

Cardiac Action Potential Observation with Multi Channel Electrodes & Digital Signal Processing

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Abstract— The ECG waveforms typically taken from an ECG recorder depend on the changes in external potential observed between body surface electrodes due to the heart's conduction of impulses. The cardiac fibers have an action potential waveform which is due to the excitation of the nerves of conduction propagating through the heart chambers. Conduction of the cardiac action potential from the endocardial to epicardial cells occurs via cell-to-cell transmission. This waveform is a trapezoidal one with a sharp rise and a plateau region. The sharpness of the rise is of course conveyed on the ECG electrodes. But the variations in the plateau region are due to the slow Ca channels, drawing large amount of Ca inside during depolarization. The externally recorded ECG waveforms provide some information about the conduction in the heart. Abnormal muscular ischemia is also reflected in the conducted waveforms. Additional disturbances caused in the path such as bundle branch block etc can also be diagnosed from these waveforms. The leads 1, 2 and 3 are limb leads, which the AV leads, which are six, are positioned one by one on the chest wall in a definite anatomical layout. These signals portray the ventricular activity. Apart from a rather broad outline of the conduction in the heart, this macro ECG signals do not enable localized problems to be identified. For this purpose, a method of multiple electrode data acquisition in a simultaneous manner is proposed and implemented in this paper. Much like the six AV leads; additionally many electrodes are kept on the chest wall in suitable points around the myocardium. These signals are all taken simultaneously. It is well known that the ECG signal externally observed is but a derivative of the action potential waveforms in the fibres. The ECG, through its peak crest and breadth of the QRS complex provides but limited information about the speed of propagation of the cardiac impulses. When we use multiple electrodes e_1 to e_n , we are able to obtain differential signals from any two consecutive electrodes. From this, by integration, the pattern of the action potential waveform propagating in this region inside is available. In the ventricular conduction, the width of the plateau period is indicative of contractile force of the fibres. The time course and space course of the variation of the plateau period is to be obtained for each and every heart beat. This information provides ample data on the uniformity of the conduction, much less the problematic conduction disturbances easily, even at a premature stage of malfunctioning. For this purpose, real time data acquisition is to be done from multiple channels. We employ the very same pre amplifiers used in standard ECG machines and then digitize the analog signals at a suitable sample rate. The SDK 6747 kit is used with its ADC in multiple channels. The data acquired is processed through a DSP program. This program does real time instantaneous calculations of the integrated signals from the n electrodes. The pattern of variations of the rise time, plateau and tail slope are recorded and displayed. The data so acquired is fed to the computer through the available communication port on the DSP kit. The data is received by a MATLAB program which evaluates many parameters about the spatial and temporal propagation of the action potential in the heart. The continuous observation of this data, with an additional superimposed model picture heart is able to provide instant information for diagnostics in critical patients, as to when and where the myopathical symptom has originated.

Index Terms— Action Potential, Cardio myopathy, Cardiac Conduction, Electrocardiogram, SDK 6747 kit.

1 INTRODUCTION

ELECTROCARDIOGRAPHY (ECG) is a graphical representation of the electric potential produced by the heart.

The process of contraction is initiated and maintained by the heart's electrical forces, which are recorded by the ECG. The externally recorded ECG waveforms provide some information about the conduction in the heart. The electrical current due to the depolarization of the sinus atria (SA) node stimulates the surrounding myocardium and spread through into the heart tissues. It is well known that the ECG signal externally observed is but a derivative of the action potential waveforms in the fibres [18]. The ECG, through its peak crest and breadth of the QRS complex provides but limited information about the speed of propaga-

tion of the cardiac impulses.

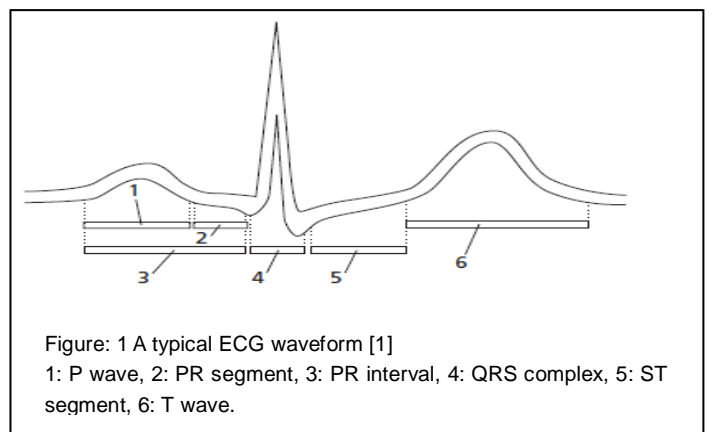


Figure: 1 A typical ECG waveform [1]
1: P wave, 2: PR segment, 3: PR interval, 4: QRS complex, 5: ST segment, 6: T wave.

