



# Freescale Technology Forum

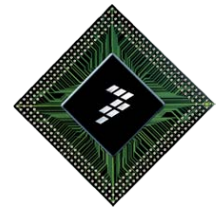
Collaboration. Innovation. Inspiration.

July 2009

## How to Create a Heart Rate Monitor and One-Lead EKG

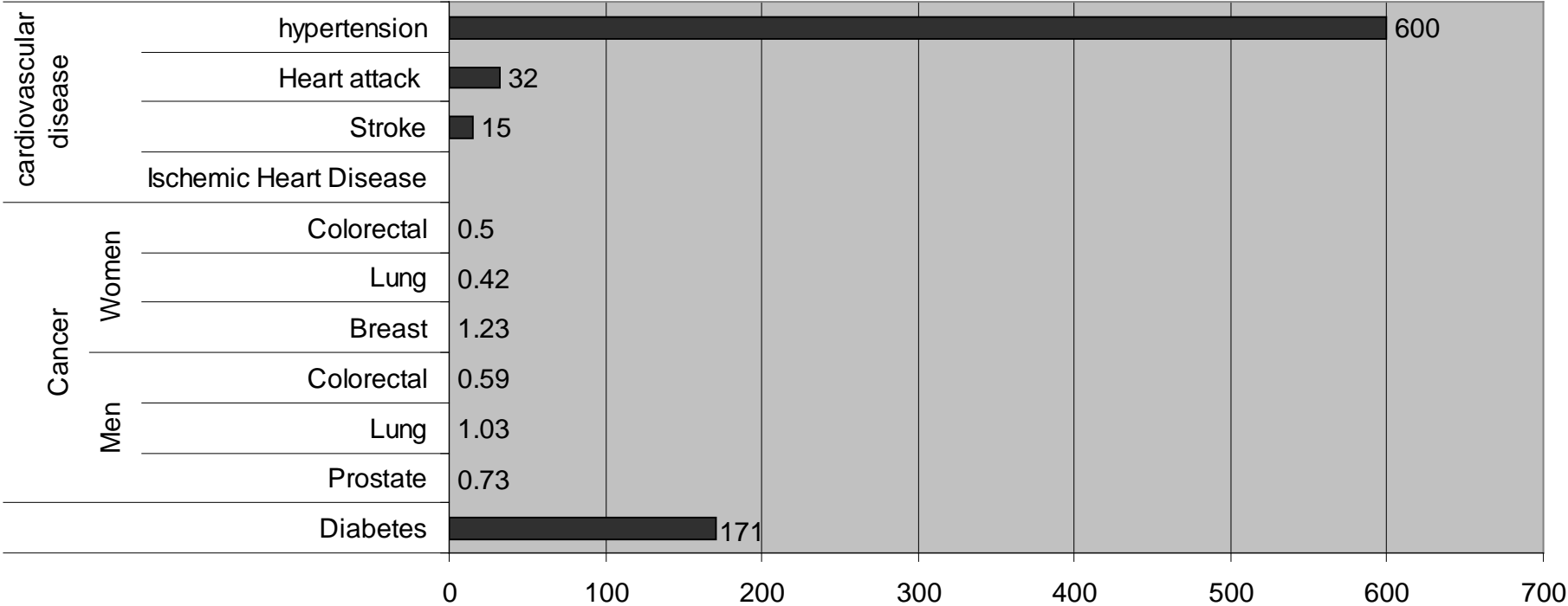
Low-cost, battery-operated system

**Jose Fernández Villaseñor, M.D.**  
Medical Microcontroller Product Marketing



# Worldwide Morbidity 2007

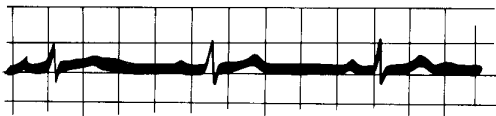
Worldwide Incidence 2007  
million



Source: World Health Organization Statistics 2007

# Heart Rate Monitoring Technologies

## Early 20th Century

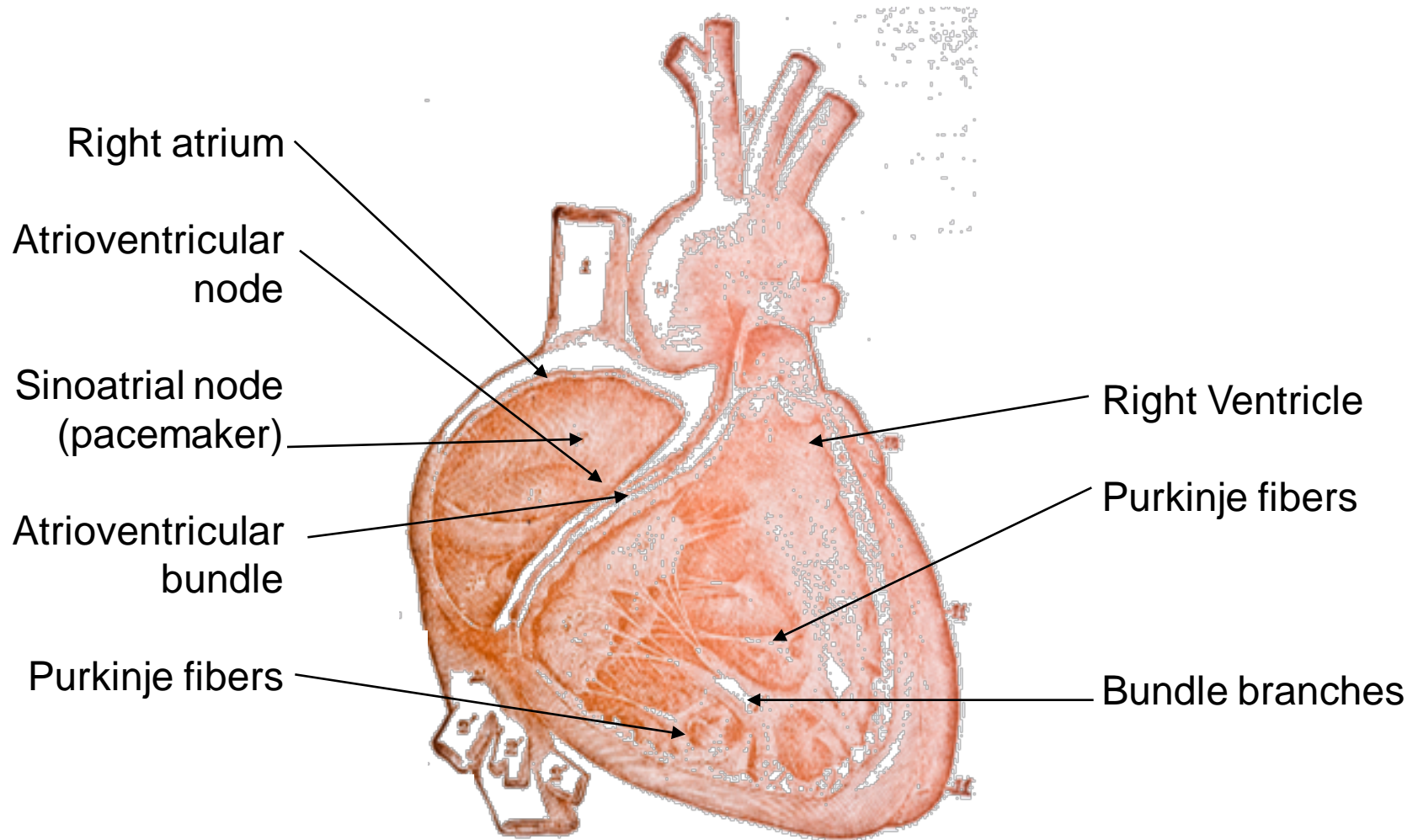


*Saline-filled bucket electrodes*

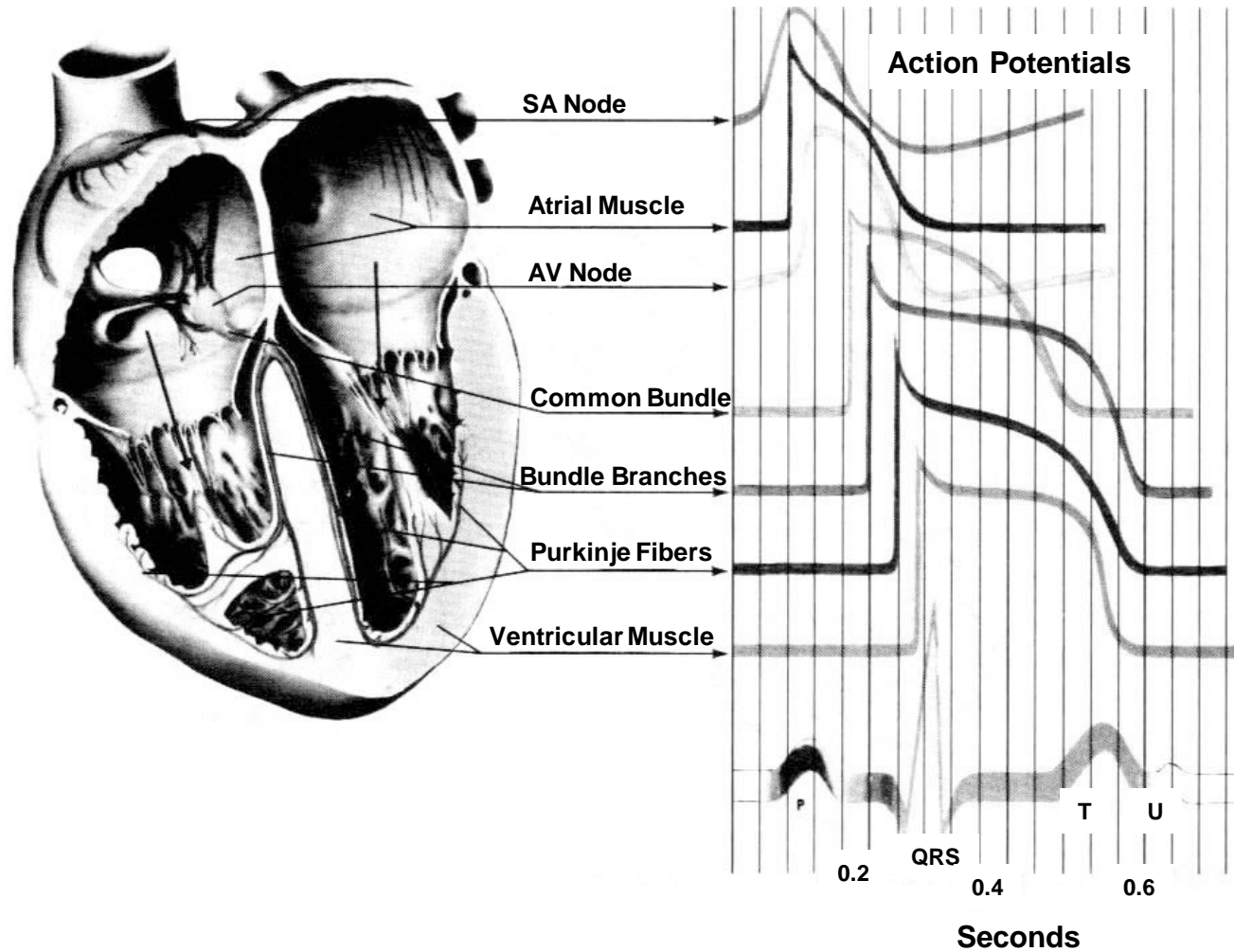
## Today



# Heart Physiology: Cardiac Conduction System

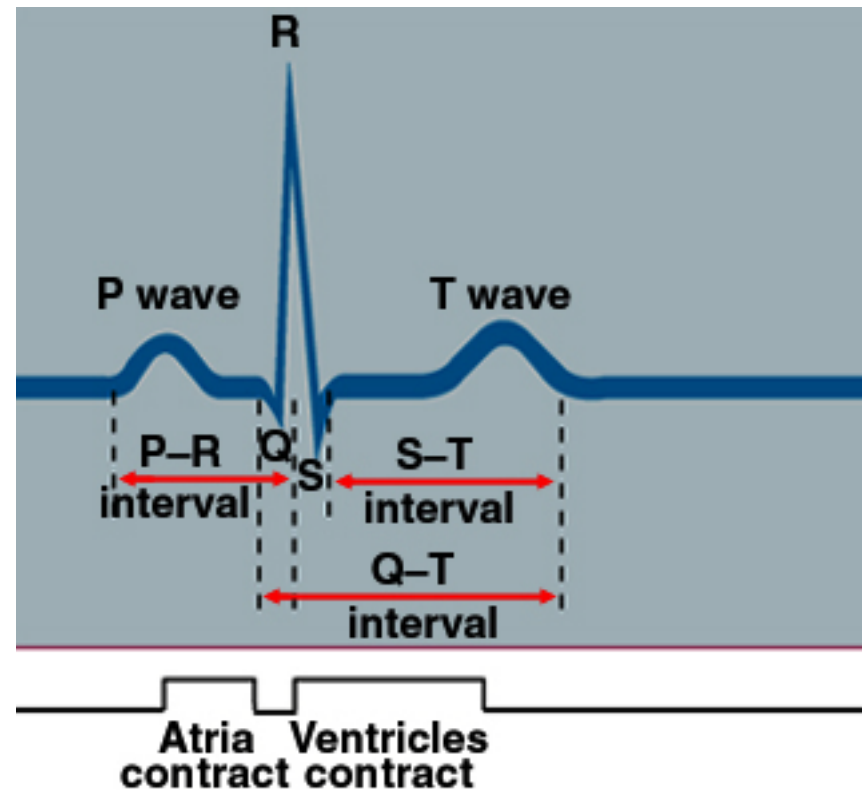


# Heart Physiology: Origin of the Electrocardiogram



# Heart Physiology: Electrocardiogram (ECG)

- ▶ Composite of all action potentials of nodal and myocardial cells detected, amplified and recorded by electrodes on arms, legs and chest



