

## Wireless Transmission of Real Time Electrocardiogram (ECG) Signals through Radio Frequency (RF) Waves\*

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### ABSTRACT

In this project the Electrocardiogram (ECG) is recorded with the help of three ECG electrodes and after amplification and frequency modulation it is transmitted as FM signal. By changing the position of ECG electrodes on the body the ECG signal of lead I, lead II and lead III are recorded. Instrumentation amplifier INA 114 is used to collect the ECG signal from the body which gives excellent accuracy. This also provides the gain of around 11. The amplifier section is used to amplify the signal so that it can be transmitted. The amplifier circuit is built around IC LM358. Total gain of around 1000 is achieved. This amplified signal is given to FM transmitter where it is frequency modulated and transmitted. The range of transmission is around 300 meters which is sufficient for the hospital applications.

In this project we used the radio receiver CXA1619/BS which receives ECG signals and after demodulation converts back into voltage form. We can adjust the frequency with the help of a tuner which is available on the receiver unit. An RC low pass filter is used to remove the unwanted noise. The output is displayed on a simple oscilloscope. Thus ECG signals can be transmitted without any direct connection of wires between ECG data acquisition part and display monitor.

**Keywords:** Electrocardiogram (ECG), amplification, frequency modulation, Instrumentation amplifier, demodulation, oscilloscope.

### 1. INTRODUCTION

The electrocardiogram (ECG or EKG) is a noninvasive test used to measure the electrical activity of the heart. An ECG can be used to measure the rate and regularity of heartbeats, the position of chambers, the presence of any damage to the heart and the effects of drugs and devices used to regulate the heart.<sup>[1]</sup>

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This procedure is very useful for monitoring people with heart diseases or to provide diagnosis when someone has chest pain or palpitation.

The circuit consists of two major sections: Transmitter section and Receiver section. In the transmitter section ECG data is acquired from the human body through the surface electrodes with the help of an instrumentation amplifier. Since the ECG signal from the body is of very low amplitude (0.5 to 1 mV) it is amplified up to an optimum gain level (gain is around 1000).

ECG Leads are placed on the body in several pre-determined locations, usually the extremities or the front of the chest, to provide information about heart conditions. ECG signals are picked up by the electrodes and are preprocessed (amplified and converted from voltage to frequency signal) and then transmitted at around 90 MHz.

These signals are received with the help of an FM radio receiver. Now the signal is converted back into voltage signal and displayed on cathode ray oscilloscope (CRO). In this way we can transmit and receive the ECG signals without any direct contact between patient and ECG monitor.<sup>[2]</sup>

Since the device has to be used on human subjects, the transmitter should be independent of all off-the-wall voltages. For safety reasons, the patient should not be in contact with the high voltages and currents that are associated with wall sockets. The transmitter broadcasts at frequency ranging between 88MHz and 108MHz (FM). In order to be received by a commercial radio, the broadcast signal must be within this range.

The transmitter and receiver are low-power circuits which do not draw more than 10mA each. This requirement is partially for safety reasons and partially because the circuits should be able to run off of a battery power source for long time. The system is portable and easy to fit in the space of a typical lab station. To be a useful solution, the system needs to be compact. In addition portability is a necessary requirement for a practical application of this system.<sup>[3]</sup>

### Basic Signal flow

Input Signal → Amplifier → voltage to frequency converter → Transmitter

Receiver → Amplifier → frequency to voltage converter → Output to oscilloscope

## 2. TRANSMITTER SECTION

The primary objective of this design project is to build a device capable of eliminating the need for lead wires to monitor the cardiac activity of subject. The integrity of the signal while it is wirelessly transmitted to the receiver or relayed to an electrocardiograph via input cables is a very important aspect of this system. It is important that a physician using continuous ECG monitoring be able to objectively notice variations in a subject's health status based on the trends of the waveform of the signal. Moreover a distorted signal can cause erroneous medical diagnosis or inaccuracy of measured values (e.g. heart rate).

