Medical Applications
User Guide

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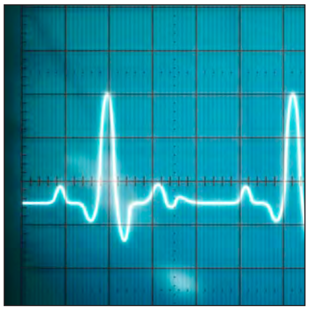
Introduction

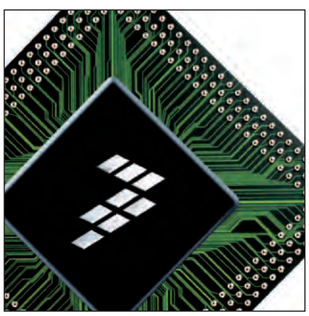


1.1

Freescale Offers Technology for Life

According to a recent study by the U.S. Centers for Disease Control (CDC), modern medical breakthroughs have raised the average global life expectancy in developed nations to over 75 years[1]. As public health has advanced and new pharmaceutical drugs have been developed, the prospect of prevalent pathologies has also changed. Where once viral and bacterial infections were the leading concerns of clinicians, today chronic and degenerative diseases are the most worrisome. The World Health Organization predicts that by 2030 the two leading causes of death will be heart disease and cancer by a wide margin[2].

Freescale believes that semiconductor technology will play a critical role in the development of new technologies that assist with patient monitoring, diagnostics, therapy and imaging. Freescale is focused on what we can do as a semiconductor company to help provide people a more healthy and active life. By designing products with the highest safety and reliability standards, medical devices running with Freescale components work when it counts. Electronic components behind future medical devices are not seen by everyone, but we recognize that they work to benefit people who are in contact with this technology. This is what is meant when we say, "Freescale offers technology for life."



1.2

Welcome to Freescale Medical Solutions

Freescale has focused on solving some of the world's most important technology challenges for over 50 years. Whether the question has been how cell phones can connect people across the world or how to harmonize all of the safety features in a car, Freescale microcontrollers have been part of the solution. At Freescale we bring that same drive and innovation to the medical industry.

The convergence of an aging population and breakthrough technological advances has created endless opportunities for automated medical devices. These devices help ensure the future health of millions of people by providing advances in home health care, clinical activities and medical imaging. Regardless of the end use, developers of medical devices face similar problems. The need to balance processing requirements with power consumption helps to ensure a fast time to market. Navigating the regulatory environment is common with all medical applications.

At Freescale we offer a wide range of products so that developers can choose processors, analog and sensor components or RF amplifiers to meet the unique needs of their designs. Developers of medical technology face many challenges today. Freescale believes that having the right silicon should not be one of them.

1) CDC, U.S National Center for Health Statistics
2) World Health Organization www.who.int/research/en/

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Home Portable Medical

2.1

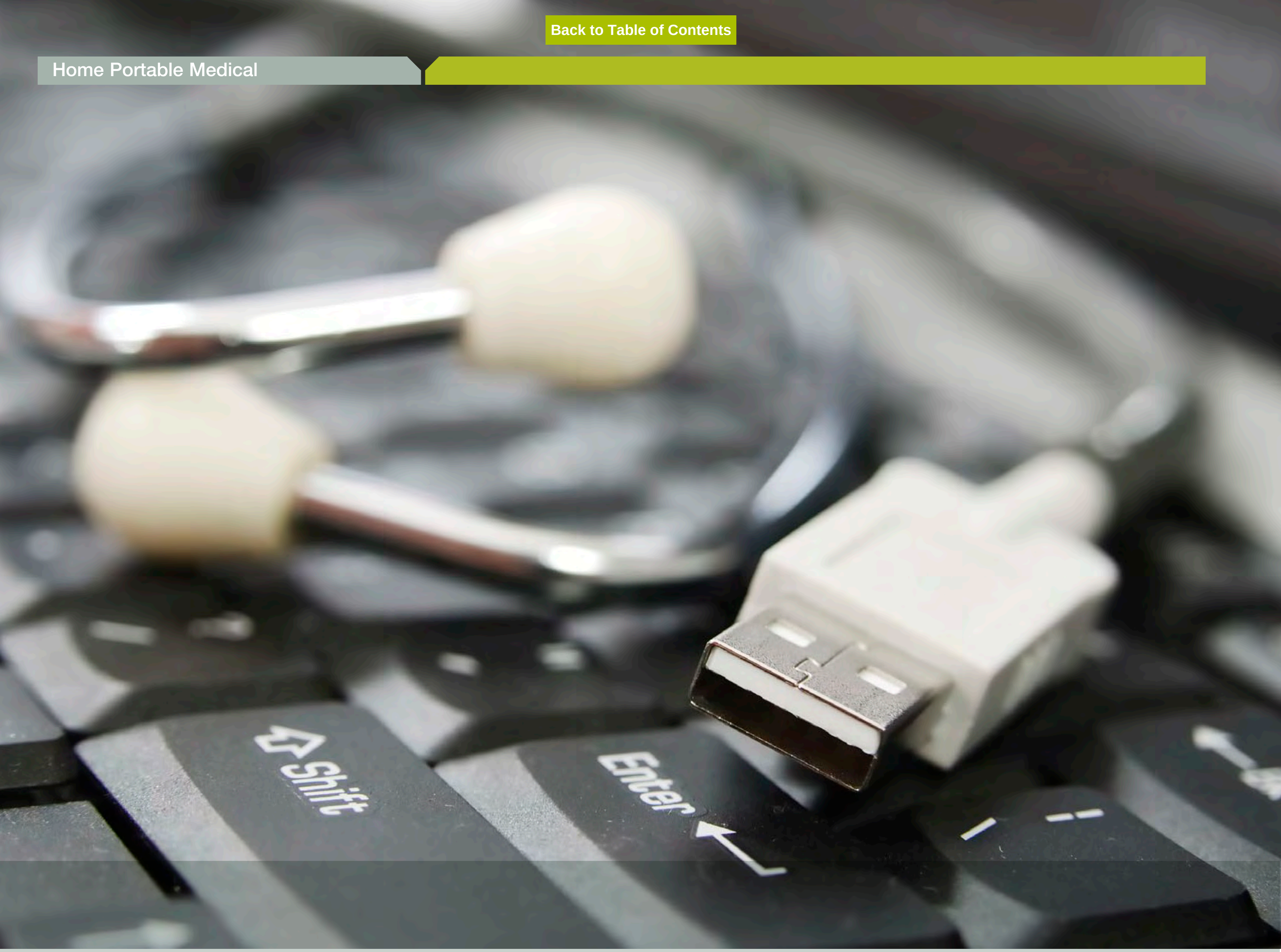
Market and Devices

The home portable medical market is one of the fastest growing markets in the medical device industry[3]. The consumer population is more health-conscious than ever before. This is reflected in devices that are now common in the home, like portable heart rate monitors, digital thermometers, electronic blood glucose meters and weight scales that also measure body fat[4]. As clinicians look for new ways to monitor patients in their natural environment, new telehealth devices are being invented[5].

These home portable medical devices share the common need for long battery life, robust data processing and a wired or wireless communication interface. Freescale microcontrollers also offer an ideal combination of high processing capabilities and low power consumption. As a pioneer in the communications market, Freescale offers solutions for wired and wireless interfaces, including USB, IEEE® 802.15.4 and ZigBee® technology. Furthermore, Freescale microelectromechanical system (MEMS)-based pressure and inertial sensors can be used to acquire physical parameters. User interfaces include touch screens, enabled by proximity sensors, that have easy-to-clean buttons and screens that can be sanitized quickly and easily.

Freescale also offers a focused integrated analog portfolio that enables maximum battery life with power management ICs that allow a precise and accurate conversion of natural continuous signals to digital signals that microcontrollers can process. Medical device customers can engage with Freescale custom product groups for specific solutions that leverage our core competencies in precision analog, mixed signal and power management technologies.

3) Databeans and Semicast 2008.
4) www.who.int/medical_devices/en/
5) World Health Organization, www.who.int/goe/ehir/trends/en/



Telehealth Systems

3.1 Introduction

One of the trends in the home medical market is the need to monitor patients away from a hospital or doctor's office[6]. Companies are now developing solutions that monitor a patient's vital signs at home and relay this information to the health care provider.

Physicians or home health care companies give patients a telemonitoring hub device to use at home. This telemonitoring hub connects home portable devices used to measure vital signs such as blood pressure, heart rate, body temperature and other measurements depending on their needs. This information is then sent to the hub via USB, Bluetooth® wireless technology or ZigBee technology. The hub then relays the patient's vital sign information to his or her physician at periodic intervals (usually once a day) via Ethernet, Wi-Fi®, phone line or cellular network.

As telemonitoring is in its infancy, there continue to be new approaches to address this medical application. Although solutions vary widely, most of them share similar features and the end result is the same. Data from the patient is monitored and transferred to the health care provider.

For more information, see the Telemonitoring Solutions article in the Health and Safety edition of Freescale's *Beyond Bits* design magazine.

Form factors for a telehealth system may vary from a simple patient monitoring system to a high-end robotic telehealth surgical assistant. The parts of a basic telehealth system are shown in Figure 3-1.

6) www.who.int/medical_devices/en/

3.1.1

Power Management

Every design needs a power source. If the power source is not stable, the system may fail while processing information. If the power source is not regulated, the system may get damaged. These failures might cause risks to the patient. Therefore, the design and implementation of a stable and regulated power management system must be carefully considered to mitigate these risks. Freescale's MC34712, MC34713, MC34716 and MC34717 are highly integrated, space-efficient, cost-effective dual and single synchronous buck switching regulators for multiple applications. A typical application for these devices is shown in Figure 3-2.

Key Features

- Integrated N-channel power MOSFETs input voltage operating range from 3.0V to 6.0V
- 1% accurate output voltage, ranging from 0.7V to 3.6V
- Voltage tracking capability in different configurations
- Programmable switching frequency range from 200 kHz to 1.0 MHz with a default of 1.0 MHz
- Programmable soft start timing
- Over current limit and short circuit protection
- Thermal shutdown
- Output overvoltage and undervoltage detection
- Active low power, good output signal
- Active low shutdown input

The use of these regulators allows the use of multiple power sources such as batteries, chargers or AC adapters.

Figure 3-1: Telehealth Gateway

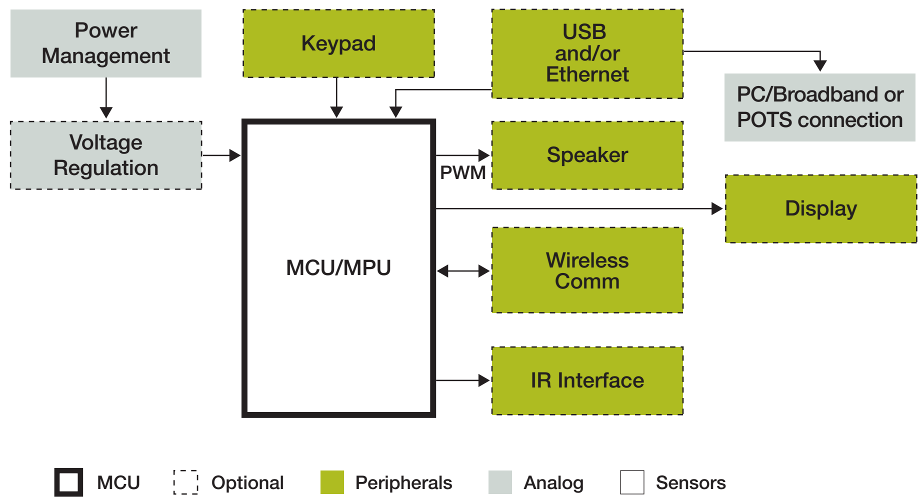
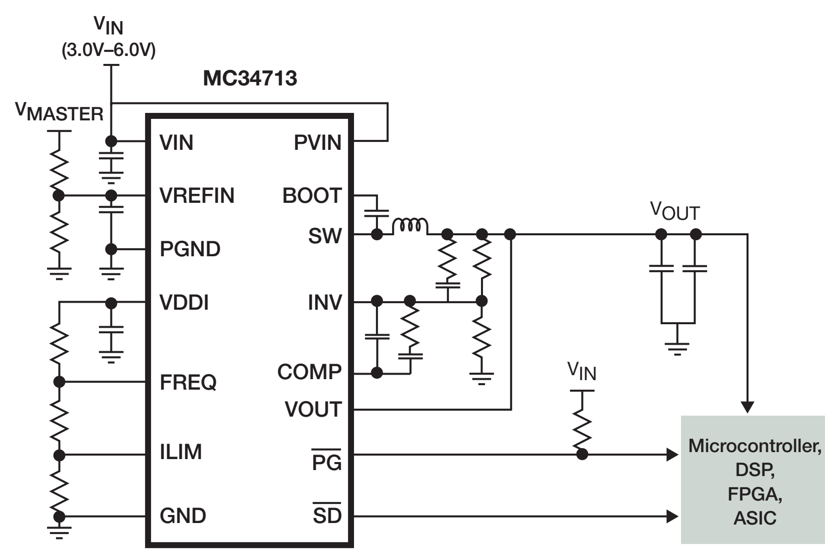


Figure 3-2: MC34713 Simplified Application Diagram



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3.1.2
Voltage Regulation

In systems where an MCU or DSP are used, the power source must be able to provide the complete range of voltage values to be applied to multiple VCC pins.

This regulation can be implemented using the Freescale MPC18730 power management device. This device regulates five independent output voltages from either a single Li-Ion cell (2.7V to 4.2V input range), a single-cell Ni-MH or dry cell (0.9V to 2.2V input range).

MPC18730

The MPC18730 is a 1.15 V/2.4 V 2-ch. DC-to-DC converter with three low-dropout regulators. Key features include:

- Operates from single-cell Li-ion, Ni-MH or alkaline battery
- Two DC-DC converters
- Three low-dropout regulators
- Serial interface sets output voltages
- Four wake inputs
- Low current standby mode

Regulation can also be implemented using the Freescale MC34704, a multi-channel power management IC (PMIC) used to address power management needs for various multimedia application microprocessors such as Freescale's ARM® core-based i.MX processor family. Its ability to provide either five or eight independent output voltages with a single input power supply (2.7V and 5.5V), together with its high efficiency, makes it ideal for portable devices powered by Li-ion and polymer batteries or for USB powered devices.

MC34704

The MC34704 is a multi-channel PMIC. Key features include:

- Eight DC/DC (34704A) or five DC/DC (34704B) switching regulators with up to ±2% output voltage accuracy
- Dynamic voltage scaling on all regulators
- Selectable voltage mode control or current mode control on REG8
- I²C programmability
- Output under-voltage and over-voltage detection for each regulator

Figure 3-3: Block Diagram Using Power Regulators

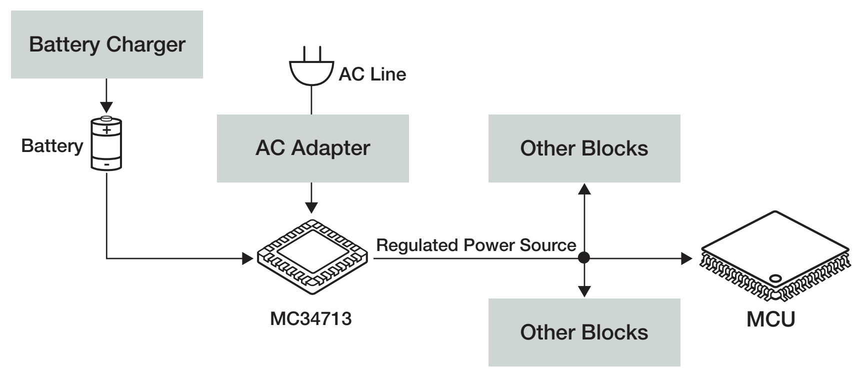


Figure 3-4: Lineal Voltage Regulator

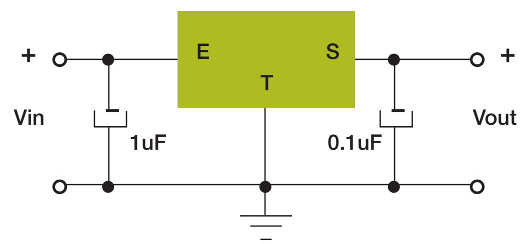
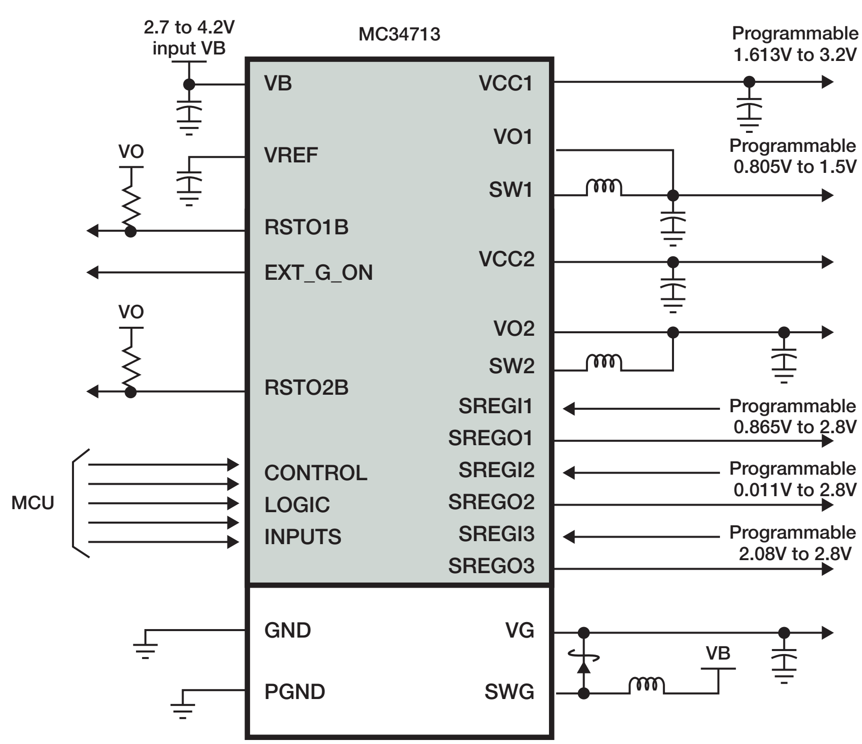


Figure 3-5: Single Synchronous Buck Switching Regulator



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- Over-current limit detection and short-circuit protection for each regulator
- Thermal limit detection for each regulator (except REG7)
- Integrated compensation for REG1, REG3, REG6 and REG8
- 5 µA maximum shutdown current (all regulators are off, 5.5V VIN)
- True cutoff on all boost and buck-boost regulators

3.1.3
Keypad

A keypad can be implemented using touch sensing. This technology has advantages over classic button-based technology, including:

- Cost effectiveness
- Smaller design
- More durability because there is virtually no mechanical wear
- Easy to keep clean

Freescale provides software libraries that implement touch-sensing algorithms using a microcontroller's general-purpose pins. The software allows the microcontroller to drive up to 64 touch pads. It needs only one pull-up resistor per electrode and timer to complete the circuit.

Freescale's MPR031, MPR032, MPR083 and MPR084 can also provide a cost-effective solution in a single-chip capacitive touch sensing controller. These devices can be connected to an MCU through an I²C interface.

Figure 3-6: MC34704 Block Diagram

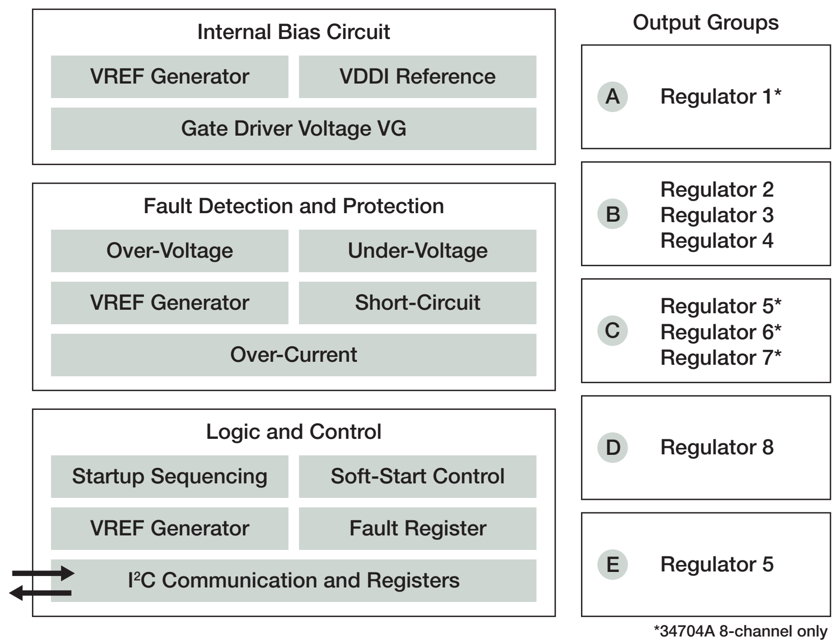
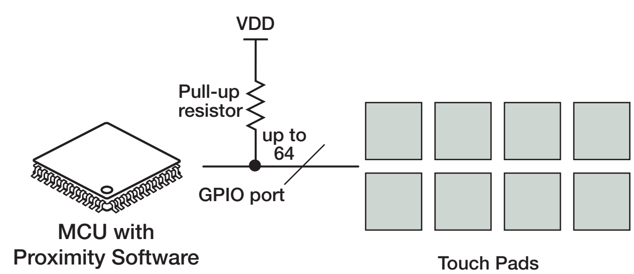


Figure 3-7: Keypad Implementation Using Proximity Software



MPR084

The MPR084 is an eight-pad touch sensor controller. Key features include:

- Current touch pad position is available on demand for polling-based systems
- Rejects unwanted multi-key detections from EMI events such as PA bursts or user handling
- Ongoing pad analysis and detection is not reset by EMI events
- System can set interrupt behavior immediately after event, or program a minimum time between successive interrupts
- Sounder output can be enabled to generate a key-click sound when the rotary is touched
- Two hardware-selectable I²C addresses allow two devices on a single I²C bus

MPR083

The MPR083 is a capacitive touch sensor controller, optimized to manage an 8-position rotary shaped capacitive array. Key features include:

- Variable low power mode response time (32 ms–4s)
- Rejects unwanted multi-key detections from EMI events such as PA bursts or user handling
- Ongoing pad analysis and detection is not reset by EMI events
- Data is buffered in a FIFO for shortest access time
- IRQ output advises when FIFO has data
- System can set interrupt behavior as immediate after event, or program a minimum time between successive interrupts
- Current rotary position is always available on demand for polling-based systems
- Sounder output can be enabled to generate key-click sound when the rotary is touched
- Two hardware-selectable I²C addresses allowing two devices on a single I²C bus

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3.1.4
Touch-Sensing Software Suite

The Touch-Sensing Software Suite (TSS) is a downloadable software package that enables a Freescale 8-bit MCU as a touch sensor. This provides cost-effective and flexible solutions for human-machine interfaces. TSS is a modular and layered software that enhances forward compatibility and simplifies touch key configurations. It also enables the integration of connectivity, LCD, LED, audio and other peripherals.

Key features of the software include:

- Intellectual property (IP) ownership in hardware layouts and software implementations such as capacitance conversion, key detection and decoding algorithms
- Modular software design to add new algorithms
- Easy to use with the simple and robust API set, including algorithms, patents and system implementations that protect customer applications from noisy/not ideal environments
- Capability to coexist with customer application code
- Available application layer software, decoders (rotary, slider, keypads), demonstrations and reference designs to expedite customer time to market
- Possible to use different materials such as electrodes, PCB, Flex PCB, membranes, glasses and foams

Figure 3-8: Keypad Implementation Using Capacitive Touch Sensing Controllers

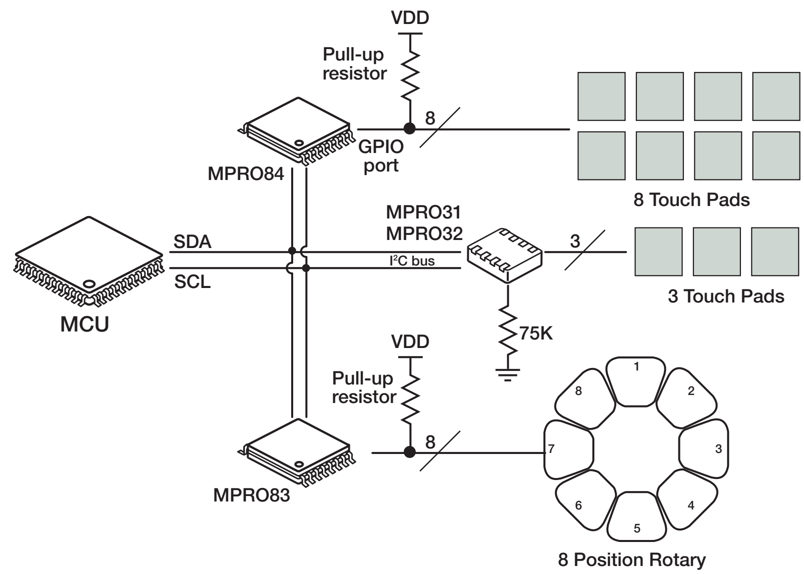
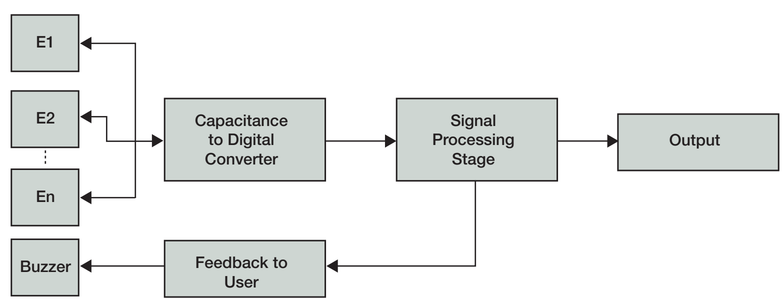


Figure 3-9: Components of a Touch Sensing System



3.1.5
How it Works

The external capacitance is charged and discharged continuously. This depends on the sample configuration. At the time the capacitance is being charged the timer is running and counting. When the electrode voltage reaches 0.7 VDD, the timer stops and the counter value is taken. The external capacitance is modified at the touch event, modifying the time charge. When the electrode is touched, the capacitance increases. Therefore the count is higher. The number of samples taken is user-configurable and determines how many times the capacitance is charged and discharged when the scanning starts.

A touch sensing system has the following components:

- Electrodes: Physical area that the user uses as the interface. Usually made of PCB or indium tin oxide (ITO)
- Capacitance to digital converter: Measures capacitance on each electrode and produces a digital value as output
- Signal processing stage: This stage translates measured capacitance to touch status and then to a logic behavior (rotary, keypad, slider and so on)
- Output: Indicates touch detection both to the user and the application

3.1.6
Freescale Proximity Technology Summary

- Extra hardware (except for pull-up resistors) is not necessary with Freescale TSS. The host's TSS code is required to process and perform more. Each touch pad must be connected to one GPIO on the MCU.
- This is a two-chip solution. Because of the I²C interface, capacitive touch sensing controllers allow the number of electrodes to be expanded by using two pins of the MCU.

- MPR083 and MPR084 can drive up to eight electrodes each. Each electrode needs a pull-up resistor.
- MPR031 and MPR032 are ultra-small touch sensing controllers that support up to three electrodes. They need one external component and do not need pull-up resistors in the electrodes.

Information about touch-sensing technology and the application note titled *3-Phase AC Motor Control with V/Hz Speed Closed Loop Using the 56F800/E* (document AN1958), which provides information about touch panel applications, can be found at freescale.com.

3.1.7
PWM Function for a Speaker Circuit

Pulse width modulation (PWM) can be implemented using a simple timer (in output compare mode) typically integrated in one of Freescale's 8-bit MCUs. The pulse width variations determine the volume of the sound (energy average per cycle). The timer has a register for the output compare function to vary the pulse width, and therefore the volume.

To vary the tone of the sound, the signal period must be changed. To change the period, the timer has a register that determines the number of counts until the timer overflows.

Figure 3-11 shows on the left side, the signal changing the pulse width but with a determined period. On the right side, the signal period is halved, but the percentage of the pulse is the same as the signals on the left side. This is the principle that can be used to vary the tone and volume of the sound.

Figure 3-12 shows a basic implementation of the circuit to generate an audio signal. The value of R_B is determined by the transistor used to amplify the signal generated by the MCU, and by the voltage level of the MCU output.

Figure 3-10: Timer Operation to Generate PWM Signal

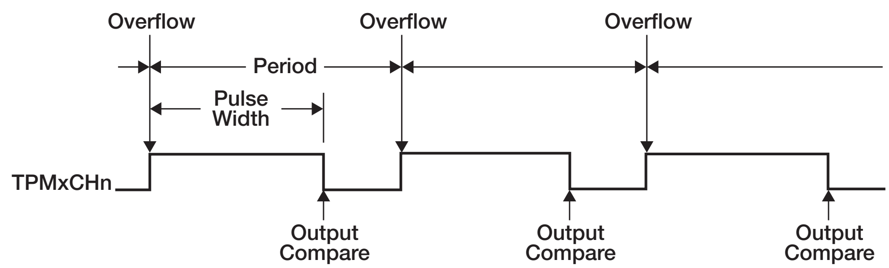


Figure 3-11: Variations in Period and Pulse Width

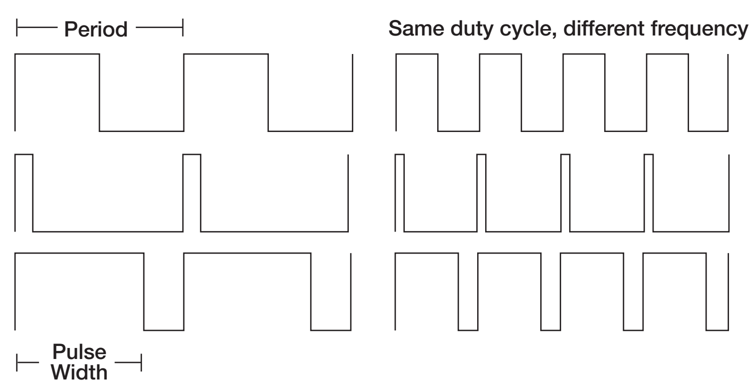
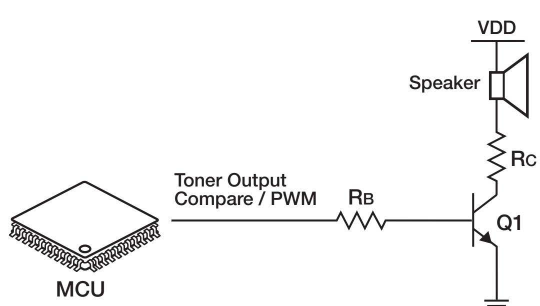


Figure 3-12: Implementation Example



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3.1.8

Wireless Communication

Offering a broad portfolio of RF products, Freescale primarily serves the wireless infrastructure, wireless subscriber, general purpose amplifier, broadcast and industrial markets. Freescale pioneered RF technology and continues to be a leader in the field by providing the quality, reliability and consistency that is associated with our RF products.

3.1.8.1

Introduction to ZigBee Technology

The ZigBee Alliance defines low-power wireless communication protocol stacks and profiles designed for monitoring and control of devices in a variety of markets and applications. These include consumer, smart energy, control and automation and medical markets. There are two different specifications (ZigBee and ZigBee Consumer) as well as multiple profiles that focus on specific markets. Freescale provides the necessary building blocks used for both ZigBee and ZigBee Consumer solutions, including hardware, software, tools and reference designs.

3.1.8.2

Freescale Solutions with ZigBee Technology

The ZigBee protocol stack is designed for monitoring and control applications such as building automation and smart energy. It features self-forming and self-healing mesh networks that help differentiate it from other technologies.

3.1.8.3

Configuration Diagrams for Freescale ZigBee Transceiver Families

Figure 3-13: MC1319x Family Block Diagram

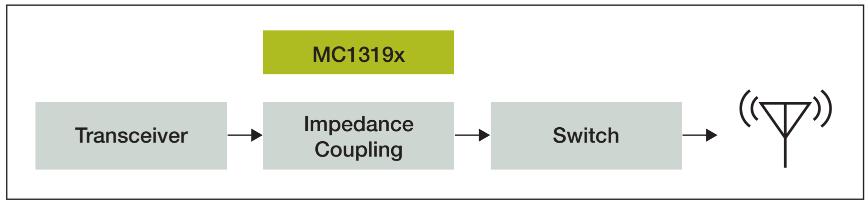


Figure 3-14: MC1320x Family Block Diagram

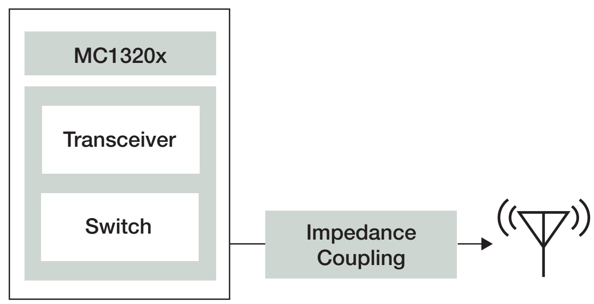


Figure 3-15: MC1321x Family Block Diagram

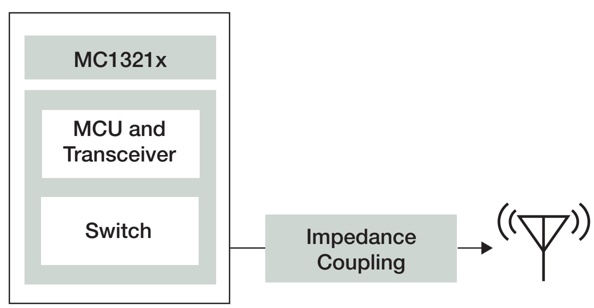
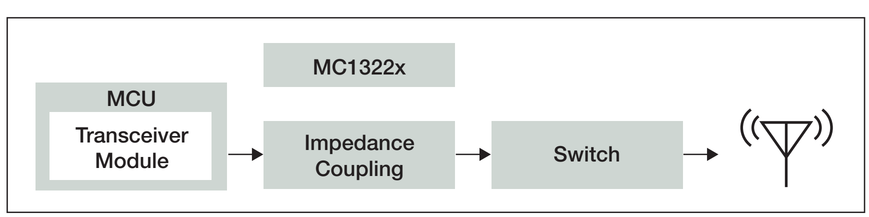


Figure 3-16: MC1322x Family Block Diagram



3.1.8.3

ZigBee Health Care Profile and IEEE 802.15.4

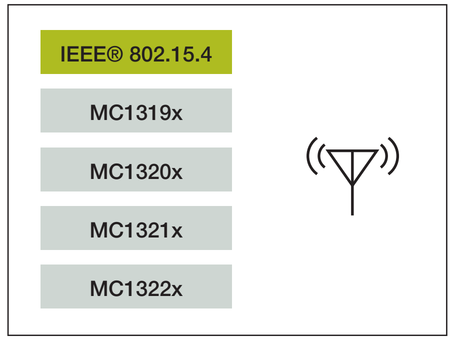
For medical care providers, access to timely and accurate information improves the ability to provide the highest quality of patient care. Decision support is not limited to just the bedside. The quality of care often depends on the ability to share vital patient data with clinicians in real time outside the care facility. This means clinicians can provide immediate feedback to attending physicians based on real-life clinical research as well as track treatment paths, and give results beyond the walls of the hospital over the patient's lifetime to improve future treatment methodologies.

ZigBee technology is rapidly proving to be useful in these applications. It can help provide greater freedom of movement for the patient without compromising automated monitoring functions. ZigBee technology can be deployed in a number of products that can help ensure better patient care and more effective care tracking by providing cost-effective, low-power wireless technology that can cover large buildings and institutions with mesh networking.

Freescale has received ZigBee® Certified product status for its ZigBee Health Care wireless health and wellness processing platforms. The ZigBee Certified products status is awarded to products that have been tested and met criteria for interoperability that enable wireless devices to securely and reliably monitor and manage noncritical, low-acuity health care services.

The Freescale processing platforms awarded the certification include the MC13202FC transceiver in combination with the MC9S08QE128 MCU, and the MC13224V integrated transceiver with a 32-bit ARM7™ MCU. These products are optimized for sensing and monitoring applications requiring low power for battery-operated or battery-backed systems.

Figure 3-17: ZigBee Transceiver Options



3.1.8.4

Why ZigBee Is Ideal for Wireless Vital Sign Monitoring

A ZigBee network for long-term care consists of a patient monitoring system and the network infrastructure to communicate with a central location or caregiver station as well as other mobile devices. Wireless monitoring provides feedback through a gateway to a central server where data is maintained. This data can be accessed by doctors, nurses and other health care professionals between caregiver visits, alerting them to changing conditions that need attention. Wireless monitoring also allows institutions to track care for accountability and insurance requirements.

3.1.8.5

Freescale Enables ZigBee Health Care Profile for Medical Devices

Freescale solutions with ZigBee technology provide the perfect combination of cost effectiveness, low power, high integration and high performance required for medical monitoring applications.

These solutions include not only silicon but also software, development tools and reference designs to help simplify development. Freescale's BeeStack ZigBee-compliant stack with BeeKit Wireless Toolkit provides a simple software environment to configure network parameters. This tool allows customers to use a wizard and drop-down menus to help configure the ZigBee network parameters.

Freescale provides an article, *ZigBee Technology for Long-Term Care Improving the Quality of Life,* in the magazine *Beyond Bits IV*.

To learn more about ZigBee technology, visit freescale.com/ZigBee.

For information on wireless communication, power management, keypad and speaker implementation modules, see the Introduction to this chapter.

