Chapter 2
System Hardware Approach

2.1 Previous Work Done

As biomedical engineering is a very important field, continuous research work is going on from the last three decades. Various methods have been developed to record and analyze ECG Signals.

A well-known Holter Recorder is developed during 2002/2003 to capture the ECG signal for analysis [34]. Normally so far Matlab is the popular tool to analyze the ECG waveform. Various algorithms so far developed and tested are based on technologies like wavelet transformation [1][5][28][31], derivative or differential algorithm, wavelet packets [3], wavelet thresholding[4], Time and frequency domain analysis [7], Discrete wavelet transform [10][15][26], Fuzzy neural network [32], Genetic segmentation of ECG signal, wavelet shrinkage [22][23], etc. Over the past few years, there has been an increased trend toward processing of the electrocardiogram (ECG) using microcomputers. A survey of literature in this research area indicates that systems based on microcomputers can perform needed medical services in an extremely efficient manner. In fact, many systems designed and implemented to perform signal processing tasks include 12-lead off-line ECG analysis, Holter tape analysis, and real-time patient monitoring [89].
2.1.1 Objective of Present Work

The basic objective of present research work is to help the patient of heart diseases by providing them, the status of their cardiovascular system on the console of the system developed. This will help more to the people of rural areas where modern medical facilities are not available.

2.1.2 Overview of Work Done

In this course research, I focused on designing an embedded control based system for capturing and analyzing ECG signal. The analyzing of the signal helps in understanding various patterns of ECG signal and execute appropriate decision about the health of the patient. The main components of the system include;

1) Hardware based on ARM7 processor LPC2103 along with analog card to capture the ECG waveform
2) Software using High level language C++ to analyze it
3) GUI designed using Visual basic
4) Transmission using GSM module MAESTRO 100-lite

This system deals with implementation of algorithms like detrending of ECG signal, RR interval detection, QRS complex detection, detection of pre ventricular contractions and other abnormalities (algorithm details are given in the next lessons) using embedded controllers.

2.2 Selection of Micro-Controller

The economy of mass production has led to the use of the desktop PC as the central computer for many types of biomedical applications. Many companies use PCs for such applications as sampling and analyzing
physiological signals, maintaining equipment databases in the clinical engineering departments of the hospitals, and simulation and modeling of physiological systems. The processor selection plays a very vital role. One can configure the PC to have very user friendly, interactive characteristics like good memory, availability of multiplexer in the chip for doing complex iterative calculations, communication ports /serial interface ports (availability of UART), power efficiency, featuring ISP/IAP via on-chip BL software, ADC provision, RAM capability etc. Along with all the listed required features, availability and affordability of the chip plays an important role. For the point of capturing system and required tasks, processor/controller selected is LPC 2103 microcontroller.

The LPC2101/2102/2103 microcontrollers are based on a 16-bit/32-bit ARM7TDMI-S CPU with real-time emulation that combines the microcontroller with 8 kB, 16 kB or 32 kB of embedded high-speed flash memory. A 128-bit wide memory interface and unique accelerator architecture enable 32-bit code execution at the maximum clock rate. For critical performance in interrupt service routines and DSP algorithms, this increases performance up to 30 % over Thumb mode. For critical code size applications, the alternative 16-bit Thumb mode reduces code by more than 30 % with minimal performance penalty. [91]

Due to their tiny size and low power consumption, the LPC2103 are ideal for applications where miniaturization is a key requirement. A blend of serial communications interfaces ranging from multiple UARTs, SPI to SSP and two I2C-buses, combined with on-chip SRAM of 2kB/ 4kB/ 8kB, make these devices very well suited for communication gateways and
protocol converters [91]. The superior performance also makes these devices suitable for use as math coprocessors. Various 32-bit and 16-bit timers, an improved 10-bit ADC, PWM features through output match on all timers, and 32 fast GPIO lines with up to nine edge or level sensitive external interrupt pins make these microcontrollers particularly suitable for industrial control and medical systems.

