EXPERIMENTS IN MEDICAL COMMUNICATIONS VIA THE ATS-1 SATELLITE

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EXPERIMENTS IN
MEDICAL COMMUNICATIONS
VIA THE ATS-1 SATELLITE

EDSAT CENTER
PARTICIPATION IN THE ALASKA
SATELLITE COMMUNICATIONS PROJECT

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The EDSAT Center
Space Science and Engineering Center
The University of Wisconsin
Madison, Wisconsin

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PREFACE

The EDSAT Center has undertaken to conduct tests and experiments to determine the optimum hardware to be used in a medical relay experimental system. This report considers the following experiments conducted under NIH71-4717:

I. The Electrowriter Experiment

II. The Slow-Scan Television Experiment

III. A Preliminary Report on the X-Ray Image Processing Experiment

IV. Satellite Base Station Operation

The combination of the telephone and satellite image transmission will provide a great potential for the development of specialized communication grids. To achieve this potential, equipment must be tested and developed and special combinations of equipment must be devised to determine and verify the communication performance of the final configurations. It is with this purpose in mind that the experiments detailed in this report have been undertaken.

The EDSAT Center wishes to acknowledge the guidance and counsel of Mr. Al Feiner, Mr. Dave Moriarty and Mr. Ben Tate of NLM in the conduct of this work. The Center further wishes to acknowledge the leadership of Doctor Edwin Wallace and Mr. James Waeffler in the organization, supervision and development of the project.

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EDSAT

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Xerox Telecopiers - Xerox Corporation

Radio Equipment - Motorola Corporation

TABLE OF CONTENTS

(cont.) TABLE OF CONTENTS

APPENDICES

(cont.) APPENDICES

I

ELECTROWRITER EXPERIMENT

THE ELECTROWRITER EXPERIMENT

BACKGROUND

The Victor Electrowriter Remote Blackboard (VERB) system, which is marketed by Victor Comptometer Corporation, is a graphic communications system that can be used to transmit written and/or drawn messages.* These messages are usually transmitted via telephone lines but FM radio transmission at 3 KHz and below is also possible.

The Electrowriter was first used by business and industry, and they remain the largest users of Electrowriter equipment to date. The Electrowriter is also used in educational situations as a visual aid in remote teaching activities. For example, the Engineering Department of the University of Wisconsin-Extension Division uses the Electrowriter Remote Blackboard in its Statewide Engineering Education Network (SEEN). SEEN is an effort to bring campus-originated engineering and science courses directly to selected localities throughout the state for those engineers who desire continuing education but cannot leave home and job to do so.

The Electrowriter, when used in conjunction with a two-way telephone network, enables remotely located students to view the development of equations, notes and sketches and listen to the lecturer as he teaches his class at a central location. Although the VERB concept has been used in engineering

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*Much of the background material appearing here is taken from a more extensive review of Electrowriter activities in Wisconsin found in Teleconferencing in Wisconsin, October, 1971, an EDSAT report on research supported by the National Aeronautics and Space Administration.

and science education, little or no experience has been had with the concept in medical education.

The Electrowriter has been designed for the transmission of handwritten information over commercial telephone lines. However, it has been demonstrated that many types of data conveyed over telephone lines can also be transmitted with little difficulty via satellite radio circuits. The purpose of this experiment is to examine the feasibility and potential medical applications of the use of the Electrowriter when transmitted via the ATS-1 experimental communications satellite.

OBJECTIVES OF THE EXPERIMENT

The objectives of the experiment are threefold:

1. To test and evaluate the technical feasibility of transmitting Electrowriter hard copy and hard copy accompanied with voice via the ATS-1 satellite in both simplex and duplex modes.

2. To test and evaluate the Electrowriter-via-satellite as a medium for conveying medically useful information.

3. To identify potential applications of the Electrowriter-via-satellite as an aid in medical communications with emphasis on providing remote health care and education to isolated areas in Alaska.

EXPERIMENTAL PROCEDURES

1. Test Plan

Tests in the experiment were conducted according to the following outline.

Electrowriter equipment check out (Tests 1-4)

Tests 1-4 were conducted to determine the feasibility of sending Electrowriter (EW) information via satellite link. Electrowriter information was exchanged between Stanford University and both satellite stations at the University of Wisconsin. Each test utilized 30-40 minutes of air time on the ATS-1 satellite.

Test time was used to determine appropriate equipment interconnection, optimum operating procedures and, in general, to familiarize project personnel, including the participating physician, Dr. Wallace, with the experimental set-up.

Transmission of medical information (Tests 5-7)

Tests 5-7 were conducted to provide the participating physician with opportunities to experiment with the transmission of different kinds of hand-written information for medical purposes.

Test 5 - A series of medical visuals were transmitted to Stanford University to document the information-carrying capability of the EW.

Test 6 - A simulated medical lecture was transmitted to Stanford University to document the use of the EW as an aid to medical voice communications. The lecture was designed to convey information relative to the surface anatomy of the abdomen to para-medicals at an isolated location: Voice and EW sketches were transmitted alternately (simplex mode).

Test 7 - A second simulated lecture was transmitted to Stanford University. The purpose was essentially the same as in Test 6 except that in this test the voice and sketches were transmitted simultaneously (duplex mode).

Experimentation with facsimile transmission (Tests 8-10)

Tests 8-10 were conducted to document the feasibility of transmitting information using the Xerox Telecopier. The purpose here was to compare the capabilities of the facsimile and Electrowriter methods of transmitting similar kinds of information

2. Technical Set-Up

The Electrowriter is an electronic writing table which converts the sender's pen position and movements into frequencies which can be transmitted and decoded to position a receiver's pen and repeat the same movements. The bandwidth of the information is between 300 and 3000 Hertz so ordinary phone lines may be used as the transmitter media. (See Appendix IV for full specifications for voice bandwidth data channels.)

Because the Electrowriter had a balanced 600 ohm output impedance, it could be connected directly to the phone lines, the transmitter and receiver. Commercially available phone couplers were used to capture the line while using the equipment. For the most part, both the receiver and transmitter were at the remote site. One of the experiments was set up as in Figure 1.

Electrowriter operation Different levels of frequency deviation were used on the radio transmitter with 3 KHz being choosen based on smoothness of response. Because of receiver noise, the signal was attentuated 8 to 10 dB before being run into the Electrowriter receiver. The operator was also required to hold the pen up high when not writing to avoid having the receiver scribble on the message. Acceptable copy was received when ever the received signal plus noise to noise ratio was greater than 18 dB. It takes up to 3 minutes to draw a typical Electrowriter sketch.

In duplex operation the operator can talk while writing. This requires that carrier levels to the satellite be matched. This could not be done because the 375 watt unit could not get down to the 100 watt unit of the other transmitter. The satellite also splits the power between the two channels with a compression effect on the weaker one. This means you are trying to receive a transmitted signal of less than 20 watts. A successful transmission and reception was made under these conditions by Stanford keying its carrier on one channel and Wisconsin transmitting the signal on another.

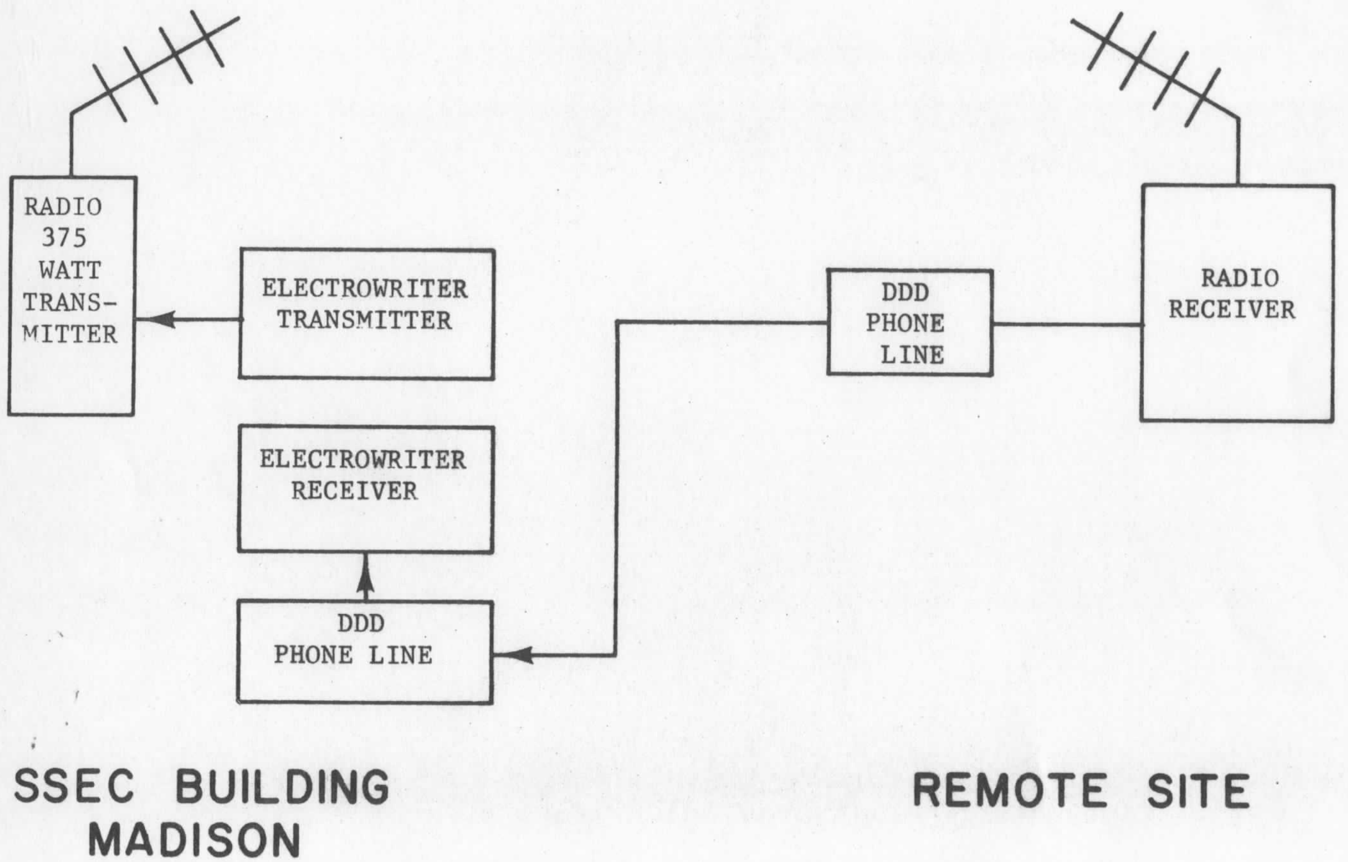


Figure 1: One of Several Test Set Ups Used in The Electrowriter Experiment

Telecopier operation The Xerox Telecopier is a commercially available piece of equipment that is designed to be used with regular telephone lines. Rather than have the material required to be written out, the Telecopier accepts hard copy (any written material, pictures, etc.) and scans it, converts it to electrical signals and plays it into the mouth piece of the telephone. The transmission of an 8 1/2 by 11 piece of paper can either be high resolution (6 minutes) or low resolution (4 minutes). No voice can be transmitted while using the Telecopier in the simplex mode. For best results, 3.5 KHz was used on the transmitter.

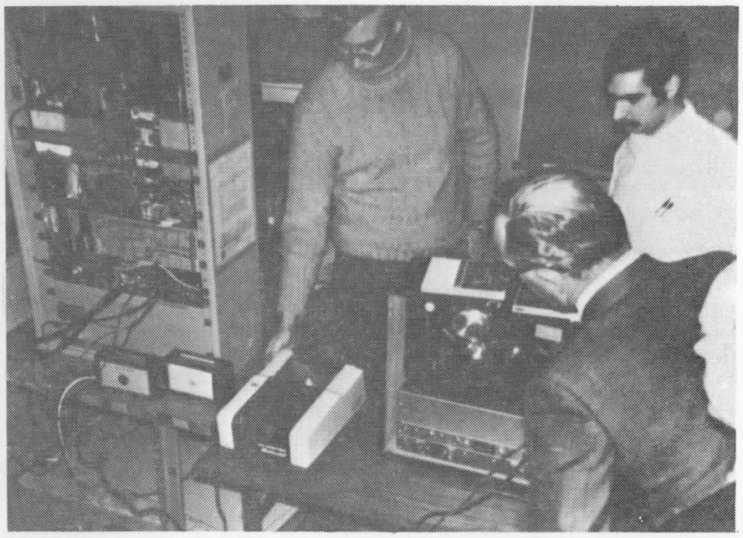
The Telecopier is available on a rental basis from the Xerox Corporation at an approximate rate of $43.00/month per unit. Each unit is designed to perform both transmit and receive functions.

DESCRIPTION OF ELECTROWRITER EQUIPMENT

The size of a basic transmitting unit is 12 by 6 inches. In the unit is a roll of paper which the user advances as he writes in the 3 1/2" x 5" writing area. Messages are written on this paper with a special pen connected to its own ink reservoir. The movement of the pen tip is "sensed" by the transmitting unit and sent as electrical impulses. There is a stylus on the receiving unit which then responds to these impulses and almost simultaneously reproduces an exact copy of the written message.

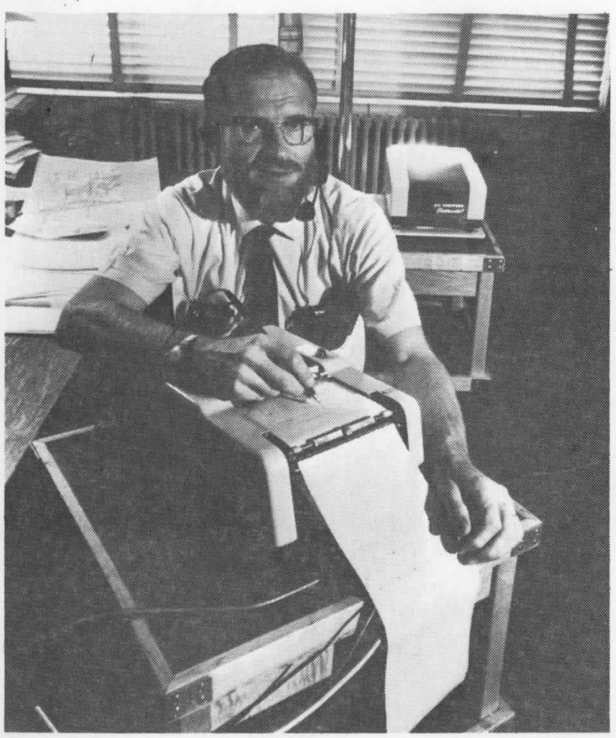
There are a number of different units and combinations of units available. First, there is the basic transmitter which has been described above. The cost is approximately $1100. The cost of a basic receiver in which the message is reproduced on paper is usually $1270. Transceivers which allow both sending and receiving from either end cost about $1875. Educators most often use a system in which the receiver is used in conjunction with an overhead projector. For this, the receiver (or transceiver)

PICTURES OF THE
ELECTROWRITER AND
BASE STATION SET UP

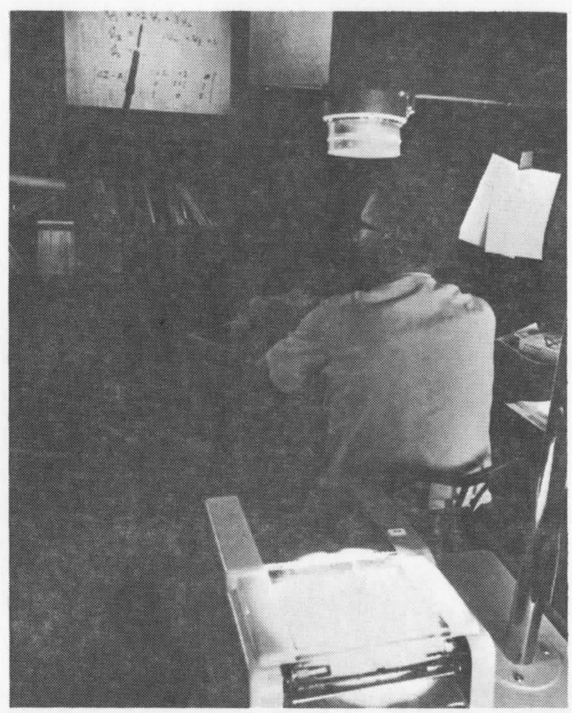


(above) The Electrowriter receiver with base station unit at the remote receiving site during actual experimental transmission via satellite

(below) Operator using the Electrowriter transmitter



(below) Operator using the Electrowriter transmitter (middle ground) with the Electrowriter receiver and overhead unit (foreground) and projected image (background)



is fitted with a roll of clear acetate rather than paper. When the message is received on the acetate, it is projected onto a standard movie screen.

A simple transmitter-to-receiver connection requires one telephone line. However, it is also possible to connect a number of receivers to a single transmitter. Each receiver requires a separate line. In the VERB overhead projector system, the 601A Data Phone is generally used, at a cost of $8 per month. This phone gives the lecturer an audio line and the students a means of feedback. A new phone is being developed that will cost about half as much to lease. "Inter-machine" phone lines can be leased at the cost of obtaining an extension phone ($1 per month). Standard telephone installation and equipment is all that is necessary to make VERB operational. Regular "lamp-cord" can be used between machines but has been found to be unreliable and very susceptible to interference. Most VERB users seek greatest transmission quality and secure telephone company lines.

Some difficulties have been experienced by Electrowriter users. Besides adjustments that must be made in teaching techniques, some technical limitations have to be overcome. Victor has had trouble with the ink and pens on the VERB units. The pen has its own reservoirs, and in some instances the ink has "eaten" through and damaged some of the machinery. Pens have been a problem because they required cleaning and maintenance. Both a lack of training for Electrowriter operators and the machines' extreme sensitivity to handling made the system susceptible to damage. Victor is now working on a felt tip pen with a new kind of ink that will not smudge or damage the equipment. This will in turn reduce the amount of regular maintenance required and will hopefully reduce equipment sensitivity to handling.

Another technical limitation is the inability to go back to a previous frame. Once the paper on the transmitter has been written on and advanced, the lecturer cannot turn back to it. The lecturer must also keep this fact in mind and be sure to call attention to particularly important frames. The new two-frame receiver and projector which show both the previous and immediate frames are answers to the problem.

TEST RESULTS

Results obtained from satellite tests with the Electrowriter fall into three categories.

1. Electrowriter performance
2. Electrowriter capability for transmitting medical information
3. Electrowriter-with-voice performance

For a summary of tests completed refer to Table I.

1. Electrowriter Performance

Results of tests conducted in the simplex (one channel at a time) and duplex (two channels simultaneously) modes appear in Figure 2-7. Both the

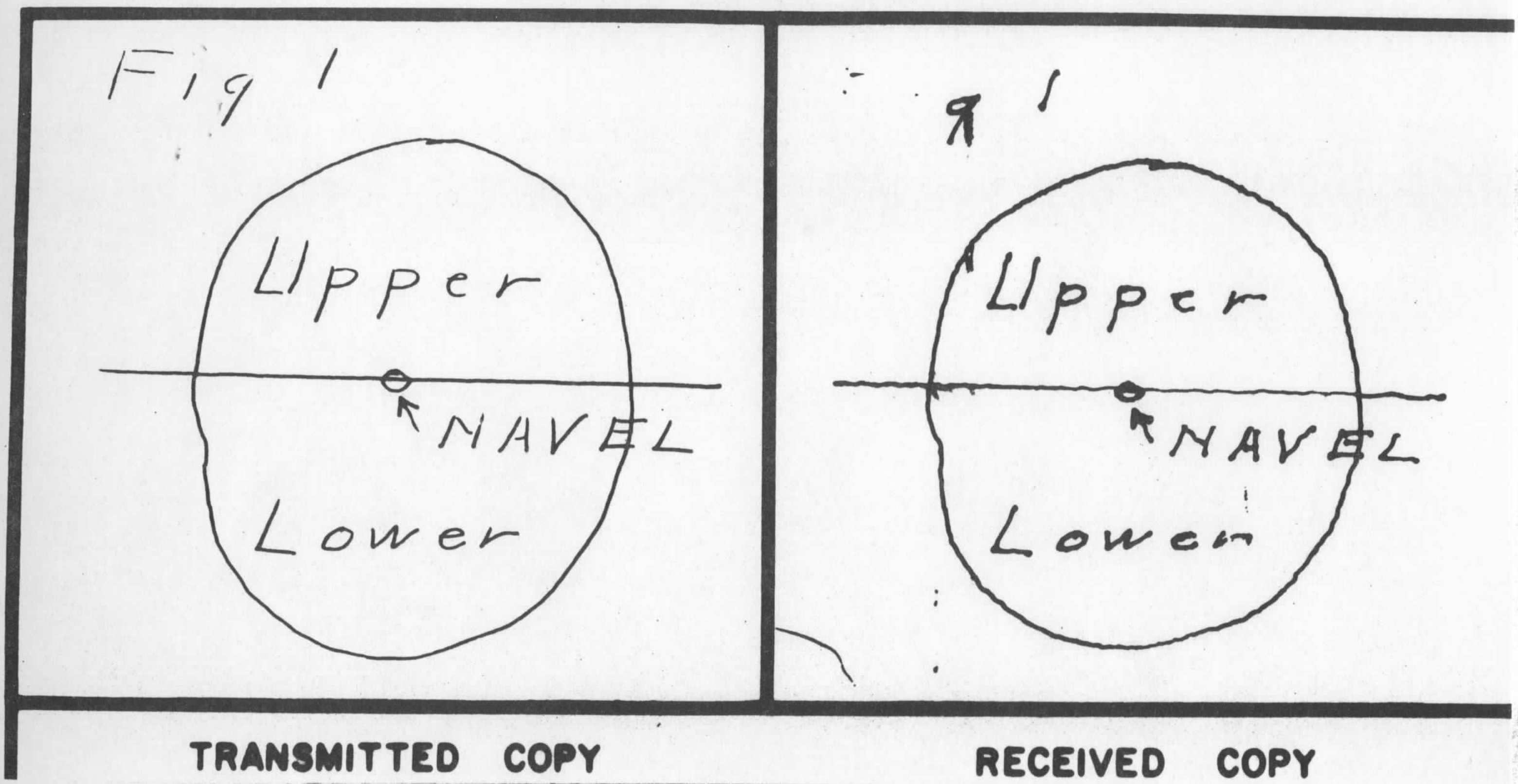


Figure 2: First Comparison of Transmitted with Received Electrowriter Copy. SIMPLEX MODE (Via ATS-1 satellite, 6 Jan 72)

TABLE I

SATELLITE TESTS COMPLETED ON THE ELECTROWRITER EXPERIMENT

Test No.	Date	Objective	Comments
1	9 Dec	Test the feasibility of EW transmission via ATS-1 satellite	Copy received at Stanford
2	14 Dec	Technical adjustments, establish operator familiarty	Copy received at Stanford and Wisconsin
3	16 Dec	Same	Same
4	23 Dec	Dr. Wallace to test feasibility of transmitting medical information with voice in simplex mode.	Copy and voice received at Stanford
5	30 Dec	Experiment with transmission of variety of medical information for evaluation. Simplex mode.	Copy received at Stanford
6	6 Jan	Demonstrate simulated medical lecture to remotely located paramedicals. EW and voice in simplex mode.	Copy and voice received at Wisconsin and Stanford
7	13 Jan	Demonstrate simulated medical lecture for comparison of simplex and duplex modes.	Poor antenna performance at Wisconsin adversely affects duplex transmission Copy and voice received at Stanford
8	10 Feb	Test feasibility of Telecopier hard copy transmission via ATS-1 satellite	Copy received at Stanford
9	22 Feb	Same	Same
10	24 Feb	Transmit medical information via Telecopier for purposes of comparison with the EW	Copy received at Stanford and Wisconsin

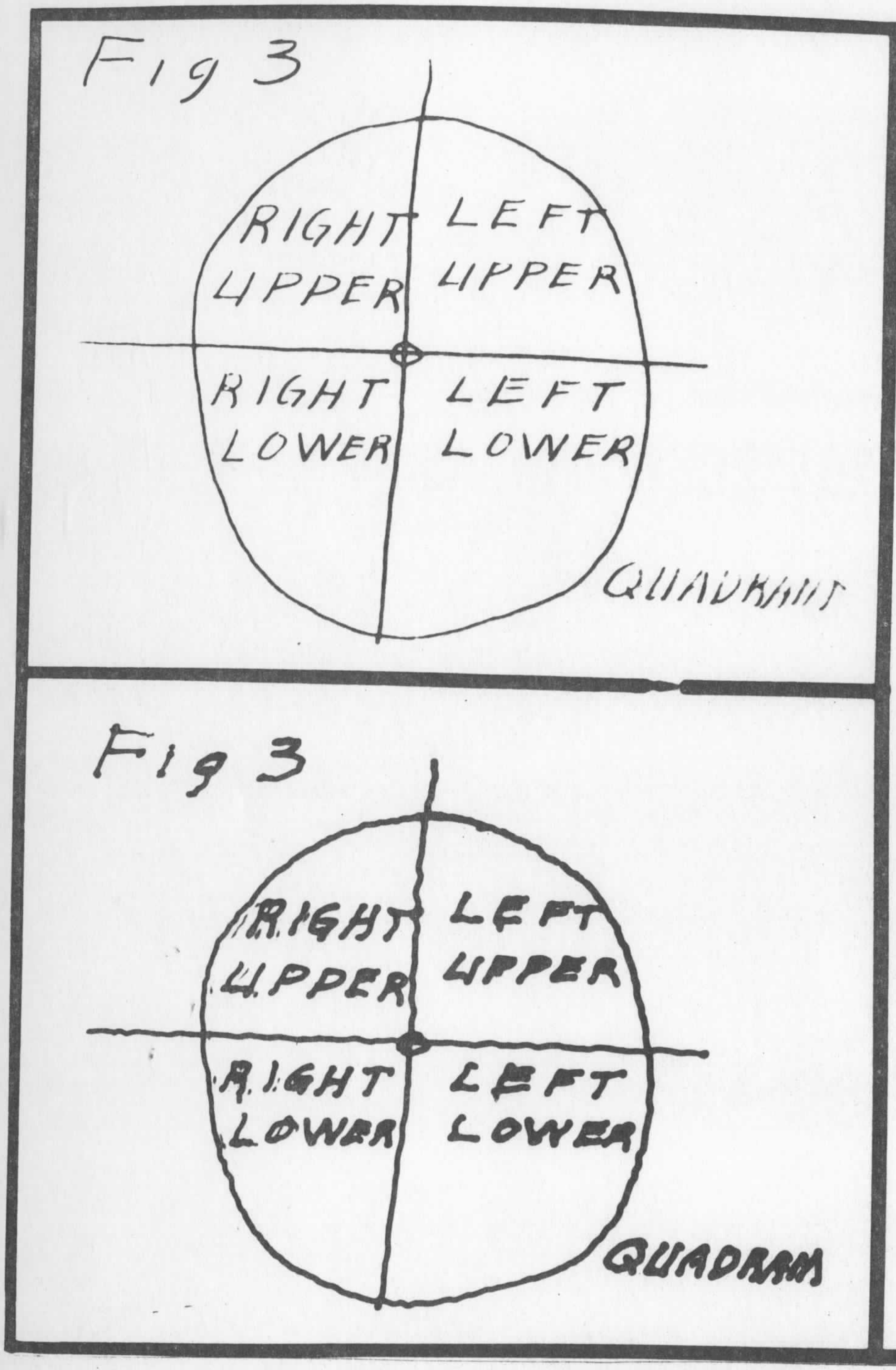
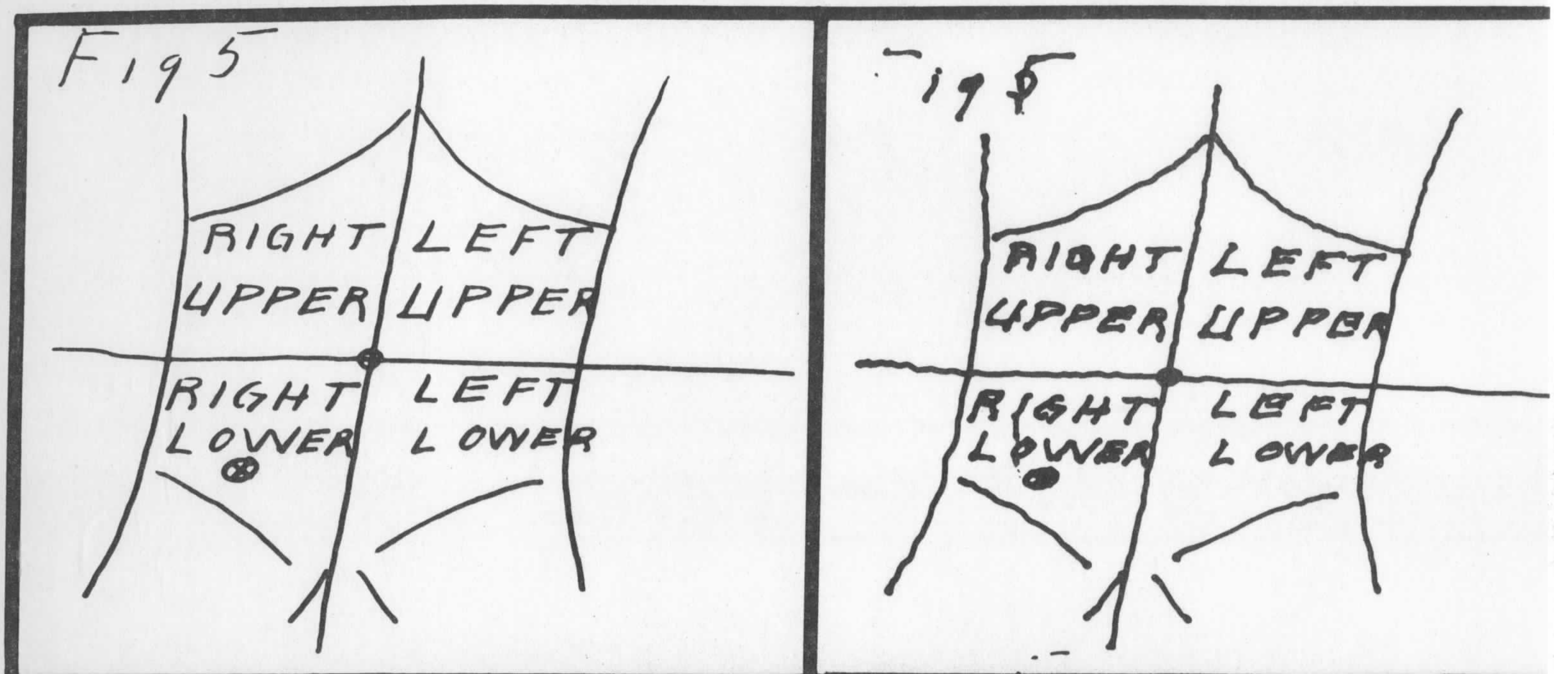


Figure 3: Second Comparison of Transmitted with Received Electrowriter Copy. SIMPLEX MODE (Via ATS-1 satellite, 6 Jan 72)

TRANSMITTED COPY

RECEIVED COPY

information originally written on the Electrowriter transmitter (the "transmitted" copy) and the information received via satellite at a second location on the Electrowriter receiver (the "received" copy) are shown for purposes of comparison.



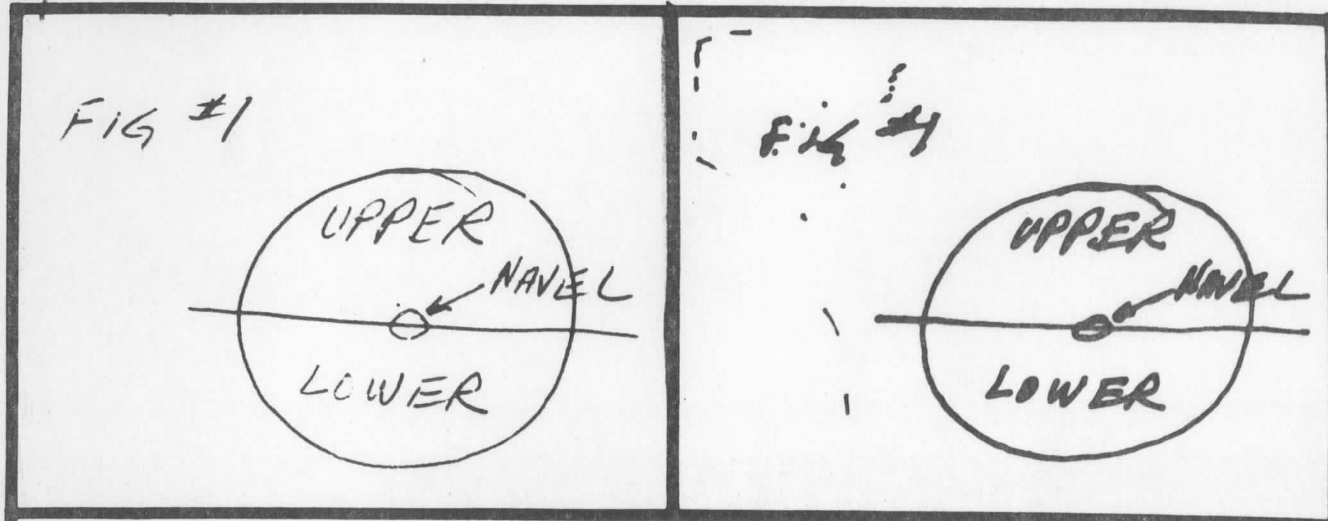
TRANSMITTED COPY **RECEIVED COPY**

Figure 4: Third Comparison of Transmitted with Received Electrowriter Copy. SIMPLEX MODE (via ATS-1 satellite, 6 Jan 72)

<u>Pen skipping</u> In Figure 2, pen skipping is apparent in the received copy in the title of the received information--"Fig 1." Pen skipping is usually the result of ink clogging or of an unbalanced writing table.

