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FINAL REPORT - Part I

Contract NAS 9-13870

FINAL REPORT - Part I

Contract NAS 9-13870 (Including Amendments 1C, 2S)

with

The Methodist Hospital
Houston, Texas

AUTOMATED ELECTROENCEPHALOGRAPHY SYSTEM

AND

ELECTROENCEPHALOGRAPHIC CORRELATES OF SPACE MOTION SICKNESS

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PREFACE

Contract NAS 9-13870 became effective on February 2, 1974. The original goal of this project was to design, develop, and test a prototype automated remote laboratory for clinical electroencephalography. This system would provide the means for data acquisition, signal transmission to a central laboratory, and display of the analysis results at the remote site.

On March 18, 1975, after achievement of the original goals, the objectives of this program were expanded to include a comprehensive evaluation of the automated system under various recording conditions to document its potential value in future spaceflight applications. In addition, a second major objective, unrelated to the first, was undertaken: to restudy the Skylab sleep data to determine possible EEG correlates of space motion sickness.

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SECTION 1

AUTOMATED ELECTROENCEPHALOGRAPHY SYSTEM

1.1. SUMMARY OF CONTRACT ACCOMPLISHMENTS

This contract resulted in the development and subsequent operational testing of a self-contained and portable device which permits clinical electroencephalography (EEG) to be conducted in remote locations by minimally trained, nontechnical personnel. The unit accomplishes semiautomatic acquisition of EEG data from the patient, simultaneous transmission of eight data channels to a central hospital facility over conventional telephone equipment, and automatic printing (at the remote site) of the EEG report generated at the central location. The Neurophysiology Laboratories at The Methodist Hospital, Houston, have been configured to communicate with the remote unit on a real-time basis, thereby making the diagnostic capabilities of this laboratory available to medical personnel at the remote location. Consequently, this system enables the delivery of high-quality EEG diagnostic services in a geographically remote site with the accuracy and speed formerly possible only in certain large medical centers. Besides obvious potential clinical applications, this system serves as an initial prototype of a unit which could provide inflight EEG during future space missions.

1.2. INTRODUCTION

This program demonstrated the feasibility of providing clinical-quality electroencephalographic (EEG) service in areas physically remote from well-equipped and adequately staffed medical centers. The development of this system was based upon the accomplishments of NASA-supported prior research by this laboratory. The results of this effort appear to be applicable to future problems in aerospace medicine and to clinical medicine in general.

1.3. BACKGROUND

EEG is currently recognized as an indispensable clinical procedure in the evaluation of many medical disorders. Its use is essential to the diagnosis of certain neurological diseases, and in a number of situations it is required to assess the efficacy of treatment. EEG is relied upon as a means for monitoring cerebral function, and it is the accepted method for determining the presence or absence of life itself. Despite this clear-cut role in clinical

medicine, and despite a rising demand for its availability in routine practice, the test has, because of its complexity, remained relatively inaccessible. Personnel skilled in its proper application and interpretation are rare, and the apparatus itself is expensive.

Prior to the beginning of this contract, we had been attempting for several years to solve some of the problems associated with delivery of high-quality EEG service in the face of increasing demand. A long-term project had been undertaken, with the goal being eventual automation of clinical EEG. Two major problem areas were identified:

(1) The data-acquisition technique required improvement. Conventional schemes in which many individual electrodes must be affixed to carefully measured scalp locations were time consuming, were subject to human error, and were not readily adaptable to many physical constraints of patient location.

(2) The data-interpretation scheme was too inflexible. Except in major centers, the results of interpretation were not accessible for hours and often days.

A significant portion of the initial work directed toward EEG automation was supported by contracts with NASA. In particular, the Sleep Monitoring System (developed for the Skylab Program) provided the opportunity to deal with many problems associated with data acquisition and also led to a number of innovations in the realm of data analysis. The work supported by the current contract was essentially a logical extension of the Skylab development program, but it had a considerably expanded scope.

1.4. DESCRIPTION OF THE SYSTEM

1.4.1. Data Acquisition/Display Unit (DA/DU)

1.4.1.a. General description. The portable DA/DU (Fig. 1) acquires the EEG at a remote site, transmits it to a central laboratory for analysis and interpretation, and displays the results of the analysis at the remote site. This unit includes the following subassemblies:

(1) EEG recording cap with 14 replaceable electrodes,
(2) eight-channel cap-mounted preamplifier,
(3) automatic electrode-testing circuitry,
(4) final amplification and band-pass filtering,
(5) eight-channel magnetically coupled telephone telemetering system,
(6) voice-communication channel and alarm circuitry, and
(7) report decoder and printer mechanism.

The interrelationships of the seven subsystems are indicated in the block diagram (Fig. 2A) and are described in detail below; Fig. 2B shows the central facility in block diagram.

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1.4.1.b. Eight-channel EEG recording cap. The recording cap used with the DA/DU is based upon the design developed for the Skylab Sleep Monitoring Experiment and subsequently modified for other ground-based applications. The original Skylab cap was disposable, and it included seven prefilled sponge recording electrodes for detection of the scalp signals. Electrode position- ing was accomplished by the fit of the cap, and the fabric's elasticity allowed accommodation of a wide range of head sizes. This cap made it possible to ob- tain reliable EEG signals under operational conditions, including space flight, where skilled technicians were not available to apply electrodes in the con- ventional manner and where preparation time had to be minimized due to rigid schedules.

Further development of the Skylab recording cap under NASA contract NAS 9-12460 resulted in the development of the clinically useful EEG recording cap which has been incorporated into the present system. The cap is constructed of an elastic fabric which easily stretches to conform to the subject's head. The 14 electrodes are detachable and disposable and snap into receptables in- side the cap (see Fig. 1).

Cap electrode locations are shown in Fig. 3. The standard electrode posi- tions (International Federation, 1958) include: F_1, F_2, C_3, C_4, O_1, O_2, T_3, T_4, T_1, T_2, T_5, and T_6, in addition to two forehead locations which serve as grounds. These 14 electrodes are arranged to provide eight EEG channels: F_1-C_3, F_2-C_4, C_3-O_1, C_4-O_2, T_1-T_3, T_2-T_4, T_3-T_5, and T_4-T_6.

Each electrode's plastic base, incorporating the connector which provides for attachment to the cap, has been injection-molded from a conductive plastic material (30% carbon, 70% polyethylene). A cone-shaped, soft silicone-rubber sponge is affixed to the base, and the entire electrode is coated with a thin layer of vinyl plastic. After the electrode is constructed, the sponge is saturated with an electrolyte gel by injection, thereby permitting storage in a ready-to-use condition. (Note: Complete construction details are given in the Final Report for Contract NAS 9-12460.)

Just prior to actual EEG recording, electrodes are snapped into the cap, and the vinyl sealing tabs are clipped from each electrode, thus exposing the moistened sponge which makes scalp contact when the cap is donned. Miniature electrical connectors, located at the vertex of the cap, permit rapid linkage with the preamplifier.

1.4.1.c. Electronic circuitry. The general configuration of the DA/DU is indicated in Fig. 2A. A schematic diagram of the electronic circuitry is provided in Fig. 4, and component values are listed in Table I.

The preamplifier attaches to the recording cap at the vertex of the head, and electrical continuity with the EEG electrodes is made through two miniature electrical connectors. Components within the preamplifier provide initial am- plification of the EEG signals received from the eight electrode pairs. After preamplification, the signals are transmitted through a connecting cable to the final amplification circuitry located within the DA/DU. Localization of the

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initial stage of amplification at a site very close to the signal source (the electrodes) minimizes the occurrence of artifactual signals which might result from extraneous electrical interference or from movement of the subject.

Each of the eight preamplification circuits consists of a matched pair of field-effect transistors (Q1013) and associated components located in the cap-mounted enclosure. Biasing of each circuit is adjusted by a potentiometer (R1023) located in the main DA/DU enclosure. The preamplifier has an input impedance which exceeds 100 MΩ and provides a gain of approximately 10. The preamplified signals from each circuit are transmitted to the main unit through miniature individually shielded cables. Diodes (D1011, D1012, D1013, and D1014) prevent interaction between the two sides of each circuit during the electrode-testing mode of operation (see below).

Upon entering the DA/DU, the preamplified signals are further amplified by ac-coupled operational amplifiers (AR1001), then led to band-rejection filters (AR1002 and AR1003) before entering the final amplification stage (AR1004). The band-rejection circuits remove 60-Hz electrical interference (approximately 40 dB attenuation) while not significantly degrading signals below 50 Hz and above 70 Hz. The final output signal level is determined by a potentiometer (R1035). The overall gain is adjusted such that a signal of ±100 μV at the preamplifier inputs results in a ±1.414 V output from AR1004.