2.2.1 Key features of LPC 2103

- 16-bit/32-bit ARM7TDMI-S microcontroller in tiny LQFP48 and HVQFN48 packages.

- 2kB/4kB/8kB of on-chip static RAM and 8kB/16kB/32kB of on-chip flash program memory.

- 128-bit wide interface/accelerator enables high-speed 70 MHz operation.

- ISP/IAP via on-chip boot-loader software. Single flash sector or full chip erase in 100 ms and programming of 256 bytes in 1ms.

- Embedded ICE-RT offers real-time debugging with the on-chip Real Monitor software.

- The 10-bit ADC provides eight analog inputs, with conversion times as low as 2.44 microsecond per channel and dedicated result registers to minimize interrupt overhead.
- Two 32-bit timers/external event counters with combined seven capture and seven compare channels.

- Two 16-bit timers/external event counters with combined three capture and seven compare channels.

- Low power Real-Time Clock (RTC) with independent power and dedicated 32 kHz clock input.

- Multiple serial interfaces including two UARTs (16C550), two Fast I2C-buses (400 kbit/s), SPI and SSP with buffering and variable data length capabilities.

- Vectored interrupt controller with configurable priorities and vector addresses.

- Up to thirty-two, 5 V tolerant fast general purpose I/O pins.

- Up to 13 edge or level sensitive external interrupt pins available.

- 70 MHz maximum CPU clock available from programmable on-chip PLL with a possible input frequency of 10 MHz to 25 MHz and a settling time of 100 microseconds.

- On-chip integrated oscillator operates with an external crystal in the range from 1 MHz to 25MHz.
Power saving modes includes Idle mode, Power-down mode with RTC active, and Power-down mode.

Individual enable/disable of peripheral functions as well as peripheral clock scaling for additional power optimization.

2.2.2 Architectural overview

The ARM7TDMI-S is a general purpose 32-bit microprocessor, which offers high performance and very low power consumption. The ARM architecture is based on Reduced Instruction Set Computer (RISC) principles, and the instruction set and related decode mechanism are much simpler than those of micro-programmed Complex Instruction Set Computers (CISC).

This simplicity results in a high instruction throughput and impressive real-time interrupt response from a small and cost-effective processor core. Pipeline techniques are employed so that all parts of the processing and memory systems can operate continuously [91]. Typically, while one instruction is being executed, its successor is being decoded, and a third instruction is being fetched from memory.

The ARM7TDMI-S processor also employs a unique architectural strategy known as Thumb, which makes it ideally suited to high-volume applications with memory restrictions, or applications where code density is an issue. The key idea behind Thumb is that of a super-reduced
instruction set. Essentially, the ARM7TDMI-S processor has two instruction sets:

- The standard 32-bit ARM set.
- A 16-bit Thumb set.

The Thumb sets 16-bit instruction length allows it to approach twice the density of standard ARM code while retaining most of the ARM's performance advantage over a traditional 16-bit processor using 16-bit registers. This is possible because Thumb code operates on the same 32-bit register set as ARM code. Thumb code is able to provide up to 65% of the code size of ARM, and 160% of the performance of an equivalent ARM processor connected to a 16-bit memory system.

The particular flash implementation in the LPC2101/2102/2103 allows for full speed execution also in ARM mode. It is recommended to program performance critical and short code sections in ARM mode. The impact on the overall code size will be minimal but the speed can be increased by 30% over Thumb mode.

2.2.3 On-chip flash program memory

The LPC2103 incorporate a 8 kB, 16 kB or 32 kB flash memory system respectively. This memory may be used for both code and data storage. Programming of the flash memory may be accomplished in several ways. It may be programmed in system via the serial port.
The application program may also erase and/or program the flash while the application is running, allowing a great degree of flexibility for data storage field firmware upgrades, etc. The entire flash memory is available for user code as the boot-loader resides in a separate memory. The LPC2101/2102/2103 flash memory provides a minimum of 100,000 erase/write cycles and 20 years of data-retention memory.

