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A MODEL FOR THE TELEPHONE TRANSMISSION OF SIX-CHANNEL ELECTROENCEPHALOGRAMS[1]

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Since late November 1968, 350 6-channel electroencephalograms have been successfully transmitted over conventional telephone lines from the Magic Valley Memorial Hospital in Twin Falls, Idaho, to the University of Utah Medical Center in Salt Lake City. This distance between the two cities is approximately 240 miles. EEGs have previously been transmitted via telephone by other investigators (Levine *et al.* 1964; Ray *et al.* 1965; Bickford *et al.* 1969). However, because the number of channels transmitted was limited, this has not been done routinely. It is the purpose of this paper to discuss the technical aspects of this telephone communication system.

METHOD

The instrumentation and transmission scheme used to accomplish EEG transmission is shown in Fig. 1. The patient at the remote site is connected to a standard Model 6 Grass encephalograph. The outputs are then conditioned through an interface conversion resistive network from the standard high-level output of the Grass machine, typically ± 8 V full scale, to a level compatible with the Bell System 604A data sets or ± 2.5 V full scale (Fig. 2). The Bell System 604A data set frequency modulates and in turn frequency multiplexes the signal onto the telephone line for transmission. The scheme used is a constant bandwidth technique. Important characteristics of this data set combination are as follows.

1. *Data channel bandwidth.* These are constant bandwidth channels, and each channel has a bandwidth of approximately DC to 100 c/sec. This is more than adequate for EEG transmission and also can permit transmission of electrocardiograms and other physiologic signals.

2. *Input voltage range.* The voltage range is −2.5 to + 0.5 V giving a full deviation and thereby maximizing the channel deviation capability.

3. *Linearity.* Tests showed that the linearity of each channel was approximately 1% (Dickman *et al.* 1969). This characteristic is important for faithful reproduction of the input signals.

4. *Signal-to-noise ratio.* Typically, there are two problems: one is the random noise and the other is crosstalk from one channel to another. Thus, transient signals from one channel can be reflected into another channel because of imperfect isolation between the channels. Signal-to-noise ratio for the 604A–604B type data sets is at best approximately 200 to 1 and at worst approximately 100 to 1.

5. *Channel delay differences.* In addition to the absolute propagation time, which depends on the length of the communications link (Bickford *et al.* 1969), there is a transmission delay difference among the three channels of the 604A data set. The absolute propagation time is about

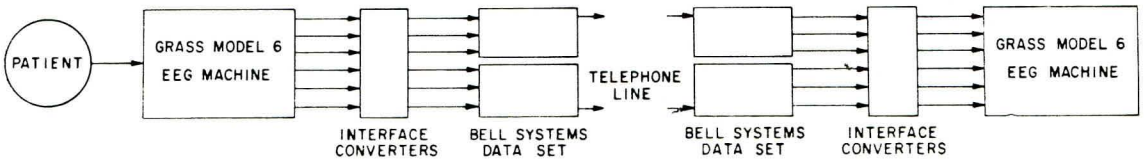

Fig. 1
Schematic diagram of instrumentation.

