Medical Applications
User Guide

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Introduction

Technology for life

According to the World Health Organization there are over one billion overweight adults, 860 million chronic disease patients and over 600 million elders age 60 or older[1]. Combine that with a study from the U.S. Centers for Disease Control (CDC) showing modern medical breakthroughs have raised the average global life expectancy in developed nations to over 75 years[2]. With a large percentage of the total healthcare spend addressing chronic disease, the issue of runaway healthcare costs and the need to abate them has never been more significant. Proactive and preventative approaches to healthcare are required.

Semiconductor technology will continue to play a critical role in the development of new technologies that assist with patient monitoring, diagnostics, therapy and imaging. NXP is focused on what we can do as a semiconductor company to not only help extend life, but to promote a better quality of life. By designing products with the highest safety and reliability standards, healthcare devices using our technologies work when it counts. Helping to extend and improve the quality of life, and provide technologies that enable proactive health and wellness monitoring, our solutions power future healthcare devices to benefit everyone who is in contact with this technology. This is what we mean when say we offer "technology for life."

These market factors, along with advancements in semiconductor technologies, provide the potential for transforming the care that we all receive. Medical imaging technology commonly found in radiology or imaging centers can now be found in ambulatory or combat situations in the field. Clinical equipment formerly relegated to the hospital or doctor's office is now moving into the home. Portable medical equipment is becoming smaller, lower power, wireless, and even wearable. These devices" are now connecting to data aggregators or hubs and transmit your personal health data to the medical cloud where is it is securely stored. Pharmaceutical companies are adopting technology at a rapid pace, specifically adding wireless communication to improve patience adherence and the user experience. All types of healthcare equipment are being pushed from their roots in clinics or hospitals and into the home.

Developers of medical devices face several challenges. The need to balance processing requirements with power consumption, the need to provide faster time-to-market and the need to navigate the regulatory environment are common to all healthcare applications. We design a range of embedded products and applicable reference designs so that developers can choose MCUs, MPUs, analog, sensors and wireless solutions to meet the requirements of their designs.

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

Our Medical Solutions

NXP 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, our MCUs have been part of the solution. 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 healthcare, 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. That's why we've implemented a review process that supports life-critical applications.

We offer a wide range of products so that developers can choose MCUs, MPUs, analog and sensor components or RF amplifiers to meet the unique needs of their designs. Developers of medical technology face many challenges today. At NXP, we believe that choosing the right silicon should not be one of them. We drive innovations that power next-generation healthcare and medical systems and applications.

Leading Technology

MCUs and MPUs

NXP is a leader in 32-bit embedded control, offering the market's broadest and best-enabled portfolio of solutions based on ARM® technology. Our large portfolio includes scalable MCU and MPU families from small, ultra-low-power, Kinetis, LPC, and Quintec MCUs to i.MX multimedia processors with advanced performance and feature integration to QorIQ communications processors that deliver industry-leading power and performance. Additionally we offer application specific processors for both Hearing and Smart Pharma solutions. Each family has been designed to offer a broad range of performance, peripheral and packaging options providing migration paths for end product platform development. All families are supported by an industry-leading proprietary software and tool enablement bundle and the extensive ARM ecosystem. Combined, our comprehensive portfolio of MPU/MCU based healthcare" solutions offer the highest level of integration, the most comprehensive software and hardware enablement and the broadest range of performance available within the ARM community. Whether you are designing portable medical, smart pharma, diagnostic, or therapy products, our ARM-based product families offer a solution that meets your requirements.

Sensors

Expanding on more than 30 years of sensing history, our sensors are designed with the right combination of intelligent integration, logic and customizable software on the platform to deliver smarter, more differentiated applications where high quality and reliability are especially important. Our pressure sensors offer a wide range of functions and features, from basic to fully amplified and temperature-compensated devices. The low-voltage pressure sensor series is designed to meet power efficiency demands to extend longevity for simpler, cost-sensitive medical and portable electronics. These pressure sensors combine advanced micro-machining techniques, thin film metallization and bipolar semiconductor processing that provide accurate and highly reliable sensors at competitive prices. We offer our acceleration sensor portfolio in the low g range (under 20 g). This range enables a fast response time, low current consumption, low voltage operation and a standby mode in a small profile package to detect orientation, shake, tap, double tap, fall, tilt, motion, positioning, shock or vibration. NXP's small, low-power digital 3D magnetic sensors offer a wide dynamic range to allow operation in PCBs with high extraneous magnetic fields. In medical applications, magnetic sensors are used for motion control in things like ventilator machines, pumps for infusion, insulin, syringes and kidney dialysis machines. They are also found as switches for medication-dispensing cabinets, bed-positioning systems and hearing aids.

