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# A DIGITALLY IMPLEMENTED COMMUNICATIONS EXPERIMENT UTILIZING THE HERMES (CTS) SATELLITE

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# A DIGITALLY IMPLEMENTED COMMUNICATIONS EXPERIMENT UTILIZING THE HERMES (CTS) SATELLITE

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## ABSTRACT

The Hermes (CTS) experiment program provides a significant effort directed toward new developments which will reduce the costs associated with the distribution of satellite services. Advanced satellite transponder technology and small inexpensive earth terminals have been demonstrated as part of the Hermes program. Another system element that holds promise for reduced transmission cost is associated with the communication link implementation.

This paper describes an experiment being conducted jointly by NASA-Lewis and COMSAT Laboratories using CTS to demonstrate digital link implementation and its advantages over conventional analog systems. 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.

Presentation of the experiment concept which concentrates on the evaluation of full-duplex digital television in the teleconferencing environment is followed by a description of unique equipment developed to provide:

1. High quality NTSC (United States - National Television System Committee) television signals from a COMSAT digital TV codec (CODIT) employing intraframe DPCM coding at a nominal 43 Mbps. The CODIT equipment also includes a time division multiplex function to permit the addition of an external data stream such as that provided by the COMSAT voice system CODEC (SIDEL).

2. Sixty channels of high quality voice from a codec (SIDEL) employing a unique combination of delta modulation and digital speech interpolation to achieve

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high quality transmission with a 4 to 1 data compression. Output bit rate is approximately 1 Mbps.

3. Optimum transmission of digital signals over a satellite path with QPSK modulation at data rates of 1, 22, 32, 43, and 49 Mbps. The unique COMSAT design makes it possible to operate one modem over a wide range of bit rates by using plug-in modules, permitting various systems to be demonstrated.

The DICE system full duplex TDM (Time Division Multiplex) scheme is presented with implementation considerations including up/down frequency conversion, earth terminal transmit and receive requirements both with and without error coding as well as space segment link budgets. Experiment evaluation will address both the technical and operational/economic objectives.

## INTRODUCTION

The demand for satellite communications services is rapidly expanding. As stated by U. S. Federal Communications Commission Commissioner Abbot Washburn (ref. 1) - Bringing together the various techniques in the advancing communications satellite technology, none of them "blue sky," as a "complete workable system" that will result in considerably lower overall costs to the users. Increasing use of digital communications techniques should mean a "modest" increase in the number of usable channels per pound in orbit.

In this light, the advanced technology provided by the CTS experimental satellite high power transponder and small inexpensive earth terminals has been demonstrated extensively.

A natural extension of the communications link experimentation on CTS is associated with the methods of transmission. Digital transmission of voice (refs. 2 to 4) as well as television (refs. 5 and 6) 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 CTS was proposed.

The proposed Digitally Implemented Communications Experiment (DICE) was designed to focus on the development and performance evaluation of a variety of video, audio, and data digital communications techniques. The primary configuration for the experiment uses the small earth terminals at NASA/LeRC and COMSAT. Full digital duplex operation is being demonstrated using both the 200 watt and 20 watt channels on the CTS. The experiment tests will provide for the technical characterization of the system. Data such as carrier-to-noise ratios, bit error rates and baseband signal quality are being measured and correlated with up/down link transmission variables in order to define levels of performance for a variety of digital configurations. Operational/economic data are also being compiled to show the cost effectiveness and practicality of the digitally compressed video/voice/data system.

This paper concentrates on the development, integration, and operation of a flexible communication system for digital satellite transmission. The primary communication medium considered is high quality color television augmented by multichannel voice and data. The system concept as well as preliminary results are described in the following sections.

## SYSTEM DESCRIPTION

Figure 1 graphically describes the communications link for a DICE demonstration. The LeRC Portable Earth Terminal shown in the figure has been configured to support DICE demonstrations in the field while a fixed terminal at LeRC will be used for in-house demonstrations and experimentation. Figure 2 is a more detailed breakdown of the baseband to microwave system configuration for the DICE/CTS communications experiment. Using figure 2 as a reference, the signal flow and DICE system description are as follows.