For this reason, the wireless bio-monitoring system must have a signal to noise ratio (SNR) deemed acceptable for ECG signals and possibly for other types of signals. Since the voltage amplitude of non-amplified ECG can be approximated to 5mV, we require the maximum amplitude of any noise present in the filtered signal to be 5 μV or less (gain is not incorporated here). Hence, the required SNR for the sensor node is given as

$$SNR = 20 \cdot \log(A_{\text{signal}}/A_{\text{noise}}) = 65 \text{ dB} \quad (1)$$

$$SNR = 20 \cdot \log(5000 \mu\text{V} / 5 \mu\text{V}) = 60 \text{ dB} \quad (2)$$

In order to optimize the performance of the signal acquisition system, the desired SNR will be set at 100 dB. This will allow our system to accommodate the needs of other biopotentials as far as the strength of the desired signals compared to the undesired ones.

Transmitter section collects the signal from the subject and transmits it after amplification. It consists of the following parts:

### 1. ECG Leads

The ECG leads used in this project are insulated ECG wires which connect the electrodes to the circuit. They are perfectly insulated in order to prevent noise interference. The length of each lead is around 1 meter. Three leads are used for left arm, right arm and ground (right leg) which are color coded as black, white and green respectively. According to the Einthoven triangle we are measuring the potential between right arm and left arm keeping right leg as ground which is Lead I configuration.

### 2. ECG Electrodes

Each disposable electrode has a central metallic portion with flat ventral disc of 1 cm diameter and small knob like structure on the dorsal surface to which a metallic prong is fixed for monitoring the patient. The prong has a long wire at its other end, which goes to the circuit. These snap electrodes provide the same signal transmission as the reusable electrodes, with added convenience and hygiene. Each peel-and-stick electrode is pre-gelled and designed for one use only.

These economical, pre-gelled electrodes have a circular contact area of 1 cm diameter and are most suitable for short-term recordings. The small (35 mm) diameter backing allows close electrode placement where necessary and a slightly less firm adhesive allows painless removal. The electrodes incorporate liquid gel and are high chloride for quick, accurate readings.

### 3. Bio-Instrumentation Amplifier and Amplifier Unit

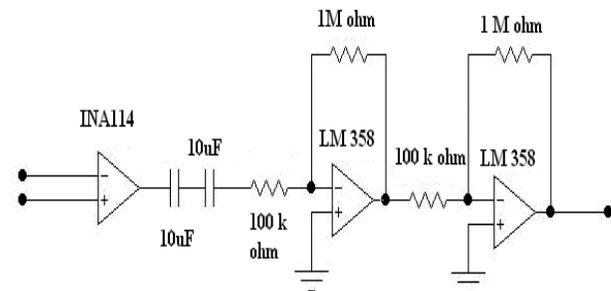


Figure 1 ECG data acquisition and amplifier circuit

With the reference lead of the subject placed to right leg (ground), each of the input leads (from the left and right hand) is sent to the input of INA114 instrumentation amplifier. A gain of 11.7 results from this stage using a 4.7k resistor. Following the instrumentation amplifier the signal is passed through two 10 uF capacitors, placed back to back. The capacitors are used to prevent baseline drift in the ECG signal. Putting two directional capacitors back-to-back forms a bi-directional capacitor. A time constant of 0.5 second was chosen to approximate the frequency of a standard ECG signal (a resistor of 100k can be connected to ground after the capacitor in order to make a time constant of 0.5 sec). This section is followed by two inverting amplifiers each with a gain of ten. The total gain of this part of the circuit is approximately equal to 1000. [5]

The INA114 is a low cost general purpose instrumentation amplifier with excellent accuracy. Its versatile 3-op amp design and small size make it ideal for a wide range of applications. A single

external resistor sets any gain from 1 to 10,000. Internal input protection can withstand up to  $\pm 40V$  without damage. The INA114 is laser trimmed for very low offset voltage (50mV). It operates with power supplies from  $\pm 2.25V$  to 5V. Maximum quiescent current is 3mA. The INA114 is available in 8-pin plastic and SOL-16 surface-mount packages. Both can be used in  $-40^{\circ}C$  to  $+85^{\circ}C$  temperature range.

