Wireless enabled implantable microelectronic platform health and social care essa...

Supply of oxygen and nutrients form respiration system and digestive system respectively todifferent types of cells within a human body takes place with the assistance of blood. Heartacts as a pump in the body that makes the circulation of blood possible. The systematic, rhythmic and controlled electrical activity of heart is necessary to carry out propercirculation and decrease possible damage or necrosis of different cells in different organs. The electrical signal is generated in sinoatrial node (SA) and then passes through atria toatrioventricular (AV) node, then to bundle of his and finally to purkinje fibres. When the genesis of the electrical signal does not occur at sinoatrial node, but occurs atsomewhere in the atria, the signal will be disturbed, rapid, and disorganised. This condition isknown as atrial fibrillation. It is not a lethal disease, but, sometimes, it might cause stroke. Paroxysmal, persistent and permanent atrial fibrillations are three types of fibrillation based on uponthe nature and frequency of occurrence. Atrial fibrillation is generally diagnosed by usingelectrocardiogram, echocardiogram and blood test. Rate control and rhythm control along withanticoagulation is the best solution to atrial fibrillation which can be achieved by pharmaceuticalcardioversion, catheter ablation and electrical cardioversion along with anticoagulation drug. Defibrillation is done with the help of special machine know as defibrillator, which may be external orinternal with automatic or manual version. Due to the different problems with different externaldefibrillators like pain, skin burn, high power requirements etc. and with internal defibrillators likechange in position of lead and battery life, there is a requirement for the development of a low costwireless enabled implantable microelectronic platform for tissue impedance monitoring anddelivering wireless power to implantable

cardioverter defibrillators in medical applications. Itbasically has two units1. Impedance monitoring unit. 2. ECG synchronization and power deliver units. Although there are always issues related due to knowledge gap, technology acceptance, regulatory compliance and so on, but use of biocompatibility materials, use of similartechniques which are already in use in market may sort out these problems. Background and IntroductionAtrial fibrillationNormal human heart beats at a constant rate of 60 to 72 per minutes at rest (10). Heat beats istriggered by electrical signal generated by bundle of neurones known as sinoatrial (SA) nodelocated in upper part of right atrium at regular interval of time. This generated signalcoordinates heart to contract and expand in the regular pattern. Signal generated by SA nodetravels through each cells of atria (left and right atrium) and assists atria to contract and pumpblood to ventricles. The signal is then passed to atrioventricular (AV) node, a group of cellslocated in between right atrium and left ventricle. Here, the electrical signal is delayed andallows ventricles to fill the blood. Then, the single is moved down towards the purkinjefibres resulting in the contraction of ventricles and delivering blood to lungs and rest of thebody (17). C: UsersAnupDesktopookm. sc. in innovative technologyconvergent technologyexternal defribrilatorcardiac-conduction-system. jpgFigure 1 Electrical system of the heart source (16)In Atrial fibrillation, the genesis of the electrical signal does not occur at sinoatrial nodeinstead occurs at somewhere in the atria. The signal is disturbed, rapid, disorganised and doesnot travel in the regular fashion. This causes atria to fibrillate and, usually, with faster ratethan normal. AF leads to insufficient pumping of blood thereby decreasing the cardiac output. Although it is not a lethal disease, it may results into stoke. Stroke is normally defined as

