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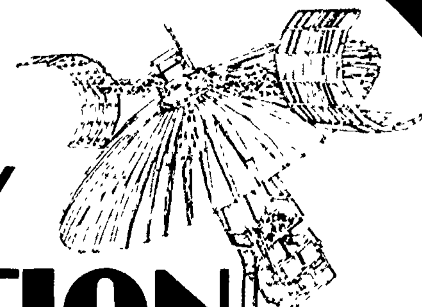
ABSTRACT

The major purpose of the Health, Education, Telecommunications experiment was to demonstrate the feasibility of distributing video materials to a large number of low-cost earth terminals located in rural areas. The receivers are of two types: one-way video receivers for the reception of video programs, and two-way voice/data terminals which permit the viewer to interact with the broadcaster. Details of the design, construction, and performance of these receivers are provided in this report. (EMH)

SATELLITE TECHNOLOGY DEMONSTRATION



FEDERATION OF ROCKY MOUNTAIN STATES, INC.

technical report

TR0423

REMOTE EARTH TERMINALS IN THE HEALTH, EDUCATION, TELECOMMUNICATIONS NETWORK

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INTRODUCTION

One of the major purposes of the Health, Education, Telecommunications (HET) experiment was to demonstrate the feasibility of distributing video material to a large number of low-cost earth terminals located not only in relatively remote areas, but also over a widely dispersed region. This paper briefly describes the design and performance of 119 Receive-Only Terminals (ROT's) with one-way video reception and 47 two-way voice/data terminals. The performance measures described include signal-to-noise ratio, intrinsic equipment failure rate, mean time to repair, operator effectiveness, and utility to the operator.

RECEIVE-ONLY TERMINALS

The Receive-Only Terminal (ROT) consisted of a 3.05-meter (10-foot) segmented parabolic antenna, an antenna-mounted low-noise transistor preamplifier, and an indoor demodulator unit. The system was supplied by the Westinghouse Corporation under a competitive procurement managed by HEW, with assistance from NASA and FRMS. The antenna and feed were built by Prodelin Company in Heightstown, New Jersey, and the receiving system was built by the Hewlett-Packard Company in Palo Alto, California.

The reflector, made from fiberglass, came in four quadrants with a central hub which supported the prime focus feed. The radiating element of the prime focus feed was a right-hand circular helix. The downlink transmissions from the ATS-6 were left-hand circularly polarized. The measured efficiency of the antenna at 2500 MHz was 53 percent, thus providing a gain of just over 35 dB.

The segmented antenna design was employed to facilitate shipping to remote areas, especially Alaska. After several design changes during the initial manufacturing process, a satisfactory technique was perfected that permitted proper alignment and easy assembly of the petals and that did not crack the fiberglass.

The positioning system (which held the reflector) was designed to mount on a pair of large timbers. These timbers, in turn, were secured either to the ground or to the substructure of a roof. The mount had an azimuth adjustment range of +20° and an elevation range from 0° to 70°. The limited range of the azimuth positioning required very careful initial location of the timbers or substructure with respect to the antenna pointing coordinates.

The orbit of the ATS-6 spacecraft was initially inclined +2°. The 3-dB beamwidth of the 3-meter (10-foot) antenna was only 2.7. Therefore, the antenna had to be repointed daily to accommodate morning, afternoon, and evening programming. However, because of the relative position of the ground receiving terminals in relation to the satellite, the only adjustment necessary was in elevation. To expedite the elevation adjustment, 89 of the terminals were retrofitted with a motorized remote control system. (It was fortunate that few adjustments in azimuth were required, because this adjustment mechanism was inconvenient to use.)

The Hewlett-Packard Receiver

The Hewlett-Packard receiver accepted a wide-band FM signal at either of two frequencies centered on 2569.2 or 2670 MHz and provided an NTSC standard video output signal at baseband suitable for driving television monitors. The receiver also provided four audio channels--from 4.64 to 5.36 MHz--which were transmitted as subcarriers on the video frequencies. Early in the development of the Hewlett-Packard receiver, a decision was made not to remodulate the video signal onto a standard television channel, because it would be too costly to provide a high-quality modulator that could cover all of the VHF (2-13) television channels.

