ECG SIGNAL TRANSMISSION THROUGH TELEPHONE CHANNELS

ABSTRACT
This paper proposes a scheme for transmission of ECG signals of a patient through telephone channels to a cardiologist. Signals are procured using skin surface electrodes clamped at left arm, right arm and right leg. A signal-conditioning unit has been used to process the signals. It comprises of an instrumentation amplifier, which provides most of the gain to the signal. Then signals are passed through a fourth order high pass butterworth filter. A notch filter is used to reject the power line frequency interference. A fourth order low pass butterworth filter is used to suppress the undesired signals in successive stages. Overall gain provided by the signal-conditioning unit is around 80 dB. The conditioned ECG signals are applied to the frequency modulator and after modulation these are transmitted through the telephone channel using an isolation transformer, which provides isolation between the telephone loop and transmitter circuit. At the receiver end signals are picked up from telephone lines using isolation transformer and fed to the frequency demodulator circuit. PLL is used as FM demodulator. Demodulated ECG signals are displayed on CRO.

1. Introduction
Much progress has been made in the field of biomedical engineering. Advanced instrumentation is extensively used for diagnosis, therapy and treatment of various diseases; both invasively and non-invasively. However people worldwide residing in remote areas are still struggling to gain access to advanced medical care. Biotelemetry is the measurement of physiological parameters over a distance. Means of transmitting data from a point of generation to a point of reception can take many forms mainly wire-line or wireless. Selection of system depends on particular requirement taking all the factors such as distance, cost, reliability etc. in account.

To save the lives of people by speeding up the medical response to the person in need, the idea of transmitting the ECG signals through telephone channels has been implemented. This scheme is especially useful for rural areas where good medical facilities and expert cardiologists are not available. Also it provides the facility of check-up of the patient from his home during critical situations or busy schedules without disturbing him. Telemedicine is a high-tech solution to the universal problem of access to health care. Due to this technology, geographical isolation need no longer be the insurmountable obstacle that was present to catering to the basic needs of timely and quality medical care. The scheme presented here is an attempt in this direction.

2. Electrocardiogram and it’s Parameters
Electrocardiograms (ECG’s) represent the recording of the electrical potential of the heart [1]. Physicians’ record ECG’s easily and non-invasively by attaching small electrodes to the chest and extremities of the body of the patient. ECG’s are standard tool used to diagnose various heart anomalies [2]. Waveform is divided in many intervals as shown in Fig 1. Amplitude and duration of different intervals are as following:

<table>
<thead>
<tr>
<th>Interval</th>
<th>Duration</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>P wave</td>
<td>&lt;0.12 Sec.</td>
<td>&lt;0.25 mV</td>
</tr>
<tr>
<td>PR interval</td>
<td>&lt;0.20 Sec.</td>
<td>---</td>
</tr>
<tr>
<td>QRS wave</td>
<td>0.1 Sec.</td>
<td>0.5-0.7 mV</td>
</tr>
<tr>
<td>T wave</td>
<td>0.4 Sec.</td>
<td>0.3-0.5 mV</td>
</tr>
<tr>
<td>Frequency range of ECG:</td>
<td>0.05-100 Hz</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 1. ECG Waveform](image1.png)

3. System Design Overview

![Figure 2. Block Diagram of the System](image2.png)
Block diagram of the proposed scheme is as shown in Fig. 2. Relevant details of the system architecture and implementation have been described below.

3.1 Electrodes and Leads
Skin surface electrodes are placed over the body of patient to measure ECG potentials. In the normal electrode placement, four electrodes are used to record the electrocardiogram; the electrode on the right leg is placed for ground reference. Since the input of the ECG recorder has only two terminals, a selection must be made among the available three active electrodes. The three bipolar limb lead selections are as follows:
- Lead I  Left Arm and Right Arm
- Lead II Left Leg and Right Arm
- Lead III Left Leg and Left Arm
Lead I has been used for this project. Other leads could also be used.

3.2 Signal Conditioning Unit
Signal conditioning unit has been designed to modify and amplify the ECG signals for further processing. ECG signals picked up using electrodes have a magnitude of around 1mV. One of the prime requirements of modulator is that modulating signal should be in the range of 1-10 volts. It is thus apparent that procured ECG signals must be amplified. A variable voltage gain of 5000-10,000 is therefore provided. The signal also, should be confined in the range of 0.05-100 Hz, since most of the information about ECG lies in this range. A low pass filter and high pass filter are used to confine signals in this range. Power line frequency i.e. 50 Hz introduces severe interference to ECG signals. A notch filter hence is used to reject this power line frequency interference. Various stages have been explained further separately.

3.2.1. Instrumentation Amplifier
The very first stage of the signal conditioner unit is Instrumentation Amplifier. Circuit is shown in Fig. 3.
This amplifier consists of two stages. The first stage is composed of op-amps U1 & U2, while the second stage is formed by U3. Gain of the amplifier is adjusted to 1500. High input impedance and high CMRR of the amplifier meets with the requirement of the correct measurement of bio-potential using electrodes. This is the biggest advantage of instrumentation amplifier as well as variable resistor R4 provides the facility to vary the gain. IC OP-07 has been used [9].

