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A DIGITALLY IMPLEMENTED COMMUNICATIONS EXPERIMENT UTILIZING THE COMMUNICATIONS TECHNOLOGY SATELLITE (HERMES)

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ABSTRACT

The Communications Technology Satellite (CTS) experiment program provides a significant effort directed toward new developments which will reduce the costs associated with the distribution of satellite services. One system element that holds promise for reduced transmission cost is associated with digital communication link implementation. A Digitally Implemented Communications Experiment (DICE) which demonstrates the flexibility and efficiency of digital transmission of television video and audio, telephone voice, and high-bit-rate data is described. This paper reports on the utilization of the DICE system in a full duplex teleconferencing mode. Demonstration teleconferencing results obtained during the conduct of two sessions of the 7th AIAA Communication Satellite Systems Conference are discussed. Finally, the results of link characterization tests conducted to determine (1) relationships between the Hermes channel 1 EIRP and DICE model performance and (2) channel spacing criteria for acceptable multi-channel operation are presented.

INTRODUCTION

Digital transmission of voice (refs. 1 and 2), as well as television (refs. 3 and 4), has been investigated worldwide with a variety of techniques evolving. In an attempt to obtain an assessment of the feasibility and implementation problems associated with different techniques of simultaneous transmission of video, voice, and data in digital form, an experimental program using the Communications Technology Satellite (CTS), or Hermes, was conducted.

The Digitally Implemented Communications Experiment (DICE) was designed to focus on the development and performance evaluation of video, audio, and data digital communication techniques. (CTS advanced transponder technology (200-W TWT) and small 2.4-meter (8-ft) inexpensive Earth terminal capabilities were utilized in the conduct of the DICE to provide for field demonstration and evaluation of the entire communication system.) The primary configuration for the initial experimental phases involving system checkout and field demonstrations used the small

Earth terminals at NASA LeRC and COMSAT. The final phase, link characterization, used only the NASA LeRC fixed terminal, a more detailed description of which is contained in reference 5.

Full digital duplex operation has been demonstrated using both the 200-watt and 20-watt channels on CTS. Carrier-to-noise ratios, bit error rates, and baseband signal quality were measured and correlated with up/down link transmission variables in order to define levels of performance. Operational experience related to DICE duplex video conference demonstrations is described.

SYSTEM DESCRIPTION

Figure 1 graphically describes the communications link for a DICE demonstration. The LeRC portable Earth terminal (PET) shown in the figure was configured to support DICE demonstrations in the field. A more detailed description of the PET is contained in the RF System section of this report.

The NASA Lewis fixed terminal was used in a loop back (through CTS) mode for link characterization experimentation. Figure 2 is a more detailed breakdown of the baseband-to-microwave system configuration for the DICE/CTS communications experiment.

DICE System

Using figure 2 as a reference, the signal flow and system description are as follows:

Program color video and the associated audio are inputs to the CODIT analog-to-digital PCM converter. The PCM video data stream (8 bits per sample and a sample rate of 10.7 MHz) is converted to DPCM (4 bits per sample) to provide a video data rate reduction of 2:1 (before input to the multiplexer). Abbreviations are defined in the ABBREVIATIONS section of this report.

The DPCM video output bit stream is then fed to the multiplexer, which formats the data to allow for the addition of line and frame synchronizing, unique words, program audio, and SIDEL audio within the horizontal sync interval. Figure 3 shows the timing of the time-division multiplexer. The four traces show the time relationship between the video (waveform) and the time slots during the horizontal sync period for the unique word, program audio, que-channel audio, and SIDEL audio/data. The inserted digital bits have been timed to avoid interference with the video synchronizing pulse edges.

The SIDEL system is a 60-channel digital speech interpolation system. The audio input signals are digitally encoded using variable rate delta modulation and time-division multiplexed into a serial bit stream. The SIDEL frame timing format is shown in figure 4. A 6-bit unique word is added for frame synchronization. The bit rate is 1.0227 Mbps and the frame rate is approximately 1 kHz. The SIDEL output is then fed to the CODIT multiplexer and time-division multiplexed as shown in figure 3 to form one data stream at approximately 43 Mbps.

