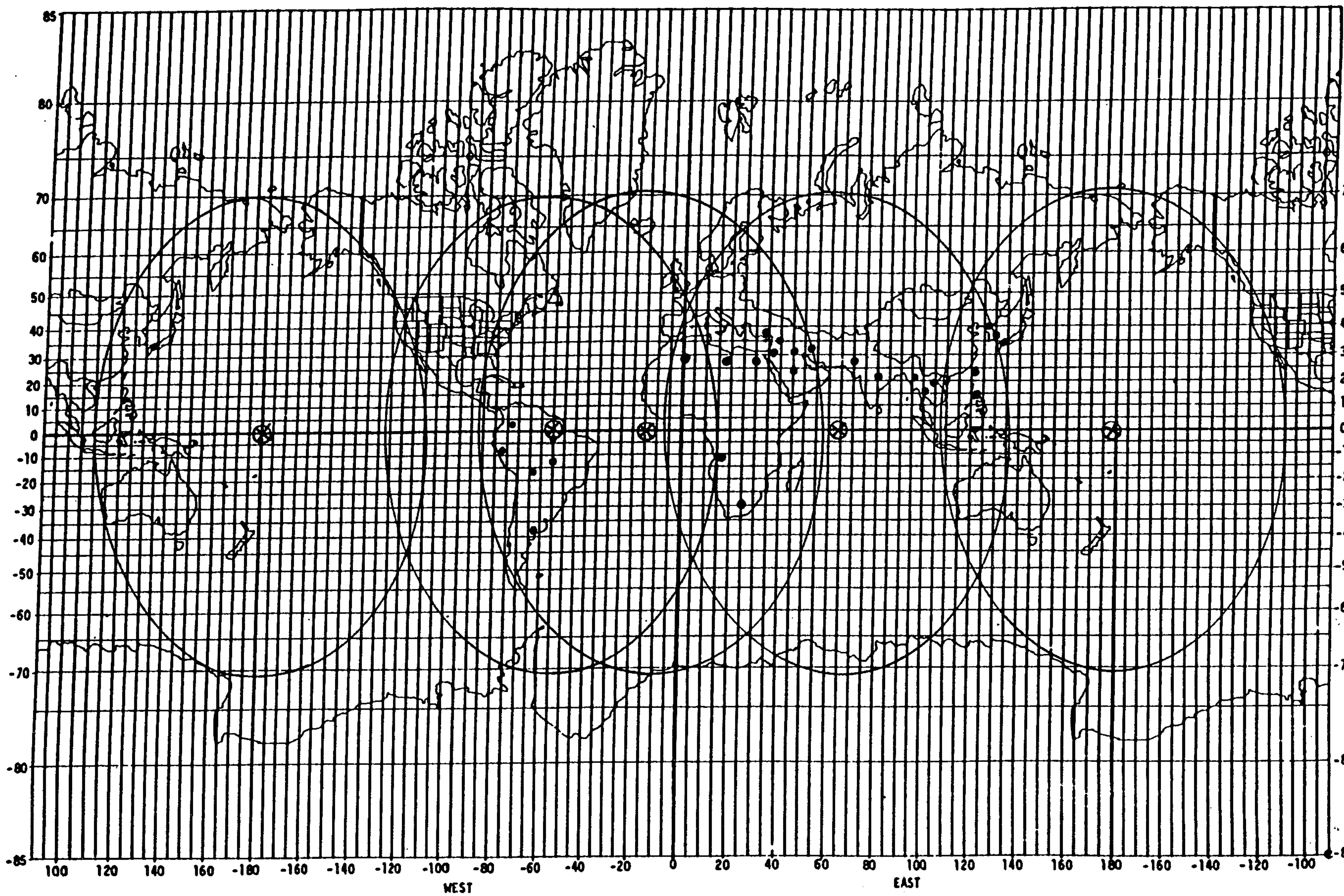


Figure 10. INMARSAT -- map of earth coverage.

Table 7. INMARSAT system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Fre. MHz	EIRP dBW
INMARSAT II	4	GEO	178° E Pacific 15.5° W Atlantic 64.5° E Indian	1,626.5-1,631.0	-12.5	1,530-1,546	39.0
				1,631.5-1,636.0	-12.5	3,600-3,604.5	24.0
				1,636.5-1,643.8	-12.5	3,605-3,609.5	24.0
				1,644.3-1,647.5	-12.5	3,610-3,617.5	24.0
				6,425-6,441	-14.0	3,617.8-3,621	24.0

Table 7 (concluded). INMARSAT system characteristics (b) antenna and orbit.

Antennas		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
L-Band A-Element Array	L-Band 61-Element Array	1	10-30-90	Operational	56° W
		2	3-8-91	Operational	15.5° W
C-Band 7-Element Array	C-Band 7-Element Array	3	91 or 92		
		4	92		

Figure 11. IRIDIUM satellite constellation.

Its main advantages will be worldwide coverage via cross satellite links, small size, weight, and power consumption. The main disadvantage may be with the complex control system and ability to provide low probabilities of detection and intercept. The first commercial service is planned for early 1998. The available satellite system characteristics are given in Table 8.

5.2.4 Tracking and Data Relay Satellite System (TDRSS)

General Description

The TDRSS system was developed to overcome the need for a worldwide network of ground stations to service LEO satellites. Because of the low-satellite altitude (<1,000 nmi), the ratio of satellite overflight to revisit times is very low (typically <15%). Three TDRSS satellites located in GEO orbits will provide 85 percent LEO satellite coverage.

Two basic services are provided. Multiple access (MA) provides one forward link to TDRSS which is sequentially shared by the users, and up to 20 simultaneous return links. The single access services provide S-band SSA and K-band KSA duplex services at high data rates. Two combined S-and K-band steerable antennas are used to handle two high data rate users.

Detailed Description

The TDRSS GEO satellite constellation consists of three satellites that are located at 53° W, 115° W, and 171° W longitudes. This optimizes coverage of North and South America, and the Atlantic and Pacific Oceans. The Pacific Ocean coverage includes Taiwan and the Philippines, and the Atlantic coverage includes Algeria and Angola, with a possibly marginal coverage of Libia and South Africa. Figure 12 shows a map of TDRSS coverage and areas of interest that are covered.

Table 8. IRIDIUM system characteristics.

Satellite System	No Sat	Orbit	Orbit Type	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
IRIDIUM	66	LEO 778 KM	Polar	2,483.5-2,500.0		1,610.0-1,626.5	

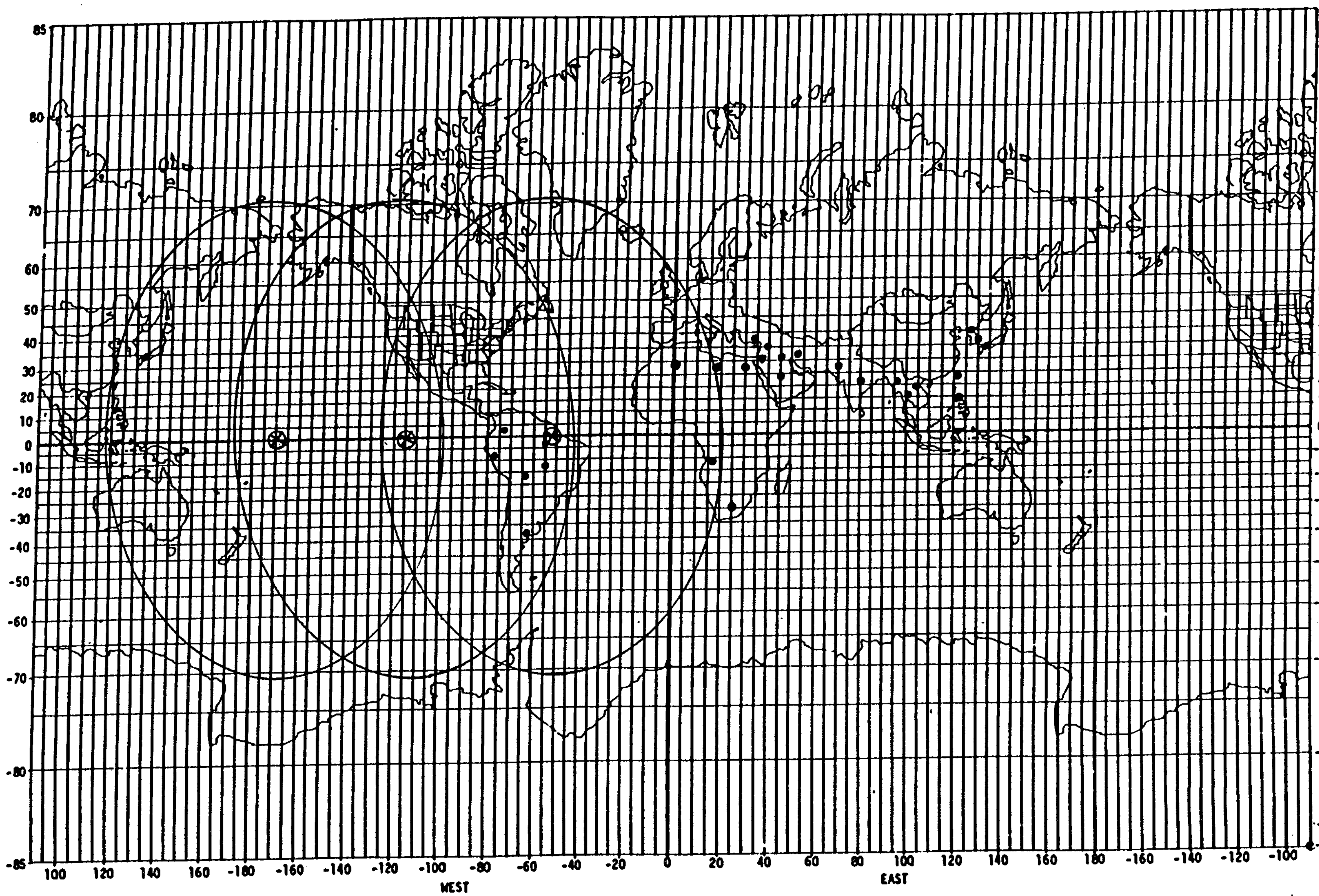


Figure 12. TDRSS -- map of earth coverage.

The TDRSS gives excellent coverage of South America, and multiple access is very compatible with the RTS requirements. It has been specially designed to communicate with low-earth orbit satellites that use low data rates. S-band frequency is especially convenient for operation in the very wet South America climate because of low rain loss. Tables 9 a and b give details of TDRSS satellite system characteristics.

5.2.5 <u>Defense Satellite Communications System (DSCS II and III)</u>

General Description

The DSCS system was developed for the worldwide military command and control system that services ground mobile forces, Navy ships, White House communications, and diplomatic telecommunications. Five satellites cover east Atlantic, west Atlantic, Indian, east Pacific and west Pacific regions with considerable overlap.

The control segment provides considerable flexibility to the user which includes antenna patterns, connectivities, EIRP, and G/T. Link capacity includes teletype, voice, and data from several kbps to 10 Mbps. Modulation formats are frequency division multiple access (FDMA) and spread spectrum multiple access (SSMA).

Detailed Description

The DSCS satellite system consists of four GEO satellites whose earth coverage is shown on the world map in Figure 13.

All the areas of interest are covered by the DSCS satellite system. The RTS ground terminal can communicate with the DSCS satellite but due to small size antenna and low RF power output has to utilize a substantial part of channel resources to obtain a positive signal-to-noise ratio (SNR). Tables 10 a and b through 11 a and b give DSCS II and II satellite system characteristics.

Table 9. TDRSS system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
TDRSS	3	GEO	41° W	MA 2,285-2,290	-1.0	M.A. 2,103.4-2,109.4	34
			115° W				
			171° W	SSA 2,200-2,300	+8.9	SSA 2,025.8-2,117.9	44.0/46.4
				KSA 14,891-15,116	+24.4	KSA 13.75-13.8	49.4

Table 9 (concluded). TDRSS system characteristics (b) antenna and orbit.

Antenna		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
MA	MA 12 Element Array	1	4-4-83	Active 89 Spare 89	42° W 170° W
20 Rec. Beams	1 Trans/Beam Gain 13 dB	2	1- -86	Destroyed	174° W
		3	9-29-88	Active	41° W
Two-16 ft. dish SSA	Two-16 ft. dish SSA	4	3-13-89	Active	
Gain 37.7 dB BW 2 deg.	Gain 36.7 dB BW 2 deg.	5	8-2-91		
KSA Gain 54.6 dB	KSA GAIN 53.5 dB	6	92		
BW 0.28 deg.	BW 0.28 deg.	7	Avail. 92 Launch 95		
Steering ±90° N-S 30°/90° E-W	±90° N-S 30°/90° E-W				

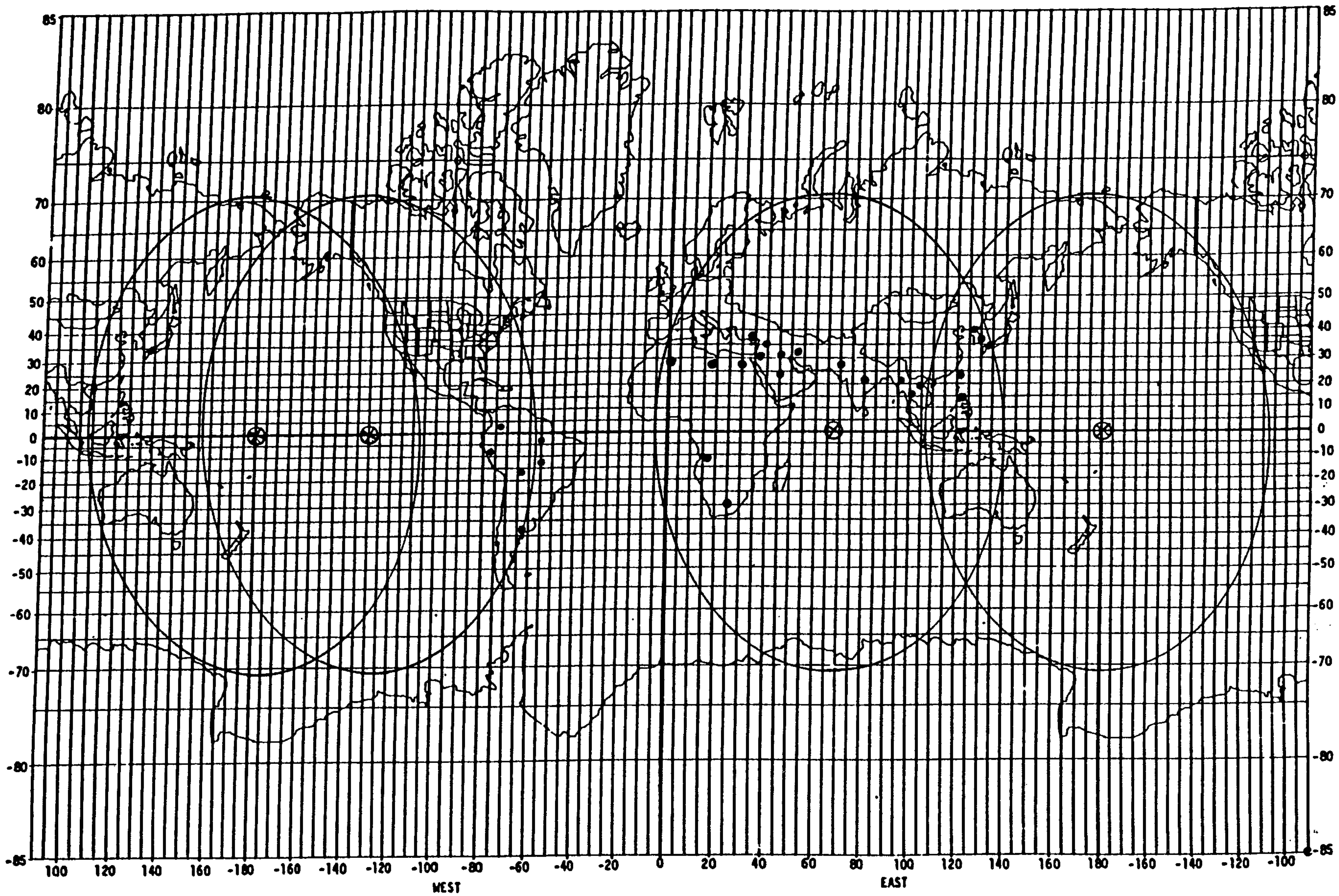


Figure 13. DSCS -- map of earth coverage.

Table 10. DSCS II system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
DSCS II	4	GEO		7,900-8,100 7,975-8,100	Earth Cov. Ant. Gain 16.8 dB NF 7.0 dB G/T 13.8	7,250-7,365	F1 - F6 28 Earth 43 N. beam 40 N. beam
				8,125-8,175 8,215-8,400	 Narrow Ant. Gain 36.5 dB N.F. 7.0 dB G/Te +5.9	7,400-7,450 7,490-7.675 7,700-7750	F7 - F12 28 Earth 43 N. beam 31 Area 46 Narrow 34 Area 41/28 Narrow and Area
							F13 - F16 31 Earth 46 Narrow 34 Area 44/33 Narrow and Area

Table 10 (concluded). DSCS II system characteristics (b) antenna and orbit.

Antenna		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
Horn Earth Cov. Gain 16.8 dB	Horn Earth Cov. Gain 16.8 dB	DSCS II 1 & 2	11-2-71	Retired	
		DSCS II 3 & 4	12-13-73	Retired	56° W
Narrow Beam 44" dia. Gain 36.5 dB BW 2.5 deg. Steering ± 10 deg.		DSCS II 5 & 6	5-20-75	Retired	
		DSCS II 7 & 8	5-12-77	Retired	
		DSCS II 9 & 10	3-25-78	Launch failure	
		DSCS II 11 & 12	12-13-78	11 Retired	79° W
				12 Spare	72° E
		DSCS II 13 & 14	11-21-79	13 Spare	180° E
				14 Spare	65° E
		DSCS II 15 & DSCS III A 2	89	Operational	
		DSCS II 16 & DSCS III A I	10-30-82	Operational	59° E

Table 11. DSCS III system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
DSCS III	4	GEO		8 GHz Band	Channels 1-6 -1.0 MBA Narrow Beam -16.0 MBA Earth -14.0 Horn Earth Cov. UHF -24.5	7 GHz Band	Channels 1 & 2 40 MBA Narrow Beam 29 MBA Earth Cov. 44 GDA Channels 3 & 4 34 MBA Narrow Beam 23 MBA Earth Cov. 25 Horn Earth Cov. 37.5 GDA Channels 5 & 6 25 Horn Earth Cov. UHF 21.3

Table 11 (concluded). DSCS III system characteristics (b) antenna and orbit.

Antenna		Orbital History			
Receive	Transmit	Sat	Launch	Status	Longitude
MBA 45" Aperture 61 Beams BW 1°	MBA 28" Aperture 19 Beams BW 1°	DSCS III - A 1 & DSCS II - 16	10-30-82	Operational	130° W
Horn Earth Cov.	GDA 33" dia. Steerable BW 3°				
UHF Crossed Dipole Gain 4 dB		DSCS III - A 2 & DSCS II - 15	89	Operational	
	Horn Earth Cov.				
	UHF Crossed Dipole Gain 4 dB	DSCS III - A 3 DSCS III - B 4 - B 5	85	In storage Operational	
		DSCS III - B 6 - B 13	92-96		
		DSCS III - B 14	92		

5.2.6 MILSTAR

General Description

In the seventies and eighties, the DoD was operating three systems (DSCS, FLTSATCOM, and AFSATCOM) for the purpose of providing secure communication links to the mobile users. The MILSTAR system was designed to provide a unified system for mobile users operating in tactical and strategic environments. The satellites and ground terminals were designed to survive and operate through all levels of conflict, and the use of a 44-GHz uplink and a 20-GHz downlink permitted use of spread spectrum to resist jamming.

The multiplexing and modulation formats are time division multiplex and frequency shift keying (FSK) and differential phase shift keying (DPSK) respectively. The waveform format is classified secret and is covered in MIL-STD-1582 (Ref. 7). The data rate per channel is limited to 2,400 bps, and 36 channels form a supergroup.

In 1982, the FLTSATCOM EMF Package (FEP) was introduced to demonstrate MILSTAR key functions and communications.

Detailed Description

The MILSTAR satellite system consists of GEO and LEO satellites that provide full earth coverage. Random frequency hopping, data encryption, data interleaving, and data repeat result in a very robust communication system that has very low probabilities of intercept and detection. All transmission timing is synchronized to an on-board precision clock and random frequency hopping key.

Communication through the MILSTAR system requires a high degree of compatibility with complex waveforms that are specified in Reference 7. As a consequence, development of the MILSTAR-compatible RTS is not a viable solution. The MIT Lincoln Labs have designed a portable MILSTAR ground terminal designated Advanced Scamp, which weighs only 30 lbs. They have used the latest technologies and large scale integration to minimize power consumption, size, and weight. Due to these constraints, the Advanced Scamp ground terminal is basically a single voice (and 2,400-bps data) channel terminal.

The Advanced Scamp terminal requires assembly at the site; however, once assembled the operation is completely automatic. The link acquisition procedure follows the following steps:

1. Operator keys in the satellite ephemeris/or position and terminal location

2. Terminal measures level, magnetic north, makes correction for the true north, and points antenna to reference position

3. Terminal computes antenna pointing and Doppler frequency shift

4. Terminal automatically performs signal acquisition in space (antenna elevation and azimuth angles), time (range), and frequency domains and then tracks the signal.

The assembled Advanced Scamp is shown in Figure 14. It consists of a base that contains batteries, a short antenna tower on which the electronics and two-foot-diameter antenna reflector are mounted, a phone/data set, and a control keyboard. Basic characteristics are given in Table 12. Advanced Scamp SNRs for reliable operation include 12-dB uplink and 5-dB downlink rain margins. Further SNR improvements can be achieved with data repeats and reduction of data rate. Data rate reduction from 2,400 bps to 75 bps will improve SNR by 15 dB. Due to the secret classification of the MILSTAR satellite parameters, link budget calculations are not given.