The Hewlett-Packard receiver differed from ordinary microwave video receivers in two important respects: (1) It used a fast, automatic gain control (AGC) loop instead of a limiter; and (2) it demodulated the signal at the received frequency rather than at an intermediate frequency. The fast AGC loop used a PIN-diode attenuator network which provided up to 40 dB of amplitude-modulation (AM) suppression over a 40 MHz bandwidth. The disadvantage of this type of AM suppression system was that the dynamic threshold (although under 11 dB) was sensitive to the peak-to-peak deviation of the video signal.

The video signal was demodulated directly at rf, using a transmission line discriminator of a balanced and compensated design. The bandwidth of the discriminator covered the entire allocation from 2500 to 2690 MHz. The desired channel was selected by a 23.5 MHz bandpass filter centered on the desired channel frequency. Because the programming transmissions operated on fixed-channel assignments throughout the Experiment, there was never a need to change the easily replaceable filters.

This direct demodulation approach was selected by Hewlett-Packard to eliminate the need for a local oscillator and to make use of economical rf gain-stages. This approach was feasible for two reasons: (1) only two channels were available for broadcasts; and (2) changes from one channel to another were neither expected nor required.

Since the receiver was a "tuned radio frequency" receiver, all the gain was at 2500 MHz. (This type of receiver dates back to the very early days of radio; it was popularly known as a "tuned radio frequency" or "TRF" receiver.) The low-noise preamplifier at the antenna provided 55 dB gain at a noise figure of under 4 dB and the remainder of the 130 dB of gain was obtained at the indoor unit. A 3/4" -diameter, low-loss, foam-filled cable was used to bring the signal from the antenna unit to the indoor unit; it was guaranteed to have fewer than 9 dB loss for a 100-foot length. This cable was difficult to work with because it had a solid aluminum outer-conductor sheath.

The final specifications for receiver performance represented a compromise between studio quality and home-receiver quality video. This compromise was made, because the received video signal in over 90 percent of the installations was used directly at that location and was not rebroadcast. Therefore, no additional degradation occurred. Only the participating public broadcast stations had the capability to detect degradation from studio quality if any occurred.

Results and Conclusions

The following computer results were obtained from cumulative readouts of Optical Mark Read (OMR) cards filled out daily by site operators.

Table 1 data shows that the signal strength for the specially-engineered 2.5 GHz Receive-Only Terminals exceeded the design specifications. The average signal strength at all sites for each month and cumulatively, during the period from October, 1974 to March, 1975, was 17 dB. (The design specifications required 11 dB or above.) A comparison of the four beams for the six-month period indicated that:

1. The strength of the signal was greatest in the Rocky Mountain Southeast (RMSE) area, with an average reading of 19.07 dB.

TABLE 1

Signal Strength During A Six-Month Period

2.5 GHz Receive-Only Terminals

	RME(N) North East	RME(S) South East	RMW(N) North West	RMW(S) South West	All
October 1974					
# Responses	316	289	259	184	1048
HP Meter Mean	17.29 dB*	19.01 dB	15.31 dB	17.45 dB	17.30 dB
HP Meter Standard Deviation	2.98 dB	3.92 dB	3.39 dB	2.81 dB	3.60 dB
HP Meter Median	18.03 dB	19.68 dB	15.74 dB	17.85 dB	17.74 dB
November 1974					
# Responses	325	273	279	138	1015
HP Meter Mean	17.28 dB	18.53 dB	14.82 dB	17.69 dB	17.00 dB
HP Meter Standard Deviation	3.27 dB	3.88 dB	3.39 dB	2.74 dB	3.70 dB
HP Meter Median	18.00 dB	19.48 dB	15.05 dB	17.92 dB	17.55 dB
December 1974					
# Responses	268	226	239	122	855
HP Meter Mean	17.40 dB	19.65 dB	15.54 dB	17.83 dB	17.54 dB
HP Meter Standard Deviation	3.29 dB	3.02 dB	2.29 dB	2.09 dB	3.20 dB
HP Meter Median	18.11 dB	19.87 dB	15.23 dB	18.04 dB	17.79 dB
January 1975					
# Responses	362	311	308	161	1142
HP Meter Mean	17.01 dB	19.20 dB	15.28 dB	17.80 dB	17.25 dB
HP Meter Standard Deviation	3.27 dB	3.76 dB	3.39 dB	2.08 dB	3.62 dB
HP Meter Median	17.39 dB	20.09 dB	15.20 dB	17.66 dB	17.47 dB
February 1975					
# Responses	347	307	316	174	1144
HP Meter Mean	17.50 dB	19.09 dB	15.22 dB	18.09 dB	17.39 dB
HP Meter Standard Deviation	2.85 dB	3.86 dB	3.61 dB	2.19 dB	3.60 dB
HP Meter Median	17.73 dB	19.95 dB	15.42 dB	18.50 dB	17.72 dB
March 1975					
# Responses	308	253	269	154	984
HP Meter Mean	17.38 dB	19.04 dB	15.62 dB	17.84 dB	17.40 dB
HP Meter Standard Deviation	2.16 dB	3.54 dB	3.21 dB	3.31 dB	3.29 dB
HP Meter Median	17.56 dB	19.90 dB	15.68 dB	19.21 dB	17.62 dB
All Six Months					
# Responses	1926	1659	1670	933	6188
HP Meter Mean	17.30 dB	19.07 dB	15.29 dB	17.78 dB	17.31 dB
HP Meter Standard Deviation	3.00 dB	3.72 dB	3.28 dB	2.59 dB	3.52 dB
HP Meter Median	17.78 dB	19.82 dB	15.37 dB	18.15 dB	17.65 dB