The DICE experiment utilized a COMSAT Labs developed universal QPSK modem which can be used over a wide range of bit rates and multiple-access methods (TDMA or FDMA). The universal model is designed to cover the bit rates of 1 Mps to 60 Mbps with a maximum of common circuitry over the entire range. Five operating bit rates were chosen over the above range with plug-in modules designed to operate at 49, 43, 33, 22, and 1 Mbps.

Demodulation is achieved by coherent detection. Carrier and clock recovery circuits complete the basic demod system, which supplies the data bit stream to the CODIT buffer and demultiplexer, which separates the various video, program audio, and SIDEL bit streams.

The received DPCM signal is decoded to recover the PCM difference, which is then added to the prediction for the sample to form the reconstructed video. The SIDEL receiver demultiplexes the speech samples and stores them in memory. After error checking, the samples are routed to their respective channels. A more detailed description of the DICE system is contained in references 4 and 6.

RF System

The RF system incorporates a variable frequency double conversion up/down converter. The converter input and output frequency is 70 MHz with an intermediate frequency of 1.5 GHz. The converter can be tuned to any frequency in either of the two CTS bands for transmit or receive (fig. 5). Tuning and stability are accomplished with synthesizer-controlled local oscillators and manually tuned phased-locked loop circuitry.

The converter output at the chosen transmit frequency is applied directly to a 2-watt TWT intermediate power amplifier and then to the high power amplifier stage. Due to the different configurations of available transmit sites, both portable and permanent, a limited parametric analysis of TB1 and TB2 link characteristics was integrated with the required BER (table I) in order to define the transmit system configuration.

The LeRC portable Earth terminal (PET) used in DICE demonstrations has a 2.4-meter (8-ft) antenna (48-dB gain) and 500-watt transmitter

with an instantaneous bandwidth of 50 MHz. More detailed information on PET is contained in reference 7. The maximum net EIRP is 74 dBW. The high power transmitter can be tuned to operate in either of the two CTS bands. Demonstrations had the LeRC signal through the satellite 200-watt channel and the COMSAT signal through the satellite 20-watt channel.

The COMSAT terminal has a 3-meter (10-ft) antenna (49-dB gain) and a 200-watt transmitter with a maximum net EIRP of 71 dBW. The receive G/T for both terminals is approximately 22 dB/K.

The LeRC fixed terminal, used for link characterization tests, consists of a high power (1.25 kW) uplink transmitting and receiving system. A 4.88-meter (16-ft) diameter Cassegrain parabolic reflector provides a 54.0-dB gain at the 14-GHz uplink frequency and, through a low noise amplifier, a 52.5-dB gain at the 12-GHz receive frequency. A more detailed description of the fixed terminal may be found in reference 5.

Link budget calculations, shown in table II, are based on the LeRC and COMSAT terminals and the following assumptions: The experiment would be conducted in a two-way transmission of digital video, data, and voice using the two Hermes transponders; the Hermes antennas would be pointed at the positions of the participating Earth stations under clear sky conditions.

DEMONSTRATIONS AND TESTS

Demonstration Concept

The experimental demonstration concentrated on the evaluation of duplex television in the teleconferencing environment. The video teleconferencing environment has been chosen to provide feedback from a user's rather than critic's perspective of digital system quality and performance.

Two duplex television teleconferences were conducted with the DICE system. The first utilization was during a communications convention (ICC-77/Chicago) exhibit in June 1977. The exhibit was structured as a duplex video teleconference/open discussion between convention attendees and COMSAT video teleconference facilities at Clarksburg, Md. Concurrent with the videoconference open discussion, the SIDEL system was actively loaded with taped conversations on 59 of 60 channels. The remaining channel was used extensively by convention attendees. Reference 6 describes this activity in more detail. The second utilization was during a communications satellite conference (7th AIAA/San Diego) exhibit in April 1978. More detailed information of this activity is contained in the RESULTS AND DISCUSSION portion of this report. The SIDEL feature of DICE was not used during this exhibit.