# Heart Physiology: Electrical Activity of Myocardium

1) Atria begin to depolarize

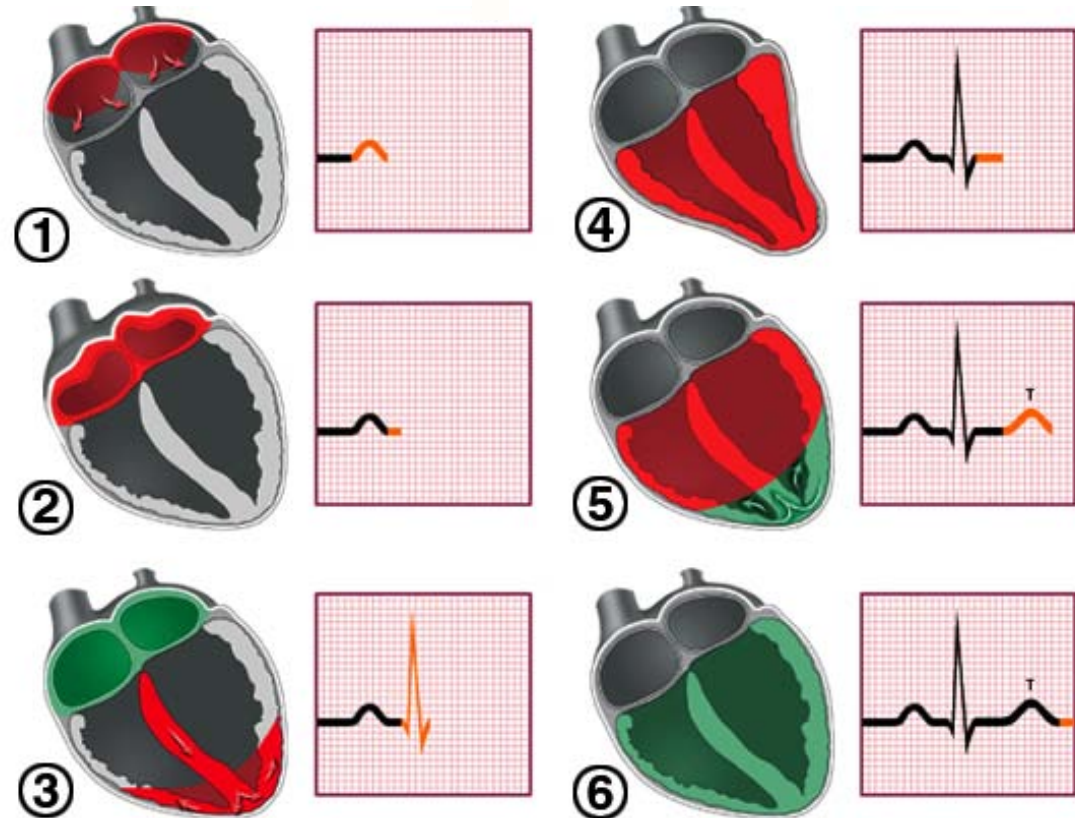
2) Atria depolarize

3) Ventricles begin to depolarize at apex; atria repolarize

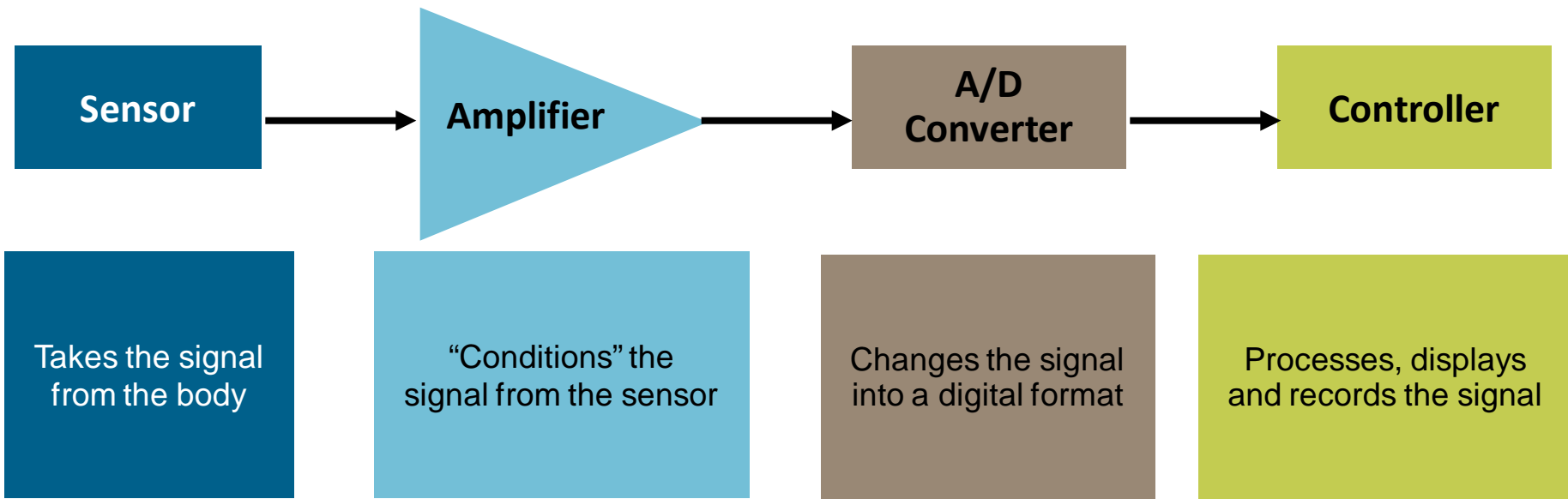
4) Ventricles depolarize

5) Ventricles begin to repolarize at apex

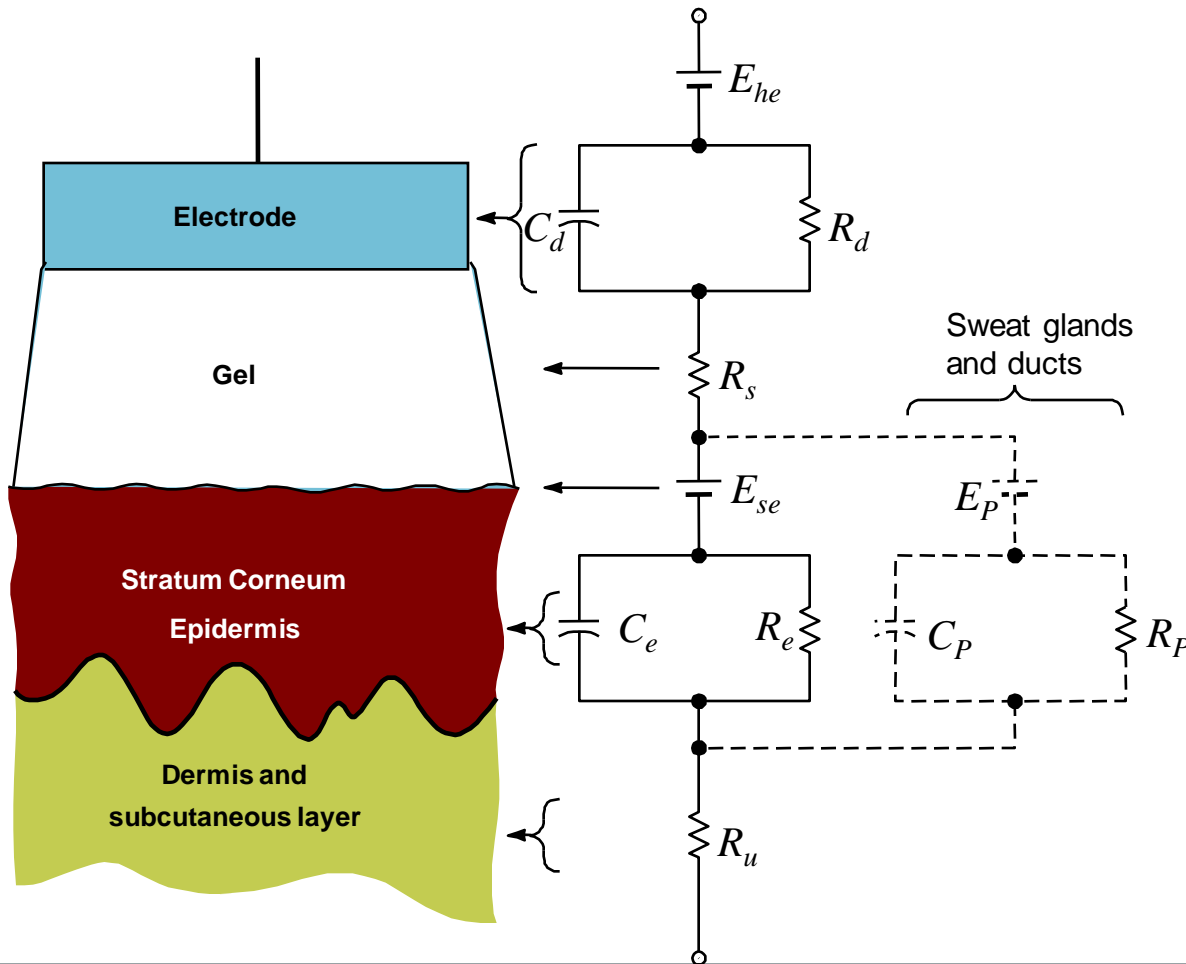
6) Ventricles repolarize



# Acquiring Heart Signals: Typical Instrumentation System



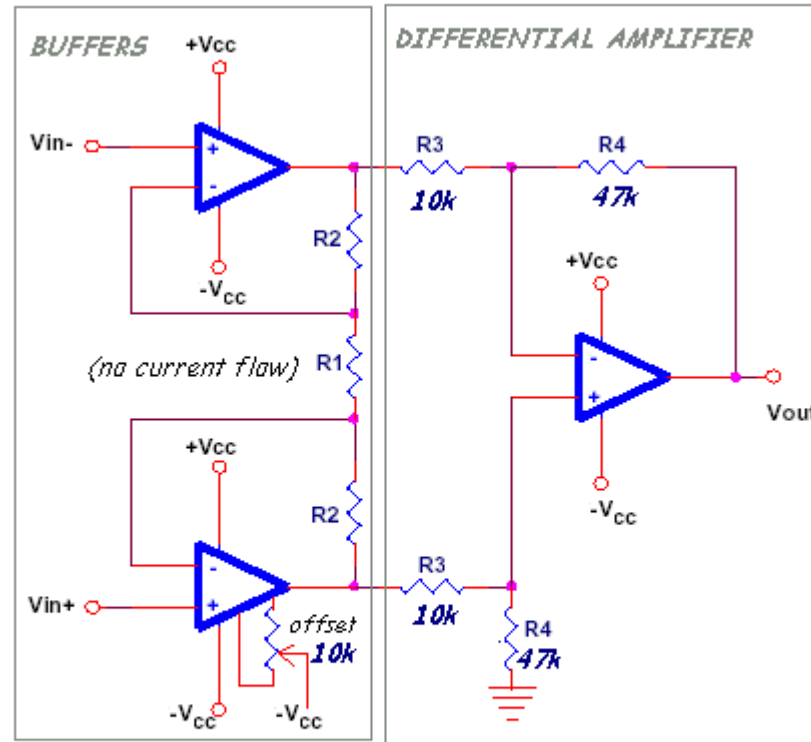
# Acquiring Heart Signals: Electrode-Skin Interface



## Offset sources:

- Electrode
- Skin
- Breathing