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These signals could be measured using leads also called as electrodes. There are three types of electrode system (3, 6 and 12 electrodes) using in ECG machines. In this proposed work using six limb leads or extremity leads system; it consists of standard limb leads I, II, III and unipolar leads aVF, aVR, aVL. These multiple leads yield signals are taken simultaneously

from the body surface electrodes and fed through ECG device.

The investigation of the ECG signal has been extensively used for diagnosing many cardiac diseases like as cardiac arrhythmias, Bundle branch block, Ischemic disease, ST elevation and QT syndrome. ECG signal not only shows defects/anomalies of the conduction of the heart, but it also shows functional part status of human body. An experienced cardiologist can easily diagnose various heart diseases just by looking at the ECG waveforms printout. In some cases, sophisticated ECG analyzers achieve a higher degree of accuracy than the cardiologist, but at present there remains a group of ECG waveforms that are too difficult to identify by computers.

Digital signal processing (DSP) is renowned as compared to analog signal processing in different applications [2],[13]. The signals are time varying quantities which carry information i.e. audio signal, video signals, biological signals (electrical pulses from the heart) and communications signals. [3]. A digital signal is define as the signal that has discrete amplitude and time. These signals are represented by sequences of numbers with finite precision and can be used when processing information by computer [4], [12]. Signal processing today is performed in the vast majority of systems for ECG analysis and interpretation. The objective of ECG signal processing is diverse and comprises the improvement of measurement accuracy and reproducibility (when compared with manual measurements) and the extraction of information not readily available from the signal through visual assessment [9]. Using the signal processing techniques in DSP processor we can enhance the ECG signal quality to convert them into localized action potential for easy assessment. In this paper proposed work, ECG signals are collected from the ECG device and fed through ADC port in the DSP processor and integrating the signal (localized action potential) using MATLAB Simulink model and drawn from DAC port.

2 MATERIAL AND METHODS

2.1 Development Procedure of 6 lead ECG electrodes

Acquisition of ECG signal can be done with 3 or 6 or 12 electrodes. Here we propose to use 6 electrodes to acquire ECG signal, two electrodes are placed on left and right wrist to provide positive and negative connection. The position of electrodes is set using the Einthoven's triangle.

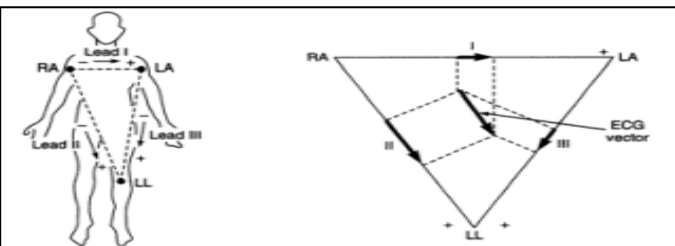


Fig.2 (a) Einthoven triangle defining for ECG electrodes [9].

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 have been universally

adopted. They are sometimes also referred to as Einthoven leads (Fig 2 (b)) [9].

