Local and Long Distance Transmission and Storage of Electrocardiograms and other Low Frequency Signals

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A procedure using frequency modulation is described for transmission of electrocardiograms and electroencephalograms over available local and long distance telephone facilities.

We have previously reported the successful transmission of electrocardiograms over telephone facilities using frequency modulation. Before seriously considering the possibility of transmitting electrocardiograms as a service it was necessary to determine whether or not acceptable transmissions could be uniformly obtained over message channels as they exist in the long distance telephone service. Since the telephone plant is designed and maintained primarily for the intelligible transmission of speech, it did not necessarily follow that electrocardiographic signals could be transmitted without distortion over all message channels. Such a study, which provided critical tests of the method used, was, of course, far beyond the scope and facilities of the Cardiovascular Service alone.*

Method

A frequency modulated tone was the method of choice for the following reasons: (1) the low frequency response of many telephone circuits is inadequate for the transmission of the extremely low frequencies encountered in the electrocardiogram necessitating the conversion of the signal to a frequency compatible with commercial telephone practice; (2) stray voltages and other forms of external interference are usually found in the form of amplitude changes and the use of frequency modulation greatly reduces the distortion of the transmitted information; (3) the frequency modulated tone is included in a well defined frequency band so that it can be transmitted on a carrier channel without overlapping into various frequency bands which are utilized in telephone practices for signalling and testing purposes; and (4) the frequency modulated tone can be recorded on ordinary magnetic tape for permanent or temporary storage, thereby simplifying operating practices at the receiving terminal.

Figure 1 is a block diagram of the complete setup. Starting with the patient, the low frequency low amplitude signal of the electrocardiograph is first...
amplified to a peak signal value of 5 to 12 volts and is then passed through the frequency modulator with the circuit diagram illustrated in figure 2. The circuit for the preamplifier is not illustrated since it is a conventional resistance-capacity coupled balanced amplifier with a gain of 100,000 and low of test and signalling frequencies used in the telephone plant and the characteristics of message telephone facilities indicated that a center frequency of 1200 cycles per second could be transmitted satisfactorily and would not be likely to interfere or be interfered with by other telephone operations.

**Fig. 2.** Modulator. The amplified electrocardiographic impulse is fed through an isolating cathode follower to the grid of a transitron Miller oscillator which varies in frequency with the amplitude of the applied signal. The frequency-modulated tone thus obtained is fed through another amplifier tube which also serves to isolate the oscillator from unwanted outside influence. From this point it is further amplified to a level sufficient for transmission by conventional audio amplifiers.

**Fig. 3.** Demodulator. The received frequency modulated tone is amplified and the negative pulses applied to the plate of a trigger tube which produces an impulse of fixed amplitude and duration for each input pulse, irrespective of the frequency or amplitude of the input signal. These pulses are counted by a diode counter circuit and fed through a filter which passes the demodulated electrocardiogram but removes any remaining traces of the frequency modulated tone.

With the telephone operation, a frequency deviation of plus and minus 150 cycles was available at this center; this provided an ample frequency band for transmitting electrocardiograms of a quality exceeding the minimum requirements recommended by the Council on Physical Medicine of the American Medical Association, but it would not meet
requirements suggested by us in 1949 or more recently by Laagner.\textsuperscript{3,4} In our private circuit applications we have used a center frequency of 5000 cycles which provides accurate recording up to 300 cycles. The output of the modulator was connected to the telephone system through a coupling transformer illustrated in figure 3. A cathode ray tube with Puckle sweep circuit was used for visual observation, and a direct writing electrocardiograph for the written record. When the transmission was to be stored on magnetic tape, this record was made before demodulation. The preferred practice was to view the transmission on the cathode ray tube and...

A switching key permitted connection to the electrocardiograph signal or to an ordinary telephone set. Transmitting levels for the telephone usage varied between $-5$ and $-3$ VU. At the receiving telephone the signals came through a similar key and coupling transformer, and then after being amplified to a peak level of 15 to 20 volts were passed through the demodulator circuit and recorded at the same time on tape. Later the tape was rerecorded and desired portions of the record demodulated and transcribed with the direct writing electrocardiograph.