3.1.8.6

Transceivers and Receivers

MC13191

The MC13191 is a 2.4 GHz low-power transceiver. Key features include:

- 16 channels
- 0 dBm (typical), up to 3.6 dBm maximum output power
- Buffered transmit and receive data packets for simplified use with cost-effective microcontrollers
- Supports 250 kbps O-QPSK data in 2.0 MHz channels and full spread-spectrum encode
- Link quality and energy detect functions
- Three power-down modes for power conservation (Hibernate, Doze, Tx and Rx)
- Rx sensitivity of –91 dBm (typical) at 1.0% packet error rate

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3.1.9

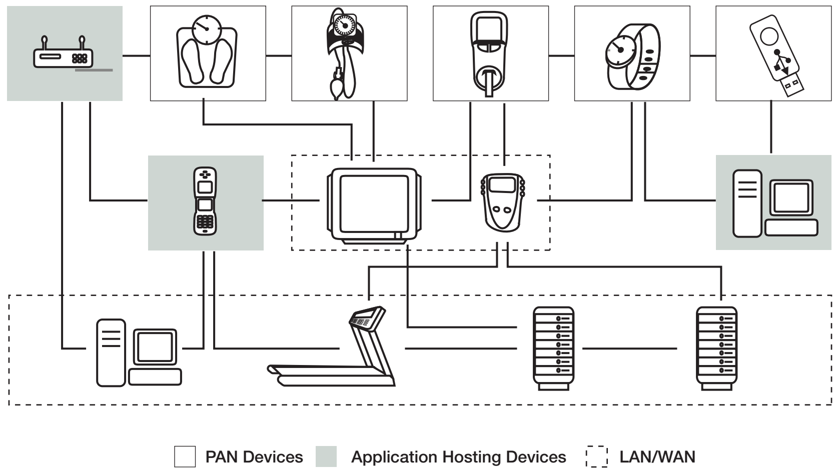
Freescale Continua Health Alliance® Certified USB Library Software

One of the most considerable challenges for medical designers is medical standard compliances. The Continua Health Alliance® (www.continuaalliance.org) consists of more than 200 members that have come together to form work groups to set standards for medical systems.

Having multi-vendor medical devices communicating among themselves is not an easy task. Every day, protocols such as USB are being implemented in medical devices. Continua provides guidelines to address standardization in connectivity.

Figure 3-18 describes a medical device system topology.

Figure 3-18: Continua Ecosystem Topology



Freescale provides complimentary stacks that enable the user with ready-to-use software to begin their path to standardization. Continua Health Alliance is responsible for certifying devices for compliance.

3.1.10

Standard Medical USB Communication

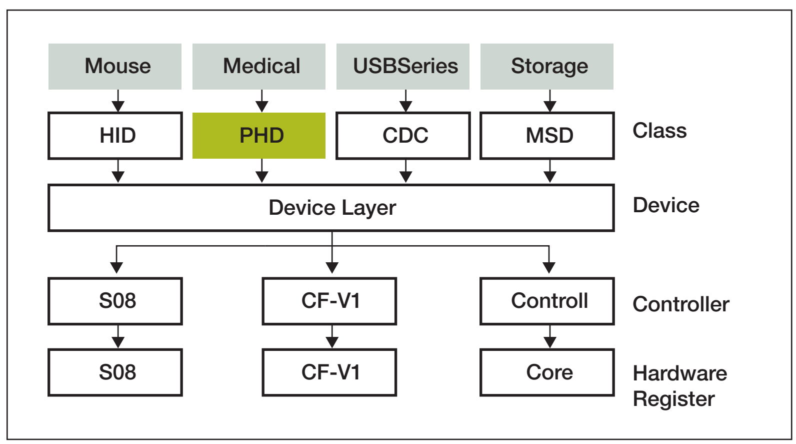
For USB communication, two main standards must be considered:

- IEEE 11073, which provides structure to the communication interface
- Personal health care device class (PHDC), which is a standard implementation of USB for medical devices

The advantage of designing medical applications with a dedicated medical stack instead of a conventional USB stack is that a medical USB stack is designed specifically for medical USB devices. It eases medical application data exchange because it has a specific device specialization layer. Designing medical applications under a conventional USB stack may not provide the added value of medical organizations' certifications.

Three main factors need to be considered when selecting a particular USB connectivity software implementation for medical devices.

Figure 3-19: Medical Applications USB Stack



1. Standardization: The solution is based on well-known standards in the industry. This helps to ensure success and proper introduction of the product to the market.
2. Connectivity: The implementation allows connecting multiple devices from different vendors within an ecosystem topology. A connectivity-friendly environment is sustained by a robust and easy-to-use software stack.
3. Portability: Multi-device independent layered architecture eases porting of code among devices. Selecting a hardware vendor with a broad portfolio is key to ensure customization and product roadmap establishment.

Software architecture ensures code robustness, portability and reliability in embedded systems development.

The medical applications USB stack provides the user with a PHDC implementation that is divided into layers for portability and simplicity. The stack can also be used as a general-purpose USB stack. The stack has been ported to 8-bit 9S08 and 32-bit ColdFire devices. The stack can be downloaded at freescale.com.

The USB protocol can be further broken into PHDC and low-level driver layers. The low-level driver abstracts USB IP to provide a generic interface to the class driver.

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The PHDC is a function-specific class layer. Its responsibility is to hide transport-specific details from the data exchange protocol layer.

Freescale additionally provides a Medical Connectivity Library that provides users with standard IEEE11073 connectivity. This library is transport-independent because of its transport independent layer (TIL). Therefore, protocols that may be used include serial, Bluetooth, USB and ZigBee. The library can be downloaded at freescale.com.

USB devices compliant with industry standards such as IEEE-11073 will be developed under organizations such as Continua Health Alliance for future use. A sample application featuring a weight scale device has been created to demonstrate the value of working under the standardization scheme and allowing multi-vendor device interoperability. The demo videos are available at freescale.com.

In the weight scale example, the personal health care application interacts with the host computer using IEEE 11073 – 20601 and IEEE-11073 – 10415 (weight scale) protocols. It is important to note that the host computer runs the same IEEE 11073 protocols. One specific example of such implementation is covered by Continua Alliance. Member companies of the Continua Alliance can obtain CESL reference software. After installing this software the host is emulated and ready to connect to the weight scale device.

Freescale has developed sample code to connect with the Continua Alliance emulator. After flashing an 8-bit 9S08JM device with this software, the device is recognized as a Continua USB interface. The supplied drivers allow the device to be recognized as a USB personal health care device. The Continua manager is then launched and transport communication starts. The weight measurements are sent from the 9S08JM device to the host. Other personal health care applications can also interact with the host system developed by Continua. These include IEEE 11073 – 10407 (blood pressure monitor IEEE 11073 – 10417 (glucose meter) and IEEE 11073 – 10408 (thermometer) protocols.

Table 3-1. Freescale MCU Families that Support the USB Personal Health Care Device

SOC	Use Case
S08	
MC9S08JM16	Low-end PAN device
MC9S08JM60	PAN device
MC9S08JS16	Low-end PAN device
CFv1	
MCF51JM128	PAN device
	Hybrid device
	Application hosting device
CFv2	
MCF5225x	PAN device
	Hybrid device
	Application hosting device

Figure 3-20: Broadband Block Diagram

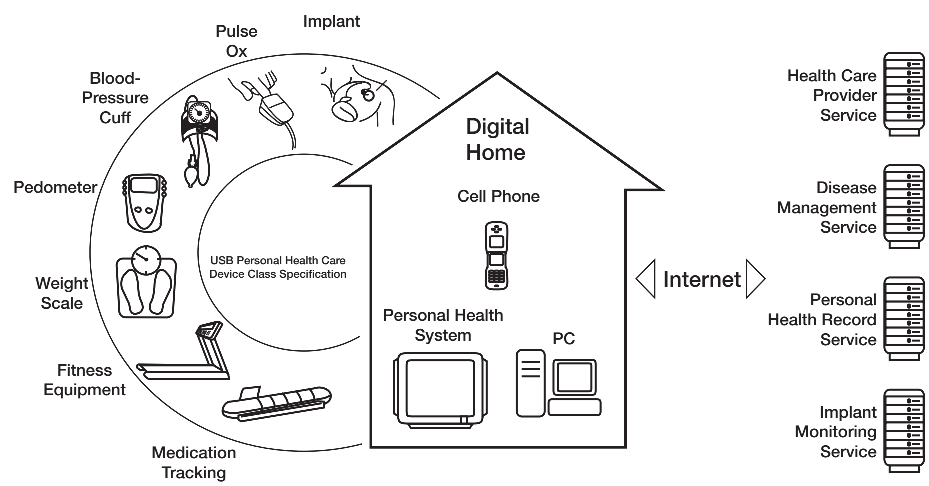
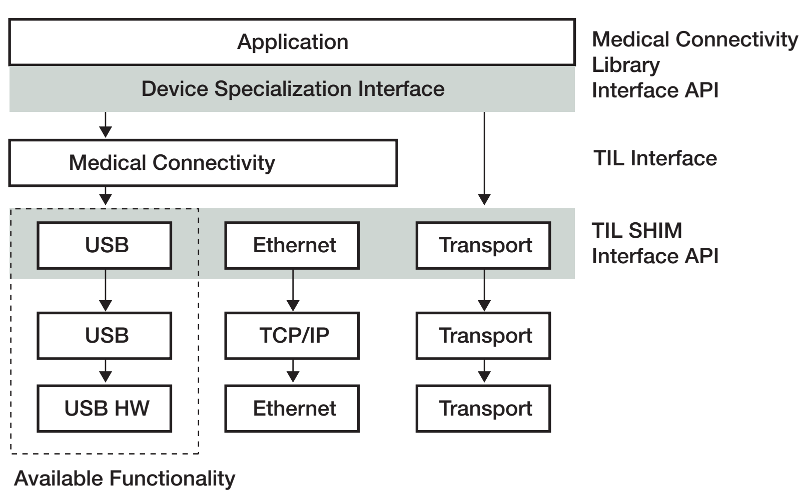


Figure 3-21: Medical Connectivity Library (IEEE 11073)



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MPC8313E: PowerQUICC II Pro Processor

The MPC8313E is a cost-effective, low-power, highly integrated processor. The MPC8313E extends the PowerQUICC family, adding higher CPU performance, additional functionality, and faster interfaces while addressing the requirements related to time to marked, price, power consumption and package size.

S08JS: 8-bit Microcontroller Family

The S08JS 8-bit microcontroller family features a full-speed 2.0 USB device controller and integrates a USB transceiver to help save cost by eliminating off-chip components.

Key features of this microcontroller family include:

- 48 MHz HCS08 core
- Integrated full-speed USB 2.0 device controller
- 16/8 KB flash, 512B SRAM, 256B USB RAM 2.7V to 5.5V operation, -40°C to +85°C operation
- ROM-based USB bootloader
- SCI, SPI, 8-channel KBI
- 16-bit timers: 1 x 2-channel
- MTIM: 8-bit timer
- One hardware CRC module
- 12 general-purpose I/O and two output-only pins
- Multiple purpose clock generation
- 24QFN, 20SOIC package options

3.1.11

Additional Freescale Technologies

This table describes additional Freescale devices that can be used for telehealth applications. Visit freescale.com to read the application notes or for more information about any of these devices.

Table 3-2. MPC8313E Processor Highlights

	MPC8313	MPC8313E
Core	e300, 2-IU, w/FPU, up to 400 Hz	
L1 I/D cache	16 KI/16 KD	
Memory controller	16/32-bit DDR2-333	
Local bus controller	25-bit/8-bit dedicted or 25-bit/16-bit MUX Add/Data up to 66 MHz	
PCI	One 32-bit up to 66 MHz wake on PME	
Ethernet	Two 10/100/1000 MACs, SGMII. 98145.452	
98145.452	One High-Speed USB 2.0 host/device+HS PHY, wake on USB	
Security	None	SEC 2.2
UART	Dual	
I²C	Dual	
SPI	1	
Boot options	NOR, NAND	
Internal controller	PIC	
MUX/dedicated GPIO	10/16	
DMA	4 channels	
Estimated core power	1.2W	
Power management	Standby power <300 mW	

Figure 3-22: MPC8313E Block Diagram

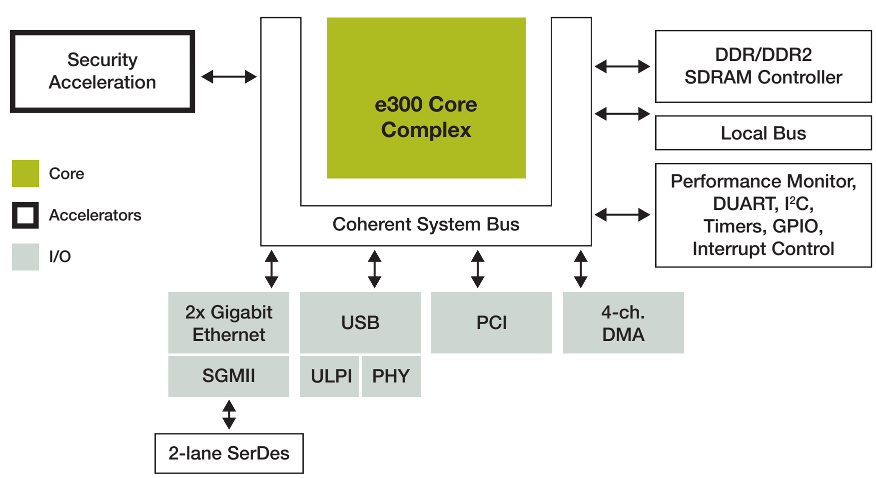

Figure 3-23: JS 16/8 Block Diagram

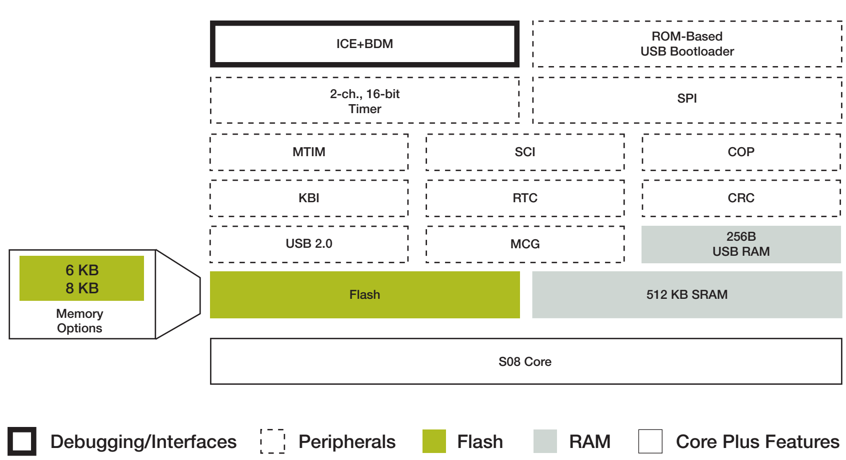

Table 3-3. Additional Freescale Technologies for Telehealth Systems

Device	Description	Key features	Applications	Application Notes
MPC5121e	32-bit embedded processors	e300 core 400 MHz 760 MIPS DDR USB 2.0 OTG	• Telehealth • Hospital Admission Machine • Powered Patient Bed	AN3765: Porting Linux for the MPC5121e AN2606: Working with Low-Frequency Oscillators AN3763: Running a FIR Filter AN3793: 3-D Graphics on the Using OpenGL ES AN3805: MPC5121e SDHC Controller AN3797: Integrated Programmable Interrupt Controller
MCF5445X	32-bit microprocessor	MACs I^2S bus DMA USB OTG DDR2/DDR	• Telehealth • Hospital Admission Machine	AN3520: Simplified EHCI Data Structures AN3631: Simplified Device Data Structures AN3517: Configuring the MCF5445x for PCI Host AN3513: ColdFire ATA Host Controller AN3522: DDR2 SDRAM on the ColdFire MCF5545x
MPC8313E	PowerQUICC II Pro processor	e300c3 2 IU with FPU 400 MHz DMA DDR2 USB 2.0 OTG	• Telehealth: Control System	AN2583: Programming DDR SDRAM Controller AN3533: Programming the User-Programmable Machine AN3645: SEC 2/3x Descriptor Programmer's Guide AN3830: Hardware Debugging Using the CodeWarrior IDE AN3369: PowerQUICC DDR2 SDRAM Controller Register AN2910: Hardware and Layout Design for DDR2 SDRAM AN3359: Performance Monitor AN3201: Using U-boot to Boot from a NAND Flash
MCF51QE	Flexis 32-bit V1 ColdFire microcontroller	50 MHz V1 ColdFire core microcontroller, 25 MHz bus speed	• Telehealth • Blood Pressure Monitors • Heart Rate Monitor • Fetal Heart Rate Monitor • Blood Glucose Monitor • Pulse Oximetry • Portable ECG	AN3460: Low-Power Enabled by QE128 (S08 and MCF51) AN3464: Migrating Code Between V1 and V2 ColdFire AN3465: Migrating within the Controller Continuum AN3500: Blood Pressure Monitor Using Flexis QE128 Device AN3552: Analog Comparator Tips and Tricks AN3586: Run uC/OS-II on MCF51QE128 AN3629: MC9S08QE32 to the MCF51QE32
S08JM	8-bit USB microcontroller	USB 2.0 full-speed device	• Telehealth • Heart Rate Monitor • Blood Pressure • Blood Glucose Monitor • Pulse Oximetry • Portable ECG • Ventilation/Spirometry • Vital Signs Monitoring • Hospital Admission Machine • X–Ray • Anesthesia Unit Monitor	AN3756: Synchronizing Internal Clock for LIN Slave AN3560: USB Device Development with MC9S08JM60 AN3561: USB Bootloader for the MC9S08JM60 AN3564: Customize the USB Application AN3565: USB and Using the CMX USB Stack AN3582: The USB Data Logger
MPC18730	1.15V/2.4V 2-ch. DC-to-DC converters with three low-dropout regulators	Cell Li-ion, NI-MH and alkaline batteries two DC-DC converters, serial sets output voltages	• Power Management	AN1902: Quad Flat Pack No-Lead (QFN) AN3247: Understanding and Using the Multi-Purpose MPC18730
MC13883	Integrated charger, USB On-The-Go transceiver and carkit interface	Li-ion battery charging through a USB connector	• Power Management	TECHOPTMLPMFS: Technologies for Optimized Power Management XTMENRGYCNSVWP: eXtreme Energy Conservation: Advanced Power-Saving Software for Wireless Devices
MC34704	Multi-channel power management IC (PMIC)	8 DC/DC (34704A) or 5 DC/DC (34704B) switching regulators	• Telehealth: Power Management	AN3809: Freescale's Power Management ICs AN1902: Quad Flat Pack No-Lead (QFN) AN3820: i.MX25 Power Management Using the MC34704
MPR083	8-position rotary	Optimized to manage an 8-position rotary shaped capacitive array	• Touch and Proximity Interfaces	AN3747: Pad Layout Application Note AN1985: Touch Panel Applications Using the MC34940/MC33794 E-Field IC AN3583: Using Low Power Mode on the MPR083 and MPR084
MPR084	8-pad touch sensor controller	Optimized to manage an 8-touch pad capacitive array	• Touch and Proximity Interfaces	AN3761: Using Freescale Devices for Contactless Touch Applications
MC13191	2.4 GHz low-power transceiver	Supports 250 kbps O-QPSK data in 2.0 MHz channels and full spread-spectrum encode	• Wireless Communication	AN3381: Using SMAC with the HCS08QD4 MCU AN2731: Compact Integrated Antennas AN2975: IEEE 802.15.4 and ZigBee Applications AN2976: MC1319x RF Test Procedures AN2935: MC1319x Coexistence in the 2.4 GHz ISM Band AN2985: MC1319x Physical Layer Lab Test Description AN2902: MC1319x Range Test AN3231: SMAC Based Demonstration Applications AN3251: Reference Oscillator Crystal Requirements AN2825: Handling MAC Erasure AN3577: Creating a USB-to-Wireless Bridge

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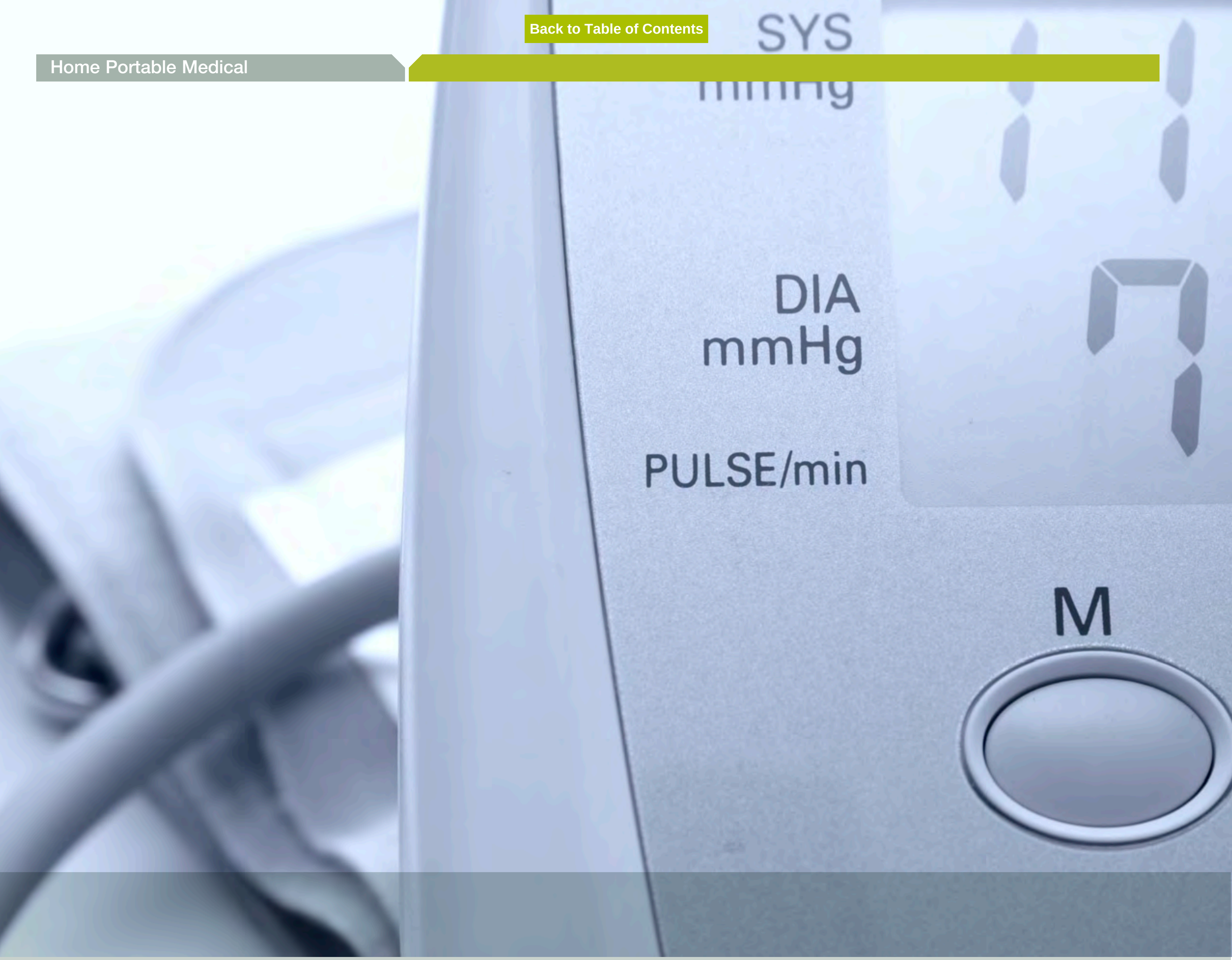

Blood Pressure Monitor

4.1 Introduction

Blood pressure monitors are medical devices for patients who suffer from hypertension who need to detect, measure and track their blood pressure. This is one of the vital signs that need to be measured to make a precise diagnosis. Up to 25 percent of patients who are diagnosed with hypertension do not suffer from hypertension, but instead from white-coat hypertension. This is the elevation of arterial pressure due to anxiety or stress produced by a health professional while taking a blood pressure test. This is why personal blood pressure monitors can help in detecting true hypertension as stipulated in the Joint National Committee and the 2003 guidelines from the European Society of Hypertension.

Blood pressure monitoring systems use techniques such as oscillometric methods and Korotkoff measurements. The oscillometric method consists of measuring the oscillations in pressure inside the cuff that the patient wears. The Korotkoff method is based on listening to sounds when taking blood pressure.

Automatic blood pressure monitoring conducted at home is increasingly used in the diagnosis and management of hypertension. This includes arm cuff and wrist cuff units. Figure 4-1 illustrates the system block diagram of a typical blood pressure monitor. This block diagram and others like it are available on the Freescale medical website, freescale.com/medical.

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4.2
Heartbeat Detection

The heartbeat rate is considered one of the vital patient measurements. The following procedure is used to obtain this measurement. While deflating a cuff that is attached to a person's arm, you can see slight variations in the overall cuff pressure (Figure 4-2). This variation in the cuff's pressure is due to the pressure change from blood circulation. This variation is amplified through a filter designed at 1 Hz, and set to an offset. This new signal is the heartbeat signal.

The signal in Figure 4-3 shows variations in the pressure signal and is a graphical representation of a patient's heartbeat over time.

4.3
Systolic and Diastolic Measurements

Heartbeat detection is a simple oscillometric method used to determine systolic blood pressure (SBP) and diastolic blood pressure (DBP). The simplified measurement is based on the idea that the amplitude of the heartbeat signal changes as the cuff is inflated over the SBP. While the cuff is deflated, the amplitude of the heartbeat signal grows as the cuff pressure passes the systolic pressure of the patient. As the cuff pressure is further reduced, the pulsations increase in amplitude until the pulsations reach a maximum pulse known as the mean arterial pressure (MAP), and then reduce rapidly until the diastolic pressure is reached (Figure 4-4).

4.4
Invasive Blood Pressure Monitors

The most accurate way to measure blood pressure is to take the measurement directly from an arterial line. The advantage of this method is continuous measurement, versus a discrete measurement in the non-invasive method.

Freescale has long been a provider of sensors for the invasive blood pressure monitoring segment. Figure 4-6 shows different types of packaging for Freescale pressure sensors.

Figure 4-1: Blood Pressure Monitor (BPM) General Block Diagram

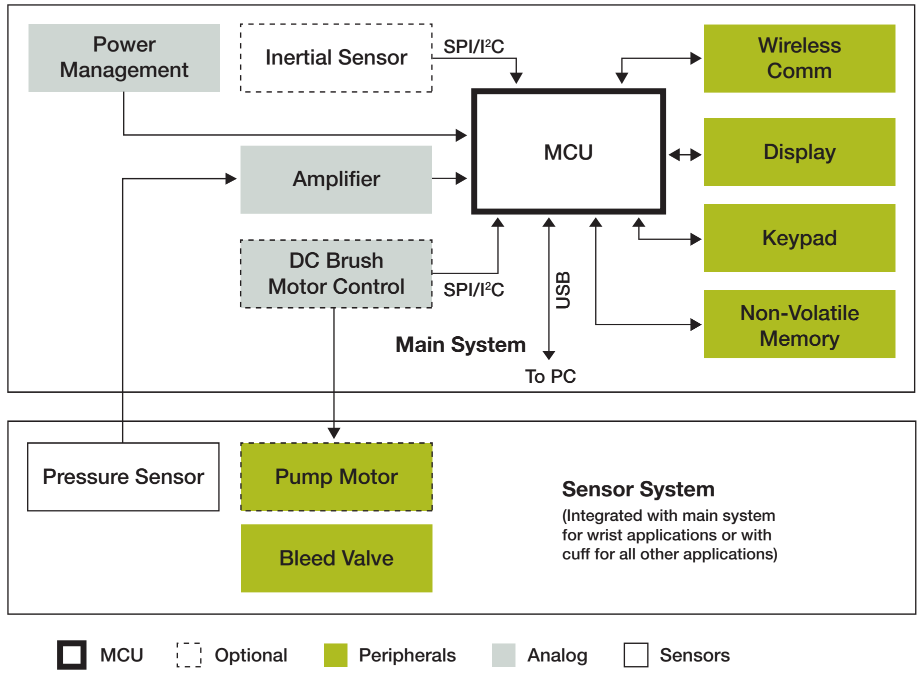


Figure 4-2: Heartbeat Signal

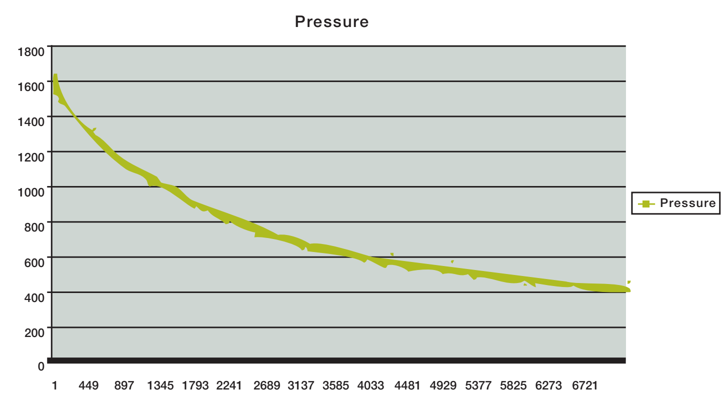
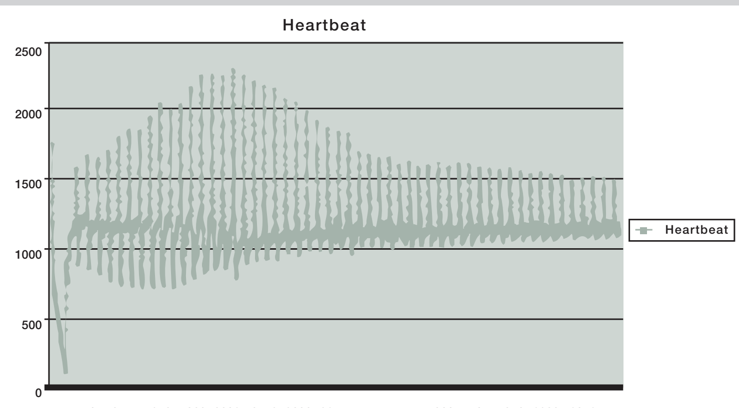


Figure 4-3: Heartbeat Over Time



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4.5
Obtaining Pressure Measurements

The basic function of a blood pressure monitor is to measure arterial pressure. One method to obtain this measurement is to use a pressure sensor that measures the present pressure. The variations in pressure change the velocity of a motor that controls an air pump. The air chamber presses the arm up to the systolic pressure. When systolic pressure is reached, the valve can deflate the cuff around the arm gradually. At the same time, the pressure sensor takes the measurements.

Some useful areas for Freescale sensors include the following health care monitoring applications:

- Blood pressure (BP) monitors
- Invasive BP monitors
- Intrauterine BP monitors
- Hospital bed controls
- Respirators
- Sleep apnea monitors
- Sports diagnostic systems
- Dialysis equipment
- Drug delivery for inhalers
- Physical therapy

Freescale pressure sensors are specifically designed for applications where high quality and reliability are important.

Freescale sensors offer a wide range of functions and features, from basic to fully amplified and temperature-compensated devices.

The amplified series can easily be connected to an MCU. The low-voltage pressure sensor series is designed to meet power efficiency demands to extend longevity for simpler, cost-sensitive medical and portable electronics. Freescale pressure sensors combine advanced micro-machining techniques, thin-film metallization and bipolar semiconductor processing that provides accurate and highly reliable sensors at competitive prices.

Figure 4-4: Heartbeat Versus Diastolic Pressure

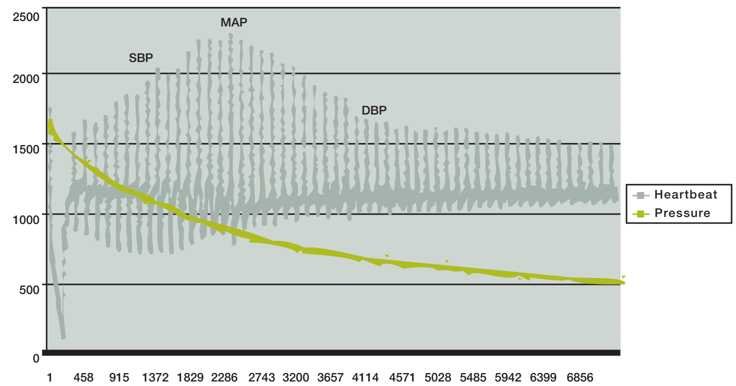
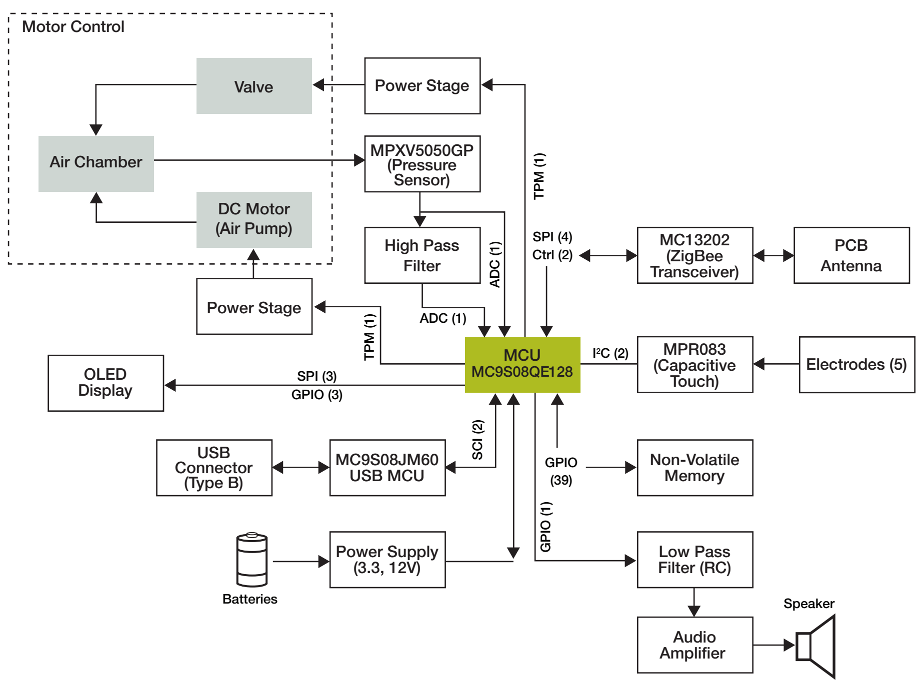


Figure 4-5: Flexis Microcontroller Blood Pressure Monitor Reference Design Block Diagram



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4.6

Blood Pressure Monitor Reference Design

For more information on how to build a blood pressure monitor with the Flexis QE microcontroller family, download the following PDF documents from freescale.com:

- Application note titled *Blood Pressure Monitor Using Flexis QE128* (document AN350)
- Complete reference design and design reference manual titled *Blood Pressure Monitor Using the Flexis QE128 Family* (document DRM101)

For more information on blood pressure monitors, see the Freescale design magazine *Beyond Bits IV*.

Find more information about the components of a blood pressure sensor in this guide:

- For Inertial Sensor, see Chapter 9, Hearing Aids Introduction.
- For Wireless Communication, Power Management, Keypad and Speaker Implementation modules, see Chapter 3, Telehealth Systems Introduction.
- For LCD screen connection, see Chapter 7, Blood Glucose Meter Introduction.
- For Pressure Sensor implementation and Motor Control devices, see Chapter 12, Ventilation and Spirometry Introduction.

MCF51QE: Flexis 32-bit V1 ColdFire Microcontroller

The QE family, comprised of a pin-compatible 8-bit and 32-bit device duo, is the first family in the Flexis MCU series. The Flexis series of controllers is the connection point on the Freescale Controller Continuum, where 8- and 32-bit compatibility becomes reality.

The MCF51QE128 device extends the low end of the 32-bit ColdFire controller family with up to 128 KB flash memory and a 24-channel 12-bit analog-to-digital converter (ADC). The 32-bit MCF51QE128 is pin, peripheral and tool compatible with the 8-bit S08QE128 device. They share a common set of peripherals and development tools, delivering the ultimate in migration flexibility.

Figure 4-6: Freescale Pressure Sensors

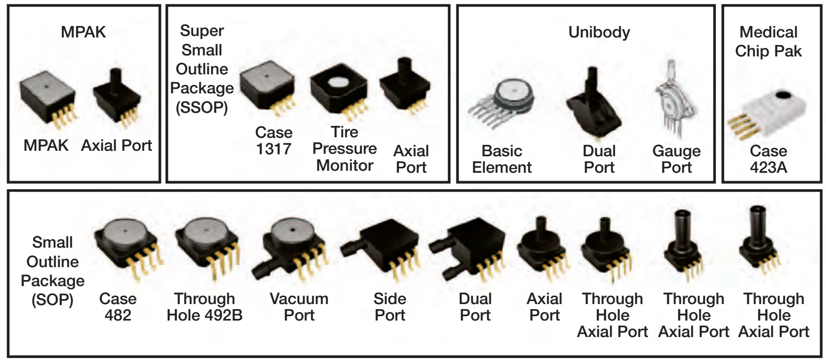
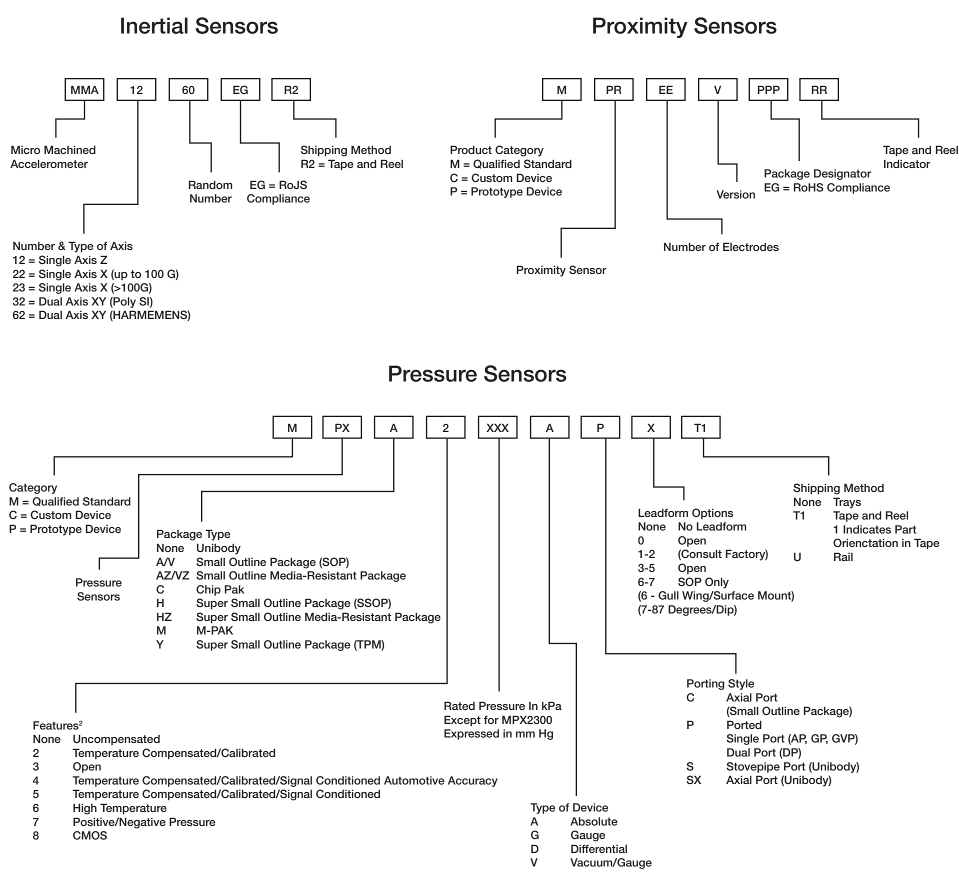


Figure 4-7: Product Numbering Systems for Sensors



1. Actual product marking may be abbreviated due to space constraints but packaging label will reflect full part number.
2. Only applies to qualified and prototype products. This does not apply to custom products.