## UPLINK

### DICE Transmit System

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) is converted to DPCM (4 bits per sample and a sample rate of 10.7 MHz) to provide a baseband video data rate reduction of 2:1 (before input to the multiplexer). This rate reduction is accomplished by a prediction circuit which uses preceding samples to predict the value of the next sample. The more accurately samples can be predicted the less bits required to represent the information.

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 composite video (near the horizontal sync) 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 (DSI) system. The audio input signals are digitally encoded using variable rate delta modulation and time-division multiplexed into a serial bit stream. The rate of delta modulation is controlled by a speech detector which periodically determines the channels that are active. The information as to which channels are active is then stored in a 60 bit speech spurt assignment word (SSAW). Based on SSAW, the active channel speech data is then stored in memory. By using the speech detector and variable rate delta modulation, the needless transmission of inactive channel noise is prevented and an effective bit rate compression ratio of approximately 4:1 over conventional 64 Kbps PCM is achieved. Both the SSAW with error encoding and the active channel information are multiplexed into the frame structure. 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 utilizes 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 modem is designed to cover the bit rates of 1 mbs 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. Each module contains the channel filters and symbol clock module for simplicity in changing from one rate to another. The 43 Mbps DICE input to the uplink modulator is processed into two parallel streams that are differentially encoded and filtered. The output of each filter is fed to two double balanced mixers that are driven in quadrature by a 70 MHz carrier oscillator. The 70 MHz carrier is routed to the up/down converter located at the transmitter site.

The Lewis RF system incorporates a variable frequency double conversion up/down converter. The input and output frequency is 70 MHz and the intermediate frequency 1.5 GHz. The converter can be tuned to any frequency in either of the two CTS bands (ref. 7) 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 in order to define the transmit system configuration.

The link budgets (table I) were based on the following assumptions: that the experiment would be conducted in a two-way transmission of digital video, data and voice using the two transponders of the spacecraft, the antennas would be pointed at the nominal positions of the participating earth stations under clear sky conditions.

## Terminal Characteristics

The LeRC portable earth terminal used in DICE demonstrations has a 2.4 m (8 ft) antenna (48 dB gain) and 500 watt transmitter with an instantaneous bandwidth of 50 MHz. The maximum net EIRP is 74 dBW. The high power transmitter can be tuned to operate in either of the two CTS bands. Demonstrations to data have 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 m (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 dBW/K.

Link budget calculations based on the LeRC and COMSAT terminals are shown in table II.

DOWNLINK

The receive downlink signal, either TB1 or TB2, is input to the downconverter whose input dynamic range is -70 to -30 dBm. The internal gain of 60 dB provides a 70 MHz signal at 0 dBm level to the demodulator.

Demodulation is achieved by coherent detection. The local carrier signal is recovered by a separate carrier recovery circuit (fig. 6). Regeneration is performed by instantaneous sampling by the clock signal which is recovered by the clock recovery circuit.

The demodulation consists of two double balanced mixers followed by two passive low pass baseband filters. The mixers act as multipliers with the inphase and quadrature phase carriers supplied from the carrier recovery circuit.

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 CODIT DPCM receiver (fig. 7) uses a predictor which is identical to that of the transmitter and a decoder which is the compliment of the coder.

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 (fig. 8), like the transmitter, demultiplexes the SSAW and delta encoded speech samples and stores them in memory. After error checking, the samples are routed to their respective channels.

# DEMONSTRATION AND TESTS

## Demonstration Concept

The experimental demonstration objective concentrates on the evaluation of full-duplex television in the teleconferencing environment. A variety of digital transmission methods which are nearing commercial availability are intended to be comparatively evaluated. The specific television experimental hardware previously described (i.e., CODIT-1 DPCM system) as well as digital television processors using frame storage and transform methods will be included.

The video teleconference environment has been chosen to provide feedback from a users rather than critics perspective of digital system quality and performance.