The output of each channel enters a voltage-controlled oscillator (Z1001) in the telemetry subassembly (supplied by SCI Systems, described in the Final Report for Contract NAS 9-12947), which accomplishes phase-modulation coding. Subcarrier center frequencies are as follows:

Ch 1 = 1322 Hz	Ch 5 = 1898 Hz
Ch 2 = 1466 Hz	Ch 6 = 2042 Hz
Ch 3 = 1610 Hz	Ch 7 = 2186 Hz
Ch 4 = 1754 Hz	Ch 8 = 2330 Hz

The outputs of all eight oscillators are combined in the multiplexer section of the SCI telemetry subassembly (AR100 and associated components) to form a composite audio signal. When the front-panel selector switch (Figs. 1 and 4) is in the EEG Run or Calibrate position, this signal is led to the magnetic induction loop (L101), located at the handset receptacle of the front panel, which transmits the audio information into the handset of a standard telephone.

The eight-channel multiplexer makes it possible to transmit the eight EEG channels over a conventional telephone line. The eight EEG signals are recovered at the receiving end after filtration and demodulation of the carrier signals. This system is capable of transmitting signals of diagnostic quality over conventional switched-network telephone systems with an overall bandwidth of 0.5 to 40 Hz (3 dB attenuation points).

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In actual use, the receiver (handset) portion of a conventional telephone is inserted into the receptacle provided on the front panel of the remote DA/DU. Magnetic couplers and speakers molded into the receptacle housing automatically provide an indirect (i.e., nonwired) pathway for transmission of the various signals between the telephone system and the electronic circuitry of the DA/DU. A built-in calibration signal, accessible on the front panel of the instrument, permits the overall gain to be readily checked at the central laboratory facility prior to each recording session, thereby contributing to accurate interpretation of EEG amplitude characteristics and asymmetries. The calibration voltage is generated by a low-frequency oscillator (Q108, Q109, and associated components), and a 50-μV signal is applied to the input of each channel when the preamplifier is disconnected from the EEG recording cap and connected to J_1 and J_2 on the front panel. The calibration voltage is adjusted by an internally accessible potentiometer (R167).

When desired, voice communication between personnel at the remote site and those at the central facility may be accomplished via the auxiliary handset provided on the DA/DU. In this mode, voice signals from the conventional telephone receiver (installed in the front-panel receptacle) are picked up by a magnetic coupler, amplified, and sent to the earphone of the handset where they are audible to the remote-site technician. Voice communication initiated at the remote site is detected by the handset microphone, amplified, and directed to a miniature speaker within the receiver-receptacle housing, thereby transmitting the message to the microphone of the conventional telephone.

Voice communication between remote-site personnel and the central facility is accomplished without removing the conventional telephone handset from the front-panel receptacle by use of the auxiliary handset provided with the unit. When the technician at the remote site speaks into the handset microphone (Fig. 4, M1) with the selector switch in the Voice position, the voice signal is amplified by the audio amplifier, composed of transistors Q115, Q116, Q117, Q118, and associated components. The amplified signals are led to a miniature speaker (SPK 1) enclosed within the front-panel receptacle and thus transmitted to the conventional telephone handset. When personnel at the central facility speak into the telephone, the signals are initially detected by L101, the pickup loop in the panel receptacle, and amplified by a second audio amplifier, composed of transistors Q111, Q112, Q113, Q114, and associated components. The output of this amplifier drives the earphone (SPK 2) of the auxiliary handset. When the selector switch is in any position other than Voice, the power supply to both audio amplifiers (Reg VR2) is disabled, thus preventing inadvertent interference during EEG transmission.

If personnel at the central facility wish to communicate during a transmission (for example, if data quality is unacceptable), an alarm system is provided to alert the technician at the remote site. A specific audio-code signal is sent from the central facility and is picked up (by magnetic coupling) at the remote console. Circuitry within the console recognizes the code and activates the alarm buzzer. The technician may then respond by utilizing the handset as outlined above. Similarly, remote-site personnel may signal the central facility of their desire to speak by activating the alarm coder of the DA/DU (accomplished

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by a button on the front panel). This signal is detected at the central end, and an alarm buzzer is sounded.

The two-way alarm system is provided as part of the SCI telemetry sub-assembly. Activation of the alarm at the remote site is accomplished by pressing a push-button (PB 1) switch on the front panel when the selector switch is in the EEG Run or Calibrate position. This activates an oscillator whose output is mixed with the composite output of the eight-channel multiplexer (AR100). When this signal is decoded by circuitry at the central facility, a warning buzzer is activated. When personnel at the central facility desire to signal the remote site during EEG transmission (or calibration), an alarm oscillator (similar to that described above) is activated and the audio signal magnetically coupled to the telephone handset. At the remote site, this signal is detected by a special induction loop (L100), which is included (with L101) in the front-panel handset receptacle. The signal is routed to a decoding network (AR101, AR102, AR103, AR104, AR105, Z104, Q104, Q105, Q106, and associated components) which, upon reception of the specified frequency, activates the alarm buzzer (sone alert). The buzzer remains operational until the front-panel selector switch is changed to the Voice mode, when the alarm system is reset.

Automatic electrode-test circuitry assesses the adequacy of the scalp contact of each recording-cap electrode. When activated by the operator at the remote site, the electrode-testing circuitry automatically determines the electrical resistance between each of the 12 cap recording electrodes and the two paired ground, or reference, electrodes. The status is displayed on the front panel of the instrument by a series of indicator lamps, each representing a sponge-electrode sensor in the cap. These panel lamps are arranged in a configuration simulating their relative positions on the subject's head (see Fig. 1).

With the cap in place on the patient's head, the technician activates the test circuitry by turning a front-panel switch. A small test current of approximately 100 μA passes through the paired ground electrodes to each of the 12 recording electrodes in succession, and the amount of electrical current passed by each electrode is sensed to provide an indication of interelectrode resistance. If a particular electrode is in proper scalp contact, its resistance will be 50,000 Ω or less, and this will result in illumination of the corresponding lamp. Improper contact, signaled by failure of any lamp to illuminate, is usually easily corrected by manipulation of the electrode to position the tip through the hair and against the scalp.

In the test mode, a battery (B 1, 6.75 V) is inserted in series with the lead to the two recording-cap ground electrodes, thus holding the ground electrodes at +6.75 V with respect to the electronic-circuit ground. The relays in the electrode-test circuit (RL1001) are also activated in this mode, and thus an electrical pathway from each EEG electrode to its corresponding test circuit exists. The field-effect transistors in the preamplifier circuit (Q1013), normally appearing as high impedances to the electrodes, are reverse-biased by the +6.75 V signal now present at the scalp and thus readily allow current to pass through them to the test circuits from the ground electrodes via the

scalp and EEG electrodes. A 50 kΩ return pathway to ground for this current is provided by R1049 in each test circuit, thus limiting the maximum current flow through any EEG electrode to ≈135 μA. An electronic switch in series with these pathways (Q1005) permits activation of each test circuit in sequence. When Q1005 is On, current flows, as noted above, and the voltage developed across R1049 is sensed by Q1007 and amplified by Q1009. Since total current flow is limited by the electrical resistance at the scalp contacts of the grounds and the specific EEG electrode, the voltage developed across R1049 is inversely proportional to the combined electrode resistance and thus is a measure of adequacy of scalp-to-electrode contact. If the voltage across R1049 exceeds a preset value, the voltage output of Q1009 is sufficient to turn Q1011 On, thereby activating the light-emitting diode (D1011) in the position corresponding to the electrode under test on the front-panel display. The R1049 values are preset such that a combined electrical impedance (i.e., grounds and EEG electrode) of 50,000 Ω or less will activate the circuit.

The 12 electrode-test circuits are activated one at a time in a repetitive sequence at a rate of 134/sec. The sequencing is controlled by a ring counter (Z100 and Z101), itself driven by a 134-Hz clock (Q100, Q101, and associated components). The output of each ring-counter element controls an electronic switch (Q1005) in one electrode-test circuit. When that element is activated, the electronic switch is turned On, and the status of the corresponding electrode is indicated. (Note: For maintenance purposes, the status of each ring-counter element is indicated internally by a light-emitting diode, D1005.)

At the conclusion of an EEG data-transmission session, the remote console is switched to the EEG Report mode by the technician, and telephone contact is maintained. In this mode, the eight-channel EEG multiplexer is disabled, and the report-decoding circuitry is activated. When EEG interpretation is completed at the central facility (within a few minutes), a written report is generated which contains a technical description of the subject's electroencephalogram and, if appropriate, a probable diagnosis. This report is then transmitted by an audio-frequency code back to the remote console and is accepted by the report-decoding circuitry. The decoding circuitry converts the incoming audio code into a series of electrical impulses that, in turn, activate the printer mechanism within the remote console. The printer thus reproduces the contents of the EEG report and provides an instantaneous record for immediate review by the patient's physician or other medical personnel.