3.2.2 High Pass Filter
A fourth order high pass butterworth filter is composed of two-cascaded section of second order high pass butterworth filter. In this case gain increases at the rate of 80 dB per decade, which gives a better, stop band as well as pass band response [3]. As ECG signal are of the range of 0.05 Hz to 100 Hz, a cut-off frequency near to 0.05 Hz has been obtained.

3.2.3 Notch Filter:
A major source of interference to ECG is the electric power system. Besides providing power to the cardiograph itself power lines are connected to...
the other pieces of equipment and appliances present nearby. A narrow band reject filter has been used to reject the 50 Hz power frequency interference. Notch filter used is the twin T-shaped network. Circuit diagram has been shown in Fig. 5.

3.2.4 Low Pass Filter

Fourth order low pass butterworth filter is used to confine the signal below 100Hz. Circuit diagram is as shown in Fig. 6. A sharp roll off of 80 db per decade is obtained which gives a good amount of attenuation to the signal outside the required frequency band i.e. after 100Hz; which is the maximum frequency of an ECG signal.

3.3 Frequency Modulator

Telephone channels are designed for audio frequency range from 300Hz to 3400Hz. Therefore to transmit ECG signals through telephone channels it is required to bring the signal in the same range. Also there is a need of high signal to noise ratio to avoid the distortion of the signal. As frequency modulation is immune to noise in comparison to another analogue modulation techniques, it has been used to serve the purpose.

IC XR-2206 is used to generate frequency-modulated waveform. It comprises of four functional block; Voltage controlled oscillator, an analog multiplier, a sine shaper, and unity gain buffer [4][8].

The amplified ECG signal voltage is applied to VCO. Selecting resistor and capacitor of appropriate value sets centre frequency of oscillation. According to ECG voltage this frequency of VCO deviates around this nominal frequency and a frequency modulated waveform is generated. Frequency deviation of the waveform is proportional to the amplitude of applied ECG signal.

3.4 Link Set-up

To connect any circuit with telephone lines, the ground of the circuit must be isolated from telephone loop. Isolation transformer has been used for the purpose.

FM signal is fed to the isolation transformer. Output from the isolation transformer is connected in parallel with telephone line through a switch. Switch has two positions as shown in Fig. 8. At position 1 switch connects telephone to line while at other position it connects transmitter to line. Initially call is established between patient’s telephone set and doctor’s telephone keeping switch in position 1. After conveying the information about the patient, transmitter equipment is connected in parallel with the telephone by throwing the switch to position 2. Handset may be put on cradle after establishing the link between ECG transmitter equipment and doctor’s phone. After hearing the tone of frequency-modulated wave, receiving equipment is connected to telephone line through similar isolation transformer. The received signal is demodulated and the ECG signal is thus retrieved.
3.5 Frequency Demodulator
At the receiver end modulated signals are obtained from the telephone channels connecting receiver in parallel with telephone using isolation transformer. Phase locked loop (PLL) is used to demodulate the frequency modulated ECG signal. The FM signal is demodulated with little or no distortion to retrieve the ECG signal. IC LM 565 has been used [6].

![Frequency Demodulator Circuit](image)

3.6 Power Supply
All the circuits explained above require a power supply for their operation. Power supply of +15 V and -15V is needed for signal conditioner unit and frequency modulator and +5V and -5V for frequency demodulator [3]. For this project work stabilised D.C. power supply of standard make were used.

4. Results
Replica of transmitted ECG signal near to original one has been obtained. Small amount of noise was present in recovered ECG waveform, which is due to noisy telephone channels. Waveforms at various stages of the circuit have been obtained.

5. Conclusion
The scheme “ECG Signal Transmission through Telephone Channels” aims at the development of a system by which ECG data can be sent over long distances without any significant distortion. Frequency modulation scheme has been used which is immune to noise in comparison to others. Exact replica of the transmitted ECG signal is essential in this case for perfect diagnosis of the patient hence high signal to noise is desired which is inherent in frequency modulation scheme.

Developed ECG signal transmission system is an innovating, indispensable, simple, efficient, economical and reliable system.

6. Future Enhancements
The scheme for transmission of ECG signals is developed for a single channel. The same unit can be extended for multichannels system. Frequency division multiplexing can be used. As signals are translated into the audio frequency range to facilitate the transmission through telephone channels, scheme can be improved to record the modulated signals on audiotapes. This will facilitate the patient in case of absence of doctor at other end. The ECG signal may be interfaced with PC by using ADC cards at both receiver and transmitter end.

The technology uses electronic signals to transfer medical data in real time from one site to another overcoming all geographical barriers. This paper is just a step in this field and it requires a lot of further research work.

References