## Baseband Tests

CODIT. - Video and audio test signals are used to characterize CODIT. The video tests are as follows:

(1) Video insertion test to measure the insertion loss of the system

(2) Differential gain and phase test to measure nonlinear distortion

(3) Signal-to-weighted-noise ratio tests to measure the systems thermal noise contribution to the output signal

(4) Chromanance signal's relative amplitude and delay compared to those of the lumanance signal

The audio tests are as follows:

(1) Audio insertion test to measure the insertion loss of the system

(2) Audio frequency response test

(3) Audio signal-to-distortion ratio test to measure the distortion in the program audio channel

SIDEL. - The following tests are used to evaluate SIDEL:

(1) Signal-to-distortion (S/D) ratio of each channel unit

(2) S/D ratio of a test tone in a channel with the DSI fully loaded

(3) Bit-error-rate (BER) measurement of the data circuit

(4) Determine proper operation of SIDEL when multiplexed with a video signal

(5) Echo suppression tests

MODEM. - The following tests are used to evaluate the MODEM:

(1) A modulator balance test to determine the proper QPSK modulation

(2) BER measurements to determine BER versus C/N, BER versus AGC, and BER versus IF variations

SYSTEM. - On a system level, the following data are being compiled:

(1) For all operational bit rates, BER and C/N ratios are measured and correlated with up and downlink transmission variables to define levels for acceptable performance.

(2) For a given system configuration and operating conditions, a subjective evaluation will be made by participants who will be asked to fill in questionnaires on their perception of the system effectiveness as a communications medium.

## RESULTS AND DISCUSSION

### Demonstration

The first utilization of the DICE experimental system was for a communications convention (ICC-77/Chicago) exhibit. The exhibit was structured as a full-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.

Quality of the CODIT-1 and SIDEL was subjectively judged as excellent to better than network quality by approximately 250 communications media personnel in attendance.

### Baseband

CODIT performance parameters are compiled in table III. Measured data equalled or exceeded all pretest limits for excellent quality television transmission and reception.

SIDEL performance parameters are compiled in table IV. Measured data equalled or exceeded all pretest limits for excellent quality audio communications.

As stated earlier, two tests are performed to evaluate the modem: the modulator balance test and the BER test. For the modulator balance test, measurements are made for proper PSK and QPSK modulation. For proper PSK modulation, the suppression of the carrier component should be $\geq$40 dB. Measurement showed it to be >40 dB. For proper QPSK modulation, side band components of the carriers are such that the upper side bands are enhanced and the lower side bands cancelled after the signals are combined. Suppression of the lower sideband should be $\geq$35 dB. Measurement showed it be be 38 dB. The BER measurements are performed by connecting the modem back-to-back. For the BER versus C/N ratio test, the C/N was converted to the energy per bit to noise power density ratio ($E_b/N_o$) by using the expression

$$\frac{E_b}{N_o} = \frac{C}{N} - 10 \log \frac{R}{B_n}$$

where R is the bit rate and $B_n$ is the noise bandwidth of the receive band pass filter.

The data is shown plotted in figure 9. The measured data exceeded the theoretical curve by 1 dB. For the BER versus AGC tests, no measurable variations in the BER were observed for input level variations from -5 dB to -15 dBm.

The BER versus IF variations test is to checkout the performance of the AFC loop. The AFC loop is designed to track between 70 MHz ± 50 kHz. BER variations between IF limits were approximately one order of magnitude which is within design limits.

## System

Preliminary system level duplex video tests have been performed utilizing the CTS and the LeRC/COMSAT terminals. For band 2 (20 W channel) operation, the uplink EIRP was approximately 70 dBW and S/C EIRP 46 dBW (10 W) to achieve a BER of $10^{-8}$. For band 1 (200 W channel) operation, the uplink EIRP was 71 dBW (approximately 4 dB S/C gain suppression) and the S/C EIRP dBW (160 W) to achieve a BER of $10^{-8}$. Simplex and duplex testing is continuing to define generalized terminal and S/C parameters required for $10^{-8}$ BER performance with DICE. Subjective evaluation tests have not begun on a systematic basis, however, results from our demonstration activities have been very encouraging.