*Decibels

2. The lowest signal strength occurred in the Rocky Mountain Northwest (RMNW) area, with an average of 15.29 dB.
3. The Rocky Mountain Northeast (RMNE) and Rocky Mountain Southwest (RMSW) areas steadily maintained similar readings at 17.30 dB and 17.78 dB, respectively.

Two facts may explain the slight differences in the above comparisons. First, the RMNW area contained the greatest number of sites located on the periphery of the beam. Second, the RMSE area contained the greatest density of sites located closest to the beam center.

Table 2 compares signal strength, video and audio intelligibility comments, and various weather conditions. Video intelligibility comments of "4 by 4," "4 by 5," and "5 by 5" constituted acceptable and operative conditions at the terminals. The mean Hewlett-Packard (HP) reading during the six-month period was as follows: (1) 15.80 dB for "4 by

TABLE 2

Six-Month Comparison of Intelligibility Comments, Weather Conditions, and HP Signal Strength

2.5 GHz Receive-Only Terminals

	Video Intelligibility Comment	5 x 5	4 x 5	4 x 4
	# Responses	4907	231	444
HP Meter	Mean	17.63*	17.96	15.80
HP Meter	Standard Deviation	3.33	2.36	2.99
HP Meter	Median	17.93	18.38	16.32

	Audio Intelligibility Comment	3 x 3
	# Responses	5476
HP Meter	Mean	17.60
HP Meter	Standard Deviation	3.21
HP Meter	Median	17.83

	Temperature	Greater than 80°	51-80°	31-50°	1-30°	Below 0°
	# Responses	18	732	2887	2310	213
HP Meter	Mean	13.83	17.29	17.10	17.51	18.46
HP Meter	Standard Deviation	2.75	3.47	3.55	3.46	3.29
HP Meter	Median	13.50	17.42	17.42	17.89	18.72

	Clouds	No Clouds	Moderate Clouds	Heavy Clouds
	# Responses	3315	1570	1273
HP Meter	Mean	17.54	17.05	17.06
HP Meter	Standard Deviation	3.59	3.44	3.34
HP Meter	Median	17.92	17.20	17.45

	Wind	No Wind	Moderate Wind	Heavy Wind
	# Responses	5036	952	92
HP Meter	Mean	17.38	17.38	17.27
HP Meter	Standard Deviation	3.49	3.41	3.06
HP Meter	Median	17.78	17.30	17.36

	Rain	No Rain	Moderate Rain	Heavy Rain
	# Responses	5768	253	42
HP Meter	Mean	17.44	16.19	15.45
HP Meter	Standard Deviation	3.47	3.12	4.12
HP Meter	Median	17.79	16.05	16.06

	Snow	No Snow	Moderate Snow	Heavy Snow
	# Responses	5128	707	239
HP Meter	Mean	17.40	17.13	17.38
HP Meter	Standard Deviation	3.47	3.49	3.64
HP Meter	Median	17.76	17.29	17.59

	Ice	No Ice	Moderate Ice	Heavy Ice
	# Responses	5308	656	154
HP Meter	Mean	17.41	16.60	17.90
HP Meter	Standard Deviation	3.42	3.95	3.46
HP Meter	Median	17.74	16.87	18.21

*Mean, Standard Deviation, and Median are in Decibels.