2.2.4 Block Diagram of LPC2103

The block diagram of microcontroller LPC2103 is shown in the above figure. It shows all the features of the controller listed. Pin configuration of the controller helps in assigning port location and register settings to implement algorithm. LPC2103 has two different buses 1) ARM7 Local bus; 2) Advanced high performance bus. Watchdog timer is used to reset the controller in case of any problem in processing. The system resets itself under set conditions after the time set in the watchdog timer.
Figure 2.1 Block diagram of LPC2103
2.3 ECG LEADS / ELECTRODES

2.3.1 Basics of ECG Leads

Two electrodes placed over different areas of the heart and connected to the galvanometer will pick up the electrical currents resulting from the potential difference between them. For example, if under one electrode a wave of 1mv and under the second electrode a wave of 0.2mv occurs at the same time, then the two electrodes will record the difference between them, i.e. a wave of 0.8mv. The resulting tracing of voltage difference at any two sites due to electrical activity of the heart is called a “LEAD”. [59]

![Einthoven’s Triangle](image)

**Figure 2.2 Einthoven’s Triangle**

The term "lead" in electrocardiography causes much confusion because it is used to refer to two different things. In accordance with common parlance the word lead may be used to refer to the electrical cable attaching the electrodes to the ECG recorder. As such it may be acceptable to refer to the "left arm lead" as the electrode (and its cable) that should be
attached at or near the left arm [60]. There are usually ten of these electrodes in a standard "12-lead" ECG.

Alternatively the word *lead* may refer to the tracing of the *voltage* difference between two of the electrodes and is what is actually produced by the ECG recorder. Each will have a specific name. For example "Lead I" (lead one) is the voltage between the right arm electrode and the left arm electrode, whereas "Lead II" (lead two) is the voltage between the right limb and the feet. (This rapidly becomes more complex as one of the "electrodes" may in fact be a composite of the electrical signal from a combination of the other electrodes. Twelve of this type of lead forms a "12-lead" ECG output. To cause additional confusion the term "limb leads" usually refers to the tracings from leads I, II and III rather than the electrodes attached to the limbs.

![Figure 2.3: Placement of Augmented Leads](image)

By definition a 12-lead ECG will show a short segment of the recording of each of the 12-leads [67]. This is often arranged in a grid of 4
columns by three rows, the first columns being the limb leads (I, II and III),
the second column the augmented limb leads (aVR, aVL and aVF) and the
last two columns being the chest leads (V1-V6). It is usually possible to
change this layout so it is vital to check the labels to see which lead is
represented. Each column will usually record the same moment in time for
the three leads and then the recording will switch to the next column which
will record the heart beats after that point. It is possible for the heart
rhythm to change between the columns of leads. Each of these segments is
short, perhaps 1-3 heart beats only, depending on the heart rate and it can
be difficult to analyze any heart rhythm that shows changes between heart
beats. To help with the analysis it is common to print one or two "rhythm
strips" as well. This will usually be lead II (which shows the electrical
signal from the atrium, the P-wave) and shows the rhythm for the whole
time the ECG was recorded usually 5–6 seconds. The term "rhythm strip"
may also refer to the whole printout from a continuous monitoring system
which may show only one lead and is either initiated by a clinician or in
response to an alarm or event.