## 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 compression 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 (160 and 10 W, respectively) is sufficient to provide system BERS of $10^{-8}$ or less without additional error encoding equipment.

## REFERENCES

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6. Gatfield, A.: CODIT, A Digital TV System for Communication Satellites. Intelcom 77, International Telecommunication Exposition, Atlanta, Ga., Oct. 9-15, 1977, Paper 3.8.2.

7. CTS Reference Bock. NASA TM X-71824, 1975, p. III-12.

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]$C/N_o = E_b/N_o + 10 \log(\text{bit rate}) = 15.0 + 76.3$, dBHz | 91.3 |
| $C/T$ = carrier/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 TB-2

(20 W)

| | |
|---|---|
| **Uplink** | |
| $P_T$ - transmitted power at earth station, dBW | 22.0 |
| $G_T$ - gain, 3 m earth station, dB | 49.0 |
| E.I.R.P., 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 |
| E.I.R.P., dBW | 47.3 |
| Path loss, dB | -206.4 |
| $P_r$, dBW | -159.1 |
| $G_A$ - 2.4 m earth station, dB | 47.8 |
| System temperature, dB (K) | 24.8 (300) |
| G/T, dBW/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 |
| E.I.R.P., 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 |
| E.I.R.P., 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 (600) |
| 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. - CODIT TEST DATA

| Measurement | Limits | Measured value |
| --- | --- | --- |
| 1. Video insertion gain | 96 to 104 IRE | 100 IRE |
| Video insertion sync | 38 to 42 IRE | 40 IRE |
| 2. Differential gain | ±5 percent | ±2 percent |
| Differential phase | $\pm 5^{\circ}$ | $\pm 1.5^{\circ}$ |
| 3. Video S/N weighted | >48 dB | 55 dB |
| 4. Chroma gain inequality | 10 percent | 0 percent |
| Chroma delay inequality | 100 ns | 40 ns |
| 5. Audio gain response | ±1 dB | ±0.1 dB |
| 6. Audio frequency response | 1 to 14 kHz ± 1 dB | ±0.15 dB |
| 7. Audio S/D | >47 dB | 50 dB |

TABLE IV. - SIDEL TEST DATA

| Measurement | Limits | Measured value |
| --- | --- | --- |
| 1. S/D ratio of each channel unit | >30 dB | >33 dB and >30 dB[a] |
| 2. S/D ratio for a channel, DSI loaded | >25 dB | >29 dB and >27 dB[a] |
| 3. BER of data circuit | $\geq 10^{-7}$ | 0 |
| 4. Echo suppression | >55 dB | >59 dB |

[a]With and without a message weighting filter.