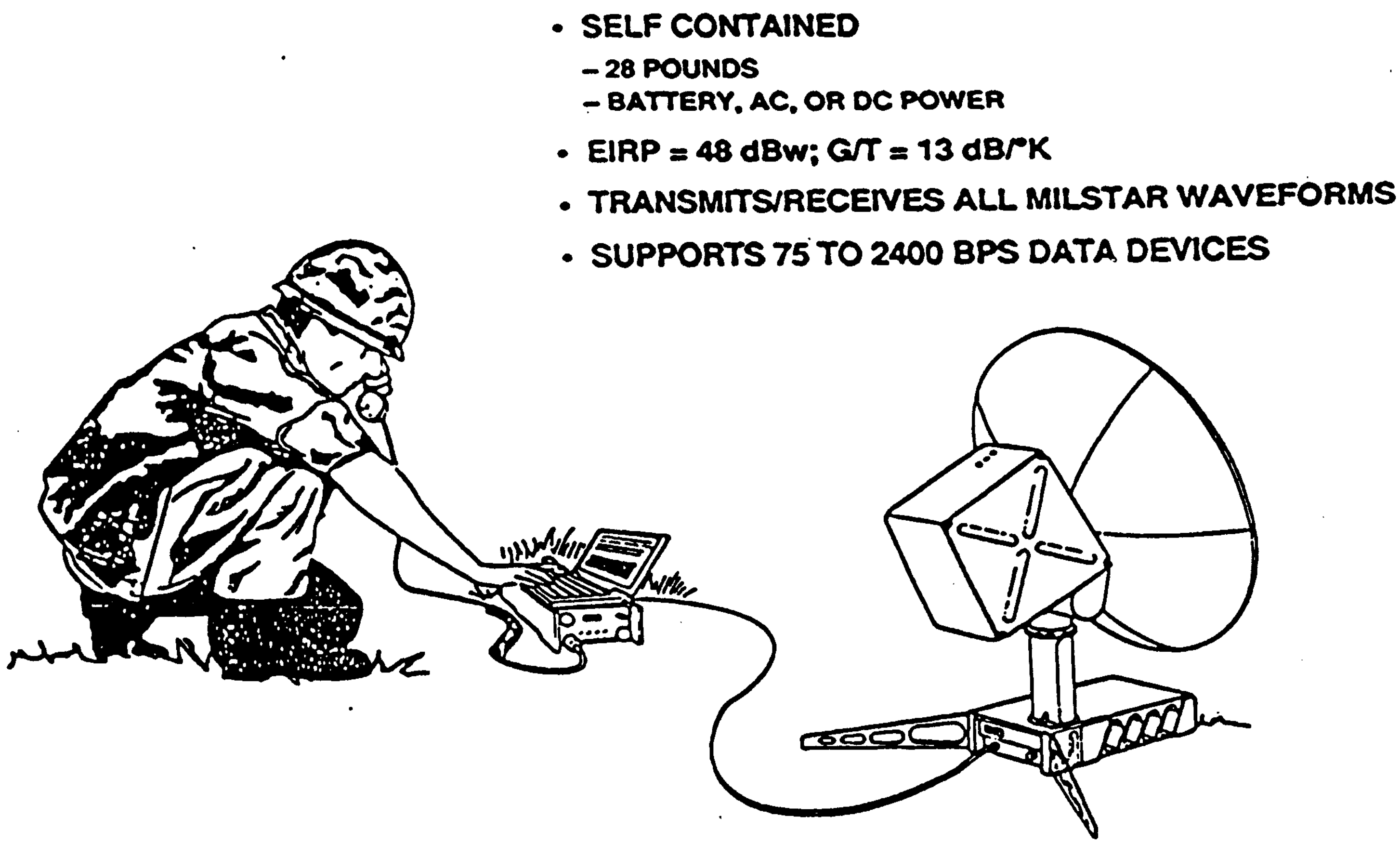


Figure 14. Assembled Advanced Scamp terminal.

Table 12. Advanced Scamp basic characteristics.

Parameter	Value
Antenna diameter	24"
EIRP	+48 dBW
G/T	+13 dB/°k
DC power transmitter	25.2 W
DC power receiver	11.7 W
Size (packed)	22"x 8"x 12"
Weight	28 lbs.

The Advanced Scamp terminal can be modified to meet RTS requirements by the addition of memory, control software, a controller, and sensor assemblies.

5.2.7 The FLTSATCOM and AFSATCOM

General Description

The UHF (225 to 400 MHz) links with mobile terminals were demonstrated with TACSAT and MIT Lincoln Labs LES-5 and -6 satellites in 1972 through 1976, and the FLTSATCOM/AFSATCOM service started in 1978.

The FLTSATCOM satellite system was developed to serve Navy surface ships, submarines, aircraft, and shore stations; and the AFSATCOM to serve Air Force strategic aircraft, airborne command posts, and ground terminals. The two systems share satellites in GEO.

Detailed Description

The FLTSATCOM/AFSATCOM satellite system consists of four geostationary orbits located at 15° W, 100° W, 78° E, and 172° E longitudes. The FLTSATCOM/AFSATCOM coverage is shown in Figure 15. The Air Force also has communication packages on several classified satellites in high-inclination orbits to provide coverage of the north polar region and single channel transponders with anti-jam improvements on DSCS III satellites.

The Navy is using one uplink broadcast channel with anti-jam capabilities at 8 GHz and eight 25-kbps relay channels at UHF. The initial use of the relay channels was to provide either 1,200- or 2,400-bps data links. To make better use of the channel capacity, the Navy is changing to TDMA format with boost rates between 9.6 and 32.0 kbps.

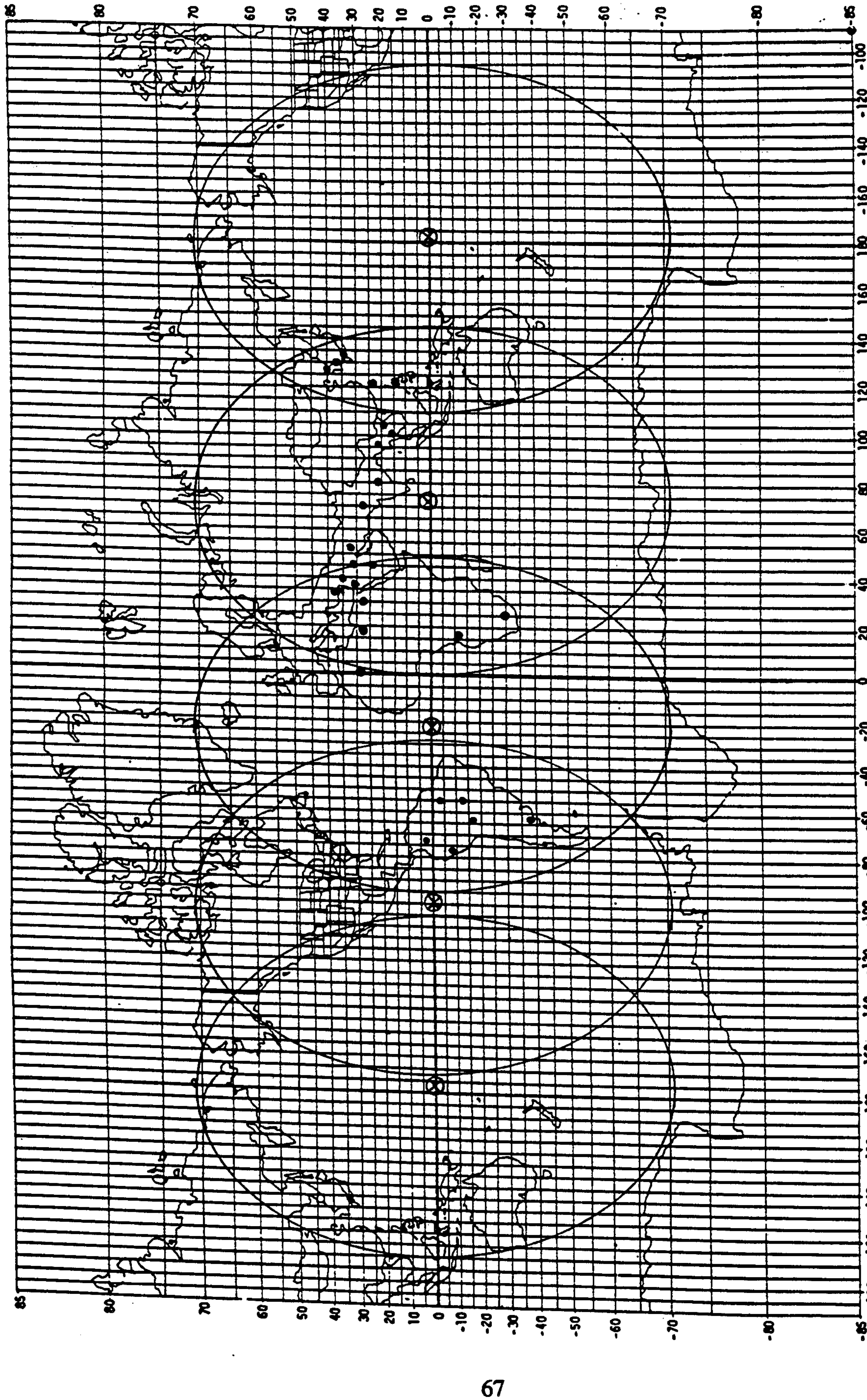


Figure 15. The FLT/AFSATCOM -- map of earth coverage.

The Air Force is using one wideband channel (500 KHz) for multiple FDMA links at a 75-bps rate each or for a single high data rate link, and twelve narrowband links at a 75-bps rate each. Tables 13 a and b give satellite system characteristics.

5.2.8 The UHF FOLLOW-ON (UFO)

General Description

The UHF (225 to 400 MHz) links with mobile terminals were demonstrated with TACSAT and MIT Lincoln Labs LES -5 and -6 satellites in 1972 through 1976, and the FLTSATCOM/ AFSATCOM service started in 1978.

The UFO system was developed to provide worldwide communication service for the Department of Defense tactical and strategic applications. The UFO satellites will be used to replace the existing FLTSATCOM and LEASAT satellites when they are no longer able to meet their mission requirements. This is expected to occur between 1997 and 2001. The UFO satellites will also carry EHF packages that are compatible with the MILSTAR satellite waveform requirements specified in Reference 7.

Detailed Description

The UFO satellite system will consist of eight GEO satellites (4 active and 4 backup) that will provide communications over four coverage areas: CONUS, the Atlantic, Pacific, and Indian Oceans. Their coverage is shown in Figure 16. The UFO system will incorporate many of the features of FLTSATCOM and LEASAT and will provide jam-resistant EHF coverage. It will have one 25-KHz fleet broadcast channel, 17 25-kHz relay channels, and 24 5-kHz channels. The MILSTAR compatible EHF package will provide anti-jam capability. The MILSTAR waveform and details of the EHF package as well as Advanced Scamp ground terminal are classified secret. However, the package will provide 2,400-bps

Table 13. FLTSATCOM/AFSATCOM system characteristics (a) electrical performance.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
FLTSATCOM AFSATCOM FEP	4	GEO and High Incl. Orbits		CH 1-Navy 8000 25 KHz BW CH 2-9-Navy 290-320 25 KHz BW CH 11-22-AF 290-320 5 KHz BW CH 23-AF 290-320 500 KHz BW EHF-Navy 44,000 26 Channels 2400 Hz BW		CH 1-Navy 240-270 25 KHz BW CH 2-9- Navy 240-270 25 KHz BW CH 11-22- AF 240-270 5 KHz BW CH 23 - AF 240-270 500 KHz BW EHF-Navy 20,000 26 Channels 2400 Hz BW	CH 1-35,7-10 26 dBW CH 4 & 6 28 dBW CH 11-22 16.5 dBW CH 23 27 dBW EHF POUT+13 dBW Ant. dia. 8 in Ant. gain 29.6 dB EIRP 42.6 dBW POUT +13 dBW Horn-Earth Cov. Gain 18.7 dB EIRP 31.7 dBW

Table 13. FLTSATCOM/AFSATCOM system characteristics (b) antenna and orbit.

Antenna		Orbit History			
Receive	**Transmit**	**Sat**	**Launch**	**Status**	**Longitude**
UHF 230-320 Helix 1 ft. dia. 12 ft. long Earth cov. (Gain 18.7 dB)	UHF 240-270 Helix 1 ft. dia. 12 ft. long Earth cov. (Gain 18.7 dB)[1]	1	2-9-78	Operational	177° W
		2	5-8-79	Operational	73° E
		3	1-17-80	Operational	22° W
Reflector 16ft. dia. (Gain 20.7 dB)[2]	Reflector 16 ft. dia. (Gain 19.4 dB)[2]	4	10-30-80	Operational	172° E
		5	8-6-81	Damaged	
X-Band 8000 Horn Earth cov. (Gain 18.7 dB)[1]		6	3-26-87	Destroyed	
		7	12-4-86	Operational	100° W
EHF (7and 8) 44,000 Reflector 8in. dia. (Gain 36.5 dB)[2] Horn Earth cov. (Gain 18.7 dB)[1]	EHF (7 and 8) 20,000 Reflector 8 in. dia. (Gain 29.6 dB)[2] Horn Earth cov. (Gain 18.7 dB)[1]	8	9-25-89	Operational	23° W

Notes:

1. Computed from earth coverage angle of 18°.
2. Computed from reflector documents.

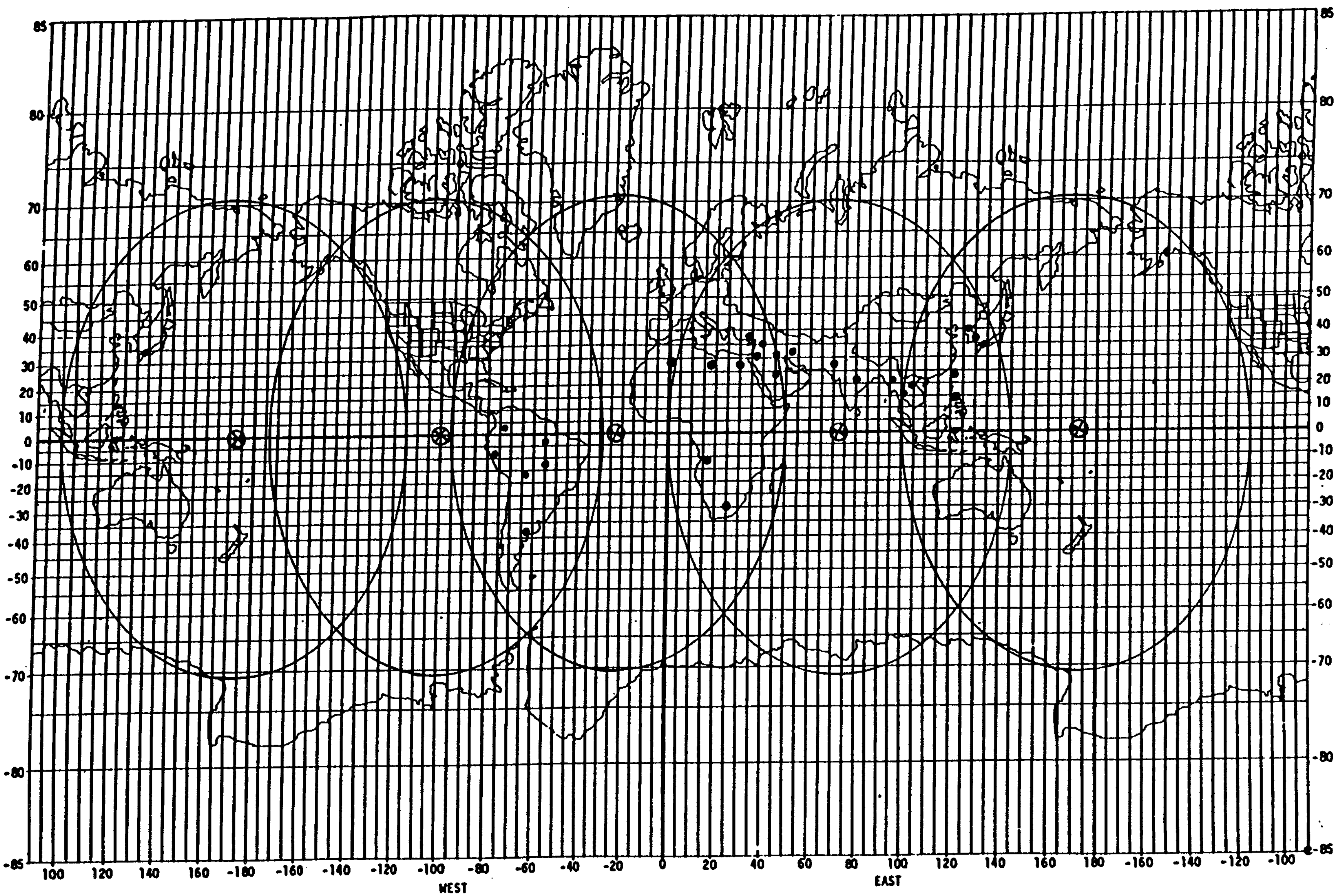


Figure 16. The UFO -- map of earth coverage.

channels operating in full duplex mode and substantial rain margins to cover rain attenuation that occurs at these frequencies. Table 14 shows the UFO satellite system characteristics.

To overcome the need for large UHF antennas, a lightweight (2.7 kg) foldable Yagi antenna was developed. It consists of crossed dipoles and consequently exhibits very low wind resistance and good visual covertness. The gain varies between 7.0 and 10.5 dB, depending upon the number of dipoles used, and the physical envelope is about 0.4 x 0.4 x 0.7 Figure 17 shows a typical crossed dipole (circularly polarized) antenna.

5.3 LINK BUDGETS

The following sections give link budgets for the selected satellite-ground terminal systems and equipment configurations. Whenever possible, available portable ground terminals were used, such as the commercial INMARSAT ship earth terminals B and C and the military MILSTAR-compatible Advanced Scamp. In addition to these, there are numerous developments in commercial portable ground terminals for various satellite systems and for various data rates. With some effort, they could be reengineered and repackaged to meet RTS size, weight, and power consumption requirements. While they are not designed to meet military requirements, they are very cost-effective and can be purchased for well under $10,000. Mechanical integrity can be substantially improved using impact resistant housing, stiffening brackets, better connectors, and various packaging and/or potting techniques. Thermal properties can be improved using large surface heat sinks, higher rating components, thermal blankets or by locating equipment up to 5 ft underground. It is a well known and established fact that temperature extremes converge very rapidly with soil depth.

Where no suitable ground terminals could be found, nominal design parameters were used. They are: antenna diameter 24 in, RF output power 1 W, and noise figure 5 dB. Antenna size trade-offs which affect EIRP and G/T are given in Section 7.0, "The RTS Design."

Table 14. The UFO system characteristics.

Satellite System	No Sat	Orbit	Satellite Longitude	Uplink		Downlink	
				Freq. MHz	G/T dB/°K	Freq. MHz	EIRP dBW
UFO	Active 4 Backup. 4 Spares 2	GEO	Conus Atlantic Pacific Indian	252-317	-16.0	244-270	Broadcast Ch. (1ch) 28.0 25 KHz CH (2ch) 28.0 (15ch) 26.0 5 KHz CH (21ch) 21.0

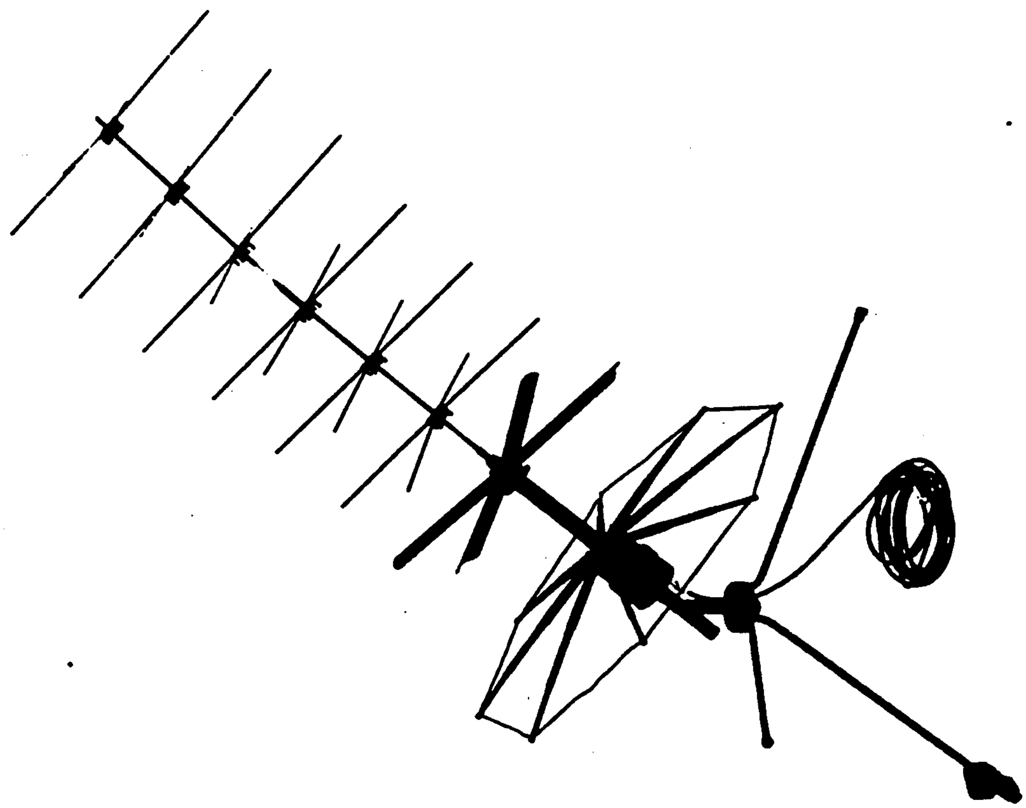


Figure 17. Portable crossed dipole antenna.