Analog

Our analog and mixed-mode integrated circuits are highly robust and provide many unique features for powering, controlling and communicating. Our proprietary SMARTMOS mixed-signal technology allows high-density logic to coexist with both analog and power functions, providing significant benefits to the applications designer. These benefits include ease of use, outstanding IC- and load-protection features, reduced parts count and high reliability.

RF power amplifiers

Our industry-leading LDMOS technology is ideally suited for medical applications requiring RF power amplifiers. We developed the EVHV6 50 V LDMOS process to meet the challenging demands required by medical applications, including MRI systems covering frequencies from 60 to 500 MHz and power levels from 1 to 30 kW. This portfolio of devices provides a combination of superior power, gain, linearity, efficiency and ruggedness. There are other medical uses for our RF technology besides MRI, including ablation and medical lasers (1 MHz–2.4 GHz, power levels to 100 W). Our high-power, high-density portfolio of RF power amplifier devices is exceptionally reliable and features industry-leading package designs. We have RF devices for your medical needs and a global applications team to support your efforts to design our power amplifiers into your solution.

Standard products

NXP Standard Products is a leading supplier of discrete components with more than 60 years of experience in the development and production of diodes, transistors, MOSFETs, ESD protection solutions and Logic components.

The business has one of the largest portfolios in the market with innovative products that are distinguished by providing high energy efficiency, ESD resistance and very small dimensions, all of which are key features required by the healthcare design community.

Why NXP?

Ecosystems

Providing value beyond the responsibility of providing key semiconductor components is paramount. We realize the need to provide our customers a running start on their next medical designs, which is why we embrace one of the strongest ecosystems in the world.

NXP partners with leading providers of IEC62304 compliant operating systems including, but are not limited to, QNX Software Systems, Green Hills Software, Mentor Graphics, Wind River® and Micrium. Development tool support is provided by ARM®, Keil®, and IAR Systems®. Additionally we have a wide range of Alliance partners that provide healthcare specific modules to speed development time.

Cactus Semiconductor

We're collaborating with Cactus Semiconductor, a medical application-specific integrated circuit (ASIC) company, to provide customized analog mixed-signal and system-on-chip (SoC) solutions to the medical market. With more than 30 years of combined experience in the medical device market, our companies and Cactus are focused on providing new generations of smaller, lighter, inexpensive and more efficient medical products designed to help improve the quality of life for millions of people. We'll initially focus on solutions for implantable medical devices, blood glucose monitors and other portable medical applications, such as blood pressure monitors, electrocardiographs and pulse oximetry devices.

Monebo Kenetic™ ECG algorithms

We're partnering with Monebo Technologies to offer an ECG-on-a-chip solution that allows customers to choose from more than 300 of our proprietary MCUs and pair them with the Monebo Kinetic family of ECG algorithms.

Benefits

▶ Highly accurate Kinetic ECG algorithms provide interval measurements, beat classification and rhythm interpretation

▶ Efficient code is ideal for use in embedded applications

▶ Designed to optimize battery life (no "warm-up" period)

▶ FDA 510(k) cleared software allows customers to streamline their regulatory filing

▶ Lowers development cost by providing a tested and validated solution

▶ Scalable solutions based on customer requirements

▶ Optimal design based on the application

Medical-specific reference designs

We understand that reducing time spent on research and development and speeding time-to-market are key concerns of medical device designers. That is why we strive to produce high-impact design guides in the form of reference designs and application notes. Reference designs give designers access to component configurations that have been proven to work. Application notes prepared by knowledgeable medical doctors and our NXP engineers take the guesswork out of project troubleshooting. Together, these documents offer developers a great jump-start for producing novel designs based on proven concepts.

For a full list of our medical reference designs and application notes, visit **www.nxp.com/healthcare**.

Development tools and software: learn once, use everywhere

We offer a wide variety of hardware development tools to meet the needs of the medical device designer. Most products feature a cost-effective demo platform for initial evaluation and a full-featured evaluation board for advanced development. The products are packaged with an NXP-developed board support Package (BSP), complete documentation, product-specific application notes and all the necessary device drivers—everything a designer needs to get started.

Processor Expert software

Processor Expert software is a rapid application design tool integrated into the NXP provided toolset that makes migrating between our MCUs a breeze. Just define the functionality you need for your application and Processor Expert software generates tested, optimized C code. When you change the MCU with the MCU Change Wizard, Processor Expert maps the software and peripheral components that describe your application's functionality to the resources available on the new MCU. All you have to do is resolve any resource issues flagged by Processor Expert software and you're finished.