According to Hartley’s Law the amount of noise appearing in any receiver is proportional to the width of the frequency band used. Analysis of early wide band transmissions showed occasional spurious...

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Fig. 4

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4/19/53 6(4) AIRSWORTH-NORFOLK 1 NORFOLK-OHMA 17 EB

4/22/53 5(9) Om-RC 18< Om-Grand Island Channel II 2-K <> Gr.Isl-North Platte Channel 5 1-K

4/22/53 5(1) 3000 MILES ROUND TRIP CIRCUITS UNKNOWN

3/21/53 4(5) OMAHA-RAPID CITY.S.D.-OMAHA OUT # 17 IN # 1 (EKG)

3/21/53 4(2A) OMAHA-RAPID CITY.S.D.-OMAHA OUT # 1 IN # 5 (BRAIN WAVES)
information being received, sufficient in some instances to distort the electrocardiogram seriously. Since the desired information was contained within a 300 cycle band width, band pass filters transmitting from 1015 to 1400 cycles were made. These filters were designed with terminal impedances of 600 ohms with 8 db impedance improving pads. They were not always necessary from the standpoint of successful transmission, but they did provide protection to the telephone lines from excess deviation or possible defective operation of the transmitting equipment and were adopted as standard practice.

For transmission over private wires the coupling transformers and band pass filters were not needed. Wires were twisted pairs without shielding and at distances up to 1200 feet.

RESULTS

Figure 4 shows some of the transmissions obtained. The top trace is a one-way transmission from Ainsworth, Nebraska to Omaha, Nebraska, a circuit distance of 260 miles. The second record is a complicated loop transmission involving a large variety of message facilities and carrier systems. Tests of this type were critically designed to include a wide variety of circuits. In this particular transmission the signal was run around the states of Nebraska and South Dakota, and the actual mileage was not recorded. The 3000 mile loop transmission does not have the critical value of some of the shorter test distances since it was made on long lines which represent more recent and advanced engineering technics. The fourth trace is a loop transmission and involves a number of the older transmission facilities of the plant. The bottom trace is a loop transmission of an electroencephalograph over 1200 miles. In all, over 50 transmission tests were made. Acceptable transmissions were obtained even though the returned signal had been reduced to 1 per cent in amplitude. Lightning and certain other transients were not confusing because of their typical appearance.

DISCUSSION

The transmission of electrocardiograms over short distances has been an accomplished fact for many years and is still a routine operation for the unamplified signal in some institutions at the present time. Frequency modulation greatly increases the reliability of transmission and makes the signal highly immune to the many interfering voltages that occur when the signal is not amplified or when amplitude modulation is used. The results reported show that when converted to a frequency modulated waveform the electrocardiograph or electroencephalograph can be transmitted over a wide variety of telephone circuits without requiring any deviation in operation from current telephone practices. We wish to stress the point that none of the circuits used were specially adjusted or maintained for the purpose of our transmissions.

The success of our transmissions makes it possible to standardize the transmitting and receiving equipment with its obvious simplification in apparatus. The application of the method to recording pressure, optical or mechanical signals requires a transducer designed for the particular problem but does not involve changes in the modulator and demodulator circuits.

Frequency modulation makes magnetic tape recording available for the recording of much physiologic data. This provides continuous recording with an economy of material and small bulk, and in addition the tape can be erased for re-use. A unique advantage is that with a cathode ray tube and suitable sweep circuit it is possible to scan records at a much faster speed than when visually recorded.

SUMMARY

1. Frequency modulation provides a method of converting low frequency signals to a form which can be transmitted over a wide variety of telephone lines, and which can be recorded on magnetic tape.

2. Transmission tests showed that the electrocardiogram and electroencephalogram could be reliably transmitted over a wide variety of telephone lines in a multiplicity of combinations.

3. Frequency modulation permits the design of standardized transmitting and receiving equipment and thus simplifies the problem of local and long distance transmission of low frequency signals.
REFERENCES


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