Link Performance Tests

Link characterization concentrated on the DICE system operational bit rate of 42.95 Mbps. Bit-error-rate performance tests were conducted utilizing the test setup of figure 6. Back-to-back operational performance of the modem and up/down converter were established during acceptance testing of the complete system to permit determination of link-only performance changes.

RESULTS AND DISCUSSION

Demonstration

The first utilization of the DICE Experimental System at the ICC-77/Chicago exhibit provided quality which was subjectively judged, for both CODIT and SIDEL, as excellent to better than network quality by approximately 250 communications media personnel in attendance.

The second utilization of the DICE experimental system in a demonstration format was for the full duplex transmission of selected sessions of the 7th AIAA Communication Satellite Systems Conference held in San Diego, California, in April 1978.

The CTS duplex link was between the LeRC/PET in California and the COMSAT terminal in Maryland. The following summary of teleconferenced session topics is provided to show that those who were involved and viewing the link quality were well acquainted with the typical large-terminal-through-satellite-to-large-terminal performance.

Duplex transmissions covered (1) Session 2 - "1980's Generation of Comm. Satellites and Key Issues in Technology" panel discussion, (2) Session 12 - "Television Via Satellite" - six papers addressing direct broadcast, (3) Session 16 - "Defense System II" - three papers addressing space laser communications, satellite-to-satellite data transfer and a report on the LES 8/9 Program, and (4) Informal System Display with hands-on interaction by conference attendees and COMSAT Labs attendees during exhibit periods.

Although no quantitative bit-error-rate (BER) measurements were made, due to the lack of spacecraft and program time, the subjective evaluation by those who have been working with the system was that the quality was equivalent to a 10^{-8} BER. The analog signal-to-noise quality of the video at both terminals is summarized below. Participants and viewers agreed that the video and audio quality were excellent and that the translation to and from a digital format had no perceptible effect.

DICE Duplex Operational Mode/Result

TB2 (20W) - 4-dB S/C atten. uplink EIRP 70 dBW

S/C EIRP 46 dBW (10 W)/BER 10^{-8}

TB2 (200W) - 5-dB S/C atten. uplink EIRP 71 dBW

4-dB S/C gain suppression

S/C EIRP 58 dBW (160 W)/BER 10^{-8}

BER 10^{-6} - 20 streaks/sec. - quite noticeable

BER 10^{-8} - .2 streaks/sec. - perceptible - not annoying

BER 10^{-9} - .02 streaks/sec. - barely perceptible

Link Characterization

Link characterization tests were conducted to define the performance relationship between the Hermes/CTS channel 1 EIRP and the DICE system. Using the LeRC fixed terminal and test setup of figure 6, the plot of the channel 1 output stage tube (OST) versus bit error rate was developed (fig. 7).

The results showed that the combined link was uplink noise limited. Although the spacecraft does provide switchable attenuators, the largest available attenuation (5 dB) constrains the maximum uplink EIRP to 71 dBW, thereby limiting the uplink C/T to -130.0 dBW/K. The data shown in figure 7 is applicable to other receive terminals whose G/T does not significantly change the combined link C/T (table II).

This data provides the means whereby simplex operating points may be chosen to provide predictable DICE receiver performance, i.e., BER operating point, with the COMSAT 3-meter (10-ft) or LeRC 2.4-meter (8-ft) terminals.

Hermes/CTS channel 1 EIRP requirement for these terminals is 57.5 dBW or an output power level from the spacecraft transmitter of 140 watts (Sat. - 1.5 dB). This level produces a BER of approximately 10^{-8}, which subjectively is a good quality picture.

Another objective in the link characterization tests was to define the channel spacing criteria for acceptable performance of 2 carriers in a single Hermes/CTS channel. The tests were performed with digital and analog video signals using the spacecraft high power channel 1. Because the spacecraft 200-watt amplifier gain response across the band of channel 1 is not constant, carrier levels were set equal on the downlink before performance evaluation. A summary of the conditions and results of these tests is shown in table III.