Whenever possible, all basic satellite communication links were examined. The computed link SNRs are for the ideal cases and exclude bit error rate (BER), as well as rain margins. Both the BER and rain margins are complex functions of modulation format and rain parameters. They apply to specific signal waveforms, climatic zones, antenna elevation angles, and rain statistics. Because of that, these link margin requirements were computed separately in Section 5.4 and must be subtracted to obtain the net values.

5.3.1 INTELSAT Link Budgets

Tables 15 a and b through 18 a and b present INTELSAT V, VA, VI, and VII up- and down-link budgets for various services. As the succeeding satellite services were improved, better signal-to-noise ratios were obtained. Due to ground terminal (RTS) antenna size (gain), output power, and noise figure constraints the system data rate is uplink constrained. The global/hemi coverage services offer SNRs between 8.5 and 17.0 dB, giving marginal performance at data rates of 2,400 bps. On the other hand, zone and spot beam services present sizeable SNRs of 15.0 to 29.0 dB. However, they are much more sensitive to rain attenuation, and consequently this must be taken out.

For example, a spot beam provides up to +29.0 dB of SNR. Allocating 12.0 dB for the BER margin and 4.0 dB for the rain margin leaves a 13-dB net margin, which translates into a 48-kbps data rate.

5.3.2 INMARSAT Link Budgets

The INMARSAT link budgets were computed using ship earth stations B and C as well as a nominal RTS ground terminal. While the B terminal was developed for ships, the C terminal was developed for use on small ships, aircraft, and trucks. Their typical antenna diameters are 18 in and < 12 in respectively. In spite of small antenna sizes, both the B- and C-type links show good link SNR for uplink and excellent link SNR for downlink. The typical RTS shows reasonable uplink SNR and very good downlink SNR. For a typical BER of 1 in 10^5

Table 15. INTELSAT V link budgets (a) uplink.

Parameter	Uplink				
	Global	Hemi.	Zone	E-Spot	W-Spot
EIRP dBW	+29.0[1]	+29.0[1]	+29.0[1]	+36.2[2]	+36.2[2]
Space Loss dB	-199.3[3]	-199.3[3]	-199.3[3]	-206.6[3]	-206.6[3]
G/T dB/°K	-16.0[4]	-11.6[4]	-8.6[4]	0.0[4]	+3.3[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+8.5	+12.9	+15.9	+24.4	+27.7

Notes:

1. Based upon antenna dia. = 24 inch, GA = 29.0 dB, Pout = 1 W, EIRP = +29.0 dBW.
2. Based upon antenna dia. = 24 inch, GA = 36.2 dB, Pout = 1 W, EIRP = 36.2 dBW.
3. Based upon subsatellite point and mid frequency.
4. Based upon satellite specification.
5. Based upon data rate of 2400 bps.

Table 15 (concluded). INTELSAT V link budgets (b) downlink.

Parameter	Downlink				
	Global	Zone	Zone	E-Spot	W-Spot
EIRP dBW	+23.5[1]	+26.0[1]	+29.0[1]	+41.1[1]	+44.4[1]
Space Loss dB	195.4[2]	-195.4[2]	-195.4[2]	-204.6[2]	-204.6[2]
G/T dB/°K	-2.9[3]	-2.9[3]	-2.9[3]	+6.2[4]	+6.2[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+20.0	+22.5	+25.5	+37.5	+40.8

Notes:

1. Based upon satellite specifications
2. Based upon subsatellite point and mid frequency
3. Based upon antenna dia. = 24 inch, GA = 25.1 dB, NF = 5.0 dB, G/T = -2.9 dB/°K
4. Based upon antenna dia. = 24 inch, GA = 34.2 dB, NF = 5.0 dB, G/T = + 6.2 dB/°K
5. Based upon data rate of 2400 bps

Table 16. INTELSAT VA link budgets (a) uplink.

Parameter	Uplink			
	Global	Zone	E-Spot	W-Spot
EIRP dBW	+29.0[1]	+29.0[1]	+36.2[2]	+36.2[2]
Space Loss dB	-199.3[3]	-199.3[3]	-206.6[3]	-206.6[3]
G/T dB/°K	-16.0[4]	-9.0[4]	+1.0[4]	+4.3[4]
K	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+8.5	+15.5	+25.4	+28.7

Notes:

1. Based upon antenna dia. = 24 inch, GA = 29.0 dB, Pout = 1 W, EIRP = +29.0 dBW.
2. Based upon antenna dia. = 24 inch, GA = 36.2 dB, Pout = 1 W, EIRP = + 36.2 dBW.
3. Based upon subsatellite point and mid frequency.
4. Based upon satellite specifications.
5. Based upon data rate of 2400 bps.

Table 16 (concluded). INTELSAT VA link budgets (b) downlink.

Parameter	Downlink					
	Global	Zone	Zone	Spot	E-Spot	W-Spot
EIRP dBW	+23.5[1]	+26.0[1]	+29.0[1]	+32.5[1]	+41.1[1]	+44.4[1]
Space Loss dB	-195.4[2]	-195.4[2]	-195.4[2]	-195.4[2]	-204.6[2]	-204.6[4]
G/T dB/°K	-2.9[3]	-2.9[3]	-2.9[3]	-2.9[3]	+6.2[4]	+6.2[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8	-33.8	-33.8	-33.8	-33.8	-33.8
SNR dB	+20.0	+22.5	+25.5	+29.0	+37.5	+40.8

Notes:

1. Based upon satellite specification.
2. Based upon sub satellite point & mid frequency.
3. Based upon antenna dia. = 24 inch, GA = 25.1 dB, NF = 5.0 dB, G/T = -2.9 dB/°K.
4. Based upon antenna dia. = 24 inch, GA = 34.2 dB, NF = 5.0 dB, G/T = +6.2 dB/°K.
5. Based upon data rate of 2400 bps.

Table 17. INTELSAT VI link budgets (a) uplink.

Parameter	Uplink				
	Global	Hemi	Zone	E-Spot	W-Spot
EIRP dBW	+29.0[1]	+29.0[1]	+29.0[1]	+36.2[2]	+36.2[2]
Space Loss dB	-199.3[3]	-199.3[3]	-199.3[3]	-206.6[3]	-206.6[3]
G/T dB/°K	-16.0[4]	-9.0[4]	-6.0[4]	+1.0[4]	+4.0[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8	-33.8	-33.8	-33.8	-33.8
SNR dB	+8.5	+15.5	+18.5	+25.4	+28.4

Notes:

1. Based upon antenna dia. = 24 inch, GA = 29.0 dB, Pout = 1 W, EIRP = +29.0 dBW.
2. Based upon antenna dia. = 24 inch, GA = 36.2 dB, Pout = 1 W, EIRP = +36.2 dBW.
3. Based upon subsatellite point and mid frequency.
4. Based upon satellite specifications.
5. Based upon data rate of 2400 bps.

Table 17 (concluded). INTELSAT VI link budgets (b) downlink.

Parameter	Downlink				
	Global	Hemi	Zone	E Spot	W Spot
EIRP dBW	+26.0[1]	+34.0[1]/ 37.0[1]	+31.0[1]	+41.0[1]	+44.0[1]
S. Loss dB	-195.4[2]	-195.4[2]	-195.4[2]	-204.6[2]	-204.6[2]
G/T dB/°K	-2.9[3]	2.9[3]	-2.9[3]	+6.2[4]	-6.2[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8	-33.8	-33.8	-33.8	-33.8
SNR dB	+22.5	+30.5/ 33.5	+27.5	+37.4	+40.4

Notes:

1. Based upon satellite specifications.
2. Based upon subsatellite point and mid frequency.
3. Based upon antenna dia. = 24 inch, GA = 25.1 dB, NF = 5.0 dB, G/T = -2.9 dB/°K.
4. Based upon antenna dia. = 24; inch; GA = 34.2 dB, NF = 5.0 dB, G/T = + 6.2 dB/°K.
5. Based upon data rate of 24 bps.

Table 18. INTELSAT VII link budgets (a) uplink.

Parameter	Uplink								
	Global	Spot	Hemi. 1	Hemi. 2	Zone B1	Zone B2	Spot 1	Spot 2 & 2A	Spot 3
EIRP dBW	+29.0[1]	+29.0[1]	+29.0[1]	+29.0[1]	+29.0[1]	+29.0[1]	+36.2[2]	+36.2[2]	+36.2[2]
Space Loss dB	-199.3[3]	-199.3[3]	-199.3[3]	-199.3[3]	-199.3[3]	-199.3[3]	-206.6[3]	-206.6[3]	-206.6[3]
GT dB°K	-11.5[4]	-3.0[4]	-8.5[4]	-7.5[4]	-6.0/ -9.0[4]	-4.0/ -7.5[4]	+1.5/ +4.5[4]	-1.0/ +2.5[4]	+0.8/ +3.8[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+13.0	+21.5	+16.0	+17.0	+18.5/ +15.5	+20.5/ +17.0	+25.9/ 28.9	+23.4/ +26.9	+25.2/ 28.2

Notes:

1. Based upon antenna dia. = 24 inch, GA = 29.0 dB, Pout = 1 W, EIRP = +29.0 dBW.
2. Based upon antenna dia. = 24 inch, GA = 36.2 dB, Pout = 1 W, EIRP = +36.2 dBW.
3. Based upon subsatellite point and mid frequency.
4. Based upon satellite specifications.
5. Based upon data rate of 2400 bps.

Table 18 (concluded). INTELSAT VII link budgets (b) downlink.

Parameter	Downlink						
	Global	Spot	Zone	Spot 1	Spot 2	Spot 2 & 2 A	Spot 3
EIRP dBW	+26.0/	+33.0[1]/	+33.0[1]	+43.4/	41.4/	41.2/	43.0/
Space Loss dB	29.0[1]	36.0[1]		+46.7	45.8[1]	44.1[1]	47.3[1]
	-195.7[2]	-195.4[2]	-195.4[2]	-204.6[2]	-204.6[2]	-204.6[2]	-204.6[2]
G/T dB/°K	-2.9[3]	-2.9[3]	-2.9[3]	+6.2[4]	+6.2[4]	+6.2[4]	+6.2[4]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	22.5/	+29.5/	29.5	39.8/	37.8/	37.6/	39.4/
	25.5	32.5		43.1	42.2	40.5	43.7

Notes:

1. Based upon satellite specifications.
2. Based upon subsatellite point and mid frequency.
3. Based upon antenna dia. = 24 inch, GA = 25.1 dB, NF = 5.0 dB, G/T = -2.9 dB/°K.
4. Based upon antenna dia. = 24 inch, GA = 34.2 dB, NF = 5.0 dB, G/T = +6.2 dB/°K.
5. Based upon data rate of 2400 bps.

and for the used modulation formats of FM, BPSK, QPSK, and FSK the required link margins are 15.1, 12.1, 14.1, and 12.0 dB respectively. Table 19 shows INMARSAT link budgets from which we can conclude that the ship earth station C and RTS are both viable ground terminals. As expected, the system is uplink limited.

5.3.3 IRIDIUM Link Budgets

Since no information about the IRIDIUM system could be found, no link budgets are offered. However, it is sufficient to state that it will handle telephone traffic, which translates into a standard voice bandwidth of at least 2,400 Hz. The main and important advantage of the IRIDIUM terminal is its *extremely small size* (hand-held). The low probability of message intercept can be obtained by message coding and by repeated redial, which each time will select a different channel.

5.3.4 TDRSS Link Budgets

The TDRSS satellite system provides one multiple access (MA) low data rate link and two single access S- and K-band high data rate links. The MA link has been specially designed for low data rate users (50 kbps uplink and 10 kbps downlink), which matches well with the RTS requirements. Table 20 gives MA, SSA, and KSA services link budgets for nominal RTS design and shows healthy margins at a data rate of 2,400 bps (23.5 dB uplink and 30.4 dB downlink) and sufficient margins at MA design rates (10.3 dB uplink and 17.4 dB downlink).

Due to the large antenna diameter (5 m) and high power transmitters, the SSA and KSA services show very large margins when all link resources are utilized. Consequently, multiple CC&Cs and RTSs can be processed by the same satellite service, together with band spreading and frequency hopping.

Table 19. INMARSAT link budgets.

Parameter	Uplink			Downlink		
	Ship Earth Station		RTS	Ship Earth Station		RTS
	B	C		B	C	
EIRP dBW	+ 26.0[1]	+19.0[1]	+17.4[4]	+39.0[2]	+39.0[2]	+39.0[2]
Space Loss dB	-187.8[3]	-187.8[3]	-187.8[3]	-187.2[3]	-187.2[3]	-187.2[3]
G/T dB/°K	-12.5[2]	-12.5[2]	-12.5[2]	-12.0[1]	-19.0[1]	-11.1[5]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[1]	-33.0[1]	-33.8[6]/ -30.0	-33.8[1]	-33.8[1]	-33.8[6]/ -30.0
SNR	+20.5	+14.3	+11.9/ +15.7	+34.6	+28.4	+35.5/ +39.3

Notes:

1. Based upon ship earth station specifications.
2. Based upon satellite specifications.
3. Based upon sub satellite point and mid frequency.
4. Based upon 24 inch dia. antenna GA 17.4 dB and Power Out = 1 W; EIRP = +17.4 dBW.
5. Based upon 24 inch dia. antenna GA = 16.9 dB and NF = 5.0 dB G/T=-11.1 dB/°K.
6. Based upon data rate of 2400 bps.
7. Based upon data rate of 1000 bps.

Table 20. TDRSS link budgets.

Parameter	Uplink			Downlink		
	MA	SSA	KSA	MA	SSA	KSA
EIRP	+ 20.4[1]	+20.1[2]	+36.7[3]	+34.0[7]	+44.0[7]/ +46.4[7]	+49.4[7]
Space Loss dB	-190.7	-190.5	-207.0	-190.0	-189.8	-206.3
G/T dB/°K	-1.0[7]	+8.9	+24.4[7]	-8.4[4]	-8.5[5]	+7.9[6]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[9]	-33.8[9]	-33.8[9]	-33.8[9]	-33.8[9]	-33.8[9]
SNR dB	+23.5	+33.3	+48.9	+30.9	+40.5/ 42.9	+45.8

Notes:

1. Based upon 24 inch diameter antenna and 1 W output power; GA = 20.4 dB and EIRP = 20.4 dBW.
2. Based upon 24 inch diameter antenna and 1 W output power; GA = 20.1 dB and EIRP = 20.1 dBW.
3. Based upon 24 inch diameter antenna and 1 W output power; GA = 36.7 dB and EIRP = 36.7 dBW.
4. Based upon 24 inch diameter antenna and NF of 5 dB; GA = 19.6 dB and G/T = -8.4 dB/°K.
5. Based upon 24 inch diameter antenna and NF of 5 dB; GA = 19.5 dB and G/T = -8.5 dB/°K.
6. Based upon 24 inch diameter antenna and NF of 5 dB; GA = 35.9 dB and G/T = +7.9 dB/°K.
7. Based upon specifications.
8. Based upon subsatellite point and mid frequency.
9. Based upon 2400 bps.

5.3.5 DSCS Link Budgets

Both the DSCS II and III have large parabolic antennas (45-in diameter) and high power amplifiers to handle high data rate (50 MHz) channels. While DSCS II is basically a two-channel repeater, DSCS III is a six-channel repeater with UHF service.

Because of their large C-band antennas, both the DSCS II and III show large SNRs with a nominal design RTS terminal. These large SNRs can be shared with other DSCS traffic or can be used to handle multiple CC&Cs and RTSs and to include low probability of intercept frequency hopping. Since the DSCS transceiver is a simple frequency converter, many different modulation and waveform formats can be passed through it.

Due to an inherently low gain of UHF crossed dipole antennas and a low RTS transmitter output power, much lower (than C-band) uplink SNR is available.

Tables 22 and 23 show DSCS II and III link budgets.

5.3.6 MILSTAR Link Budgets

The MIT Lincoln Labs have developed a truly portable MILSTAR-compatible ground terminal, Advanced Scamp, that services multiple 2,400-Hz voice and data channels. Due to high uplink (40 GHz) and downlink (20 GHz) frequency, rain will cause substantial link attenuation.. Often, the quoted required uplink and downlink rain margins are 12.0 and 6.0 dB respectively. A look at the figures depicting rain attenuation coefficients will show that these margins are sufficient if we restrict ourselves to reasonable percentage values for time of year rainrate exceeded, such as 1 percent (3 days 16 hrs), and exclude extreme rain rates that occur in tropical zones. Due to the classified nature of the MILSTAR satellite and a desire to keep this report unclassified, no link budgets for the Advanced Scamp are presented. It is, however, sufficient to say that the MILSTAR–Advanced Scamp link margins are sufficient for a 2,400 bps data rate.

Table 21. DSCS II link budgets.

Parameter	Uplink		Downlink	
	Global Coverage	Spot Coverage	Global Coverage	Narrow Beam
EIRP dBW	+31.4[1]	+31.4[1]	+28.0[3]	+46.0[3]
Space Loss dB	-192.6[4]	-192.6[4]	-192.3[4]	-192.3[2]
G/T dB/°K	-13.8[3]	+5.8[3]	+2.9[2]	+2.9[2]
K	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+19.8	+39.4	+33.4	+51.4

Notes:

1. Based upon 24 inch diameteer antenna and 1 W output power; GA = 31.4 dB and EIRP = 31.4 dBW.
2. Based upon 24 inch diameter antenna and NF of 5.0 dB; GA = 30.9 dB and G/T = + 2.9 dB/°K.
3. Based upon satellite parameters.
4. Based upon subsatellite point and mid frequency.
5. Based upon band width of 2400 Hz.

Table 22. DSCS III link budgets.

Parameter	Uplink			Downlink		
	CH 1-6 Narrow Beam	CH 1-6 Earth Coverage	UHF	CH 1 and 2 GDA	CH 3-6 Horn Earth Coverage	UHF
EIRP dBW	+31.4[1]	+31.4[1]	+21.0[6]	+44.0[3]	+25.0[3]	+21.3
Space Loss dB	-192.6[4]	-192.6[4]	-178.3[8]	-192.3[4]	-192.3[4]	-177.5[8]
G/T dB/°K	-1.0[3]	-16.0[3]	-24.5	+2.9[2]	+2.9[2]	-13.6[7]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8	-33.8[5]	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+32.6	+17.6	+13.0	+49.4	+30.4	+24.7

Notes:

1. Based upon 24 inch diameter antenna and 1 W output power; GA=+31.4 dB and EIRP = +31.4 dBW.
2. Based upon 24 inch diameter antenna and NF of 5 dB; GA = 30.9 dB and G/T = +2.9 dB/°K.
3. Based upon satellite parameters.
4. Based upon subsatellite point and mid frequency.
5. Based upon bandwidth of 2400 Hz.
6. Based upon multiple crossed dipole UHF antenna and 10 W output power; GA = 11.0 dB and EIRP = 21.0 dBW.
7. Based upon multiple crossed dipole UHF antenna and NF of 3.0 dB; GA = 11.0 dB and G/T = -13.6 dB/°K.
8. Based upon subsatellite point and 300 MHz uplink and 250 MHz downlink.

The major advantage of the Advanced Scamp terminal is its full compatibility with MIL-STD-1582 (Ref. 7) waveforms, which includes low probability of detection (LPD) and intercept (LPI). This is achieved by coding and frequency hopping. The major disadvantage is the very high cost and technology compromise if the equipment is seized by the enemy.

5.3.7 FLTSATCOM/AFSATCOM Link Budgets

Tables 23 a and b show satellite system up- and down-link budgets. The X-band uplink shows a healthy SNR because of high gain developed by the 24-in diameter ground terminal antenna. The frequency is still low enough not to be of major concern as far as rain loss is concerned. However, it could become a problem in tropical areas and for very low percentage time of year rain rate exceeded statistics. The UHF uplink also shows a healthy SNR but does not exhibit any significant rain attenuation. The EHF uplink using 24-in diameter ground and 8-in satellite antennas shows a large SNR which will be reduced substantially by the large rain attenuation occurring at 44 GHz (see Section 5.4, "Parameters Affecting Link SNR Margins"). While rain attenuation coefficient for 1% (3 days 16 hrs) time of year rain rate exceeded and temperate climatic zone is about 2.0 dB/km for 0.1 percent (8.8 hrs) time of year rain rate exceeded and tropical climatic zone, it can be above 15.0 dB/km. Thus, the resulting SNR in tropical zones could become negative under certain conditions. A negative SNR results for the earth coverage satellite antenna.

The EHF downlink shows a reasonably large SNR, which will be reduced by rain attenuation. At 20 GHz, this rain attenuation is not as great as at 44 GHz (uplink), and consequently downlink SNR will be positive under most conditions, except for extreme tropical rainfall. The UHF link budgets show uniformly good link SNRs for all channels and do not experience any rain attenuation.

Table 23. FLTSATCOM/AFSATCOM link budgets (a) uplink.

Parameter	Uplink						
	1 X-Band	2,3,5 and 9 UHF	7 and 8 8" Dish EHF	7 and 8 Earth Cov. EHF	4 and 6 UHF	11-22 UHF	23 UHF
EIRP dBW	+31.2[1]	+21.0[2]	+36.5[3]	+19.2[4]	+21.0[2]	+21.0[2]	+21.0[2]
S.Loss dB	-201.6[5]	-173.0[5]	-216.4[5]	-216.4[5]	-173.0[5]	-173.0[5]	-173.0[5]
G/T dB/°K	+3.2[8]	-17.0[9]	+8.5[10]	-8.8[11]	-17.0[9]	-17.0[9]	-17.0[9]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-44.0[6]/ -33.8[7]	-44.0[6]/ -33.8[7]	-33.8[7]	-33.8[7]	-44.0[6]/ -33.8[7]	-37.0[6]/ -33.8[7]	-57.0[6]/ -33.8[7]
SNR dB	+17.4/ +27.6	+15.6/ +25.8	+23.4	-11.2	+15.6/ +25.8	+22.6/ +25.8	+2.6/ +25.8

Notes:

1. Based upon 24in. diameter antenna and 1 W output power; GA = 31.2 dB and EIRP =31.2 dBW.
2. Based upon UHF crossed dipole antenna and 10 W output power; GA = 11.0 dB and EIRP = 21.0 dBW.
3. Based upon 8" inch diameter antenna and 1 W output power; GA = 36.5 dB and EIRP = 36.5 dBW.
4. Based upon earth coverage (17°) horn and 1 W output power; GA = 19.2 dB and EIRP = 19.2 dBW.
5. Based upon subsatellite point and mid frequency.
6. Based upon specifications.
7. Based upon 2400 Hz bandwidth.
8. Based upon GA = 31.2 dB and NF = 5 dB; G/T = +3.2 dB/°K.
9. Based upon GA = 11.0 dB and NF = 5 dB; G/T = -17.0 dB/°K.
10. Based upon GA = 36.5 dB and NF = 5 dB; G/T = +8.5 dB/°K.
11. Based upon GA = 19.2 dB and NF = 5 dB; G/T = -8.8 dB/°K.