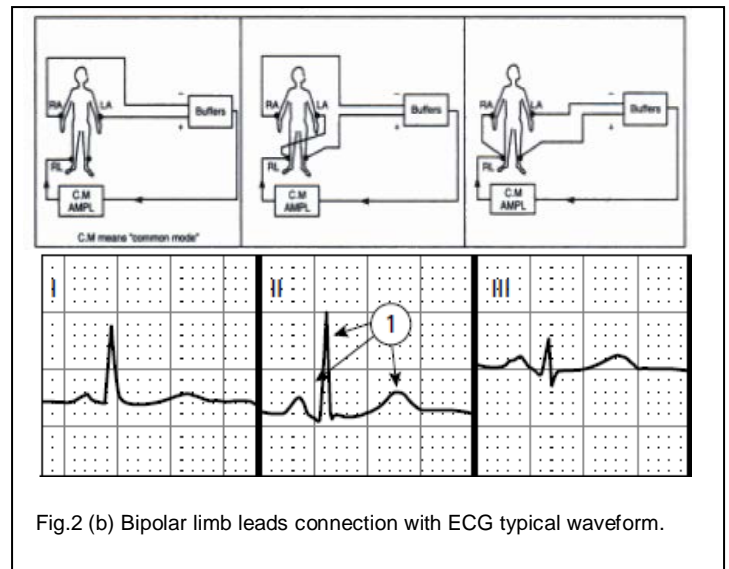


Fig.2 (b) Bipolar limb leads connection with ECG typical waveform.

In standard lead I, the electrodes are placed on the right and the left arm (RA and LA). In lead II, the electrodes are placed on the right arm and the left leg and in lead III; they are placed on the left arm and the left leg. In all lead connections, the difference of potential measured between two electrodes is always with reference to a third point on the body. This reference point is conventionally taken as the "right leg". The records are, therefore, made by using three electrodes at a time, the right leg connection being always present.

In defining the bipolar leads, Einthoven postulated that at any given instant of the cardiac cycle, the electrical axis of the heart can be represented as a two dimensional vector. The ECG measured from any of the three basic limb leads is a time-variant single-dimensional component of the vector. He proposed that the electric field of the heart could be represented diagrammatically as a triangle, with the heart ideally located at the centre. The triangle, known as the "Einthoven triangle", is shown in the fig 2(a). The sides of the triangle represent the lines along which the three projections of the ECG vector are measured. It was shown that the instantaneous voltage measured from any one of the three limb lead positions is approximately equal to the algebraic sum of the other two or that the vector sum of the projections on all three lines is equal to zero. In all the bipolar lead positions. QRS of a normal heart is such that the R wave is positive and is greatest in lead II.

Limb leads or extremity leads: 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. In the AVF lead, the left leg is recorded with respect to the two arm electrodes tied together. They are also called augmented leads or 'averaging leads'. The resistances inserted between the electrode-machine connections are known as 'averaging resistances'.

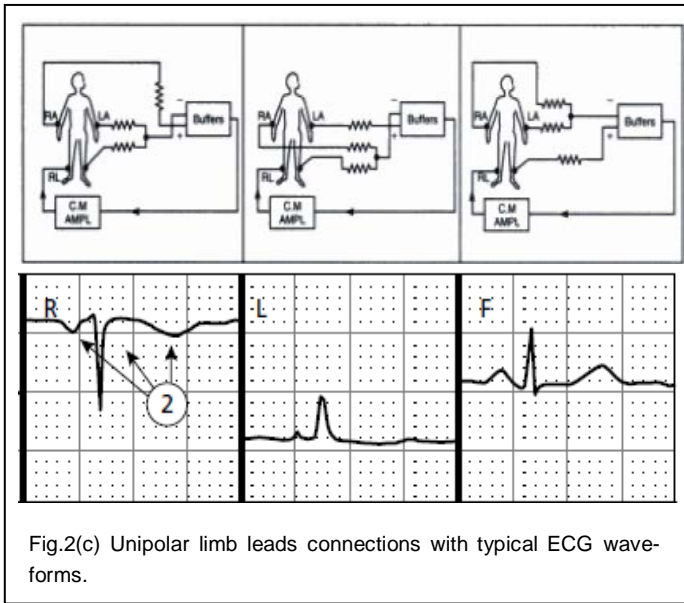


Fig.2(c) Unipolar limb leads connections with typical ECG waveforms.

2.2 TMS320C6747 DSP Kit

A Texas Instruments TMS320C6747 device with a DSP floating point processor and processor operating up to 300 MHz, with the following features:

- Low-power consumption
- advanced VLIW architecture
- Up to eight 32-bit instructions executed each cycle
- On-board A/D and D/A converters
- Code Composer Studio IDE with C compiler, software pipeline support, profiler capability, debugging capabilities
- Real time data exchange (RTDX) between target and host

The bulk of the development effort was done in Simulink (and Matlab). Using the tools below, the Simulink model files were programmed onto the DSP.