The table III results, although showing a TASO quality for a given set of conditions, require some additional explanation to better visualize the performance. In the FM/FM case, the interference was crosstalk; however, its perceptibility was a function of picture content. For active pictures, the crosstalk was negligible and for static pictures it was there but not annoying. For the QPSK/FM cases, the interference presents itself as video noise rather than crosstalk. For all carrier separations, the interference was more evident on the FM signal. For the 50- and 40-MHz carrier separations, the digital signal showed no change in picture quality from operation in the simplex mode at the duplex link levels. Subjectively, the picture quality was very good to good for both channels. With a 30-MHz carrier separation, both pictures became unacceptably noisy; however, horizontal lock was maintained. Subjectively, the QPSK signal was fair to poor and the FM signal poor. It is, therefore, concluded that a spectrum separation of at least 10 MHz is required for reception of a good quality, single channel QPSK/FM video transmission.

CONCLUDING REMARKS

The system design described will provide full duplex teleconference capability in addition to 60 channels of digital voice and 1-Mbps data. The CODIT and SIDEL compressions of approximately 2:1 and 4:1, respectively, provide excellent quality transmission equivalent to NTSC standards.

The CTS satellite link performance provided by small Earth terminals and using either the 200-watt or 20-watt channels at backed off levels (140 and 10 W, respectively) is sufficient to provide a system BER of 10^{-8} or less without additional error encoding equipment.

ABBREVIATIONS

BER	bit error rate
CODIT	a COMSAT Laboratories developed digital TV coder employing an advanced form of intraframe DPCM coding to transmit a high quality NTSC television signal with a nominal bit rate of 43 Mbps
CTS	Communications Technology Satellite (Hermes)
duplex	bidirectional transfer (two-way transmission)
DPCM	differential pulse code modulation
EIRP	effective isotropic raidated power
FDMA	frequency division multiple access
LeRC	NASA Lewis Research Center
NTSC	National Television System Committee
OST	output stage tube
PET	portable Earth terminal
PCM	pulse code modulation
QPSK	quadrature phase-shift keying
S/C	spacecraft
simplex	unidirectional transfer (one-way transmission)
SIDEL	a COMSAT Laboratories developed voice coding system employing a unique combination of delta modulation and digital speech interpolation (DSI) to achieve high quality transmission of 60 voice channels plus data in a 1-Mbps bit stream
TASO	Television Allocations Study Organization
TB1,2	transmit bands 1, 2 (fig. 5)
TWT	traveling wave tube
TDMA	time division multiple access

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TABLE I. - C/N_o REQUIREMENTS

Limiting error rate	10^{-8}
Bit rate, Mbps	42.9
[a]E_b/N_o (back-to-back) required to achieve 10^{-8} error rate, dB	15.0
[b]$C/N_o = E_b/N_o + 10 \log$ (bit rate) = 15.0 + 76.3, dBHz	91.3
$C/T = \frac{\text{Carrier power}}{\text{Noise temperature}} = 228.6 - C/N_o$, dBW/K	-137.3

[a]E_b/N_o = bit energy/noise power density.

[b]C/N_o = carrier power/noise density limiting error rate = error rate above which video impairments are perceptible.

TABLE II. - LINK BUDGET

(20 W)

Uplink	
P_T - transmitted power at Earth station, dBW	22.0
G_T - gain, 3 m Earth station, dB	49.0
EIRP, dBW	71.0
Path loss, dB	-207.6
G_R (S/C antenna gain), dB	37.6
P_R received power, dBW	-99.0
G/T (S/C), dB/K	6.6
C/T (uplink), dBW/K	-130.0
Downlink	
P_T - transmission power S/C, dBW	11.0
G_T - S/C antenna gain, dB	36.3
EIRP, dBW	47.3
Path loss, dB	-206.4
P_r, dBW	-159.1
G_A - gain, 2.4 m Earth station, dB	47.8
System temperature, dB(K)	24.8 (300)
G/T, dB/K	23.0
C/T (downlink), dBW/K	-136.1
Combined Link	
C/T combined, dBW/K	-137.1
C/T required, dBW/K	-137.3
Margin, dB	0.2

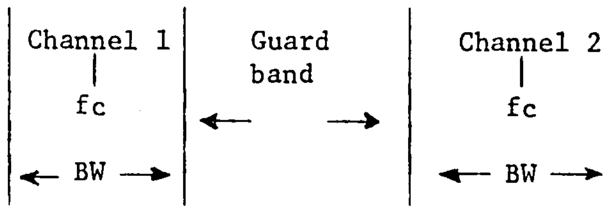
TABLE II. - Concluded

(200 W)