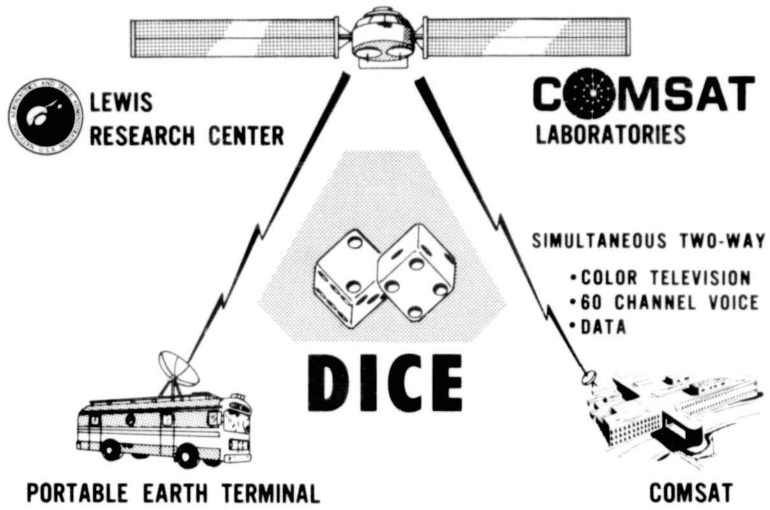


Figure 1. - Digitally implemented communications experiment. CD-12112-32

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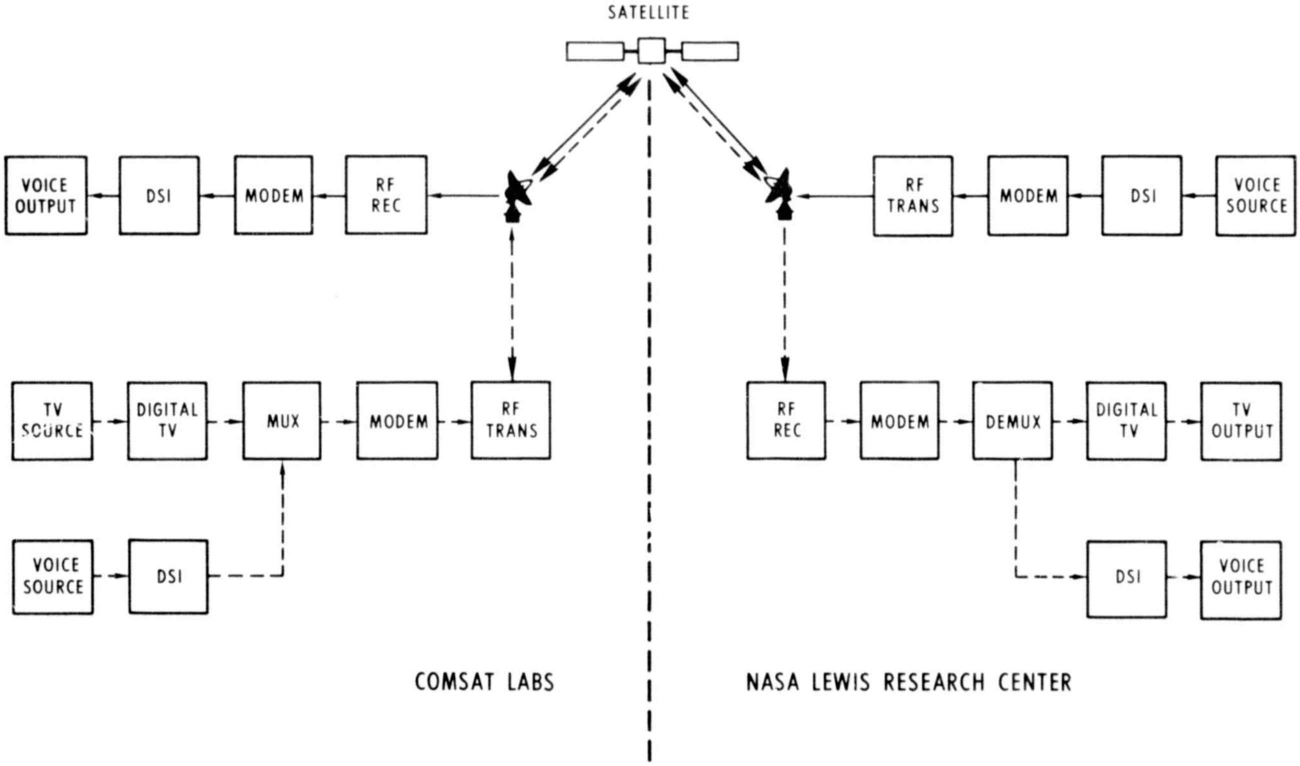


Figure 2. - Communications Technology Satellite Digitally Implemented Communications Experiment.