Multimedia Alliance Network

The Multimedia Alliance Network is a global program designed to provide developers with software tools, such as IDEs, compilers, debuggers and performance analysis tools, from a comprehensive network of industry-leading partners that support the i.MX ARM-based family of processors. Our rich ecosystem has the essential tools developers need to help speed their design projects through to market adoption.

Leadership and longevity

Through leadership in the Continua Health Alliance, our company helps to set standards for the industry. We retain a medical doctor on staff and we have a Medical Center of Excellence to develop new technologies.

The product longevity program provides a minimum 15 years of assured supply for devices for medical applications. (For terms and conditions and to obtain a list of available products, visit **www.nxp.com/productlongevity**.) With an internal review defined in a standard operating procedure, our company supports FDA class III or life-critical applications in the U.S. and globally. Quality, reliability, supply assurance and company and product longevity are key to understanding the needs of the healthcare market.

From portable medical solutions to diagnostic, patient monitoring and therapy systems, we provide ultra-low-power, mixed-signal MCUs, high-performance analog, as well as wired and wireless connectivity solutions that help solve true clinical problems. Our company offers not only one of the strongest portfolios of semiconductor products, but also custom IC development in support of this segment. Additionally, we provide a robust portfolio of medical-centric reference designs and application notes that help customers go to market faster. Our business is much more than a semiconductor company. By offering several application-specific reference designs that include schematics, layouts (Gerber files) and example application code and user interface software, customers can get up and running with their applications much more quickly. Vital technology, expertise and leadership make NXP the trusted provider of high-quality technical solutions that enable the development of breakthrough medical systems from health and wellness to life-critical applications.

Home Portable Medical

1.1

Introduction

The home portable medical market is one of the fastest growing market segments in the medical device industry. Portable home medical devices share the need for long battery life, robust data processing and a wired or wireless communication interface. NXP's wide portfolio of MCUs offer the perfect mix of high processing capabilities, low power consumption, analog content, and wirless connectivity. The Kinetis, LPC, and QN families of MCUs built on the ARM Cortex-M class core are well suited for designs where power consumption, cost, size, and connectivity are key design considerations. For medical devices in the home that require a more sophisticated user interface, our i.MX portfolio of ARM core-based MPUs provides various levels of options for performance, power, connectivity and multimedia capabilities. Furthermore, as a pioneer in the communications market, we offer solutions for wired and wireless interfaces, including USB, IEEE® 802.15.4, sub-Gigahertz, ZigBee® and Bluetooth Low Energy technology.

Our micro-electromechanical system (MEMS)-based pressure and acceleration sensors and magnetometers can be used to acquire physical parameters. User interfaces embedded with touch sensors enable medical-friendly buttons and touch screens that can be sanitized quickly and easily.

We offer a focused, integrated analog portfolio that enables maximum battery life via power management integrated circuits (PMICs) and allows precise and accurate conversion of natural, continuous signals to digital signals that MPUs can process. Medical customers can also benefit from custom solutions that leverage our core competencies in precision analog, mixed-signal and power management technologies.

Blood Pressure Monitor

1.2

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 diagnosed with hypertension actually suffer from what is known as "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. 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 1-2a illustrates the system block diagram of a typical blood pressure monitor.

Heartbeat detection

The heartbeat rate is a vital patient measurement. The following procedure is used to obtain this measurement. While deflating a cuff that is attached to a person's arm, slight variations in the overall cuff pressure may be detected (Figure 1-2b). 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 1-2d shows variations in the pressure signal and is a graphical representation of a patient's heartbeat over time.

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 1-2d).

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.

Our company has long been a provider of sensors for the invasive blood pressure monitoring segment. Figure 1-2F shows different types of packaging for our proprietary pressure sensors.