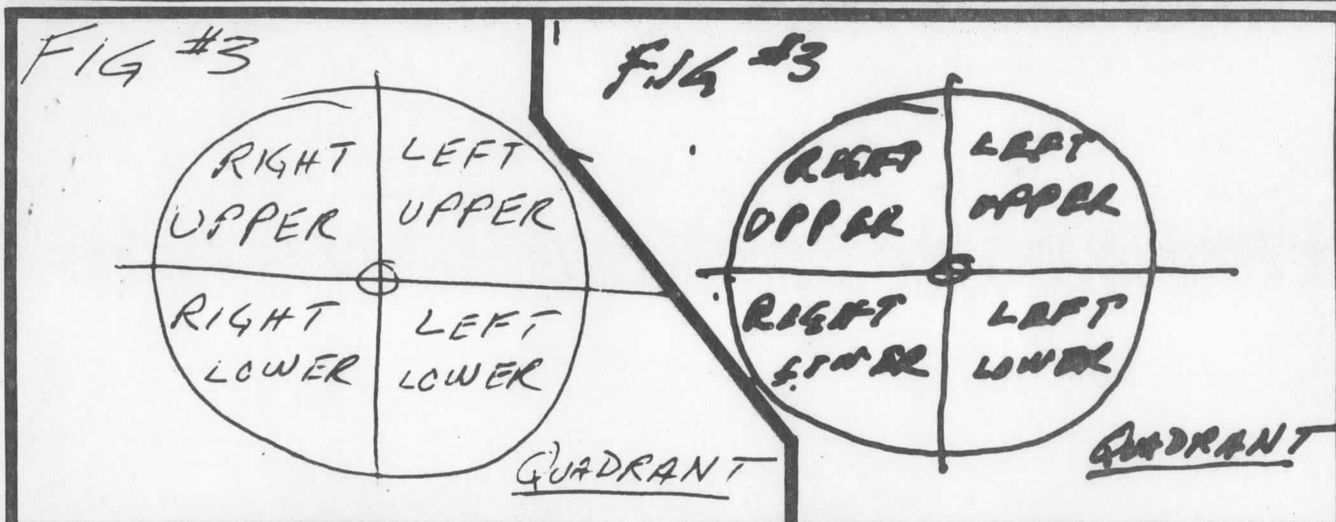
<u>Pen wobble</u> In Figures 3 and 4, pen wobble is apparent in the received copies in, for example, the horizontal and vertical lines which run through both diagrams. This is due to signal degradation in the satellite link.

<u>Operator haste</u> In Figures 5, 6 and 7, the effects of operator haste are apparent in the original, transmitted diagrams. Because of a shortage of satellite time, the operator was rushed and took less care in sketching these diagrams than he did with earlier diagrams. Somewhat more rapid pen



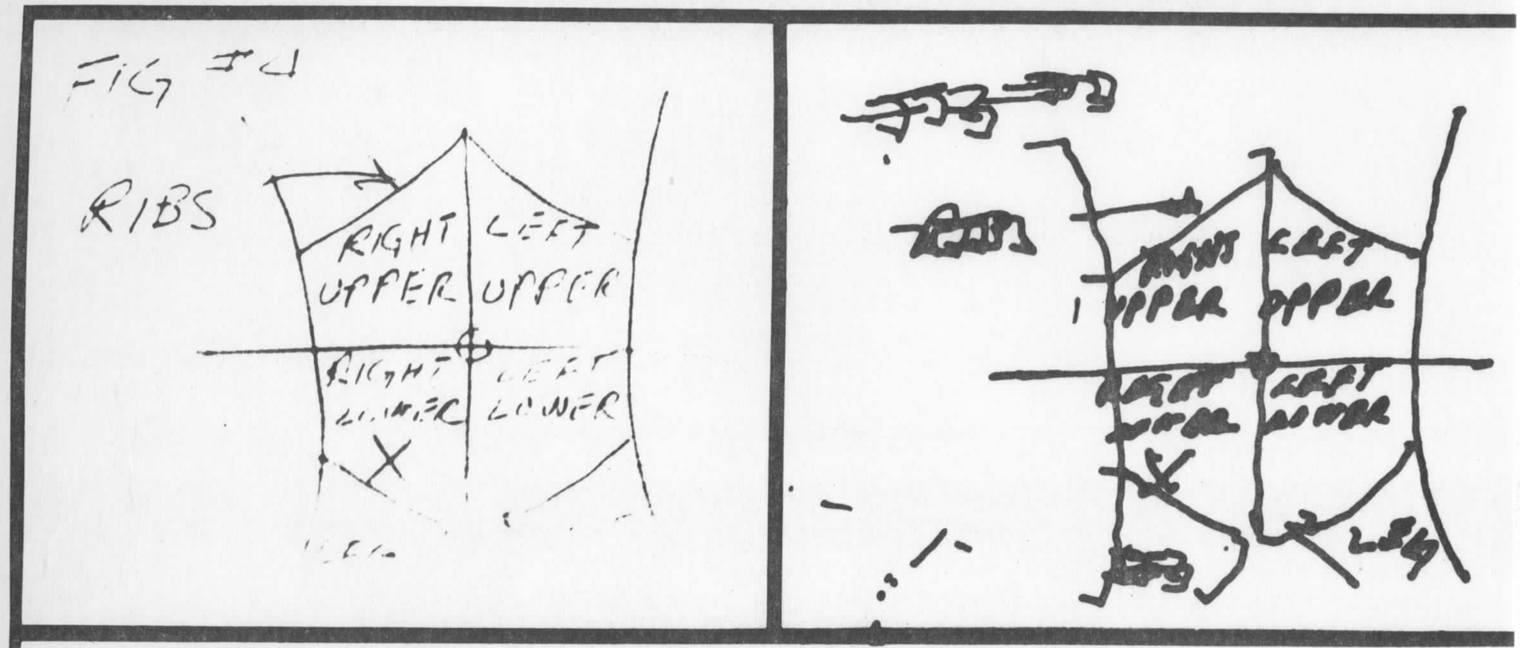
TRANSMITTED COPY **RECEIVED COPY**

Figure 5: First Comparison of Transmitted with Received Electrowriter Copy. DUPLEX MODE (Via ATS-1 satellite, 13 Jan 72)



TRANSMITTED COPY **RECEIVED COPY**

Figure 6: Second Comparison of Transmitted with Received Electrowriter Copy. DUPLEX MODE (Via ATS-1 satellite, 13 Jan 72)



TRANSMITTED COPY **RECEIVED COPY**

Figure 7: Third Comparison of Transmitted with Received Electrowriter Copy. DUPLEX MODE (via ATS-1 satellite, 13 Jan 72)

movement was also required. Some of the distortion in the received copies is attributable to these factors.

Limitations on size of lettering In Figure 7, the operator used lettering in the original sketch that was smaller than he had used in other sketches. This again was largely because he was rushed to complete the diagram within alloted program time. Notice that the lettering on the received copy is almost too small to be legible.

Comparison of simplex and duplex transmission In Figure 8, a comparison of simplex and duplex received copies is shown. Additional signal degradation characteristic of the duplex mode is apparent in pen jitter (middle "duplex" diagram) and pen skipping (both middle and lower "duplex" diagrams.)

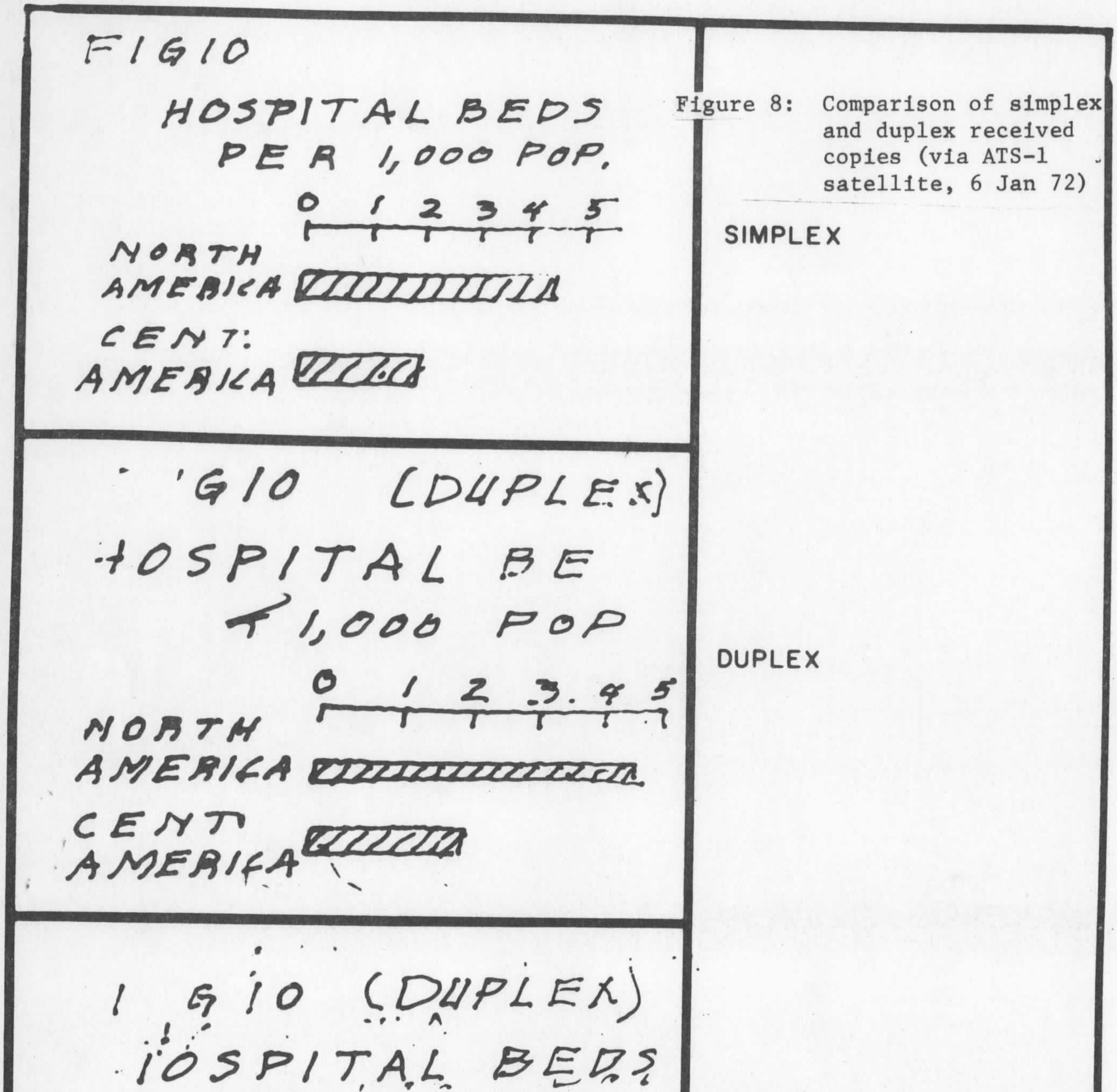


Figure 8: Comparison of simplex and duplex received copies (via ATS-1 satellite, 6 Jan 72)

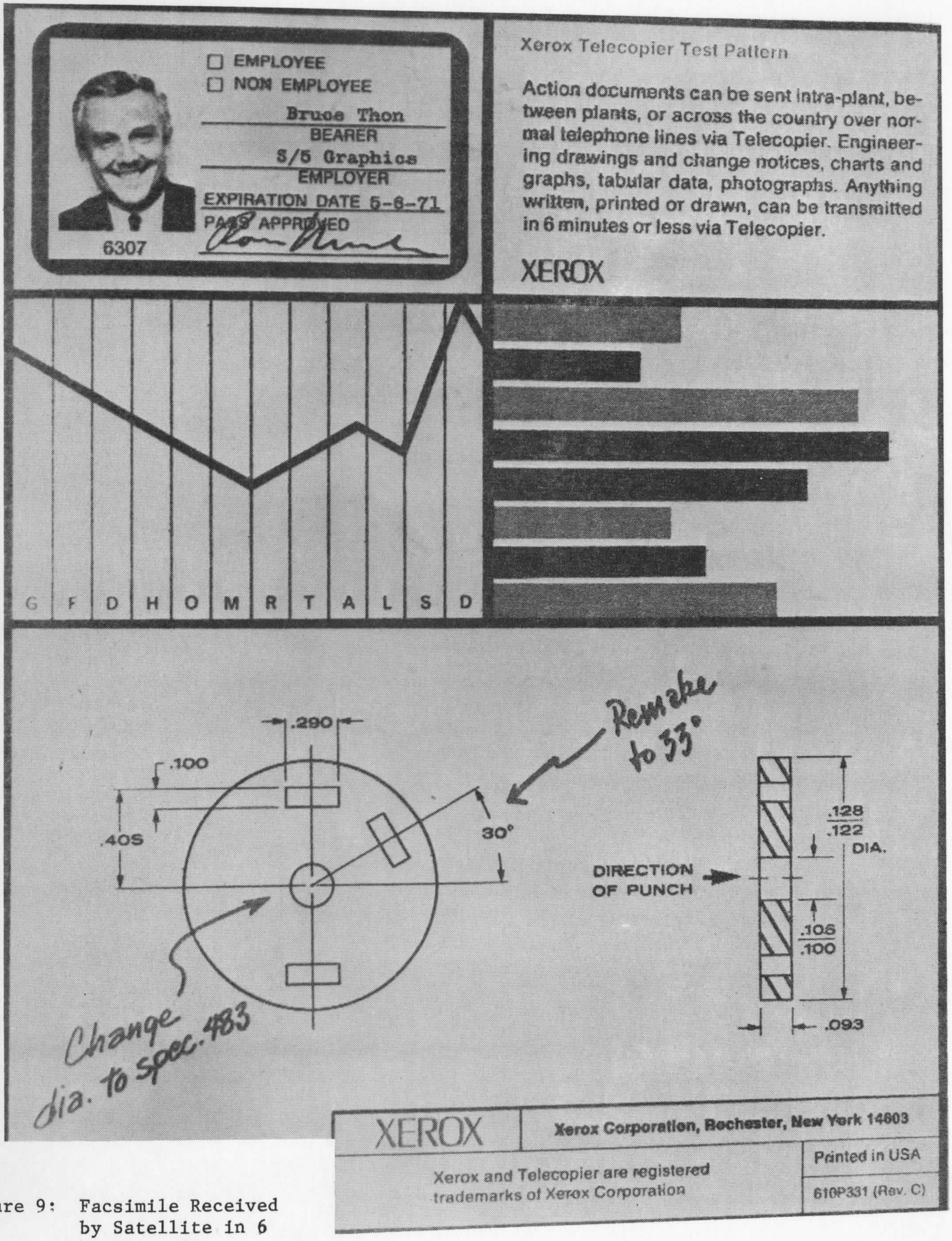
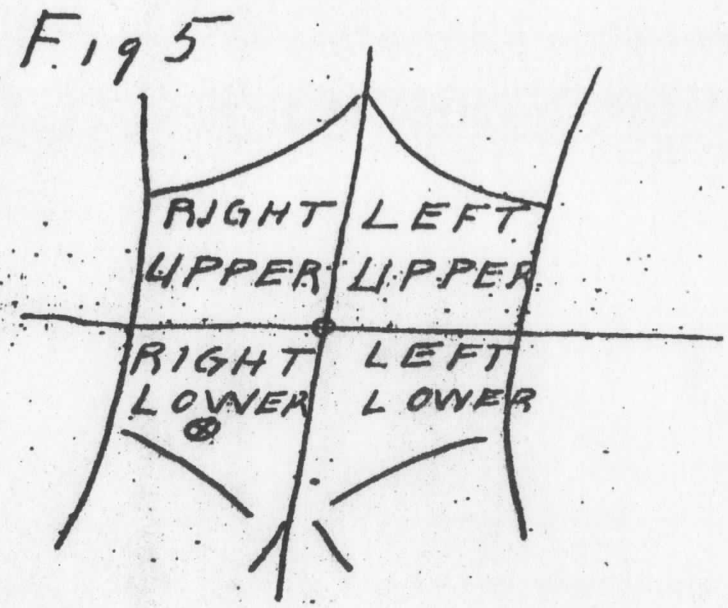


Figure 9: Facsimile Received by Satellite in 6 minute mode

ELECTROWRITER TRANSMISSION
VIA ATS-1 SATELLITE
6 JAN 72

E5

TRANSMITTED
COPY
(MADISON, WI)



RECEIVED
COPY
(ARLINGTON, VA)

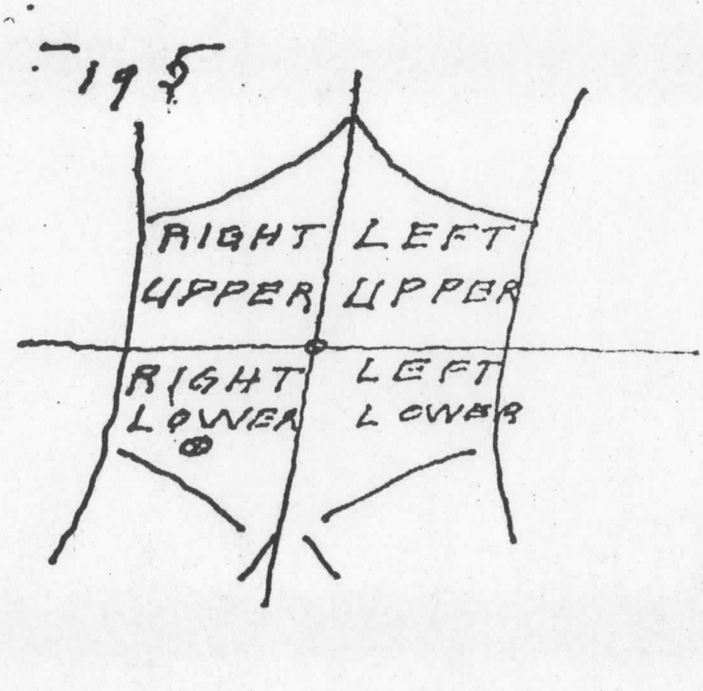


Figure 10: Facsimile Transmission of Previous Electrowriter Results

Comparison of the Electrowriter and Telecopier In Figures 9 and 10, results of Telecopier facsimile transmission are displayed. In Figure 10, particularly, it is apparent that the Telecopier is able to reproduce the Electrowriter sketches with almost no loss in detail. Notice that distinctions between the "transmitted" and "received" information (recorded in an earlier Electrowriter transmission and later retransmitted using the Telecopier) are clear and immediately recognizable.

2. Electrowriter Capability for Transmitting Medical Information

Figures 11 and 12 contain additional examples of Electrowriter information that was transmitted from Madison to Stanford via ATS-1 satellite in the simplex mode. The purpose in attempting these transmissions was to document the versatility of the Electrowriter as an information-carrying medium in medical communications. Sketches appearing in these figures include one table, one chart, one chemical equation, one set of instructions for emergency medical care and two graphs. Only the information received via satellite is shown.

By comparing Electrowriter sketches with the Telecopier results in Figures 9 and 10, it is evident that the two media differ substantially in terms of information-carrying capabilities. When interpreting results, it might be helpful for the reader to consider some of these contrasting capabilities. For example, Electrowriter sketches are developed by the lecturer as he speaks allowing a certain flexibility in presentation of material and adaptability in responding to unanticipated problems and questions. On the other hand, the Telecopier facsimile allows the transmission of very detailed information in the form of charts, graphs, and even photographs.

Figure 11: Examples of Medical Information Received at Stanford from Madison. SIMPLEX MODE (via ATS-1 satellite 30 Dec 71)

FIG ①

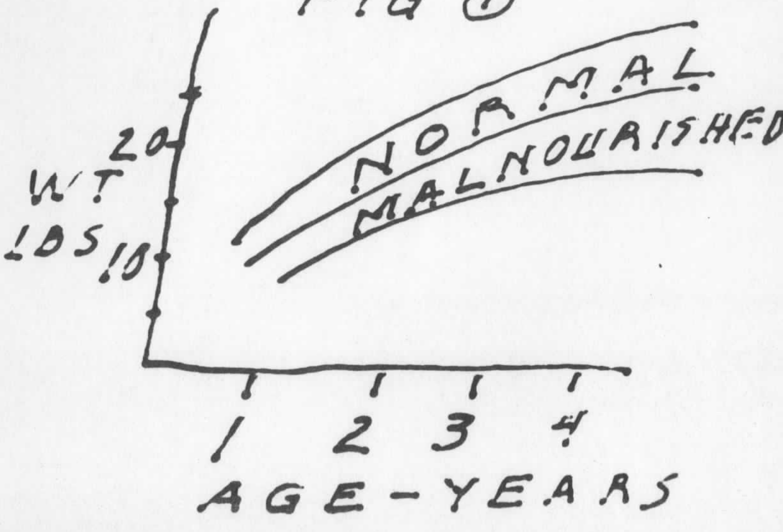


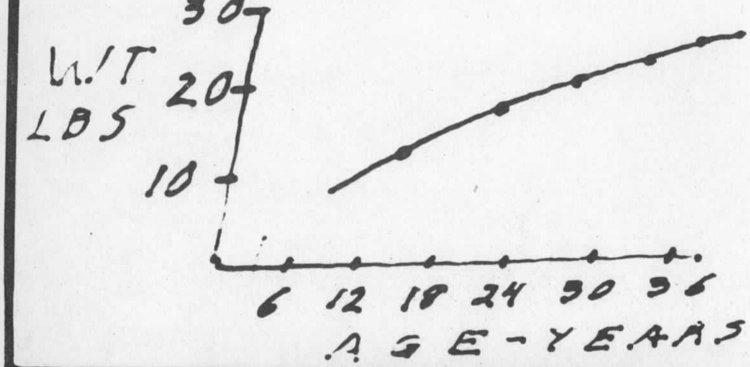
FIG ②

GROWTH DATA

AGE (MONTHS)	WEIGHT (POUNDS
6	12.2
12	16.1
18	18.3
24	20.5
30	22.2

FIG ③

GROWTH CURVE



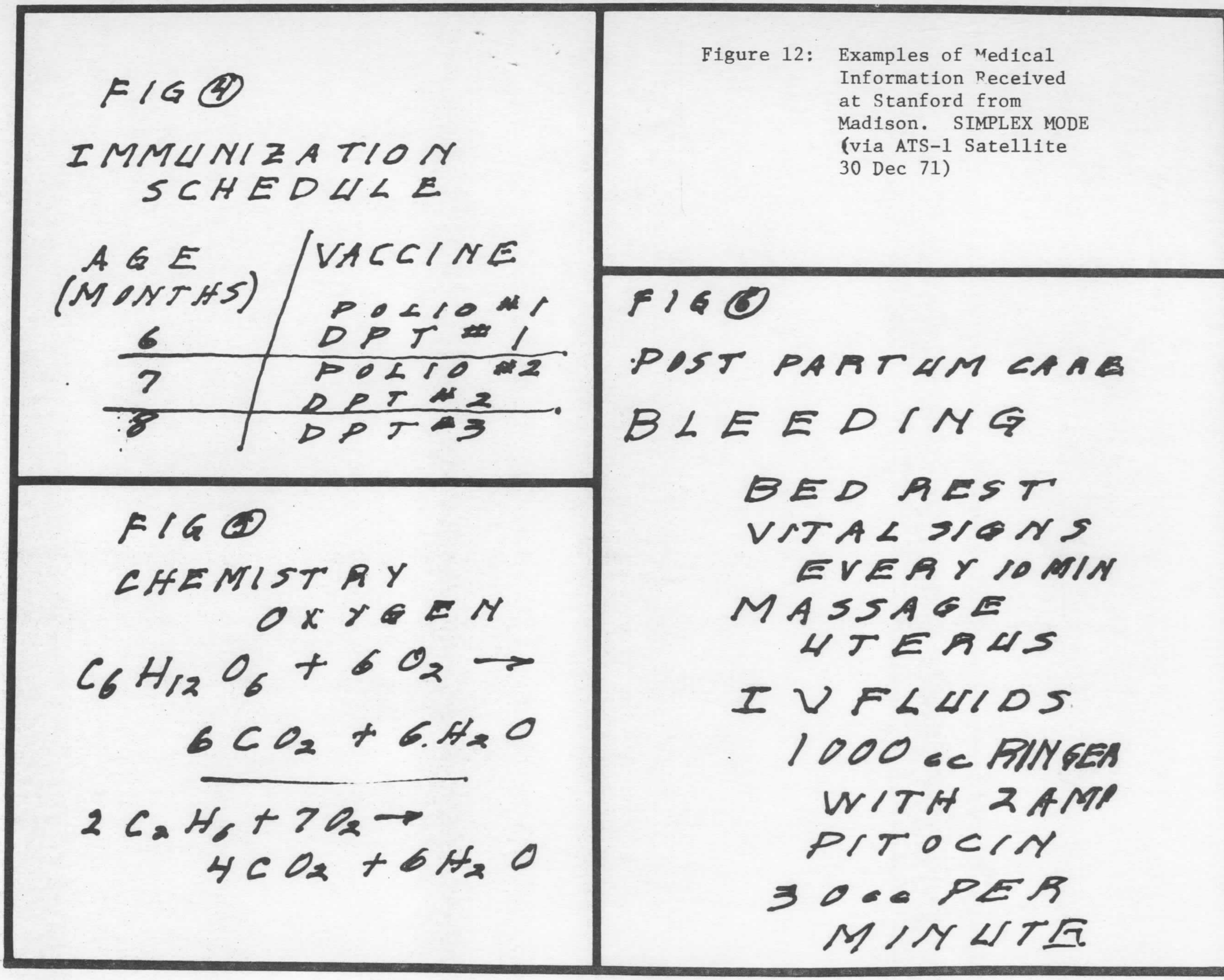


Figure 12: Examples of Medical Information Received at Stanford from Madison. SIMPLEX MODE (via ATS-1 Satellite 30 Dec 71)

3. <u>Electrowriter-With-Voice Performance</u>

Information displayed in Figures 2-7 was originally transmitted in the form of visual aids for two simulated lectures to remotely located para-medical personnel. The subject of both lectures was "The Surface Anatomy of the Abdomen." There was no live audience.

The first lecture was transmitted in the simplex mode, i.e., voice and Electrowriter sketches were transmitted alternately. The second lecture was transmitted in the duplex mode, i.e., voice and Electrowriter sketches were transmitted simultaneously.

The voice portions of each lecture were recorded on audio tape. A cassette tape recording of the two transmissions accompanies the submission of this report to the granting agency.

<u>Simplex/duplex voice results</u> In the audio recording of the two lectures, simplex voice quality is noticeably superior to duplex voice quality. Some degradation of voice quality in duplex is to be expected since repeater power at the satellite (40 watts at full power) is split between two channels (20 watts on each of two channels). However, earlier voice tests with Stanford University indicate that a signal of acceptable quality is possible in duplex if atmospheric conditions are good and the power levels of the two signals reaching the satellite are approximately equivalent. Since the duplex Electrowriter lecture was conducted under adverse atmospheric conditions (constant polarization shifts) with damaged antennas, and since the two transmitters at Wisconsin were of significantly different power outputs (375 watts for the Electrowriter signal and 100 watts for the voice signal), some of the degradation in voice quality apparent in the duplex segment of the audio recording may be discounted.

EVALUATION

At the conclusion of the experiment, a demonstration was developed which included a tape recording and visuals of pertinent segments of the voice and Electrowriter image transmissions. This demonstration was presented to a group of medical educators at both the Stanford and University of Wisconsin Schools of Medicine. Evaluation procedures used in the demonstration are presented in Appendix V. A questionnaire similar to the one administered appears in Appendix VI. The mean scores of responses are indicated in the sample questionnaire. The overall evaluation presented below is an interpretation of these results in the context of total project experience with the Electrowriter.

1. Evaluation of the technical feasibility of transmitting Electrowriter sketches via ATS-1 satellite

The feasibility of transmitting Electrowriter sketches via the ATS-1 satellite on specified equipment was clearly demonstrated in both simplex and duplex modes. However, the quality of sketches transmitted in the duplex modes was considered inadequate for most medical purposes. The quality of sketches transmitted in the simplex mode was considered adequate for most medical purposes, especially where no other means of data transmission are available.

2. Evaluation of Electrowriter transmission accompanied by voice

Utilizing the equipment selected and given a choice between voice and data transmitted alternately (simplex) and voice and data transmitted simultaneously (duplex), the evaluators prefered the first. Given the state-of-the-art, the possible advantages of simultaneous transmission are outweighed by the corresponding losses in voice and data quality and the added cost and complexity involved in duplex transmissions. (In duplex operation, two base station transmitters at the site of program origin and two receivers at the site of reception are required in order to send both voice and data in the same direction simultaneously.)

3. Evaluation of the Electrowriter as a medium for transmitting medical information

Evaluators considered the Electrowriter as a "moderately practical" medium for conveying medical information. In general, the main disadvantage cited was that the Electrowriter is limited to the transmission of relatively simple, hand-written material. A disadvantage of simplex transmission of sketches is that students (and others) may be distracted by the 2-4 minute time delay involved in actual sketching.

Four main potential applications of the Electrowriter were identified early in the project. An evaluation of each follows.

Transmission of records The limitation of the Electrowriter medium to hand-written messages is considered a serious disadvantage. Facsimile transmission of records, as demonstrated in this project with the Xerox Telecopier, is much better suited to providing reliable transmission of detailed information.

Aid to Remote Teaching For remote teaching in isolated areas, the Electrowriter does not seem to compare favorably with some other media, such as tape slide presentations which are more versatile. The limited content of Electrowriter visuals seem to be their primary disadvantage. The "remote blackboard" or chalkboard capability of the Electrowriter is not often required in many areas of health education. Remote medical lectures would have to be designed carefully to fit within system limitations. Few medical lectures have content easily adaptable to this format.

Aid to Remote Diagnosis and Patient Care Evaluators asked to identify potential applications of the Electrowriter indicated that its particular virtues as a medium would seldom be applicable to remote diagnosis and treatment of acutely ill patients. In emergency care situations, voice alone is considered adequate under most circumstances. Because of the limitations of the medium to hand-written notes and sketches, the addition of information via Electrowriter would seldom add significantly to the solution of a given medical problem. Also, the Electrowriter lacks the high level of accuracy necessary in conveying data and instructions regarding patient care. By comparison, facsimile transmission is more accurate and probably preferable.

Aid to Peer Group Teleconferencing In several areas of the health sciences such conferencing could be practical. Basic sciences such as biochemistry, genetics and similar subjects which lend themselves to chalkboard - type of discussions would be most appropriate for teleconferences.

GENERAL CONCLUSIONS

On the basis of evaluation, the following conclusions are made regarding the use of the Electrowriter in medical communications.

Transmission of Records The Electrowriter is generally not practical for the transmission of medical records. Other means, such as hard copy (facsimile) transmission, are generally more practical.

Aid to Remote Teaching The Electrowriter is generally not practical as an aid to remote medical teaching; however, it may be practical in specific cases depending on the topic and preferences of the instructor especially when the topic lends itself to chalkboard - type presentations; other means, such as tape-slide presentations, are more practical.

Aid to Remote Diagnosis and Treatment The Electrowriter is generally not practical as an aid to remote diagnosis and treatment; in many cases, voice communications will suffice; facsimile with voice seem to have considerable potential in this area, and their application in diagnosis and treatment should be studied further.

Aid to Peer Group Teleconferencing The Electrowriter may be practical for teleconferencing on subjects which lend themselves to "chalkboard" types of discussions.

SUMMARY AND RECOMMENDATIONS

The Electrowriter may be applicable in teleconferencing situations and, to a limited extent, in remote medical teaching situations when the need exists for a "chalkboard-type" capability. However, its applicability to medical communications is not general and, in most cases, other media (such as facsimile, teletypewriter and tape-slide presentations) when combined with voice communications seem to offer more flexibility. Based on its limited applicability in medical communications,

(1) it is recommended that the Electrowriter not be used in the Alaska Experimental Satellite Network at this time.

It is quite possible that future remote teaching and teleconferencing activities may arise for which the Electrowriter "chalkboard" capability would be particularly well-suited. On this basis,

(2) it is recommended that consideration be given to possible future Electrowriter applications in medical teaching and teleconferencing in which the Electrowriter's unique "chalkboard" capability may be useful.

Further experimentation with Electrowriter applications in medical teaching and teleconferencing may be appropriate in the upcoming ATS-F experiments in the Rocky Mountain region.

II

SLOW-SCAN TELEVISION EXPERIMENT

SLOW-SCAN

TELEVISION EXPERIMENT

BACKGROUND

Slow-scan television is a device for transmitting still television pictures over narrow-band, telephone-grade communications channels. By and large, slow-scan technology is still in the developmental stages.

In the Spring of 1971, the University of Wisconsin Department of Continuing Medical Education undertook a pilot project to test the use of slow-scan television (SSTV) for providing lectures to remotely located third year medical students. Results of the experiment were not considered satisfactory by the Medical Center. Major problems encountered included equipment malfunction (power supply failure), operator error and reluctance of faculty to adapt their presentations to the particular limitations and capabilities of the SSTV network.

Improvements in power supply technology at the beginning of the present experiment indicated that equipment malfunction could be minimized. The purpose of the experiment was to continue to explore the applications of SSTV technology to medical communications. Specifically, the effort was directed at determining the feasibility of transmitting SSTV pictures via ATS satellite for medical purposes.

OBJECTIVES

The objectives of the experiment were threefold:

1. To test and evaluate the technical feasibility of transmitting slow-scan television pictures via the ATS satellites.

2. To develop criteria for preparing visuals for use with slow-scan television via satellite.

3. To identify potential applications of slow-scan television as an aid in medical communications with emphasis on providing remote health care and education to isolated areas in Alaska.

EXPERIMENT PROCEDURES

1. Test Plan

The test plan originally projected for the experiment was as follows:

Equipment Checkout (Tests 1,2)
Two preliminary tests were planned to establish the feasibility of transmitting SSTV pictures via ATS satellite.

Medical Lectures (Tests 3-7)
Five medical transmissions were planned to develop data for evaluation.

Demonstration Lectures (Tests 8,9)
Two demonstration lectures were planned to assist medical personnel at Stanford and Wisconsin in evaluation.

The completion of medical and demonstration lecture transmissions was, of course, contingent upon the success of equipment check out tests. Since the technical feasibility of transmitting acceptable SSTV pictures was not fully established in the experiment, the medical lectures and demonstration programs were not attempted.

Tests actually conducted were limited to the Equipment Check-Out phase of the experiment and were of two basic types:

(1) actual satellite transmission of SSTV pictures,

(2) simulation of satellite transmission of SSTV pictures to determine the minimum link requirements (S/N ratio) for transmission of SSTV pictures of acceptable quality.