Uplink	
P_T, dBW	23.0
G_T - gain, 2.4 m Earth station, dB	48.0
EIRP, dBW	71.0
Path loss, dB	-207.6
G_R, dB	37.6
P_r, dBW	-99.0
G/T, dB/K	6.6
C/T uplink, dBW/K	-130.0
Downlink	
P_T, dBW	22.0
G_T, dB	36.3
EIRP, dBW	58.3
Path loss, dB	-206.4
P_r, dBW	-148.1
G_A - 3 m Earth station, dB	48.0
System temperature, dB(K)	27.0 (500)
G/T, dB/K	21.0
C/T (downlink), dBW/K	-127.1
Combined Link	
C/T combined, dBW/K	-131.7
C/T required, dBW/K	-137.3
Margin, dB	5.6

TABLE III. - LINK CHARACTERIZATION

Multi Channel Operation Format



Two Carrier Performance

No. of carriers	Mod. C1/C2	BW MHz C1	BW MHz C2	Carr. sep., MHz	Guard band, MHz	TASO[a] quality C1	TASO[a] quality C2
2	FM/FM	25	25	25	0	2	2
2	QPSK/FM[b]	33	25	50	20	2	2
2	QPSK/FM[b]	33	25	40	10	2	2
2	QPSK/FM[b]	33	25	30	0	3	4

[a]TASCO Grade 1 - Optimum reception.
Grade 2 - Slight but perceptible degradation.
Grade 3 - Degradation but usable.
Grade 4 - Severe degradation but usable.
Grade 5 - Poor to unusable.

[b]QPSK 43 Mbps DPCM.

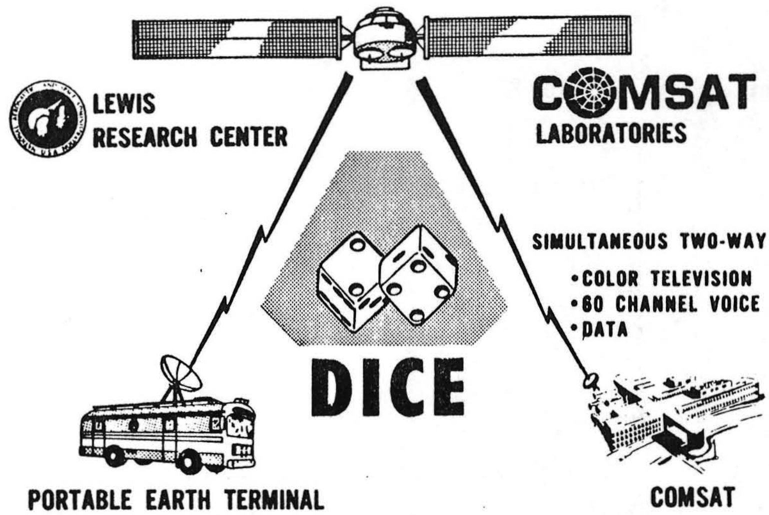


Figure 1. - Digitally implemented communications experiment.

CD-12112-32

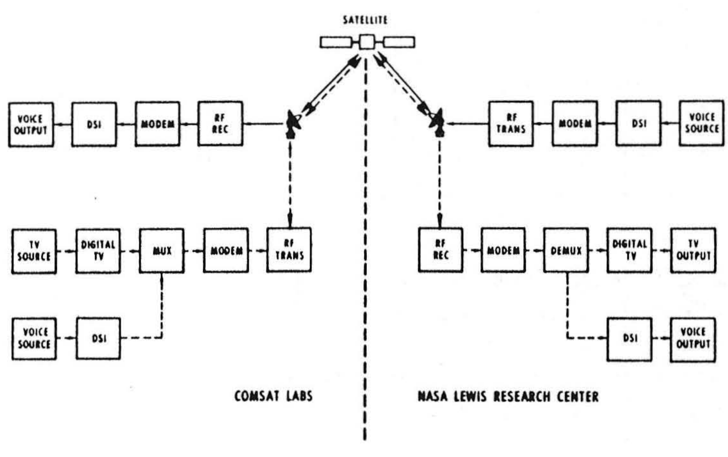


Figure 2. - Communications Technology Satellite Digitally Implemented Communications Experiment.