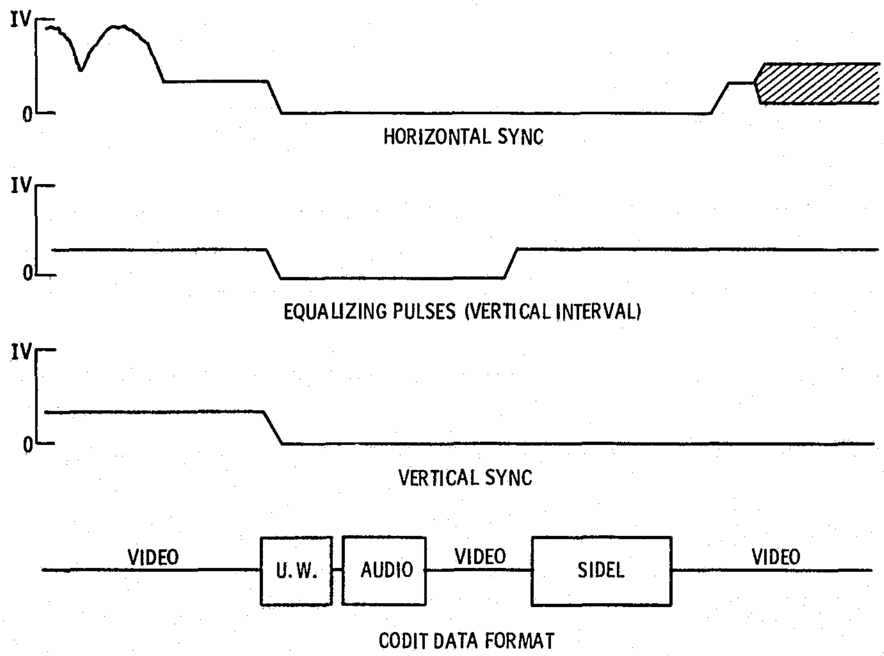


Figure 3. - Time-division multiplex format.

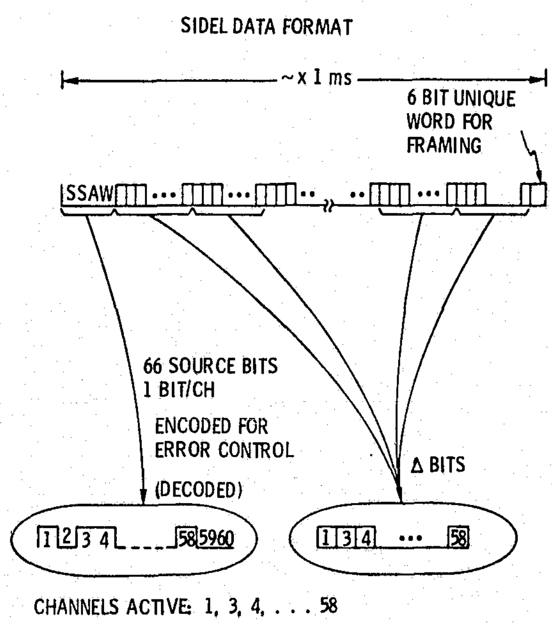


Figure 4. - SIDEL-1 frame format.

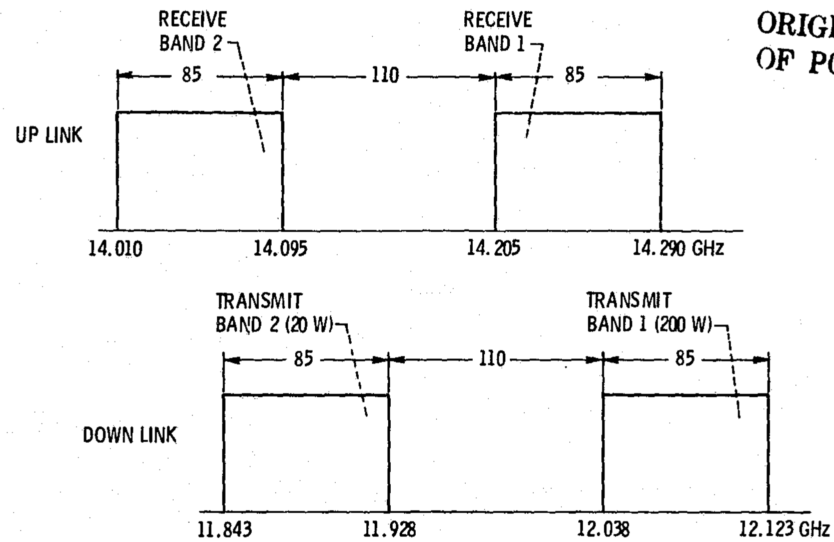


Figure 5. - Communications technology satellite frequency plan.