# Acquiring Heart Signals: OPAMP array for an INA

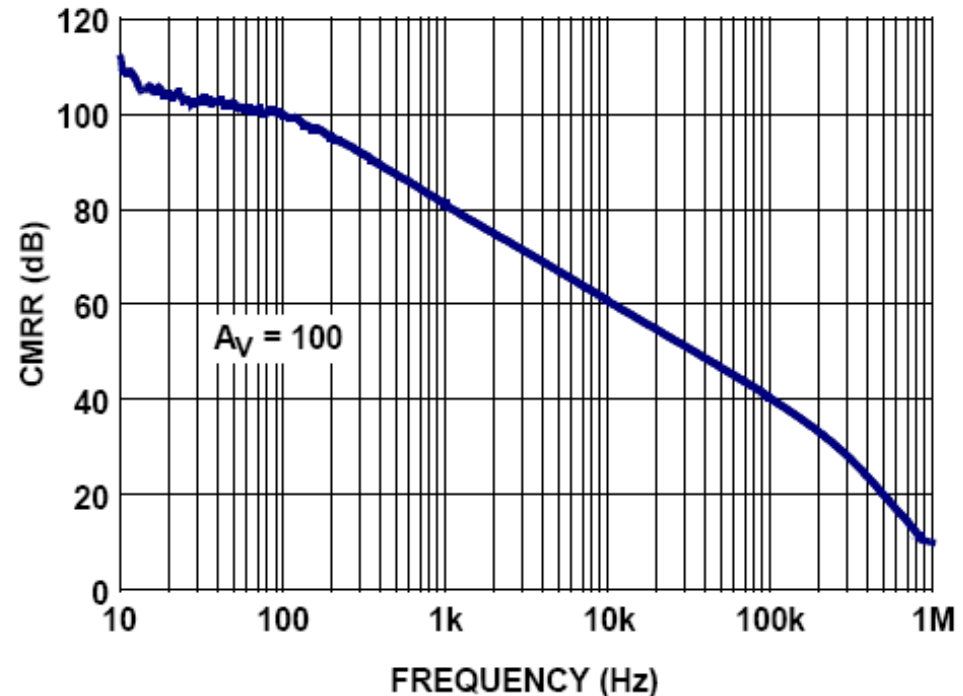


$$CMRR = 10 \log (1 + 2R2/R1)$$

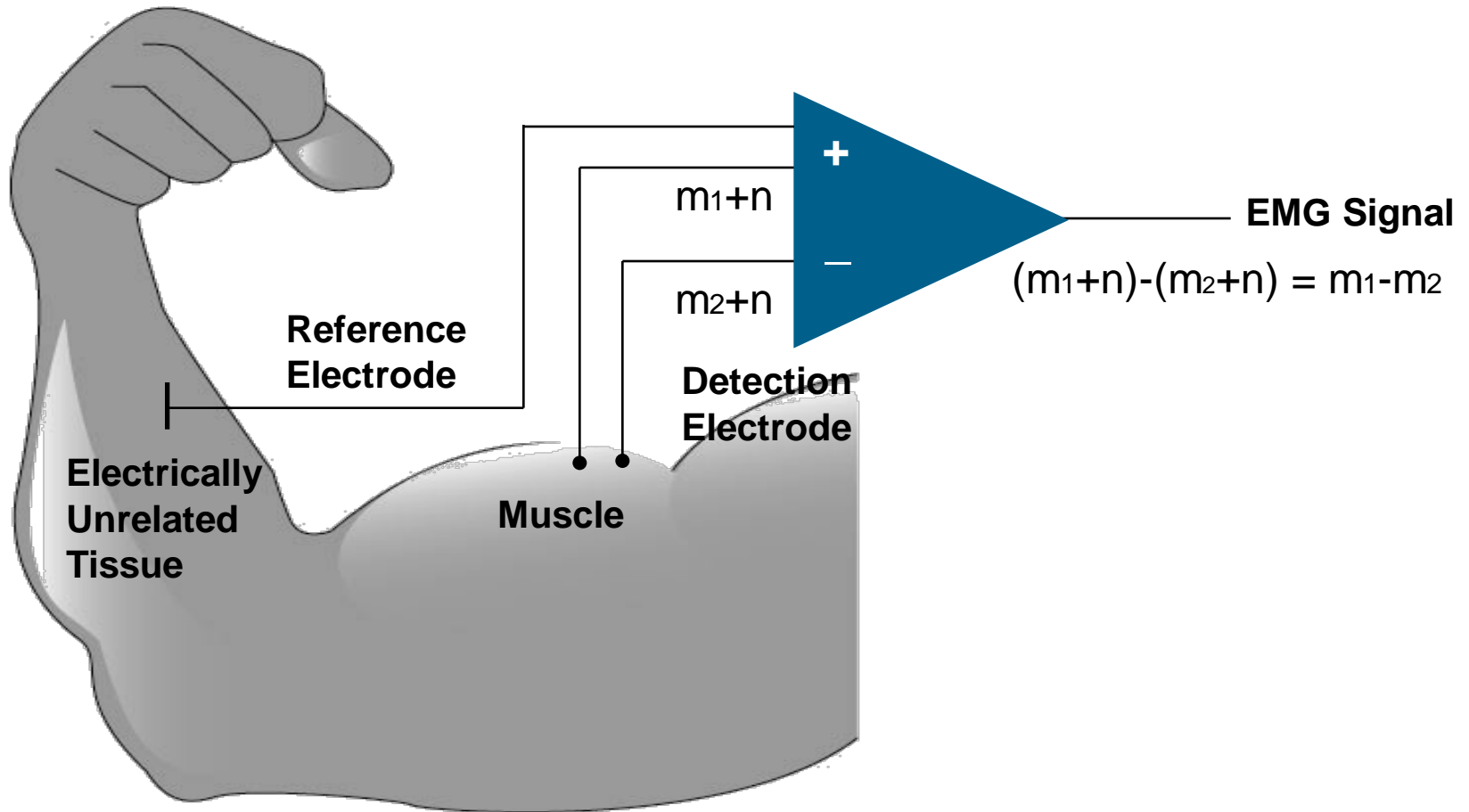
$$\text{Gain} = R4/R3(1 + R2/R1)$$

# Acquiring Heart Signals: Common Mode Rejection Ratio (CMRR)

- The CMRR defines the ability of the amplifier to reject signals that are common to both inputs
- This is important for 60Hz rejection
- CMRR is a function of gain
- CMRR is frequency-dependent
- Highest CMRR between 0-100 Hz



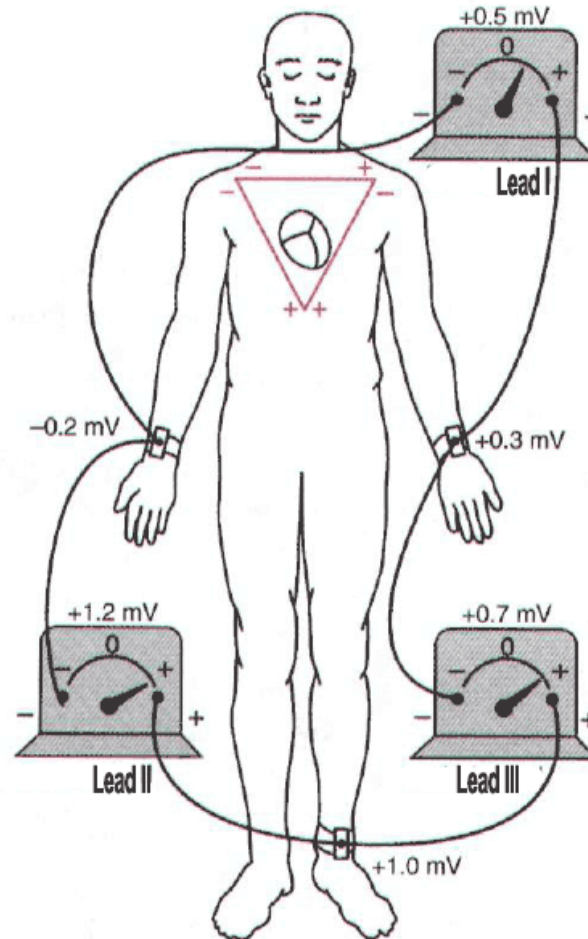
# Acquiring Heart Signals: Connections to INA