The audio-coded information is initially detected by the induction loop (L101) in the front-panel handset receptacle. When the selector switch is in the EEG Report position, the received signals are led to AR106, which provides initial amplification. The output of AR106 then enters the input of the Texas Instruments, Inc., Model 733KSR (modified for receive only) Silent 700 Printer mechanism, where the audio code is interpreted, and a printed report is generated. Complete maintenance instructions and a schematic diagram of this subassembly are provided in the Texas Instruments document (Manual No. 960129-9701, 1973), provided as an Appendix to this report. The printing unit is disabled by relay RL100 in all selector-switch positions other than EEG

Report mode. A push-button (PB 2), located on the top surface (to the left of the printer) of the DA/DU, activates the paper-advance mechanism of the Texas Instruments 733KSR printer.

1.4.2. Central EEG Interpretation Facility

1.4.2.a. General description. As indicated in Fig. 2B, the central facility is responsible for a number of functions which are required by the remote DA/DU:

(1) recognition, decoding, and display of the remotely generated EEG signals,
(2) provision of advice and assistance to the remote-site personnel by voice communication,
(3) EEG interpretation, and
(4) transmission of the EEG report.

1.4.2.b. Reception, decoding, and display of EEG signals. The audio-coded eight-channel EEG information transmitted from the remote location is detected by magnetic coupling at the telephone receiver and routed to an eight-channel decoding unit that resynthesizes the original EEG activity. (Details of this procedure are provided in the Final Report for NASA Contract NAS 9-12947 to SCI Systems.)

After suitable normalization of gains, signals from the decoding unit are displayed on a conventional graphic recorder, such as an EEG machine. This provides a record in the proper format for visual interpretation, and it also permits personnel within the central facility to quickly detect any mistake in procedure which may have occurred at the distant site. In addition, various signal-conditioning procedures (filters, etc.) may be introduced at this point, if necessary, to improve the visual quality of the record. When desired, the EEG signals may also be recorded on magnetic tape to permit off-line analysis by computer techniques.

1.4.2.c. Assistance to remote-site personnel. Essential to the central-ized data-analysis system is the capability of personnel at this location to communicate effectively and rapidly with the personnel at the remote site. If the technician at the remote site desires to communicate with personnel in the central facility, activation of the alarm system at the remote site will be in-stantly recognized within the central laboratory, and voice communication can be instituted. If personnel within the central facility wish to speak with the technician at the remote location, a warning alarm code is transmitted over the telephone line, where it is decoded by the alarm circuitry in the remote con-sole.

This capability circumvents the major problems which might be anticipated to result from the lack of experienced technical personnel at the remote location. In addition, since no display of the EEG signals is provided at the point of

origin, many basic technical aspects (e.g., recognition of improper electrode function, electrical-interference problems, etc.) must be monitored at the central end and corrective measures relayed to the remote site.

1.4.2.d. EEG interpretation. Although the development of EEG-analysis techniques was not a part of this contract, the ability of the central facility to accomplish EEG interpretation is essential to the proper function of the remote unit. Consequently, the facilities of the Neurophysiology Laboratories concerned with this aspect are summarized below.

At present, essentially all data analysis in clinical EEG is accomplished by human visual analysis of graphic records. This is a time-consuming process, and the ability to supply immediate service depends upon the continued presence of highly skilled professional personnel. While the long-range goal is complete automation of the interpretation process, the present system is one of computer-assisted human analysis in which various techniques are employed to increase the efficiency of highly trained personnel and to decrease the role of such personnel in the performance of certain routine and well-established procedures. Computer-generated results, at this time, are not relied upon for routine interpretation of EEGs, but they are available for comparison and evaluation.

The automatic-analysis scheme is divided into three orders of complexity (Fig. 2B). First-order analysis is accomplished by special-purpose electronics and includes dedicated hybrid analysis devices which act upon the incoming signals in a continuous manner and which provide outputs to the second-order system.

Components in the first-order, or special-purpose, analysis category at this time include circuits for detecting the wavelength, or period, of successive EEG waves in a real-time fashion on 32 channels, similar capability for determination of peak-to-peak amplitudes, multiplexing interfaces to provide outputs to the PDP-11/40 computer, and automatic spike detectors. This system effectively permits characterization of the background activity of a standard eight-channel EEG, in a wave-for-wave fashion, and allows sorting of individual waves into four bandwidth categories. By sampling only two channels of the first-order system at 2 kHz, the PDP-11/40 can obtain frequency and amplitude information equivalent to 64 analog channels, each sampled at a rate of approximately 400 Hz. Again, this hardware system allows more effective utilization of the small computer by accomplishing standardized tasks in a real-time fashion.

The small computer (second-order analysis) system actually becomes the central component in the automatic-analysis scheme, serving to collate all information obtained from the first-order system and to obtain other information directly from the EEG signals. The combination of special-purpose electronics and the small computer consequently makes possible the effective processing of a large quantity of data without overwhelming the system's capacity.

Third-order analysis (time-shared IBM 360/50 computer facility) has thus far been used primarily for bulk storage, and it is used in an intermittent fashion, not being relied upon for real-time processing. In the future, we plan to expand the scope of this section, with the implementation of various statistical routines necessary in the problems associated with normality versus abnormality in generation of the final report. A hard-wire, dedicated-line interface between the second- and third-order analysis systems assures reliable communication on a near real-time basis. Thus, while the second-order analysis scheme must operate on-line and interacts directly with the incoming data, the third-order system is effectively buffered from this responsibility and thus imposes no short-term restriction upon the operation of the overall automatic-analysis scheme.

The automatic-analysis system, as it now stands, has proven valuable in specific situations. For example, in the long-term monitoring of epileptic subjects undergoing evaluation for problems of seizure control, the system is used to chart seizure-discharge frequencies versus time. In these cases, when the type of abnormality to be expected may be specified beforehand, the performance agrees quite well with human evaluation. Similarly, specification of certain EEG characteristics, such as alpha frequency, the amount and type of fast activity present, slow-wave activity, and other features, is often accomplished quite well.

1.4.2.e. EEG report coding and transmission. The electroencephalographer sees the computer-analysis sections' outputs on a video-display terminal, and these results can then be compared to the results of conventional visual analysis of the graphic EEG record. A final EEG report, generated by these procedures, is then compiled on the screen of the video-display terminal, where it may be reviewed and corrected. The report generated by the EEG-analysis procedures is then automatically transmitted over the telephone system to the remotely located DA/DU, where a printed report is generated. This transmission is accomplished by a form of audio coding similar to the system utilized for transmission of the EEG information.

1.5. OPERATING INSTRUCTIONS

1.5.1. General Requirements

The remote EEG system, including the DA/DU and associated EEG recording cap and preamplifier, reliably operates in typical hospital environments, and thus no special shielding or external grounding is required. A conventional outlet providing 110-130 V ac at 60 Hz is the only power requirement. A standard desk or wall-mounted telephone with internal handset configuration similar to the Bell System (Western Electric) equipment is necessary to establish communication with the central interpretation facility.

1.5.2. Procedural Checklist

(1) Place the POWER switch (top panel, left side) in the OFF position.

(2) Insert the power cord connector of the unit into a 110-130 V, 60-Hz ac source.

(3) Place the SELECTOR switch in either of the two VOICE positions.

(4) Connect the preamplifier cable to the DA/CU at the point labeled EEG PLUG.

(5) Connect the two CALIBRATION SIGNAL leads to the two matching connectors on the preamplifier.

(6) Turn the POWER switch to the ON position.

(7) Make a telephone to the central facility:
   The Methodist Hospital, 713-790-3105

(8) After establishing voice contact with the central-facility personnel, remove the DA/DU handset from its front-panel receptacle, and insert the handset of the standard telephone into the receptacle. Continue voice communication through the DA/DU. NOTE: When inserting the handset into the receptacle, place the mouthpiece and the earpiece into the respectively labeled positions.

(9) When requested by personnel at the central facility, switch the selector to the CALIBRATE position. NOTE: This automatically transmits a 50 μV calibration signal through all eight channels to permit gain adjustments to be made at the receiving end.

(10) Voice communication is not possible in the CALIBRATE mode. You may signal the central facility by pressing the button labeled PUSH TO SIGNAL RECEIVER (thereby activating the alarm buzzer at that end). Then switch the selector to the VOICE position and wait for an answer. Similarly, if the alarm buzzer on the DA/DU sounds (indicating that central-facility personnel desire voice communication), switch the selector to the VOICE position and answer the call.

(11) When the desired amount of calibration has been accomplished, as instructed by central-facility personnel, switch back to the VOICE mode and resume voice communication.

(12) Remove the EEG recording cap from the plastic bag and attach the preamplifier at the vertex with the velcro patch and the dual electrical connectors.

(13) Remove 14 electrodes from their plastic storage bag and wipe off excess moisture from their gripper-snap connectors. Insert one electrode in each of the recording-cap gripper receptacles.