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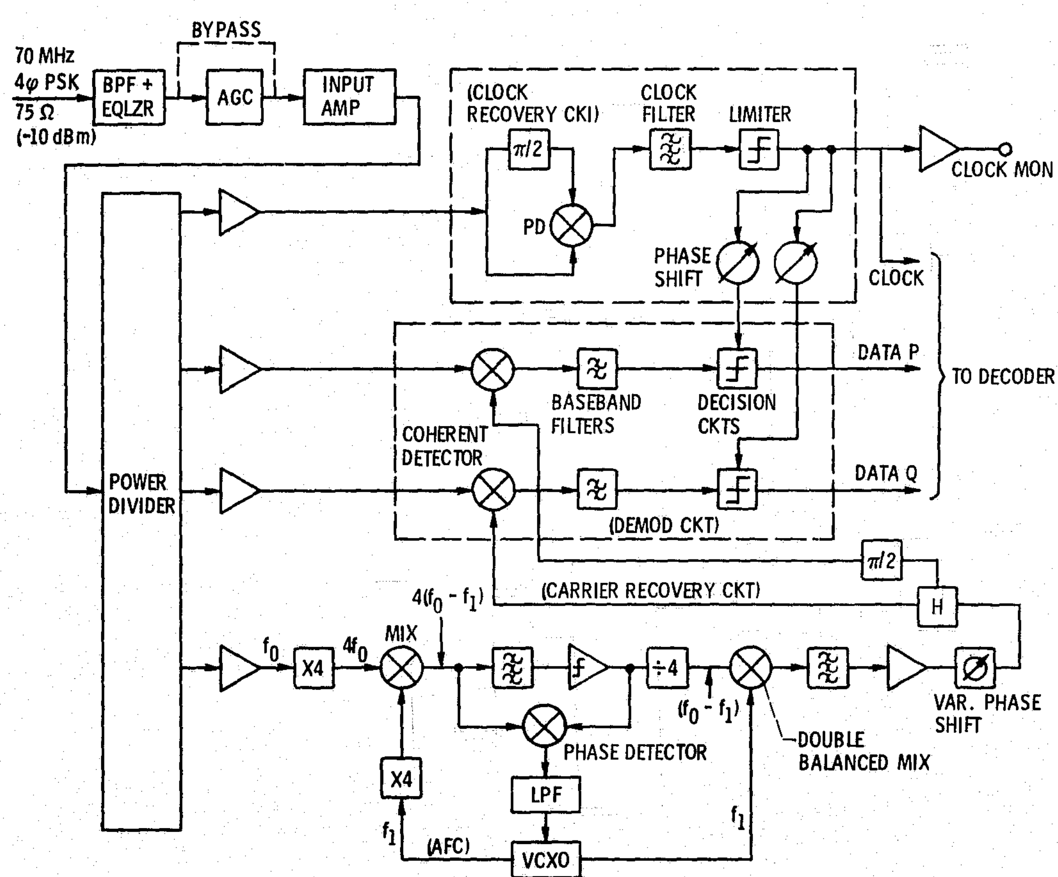


Figure 6. - Demodulator block diagram.

