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CTS UNITED STATES EXPERIMENTS - A PROGRESS REPORT

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TECHNICAL PAPER to be presented at the
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Abstract

The Communications Technology Satellite (CTS) is a high power broadcast satellite launched by NASA on January 17, 1976. CTS is the first satellite to operate at a frequency of 12 gigahertz and incorporates new technology making possible new satellite telecommunications services. CTS is a cooperative program of the United States and Canada. This paper presents the results of the United States experiments activity to date. Wide segments of the population are involved in the Experiments Program including the scientific community, other government agencies, industry, and the education and health entities. The experiments are associated with both technological objectives and the demonstration of new community and social services via satellite.

I. Introduction

The need for communications services is increasing worldwide. Communications satellites are already playing a significant role in providing new and expanded telecommunications services. Because of the increased use of the current commercial satellite frequencies (4 and 6 GHz) and the great potential of expanded service with small earth terminals, satellite power levels and satellite frequencies must increase to meet the demands. The trends in satellite system development, therefore, have been clear - moving in the direction of higher power, higher frequencies, and increased lifetime. These trends provide exciting possibilities for more economical and expanded service world wide.

In a satellite research and development sense, many activities are underway and additional effort is required to explore higher frequency operation and to demonstrate advanced satellite systems for new applications.

NASA, for nearly two decades, has pursued the development of advanced communications satellite systems. Initial efforts in the early 1960's culminated in the first successful demonstration of a synchronous satellite called SYNCOM, [1] which created a new industry - the worldwide communications satellite industry. After SYNCOM, NASA gradually diverted its activities from communications satellite programs which were highly scientifically oriented, to one of applications demonstrations. These applications demonstrations, which are called experiments, manifested the practicality of utilizing advanced satellite technology for satisfying global needs. NASA's Applications Technology Program (ATS) was the key to this successful endeavor. Literally, hundreds of experiments have been performed on these satellites. The most visible and successful applications demonstrations of these satellites have been associated with weather, maritime, and aeronautical applications. Partially as a result of these experiments, weather and maritime satellites are already operational and commercial satellites for aeronautical applications will be available later in this decade.

NASA's ATS-6 satellite, [2] the world's first broadcast satellite, added a new and exciting dimension to the experiments program. For the first time, television could be received by small low-cost ground terminals. ATS-6 is still active and has successfully demonstrated the distribution of social services (health care and education) both in the United States[3] and India. [4]

Geostationary satellites, because of the vast geographic area they can view, are global in nature. Therefore, United States and NASA Policy has encouraged international cooperation in their satellite programs. The Communications Technology Satellite (CTS) Program is an outstanding example of this cooperation. Both the United States and Canada have extensive and similar communications needs and the social and economic development of both countries is linked to telecommunications.

The purpose of this paper is to describe the United States needs for expanded satellite telecommunications services and the relationship of the CTS Experiments Program to those needs. The discussion is focused upon United States experiments, however, a parallel experiments program is being conducted in Canada. [5, 6]

Periodic meetings have been held with CTS United States experimenters. Some of the material contained herein was obtained from the experimenters during these meetings. Where possible a reference is cited.

II. Technology Experiments

NASA has traditionally been the lead U.S. government agency in civilian space communications research and development. NASA satellites have always incorporated, demonstrated, and evaluated new technology and CTS is no exception. In this light NASA, for a number of years, has been engaged in the detailed

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characterization of the radio-frequency spectrum. A large part of this activity is directed toward United States activities related to worldwide frequency allocations. CTS, since it operates in a new frequency band (14/12 GHz), provides a unique opportunity for the characterization of that portion of the spectrum.

In addition to the spectrum related activities, CTS provides the system for the evaluation of new satellite and ground station technology. This evaluation is also underway. Traditionally, in the early stages of communications satellite programs, the technological experiment results lead the application experiments. This pattern is being followed in CTS.

Link Characterization

One of the primary objectives of the Communications Link Characterization Experiment (CLCE) is to define the propagation phenomena at CTS frequencies (14/12 GHz) that occur primarily during precipitation periods (rain or wet snow) and result in attenuation, depolarization and phase distortion of the transmitted signal.

The primary participants in the data collection and analysis are as follows:

(1) Goddard Space Flight Center - Greenbelt, Maryland
(2) NASA Rosman - Rosman, North Carolina
(3) Ohio State University - Columbus, Ohio
(4) Virginia Polytechnic Institute - Blacksburg, Virginia
(5) University of Texas - Austin, Texas

The data gathering has been underway since early in 1976. Preliminary results are shown in figure 1, where signal attenuation is plotted against rain rate.[7] The data were collected at the NASA Goddard Space Flight Center in Greenbelt, Maryland. Although the amount of data to date is small, the measured and predicted data are in general agreement.

Additional attenuation measurements will be made throughout the United States utilizing the CTS beacon and 200 watt signals. These results will be used to upgrade the current prediction models.

Small Earth Terminal Evaluation

There is a worldwide interest in the use of satellite systems with small earth terminals (0.6 to 8 m in diam) for a range of social and commercial services. For a number of years NASA, in conjunction with the ATS-6 and CTS satellites, has pursued the development and evaluation of small earth terminals over a range of frequencies. Both ATS-6 and CTS small earth terminal evaluations have involved international cooperation.

One facet of this activity has concentrated upon the development of reliable and low cost "receive only" television terminals. The joint NASA Goddard Space Flight Center/Japan Broadcasting Company experiment is an example of this type of experiment. The design and development of the receivers were done by Japan for use with the experimental Japanese Broadcast Satellite (BSE).[8] The ground receivers are currently under evaluation with CTS. Twelve receivers will be deployed throughout the United States and the performance and reliability of these receivers will be evaluated over a period of 1 year. The noise figure of the receivers is approximately 4.1 - 4.9 decibels. Antenna sizes are 1, 1.6, and 2.4 meters. Extensive preoperational checkouts have indicated that the receivers are performing satisfactorily and will be suitable for the Japanese Broadcast Satellite.