2.3.2 Types of Leads

**Bipolar Leads:** In Bipolar leads, ECG is recorded by using two
electrodes such that the final trace corresponds to the difference of
electrical potentials existing between them. They are called standard leads
and are universally adopted. They are sometimes referred to as
EINTHOVEN Leads. Refer figure 2.2
**Unipolar Leads:** The standard leads record the differences in electrical potential between two points on the body produced by the heart’s action. Quite often, this voltage will show smaller changes than either of the potentials and so better sensitivity can be obtained if the potential of a single electrode is recorded. In practice, the reference electrode or central terminal is obtained by a combination of several electrodes tied together at one point [70]. Two types of unipolar leads are employed which are: (i) limb leads, and (ii) pre-cordial leads.

i) **Limb Leads:** [66] In unipolar limb leads, two of the limb leads are tied together and recorded with respect to the third limb. In the lead identified as AVR, the right arm is recorded with respect to a reference established by joining the left arm and left leg electrodes. In the AVL lead, the left arm is recorded with respect to the common junction of the right arm and left leg.

ii) **Pre-cordial leads:** The second type of unipolar lead is a pre-cordial lead. It employs an exploring electrode to record the potential of the heart action on the chest at six different positions [64]. These leads are designated by the capital letter ‘V’ followed by a subscript numeral, which represents the position of the electrode on the pericardium.
2.3.3 Relation between Various Leads

The designed hardware gives only eight output lines i.e. L2, L3; and V1 to V6. Using these hardware lines, and from the below explained relation between the various other leads of the electrocardiography, the software determines the voltage and current values for other leads. Thus, finally a complete 12 lead output signal is obtained. Data is transmitted as continuous frames at interval of 2 milliseconds. (i.e. 500 frames). Each frame consists of 18 bytes. [67]

The figure shows a typical connection of Leads 1, 2 and 3 between the limbs as indicated. RA and LA are the right and left arms and LL is the left leg. From the figure, we can conclude that three voltages form a closed measurement loop. From Kirchhoff’s voltage law, the sum of the voltages around a loop equals zero.

Thus,

\[ L2 - L1 - L3 = 0 \]

i.e. \( L1 = L2 - L3 \)
Leads aVR, aVL, and aVF are *augmented limb leads*. They are derived from the same three electrodes as leads I, II, and III. However, they view the heart from different angles (or *vectors*) because the negative electrode for these leads is a modification of Wilson's central terminal. This zeroes out the negative electrode and allows the positive electrode to become the "exploring electrode". This is possible because *Einthoven's Law* states that $I + (-II) + III = 0$. The equation can also be written $I + III = II$. It is written this way (instead of $I - II + III = 0$) because Einthoven reversed the polarity of lead II in Einthoven's triangle, possibly because he liked to view upright QRS complexes. Wilson's central terminal paved the way for the development of the augmented limb leads aVR, aVL, aVF and the pre-cordial leads $V_1, V_2, V_3, V_4, V_5$ and $V_6$. 
• Lead augmented vector right (aVR) has the positive electrode (white) on the right arm. The negative electrode is a combination of the left arm (black) electrode and the left leg (red) electrode, which "augments" the signal strength of the positive electrode on the right arm:

\[ aVR = RA - \frac{1}{2}(LA + LL). \]

• Lead augmented vector left (aVL) has the positive (black) electrode on the left arm. The negative electrode is a combination of the right arm (white) electrode and the left leg (red) electrode, which "augments" the signal strength of the positive electrode on the left arm:

\[ aVL = LA - \frac{1}{2}(RA + LL). \]

• Lead augmented vector foot (aVF) has the positive (red) electrode on the left leg. The negative electrode is a combination of the right arm (white) electrode and the left arm (black) electrode, which "augments" the signal of the positive electrode on the left leg:

\[ aVF = LL - \frac{1}{2}(RA + LA). \]

• The augmented limb leads aVR, aVL, and aVF are amplified in this way because the signal is too small to be useful when the negative electrode is Wilson's central terminal. Together with leads I, II, and III, augmented limb leads aVR, aVL, and aVF form the basis of the hexaxial reference system, which is used to calculate the heart's electrical axis in
the frontal plane. The aVR, aVL, and aVF leads can also be represented using I and II limb leads.