4" intelligibility; (2) 17.96 dB for "4 by 5" intelligibility; and (3) 17.63 dB for "5 by 5" intell.gibility. The audio intelligibility comment for the period averaged "3 by 3", with a corresponding 17.60 dB mean HP reading.

For the varying temperature ranges, the mean HP reading was 13.83 dB for environmental changes greater than 80°. However, this result is not significant: The 18 responses used to obtain that mean were insufficient in number; and computer readouts of the individual sites indicated that the two sites recording this data were peripherally-located installations. For these reasons, and because no significant changes occurred during any other temperature variances, it was concluded that temperature had no significant impact on signal strength.

In varying cloud and wind conditions, there were no significant changes in HP readings. The fact that there were no changes in HP readings due to snow and ice conditions suggests that site operators removed snow and ice collected in the parabolic reflector, as instructed. (When snow and ice accumulate in one area of the antenna, there is degradation in the signal strength.) There was a correlation between the varying rain conditions and received signal strength. However, the conclusion that rain affected the strength of the signal at 2.5 GHz has to be qualified. For most of the period during which the readings were taken, site operators had to go outdoors and manually adjust the antenna. The factor of human inconvenience in having to go outdoors during a rainstorm may have caused many operators to elect not to make this adjustment and to be satisfied with a reading which was lower but which did not diminish picture quality to any significant degree.

Table 3 shows that signal strength exceeded 11 dB 98 percent of the time. These results again confirm the excellent performance levels achieved at the ROT sites.

Table 4 provides a summary of conclusions and a discussion of additional performance characteristics, based on an engineering analysis of the sites. Within the 4-dB contours of the satellite antenna footprints, the video signal-to-noise ratios met or exceeded expectations.

Equipment reliability information was obtained by the site status reporting system, which gave complete information on the daily operational status of all remote installations. Most information required no action by the site operators; it was included only for documentation purposes.

TABLE 3

Cumulative Percentage of

HP Signal-Strength

Readings

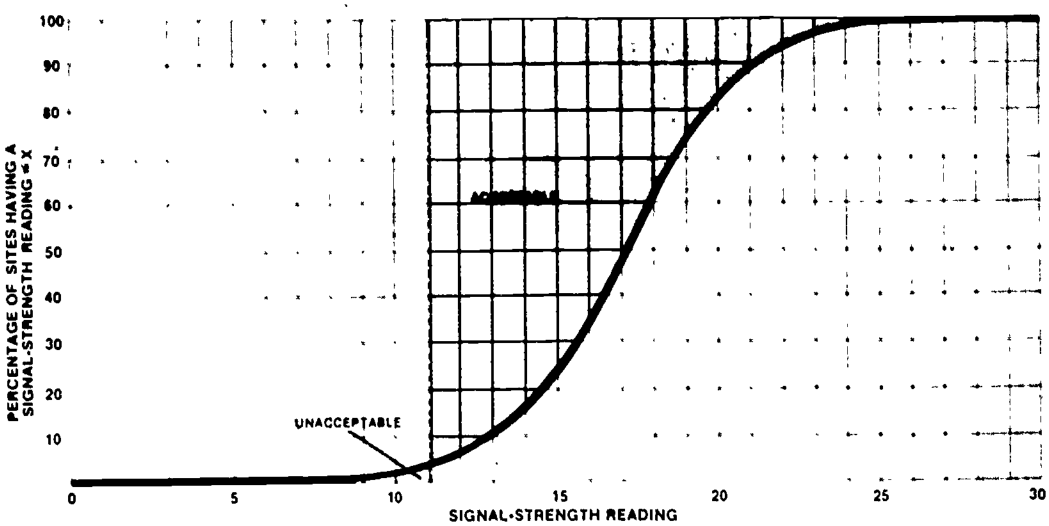

TABLE 4
Signal Quality

Summary of Conclusions:
2.5 GHz Receive-Only Terminals
Based on Data Between
October, 1974, and March, 1975.