2. Technical Design

The experiment, utilizing the ATS-1 satellite, involved connection of a telephone company data line (Class C-2) from the University of Wisconsin

SLOW-SCAN TELEVISION MAIN CONSOLE

Hospital, where the Westinghouse SSTV console is located, to the EDSAT radio transmitter in the Space Science and Engineering Center (See Figure 1). This line was to carry picture content for medical lectures originating at the hospital. The audio portion of the lectures was to be fed to a second EDSAT radio transmitter located at a remote site on a farm north of Madison by a conventional dial telephone line. This line was to utilize a Bell Telephone KS-19645-L2 recorder connector in the hospital control room and a Bell Telephone KS-19522-L1 recorder coupler at the farm, where voice transmission to the satellite was to take place. Additional dial telephones were provided at University Hospitals, EDSAT, and the remote site for coordination of the experiment. Reception of both the audio and video portions of the program was assigned to the remote base station because of the low-noise environment there.

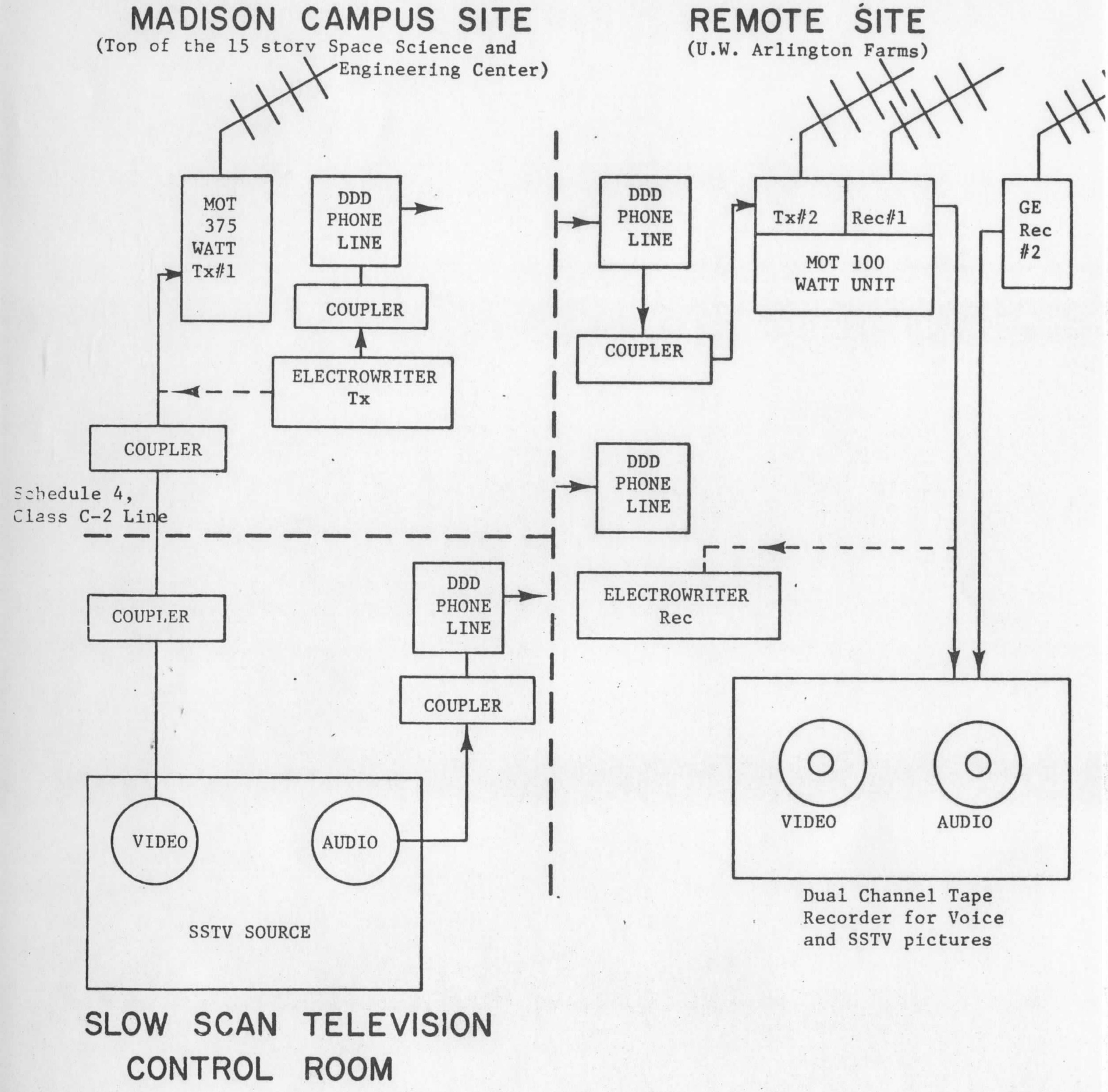


Figure 1: Diagram of Slow-Scan Television Test Set Up

3. Use of Audio Recorders for Reception from Satellite

The original experiment plan called for movement of two SSTV receivers, one to the Arlington Farms base station and the other to Stanford University. Because of the sheer bulk and complexity of the equipment, transportation, especially to Stanford, was determined to be very expensive. With all of the program content falling within the audio spectrum, it seemed that securing the lease of reliable two-channel audio recorders would be a far more economical method of doing this series of tests. To this end, a search was instituted for a suitable machine*, and, as a result, two Crown International CX-722/20K2-2/2CX-6/Q units were leased and utilized for recording and later play back and display of voice and SSTV pictures received from the satellite at Wisconsin.

Figure 2 illustrates that the use of the Crown Recorder does not noticeably affect picture quality. The first picture shows a slide as displayed on the SSTV monitor. The second picture shows the same slide after it was recorded on audio tape and then played back again on the monitor.

4. Further Details on Procedure

For further details on experimental procedures relating to satellite test format, recording and documentation, consult Appendix VII.

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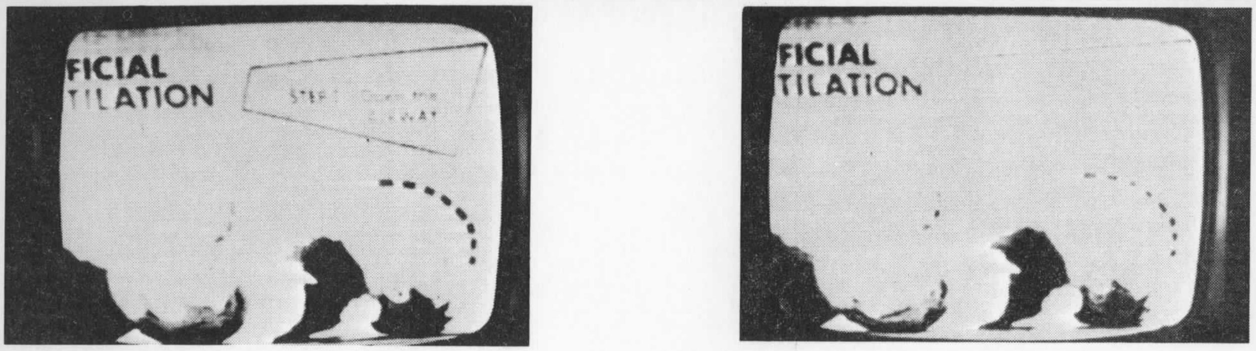
*The state-of-the-art in audio recorders of the reel-to-reel type today is such that bandwidth, signal-to-noise, and distortion are maintained well within the limits necessary for our purpose. On the other hand, wow and flutter of the tape transport could seriously degrade the slow-scan picture by making it appear to swim in circular motion about the television screen. After reviewing specifications of those recorders available to us, the Crown International product was selected. The published wow and flutter specifications of .06 per cent at 15 inches per second and .09 per cent at 7 1/2 inches per second would, we knew, induce some picture movement, but because this picture degradation could be easily identified as a function of the recorder, it would not influence the results of the experiment.



ORIGINAL SLIDE DISPLAY

SLIDE DISPLAY AFTER AUDIO TAPE RECORDING AND PLAYBACK

Figure 2: Illustration of the Effects of the Audio Tape Recorders on Picture Quality

DESCRIPTION OF EQUIPMENT AND OPERATION

The slow-scan television system used in these experiments was constructed for the University of Wisconsin Medical Center by the Westinghouse Learning Corporation. It consists of five separate pieces of equipment: the transmitting console and four slow-scan receivers with their attendant television monitors.

1. SSTV Console and Receivers

The console (Figure 3) permits the selection of still television pictures and their subsequent transmission to the receivers from three sources: a conventional television camera viewing a lecturer or blackboard, a similar camera viewing selected charts or radiographs, and a slide camera capable of viewing either 2 x 2 or 3 1/4 x 4 slides. There are picture storage facilities for three pictures before transmission and for five received pictures before display. All pictures conform to the conventional Electronic Industries Association (EIA) format, insuring system compatability with existing television equipment.

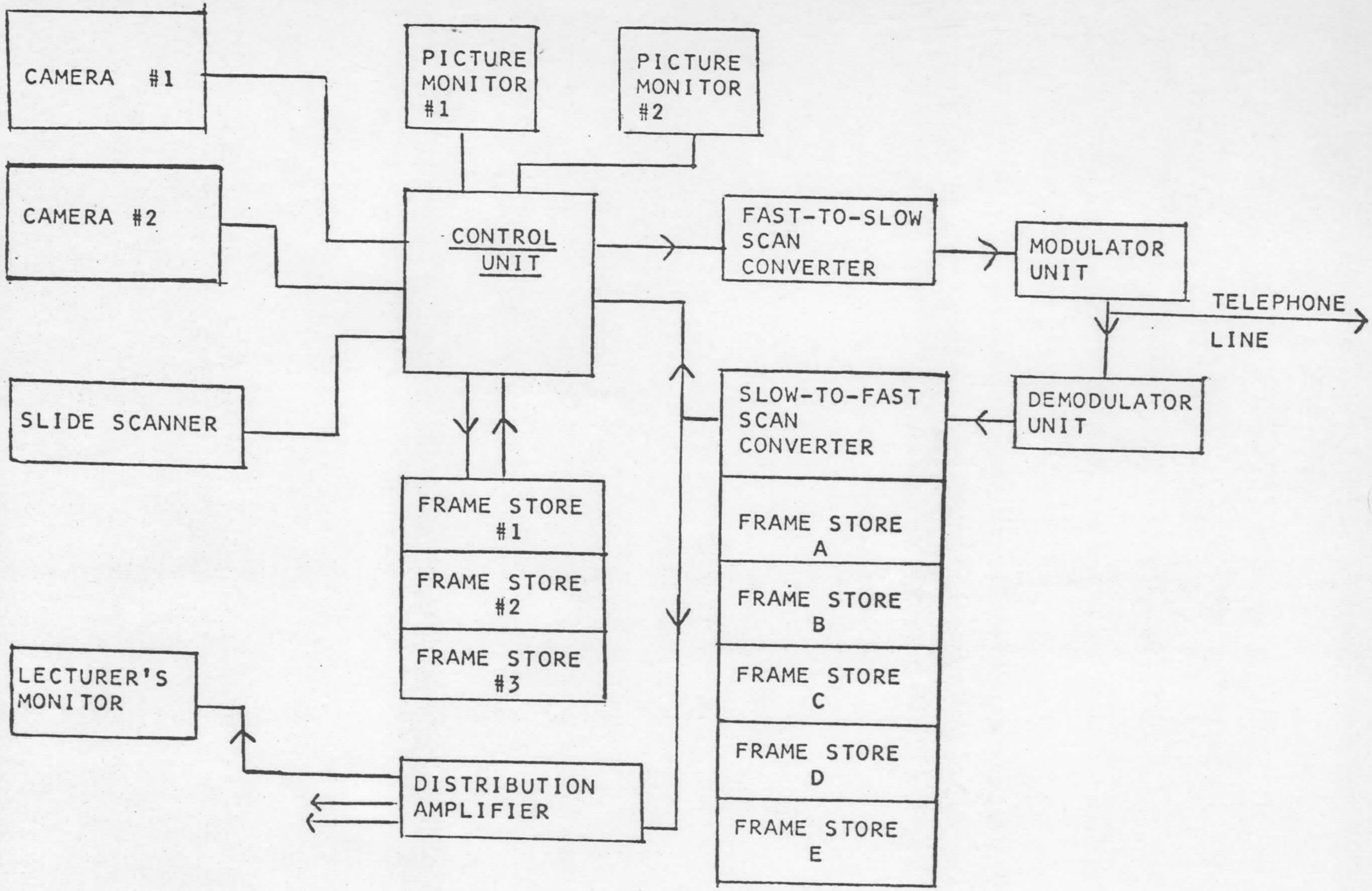


Figure 3; Diagram of Slow-Scan Television Console at the U.W. Medical Center

Operation of remotely located SSTV receivers (Figure 4) is completely dependent on signals originating from the central transmitting console. Video, in the form of audio signals, is received via the connecting data line or satellite link, scan-converted back to video format and stored in a pre-display track. The received picture is held until a display code is transmitted from the console, at which time it is shown to the audience on a television monitor. Because all receivers used for display are connected to the data line in parallel, all receive the same commands and picture content. It is, therefore, not possible to send different program content to different receivers.

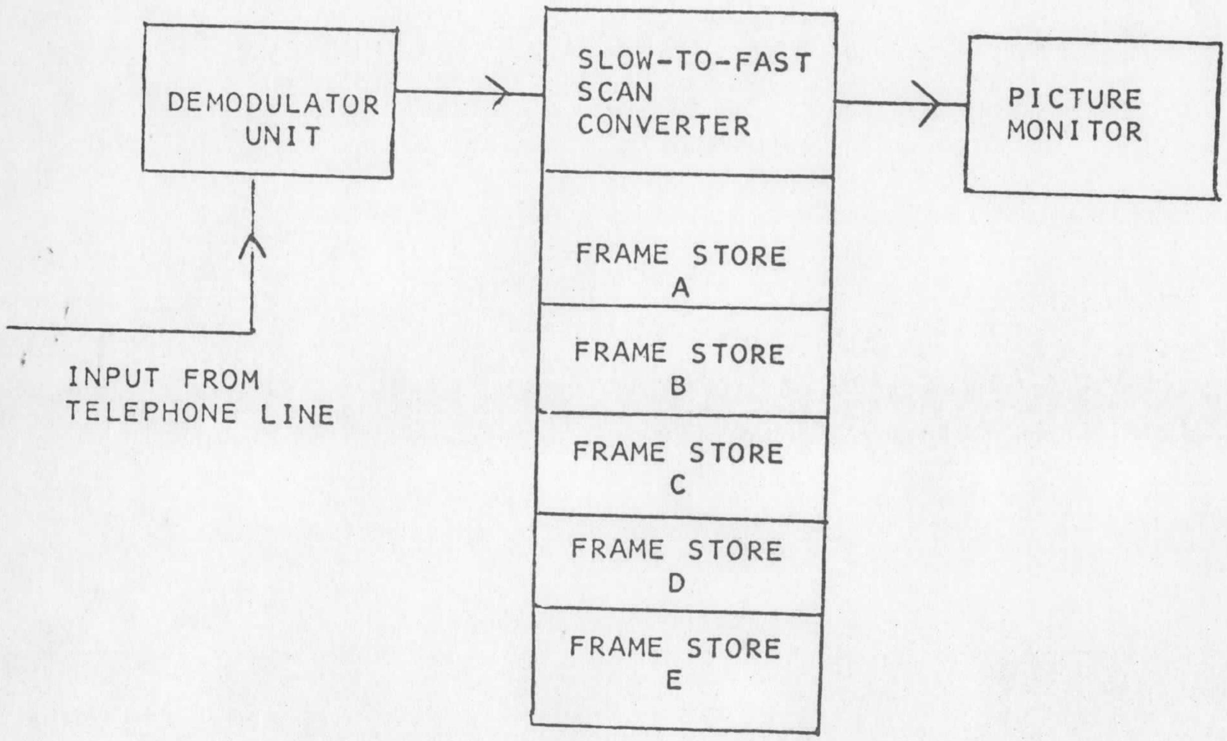


Figure 4: Diagram of Slow-Scan Television Receiver at U.W. Medical Center

2. SSTV Operation

It is possible to send any visual in one of two resolution states. High resolution, with a transmission time of two minutes and eighteen seconds, has a resolution of 600 lines. The low resolution mode transmits in half the time and offers 300 lines of resolution. Visuals containing no detailed information can take advantage of the low resolution transmit time, while most graphs, charts and the like need higher resolution for effective display. The console operator transmits and stores the first three visuals in the pre-display tracks, continuing to fill the pre-transmit and pre-display tracks until all five of the latter have picture content. During this phase of operation, the receiver television monitor screens display no picture.

The lecturer conducts his presentation as he normally would, calling for visuals in sequence. The audience in the central lecture hall sees the slides projected on a conventional movie screen, while the remote audience views them on a television monitor as each picture is displayed by the console operator. When the lecturer is finished with the first visual, the console operator stores the sixth visual on that storage track. This process continues until the lecture is finished.

This system was designed to operate on a Schedule 4, Class C-2 conditioned telephone line. Its characteristics are similar to those furnished for private line telephone service.*

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*Line conditioning guarantees the envelope delay distortion will not exceed 500 milliseconds between 1000 and 2600 Hz, 1500 milliseconds between 600 and 2600 Hz, and 3000 milliseconds between 500 and 2800 Hz. Frequency response is controlled to within 4 dB from 1000 to 2400 Hz, (with reference to 1000 Hz), and within 8 dB from 300 to 2700 Hz. The expected steady-state noise varies with circuit length and the number of points connected. Typical figures are 28 dBrnc, (-62 dBm) from 0 to 50 miles; 31 dBrnc, (-59 dBm) from 50 to 100 miles; 34 dBrnc, (-56 dBm) from 100 to 400 miles; and 50 dBrnc, (-40 dBm) from 8000 to 16,000 miles.

3. SSTV Equipment Costs

The slow-scan television equipment used in this experiment was built by Westinghouse for approximately $115,000.00. The equipment was custom made for the University. Westinghouse does not presently manufacture SSTV equipment commercially. Estimates from the corporation are that similar but updated SSTV systems could be produced in quantity for costs ranging from $10,000.00 to $100,000.00 depending on equipment features desired.

Some manufacturers indicate that they have designed SSTV systems costing less. For example, Colorado Video Corporation estimates a cost of $5000.00 for their system. This system and others like it do not have many of the features of the present Westinghouse systems such as the picture storage capability discussed above.

SUMMARY OF TEST RESULTS

A summary of tests conducted is shown in Table I. Of the fourteen tests conducted the first twelve related to actual transmission of slow-scan television pictures. Test thirteen simulated the transmission and reception of pictures at different S/N (signal-to-noise) levels to determine the minimum satellite link performance requirements for transmission of pictures of acceptable quality.

1. Results of Actual Picture Transmission

Examples of pictures actually transmitted via ATS-1 satellites are shown in Figures 5a and 5b. Figure 5a shows a black and white test slide before and after transmission. Figure 5b shows a medical slide ("artificial ventilation") before and after transmission. Both slides were transmitted and received under good conditions (-22 dB carrier quieting*). The quality of both received slides shown in these pictures was considered unacceptable for medical purposes.

2. Determination of the Minimum Link Requirements (Signal/Noise Ratio) For Transmission of Acceptable Pictures

Optimization of system performance in tests one through twelve produced results such as those shown in Figures 5a and 5b. On the basis of these results, it was apparent that pictures of acceptable quality could not be transmitted given optimum performance of all system components, i.e., the satellite, base station equipment and the slow-scan television equipment. Consequently, a scheme was devised to determine exactly what the minimum requirements would be for satellite link (satellite and base station com-

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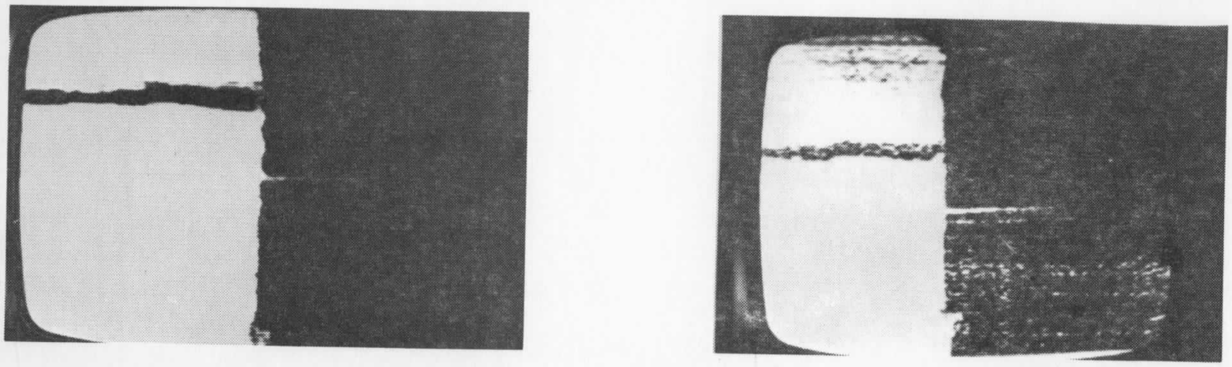
*Carrier quieting (without modulation) measurements bear no numerical relation to S/N or $\frac{S+N}{N}$ measurements. However, both are a measure of system performance. Carrier quieting measurements will be usually higher valued (in absolute terms) than S/N or $\frac{S+N}{N}$ measurements taken at the same time.

SATELLITE TESTS COMPLETED FOR SLOW-SCAN TELEVISION EXPERIMENT

TABLE I

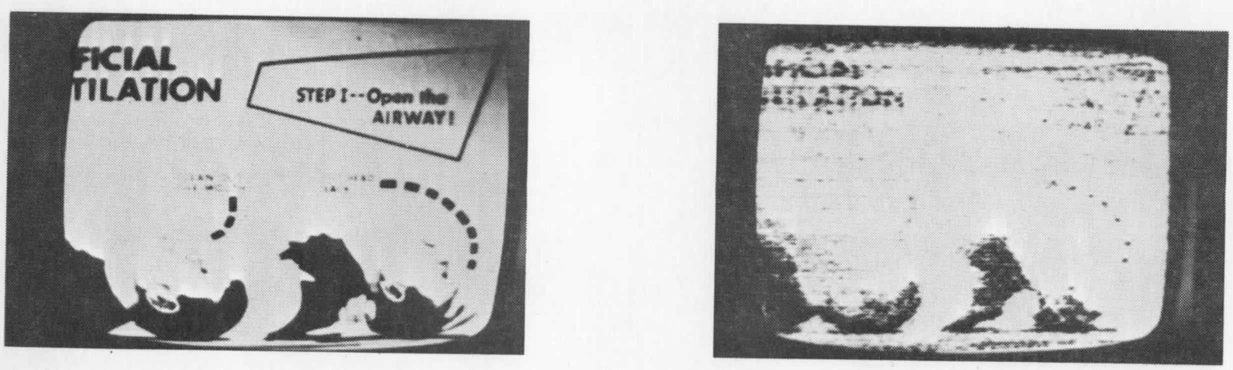
Test No.	Date	Objective	Comments
1	29 Oct	Preliminary Test	--
2	15 Nov	Compare ATS-1 to ATS-3	ATS-1 preferred due to high spin modulation on ATS-3
3	24 Nov	Test feasibility of transmitting pre-recorded SSTV signals.	SSTV tape must be of a continuous run to permit servo for pictures.
4	30 Nov	Same	Unsuccessful
5	2 Dec	Check for frequency offset at the satellite	Plot of results indicates another test required.
6	9 Dec	Check frequency response curve for data line in ground link	Data line functioning properly.
7	14 Dec	Check frequency response curve again.	Discovered that receiver notch filters are affecting response curve.
8	16 Dec	Check frequency response curve with notch filter removed.	Plot of results indicates improvement.
9	21 Dec	Determine best deviation level for optimizing signal to noise ratio for a multiple frequency SSTV signal	Completed successfully
10	28 Dec	Test feasibility of transmitting audio and video portions of medical program in sequence in the simplex mode	Test not completed for lack of air time. Audio received successfully. Two-three pictures received but of poor quality.
11	4 Jan	Test to optimize quality of transmitted pictures.	Test completed. Picture quality remains poor
12	11 Jan	Same	Same
13	18 Jan	Test SSTV console using "white noise test."	Test completed. High S/N ratio required for good pictures.
14	20 Jan	Test frequency response of the satellite link using frequency compensator at input of data line at U.W. Hospital	Test completed. Compensator is not sufficient for picture code transmission. Pictures are better but still poor.



BEFORE TRANSMISSION

AFTER TRANSMISSION

Figure 5a: Black and White Test Slide Before and After Satellite Transmission



BEFORE TRANSMISSION

AFTER TRANSMISSION

Figure 5b: Artificial Ventilation Slide Before and After Satellite Transmission ponents of the total system) performance in order to transmit acceptable pictures assuming no change in the Westinghouse slow-scan television equipment. Test thirteen was the primary test conducted along these lines.

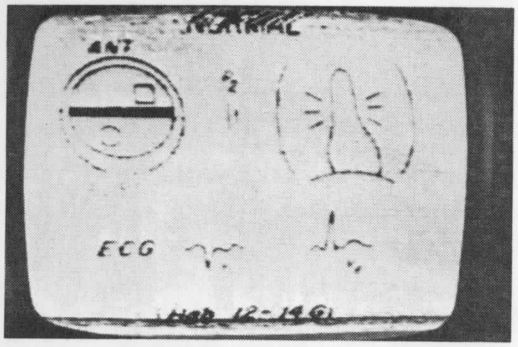
Test thirteen (the "white noise test" discussed in a later section) consisted of the deliberate artificial degradation of picture quality to correspond to hypothetical levels of satellite link performance. Original picture quality was degraded by the introduction of progressively higher levels of electronic "noise." This resulted in a series of pictures illustrating the effects of eight different hypothetical levels of satellite link performance. The test was applied to two different medical slides and the two sets of results are shown in Figures 6 and 7. Both series were examined to determine the minimum performance levels (i.e., the maximum permissible noise levels), that would be required for the transmission of readable pictures. (When examining the pictures, please disregard the white and dark bands running diagonally across the face of the monitor. They are related to photographic technique and do not bear on the quality of the pictures themselves.)

A discussion of these results appears in the section on Evaluation.

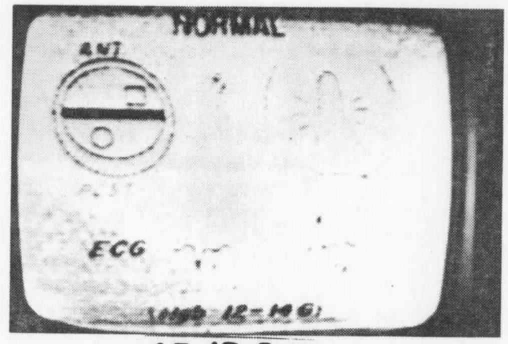
3. Results Related to the Establishment of Criteria for the Preparation of SSTV Visuals

The development of criteria for SSTV visuals was to have proceeded in two stages. First, baseline criteria were to have been developed for the use of visuals with a properly functioning SSTV ground network. Second, a set of modified criteria was to have been developed to account for any added degradation due to satellite transmission of pictures. However, while the SSTV ground link functioned satisfactorily, pictures of sufficient quality for development of meaningful criteria were not successfully transmitted so that stage two was not attempted. A full discussion of criteria established in stage one appears in Appendix VIII.

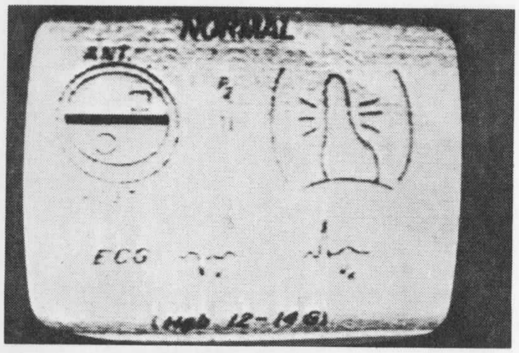
Figure 6: Picture Quality at Different Hypothetical Levels of Signal Degradation Caused by Satellite Transmission



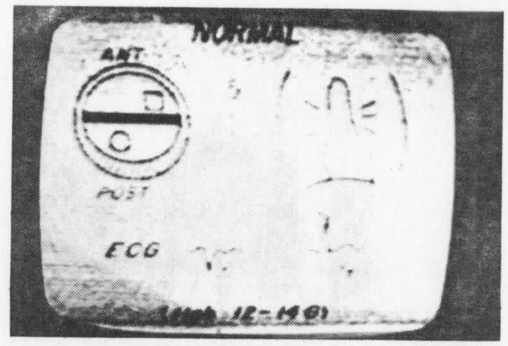
-50 dB S/N



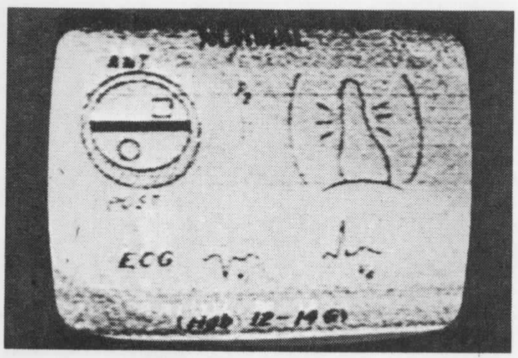
-45 dB S/N



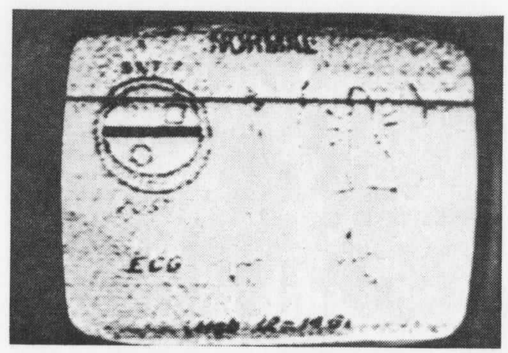
-40 dB S/N



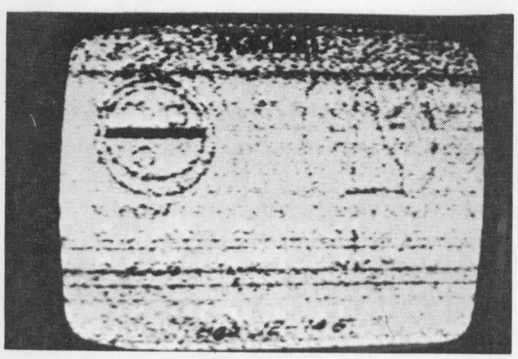
-35 dB S/N



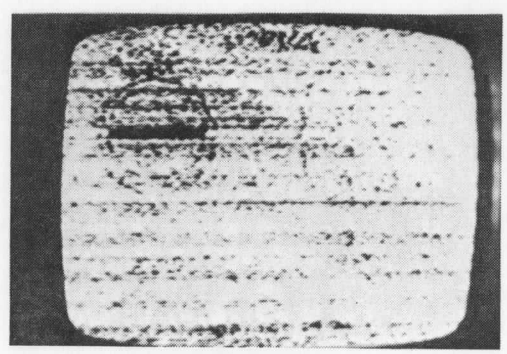
-30 dB S/N



-25 dB S/N



-20 dB S/N



-15 dB S/N

Figure 7: Picture Quality at Different Hypothetical Levels of Signal Degradation Caused by Satellite Transmission

TECHNICAL DISCUSSION OF RESULTS

The Westinghouse SSTV system was designed to operate on a Schedule 4, Class C-2 conditioned telephone line. However the equipment used for the satellite ground station was designed for voice-only communications. This conflict led to many technical difficulties in interfacing. Audio notch filters used in the control system of the Motorola base station equipment prevented transmission of portions of the SSTV signal. The modulation acceptance of the receiver limited the amount of transmitter deviation with SSTV to well below that normally used for voice communications. And the base station audio passband (meant for voice communications) also hampered transmission of the SSTV signal.

A complete discussion of these problems which relate to the slow-scan television/base station interface follows.

1. Attenuation of Video Information

It was determined, upon viewing results of early tests, that video signals from 1740 Hz to 2290 Hz were severely attenuated. During investigation of the radio transmitter, a notch filter was discovered at 2175 Hz which so attenuated the video frequencies that no picture could be received. This notch filter was normally used for a remote control function and was not necessary for the SSTV experiment since the remote control capability of the transmitter was not utilized. Subsequently, the notch filter was bypassed.

The effect of the notch filter can be seen in Figure 8. Figure 9 is a plot of the frequency response of the transmit-receive link after removal of the notch filter.