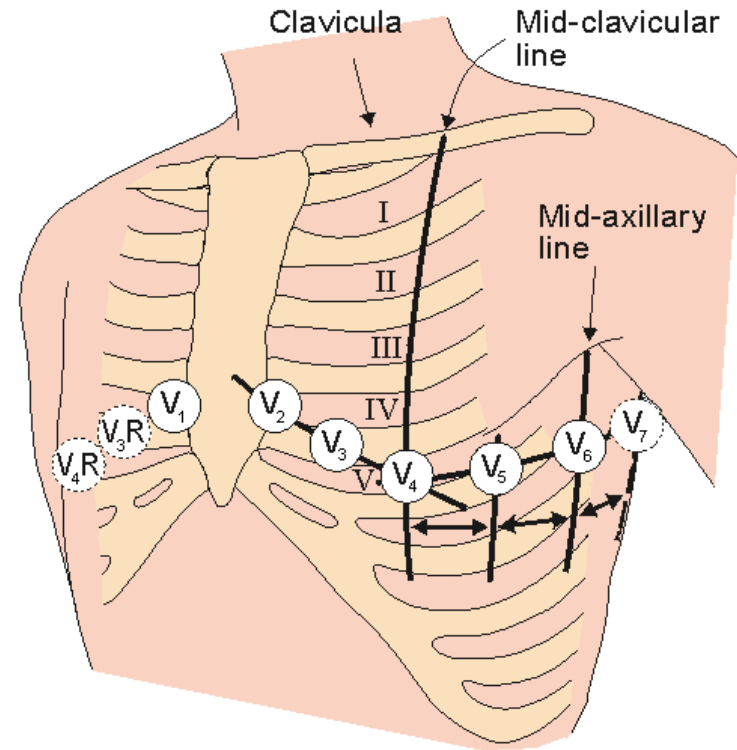
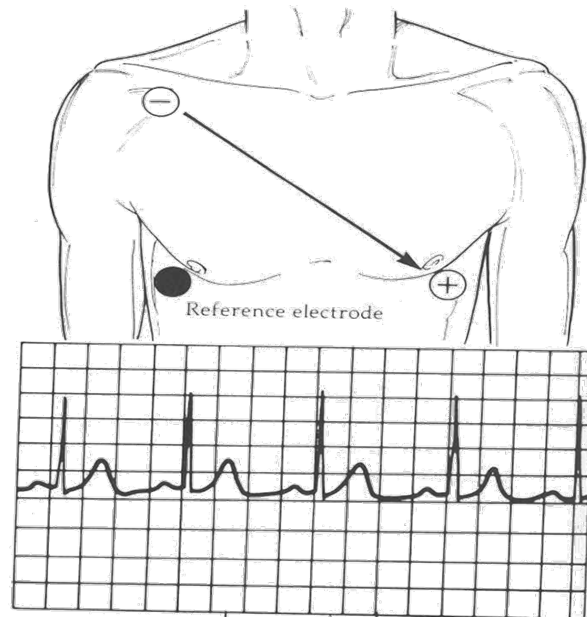
**$m$  is signal from muscle,  $n$  is noise**  
**Differential Amplification**

# Acquiring Heart Signals: Limb Leads

**Bipolar limb leads:  
I, II, III**

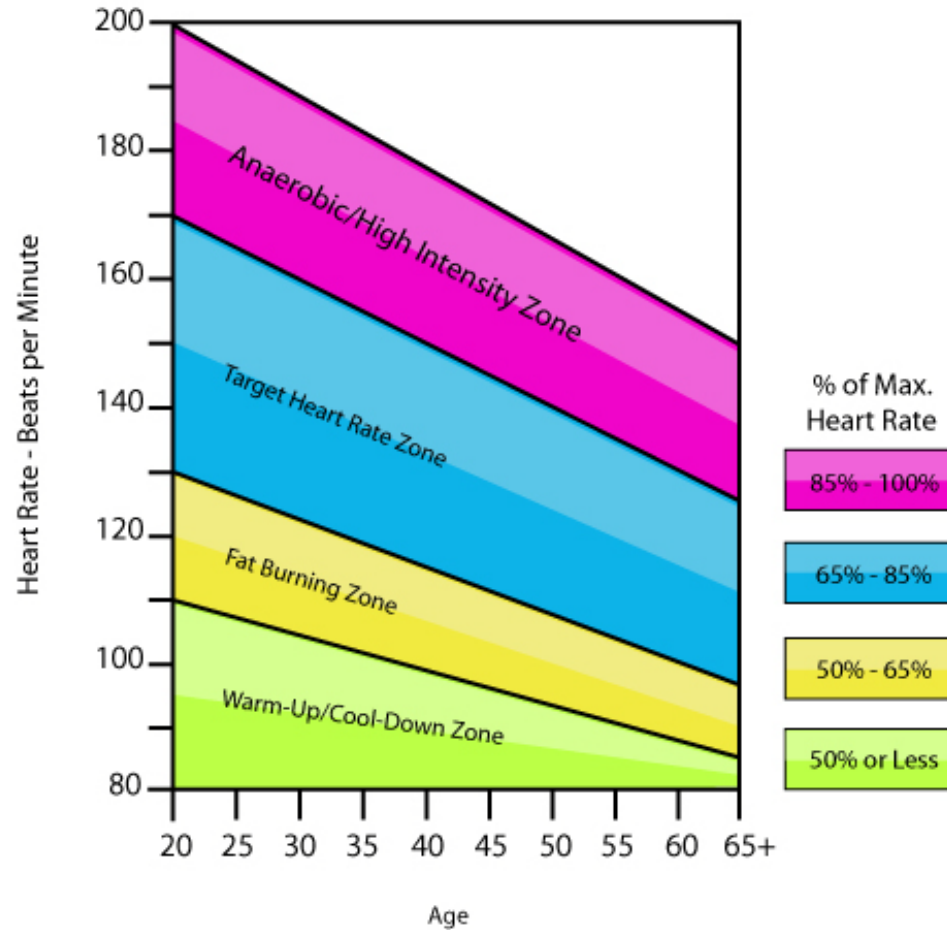


# Acquiring Heart Signals: Chest Leads

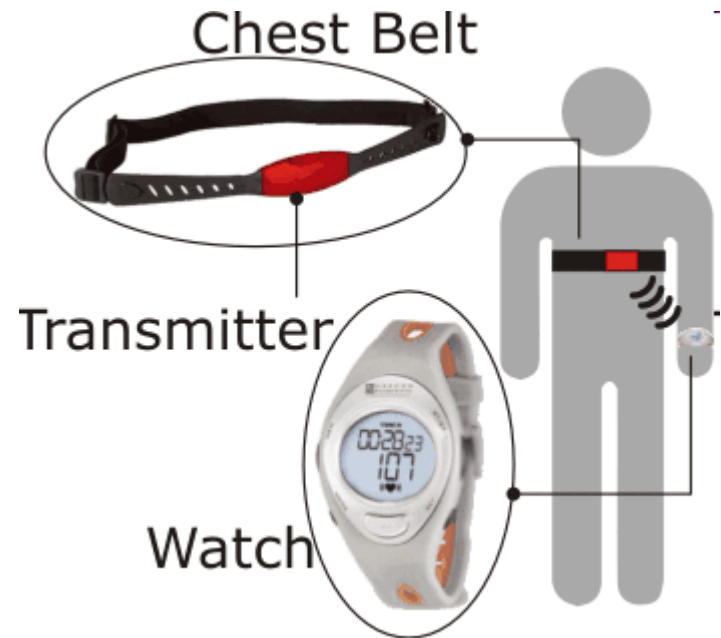


► **Additional set of six leads, placed on the chest**

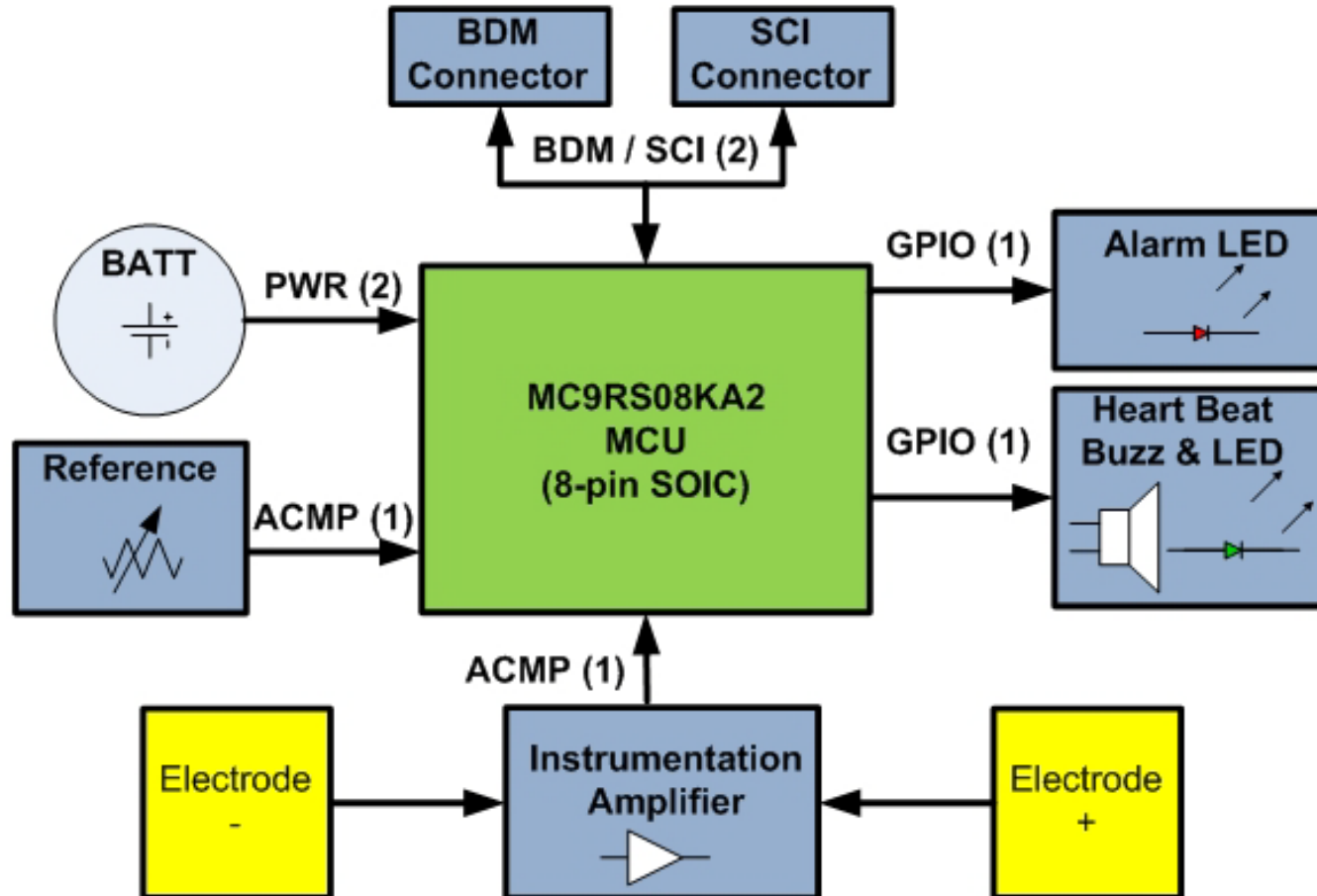
# Low-cost Heart Rate Monitor: Importance of Measuring Heart Rate