Gain of the INA114 is set by connecting a single external resistor,  $R_G$ :

$$G = 1 + \frac{50k\Omega}{R_G} \quad (3)$$

Two decoupling capacitors of value  $0.1 \mu F$  are connected with pin no 4 and 7 on one end and grounded on the other end to reduce noise interference. [6]

The LM358 consist of two independent high gain internally frequency compensated operational amplifiers. They are designed specifically to operate from a single power supply over a wide range of voltage. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

#### 4. FM Transmitter

FM transmitter circuit is built around transistor BEL 548. This circuit receives the amplified signal from amplifier unit and after frequency modulation transmits it through an antenna.

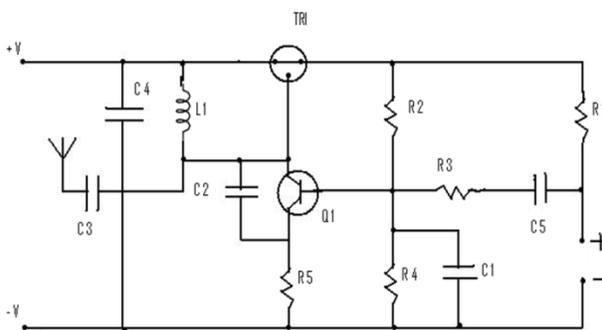


Figure 2 Circuit diagram of FM transmitter

Where  $R1 = 10K$ ,  $R2 = 15K$ ,  $R3 = R4 = 4.7K$ ,  $R5 = 47\Omega$   
 $C1 = C5 = 10KpF$ ,  $C2 = 10KpF$ ,  $C3 = 0.001KpF$ ,  
 $C4 = 2.2\mu F$ ,  $Q1 = BEL 548$ ,  $L1 = 4$  turns,  $TRI = 2-22pF$   
 $+ V = + 9V$

The range of this transmitter is up to 300 meter which is sufficient for hospital applications. It can broadcast on any FM frequency from 88.0 to 108.0 MHz. The transmitting frequency can be set by adjusting the variable capacitor and spacing between coil turns of

the inductor. The length of antenna is about 1 meter and for better output antenna should be kept outside.

### 3. RECEIVER SECTION

The receiver unit is designed to be portable and considerably lighter than most of the commercial devices. One of the principal features of the receiver unit is the flexibility it offers as a device which can be used as a portable bio-monitor system or as a wireless adapter that links a wireless sensor unit to other physiological monitoring systems such as bedside monitors, other bio-monitors, or even a computer. If the user is stationary and is close to a monitor, the signal transmitted by the sensor can be transferred physically to the monitor via output ports.

Receiver unit receives ECG signal with the help of an FM audio board and amplifies it after converting the signal back into voltage form. Further it is passed through a low pass filter to remove noise. We have used in-built radio circuit in place of a commercial FM radio to make the project cost-effective.

#### 1. FM Audio Board

For this project we used CXA 1619BS as FM receiver. It is an FM/AM radio IC designed for radio-cassette tape recorders and headphone tape recorders. With the help of an antenna it receives FM signals. It has small number of peripheral components. It works well on 9 Volt supply.

#### 2. RC Low Pass Filter

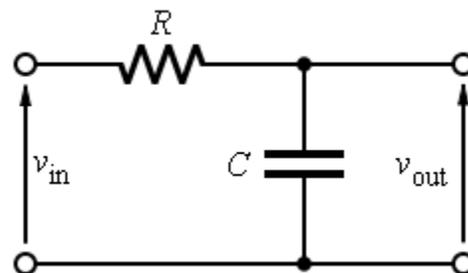


Figure 3 RC low pass filter

An RC low pass filter consists of a resistor and a capacitor. Output voltage is taken across the capacitor. This filter passes low-frequency signals but stops the signals with frequencies higher than the cutoff frequency. It is sometimes called a high-cut filter, or treble cut filter when used in audio applications.