\[
\begin{align*}
aVR &= -\frac{I + II}{2} \\
aVL &= I - \frac{II}{2} \\
aVF &= II - \frac{I}{2}
\end{align*}
\]

2.3.4 Unipolar vs. bipolar leads

Wilson's central terminal \( V_w \) is produced by connecting the electrodes, RA; LA; and LL, together, via a simple resistive network, to give an average potential across the body, which approximates the potential at infinity (i.e. zero):

\[
V_w = \frac{1}{3}(RA + LA + LL)
\]

2.4 Placement of ECG Leads

Ten electrodes are used for a 12-lead ECG. The electrodes usually consist of a conducting gel, embedded in the middle of a self-adhesive pad onto which cables clip. Sometimes the gel also forms the adhesive. They are labeled and placed on the patient's body as follows:
<table>
<thead>
<tr>
<th>Electrode Label</th>
<th>Electrode Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>On the right arm, avoiding bony prominences</td>
</tr>
<tr>
<td>LA</td>
<td>In the same location that RA was placed, but on the left arm this time</td>
</tr>
<tr>
<td>RL</td>
<td>On the right leg, avoiding bony prominences</td>
</tr>
<tr>
<td>LL</td>
<td>In the same location that RL was placed, but on the left leg this time</td>
</tr>
<tr>
<td>V1</td>
<td>In the fourth intercostal space (between ribs 4 &amp; 5) just to the right of the sternum (breastbone).</td>
</tr>
<tr>
<td>V2</td>
<td>In the fourth intercostal space (between ribs 4 &amp; 5) just to the left of the sternum.</td>
</tr>
<tr>
<td>V3</td>
<td>Between leads V₂ and V₄.</td>
</tr>
<tr>
<td>V4</td>
<td>In the fifth intercostals space (between ribs 5 &amp; 6) in the mid-clavicular line (the imaginary line that extends down from the midpoint of the clavicle (collarbone)).</td>
</tr>
<tr>
<td>V5</td>
<td>Horizontally even with V₄, but in the anterior axillary line. (The anterior axillary line is the imaginary line that runs down from the point midway between the middle of the clavicle and the lateral end of the clavicle; the lateral end of the collarbone is the end closer to the arm.)</td>
</tr>
<tr>
<td>V6</td>
<td>Horizontally even with V₄ and V₅ in the midaxillary line. (The midaxillary line is the imaginary line that extends down from the middle of the patient's armpit.)</td>
</tr>
</tbody>
</table>
2.5 ECG ANALOG CARD

2.5.1 Filters

Modern ECG monitors offer multiple filters for signal processing. The most common settings are monitor mode and diagnostic mode. In monitor mode, the low frequency filter (also called the high-pass filter because signals above the threshold are allowed to pass) is set at either 0.5 Hz or 1 Hz and the high frequency filter (also called the low-pass filter because signals below the threshold are allowed to pass) is set at 40 Hz. This limits artifact for routine cardiac rhythm monitoring. The high-pass filter helps reduce wandering baseline and the low-pass filter helps reduce 50 or 60 Hz power line noise (the power line network frequency differs between 50 and 60 Hz in different countries) [29]. In diagnostic mode, the high-pass filter is set at 0.05 Hz, which allows accurate ST segments to be recorded. The low-pass filter is set to 40, 100, or 150 Hz. Consequently, the monitor mode ECG display is more filtered than diagnostic mode, because its pass-band is narrower.