theinsufficient supply of blood in brain. So, early detection and prevention of AF is necessary inorder to improve health of the patients along with further complications like stroke associatedwith it (4). During the AF, heartbeat normally goes as high as 200 beats per minutes. The commonsymptoms of heart beat are dizziness, breathlessness, and even fainting, but some of thepatients may not be informed about the diseases until it is diagnosed. AF is considered to beone of the most common cardiac arrhythmia and affected by several factors like age, sex etc(4)Atrial fibrillation can be classified into three types depending upon the nature and frequency ofoccurrence. 1. Paroxysmal atrial fibrillationIn paroxysmal atrial fibrillation, the abnormal functioning of heart lasts less than 7days with different recurrent number of episodes within this period. The time of eachepisode is variable and cannot be predicted (14). 2. Persistent atrial fibrillationThis atrial fibrillation last longer than 7 days and can’t be cured until and unless it istreated (14). 3. Permanent atrial fibrillationThis lasts for a long time and can’t be cured with cardiovesion (14). Atrial fibrillation can be detected through a number of techniques like electrocardiogram, transesophageal echocardiogram and blood tests. 1. Electrocardiogram (ECG)Electrocardiogram measures the electrical activity of the heart. A normal ECG signalconsists of a P wave, a QRS complex and a T wave. In AF, normally, there is absenceof P wave, a wave which is related to atrial depolarization. The P wave is replaced bysaw tooth like pattern of waves (8). Figure 2 Fibrillatory ECG wave (left) and normal ECG (right) (8)2. EchocardiogramEchogram is a non invasive way taking the moving picture of the heart by placing theprobe on the chest wall. Echocardiogram uses ultrasonic sound to generate the picture of moving heart. Thetransducer, a piezoelectric crystal, uses electrical energy to

produce ultrasonic soundwhich is passed through skin towards the heart. At different interface, signal isabsorbed, reflected and transmitted. The reflected signal is recollected by transducerand echocardiogram gives information about the shape, size and performance of theheart based on the information provided by the transducer. Moreover, it also gives theinformation regarding the performance of the heart's chambers, blood flow, and siteof injury caused by poor blood flow (18). 3. Transesophageal EchocardiogramTransesophageal takes the picture of the heart by passing a catheter through theoesophagus. Like echogram, it also contains the ultrasonic tip at its tip. Comparingwith thoracic echocardiogram, the picture of heart can be captured better with thistechnology. Transesophageal Echocardiogram is not only used to find the AF, but alsoused to find colts due the presence of AF (18). 4. Blood TestsThe level of thyroid hormone and the electrolytes within human body is the foodindicator of normal health and functioning of organs and cells. So, blood test can beused to measure the heart performance and its functionality (18). Solutions to AFAtrial fibrillation can be managed with the proper management of rate control of the heart, anticoagulation and rhythm control of the atria, but for rhythm control or rate control withanticonguation strategy requires integration of different factors like intensity of disease, probability of success for cardioversion, and so on. Rate controlDuring atrial fibrillation, the ventricular rate excess more than normal heart rate (12). Duringthe atrial fibrillation, many intrinsic and extrinsic factors enable atrioventicular (AV)conduction with faster pace causing faster ventricular beat rate. Sympathetic andparasympathetic impulses also change the atrioventricular nodal conduction properties. Maintaining the ventricular rate at normal (50-90 beats per min at rest and

90-115 beats permin at exercise) with increase in cardiac output is the main aim of rate control (12). Ventricular rate is generally control with the use of drugs like beta-blockers, non-dihydropyridine calcium channel blockers etc (5). Rhythm controlRhythm control in an atrial fibrillation generally means restoration as well as maintenanceof normal rhythm of the heart. Electrical cardioversion or antiarrhythmic drugs are generallyused for the treatment. Although antiarrhythmic agents can improve heart rate and reduce thechances of stroke, they might cause adverse effects and alter the forces of musclescontractions (5). AnticoagulationDuring the management of atrial fibrillation with cardioversion, it might causes thethromboembolic diseases which in turn is responsible for causing stroke giving higher risk tothe patients. So anticoagulation therapy reduces the risk of stroke caused due to the blockageof blood flow in the brain or other parts of the body (9). The main goal of treatment of atrial fibrillation is to get rid of circulation instability andpossible stoke. Long term management is preformed in order to prevent form occurrence ofatrial fibrillation along with reduction of correlated diseases and probability of those diseases. The primary focus for the management of atrial fibrillation is to control ventricular rate andstroke. Appropriate management of atrial fibrillation is required in order to reduce episodesof atrial fibrillation and prevent of mortality and mobility. Pharmacological, medical ablationand electrical cardioversion are generally used for the long term management of this disease. Pharmacological cardioversionIn most of the cases, pharmacological cardioversion is used as a first line strategy, but it alsowidely used if the electrical cardioversion fail to control the normal heart rate. Drugs areused to control either the heart rate or rhythm of the heart or both. The main function ofrhythm control drug