- Real Time Workshop
- Plug-in for Code Composer Studio
- Signal Processing Toolbox / Signal Processing Block set
- Texas Instruments (TI) Embedded Target for C6000.

ADC and DAC Channels have been selected by the following table:

ADC Channel	SOC Address	Write Value
1	0x60000558	0x00
2	0x60000558	0x01
3	0x60000558	0x02
4	0x60000558	0x03

DAC Channel Selection		Update DAC Output	
D15	D14	DAC Output	
0	0	DAC 1	0 1
0	1	DAC 2	
1	0	DAC 3	
1	1	DAC 4	

2.3 Multi Channel electrode with DSP C6747 using MATLAB Simulink Model

In the present approach, the developed system comprises of electrodes, ECG acquisition circuit, and a computer system using the MATLAB software [11].

The data so acquired is fed to the computer through the available communication port on the DSP kit [10]. The data is received by a MATLAB program which evaluates many parameters about the spatial and temporal propagation of the action potential in the heart. The continuous observation of this data, with an additional superimposed model picture heart is able to provide instant information for diagnostics in critical patients, as to when and where the myopathical symptom has originated.

Using m-file for getting the ECG data points to workspace and converts into 12 bit for ADC port in DSP C6747 kit. Because of ADC and DAC ports are 12 bit only, the remaining 4 bits are channel selection for ADC and DAC port each 2 bits. After conversion of the ECG signal data points applying the discrete time integration for getting localized action potentials. The resultant signals are fed through DAC for displaying the output in CRO/DSO.

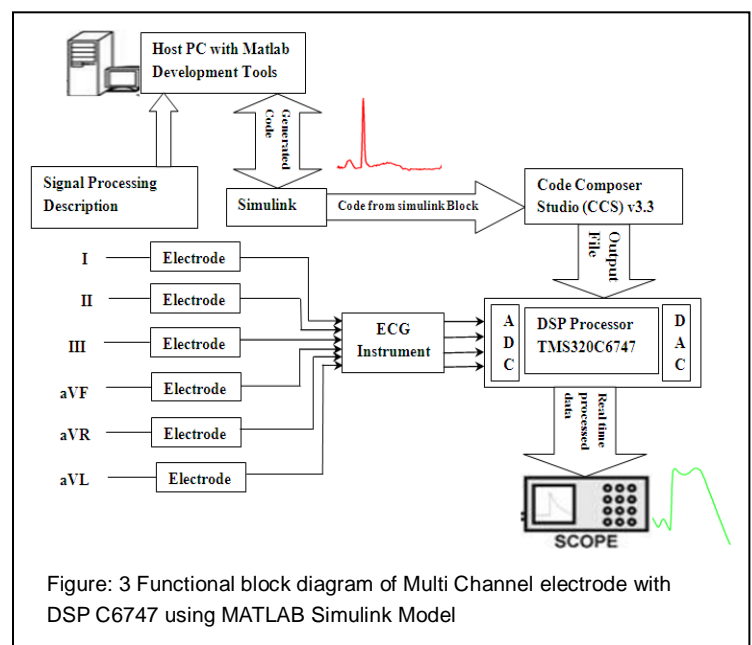


Figure: 3 Functional block diagram of Multi Channel electrode with DSP C6747 using MATLAB Simulink Model

2.4 Implementation of MATLAB Simulink Model for ECG signal

The method is to use a set of electrodes similar to bipolar leads 1-3 and unipolar aVF, aVR, aVL, placed on the external chest wall in a definite anatomical layout. These signals are all taken simultaneously. The outputs available are connected to the ADC channels of a 6747 DSP kit. Then the Matlab based program reads the data and processes the multi variable definite integral relation in each cardiac cycle using Matlab's command functions. Since it is possible to transport Matlab codes through Simulink to an embedded target which is a 6747 DSP, the code compressor studio (CCS v3.3) program of the 6747 processor will convert the program into the DSP's machine code and run the program in real time [10], [11], [18]. Thus, from one beat to another, the calculated action potential characteristic data can be displayed through the DAC outputs provided on the same 6747 kit.