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Key features

- 50 MHz V1 ColdFire core, 25 MHz bus speed
- Up to 128 KB flash memory
- Up to 8 KB RAM
- 1.8 to 3.6V operating voltage range
- Loop-control oscillator
- Highly accurate internal clock (ICS)
- Single-wire background debug interface
- Up to 70 GPIO ports, plus 16 bits of rapid GPIO
- 16 keyboard interrupt pins
- -40°C to +85°C temperature range
- Pin compatibility in 64- and 80-pin LQFP packages
- Common development tools including CodeWarrior for Microcontrollers 6.0

Figure 4-8: Pressure Gauge Block Diagram

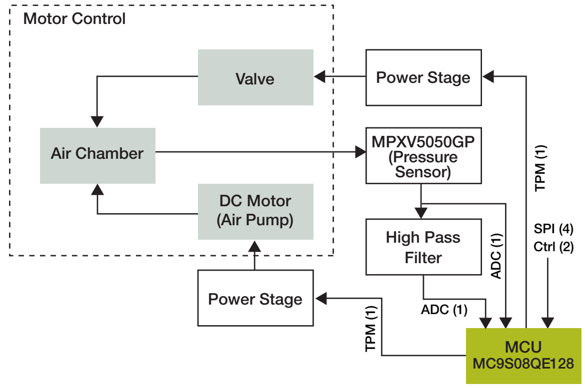
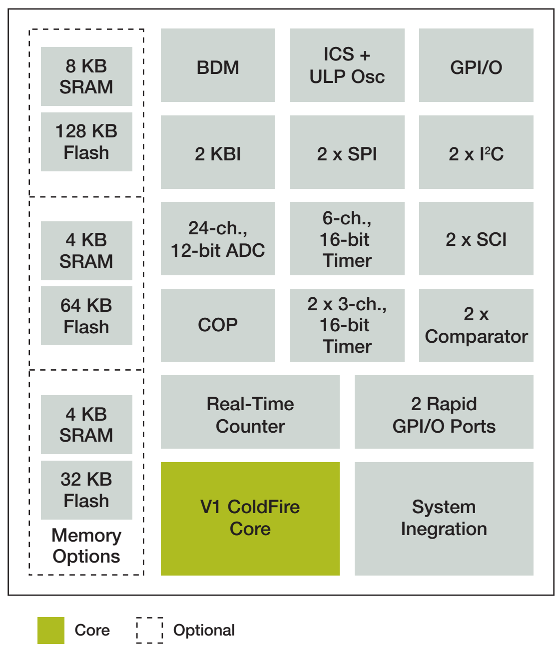


Figure 4-9: MCF51QE Block Diagram



4.7 Additional Freescale Technologies

Table 4-1 describes additional Freescale devices and application notes that can be used for blood pressure applications. To read the application notes or for more information about any of these devices, visit freescale.com.

Table 4-1. Additional Freescale Technologies for Blood Pressure Applications

Device	Description	Key features	Applications	Application Notes
MPC17C724	0.4 Amp dual H-bridge motor driver IC	Built-in 2-channel H-bridge driver provides four driving modes (forward, reverse, break, high impedance)	• Blood Pressure Monitors • Pump Motor	AN1902: Quad Flat Pack No-Lead (QFN) AN3302: Interfacing the MPC17C724 with an 8-bit Processor

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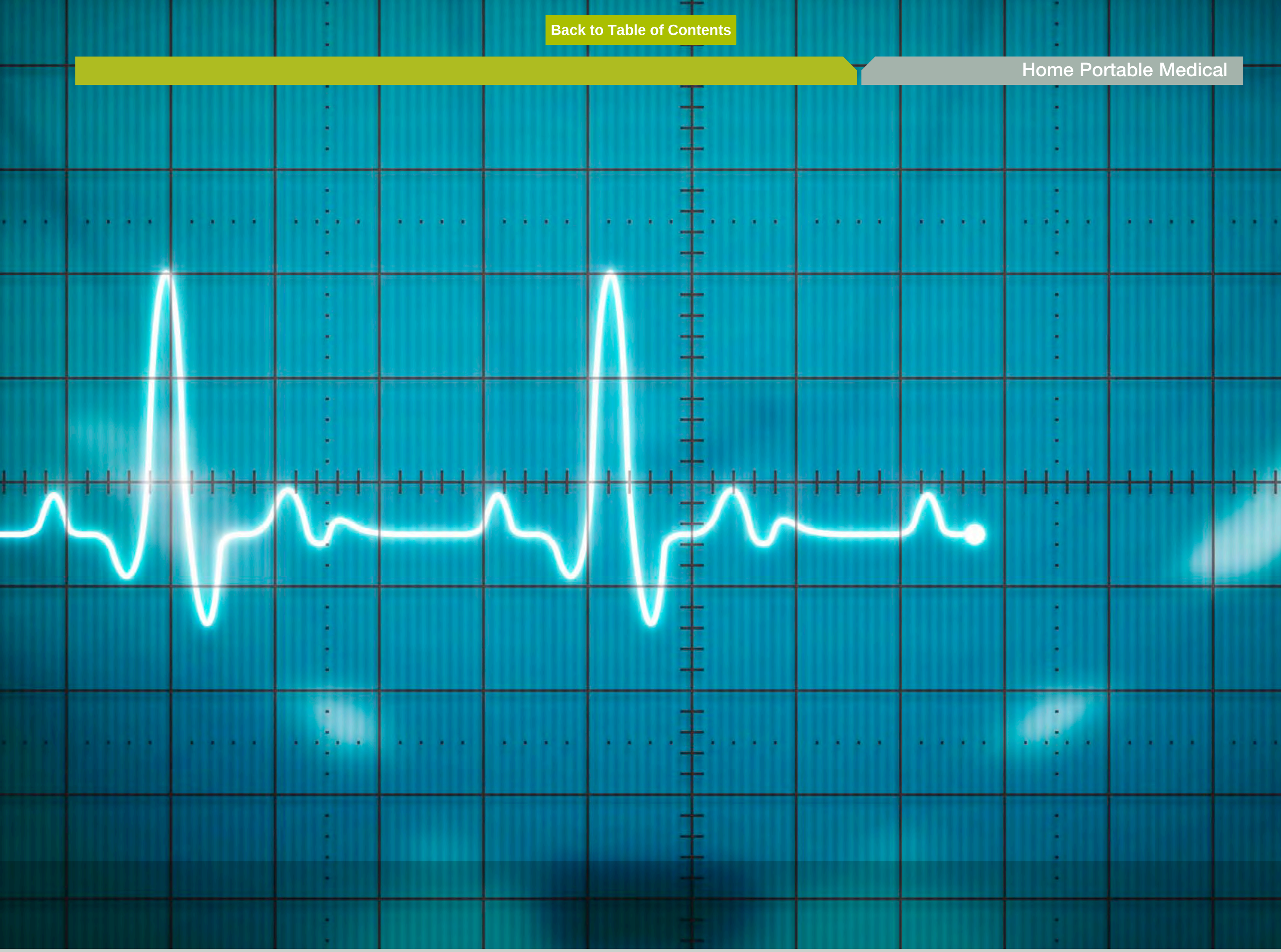

Heart Rate Monitor

5.1
Heart Signals Overview

Figure 5-1 shows a typical heart signal. In this signal, the heart muscles generate different voltages. P represents an atrial depolarization. Q, R, S and T represent the depolarization and repolarization of the ventricles. Each time this signal is present, a heartbeat is generated. The principal purpose of this application is to provide a heartbeat average, so it is only necessary to work with the QRS complex (see section 5-4, Obtaining QRS Complexes). For this reason it is important to develop analog and digital signal conditioning. First, the signal is amplified and the noise is filtered, and then the QRS complex can be detected.

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Figure 5-1: Typical Heart Signal

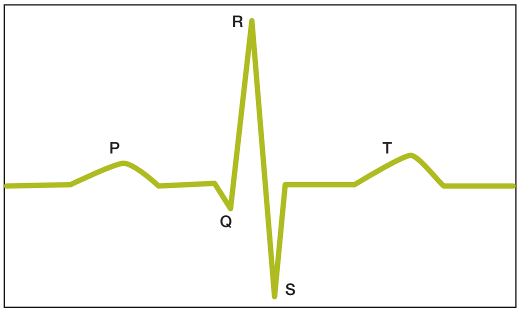
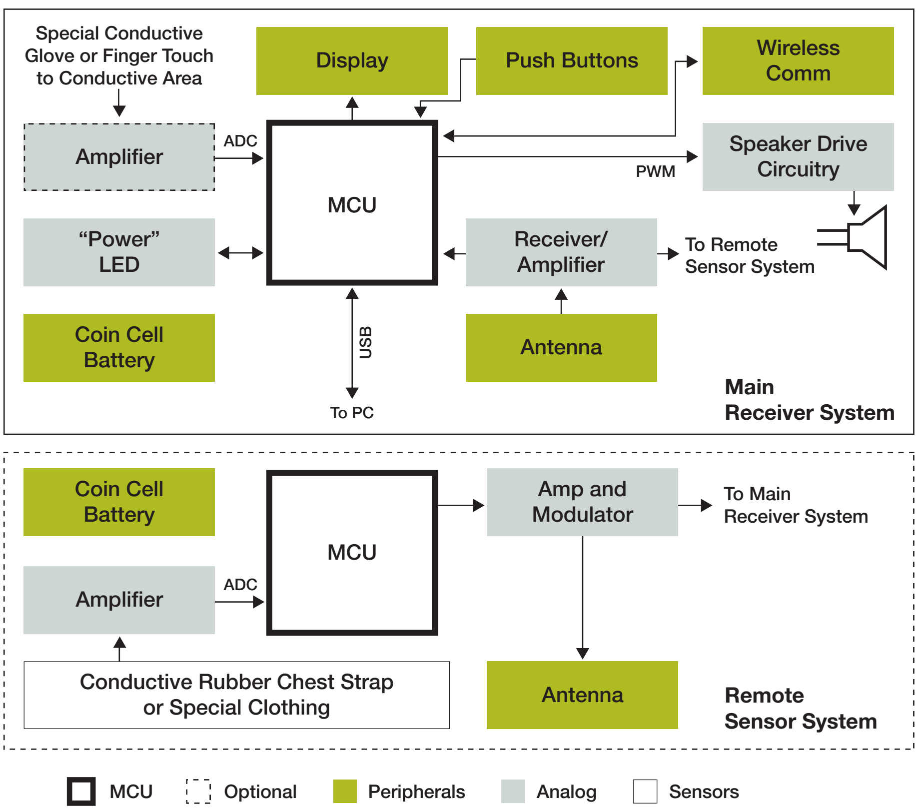


Figure 5-2: Heart Rate Monitor (HRM) General Block Diagram



5.2 Filters and Amplification

Noise and interference signals acquired in this type of system can be caused by electricity, such as radiation from electric-powered fluorescent lamps. These generate a lot of common-mode voltage and noise. Other aspects that generate noise are muscle contractions, respiration, electromagnetic interference and noise from electronic components. Because the electrical signals from the heart are not strong enough, it is necessary to amplify the signals and reduce the common-mode voltage in the system.

The RS08KA2 microcontroller provides high performance at low power for applications such as heart rate monitors. It operates from 1.8V to 5.5V at 10 MHz. RS08KA2 features are listed in Table 5-1.

Table 5-1. Features

Features	RS08KA2
BUS Speed (MHz)	10
Flash (KB)	2
RAM (Bytes)	63
GPIO	2/4
Keyboard Interrupt ADCMP Mondule	3/5 Yes
MTIM Module	Yes
Timers	None
Package	6-pin DFN 8-Pin SOIC/PDIP

Cardiac motion generates electrical currents with different potentials in the body. These can be sensed with electrodes, usually connected to the right and left hands. The electrical potential is an AC signal in a bandwidth from 0.1 Hz to 150 Hz with a magnitude of approximately 1 mV peak to peak, and with presence of common-mode voltage noise in a frequency range from approximately 40 Hz to 60 Hz. Knowing this information, a circuit can be designed for amplification and filtration (see figures 5-3, 5-4, 5-5 and 5-6 for details).

5.3

Amplifier and Filtering Requirements

The amplification is fixed at 1000 with a band-pass filter and cut frequencies of 0.1 Hz and 150 Hz. The reject-band filter has cut frequencies of 40 Hz and 60 Hz.

Frequency Response

- Diagnostic grade monitoring

  –3 dB frequency, bandwidth of 0.1 Hz–150 Hz
- Band-pass filter

  Rl_{lp} = 1 kΩ R_{hp} = 1.5 MΩ C_{lp} = C_{hp} = 1 uF
- AC line noise

  –3 dB frequency bandwidth of 40 Hz–60 Hz
- Reject–band filter

  R_{lp} = 1 kΩ R_{hp} = 1.5 MΩ C_{lp} = 4 uF C_{hp} = 1.7 nF

This application requires two types of amplifiers: an instrumentation amplifier and an operational amplifier.

Instrumentation amplifier requirements include:

- Low gain 10
- High common-mode rejection ratio (CMRR)
- Low offset

  R1 = 500 Ω R2 = 4.5 kΩ

Requirements for the operational amplifier, the second part of the instrumentation amplifier, include:

- High gain 100
- Output voltage around 1 V
- Low offset

  R3 = 1 kΩ R2 = 100 kΩ

5.4

Obtaining QRS Complexes

The QRS complex has to be detected in every heartbeat. This complex is the highest peak generated from the heart waveform. Although the signal has been filtered and amplified, it is necessary to include a digital band-pass filter with a bandwidth of 10 Hz to 25 Hz to remove high-frequency noise and low-frequency drift. Afterwards, filtering a derivation is implemented and a threshold is taken to determine whether the data is part of the QRS signal.

Figure 5-3: Signal Conditioning Block Diagram

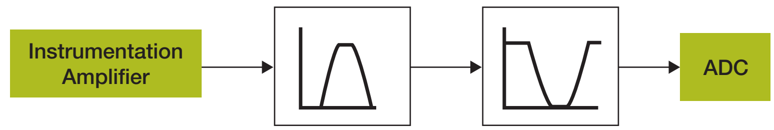


Figure 5-4: Instrument Amplifier to Acquire Heart Signal

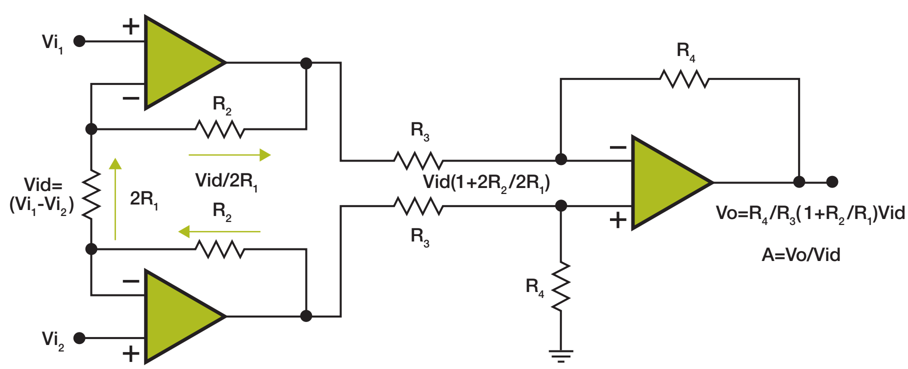


Figure 5-5: Band-Pass Filter Circuit Operating Frequencies 0.1 Hz–150 Hz

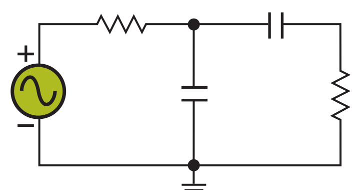


Figure 5-6: Band-Pass Filter Circuit Operating Frequencies 0.1 Hz–150 Hz

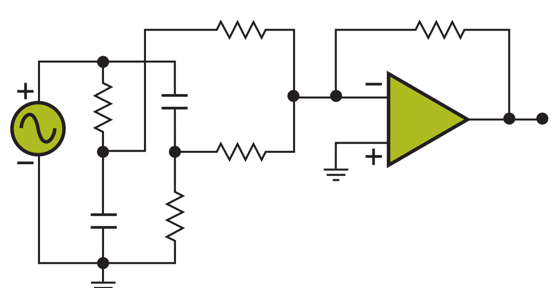


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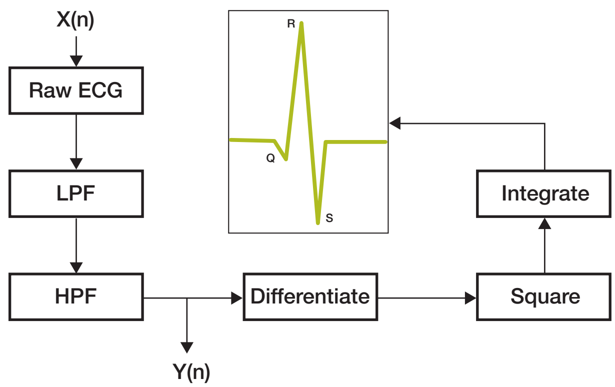
Figure 5-7: Digital Signal Processing to Obtain the QRS Complex



5.5

Additional Freescale Technologies

This table describes additional Freescale devices that can be used for heart rate monitor applications, and application notes. To read the application notes, or for more information about any of these devices, visit freescale.com.

Table 5-2. Additional Freescale Technologies for Heart Rate Monitors

Device	Description	Key features	Applications	Application Notes
MCF51JM	Flexis 32-bit V1 ColdFire USB microcontroller	Dual-role USB OTG CAN CAU	• Heart Rate Monitor • Blood Pressure Monitors • Blood Glucose Monitor • Pulse Oximetry • ECG • Portable X-Ray	Heart Rate Monitor and ECG Fundamentals
S08LL	S08 ultra-low-power MCU with LCD driver	20 MHz LCD driver supports 3V and 5V LCD glass	• Heart Rate Monitor • Blood Pressure Monitors • Fetal Heart Rate Monitor • Blood Glucose Monitor • Pulse Oximetry	AN2717: M68HC08 to HCS08 Transition AN3041: ICS Module on the HCS08s in Depth AN2111: A Coding Standard for HCS08 Assembly AN3756: S08's Internal Clock for LIN Slave AN3796: LCD Driver Specification
S08QE	Flexis 8-bit HCS08 microcontrollers	50 MHz 4 KB to 128 KB flash memory 8 KB to 256 KB RAM	• Blood Pressure Monitors • Heart Rate Monitor • Fetal Heart Rate Monitor • Blood Glucose Monitor • Pulse Oximetry • Hospital Admission Machine • Powered Patient Bed	AN3291: Use IIC on M68HC08, HCSO8, and HCS12 AN3464: Migrating Code Between V1 and V2 ColdFire AN3500: Blood Pressure Monitor Using Flexis QE128
RS08KA	8-bit microcontroller family	1.8V–5.5V at 10 MHz More flash and RAM than competitor analog controls	• Heart Rate Monitor—Remote Sensor System	AN3266: Getting Started with RS08 AN3321: High-Brightness LED Control Interface AN3604: Writing the RS08 MCU Program in C AN3304: I²C Slave on RS08KA2 AN3317: I²C Master on the MC9RS08KA2 AN3394: Resetting During Power Transitions AN3410: Implementing a Sewing Machine Controller AN3481: Ultrasonic Distance Measurer
S08SH	5V 8-bit microcontrollers	SCI, SPI, I²C ADC	• Heart Rate Monitor	AN3756: Using and Synchronizing the S08's Internal Clock for LIN Slave Implementations
MC34712	Switching regulator	3.0A 1.0 MHz fully integrated DDR switch mode power supply	• Coin Cell Battery and Power Management Interfaces	AN1902: Quad Flat Pack No-Lead (QFN) and Micro Dual Flat Pack No-Lead (μDFN)
MC34713	Switching regulator	5.0A 1.0 MHz fully integrated single switch mode power supply	• Coin Cell Battery and Power Management Interfaces	AN1902—Quad Flat Pack No-Lead (QFN) and Micro Dual Flat Pack No-Lead (μDFN)
MC34716	Switching regulator	1.0 MHz dual switch mode DDR power supply	• Coin Cell Battery and Power Management Interfaces	AN1902—Quad Flat Pack No-Lead (QFN) and Micro Dual Flat Pack No-Lead (μDFN)
MC34717	Switching regulator	5.0A 1.0 MHz fully integrated dual switch mode power	• Coin Cell Battery and Power Management Interfaces	AN1902—Quad Flat Pack No-Lead (QFN) and Micro Dual Flat Pack No-Lead (μDFN)

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Fetal Heart Rate Monitor

6.1

Doppler Fetal Heart Rate Monitor

A Doppler fetal heart rate monitor is a hand-held ultrasound transducer that uses the Doppler effect to provide an audible simulation of a heartbeat and display the number of beats per minute on a screen.

The Doppler effect is the wavelength variation of any wave sent or received by a moving object.

In this case, the source sends acoustic waves to the heart of a fetus inside the mother's womb. Part of the energy bounces back. However, because the heart is beating, the bounced waves are affected by the Doppler effect. This changes their frequency. Therefore, with simple algorithms the fetal and mother's heartbeats are detected separately because of the different frequencies of the mother's and fetus's heartbeats.

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6.2
Ultrasonic Probe

The ultrasonic probe may consist of an oscillator (X1 in Figure 6-3) that generates an ultrasound frequency (for these applications, the range is 1–3 MHz) followed by an amplifier (U2 in Figure 6-3) to condition the sine waveform in volts.

This waveform is applied to the transmitter transducer to send vibrations through the body and bounce back when the density of the medium changes. Another transducer is used to receive the bounced vibrations and convert them to electrical signals. This signal is amplified using an instrumental amplifier and is sent to a band-pass filter. The filtered signal is sent to a phase-locked loop to generate a voltage signal, which depends on the frequency applied.

For implementations of the instrumentation amplifier and band-pass filter, see the Appendix of this document.

6.3
Electrical Protection

Any time an AC-powered medical device comes into contact with a patient, the system must be designed with electrical protection in mind. Electrical protection limits the current to a non-harmful range of 6–10 mA maximum, avoiding the probability of electrical discharge. This also should provide isolation between the power source of the device and the sensor that is in contact with the person.

In the transmitter ultrasound probe example (Figure 6-3) the resistor R3 limits the current to transformer T1. Transformer T2 provides isolation between the circuit and the patient's body. Transformers T1 and T2 must have a 1:1 relationship, and should not be affected by the operational frequency of the transducers.

For more information about isolation, refer to the article Beyond Isolation in Freescale's *Beyond Bits* design magazine.

Figure 6-1: Fetal Heart Rate Monitor General Block Diagram

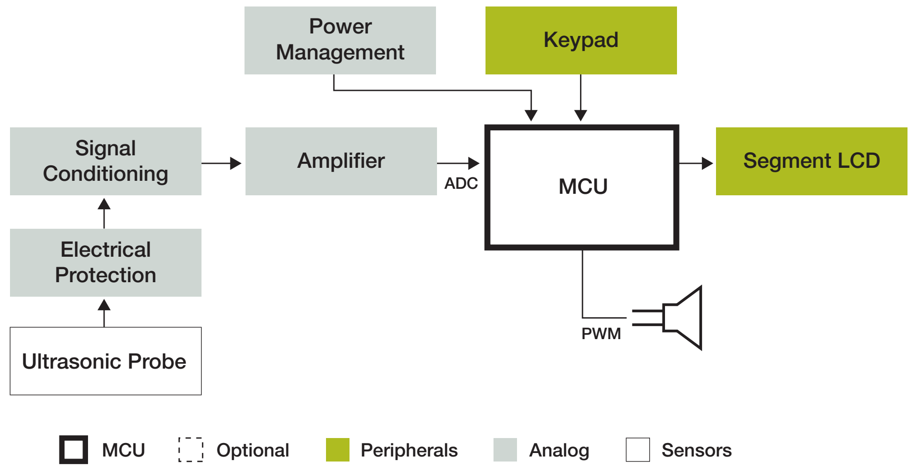
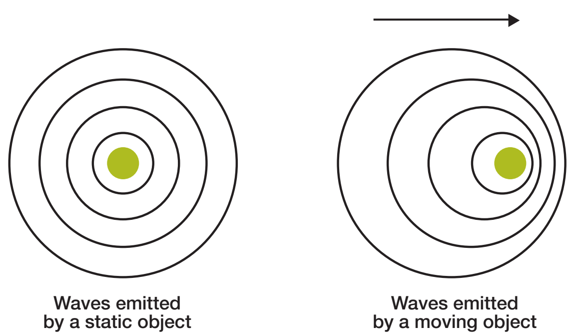


Figure 6-2: Doppler Effect Example



6.4
Signal Conditioning

Signal conditioning can be implemented using a band-pass filter to reject noise. Using an active filter, the signal can be conditioned to determine values. For details about filter design, refer to the Appendix.

The signal at the output of the band-pass filter is sent to a phase-locked loop to generate a frequency-dependent voltage. The phase-locked loop must be configured so that the frequency of the look-in range matches the band-pass filter bandwidth. This signal is applied to an input of the analog-to-digital converter embedded on the microcontroller.

The microcontroller is responsible for processing the information acquired according to an algorithm and displaying the data on an LCD screen. Freescale provides microcontrollers with embedded LCD controllers such as the MC9S08LL, MC9RS08LE, MC9RS08LA, and MC9S08LC families. Ultra-low-power MCUs with LCD drivers are in the LL family.

For more information about LCD devices and connections, see Chapter 7, Blood Glucose Meter.

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S08QE—Flexis 8-bit HCS08 Microcontrollers

Key features of these microcontrollers include:

- Up to 50 MHz CPU core and 25 MHz bus speed
- 4 KB, 8 KB,16 KB,32 KB, 64 KB, 96 KB, 128 KB flash memory
- 256 KB, 512 KB, 1 KB, 2 KB, 4 KB, 6 KB, 8 KB random access memory (RAM)
- Loop-control oscillator
- Single-wire background debug interface (DBM)
- Fast startup from Stop mode (6 µs)
- Flash programming from 1.8V to 3.6V
- Flexible clock modules

Integrated Peripherals

- Up to 24 channels, up to 12-bit low-power ADC
- Highly accurate internal clock (ICS)
- Up to two serial communications interfaces (SCI/UART)
- Up to two serial peripheral interfaces (SPI)
- Up to two I²C buses
- Up to 70 general-purpose input and output ports (GPIO)

MCF51QE—Flexis 32-bit V1 ColdFire core

Key features of these microcontrollers include:

- 50 MHz V1 ColdFire core/25 MHz bus speed
- Up to 128 KB flash memory
- Up to 8 KB RAM
- 1.8V to 3.6V operating voltage range
- Loop-control oscillator
- Highly accurate internal clock (ICS)
- Single-wire background debug interface
- Up to 70 GPIO ports, plus 16 bits of rapid GPIO
- 16 keyboard interrupt pins
- -40°C to +85°C temperature range
- Pin compatibility in 64- and 80-pin LQFP packages
- Common development tools including CodeWarrior for Microcontrollers 6.0

The QE family, comprised of pin-compatible 8-bit and 32-bit devices, is the first family in the Flexis series. The Flexis series of controllers is the connection point on the Freescale Controller Continuum, where 8-bit and 32-bit compatibility becomes reality.

Figure 6-3: Transmitter Ultrasonic Probe Example

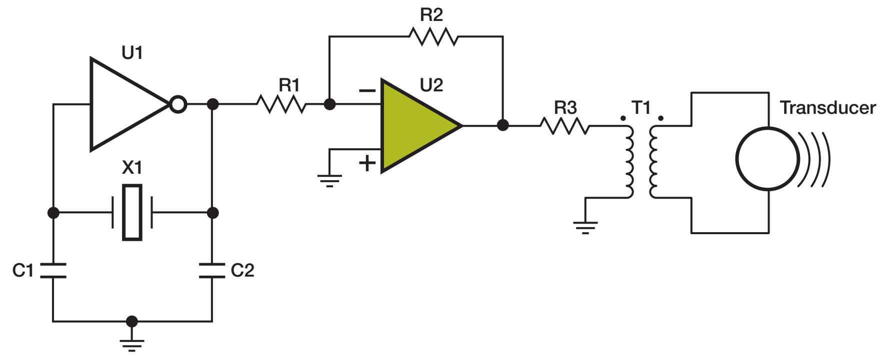


Figure 6-4: Receiver Ultrasonic Probe Example

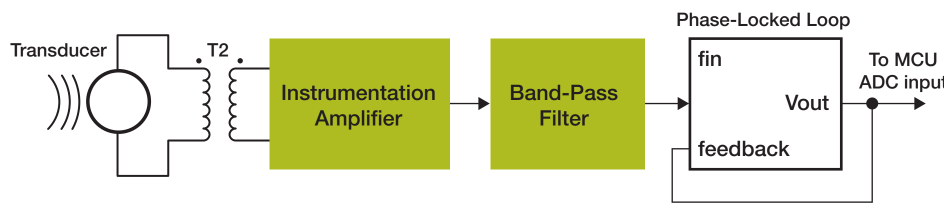
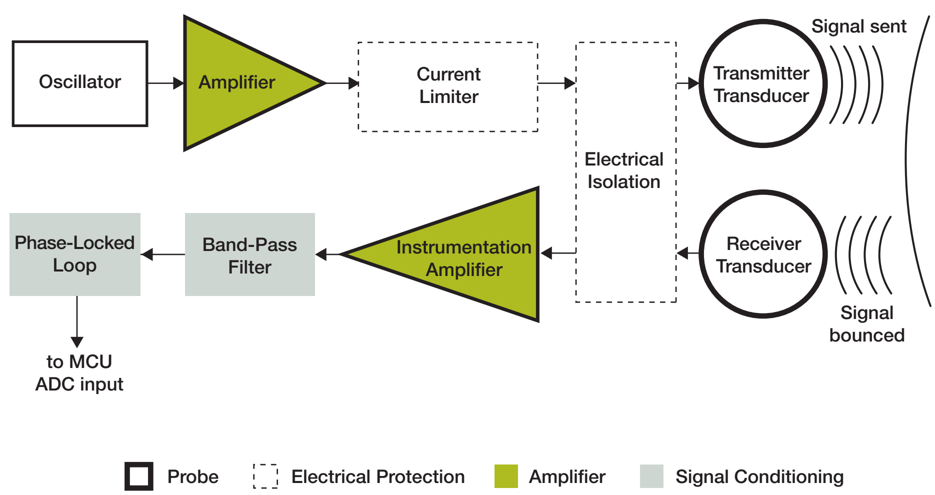


Figure 6-5: Ultrasonic Probe Elements Block Diagram



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6.5 Additional Freescale Technologies

This table describes additional Freescale devices that can be used for fetal heart rate monitor applications, as well as application notes. To read the application notes or for more information about any of these devices, visit freescale.com.

For wireless communication, power management, keypad and speaker implementation modules, see Chapter 3 Introduction.

Table 6-1. Additional Freescale Technologies for Fetal Heart Rate Monitors

Device	Description	Key features	Applications	Application Notes
RS08LA	RS08 cost-effective MCUs with LCD driver	10 MHz integrated LCD driver supports both standard 3V and 5V LCD glass	• Fetal Heart Rate Monitor Display and Control System	AN3741: Implement an In-Application-Programmable Data Storage on the MC9RS08KA8 System Configuration and Sensor Calibration
MC56F81xx/83xx	56800/E digital signal controller	Four 36-bit accumulators Two 16-bit quad timer modules FlexCAN (832X devices)	• Fetal Heart Rate Monitor • Portable ECG • Ventilation and Spirometry • X-Ray Control System	AN1916: Three-Phase BLDC Motor Control AN1983: HCS12/16 to 56800/E Software Porting AN1965: Design of Indirect Power AN3257: Meeting IEC 60730 Class B Compliance AN3301: Design of a PMSM Servo System AN3312: CAN Bus Bootloader for DSC 56F83xx AN3476: Machine Three-Phase AC Induction Vector AN3337: MC56F8013 Gang Programming AN3814: Static Serial Bootloader AN3815: Modular High Brightness RGB LED AN3843: Two-Channel Interleaved PFC Converter AN3607: A Low-Cost Soft Modem AN3599: Digital Signal Processing and ADC/DAC
DSP563xx	Digital signal processor	100 MHz DMA MMACS	• Fetal Heart Rate Monitor • Hearing Aids • Portable ECG • X-Ray Control System	AN3653: Migrating DSP563xx to Symphony DSPs AN2277: DSP56002 Designs to DSP56300 Designs AN2085: ECP Standard Parallel Interface DSP56300 AN2084: Enhanced Filter Coprocessors (EFCOPs) AN1980: Using the 56F83xx Temperature Sensor

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Blood Glucose Meter

7.1
Introduction

A glucometer is a device for determining the approximate concentration of glucose in the blood. It is a key element of home-based blood glucose monitoring (BGM) for people with diabetes mellitus (Type 1 and 2).

The conductivity of blood is affected by the quantity of glucose present. This is the principle used to determine the concentration of glucose in a sample of blood. This biological phenomenon can be modeled with an electrical circuit where a variable resistor is connected in series with a resistor to a fixed voltage source. The voltage drop in the variable resistance is determined by conductivity of the resistance. When the conductivity is high, the voltage drop is low, and when the conductivity is low, the voltage drop is high. These variations can be analyzed to determine the glucose concentration.

7.2
Test Strip

A test strip consists of an electrode with chemical elements where a blood sample is deposited. The elements present in the strip generate a reaction and an electric current is sent to a transimpedance amplifier that converts the current into voltage. The output voltage is proportional to the input current, following the equation of the transimpedance amplifier.

The transimpedance amplifier embedded on the Flexis MM MCUs (S08MM and MCF51MM) allows the user to acquire the current generated by the glucose's chemical reaction to the enzyme. The external components are used to configure the desired gain value of the amplifier. The transimpedance module is called TRIAMPV1 and it is managed through the values of the TIAMPCO register. The TIAMPEN bit of this register enables the transimpedance module and the LPEN bit enables low-power mode (LPEN = 1) and high-speed mode (LPEN = 0). Low-power mode is commonly used for battery-dependent systems, but it compromises the response speed of the system.

The TRIOUT pin of this module must be connected with an external resistor (gain resistor) to the VINN pin, which is the inverting input of the operational amplifier. The VINP pin must be connected to ground.

A general block diagram of the test strip is shown in Figure 7-4.

The basic sensor for a glucometer is an enzymatic strip. These are based on the detection of hydrogen peroxide formed in the course of enzyme-catalyzed oxidation of glucose.

Glucose GOD gluconolactone hydrogen peroxide

$C_6H_{12}O_6 \rightarrow C_6H_{10}O_6 + H_2O_2$

These strips are amperometric sensors that use a three-electrode design. This approach is useful when using amperometric sensors because of the reliability of measuring voltage and current in the same chemical reaction. The three-electrode model uses a working electrode (WE), reference electrode (RE) and counter electrode (CE).

Figure 7-1: Blood Glucose Monitor (BGM) General Block Diagram

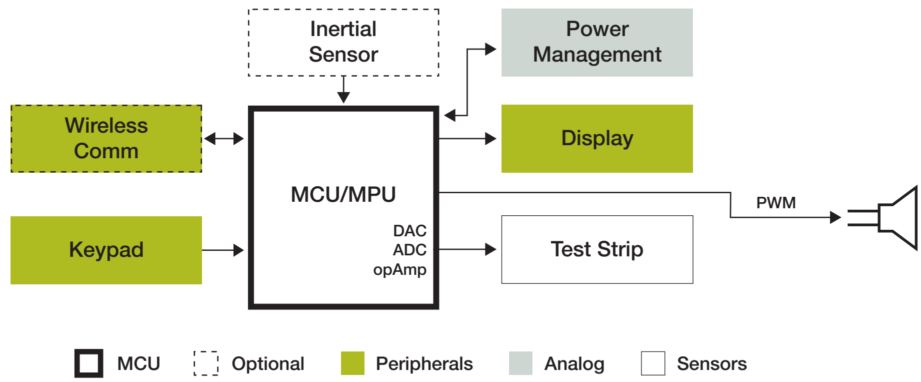


Figure 7-2: Equivalent Circuit with Rv Equal to Blood Conductivity

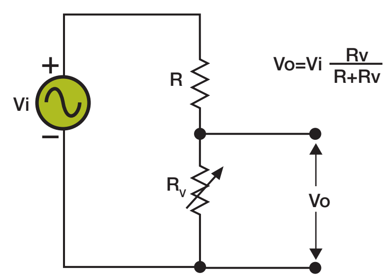


Figure 7-3: Basic Transimpedance Amplifier

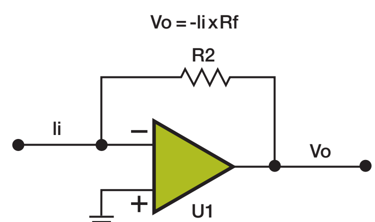
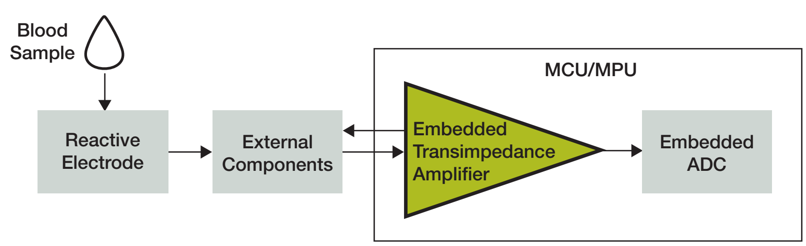


Figure 7-4: Test Strip Basic Block Diagram Using Flexis MM



7.3
Wired and Wireless Communication

The functionality of a blood glucose meter can be expanded to allow wired or wireless communication with other devices such as PDAs, smart phones, insulin dispensers or calorimeters. This can be useful for telehealth applications and remote patient monitoring.