Table 23 (concluded). FLTSATCOM/AFSATCOM link budgets (b) downlink.

Parameter	Downlink Channels						
	1 UHF	2,3,5 and 9 UHF	7 EHF	8 EHF	4 and 6 UHF	11-22 UHF	23 UHF
EIRP dBW	+26.0[1]/	+26.0[1]	+26.0[1]	+26.0[1]/	+16.5[1]	+27.0[1]	+27.0[1]
S. Loss dB	-171.5[2]	-171.5[2]	-209.5[2]	-209.5[2]	+171.5[2]	+171.5[2]	-171.5[2]
G/T dB/°K	-17.0[3]	-17.0[3]	+11.2[4]	+11.2[4]	-17.0[3]	-17.0[3]	-17.0[3]
K	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6	+228.6
B dB Hz	-44.0[5]/ -33.8[6]	-44.0[5]/ -33.8[6]	-33.8[6]	-33.8[6]	-44.0[5]/ -33.8[63]	-44.0[5]/ -33.8[6]	-57.0[5]/ -33.8[6]
SNR dB	+22.1/ +32.3	+22.1/ +32.3	+22.5	+22.5	+12.6/ +22.8	+23.1/ +33.3	+10.1/ +33.3

Notes:

1. Based upon specifications.
2. Based upon subsatellite point and mid frequency.
3. Based upon GA = 11.0 dB and NF = 5.0 dB; G/T = -17.0 dB/°K.
4. Based upon 24 ft diameter antenna and GA = 39.2 dB and NF of 5.0 dB; G/T= +11.2 dB/°K.
5. Based upon specifications.
6. Based upon 2400 Hz.

5.3.8 The UHF FOLLOW-ON (UFO) Link Budgets

Due to limited antenna gain, both the uplink and downlink SNRs are marginal at a data rate of 2,400 bps. Thus, the UFO links can be used only for low data rates that are more compatible with teletype services. Table 24 shows UFO link budgets.

5.4. PARAMETERS AFFECTING LINK SNR MARGINS

Two basic parameters affect link SNR margin. They are the information modulation method and the rain attenuation coefficient. While fixing the modulation method fixes the BER curve, the rain attenuation is function of multiple parameters. They are climatic zone, rain statistics, ground terminal height, rain layer height and its statistics, frequency, and antenna elevation angle. As a consequence, it is possible to compute rain attenuation only for well defined conditions. The following sections attempt to cover the broadest possible range and multiple conditions. These values must be subtracted from the ideal SNR computed in the previous sections.

Modulation Format

The modulation format directly affects the required SNR for a given BER. Table 25 provides the required SNR (E_b/N_o) for most modulation formats used in the satellite communications and for two different values of BER. It can be seen that there is a substantial range in the required SNR. Figure 18 shows typical "waterfall" curves for the selected modulation formats and indicates high BER sensitivity to the SNR. Depending upon the modulation format and BER selected, the SNR is between 7 and 13 dB.

Rainfall Effects

The selected regional powers and third world countries, given in Table 26, cover five different climatic zones that possess different rainfall statistics. Table 27 gives number of

Table 24. UHF follow-on link budgets.

Parameter	Uplink		Downlink
EIRP dBW	+21.0[2]	+20.0[1]	+28.0[1]
Space Loss dB	-192.6[4]	-192.3[4]	-192.3[4]
G/T dB/°K	-16.0[1]	-13.6	-13.6
K	+228.6	+228.6	+228.6
B dB Hz	-33.8[5]	-33.8[5]	-33.8[5]
SNR dB	+7.2	+8.9	+16.9

Notes:

1. Based upon UFO specifications.
2. Based upon multiple crossed dipole UHF antenna and 10 W output power; GA = 11.0 dB and EIRP = 21.0 dBW.
3. Based upon multiple crossed dipole UHF antenna and NF of 3.0 dB; GA = 11.0 dB and G/T = -13.6 dB dB/°K.
4. Based upon subsatellite point and 300 MHz uplink and 250 MHz downlink.
5. Based upon bandwidth of 2400 Hz.

Table 25. Digital transmission BER characteristics.

Modulation	Phases, Bits per Symbol (R_b/S)	E_b/N_0, BER = 10^{-5} (dB)	E_b/N_0, BER = 10^{-7} (dB)
FM	2	13.4 dB	15.1
	4		21.2
	8		25.1
DPSK, differentially detected PSK	2 (BPSK)	10.3	12.1
	2 ($R\frac{1}{2}$)	6.5[b]	—
	4 (QPSK)	12.3	14.1
	4 ($R\frac{7}{8}$)	9.4	10.6
	4 ($R\frac{3}{4}$)	7.1[b]	8.5
	4 ($R\frac{1}{2}$)	6.3	7.4
	8	16.2	18.2
	16	21.0	23.2
	32	26.0	28.2
CPSK, coherent PSK	2	8.3	11.3
	2 ($R\frac{7}{8}$)	7.3	—
	2 ($R\frac{3}{4}$)	4.6	8.6
	2 ($R\frac{1}{2}$)	3.6	5.8
	4	12.5	11.3
	8	17.6	14.9
	16	23.0	19.6
	32	28.2	24.6
	64		29.9
QASK, four-phase ASK	2	1.6-2	—
CPFSK, continuous-phase FSK	2	9.5	12
	3	8.6	10.4
	5	8.4	10.2
MPSK, matched filter PSK	2	9.8	11.2
	4	12.6	14.3
QASK, MAMSK, multitone AM	4	13.4	—
VSB/SC or QAM/SC,	4	—	15.1[c]
Vestigial sideband or four-phase AM supressed	16	—	21[c]
Carrier	64	—	27.3[c]

[a]Coding: Rate 1 (no coding) unless otherwise noted.

[b]Viterbi decoder.

[c]At 10^{-8} BER; two-phase shift keying = BPSK, four-phase = QPSK, M-phase = MPSK, ASK = amplitude shift keying.

Note: These data come from many sources with various margins. This table should be used only as a guide for comparison.

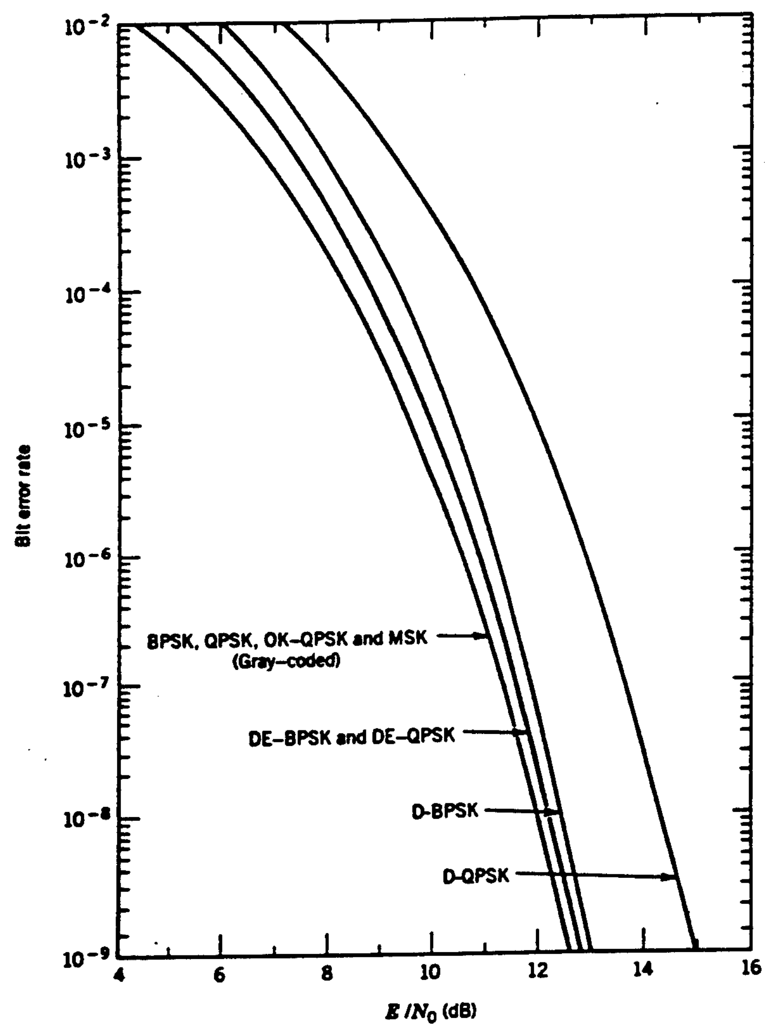


Figure 18. Digital transmission BER curves. Ideal performance of various digital modulation schemes (E, energy per bit; N_o, one-sided noise spectral density in watts per hertz; $E = E_b$ if no coding, $E = E_c$ if coding). Reprinted with permission from Maral and Bousquet, *Satellite Communications Systems*, Wiley, 1986 (Ref. 8).

Table 26. Intelligence interest combines geographical locations and climatic zones.

INTELLIGENCE INTEREST	COUNTRY	GEOGRAPHICAL LOCATION	CLIMATIC ZONE
		SOUTH AMERICA	
Arms	Argentina	25-50 S 55-70 W	F-D
Arms	Brazil	00-25 S 35-75 W	G-H
Drugs	Bolivia	10-23 S 57-69 W	G-H
Drugs	Columbia	10-03 S 68-77 W	H
Drugs	Peru	00-18 S 69-88 W	F-G
Drugs	Suriname	02-05 N 53-57 W	H
		ASIA	
Arms	Burma	12-29 N 91-100 E	D-G
Arms	India	09-35 N 70-89 E	G
Arms	Iran	25-40 N 45-62 E	D-F
Arms	Iraq	29-33 N 40-48 E	F
Arms	Israel	29-33 N 35-36 E	F
Arms	Korea, South	35-38 N 127-130 E	D
Drugs	Korea, North	38-42 N 125-130 E	D
Arms	Laos	15-23 N 100-107 E	G
Arms	Pakistan	22-36 N 62-77 E	D
Drugs	Philippines	07-19 N 120-126 E	H
Arms	Saudi Arabia	16-32 N 3555 E	F
Arms	Syria	32-37 N 36-42 E	F
Arms	Thailand	12-20 N 97-105 E	G
Arms	Taiwan	22-25 N 120-122 E	E
Arms	Turkey	36-41 N 27-44 E	F
		AFRICA	
	Algeria	20-37 N 09 W-10 E	F
	Angola	06-17 S 12-23 E	G-H
Arms	Egypt	22-31 N 24-35 E	F
Arms	Libya	20-32 N 10-24 E	F
Arms	South Africa	23-34 S 18-31 E	F

Table 27. Rain rate statistics for countries of interest.

Zone	Number of Countries	Rain Rate for % of Year Rain Rate Exceeded			
		0.001 %	0.01 %	0.1 %	1.0 %
F - Arid	12	66	23	5.5	1.7
D2 - Continental	6	102	49	15	3.0
G - Moderate	8	129	67	22	3.7
E - Wet	1	164	98	35	4.0
M - Wet	6	251	147	51	6.4

countries per climatic zone and rainfall statistics in terms of rain rate versus percent of the year the rain rate is exceeded.

These rain statistics are the base from which the rain attenuations are calculated for communication with satellite. The rain attenuation coefficient in decibels per kilometer is given by the following expression:

$$A = aR^b$$

where A - rain attenuation in dB,

a - frequency dependent constant,

b - frequency dependent constant, and

R - rain rate in millimeters per hour for a given climatic zone as a function of percent of year rain rate exceeded.

To obtain total attenuation, we must solve a geometrical problem given in terms of RTS antenna elevation angle, RTS altitude, and rain layer 0°C isotherm altitude which is given in terms of latitude and probability of occurrence.

For a GEO satellite, the calculations are straightforward because the parameters are fixed. However, this is not so for a LEO satellite where the angle of arrival is continuously changing for a given satellite and for handover between different satellites (such as IRIDIUM constellation.

Table 28 gives point rainfall and the resulting rain attenuation in terms of climatic zone rainfall, percent of year the rain rate is exceeded, and signal frequency. Figure 19 shows graphically the rain rate in terms of climatic zone and percentage of year rain rate is

Table 28. Rain rates and resulting signal attenuation coefficient.

FREQ		F		D2		G		E		H		Computational Parameters Att = aR^b dB/km
		mm/hr	dB/km	mm/hr	dB/km	mm/hr	dB/km	mm/hr	dB/km	mm/hr	dB/km	
10 GHz	0.001 % 0.01% 0.1% 1.0%	66 23 5.5 1.7	1.7 0.47 0.09 0.02	102 49 15 3	2.8 1.2 0.4 0.05	129 67 22 3.7	3.7 1.7 0.4 0.05	164 98 35 4	4.9 2.6 0.8 0.06	251 147 51 6.4	8.1 4.3 1.2 0.1	aL = 1.17×10^{-2} bL = 1.178 aH = 1.14×10^{-2} bH = 1.189
20	0.001 0.01 0.1 1.0	66 23 5.5 1.7	6.6 2.1 0.4 0.1	102 49 15 3	10.6 4.8 1.3 0.2	129 67 22 3.7	13.7 6.7 2.0 0.3	164 98 35 4	17.7 10.2 3.3 0.3	251 147 51 6.4	28.1 15.8 5.0 0.5	aL = 6.26×10^{-2} bL = 1.119 aH = 7.09×10^{-2} bH = 1.083
30	0.001 0.01 0.1 1.0	66 23 5.5 1.7	12.8 4.5 1.0 0.3	102 49 15 3	19.5 9.6 2.7 0.5	129 67 22 3.7	24.5 13.0 4.3 0.6	164 98 35 4	30.8 18.8 7.0 0.7	251 147 51 6.4	46.5 27.8 10.0 1.2	aL = 0.162 bL = 1.061 aH = 0.226 bH = 0.864
40	0.001 0.01 0.1 1.0	66 23 5.5 1.7	17.3 6.8 1.7 0.5	102 49 15 3	25.4 13.5 4.4 0.9	129 67 22 3.7	31.1 17.7 6.5 1.1	164 98 35 4	38.3 24.5 10.1 1.2	251 147 51 6.4	55.3 34.8 13.9 1.9	aL = 0.313 bL = 0.981 aH = 0.467 bH = 0.864

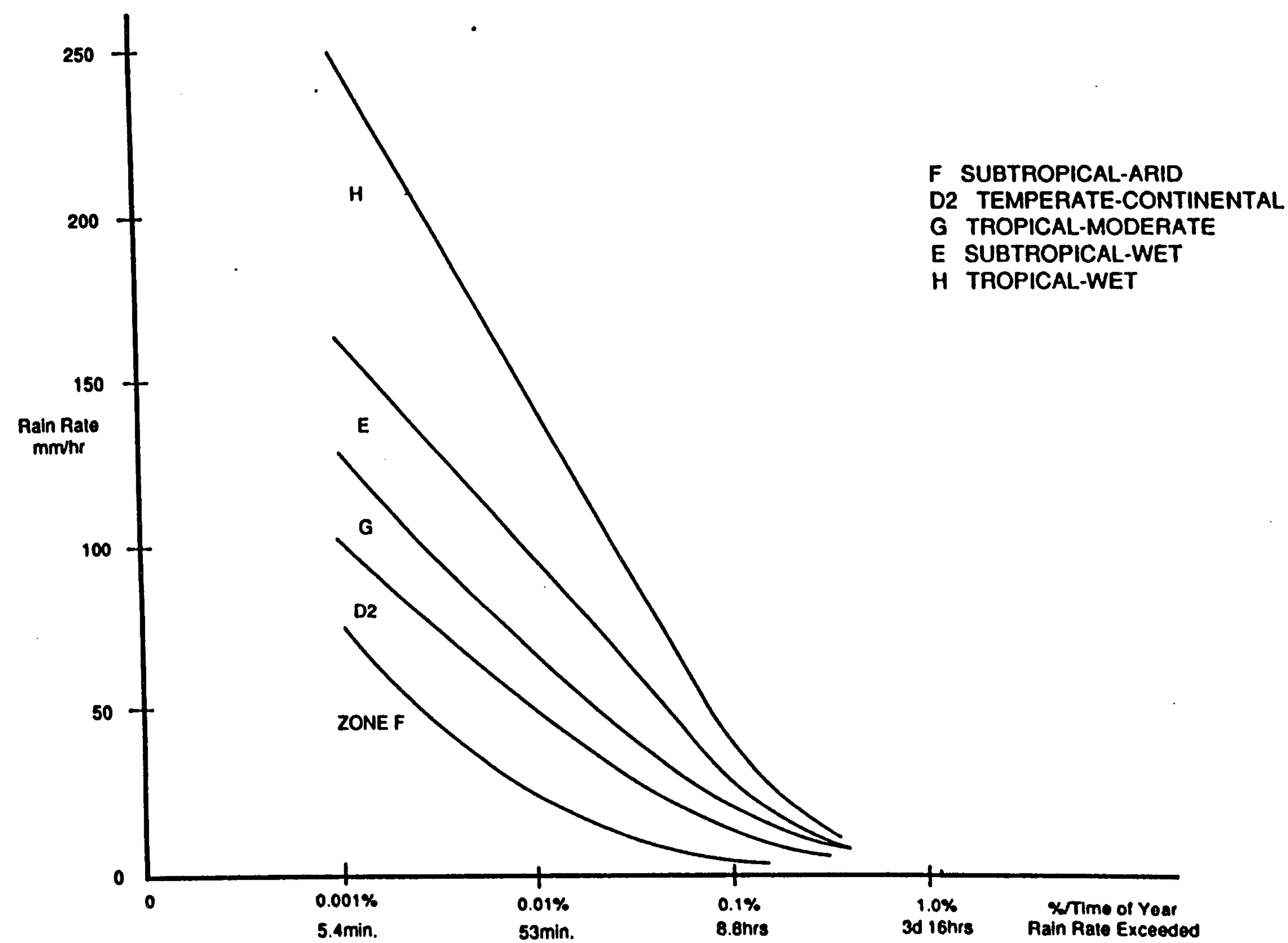


Figure 19. Rain rate for different climatic zones.

exceeded. We see that the rain rate and attenuation increase very rapidly as the percentage of year the rain rate exceeded is reduced for each climatic zone.

For 99.0 percent of the year, rain rate is <10 mm/hr; for 99.9 percent, <50 mm/hr; for 99.99 percent, <150 mm/hr; and for 99.999 percent, <250 mm/hr.

Figures 20 through 24 show the rain rate translated into signal attenuation coefficient in decibels per kilometer given in terms of frequency and percentage of year the rain rate is exceeded. To obtain a reasonably low rain margin, we must use frequencies below, say, 10 GHz and accept downlink times of 0.1 to 1.0 percent of the year (8.8 hrs to 3 days 16 hrs.).

Since all the areas of interest lie within ± 40° latitude and the minimum RTS antenna elevation angle is above 45° the latitude location has only a moderate effect upon rain attenuation for GEO satellites. However, the areas of interest are well spread along earth's longitude, and the RTS antenna elevation may be very low at coverage extremes. This may have a large effect upon length of rain path and, consequently, upon rain attenuation and will require preventive measures such as data rate reduction, data repeat, frequency diversity, and space diversity if satellites at different locations are available. In general, all of the above measures can be traded to minimize the rain effects.

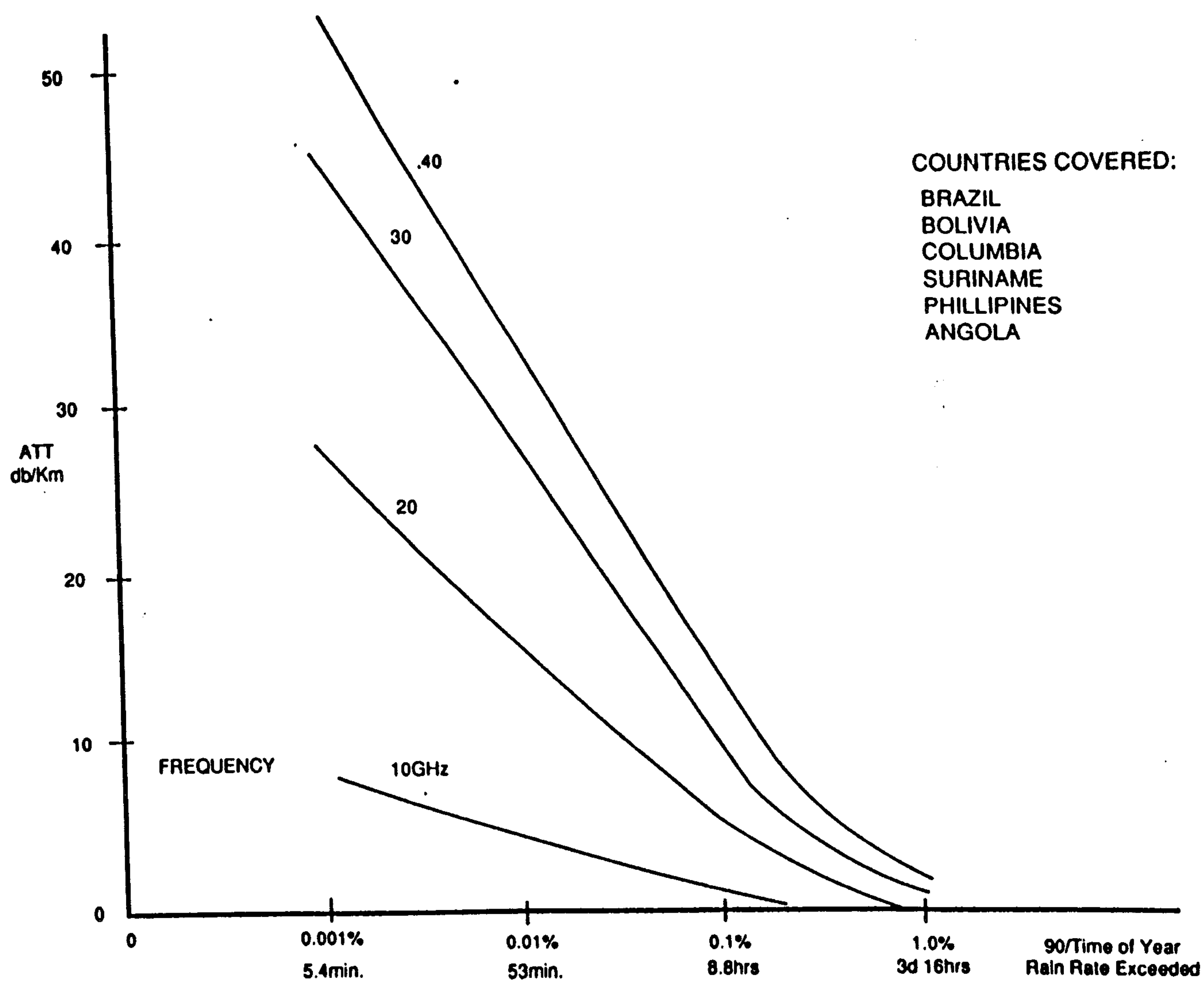


Figure 20. Rain attenuation coefficient for Zone H (tropical-wet).