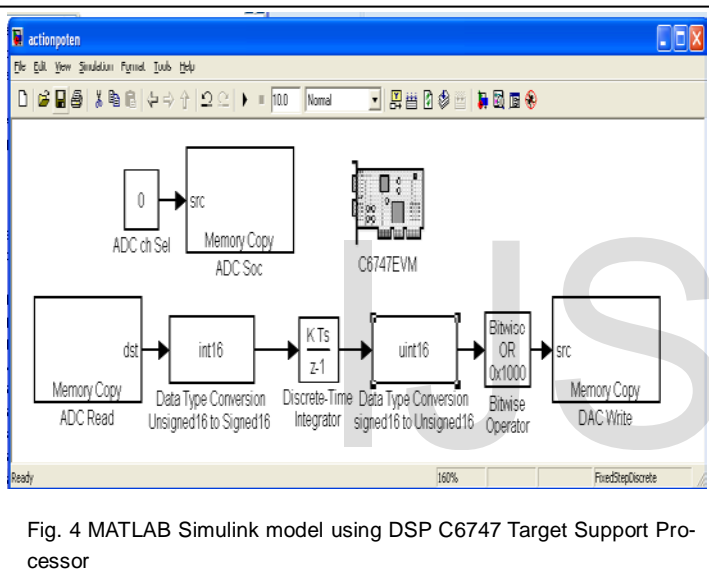


Fig. 4 MATLAB Simulink model using DSP C6747 Target Support Processor

Building the Model in Simulink Workspace Including the TI's Kit:

- **Memory copy**

It is used for Read and Write operation in a specific memory address. Here we need three block one for ADC channel select, next is Read the ADC value and another one is Write the output value.

- **ADC channel select block**

- i) First click the source button to change the following.
 - Copy from: input port (before set the constant block)
 - Data type: uint16
- ii) Next click destination button
 - Copy to: Specified address
 - Specified address source: specify via dialog
 - Address: hex2dec ("60000558")
 - Data type: uint16
 - Sample time: 1/20000

- **ADC Read block**

- i) First click the source button to change the following.
 - Copy from: Specified address

Specified address source: specify via dialog Address: hex2dec ("60000554")

Data type: uint16

- ii) Next click destination button

Copy to: Output port

Data type: uint16

Sample time: 1/20000

- **DAC write block**

- i) First click the source button to change the following

Copy from: Input port

Data type: uint16

- ii) Next click destination button

Copy to: Specified address

Specified address source: specify via dialog

Address: hex2dec ("60000554")

Data type: uint16

Sample time: 1/20000

- **Data type conversion**

It is used to convert the unsigned data into signed data because filter block perform operation in signed no only. Double click the block and set output data type in int16 or int32 or single or double. Then set sampling frequency 1/20000.

- **Discrete time integrator**

Main: Integration Forward Euler

Signal Attributes: Inherit from internal rule

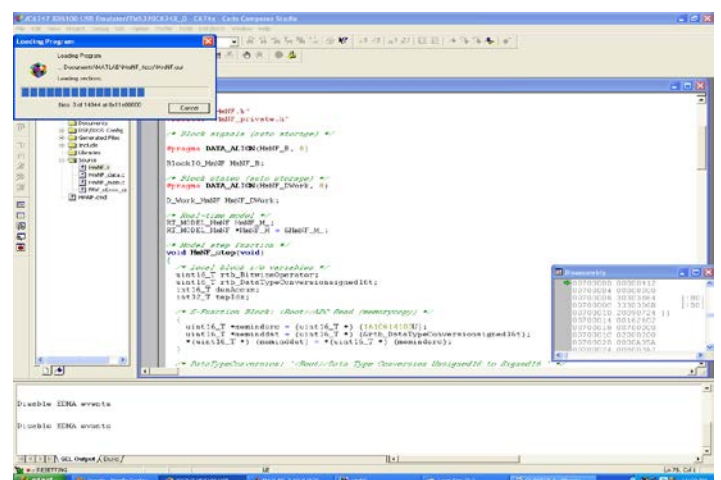
- **Bitwise operator block**

Bitwise operator block is used for select DAC channel selection. Do OR operation with following data (0x1000, 0x5000, 0x9000, 0xD000) to Data conversion output. And high pass, band pass filter need AND & EX-OR operation to generate the filter output.