In addition to the video receive terminals, NASA, in conjunction with United States manufacturers, have developed a narrow band receiver for audio and facsimile applications. This receiver has been evaluated with the satellite and performed satisfactorily in an experiment that was conducted in Alaska that will be described later.

Low-cost, wideband parametric amplifier development is also being pursued. The noise figure of these amplifiers will be approximately 150 K and demonstrations of the hardware with CTS will be performed in 1977.

A Small Earth Terminal Station (SETS) is now operational at the NASA Lewis Research Center in Cleveland, Ohio and is being utilized for a variety of ground station evaluations. This station has the capability of narrow band transmissions and reception of television, voice and data in both the 20 watt and 200 watt CTS bands. A picture of the facility is shown in figure 2. Antenna sizes range from 0.6 meter to 4.6 meters in diameter. The facility is utilized for experiments and demonstrations to all interested parties.

Digital System Technology

Digital implementation of satellite links when compared to the analog transmission systems now in use, can offer substantial savings in both satellite power and radio-frequency bandwidth.[9] Power and bandwidth savings, of course, will result in lower distribution costs.

NASA Lewis Research Center and COMSAT Laboratories have under development a digital communications system which will be capable of color television, voice, and data transmissions. This system will be

demonstrated with the CTS satellite. As a part of this experiment, the performance of the link will be characterized. The practicality of reducing bandwidth and satellite power requirements for video, voice, and data distribution will be pursued. A variety of bandwidth compression equipment will be utilized as part of the experiment. The digital modem which will be utilized is capable of selected BIT rates from 1 to 60 megabits per second. A block diagram of the system is shown in figure 3. One set of terminal equipment will be located at the NASA Lewis Research Center in Cleveland, Ohio and the other at COMSAT Laboratories in Clarksburg, Maryland. The ground terminal equipment will be configured such that it is easily portable and, therefore, can be made available to other interested experiments.

High Power Satellite Communications System

The CTS satellite (fig. 4) was designed and integrated by the Communications Research Centre in Canada. The overall performance of the satellite has been excellent.[10] The satellite transponder has two basic elements - a 200 watt system and a 20 watt system. The 200 watt and 20 watt systems can be operated either individually or simultaneously by means of separate antennas on the spacecraft. A footprint of either beam covers approximately one-third of the 48 contiguous states in the United States[11] (fig. 5).

NASA Lewis Research Center developed and provided the high efficiency 200 watt Traveling Wave Tube Amplifier, its power supply and thermal control device which consisted of a variable conductance heat pipe system.[12] This development has been truly revolutionary from a space communications viewpoint in that it permits very high radiated power levels over large areas. This, in turn, makes possible television reception with small low-cost ground terminals. An extensive investigation has been conducted on the high power transmitter package and its integration with the rest of the transponder since launch. A summary of the on-orbit performance is shown in table I. All transponder operating modes were thoroughly investigated including:

(1) Single channel video (in both 200 and 20 W bands)
(2) Dual channel video (2 TV channels in the 200 W band)
(3) Dual band video (simultaneous operation of 2 TV channels - one in each band)

The performance of the system has been excellent. All specification requirements have been met and intermodulation and cross-modulation problems have been minimal. Over 2500 hours of on-orbit operations have been accumulated to September 1976. No degradation in performance has occurred sinch launch.

Spacecraft Charging

As a result of periodic anomalous behavior of many military and commercial communications spacecraft, attributed to electromagnetic phenomena in geostationary orbit, NASA provided instrumentation on-board the CTS spacecraft capable of counting any strong static electrical discharges on or in the vicinity of the satellite.[13] This instrument, the first satellite electrical harness transient detector, is called a Transient Event Counter (TEC). The TEC senses and counts electrical transients having a voltage rise of greater than 5 volts in three separate wire harnesses: the attitude control harness, the solar array instrumentation harness, and the solar array power harness.

The data from the TEC has shown that the satellite is being charged to the point that discharges occur inducing transients in the satellite electrical system. Hundreds of discharges have been recorded to September 1976, however, these transients have not caused any anomalous events in the satellite operation. The data indicate that discharges can occur at any time during the day without preference to any local time quadrant. This information will be collected throughout the spacecraft lifetime and an attempt will be made to correlate it with electromagnetic phenomena that occurs in the vicinity of the spacecraft.

Spacecraft Dynamics

The CTS spacecraft is shown in figure 4. The predominant feature of the spacecraft is the large flexible solar arrays, which extend approximately 16 meters from tip to tip. On-orbit, the arrays are in motion because they track the sun. They also move as a result of attitude changes in the spacecraft. There, of course, was considerable interest in the array dynamics and, in particular, in the interaction between the array motion and the spacecraft movements. The experience to date indicates that the array, for all practical purposes, acts like a rigid body.[14] No array motion can be detected during attitude, momentum dumping or stationkeeping maneuvers. Sun tracking which normally occurs in a step track mode results in twist deformations of less than $1/2^{\circ}$ and well within the design criteria.

III. Applications Experiments

Experiments using CTS are also associated with both public service functions (education, health care, etc.) and industrial/commercial demonstrations.[11] The locations of CTS experiments are shown in figure 6; United States experiments are listed in table II. Ground station locations in Canada are associated with Canadian experiments. Several experimenters are currently in

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the process of preoperational checkouts. These experiments will become operational later this year or in 1977.

The discussion herein is limited to those experiments that have been active with the satellite. The results to date are summarized.

Public Service Experiments

A public service function in which satellites could play a significant role in the future is in the area of emergency communications. For this application, COMSAT Laboratories has developed a small lightweight transportable earth terminal which can be moved to a disaster area by an automobile, small airplane or boat. On arrival, the terminal can be set up and operational in less than 1 hour.

On July 29, 1976 COMSAT Laboratories in conjunction with the American Red Cross transported the terminal by means of a small van to a remote area in the Blue Ridge Mountains in Virginia. In a very short time telephone communications were established via CTS to the COMSAT Laboratories in Maryland. This demonstration proved the concept of rapidly establishing communications via satellite in areas of the world where no other communications exist. Throughout the life of the satellite, other demonstrations will be performed associated with both simulated and real emergencies. The effectiveness of the communications link will be evaluated by United States Disaster Relief agencies.