Freescale offers several cost-effective low-power MCUs with integrated USB interfaces for wired communication. For wireless options, Freescale offers ZigBee solutions and examples in its own BeeKit. Figure 7-6 is an example of ZigBee implementation.

See Chapter 3.1.8, *Wireless Communication*, for more details.

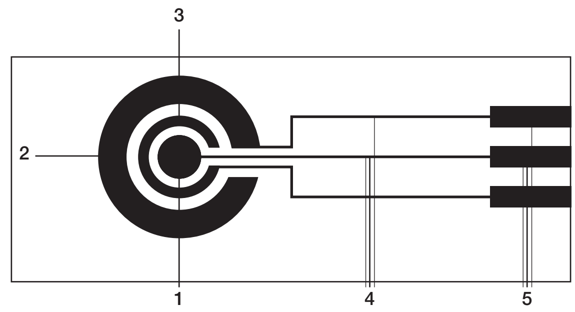
7.4
Liquid Crystal Display (LCD) Module

The LCD module shows the glucose level. Freescale provides an application note titled *LCD Driver Specification* (document AN3796) about how to implement an LCD controller and the driver software. The application note is available at freescale.com.

The capacity of digits is determined by the LCD used. It must be supported by the number of segments that can drive the LCD controller. The MC9S08LL16 processor supports up to 4 x 28 or 8 x 24 segments.

To learn more about about LCD technology and diabetes monitoring, see the *Gestational Diabetes* article in the Freescale design magazine *Beyond Bits IV*.

Figure 7-5: Chip Schematic



1) WE, 2) CE, 3) Ag/AgCl RE, 4) Conductive lines, 5) Pads

Figure 7-6: Example of Communication Interface for Blood Glucose Monitor

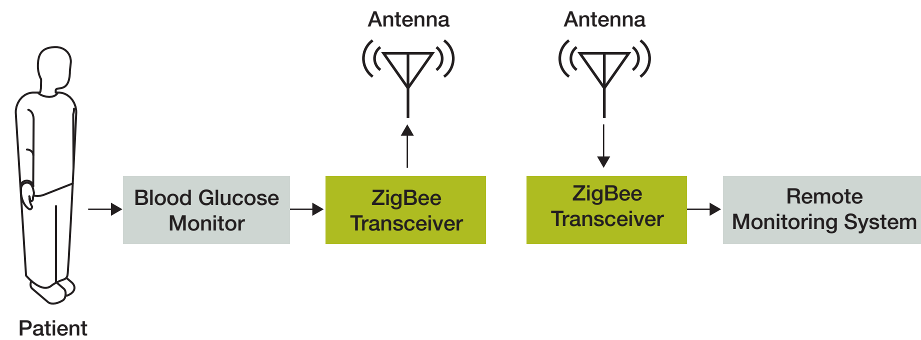
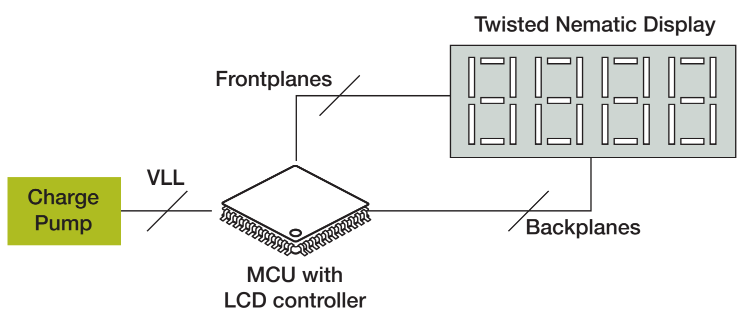


Figure 7-7: LCD Connection



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S08LL—S08 Ultra-Low-Power MCU with LCD Driver

Key features of this processor include:

- Up to 20 MHZ HCS08 CPU from 1.8V to 3.6V and across a temperature range of -40°C to +85°C
- Two ultra-low-power stop modes
- Advanced low-power run and wait modes
- Internal clock source (ICS)
- Integrated LCD driver supports both 3V and 5V LCD glass standards
- Configurable display for 8 x 36 or 4 x 28 segment display
- LCD driver pins are mixed with GPIO and other functions
- Up to 64 KB flash read, program and erase over full operating voltage and temperature
- Analog-to-digital converter (ADC)—10-channel, 12-bit resolution
- Timer—Two 2-channel
- Two serial communications interface (SCI)
- Analog comparator with selectable interrupt on rising, falling or either edge of comparator output
- Serial peripheral interface (SPI)—One module with full-duplex or single-wire bidirectional
- I²C with up to 100 kbps
- 38 general purpose input and output (GPIO), two output-only pins
- Single-wire background debug interface

7.5
Inertial Sensor

An inertial sensor can be used to detect when a patient falls due to any irregular situation in the patient's body. For example, if glucose levels are too low the patient may lose consciousness and faint. This sensor consists of an accelerometer that detects freefall. The output of the sensor can be used to activate an alarm with a PWM block or send an alert through wireless communication.

Freescale's MMA7455L and MMA7456L are digital output (I²C and SPI), low-power, low-profile capacitive micro-machined accelerometers featuring signal conditioning, a low-pass filter, temperature compensation and self-test. They are configurable to detect 0g, and have a pulse detector for quick motion detection.

Figure 7-8: Implementation of the Digital Accelerometer

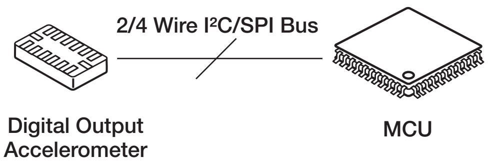
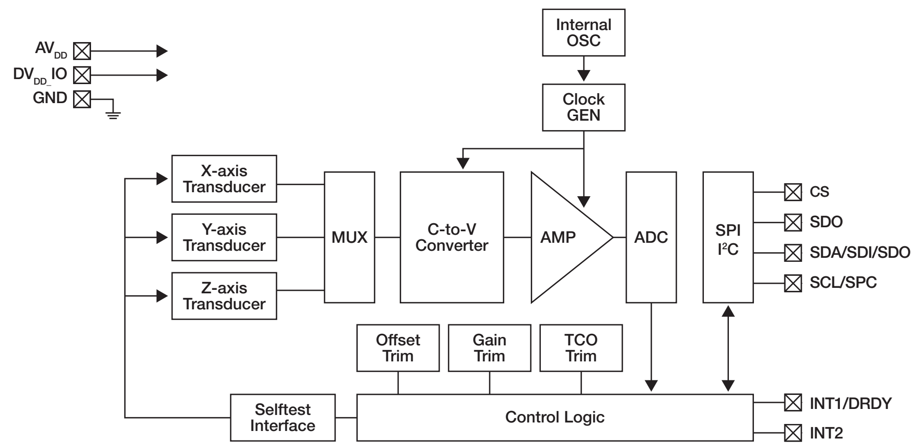


Figure 7-9: MMA745xL 3-axis Digital Output Acceleration Sensor



To learn more, see the article *Beyond Accidental Falls* in the design magazine *Beyond Bits IV*.

With the increasing consumer focus in the design of medical devices, inertial sensors are also being used for simple portrait and landscape functionality to improve the end-user experience. This is especially applicable for high-end blood glucose meters with graphical displays. Freescale's MMA7660 was designed specifically for portrait and landscape functions.

MMA745xL—3-Axis Digital Output Acceleration Sensor

Key features of this sensor include:

- Self-test for Z-axis
- Low voltage operation: 2.4V–3.6V
- User-assigned registers for offset calibration
- Programmable threshold interrupt output
- Level detection for motion recognition (shock, vibration, freefall)
- Pulse detection for single or double pulse recognition
- Sensitivity (64 LSB/g at 2g and at 8g in 10-bit mode)
- Selectable sensitivity (±2g, ±4g, ±8g) for 8-bit mode
- Robust design, high shock survivability (5,000 g)
- Environmentally preferred product
- Cost effective

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7.6
Additional Freescale Technologies

This table describes additional Freescale devices that can be used for blood glucose meter applications, and application notes that can explain more. To read the application notes or for more information about any of these devices, visit freescale.com.

For wireless communication, power management, keypad and speaker implementation modules, see the Chapter 3 introduction.

Table 7-1 Additional Freescale Technologies for Blood Glucose Meters

Device	Description	Key features	Applications	Application Notes
S08JS	8-bit microcontroller family	48 MHz HCS08 core ROM-based USB bootloader USB RAM	• Blood Glucose Monitor • Blood Pressure Monitors • Pulse Oximetry • Portable ECG • Hospital Admission Machine • X-Ray • Anesthesia Unit Monitor • USB Communication and Control System	AN3560: USB Device Development with MC9S08JM60 AN3561: USB Bootloader for the MC9S08JM60 AN3564: USB Application Using the MC9S08JM AN3565: Using the CMX USB Stack with 9S08JM Devices
i.MX27	Multimedia applications processor	ARM926EJ-S™ 400 MHz core SDRAM 16/32-bit, 133 MHz Crypto accelerator Ethernet/IEEE 802.3MAC IrDA CPU complex—400 MHz at 1.45V, 266 MHz at 1.2V System—133 MHz	• Blood Glucose Monitor • Portable ECG • Defibrillators • Vital Signs Monitoring • Hospital Admission Machine • Ultrasound • Anesthesia Unit Monitor • Control System	Visit freescale.com
MMA745xL	3-axis digital output acceleration sensor	ARM926EJ-S 400 MHz core 16 KB L1 I-cache and D-cache 16-channel DMA ETM real-time debug Smart Speed switch	• Blood Pressure Monitors • Blood Glucose Monitor • Hearing Aids—Inertial Sensor	AN3468: The MMA745xL Digital Accelerometer AN3783: Proximity Sensor-Based Remote Control AN3484: Soldering and Mounting Guidelines for the LGA Accelerometer Sensor to a PC Board

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Pulse Oximetry

8.1

Theory Overview

Oxygen saturation (SpO2) is defined as the ratio of oxyhemoglobin (HbO2) to the total concentration of hemoglobin (HbO2 + deoxyhemoglobin). The percentage is calculated by multiplying this ratio by 100. Two different light wavelengths are used to measure the actual difference in the absorption spectra of HbO2 and Hb. The bloodstream is affected by the concentration of HbO2 and Hb and their absorption coefficients are measured at two measurement wavelengths. The light intensity decreases logarithmically with the path length according to the Beer-Lambert Law. It is important to mention that when the light attenuated by body tissue is measured, DC components and AC components indicate artery absorption.

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8.2

Signal Acquisition

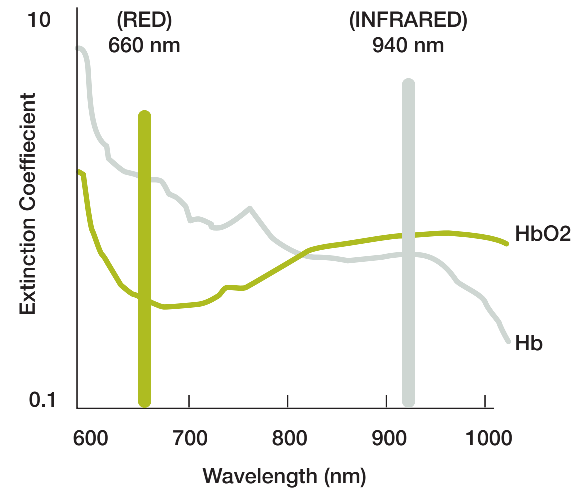
This application is non-invasive because the optical sensor is composed of two LEDs that transmit light through the skin (finger or earlobe) to a photodiode. One LED is red with a wavelength of 660 nm and the other is infrared with a wavelength of 910 nm. The skin absorbs the light received by the photodiode. Each wavelength provides different data to calculate the percentage of hemoglobin. Deoxygenated and oxygenated hemoglobin absorb different wavelengths. Deoxygenated hemoglobin has absorption of around 660 nm and oxygenated hemoglobin has higher absorption at 910 nm. These signals depend on the actual blood pressure, therefore the heart rate can also be measured.

$$R = \frac{\log_{10}(I_{ac})_{\lambda 1}}{\log10(I_{ac})_{\lambda 2}}$$

SaO2 as R

Iac= Light intensity at λ1 or λ2, where only AC level is present λ1 or λ2 are the wavelengths used.

Figure 8-1: Spectrum of Oxyhemoglobin and Deoxyhemoglobin



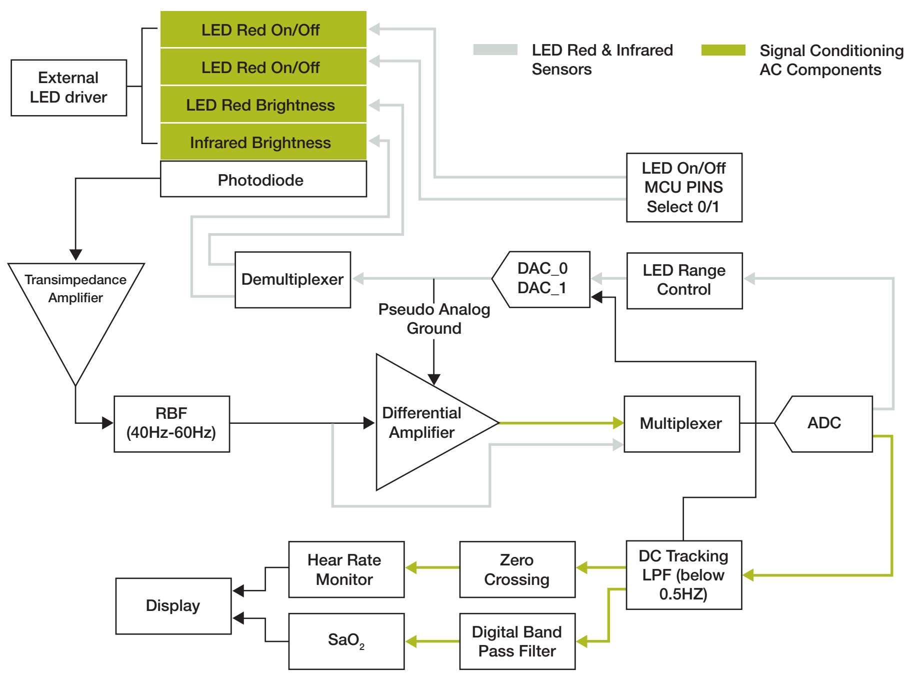
8.3

Circuit Design Overview

This application starts with an optical sensor that is composed of two LEDs and a photodiode. The two LEDs have to be multiplexed to turn on. The photodiode detects when light is present by detecting current that is proportional to the intensity of the light, then the application uses a transimpedance amplifier to convert this current into voltage. Automatic gain control (AGC) controls the intensity of LEDs depending on each patient. A digital filter then extracts the DC component. The signal is passed to a digital band-pass filter (0.5 Hz–5 Hz) to get the AC component, then through a zero-crossing application to measure every heartbeat. Finally, this signal is passed as a voltage reference to the second differential amplifier to extract only the DC component and separate the AC and DC components. After this, the following ratio formula to obtain the oxygenated hemoglobin (SaO2) levels is used:

R = [log (RMS value) x 660 nm] / [log (RMS value) x 940 nm]

Figure 8-2: Pulse Oximetry General Voice Diagram



8.3.1

Circuit LED Driver

The circuit is used for both red and infrared LEDs. When the LEDs are placed in parallel they can be multiplexed. Two ports of the DAC_0 control the brightness of the LEDs. The MCU controls brightness and multiplexing frequency of the LEDs depending on the designer's specifications. The LEDs are turned on and off to calculate the ratio between both signals and compute the amount of oxygen saturation.

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8.3.2
Signal Processing

The current proportioned by the photodiode depends on the intensity of the light. This signal has to be changed to voltage and amplified by the transimpedance amplifier. The signal generated is around 1V for DC and 10 mV for AC. Freescale's S08MM has four integrated op-amps. Both of the transimpedance and non-inverting amplifiers shown in figure 8-5, as well as more active filters, can be developed using this MCU. The AC component is generated by the oxygen present in the blood; to process the signal it is only necessary to obtain the AC component. A digital filter is placed to remove the DC component and this filter is taken as a voltage reference for the second amplifier.

The DC tracking filter allows the system to separate the DC and AC components. The AC component is used to calculate oxygen levels and to detect zero crossing to detect the heartbeat. The digital filter can be developed using Freescale's MC56f8006 DSC. The information can be shown on any kind of display.

For wireless communication, power management, keypad and speaker implementation, see Chapter 3 Introduction.

S08JM—8-bit USB Microcontroller

Key features of this microcontroller include:

- HCS08 core at 48 MHz with 24 MHz of internal bus speed
- Flash—8 KB, 16 KB, 32 KB and 60 KB
- RAM—up to 4 KB
- USB RAM—256 bytes

Integrated Peripherals

- USB 2.0 full-speed device
- ADC—12-channel, 12-bit
- Analog comparator module (ACMP)
- I²C
- Two SCI
- Two SPI—8-bit or 16-bit
- Two timers—2/6 channels
- 8 KBI

Figure 8-3: Optical Sensor

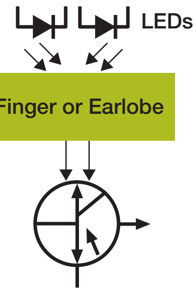


Figure 8-4: LED Drive Circuit

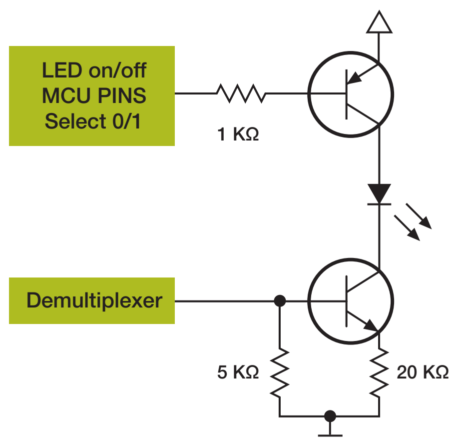
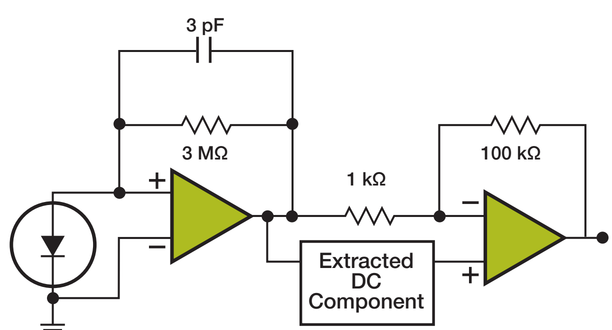


Figure 8-5: DC/AC Tracking



The extracted DC is composed of ADC-DC tracking-DAC

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MCF51JM—Flexis 32-bit V1 ColdFire USB

Key features of this processor include:

- Up to 50.33 MHz V1 ColdFire core offering 2.7 to 5.5V across a temperature range of -40°C to +105°C
- Up to 128 KB flash read/program/erase over full operating voltage and temperature
- Up to 16K RAM with security circuit
- Four low-power modes

Integrated Peripherals

- Dual-role USB On-The-Go (OTG) device supports USB in either device, host or OTG configuration
- Controller area network (CAN)
- Cryptographic acceleration unit (CAU)
- ADC 12-channel, 12-bit resolution
- Random number generator accelerator (RNGA)
- Low voltage detection and a computer operating properly (COP) module
- Two SCI
- Two SPI
- Two I²C
- Two 16-bit timers—2/6 channels
- Up to 16 KBI
- Up to 66 GPIOs

Figure 8-6: S08JM Family

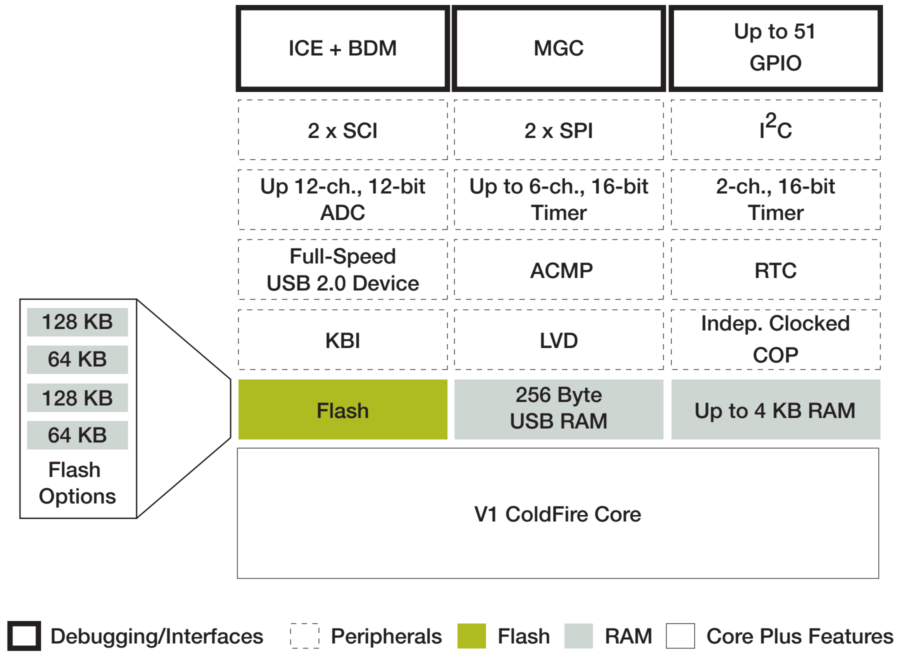
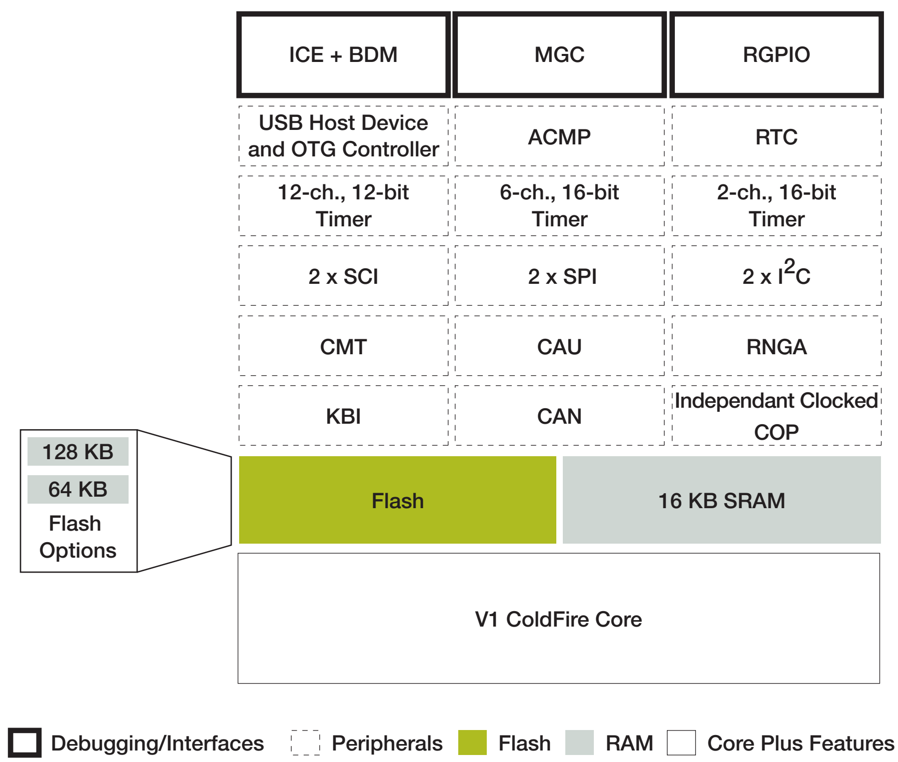


Figure 8-7: MCF51JM Family



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Hearing Aids

9.1
Introduction

A hearing aid is a small electronic device worn in or behind the ear that amplifies incoming sounds. A hearing aid can help people with hearing loss hear better in both quiet and noisy situations. Low power, digital and adaptative filtering are key design elements for battery-operated hearing aids to reduce the environmental noise so that only the desired signals are amplified and sent to the speaker.

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9.2
Microphone Amplifier

The microphone and amplifier are used to convert sound into electrical signals. The microphone is a transducer that converts vibrations in the air to electrical signals. The microphone can be connected to a preamplifier to couple the impedances and normalize the audio levels. The preamplifier output is connected to the amplifier input to condition the signal-in voltage levels used by the analog-to-digital converter (ADC).

The analog-to-digital converter transforms the continuous audio signal into digital samples to be processed and filtered by a digital signal processor (DSP).

9.3
Li-ion Battery Charger Circuit

Because this device is designed to be worn in or behind the ear, the power source must be batteries. Using rechargeable batteries eliminates the need to replace or purchase batteries.

MC13883—Integrated Charger, USB On-the-Go Transceiver and Carkit Interface

The Freescale MC13883 is a monolithic integration of a lithium ion battery charger with a CEA-936 carkit with interfacing support and a USB OTG transceiver.

Key features include:

- Li-ion battery charging through a USB connector
- Multiple charger modes and configurations supported
- Overvoltage protection for shielding products from faulty (high-voltage) charging sources
- Trickle pre-charge of deeply discharged batteries
- Reverse path capability allows power to be sourced to the VBUS pin from the battery and can be used to support phone-powered devices through the USB connector
- Charge indicator LED driver

Figure 9-1: Hearing Aid General Block Diagram

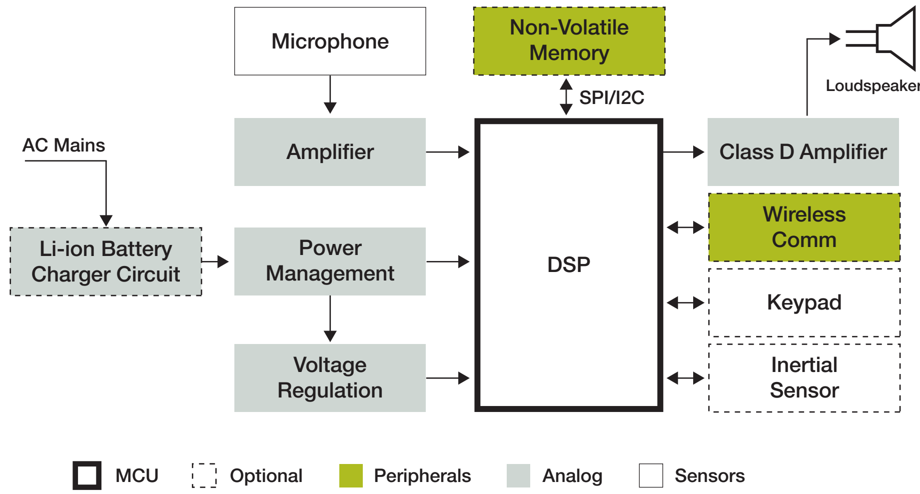


Figure 9-2: Signal Acquisition Block Diagram

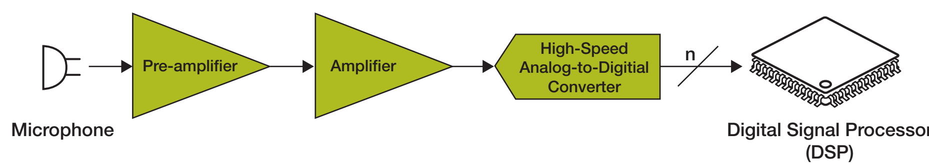
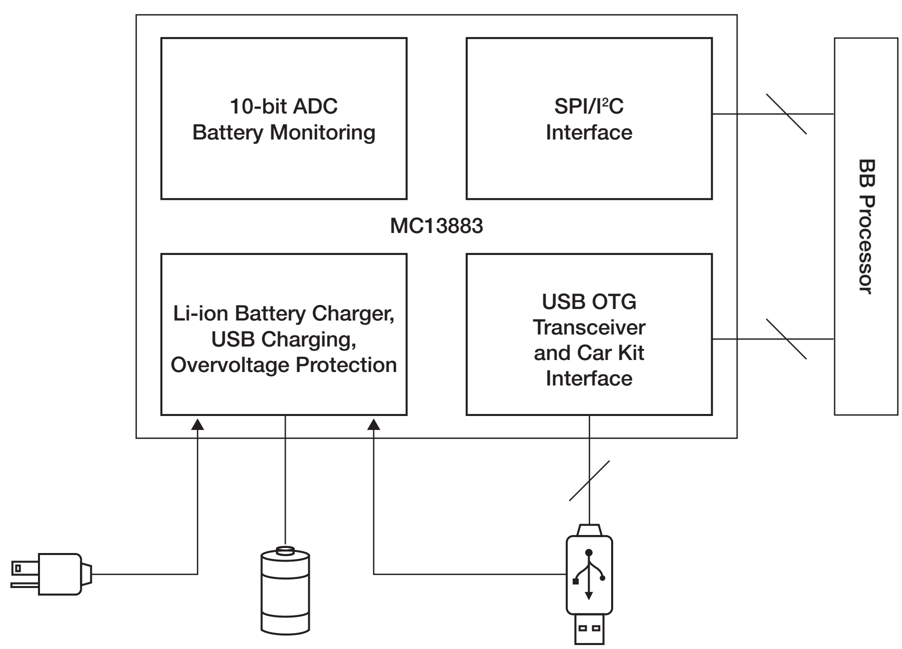


Figure 9-3: MC13883 Block Diagram



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- USB 2.0 OTG transceiver with regulated supplies, ID detection and interrupt generation
- Communication and audio control follows the protocol defined by the CEA-936 carkit specification
- Serial peripheral interface (SPI) and inter-integrated circuit (I²C) support for flexible processor interfacing and system integration
- 40-pin QFN package, 6 mm x 6 mm

9.4
Class D Amplifier

For applications in audio amplification there are several available technologies. Analog Class AB has been the predominant technology for these applications, however, the industry uses Class D amplifier technology. Class D amplification offers many advantages over other technologies. Pulse width modulation is often used to improve power performance. This results in lower heat dissipation which allows more audio channels and higher wattage in smaller form factors.

Freescale DSP5680x devices offer a combination of peripherals and software to enable Class D amplifiers to work at peak performance.

DSP5680x Architecture

The architecture of the DSP5680x device captures the best of the DSP and MCU worlds. Its key features include:

- Advanced pulse width modulation
- Dual analog-to-digital converters
- Programmable 16-bit timers
- 8 MHz crystal oscillator and PLL with integrated pre- and post-scalars
- Onboard power conversion and management
- JTAG/OnCE debug programming interface

9.5
Digital Signal Processor

The digital signal processor (DSP) performs the signal's digital filtering. The audio signal samples taken from the ADC are stored in memory. A filter algorithm is applied to the sampled signal.

Figure 9-4: General Diagram of Class D Amplifier Implementation

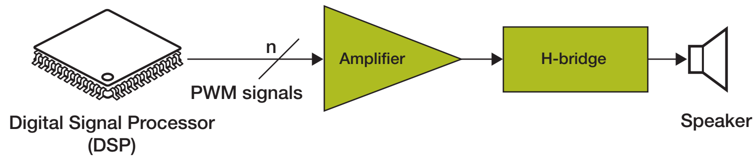


Figure 9-5: Principle of PWM Modulation

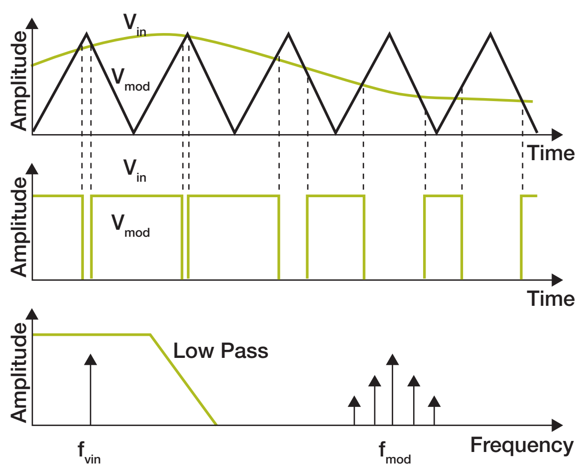
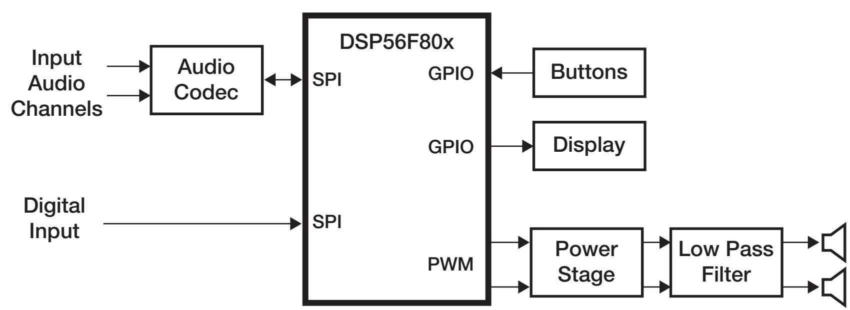


Figure 9-6: DSP Audio Application



A digital signal controller (DSC) such as Freescale's MC56F8006 can take the place of an amplifier, ADC and PWM/timers. See Figure 9-7. The advantages to replacing these discrete devices with one DSC include board real estate savings (critical for small hearing aids), increased reliability by reducing the number of failure points, and a reduced cost.

The Freescale MC56F8006 DSC provides the following features:

- 16-bit 56800E core
- Programmable gain amplifier connected to ADC inputs
- Dual 12-bit ADC
- Six-channel, 15-bit PWM

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For wireless communication, power management, keypad and speaker implementation, see Chapter 3 Introduction.

MC56F800x—MC56F8006 and MCF56F8002 Digital Signal Controllers

Key features of these DSCs include:

- Single-cycle 16 × 16-bit parallel multiplier-accumulator (MAC)
- Four 36-bit accumulators including extension bits
- Two 2x-16x programmable gain amplifiers (PGAs)
- Three analog comparators
- Two 12-bit ADCs
- Six output PWMs with programmable fault capability
- Two 16-bit timers, one 16-bit periodic interval timer and a programmable delay timer
- Ultra-low-power operation (nine different power modes)

Ideal Applications

- Motor control
    - Three-phase BLDC motor control
    - Entry level field-oriented control
    - Permanent magnet synchronous motor (PMSM) control
    - Large and small home appliances
- Advanced power conversion
    - Board-mounted and industrial power supplies
    - Switched-mode power supply and power management
    - Arc fault protection
    - Advanced lighting control
- Power-sensitive applications
    - Medical portable diagnostic and therapeutic devices
    - Hand-held power tools
    - Instrumentation

Figure 9-7: Simplified Application Using Digital Signal Controller

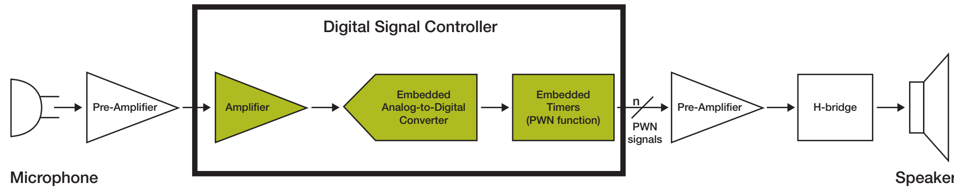
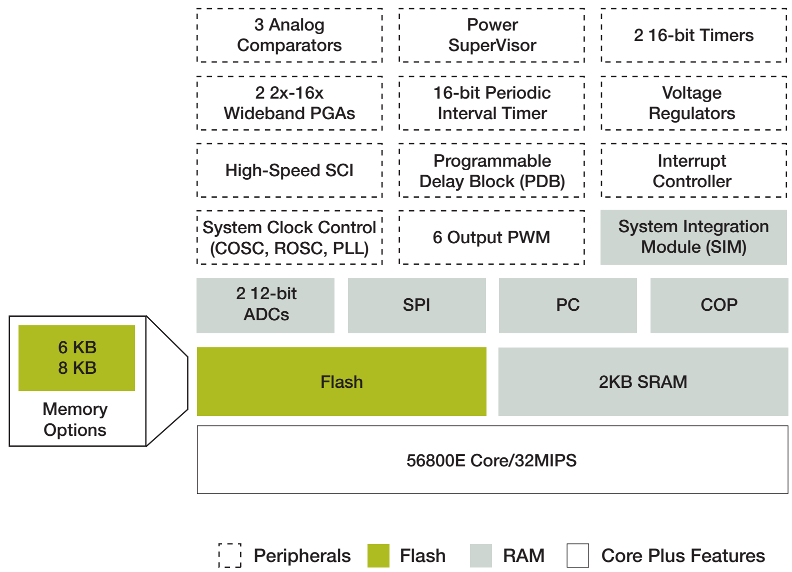


Figure 9-8: MC56F800x Block Diagram



Application Notes

- *Static Serial Bootloader for MC56F800x/801x/802x/803x* (document AN3814)
- *Implementing a Modular High Brightness RGB LED Network* (document AN3815)
- *Single-Phase Two-Channel Interleaved PFC Converter Using MC56F8006* (document AN3843)

9.6 Additional Freescale Technologies

Table 9-1 describes additional Freescale devices that can be used for hearing aid applications. In addition to the standard off-the-shelf devices described previously, Freescale also has the ability to mix and match state-of-the-art IP to create a custom solution for hearing aids. For more information about any of these devices and application notes, visit freescale.com.