A first-order filter, will reduce the signal amplitude by half (so power reduces by 6 dB) every time the frequency doubles (goes up one octave); more precisely, the power roll-off approaches 20 dB per decade in the limit of high frequency. The magnitude Bode plot for a first-order filter looks like a horizontal line below the cutoff frequency, and a diagonal line above the cutoff frequency. There is also a "knee curve" at the boundary between the two, which smoothly transitions between the two straight line
regions. If the transfer function of a first-order low-pass filter has a zero as well as a pole, the Bode plot will flatten out again, at some maximum attenuation of high frequencies; such an effect is caused for example by a little bit of the input leaking around the one-pole filter; this one-pole–one-zero filter is still a first-order low-pass. [2]

A second-order filter attenuates higher frequencies more steeply. The Bode plot for this type of filter resembles that of a first-order filter, except that it falls off more quickly. For example, a second-order Butterworth filter will reduce the signal amplitude to one fourth its original level every time the frequency doubles (so power decreases by 12 dB per octave, or 40 dB per decade). Other all-pole second-order filters may roll off at different rates initially depending on their Q factor, but approach the same final rate of 12 dB per octave; as with the first-order filters, zeroes in the transfer function can change the high-frequency asymptote.

Third- and higher-order filters are defined similarly. In general, the final rate of power roll-off for an order-\(n\) all-pole filter is \(6n\) dB per octave (i.e., \(20n\) dB per decade).

2.5.2 Notch Filter

In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels. It is the opposite of a band-pass filter. A notch filter is a band-stop filter with a narrow stop-band (high Q factor) [3][6]. Notch filters are used in live sound reproduction (Public Address systems, also known as PA systems) and in instrument amplifier (especially amplifiers or preamplifiers for acoustic instruments such as
acoustic guitar, mandolin, bass instrument amplifier, etc.) to reduce or prevent feedback, while having little noticeable effect on the rest of the frequency spectrum. Typically, the width of the stop-band is less than 1 to 2 decades (that is, the highest frequency attenuated is less than 10 to 100 times the lowest frequency attenuated). The 60Hz mains power line frequency and its components are the most common source of interference in a biomedical signal. The coupling mechanism can be either capacitive or magnetic, but the capacitive mechanism is the more prevalent one. [14]

The same has been taken care in the software and implemented as follows;

```cpp
void CStPlotCtrl::OnBaselinefilter()
{

    if (m_setBaseLineFilter)
    {
        m_setBaseLineFilter = FALSE;
        FireBaselineState(0);
    }
    else
    {
        m_setBaseLineFilter = TRUE;
        FireBaselineState(1);
    }
    CMenu menu;
    if (menu.LoadMenu(IDR_POPUP))
    {
        CMenu* pPopup = menu.GetSubMenu(0);
        if (m_setBaseLineFilter)
        {
            (menu.GetSubMenu(0))->CheckMenuItem(8, MF_BYPOSITION | MF_CHECKED);
        }
        else
        {
            (menu.GetSubMenu(0))->CheckMenuItem(8, MF_BYPOSITION | MF_UNCHECKED);
        }
    }
}
```
2.5.3 Analog to Digital Signal Conversion

To capture and analyze signals, the general processing steps are required. Figure 2.4 illustrates a general analog to digital (A/D) signal conversion system. First the signal must be captured. Since the signal is electrical in nature, electrodes are used to capture the same. The signal from the electrodes is usually very small in amplitude, an ECG range from 10 micro-Volts to 5 milli-Volts. Amplification is necessary to bring the
amplitude of the signal into the range of analog to digital converter. The amplification should be done as close to the signal source as possible to prevent any degradation of the signal. If there are several input signals to be converted, an analog multiplexer is needed to route each signal to the A/D converter. In order to minimize aliasing, a low pass filter is often used to band-limit the signal prior to sampling [37]. A sample and hold circuit is required at the input to the A/D converter to hold the analog signal at a constant value during the conversion process. Finally, the A/D converter changes the analog voltage stored by the sample and hold circuit to a digital representation.