HP Signal Strength Readings	
Mean	17.31 dB
Standard Deviation	3.52 dB
Median	17.65 dB
Video Intelligibility	
Mean	5 by 5
Audio Intelligibility	
Mean	3 by 3
***Design Adequacy**	
(Threshold curve set at 11 dB) 98%	
Weather Impact	
Temperature	None
Clouds	None
Wind	None
Rain	Reduction in Signal Strength No impact on Signal Quality
**Snow Ice	No impact observed Snow was cleared from the parabolic
Signal-to-Noise Ratio	
(Weighted peak-to-peak video to rms noise) >49 dB, 99%	
Color Fidelity	
Phase	Within $\pm 2.5°$
Amplitude	Within $\pm 4\%$
Associated Audio	>44 dB, 99%

*Design adequacy is the probability that the system will successfully accomplish its mission, given that the system is operating within design specifications.

**No environmental tests on the parabolic have been performed for snow and ice conditions. However, in general, when ice or snow accumulates in one area on the parabola, there is a degradation in the signal strength, but no degradation in signal quality until the threshold time is met.

The failure rate was defined as "the ratio of the number of program hours missed due to equipment failure at all sites to the number of total program hours available." The failure rate of all equipment was less than 1.1 percent. Intrinsic equipment availability was defined as "the probability that the system is operating satisfactorily at any point in time, including operating time and active repair time, when used under stated conditions."* The intrinsic availability was greater than 98.9 percent. This measure excluded program time lost due to operator error which, during the startup phase, was the significant factor in overall downtime. The meantime to repair the actual failures averaged 24 hours; thus, the actual downtime due to equipment failures was one program interval or less.

VHF/TX/RX TERMINALS

Twenty-four STD remote sites were equipped with VHF transmitter/receiver systems, which were used in conjunction with the ATS-1 and ATS-3 spacecraft. This setup enabled "live" voice interaction between the various HET coordination centers and the sites, as well as among the sites themselves. Additional requirements for the HET system included teletype capability and the STD's experiment with the digital system.

The VHF terminal consisted of: a specially-modified General Electric 90-watt transmitter/receiver; a helical antenna which was used for simultaneous transmission and reception; a diplexer; a low-noise preamplifier; and a digital coordinator. The transmitter/receiver and the digital coordinator were housed in a cabinet on casters with a desktop. The antenna configuration was chosen, because it provided the necessary circular polarization with no installation or operator adjustments. A transportable design was developed, permitting easy erection of the equipment in the field. The diplexer filter and preamplifier were commercially-available subsystems.

The digital coordinator was the device which performed all control functions for the VHF equipment, sending and receiving digitally-coded commands to and from the sites to Denver. To simplify its use, the coordinator was designed to act as the complete control device for all the equipment and also to serve as the control panel for the VHF transmitter/receiver.

* See Reliability Engineering, ARINC Corporation, Prentice-Hall, Inc., Englewood, New Jersey, 1964, page 15.

To conform with requirements placed on the HET experiments by the Interagency Radio Advisory Committee, the VHF terminal had to operate in a half-duplex mode; that is, there had to be an open receive channel at the remote site, even during transmissions. Only in this manner was it possible to terminate transmissions from a remote site upon a command from NASA or the NCC during emergencies or unauthorized transmissions.

Each station was assigned a unique address number, digitally coded. This address was to be transmitted in a five-word preamble each time the site transmitter was keyed on, thus providing positive identification for all terminals at the Network Coordination Center (NCC). Transmissions to remote sites from the NCC also were preceded by the same type of digital preamble, thus enabling the NCC to control terminal functions at any site (on a selective basis).

The preamble and all data transmissions (except teletype) were sent in asynchronously at 1200 bits per second. This rate was chosen to permit the substitution of a standard phone link in the event that the ATS-1 or ATS-3 spacecraft failed during the course of the Experiment. The five words in the preamble consisted of a start word, an address, a status or command word (depending on whether it was to be transmitted from a remote site or from the NCC), a repeat of the third word as redundant check, and an "end" word. The coordinator automatically converted this serial data stream for transmission over the link to a parallel format for processing using integrated circuits. The transmissions to the NCC were phase-shift-keyed for increased protection from errors on the link, but all transmissions from the NCC to remote sites were frequency-shift-keyed. This change was initiated, because the Denver transmitter had a 300-watt capability and all other things being equal, the signal-to-noise ratio was higher at the remote sites than at the NCC.