(14) Using a pair of scissors, clip the sealing tab from each electrode, making the cut at the junction of the sealing tab and the conical portion of the sponge electrode.

(15) Position the cap on the subject's head and secure with the chin strap.

(16) Turn the selector switch to the CHECK position.

(17) Examine the simulated electrode display on the front panel of the DA/DU. All 12 recording-electrode status indicators should flash continuously. (The two ground-electrode locations are purposely not supplied with light-emitting diodes in the simulated display, so of course will not illuminate.) Failure of any indicator to illuminate indicates faulty scalp contact of the respective electrode(s), and these electrodes should be gently rocked back and forth until the indicator shows proper conductivity has been achieved.

(18) When a proper indication is achieved at all 12 recording-electrode sites, turn the selector switch back to the VOICE position and resume voice communication.

(19) When instructed by the central-facility personnel, begin the EEG transmission by moving the selector switch to the EEG RUN position. The patient should be seated or reclining, in a comfortable and relaxed position with his eyes closed.

(20) Voice communication is not possible in the EEG RUN mode. Follow the procedure described in item 10, above, to establish voice communication.

(21) When an adequate EEG sample has been recorded, as determined by the central-facility personnel, return the selector switch to the VOICE mode.

(22) While the EEG is being interpreted at the central facility, voice contact will be maintained.

(23) Press the PAPER ADVANCE button located on the top panel mounting to ensure removal of material printed previously, and tear off extra paper.

(24) When the interpretation process is completed, the central-facility personnel will instruct you to switch to the EEG REPORT mode to permit reception of the report.

(25) The report will be printed automatically.

(26) At the conclusion of the printing cycle, return the selector switch to the VOICE mode for final communication with the central facility.

(27) Remove the handset from the receptacle and hang up the telephone. Place the DA/DU handset in its receptacle.

(28) Remove the recording cap from the subject's head and wipe excess electrolyte from the scalp.

(29) Remove and discard the 14 electrodes. Allow the cap to dry thoroughly before storing.

(30) Disconnect and store the preamplifier.

(31) Press the PAPER ADVANCE button to advance the paper as necessary, and tear off the printed report.

(32) Switch POWER to the OFF position.

(33) Unplug the POWER CORD from the 110-130 V ac outlet.

1.6. OPERATIONAL TESTING RESULTS

1.6.1. General

The Automated EEG System, including the remote DA/DU and the central-facility link, was extensively tested in the latter portion of this contract period to evaluate its capabilities and limitations. Besides numerous tests under laboratory conditions, the system has been used to transmit a number of EEGs from various remote locations to The Methodist Hospital Neurophysiology Laboratories for interpretation, and the results have been successfully reported back to the site of origin. A selected and representative sample of these testing procedures is outlined below to demonstrate the data quality and to illustrate the general ways in which the system might be used in the future.

1.6.2. Example 1 - Comparison of Transmitted and Received EEGs

Since the DA/DU contains no means for displaying the EEG at the remote site, it is necessary to carefully document the fidelity with which signals are relayed through the entire system and to identify potential sources of artifact.

Performance of this test necessitated the use of an EEG machine at the transmission site in addition to the one normally used for reception at the central facility. The input to the EEG machine was derived from the output of the eight-channel amplification system within the DA/DU (output of AR1004, Fig. 4). A record was thus obtained, at the remote site, of the EEG signals

actually presented to the telephone telemetry system. A simultaneous record at the central facility permitted comparisons to be made, thus allowing detection of possible extraneous signals introduced by the telephone system and determination of any degradation of signal quality.

A 10-sec sample of the transmitted EEG obtained directly from the DA/DU is shown in Fig. 5A. The record received simultaneously from the telephone decoder at the central facility is illustrated in Fig. 5B. Note: For the purposes of this test, the transmitting and receiving units were located within The Methodist Hospital, with transmission on telephone line 790-3107 and reception on line 790-4390.

The only noticeable discrepancy between the two records is seen in channels 5 and 7. These channels of the transmitted EEG (Fig. 5A) are contaminated by a low-voltage, high-frequency activity originating from muscle activity in the vicinity of electrode T_3 (left temporal). This artifact has been removed from the received record (Fig. 5B) by the high-frequency filtration inherent in the telephone telemetry system. Other characteristics of the two records are comparable, and no difficulty with respect to interpretation was encountered.

The actual EEG report generated at the central facility and transmitted back to the DA/DU printing mechanism is reproduced in Fig. 6. (Note: The subject's name has been removed.)

1.6.3. Example 2 - Short-Range Transmission

After confirming the ability of the system to transmit EEGs of acceptable clinical quality under controlled conditions (e.g., see section 1.6.2 above), it was necessary to evaluate the performance of the system under the typical environmental situations which might be expected in actual operational use.

In this example, the DA/DU was taken to a location (a private residence) approximately four miles from the central facility. The entire operating sequence (see section 1.5 above) was followed, and no problems were encountered with respect to data quality. A selected 10-sec sequence from the EEG received in the central facility is reproduced in Fig. 7. The EEG report printed at the remote site is shown in Fig. 8; the subject's name has been removed.

1.6.4. Example 3 - Long-Range Transmission

Although the actual distance from the transmitting to the receiving site theoretically imposes no limitations on signal quality, longer distances do involve some differences in the telephone company's switching apparatus. The possible influence of these factors was evaluated by testing the system with the remote site located outside the Houston metropolitan area.

The EEG recording shown in Fig. 9 was transmitted from the NASA LBJ Space Center, a distance of approximately 30 miles from The Methodist Hospital.

No differences in the performance of the system could be detected, and signal quality was comparable to that obtained in the laboratory tests. The EEG report recorded at NASA is reproduced in Fig. 10, and again the subject's name has been removed.

1.6.5. Problem Areas and Limitations of System

The most significant limitation imposed by the automated EEG system is the restricted high-frequency response of the telephone telemetry system. The EEG Instrumentation Standards Committee of the International Federation of Societies for Electroencephalography and Clinical Neurophysiology has recommended an upper-frequency response of 100 Hz for all EEG storage and transmitting systems. Currently available voice-grade telephone lines, however, impart an upper limit of 40-50 Hz for an eight-channel FM system. This degradation of frequency response does not appear to pose a significant problem in terms of recognition of currently known EEG abnormalities, and even sharp-transient forms and "fast activity" are reproduced with very little noticeable distortion. It does, however, create some difficulty with respect to identification of certain artifactual signals. This problem is demonstrated in Fig. 11, where muscle activity superimposed upon relatively low voltage EEG activity is clearly visible in the original, or transmitted, record (Fig. 11A) and would be easily identifiable by an electroencephalographer. (The test scheme used here is similar to that discussed in section 1.6.2.) The received record (Fig. 11B) demonstrates the effect of the high-frequency response limitation upon the muscle activity. The character of this artifactual signal is altered considerably, and it now somewhat resembles fast EEG activity. Thus, it is clear that a higher frequency response would be desirable although not absolutely essential.

In addition to inherent problems such as the limited frequency response, telephone transmission systems are also susceptible to an as yet incompletely defined spectrum of unique artifacts.

Occasional spike-like transient wave forms have sometimes been seen in the received record, occurring variously in one, several, or all eight channels. While their origin is not certain, it seems most likely that they are related to switching transients within the telephone system, although it is also possible to duplicate such events by producing high-amplitude audio background noise at the transmission site (which is picked up by the telephone receiver). While these artifacts have not closely resembled wave forms considered significant in clinical EEG, it is of course conceivable that under some circumstances they might lead to confusion. Fortunately, the appearance of these forms has so far been rare.

A relatively low voltage, irregular fast activity has been associated with low signal strength of the received audio telemetry signal. Such situations have usually been corrected readily by redialing the desired telephone connection.