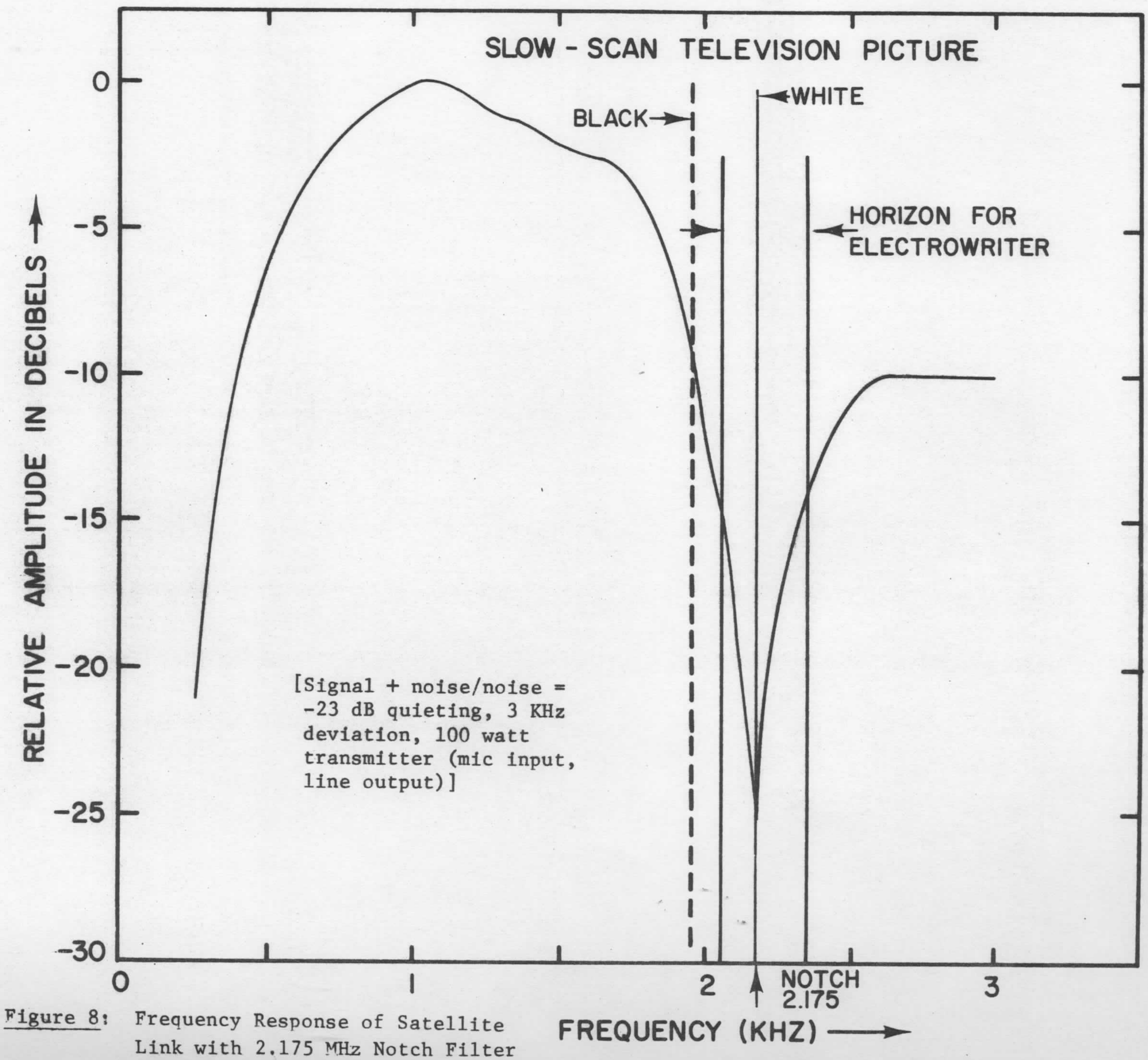


Figure 8: Frequency Response of Satellite Link with 2.175 MHz Notch Filter Present in Receive Line

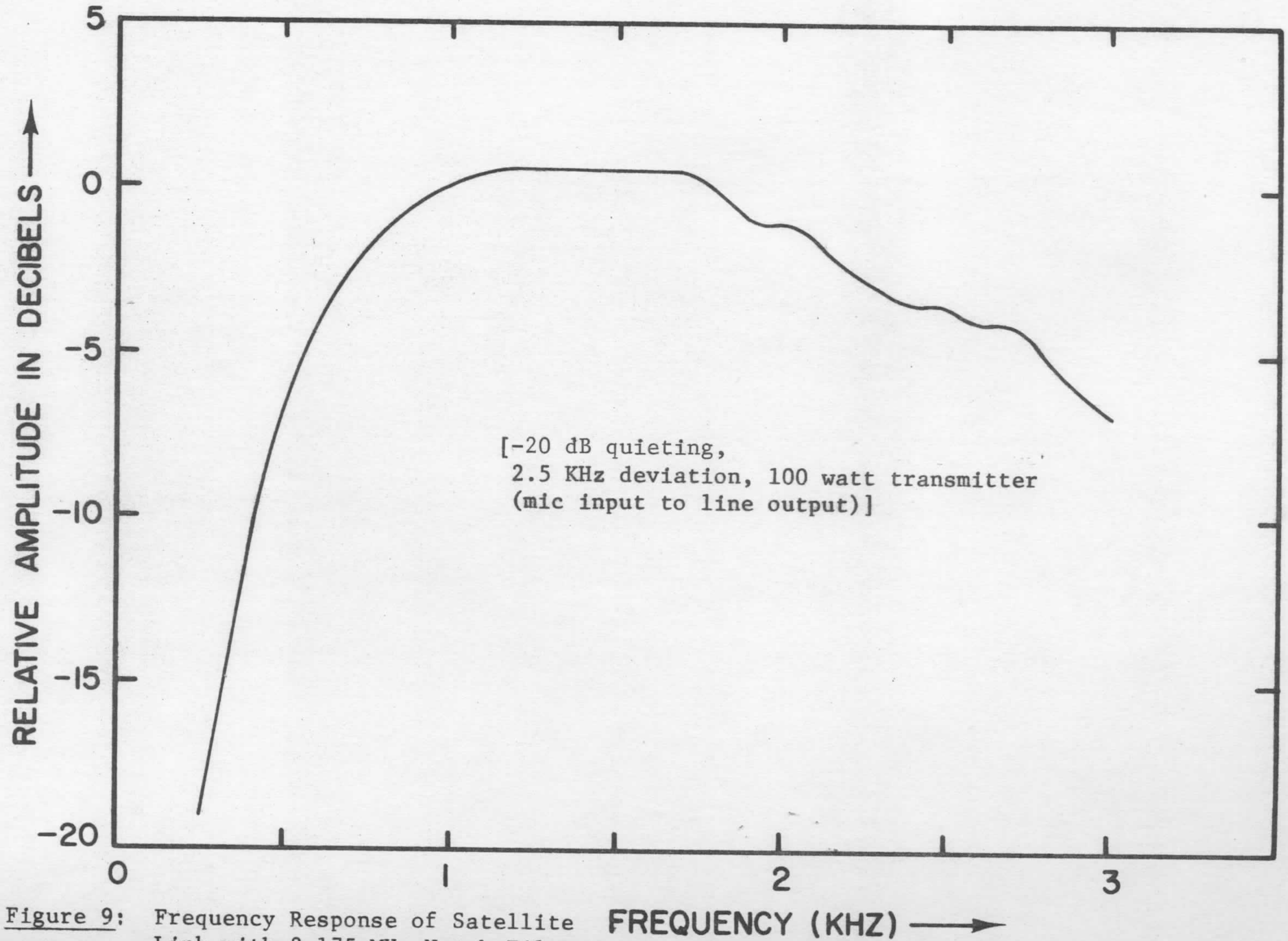


Figure 9: Frequency Response of Satellite Link with 2.175 MHz Notch Filter Removed from Line

2. Attenuation of Code Information

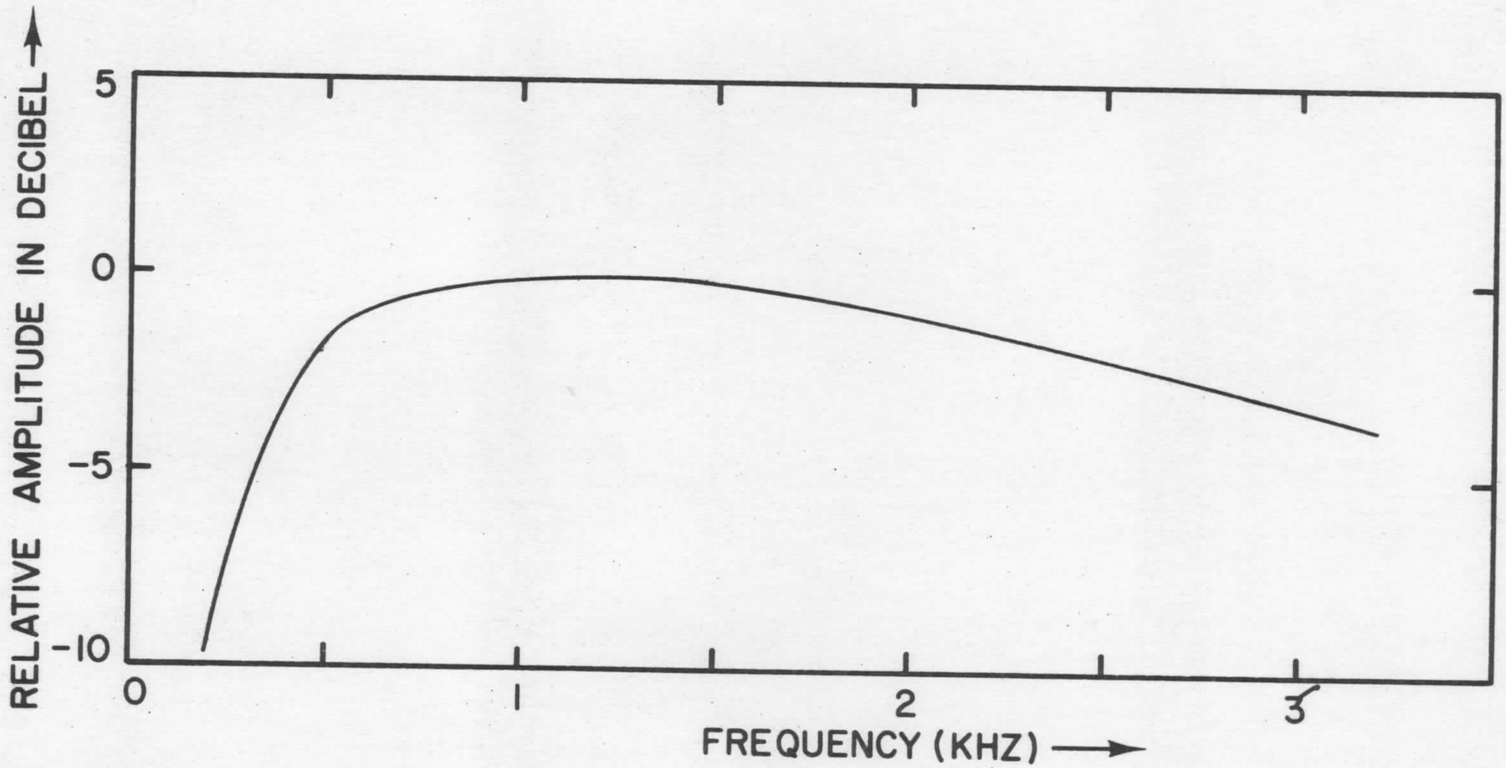
A second difficulty arose in the lack of reception of the code frequency at 310 Hz. A frequency response of the data line from the University of Wisconsin Hospital to SSEC, Figure 10, indicated that the data line would attenuate the code frequency at 310 Hz by 4 dB relative to 2 KHz. The frequency response of the transmit-receive link (Figure 9) produces an extra 14 dB of attenuation. Thus the entire loop attenuates a single tone at 310 Hz, 18 dB relative to a single tone at 2 KHz.

A Hewlett-Packard audio spectrum analyzer was used to examine the SSTV SERVO signal. The resultant spectrum is shown in Figure 11. It is shown that the code frequency at 310 Hz is normally 7 dB down from the video portion at 2 KHz. Thus, it would be expected that the code frequency at 310 Hz would be (18 dB + 7 dB) 25 dB down from 2 KHz through the entire link. If the signal to noise ratio on the link was less than 25 dB the codes would not be above the noise.

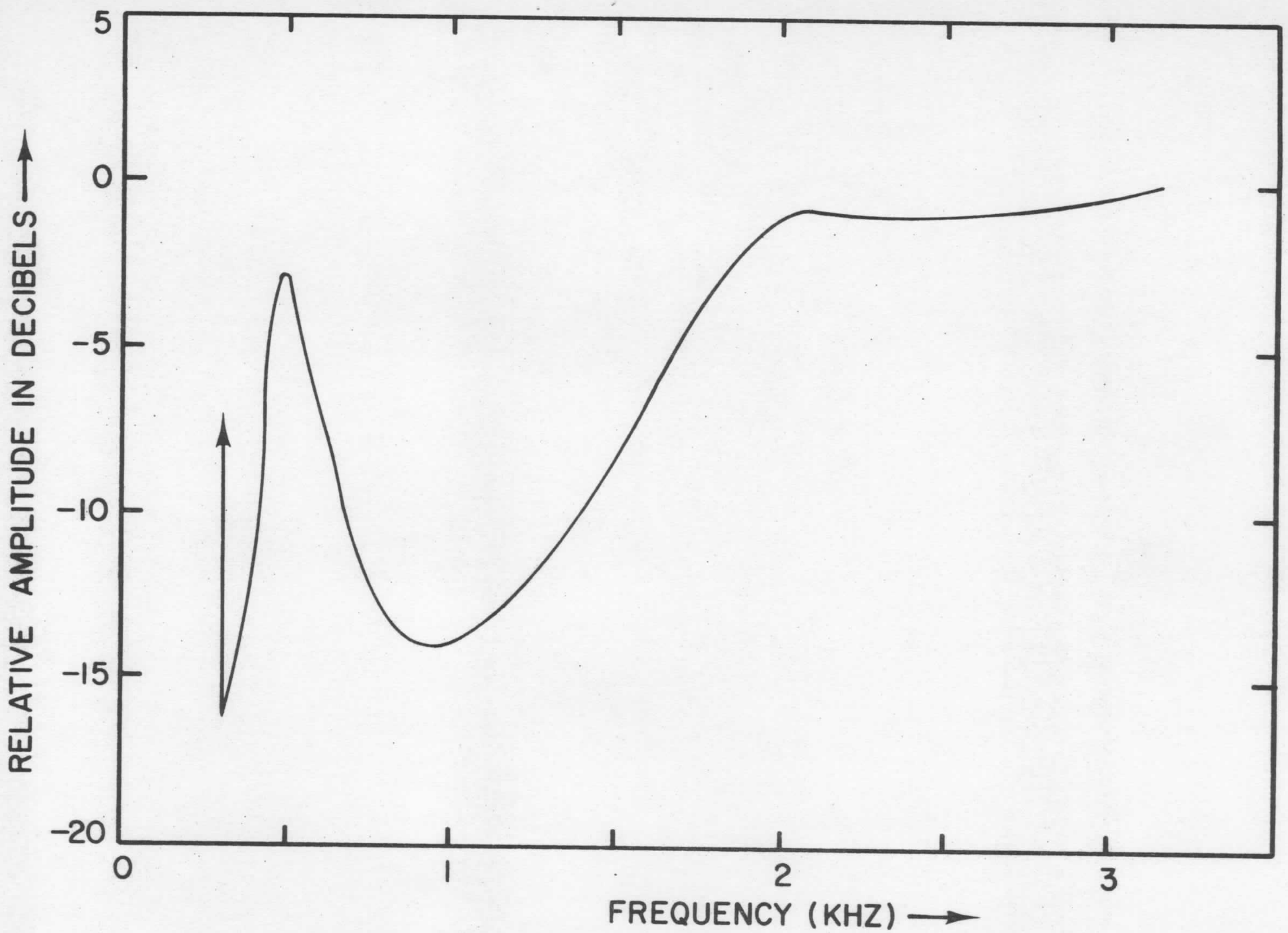
The spectrum of an actual SERVO signal through the satellite link is shown in Figure 12. Here the codes are only 5 dB down from normal in comparison to Figure 11.

A white noise signal was transmitted through the entire link, and its spectrum is shown in Figure 13. Here the 310 Hz component is shown to be 6 dB down from 2 KHz. This would tend to confirm the result of 5 dB with the actual SERVO signal

This discrepancy may be due in part to the "modulation acceptance" of the system to various forms of audio signals, described in the following section. The higher frequency signals may have had more noise generated due to the passband of the receiver. In using an averaging AC voltmeter for monitoring the receiver output levels, this additional noise at the



<u>Figure 10</u>: Data Line Frequency Response
(U.W. Hospital to SSEC)



<u>Figure 11</u>: Spectrum of "Servo" Signal From the Slow-Scan Television Console

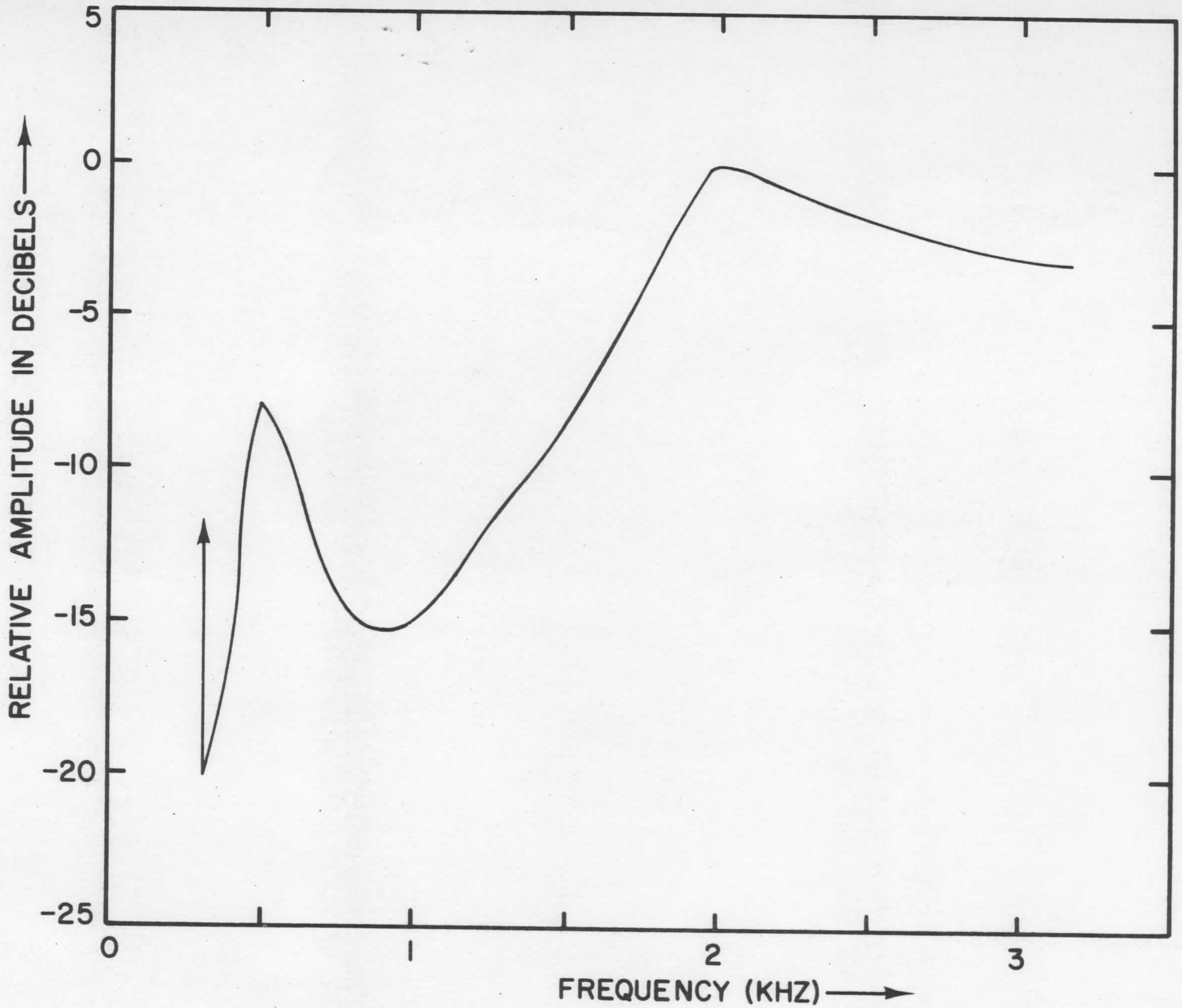


Figure 12: Spectrum of "Servo" Signal From the Satellite

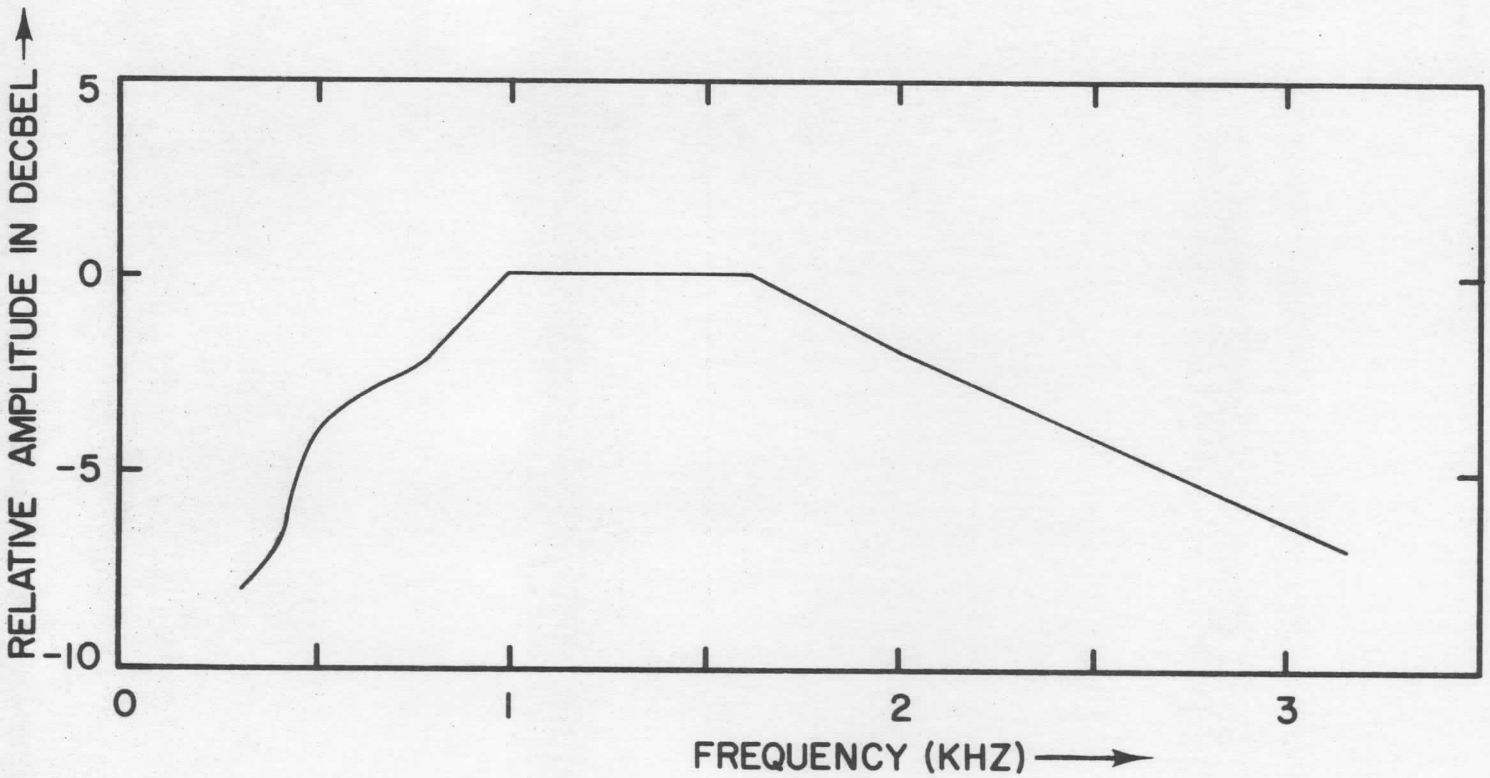


Figure 13: White Noise Spectrum Plot
(From slow-scan television console through data line to 375 watt transmitter to satellite to Arlington satellite receiver, to Crown tape deck to console.)

higher frequencies may have made it appear that the lower frequencies were attenuated more greatly than they actually were.

The discrepancy may also be due in part to the audio limiter in the transmitter modulator producing non-linear effects on the complex SSTV signal and white noise signal.

Motorola rates their transmitter to have an audio passband of +1 to -3 dB for 6 dB/octave pre-emphasis for 300 Hz-3 KHz and their receiver to have a response of +1 dB to -3 dB for a 6 dB/octave de-emphasis. The variation in response of the receiver may have added to the severe attenuation of the lower frequencies.

An audio frequency compensator was utilized to adjust for the low frequency attentuation and did aid in the reception of the necessary codes.

Modulation Acceptance

Assume a sine wave modulating signal at fo. If the transmitter deviation is set to some modulation index, it will have an infinite number of sidebands spaced at nfo from the carrier where "n" is an integer. The amplitudes of these sidebands are given by the Bessel functions corresponding to that modulation index. If the receiver had an infinite passband, the recovered signal would be proportional to the deviation or modulation index of the transmitter. However, in practice, the receiver passband is limited. In the case of the Motorola narrow band receiver, the modulation acceptance is ±7 KHz minimum. Thus the number of sidebands accepted by the receiver is dependent on the frequency of the modulating signal. A signal at 1 KHz will have a larger number of sidebands accepted by the receiver than will a signal at 3 KHz. And for deviation levels beyond a certain point, background noise and distortion will increase as total receiver input signal power decreases due to the transmitter power going more into sidebands outside the receiver passband. Thus a given receiver will have a certain "modulation acceptance" dependent on the modulating frequency and modulation index of the transmitted signal.

The modulation acceptance of the receiver will dictate that for given distortion and noise, the modulation index or deviation of the transmitter must be limited. For a 1 KHz test signal the transmitter may be set at the full 5 KHz deviation. For a typical voice signal, which has a power density concentrated around 1 KHz, the transmitter may also be set at the full 5 KHz deviation.

However, a SSTV signal which has a high power density near 2 KHz and 3 KHz, the deviation must be reduced from what it was at 1 KHz to produce the same distortion. A plot of apparent $\frac{s+n}{n}$ versus deviation for a SSTV SERVO signal is given in Figure 14. It can be seen that the slope of the curve decreases beyond 2.5 KHz due to the addition of increasing noise and distortion beyond this point. Thus the curve is not actually a representation of $\frac{s+n}{n}$ at deviation levels higher than 2.5 KHz since the noise was not constant and was in fact an increasing function with signal level. Below 2.5 KHz deviation, the noise due to carrier quieting masks the noise increasing with signal deviation and thus the noise is relatively constant.

Due to the previously observed phenomenon, individual SSTV pictures were transmitted at different deviation levels and observed in order to determine the best deviation level to use with SSTV. Results are shown in Table II.

The best picture, although still poor, was at 3 KHz deviation. This confirms the plot of Figure 14. Thus a SSTV signal of this type with a high power density in the region of 2-3 KHz operates at a disadvantage over voice

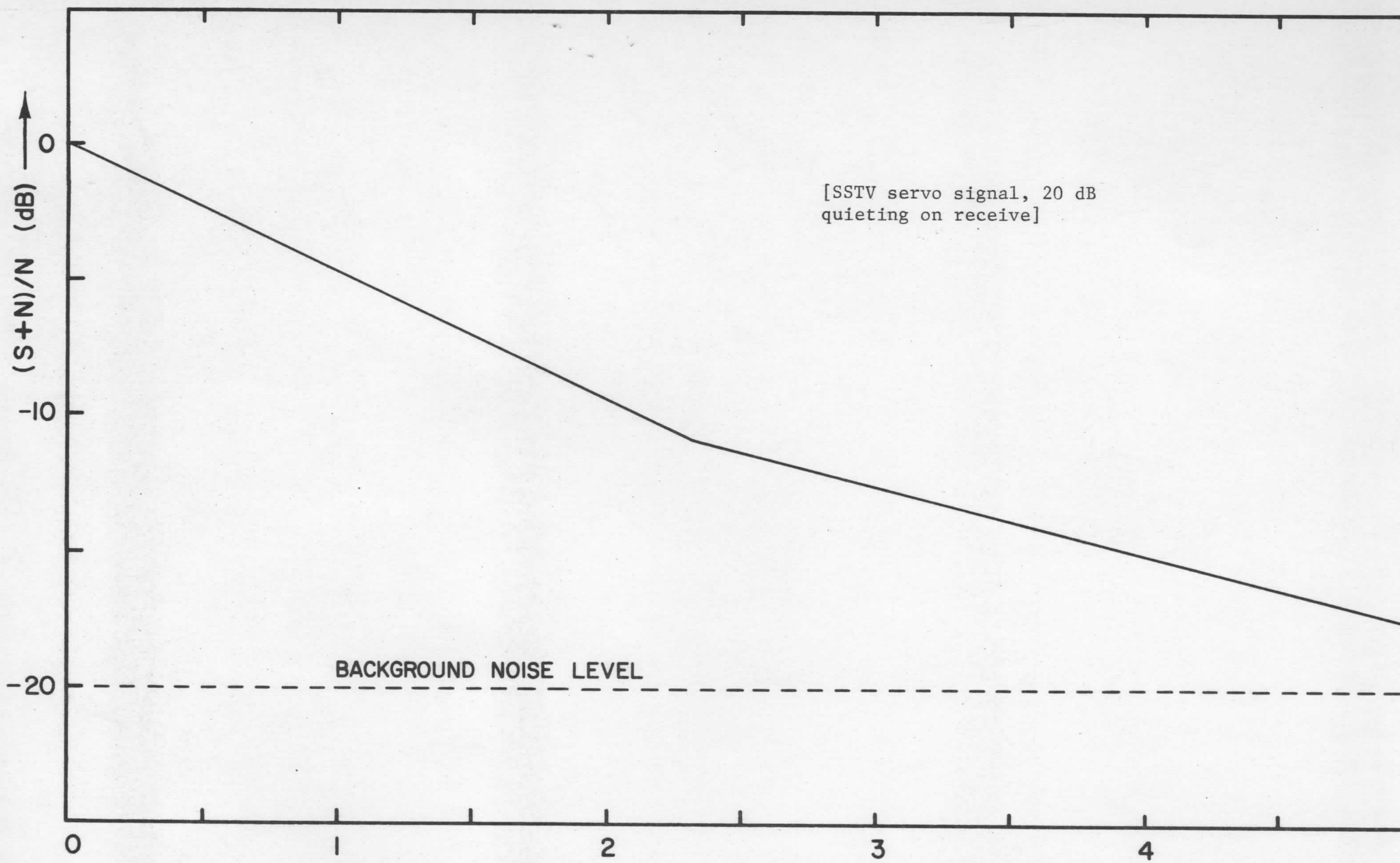


Figure 14: Variation in Apparent $\frac{s+n}{n}$ Ratio with Transmitter Deviation

Table II

SSTV DEVIATION TEST RESULTS

Trial No.	Average Deviation (KHz)	Results (High resolution)
1	4	Very grainy
2	3	Better picture than No. 1
3	2	Worse than Trial No. 2
4	5	Errors and distortion in signal (no picture)

transmission concentrated at 1 KHz since it's $\frac{s+n}{n}$ ratio is much less due to the signal level being restricted to 1/2 times that of the signal level for a typical voice signal, while the carrier noise remains constant.

4. Determination of Minimum Acceptable S/N Ratio for Successful SSTV Transmission

Using the test set-up shown in Figure 15, a test was performed to determine the maximum allowable signal to noise level required to seriously degrade a typical SSTV signal. By independently setting the levels of the noise generator and the SSTV signal with the VU meter, outputs with known S/N levels could be generated. These were recorded and then played back and displayed for later evaluation to determine what S/N level would provide a picture of minimal acceptable quality. (Refer back to Figures 5 and 6 for picture results.)

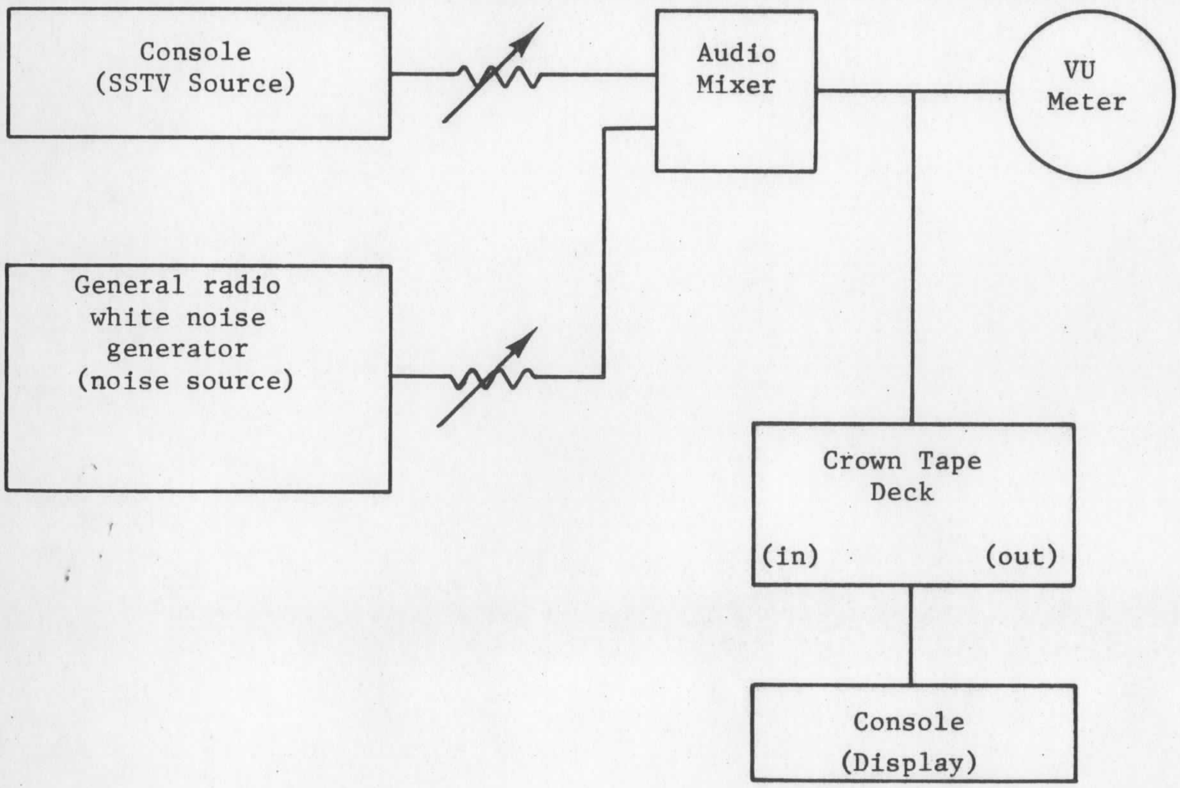


Figure 15: Set up for White Noise Test

EVALUATION OF RESULTS

On the basis of tests run to determine the S/N ratio required to transmit a picture of minimum acceptable quality, it was concluded that, for most medically useful visuals, a S/N ratio of at least 30-35 dB is desirable. Higher ratios would be required for low contrast type visuals. (Refer again to Figures 6 and 7 for illustrations of picture quality at different S/N ratios.) The maximum $\frac{S+N}{N}$ ratio ever measured during SSTV tests was 19 dB at a deviation of 3.5 KHz. On this basis, it appears that present performance levels are at least 11 dB (30 dB - 19 dB) below the minimum acceptable level.*

Based on test results, several solutions to the problem of sending quality SSTV pictures via satellite are possible:

Modifying the SSTV signal If the high frequency components of the SSTV signal could be heterodyned down to lower frequencies, the $\frac{S+N}{N}$ could be increased since the allowable deviation could be increased.

Modifying the satellite ground station equipment Broadening the audio passband of the equipment might aid in better reception of the code frequencies. Using wideband FM equipment instead of narrowband equipment may aid in improving the modulation acceptance, although the sensitivity of such equipment is less.