The basic General Electric receiver needed only minor modifications to detect data transmissions. The receiver's digital coordinator had three main functional circuits: (1) receive and decode logic; (2) encode and transmit logic; and (3) command and control logic. There were four modes of operation: CALL, VOICE, DATA, and AUTOMATIC DATA. In the Call mode, the remote operator indicated a desire to establish contact with the NCC by using Channel 2. In the Voice mode, normal two-way communications took place on Channel 4 in the lower 48 states and on Channel 3 in Alaska. In the Data mode, teletype transmissions were sent from site to site. In the Automatic mode, the NCC operator could collect data from peripheral (digital) devices directly, without any remote operator assistance. In addition, the NCC could transmit up to 20 separate commands to perform special tasks, such as the automatic shutoff of equipment in the event of an unauthorized transmission or a network emergency and the activation of other peripheral equipment via dry-contact closures on internal relays. The last feature, which was not used operationally, was designed to activate videotape recorders at unattended sites and was supposedly used to record early morning transmissions for later playback.

The utilization of the digital coordinator was experimental in nature. The capabilities previously described were built into all the VHF remote equipment and were available for use at any time during the Demonstration.

Results and Conclusions

Signal quality at the VHF terminals consisted of two categories: voice signals and digital signals. The system was used almost exclusively in the Voice mode. System performance was dependent on whether the signal was transmitted from the remote sites or from the NCC.

Daily operation of the network generated a considerable quantity of data concerning the quality of voice signals received from the NCC. The data neither reflected the sites' abilities to hear each other nor indicated the quality of reception at the NCC from the remote sites. In evaluating the data, it must be understood that the NCC voice uplink used a 300-watt transmitter which was not only more powerful but also less subject to interference than the 90-watt transmitters used at remote sites.

The numerical data was usually obtained from OMR readout cards at the remote sites. The data used readability and strength scales from 1 to 3, with quality increasing in that direction. Thus, maximum quality was indicated by a 3x3x1 reading. This data was collected from October 7, 1974 to March 31, 1975 and included only the OMR card reports in which no entry errors were detected by the computer.

Both site-to-site and site-to-center reception was characterized, at times, by fluctuations in quality. These fluctuations were not predictable, and definite causes were not found, even though considerable effort was expended seeking causes and solutions. Extensive modifications and tests were made at the receiving antenna system at the Denver Uplink Terminal (DUT). One test, for example, was conducted by a field team with portable radio frequency interference (RFI) detecting instruments from the Institute for Telecommunications Sciences, the U.S. Department of Commerce. Other tests seemed to indicate that signal quality was a function of antenna location, but the results of these tests were not conclusive over time. However, signal results at both Denver, Colorado, and Tucson, Arizona, did indicate that RFI was more prevalent in metropolitan areas and that reception at the NCC's headquarters in Denver was difficult.

The digital capabilities of the VHF terminals (which were originally intended for program services) were used only for brief periods of testing. The digital coordinator did, however, perform the function of a VHF terminal control panel by selecting operating modes and frequencies and by keying the transmitter. There were a number of reasons for the transmission of digital data never being routinely employed:

1. The decision to use VHF was late.
2. Procurement of the field radio equipment was not under the control of the STD's Broadcast and Engineering Component.
3. A delivery delay of approximately three months was encountered. This delay held up the engineering of vital modifications to the equipment, as well as the design and testing of associated NCC equipment.

The design of the equipment modifications encountered further problems, and testing of the system was postponed until the operational period. An additional problem was the delay in the design of the computer software. A data transmission test performed for NASA toward the end of the programming year was, however, very successful. This and other brief but successful tests proved that a fully-operational digital system would have greatly enhanced both the capabilities and effectiveness of the VHF network.

Table 5 gives the results of the OMR-card reports of VHF signal quality. Note that 96 percent of all the reports received a 3x3x1 rating--the highest possible. This data reflected the sites' consistent reception of NCC transmissions with the 300-watt transmitter.