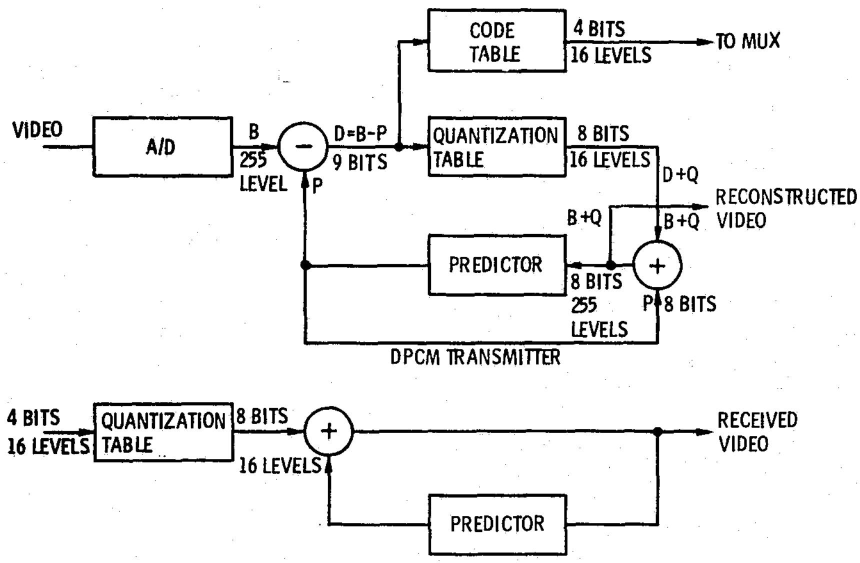


Figure 7. - DPCM receiver.

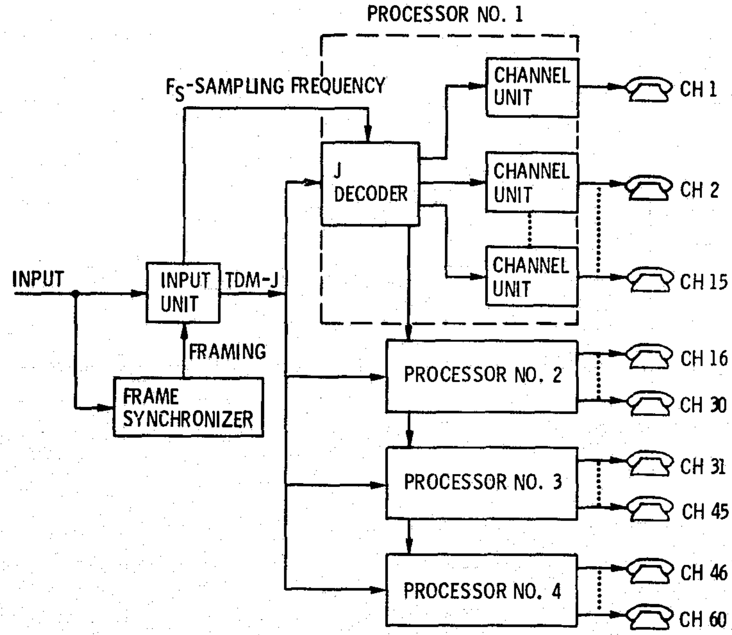


Figure 8. - Sidel receiver.

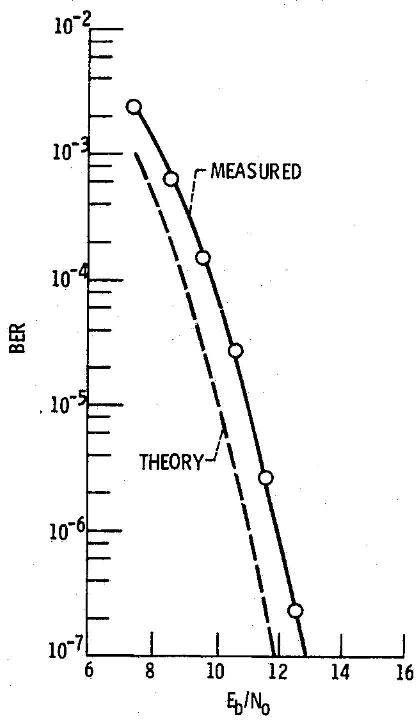


Figure 9. - $E_b/N_o$ vs BER.