Utilizing better antennas and a higher powered transmitter will of course increase the S/N ratio obtainable through the satellite. The receiver was operating at about maximum obtainable sensitivity for this mode

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*Thirty (30) dB S/N is approximately equivalent to 30 dB $\frac{S+N}{N}$ for high S/N ratios. Also, A/N ratios are always lower than $\frac{S+N}{N}$ ratios since noise is an increasing function with deviation beyond 2.5 KHz for SSTV signals and because of the presence of noise (N) terme in the numerator of the $\frac{S+N}{N}$ ratio.

of communications and thus little improvement can be expected here. Location of the ground station closer to the projected ground location of the satellite will result in better reception due to less susceptibility to tropospheric variations.

While such modifications might make it feasible to utilize the Westinghouse SSTV equipment now on hand at Wisconsin, they would be expensive and impractical. It might be better to investigate the use of other types of SSTV equipment which may be more adaptable to inexpensive ground station operation.

CONCLUSIONS

1. The quality of slow-scan television images transmitted via the ATS-1 satellite in this experiment was inadequate for medical purposes.

2. Given the "state-of-the-art" of slow-scan television and satellite communications technologies utilized in this experiment, the transmission of medically useful SSTV pictures via the ATS-1 satellite is not presently feasible.

RECOMMENDATIONS

1. Inclusion of slow-scan television into the present Alaska ATS-1 medical satellite system should not be attempted.

2. Since the next generation of educational satellites will include the technical capability for regular television transmission, and since regular television is far superior to slow-scan television for educational and patient care purposes, it would seem unlikely that slow-scan television will be a practical consideration. If, however, narrow band widths are necessary because of the limited number of available television channels, slow-scan television should be tested, evaluation with cost/benefit considerations in mind. Appropriate experiments should be planned and designed at this time for implementation using a ATS-F.

3. The design of effective visuals for use in any form of slow-scan television programming should follow specific guidelines such as those which have been devised in this experiment.*

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* See Appendix VIII.

III

PRELIMINARY REPORT ON THE X-RAY IMAGE PROCESSING EXPERIMENT

PRELIMINARY REPORT ON THE X-RAY IMAGE PROCESSING EXPERIMENT:

An Analysis of Image Processing Techniques and Equipment for Transmitting X-Ray Information via ATS Satellite

BACKGROUND

Information of critical importance is often barely discernible in normal X-ray images because, for example, of small differences in density between normal and abnormal tissue or between tissue and non-metallic foreign bodies. When an X-ray image is scanned, transmitted and reconstructed, the image suffers loss of resolution because of the addition of noise. Equipment capable of high quality data transmission is complex and expensive and, at best, may not be able to transmit X-ray images without losing the information of critical importance.

The University of Wisconsin Space Science and Engineering Center (SSEC) has developed an extensive capability to process earth images obtained from the ATS satellites. Both analog and digital techniques are employed to select and treat portions of the image so as to increase readability. Equipment and software are applicable to other data processing with relatively minor modifications.

The successes achieved in processing ATS pictures have suggested application of the same or similar techniques where low cost and high reliability are important. The interest of the National Library of Medicine in investigating methods of providing medical communications in Alaska has focused our attention on the possible application of image processing techniques in the transmission of X-ray images. It is expected that information loss during image transmission and reconstruction can be minimized by performing pre-transmission and, perhaps, post-transmission image processing. Image processing may be useful also in increasing readability of X-rays in ordinary hospital use.

EXPERIMENT OBJECTIVE

The objective of the experiment is to provide a basis for design of low-cost equipment to be used in transmitting X-ray information from remote terminals to a Medical Center where experts in interpreting X-ray images are located. To accomplish this objective it is necessary to define an acceptable X-ray image in communication engineering terms, e.g., contrast, edge definition and information density. Using this definition as the required output characteristic and examples of typical X-ray images as the input characteristic, the required information transfer function of the transmitting channel can be described. With the required characteristics of the communication and display process established it is then possible to determine the type and degree of image processing required. Upon completion of the theoretical analysis, the complete communication and display channel including pre- and post-transmission processing will be simulated using existing equipment. Images processed by the simulated system will be evaluated to confirm expected performance, and specifications will be prepared describing the performance characteristics and basic design of low-cost terminal equipment capable of reproducing similar results in field application.

It is not expected that eventual field operational equipment will be digital. However, because of its great versatility, digital processing is advantageous in simulating the ATS channel and the input-output device transfer functions and in determining optimum X-ray image processing schemes.

STATUS OF THIS REPORT

This is a report of preliminary work completed for the X-Ray Image

Processing Experiment. This work included the modification of an optical cloud correlator to serve as a scanning microdensitometer and the following preliminary analysis of image processing techniques and equipment options. Work on the experiment is being continued on a follow-on contract with the National Institutes of Health.

TYPES OF X-RAY IMAGE PROCESSING

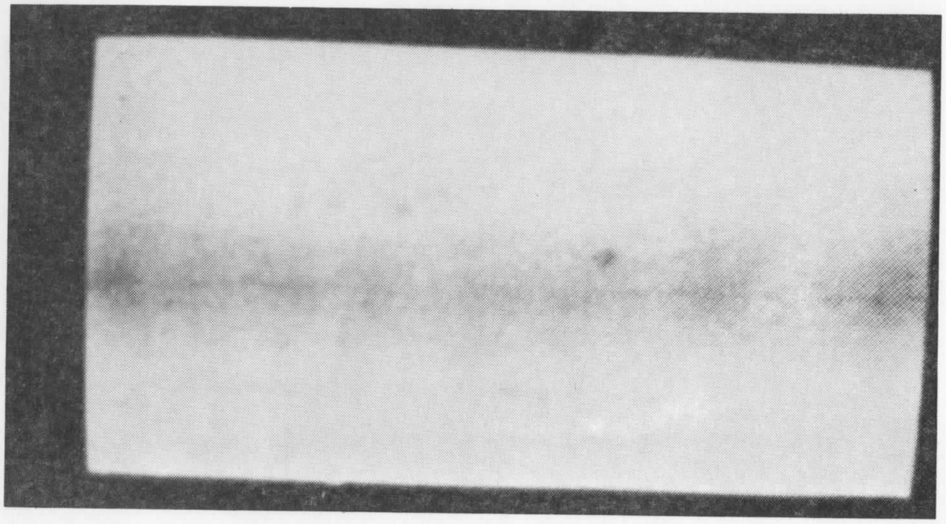
Two basically different types of X-ray images are considered here: the broken bone and the lung abnormality.

The important information in the broken bone image is in the sharp edges of the bone break. This information is revealed on the X-ray as a large change in image contrast (transmittance) for small spatial displacements. In other words, the useful information is concentrated in the high spatial frequencies of the image.

The image of the lung abnormality is characterized by subtle, diffuse variations in image contrast covering a relatively large area. However in this case also, as will be seen, the information is contained in the higher spatial frequencies.

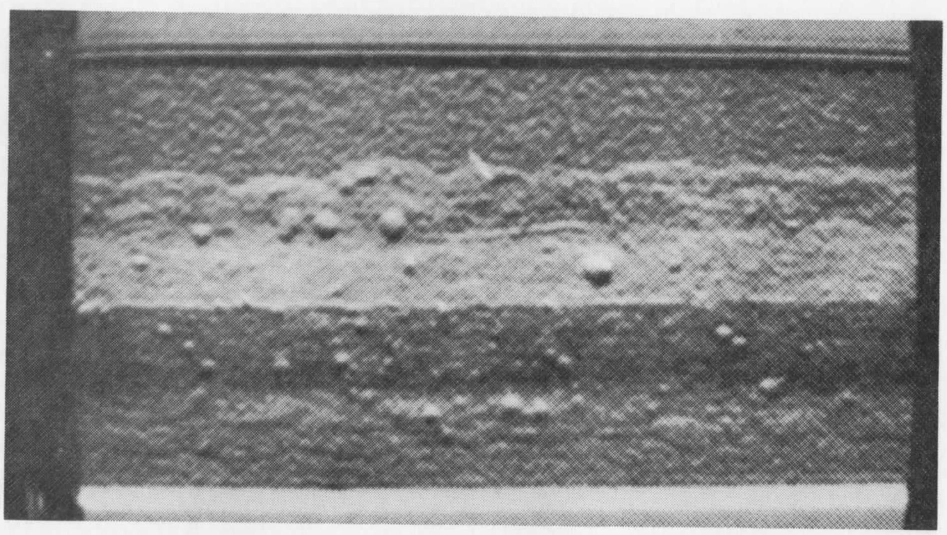
In either case, it is seen that the information content can be optimized by retaining the high spatial frequencies and supressing the low spatial frequencies. We cannot increase the information content of an image but we can increase the apparent information by increasing the signal (the desired information) -to-noise (the undesired information) ratio. By maximizing the signal-to-noise ratio before transmission, we are assured of the maximum signal-to-noise ratio at the receiver after transmission through the ATS channel.

As mentioned above, the broken bone and lung abnormality X-rays contain useful information in the higher spatial frequencies. Figure 1a is a



WELD X-RAY

Figure 1a



ENHANCED WELD X-RAY

Figure 1b

re-photographed picture of an X-ray of a weld between two metal plates. A fine but blurry and interrupted line is seen to run horizontally through the middle of the picture. This is the junction between the two metal plates and is analogous to the bone break. The range of contrasts in this picture is not great, but the spatial rate of change of contrast in the vertical direction is very great. The useful information can be obtained, therefore, by emphasizing the higher spatial frequencies in this figure.

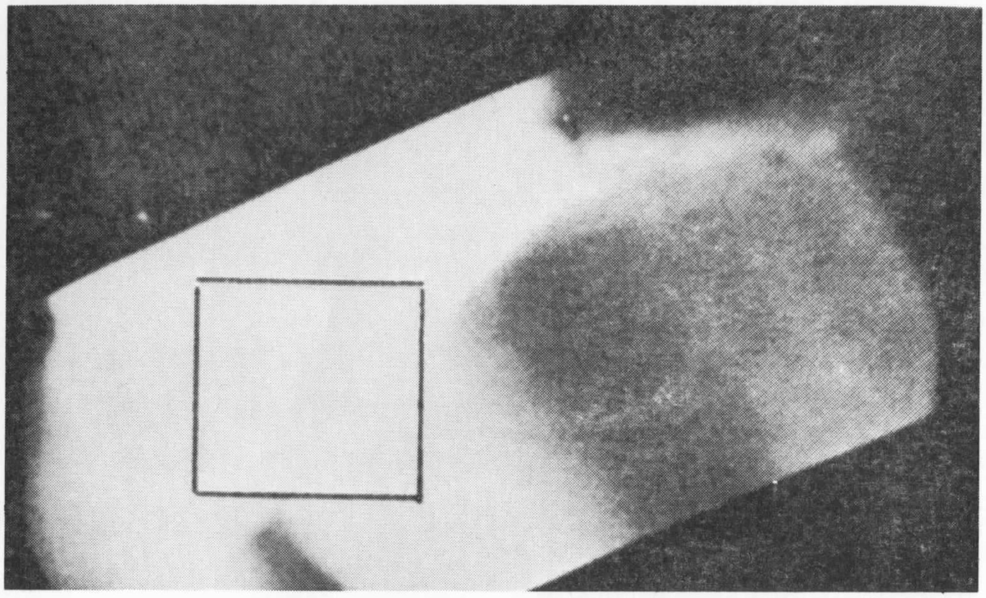
Figure 1b illustrates this by showing the derivative of the image reflectance (Figure 1a) with respect to the vertical spatial dimension. The image is not differentiated horizontally. The differentiation could be done electronically by high-pass filtering in the vertical dimension only. It is obvious from Figure 1b that the presence of the break is more noticeable, i.e., that the signal-to-noise ratio has been increased.

The signal-to-noise ratio could be further increased with nonlinear contrast enhancement. For example, all gray levels below a certain threshold could be made black, and all gray levels above the threshold could be made white.

The lung abnormality X-ray is analogous to the X-ray weld defect shown in Figure 2a. Here the actual defect (inside the small box) is not readily visible. However, if we again differentiate in the vertical dimension, the defect becomes apparent. Again, contrast enhancement might improve the diagnostic usefulness of such an X-ray even more.

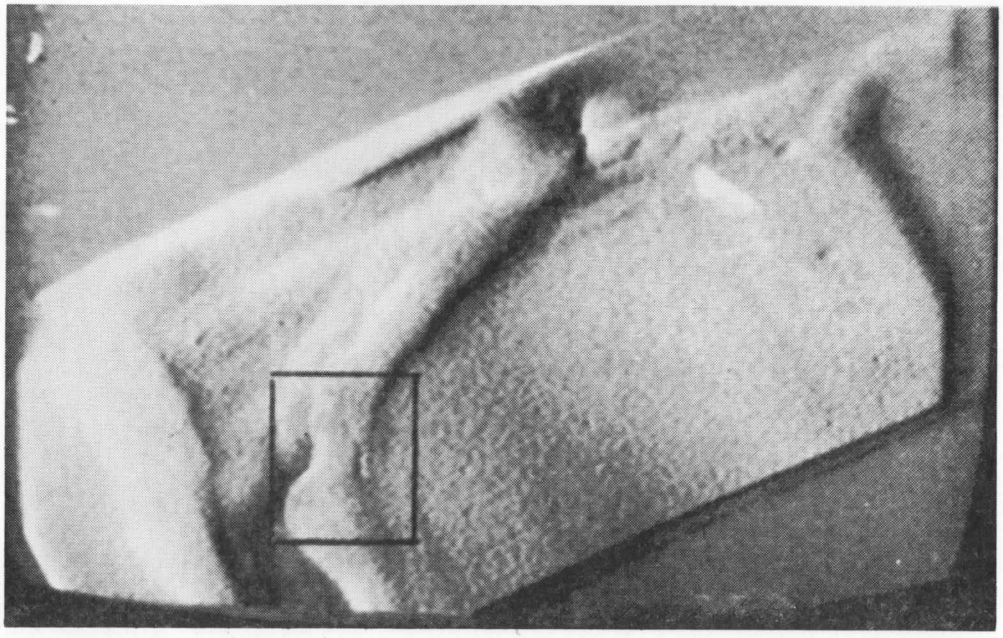
We have argued that two types of processing would improve the readability of medical X-rays: (1) differentiation and (2) nonlinear contrast enhancement. The questions which must yet be answered are:

1. What time constants must be used in the differentiation?
2. What nonlinear contrast enhancement must be used?



ORIGINAL X-RAY WELD DEFECT

Figure 2a



ENHANCED X-RAY WELD DEFECT

Figure 2b

3. In what order must the two processing methods be done?

4. In what orientation must the one-dimensional differentiation be done?

These details of the processing are best done experimentally on actual X-rays.

X-RAY IMAGE PROCESSING TECHNIQUES

It must be decided initially what general type of X-ray image processing technique is to be used. Three possibilities come to mind: (1) processing of sample-valued X-rays by a digital computer, (2) two-dimensional coherent optical processing and (3) analog (or digital) processing of one-dimensional X-ray scans. The three techniques are considered below.

1. Processing of Digitized X-Rays

In this image processing scheme, sample values of an X-ray image are stored as three-dimensional vectors--the two spatial coordinates of a sample point and the transmittance of the X-ray transparency at that point. It is important to note that this data form does not imply a scan of the X-ray in the sense that each data point is uniquely identified by its own spatial coordinates rather than by its relative position in a sequence of data points.

It is quite likely that the data would, in fact, be obtained by a scanning operation, i.e., linear scans of a microdensitometer across an X-ray. But once the X-ray is sampled and stored (preferably in a random access memory), it is possible to process the data in directions different from the original scan direction. The only precaution which must be taken is that the data must be sampled at greater than the Nyquist rate, i.e., at a rate at least twice as great as the highest frequency present in the data, to ensure that the information content is preserved.

Actual image processing is accomplished on a digital computer. The resultant processed sample points are read out in sequence to a digital-to-analog converter and then to a facsimile machine or to a cathode ray tube display.

This image processing technique is advantageous because it uses a digital computer, which is the most versatile method for determining exactly what constitutes an effective X-ray enhancement. Once the most suitable type of enhancement is determined, the digital computer could be replaced by a specialized analog computer for an operational system.

The digital computer is particularly suited to contrast enhancement and one-dimensional spatial filtering. Two-dimensional spatial filtering is also possible but at the expense of a great deal of computer time.

2. Two-Dimensional Coherent Optical Processing

Two-dimensional spatial filtering can be accomplished with Fourier optical techniques. The method is based on the fact that a lens can take the two-dimensional Fourier transform of a transparency (the X-ray). The Fourier transform can then be modified by spatial filters (also transparencies), and Fourier-transformed again by a second lens. The result can be shown to be equal to the convolution of the original X-ray and the impulse response of the spatial filter.

Two-dimensional spatial filtering could be an extremely useful enhancement technique; however, the complications of performing such an enhancement by coherent optical means are formidable. The optical technique requires a sizeable investment in precision optical components. In particular, a continuous output (CW) laser with a coherence length greater than approximately the diagonal dimension of the X-ray is needed. This limits X-rays to small sizes. In fact, photographically reduced copies of the X-rays would probably be required. This is, by itself, not a difficulty. But if this technique were to be adapted to a low-cost operational package, the extra step of photographic reproduction would be undesirable. Two high quality, large aperture lenses, an optical bench and two liquid gates (devices to eliminate wavefront distortion due to photographic emulsion thickness irregularities) would also be needed. The basic set-up is shown in Figure 3.

The spatial filters would probably be nothing more than appropriately positioned masks which would do high-, low-, bandpass- and bandstop-filtering of spatial frequencies. However, it is possible to have complex filters which affect the phase as well as the amplitude of the spectrum of the X-ray. If this type of filter is used, additional optical components are needed so that a modification Mach-Zehnder interferometer can be built to make the filters.

The optical processing method is dependent on the scale and orientation of the X-ray relative to that of the spatial filter. Again, this is not a problem in a laboratory because the scale and orientation can be carefully controlled. But for operational equipment the alignment of the transparencies would be a major problem.

The conclusion to be drawn from the above discussion is that the coherent optical processor, despite its unique two-dimensional processing capability, is unsuitable for X-ray enhancement on an operational basis.

3. Analog (or Digital) Processing of One Dimensional Scans

This technique consists of scanning an X-ray transparency in one dimension and processing that scan line as an entity. Thus, each scan line is treated independently of adjacent scan lines. The processing could be done digitally by sampling each scan line, converting the sample

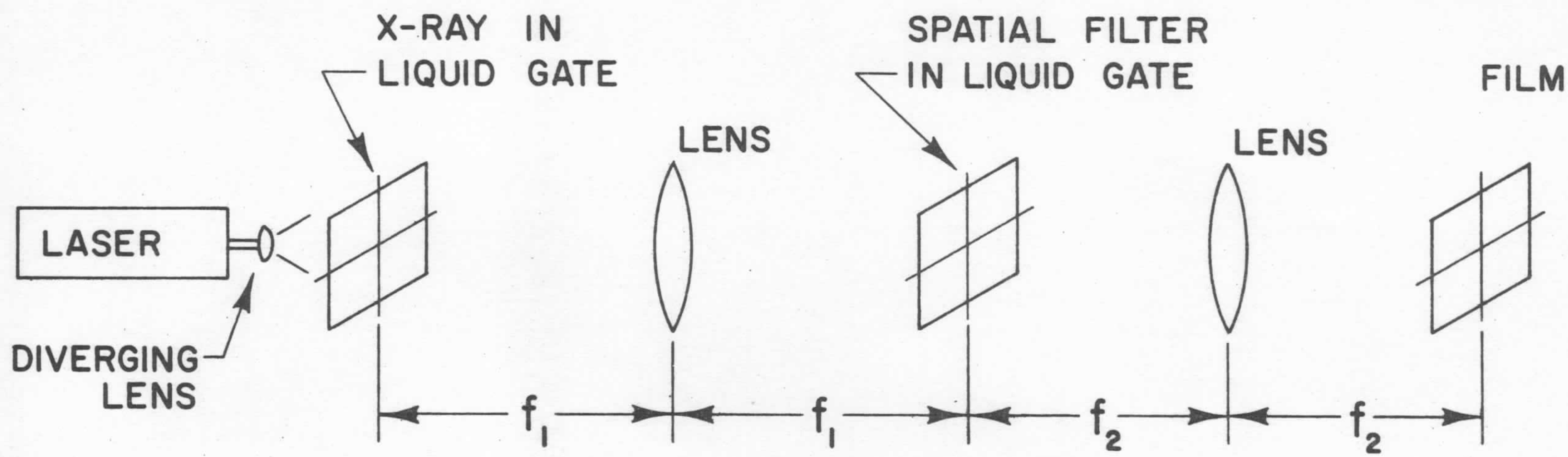


Figure 3: Coherent Optical Processor

values into digital words and processing the digitized scan line as an entity with the digital computer. This technique is versatile, but an operational system would be cheaper and faster if it used an analog computer to do the processing.

Processing individual scan lines is a severe limitation of the X-ray enhancement possibilities. It does, however, offer the possibility of a relatively cheap operational system. Furthermore, there is evidence that one-dimensional processing may be adequate. Figures 1 and 2, the X-rays of welds, have been edge-enhanced (high-pass filtered) in the vertical domension only. It is this system which is being pursued at SSEC.

X-RAY IMAGE PROCESSING EQUIPMENT

This section considers the equipment that is required to perform one-dimensional (scan line) processing. The X-ray processor requires the following subsystems: (1) an optical scanner to convert the X-ray image into an electrical signal, (2) an electronic pre-processor to do the enhancing of the X-ray, (3) an interface to the transmitter, (4) an interface to the receiver, (5) an electronic post-processor to either process the received signal further or to "un-do" the original processing and (6) a reproducer which converts the final electrical signal back into a picture.

There are two basically different design concepts for the scanner/reproducer subsystem. The first concept is a mechanical system similar to a facsimile machine. The basic idea is that the X-ray is placed on a rotating drum and illuminated by a light source. A photocell records light variations at a small point as the X-ray spins on the drum, thus producing a photocell voltage that is proportional to the X-ray film density along the narrow path scanned by the photocell. With each rotation of the drum, a leadscrew mechanism moves the photocell along the drum axis by one scan line width. As the photocell advances across the X-ray, it produces, scan line by scan line, an electrical signal related to the original X-ray.

In the reproducer, a piece of unexposed film is placed on the drum, and a light source, modulated by the received signal, is moved across the rotating drum in synchronism with the transmitter scanner. The light source exposes the film which, when developed, is a copy of the transmitted X-ray.

The advantage of such a scheme is that a conventional facsimile machine could be adapted to the X-ray problem. The modification, however, would be extensive since the device must work on a transparency and, therefore, must be capable of preserving the wide dynamic range of transparency density values.

The second scanner/reproducer concept is the electronic flying spot scanner. This technique, illustrated in Figure 4, consists of a small, constant intensity spot which scans across the face of a low-persistence cathode ray tube (CRT) face to form a raster. The CRT face is imaged onto the X-ray (or a photo-reduced copy of the X-ray) and is, in turn, imaged onto a photomultiplier tube. The photomultiplier tube output is proportional to the X-ray transmittance.

The reproducer would consist of the same CRT flying spot, but now the spot intensity is modulated by the received signal. A polaroid or conventional camera is placed in the image plane of the CRT lens, and, as the flying spot scans the CRT face, the camera records the light intensity variations. The result is a copy of the transmitted X-ray.

This technique offers more flexibility in design and operation than the facsimile device. However, it is generally more complicated and expensive.

The other X-ray enhancement subsystems--the pre- and post-processors and the interfaces--are similar for both scanning subsystems. The processors

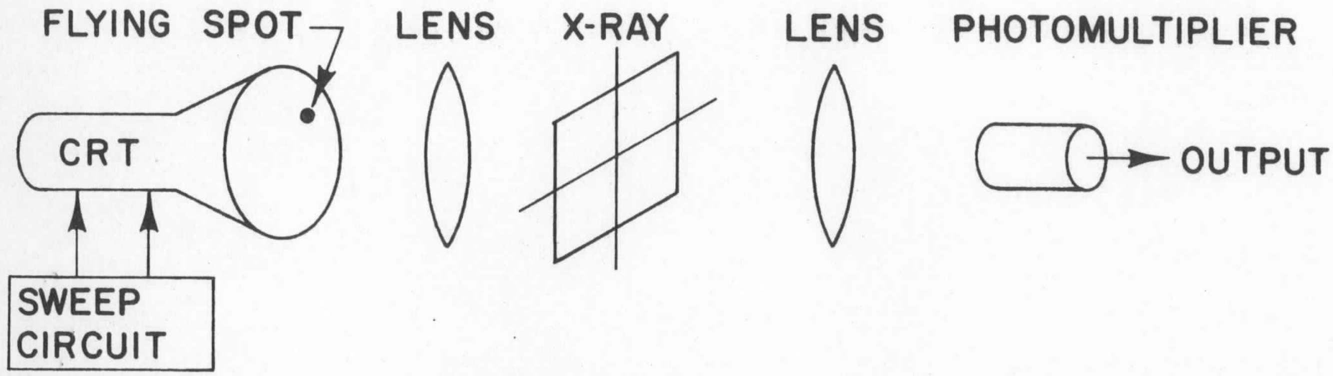


Figure 4: Flying Spot Scanner System

would be nonlinear gain amplifiers for contrast enhancement and electronic filters for spatial filtering. The interfacing circuitry would simply match voltage and impedance levels for compatibility with the available satellite FM communication equipment.

DESCRIPTION OF EQUIPMENT TO BE USED IN THE EXPERIMENT

This section considers a piece of equipment needed to perform the processing of digitized X-rays described above. In particular, a device is discussed which records sample values (two spatial coordinates of a sample point and the X-ray density at that point) in a form suitable for digital processing.

Either the facsimile machine or the flying spot scanner could be used for this. However, a more versatile system would have independent x- and y-position control. Such an arrangement is shown in Figure 5. A transparent table holding the X-ray is rigidly mounted to a frame. A photomultiplier-lightbulb combination, controlled by x- and y-axis stepper motors, moves across the X-ray table and measures the transparency density.

This arrangement would be too slow and expensive for an operational system. However, it is very flexible when used in conjunction with a digital computer for preliminary work to determine exactly what types of enhancement are optimum. Furthermore, this arrangement is particularly attractive because a piece of equipment already exists at SSEC which is being modified for use as a two-dimensional X-ray scanner/reproducer. The piece of equipment is the SSEC optical cloud correlator. The mechanical drive portion of the cloud correlator was a great success. The unsuccessful portions were in the correlator subsystem which will not be used in the X-ray enhancement device. The xy-transport of the cloud correlator has been removed, and

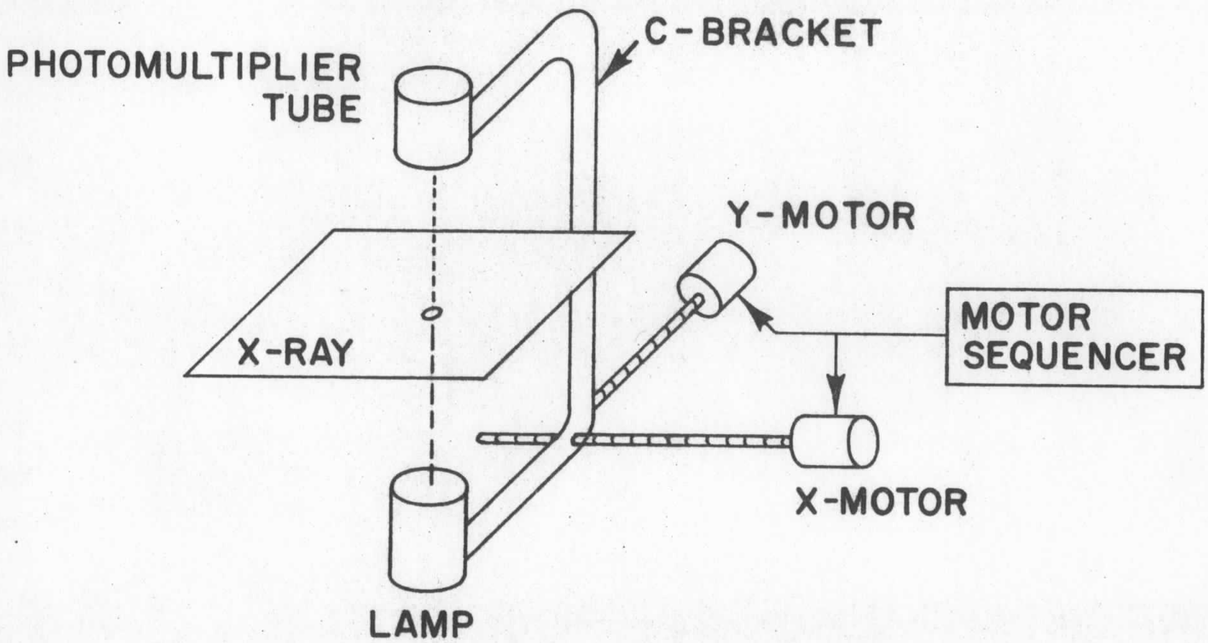


Figure 5: Two-Dimensional X-Ray Scanner

the photomultiplier-lightbulb combination has been fitted to it with a C-bracket as shown in Figure 5.

The system is capable of scanning a transparency up to 5 3/4" by 6 1/2" maximum, with 1008 lines per inch resolution. This would be a maximum of about one million data points per square inch--far more than are needed for sharp resolution. The stepper motors are currently capable of about 240 steps per second, so that 4.5 seconds are required for each inch of scanning in one dimension. (It would take 48 hours to scan a single full-sized transparency!)

The time for one inch of scan can very easily be reduced to about 2.6 seconds per inch with a resolution of 576 samples per inch. If a small photographic reproduction of the X-ray is used instead of the X-ray--say a 2" by 2" transparency--the scan time can be reduced to about 100 minutes. Even 576 samples per inch is more than necessary. By reducing this by a factor of two (by changing motor gearing) a 2" by 2" picture would require 25 minutes for a complete scan.

The data rates are seen to be very low. With further mechanical work, the data rates could be increased. But, for the task of using a digital computer to determine the optimum enhancement process, the low data rates are acceptable. Faster data rates can be obtained (but not in real time) by recording the data on tape at a slow speed and playing the tape back for processing and transmission at a higher speed.

To use the same apparatus as a reproducer requires only that the point light source be capable of being modulated or pulsed. The method of operation would be to put a piece of unexposed film on the X-ray table, scan across the film in synchronism with the original scan and modulate or pulse the light with the received signal. Upon development, the film will be a copy of the received X-ray.

Construction/Modification Progress

Electronic circuitry which controls the stepper motors has been designed, built and successfully tested. This circuitry consists of all the necessary subsystems including power supplies, motor-driver circuits, digital counters and control logic, drive oscillator, manual override circuitry and photomultiplier circuitry.

The photomultiplier circuit has been tested, and a plot of photomultiplier voltage output versus test transparency density has been made. The curve is approximately linear for densities from 0.0 to 3.0. The output voltage at 0.0 density is 20 volts. This will have to be scaled by a factor of two for compatibility with the analog-to-digical (A/D) converter associated with our Raytheon 440 digital computer. A sample pulse signal generator (which tells the A/D converter when to take a sample) must still be made. Both of these are simple tasks.

The original cloud correlator has been modified mechanically for use as an X-ray scanner. In particular, the unnecessary equipment of the correlator has been removed, and brackets for the photomultiplier and light source have been added. In addition, an enclosure has been built for the apparatus so that it can operate in a lighted room. A precision variable-spot-size light source has been fabricated, but it has not yet been aligned and tested.

The final remaining task is to write the computer software to interface with the A/D converter. This has been done frequently at SSEC and is a routine task.

SUMMARY

This report has argued that X-rays contain their useful information in the rapid contrast changes (high spatial frequencies) of the image. It is necessary, therefore, to preserve or even to enhance these spatial frequencies in order to assure faithful X-ray transmission via ATS satellite.

The characteristics of several X-ray processing hardware concepts including digital processing of sampled X-rays, two-dimensional optical processing, and analog or digital processing of one-dimensional scan lines are discussed. It is argued that the one-dimensional analog scanner appears to be the most promising for an operational system. But the method of digital processing of one-dimensional scan lines is the most promising for experimental work because of the available equipment and experience at the Space Science and Engineering Center. The digital processing hardware acts as an input-output device to the digital computer which then simulates the X-ray electronic conversion and enhancement process, the ATS communication channel, and the post-reception processing and conversion back to the image.

IV

SATELLITE

BASE STATION OPERATION

SATELLITE

BASE STATION OPERATION

INTRODUCTION

This section of the report conveys the results of investigations into small terminal satellite ground station operating techniques utilizing the ATS (Applications Technology Satellite)-1 and ATS-3 satellites. The investigations were made over a nine month period at the University of Wisconsin-Madison in cooperation with similar efforts at Stanford University, Stanford, California, and the University of Washington, Seattle, Washington.

Tests conducted in the course of the project involved a series of experiments with voice and data transmission capabilities including hand-written messages (Electrowriter), facsimile (Xerox Telecopier) and slow-scan television. Both the simplex voice (one-way at a time) and the duplex voice (simultaneous two-way) modes of communication were tested. The results of each particular experiment appear elsewhere in this report and in the reports of the other cooperating universities.

It is hoped that the experience gained in ground station operating techniques set forth here will be of value to others who are presently engaged in setting up and operating similar satellite communications ground terminals.

ANTENNA PERFORMANCE

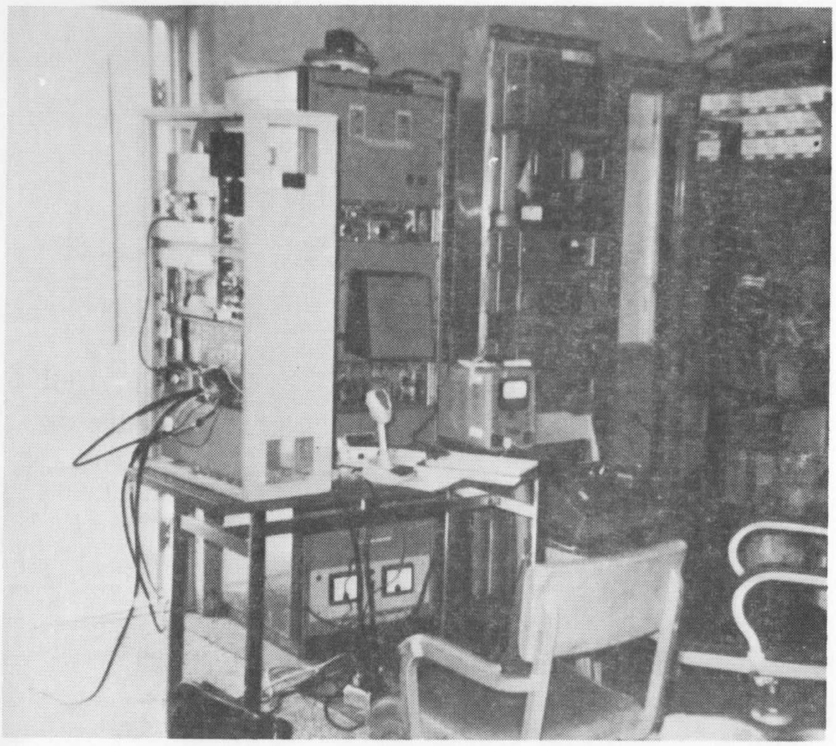
1. General Requirements

Gain The minimum antenna gain suitable for satellite communications can be calculated from power budget requirements. In using a Yagi array, gain can be increased by either adding elements or by "stacking" arrays. In either case, alignment of the antenna and matching harness becomes more difficult for more gain, minimum side lobes in the antenna pattern, and pattern stability. However, practical Yagi antennas with ten elements in the frequency range desired can be constructed by stacking in groups of two or four.