REFERENCE

International Federation. The ten twenty electrode system of the International Federation. <u>Electroencephalogr. Clin. Neurophysiol.</u>, 1958, <u>10</u>: 371-375.
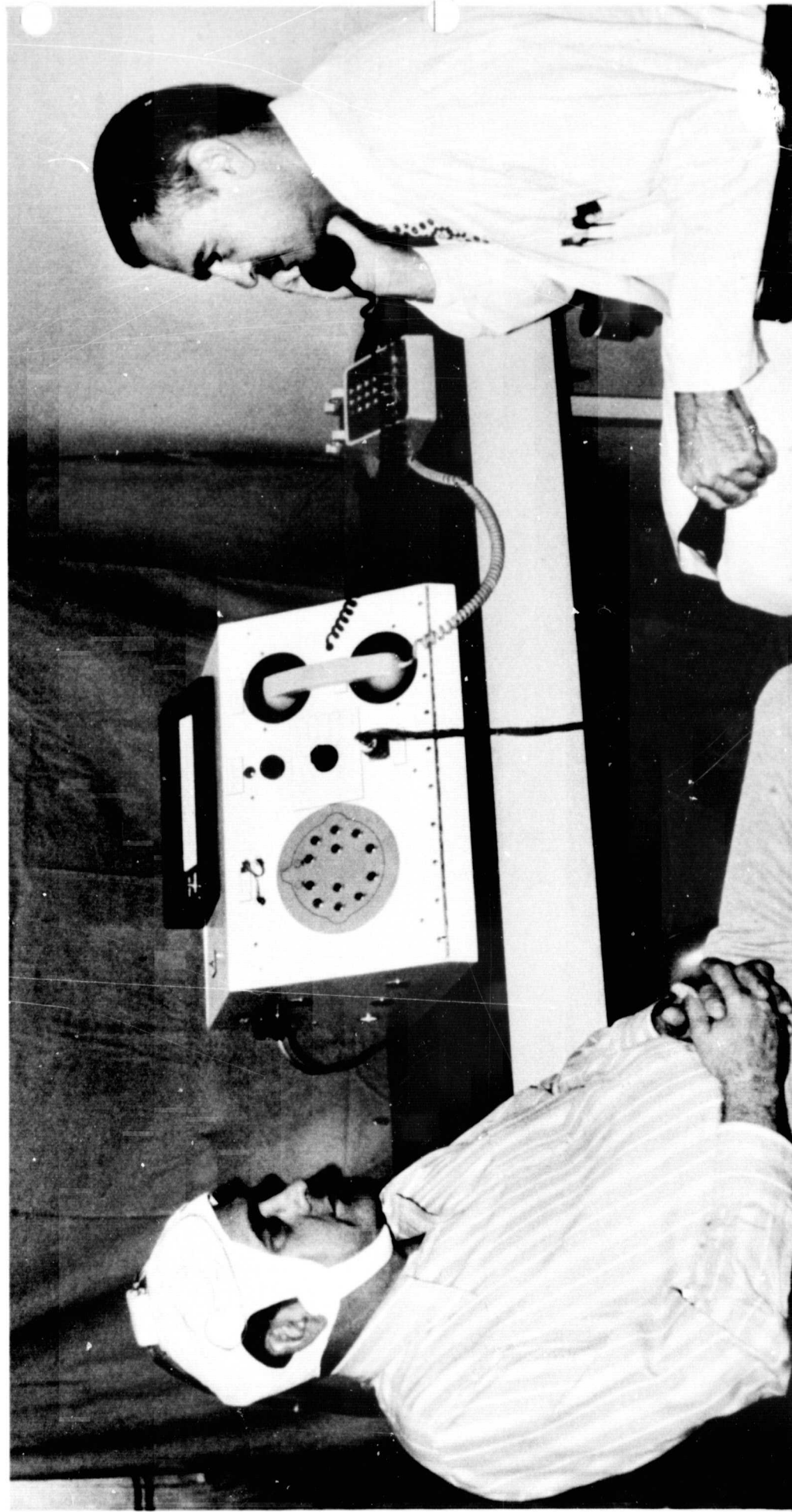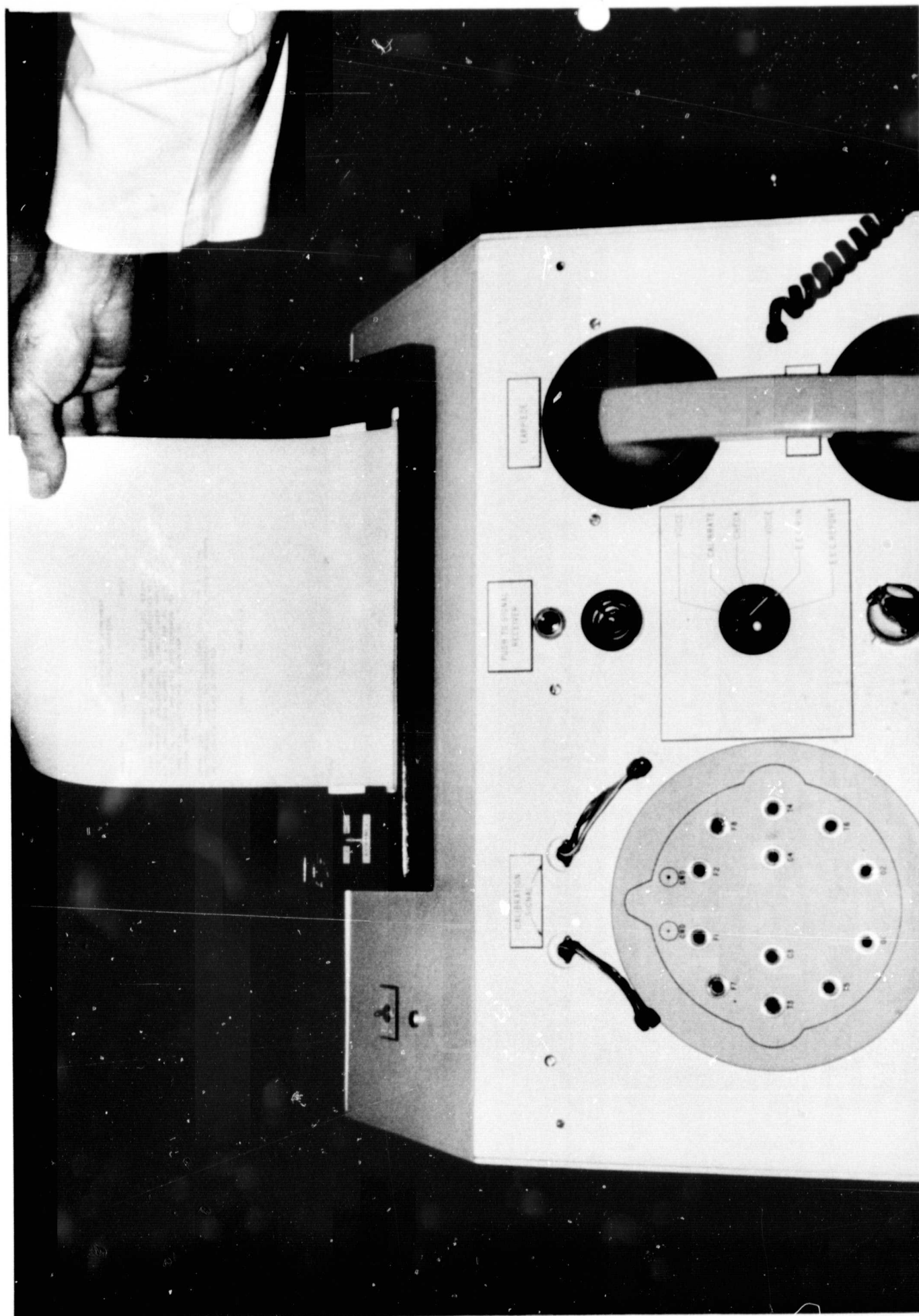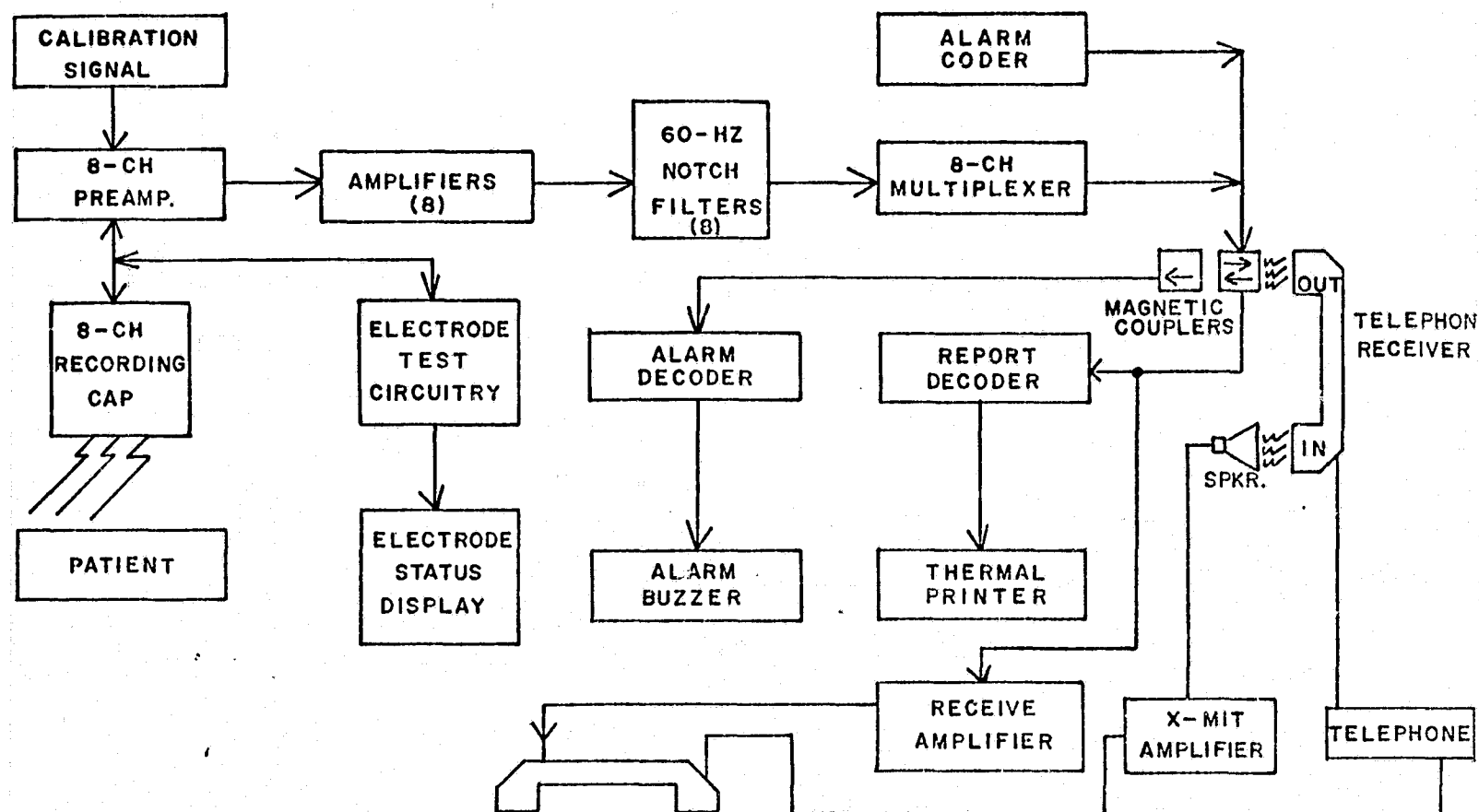
FIGURES AND TABLE