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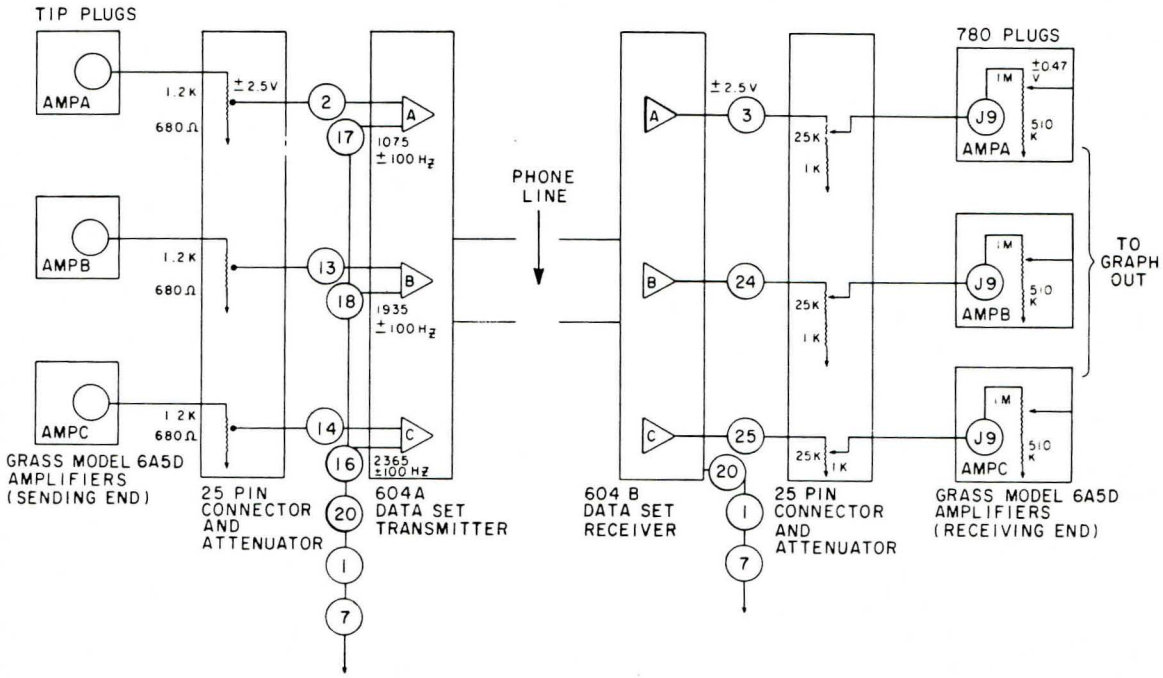

Fig. 2
Diagram of the interface conversion resistive network.

the same for all frequencies and does not cause a time distortion of the signals (Martin 1969). Because of the channel delay difference, information on channel A, which is the low frequency channel, arrives sooner than information on channels B or C. The time delay difference has been measured over short distances (250 miles) and has been found to be approximately 2–4 msec. This is of no major consequence for transmission of routine EEGs, since at the usual paper speeds (3 cm/sec), a time difference of this magnitude (0.1 mm on chart) is not clinically significant. EEGs were transmitted from Twin Falls, Idaho, to San Diego, California, a distance of approximately 1000 miles, during the VIIth International Congress of Electroencephalography and Clinical Neurophysiology. (Bennett and Gardner 1969). There was no obvious channel delay difference even at this distance.

Although initial studies were conducted on private telephone lines, the data can be transmitted over the conventional direct distance dialing (DDD) network. The equipment may therefore be moved to any site desired, and costs are lowered greatly since the communications network is used only when needed. The advantages of the frequency mutliplex transmission scheme over telephone lines are its ability to transmit low frequency down to DC, its inherent noise immunity, and its ability to transmit multiple simultaneous signals on the same transmission link. For this demonstration and clinical trial, only 3 channels of information were transmitted on the same telephone line. Therefore, to transmit 6 channels of EEG, two telephone lines were required. Two recent developments make it possible to consider transmission of up to 8 channels of EEG over a single telephone line: a recent ruling of the United States Federal Communication Commission allowing direct access to the telephone network, and development of integrated circuit "phase-lock-loop" technology (Moschytz 1965; Grebene and Camenzind 1969). The first development permits high quality electrical coupling to the telephone network. The second development which the authors are pursuing makes multiple-channel transmission feasible both economically and technically. The design specifications for this 8-channel system are for each channel to have a bandwidth of approximately 60 c/sec and a signal-to-noise ratio of at least 100 to 1.