Polarization Another requirement for reliable communications through ATS-1 and ATS-3 is that the antenna be circularly polarized. Both satellites receive as well as transmit using linear polarization. Because of the unpredictability of the sense of this polarization at any given moment, due to satellite position and Faraday rotation of the polarized signal through the ionosphere, it is necessary to utilize ground station antennas which are not influenced by these variations. Therefore, the use of circular polarization is desirable. In the experiments at Wisconsin, major polarization shifts have been detected in less than 15 minutes.

A Yagi array can be constructed for circular polarization utilizing two linearly polarized arrays fed 90° apart in phase through the use of a one-quarter wavelength wiring harness. Several difficulties in utilizing this scheme will be pointed out later.

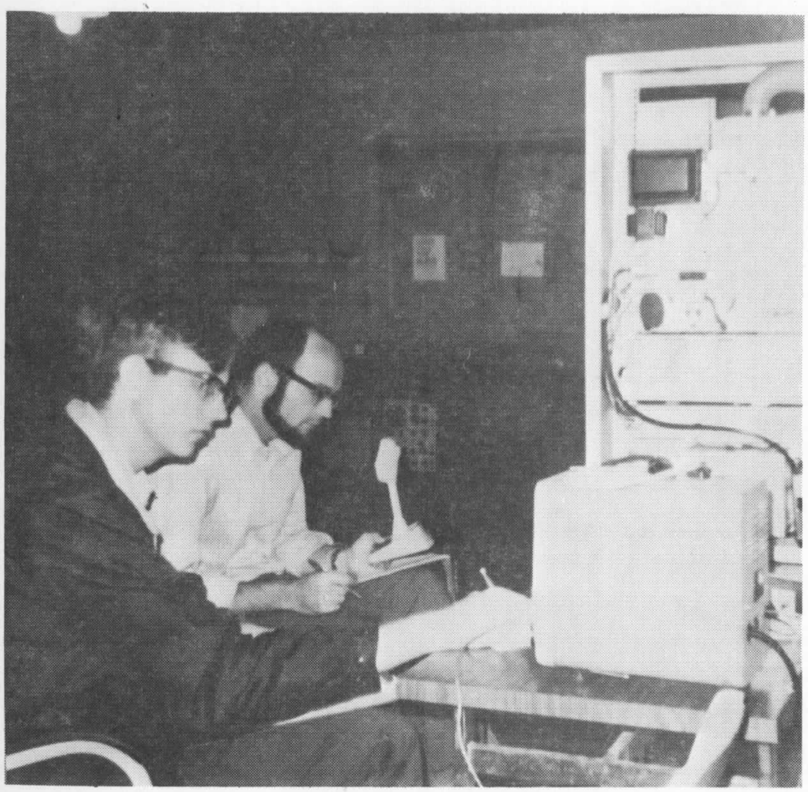
Bandwidth Another desirable quality of an inexpensive satellite communications antenna is large bandwidth. Unless a log periodic structure is involved, the Yagi array will not suffice for both receive and transmit



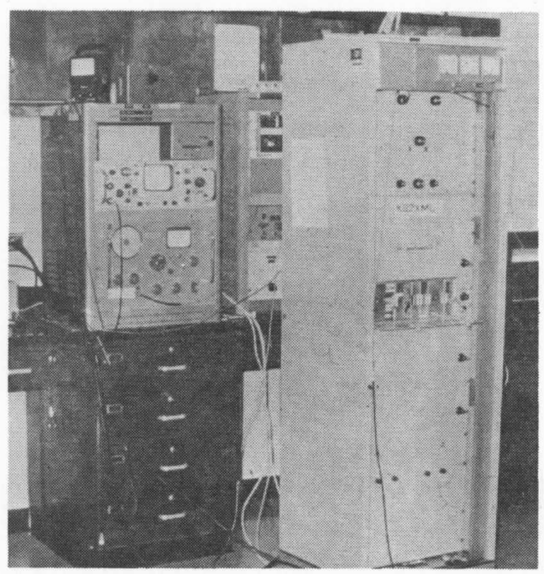
PICTURES OF SATELLITE
BASE STATIONS

(left) Base station at University of Wisconsin Arlington Farms in the rural Madison area. (Motorola 100 watt transceiver in left foreground)

(below) Staff at the Arlington Farms station during medical discussion with Stanford University (October, 1971)



(below) Base station at the Space Science and Engineering Center on the Madison Campus (Motorola 375 watt transceiver)



functions on ATS-1 or ATS-3 due to the large difference between the 135.60 MHz (receive) and 149.22 MHz (transmit) frequencies. Thus, two Yagi antennas are required at the station for simplex operation. This is also necessary in most cases, however, for duplex operation. (A single antenna may be used for both transmit and receive functions simultaneously if a "duplexer" is utilized, at a sacrifice in cost and, usually, with a resultant loss of signal strength.) A helical antenna, on the other hand, has a broad bandwidth and can be used for both transmit and receive functions.

Reliability Other desirable features of a commercially produced ground station antenna are reliability and guaranteed specifications. The following factors should be carefully considered before selection of an antenna:

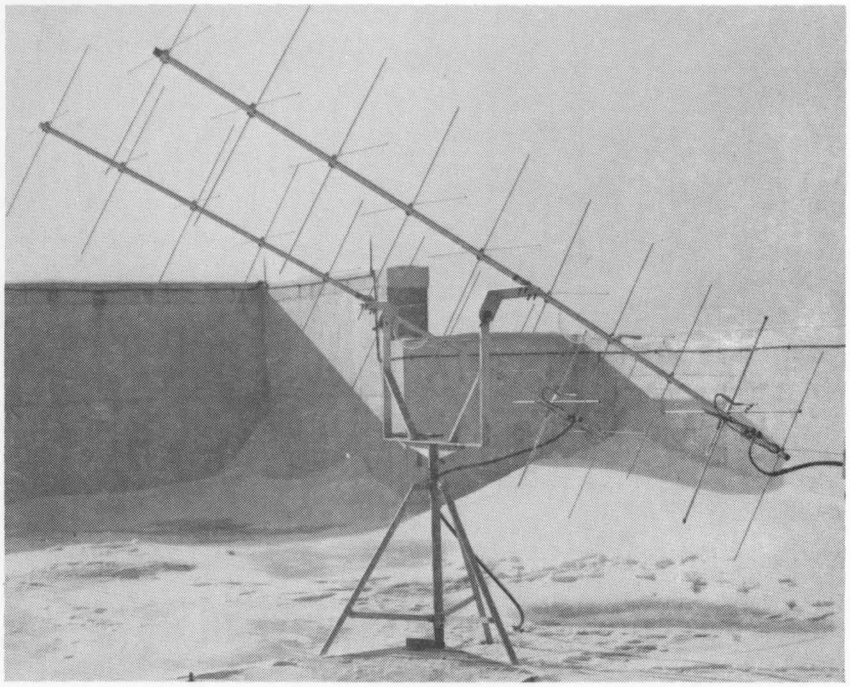
- the effect of weathering and aging on gain and polarization characteristics
- the reliability of the manufacturer's specifications for gain and polarization
- dependability of operation under extreme weather conditions.

2. Evaluation of an Inexpensive Commercial Yagi Array

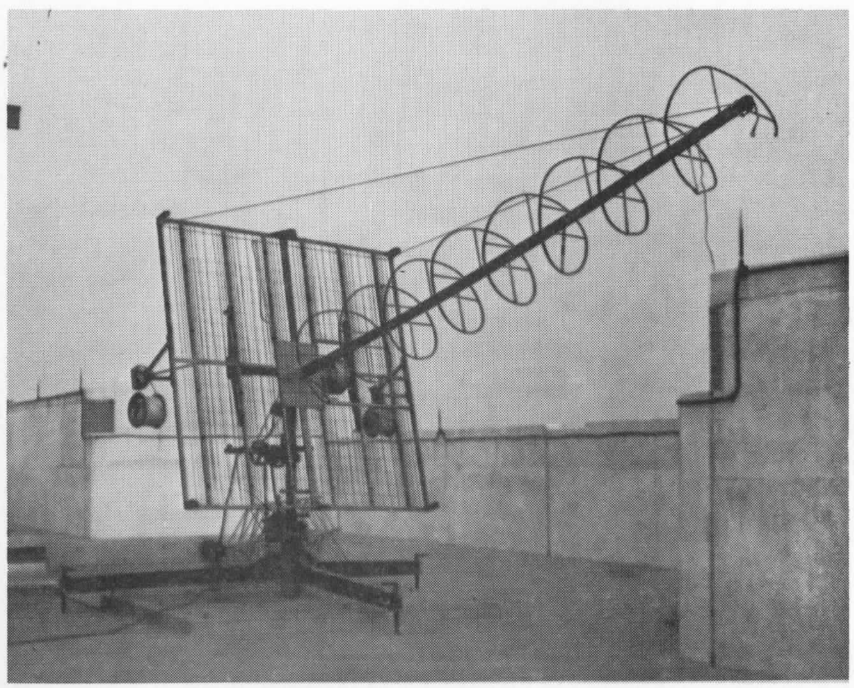
At the outset of the project, it appeared that an inexpensive commercial Yagi array could meet the necessary requirements. Specifications for the antenna cut to frequency were 13.6 dB forward gain at 400 KHz bandwidth for circular polarization. The cost of such a unit was approximately $50.00. A quad array of these antennas costs approximately $250.00. As a result, a quad array was purchased along with two single receive arrays and two single transmit arrays.

Water damage Several difficulties related to effects of water damage presented themselves with these antennas: the gamma matches on the driven elements were damaged; the heat-shrinkable tubing protecting the fixed

PICTURES OF ANTENNAS



(above) Cushcraft Crossed Yagi Antenna



(left) Example of a Helical Design Antenna capacitor of the gamma match allowed water seepage between it and the aluminum it was covering; and the "UHF" style coaxial cable connectors on the gamma matches were damaged. Because of the construction of these connectors, it was impossible to repair or replace them once damaged. Even after extensive weatherproofing utilizing rubber tape, plastic tape, and silicone grease the problem remained. (In planning to construct an antenna, it would be advisable to use type "N" connectors or some other similar constant impedance weather proof connector.)

Polarization Another difficulty involved the poor circular polarization characteristics of these antennas. Even though the antennas were mounted away from any metal booms by using wood standoffs, carrier quieting could be varied by as much as 11 dB by rotating the antenna about its longitudinal axis, thus indicating poor circular polarization. In Figure 1 (a graph of carrier quieting versus signal input power for the Motorola base station receiver), the 11 dB quieting variation indicates an actual variation in polarization of approximately 8 dB. Thus, these antennas had to be continually readjusted during transmission to match the sense of polarization received from, as well as that transmitted to, the satellite.

Because of the critical nature of the Yagi array related to the physical dimensions of construction required for proper operation, other problems which may occur are aging of the wiring harness, causing a degradation in circular polarization, and movement of the antenna elements due to wind, causing a decrease in gain and circularity.

3. Discussion of the Merits of Helical Antennas

Because of the unsuitability of the inexpensive commercial antenna and because of the critical nature of the Yagi array itself, it is suggested that a helical antenna be utilized.

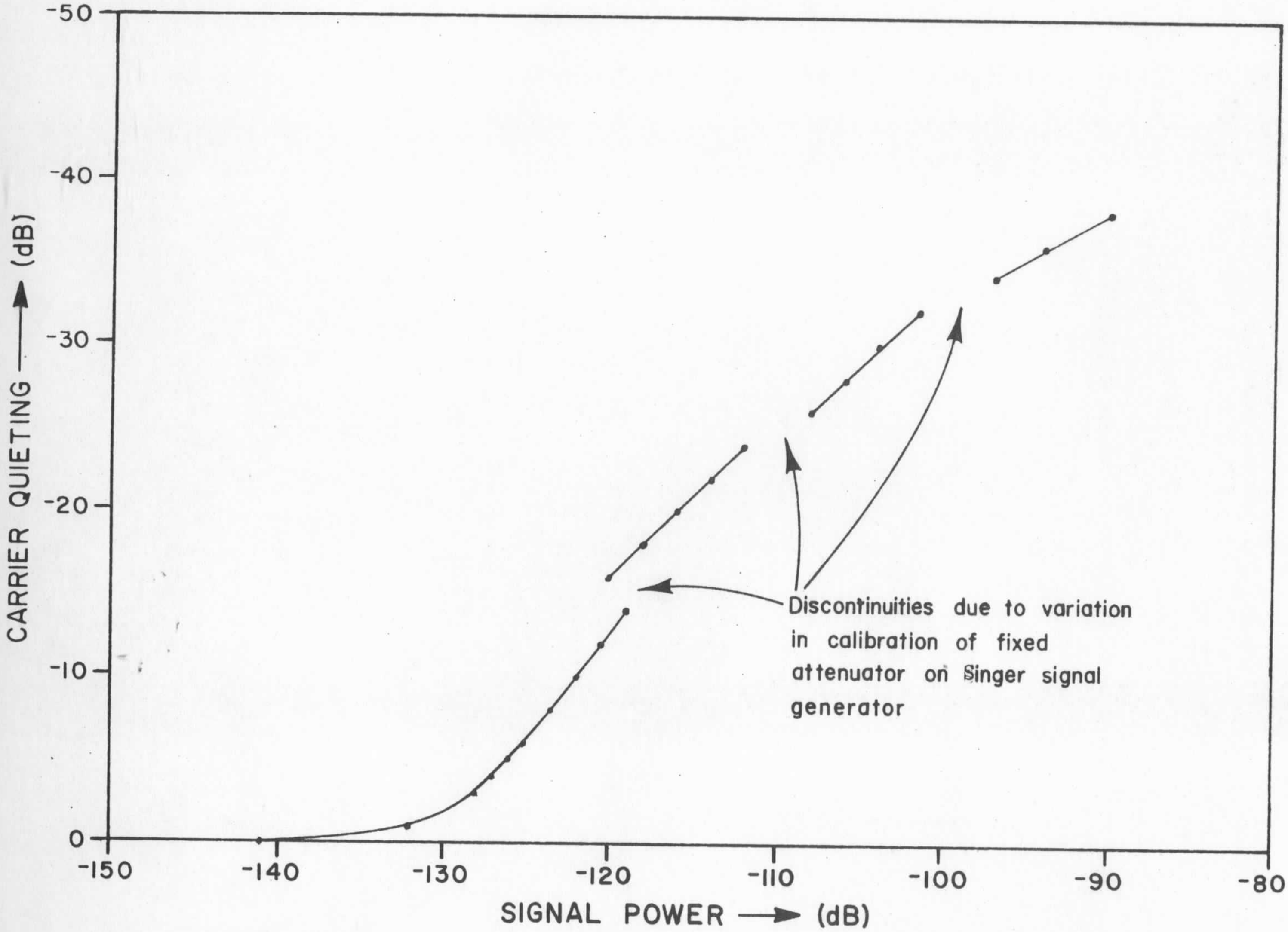


Figure 1: Carrier Quieting vs. Signal Input Power for the Motorola Base Station Receiver

Advantages A helical antenna has many advantages over the circularly polarized Yagi array, for the same forward gain.

1. It is a broadband device and can be used for both transmit and receive in a simplex situation.

2. Being a broadband antenna, it is less critical with respect to construction than a similar Yagi array. Thus it is easier to align. The length of the 90° phasing harness with the Yagi array directly influences the circularity of polarization, and is thus quite critical. Due to the symmetry of the helical antenna, however, the polarization will not be influenced by the length of the matching section. Only the power transfer will be affected.

3. A helical antenna's gain increases linearly with length whereas the increase in gain of a Yagi array is not linear with length. Thus it would be possible to double the effective radiated power of a helical antenna by doubling the physical length. However, to double the effective radiated power of the Yagi array, more than double the length would be required. Thus, stacking two or more Yagi arrays is the usual procedure for increasing gain. This leads to more complications again with the phasing harness and spacing for optimum gain with minimum side lobe structure.

4. In certain situations the side lobe structure of the antenna may be of significance with reference to the ground reflection problem. This is shown in Figure 2. If a phased array is utilized, more side lobes will be present thus adding to the complexity and unpredictability of the problem. A single helical array will have fewer side lobes than a comparable Yagi array. In either case, it is best to mount the antennas near the ground to minimize this effect.

Disadvantages A helical antenna does have some disadvantages in comparison to a Yagi array.

1. It is usually more bulky and more difficult to support mechanically.

2. It usually has more wind loading and, thus, may be more subject to mechanical stress.

3. There are no inexpensive helical arrays suitable for satellite use available commercially.

College Alaska, the University of Washington, and Stanford University have successfully utilized helical antennas of their own design in their programs. Because of their superiority over the Yagi array, as outlined previously, this type of antenna is advisable for use with ATS-1 and ATS-3 satellite communications.

SITE LOCATION

The site location for a satellite ground station is an important factor for successful and reliable communications. When selecting a site, five potential sources of signal degradation must be considered: satellite path obstructions, ground reflection cancellation, propagation changes, electrical interference, and interference from other transmitters.

1. Satellite Path Obstructions

A clear path to the satellite should be of first concern in selecting a site. Even if the path is only partially obstructed by, for example, buildings, hills or mountains, there may be considerable signal degradation due to knife edge diffraction around these obstacles. This may occur, even if the obstruction is some angular distance from the line of sight path to the satellite.

2. Ground Reflection Cancellation

The geometry of ground reflection is shown in Figures 2a and 2b. At low angles of incidence, an antenna is particularly subject to phase cancellation from the reflected wave since the angle of the reflected wave is within the beamwidth of the receive antenna. At higher angles, the antenna side lobe structure may also influence this degradation.

As was indicated in tests related to establishing a better site for the location of the ground station, the best way to deal with this problem is to mount the antennas on the ground in a flat area with a clear view to the satellite. This will eliminate most of the ground reflections and subsequent fading due to changing relative phase shifts between the two paths.

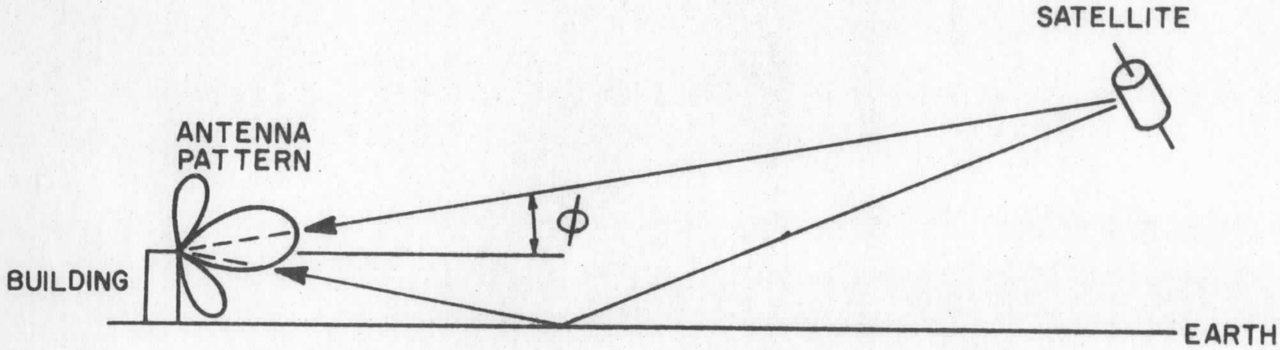


Figure 2a: The Geometry of Ground Reflection at Low Angles (Due to the low angle, ϕ, of the satellite, lobe structure has little effect on ground reflection.)

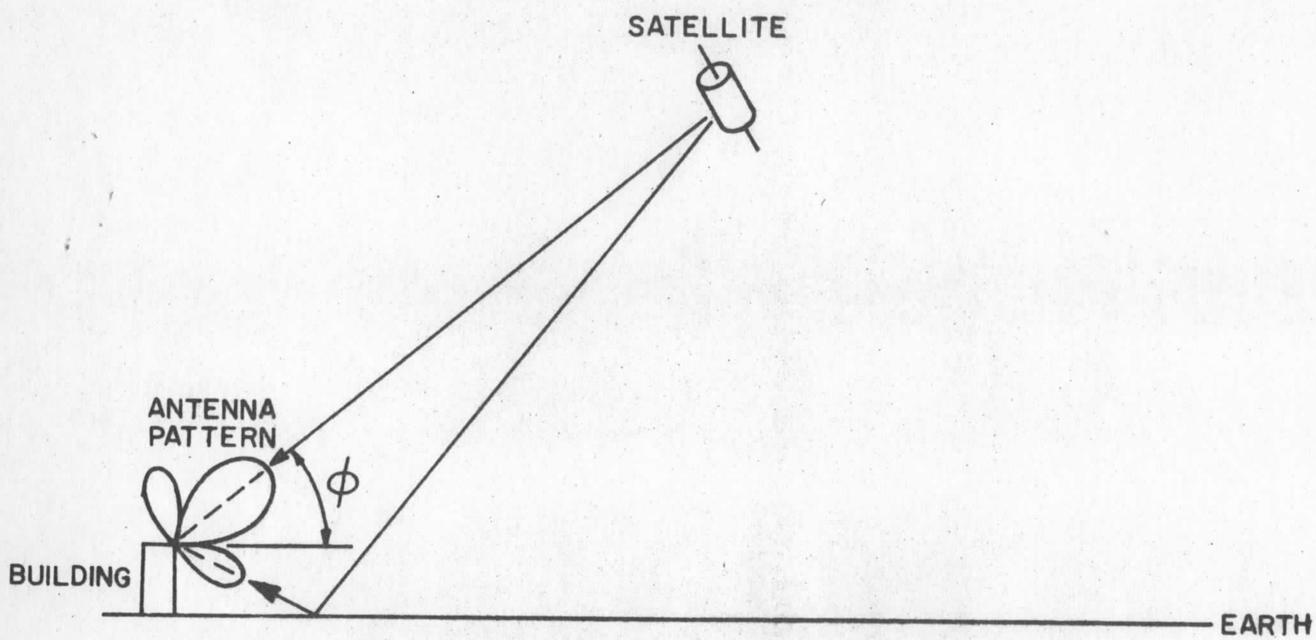


Figure 2b: The Geometry of Ground Reflection at High Angles (With higher angle, ϕ, the side lobe mitigates the ground reflection problem.)

Degradation of signal strength at SSEC, observed during site tests, was due to ground reflection and antenna polarization, since comparable antennas and equipment were utilized at all sites (see Table 1).

One noteworthy result is that reception at remote sites was more consistent (25 dB or greater) than reception at SSEC. Polarization and ground reflection problems create gross fluctuations as well as simple degradation in reception.

TABLE I

SATELLITE RECEPTION AT REMOTE SITES COMPARED TO SIMULTANEOUS RECEPTION AT SSEC

Remote Site	Best Quieting Achieved At Remote Site	Best Quieting Achieved At SSEC
Site 1	25 dB	≈20 dB
Site 2	26 dB	18 dB
Site 3	28 dB	17 dB
Site 4	25 dB*	15 dB
Site 5	27 dB*	10 dB

*Adjusted antennas for Polarization

3. Propagation Changes

Due to the low angle of the path to the ATS-1 satellite from Madison, more atmosphere is encountered along the path thereby increasing propagation difficulties.

One frequent propagation difficulty is degradation of signal strength due to polarization shifts. These shifts are caused by Faraday rotation through the ionosphere. The best solution to this problem is obtained by the use of good, circularly polarized antennas. If such an antenna is used, the polarization of the incoming signal and changes in polarization will be of little consequence.

Another difficulty encountered is related to tropospheric inversion layers. These layers, which consist of warm, moist air over cold air, refract satellite signals which will then be attenuated along the line of sight path. This must be taken into account in the fade margin budget.

4. Electrical Interference

Many types of electrical interference may effect selection of a site. Ignition noise is usually the most common type. Any site should be kept away from well-traveled roads and highways. If located on a farm, attention should be given to keeping tractors and trucks out of the immediate area.

Any type of electrical machine or appliance is also a potential source of interference. Because of the difficulty in suppressing this interference at the source, it is best to place the site away from industrial areas, construction sites, high voltage power transmission lines and highways.

One of the advantages of frequency modulation is its impulse noise suppression property due to hard limiting. However, this noise suppressing property is seriously degraded under marginal reception since the limiters are not fully saturated. Because marginal reception is often encountered, electrical interference is of serious consequence in the average ground station receiver.

5. Interference from Other Transmitters

Aircraft interference One of the difficulties in the use of the ATS-1 and ATS-3 satellites is that their transmitter output frequencies coincide with some aircraft frequencies. As a result, ground station receivers may encounter some interference from either the aircraft itself or the aircraft ground facility transmitter.

At Wisconsin interference has been encountered on 135.60 MHz. A Chicago sectional aeronautical chart indicates that a transmitter exists in Burlington, Wisconsin, operated by the Chicago air route traffic control center on 135.60 MHz. To alleviate this problem on a temporary basis, it is possible to use another channel through the satellite thereby avoiding the signal entirely. Notification of any problems such as these should be made to NASA headquarters.

Receiver Intermodulation If the ground station receiver is located in an area of congested "high band commercial operation" along with VHF broadcasting service operation, there may be a combination of certain frequencies in use which may mix in the receiver and produce a spurious response on the receive frequency. Direct "intermod" such as this is usually characterized as a carrier, with or without audio, and usually a squeal or screech associated with it. Three actions can be taken to minimize this problem: (1) The best alternative is to move the receiver site away from the sources of interference. Because of the unpredictability of this type of interference, it is usually wise to place the receiver outside of any cities and away from broadcasting transmitters. (2) If the interfering signals are spaced far enough away from the receive frequency, a filter (either cavity or special crystal) may be used in the receive line to reduce the strength of the interfering signals. However, there is usually a loss associated with these devices which may be unacceptable under marginal conditions. (3) Another possibility is to obtain a receiver with better intermod performance. Manufacturer's specifications will aid in this matter.

An external preamp will usually degrade intermod performance. If the intermod mixing is occurring in the receiver, the additional gain of the preamp may increase the level of the interfering signals. Also, the intermod may be occurring in the preamp itself. This is especially true of many bipolar transistor preamps. Removing the preamp thus may aid in this problem.

Jamming One of the disadvantages of any repeater system is its susceptibility to deliberate jamming. With the recent publication of the satellite's channel 1 frequencies in a popular magazine, this problem has become potentially more dangerous. If jamming does occur, it may possibly originate from anywhere in an area covering 1/3 of the globe. If there is reason to suspect that it may be originating in a given area, a receive crystal for the ground station transmit frequency may be of aid in locating the source.

In some cases it may be possible to switch to another channel after which the jammer (if he is crystal controlled on the well-known frequency) may give up.

* * * * *

In summary, it is advisable to locate a ground station on flat land with a clear view to the satellite and with antennas as close to the ground as possible. The site should be located far away from possible sources of interference. Heavily populated areas should be avoided if possible.

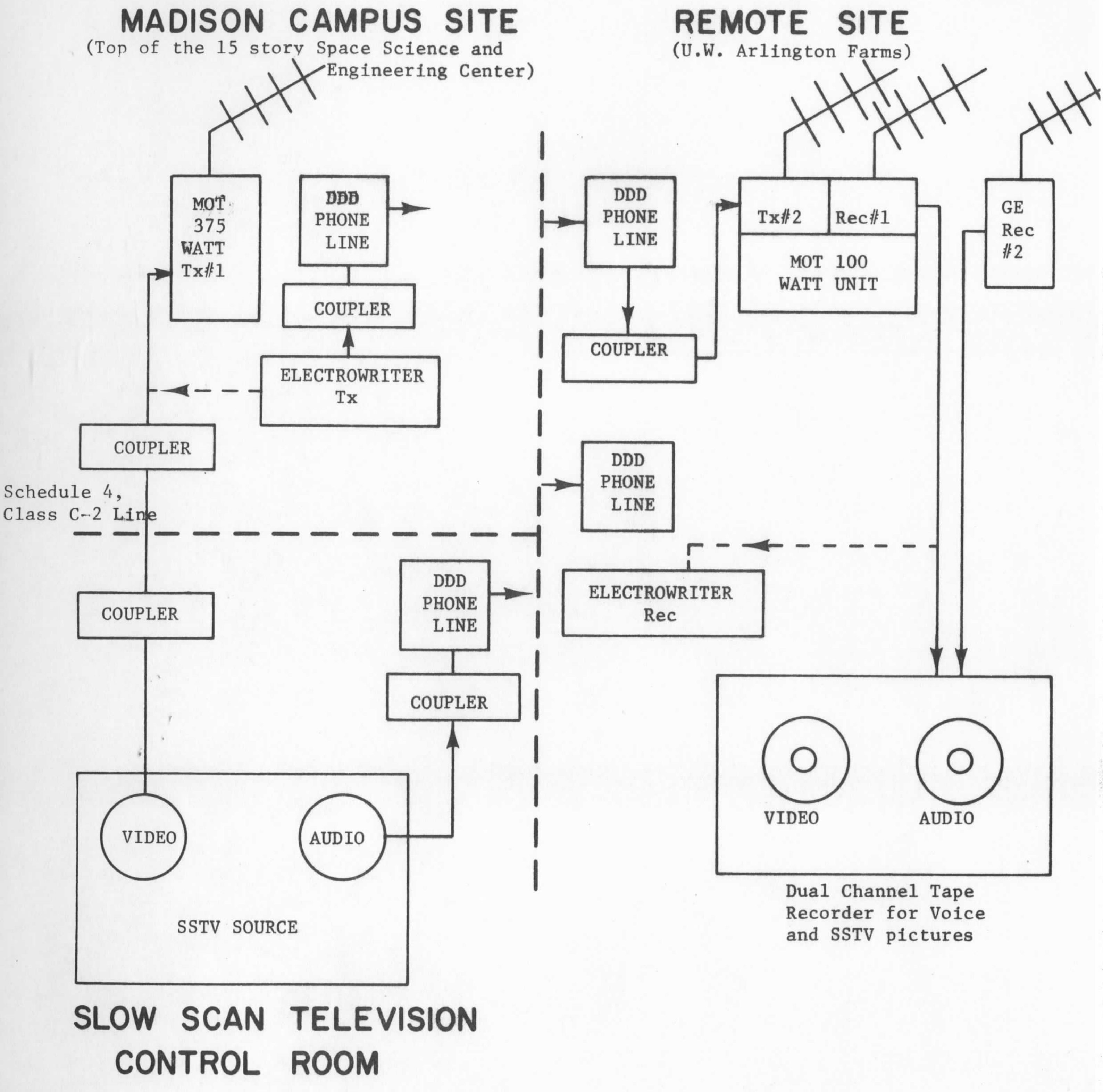
RECEIVER SENSITIVITY

Receiver sensitivity is an important factor in any communications link, especially in the case of the ATS-1 satellite where the satellite's transmitted power is 40 watts at more than 22,000 miles away. The 375 watt

Motorola base station (model #B93 MPB-1136A) receiver has a specified receiver sensitivity of less than 0.5 microvolts (μv) for 20 dB quieting. This is also true of the 100 watt unit (model #C73MHX-1126AR-W-SP1). An alignment by the manufacturer's representative was done on the receiver to ensure performance within specifications. In addition, a preamplifier was used with the receivers producing a minimum specified sensitivity of 0.25 μv for 20 dB quieting. Sensitivities as low as 0.175 μv were measured. During early project tests from the 15 story Space Science and Engineering Center (SSEC) building, reception was poor (at times, 10 dB or less) due to poor site location and antenna performance. (See Figure 3 for diagram of base station set-up.) At that time, special attention was paid to receiver sensitivity in order to obtain better reception. However, improved sensitivity was not the key to better performance as was proved later at the remote site. There, 20 dB and better quieting were experienced with the same sensitivities measured before. The 0.175 μv sensitivity represents about the lowest figure obtainable in standard communication equipment. When using a receiver in an experiment that runs over several months, it is recommended that the sensitivity be periodically checked. A down link power budget for the 40 watt ATS-1 satellite is shown in Table II.

TRANSMITTED POWER

Effective communications links were established through the ATS-1 satellite using two transmitters with different power levels. The SSEC building transmitter was a 375 watt unit with a 70 watt loss in the antenna feed. The transmitter was used with an antenna which had a specified gain of 13.6 dB. This power level usually saturated the satellite and was more than adequate even for the low (poor) transmitting angle to ATS-1 (8-10°



<u>Figure 3</u>: Diagram of Basic Satellite Test Set Up

above the horizon) and the wide antenna beam width (10-20°). The second transmitter was a 100 watt unit used at the remote site which on days with poor atmospheric conditions and low antenna gain did not always provide optimum satellite repeater signals. If the transmit angle is better (greater than 10° to the horizon), if there are low losses in the coax (less than 40 watts), and if an antenna is used which has 10 dB or greater gain, a 100 watt unit is adequate for effective transmissions, as shown in Table III.

Maximum power, as stated in the FCC's Rules and Regulations, Part 5, Paragraph 5.015,... "shall not be in excess of the maximum obtainable power of the transmitter consistent with satisfactory technical operation."

Limits on types of emissions are stated in that document and are listed under Paragraph 5.103. The reader is referred to that document for definitions and regulations.

OPERATOR INTERFACE

Prior to an experiment, actual operator convenience is all too often given little thought. Yet it is this man-machine interface that makes for a successful and efficient experiment.