Output signal  $V_{out}$  contains frequencies from the input signal, with high frequencies attenuated, but with little attenuation below the cutoff frequency of the filter determined by its RC time constant. For current signals, a similar circuit using a resistor and

capacitor in parallel works the same way. The cutoff frequency (in hertz), is determined by the time constant:

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC} \quad (4)$$

And in radians per second:

$$\omega_c = \frac{1}{\tau} = \frac{1}{RC} \quad (5)$$

For ECG signal frequency is around 100 Hz, hence if we use the capacitor with capacitance 0.1 μF then the resistance value becomes around 160 kΩ.

#### 4. RESULTS ANALYSIS

We recorded the ECG signal at two places, first just after ECG acquisition part to see whether the ECG signal is acquired correctly or not and then at the output of the receiver unit. Both the outputs were displayed on the oscilloscope.



Figure.4 Transmitter section

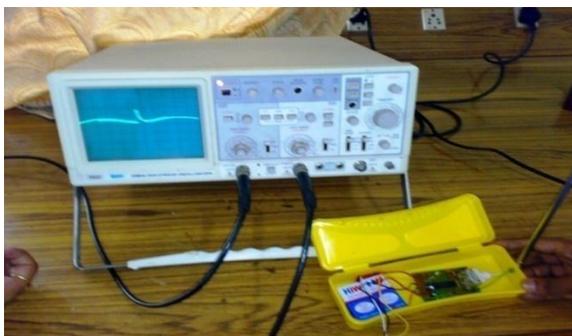


Figure 5 Receiver section

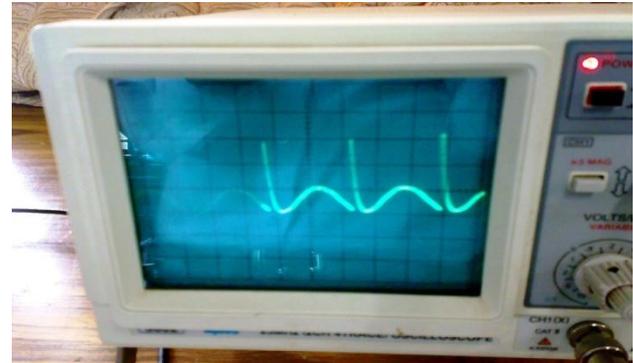


Figure 6 ECG waveform on oscilloscope

**Table 1 Result interpretation**

Parameter	Remarks
Measured Parameters	In this project we measured the real time ECG signal of human being
amplitude of ECG signal	The voltage amplitude of ECG signal is approximately 22mV
Wireless Transmission Range	Wireless transmission range of this system is approximately 300 meters.
Power Supply	Here we used three 9V batteries, two for transmitter section and one for receiver section
Battery Life	Battery life is very long. It can be used continuously for more than 12 hours
Gross Weight	This ECG monitor is very light weight which is preferable for portable applications. Gross weight of transmitter and receiver section is less than 500 grams.
Dimensions (Antenna & wires not included)	Dimension of transmitter section is 8cm x 4cm and the dimension of receiver section is 6cm x 4cm.
Wireless Transmission Frequency Range	Transmission frequency range is between 88 and 108 MHz.

## 5. CONCLUSION AND FUTURE WORK

In this project three ECG leads are used to obtain the real time ECG signal from the human body. Signal is collected with the help of an instrumentation amplifier (INA 114). Amplifier LM358 is used to amplify the signal so that the desired gain can be achieved. Total gain is around 1000.

Signal is transmitted through the FM transmitter at around 90 MHz. Range of transmission is around 300 meters that means the receiver can receive the signal within this range. Tuning is done by varying the distance between inductor coils.

Finally we observed that this monitor works well in normal range and frequency.

Further we can use 10 ECG leads in place of 3, in this way we can get more accurate and extensive result.

By using FM transmitter with more range of transmission, we can transmit the ECG signal at desired distance.

Output can be interfaced with the computer so that the result can be automatically recorded and interpreted.

By modifying the range and accuracy of the system we can design ECG monitor for pilots and astronauts.

With the help of this system we can transmit other biological signals also like EMG, EEG, and EGG etc.

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