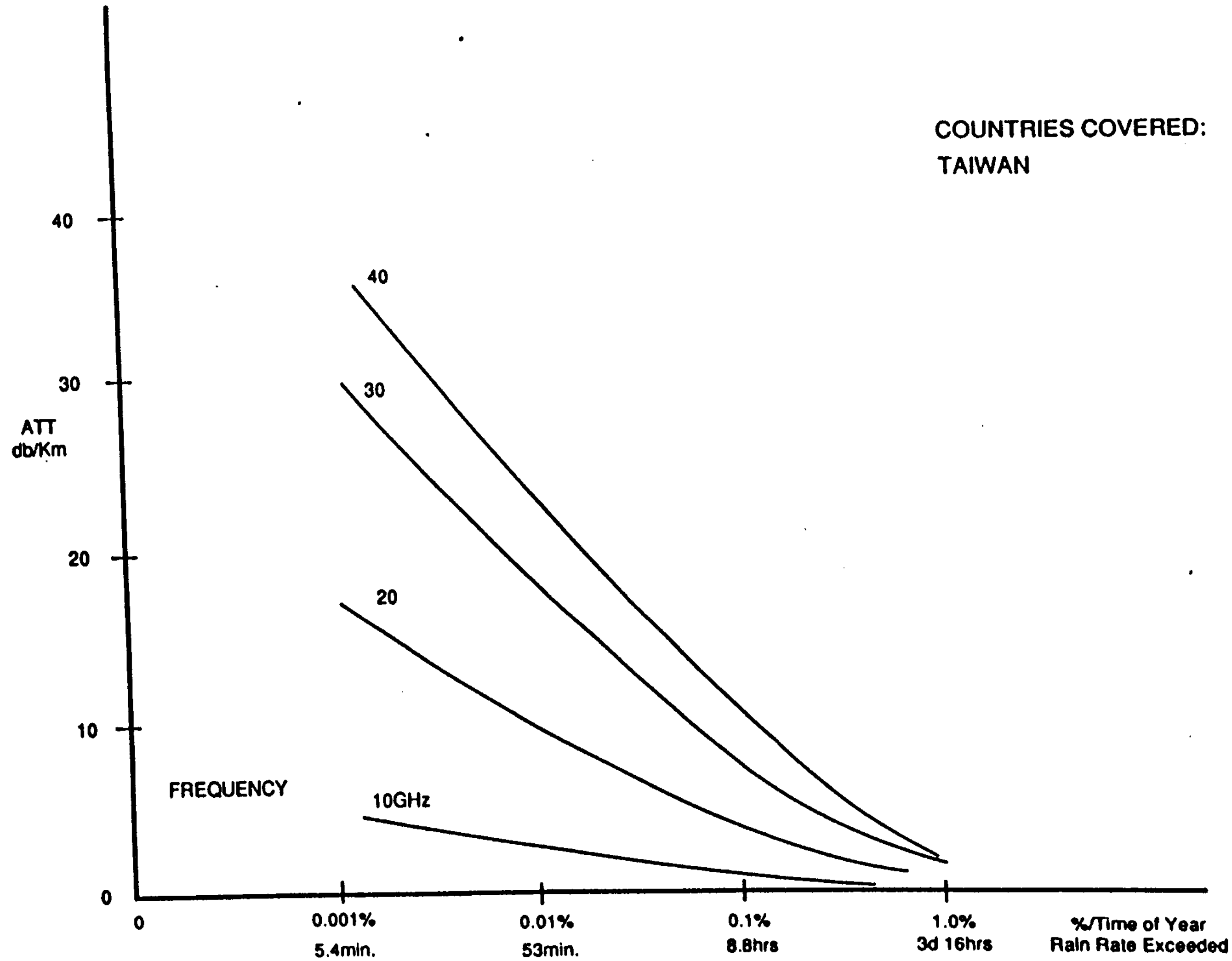


Figure 21. Rain attenuation coefficient for Zone E (subtropical-wet).

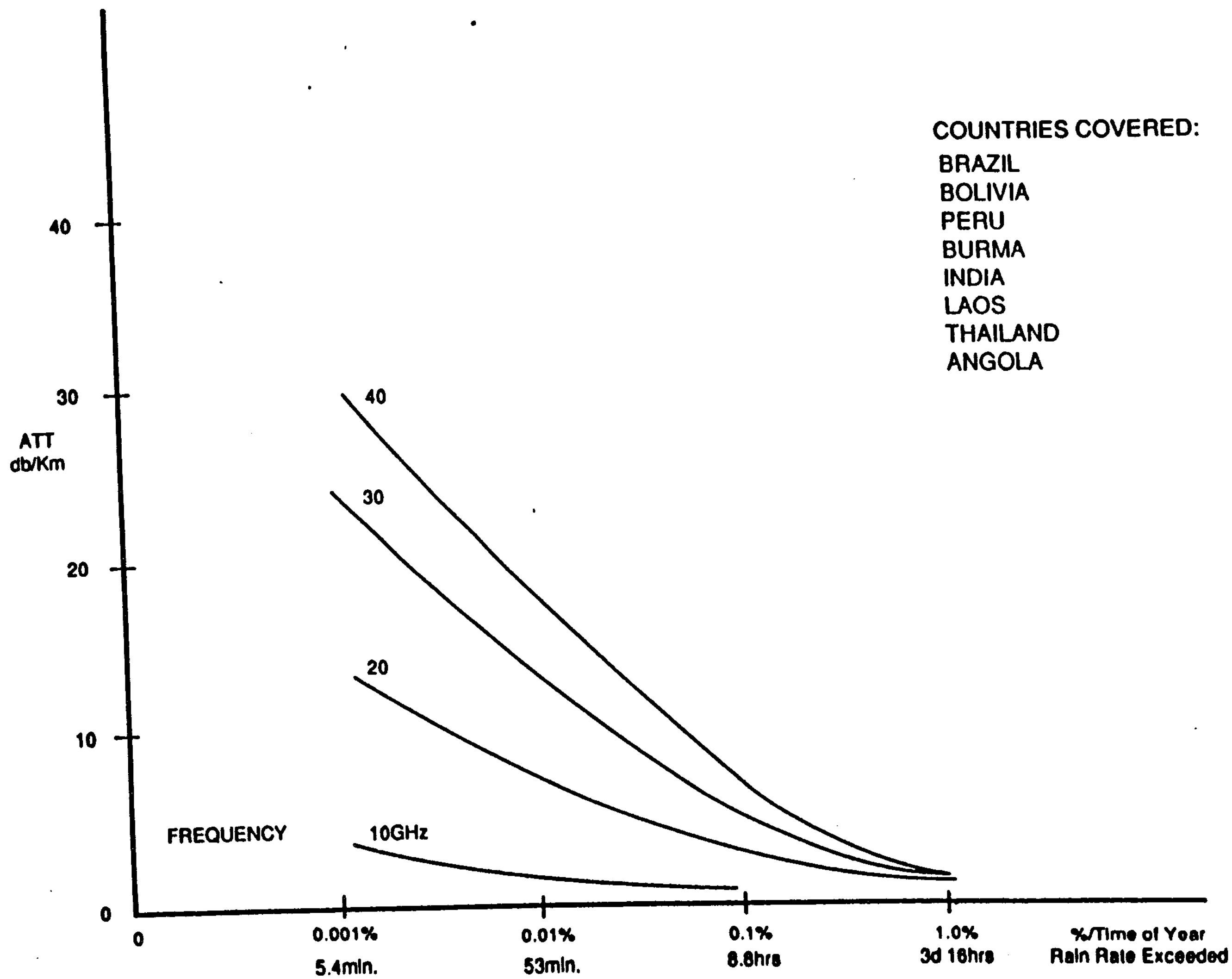


Figure 22. Rain attenuation coefficient for Zone G (tropical-moderate).

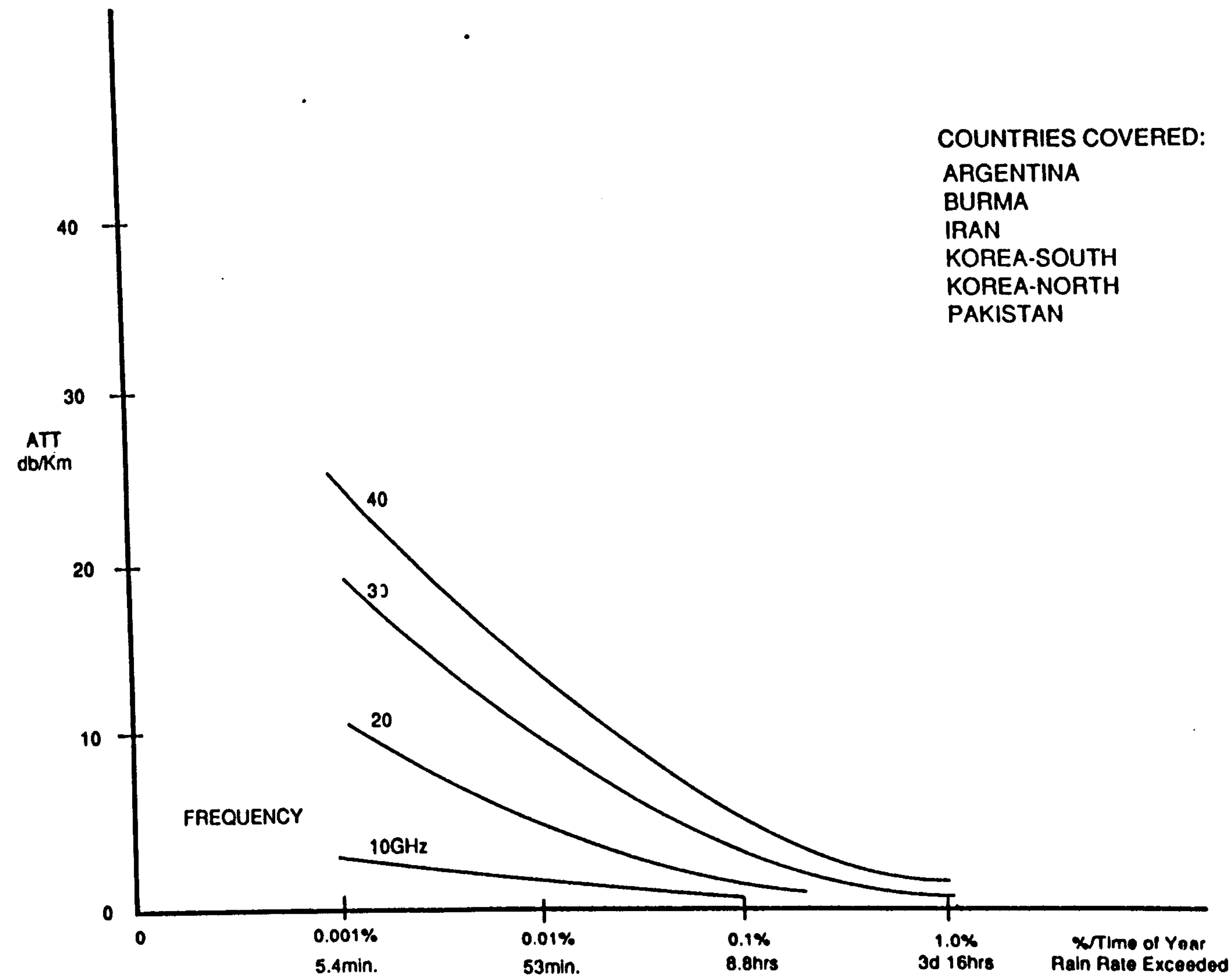


Figure 23. Rain attenuation coefficient for Zone D2 (temperate-continental).

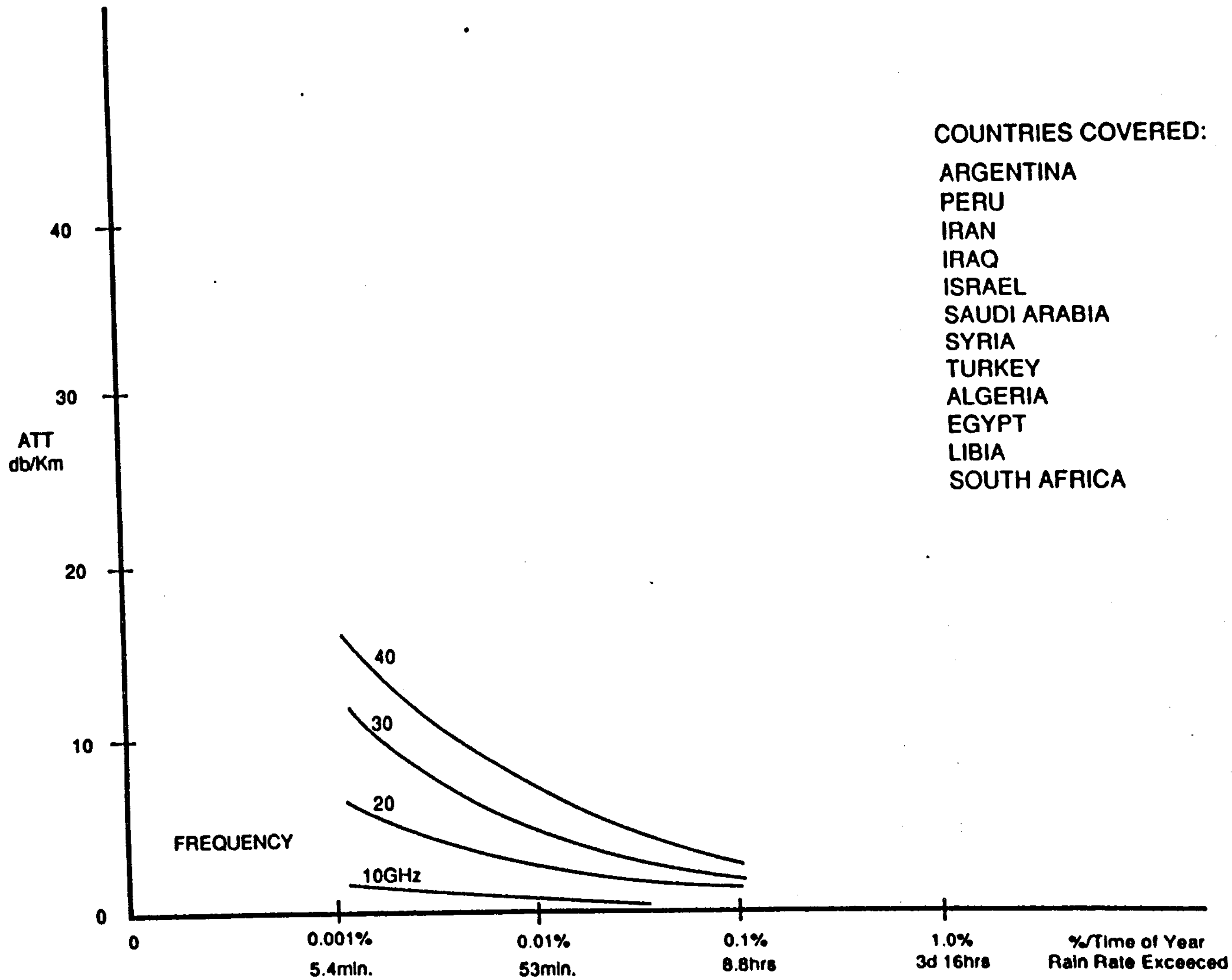


Figure 24. Rain attenuation coefficient for Zone F (subtropical-arid).

6.0 SATELLITE - RTS COMMUNICATIONS SYSTEM

In this section, we review end-to-end satellite-RTS link characteristics. Because of the RTS size, weight, and power constraints and large uplink sensor data rate to downlink command rate ratio, the system is constrained by the uplink data rate. However, under a given set of constraints there is a substantial trade-off area which can be used to optimize system performance.

The satellite system characteristics are given in Section 5.2, link budgets in Section 5.3, and RTS design discussion in Section 7.0. Together, these sections provide the major portion of communication link characterization.

6.1 SATELLITE SYSTEM ARCHITECTURE

To take full advantage of the GEO satellite communication system for intelligence-gathering systems, the following architecture is proposed. Figure 25 shows C&CCs communicating with their designated RTSs via a GEO satellite. The usual constraints of RTS's allocations to C&CCs and RTS-C&CC geometry do not apply in such architecture.

A single satellite acts as a transparent repeater for all the links, and channels are multiplexed in frequency, time, and code domains according to a priori established rules of allocations priorities and demand. This flexibility permits load sharing and instantaneous replacement of downed C&CCs.

Designating one C&CC as a master C&CC will permit real-time coordination of resources according to needs and to overcome C&CC failures and overloads. The C&CCs now can be allocated special analysis equipment that can be shared by many RTSs. This will eliminate the need for every C&CC to have all the specialized equipment, reduce costs, and optimize performance.

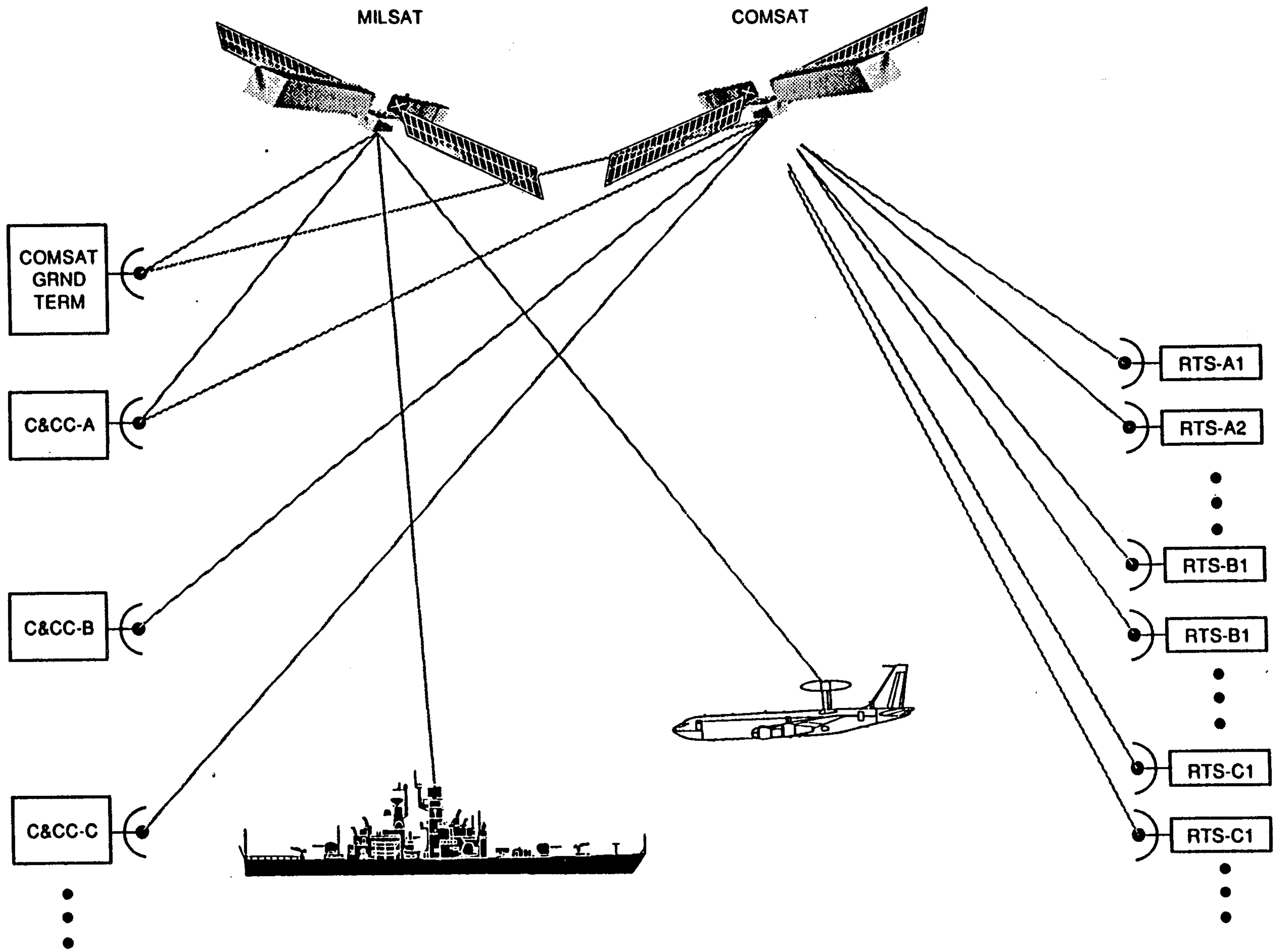


Figure 25. Satellite-RTS system architecture.