In a real emergency situation, effective emergency communications via CTS was also demonstrated by the Canadians in a remote area of Northern Quebec. CTS eperimenters made use of a CTS terminal to assist in planning for the evacuation of a survey camp threatened by a forest fire. The satellite link was very effective in this situation.

Two other Public Service Experiments are scheduled to commence following the eclipse season which ends in mid-October. The Southern Educational Communications Association (SECA) intends to evaluate the feasibility of satellite networking for education and public broadcast applications. Television programming to member stations in the southeastern United States has already been successfully distributed in the preoperational phase.

In addition, the preoperational checkouts have been completed on the Digital College Curriculum Sharing Experiment via satellite in which students in one university will take courses in another, approximately 2500 miles away. Stanford University in California and Carleton University in Ottawa, Canada are the universities involved.[15] NASA Ames Research Center is utilized as the west coast earth station. NASA Ames is also providing digital bandwidth compression equipment for the experiment.

Industrial/Commercial Applications

One of the primary objectives of the United States experiments program is to develop new commercial satellite applications. Over the past several years, the market for voice and data communications has greatly expanded. The market for television services via satellite has lagged the voice and data markets primarily because of the high cost of television distribution. At the same time there has been a recognition of the great value that interactive television can provide, particularly for industrial applications. As our society becomes more global in nature, the need for real time information transfer increases and those companies whose business is multinational in nature must spend an increasing amount of their resources for rapid information transfer. It is felt that video teleconferencing is one technique for fulfilling those needs.

Video Teleconferencing

CTS is particularly well suited for interactive video applications and as a result, two teleconferencing experiments are in progress. The Westinghouse Electric Corporation[16] is conducting one of the experiments and NASA is conducting the other.

There are three facets of video teleconferencing which are being addressed. The initial evaluations have been of a technical nature associated with the establishment of the satellite link. This evaluation is essentially complete. Results have indicated that a satellite (CTS) is a very effective vehicle for interactive video teleconferencing. No major problems have been encountered with either the satellite or ground stations.

The second phase of teleconferencing activities is currently underway. This phase is directed toward the behavioral aspects of teleconferencing. Initial evaluations have addressed effectiveness issues such as:

(1) Is television teleconferencing an effective substitute for face-to-face meetings?

(2) What is the best configuration for a video teleconferencing facility?

(3) Can teleconferencing be used as an effective substitute for travel?

The results to date from a sample of 100 to 200 people indicate that teleconferencing capability is useful, effective, and convenient. One of the facilities utilized in the experiment (Westinghouse-Lima, Ohio) is shown in figure 7.

The last (and most important) issue of video teleconferencing that is being addressed is the economic viability of such a system. Currently television teleconferencing from New York to Los Angeles costs several thousand dollars per hour. It is believed, however, that new technology under development by NASA and others will permit television distribution via satellite for teleconferencing with greatly reduced bandwidths and therefore substantial cost savings. Plans for 1977 include the demonstration and evaluation of this new technology.

Alaska North Shore Ice Information (ANSII)

Another experiment with CTS is the dissemination of ice information along the Alaskan North Shore. This experiment, being conducted in conjunction with the United States Coast Guard and the United States National Weather Service should demonstrate the capability and usefulness of providing near real time radar ice image information to ships operating along the Alaskan North Shore. This experiment is an extension of the activity that was conducted on the Great Lakes.[17] The experiment concept is shown on figure 8. The ice information along the Alaskan North Shore (Chukchi and Beaufort Seas) is gathered by a Coast Guard aircraft equipped with side-looking radar (SLAR). The raw data is then relayed from the aircraft via GOES (Geostationary Operational Environmental Satellite). The data is then sent by landline to Cleveland, Ohio where it is annotated in a form that illustrates the ice coverage and thickness. The annotated information is then transmitted from Cleveland, Ohio to Barrow, Alaska via CTS. The Coast Guard disseminates the information to the ships along the Alaskan North Shore. The ice information, not previously available to the ships in the area, should prove to be a valuable navigation aid in the Northern Alaskan waters where ice flows are always present.

The equipment at Barrow, Alaska for the ANSII experiment and the equipment at NASA Lewis for the teleconferencing experiment were combined on August 25, 1976. The combination resulted in the first live color TV teleconference to an audience at Barrow (71.2° N, 156.5° W) from the lower 48 states (NASA in Cleveland - 41.5° N, 81.7° W). Barrow is the northernmost city on the North American continent. A key element is that the reception at Barrow was achieved with a small, low-cost terminal with a 1.2-meter (4-ft) antenna.

IV. Short Term Applications Demonstrations

In addition to the approved experiments, a series of satellite demonstrations has been successfully conducted. The demonstrations that have been completed are summarized in table III. Included are conduct of technical society meetings, support for the United States Bicentennial, Public Broadcast Networking, Teleconferencing Demonstrations, and demonstrations for other special events. For these special demonstrations NASA provides the entire satellite link including the ground receiver/transmitter. The facilities available for special demonstrations are shown in figure 9.

V. Concluding Remarks

The CTS Satellite, whose utilization is just beginning, has already demonstrated the practicality of an advanced high-power communications satellite system which operates in a new frequency band (14/12 GHz) and is effectively able to utilize small low-cost earth terminals with antennas of 3 meters or less. Early experiment results have indicated that the series of applications experiments in progress will lead to new markets for commercial services in the future.