2.6 Overview of ECG Analog Card

Electrocardiography (ECG or EKG) is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes. It is a noninvasive recording produced by an electrocardiographic device. The ECG works by detecting and amplifying the tiny electrical changes on the skin that are caused when the heart muscle "depolarises" during each heart beat. At rest, each heart muscle cell has a charge across its outer wall, or cell membrane. Reducing this charge towards zero is called de-polarisation, which activates the mechanisms in the cell that cause it to contract. During each heartbeat a healthy heart will have an orderly progression of a wave of depolarisation that is triggered by the cells in the sinoatrial node, spreads out through the atrium, passes through "intrinsic conduction pathways" and then spreads all over the ventricles [22].
This is detected as tiny rises and falls in the voltage between two electrodes placed either side of the heart which is displayed as a wavy line either on a screen or on paper. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle.

ECG analog card has been developed using linear devices such as Operational amplifiers, while selecting Op-amp care has been taken to see that it’s offset voltage should be minimum. Hence in our card TL-064 Op-amp IC has been used. This analog card is capable of generating 8 lead ECG signals L2, L3 and V1 to V6 which is then interfaced to the armed processor. Remaining four signals are calculated based on the relationship amongst the various signals (L2, L3 and V1 to V6) and hence, complete 12 lead ECG signals is available for analyzing the ECG waveforms.

This card is having all the important features such as low pass filters, notch filters, removals of base line wandering filter, high voltage protection when defibrillator is used for patient, level shifter, instrumentation amplifier, etc. this analog signal is given to 10 bit A-D converter which is inbuilt in the ARM processor.

DB-15(Female) Connector J1 is used to take the inputs from the patients using standard ECG leads. This inputs are now connected to the Op-amp through DEFIB protection neon’s (D1 to D10). Low Pass filter Circuits are designed at cut off frequency 150Hz using suitable RC combination to pass the ECG wave forms and reduce the high frequency noise {(R1,C1), (R4,C2), (R7,C4), (R16,C7), (R18,C8), (R19,C9), (R22,C10), (R23,C11), (R26,C12), (R13,C6)}. U1, U2 and U3C (TL064) are used as a buffer.
After this, the differential amplification of the signals is done with GAIN (10) through the (TL064) amplifiers (U4B, U4C, U5B, U5C, U7B, U7C, U8B, U8C) to get the readable signal. This signal which is normally having the bandwidth in the range of 10-150 Hz is given to high pass filter which is designed to pass this signal and eliminate 0.05-2 Hz signal resulting from baseline wandering effect.

e.g. (C13/C14, R32+R34/R33)

The output of differential amplifier is again amplified with the GAIN (23) through the (TL064) amplifiers (U4A, U4D, U5A, U5D, U7A, U7D, and U8A, U8D) to get the readable signal.

After this amplification, GAIN (2) is done through the (TL064) U6 and U9 along with level shifting arrangement. Now again Low pass filter stage is added with the frequency 125Hz to eliminate the frequency above 125Hz and to pass clear ECG signal which is normally in the range of 50-100Hz. To reject the line frequency noise notch filter is used, which is derived through the U3D. A 16 pin FRC (J2) is used to connect output of analog card (L2, L3, V1-V6) to the ARM processor.

Following Figures shows all the details regarding ECG analog card;

1) Fig. 2.6: Port Configuration of ARM7 processor
2) Fig. 2.7: Schematic to generate L2 and L3 signal
3) Fig. 2.8: Schematic to generate V1 and V2 signal
4) Fig.2.9: Schematic to generate V3 and V4 signal
5) Fig. 2.10: Schematic to generate V5 and V6 signal
6) Fig 2.11: Schematic to generate L-signal
7) Fig 2.12: Schematic to generate L-offset signal
Figure 2.6: Port Configuration of Arm7 Processor
Figure 2.7: Schematic to generate L2 and L3 signal
Figure 2.8: Schematic to generate V1 and V2 signal
Figure 2.9: Schematic to generate V3 and V4 signal
Figure 2.10: Schematic to generate V5 and V6 signal
Figure 2.11: Schematic to generate L-signal
Figure 2.12: Schematic to generate L-Offset signal
Figure 2.13: ECG Analog Card
Figure 2.14: ECG Analog Card interfaced with LPC2103