Table 9-1 Additional Freescale Technologies for Hearing Aids

Device	Description	Key features	Applications	Application Notes
MC3467x	Battery management	Constant current (CC) charge mode. Constant voltage (CV) charge mode	Power management	AN1902: Quad Flat Pack No-Lead (QFN) Micro Dual Flat Pack No-Lead (µDFN)

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Diagnostic and Therapy Devices

10.1
Introduction

Reliability and accuracy are key considerations for diagnostic and therapy devices. These devices are used in health-critical situations where physiological events need to be recognized quickly and addressed appropriately. Whether a therapist is using a high-tech stationary bicycle helping a patient undergo rehabilitation, or monitoring the EKG wave of patients after surgery, these devices need a core that is powerful enough to acquire, process and interpret several parameters all at once. Freescale's 32-bit processors are ideal to do this and more.

Freescale offers a spectrum of processors (ColdFire, i.MX and Power Architecture) in terms of performance and integration. Integrated USB facilitates convenient data transfer from a device to a PC for processing or long-term storage. LCD interfaces common on ColdFire and i.MX processors provide clinicians and patients a meaningful way to visualize clinical data in real time.

Integrated Ethernet allows for data sharing in a variety of ways. Diagnostic or therapeutic medical devices can be positioned for the home or clinical market. Freescale's Controller Continuum enables development on an 8-bit platform for simple home devices that can then be upgraded to 32-bit platforms as new application needs arise for the clinical market. The Controller Continuum serves as a powerful resource for building fully integrated scalable medical solutions for the home or a clinic.

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10.2

Electrocardiograph and Portable ECG

An electrocardiogram (ECG or EKG) is a graph produced by an electrocardiograph that records the electrical activity of the heart over time. This allows health care providers to diagnose a wide range of heart conditions.

A portable ECG is a device which plots the electrical activity generated in the heart against time. It is the test most used to measure the functionality and pathologies of the heart, such as arrhythmias. The function of the electrocardiograph is based on the electrical activity of heart cells due to the depolarization that contracts the heart and creates heartbeats. The obtained signal is called a QRS complex.

10.3

QRS Complex

A typical ECG period consists of P, Q, R, S and T waves (see Chapter 5, Heart Rate Monitor). Each wave represents something and helps in diagnosis. Sometimes the signal is represented as QRS complex and P and T waves. The QRS complex is separated from the signal to receive specific information.

To obtain the QRS complex, a digital high-pass filter is implemented to remove noise and drift. A differential is used to emphasize R and smooth T, and square the signal and integrate it to smooth noise. This is done over a short period so as not to smooth the R wave.

The beating heart generates an electric signal that helps to diagnose or examine the heart. This signal can be represented as a vector quantity. Therefore, the location of the electrical signal that is being detected needs to be known. To get a typical signal it is necessary to place three electrodes: one on the patient's left arm, the other on the right arm, and the ground electrode on the patient's stomach or left leg.

Figure 10-1: Electrocardiograph Block Diagram

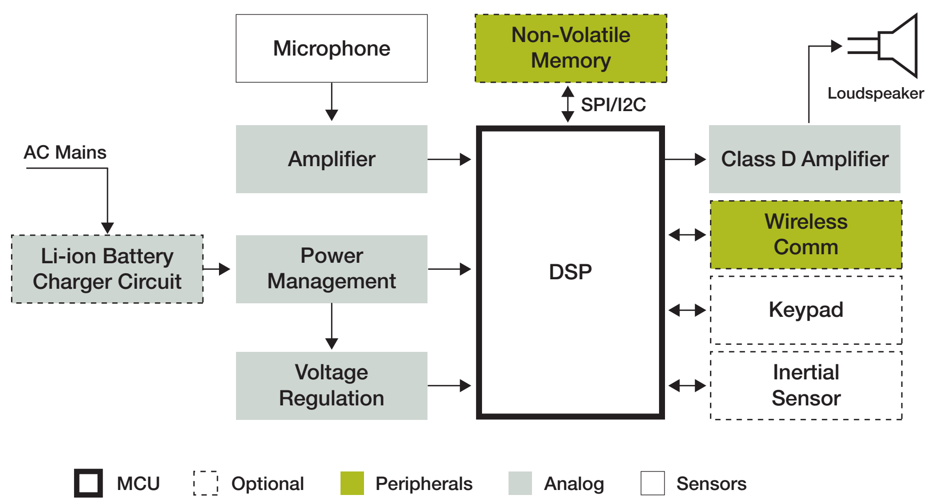


Figure 10-2: Portable ECG Block Diagram

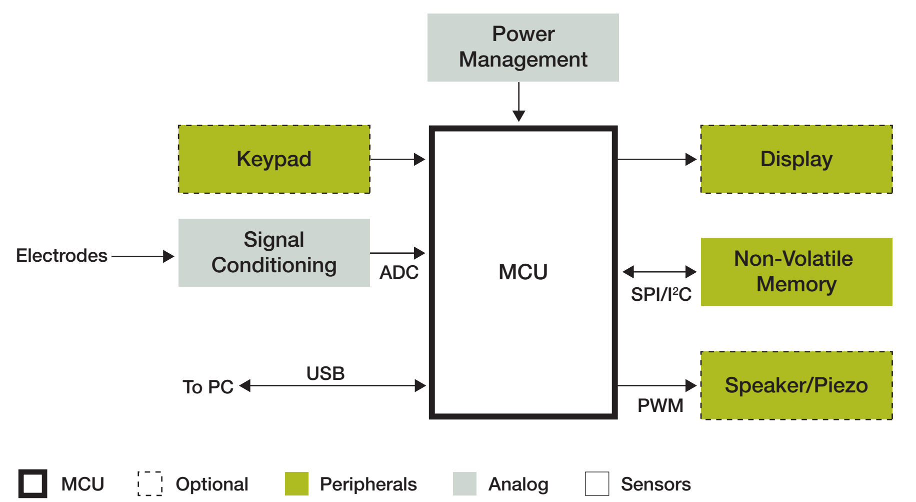
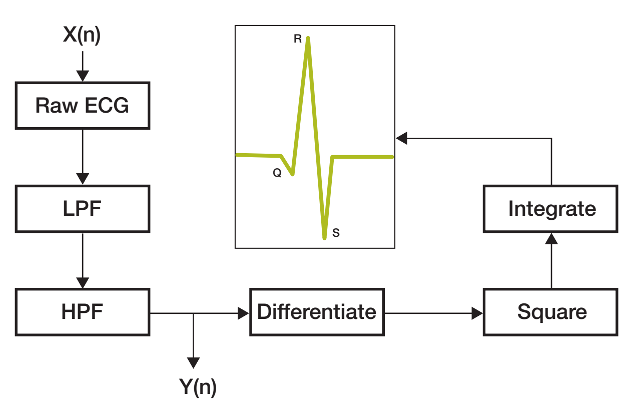


Figure 10-3: Digital Signal Processing to Obtain the QRS Complex



10.4
Filtering ECG

The ECG has three common noise sources:

- Baseline wander
- Power line interference
- Muscle noise

The baseline wander is caused by electrode impedance, respiration, body movements and low- and high-frequency noise. This makes it necessary to use a band-pass filter as described in Chapter 5, Heart Rate Monitor. To eliminate the low-frequency noise, a high pass filter with a cut-off frequency of 0.67 Hz is used, because this corresponds to the slowest heart rate of around 40 beats per minute. However, because this is not an absolute data point, it is better to use a cut-off frequency of 0.5 Hz. Figure 10-5 shows a basic implementation circuit that detects the electrical currents through the electrodes.

10.5
Electrodes Interface

The amplitude of the signals detected by the electrodes is too small. The signals are connected to operational amplifier inputs through series limiter resistors (typically 100K), and amplified a little. The feedback network helps to stabilize the system at the beginning of the capture time, reducing fluctuations. Finally, the signal is sent to an active low-pass filter. The filter eliminates the high-frequency noise which might be induced by the AC line.

Other noise sources such as respiration and muscular movement (low-frequency noise) are filtered using a high-pass filter. These noise sources require a band-pass filter and not just a low-pass filter.

MCF5227X: V2 Microcontroller with a Touchscreen, LCD Controller and USB

Key features of this MCU include:

- 8 KB configurable I/D cache
- 128 KB bytes SRAM
- Integrated LCD controller
    - CSTN and TFT w/up to 800 x 600 (SVGA) resolution

Figure 10-4: Einthoven Triangle

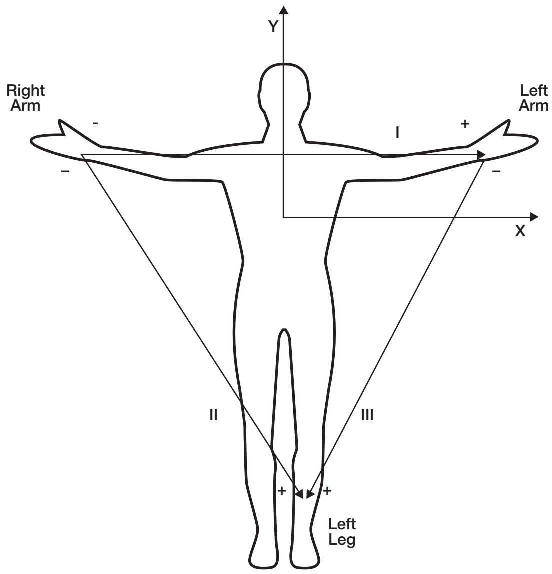


Figure 10-5: Electrodes Connection Circuit and Signal Conditioning

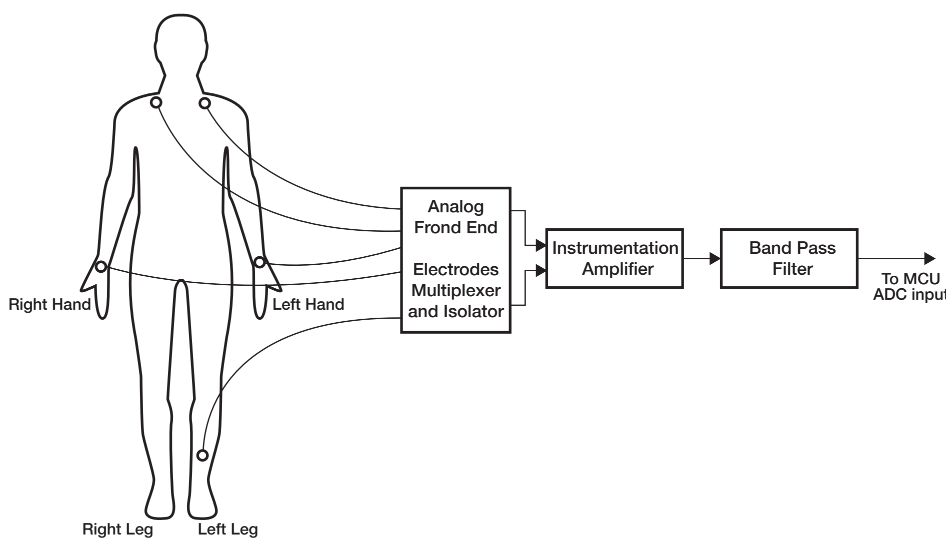
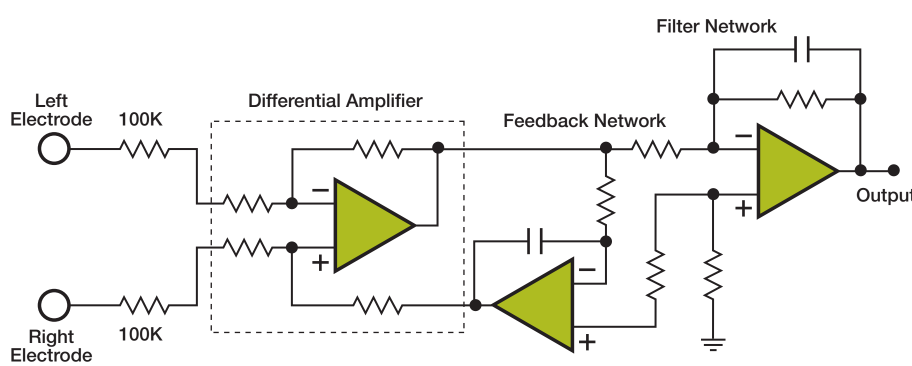


Figure 10-6: ECG Analog Front End



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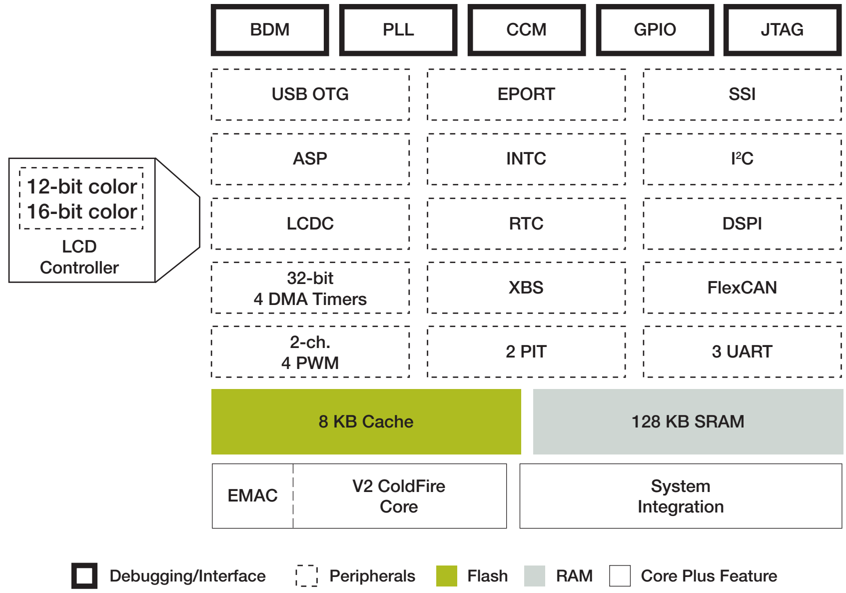
- 8x12-bit ADC w/touch-screen controller
  - Real touch screen controller
- USB 2.0 full-speed On-The-Go controller
- CAN 2.0B controller (FlexCAN)
- Three UARTs
- DMA serial peripheral interface (DSPI)
- I²C bus interface
- Synchronous serial interface (SSI)
- 4-ch., 32-bit timers with DMA support
- Real-time clock
- 16-ch. DMA controller
- 16-bit DDR/32-bit SDR SDRAM controller
- Up to 55 general-purpose I/O
- System integration (PLL, SW watchdog)
- 1.5V core, 1.8V/2.5V/3.3V bus I/O

Power management and wireless communication blocks are explained in Chapter 3, Telehealth Systems.

Figure 10-7: MCF522x Family Block Diagram



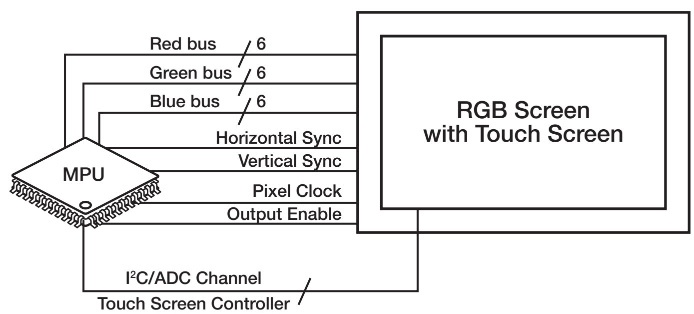
10.6 Display Driver and Touch Screen Controller

An LCD screen shows graphically the heart's electrical signals and allows for a diagnosis of any cardiac anomalies or other problems. A touch screen offers developers an easy way to enhance their applications with touch-based user interfaces.

Connecting screens to the MCF5227x is shown in Figure 10-8.

For more information about these connections, see the MCF5227x Reference Manual and application notes about touch screens and LCD memory, available at freescale.com.

Figure 10-8: Screen Connection on MCF5227x

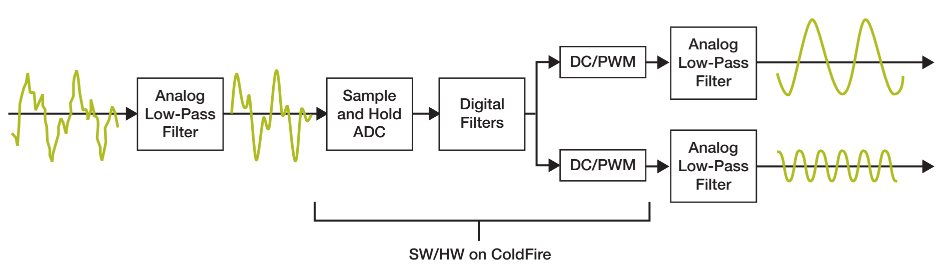


10.7 Enhanced Multiply-Accumulate (eMAC) Module

A ColdFire microprocessor such as the MCF5227x can process the digital signals of the heartbeat, avoiding the need to use a separate DSP or DSC.

The eMAC design provides a set of DSP operations that can improve the performance

Figure 10-9: Typical DSP Chain



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of embedded code while supporting the integer multiply instructions of the baseline ColdFire architecture.

The ColdFire family supports two MAC implementations with different performance levels and capabilities. The original MAC features a three-stage execution pipeline optimized for 16-bit operands with a 16 x 16 multiply array and a single 32-bit accumulator. The eMAC features a four-stage pipeline optimized for 32-bit operands with a fully pipelined 32 × 32 multiply array and four 48-bit accumulators.

The eMAC improvements target three primary areas:

- Improved performance of 32 × 32 multiply operation
- Addition of three more accumulators to minimize MAC pipeline stalls caused by exchanges between the accumulator and the pipeline's general-purpose registers
- A 48-bit accumulation data path to allow a 40-bit product plus eight extension bits to increase the dynamic number range when implementing signal processing algorithms

The logic required to support this functionality is contained in a MAC module (Figure 10-10).

Figure 10-11 is a typical implementation of digital signal processing using ColdFire.

Freescale provides two documents describing DSP algorithms functionality:

- ColdFire DSP Library Reference Manual Rev 0.4
- Digital Signal Processing Libraries Using the ColdFire eMAC and MAC
  - Fast-Fourier transform (FFT)
  - Finite impulse filter (FIR)
  - Infinite impulse filter (IIR)

ColdFire microprocessors such as the MCF5227x can perform digital signal processing using the enhanced multiply-accumulate module. This allows medical applications such as an electrocardiograph to perform heart signal filtering more efficiently.

Figure 10-10: Multiply-Accumulate Functionality Diagram

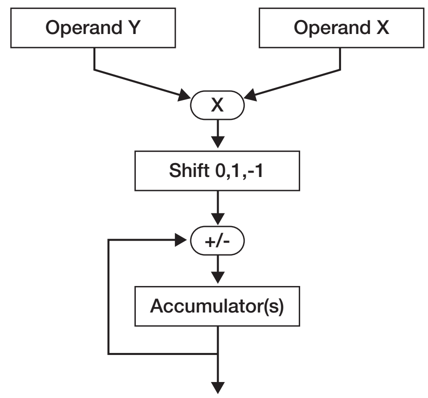
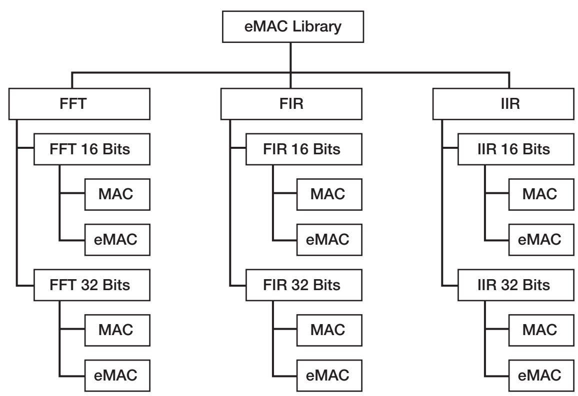


Figure 10-11: DSP Library Structure



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10.8 USB Connection

The USB connection allows the EGC to communicate with other devices such as hospital servers, remote monitoring systems and computers. This can be implemented using the USB On-the-Go module in the MCF5227x. This module can be implemented as a host or as a device. The MCF5227x has internal PHY and the connection requires only external pull-up or pull-down resistors.

Figure 10-12: Hardware Configuration in Host Mode

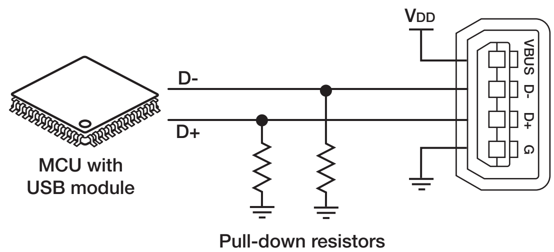
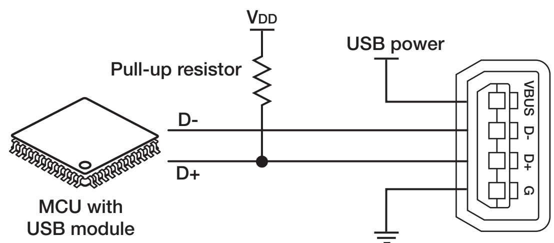


Figure 10-13: Hardware Configuration in Device Mode



10.9 Additional Freescale Technologies

This table describes additional Freescale devices that can be used for electrocardiograph and portable ECG applications. To read the application notes or for more information about any of these devices, visit www.freescale.com.

Table 10-1. Additional Freescale Technologies for Electrocardiograph and Portable ECG Applications

Device	Description	Key features	Applications	Application Notes
MCF5225X	One-stop-shop connectivity 32-bit microcontrollers	External mini-FlexBus interface	• Portable ECG • Ventilation/Spirometry • Hospital Admission Machine	AN3905: Writing First MQX Application AN3906: Serial-to-Ethernet Bridge Using MCF51CN Family and FreeRTOS
MCF5227X	V2 microcontroller with touch screen	LCD controller and USB	• Portable ECG • Defibrillators • Vital Signs Monitoring • Ultrasound Control System • Anesthesia Unit Monitor	AN3300: General Soldering Temperature Process AN3298: Solder Joint and Package Peak Temperature AN3631: Simplified Device Data Structures for ColdFire AN3606: LCD Memory and Bus Bandwidth AN3632: Touch Screen Controller on the MCF5227x AN3631: Simplified Device Data Structures for the High-End ColdFire Family USB Modules AN3750: Using a USB Device with ColdFire OTG Module MCF522xx and a PC
MC34940	Proximity sensor	Appliance control panels and touch sensors linear and rotational sliders spill over flow sensing measurement	• Portable ECG • Vital Signs Monitoring • X-Ray User Interface	AN3747: Pad Layout Application Note AN1985: Touch Panel Applications AN3456: Generating a Supply Rail for the MC34940 and MC34941 in Low Voltage Systems

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Defibrillators

11.1

Automated External Defibrillator (AED)

An automated external defibrillator (AED) is a portable device used to restore normal heart rhythm to patients in cardiac arrest by delivering an electrical shock to a patient through the chest wall. Cardiac arrest is an abrupt loss of heart function. This occurs mainly because of ventricular fibrillation. This is a medical emergency.

Ventricular fibrillation is a condition where there is an uncoordinated contraction of the ventricles in the heart, making them tremble rather than contract properly. The urgency of ventricular fibrillation requires that the heart must be defibrillated quickly; a victim's chance of surviving drops by 7 to 10 percent for every minute a normal heartbeat is not restored.

An MCU calculates whether defibrillation is needed and a recorded voice indicates whether to press the shock button on the AED. This shock momentarily stuns the heart and stops all activity, giving the heart an opportunity to resume beating effectively.

The charge is generated by high-voltage generation circuits from energy stored in a capacitor bank in the control box. The capacitor bank can hold up to 7 kV of electricity. The shock delivered from this system can be anywhere from 30 to 400 joules.

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11.2
Circuit for Capacitive Discharge Defibrillators

In Figure 11-2, a step-up transformer (T2) drives a half-wave rectifier and charges the capacitor (C1). The voltage where C1 is charged is determined by a variable autotransformer (T1) in the primary circuit. A series resistor (R1) limits the charging current to protect the circuit components, and determines the time constant Tao (T = R x C).

Five times the time constant for the circuit is required to reach 99 percent of a full charge. The time constant must be less than two seconds to allow a complete charge in less than ten seconds.

11.3
Circuit for Rectangular-Wave Defibrillators

In a rectangular-wave defibrillator, the capacitor is discharged through the patient by turning on a series of silicon-controlled rectifiers (SCR). When sufficient energy has been delivered to the patient, a shunt SCR short circuits the capacitor and terminates the pulse. This eliminates the long discharge tail of the waveform. The output may be controlled by varying either the voltage on the capacitor or the duration of discharge. Figure 11-3 shows a general diagram of circuit implementation.

Bipolar defibrillators are more efficient because they need less energy while providing the same results as unipolar defibrillators. A bipolar defibrillator needs just 120 J to discharge. It has the same efficiency as the 200 J of discharge used by a unipolar defibrillator.

An ECG unit must be included in the defibrillator's system to monitor heart activity and to control the moment when the discharge can be applied to the patient. The electrodes perform both functions, capturing the patient's ECG and delivering a high current.

Figure 11-1: Defibrillators General Block Diagram

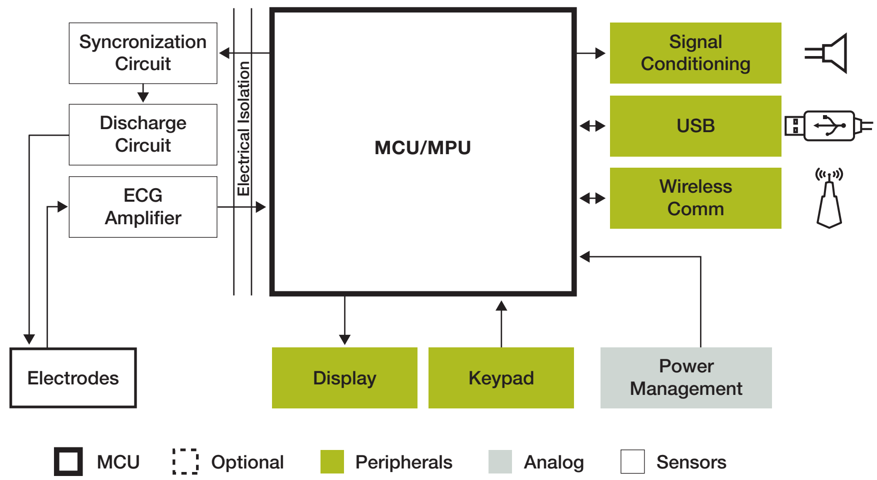


Figure 11-2: Basic Circuit Diagram for a Capacitive Discharge Defibrillator

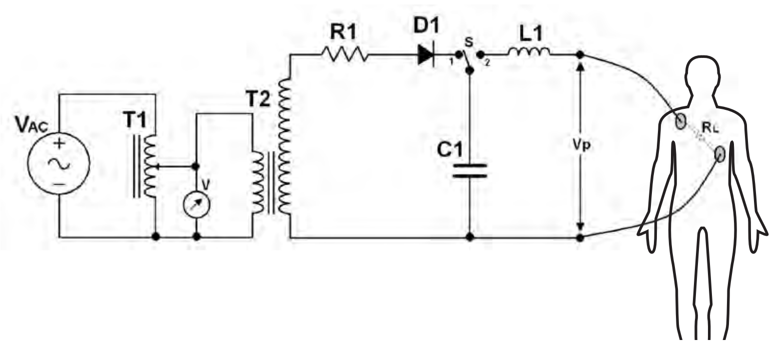
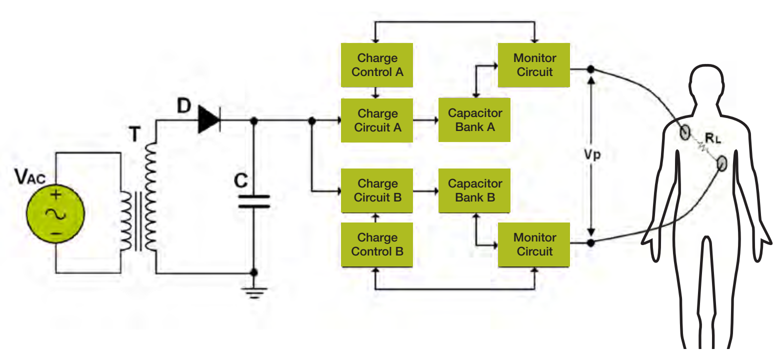


Figure 11-3: Block Diagram for a Rectangular-Wave Defibrillator



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11.4
Additional Freescale Technologies

Table 11-1 describes additional Freescale devices that can be used for defibrillator applications. To read the application notes, or for more information about any of these devices, visit freescale.com.

For power management, keypad and signal conditioning (for speaker) and wireless communication modules, see Chapter 3 Introduction. For display (optionally with touch screen) and USB communication modules, see Chapter 10.2 Electrocardiograph and Portable ECG.

Figure 11-4: Unipolar Defibrillator Waveform

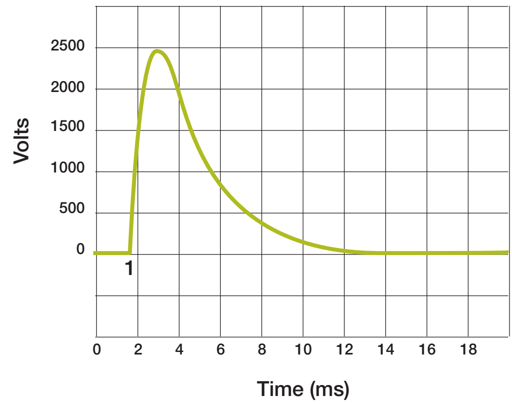

Figure 11-5: Bipolar Defibrillator Waveform

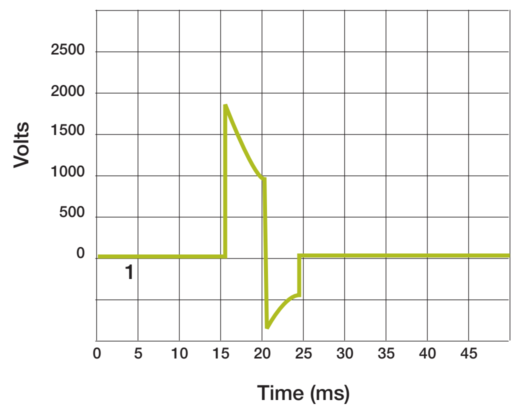

Table 11-1. Additional Freescale Devices For Defibrillator Applications

Device	Description	Key features	Applications	Application Notes
MC3467x	V3 ColdFire microprocessor	LCD driver Ethernet USB CAN	• Defibrillators • Vital Signs Monitoring Hospital • Admission Machine • Control System • Anesthesia Unit • Monitor • Powered Patient Bed	AN3324: Hardware Configurations for the MCF532x AN3408: Building a Sample CGI Application AN3757: Using MCF5329EVB NAND Flash to Host uClinux Root File System

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Ventilation and Spirometry

12.1

Introduction

A ventilator is a machine designed to mechanically move air in and out of the lungs to intermittently or continuously assist or control pulmonary ventilation. This apparatus is principally used in intensive therapy to help improve the patient's breathing by regulating the flow of gas in the lungs. The most common indices of the ventilation apparatus are the absolute volume and changes of volume of the gas space in the lungs achieved during a few breathing maneuvers. The ventilator is constantly monitored and adjusted to maintain appropriate arterial pH and PaO2.

This system requires a set of sensors for pressure, volume and flow. The information from the sensors modulates the operations in the MCU. This MCU receives information from the airways, lungs and chest wall through the sensors and decides how the ventilator pump responds.

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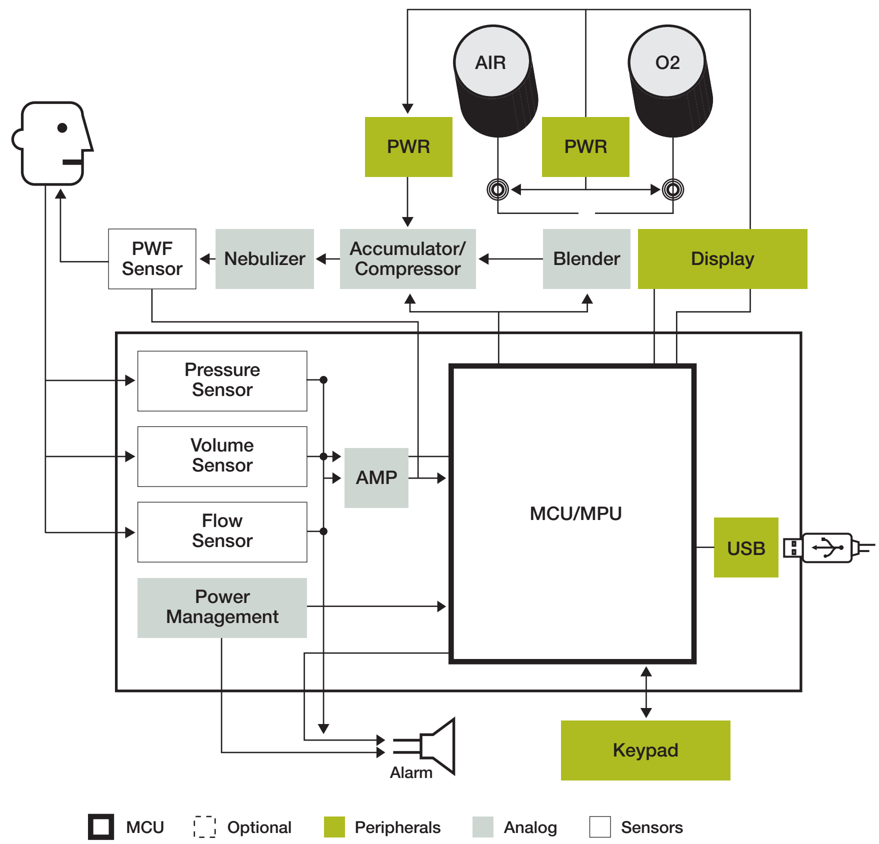
12.2
System Sensors

The signal that shows lung volume is a differential signal, but this is not the signal measured directly from the lungs. To get this signal, it is necessary to transduce the pressure to voltage. This is done by using a pneumotachometer that contains a pressure sensor.

Freescale provides a variety of sensors that use integrated circuits for signal conditioning. This is an advantage because external components are not necessary. However, it is necessary to check the resolution of the sensor and the ADC. If the resolution of the ADC is greater than the sensor, amplifying the signal is recommended. Some sensors provide differential outputs for when it is necessary to pass the signal through an instrument amplifier. The sensor used is a differential pressure sensor that can accept two sources of pressure simultaneously. The output is proportional to the difference of the two sources. It is important to mention that the normal pipeline gas source of a hospital is 50 PSI, a measurement that can be taken by Freescale's pressure sensors. Freescale pressure sensors include MPX2301DT1, MPXC2012DT1, MPXx5050 and MPXx5050.

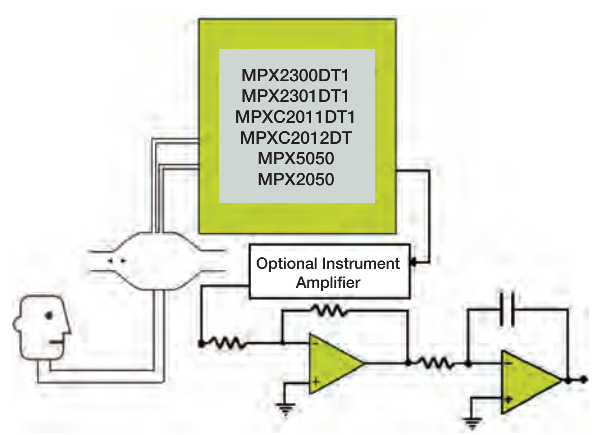
Figure 12-1: Ventilation/Respiration General Block Diagram



12.3
Spirometer

Spirometers measure static pulmonary volumes, except the functional residual capacity (FRC) and total pulmonary capacity (TPC). The measurement is done after a maximum inspiration that requires the patient to expel the entire volume of air that he or she can. The results are interpreted and compared with the values for age, height, sex and race of the patient. Due to variations among normal individuals, normal values can fall between 80 to 120 percent of the expected volume. Figure 12-2 illustrates how to configure a spirometer using a pressure sensor. The next two figures observe the different volumes of lungs.

Figure 12-2: Spirometer



Lung volume measurements include:

- Tidal volume (TV)—The amount of gas inspired or expired with each breath (500 ml)
- Inspiratory reserve volume (IRV)—Maximum amount of additional air that can be inspired at the end of a normal inspiration (2500 ml)
- Expiratory reserve volume (ERV)—The maximum volume of additional air that can be expired at the end of a normal expiration (1500 ml)
- Residual volume (RV)—The volume of air remaining in the lungs after a maximum expiration (1500 ml)

These measurements can be used in the following equations to express lung capacities:

- Total lung capacity (TLC)
  TLC=RV+IRV+TV+ERV (6000 ml)
- Vital capacity (VC)
  VC=IRV+TV+ERV=TLC-RV (4500 ml)
- Functional residual capacity (FRC)
  FRC=RV+ERV (3000 ml)
- Inspiratory capacity (IC)
  IC=TV+IRV (3000 ml)

12.4
Graphic LCD MPU

Freescale offers the following devices that generate graphics. These devices can be used to show lung volume.

- MCF5227X V2 microcontroller with touch screen, LCD controller, and USB: The 32-bit ColdFire microprocessor portfolio is expanding with low system cost LCD solutions, giving control, flexibility and performance options for human machine interface and industrial control applications
- MCF532X V3 ColdFire microprocessor with LCD driver, Ethernet, USB and CAN: By introducing the integrated LCD controller on a 68K and ColdFire device, the MCF532x family of microprocessors addresses the growing demand for human interfaces on machine and industrial control applications while maintaining a rich level of connectivity and security integration.