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TABLE I. - CTS COMMUNICATIONS OPERATING SUMMARY

Requirement	Operating summary
200 watt channel	
Transponder gain, 122 dB	125 dB
Transponder EIRP, 59 dBW	59 dBW
20 watt channel	
Transponder gain, 107 dB	110 dB
Transponder EIRP, 49.5 dBW	48.7 dBW
Single channel video	
200 watt per channel	S/N 46 dB (unweighted)
20 watt per channel	S/N 43 dB
Dual channel video (two TV channels in one band)	
70 watt per channel	No interference
Three channel video	
(Two TV channels in 200 W band)	
(One TV channel in 20 W band)	No interaction between bands
Dual band video (one TV channel in each band)	Video interference barely perceptible

E-3918

TABLE II. - UNITED STATES EXPERIMENTS

Category	Title	Organization
Health Care	Biomedical Communications	U.S. Dept of Health, Education & Welfare
	Health Communications	Veterans Administration
	Communications Support for Decentralized Education	WAMI
Education	College Curriculum Sharing	NASA-Ames; Stanford Univ. - Carleton Univ.
	Project Interchange	Archdiocese San Francisco
Community Services	Transportable Earth Terminal	COMSAT
	Satellite Library Information Network	SALINET
	Satellite Distribution	SECA
Industrial/Commercial Applications	Communications in Lieu of Transportation	Westinghouse
	Alaska North Shore Ice Information	NASA/Coast Guard/NWS
	Digitally Implemented Communications Experiment	NASA/COMSAT
Technology	Link Characterization	NASA
	Advanced Ground Receiving Equipment	NASA/NHK
	200 Watt Tube	NASA
	Transient Event Counter	NASA
	Solar Array Experiment	CRC/NASA

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TABLE III. - CTS DEMONSTRATIONS

Date	Event	Location	Purpose
5/6	IEEE Joint Meeting	Baltimore, MD & Lima, OH	Technical Society Meeting
5/10-14	Bicentennial Satellite Demonstration	Kalamazoo, MI	Support of Michigan Activity
5/20	CTS Experiment Inaugural	Cleveland, OH & Ottawa, Canada	Teleconference to Initiate CTS Experiments
6/14	IEEE International Conference on Communications - ICC-76	Cleveland, OH - Greenbelt, MD Ottawa, Canada - Palo Alto, CA & Philadelphia, PA	Televised Technical Society Meeting
6/16	Conference on Open Learning	Lincoln, Nebraska	
7/4	NBC - Bicentennial - "The Glorious Fourth"	Yellowstone National Park - Cleveland, OH - NBC Network	CTS Support for NBC at Remote Location
7/10	Scottish Games	Grandfather Mountain, NC - Columbia, SC Southeastern Public TV Network	CTS Support for PBS at Remote Location
7/14-30	Olympics	Bromont, Ont. - Montreal, Que. Canadian Broadcasting Co.	CTS Support to CBC at Remote Location
8/4-14	Chicago Science & Natural History Demonstration	Chicago, IL - Cleveland, OH	NASA Public Information Satellite Demonstration
8/25	Color Television Demonstration	Barrow, Alaska - Cleveland, Ohio	CTS Satellite Demonstration to Barrow Residents

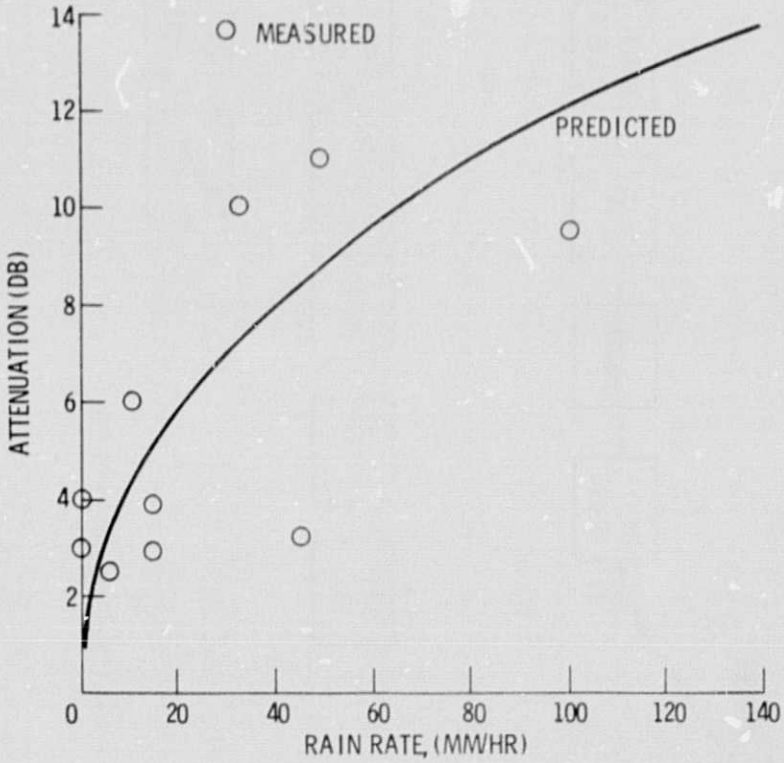

Figure 1. - 11.7 GHz Beacon measurements summary - Green Belt, MD. May-July 76.

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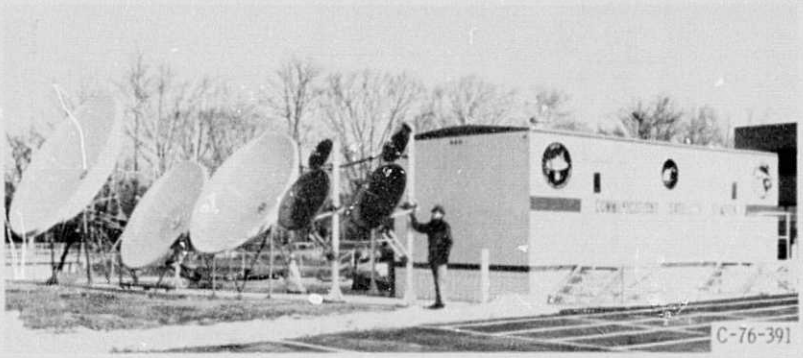

Figure 2. - NASA LeRC small earth terminal station.