DISCUSSION

The total time for each record transmission, including a phone report of the interpretation, has averaged approximately 35 min. This amounts to 204 h of total transmission time with the original data sets (350 records × 35 min). Not one interruption or termination of the recording because of data set malfunction or interference in line transmission has occurred. As many as five EEGs have been transmitted per day. The transmitted records have been compared with the original records, and they are almost identical (Fig. 3). The record in Fig. 4 has been selected to show not only that the signal transmission is of high fidelity but also that there are occasions when noise pulses do appear in the system. These are usually re-

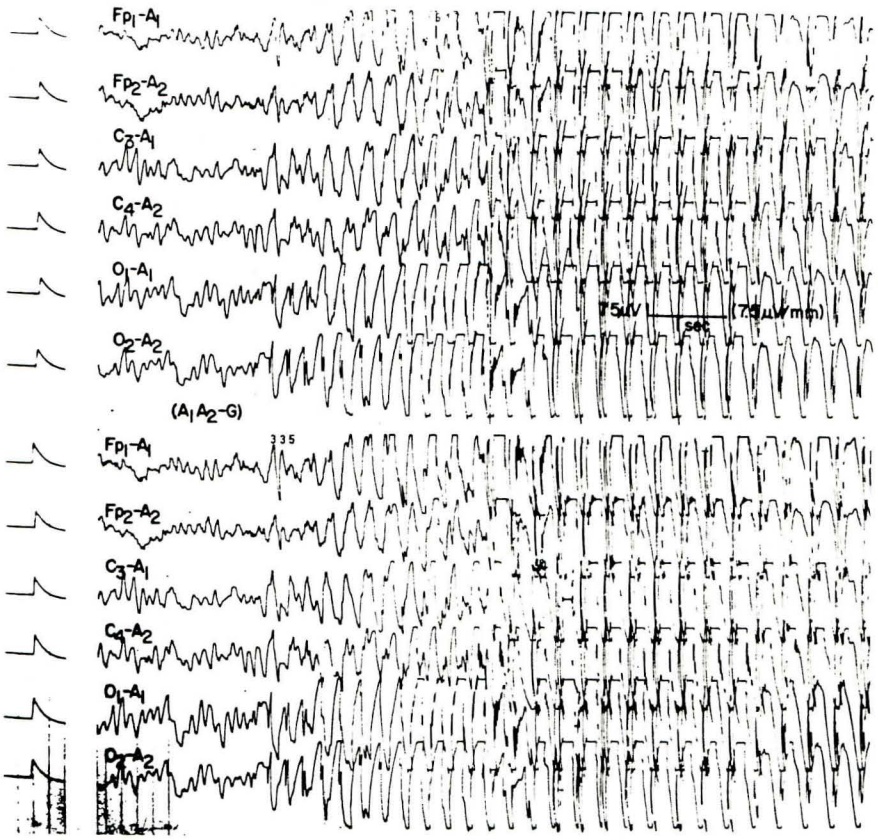

Fig. 3
Comparison of an original (the first 6 channels) with transmitted record. The calibration is also shown. The patient is 8 years old with a history of staring spells.

TABLE I

Major expenses of telephone transmission

Rental of 2 AT+T X604A-M10 transmitter data sets	$130/month ($65 each)
Rental of 2 AT+T X604B-M10 receiving data sets	$260/month ($130 each)
Rental of 4 AT+T business phones	$66/month ($17.50 each)
Cost of station-to-station line transmission (weekday, daytime) for a 35 min record from Twin Falls, Idaho, to Salt Lake City (2 lines required for 6 channels)	$17.50 record ($8.75/line)

flected in one channel or perhaps all 3 channels of one data set and can be easily detected as artifact by looking at all 6 channels simultaneously. In the case in Fig. 4, the noise burst was probably caused by a switching transient in one of the telephone central switching units. This re-

TABLE II

Patient cost based on transmission of approximately 30 records per month. Professional fee for interpretation not included

Data set rental	$ 13.00
Business phone rental	2.20
Cost of transmission (2 lines)	17.50
Paper and miscellaneous expenses	5.00
Technician's salary	
Halftime technician, Twin Falls (80 h/month)	7.33
Salt Lake City technician (20 h/month)	1.82
	$ 46.85