Figure 12-3: Normal Spirometer

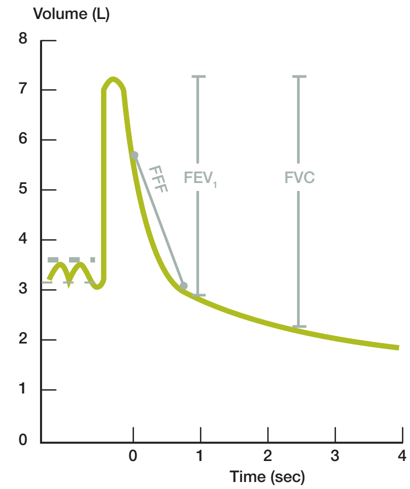
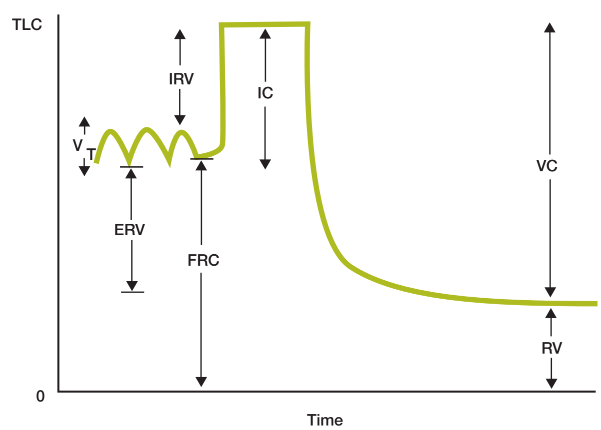


Figure 12-4: Normal Lung Volume



For more information, see the application note titled *Understanding LCD Memory and Bus Bandwidth Requirements* (document AN3606) available at freescale.com.

12.5
Alarm System

An important part of this application is an alarm that can indicate different patient parameters such as exhaled volume or airway pressure. The ventilation system must be able to detect whether a breath has been taken. The MCU measures changes in aspiratory flow and pressure by using sensors. If no inspiration is detected within a certain period of time, the monitor sounds an alarm. The conditions to be programmed depend on each system. PWM cycles can be programmed to sound the alarms. Sometimes, the ventilation system uses different alarms for different situations. To see the alarm circuit, refer to Chapter 3, Telehealth Systems.

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12.6
Air and Oxygen Blender and Mix Control

The air and oxygen blender provides a precise oxygen concentration by mixing air and oxygen. The concentration may be adjusted to any value from controlled air to 100 percent oxygen. Internally, a proportioning valve mixes the incoming air and oxygen as the oxygen percentage dial is adjusted. Variation in line pressure, flow or pressure requirements for any attached device will not affect the oxygen concentration.

The preparation of an air and oxygen blender generally consists of attaching a 50 PSI air and oxygen source to the device. After the source gases are attached, inlet pressures may be checked on some blenders by checking the pressure-attached pressure gauge. After the inlet gases are attached and the air and oxygen blender is well secured to a stand or wall mount, it is ready for use. The MCU uses a PWM to control the blender electro valves through a motor control design.

Early ventilator designs relied on mechanical blenders to provide premixed gas to a single flow control valve. With the availability of high-quality flow sensors and processing capabilities, accurate mixing becomes possible by using separate flow valves for air and oxygen. Because air already contains about 21 percent oxygen, the total flow control command between the oxygen and air valve is divided ratiometrically. For extreme mix settings, the valve that supplies the minor flow at low total flow requirements may fall below the resolution limits that either flow delivery or measurement can provide. An accurate delivered mix depends on accurate flow delivery, but if accurate and reliable oxygen sensors are used, improved mix accuracy may be possible by feeding back a measured concentration for mix correction. Then, if the patient needs more pressure, the MCU activates the compressor.

To learn more, see the article *Automatic Ventilation Control* in the Freescale design magazine *Beyond Bits IV*.

Figure 12-5: Graphic LCD Product Map

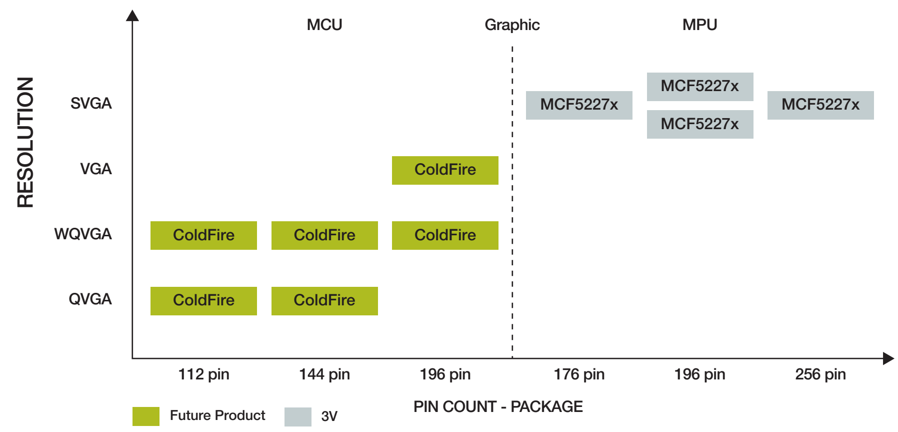
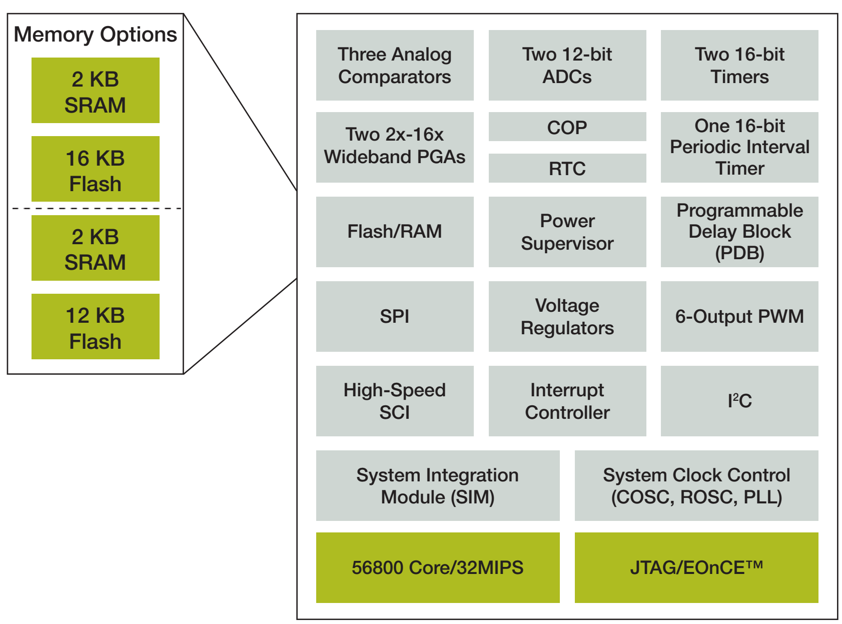


Figure 12-6: MC56F8006/2 Block Diagram



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MCF5225X: One-Stop-Shop Connectivity in 32-bit Microcontrollers

Key features of this MCU include:

- V2 ColdFire core with 66 MHz and 80 MHz options
- Complimentary Freescale MQX software solutions
- Connectivity—USB 2.0 full-speed host/device/OTG controller, FlexCAN controller and 10/100 Ethernet controller
- External mini-FlexBus interface
- Cryptographic accelerator unit
- Up to 512 KB of flash memory
- Up to 64 KB SRAM

MPX230xDT1: High Volume Pressure Sensor

Key features of this sensor include:

- Cost effective
- Integrated temperature compensation and calibration
- Ratiometric to supply voltage
- Polysulfone case material (ISO 10993)
- Provided in tape and reel

MPXx5050: –50 to 0 kPa and 0 to 50 kPa Integrated Silicon Pressure Sensor, Temperature Compensated and Calibrated

Key features

- 2.5% maximum error over 0° to +85°C
- Ideally suited for microprocessor or microcontroller-based systems
- Temperature compensated from over -40°C to +125°C
- Patented silicon shear stress strain gauge

MPXx2050: 50 kPa Pressure Sensor

Key features of this sensor include:

- Temperature compensated over 0°C to +85°C
- Silicon shear stress strain gauge
- Available in rails or tape-in-reel shipping options
- Ratiometric to supply voltage
- Differential and gauge options
- ±0.25% linearity

Figure 12-7: Blender Configuration

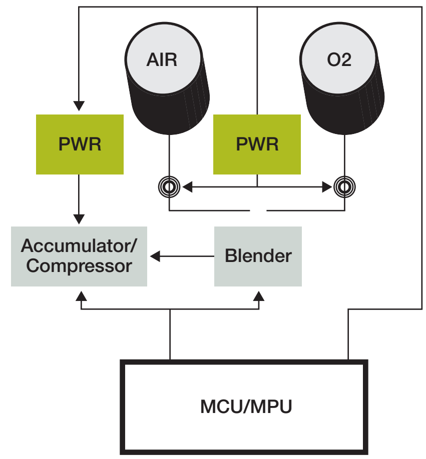

Figure 12-8: MCF5225x Block Diagram

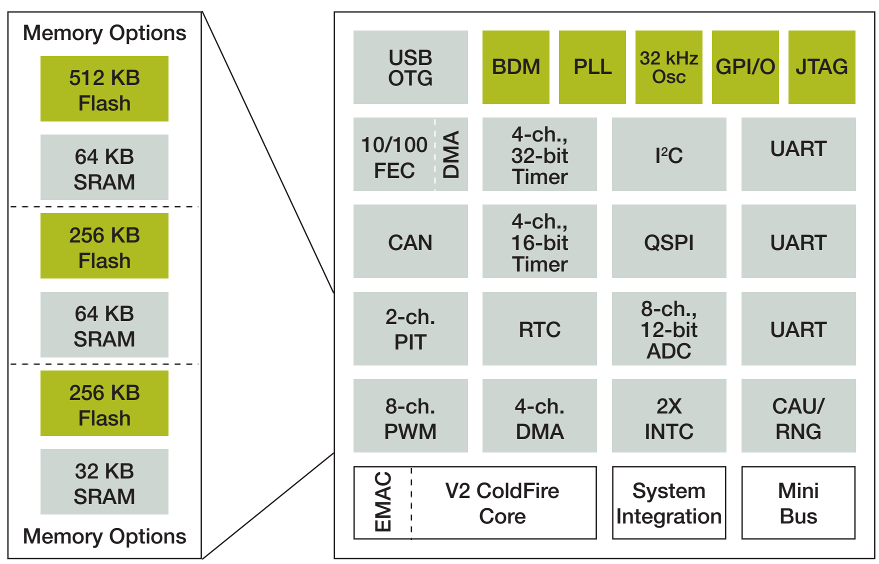

Table 12-1. MPXx2050 Packaging Information

Device Type	Packing Options	Case
MPX2050D	Differential	344
MPC2050DP	Differential, Dual Port	423 A
MPX2050GP	Gauge	344B
MPX2050GSX	Gauge Axial PC Mount	344F

12.7

Additional Freescale Technologies

This table describes additional Freescale devices that can be used for ventilation and spirometry applications. To read the application notes, or for more information about any of these devices, visit freescale.com.

For power management, keypad, signal conditioning and wireless communication modules, see Chapter 3 Introduction.

Table 12-2. Additional Freescale Technologies For Ventilation and Spirometry Applications

Device	Description	Key features	Applications	Application Notes
MCF5221X	32-bit microcontroller	USB On-The-Go	• Ventilation/Spirometry • X-Ray Control System • Anesthesia Unit Monitor	AN1984: Handling Freescale Pressure Sensors AN3150: Soldering Recommendations for Pressure Sensor Devices
MPX2300DT1	Compensated pressure sensor medical grade	Patented piezoresistive strain gauge implant, temperature compensation and calibration all integrated on a single, monolithic sensor die	• Blood Pressure Monitors • Ventilation/Spirometry • Sensors • Anesthesia Unit Monitor	AN1984: Handling Freescale Pressure Sensors AN3150: Soldering Recommendations for Pressure Sensor Devices
MPXx5050	Pressure sensor	-50 to 0 kPa and 0 to 50 kPa Temperature compensated and calibrated	• Blood Pressure Monitors • Ventilation/Spirometry • Sensors • Anesthesia Unit Monitor	Beyond Bits IV: Blood Pressure Monitors Beyond Bits IV: Automatic Ventilation Control
MPXx2050	50 kPa pressure sensor	Silicon shear stress strain gauge	• Blood Pressure Monitors • Ventilation/Spirometry • Sensors • Anesthesia Unit Monitor	AN1315: An Evaluation System Interfacing the MPX2000 Series AN1316: Frequency Output Conversion for MPX2000 Series AN1082: Simple Design for a 4–20 mA Transmitter Interface AN1097: Calibration-Free Pressure Sensor System AN1100: Analog to Digital Converter Resolution Extension Using a Pressure Sensor

Anesthesia Unit Monitor

13.1

Introduction

An anesthesia unit monitor is a machine that administers anesthesia to patients by one of two ways: intravenous or inhaled gas anesthesia.

It exchanges respiratory gases and administers anesthetic gases. It maintains a balance of gases through the respiratory and cardiovascular system.

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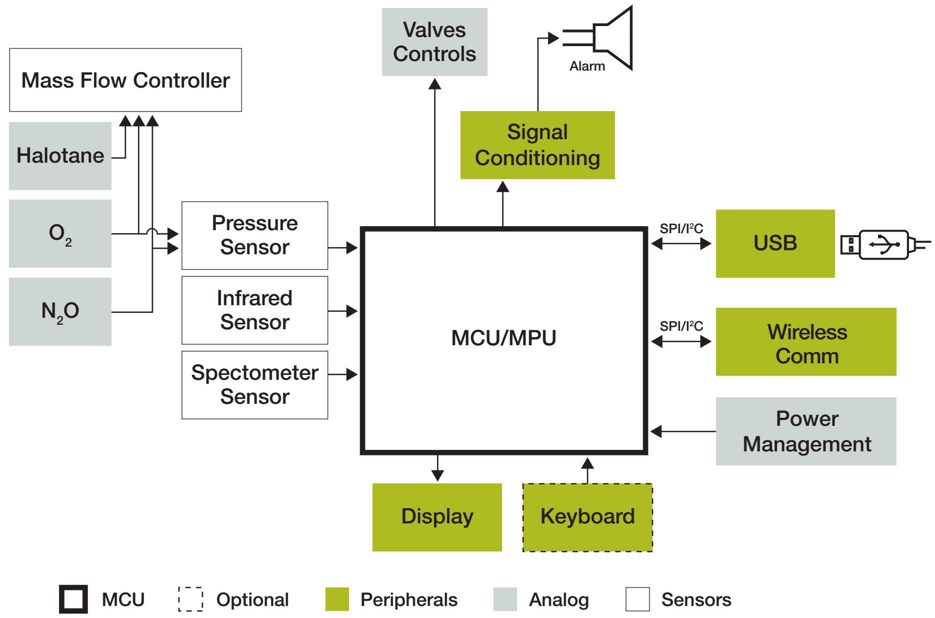
13.2
Brief Theory

As mentioned in Chapter 12, *Ventilation and Spirometry*, the hospital pipeline is the primary gas source at 50 PSI. This is the normal working pressure of gas machines. Oxygen is supplied at approximately 2000 PSI. Anesthesia flow is composed of different sections. The first is the gas supply and substance-delivery (Halotane, O2, and N2O) system. In this part the O2 and the N2O are mixed in the desired proportion. The mass flow controller indicates the amount of anesthetic substance delivered to the patient. The MCU controls the electromechanical valve that adjusts the flow rate and the volume of the gases (Halotane, O2, and N2O).

Figure 13-1: Anesthesia Unit Monitor

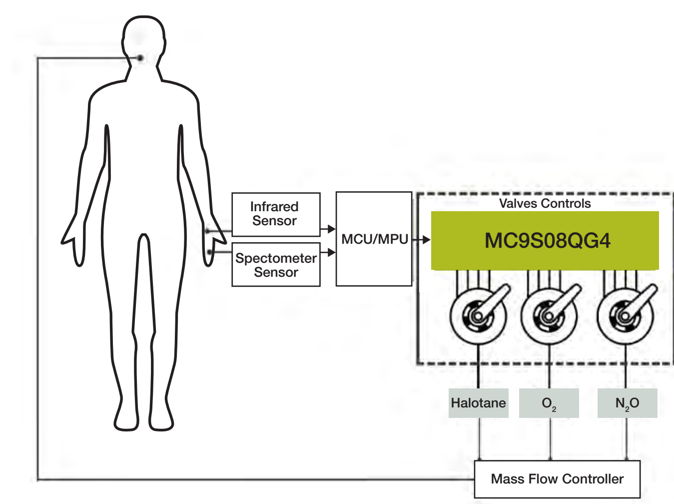


13.3
Pressure Sensor

This sensor helps the principal MCU take the pressure of the O2 and N2O. This measurement and the concentration of the substance are the variables that control the valves.

To see the configuration of the pressure sensor and the Freescale portfolio, see Chapter 12, *Ventilation and Spirometry*.

Figure 13-2: Anesthesia Application General Overview



13.4
Valve Control

Using a sensor, the MCU takes the concentration of the substances in the blood. With these parameters, the MCU knows how much drug/air/oxygen needs to be delivered to the patient and the required power to apply to the valves.

13.5
Principal MCU

The remainder of the process occurs in the second part, the vaporizer (there is a special apparatus to make this). Here, Halotane, O2 and N2O are mixed. These substances need to be vaporized so that the patient can breathe them and receive the necessary anesthesia. Therefore the principal MCU has to control the rate by adjusting the valves, depending on the pressure of the substances and their concentrations in the patient.

Finally, the patient breathes the anesthesia mixed through the mass flow controller.

The Freescale MCF520X and the MCF532X microcontrollers are recommended for this application.

MCF520X: Integrated V2 ColdFire External Memory and Ethernet Microprocessor

Key features of this processor include:

- High-performance V2 ColdFire core, 166 MHz
- eMAC (32 x 32) module, hardware divided

Integrated peripherals

- Flexible 16-bit DDR/32-bit SDR SDRAM memory controller
- Four channels, 32-bit timers with DMA support
- 16 channels, DMA controller
- 16-bit DDR/32-bit SDR SDRAM controller
- 50 general-purpose I/O

MCF532X: V3 ColdFire Microprocessor with LCD driver, Ethernet, USB and CAN

Key features of this processor include:

- V3 ColdFire core delivering up to 211 (Dhrystone 2.1) MIPS at 240 MHz
- 32 KB RAM
- 16 KB I/D-cache
- Enhanced MAC module, manages DSP-like instructions

Integrated peripherals

- USB Host/USB OTG
- 10/100 Fast Ethernet Controller (FEC)
- QSPI
- Serial Synchronous Interface (SSI)
- PWM—4 channels
- DMA—16 channels
- 16-bit DDR/32-bit SDR SDRAM controller
- Integrated SVGA LCD controller

Figure 13-3: MCF520x Family

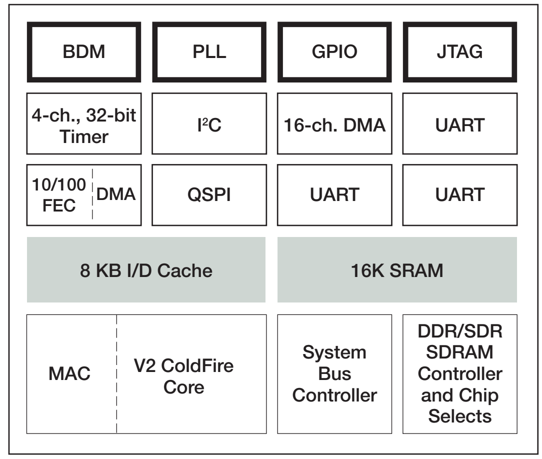
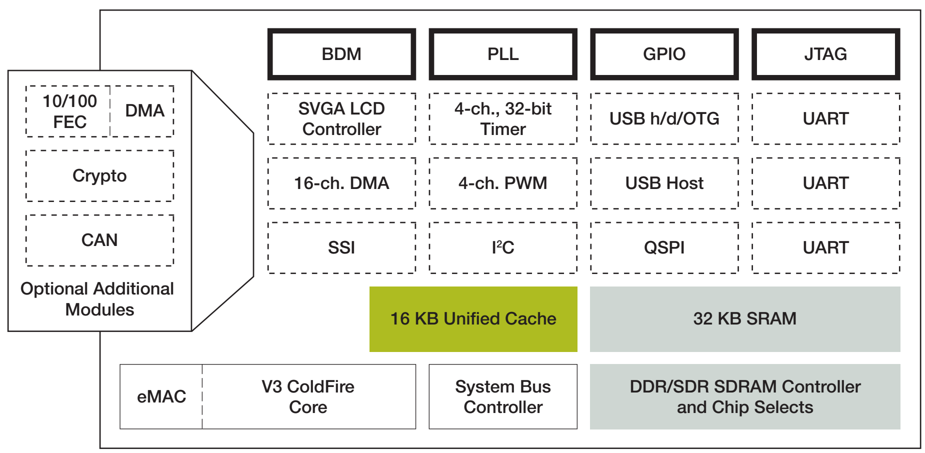


Figure 13-4: MCF532x Family Block Diagram



Vital Signs

14.1
Introduction

A vital sign monitor is a multi-parameter device that measures blood pressure, temperature, oxygen saturation and heart electrical activity to give a clear view of patient information.

This application constantly monitors the measurements from the ECG, pulse oximetry, blood pressure and temperature of the patient. For this application, Freescale offers medical solutions that use our product expertise in microcontrollers, sensors, analog and wireless technology for home portable medical devices, diagnostic and therapy devices and medical imaging devices. Freescale is dedicated to helping patients live a better life by driving innovation and enabling medical device manufacturers to leverage the latest available technology.

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14.2
Measuring Temperature

The Freescale S08QG family includes a temperature sensor whose output is connected to one of the ADC analog channel inputs. The approximate transfer function of the temperature sensor can be expressed by this equation:

Temp = 25 – ((VTEMP – VTEMP25)/m)

For more information about the temperature sensor, see the datasheet titled *MC9S08QG8/QG4 Device Datasheet,* available on the Freescale website at www.freescale.com.

Features of the ADC module include:

- Linear successive approximation algorithm with a 10-bit resolution
- Output formatted in 10- or 8-bit right-justified format
- Single or continuous conversion (automatic return to idle after a single conversion)
- Configurable sample time, conversion speed and power
- Conversion complete flag and interrupt
- Input clock selectable from up to four sources
- Operation in Wait or Stop3 modes for low noise operation

For more information about how to send the ADC values to the main MCU, see the application note titled *Analog-to-Digital Converter on an IIC Bus Using MC9S08QG8* (document AN3048), available on the Freescale website at www.freescale.com.

14.3
ECG Monitoring

For more information about designing ECG, pulse oximetry and blood pressure applications, see the relevant chapters.

14.4
Pulse Oximetry Monitoring

A pulse oximeter is a device that measures the amount of oxygen saturation in the blood. This parameter is useful for patients with metabolic disorders like respiratory acidosis, alcalosis, chronic obstructive pulmonary disease (COPD), and restrictive pulmonary disease.

Figure 14-1: Vital Signs Monitoring General Block Diagram

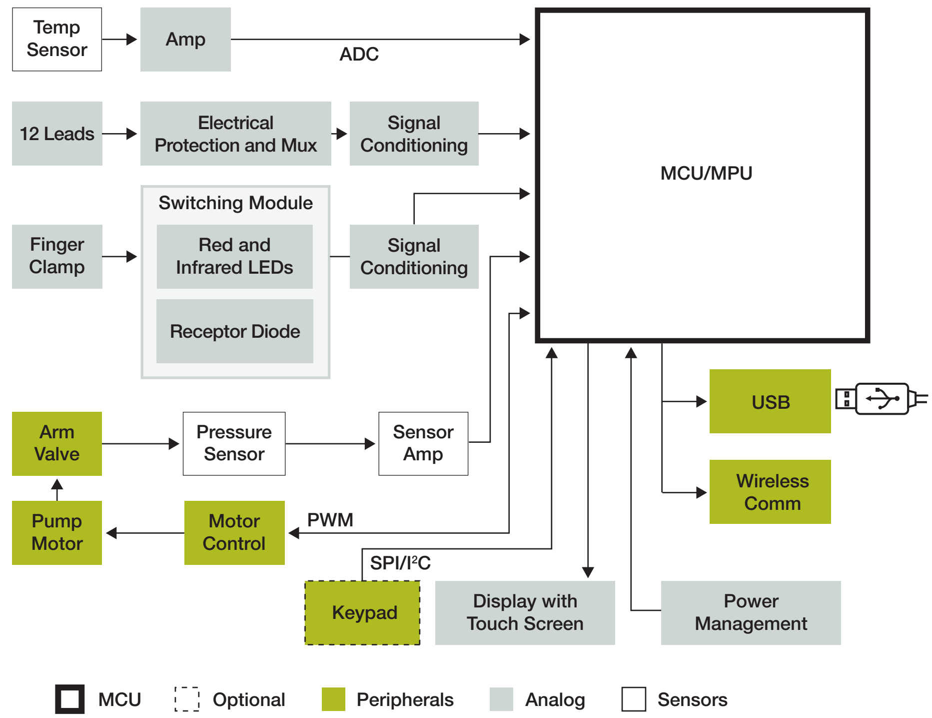


Figure 14-2: General Overview of Temperature Measurement

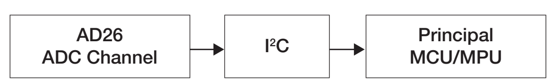
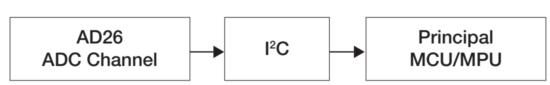


Figure 14-3: ECG Monitoring General Overview



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14.5 Blood Pressure Monitoring

A blood pressure monitor is a device that measures the systolic and diastolic blood pressure by inflating a cuff until it equals the systolic pressure and then deflates until the diastolic pressure is bypassed. Other parameters can be measured like mean arterial pressure and heart rate.

14.6 Motor Control with Freescale Devices

The Freescale MPC17C724 is a 0.4 amp dual H-bridge motor driver IC with the following features:

- Built in 2-channel H-bridge driver
- Provides four driving modes
  - Forward
  - Reverse
  - Break
  - High impedance
- Direct interface to the MCU
- Low ON-resistance, RDS(ON) = 1.0 Ω (typical)
- PWM control frequency 200 kHz (max)

To design Keypad, Power Management, Wireless Communications, and USB modules, see Chapter 3 Telehealth Systems Introduction. For a display with a touch screen see Chapter 10.2, Electrocardiograph and Portable ECG.

Figure 14-4: Signal Conditioning to ECG Monitoring

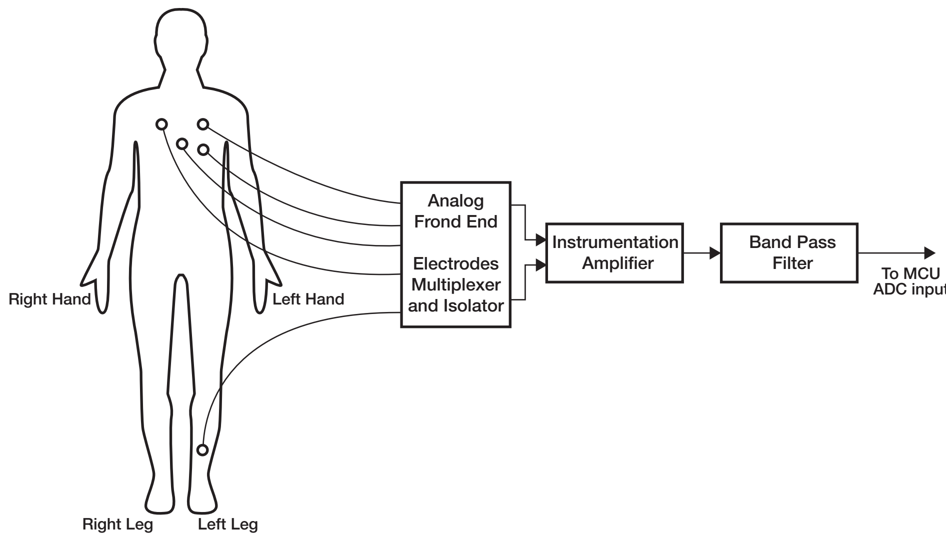

Figure 14-5: General Overview of Pulse Oximetry Monitoring

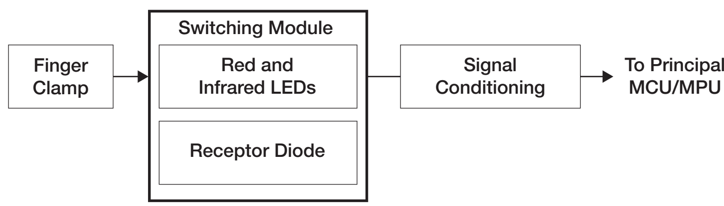

Figure 14-6: Signal Conditioning for Pulse Oximetry Monitoring

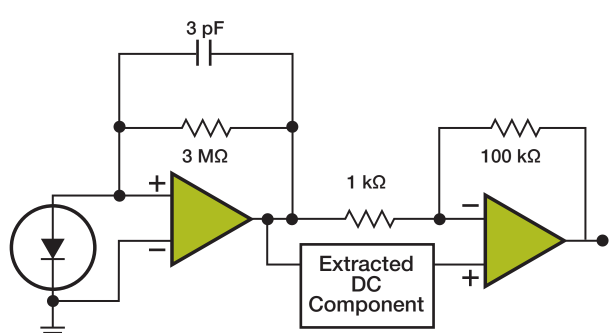

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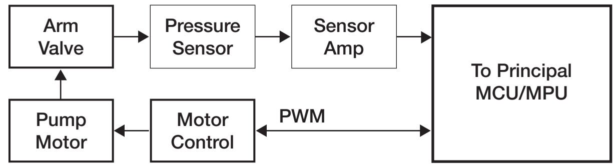
Table 14-1. S08QG Microcontroller Family	
Features	**S08QG**
Core	HCS08
Flash (byte)	8K/4K
RAM (byte)	512/256
Bus frequency	10 MHz
ADC	Up to 8 channels (10 bits)
Analog comparator	Yes
Keyboard interrupt	Up to 8 pins
Timers (up to)	1- to 16-bit timer (2 channels), one 16-bit timer
SCI	1
SPI	1
IIC	1
Operational voltage	1.8V to 3.6V

For Wireless Communication, Power Management, Keypad, and Speaker Implementation modules, see Chapter 3, Telehealth Systems Introduction.

Figure 14-7: General Overview of Pressure Monitoring



14.7

Additional Freescale Technologies

This table describes additional Freescale devices that can be used for vital sign monitoring applications. To read the application notes or for more information about any of these devices, visit www.freescale.com.

Table 14-2. Additional Freescale Technologies For Vital Sign Monitoring Applications

Device	Description	Key features	Applications	Application Notes
MCF520X	Integrated ColdFire V2 core	External memory Ethernet	• Vital Signs Monitoring • Ultrasound • Anesthesia Unit Monitor	AN2981: Migrating from the MCF5206e to the MCF5208 AN2982: System Design Using the Split Bus Architecture
S08QG	Microcontroller family	ADC with temperature sensor	• Vital Signs Monitoring • Temperature Sensor	AN3041: ICS Module on the HCS08s in Depth AN3552: Analog Comparator Tips and Tricks AN2111: A Coding Standard for Assembly Language AN2295: Developer's Serial Bootloader AN3048: ADC on an IIC Bus Using MC9S08QG8 AN3381: Using SMAC with the HCS08QD4 MCU AN3500: Blood Pressure Monitor Using Flexis QE128 AN3592: Low Power Management Unit with MC34700 AN3601: A Miner's Lamp Using MC9S08QG4 AN3031: Temperature Sensor for the HCS08 Microcontroller Family
MPC17C724	0.4 amp dual H-bridge motor driver IC	Driving modes—forward, reverse, break, high impedance	• Vital Signs Monitoring • Motor Control	AN3302: Interfacing the MPC17C724 with an 8-bit Processor

Intelligent Hospitals

15.1 Introduction

The connected hospital is the wave of the future. With the increasing acceptance of technology in the medical market, administrators are open to infusing that technology into hospitals to help increase the quality of service.

Automated hospital admittance kiosks, tracking devices/bracelets and automatic inventory control are just some of the applications the medical team is working on at Freescale. By leveraging our strengths in ColdFire and ARM® (i.MX) embedded processing, wireless communications and PowerQUICC network processing, Freescale strives to put the intelligence in hospitals.

15.2 Hospital Admission Machine

A hospital admission machine helps patients and doctors increase the efficiency of a hospital through automating procedures which usually take time from the nurses and administrative employees.

These solutions need to integrate a broad range of medical devices in order to perform necessary functions for the physician and increase the range of early diagnosis/ symptoms and signs that can alert medical staff to acute complications in patients being monitored at home (using portable mode) or in specific strategic places such as malls (using medical kiosks).

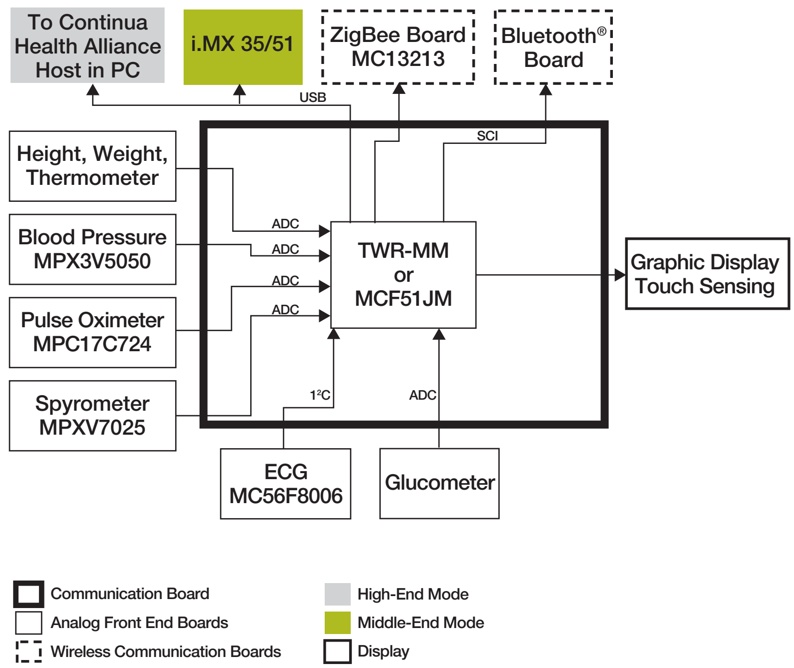
State-of-the-art technology—including low power, analog integrated microcontrollers such as Freescale's 8-bit 9S08MM and 32-bit MCF51MM—allow the designer to achieve portability for touch sensing and medical-grade communication (following Continua Health Alliance™ guidelines) with libraries that are downloadable from the Freescale webpage, http://www.freescale.com/medical. These elements enable solutions focused on preventive medicine, which ultimately reduce patients' acute complications and costs related to their treatment. This can help health institutions redirect money used for treatment toward prevention, and can help insurance companies cut costs.

The hospital kiosk includes a touch-sensing interface that allows the user to navigate the machine's interface. This flat surface makes the machine easier to disinfect after each user. It is more difficult to disinfect a machine with mechanical buttons that can hold pathogens such as bacteria and viruses in the edge of the buttons.

The kiosk includes a magnetic card reader used to identify the patient and to keep a record of the patient's abbreviated e-chart. The e-chart contains the following data:

- ID fields: first name, last name, birth date, gender, contact information
- Family medical history: Cancer, cardiovascular disease, chronic degenerative diseases such as arthritis, kidney disease, asthma, neurological disorders, etc.
- Personal medical history: Medicines, surgeries, diseases, etc.
- Non-pathological personal history: Blood type, alcohol and tobacco use, drug abuse, allergies, etc.)

Figure 15-1: Hospital Admission Machine General Block Diagram



Once the patient is identified through the magnetic card, the machine can take the following measurements:

- Capillary blood glucose levels
- Systolic, diastolic and mean arterial pressure
- Weight, height and body mass index
- Temperature
- Heart rate
- EKG DI
- Oxygen saturation level (SaO2)
- Maximum expiratory and inspiratory flow peak
- Inspiratory and expiratory lung volume

After that a test result paper is printed and a remote database is updated with these readings. If the kiosk detects a critical problem, it sends the report to a mobile device that could report the finding to a physician or healthcare provider.

A step-by-step video shows how to perform these tests so that the user can perform the tests without help from a healthcare professional. With language support in English, Spanish and Japanese, the user sees and hears how to perform these tests. As users become more familiar with the device, they may pay less attention to the instructions. This is why we also offer the patient monitor interface.

For an easy-to-use mode, the main core of the kiosk can be separated. This creates a USB-powered portable device for home use or use at remote facilities when a physician is not nearby.

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The following sections describe the parts of the system (some of them have already been described in previous chapters):

- Weight scale
- Height ultrasonic sensor
- Thermometer
- Blood pressure monitor (systolic, diastolic, mean arterial pressure)
- Heart rate monitor
- 1-lead EKG (DI)
- Pulse oximeter
- Blood glucose meter
- Spirometer (air flow and lung volume)

Figure 15-2: Portable Monitoring System

15.3
Patient Height and Weight

The patient's height is taken by an ultrasonic sensor which measures the distance between the head and the sensor. An MCU takes the data produced by the transducer and uses an equation to calculate the distance between the sensor and the head, then calculates the difference between this distance and the total distance to the floor.

The patient's weight is taken by a pressure sensor. This operation is explained in the "Ventilation and Respiration" application article. In general, after signal conditioning produces a voltage, this voltage is passed through the ADC of a microcontroller to be processed and then could be passed by RS-232 or USB to the principal microprocessor. The general block diagram shows that the weight of the patient is passed through RS-232, although you can transmit by USB (optional). If you use RS-232, it is necessary to add a MAX232 device according to the protocol (see Figure 15-4).