During a typical experiment, an operator will be required to operate the transmit switch, volume control, squelch control; read the power output meter, frequency deviation meter; make quieting measurements; switch in auxiliary equipment (e.g., Electrowriter, tape recorder); operate the equipment, and record measurements all within alloted satellite time. If excessive air time is spent getting equipment positioned and married together, this robs valuable experiment or satellite programming time.

TABLE II

VHF Communication Link

Power Budget for ATS-1

Down Link fo = 135.6 MHz

Required Received Carrier Power in dBw For .25 v Sensitivity for 20 dB Quieting	-149.2
Transmitter Power, dBw	16.0
Transmitting Losses, dB	-2.4
Path Losses, dB	-166.6
Polarization Loss, dB	-3.0
Line Loss	-1.0
Receiving Antenna Gain	13.6
Spin Modulation Fading Allowance	-3.0
Degradation Due to Tropospheric Refraction (Depends on Weather)	?
Probable Received Carrier Power Under Stable Conditions	-137.4

TABLE III

VHF Communication Link Power Budget

Up Link fo = 149.20 MHz
B = 25 KHz

Receiver Noise Figure, dB	5
Receiver Noise Temperature, °K	660
Receiving Antenna Noise Temperature, °K	300
Total Noise Temperature, °K	960
Total Noise Temperature, dB above 1°K	29.8
Boltzmann's Constant, dBw/°K/Hz	-228.6
RF Bandwidth, dB above 1 Hz	44.0
Total Receiver Noise Power dBw	-154.8
C/N Allowance, dB	10
Required Received Carrier Power, dBw	-144.8
Transmitted Power, dBw	20
Transmitted Posses, dB	-1
Transmitting Antenna Gain	13.6
Path Losses, dB	-167
Receiving Antenna Gain	8.5
Receiving Losses, dB	-1
Polarization Loss, dB	-3
Spin Modulation Fading Allowance	-3
Probable Min. Received Carrier Power, dB	-132.9

Power Margin 9.9 dB

All equipment which must be operated and material that is to be read by the controller must be within arm's reach from a seated central location. All equipment that must feed into the transmitter should be wired to a central selector switch to provide convenient operator selection and isolation. In many cases, the person giving the lecture may need one hand on his notes and another to operate a visual aid, requiring a complete hands-off operation of the radio. In the case of simplex operation, a simple toggle switch is required to convert from voice to visual aid transmission.

While each station site and test set-up is different, it cannot be over-emphasized that each transmission be proceeded by a dry-run to check for equipment interface and possible operator inconvenience and confusion. All switch positions must be labeled and diagrams of the controls posted in a convenient spot for immediate reference.

It is imperative that courtesy and consideration always be used when working with a satellite communications link that has many users and listeners. General rules of operation having to do with station identification, test identification, time usage and sign off calls are the radio operator's "punctuation marks." They should be carefully followed. Proper air time authorization from ATS Operations Control is important. Unless test times are carefully confirmed, resulting confusion may lead to interference with another station's test. "Keying" the carrier signal at the wrong time, for example, can destroy the experiment of another group.

V

GENERAL RECOMMENDATIONS

GENERAL RECOMMENDATIONS

1. The versatility and scope of coverage offered by the combination of telephone and satellite image transmission offers great potential for the future. Such a combination will unite the extensive coverage capability of telephone with the long distance isolated coverage advantages of satellites. Research effort on future satellites (ATS-F&G) is recommended to develop a technical capability for combining the media of telephone and satellite.

2. ATS-1 experimentation should continue as long as possible focusing on the utilization of the voice and facsimile transmission. These forms have already been demonstrated to be technically feasible. The development of software and the application of this media to solve present problems and experiment with new projects can continue without waiting for more sophisticated satellites. Demonstration of the versatility and practicality of satellites in the near future can provide visibility essential for long range future support and development.

3. In the future, there will be circumstances when narrow band with television via satellite will be feasible and practical for education and service purposes. Research and development should be continued using ATS-F.

A P P E N D I C E S

Appendix I

OBTAINING NASA AND FCC APPROVAL FOR EXPERIMENTAL OPERATION

The first step toward authorization for the use of ATS-1 or ATS-3 is to write a letter to

Mr. Richard B. Marsten
Director, Communications Programs
Office of Space Science and Applications
National Aeronautics and Space Administration
400 Maryland Avenue, S.W.
Washington, D.C. 20546

Once authorization is obtained, the contact for operational matters is

ATS Ground Support Manager
Code 460
Goddard Space Flight Center
Greenbelt, Maryland 20771

Further information can be found in the "ATS UHF Experimenter's Guide."

In addition to NASA approval, the experimenter needs a radio station license to transmit on 149.22 MHz and 149.25 MHz.

The necessary forms can be obtained from

Federal Communications Commission
Washington, D.C. 20554

The two forms required are

1. FCC Form 440
   Application for New or Modified
   Radio Station Construction Permit
   Under Part 5 of FCC Ruler

2. FCC Form 403
   Application for Radio Station License
   or Modification Thereof

Approximately 90 days are required for receipt of the license. Further information is in "Rules and Regulations Part 5" of the Federal Communications Commission.

Appendix II

MODIFICATIONS REQUIRED FOR OPERATION OF THE MOTOROLA 100 WATT COMPA-STATION

(Model No. C73MHX-1126AR W SP1)

The use of separate receive and transmit antennas is required when using the Yagi array since the transmit and receive signals are on widely separated frequencies. The receiver input cable was disconnected from the antenna relay and connected to an additional UHF connector that was mounted on the back panel. The transmit antenna connections were left unchanged.

It became necessary to disable the receiver mute control circuitry in order to prevent receiver muting when operating in the "duplex" mode. This modification also permits monitoring of the transmitted signal coming back. Diode CR7, line driver disable, was removed from the line driver module. Receiver wires for audio disable (#13) and receiver mute (#14) were also removed.

The receiver control circuitry automatically connects channel element number one to the receiver when the transmitter is operated on transmit channel one. The receive and transmit elements for channel number two function in a similar manner. The automatic switching was disabled by the removal of diodes CR12 and CR13 on the C2-R2 control module. A SPOT toggle switch was connected between ground and the two receiver channel elements to allow amnual channel selection. The switch was physically mounted on a small metal bracket that was mounted on the C2-R2 control module.

Two notch filters, one for receive and one for transmit are located on the F1 control module. The notch filters, which have a center frequency of 2175 Hz, suppressed desired signal information in the Electro-writer and slow-scan television experiments.

The filters were disabled by removing the input and output leads from the filter and then coupling these leads together with a capacitor.

Appendix III

MODIFICATIONS REQUIRED FOR OPERATION OF THE MOTOROLA 375 WATT BASE STATION

(Model No. B93MPB-1136A)

Modifications on the Motorola 375 watt Base Station were more extensive than the modifications to the 100 watt Compa-Station. This is due partly to the fact that the Base Station has two receivers and partly to the addition of the manual mute control.

A list of wire and component changes and a circuit diagram are shown below, as well as a block diagram of the modified base station control circuitry. Antenna connection changes are identical to those on the Compa-Station.

The mute control modifications provide several options. Switch S4 is a SPDT "center-off" toggle switch. In the "center-off" position, neither receiver is muted at any time. In the "up" position, receiver one or receiver two, depending on the position of switch S3, will be muted at all times. In the down position, the receiver selected by Switch S3, will be muted only when the transmitter is operated.

The manual, channel selection modification on the Base Station was identical to the modification on the Compa-Station, with the exception that two switches were added because the Base Station has two receivers. The squelch and level controls for receiver number two were trim pots mounted on the C2-R2 control module. These pots were replaced by conventional one-turn carbon pots in order to provide easier access. The switches and pots are mounted on a bracket that is mounted on the C2-R2 control module. The notch filter modification that applied to the Compa-Station also applied to the Base Station.

Wire Changes

1. Remove (Cut P.C. Line) connection from Pin #19 of Station Logic Module to Pin #3 of C2-R2 Control Module.

2. Remove (Cut P.C. Line) connection from Pin #9 of OP Module to Pin #9 of C2-R2 Control Module.

3. Add wire from Receiver 1 Mute (Pin #C-1) to Pin #19 of C2-R2 Control Module.

4. Add wire from Station Logic Module (Pin #3) to Pin #18 of C2-R2 Control Module.

5. Add wire from Receiver 2 (Pin #F-2) to Grey Wire Pin #3 of C2-R2 Control Module.

6. Add wire from Receiver 2 (Pin #F-3) to Pin #9 of C2-R2 Control Module.

Components Removed

1. Line Driver Module -- diode CR7

2. C2-R2 Control Module -- diode CR10

3. C2-R2 Control Module -- diode CR12

4. C2-R2 Control Module -- diode CR13

Components Added - C2-R2 Control Module

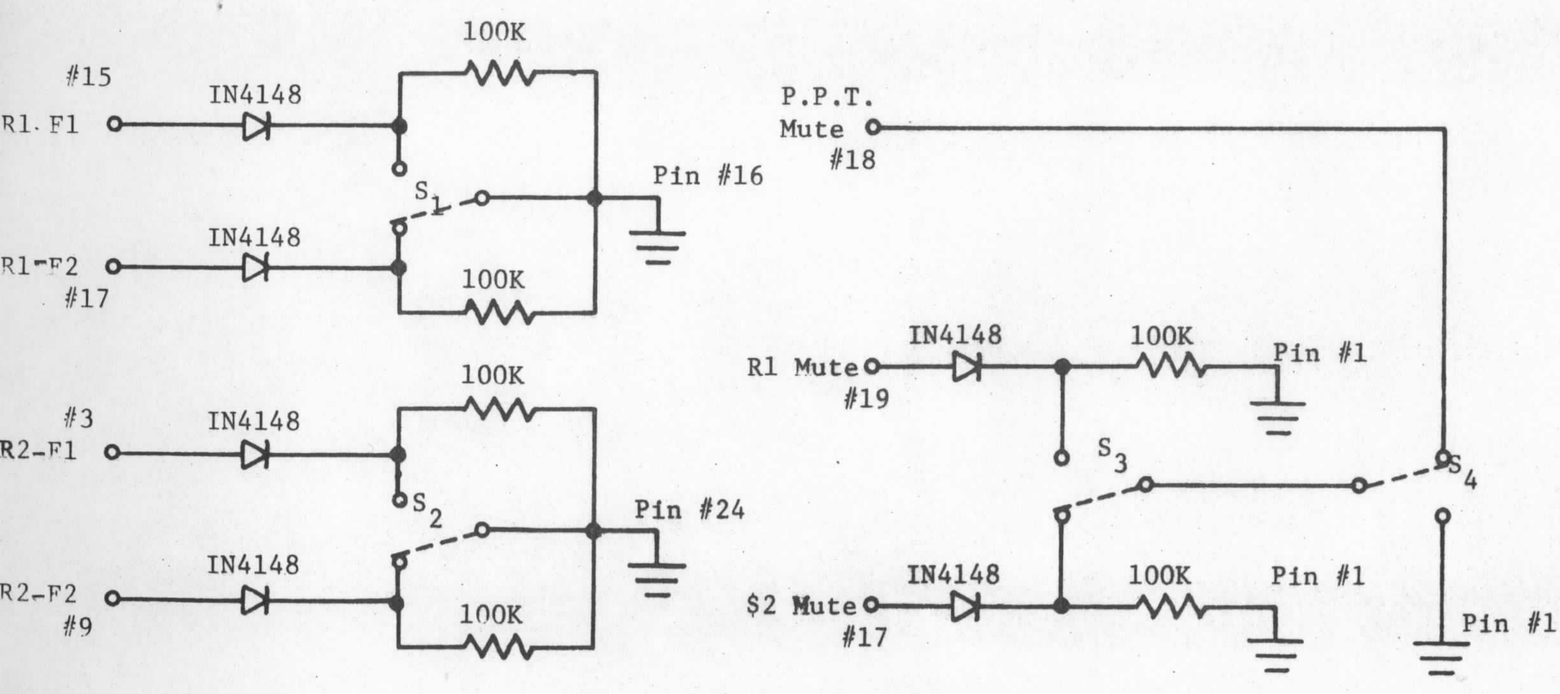


Figure 1: Diagram of Circuit Changes

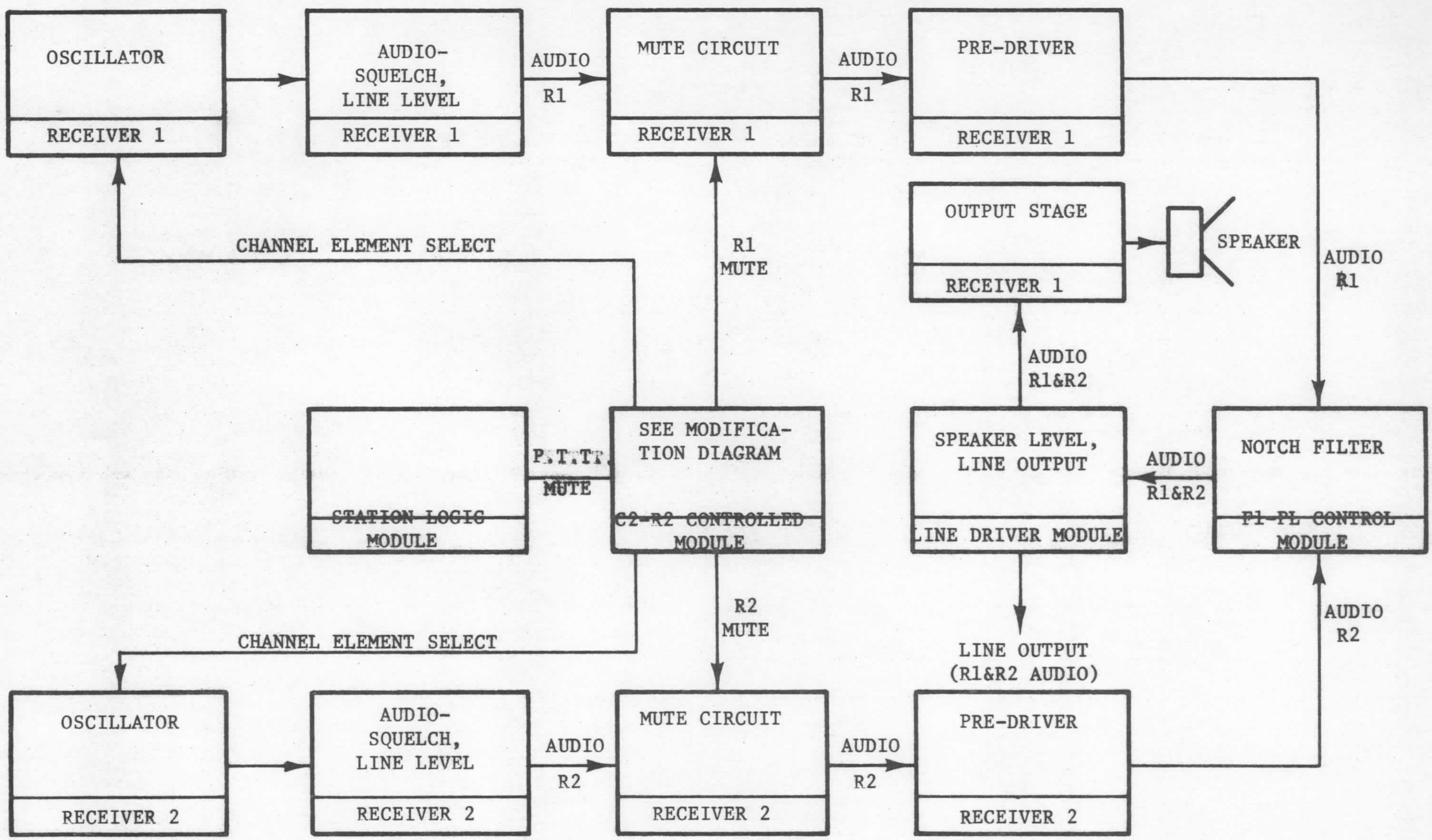


Figure 2: Modified Base Station Control Circuitry

APPENDIX IV

SPECIFICATIONS FOR VOICE BANDWIDTH DATA CHANNELS

AT&T, the source of most communication channels of this nature, specifies and guarantees the electrical characteristics of most of its leased telephone lines. FCC Tariff No. 260 describes the most commonly used line, Type 3002. This line is virtually the same as lines used on a dial-up telephone network. The Type 3002 is designed primarily to handle the electrical characteristics of voice, but it can also transmit data alternately such as the Electrowriter. Aside from AT&T administrative instructions, the type 3002 has no FCC regulated distortion specifications. Even though the line's frequency response extends from about 300 Hertz to over 3000 Hertz, its usable bandwidth is very narrow; only about 1800 Hz. AT&T only specifies distortion levels between 800 and 2600 Hz. Within that frequency range, its frequency response can vary in amplitude by as much as 10 dB. Its bandwidth can vary, its envelope delay can vary, and its characteristics can even vary with the weather. To widen the usable bandwidth, AT&T offers at additional cost, line equalization to specified and federally regulated electrical characteristics.

Table of

Specifications for a Voice Bandwidth
Data Channel (3002) (Courtest of AT&T)

General Characteristics	
Type of Service	2 Point or Multipoint
Mode of Operation	Half- or Full-Duplex
Method of Termination	2-wire or 4-wire
Imped-Source & Load	600 ohm- Resistive-Bal.
Maximum Signal Power	0 dBm for Composite Data Signal, 0 VU for Voice
Attenuation Characteristics	16 dB ± 1 @ 1000 Hz
Measured between 600 ohm Impedances at Lineup (Recommended)	Short-term ± 3 dB
Expected Max. Variation of Loss	Long-term ± 4 dB
Frequency Response (Ref.) 1000 Hz	Freq. Range-Var. dB 300-3000, -3 to +12 500-2500, -2 to +8
Frequency Error	±5 Hz
Delay Characteristics	
Absolute Delay	Not Specified
Envelope Delay Distortion	Less than 1750 us @ 800-2600 Hz

APPENDIX V

University of Wisconsin--Madison

EDSAT Center

NLM Project

SATELLITE EXPERIMENT: MEDICAL USES OF ELECTROWRITER EVALUATION PROCEDURES

I. Introduction

Satellite communication systems utilize "stationary" satellites to relay radio signals. Using the present experimental educational satellite system, radio transmissions which would originate from any location can be beamed to a satellite, which would then retransmit the same information. Because of the height of the satellite above the earth, any receiving equipment within an area covering 1/3 of the surface of the earth can utilize the transmitted information.

Communication satellites have been used commercially for several years. Many applications, some in the field of education and health are in the process of being developed and evaluated. Such systems offer the opportunity for 1) communication over long distances (often where telephones are unavailable or impractical) and 2) the origination of messages from any site within the communication "shadow" (area) of the satellite and 3) dissemination and reception of the communication over an area as large as 1/3 of the surface of the earth.

Electrowriter is a method of transmission of a handwritten copy over distance. The equipment has been designed for the transmission of the image over commercial telephone lines. However, it has been demonstrated that many types of data signals conveyed over telephone lines can also be transmitted with little difficulty over long distances via radio. This fact has prompted the experimentation of sending many different kinds of data - designed for telephone transmission - via radio.

II. Experiment

The EDSAT Center has recently completed a series of tests with Stanford University sponsored by the National Library of Medicine which were designed to investigate the use of satellite communications for medical purposes. The NASA experimental satellites ATS-1 and ATS-3 were utilized. These same satellites are now being used for actual health care and health education purposes in isolated areas within the State of Alaska.

A main objective of the Electrowriter experiment is to assess and evaluate the Electrowriter as used via experimental satellite in the health sector. This includes the evaluation of this medium--at the present state-of-the-art--for such areas as acute patient care, education of health professionals, health education of a public, medical research and administration.

In this phase of evaluation there will be participation by those involved in health education at both the University of Wisconsin and at Stanford. The results of several experiments will be presented. It is important to note that the medium and not the program content is to be evaluated.

To demonstrate the potential of the medium, several types of information have been transmitted--charts, graphs, line drawings, words, phrases, numbers and combinations of these.

III. Evaluation

This evaluation will have seven (7) parts.

1. Demonstration of the Electrowriter
2. Evaluation of Electrowriter performance via satellite in mode 1
3. Evaluation of Electrowriter performance via satellite in mode 2
4. Comparative evaluation of Electrowriter with voice in modes 1 and 2
5. Evaluation of the Electrowriter as a medium for conveying medical information
6. Evaluation of potential applications
7. General comments

In this experiment, two alternative modes have been examined for the transmission of Electrowriter messages (images) accompanied by voice.

Mode 1 utilizes a single transmitting channel so that only the voice or the written message may be transmitted at any given time. In this mode, the two signals cannot be sent simultaneously.

Mode 2 utilizes two transmitting channels so that the two signals can be transmitted simultaneously.

An important characteristic of mode 1 is that the total time consumed by transmitting voice commentary and a written message separately is more than the time consumed by transmitting the same information simultaneously as in mode 2. Typical Electrowriter messages require two-four minutes for transmission depending on their complexity.

An important characteristic of mode 2 is that, given the present state-of-the-art, the two signals when transmitted simultaneously are weaker and therefore "noisier." This means that either the quality of the voice or the message or both may not be as good as in mode 1.

Please keep in mind that the Electrowriter is being considered primarily as an aid to voice communications to isolated areas where communications are presently marginal and where telephones could not be used. It is assumed that two-way communications between a central location and isolated areas would be available. This means that each station could transmit and receive the Electrowriter messages along with voice communications. Communications may be between a single source and single receiver or a single source and many receivers (e.g., villages in Alaska).

Part 1 - Demonstration of the Electrowriter

a) The person in charge of the demonstration will write a few words and sketch 1 or 2 simple figures to show you how the Electrowriter works. [The EW transmitter will be connected directly to the EW receiver and to the EW overhead projector.]

b) Person in charge will briefly explain principles of operation.

Part 2 - Evaluation of Electrowriter Performance via Satellite in Mode 1

a) Person in charge will play segment 1 of cassette tape. This recording was made 6 January 1972. Transmission originated at Madison and was received at Stanford and Arlington, Wisconsin. This recording was made at Arlington. [While tape is playing, person in charge will simulate free hand the messages actually transmitted while the EW tone is transmitted. Use EW overhead projector.]

b) When segment 1 of tape is completed, person in charge will project actual results (transparencies E1-E5) obtained via satellite on a normal overhead projector.

c) Evaluators will at this point respond to questions A-1 and A-2 on the questionnaire.

Part 3 - Evaluation of the Electrowriter Performance via Satellite in Mode 2

a) Person in charge will play segment 2 of cassette tape. This recording was made 13 January 1972. Transmission originated at Madison and was received and recorded at Stanford. [While tape is playing, person in charge will again simulate free hand the messages actually transmitted while voice was being transmitted. Use EW overhead projector.]

b) When segment 2 of tape is completed, person in charge will project actual results (transparencies E6-E9) obtained via satellite on a normal overhead projector.

c) Evaluators will at this point respond to questions A-3 and A-4 on the questionnaire.

Part 4 - Comparative Evaluation of Electrowriter with Voice in Modes 1 and 2

a) Person in charge will project actual results obtained via satellite in modes 1 and 2 to serve as additional data for comparison. (Transparency E17)

b) Evaluators will respond to question B on the questionnaire.

Part 5 - Evaluation of the Electrowriter as a Medium for Conveying Medical Information.

a) Please read:

As a medium for conveying medical information the Electrowriter has some obvious advantages and disadvantages. For example, it permits the speaker to make written notes, comments, diagrams, etc. as he talks.

The pen itself can be used as a pointer to emphasize particular notes. The whole message may be projected on to a screen for simultaneous large-group viewing at remote sites. On the other hand, the Electrowriter cannot transmit photographs or very complex charts and figures as can be done via satellite with the Xerox Telecopier.

The purpose of this part of evaluation is to get your reaction to the information-carrying capability of the Electrowriter as it might be applied in several kinds of medical communications.

b) Person in charge will show actual results (transparencies E10-E16) on normal overhead projector. These results, together with what you have already seen will serve to illustrate the kinds of information that can be successfully transmitted.

c) Evaluators will respond at this point to question C on the questionnaire.

Part 6 - Potential Applications of the Electrowriter in Medical Communications to Remote Areas

(Please respond to question D on the questionnaire.)

Part 7 - General Comments

(Please respond to question E on the questionnaire.)

16 February 1972

APPENDIX VI

Electrowriter Satellite Experiment

QUESTIONNAIRE

SAMPLE

(Mean scores actually obtained in evaluation are indicated.)

Evaluator's Name ______________________________

Evaluator's Professional Field ________________

Mode 1 - Electrowriter image alternated with voice
Mode 2 - Electrowriter image simultaneous with voice

A. Quality of the Electrowriter Image Received via Satellite (Note: Some of the transmitted images appear faded. This is because the kind of ink used in the original drawing did not reproduce well on the xerox machine. Please disregard this fading of the transmitted images in your evaluation.)

1. Select a number from the scale to indicate how you felt about the quality of the received Electrowriter image in mode 1 when compared to the transmitted image.

POOR — EXCELLENT

1 2 3 4 5 6 7

5.6 (Place a number from the scale)

2. Select a number from the scale to indicate the extent to which you felt the quality of the received Electrowriter image in mode 1 was adequate for the following purposes.

VERY INADEQUATE — VERY ADEQUATE

1 2 3 4 5 6 7

a. Transmitting records (charts, graphs, memos, patient records, etc.) 5.4

b. Visual aid in remote teaching 6.0

c. Aid in remote diagnosis and patient care (description of injuries, instructions for care of patient, etc.) 6.2

d. Visual aid in peer group teleconferencing (among researchers, teachers, administrators, etc.) 5.7

3. Select a number from the scale to indicate how you felt about the quality of the received Electrowriter image in mode 2 when compared to the transmitted image.

POOR — EXCELLENT

1 2 3 4 5 6 7

3.9

4. Select a number from the scale to indicate the extent to which you felt the <u>quality</u> of the received image in <u>mode 2</u> was adequate for the following purposes.

VERY INADEQUATE — VERY ADEQUATE

1 2 3 4 5 6 7

a. Transmitting records (charts, graphs, memos, patient records, etc.) 3.5

b. Visual aid in remote teaching 4.1

c. Aid in remote diagnosis and patient care (description of injuries, instructions for care of patient, etc) 3.8

d. Visual aid in peer group teleconferencing (among researchers, teachers, administrators, etc.) 4.2

B. <u>Comparison of the Electrowriter in Modes 1 and 2</u>

Select a number from the scale to indicate what, given the present state-of-the-art, would be your preferred mode of Electrowriter-with-voice operation in the following situations.

MODE 1 STRONGLY PREFERRED — MODE 2 STRONGLY PREFERRED

1 2 3 4 5 6 7

a. Transmitting records 2.4

b. Remote teaching 2.6

c. Remote diagnosis and patient care 2.5

d. Peer group teleconferencing 2.8

C. Suitability of the Electrowriter for Use in Conveying Medical Information

The Electrowriter can transmit a variety of images (messages) as illustrated. Select a number from the scale to indicate the extent to which you feel this capability is practical for conveying medical information for the following purposes.

VERY IMPRACTICAL — VERY PRACTICAL

1 2 3 4 5 6 7

a. Transmitting records (charts, graphs, memos, patient records, etc.) 5.2

b. Visual aid in remote teaching 5.5

c. Aid in remote diagnosis and patient care (description of injuries, instructions for care of patient, etc.) 5.3

d. Visual aid in peer group teleconferencing (among researchers, teachers, administrators, etc.) 5.1

D. <u>Potential Application of the Electrowriter in Medical Communications</u>

1. Have you personally been involved before in any of the following activities:

a. Electronic transmission of medical records? ____ yes ____ no

b. Remote teaching or "tele-lecturing?" ____ yes ____ no

c. Remote diagnosis or patient care? ____ yes ____ no

d. Peer group teleconferences? ____ yes ____ no

2. Please list and/or comment on potential medical applications of the Electrowriter-via-satellite.

E. General Evaluation

(Please comment freely)

APPENDIX VII

FURTHER DETAILS OF SLOW-SCAN TELEVISION OPERATING PROCEDURES

1. Satellite Test Format

An experiment procedure sheet was distributed to all personnel by the Medical Communications Center to reduce the possibility of wasting valuable satellite time. The first ten minutes of the hour were devoted to identifying the transmitting stations and optimizing the radio frequency transmitters, receivers and antennae. At 00:10:30 Arlington Farms was to transmit a 1 KHz tone until 00:12:00, while the transmitter at EDSAT sent SSTV SERVO signals to synchronize the SSTV console and the "slave" television receiver.

A series of clearing codes were generated by the SSTV console for the next fifteen seconds to insure that both the console and receiver were in the proper logic states. Because the frequency response, levels, and frequency offset of the total transmission path was unknown, a series of test slides were transmitted and displayed from 00:12:15 to 00:17:55 so adjustments could be made at the SSTV receiver.

During this period, the Arlington Farms transmitter sent a 100 Hz tone to facilitate later identification of events by the personnel operating the SSTV receiver. The audio channel was to be silent from 00:17:55 to 00:18:00 while one additional code was sent on the data channel to blank the screen of the SSTV receiver. Program transmission then was to take place, with the last five minutes of the hour reserved for blanking the television screen, SERVO signals, and station sign-off.

Early in the experiment, it was learned that a full hour of satellite time at full power was not always available. As a result, many tests were necessarily condensed into thirty- and forty-minute segments to match available air time.

2. Recording Procedures

Most tests involved the sequential transmission of program audio and video information utilizing the excellent running time reliability of the Crown Recorders for recording purposes.

A cueing point was first established on channel one of the audio tape (voice count-down), followed by six minutes of silence and the program audio. The program tape and the recorder were then carried to the console location and the audio was sent by telephone line to the radio transmitter site, through the satellite, and recorded on channel one of the second Crown Recorder located at Arlington Farms. When the program audio had finished, both tapes were rewound, the machines put in ready mode at the cueing point and changed to record on channel two of the tapes. A "ready, set, go" countdown was given to both the slow-scan console operator and to the personnel at Arlington Farms by land line, and the recorders were started simultaneously. The first six minutes of audio silence were utilized for SERVO and code transmission, as well as test pictures to adjust the slow-scan receivers for envelope delay distortion and transmission of the first program visuals. When the program audio began, it was monitored by the console operator who, taking into account the time delay imposed by the satellite transmission path, displayed each visual as called for by the lecturer and continued to transmit, store, and display visuals until the end of the program.

After each experiment, both audio tapes were evaluated to determine the quality of transmission, as well as reception. During these evaluations, it was possible to determine which part of the video frequency spectrum was failing whenever unsatisfactory reception was received.

3. Documentation

The Crown recorders were also used to document test results. During early tests, only visuals were sent over the satellite. A test slide designed for SSTV system checks by Westinghouse Research and Development engineers was selected so that information could be simultaneously gathered on equipment used in tests. During later tests, both voice and picture transmissions were sent and recorded using slides typical of the visual content of medical lectures.

APPENDIX VIII

CRITERIA FOR THE PREPARATION OF VISUALS FOR SLOW-SCAN TELEVISION

1. General Comments on Technique

In preparing visuals for slow-scan television presentations, one must be ever mindful of certain legibility standards. Like other media, slow-scan has certain characteristics which limit legibility. The following visuals have been prepared to help define these limits.

Each visual was produced on medium grey TV illustration board using a 9 x 12 format. All inking was done with K & E Leroy pens and black India ink. Thirty-five mm slides were made with Kodak Ektachrome film and bound with standard 2 x 2 mounts. It has been demonstrated by previous experiment that color film is most suitable for slow-scan projection. Black and white orthochromic film is less suitable because of the high intensity of light passing through the transparency. If such film is used, one must introduce a dense blue filter between the light source and the scanner.

2. Criteria for Use of Lines

The first slide (Figure 1) is a sample of vertical lines of varying thickness, ranging from a #1 pen to a #6 pen. The numbers appearing beneath the lines were made with K & E Leroy templates, from left to right: 140, 175, 200, 240, 425, and 500. It is noted that on high resolution the lines made with pens #1 through #3 were visible but would be substandard in regards to legibility if used on a graph or chart presented on slow-scan. On low resolution, a #4 pen was marginal in regards to legibility. Pen #5 and #6 are satisfactory on both high and low resolution.

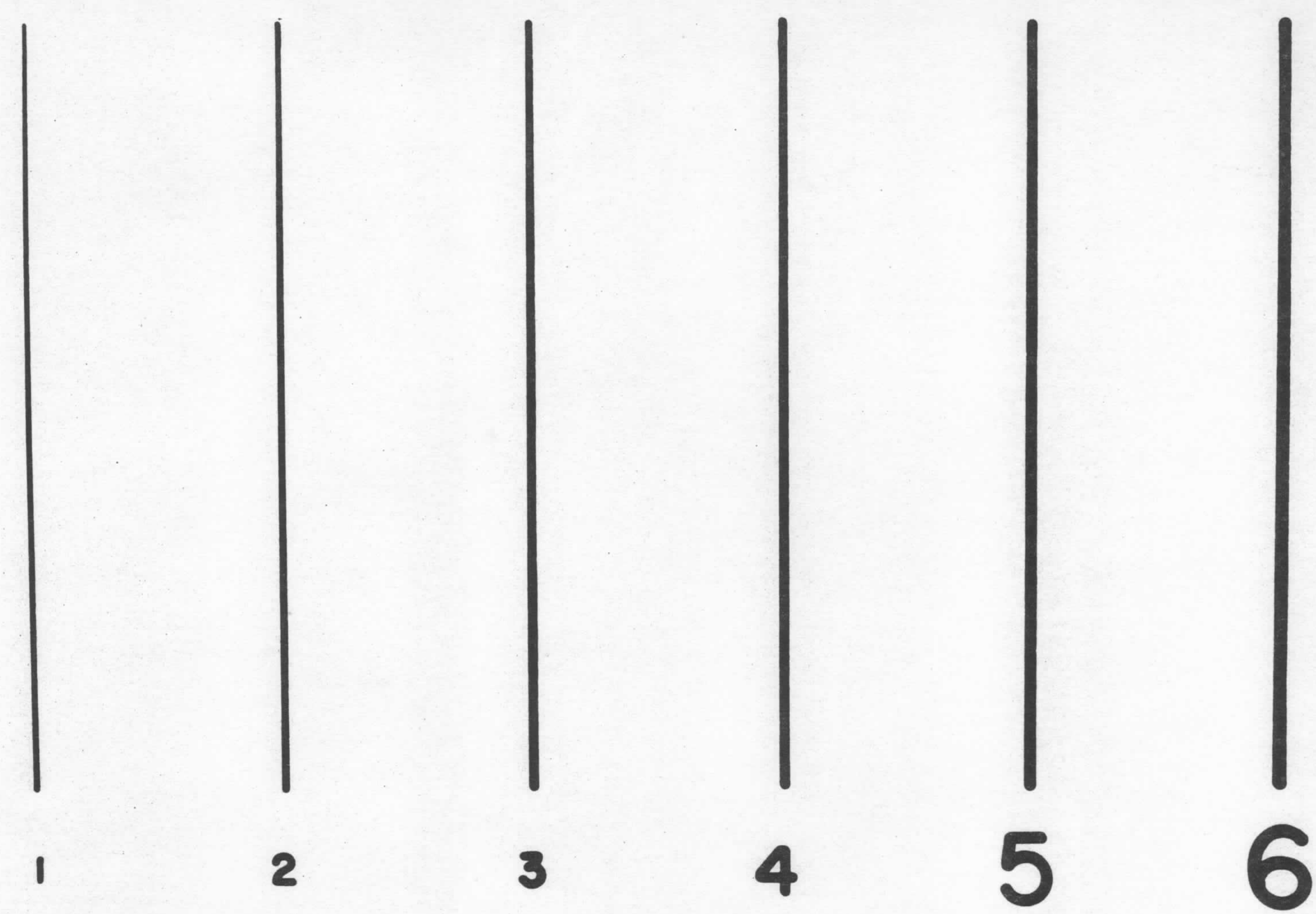


Figure 1: Vertical Lines in Slow-Scan Television Visuals

The second slide (Figure 2) was prepared with the same pens and templates as slide one. The lines, however, were slanted 22 1/2 degrees, the full slant position on the Leroy scriber. On high resolution the diagonal lines give a better differentiation of line thickness. All lines are visible Pens #1 through #4 are marginal and, again, #5 and #6 pens are the only acceptable ones.