is to re-establish the rhythm of the heart. Drug can be deliveredintravenous or oral depending upon the condition of the heart (20). Anti-arrhythmic drugs are even used after giving the electrical shock to the patients. This isdone in order to prevent from future episodes of atrial fibrillation (15). Anti arrhythmic drugslengthen the refractory period. The increase in refractory period results in low cardiac rateand prevents the occurrence of atrial fibrillation. This may even terminate the atrialfibrillation changing the abnormal heart beat to normal. In paroxysmal atrial fibrillation, prophylactic durgs are usually taken after sinus rhythm hasestablished to normal. Several studies shows that drugs like flecainide, propafenone, amiodarone, sotalol are said to be effective drugs for maintaining sinus rhythm in paroxysmalatrail fibrillation treatment (6). The treatment of chronic atrial fibrillation is achieved by use of different types of ionschannel blockers like like digoxin, verapamil and diltiazeem, and beta-blockers such asatenolol, propranolol, and metoprolol (6). The main disadvantage of using the drugs causes adverse effect on muscles contractions (5). Catheter ablationIn catheter ablation, the electrical signal is disconnected at pulmonary vein, so that thesignal no longer reaches the atrium to use atrial fibrillation. During this procedure, a thincatheter is placed in the heart near the pulmonary vein and radio frequency wave is used toablate the heart tissue providing electrical isolation of pulmonary vein form left atrium (22). Instead of radio frequency wave, ablation can be achieved by applying electrical energy or byfreezing the area to make scar and make it passive to conduct the electrical energy. Some ofthe catheter ablation procedure might require pacemaker (22). Although there are some complications like vascular complications, cardiac perforation, valvular injury, emboli formation with

stroke, pulmonary stenosis etc. during this procedure, this procedure is considered to be safer and has higher success rate than others (22). Direct current electrical cardioverisonIn this procedure, electrical energy is delivered to the patient's heart under sedation. Theelectrical shock is synchronised with QRS complex of electrocardiogram (ECG) wave anddelivered to the patient. While performing this cardioversion, two pads with conduction gelare used to deliver the shock to the human heart. Heart re-establishes its normal rhythm asthe electrical shock depolarises the myocardial cells and interrupt abnormal impulses (4). In direct current cardioversion, the synchronised electrical current is supplied to the humanheart either in the form of monophasic or in the form of biphasic waveform. Biphasicwaveform is generally performed these days due to low power requirement. The energyrequirement of monophasic waveform to re-establish the normal rhythm is around 100-200Joule, but sometime higher energy is required. In biphasic waveform the energy requirementis comparatively low than that of monophasic waveform (20). In most cases, this procedure is done in parallel with drug therapy until the sinus rhythm isobtained. The emboli formation is most common complication during the electricalcardioversion procedure patient need to have anticoagulants at least for 4 weeks after theprocedure time period (20).

•

Long-Term ManagementLong time management of atrial fibrillation focuses on re-establishment of the normal heartrhythm with decrease in atrial fibrillation reoccurrence and stoke along with high ventricularrate control. Long term management mainly focuses on reduction in future episodes of