Figure 15-3: Measuring Patient Height

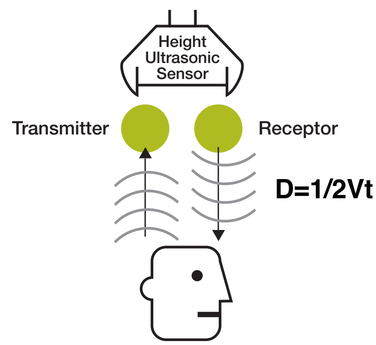
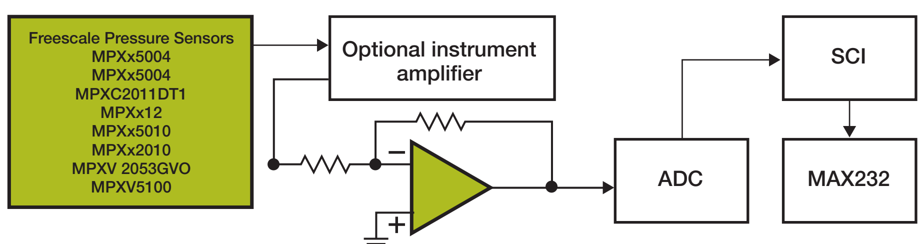


Figure 15-4: Configuration to Measure Patient Weight



15.4
Patient Interface

The patient has an interface to communicate with the admission machine. This interface is composed of a touch screen display, LEDs and a buzzer to warn if a decision must be made or if a process is finished. This module is developed with a secondary microcontroller, which could be the Freescale S08QE.

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15.5
Communication Interfaces

USB Power Switch

When the patient arrives at the hospital, special devices take the principal vital signs of height, weight and heart rate. These devices are connected to the principal system. When the devices are connected by USB, this turns on the devices and the principal MPU starts the communication as host.

The USB port is implemented in a regulator (MC33730) that provides 5V @ 2A out. However, the devices only support 500 mA. Therefore it is necessary to add a 500 mA fuse to regulate the current. The USB module of the principal MPU is configured as a host that can turn on the external devices and start communication between the external devices and the principal MPU.

The microprocessors recommended for this application have two or more hosts integrated; therefore, you can use more than one USB device without using a hub. To see recommended microprocessors, go to www.freescale.com/medical.

Serial Communication Interface

SCI (Serial Communications Interface) is an asynchronous serial communications bus that an MCU uses to communicate with other MCUs or external devices using SCI. Two signal lines are used with SCI: TXD (transmit) and RXD (receive). The two-wire SCI bus operates in full-duplex mode (transmitting and receiving at the same time). SCI uses either an 8- or 9-bit data format, with data sent using NRZ (non-return-to-zero) encoding. The SCI bus may also be set up as a single wire interface, using the TXD pin to both send and receive data. The SCI is a generic controller which allows the integration of RS232, RS422 and RS485 serial transceivers.

Figure 15-5: Analog Configuration for LEDs and Buzzer

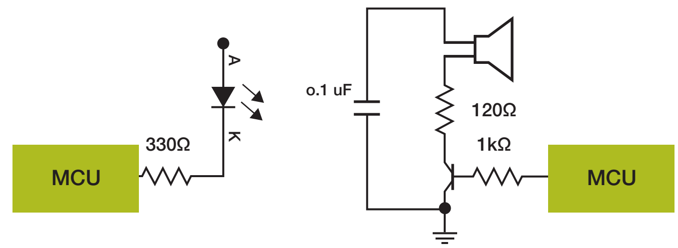


Figure 15-6: USB General Configuration

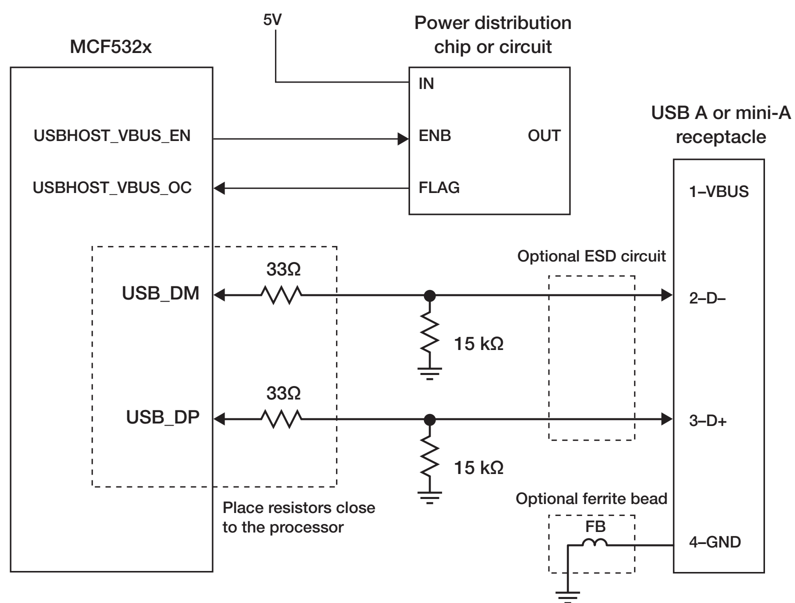
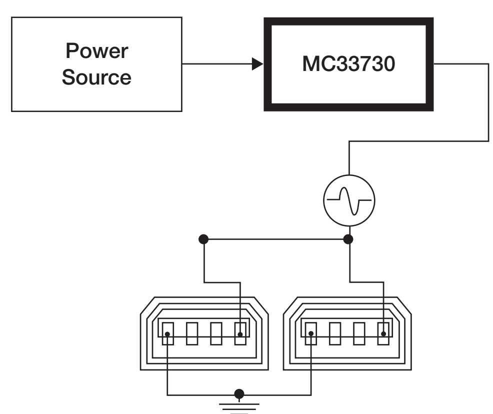


Figure 15-7: USB Port Connections



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Data can be sent as 8- or 9-bit words, least significant bit (LSB). A START bit marks the beginning of the frame. The start bit is active low. The figure above shows a framed 8-bit data word. The data word follows the start bit. A parity bit may follow the data word after the most significant bit (MSB) depending on the protocol used. A mark parity bit (always set high), a space parity bit (always set low) or an even/odd parity bit may be used. The even parity bit will be a one if the number of ones/zeros is even or a zero if there is an odd number. The odd parity bit will be high if there are an odd number of ones/zeros in the data field. A stop bit will normally follow the data field. The stop bit is used to bring the signal rests at logic high following the end of the frame, so when the next start bit arrives it will bring the bus from high to low. Idle characters are sent as all ones with no start or stop bits. Freescale MCUs provide 13-bit baud. The SCI modules can operate in low power modes.

Ethernet PHY (100 Mbps)

To connect the MCU to the internet or to control the system remotely, you can implement an Ethernet communication interface. This needs coupling impedance for the RJ-45 connection.

15.6
Backlight Inverter

A backlight is a form of illumination used in liquid crystal displays (LCDs). Backlights illuminate the LCD from the side or back of the display panel, unlike front lights, which are placed in front of the LCD.

Figure 15-8: SCI Tram

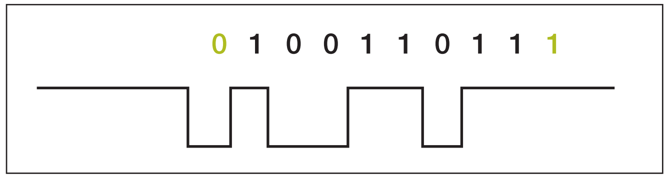


Figure 15-9: Serial Communication Interface General Configuration

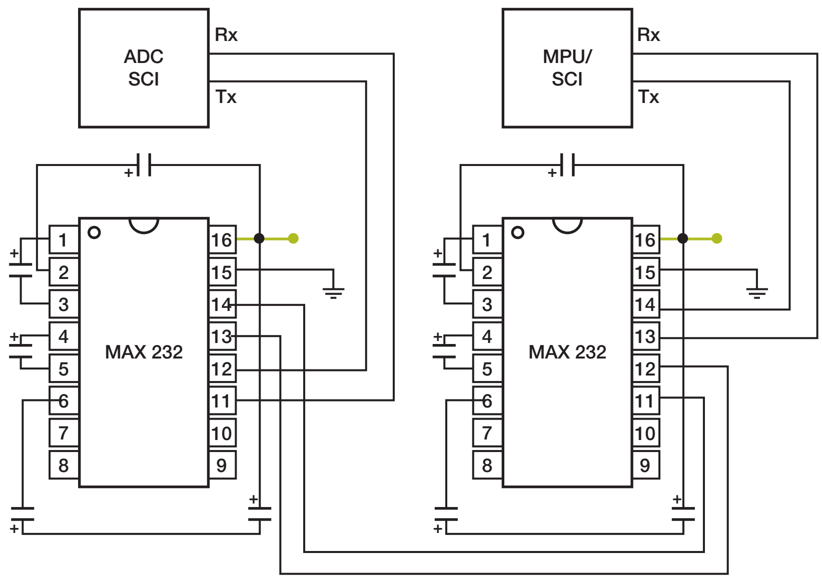
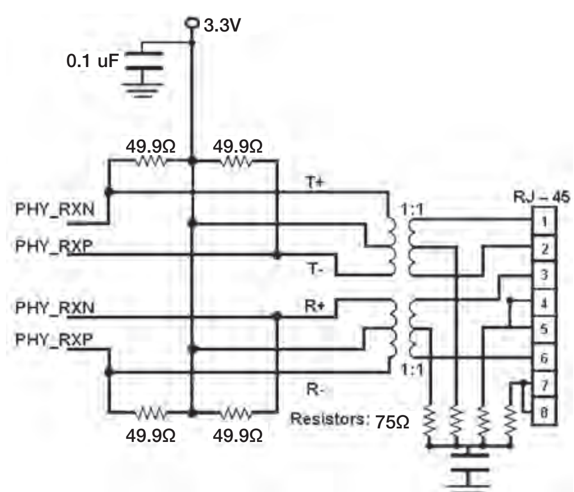


Figure 15-10: Ethernet Interface Circuitry



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15.7
Multimedia Applications with i.MX513

The i.MX513 multimedia applications processor offers high performance processing optimized for the lowest power consumption and hardware accelerated video codecs for IP cameras, V2IP media phones, digital signage and HMI used in medical applications such as telemonitoring. It features advanced and power-efficient implementation of the ARM Cortex™-A8 core, which operates at speeds up to 800 MHz.

CPU Complex

- 800 MHz ARM Cortex-A8 CPU
- 32KB instruction and data caches
- Unified 256KB L2 cache
- NEON SIMD media accelerator
- Vector floating point co-processor

Multimedia

- Multi-format HD720p video decoder and D1 video encoder hardware engine
- 24-bit primary display support up to WXGA resolution
- 18-bit secondary display support
- Analog HD720p component TV output
- High quality hardware video de-interlacing
- Image and video resize, inversion and rotation hardware
- Alpha blending and color space conversion
- Display quality enhancement: color correction, gamut mapping, gamma correction

External Memory Interface

- mDDR and DDR2 SDRAM, 16/32-bit, 200MHz
- SLC/MLC NAND flash, 8/16-bit

Graphic LCD Applications with ColdFire

For other applications in which graphic LCD display is fundamental the ColdFire products offer a wide range of on-chip drivers for different screen resolution. Figure 103.

Figure 15-11: i.MX513 System Power Block Diagram

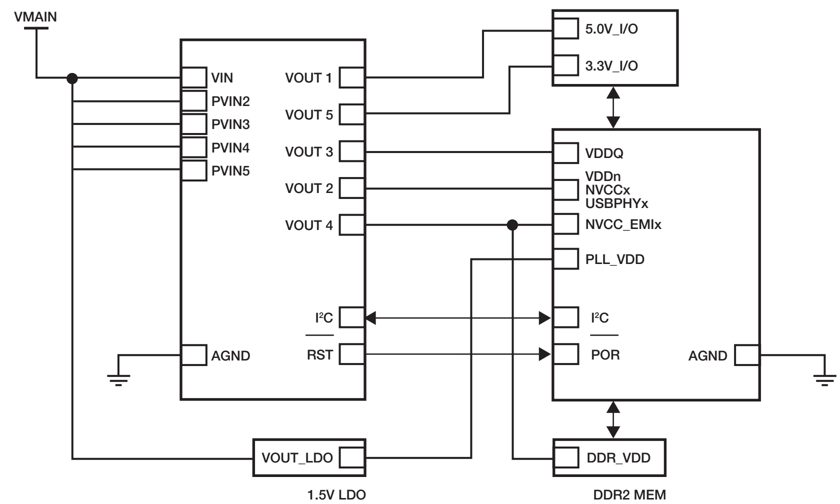

Figure 15-12: Graphic LCD Product Map

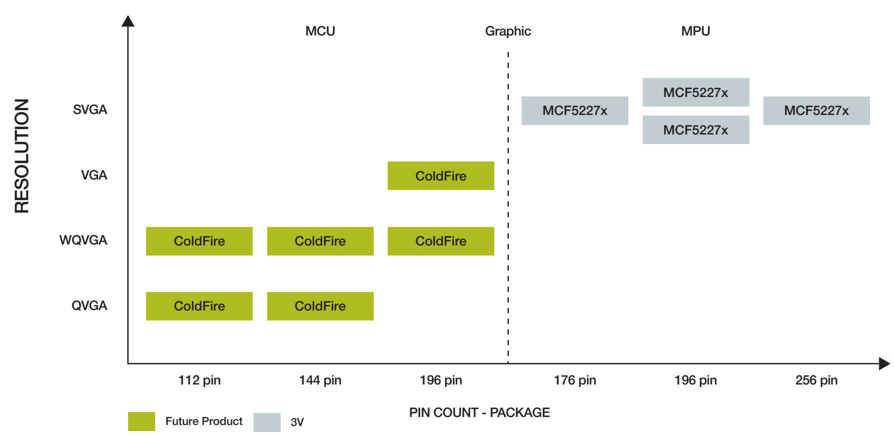

Figure 103. Freescale LCD Microprocessor Roadmap

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15.8
Additional Freescale Technologies

Table 12-1 describes additional Freescale devices that can be used for hospital admission machine applications, and the application notes and datasheets that explain more. To read the application notes, or for more information about any of these devices, visit www.freescale.com.

For wireless communication, power management, keypad and speaker implementation modules, see the "Telehealth Systems" application article beginning on page 6.

Table 12-1: Additional Freescale Technologies for Hospital Admission Machine Applications

Device	Description	Key Features	Applications	Application Notes
MPXx5004	Pressure sensor	0 to 3.92 kPa Temperature compensated and calibrated	Digital Weight	Datasheets available at: http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MPXx5004
MPXC2011DT1	Compensated pressure sensor, medical grade	Polysulfone (Mindel S-1000) Case material (medical, Class V)	Digital Weight	AN1984: Handling Freescale Pressure Sensors AN3150: Soldering Recommendations for Pressure Sensor Devices
MPXx12	Pressure sensor	10 kPa	Digital Weight	Datasheet: http://www.freescale.com/files/sensors/doc/data_sheet/MPX12.pdf
MPXx5010	Pressure sensor	0 to 10 kPa Temperature compensated and calibrated	Digital Weight	AN3728: Media Compatibility for IPS PRT Pressure Sensors AN1636: Implementing Auto Zero for Integrated Pressure Sensors AN1646: Noise Considerations for Integrated Pressure Sensors AN1326: Barometric Pressure Measurement AN1322: Applying Sensors to Bar Graph Pressure Gauges AN1318: Interfacing Pressure Sensors to Microcomputers AN1668: Washing Appliance Sensor Selection AN1586: Designing a Homemade Digital Output for Analog Voltage Output Sensors
MPXx2010	Pressure sensor	10 kPa	Digital Weight	AN1516: Liquid Level Control Using a Pressure Sensor AN936: Mounting Techniques, Lead Forming, and Testing AN1082: Simple Design for a 4-20 mA Transmitter Interface AN1097: Calibration-Free Pressure Sensor System AN1950: Water Level Monitoring AN4010: Low-Pressure Sensing Using MPX2010
MPXV5100	Integrated pressure sensor	Available in gauge and upon request, absolute and differential	Digital Weight	AN1660: Compound Coefficient Pressure Sensor PSPICE Models AN1304: Integrated Sensor Simplifies Bar Graph Pressure Gauge

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Powered Patient Bed

16.1 Introduction

A simple hospital bed has evolved into a highly networked appliance that integrates sophisticated processors to monitor patient status and control the bed's power-assisted functions. This improves patient comfort and makes it easier for healthcare professionals to maneuver the beds.

Figure 16-1: Powered Patient Bed General Block Diagram

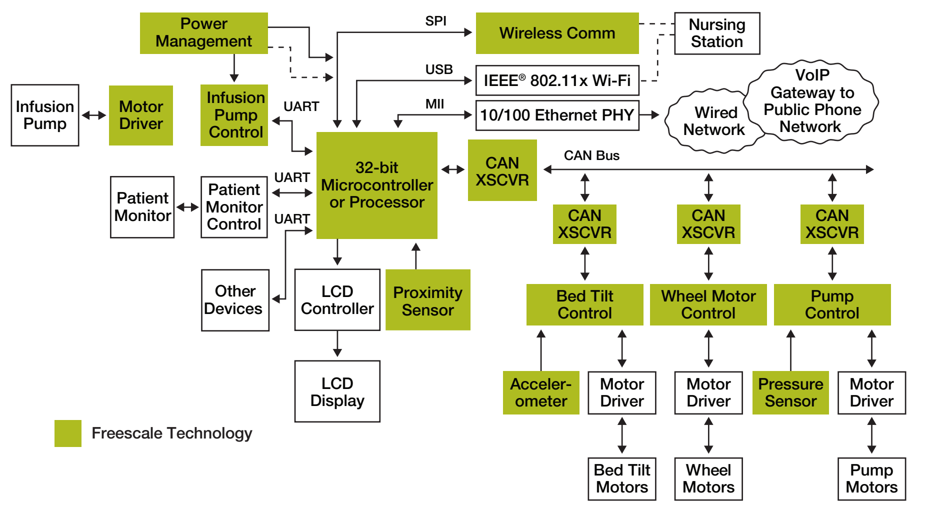
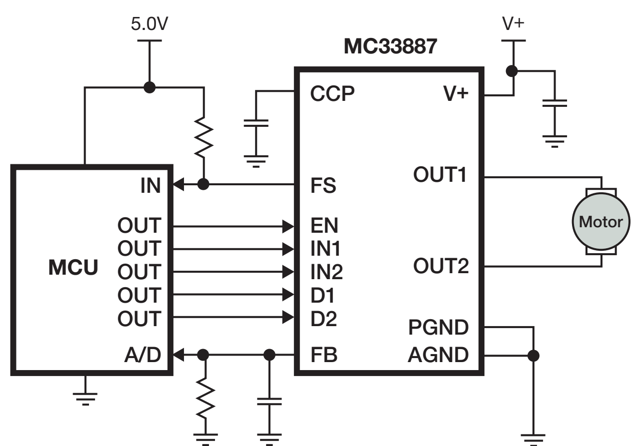


Figure 16-2: Electronic Motor System



16.2

Using Motors for Patient Positioning

Pressure ulcers or decubitus ulcers (bedsores) are one of the most common complications of patients who cannot change position in a bed. Bedsores can be caused by sweat, humidity and temperature but are mainly caused by the unrelieved pressure applied by the bones to the skin and tissue. This is why the most common places for bedsores are the sacrum, elbows, knees and ankles.

To avoid bedsores, hospitals and healthcare providers use irregular bed surfaces to distribute pressure along the whole body and use electric motors to let the patient easily switch positions with just the push of a few buttons.

Electric motors are clean and relatively efficient. This makes them a much better fit for use in hospital beds rather than pneumatic or hydraulic alternatives. An electronic motor system can be used to incline or decline the bed and provide movement to the bed's wheels. A typical system containing a microcontroller (MCU), an H-bridge and a motor is shown in Figure 16-2.

The requirements for a microcontroller vary, based on the size of the motor and the required efficiency. Most patient bed applications require between 32-100 MHz, 16 K to 256 K bytes of flash memory, 2 K to 64 K SRAM, a highly accurate timer and the ability to synchronize the timer with the analog to digital converter (ADC). The requirements for an H-bridge also vary, but most beds require a monolithic power IC comprising control logic, charge pump, gate drive and low RDS(ON) MOSFET output H-bridge circuitry in a small surface mount package.

Freescale offers a wide variety of products specifically for motor control systems ranging from digital signal controllers (DSC) to microcontrollers and H-bridges. An ideal MCU and H-bridge solution for a bed is an MCF51AC256 paired with an MC33887. This helps to give the designer a low power and flexible solution. In some cases, depending on the complexity of the motor system, a single DSC may be sufficient to control the motor. Freescale's MC56F800x family is an alternative, cost optimized solution for real time motor control.

16.3

Integrated Real-Time Patient Monitoring

A powered patient bed must be equipped to monitor the status of the patient and transmit the data remotely to a nurse station. Typical patient monitoring functions consist of blood pressure monitoring, heart rate monitoring, a pulse oximetry unit, electrocardiograph (ECG), blood glucose meters and an infusion pump.

The modules shown in Figure 16-1 provide extra features allowing health care providers and the patient's relatives to offer comfort to the patient. Some of these modules include a tilt accelerometer and motor driver to control the bed's tilt, powered wheels to facilitate movement of the patient to different areas of the hospital, USB and Ethernet ports to provide connection with a PC or the hospital network, VoIP gateway to provide direct communication to the nurses' station, and an LCD screen and keypad for user interface.

16.4
Integrated Tilt Control

The tilt control module is used mainly for the safety and comfort of the patient. Although hospital beds are often maneuvered in many directions and in some cases, in an urgent manner, the safety of the patient needs to be paramount at all times. Electronic sensors can be used to monitor the tilt of the bed and provide an alarm if the bed is at an unsafe angle. Furthermore, the tilt control module is used to position the patient in the bed at the most ideal angle for the patient's comfort. This is the most prevalent use of the tilt control module.

Accelerometers can be used to measure both dynamic and static acceleration. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree of resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required. The Freescale MMA7361L (analog) and MMA745xL (digital) series accelerometers are ideal solutions for XY and XYZ tilt sensing.

A simple tilt application can be implemented using a microcontroller that has one or two ADC channels to read the analog output voltage of the accelerometers. For a safety application, an I/O channel can be used to send a signal to the MCU to turn on or turn off a particular medical device at a determined angle.

Selecting the right accelerometer depends on the angle of reference and how the device is mounted. This allows the designer to achieve a high degree of resolution for a given solution due to the nonlinearity of the technology.

To obtain the most resolution per degree of change, the sensor must be mounted with the sensitive axis parallel to the plane of movement where the most sensitivity is desired. For example, if the degree range that an application is measuring is 0° to 45°, then the printed circuit board (PCB) would be mounted perpendicular to gravity. An X-axis device would be the best solution.

16.5
Integrated Intercom Using VoIP

VoIP intercom applications can improve communications throughout a facility across either wired or wireless networks. Maintaining support resources for only one network can lead to substantial cost savings; however, the greatest opportunity lies in the ability to deploy and integrate new productivity applications and enhanced voice services. A VoIP gateway, for instance, can help seamlessly integrate a patient's monitored data into the underlying hospital network.

A VoIP intercom application should deliver an attractive and intuitive user interface and maintain good audio quality from end to end with options for video connectivity. No special switching equipment is required to implement these systems across an existing network. To meet these needs, the system microprocessor must feature a high level of integration to simplify a design for seamless video, voice and network connectivity. It must have enough processing performance and network bandwidth to simultaneously transfer data from many sources, including a keypad, touch screen display panel and voice inputs and outputs.

Freescale offers a comprehensive hardware and software solution for commercial VoIP applications that meet these specific requirements. The ColdFire product family contains processors up to 266 MHz with the proper mix of memory and peripherals for creating the VoIP solution. The ColdFire VoIP system includes all required software components to develop a feature-rich VoIP product and does not require non-recurring engineering (NRE) costs, giving customers a comprehensive, easy-to-use and cost-effective solution.

16.6
Additional Freescale Technology

Table 16-1 describes additional Freescale devices that can be used for powered patient bed applications. To read the application notes, or for more information about any of these devices, visit www.freescale.com.

Power Management, Wireless Communication, and Keypad (with touch technology) are explained in Chapter 3 Telehealth Systems Introduction. USB Power Switch, UART Interface, and Ethernet PHY are shown in Chapter 15-2 Hospital Admission Machine. USB connection, LCD Controller, and display connections are shown in Chapter 10.2 Electrocardiograph and Portable ECG.

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Table 16-1. Additional Freescale technologies for powered patient beds

Device	Description	Key features	Applications	Application Notes
MC1319x	IEEE 802.15.4 transceivers	Provides leading-edge performance for wireless sensing and control applications	Powered Patient Bed	AN2731: Compact Integrated Antennas AN1902: Quad Flat Pack No-Lead (QFN) AN2976: MC1319x RF Test Procedures AN2935: MC1319x Coexistence in the 2.4GHz ISM Band AN2985: MC1319x Physical Layer Lab Test Description AN2902: MC1319x Range Test AN2762: 13192 Developer's Starter Kit (13192DSK) AN3231: SMAC Based Demonstration Applications AN3251: Reference Oscillator Crystal Requirements AN2825: Handling MAC Erasure AN3577: Creating a USB-to-Wireless Bridge AN2975: Range Extension for IEEE 802.15.4 and ZigBee
MC1320x	IEEE 802.15.4 Transceivers	Low-cost, simple point-to-point star networks	Powered Patient Bed	AN3819: Upgrading Freescale BeeStack Codebases
MC1321x	IEEE 802.15.4 platform ICs	The platform provides for scalable FLASH memory size from 16K to 60K	Powered Patient Bed	AN3783: Proximity Sensor-based Remote Control AN3792: Computer Operating Properly Watchdog AN3311: Radio Frequency Module Land Grid Array AN3230: MC1321x Accelerometer Demonstration AN3232: Accelerometer Demonstration AN3248: MC1321x Internal Transmit/Receive Switch AN2825: Handling MAC Erasure
MC33742	System basis chip (SBC) with enhanced high-speed CAN transceiver	High-speed 1.0 Mbps CAN interface with bus diagnostic capability	Powered Patient Bed—Power Management	AN2409: Small Outline Integrated Circuit -Fine Pitch Package
MC34701	Microprocessor power supply (1.5 A)	Obtaining power for advanced microprocessors	Powered Patient Bed—Power Management	AN3278: Freescale Power Management ICs for High End Processors
MC34717	Switching regulator	5.0 A 1.0 MHz fully integrated dual switch-mode power supply	Powered Patient Bed—Power Management	AN1902: Quad Flat Pack No-Lead (QFN)
MC33880	Low side switch	0.55 Ohm; RDS(on) configurable eight output switch with SPI I/O control	Powered Patient Bed—Motor Driver	AN1902: Quad Flat Pack No-Lead (QFN)
MC33886	H-bridge integrated circuit	Output current limitation at min. 5.2A with PWM current regulation	Powered Patient Bed—Motor Driver	AN1902: Quad Flat Pack No-Lead (QFN)
MC33887	Integrated H-bridge with sleep mode	Withstands transients up to 40V at V BAT Diagnostic Status flag output, current mirror output	Powered Patient Bed—Motor Driver	AN2467: Power Quad Flat No-Lead (PQFN) Package AN2388: Heatsink Small Outline Package (HSOP) AN2409: Small Outline Integrated Circuit - Fine Pitch Package
MCF532x	V3 ColdFire microprocessor	LCD driver Ethernet USB CAN	Powered Patient Bed—Infusion pump control	AN3298: Solder Joint and Package Peak Temperature AN3520: Simplified EHCI Data Structures AN3631: Simplified Device Data Structures AN3324: Hardware Configurations for the MCF532x Family USB AN3606: LCD Memory and Bus Bandwidth Requirements
MC33897	Single-wire CAN transceiver	Using a carrier sense multiple access/ collision resolution (CSMA/CR)	Powered Patient Bed—CANXSCVR	Powered Patient Bed: CANXSCVR
MC33899	Programmable H-bridge power IC	Drives inductive loads in a full H-bridge configuration	Powered Patient Bed—CANXSCVR	AN2388: Heatsink Small Outline Package (HSOP)
S08AC	Flexis AC family	Exceptional migration flexibility	Powered Patient Bed—Bed Tilt Control Wheel Motor Control, Pump Control	AN1837: Non-Volatile Memory Technology Overview AN2438: ADC Definitions and Specifications AN2717: M68HC08 to HCS08 Transition AN2295: Bootloader for M68HC08 and HCS08 AN3499: Clock Options on the HC9S08 Family AN1516: Liquid Level Control Using a Pressure Sensor AN2093: Creating Efficient C Code for the MC68HC08 AN1752: Data Structures for 8-Bit Microcontrollers AN3257: Meeting IEC 60730 Class B Compliance AN2616: HCS08 and CodeWarrior Using C AN3494: From the MC9S08AW60 to MC9S08AC60 AN2140: Serial Monitor for MC9S08GB/GT AN2493: MC9S08GB/GT Low Power Modes AN3730: Understanding Memory Paging in 9S08 AN3732: Migrating Between MC9S08AC and MCF51AC
MMA6280QT	XZ-axis acceleration sensor with g-select	Selectable sensitivity (1.5g/2g/4g/6g)	Powered Patient Bed	AN3107: Measuring Tilt with Low-g Accelerometers AN3397: Implementing Positioning Algorithms AN3461: Tilt Sensing Using Linear Accelerometers AN1611: Impact and Tilt Measurement AN1612: Shock and Mute Pager Applications AN3109: Using the Multi-Axis g-Select Board AN3112: Using the Sensing Triple Axis Board AN3152: Using the Wireless Sensing Triple Axis R D. AN3380: g-Sensor High-Brightness LED Brake Lamp AN4004: 2g Acceleration Sensing Module Based on a 40g Integrated Accelerometer
MPXx5010	Pressure sensor	0 to 10 kPa integrated silicon pressure sensor, temperature compensated and calibrated	Powered Patient Bed	AN1585: ARCHIVED 2005 - High-Performance, Dynamically-Compensated Smart Sensor System AN1655: ARCHIVED 2005 - ASB200 Sensor Development Controller Board

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Medical Imaging

17.1
Introduction

The complexities of medical imaging require extraordinary processing and RF power. Modalities such as magnetic resonance imaging (MRI), computed tomography (CT) scans and ultrasound all push performance limits for advanced integrated I/O, rigorous data processing, powerful display capabilities and high levels of connectivity. These needs are addressed by Freescale's family built on Power Architecture® multi-core processors and RF amplifiers. The Power Architecture family is designed for applications requiring a rich user interface, complex displays and network integration. Freescale's RF power amplifiers provide the high output power required to achieve the desired frequency of resonance, or Larmour frequency. These components are engineered to assist medical imaging equipment manufacturers in meeting their processing and performance needs, to control a rich user interface display and to allow connectivity through various standard protocols.

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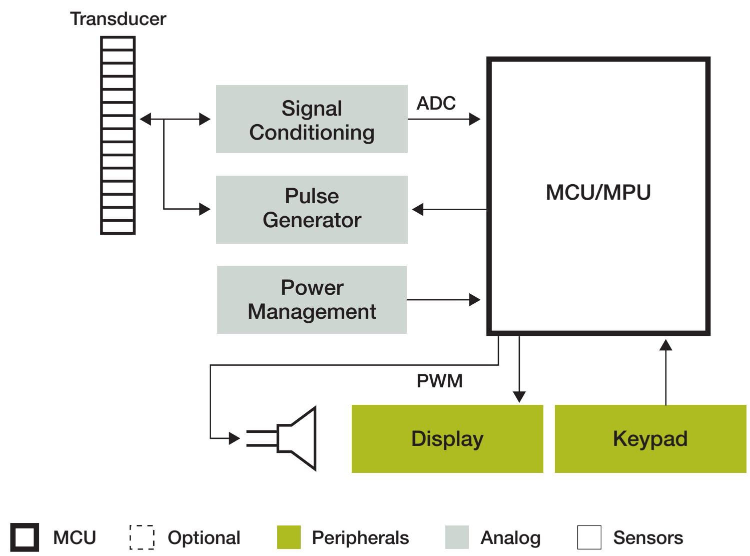
17.2

Ultrasound

Ultrasound is a non-invasive medical imaging technique used to visualize muscles, tendons, pathological lesions and many internal organs and other structures. It plays an important role during prenatal care and is commonly used as a diagnostic tool.

One of the most common uses of ultrasound is for fetal monitoring. Ultrasound uses sound waves to create images of a fetus inside a uterus. Because it uses sound waves instead of radiation, ultrasound is safer than X-rays. Gradually, ultrasound has become an increasingly important part of prenatal care, providing information that can help the doctor to plan the monitoring of a pregnant woman, thus improving the chances of successful pregnancy.

Figure 17-1: Ultrasound General Block Diagram



17.3

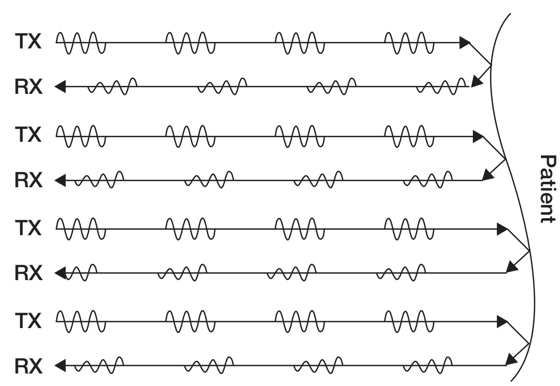
How Ultrasound Works

Ultrasound is based on bouncing sound waves into the body of the developing fetus. The echoes produced by these waves are converted into a picture called a sonogram, which appears on a monitor. This technique is also often referred to as sonography or sonar.

Propagation and reflection rules that govern electric signals are also applied to ultrasound. A transmission line must be terminated in its characteristic impedance to avoid reflections. In the equation below, acoustic impedance Z is a fundamental property of matter and is related to the density ρ and the velocity of sound v : $Z = \rho v$. The fraction of energy R refracted at the normal interface of two different tissue types is:

$$R = \left[\frac{(Z_2 - Z_1)}{(Z_2 + Z_1)}\right]^2$$

Figure 17-2: Ultrasound Transducer Diagram



17.4

Transducer

The transducer is the element that converts electrical signals into ultrasound waves. It consists of a set of transmitter and receiver transducers arranged in a linear array. A unique transducer is explained in Chapter 6, *Fetal Heart Rate Monitor*. Pulse trains are sent by transmitter transducers, and receiver transducers receive bounced waves. The operating frequency for this kind of device is from 5 MHz to 8 MHz.

The blocks needed for signal conditioning/ pulse generator blocks are shown in Figure 17-3.

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17.5
Multiplexer for Tx/Rx Transducers

This block may be implemented using analog gates controlled by the MCU/MPU. This allows the use of transducers as transmitters, and later the ability to switch the multiplexer to use as receivers. Multiplexing reduces the number of connections needed, because the transducers array can range from 8 to more than 256.

17.6
Instrumentation Amplifier and Variable Gain Amplifier

Ultrasonic wave energy sent though a patient's body is very attenuated by multiple factors (absorbing, attenuation due to the medium, inverse square law, etc.). Before processing information, the instrumentation amplifier conditions the signal to adequate levels, and eliminates common-mode noise.

A variable gain amplifier is used due to exponential attenuation of the bounced waves. Applying an exponential gain reduces the effect of the attenuation. Figure 17-4 shows the behavior of this element.

Figure 17-5 shows a simple analog implementation of the circuit (left side). At the right side, a block diagram of a control system is shown. This can be implemented by an MPU using software.

17.7
Beamformer

A beamformer is a device that directs waves in a specific direction by means of algorithms that control the transducer array to form a wave front that generates constructive interference. This is used to generate the sweep required to build the image to be shown. Figure 17-7 is a diagram of the direction of propagation of waves controlled by a beamformer.

Figure 17-3: Ultrasound Probe Block Diagram

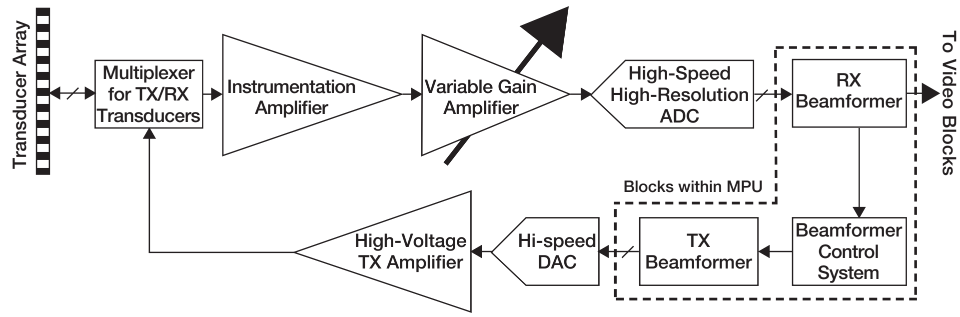


Figure 17-4: Variable Gain Amplifier Function

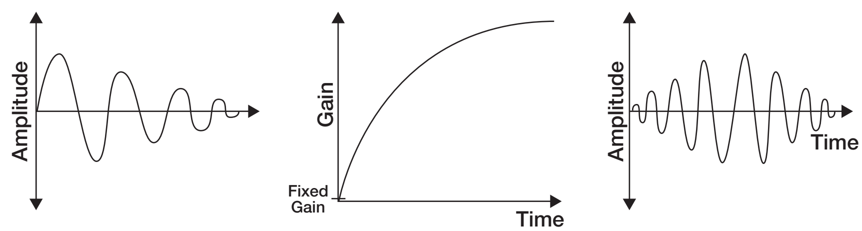
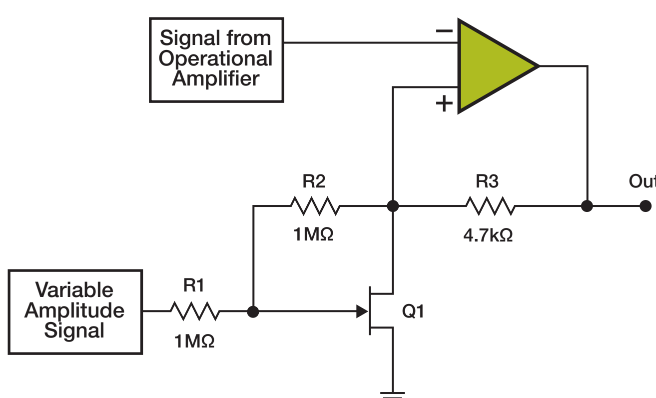


Figure 17-5: Analog Implementation of Variable Gain Amplifier



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17.8
Microprocessors

MPC5121e

The Freescale MPC5121e integrated processor uses an e300 CPU core based on Power Architecture technology. It provides an exceptional computing platform for multimedia and is excellent for embedded solutions that require graphics, a graphical user interface and network connectivity.