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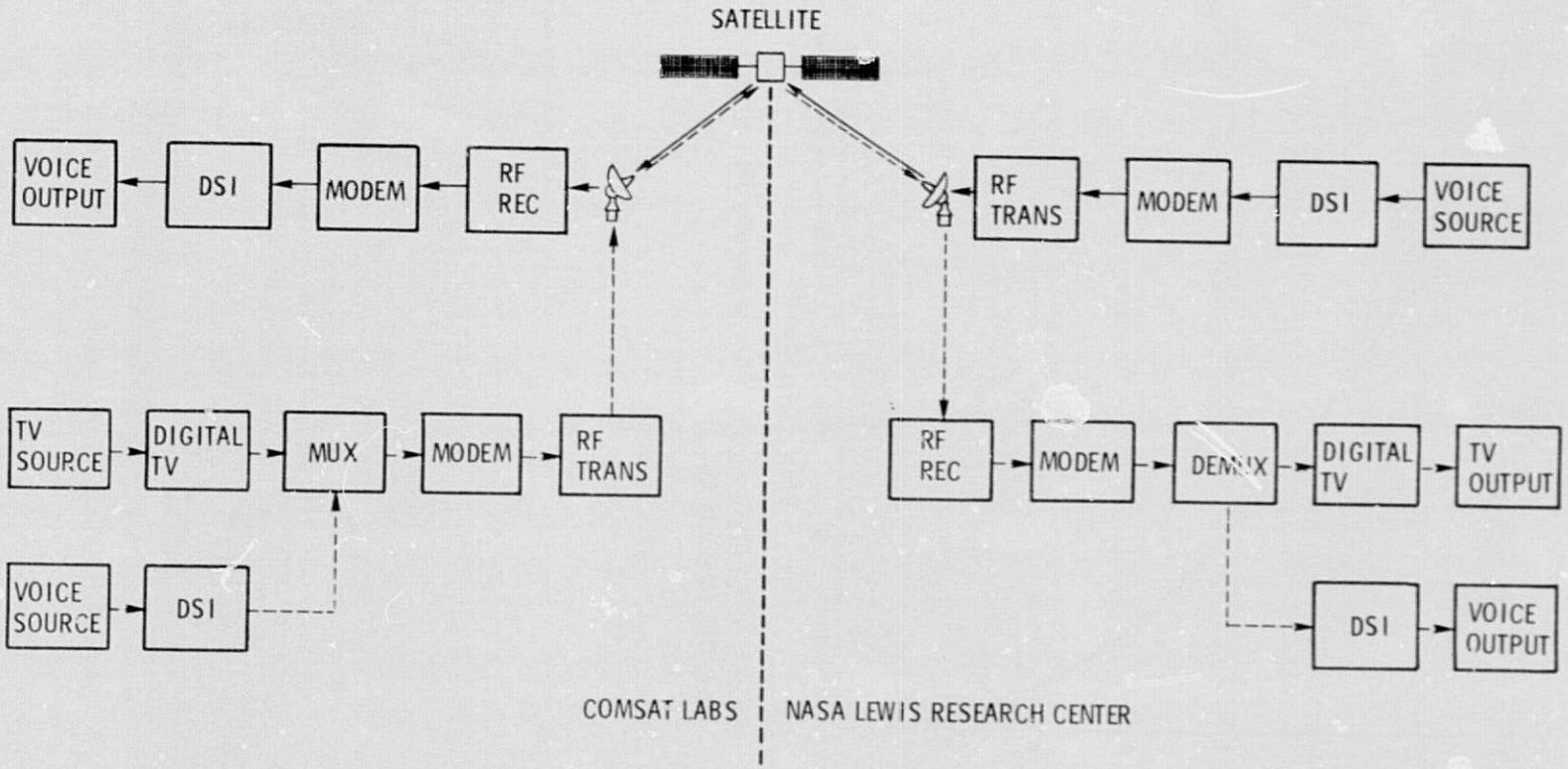

Figure 3. - Communications technology satellite digitally implemented communications experiment.

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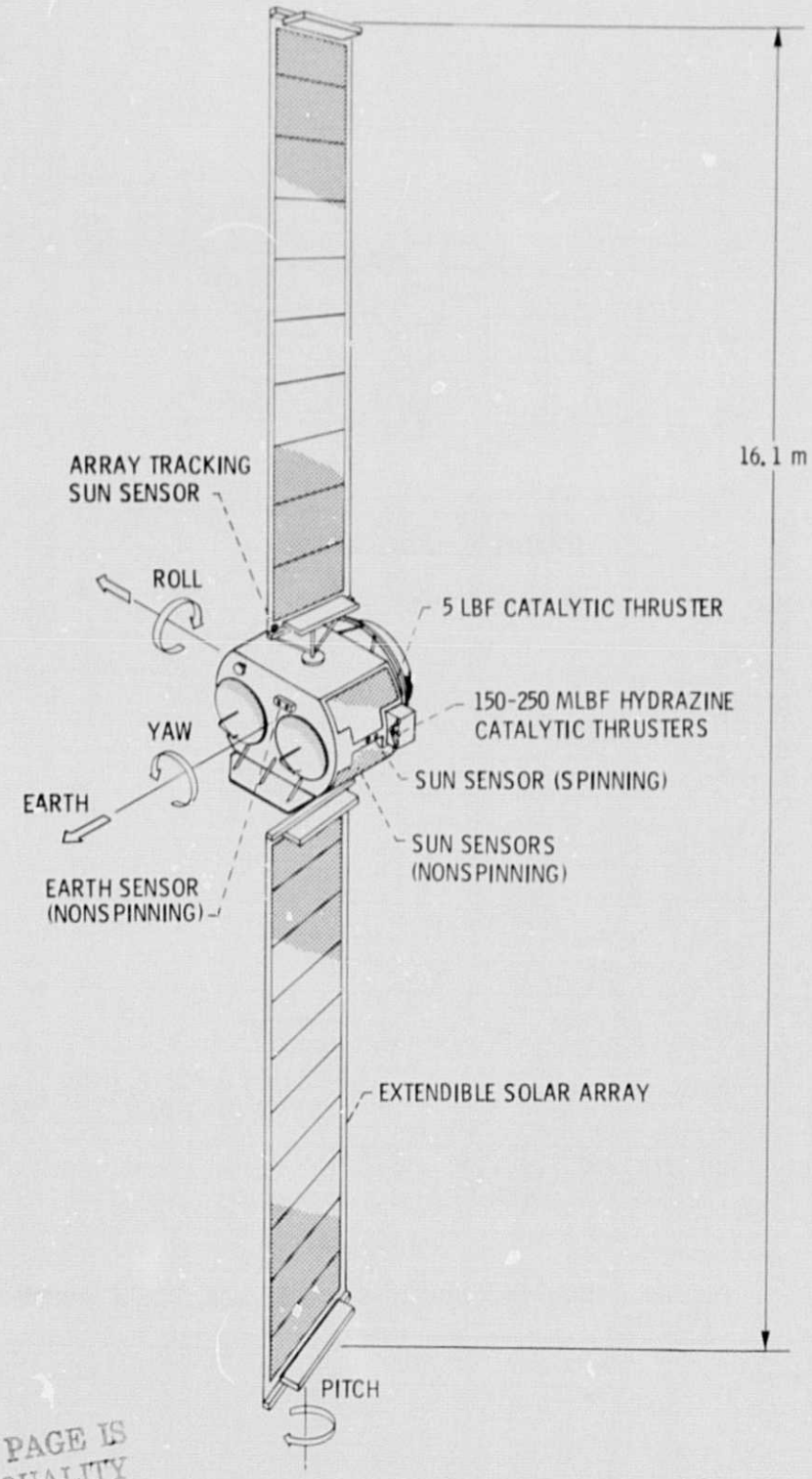