atrialfibrillation thereby reducing mortality and mobility. Anticoagulation along with restoring ofnormal heart beat is the main aim of the long term management of atrial fibrillation (20). Technical reviewThe first commercialised defibrillator was introduced in 1961(7). Since then, withadvancement in technology, many defibrillators were made and tested. Nowadays, defibrillators can be external, wearable or implanted, but all operate on the same basicprincipleWorking principle of defibrillatorDefibrillator supply high amount of energy to human heart. The capacitor is charged tocertain level and ECG is continuously monitored during the energy delivery process. Whenthe energy delivery system synchronises with QRS complex of ECG signal the energy isdelivered form fully charged capacitor to heart in a controlled manner. This direct shockinterrupts the arrhythmia and restores the normal heart condition. All defibrillators work inthe same principle, but the energy requirement for internal defibrillator is comparatively lessthan that of external defibrillator. http://www. power-eetimes. com/images/01-edit-photo-uploads/2011/2011-08-august/c0832-figure1. gifFigure 3 Simplified circuit diagram of defibrillator (19)TypesExternal defibrillatorsExternal defibrillator can be further classified into manual and automatic. Externaldefibrillator uses either monophasic or biphasic waveform, but monophasic defibrillators aremore efficient than that of biphasic external defibrillators. Manual external defibrillatorsManual defibrillators are used only by health care professionals like paramedics, nurses orphysicians (7). They interpret ECG signal and decide whether or not the sock is required. They are specially designed for three general purposes and defibrillators used for theseapplications are1. Fixed location defibrillatorsThey are heavy and used in hospitals (7). 2. In hospital transport

defibrillatorsThey are lighter compared to fixed location, but do have a property of expanded monitoringcapability (7). 3. Prehospital transport defibrillatorsThey are light and can operate in harsh environment. They are used in ambulances (7). In these types of external defibrillators, a number of external devices are embedded. Commonembedded systems are. ECG monitoring system in order to monitor the ECG signal.. SPO2 monitoring system in order to monitor the partial pressure of oxygen.. Carbon dioxide monitoring system.. Temperature monitoring system.. Non invasive blood pressure unit. Automated external defibrillatorsAutomatic external defibrillators are first discovered by Dyack and Wellborn 1970's whichwas completely automatic in nature. Automated external defibrillator is also known as smartdefibrillator. They can interpret and analysed the ECG signal and recommend an automaticshock if it is required. They just don't recommend the shock if it is required but also theycan even deliver the shock. This functionality depends on the type of device being used. These devices measure and analyse the ECG waveform, makes decision based uponsophisticated algorithms like within a device and finally recommends if the shock is required(7). Problem with external defibrillators. High cost.. Pain to the patients.. High power requirements.. Different complication which may include hypotension, myocardial infection, skinburns. It is also assumed that it causes change in ST and T wave of ECG signal. Internal manual defibrillatorThey are similar to that of external manual defibrillator. The basic difference betweenexternal manual defibrillator and internal defibrillator is that the internal defibrillators are indirect contact with the human heart. They are generally used in operating theatres inintensive care unit or electrophysiology laboratory (2). Implantable cardioverter

defibrillatorImplantable cardioverter defibrillators are implanted inside the human body. They consists ofsensing system that senses the ECG , cognitive system that decides the abnormality of heartbeat and finally the electrode through which shock is given to the heart. When there isabnormality in the heart beat, the system detects the abnormality and shock is then deliveredto the heart. Implantable cardioverter defibrillator is proven to be effective and safe forterminating atrial fibrillation without much damage in the heart and other system of the body(11). Associated problemsThey are numbers of problems associated with this device. Some of them are. The big issue with the active device sensing is the life of the battery and the way ofenergy harvesting.. They rely on leads, a sensing system, for decision making process, but lead failure ismain problem which may be due to dislocation of the lead. So lead failure causesinappropriate shock or inappropriate therapy (3). ConceptsA low cost wireless enabled implantable microelectronic platform for tissue impedancemonitoring and delivering wireless power to implantable cardioverter defibrillators inmedical applications3. Impedance monitoring to find out the position of electrodes in the heart4. ECG synchronization and deliver the power to the heartDesign proposalBlock diagram of designed low cost wireless enabled implantable microelectronic platformfor tissue impedance monitoring and delivering wireless power to implantable cardioverterdefibrillators in medical applications is given below. Figure 4 Block diagram of the design. Flow chartFigure 5 Flow chart with working principleTechnological requirementsThe technological system consists of external and internal components. External componentsare outside remain outside the human body, whereas the internal components are implantedinside the human bodyExternal componentsExternal