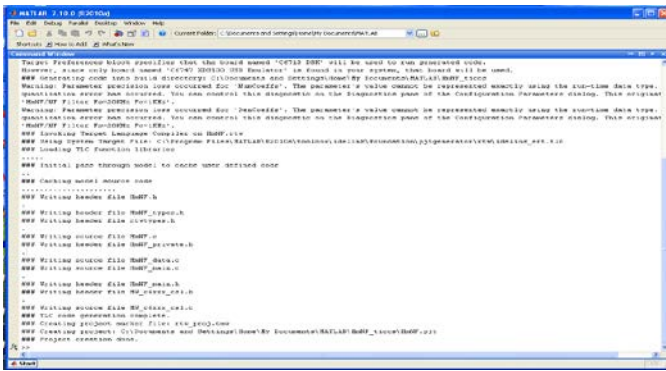
Next click simulation button then click configuration parameters → Embedded IDE link → run time → build option to set create project → click ok.

- Click Incremental build button in MATLAB Simulink model the project created into C programming in CCS, Rebuild All and Run (F5).

Matlab Command window



Code Composer Studio Window



3 RESULTS

An attempt has been made to obtain real time action potential time varying signal form the ECG leads for better diagnosis in cardiac care. The input and output of ECG and Localized Action potentials are:

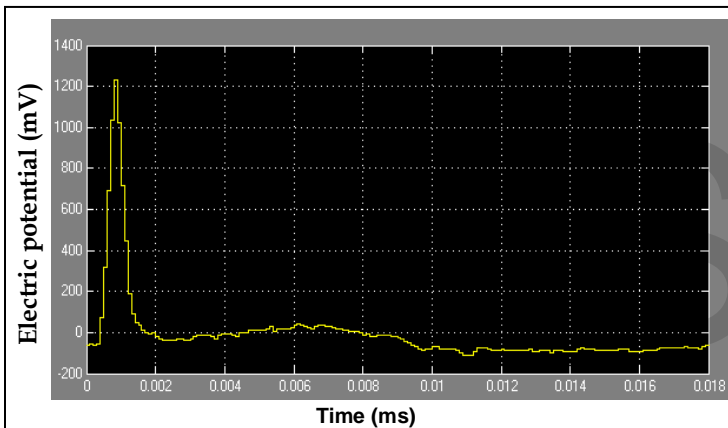


Fig.5. Input ECG signal (QRST segment)

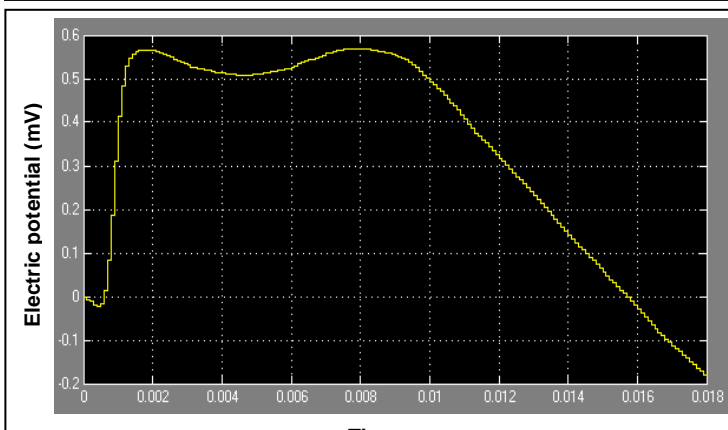


Fig.6 Output Action potential waveform

4 CONCLUSION

The assessment of the ECG signal has been broadly used for diagnosing many cardiac diseases. Real time ECG processing holds a great potential for development. Automated arrhythmia detection could not only help in early detection of diseases but also in

reducing the workload of the medical data analyst. The present work introduces in real time data acquisition is to be done from multiple channels using DSP processor TMS320C6747 with MATLAB. We employ the very same pre amplifiers used in standard ECG machines and then fed through the ADC port for digitize the analog signals. The SDK 6747 kit is used with its ADC in multiple channels. The data acquired is processed through a DSP program. This program does real time instantaneous calculations of the integrated signals from the n electrodes. The pattern of variations of the rise time, plateau and tail slope are recorded and displayed through the DAC port channels.

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