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Figure 4. - CTS Spacecraft.

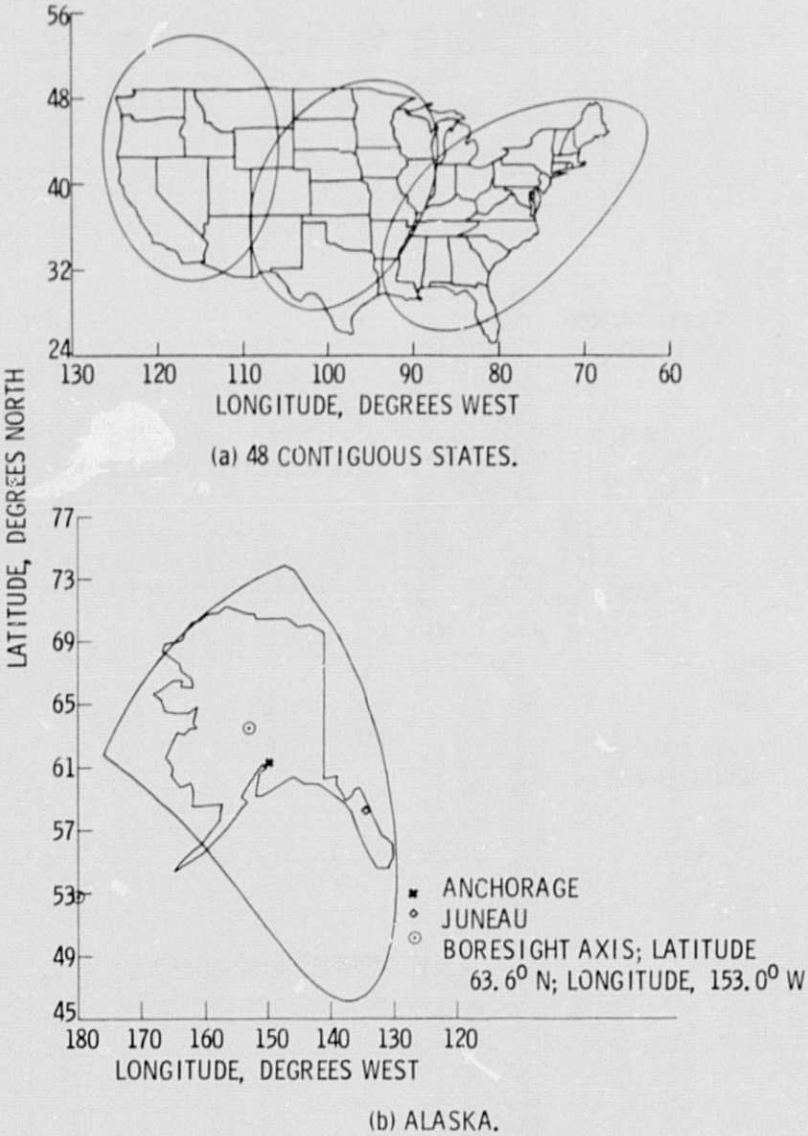
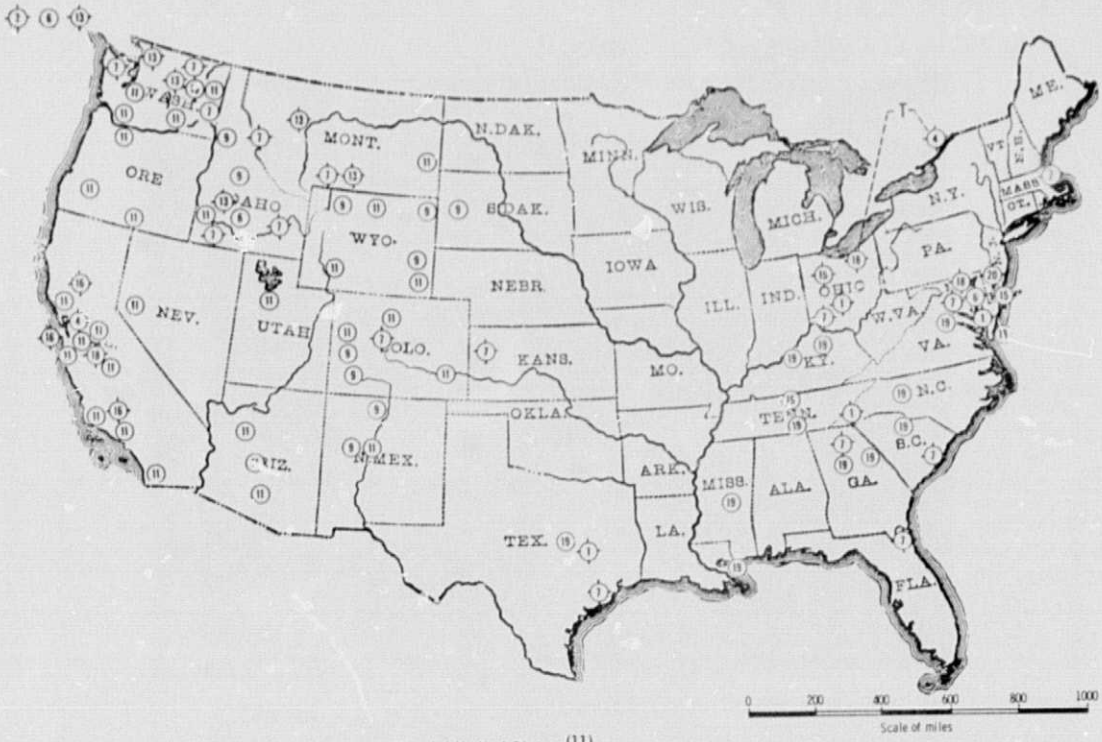