components of the system consists of ECG Synchronisation and External Powersupply unit and External data deliver collection and display unitECG synchronisation and external power supply unitECG synchronisation and external power supply unit consists of1. ECG monitoring and analysing componentsECG monitoring is used to monitor the electrical activity of the heart. The measuredECG is then transferred to microcontroller which consists of cognitive system withinit. Then, the cognitive system within a microcontroller does not only analysis thesignal but also synchronise with RQS complex of the ECG signal and commands thepower supply units whether or not to deliver the power to internal system based in thecondition of the atria. 2. External power supply componentExternal supply unit consists of inductive power. It transfers magnetic energy to theinternal inductive power supply unit. Internal power supply and external power areelectrically isolated but magnetically connected. While the current is circulatingthrough the external inductive produces the magnet flux. This produced magnetic fluxto magnetically transfer to the internal inductive power unit. External data deliver, collection and display unitExternal data deliver collection and display unit performs the following task1. It delivers the data to the internal data collection and deliver unit through med radio2. It collects the data from internal data collection and deliver units3. It informs the patients if the electrodes are not in proper place. Internal componentsInternal components of the total systems consists of following units1. Inductive power unit2. Rectifying and smoothing with voltage controller units3. Biphasic waveform generator and energy delivery unit4. Structural monitoring unit5. Data collection and data deliver unitInternal components of the system are well packaged in a biocompatible material

and implantedinside the human body near the collar bone. Inductive power unitInductive power unit consists of inductive coil which responses to change in magnet flux produced bythe external power supply. The varying magnetic field in internal inductor induces theelectromagnetic force or voltage. The induction of voltage is directly proportional to the varyingmagnetic field. The voltage induces is fed to rectifying and smoothing circuit with voltage controllerunitsRectifying and smoothing with voltage controller unitsThis unit consists of rectifying and smoothing unit along with voltage controller. Rectifyingcircuit converts the alternating current into direct current. Rectifying circuit consists of diodesarranged in different fashion. The direct current consists of ripple factor associated with itwhich is then smoothed by the use of smoothing circuit. Smoothing circuit generally consistof capacitor with other necessary electronic components. Smoothing circuit reduces theripple and makes the voltage constant. The voltage controller consists of voltage divider. This unit provides different voltages required for different units based upon their powerconsumption. Generally, lowest voltage is required for impedance monitoring unit, followedby data collection and data deliver unit. The highest voltage is required for biphasic wavegenerator and energy generator unit. First of all, this unit only provides power to structural monitoring circuits and data collection anddata deliver unit. If the structural monitoring circuit provides the information that leads are in correctposition then only it supplies energy to biphasic wave generator and energy generator unit toprovide the electrical shock to heart. Biphasic wave generator and energy generator unitBiphasic wave generator and energy generator unit does the following functions1. It converts the monophasic waveform provided by voltage regulator to biphasic2. It delivers the

electrical energy to the heart through the electrodes. Structural monitoring unitStructure monitoring unit consists impedance measuring chip along with cognitive systemthat tells the exact position of electrodes. When there is change in the position of theelectrodes, there is change in impedance monitored by the system. When this system finds lead position in correct position, the microcontroller within thissystem sends the command signal to rectifying and smoothing with voltage controller unit togive electrical power to the biphasic wave generator and energy generator unit. Data collection and data deliver unitDate collection and data deliver unit consists of med radio responsible for communicatingwith external data deliver collection and display unit. Its communication is bidirectional. Itcommunicates with the external system and gives the information about position of the leadsin the system. PackagingThe electrical and electronics components of the internal system needs to hermeticallysealed and sterilised. Packaging is important all the electrical and electrical componentsmust be isolated from the human tissues and blood as much as possible just to reduce tissuedevice interaction. Materials that used for packaging of these components must bebiocompatible as many people in suggests biocompatibility as the most complex issue for invivo sensor development. Design evaluationRegulatory complaintsMedical devices are classified on the basis of complexity and risk factors associated withthem (21). Risk factors are analysed based upon tissue or biofluid device interaction, durationof contact and possible effects on body systems (local vs systematic). Regulatoryrequirements for specific medical product are defined by regulatory bodies within thatregion (21). Medical devices are classified as class I, class II and class III in European Unionand United states (21). According to European union directive