Fig. 1A

Fig. 1B

A. REMOTE DATA ACQUISITION/DISPLAY UNIT

- CALIBRATION SIGNAL
- 8-CH PREAMP.
- AMPLIFIERS (8)
- 60-HZ NOTCH FILTERS (8)
- 8-CH MULTIPLEXER
- ALARM CODER
- 8-CH RECORDING CAP
- PATIENT
- ELECTRODE TEST CIRCUITRY
- ELECTRODE STATUS DISPLAY
- ALARM DECODER
- ALARM BUZZER
- REPORT DECODER
- THERMAL PRINTER
- MAGNETIC COUPLERS
- OUT
- TELEPHON RECEIVER
- SPKR.
- IN
- RECEIVE AMPLIFIER
- X-MIT AMPLIFIER
- TELEPHONE

B. CENTRAL EEG INTERPRETATION FACILITY

- SPECIAL PURPOSE ANALYSIS ELECTRONICS
- ALARM CODER
- HUMAN VISUAL ANALYSIS
- 8-CH EEG GRAPHIC DISPLAY
- 8-CH DE-MULTIPLEXER
- TELEPHONE RECEIVER MAGNETIC COUPLERS
- OUT
- IN
- PDP II/40 COMPUTER
- TIME SHARED COMPUTER FACILITY IBM 360/50
- VIDEO TERMINAL
- EEG REPORT CODER
- ALARM DECODER
- ALARM BUZZER
- TELEPHONE
- VOICE COMMUNICATION HANDSET

FIG. 2

CHANNEL 1 CHANNEL 2

CHANNEL 5 CHANNEL 6

GND GND

F_1 F_2

F_7 F_8

T_3 C_3 C_4 T_4

T_5 T_6

CHANNEL 7 CHANNEL 8

O_1 O_2

CHANNEL 3 CHANNEL 4

ELECTRODE POSITIONS
TOP VIEW
FIG. 3

Fig. 4 is the large schematic packed in the envelope
at the back of this report.

A.

F₁ – C₃

F₂ – C₄

C₃ – O₁

C₄ – O₂

C₃ – T₃

C₄ – T₄

T₃ – F₁

T₄ – F₂

50 μV
1 sec

B.

F₁ – C₃

F₂ – C₄

C₃ – O₁

C₄ – O₂

C₃ – T₃

C₄ – T₄

T₃ – F₁

T₄ – F₂

50 μV
1 sec

Fig. 5.

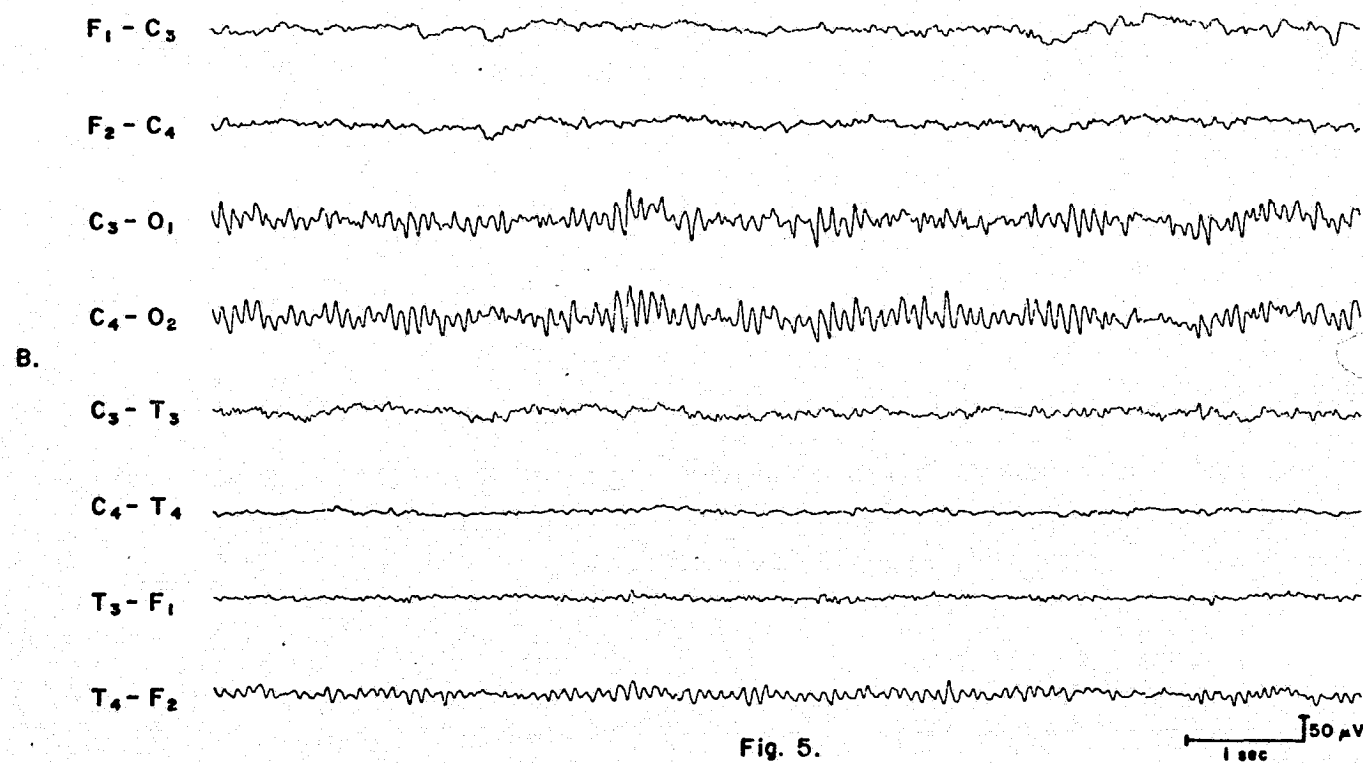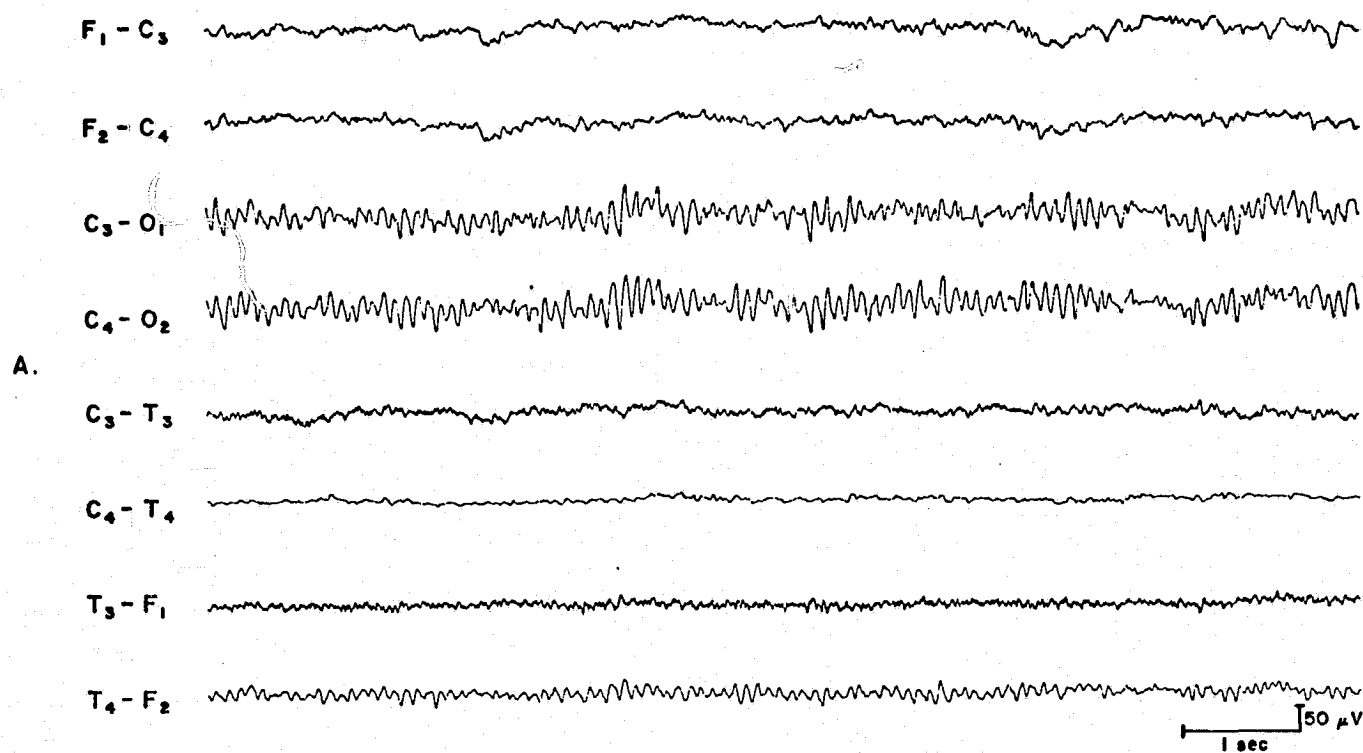EEG REPORT