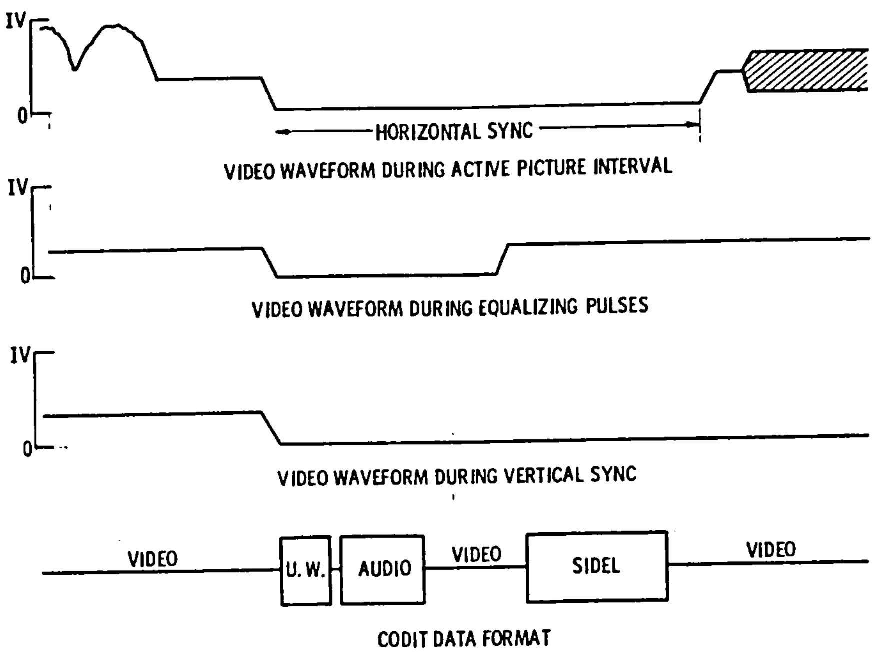


Figure 3. - Time-division multiplex format.

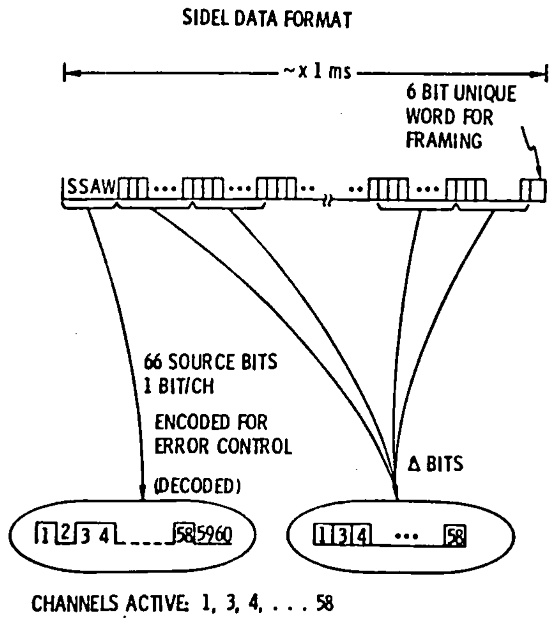


Figure 4. - SIDEL-1 frame format.