Locally placed C&CCs will still perform the primary function and control their RTSs and respond directly to the area commander's needs. However, the ability of C&CCs to communicate between themselves will allow additional degrees of freedom not possible with terrestrial systems.

Furthermore, the ability to utilize existing commercial resources and to expand rapidly into commercial systems in times of need and high activity will provide responses needed by today's highly-efficient and mobile armed forces without overloading existing military communication links.

Transferring information to military satellites will permit direct assistance to the individual users -- such as Army artillery, Navy ships, or Air Force planes -- to aid them in guidance to the selected targets. This can be done in several layers of pointing accuracy. A single RTS can be used as a homing beacon, or several RTSs can be used to perform triangulation upon a target. Also, the RTS may include a global positioning system (GPS) receiver and broadcast its position. The C&CC or group of C&CCs retransmit the relevant data in reduced and compatible format via the communication satellite to either a designated C&CC or a commercial satellite ground terminal. This, in turn, transmits the data through the military satellite to the data user.

6.2 FREQUENCY AND COVERAGE CONSIDERATIONS

In the extreme case of a ground terminal antenna elevation angle off 10°, a geostationary satellite will cover an area of 15,000 km in diameter. Such a coverage will encompass hundreds of RTSs and C&CCs. Even at a high antenna elevation angle of 45° where there cannot be any propagation path obstacles, the satellite coverage extends over 8,500 km diameter and over ± 39° of latitude. Such a link provides an unobstructed and direct view to many areas of interest. This overcomes many problems associated with relatively short-range communication systems, such as terrestrial and meteor burst.

For terrestrial systems at a frequency of about 30 MHz (a quasi line-of-sight propagation), the direct path is in tens of kilometers and has a very shallow angle of propagation. The ionosphere bounce path, on the other hand, has a range of hundreds of kilometers but includes definite geometry constraints and large, daily varying components.

At frequencies above 50 MHz, the propagation is via line-of-sight path only, and low elevation angles expose the propagation to natural land obstacles. Though the diffraction effect will pass the signal over obstacles, the attenuation follows rates higher than the distance squared and will attenuate the signal very rapidly.

Frequencies between 50 and 250 MHz are often used for meteor burst communications. Because the ionized layer lies below 100,000 ft, the communication range is limited by geometry to several hundred kilometers. Incidence (elevation) angle varies from 33° for a 100-km hop to 5° for a 600-km hop, making signal reception sensitive to natural land obstructions.

By definition, meteor burst communication has very irregular transmission characteristics, with deep propagation fades lasting tens of seconds, and messages must be repeated. In addition to this, the propagation characteristic has definite daily patterns and geographical latitude preference due to the earth's magnetic field.

Thus, the meteor scatter communications are not suitable for reliable and upon-demand communications.

At frequencies above 1,000 MHz, the antenna becomes relatively small but maintains reasonable gain. This overcomes large space losses associated with high frequencies and large distances between the ground terminals and the GEO satellites. As mentioned at the beginning, this offers an unobstructed propagation path and a very reliable and steady communication environment. For frequencies below 10 GHz, the atmospheric and rain losses are very small.

The small antenna size makes those frequencies very suitable for space and terrestrial use where antenna size is a constraint.

At frequencies above 10 GHz, the atmospheric and rain attenuations become major issues. This, coupled with high link availability statistics, results in the high rain margin required for wet tropical climate zones.

6.3 DATA RATE

The major constraints on the RTS are small size, low weight, and visual and electromagnetic covertness. Together they determine antenna size which directly controls permissible data rates. Section 5.3, Link Budgets, provides link budgets for the selected satellite systems and ground terminals. It can be seen that the uplink data rates vary from 1 kHz to above 100 kHz, depending upon the satellite, ground terminal, modulation type, and rain margin selected.

For the RTS the data memory size, data rate, transmission time, and dc power consumption are interrelated. The larger the data amount to be transmitted the greater the data rate or transmission time. Similarly, the greater the data rate or transmission time, the greater the energy required. As mentioned earlier, Figure 8 depicts data memory size in terms of data rate and transmission time.

These are limits within which the RTS must operate under the above-enumerated constraints.

7.0 THE RTS DESIGN

Based upon work done and described in Sections 4.0, "Operational Concepts," 5.2, "Survey of Satellite Systems," and 5.3, "Link Budgets," it can be concluded that there cannot be a unique RTS design that covers all the satellites. This is because the satellite frequencies cover the range from UHF to EHF bands and use different modulation and multiplexing systems. Further, Satellites such as MILSTAR require strict compatibility with waveforms specified in Reference 7.

As a consequence, the selected approach is to use a modular breakdown and to describe requirements/functions for each module. This is of specific interest when existing ground terminals are to be adapted and modified to fulfill RTS requirements.

7.1 THE RTS ARCHITECTURE

The RTS system will be broken into functional modules that perform specific and different functions. This will permit RTS adaptation to different mission requirements such as different frequencies, waveforms, satellite systems, RF output powers, antennas, memory sizes, and mission durations. Further, as the RTS requirements finalize, it will avoid costly and time-consuming redesign.

Modular construction will also enable purchasing and adaptation of available modules to reduce cost and design cycle. In cases such as government-developed MILSTAR Advanced Scamp ground terminal or commercially-developed INMARSAT ship earth station, the modular construction will help in defining clear interfaces between the communication, control, memory, DC power, and sensor modules.

This will also provide large latitudes in trade-offs between performance, schedule, costs, and RTS system adaptability to changing requirements. For communications with GEO satellites, it is the RTS small size antenna and low RF power output that limit the uplink data rates. Consequently, optimization of uplink for different satellites (G/T) and RTS (output power and direction), and mission types will have major effects upon permissible data rates. Figure 26 shows RTS breakdown into seven basic functional modules. They are:

- Antenna and duplexer
- Receiver
- Transmitter
- Sensors
- Sensor data memory
- Controller
- DC Power

While the antenna, receiver, and transmitter assemblies perform the standard communication functions -- the sensor, memory, and controller assemblies perform the specific RTS functions of intelligence information gathering and mission mode control.

Frequencies for different satellites are given in Table 29. They range from a low of 250 MHz to a high of 44 GHz. This spread provides a substantial range for the selection of frequencies to implement frequency hopping between different satellites.

Satellite longitude positions are shown in Figure 27. Due to both the earth's natural land mass locations and earth population distribution, optimum satellite locations tend to group

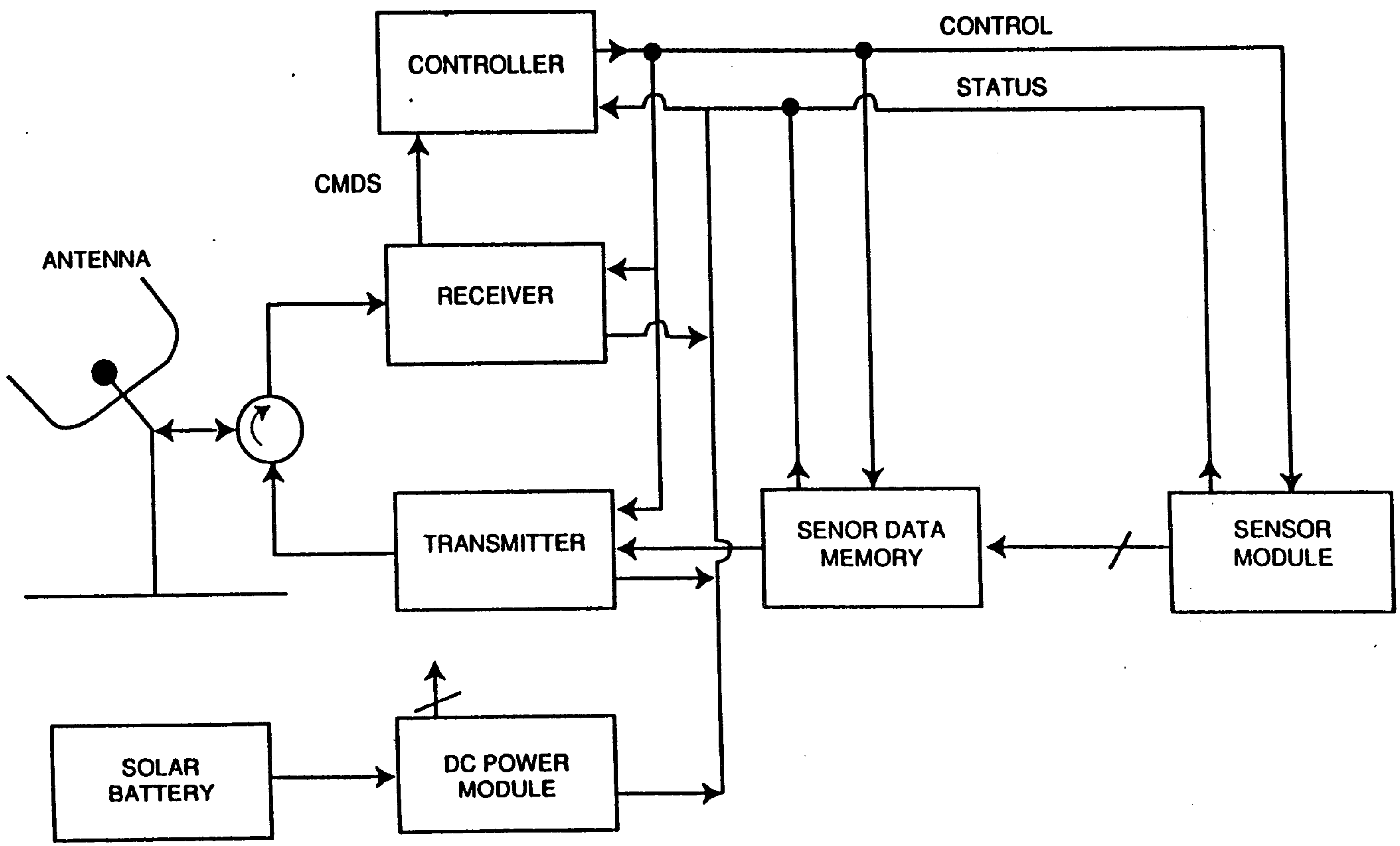


Figure 26. RTS block diagram.

Table 29. The GEO satellite frequency allocations.

Satellite	Uplink		Downlink	
	Freq. MHz	BW MHz	Freq. MHz	BW MHz
INTELSAT	5,929-6,423	494	3,707-4,198	491
INMARSAT	14,004-14,498	494		
IRIDIUM	2,483.5-2,500.0	16.5	1,610.0-1,626.5	16.5
TDRSS				
MA	2,285-2,290	5.0	2,103.4-2,109.4	6.0
SSA	2,200-2,300	100	2,025.8-2,117.9	92.1
KSA	14,891-15.116	225	13,750-13,800	50
DSCS	7,900-8,100	200	7,250-7,375	125
	7,975-8,100	125	7,400-7,450	50
	8.125-8,175	50	7,490-7,675	185
	8,215-8,400	185	7,700-7,750	50
MILSTAR	44,000			
FLTSATCOM	290-320	30 (23 CH)	240-270	
AFSATCOM	8,000 (1 CH)			
	4,400	26 CH at 2400 Hz	20,000	26 CH at 2400 Hz
			10,945-11,191	246 MHz
	1,636.5-1,644.5	8.0	11,459-11,698	239 MHz
	6,417.5-6,425.0	7.5	1,535-1,542.5	7.5 MHz
			4,192.5-4,200.5	
	1,626.5-1,631.0	4.5		8.0 MHz
	1,631.5-1,636.0	4.5	1,530-1,546	
	1,636.5-1,643.8	7.3		16 MHz
	1,644.3-1,647.5	3.2	3,600-3,604.5	4.5 MHz
	6,425-6,491	16.0	3,605-3,690.5	4.5 MHz
			3,610-3,617.5	7.5 MHz
			3,617-83,621	3.2 MHz
UFO	292-318	17 CH at 25 KHz	243-270	17 CH at 25 KHz
		21 CH at 5 KHz		21 CH at 5 KHz
	8,000	Broadcast		
	44,000	11 CH at 2.4 KHz	20,000	11 CH at 2.4 KHz

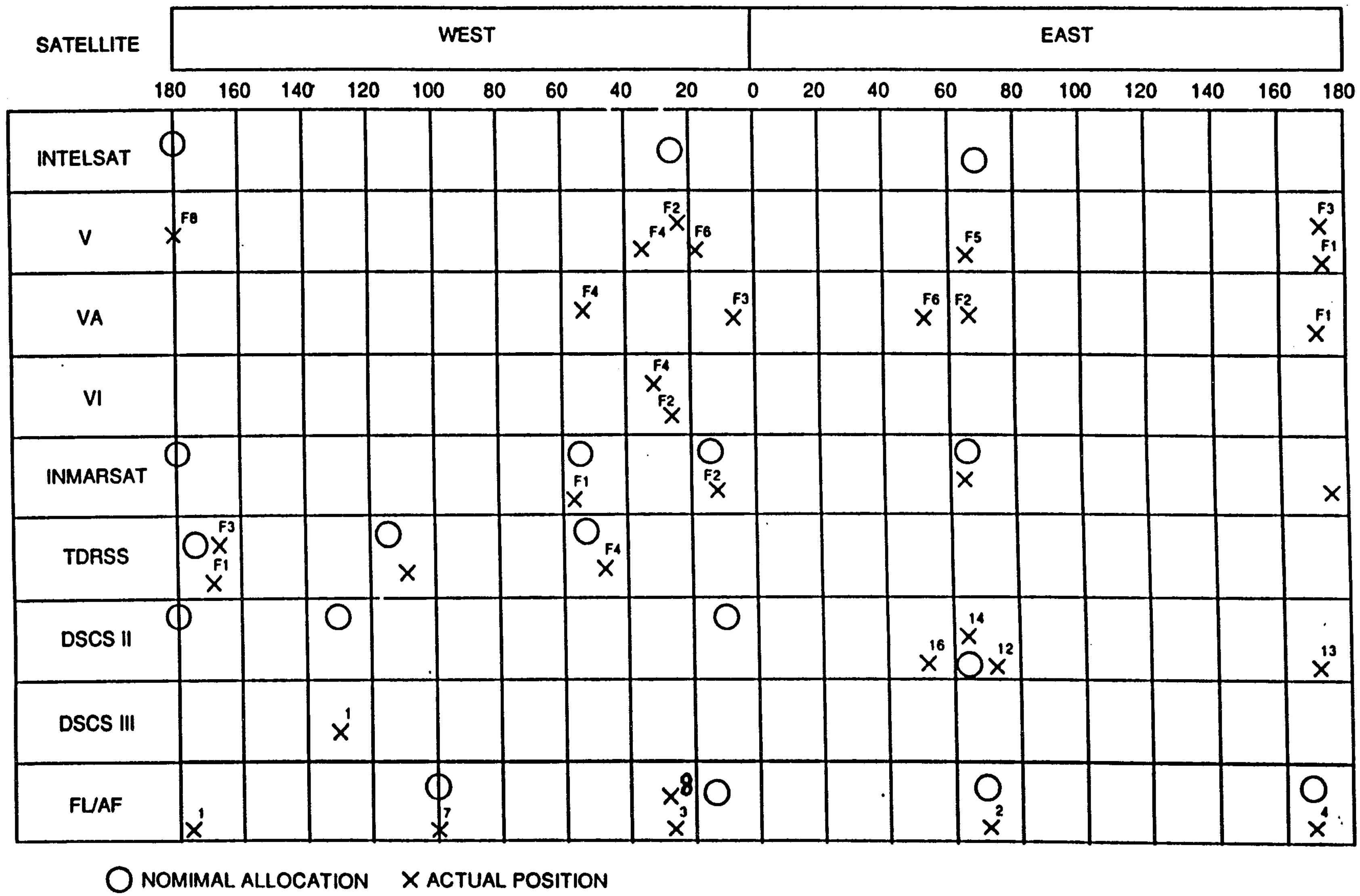


Figure 27. Satellite longitude positions.

together for different satellite systems. Basically there are three areas to cover -- Europe, America, and Asia-- and satellites are located in such a way as to optimize coverage. It can be seen that the satellite locations bunch together at 30° W, 120° W, 180° W, and 65° E longitudes.

This overlapping coverage by satellite systems makes it feasible to frequency hop between different satellites, frequencies, and modulation formats to provide substantial degrees of security to RTS uplinks.

7.2 THE RF EQUIPMENT

7.2.1 Transmitter and Receiver

The RTS transmitter EIRP and G/T requirements are uniquely defined by satellite capabilities, range, atmospheric losses, data rates, and required SNR ratio. Using GEO satellites for worldwide coverage, predicted rain statistics for different climatic zones, and minimum SNRs for different modulation formats, we can determine minimum values for transmission data rates under the constraints of maximum EIRP and G/T at the satellite and RTS. The major constraints at the RTS are total equipment weight, antenna size, and DC power consumption.

A maximum antenna diameter of 2 ft, a maximum RF power output of 1 W, and a maximum system noise figure of 5 dB were selected as a baseline. Figures 28 through 31 give EIRP, beam-width, and G/T parameters as functions of frequency and antenna diameter. These graphs permit parameter trade-offs under given constraints. The system noise figure varies with frequency and diplexer losses however, corrections for actual noise figures and diplexer losses can easily be introduced into link budget calculations. Modulation format SNR and rain attenuation margins must be added to these trade-offs.

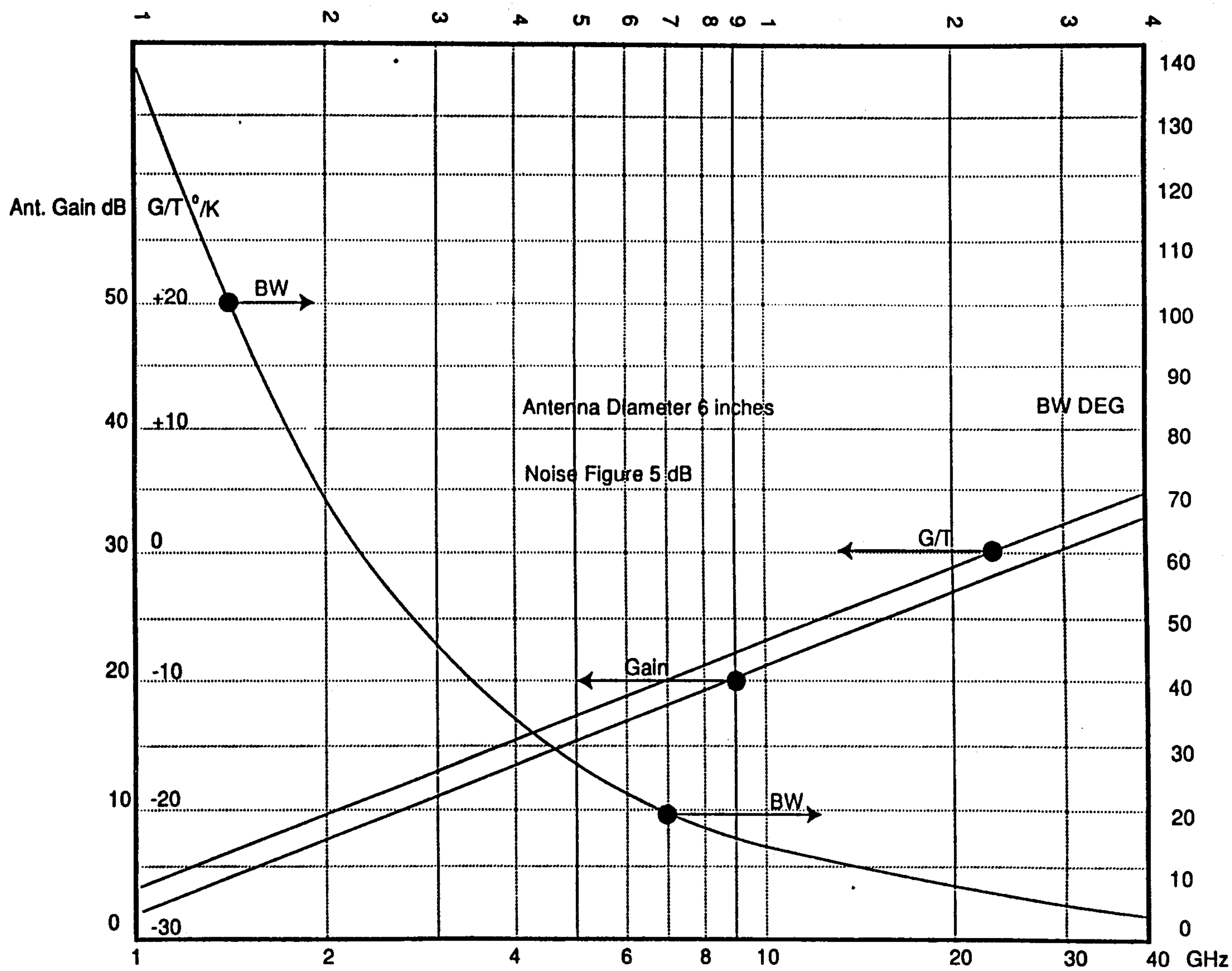


Figure 28. The RTS parameters as a function of frequency -- antenna diameter six in.