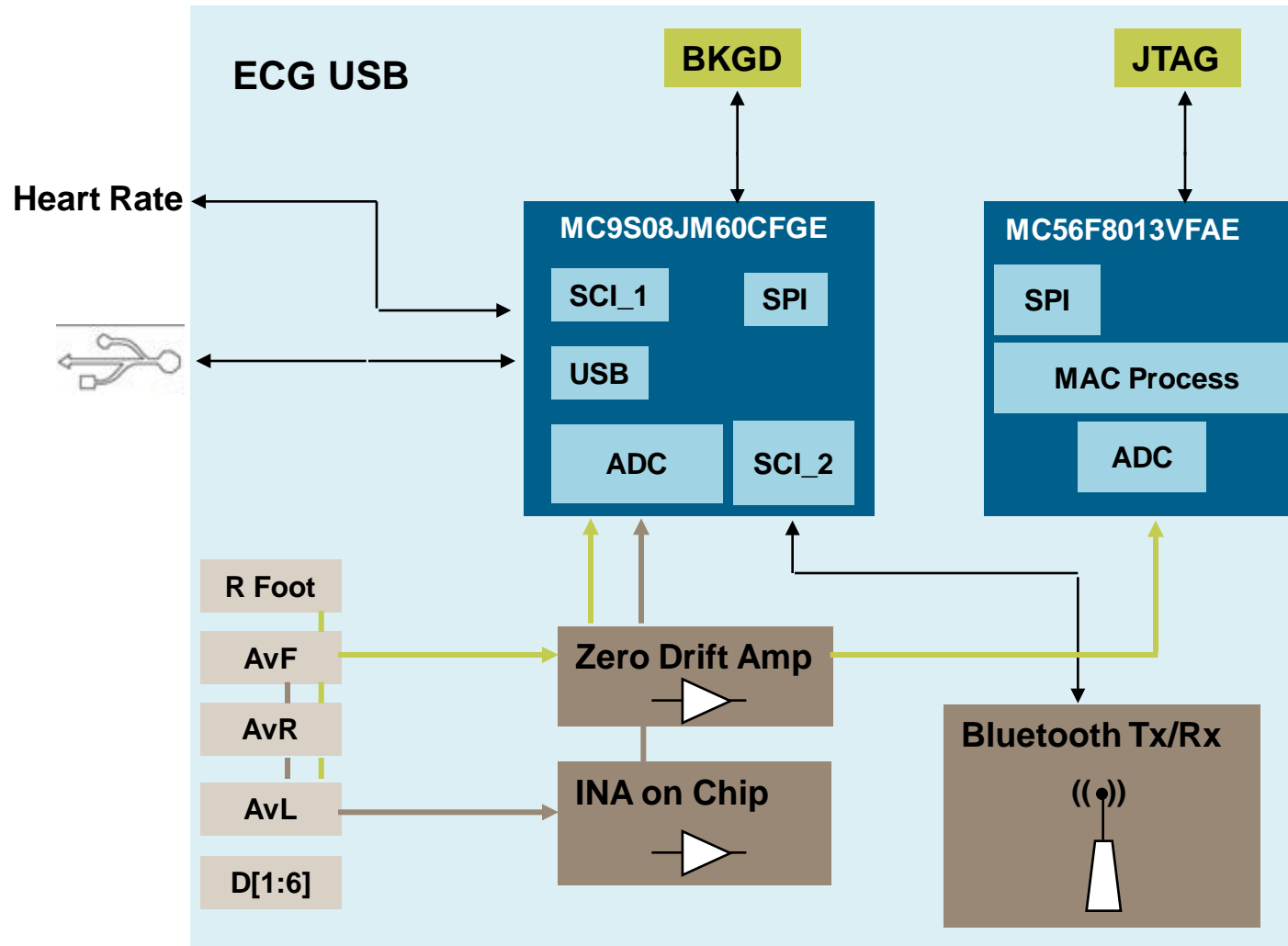
# Low-cost Heart Rate Monitor: Market Solutions



# Low-cost Heart Rate Monitor



# 1 to 12-Lead ECG Solution



# The Flexis™ USB Family

## S08JM60 and MCF51JM128

- ▶ 48MHz S08 or ColdFire® V1 core
- ▶ 24MHz bus frequency
- ▶ 2.7 – 5.0V operating range

### ▶ **Memory**

#### ▶ **S08**

- ▶ Up to 4KBytes SRAM; up to 60KB flash

#### ▶ **ColdFire V1**

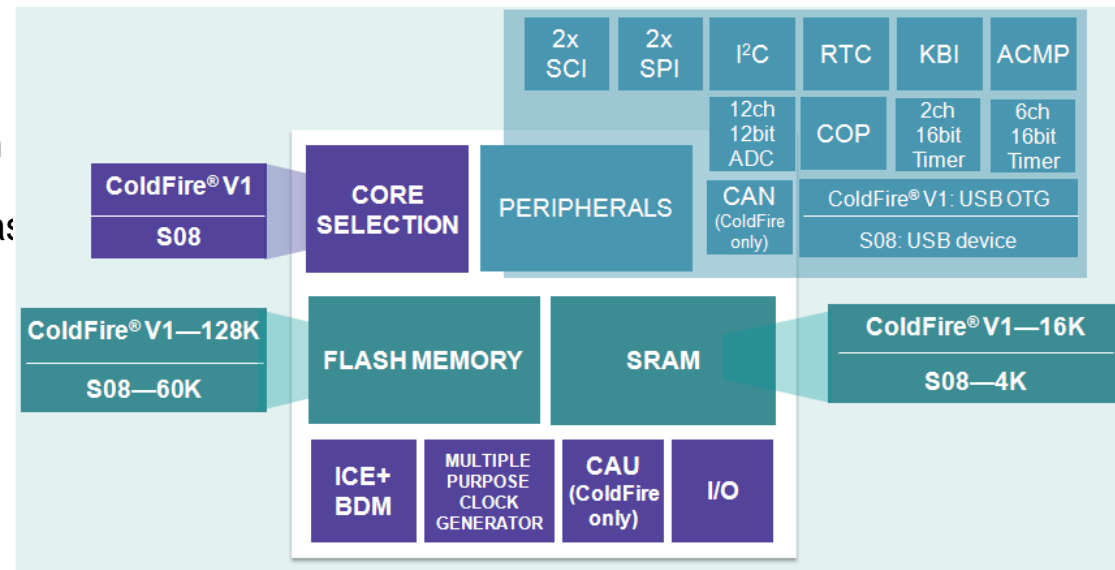
- ▶ Up to 16KBytes SRAM; up to 128KB flash

### ▶ **Features**

- ▶ 2x SCI, I2C, 2x SPI
- ▶ 8 channel KBI
- ▶ 16-bit timers: 1 x 2-ch, 1 x 6-ch
- ▶ 12-bit 12 channel A-to-D converter
- ▶ Analog comparator
- ▶ Up to 51 general purpose I/O
- ▶ Multiple purpose clock generation
- ▶ PLL
- ▶ On-chip oscillator
- ▶ External crystal support
- ▶ Integrated CAN module (ColdFire V1 only)
- ▶ Cryptographic acceleration unit (ColdFire V1 only)

### ▶ **Complete USB solution**

- ▶ Integrated USB device (S08) or USB on-the-go (ColdFire V1)
- ▶ Complimentary USB software stack
- ▶ CodeWarrior® for Microcontrollers
- ▶ Processor Expert