NEUROPHYSIOLOGY DEPARTMENT
THE METHODIST HOSPITAL
HOUSTON, TEXAS

NAME: AGE: 19 YRS
MEDICATIONS: NONE   DATE: 1/29/75

     OCCIPITAL DOMINANT 10.5 TO 11 C.P.S. ALPHA. SOME LOW
VOLTAGE FAST ACTIVITY IN ALL LEADS. OCCASIONAL LOW VOLTAGE
4 TO 6 C.P.S. ACTIVITY IN FRONTAL LEADS.   RIGHT POSTERIOR
TEMPORAL REGION IS HIGHER IN VOLTAGE THAN THE LEFT.

IMPRESSION: THIS ELECTROENCEPHALOGRAM IS CONSIDERED TO BE
              WITHIN THE RANGE OF NORMAL VARIATION.

          SIGNED: JAMES D. FROST, JR.   M.D.

Fig. 6

$F_1 - C_3$

$F_2 - C_4$

$C_3 - O_1$

$C_4 - O_2$

$C_3 - T_3$

$C_4 - T_4$

$T_3 - F_1$

$T_4 - F_2$

$50 \mu V$

1 sec

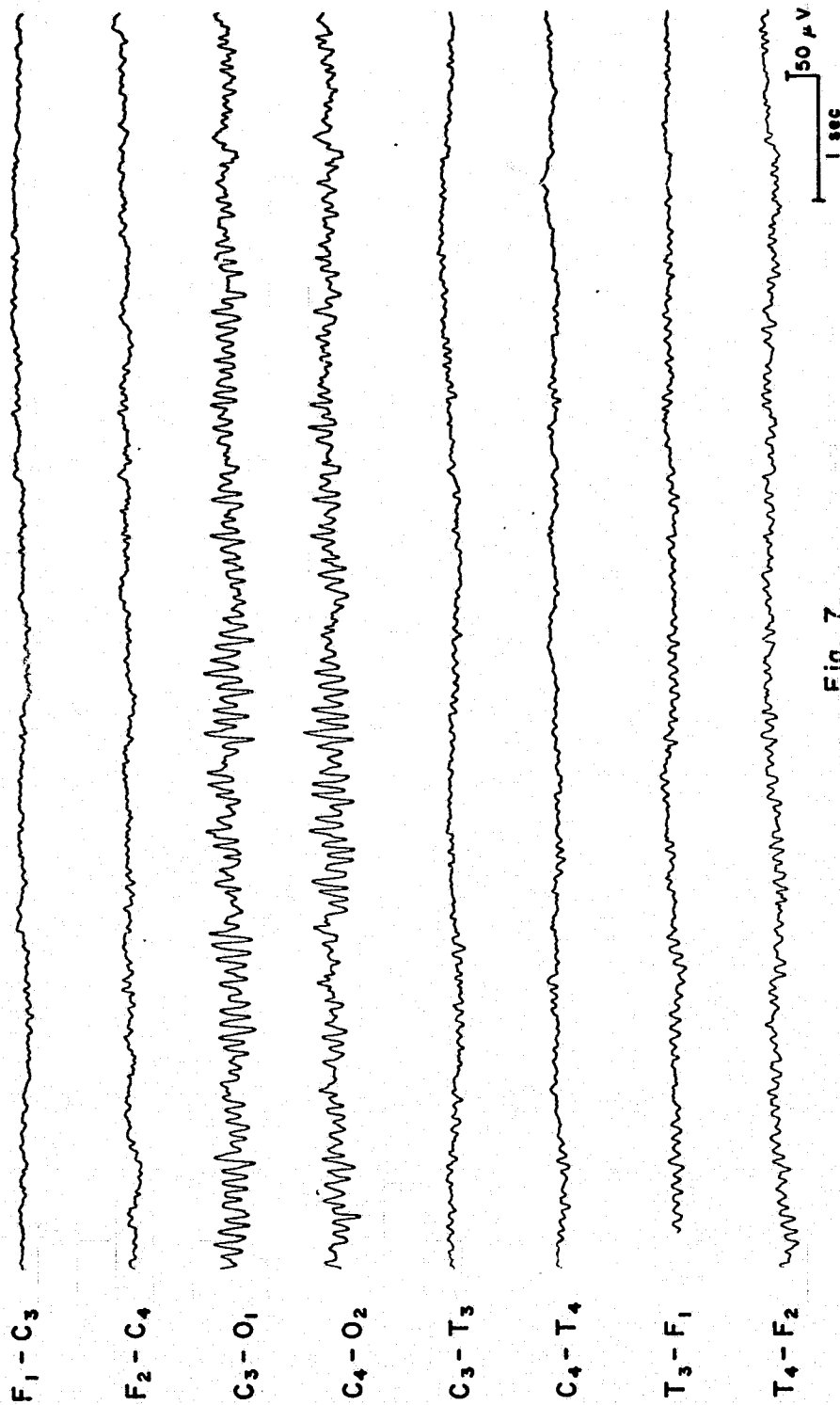Fig. 7.

EEG REPORT
NEUROPHYSIOLOGY DEPARTMENT
THE METHODIST HOSPITAL
HOUSTON, TEXAS

NAME: AGE: 47 YRS.

SUMMARY: OCCIPITAL DOMINANT 9.5 TO 10 HZ ALPHA. SOME
LOW VOLTAGE FAST ACTIVITY ,PREDOMINANTLY IN FRONTAL LEADS.
NO FOCAL OR LATERALIZING SIGNS.

IMPRESSION: THIS ELECTROENCEPHALOGRAM IS CONSIDERED TO
BE WITHIN THE RANGE OF NORMAL VARIATION.