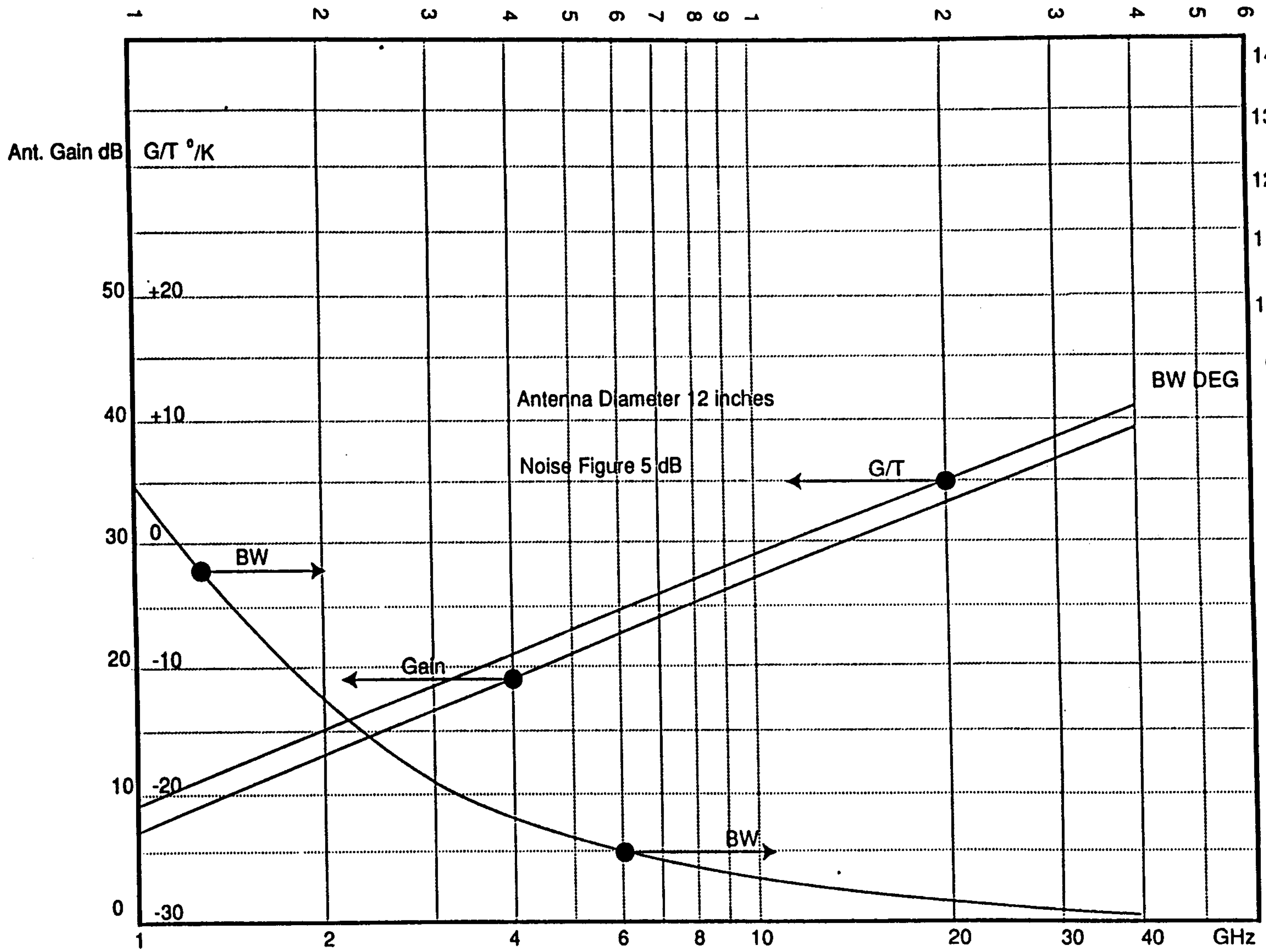


Figure 29. The RTS parameters as a function of frequency -- antenna diameter 12 in.

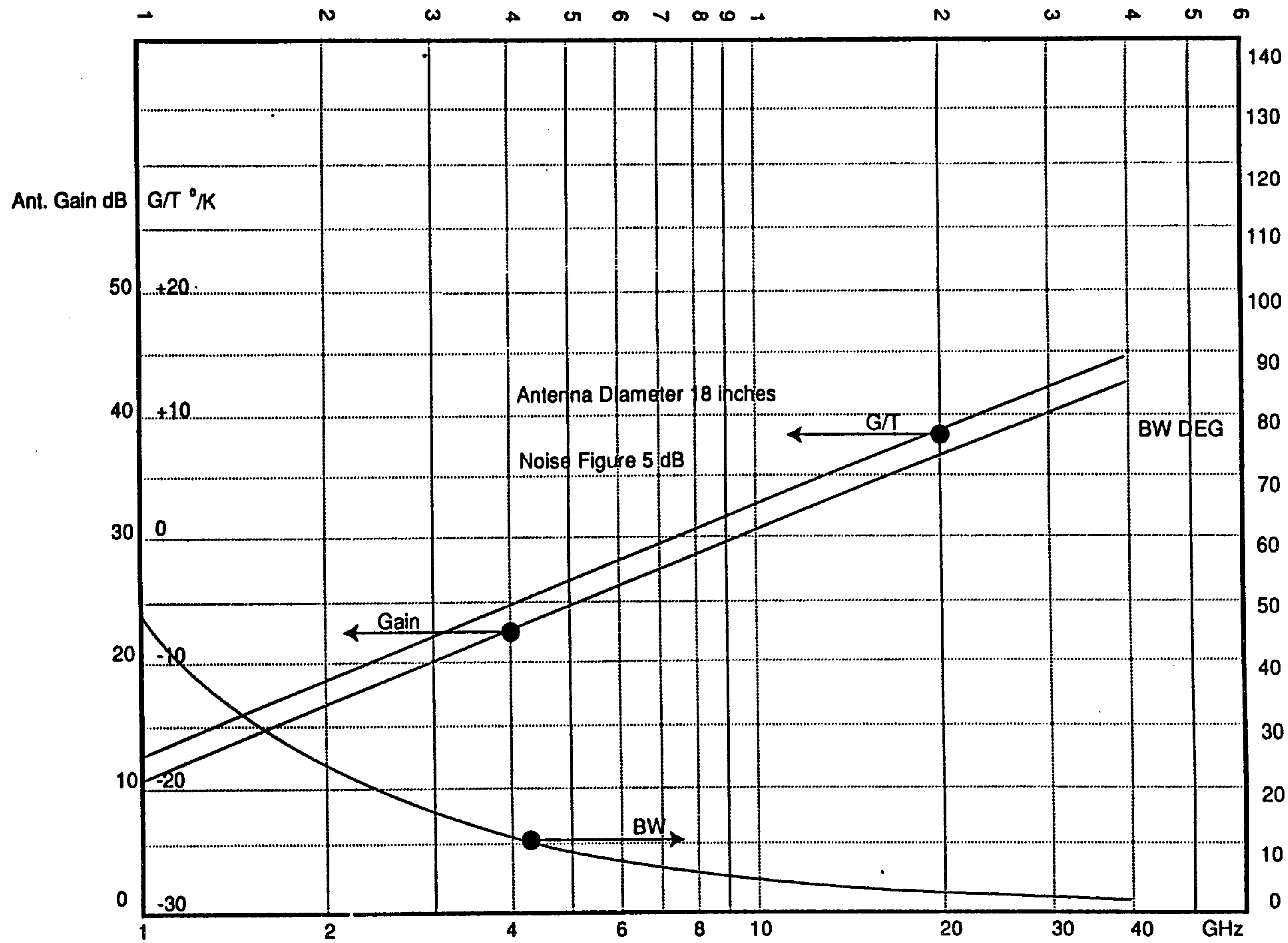


Figure 30. The RTS parameters as a function of frequency -- antenna diameter 18 in.

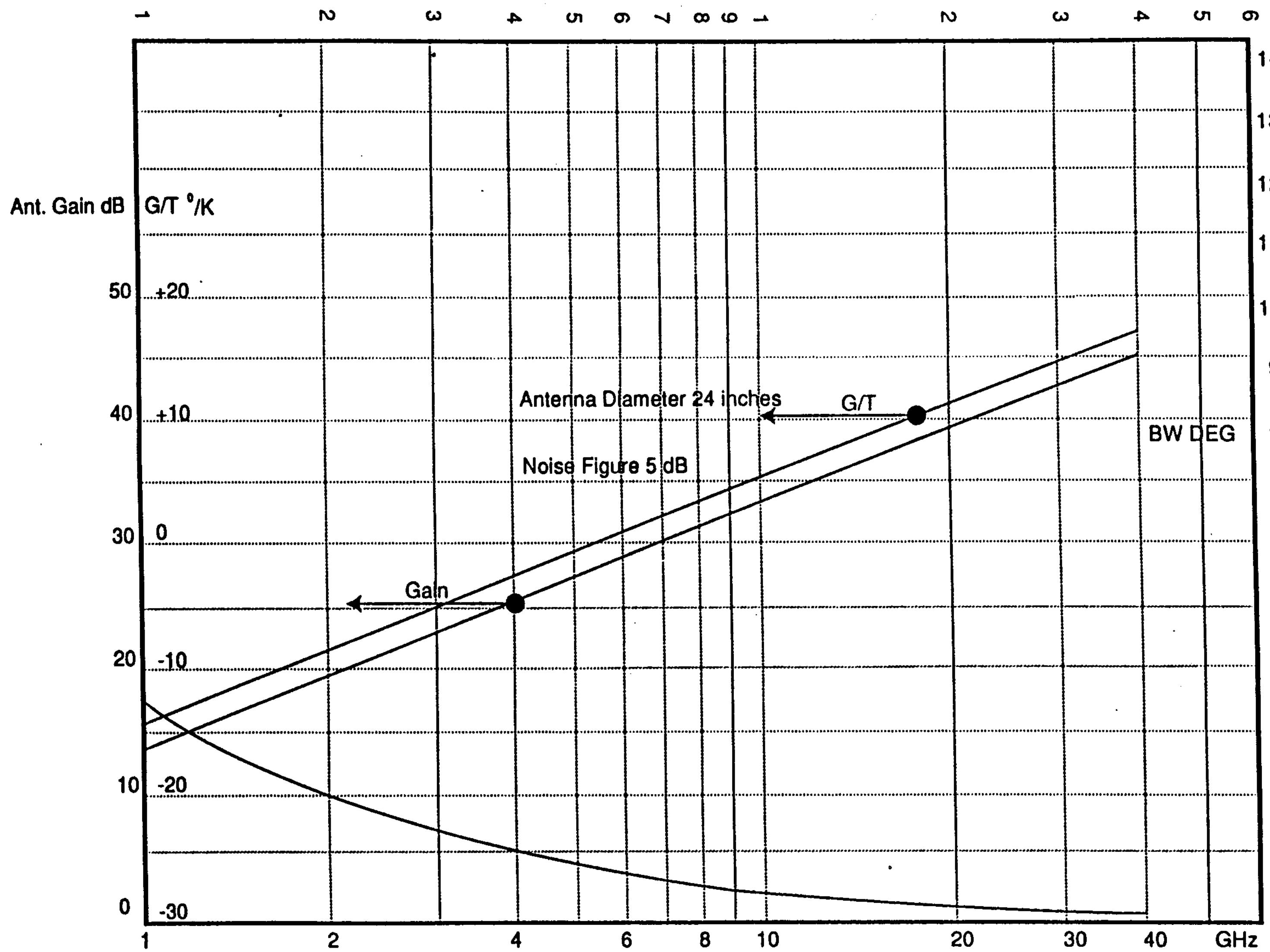


Figure 31. The RTS parameters as a function of frequency -- antenna diameter 24 in.

Link budget calculations were made for suitable satellite systems and ground terminals that were postulated or were available from commercial or government sources. It is evident from the resulting SNRs that data rates are constrained by the ground terminal. Depending upon satellite and offered services the maximum uplink data rates vary from 1,000 bps to tens of kilobits per second.

7.2.2 Antenna

The antenna provides the greatest challenge in the design of a small, lightweight, portable, low-profile and covert RTS. It must be stowed for transportation, be easily and speedily erected at the site, and be visually covert. One approach is to use the newly emerging FLAPS (flat parabolic surface) technology. Flaps technology utilizes dipoles mounted on a physically flat and RF-transparent surface, followed by a ground plane to reflect signals at their resonant frequency. Modifying dipole size and spacing forms an electrically-parabolic surface which provides directicity and gain. Since the dipoles are photo-etched, the antenna is very cheap -- and it should be sturdy if it is made to be part of the RTS housing. Figure 32 shows a FLAPS dual-frequency antenna, and Figure 33 an example of how it can easily be stowed.

7.2.3 Existing Ground Terminals

At the present time, there are several transportable ground terminals available on the market. They are for INTELSAT, IMMARSAT, DSCS and MILSTAR satellite systems. Of these IMMARSAT, DSCS, and MILSTAR terminals are compatible with RTS requirements for size and weight constraints but will require interface with the controller and memory. These interfaces should be very simple to implement, since both the DSCS and Advanced Scamp terminals have external control terminal. Both the INTELSAT and another DSCS terminal have large antennas and high-power amplifiers. These would have to be replaced by smaller units and the equipment repackaged to make them man-transportable.

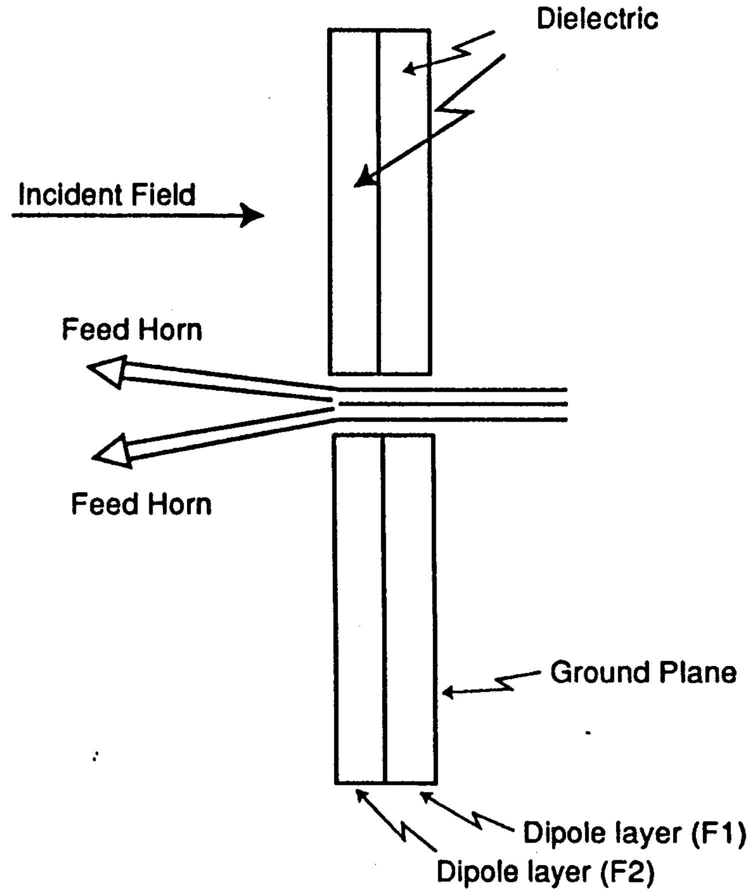
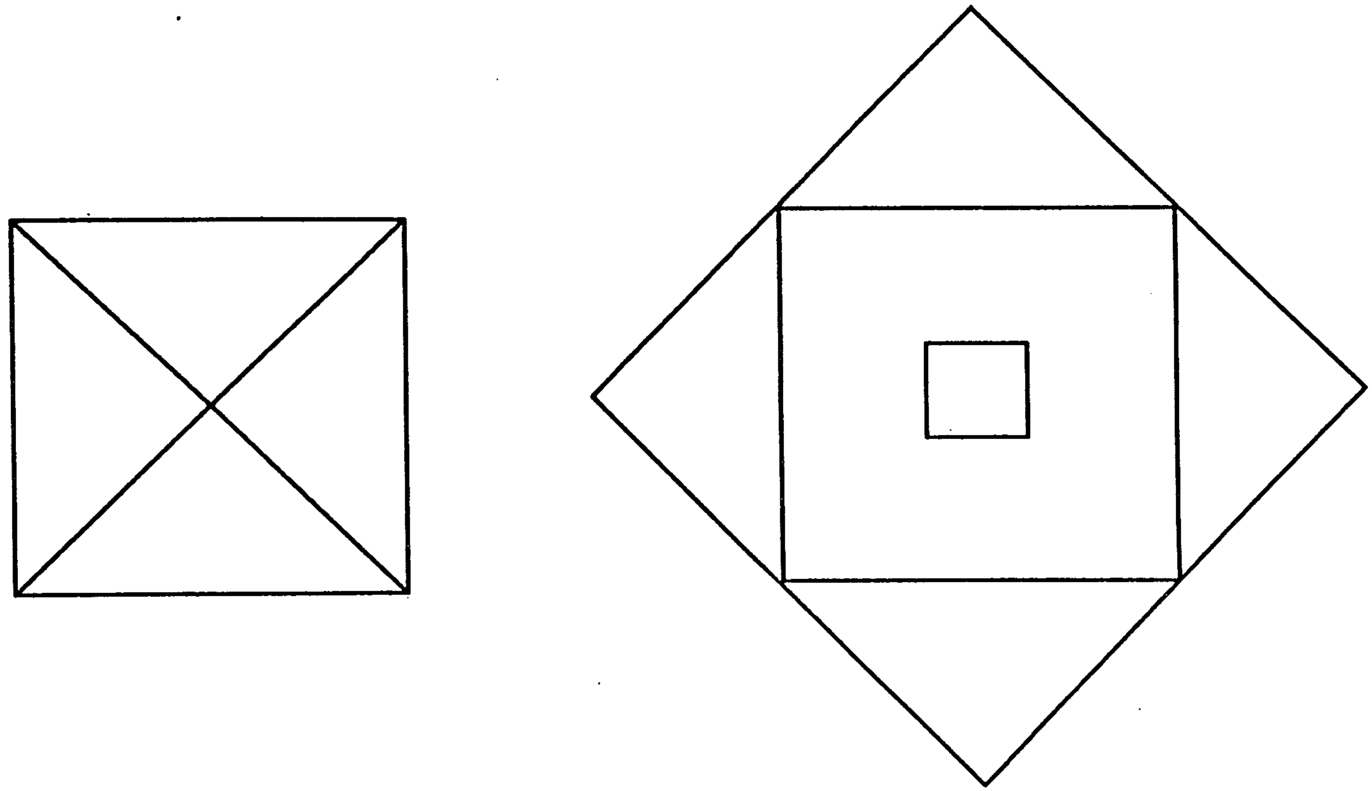


Figure 32. FLAPS dual-frequency antenna.



Stowed FLAPS Antenna Reflector

Open FLAPS Antenna Reflector

Figure 33. FLAPS antenna -- reflector stowed and open.

Table 30 provides terminal designations, satellite systems, manufacturer, and modifications required. The actual modifications required are difficult to assess without detailed mechanical and electrical drawings and system descriptions.

7.3 SOFTWARE REQUIREMENTS/SENSORS AND DATA MEMORY

7.3.1 Sensor Assembly

The sensor assembly collects the selected data defined by individual sensor types and by controller commands. Sensor activity is monitored by the RTS controller which reacts according to the preprogrammed monitor mode. This includes, among other reactions, squelching of low activity/noise sensors, activation of high activity operational modes, establishing priorities, and preventing system overload. The sensor assembly will convert the data to a digital format for recording onto a solid state, magnetic tape, or disc media. The nominal complement of sensors would include sensing of:

- Voice
- Earth vibration
- Acoustic (traffic and explosions)
- RF transmission
- Movement
- Heat transmission
- Presence

Table 30. Existing ground terminals.

Terminal	Satellite	Manufacturer	Modifications
CSAT Digital Earth Station	INTELSAT	Satellite Transmission Systems	Moderate-Replace Power Amplifier and Antenna Interfaces so the Controller and Memory
Ship Earth Station "C" Galaxy-INMARSAT	INMARSAT	Trimble Navigation	Minimal-Interfaces to the Controller and Memory.
X-SAT Terminal	DSCS	Satellite Transmission Systems	Moderate-Replace Power Amplifier and Antenna Interfaces to the Controller and Memory
SHF Man Transportable Terminal	DSCS	Hum's	Minimal-Interfaces to the Controller and Memory
Advanced Scamp	MILSTAR	Raytheon	Minimal-Interfaces to the Controller and Memory

- Air chemical composition analyzer

- Nuclear radiation analyzer

The individual RTS will contain only the sensors of interest to its mission.

7.3.2 Sensor Data Memory

Reference 1 discusses types of signals, bandwidth compression, and memory size.

The reduced RTS data storage capacity requirement is 32 Mbytes, which is equivalent to 13.5 hours recording of audio at 4.8 kbps rate. This is well within the capabilities of the existing hard discs used in personal and lap top computers, which have capabilities in excess of 200 Mbytes. System limitation lies in maximum uplink data rate and not in memory size.

In many instances the activity time to total time has a low duty cycle, and substantial recording time can be saved by basic data compression techniques. Figure 34 shows a typical data compression reduction technique where the received signals are first recorded on fast loop memory where signal recording decisions are made. They are based upon predetermined criteria, and only signals meeting these criteria are passed to magnetic memory. These criteria may be signal magnitude, correlation between sensors, and priority among others.

After compression, the data will be tagged with time and other flags such as priority, activity level and correlation between sensors. This technique is extensively and successfully used in radars where very large numbers of signals are being detected and a limited number are being processed for further use. Large compacting ratios cannot be expected in this application but should go a long way toward reducing the maximum uplink data rate.