To connect a screen to show the processed images received by the ultrasound probe, this processor has the following characteristics:

- MBX Lite 2D/3D graphics engine licensed from Imagination Technologies™ Group Plc.; includes PowerVR® geometry processing acceleration.
- Integrated display controller supports a wide variety of TFT LCD displays with resolution up to 1280 × 720 at a maximum refresh rate of 60 Hz and a color depth up to 24 bits per pixel.

Key features

- e300 core built on Power Architecture technology
- Up to 400 MHz performance and 760 MIPS
- AXE, a 32-bit RISC audio accelerator engine
- PowerVR MBX Lite 2-D/3-D graphics engine (not included in the MPC5123)
- DIU integrated display controller supports up to XGA resolution
- 12 programmable serial controllers (PSC)

MobileGT Products

The MPC5121e and MPC5123 are the latest addition to the mobileGT family of processors. Freescale is working closely with mobileGT alliance member companies to provide widespread firmware and software driver support.

17.9
Digital X-Ray

Digital X-ray is a form of X-ray imaging where digital X-ray sensors are used instead of traditional photographic film.

Figure 17-6: Control System Block Diagram

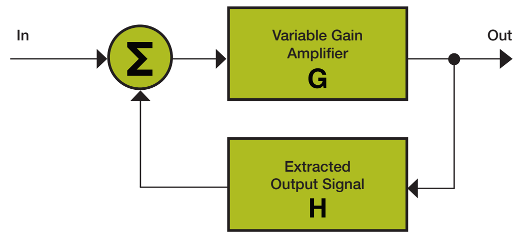
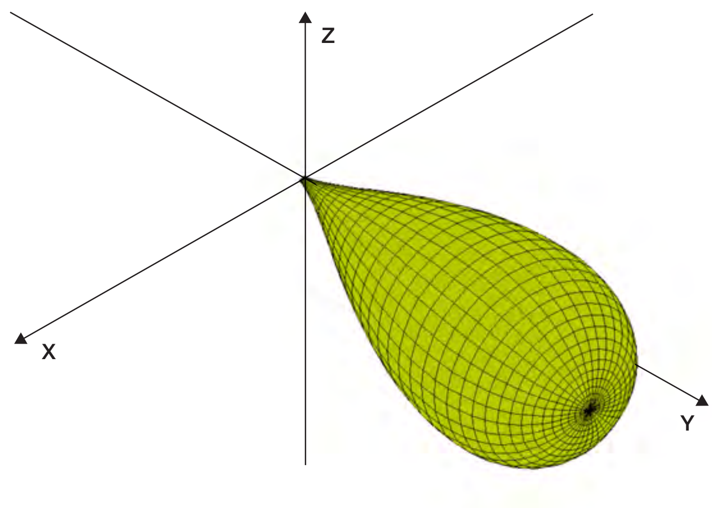


Figure 17-7: Concentrated Energy Diagram of a Beamformer



17.10
Analog Front End

The analog part is composed of a cathode ray tube and a grid of photo detectors. Because these generate current, it is necessary for each photo detector to have a transimpedance amplifier. It is also necessary to have an analog multiplexer to allow different measurements depending on the radiography.

17.11
Photo Detector Grid

The X-ray emitter generates cathode rays that pass through the body. A grid of photo detectors receives the light, providing information and signals to be processed before the system shows a result.

17.12
DSP/DSC

The signal processing and signal conditioning to generate radiography is through a DSP or DSC.

The Freescale 56800/E family offers up to 120 MIPS processor performance. These processors combine, on a single chip, the processing power of a DSP and the functionality of an MCU with a flexible set of peripherals to create a cost-effective solution for industrial control, motion control, home appliances, general-purpose inverters, smart sensors, advanced lighting, fire and security systems, switched-mode power supply, power management and medical monitoring applications.

In X-ray applications it is necessary to implement signal processing and image recognition. Freescale's DSP and controller portfolio includes the following processors designed to perform mathematically intensive computations for a single group of tasks in real time. DSPs are highly specialized and normally used as embedded controllers.

For medical applications Freescale offers the DSP56300 core DSP family. These DSPs offer a rich instruction set and low power dissipation, as well as speed and power to enable wireless, telecommunications and multimedia products. The DSP56300 core includes a barrel shifter, 24-bit addressing,

Figure 17-8: Digital X-Ray General Block Diagram

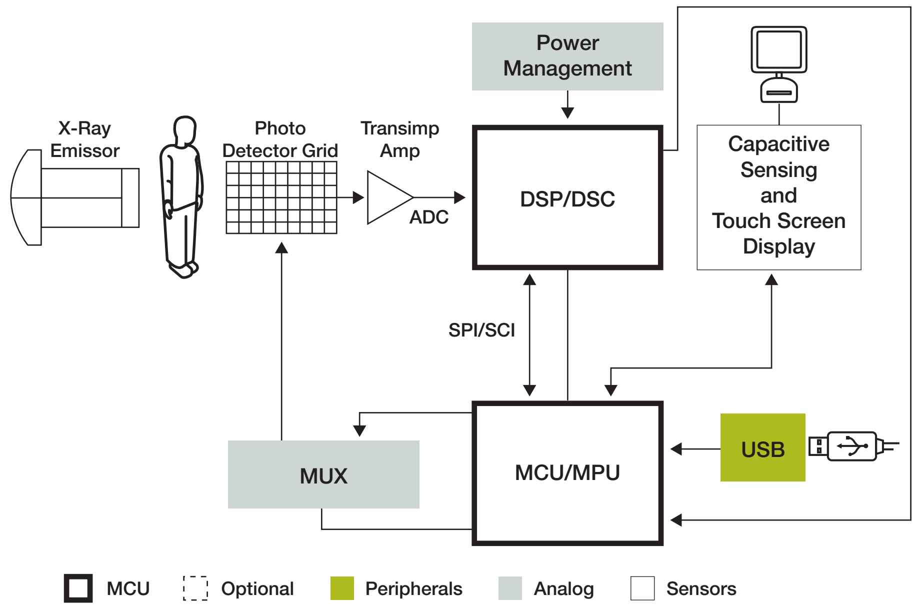


Figure 17-9: General Analog Configuration

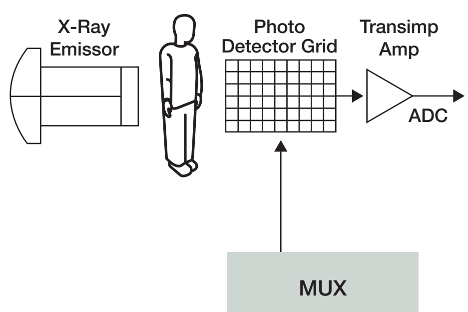
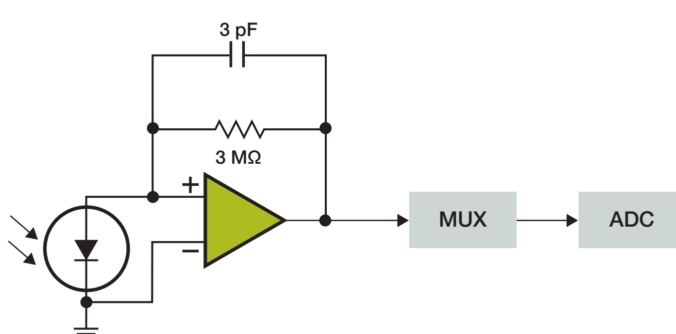


Figure 17-10: Photo Detector Configuration



instruction cache and DMA, and offers 100 MMACS using an internal 100 MHz clock at 3.0–3.6 volts. The DSP56300 family of devices is intended for use in telecommunication applications such as multi-line voice/data/fax processing, video conferencing, audio applications, control and general digital signal processing.

56800/E Digital Signal Controller Products

16-bit StarCore-based DSPs

- StarCore SC3850 (MSC815x)
- StarCore SC3400 (MSC8144)
- StarCore SC140 (MSC811x, MSC812x)
- StarCore SC1400 (MSC711x, MSC712x)

24-bit general purpose DSPs

- Symphony DSP56xxx
- DSP563xx
- DSP5685x
- DSP56F80x/2x
- MC56F81xx/83xx
- MC56F80xx

16-bit 56800/E digital signal controllers

17.13 Capacitive Sensing and Touch Screen Display

The MC34940 is intended for cost-sensitive applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created. The MC34940 detects objects in this electric field. The IC generates a low-frequency sine wave, which is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference. The MC34940 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

For more information about touch panel applications, see the application note titled *Touch Panel Applications Using the MC34940/MC33794 E-Field IC* (document AN1985), available at www.freescale.com.

For Wireless Communication, Power Management, Keypad, and Speaker implementation modules, see Chapter 3 Telehealth Systems Introduction.

Figure 17-11: 56800/E Digital Signal Controller Products

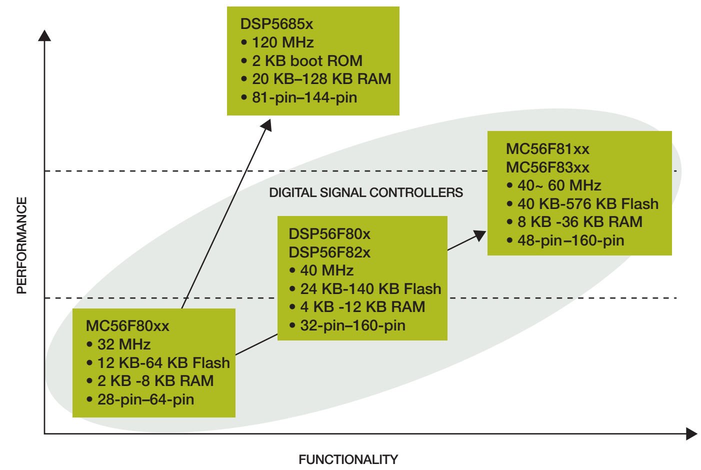


Figure 17-12: Digital Signal Processors and Controllers Portfolio

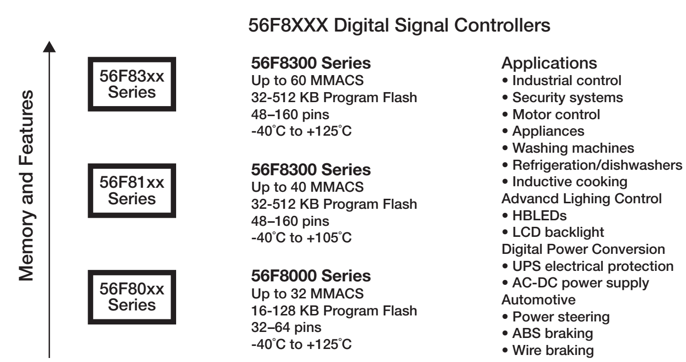
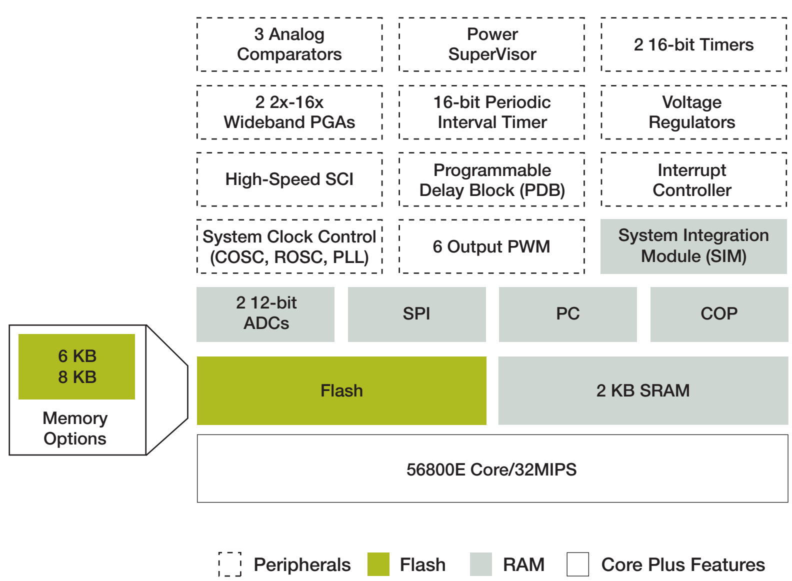


Figure 17-13: MC56F800x: MC56F8006 and MCF56F8002 Digital Signal Controllers



Summary

Applications	Freescale Productus	Freescale Differentiators
Diagnostics and Therapy		
Ablation Laser Anesthesia Unit Monitors Clinical Patient Monitoring Clinical/Surgical Equipment Defibrillators/AEDS Dialysis Equipment Electrocardiogram (ECG or EKG) Electromyograph Fitness/Wellness Hospital Admission Machines Implantable Devices Infusion Pumps Ventilator/Respirators Wound Management	Flexis family: Low-end to high-end pin-to-pin compatibility, 8- and 32-bit ColdFire technology: MCF5225x 32-bit, USB, Ethernet Digital signal controllers (DSCs): MC56F801x, MC56F802x, MC56F8100, MC56F8300 i.MX Series (ARM® Core, 32-bit) –i.MX257: LCD controller w/touch screen, LCD, USB, Ethernet, camera, CAN –i.MX357: adds graphics –i.MX515: adds video High-Performance 32-bit Microprocessors (MPUs): MPC5121e, MPC8377, MPC8641, MPC8535, P1022, P1013 Wireless: MC1322x (IEEE 802.15.4/ZigBee® technology) Pressure sensors: MPXV5004G, MPXV4006G, MPL115A, MPXC2011DT1, MPX12GS, MPX5010DP, MPX2010DP, MPXV2053GVP, MPXV5100G, MPX2300DT1 Touch sensors: MPR03x, MPR121QR2 Accelerometers: MMA736xL, MMA7455L Power management: MPC18730, MC13883, MC13892, MC34700, MC34712, MC34713, MC34716, MC34717 Motor drivers (H-bridges): MC33887, MPC17511, MPC17C724 LED backlight: MC34844, MC34845 Radio frequency (RF) LDMOS power transistor: MRF6VP11KH	Product Differentiators • Highest quality standards • Product life: 15-year longevity • Breadth and scalability of portfolio • Low-power solutions • i.MX series, Flexis, ColdFire: High level of integration - Connectivity (USB and Ethernet) - LCD control (graphic and segment) - Internal memory - High precision analog • ColdFire: embedded high-performance digital signal processor (DSP) functionality with integrated MAC • i.MX series: video and graphics acceleration • Strong RF portfolio - Highest gain - Exceptional efficiency - Higher power density Solution Differentiators • Touch U/I suited for sterile clinical equipment • Cost-effective, amplified, small form factor sensors with high sensitivity USB for Medical • Continua ready, IEEE compliant PHDC USB software stack available
Home Portable		
Blood Pressure Monitor (BPM) Diabetes Care (blood glucose monitor and insulin pumps) Digital Scale Digital Thermometer Fetal Heart Rate Monitor Heart Rate Monitor (HRM) Pulse Oximetry Telehealth/Telemonitoring	Flexis Families (8- and 32-bit) - MC9S08QE, MCF51QE: general purpose, low power - MC9S08JM, MCF51JM: USB, low power - MC9S08AC, MCF51AC: FlexTimer 8-bit Microcontrollers (MCUs) - MC9S08LL: low power, segment LCD - MC9S08JS: low power, USB Ultra Low-End 8-bit MCUs - MC9RS08KA: general purpose - MC9RS908LA, MC9RS08LE: segment LCD controllers ColdFire Technology - MCF5225x: 32-bit, USB, Ethernet i.MX Series (ARM Core, 32-bit) - i.MX233: USB, LCD controller with touch-screen - i.MX257: LCD, USB, Ethernet, camera Wireless: MC1322x (IEEE 802.15.4/ZigBee technology) Pressure sensors: MPX2300DT1, MPXV5050GC6, MPXM2053GS (blood pressure monitoring) Touch sensors: MPR03x, MPR121QR2, proximity IP Accelerometers: MMA736xL, MMA7455L (arm angle detection for blood pressure monitoring), MMA7660 (portrait/landscape) Power management: MPC18730, MC13883, MC3467x, MC34704, MC13892 Motor drivers (H-bridges): MC33887, MPC17511, MPC17C724, MC33931, MC33932, MC33926 LED backlight: MC34844, MC34845	Product Differentiators • Highest quality standards • Product life: 15 year longevity • MC9S08QE, MC9S08LL: low power consumption to enable longer battery life - 370 nA, 1.8V, 6 usec wake up in lowest power mode • MC9S08LL: superior LCD controller IP • Connectivity: USB, ZigBee • Pressure sensors: packaged specifically for medical applications • High-end microprocessors with graphics acceleration Solution Differentiators • Solutions that enable a lower system cost • Touch U/I suited for sterile hand-held monitors • Cost-effective, amplified, small form factor sensors with high sensitivity • USB for medical: Continua ready, IEEE compliant PHDC USB software stack available
Imaging		
Bone Densitometer Computed Tomography (CT) Fluoroscopy, Angiography Magnetic Resonance Imaging (MRI) Positron Emission Tomographer (PET) Ultrasound X-Ray And Related Applications	ColdFire Microprocessors (MPUs) –MCF5227: 32-bit, USB, graphical LCD controller –MCF532x: 32-bit, USB, graphical LCD controller, Ethernet –MCF5445x: 32-bit USB, 2x Ethernet, PCI High performance: MPC837x, MPC831x, MPC85xx, P2020 High-end image processing: MPC512x, MPC8610, MSC8122, MSC8144, MPC8536, MPC8315, MSC8144, MAC8154, MSC8156, P1022 i.MX Series (ARM Core) –i.MX257 –i.MX357: 32-bit, LCD, USB, Ethernet, video and camera –i.MX515: 32-bit, Video, Graphics, Ethernet, LCD with touch screen, USB Wireless: MC132xx ZigBee technology Accelerometers: MMA736xL (vibration sensing) Touch sensors: MPR03x, MPR121QR2 Power management: MPC18730, MC13883, MC13892, MC34704, MC34712, MC34713, MC34716, MC34717 LED backlight: MC34844, MC34845 General purpose amplifiers High-power RF amplifiers: MRF6VP11KH, MRF6VP2600H, MRF6V4300N	Product Differentiators • Highest quality standards • Product life: 15-year longevity • Breadth and scalability of portfolio • Low-power solutions • i.MX series, Flexis, ColdFire: high level of integration - Connectivity (USB and Ethernet) - LCD control - Internal memory - High precision analog • ColdFire: embedded high-performance digital signal processor (DSP) functionality with integrated MAC • i.MX series: video and graphics acceleration • Strong RF portfolio - Highest gain - Exceptional efficiency - Higher power density • High-performance processors: PCI Express® support and Serial ATA (SATA) for storing images Solution Differentiators • Touch U/I suited for sterile clinical equipment • Cost-effective, amplified, small form factor sensors with high sensitivity • AltiVec® engine for image processing

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Appendix

Digital Signal Processing Concepts

A digital filter is characterized by its transfer function, or equivalently, its difference equation. Mathematical analysis of the transfer function can describe how it will respond to any input. As such, designing a filter consists of developing specifications appropriate to the problem, and then producing a transfer function which meets the specifications.

Figure A-1: Signal Responses

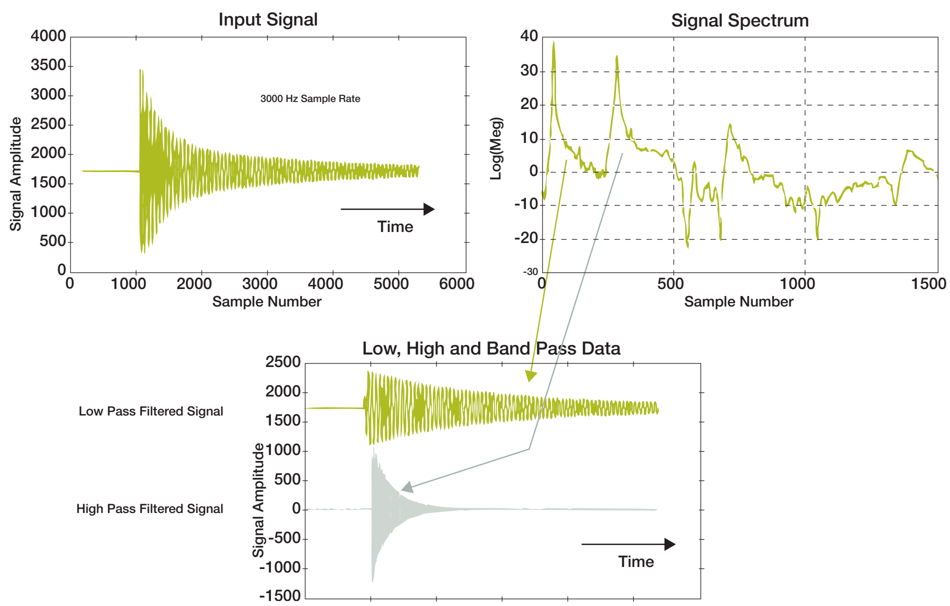
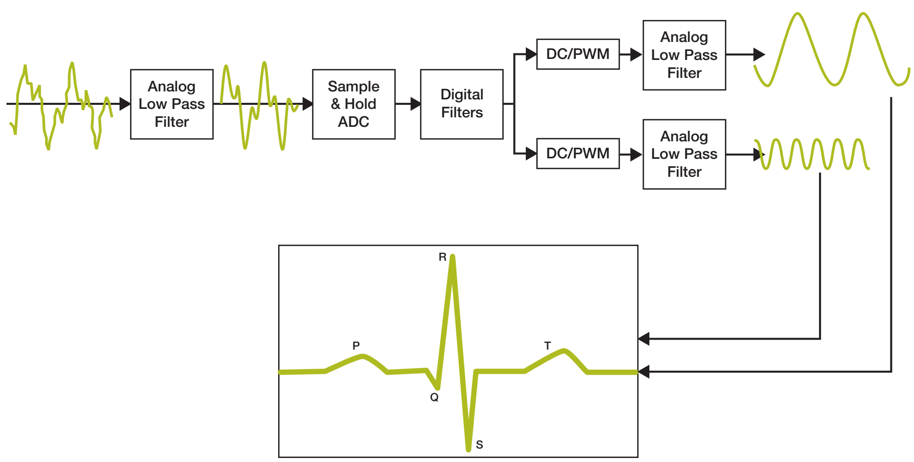


Figure A-2: Signal Processing for HRM and Pulse Oximetry



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Digital Filter Examples

Digital FIR vs. IIR Filters

A digital finite impulse response (FIR) filter can implement non-realizable analog functions, with many more multiplies, adds and data moves.

$$y(n) = \sum_{i=0}^{N-1} a(i)x(n-i)$$

A digital infinite impulse response (IIR) filter provides a digital imitation of analog filters. It generally has the fewest operations, but is often 10x more efficient.

$$y(n) = \sum_{i=0}^{N-1} a(i)x(n-i) + \sum_{j=1}^{M} b(j)y(n-j), \quad M \geq N$$

Signal Reconstruction

To reconstruct the signal to the original one, we use the digital signal reconstructed by the DAC and then use passive filters to shape it in a smooth manner. See Figure A-5.

Figure A-3: Anti-Aliasing Filter and Sampling

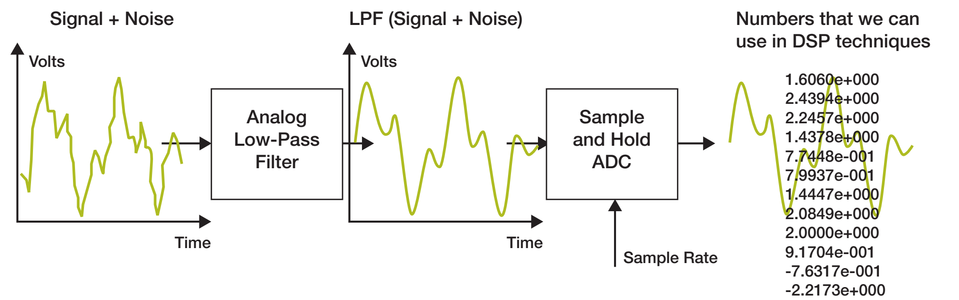


Figure A-4: Low- and High-Pass Filters

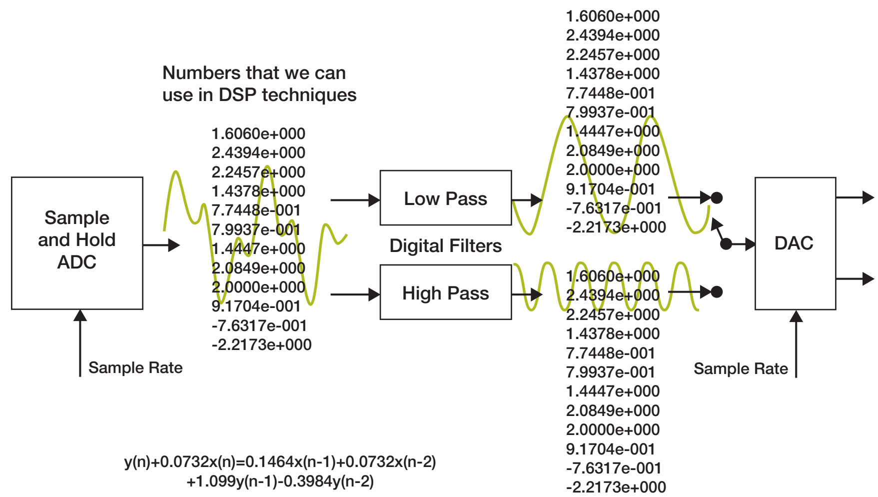
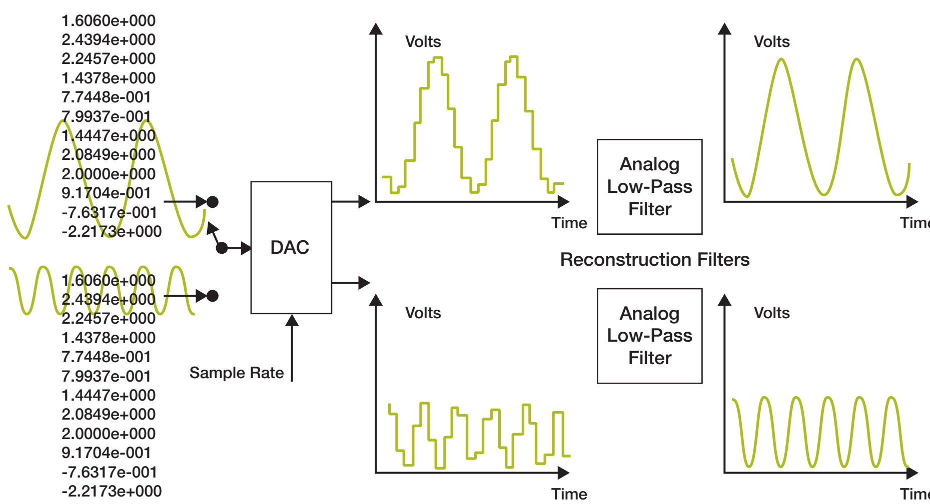


Figure A-5: Signal Reconstruction



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Freescale Technologies

- ColdFire MAC architecture enables DSP algorithms
- IIR and FIR filters gain performance with MAC instructions
- Single instruction: multiply-accumulate with load
  - Multiply two 16-bit word or 32-bit longword operands
  - Add 32-bit product to 32-bit accumulator (ACC) register
  - Load 32-bit longword for next instruction and increment address register (ptr)
- Sample analog accelerometer data with ADC (3 kHz)
- Execute two parallel digital filters
- Send via USB: raw and filtered data, timestamp, filter execution cycles

For more information, download the PDF *ColdFire Technology and DSP* from http://freescale.com/files/dsp/doc/ref_manual/CFDSPTechnology_DSP.pdf.

Instrumentation Amplifier

In medical instrumentation it is common to process signals with a lot of noise and small amplitude. For these reasons an instrumentation amplifier, which has high entrance impedance and high CMRR, is often used. This device can be built with discrete elements or can be obtained pre-built. The amplifier gets the differential between the signal and amplifier depending on the gain, and the gain determines the signal amplitude.

The gain recommended for medical applications is 1000 because the signal oscillates around 1mV, and with this gain the signal can be amplified up to 1V. It is also recommended that for the first part you generate a gain of only 10 to avoid amplifier common-mode signals. Only filter the noise signals with this part, and amplify the rest of the signal with the differential amplifier.

Figure A-6: ColdFire Demo Board (M52221DEMO)

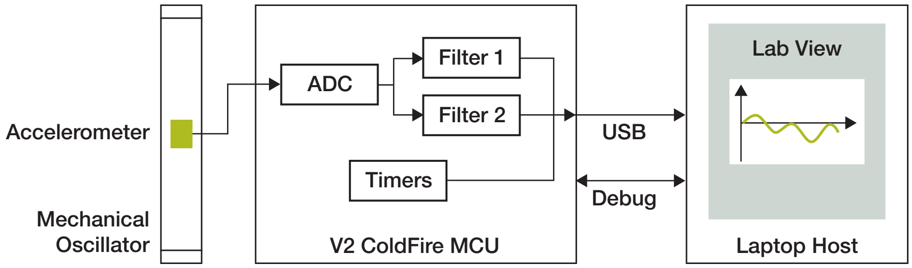
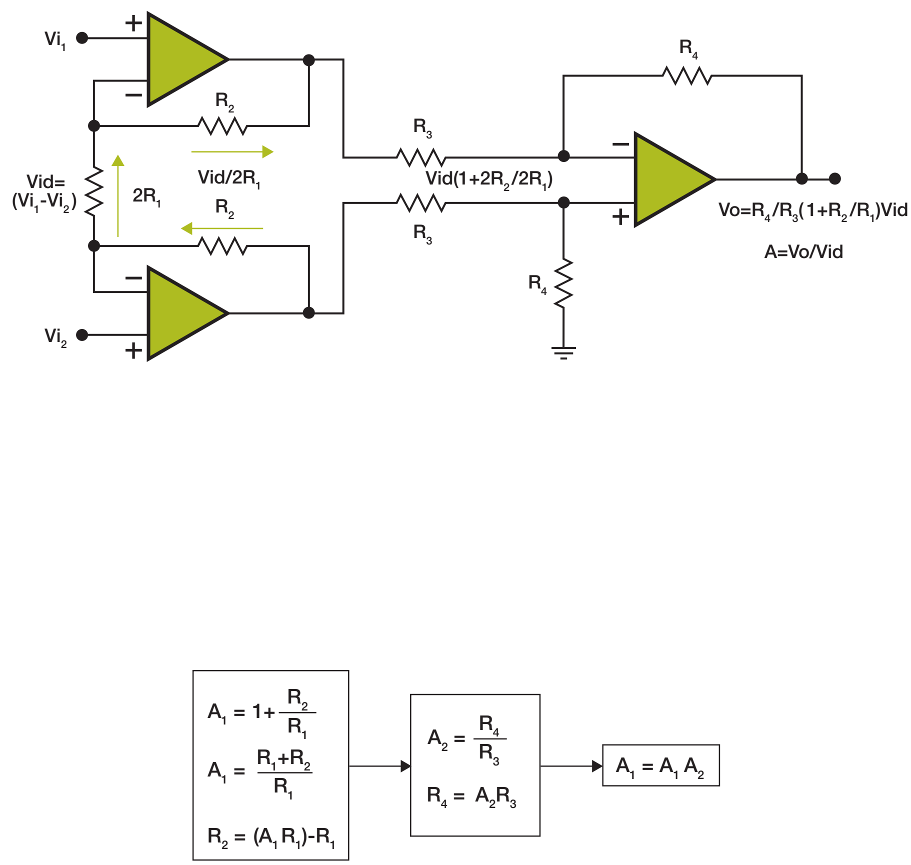


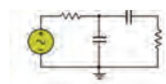
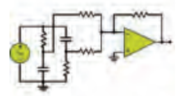
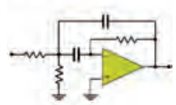
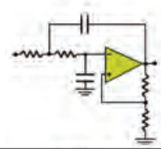
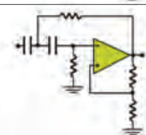
Figure A-7: Instrumentation Amplifier Design Diagram



Values to obtain a Signal Around 1V: Low Gain: 10, High gain: 100, Total gain: 1000

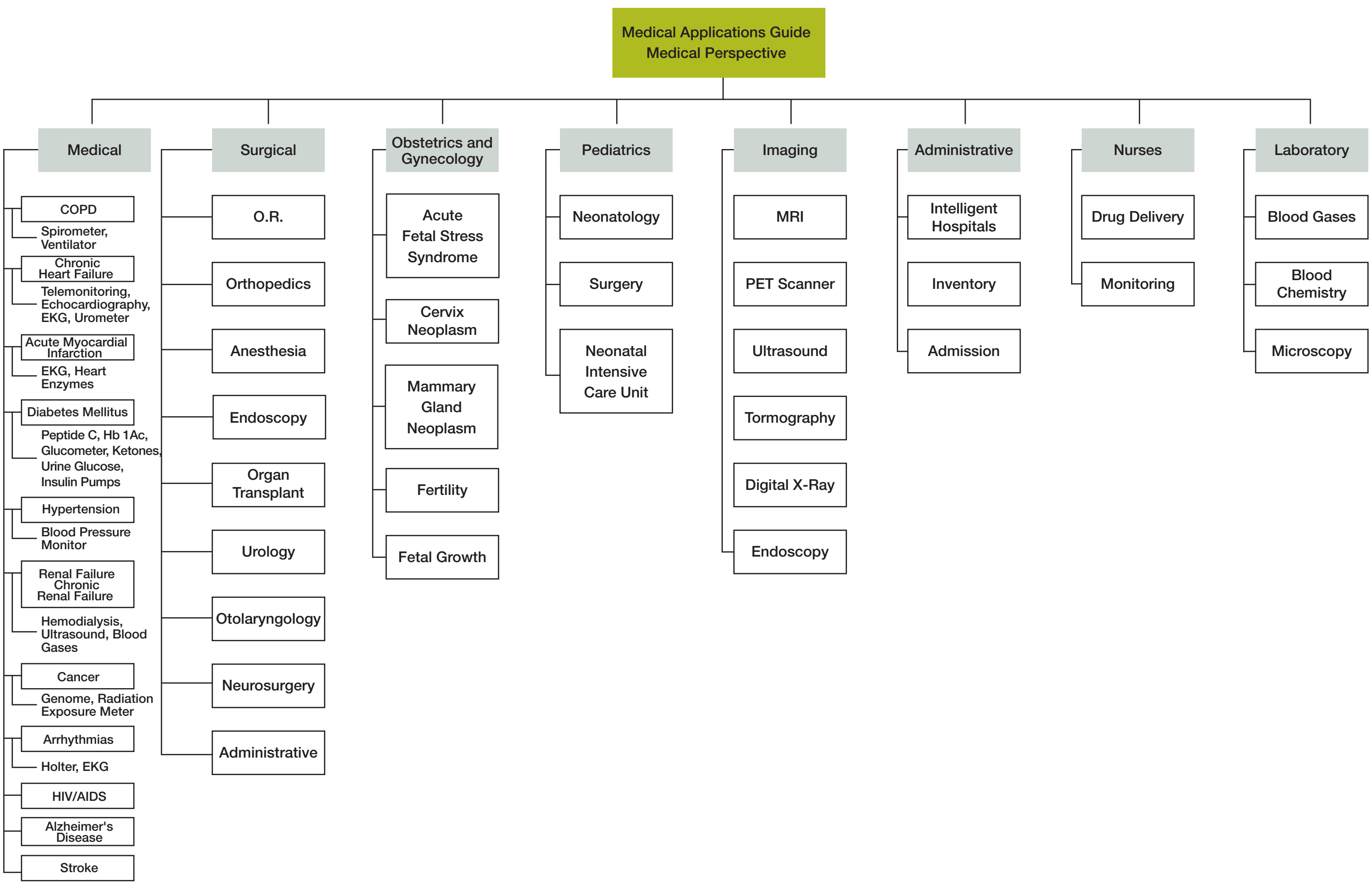
Filter Design

A lot of noise is present in biophysical signals. To attenuate this noise, low pass filters and high pass filters are used to amplify the small AC components and reject DC components. The filters allow only the useful signals, which helps make a better diagnosis. These filters can be built with passives or actives (op amps) depending on the application, although active filters are more effective at rejecting noise. Passive filters are more cost-effective and in some cases are suitable. Sometimes the MCU does not have a DAC. This can be built by the PWM module and external low pass filter to convert digital data to analog data.

Type	Circuit	Cut frequency	Equation
Band-pass passive		0.1 Hz–150 Hz Heart operating range	$f_0 = \frac{1}{2\pi RC}$
Reject-band passive		40 Hz–60 Hz Noise signal from the line	
Band-pass active		400 Hz–4 KHz Sound wave bounced (range depends of the transducer)	
Low-pass active		150 Hz Heart operating range (if the passive filter is not enough, use an active filter)	
High-pass filter active		Some medical applications Not specific	$f_0 = \frac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$

Medical Perspective

The following chart outlines some medical applications based on medical professionals' specialties.



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Web Support:
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USA/Europe or Locations Not Listed:
Freescale Semiconductor
Technical Information Center, EL516
2100 East Elliot Road
Tempe, Arizona 85284
+1-800-521-6274 or +1-480-768-2130
freescale.com/support

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
freescale.com/support

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor China Ltd.
Exchange Building 23F
No. 118 Jianguo Road
Chaoyang District
Beijing 100022
China
+86 10 5879 8000
support.asia@freescale.com

For Literature Requests Only:
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