TABLE 5

Site #	Name	No. of Valid Reports (3x3x1	3x2x1	2x3x1	2x2x1	1x1x2)
11	Hayden	60				
12	McNary	48			3	
13	Tuba City	77		1	1	
21	Meeker	21	1	2	3	
22	Monte Vista	81		1	1	
23	Montrose	68			1	
31	Challis	3				
32	Lapwai	132	5	1	4	
33	McCall	97		1	3	
41	Busby	144		1	1	
42	Colstrip	105		9	3	
43	Ft. Benton	74			2	
51	Carlin	43			4	
52	McDermitt	60				
53	Owyhee	86				
61	Cuba	93		2		
62	Dulce	80				
63	Penasco	68		2	5	
71	Blanding	78			1	1
72	Enterprise	91		1	3	
73	Heber	48				
81	Pinedale	69		1	3	
82	Riverton	93		2		
83	Saratoga	99		4	2	
	TOTALS	1818	6	28	40	1

Although little quantitative data on NCC reception was available, observers noted that, in some cases, up to 18 percent of attempted responses were inaudible (Dale, Joyce B., "The Use of a Satellite Human Interaction System in Conjunction with a Satellite Media Distribution System," April, 1975). This observation is in sharp contrast to the favorable results mentioned above. Some of the factors involved in the poor quality of reception at the NCC were: (1) occasional operation of the satellite at reduced power; (2) interference from local RF sources as well as from sources as far away as Mexico; (3) ionospheric variations; (4) the failure of users at remote sites to fully modulate their signal by speaking into the microphone too softly and/or from too far away; (5) receiving-equipment problems, including conflicting simultaneous equipment testing; and (6) other, undetermined factors. Engineering measurements made at the DUT of incoming signals from remote sites showed carrier frequencies to be mistuned from center frequency by as much as 1 KHz, with considerable variation in relative strength from site to site. On-site modification of a power supply improved operation.

Although transmissions received at remote sites showed consistently usable quality, transmissions received at the NCC from remote sites were of marginal quality for a significant portion of the time the system was in use. Despite this, the system was useful for maintaining communications with the sites. Had the original frequency request (2.25 GHz) been granted to permit the use of two-way voice communications over the same link used by the video programming, the interactive system would have been more useful, and engineering and field costs would have been substantially reduced.

The data on VHF equipment reliability was taken from the log of sites reporting downtime. It was measured in days rather than program intervals, because failure data was available in that measurement and because the equipment was essentially available, though not used, on an around-the-clock basis. Included in the data are a number of instances which involved problems associated with atmospheric conditions and operator error. (See Table 6.)

Forty-four reported malfunctions, classified according to type of failure, have been shown in Table 6. The intrinsic reliability (ratio of the total operating time to the total time available) was 98.1 percent. The mean time to repair for VHF equipment was 1.8 days.

TABLE 6

OCCURRENCES OF VHF EQUIPMENT FAILURES

Failure Type	No. of Days Down (1	2	3	5	6)
Enable Button	3	2	2		
Antenna Alignment	2		1		
Transmitter Alignment	6	1	1	1	
Poor Reception	4				1
Connector	1		1	1	
Preamp (Antenna)		1	1		
Preamp (Mike)	1				
Digital Coordinator	1	2			
Enable Lamp	1				
Fan	1				
Operator Error	5				
Other, Undetermined Factors	3			1	
TOTALS	28	6	6	3	1

The unavailability of the digital capability made it impossible to enable the remote transmitters upon command from Denver. As a result, a push button attached by epoxy to one of the circuit boards in the back of the remote digital coordinator had to be utilized. In addition to the inconvenience to the operator (who had to open the back of the equipment and push this button before each transmission), the buttons began breaking off the circuit board after a period of use. This problem was the largest contributor to the failure rate.

The transmitter alignment failures were linked to the difficulty of hearing the sites at the NCC and primarily consisted of the need to get more power to the antenna, as opposed to the need for frequency alignment. Failures also indicated the existence of a "burn-in" time of the transmitters, in which power output tuning characteristics varied significantly with time.

The HET experiment demonstrated that low-cost earth terminals could be used effectively to distribute data, audio, and video materials to isolated communities in many regions. The experiment also suggested that, with greater lead time and more funds, similar experiments could increase effectiveness substantially.

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