                    SIGNED: JAMES D. FROST,JR. M.D.
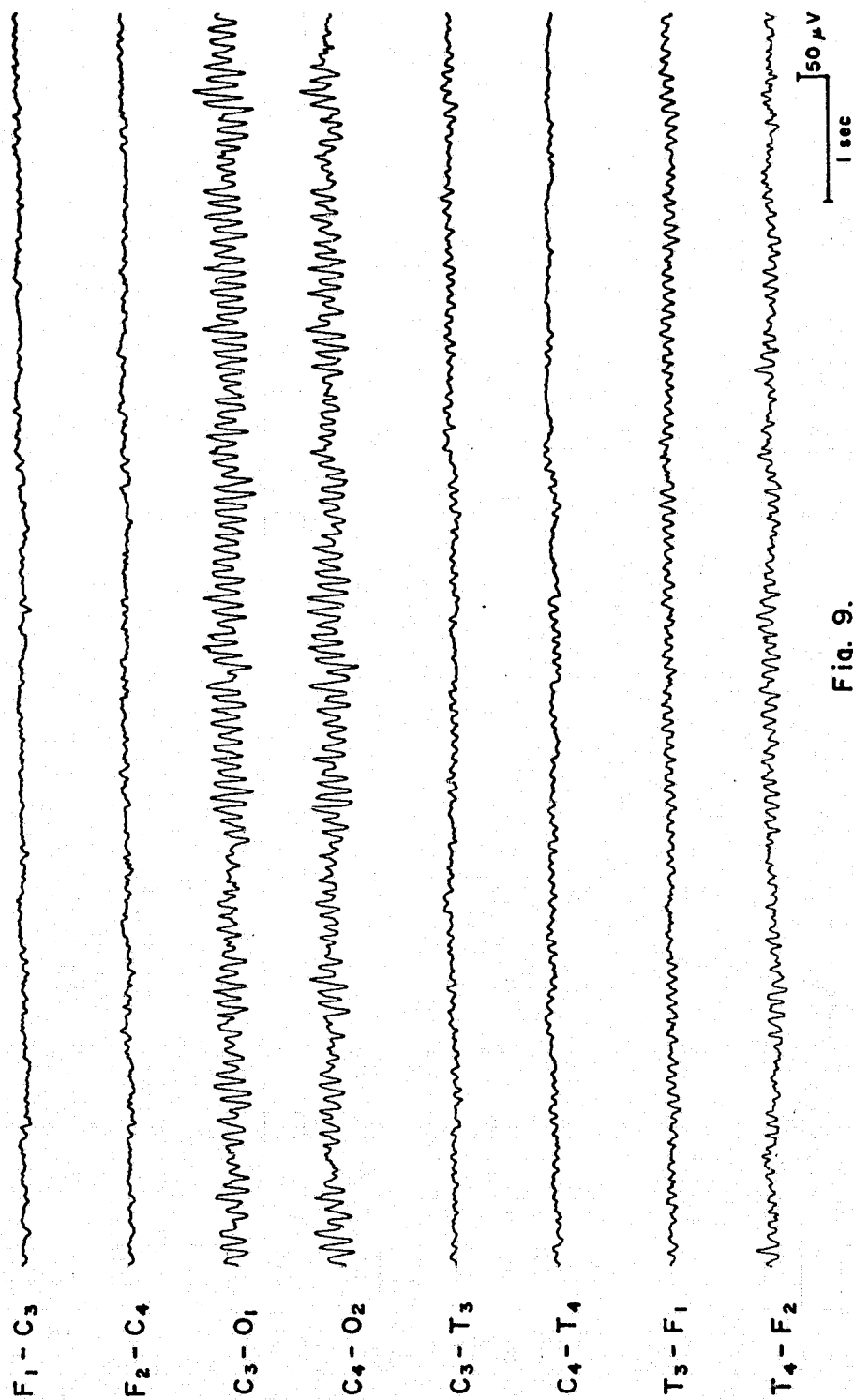   DATE: 2/4/75

Fig. 8

$F_1 - C_3$

$F_2 - C_4$

$C_3 - O_1$

$C_4 - O_2$

$C_3 - T_3$

$C_4 - T_4$

$T_3 - F_1$

$T_4 - F_2$

$50 \mu V$

1 sec

Fig. 9.

EEG REPORT

NEUROPHYSIOLOGY DEPARTMENT
THE METHODIST HOSPITAL

NAME: AGE: 47 YRS
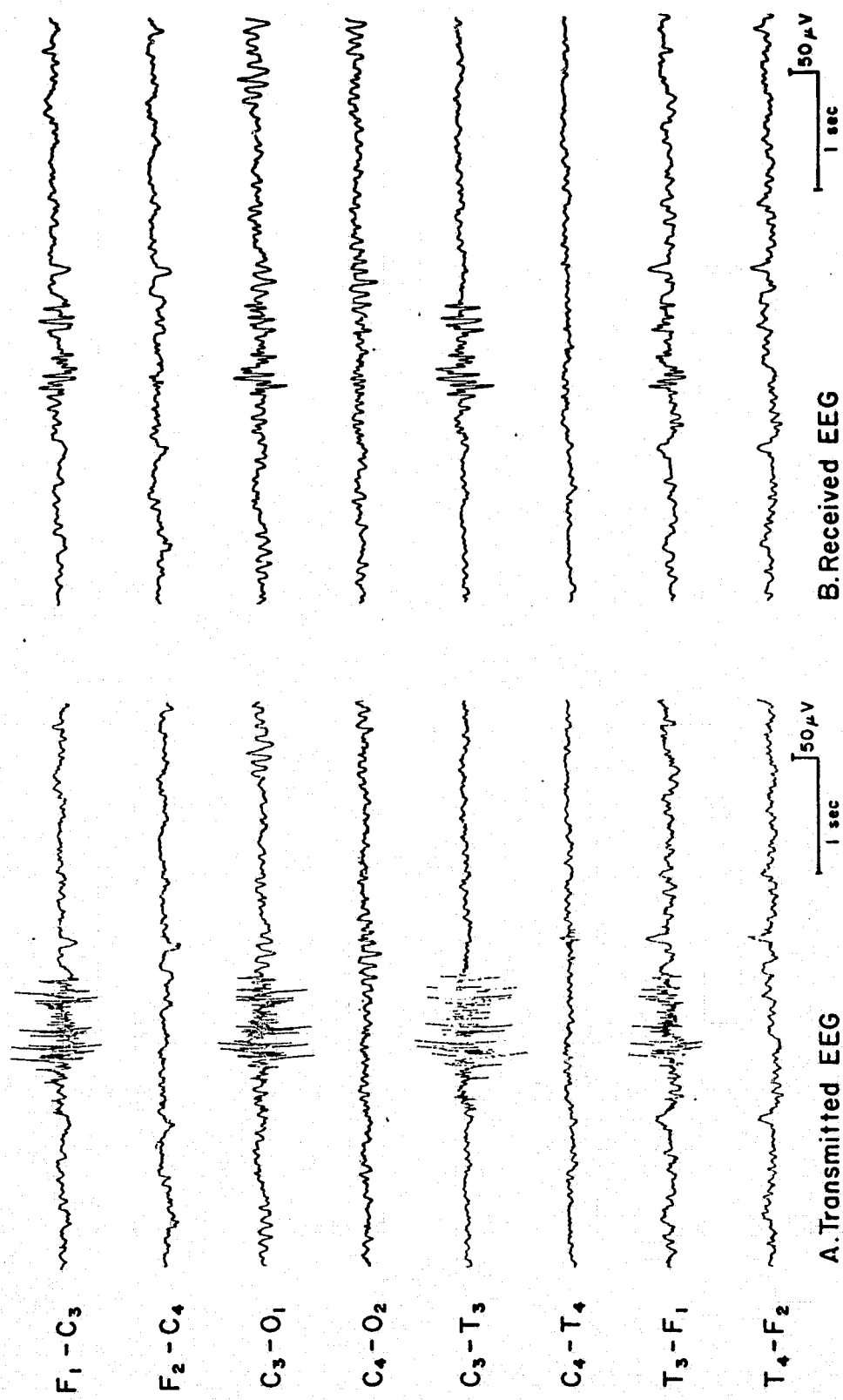DATE: FEB. 6, 1975

TECHNICAL SUMMARY:
     OCCIPITAL DOMINANT 9.5 TO 10 HZ ALPHA ACTIVITY. SOME
LOW VOLTAGE (LESS THAN 15 MICROVOLTS) ACTIVITY IN ALL
LEADS, WITH HIGHEST AMPLITUDE IN THE FRONTAL REGION.
NO FOCAL OR LATERALIZING SIGNS.

IMPRESSION: THIS ELECTROENCEPHALOGRAM IS CONSIDERED TO
BE WITHIN THE RANGE OF NORMAL VARIATION.

                    SIGNED: JAMES D. FROST, JR. M.D.

ORIGINAL PAGE IS
OF POOR QUALITY

Fig. 10

F₁ - C₃

F₂ - C₄

C₃ - O₁

C₄ - O₂

C₃ - T₃

C₄ - T₄

T₃ - F₁

T₄ - F₂

50μV

1 sec

A. Transmitted EEG

50μV

1 sec

B. Received EEG

Fig. 11

Table I

ELECTRONIC COMPONENT VALUES

AR

AR100	LM380	National audio power amplifier
AR101	μ741	Fairchild operational amplifier
AR102	"	" " "
AR103	"	" " "
AR104	"	" " "
AR105	"	" " "
AR106	"	" " "
AR1001	"	" " "
AR1002	"	" " "
AR1003	"	" " "
AR1004	"	" " "

Z

Z100	8273B	Signetics 10-bit serial in parallel out shift register
Z101	"	" " " "
Z102	7404	Texas Instruments hex inverter
Z103	LM566	National voltage-controlled oscillator
Z104	NE567V	National tone decoder
Z1001	LM566	National voltage-controlled oscillator

VR

VR1	μA7805	Fairchild three-terminal positive voltage regulator - 5V
VR2	μA7806	Fairchild three-terminal positive voltage regulator - 6V
VR3	"	" " " "

APPENDIX