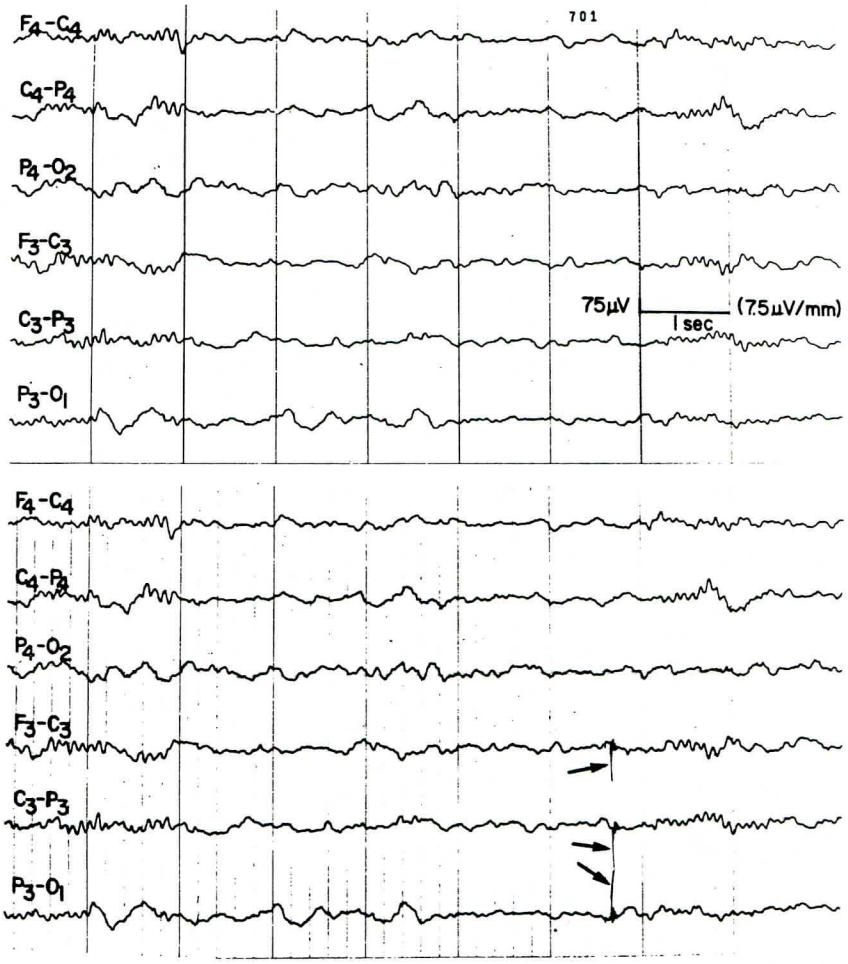

Fig. 4
The noise artifact is indicated by the arrows in the transmitted record.

sponse is quite atypical and is only presented to show that, in fact, there are occasional noise problems and that these can usually be easily detected.

The major expenses for this communication link are shown in Table I. However, within the United States there are regional variations in the cost of rental and installation of the Bell 604 data sets. Presently the cost to the patient for a transmitted 6-channel EEG is approximately $20 greater than local charges for a conventional record (Table II). The difference is not excessive when one considers that, before this system was established, the patients in the Twin Falls region had to travel either 150 miles to Boise, Idaho or 240 miles to Salt Lake City. The expense is small in comparison with the costs of travel and absence from work, and immediate availability of reports is a great advantage.

SUMMARY

Three hundred and fifty 6-channel electroencephalograms have been successfully transmitted over conventional telephone lines from a distant community. The transmission scheme and the ability to use the communications channel as both a voice and data link has proved to be extremely valuable. Financial feasibility is dependent on the number of channels transmitted, the number of records obtained and the distance between the two laboratories. Developments are under way to reduce the cost by improved technology in the transmission scheme.

RESUME

MODELE POUR TRANSMISSION TELEPHONIQUE D'ELECTROENCEPHALOGRAMMES A SIX CHAINES

Trois-cent-cinquante électroencéphalogrammes à 6 canaux ont été transmis avec succès au moyen de lignes téléphoniques conventionnelles depuis un lieu éloigné. Le schéma de transmission et la possibilité d'utiliser les chaînes de communications à la fois pour la voix et pour les données s'est révélé extrêmement valable. Les implications financières dépendent du nombre de chaînes transmises, du nombre de tracés obtenus et de la distance entre les deux laboratoires. De nouveaux développements sont en cours afin de réduire le prix en améliorant la technologie du schéma de transmission.

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