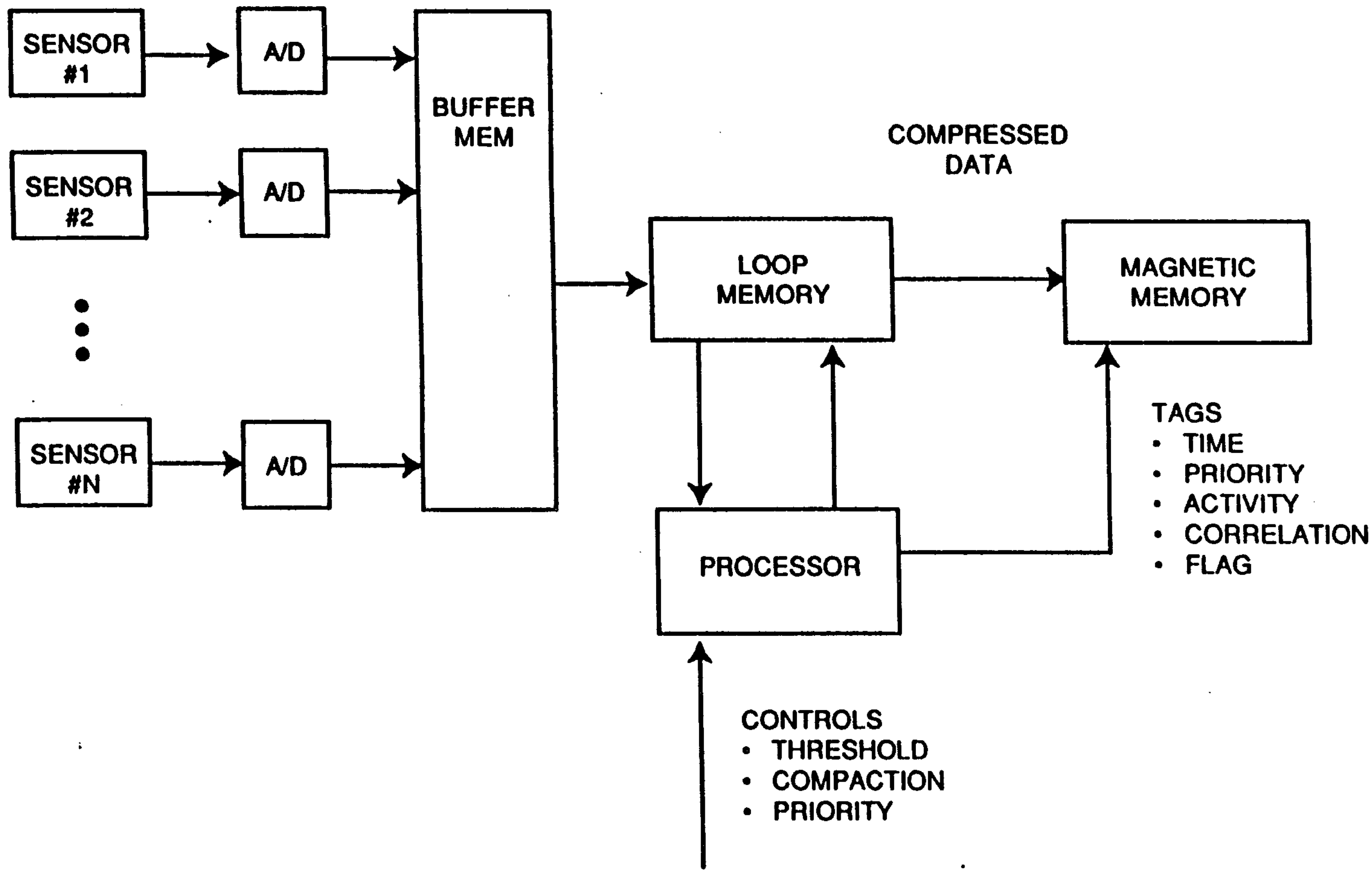


Figure 34. Data compression/reduction technique.

7.4 CONTROL AND SOFTWARE

7.4.1 Controller

The controller performs all the control functions required by the RTS. Under the remote control mode, the control signals are generated by the C&CC operator -- who selects the sensors, operational modes, and the preprogrammed software. Under the local control mode, the control signals are generated by the preprogrammed software, control flags, and the clock.

The controller performs the following:

- Executes commands generated by the C&CC operator and internal software;
- Time tags and identifies data types;
- Formats and reduces the data;
- Sets up alert and control flags for use by the C&CC operator and RTS controller; and
- Monitors hardware, software, memory fill status and battery status.

Control flags provide (at least) the following information and/or instructions to the controller:

- Data priority
- Activity level

- Initiate specific operational modes

- Memory fill status

- Alert

7.4.2 Software Requirements

Software requirements for the operation of the RTS are rather small in both magnitude and complexity and will not require extensive programming. The following activities/functions/hardware must be controlled by software:

- Hardware

- Antenna Pointing

- System Operation

- Sensor Data

- Data Compacting

In most cases, the control algorithms are based upon simple logic functions of comparison of preset with measured values. They are time, magnitude, activity, status (etc.) comparisons. Correlation of sensor data requires a more complex algorithms for it must put a time range gate, set up magnitude and/or activity thresholds, and detect activities that meet both requirements. Antenna pointing is of the same general complexity. It requires measurement of magnetic north and using a look-up table to correct for geographic location, and measurement of level. Corrected magnetic north and level are used to establish references from which the antenna is moved.

The most complex software algorithm is for data compacting. It requires comparison with threshold and assigning start and stop addresses for detected activity. Thus, defined data is then moved forward to coincide with the last recorded address. Table 31 gives generic software requirements for the five above-discussed activities. It is seen that most of the software algorithms are of the simple measure - compare - decide type.

7.5 THE DC POWER

Reference 1 provides very good insight into RTS operating modes, daily tasking, and total mission scenarios. Tables 32 through 34 give configuration and operating modes, daily scenarios, and total mission scenarios respectively. It can be concluded that a large percentage of time is spent in low power keep-alive and/or listen modes. This keeps the total power consumption low. For the referenced RTS, this varies between 82 and 182 W, depending upon the scenario.

The RTS power consumption estimate is given in Table 35 and concludes that the average consumed power will be about 139 W-hr per day. This is within the above estimate. It is expected that data compacting described in Section 3.6.3 entitled "Memory Capacity" will reduce total power consumption even further. It can be concluded, therefore, that the total power consumption will be the same or lower and that a similar battery pack of 16 Electrochem CSC 3B6s (size DD) can be used. Should solar batteries be used, a further reduction of battery size would be expected.

Table 31. ,RTS software requirements.

Hardware	- Control Units Turn On and Off - Monitor Units Status - Flag out of Tolerance Status - Select Sensors
Antenna Pointing	- Measure Magnetic North - Command Azimuth - Command Elevation - Apply Corrections - Initiate Small Scan - Select Max Signal Angles
System Operation	- Select Algorithms - Select Operations Mode - Select Operations Scenario - Apply Time Tag and Warning Flags
Sensor Data	- Monitor Sensor Activity - Flag Specific Activity - Compare with Threshold - Correlate Sensor Activities
Data Compacting	- Compare with Threshold - Compact Data - Monitor Memory Loading - Generate Memory Overload Flags

Table 32. Configuration and operating modes.

Mode	Function	Description
0	Sleep	All system power off except for timer clock
1	Doze	Periodically end sleep mode and listen on the command channel for instructions
2	Search	All systems powered down except for receiver (and df) building signal data base
3	Copy	Receiver in directed search mode. When signal is present, audio is encoded into flash memory
4	Send	Stored data (either signal list or audio) is transmitted
5	Real time commo	Modes 3 and 4 combined; no flash memory
6	Cmd/status	Various subgroups powered on for configuration change which could include gps, receiver configuration, etc.

Table 33. Daily scenarios.

Functions Performed Over 24 Hours	Daily Scenarios					
	A	B	C	D	E	F
Search	12.00	12.00	0.00	9.00	10.00	18.60
Record/Copy	0.40	1.00	0.00	3.50	0.55	2.20
Df/Copy	0.15	0.15	0.00	.35	0.15	0.40
Real Time Playback	0.00	0.00	3.50	0.00	0.00	0.00
Total (hrs)	12.55	13.15	3.50	12.85	10.70	21.20
Sleep (hrs)	11.03	9.58	20.50	6.53	12.67	.08
Other (hrs)	0.42	1.27	0.00	4.63	0.63	2.72
Watt-Hours Consumed Over 24 Hours						
Sensor Assembly	34.00	36.84	1.26	40.98	29.60	59.34
Transmitter Assembly	48.04	68.01	126.04	140.86	53.73	95.70
Total (whrs)	82.04	104.85	127.30	181.84	83.33	155.04

Table 34. Total mission scenarios.

Daily Scenario	Mission Scenario			
	1	2	3	4
A	1	2	3	4
B	2	2	4	
C	5	5	6	
D	5			
E		5	5	
F				8
Mission Duration (Days)	12	11	15	8
Energy Consumed (Watt-Hrs)	1,315	1,406	1,362	1,240

Table 35. The RTS DC power consumption estimate.

Module	DC Power	Duty Cycle	Daily Power
Receiver	1.0 W	25%	0.25
Local Osc.	3.0 W	25%	0.75
Trans	1.5 W	1hr/24hr	0.06
Power Amp.	4.0 W	1hr/24hr	0.17
Processor	0.75 W	25%	0.19
Dyn. RAM 1MB	0.5 W	25%	0.12
Hard Disc	10.0 W	25%	2.5
Clock	1.0 W	100%	1.0
Sensor	1.0 W	25%	0.25
Misc.	2.0 W	25%	0.5
Total Power			5.79.W
Total Power Coms. Per 24 hr			139 W HR

7.6 SECURITY CONSIDERATIONS

Both the downlink and uplink have to meet LPI and LPD security requirements. While both links have to meet the security requirements, it is the uplink that can compromise the RTS location and the sensor-data contents and, therefore, is more important. Recent cuts in the defense budget have forced the DoD to rethink the whole security approach to satellite communications. As a result, the DoD has come up with a new approach that uses both commercial and military satellites with varying degrees of security levels. While some messages require absolute security, many others require lesser degrees of security and only for a limited time.

The following sections provide insight and descriptions how this new DoD-initiated approach can be used for RTS.

7.6.1 Classical Security Methods

Classical security methods utilize data encryption to satisfy the LPD requirements and bandwidth spreading or frequency hopping to satisfy the LPI requirements. FLTSATCOM and MILSTAR systems have used this approach. MILSTAR, in particular, uses time division multiplex with FSK and DPSK modulation, data encryption, and interleaving to obtain a secure system. High frequency hopping over a very wide band makes the link difficult to intercept and jam.

7.6.2 "Bent Pipe" Wideband System

Use of "bent pipe" wide-band satellite transponders permits the use of encryption and frequency hopping at the source. The satellite transponder in this case performs just a repeater function. Dehopping and decryption are performed at the receiving end.

Satellites that may provide sufficiently wide bands are INTELSAT (494 MHz), TDRSS (100 and 275 MHz), and DSCS (50, 125, 185 and 200 MHz).

7.6.3 Channel Switched Data Bursts

In cases where individual satellites offer different frequency bands, or where satellites that have the same or overlapping coverages offer different frequency bands, a channel switched data bursts approach may be used. Frequency channels are allocated according to a predetermined key that includes access to a clock. Data are then transmitted in bursts at different frequencies. Since the RTS data rate will be well below 100 kbps, only narrow-band channels are required.

Satellites that could provide such services are INTELSAT (8 MHz), IMMARSAT (3.2 to 7.3 MHz), TDRSS MA (5 MHz), and FLTSATCOM (5 and 25 KHz).

7.6.4 Multiplexed Channels

Frequency, time, and code domains in multiplexed channels may be used to interleave RTS data with traffic data. Using this technique and filling the unused channels with commercial traffic will accomplish substantial security. Though the frequencies may be close together the information will be buried in different modulation formats in different multiplexing domains. INTELSAT, IMMARSAT, and IRIDIUM are the systems that may provide such capabilities.

7.6.5 Receiver and Transmitter Designs

Receivers pose no design problem to multifrequency transmissions because they can be instantaneously tuned over wide-band ranges.

Transmitters may pose a problem especially when low power consumption is of paramount importance. The simplest approach is to use a single transmitter for narrow-band frequency hopping and separate transmitters for very wide-band frequency hopping.

8.0 CONCLUSIONS

The multiplicity of frequencies, channels, antennas, signal waveforms (modulation and multiplexing), repeater types (bent pipe or onboard processing), and satellite coverage make it difficult to arrive at a unique solution. However, this does not prevent general conclusions and guidelines that will help in zeroing in on a solution or solutions that will be relatively easy to implement and have a high probability of success.

8.1 FREQUENCY

The frequency should be above 1 GHz in order to obtain a ground terminal antenna that is of reasonable size and gain. This will satisfy the visual covertness requirement at a gain that will produce a reasonable data rate. The selected maximum antenna size baseline is 2 ft in diameter. At a frequency of 1 GHz, it will have a gain of 13.0 dB.

The frequency should be below 20 GHz to avoid large rain attenuation coefficients, which could be as high as 28 dB/km for a probability of occurrence of 0.001 percent in tropical zones. However, as a probability of occurrence of 1.0 percent approaches, the rain attenuation value drops very rapidly.

The frequency should be below 20 GHz to avoid the use of state-of-the art and inefficient power amplifiers.

The advantage of 44-GHz uplink and 20-GHz downlink frequency bands is a compatibility with the MILSTAR satellite that provides excellent LPD and LPI.

8.2 REPEATER TYPE

The satellite repeater type preferably should be the simple frequency conversion type to allow use of many modulation and multiplexing methods. However, this should not prevent adopting a standard that can be covered by the selected satellites.

What should be avoided is the use of a complex standard, such as Reference 7, which requires a high level of compatibility, unless there is a prevailing reason in favor of it, such as a high level of comsec and transec.

8.3 CHANNEL BANDWIDTH

From the point of view of a LPD the channel bandwidth should be greater than, say, 20 MHz to permit frequency hopping. The larger the frequency hop, the lower the probability of intercept.

A similar effect can be obtained with narrow-band channels by hopping between different services provided by single or multiple satellites that are widely dispersed in frequencies.

8.4 SATELLITE COVERAGE

Full-earth coverage by satellite is preferred unless the spot beam can be steered over a full-earth coverage of 18°. This also provides instantaneous transmission as well as response from a multiplicity of ground terminals.

As mentioned in the survey of satellite systems, 20 out of 26 locations of interest can be covered by a single satellite located over the Indian Ocean. Due to land mass and population distributions, this satellite is located in a position that optimizes coverage. An Indian Ocean coverage satellite location of 63° E longitude groups many satellites. Figure 27 in Section

7.0, RTS Design, shows satellite locations grouping over the Indian ocean. Other satellite groupings occur over the Atlantic and Pacific Oceans and the continental USA.

8.5 RAIN ATTENUATION

For tropical locations near the equator and satellite point, the RTS antenna elevation angle will be close to the vertical. For locations near the equator and at the limit of coverage, there is substantial coverage overlap between adjoining satellites. As a consequence, the RTS antenna will either be pointing nearly vertical or have a choice of two satellites. This will shorten the signal path through the atmosphere down to several kilometers and minimize rain attenuation. This is totally different from terrestrial links where the path through the atmosphere may be in tens of kilometers. At L- and S-bands rain attenuation is minimal.

8.6 SATELLITE ORBIT

The main and extremely important advantage of a GEO satellite link is its large area of coverage, which extends into several thousands of kilometers. This size area will encompass hundreds of C&CCs and RTSs. Appropriate frequency and time division multiplexing as well as coordination between RTSs will result in steady satellite channel loading.

Such a large area of coverage will eliminate any location constraints of C&CCs with respect to RTSs, whether they be of military, political, geographical or logistic importance. The C&CCs scheduled or unscheduled for maintenance, repair, relocation, or replacement can be instantly replaced by C&CCs located anywhere in the covered area. Any new and out-of-the-way located RTS can be serviced immediately without waiting for coordination with a new and local C&CC. All that the RTS needs to do is to send up a message identifying its approved existence.

Finally, any theater of operation activity can be coordinated, and events detected by all the RTSs correlated, by designating one C&CC as a master controller and data receiver. This master C&CC will send requests for specific data to all C&CCs and/or RTSs, which in turn will transmit the requested data.

8.7 MODULAR CONSTRUCTION

To maximize the use of existing modules and units, modular construction should be used to the maximum extent possible. This will reduce development cost and schedule, avoid specialized design, and allow adaptation to changing requirements.

8.8 GENERAL CONCLUSION

From the survey of satellite systems, it is obvious that the most used and suitable satellites are INTELSAT and DSCS. Their frequency bands are 4/6, 11/14, and 7/8 GHz respectively and can be covered with a single antenna using FLAPS technology. This allows at least two levels of security, use of a common carrier, and instantaneous switching between frequency bands as well as satellites.

9.0 RECOMMENDATIONS

- Give priority to the use of INTELSAT and DSCS satellites.
- Perform detailed end-to-end analysis of the selected satellites modulation, waveforms, multiplexing methods and protocols, and identify any constraints.
- Perform statistical analysis of the satellite channels loading, and establish loading.
- Perform detailed review and analysis of the existing ground terminals for adaptation to RTS.
- Identify the desired comsec and transec levels and implementations.
- Establish satellite communications architecture, including the use of multiple channels, multiple satellites, and master control C&CC.
- Select optimum RTS - satellite - C&CC - RTS system architecture, and propose a point design.
- Design and fabricate an engineering model RTS and perform field verification.

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GLOSSARY

ABBREVIATIONS AND ACRONYMS

ACTS	Advanced Communications Technology Satellite (NASA)
ADCSP	Advanced Defense Communication Satellite Program
AFSATCOM	Air Force Satellite Communications
AFSCN	Air Force Satellite Control Network
AM	amplitude modulation
AMSC	American Mobile Satellite Corporation (United States)
ARPA	Advanced Research Projects Agency (was DARPA)
ATS	Applications Technology Satellite (NASA)
AW	Advanced Westar
BER	bit error rate
BFN	beam forming network
bps	bits per second
BPSK	bi-phase shift keying
C&CC	command and control center
C-band	3 to 7 GHz
CCIR	from the French for International Radio Consultative Committee
CDAS	command and data acquisition station
CDMA	code division multiple access
Comsat	Communications Satellite (Corporation)
CFDM	compounded frequency division multiplexing
CONUS	Continental United States
CW	continuous wave
DARPA	Defense Advanced Research Projects Agency (now ARPA)
dB	decibel
DBS	direct broadcast satellite (or system)
dBW	decibel watt
dc	direct current

DCA	Defense Communications Agency (now Defense Information Services Agency)
DCP	data collection platform
DF	direction finding
DNA	Defense Nuclear Agency
DoD	Department of Defense
DPSK	differential phase shift keying
DQPSK	differential quadriphase shift keying
DSCS	Defense Satellite Communication System
EC	earth coverage
EHF	extremely high frequency (30-300 GHz)
EIRP	effective isotropic radiated power
ERP	effective radiated power
FCC	Federal Communications Commission
FDM	frequency division multiplexing
FDMA	frequency division multiple access
FEP	FLTSATCOM EHF package
FLAG	software bit indicating alert
FLAPS	flat parabolic surface antenna technology
FLTSATCOM	Fleet Satellite Communications (DoD)
FM	frequency modulation
FSK	frequency shift keying
GDA	gimbaled dish antenna
GEO	geosynchronous earth orbit
GHz	gigahertz (1 GHz = 1000 MHz)
GPS	global positioning system
G/T	gain-to-noise-temperature ratio
HEO	highly eliptical orbit (Molnya)
HF	high frequency (3 to 30 MHz)
HIC	high intensity conflict

Hz	hertz
IDR	Intermediate Data Rate (INTELSAT)
IF	intermediate frequency
IMO	Intergovernmental Maritime Organization
INMARSAT	International Maritime Satellite Organization
INTELSAT	International Telecommunication Satellite Organization
ISS	Intersatellite Service
K	Kelvin
K-band	10 to 31 GHz
Ka-band	17 to 21 GHz and 27 to 31 GHz
kbps	kilobits per second
kHz	kilohertz
KSA	K-band single access (TDRSS)
Ku-band	10.7 to 14.5 GHz
kWh	kilowatt hours
L-band	1.5 to 1.7 GHz
LEO	low earth orbit
LHCP	left-hand circular polarization
LIC	low intensity conflict
LOB	line of bearing
LPD	low probability of detection
LPI	low probability of intercept
MA	multiple access (TDRSS)
Mb	megabyte
MB	multibeam
MBA	multibeam antenna
Mbps	megabits per second
MCS	maritime communication subsystem (INTELSAT V)
MEO	medium earth orbit
MHz	megahertz

MIC	medium intensity conflict
MMW	millimeter wave
Molnya Orbit	highly-inclined elliptic orbit for coverage of northern latitudes
MSS	Mobile-Satellite Service
NASA	National Aeronautics and Space Administration
NB	narrow band
NiCd	nickel cadmium (battery)
NiH_2	nickel hydrogen (battery)
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
OV	orbiting vehicle
PAM	pulse amplitude modulation
PCM	pulse code modulation
PM	phase modulation
PSK	phase shift keying
QPSK	quadriphase shift keying
RF	radio frequency
RFI	radio frequency interference
RHCP	right-hand circular polarization
rpm	revolutions per minute
RTS	remote transmit system
SAMSO	Space and Missile Systems Organization (United States Air Force) (now Space and Missiles Center)
S-band	1.7 to 2.7 GHz (in satellite communications)
SCPC	single channel per carrier
SCT	single channel transponder (AFSATCOM)
SGLS	Space-Ground Link Subsystem (AFSCN)
SHF	super high frequency (3-30 GHz)
SMSK	serial minimum shift keying
SNR	signal-to-noise ratio

SOF	Special Operating Forces
SOW	statement of work
SSA	S-band single access (TDRSS)
SSMA	spread spectrum multiple access
SSPA	solid-state power amplifier
SS-TDMA	satellite-switched TDMA
TAG	software description identifying data characteristics, e.g., Fine
TDA	tunnel diode amplifier
TDMA	time division multiple access
TDRS(S)	Tracking and Data Relay Satellite (System) (NASA)
TT&C	telemetry, tracking, and command
TV	television
TWT	traveling wave tube
TWTA	traveling wave tube amplifier
UFO	UHF follow-on
UHF	ultra high frequency (300-3000 MHz)
VHF	very high frequency (30-300 MHz)
VSAT	very small aperture terminal
WB	wideband
W-hr	Watt-hour
WSGT	White Sands Ground Terminal (TDRSS)
X-band	7.2 to 8.4 GHz

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