### **S08JM60 Packages**

64LQFP, 64QFP 48QFN, 44LQFP

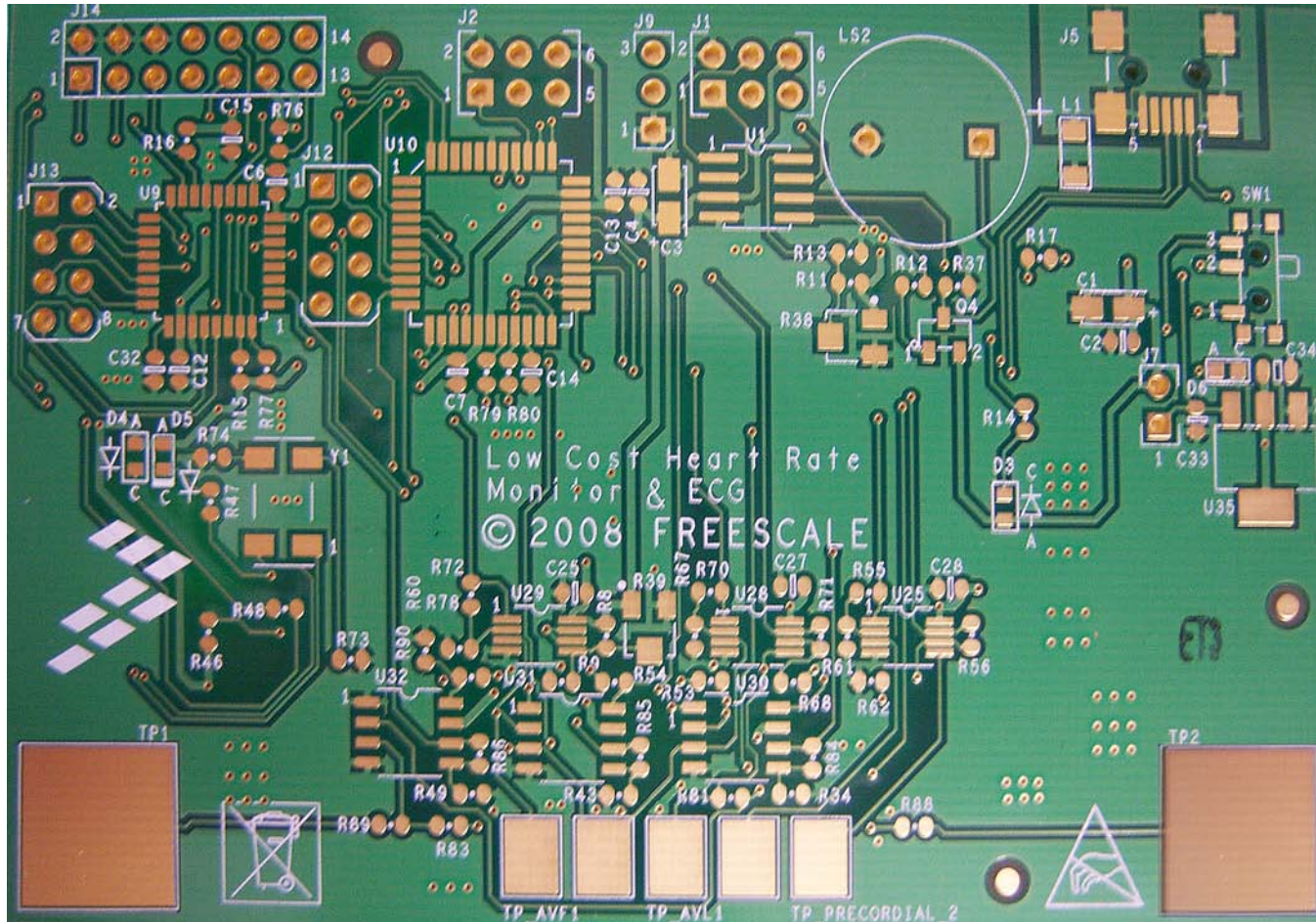
### **ColdFire JM128 Packages**

80LQFP, 64LQFP, 64QFP, 44LQFP

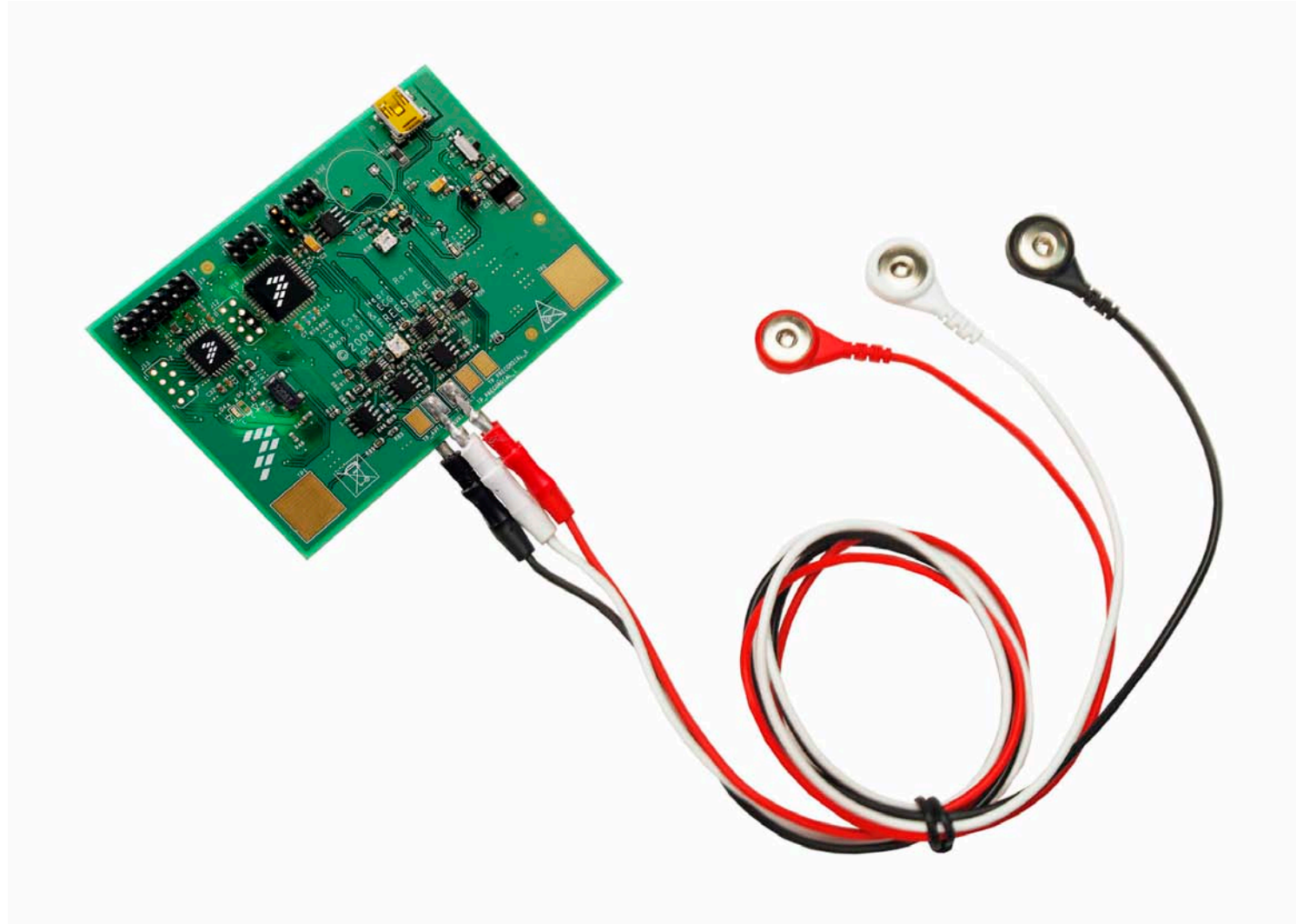
### **Temperature Range**

-40C to 85C

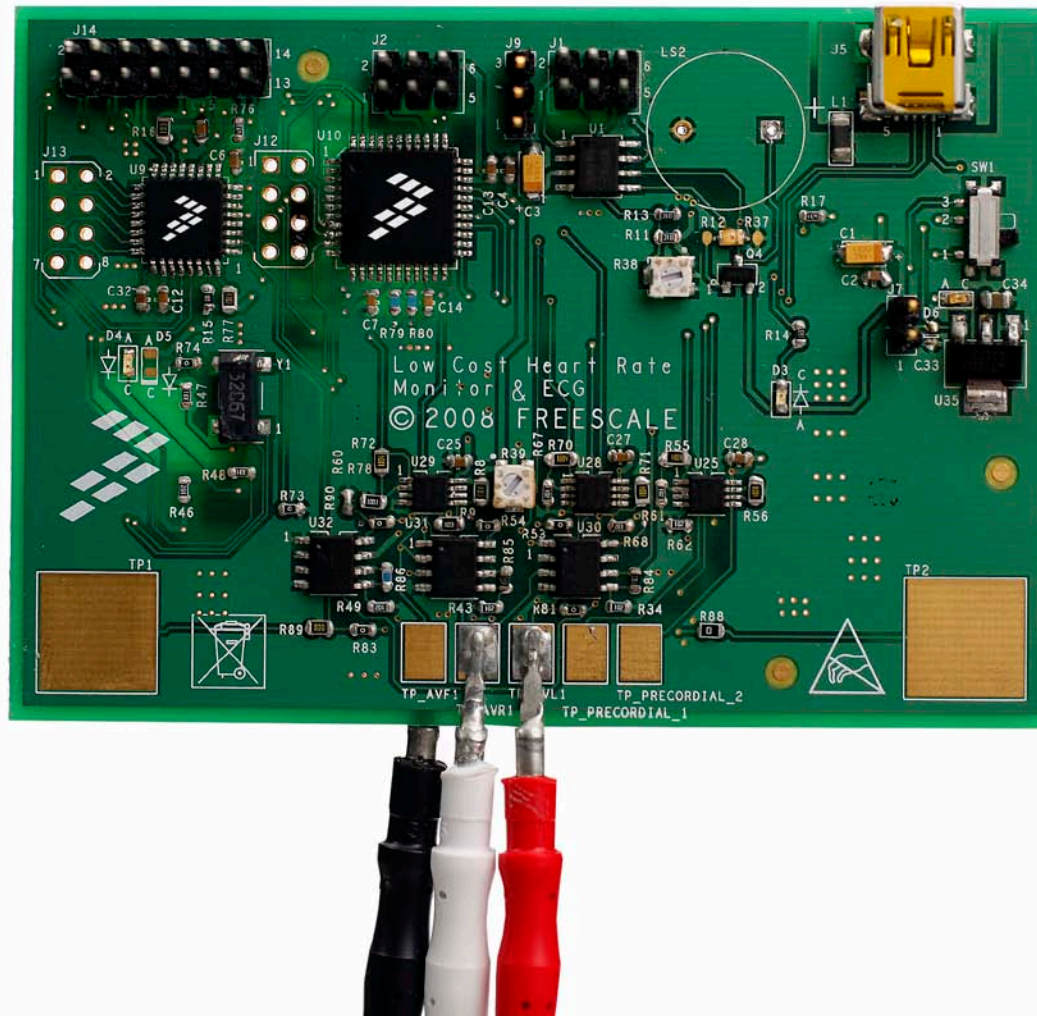
# Complete Solution



# Complete Solution



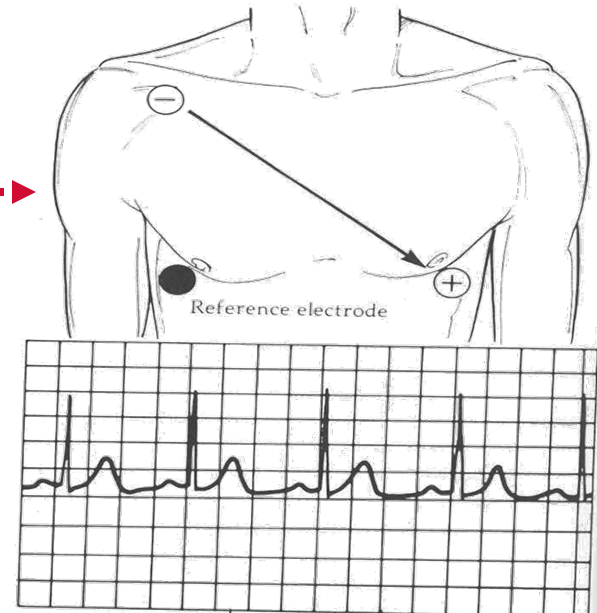
# Complete Solution



# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

Connect the chest electrodes

**Like this!** .....



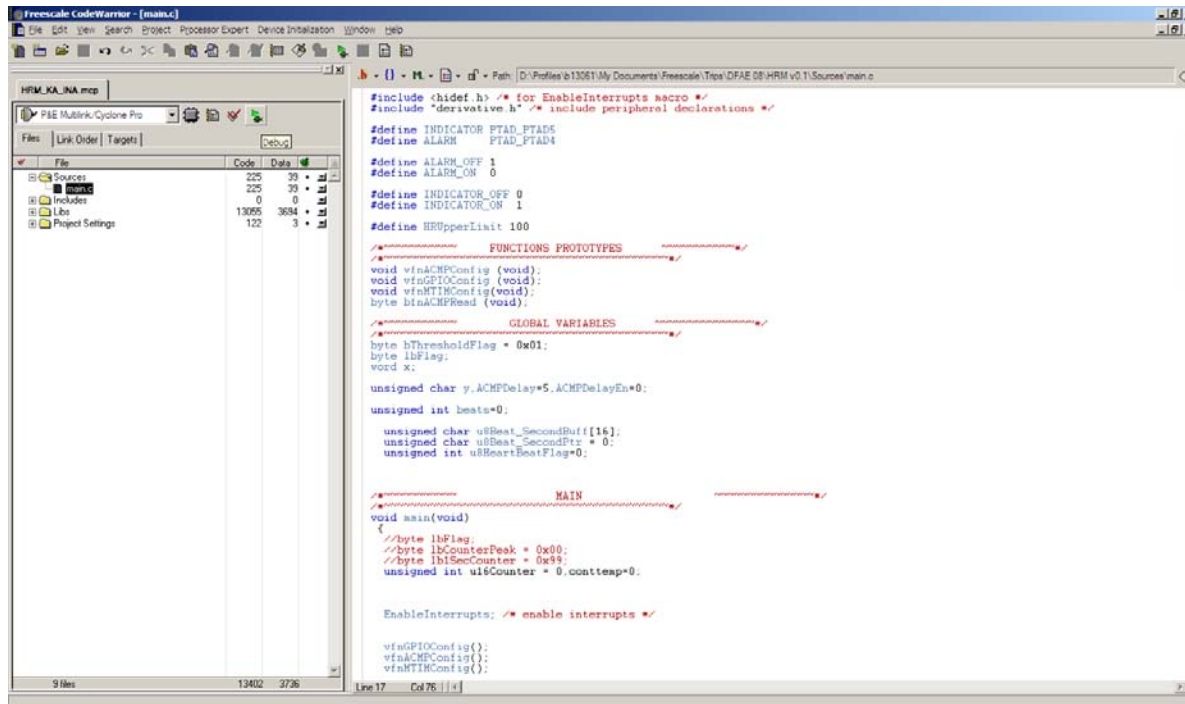
# Low-cost Heart Rate Monitor

## Lab0. Get familiar with the HRM

1. **Connect the board to the laptop (USB).**
2. **Make sure the buzzer is beeping at the same rate as your heart beats.**
3. **If your heart rate is greater than 100, the alarm indicator (red LED) will turn ON.**
4. **Go to the HRM\_KA folder in the desktop and open the CodeWarrior project (HRM\_KA.mcp).**

# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

5. Download the code to the board (Connect the BDM to the closest header from the KA2)



```
#include <hidef.h> /* for EnableInterrupts macro */
#include "derivative.h" /* include peripheral declarations */
#define INDICATOR_FTAD_FTAD5
#define ALARM FTAD_FTAD4
#define ALARM_OFF 1
#define ALARM_ON 0
#define INDICATOR_OFF 0
#define INDICATOR_ON 1
#define HRUpperLimit 100

/*=====
FUNCTIONS PROTOTYPES
=====*/
void vfnACMPConfig(void);
void vfnGPIOConfig(void);
void vfnMTIMConfig(void);
byte bfnACMPRead(void);

/*=====
GLOBAL VARIABLES
=====*/
byte bThresholdFlag = 0x01;
byte lbFlag;
word x;

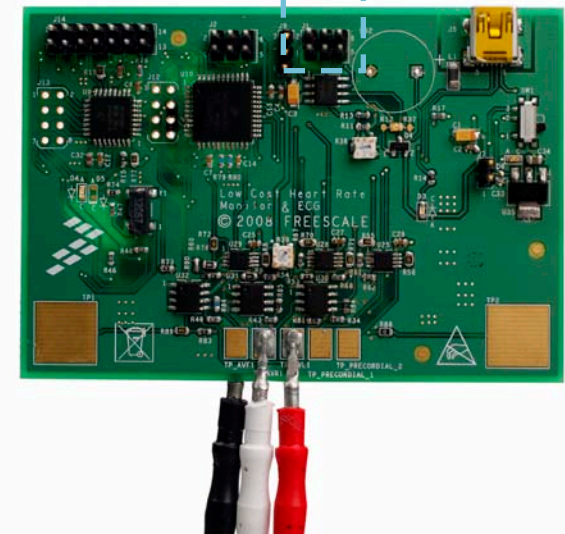
unsigned char y.ACMPDelay=5.ACMPDelayEn=0;
unsigned int bbeats=0;

unsigned char u8Beat_SecondBuf[16];
unsigned char u8Beat_SecondPtr = 0;
unsigned int u8HeartBeatFlag=0;

/*=====
MAIN
=====*/
void main(void)
{
    /*byte lbFlag;
    /*byte lbCounterPeak = 0x00;
    /*byte lb1SecCounter = 0x55;
    unsigned int u16Counter = 0,contemp=0;

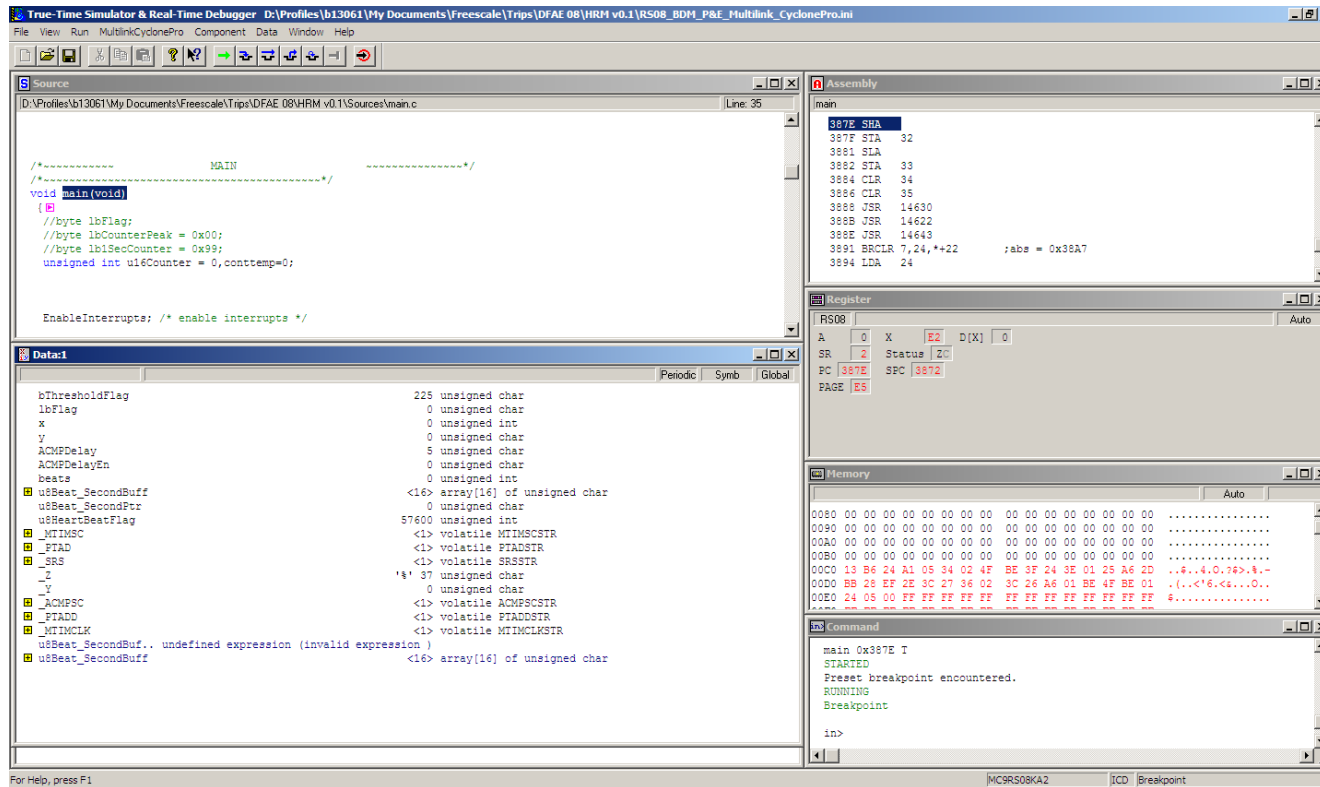
    EnableInterrupts; /* enable interrupts */

    vfnGPIOConfig();
    vfnACMPConfig();
    vfnMTIMConfig();
```



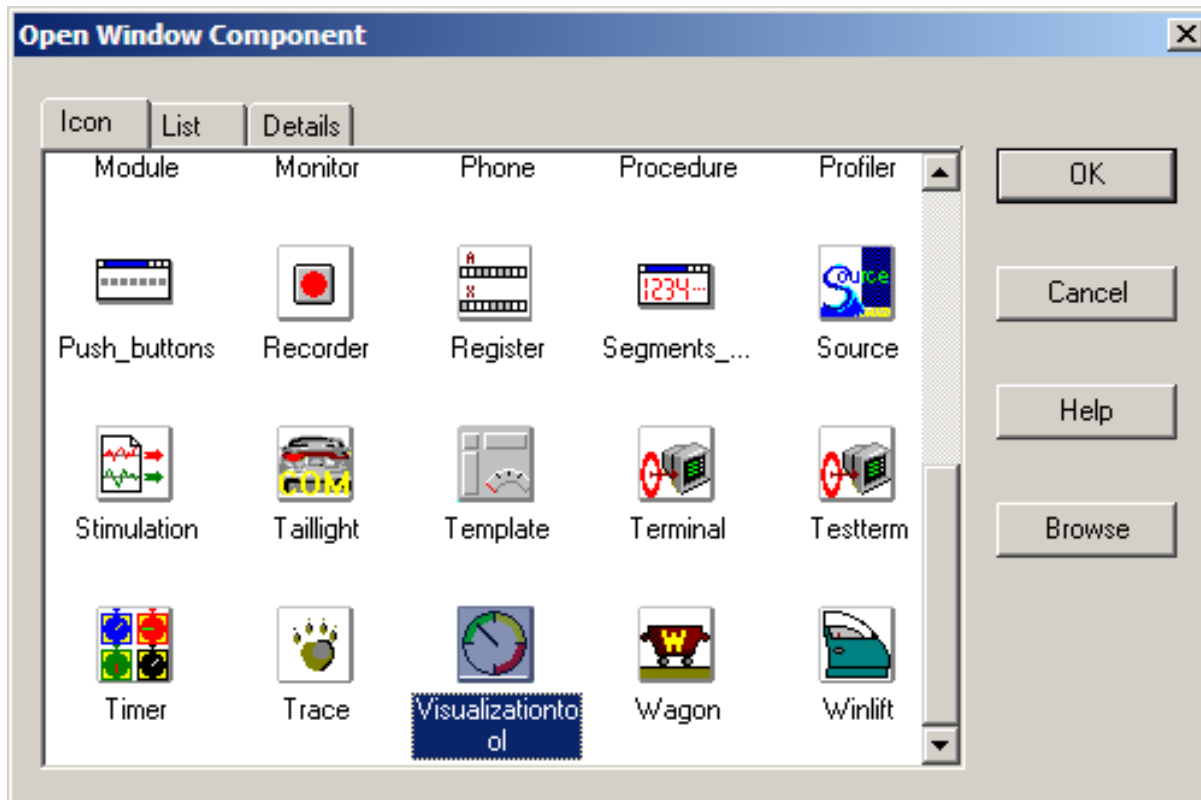
# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

## 6. Go to Component → Open



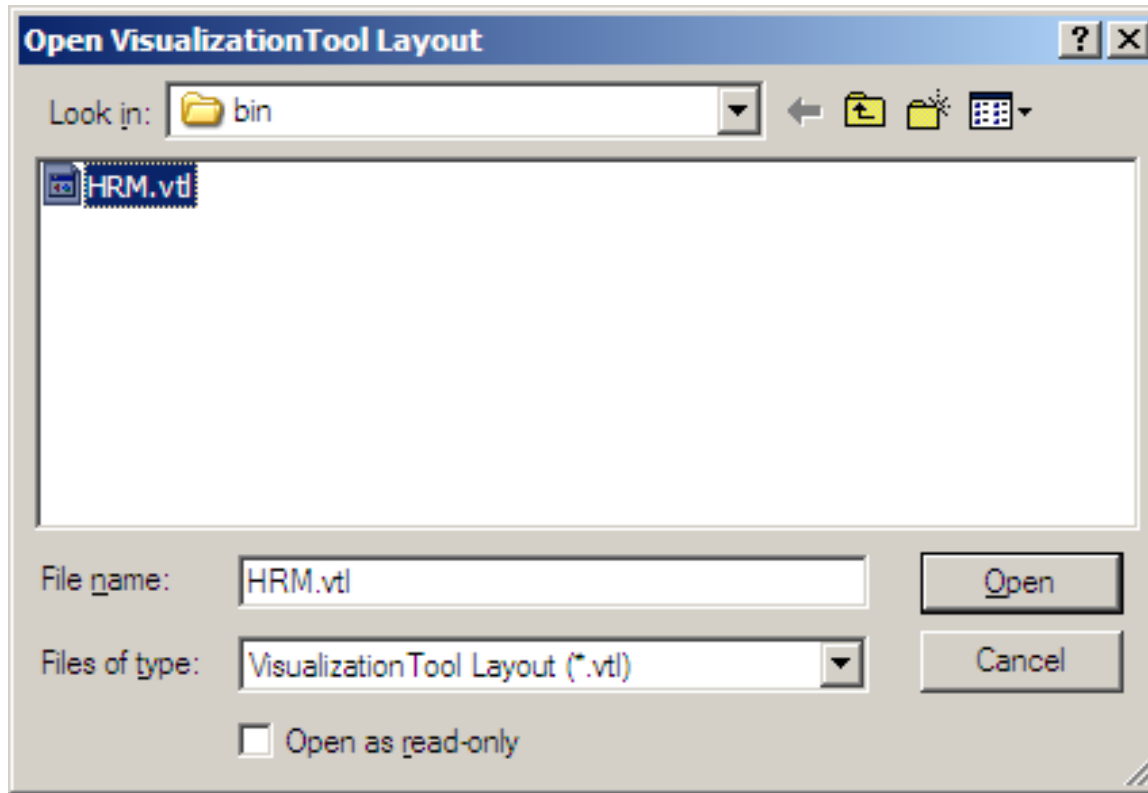
# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

## 7. Open the visualization tool



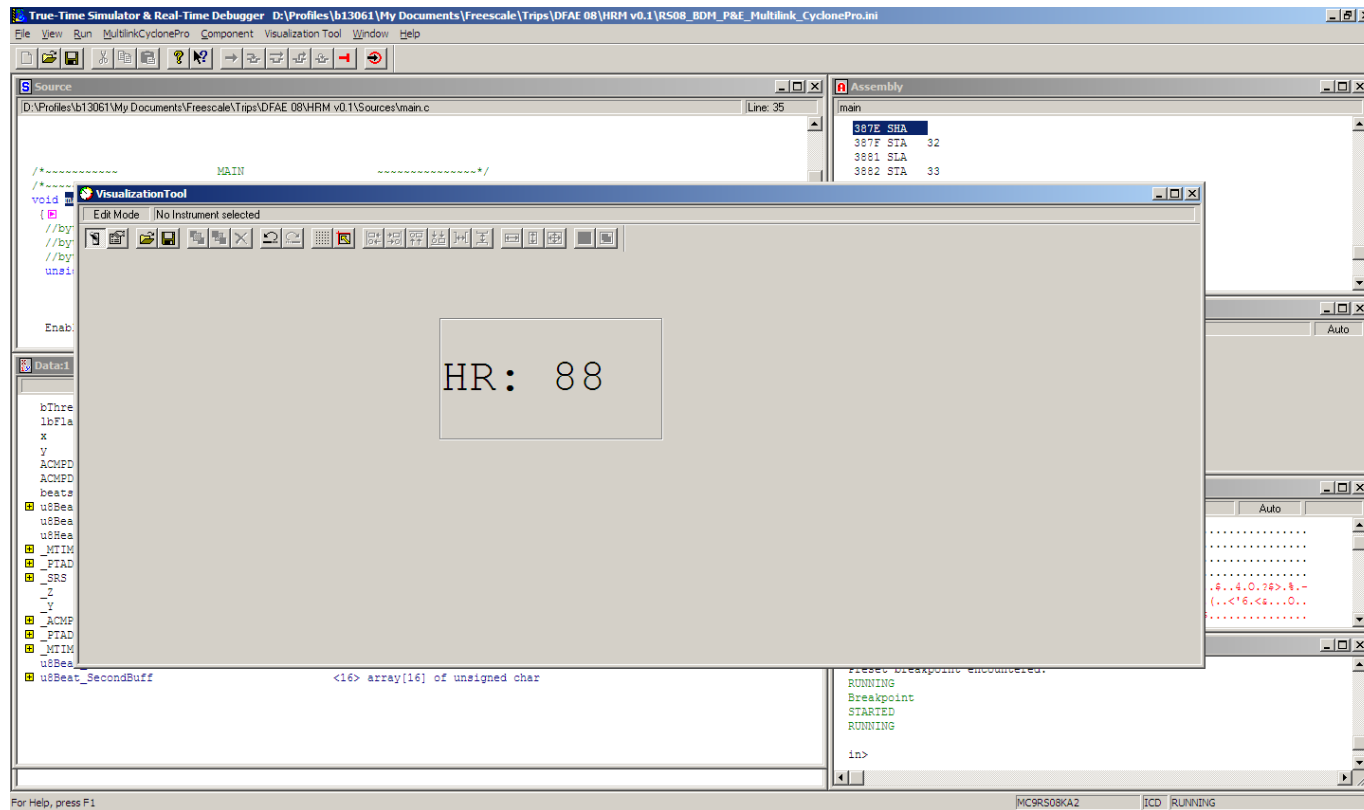
# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