Figure 5. - Three-decibel contours for U. S. from CTS SHF antenna (ref. 11).



(a) United States.[11]

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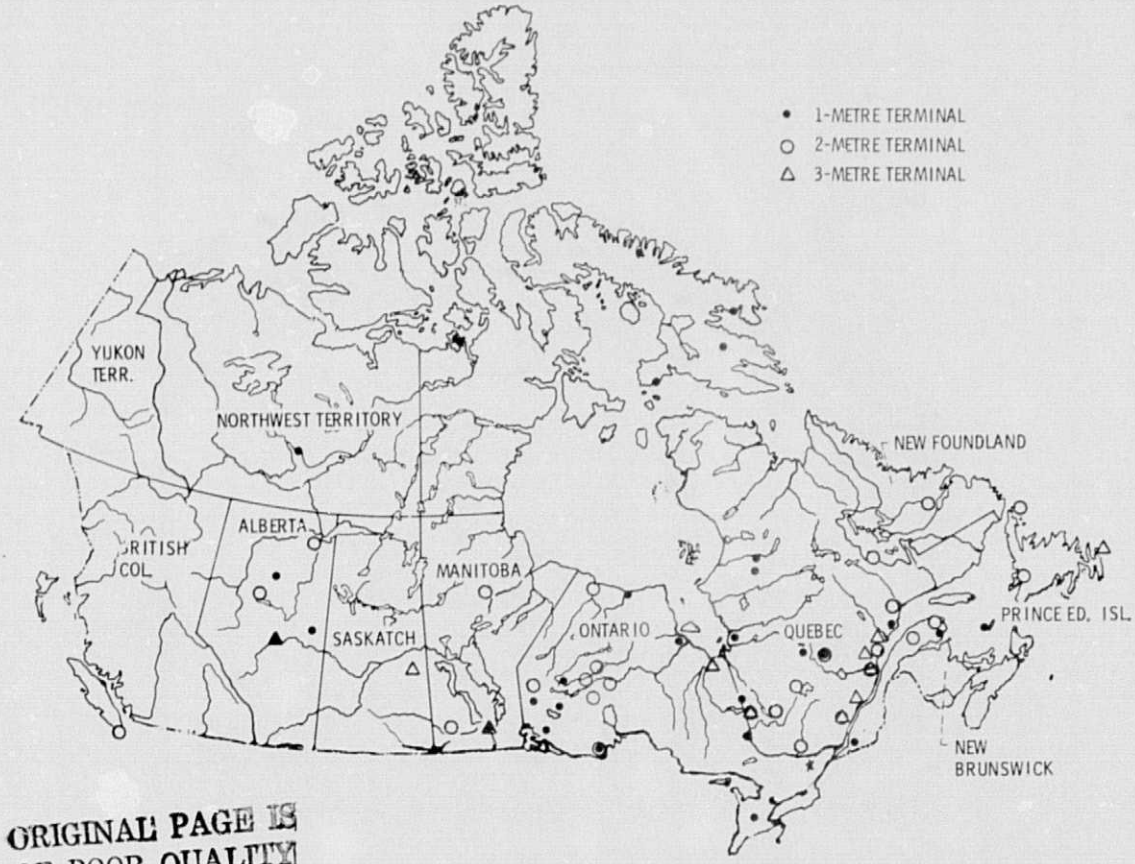

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(b) Canada.

Figure 6. - CTS Earth terminal locations.

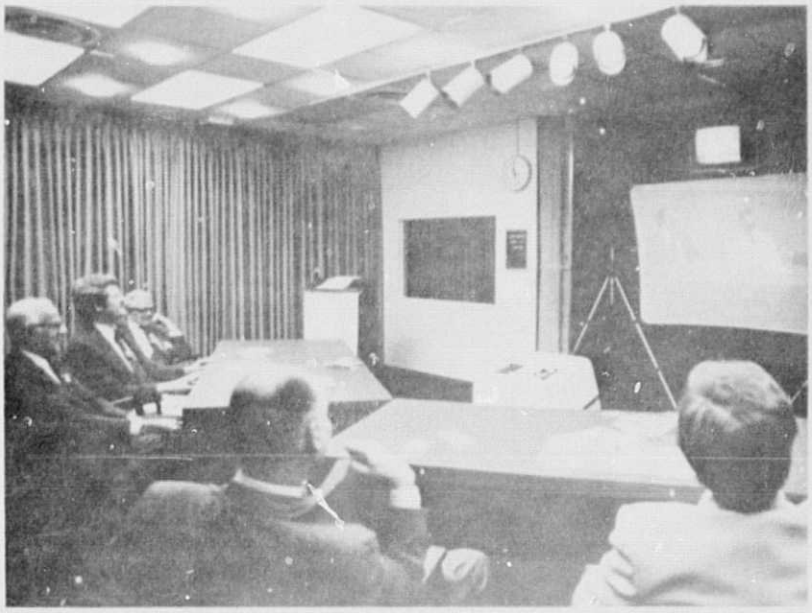

Figure 7. - Video teleconferencing facility operating with CTS.