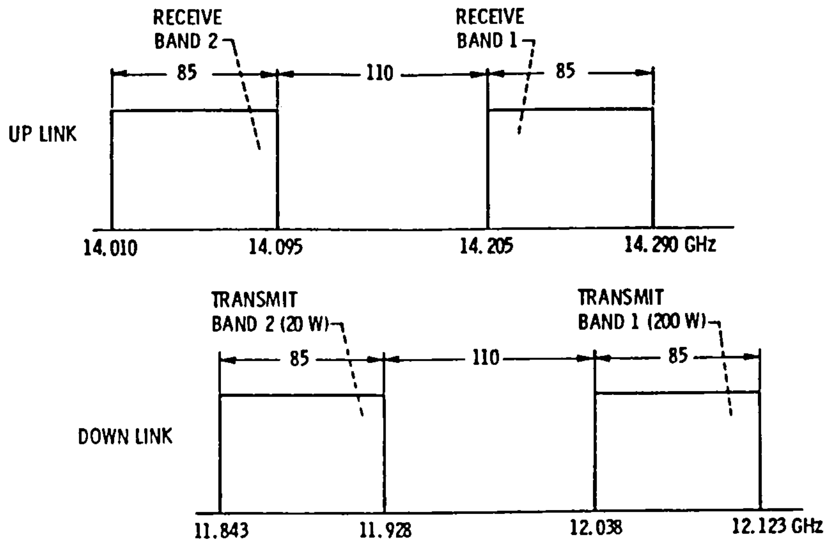


Figure 5. - Communications technology satellite frequency plan.

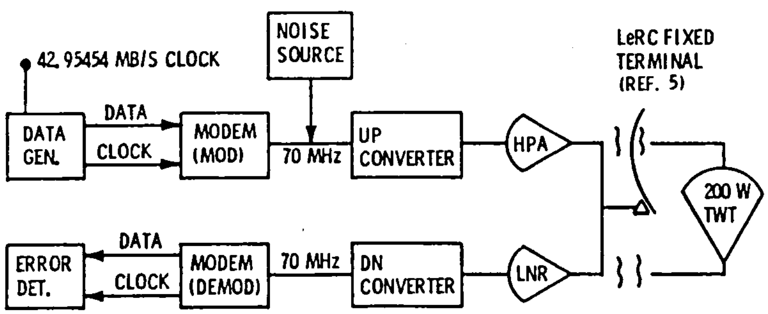


Figure 6. - Performance measurement test setup.

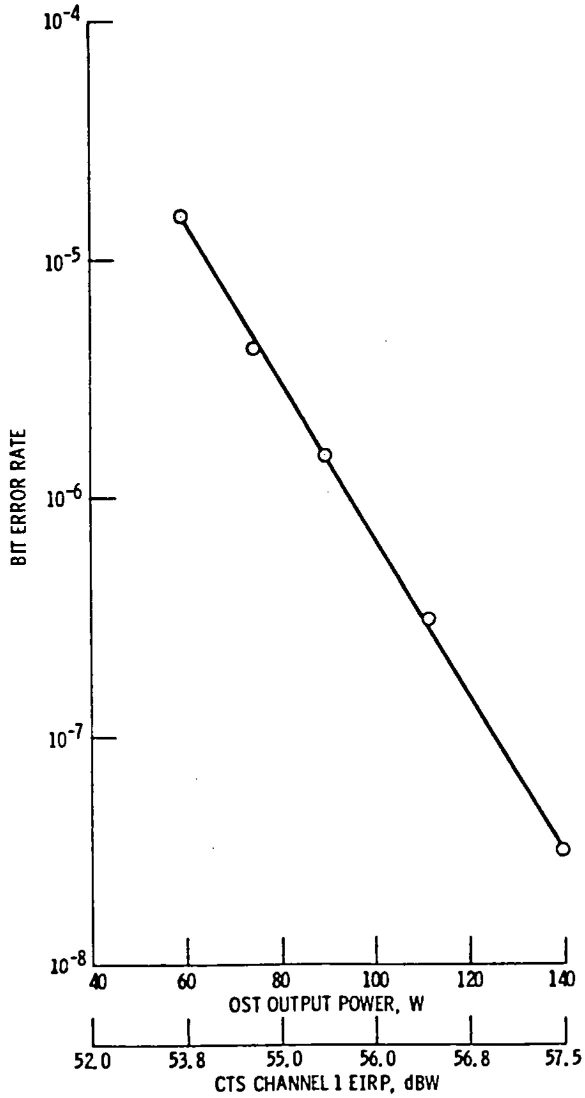


Figure 7. - CTS/DICE performance at 43 MBS. Bit rate, 43 MBS; bandwidth, 33 mHz.

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15. Supplementary Notes

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