3. Criteria for Use of Points

The third slide (Figure 3) is a sample of various dot sizes. From left to right, the sizes are: 1/6, 3/32, 1/8, 5/32, 3/16, 1/4, 5/16, and 3/8 inches. On low resolution, the 3/16 inch dot is marginal and the 1/4 inch and above are acceptable. The same information holds true on high resolution.

4. Criteria for Use of Lettering

Slide four (Figure 4) is a sample of the word Leroy in upper and lower case, using standard Leroy templates and pens, from left to right, top to bottom: 500 template and #6 pen; 240 template and #3 pen; 200 template and #2 pen, 175 template and #2 pen; and 140 template and #1 pen. It has been found that the 500 template and #6 pen is the only acceptable combination acceptable for low resolution. On high resolution, the 500 and #6 pen is the only combination acceptable for lower case while the 240/3 combination is marginal. The upper case samples conform to the same information as on high resolution. Slide five (Figure 5) is a sample of the previous words on a 22 1/2 degree slant. Again, the 500/6 combination is the only acceptable one on low resolution. None of the words in lower case are acceptable. On high resolution, the 500/6 combination is preferred, but the 240/3 combination is marginal.

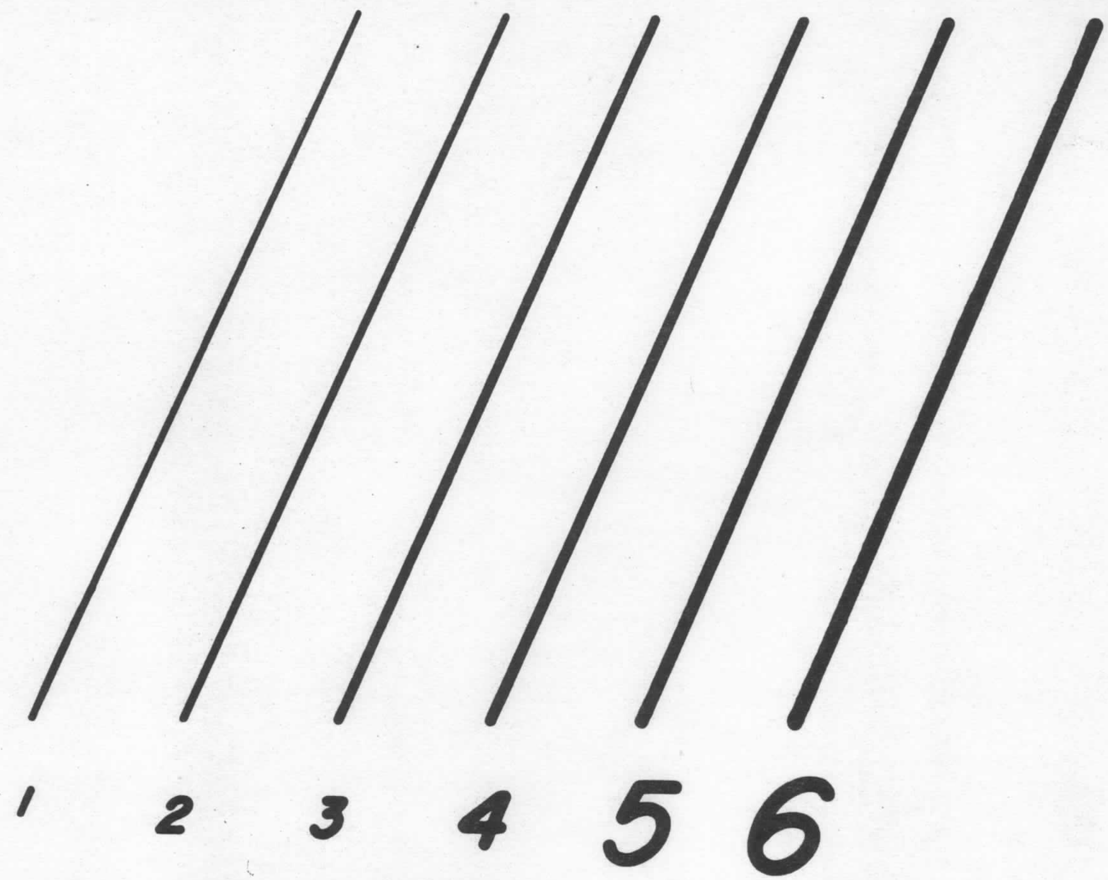


Figure 2: Slanted Lines in Slow-Scan Television Visuals

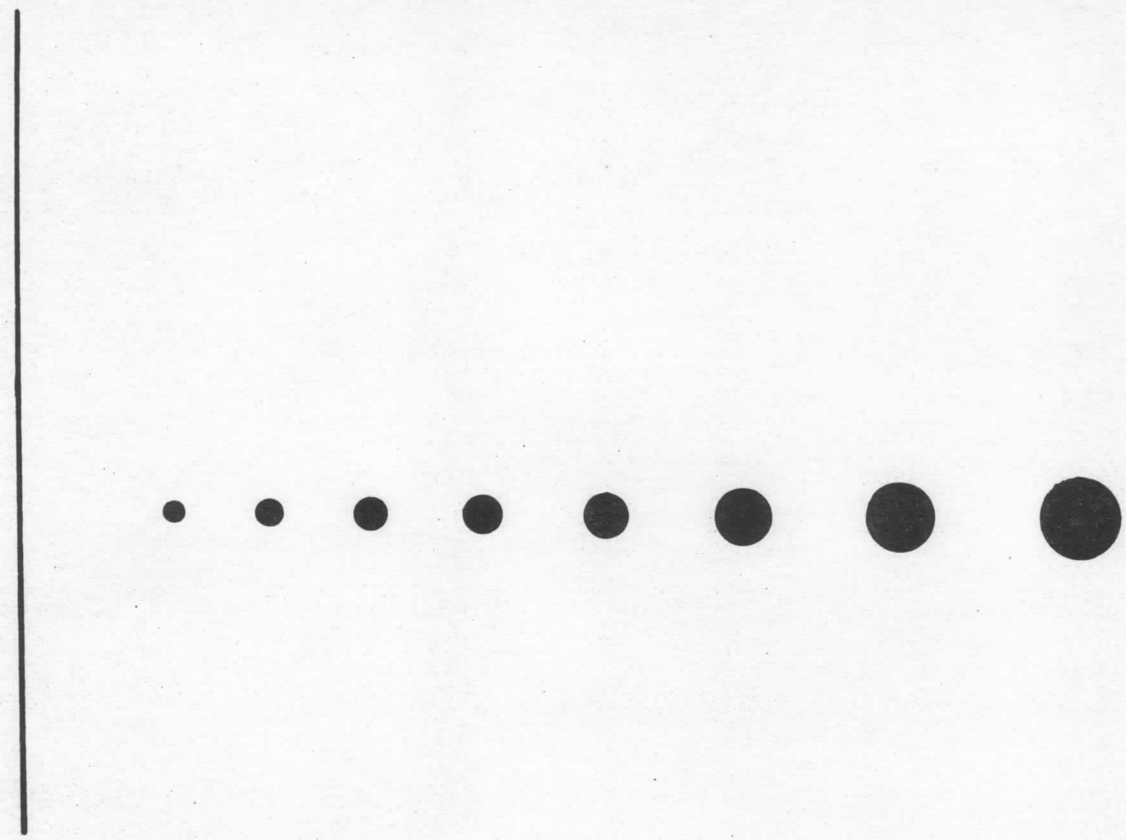


Figure 3: Dot Sizes in Slow-Scan Television Visuals

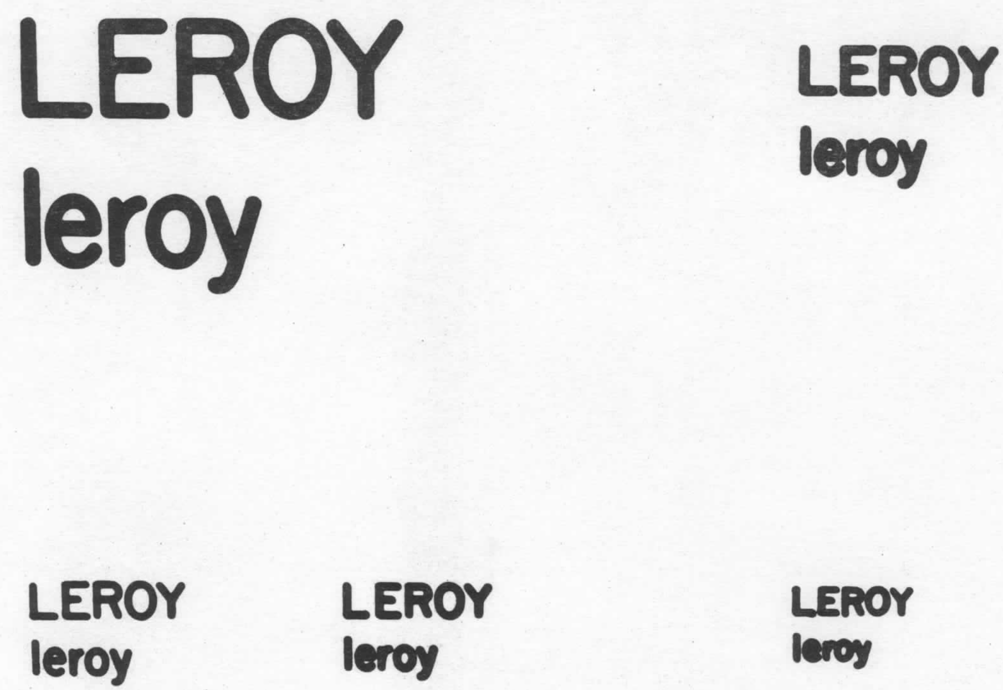


Figure 4: Lettering in Slow-Scan Television Visuals

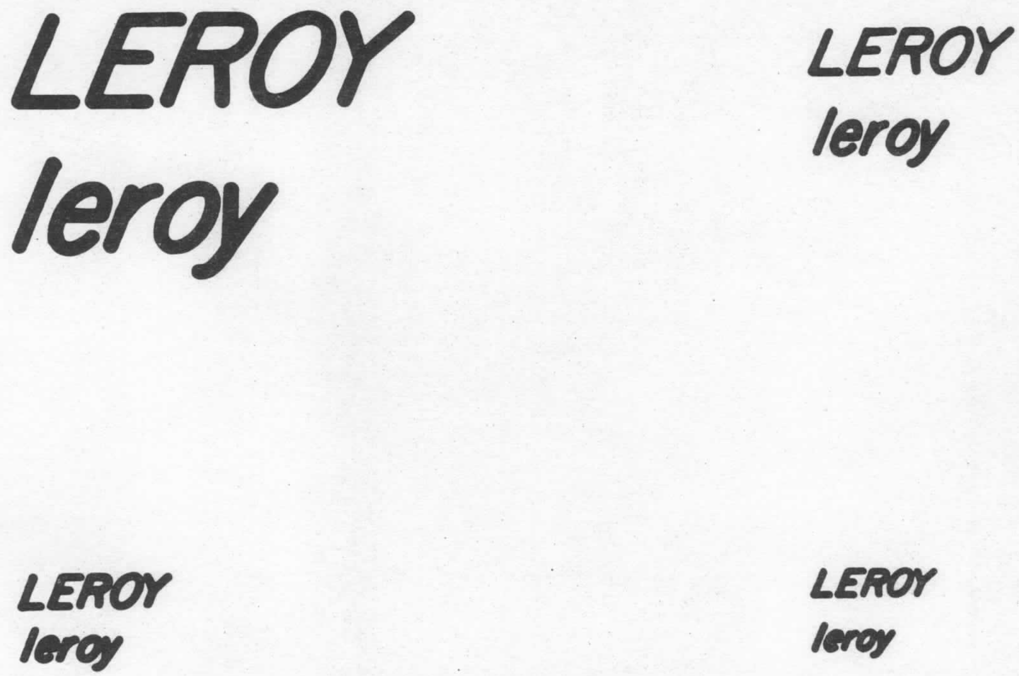


Figure 5: Slanted Lettering in Slow-Scan Television Visuals

5. Criteria for Use of Geometric Shapes

Slide six (Figure 6) shows a sample of two geometric shapes. By using two pen sizes, #3 and #5, it was intended that an optical illusion would be presented. The box on the left should appear normal, but the box on the right should appear as the top view of a truncated pyramid. On low resolution, the difference is a bit clearer, but the effect intended is still lost.

6. Criteria for Use of Graphs

Slide seven (Figure 7) is a sample of a typical graph with standard size lines and letters for this size format. The template and pen combinations are indicated on the graph. On low resolution, it is noted that the lines are not very legible yet are visible, especially the axis lines which were made with a #1 pen. From this information, I would be inclined to step up to a #3 pen for the axis lines. Also this experiment indicates a need for a step up in template sizes, as the numerals and letters are not legible enough. On high resolution, the lines and letters are acceptable, but a step up in pen and template size is indicated.

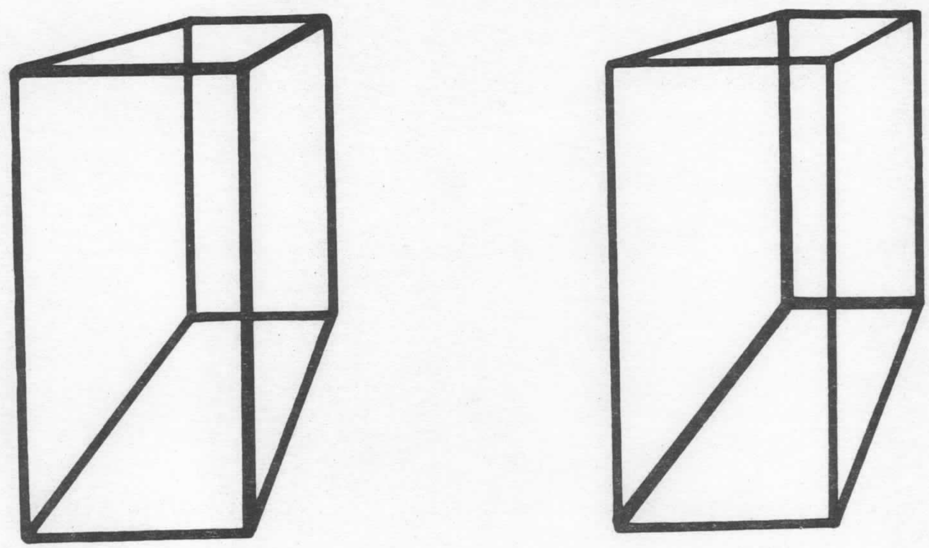


Figure 6: Geometric Shapes in Slow-Scan Television Visuals

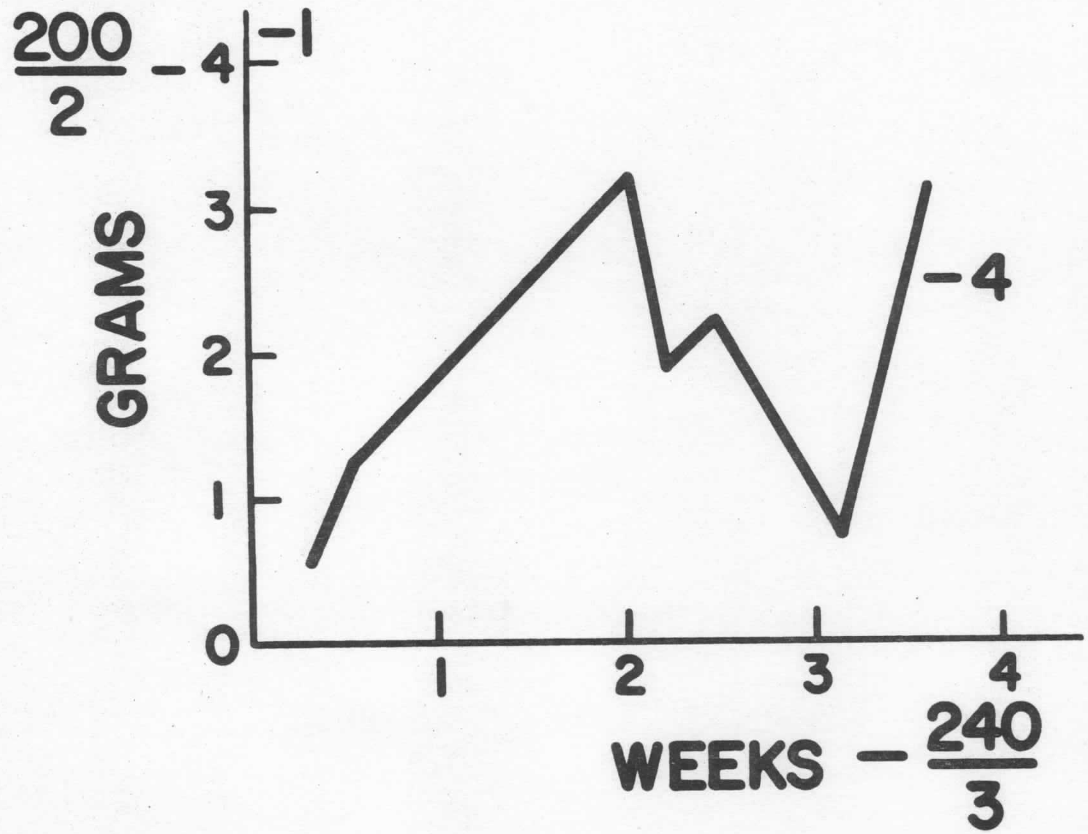


Figure 7: A Typical Graph in Slow-Scan Television Visuals

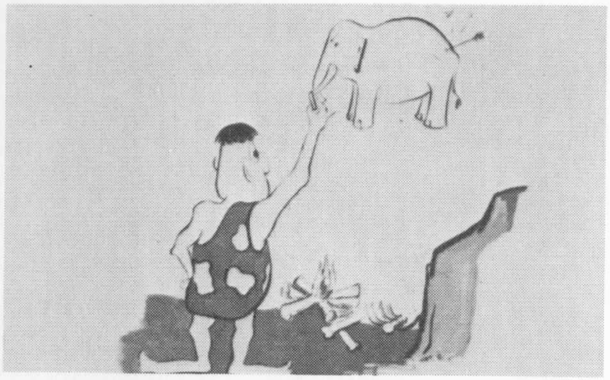
7. Examples of Good Visuals

The six slides shown in Figure 8 were prepared for a presentation adapted to slow-scan television. They include various media commonly used in producing slide visuals and should give a true representation of acceptable quality in both tone and line legibility. The first slide is a cartoon. This visual was rendered with opaque gouache and colors outlined with black India ink. The lines were made with a brush rather than a pen for added thickness. Ektachrome film was used in making the slide.

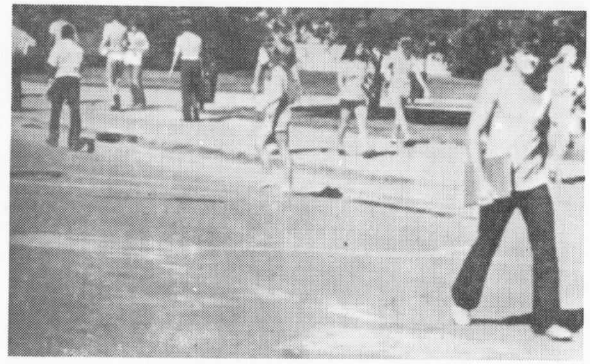
Slide two is a color photograph taken on Ektachrome film. The intensity of this photograph is acceptable for slow-scan use though the composition could be improved by arranging the subjects more toward the center. Slide three is a sample of a color anatomical diagram. It was rendered with opaque gouache colors and outlined in black India ink. Again a brush was used in making bolder lines. This is an example of an acceptable slow-scan visual. If it were to be labeled, I would suggest using acetate overlays with a minimum number of labels on each.

Slide four is an example of a low intensity photograph on Ektachrome film. It is not as effective as the first photograph seen on slide two, but it passes legibility standards. The composition in this slide is superior to slide two. Slide five is an example of a typical bar graph. It was produced on blue color match (Craftint, Mfg., Co.) with red film (Chartpak Co.) for the colored bars. Standard K & E Leroy templates and pens were used for all letters and numbers. Again black India ink was used for all lettering and drawing.

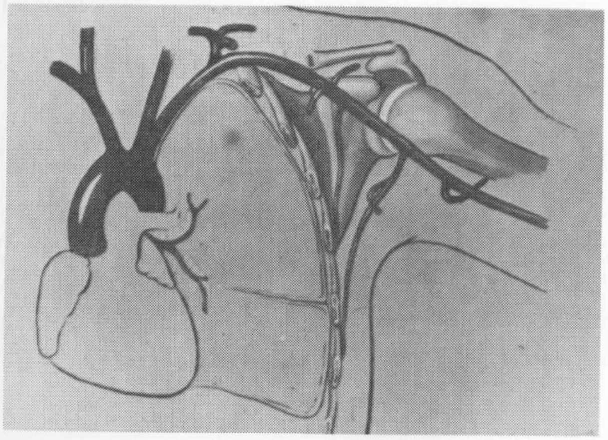
The last slide, slide six, is an example of a map using four colors. The base is Blue Color Match, Yellow and Orange Color Match sheets were cut to the proper shapes and applied to this base. The letters were made



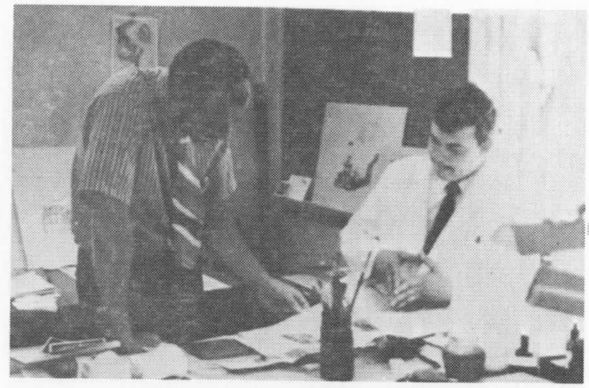
SLIDE ONE



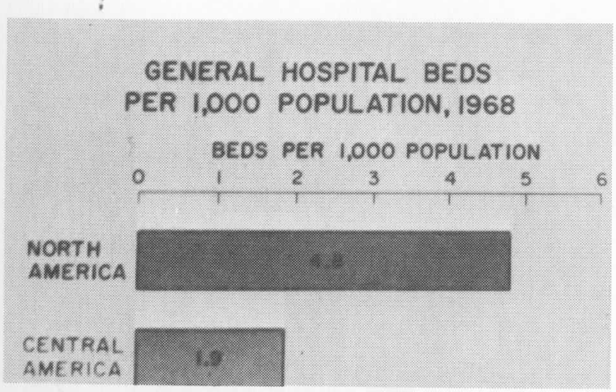
SLIDE TWO



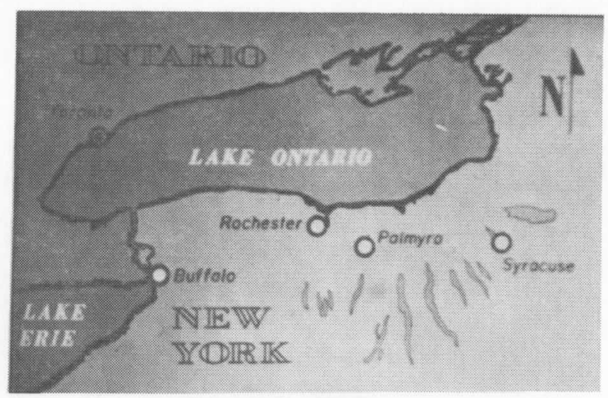
SLIDE THREE



SLIDE FOUR



SLIDE FIVE



SLIDE SIX

Figure 8: Examples of Good SSTV Visuals

with a Varigraph Head writer (Varigraph Co.) and standard Leroy templates and pens. Black India ink was used for the letters and outlines of the lake and white ink was used for the cities indicated, and the names of the lakes. The entire map was mounted on a sheet of dark brown Cresent illustration board.

In preparing and viewing these visuals for slow-scan presentation, as many samples and variations as possible have been covered. The lecturer has been kept in mind; first, because he must be cognizant of the characteristics of slow-scan, and secondly, he must know what to expect of his visuals when they are presented on this unique communication medium. The artist and the draftsman have been included in these thoughts because it is their responsibility to produce effective visuals for slow-scan presentations.

APPENDIX IX

TECHNICAL SUMMARY OF SIMPLEX/DUPLEX VOICE TESTS IN SUPPORT OF STANFORD UNIVERSITY

INTRODUCTION

University of Wisconsin participation in the Alaska Satellite Communications Project involved cooperation with Stanford University and the University of Washington. Each of the three schools took primary responsibility for a particular set of experiments, as well as providing support for test activities of the other schools as their experiments required. Stanford University, for example, provided extensive test support for Wisconsin's Electrowriter tests. This section of the report outlines tests conducted at the University of Wisconsin early in the project to establish successful voice communications with Stanford University to serve as a basis of technical support for the simplex/duplex voice communications experiment conducted by Stanford.

DETAILS OF INITIAL VOICE TESTS

Initial voice tests at Wisconsin were conducted in order to optimize base station transmission and receiving capabilities. An informal log of these tests follows.

Test No.	Date	Objective	Comments
1	19 Aug	Preliminary equipment checkout	SWR bridge used to align antenna, went through alignment procedure on power amplifier, TX, and receiver
2	20 Aug	Check received signal strength	Directed antennas, tried resonant cavity in receive and transmit lines with no noticeable improvement. (Keyed the carrier and measured the returned signal strength)
3	23 Aug	First voice communications with Stanford and ATS Control	Transmitted 1 KHz test tone at 5 KHz deviation. (Compared relative signal strengths)
4	7 Sept	Checked equipment	Measured antenna coax losses, checked receiver sensitivity, measured the loss through a resonant cavity. We decided at this time to try a remote site because of high ambient noise and ground reflections
5	17 Sept	Test remote site at Arlington Farms	Measurements at Arlington Time — Quieting 1:05 — 20 dB 1:10 — 20 dB 1:14 — 17 dB 1:20 — 22 dB 1:25 — 23 dB 1:35 — 25 dB This was much better reception than what we had received at the Space Science Building (10-14 dB)
6	22 Sept	Antenna performance test	The Quad Yagi did not provide any better reception than the single array
7	23 Sept	Support Stanford's test	Tested the satellite compression effects of the repeater (Ref. "ATS VHF EXPERIMENTER'S GUIDE," p. 11)
8	24 Sept	Test remote site at Oregon, Wisconsin	Time — SSEC — Oregon 3:00 — 17 dB — 25 dB 3:05 — 15 dB — 23.5 dB 3:10 — 17 dB — 25 dB 3:15 — 17 dB — 25 dB 3:20 — 16 dB — 25 dB 3:25 — 16 dB — 25 dB 3:30 — 16 dB — 26 dB Receivers of identical sensitivity were used, with SSEC using the Quad Yagi and Oregon using the single array.
9	29 Sept	Test remote site at Hill Farm Park in Madison	Again better reception experienced at the remote site (8-10 dB higher)

Test No.	Date	Objective	Comments
10	1 Oct	Test remote site at Bjorksten Research Lab in Madison	Discovered in this test that the Yagi's were not circularly polarized, thus more subject to atmospheric effect
11	6 Oct	Test remote site at University Farms at Mineral Point Road in Madison	Remote site is as high as 18 dB better than SSEC building. Reception improved by votating Yagi antenna about its boom's axis.
12	15 Oct	Selected Arlington as the remote site and did a preliminary simplex/duplex experiment with Stanford	The remote site operated marginally with 70 watts of transmitted power. Antennas were positioned and checked for mutual interference. Had trouble with ignition noise from a farm vehicle, also channel elements had to be switched manually to facilitate duplex operation.
13	20 Oct	Preliminary simplex/duplex experiment	Antennas repositioned and aligned. Signal fading experienced due to inversion layer. University of Washington participated also. University of Wisconsin transmitted 75 watts of power for this test.

THE SIMPLEX/DUPLEX VOICE EXPERIMENT

A formal demonstration of simplex and duplex voice communications was designed to simulate a medical emergency in a remote villiage in Alaska which required consultation between a medical person in the village and a doctor at a central hospital.

With the cooperation of Dr. John Johnson from Stanford Medical Center and Dr. Edwin Wallace from the University of Wisconsin, a test was generated that would enable both doctors to discuss the problem in the basic communications formats of simplex and duplex under varying signal-to-noise ratios. The intent was to establish the technical requirements for adequate voice communications between medical personnel and to determine if there is any preference shown by such personnel for either duplex or simplex voice communications as a function of the signal-to-noise ratio.

The basic equipment layout is shown in the following figure. Stanford University represented the central hospital and therefore the VHF transceiver was connected by telephone lines to Dr. John Johnson's office. The University of Wisconsin served as the remote site. Dr. Edwin Wallace was located at the remote site and used the transceiver directly.

The results of this experiment appear in the Stanford University report together with an evaluation of the simplex and duplex modes of voice communications for medical purposes.

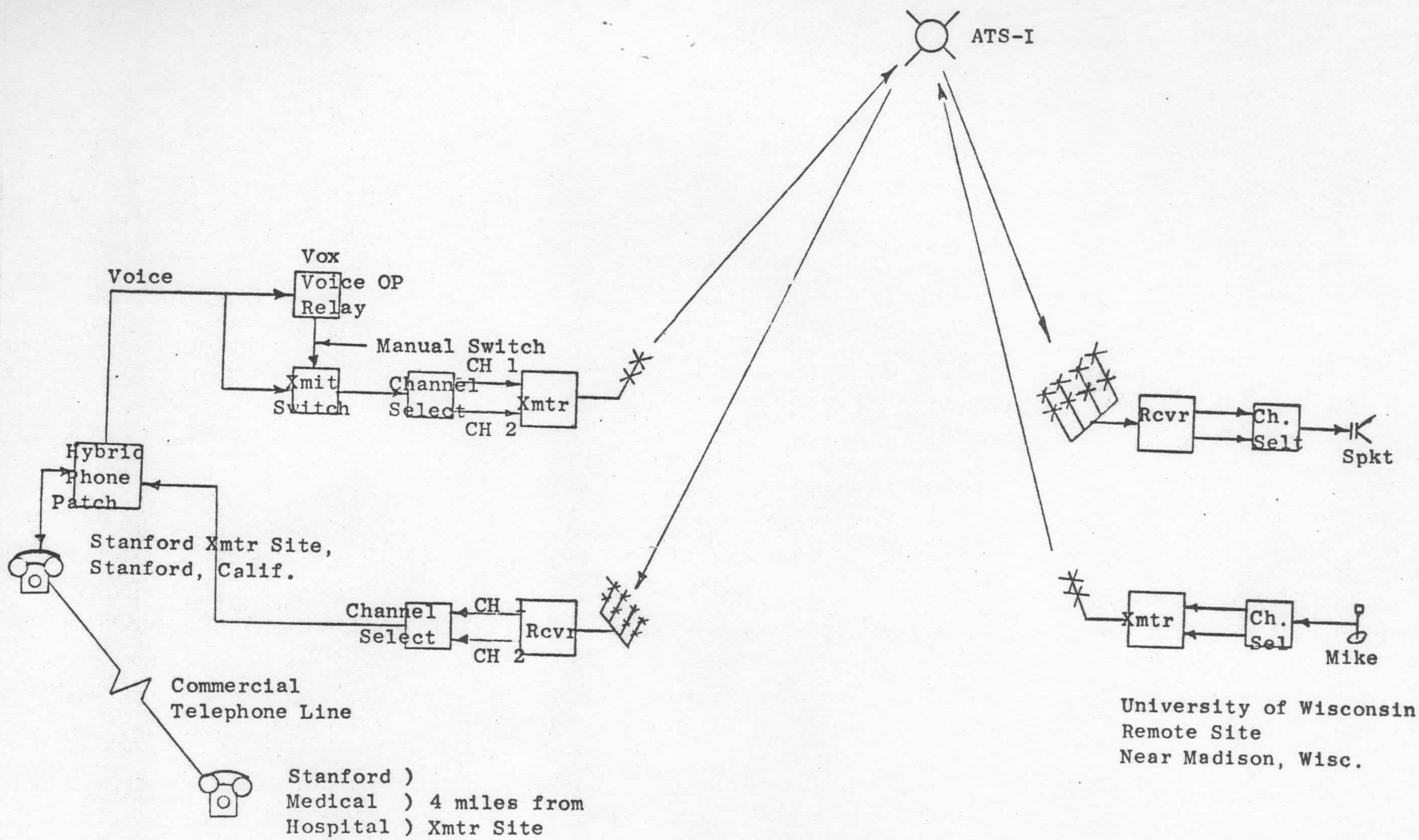


Fig. 1 General Layout of Experiment Equipment (Provided by Stanford University)