## 7. Open the HRM.vtl file



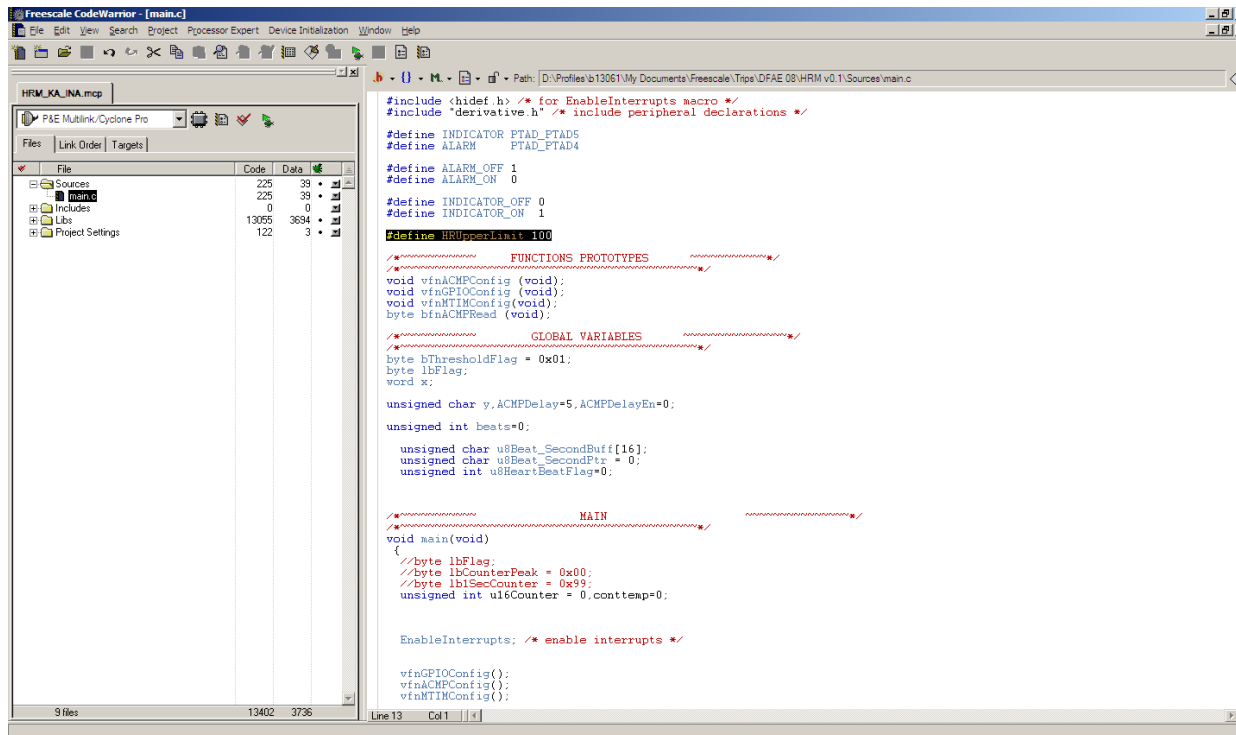
# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

## 8. Run the code



# Low-cost Heart Rate Monitor Lab0. Get familiar with the HRM

9. If you never reach the value of 100 to set the alarm, change the maximum value for the alarm in the code



```
Freescle CodeWarrior - [main.c]
File Edit View Search Project Processor Expert Device Initialization Window Help
Path: D:\Profiles\b13061\My Documents\Freescale\Trios_DFAE 08\HRM v0.1\Sources\main.c

HRM_KA_INA.mcp
P&E Multilink Cyclone Pro
Files Link Order Targets
File Code Data
Sources 225 39
main.c 225 39
Includes 0 0
Libs 13055 3694
Project Settings 122 3

#include <hidef.h> /* for EnableInterrupts macro */
#include "derivative.h" /* include peripheral declarations */

#define INDICATOR PTAD_PTAD5
#define ALARM PTAD_PTAD4

#define ALARM_OFF 1
#define ALARM_ON 0

#define INDICATOR_OFF 0
#define INDICATOR_ON 1

#define HRUpperLimit 100

//***** FUNCTIONS PROTOTYPES *****/
//***** GLOBAL VARIABLES *****/
byte bThresholdFlag = 0x01;
byte lbFlag;
word x;

unsigned char y, ACOMPDelay=5, ACOMPDelayEn=0;

unsigned int beats=0;

unsigned char u8Beat_SecondBuff[16];
unsigned char u8Beat_SecondPtr = 0;
unsigned int u8HeartBeatFlag=0;

//***** MAIN *****/
void main(void)
{
//byte lbFlag;
//byte lbCounterPeak = 0x00;
//byte lbSecCounter = 0x99;
unsigned int u16Counter = 0, conttemp=0;

EnableInterrupts; /* enable interrupts */

vfnGPIOConfig();
vfnACMPConfig();
vfnNTIMConfig();
```

# Low-cost Heart Rate Monitor

## Lab1. Your ECG Signal in the Computer

Open the JM60 GUI (the shortcut is on the desktop)



# Low-cost Heart Rate Monitor

## Lab1. Your ECG Signal in the Computer

**Freescale JM60 Data Acquisition V1.0 (AN3582)**

**freescalse™**  
semiconductor

**Buzzer**  
Frequency: 3500 Hz  
PWM %: 50  
Start Stop

**GPIO**  
PB1 PB2 PB3 PB4  
L1 L2 L3 L4 L5 L6 L7 L8

**Channels**  
Ch 0 Ch 4 Ch 8  
Ch 1 Ch 5 Ch 9  
Ch 2 Ch 6 Ch 10  
Ch 3 Ch 7 Ch 11  
Bangap Temperature

**Trigger**  
Mode: Software  
Delay  
Channel: 0  
Less than Level %  
Precision: 8 Bits  
Sample rate: 100 Hz  
Start ADC Stop ADC

**Scope Window**  
Y-axis: 255, 204, 153, 102, 51, 0  
X-axis: 0, 500, 1000  
Time / Div = 25 s  
Samples to capture: 1000  
Export to Excel File

**S08JM60 USB GPIO/ADC Demo**

# Low-cost Heart Rate Monitor

## Lab1. Your ECG Signal in the Computer

**Freescale JM60 Data Acquisition V1.0 (AN3582)**

**freescalse™ semiconductor**

**Buzzer**  
Frequency: 3500 Hz  
PWM %: 50  
Start Stop

**GPIO**  
PB1 PB2 PB3 PB4  
L1 L2 L3 L4 L5 L6 L7 L8

**Channels**  
Ch 0 Ch 4 Ch 8  
Ch 1 Ch 5 Ch 9  
Ch 2 Ch 6 Ch 10  
Ch 3 Ch 7 Ch 11  
Bangap Temperature

**Trigger**  
Mode: Software  
Delay  
Channel: 0  
Less than Level %  
Precision: 8 Bits  
Sample rate: 100 Hz  
Start ADC Stop ADC

**Scope Window**  
Y-axis: 255, 204, 153, 102, 51, 0  
X-axis: Time / Div = 25 s  
Samples to capture: 1000  
Export to Excel File

**S08JM60 USB GPIO/ADC Demo**

# Low-cost Heart Rate Monitor

## Lab1. Your ECG Signal in the Computer

**Freescale JM60 Data Acquisition V1.0 (AN3582)**

**freescale**  
semiconductor

**Buzzer**  
Frequency: 3500 Hz  
PWM %: 50  
Start Stop

**GPIO**  
PB1 PB2 PB3 PB4  
L1 L2 L3 L4 L5 L6 L7 L8

**Channels**  
Ch 0 Ch 4 Ch 8  
Ch 1 Ch 5 Ch 9  
Ch 2 Ch 6 Ch 10  
Ch 3 Ch 7 Ch 11  
Bangap Temperature

**Trigger**  
Mode: Software  
Delay  
Channel: 0  
Less than  
Level %  
Precision: 12 Bits  
Sample rate: 100 Hz  
Start ADC  
Stop ADC

**Scope Window**  
4095  
3276  
2457  
1638  
819  
0  
Time / Div = 250ms  
Samples to capture: 1000  
Export to Excel File

**S08JM60 USB GPIO/ADC Demo**

# Low-cost Heart Rate Monitor

## Lab1. Your ECG Signal in the Computer

The screenshot displays the Freescale JM60 Data Acquisition V1.0 (AN3582) software interface. The interface is divided into several sections:

- Channels:** A grid of checkboxes for selecting channels (Ch 0 to Ch 11) and sensors (Bangap, Temperature). Ch 0 is selected.
- Trigger:** Settings for Mode (Software), Delay, Channel (0), and Level % (Less than).
- Precision and Sample rate:** Precision is set to 12 Bits and Sample rate is set to 100 Hz. Start and Stop ADC buttons are present.
- Buzzer:** Frequency is set to 3500 Hz and PWM % is set to 50. Start and Step buttons are present.
- GPIO:** A control panel for PB1-PB4 and L1-L8 pins, with L1-L8 LEDs shown as lit.
- Scope Window:** A graph showing an ECG signal. The y-axis ranges from 0 to 4095, and the x-axis is Time / Div = 250ms. The signal shows regular heartbeats. The Scope Window also includes a 'Samples to capture' field set to 10000 and an 'Export to Excel File' button.

At the bottom of the interface, the text 'S08JM60 USB GPIO/ADC Demo' is displayed, along with the Freescale logo and a USB icon.

# Freescale Introduces Product Longevity Program

- ▶ The embedded market needs long-term product support, which allows OEMs to provide assurance to their customers.
- ▶ Freescale has a longstanding track record of providing long-term production support for our products.
- ▶ Freescale is pleased to introduce a formal product longevity program for the market segments we serve.
  - For the automotive and **medical** segments, Freescale will manufacture select devices for a minimum period of 15 years.
  - For all other market segments in which Freescale participates, Freescale will manufacture select devices for a minimum period of 10 years.
- ▶ A list of applicable Freescale products is available at [www.freescale.com](http://www.freescale.com).

- ▶ Thank you for attending this presentation. We'll now take a few moments for the audience's questions and then we'll begin the question and answer session.