90/385/EEC (ActiveImplantable Medical Devices [AIMDD]) and United States Code of Federal Regulations (21CFR 800-900, FDA Center for Devices and Radiologic Health) , internal defibrillator is inclass III medical device because it is surgically implanted inside the body and duration ofcontract is more than 30 days (21).. According to FDA, Implantable defibrillator being in class III device needs a premarketapproval or equivalent for its release in the marketMaterials and biocompatibilityAs the device needs to be biocompatible, they have to be made from biocompatible materialwhich is already in market. Titanium is generally in medical purpose and had show greatbiocompatibility in vivo. So, this can be used for defibrillator leads and SU-8 can be used forsurface modification of the device and wire to provide insulation (13). For the safety requirement of the implantable device (class III for more than 30 days), following tests are recommended by the Biological Evaluation of Medical Devices technicalcommittee of ISO 10993 (21).. Cytotoxicity. Sensitization. Irritation or Intracutaneous Reactivity. Systemic Toxicity (acute). Subchronic Toxicity (Subacute Toxicity). Genotoxicity. Implantation. Chronic Toxicity. Carcinogenicity. Reproductive/Developmental. BiodegradationLeads of the device need additional test i. e. hemocompatibility. CommercialisationFor the commercialisation of the product all, different issues related to it have to be handledand addressed correctly and maintain them. Issues might be in case of bio compatibility orliability or technology acceptance issues of the product. There is a wide knowledge gap foracceptance of this kind of medical device. Health issues are very serious and are takenseriously in each and every part of the world. So for the commercialisation of the product, itseems quite difficult to make patient to adopt this technology. For the

propercommercialization, knowledge transfer from specialist to general physician followed bypatient is required. Figure 6 Market development model for new technology (1)Figure 6 shows how the technology is adopted in the society. Form above figure, it is clearthat there is huge chasm between technology early market adaptors (visionaries) andearly majority market adopter (pragmatists) which makes the new technology difficult formarketing (1). The chasm seen between the visionaries and pragmatists can only if fulfilled ifthe invention can close the knowledge gap between these two groups. So, proper knowledgetransfer from specialists to physician followed by consumers is must. Liability issuesLiability issue such as using a device in an appropriate way by non medical professional is abig concern. There is always a big question regarding who will be responsible if the patientcould not correctly implement and use the equipment for the desire purpose. No doubt thatthe wireless monitoring system with defibrillator can dramatically change the quality of lifeof the patient with atrial fibrillation, but lack education for proper implementation andmaintenance of this device will surely limit its usage. Moreover, energy is supplied to the internal components through induction. This may causeproblem for the patient when the patient near to inductive sources. In addition to that, lowfrequency magnetic field generated by power sources will induce magnetic field in the body. This induced magnetic field produces circulating current which may effects in nerve, musclesand other biological processes. Technology acceptance issuesAnother big issue in marketing a new technology is the acceptance of new technology bygeneral public. The acceptance of the technology is only possibility if they are familiar withtechnology because of human behaviour of resisting change. Technology acceptance issuemust be

fulfilled by training the consumers for proper use of the device. Moreover, inabilityof continuous monitoring system by the device may be another big issue. ConclusionAtrial fibrillation, a most common arrhythmia, can be managed with different techniques, butthe side effects and other problems associated with it limit the long term care for atrialfibrillation. So, development of a low cost wireless enabled implantable microelectronicplatform for tissue impedance monitoring and delivering wireless power to implantablecardioverter defibrillators in medical applications is required. Biocompatibility, liability andtechnology acceptance issues should be properly handled and managed before bringing it tothe market.