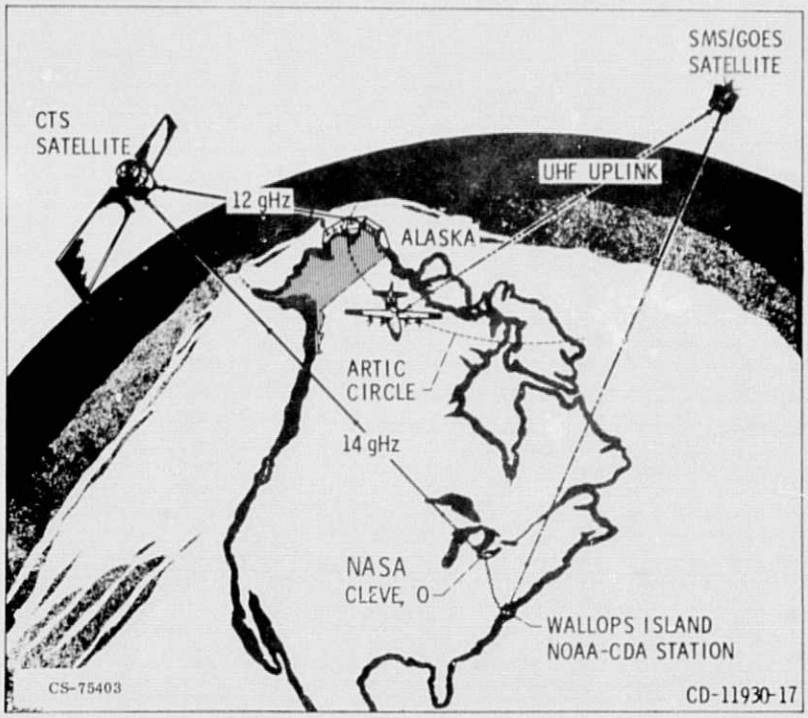

Figure 8. - CG/NWS/NASA - Alaska north shore ice information.

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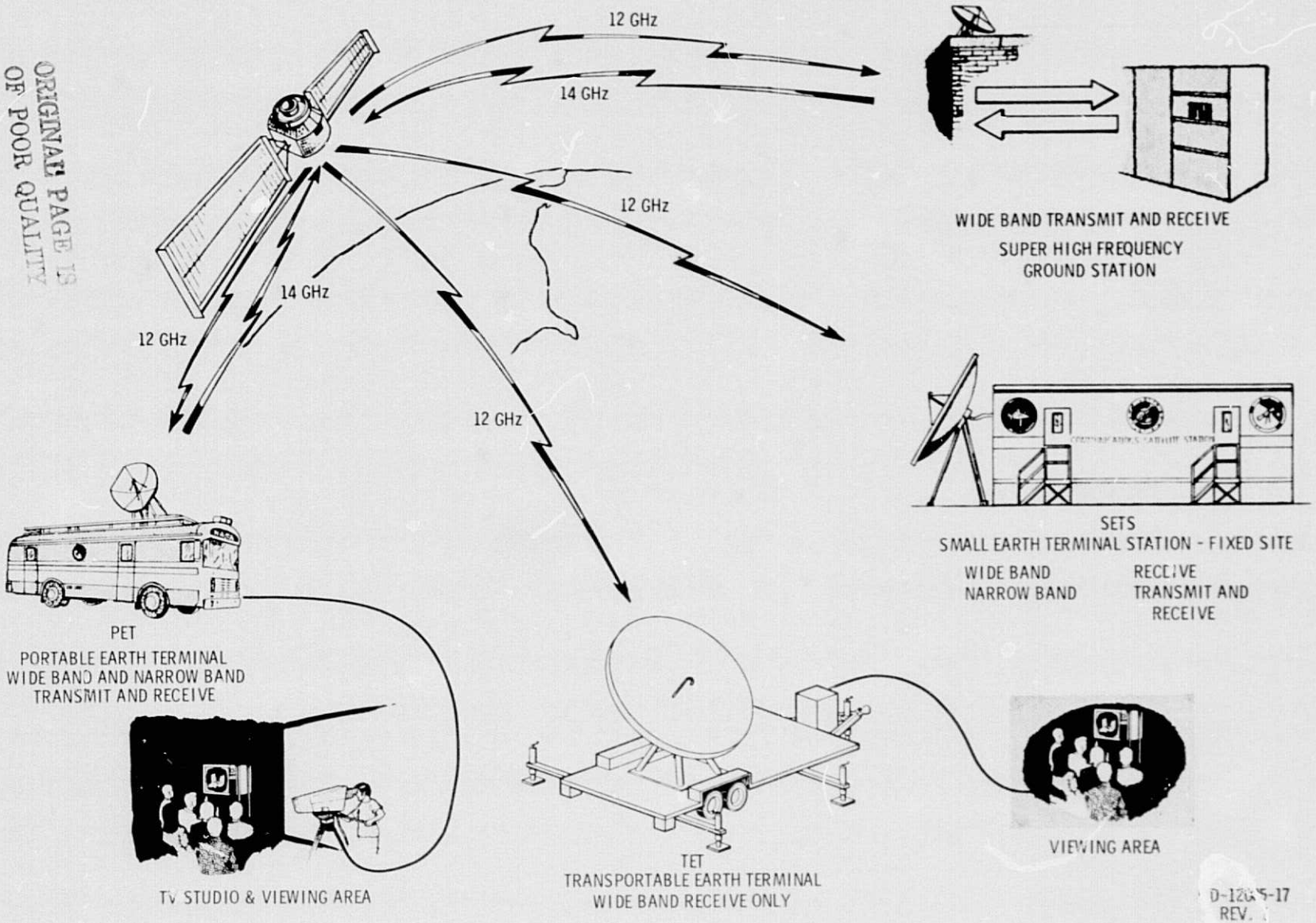

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Figure 9. - Communications technology satellite (CTS) NASA/LeRC experimental earth terminals.