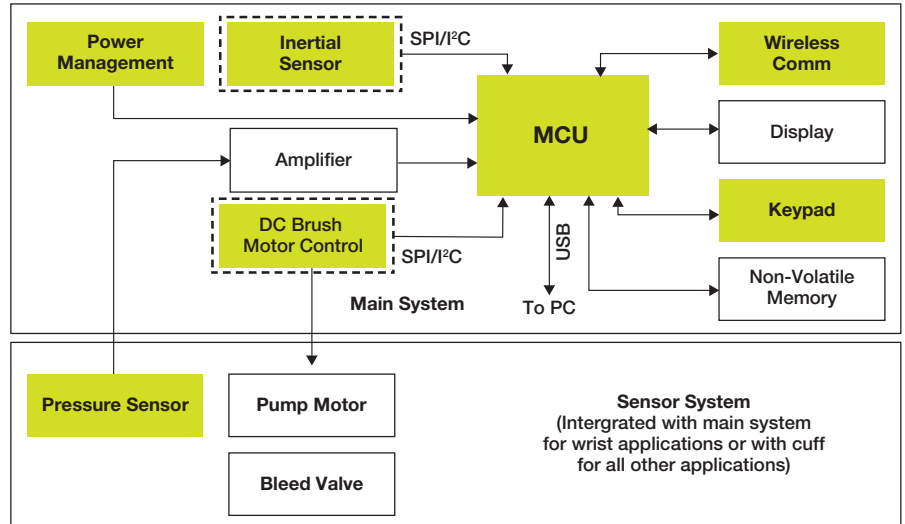### FIGURE 1-2a: BLOOD PRESSURE MONITOR GENERAL BLOCK DIAGRAM
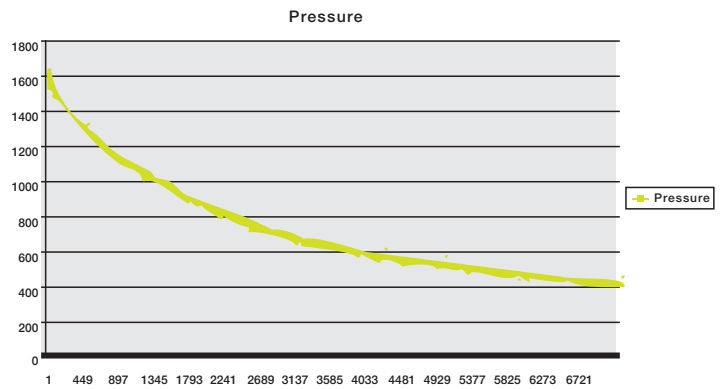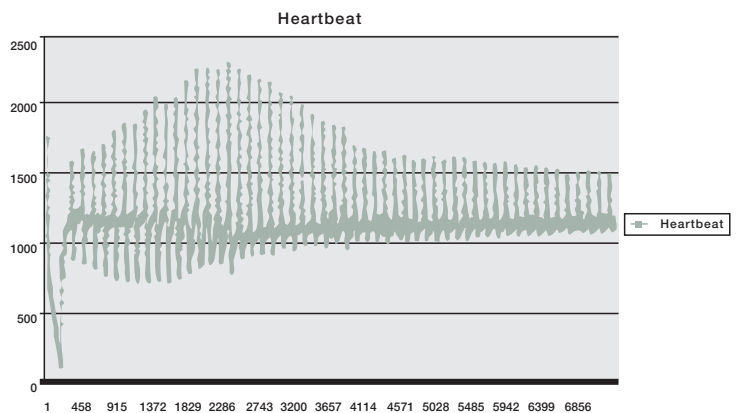

FIGURE 1-2b: HEARTBEAT SIGNAL

FIGURE 1-2c: HEARTBEAT OVER TIME

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 our sensors include the following healthcare monitoring applications:

▸ Blood pressure monitors
▸ Invasive blood pressure monitors
▸ Intrauterine blood pressure monitors
▸ Hospital bed controls
▸ Respirators
▸ Sleep apnea monitors
▸ Sports diagnostic systems
▸ Dialysis equipment
▸ Drug delivery for inhalers
▸ Physical therapy

Our proprietary pressure sensors are specifically designed for applications where high quality and reliability are especially important.

Our 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. Our pressure sensors combine advanced micro-machining techniques, thin-film metallization and bipolar semiconductor processing that provides accurate and highly reliable sensors at competitive prices.

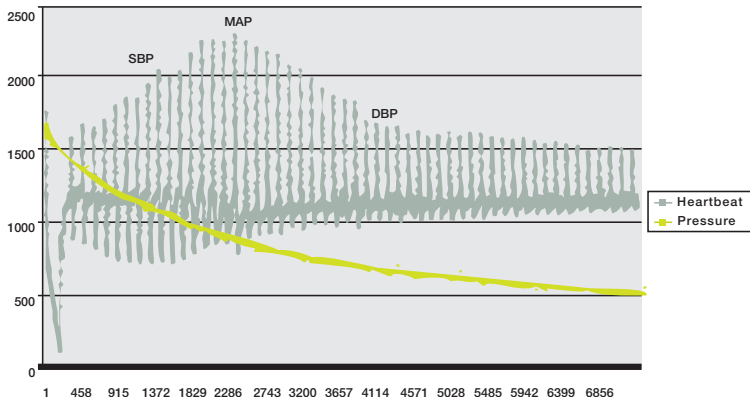### FIGURE 1-2d: HEARTBEAT VERSUS DIASTOLIC PRESSURE

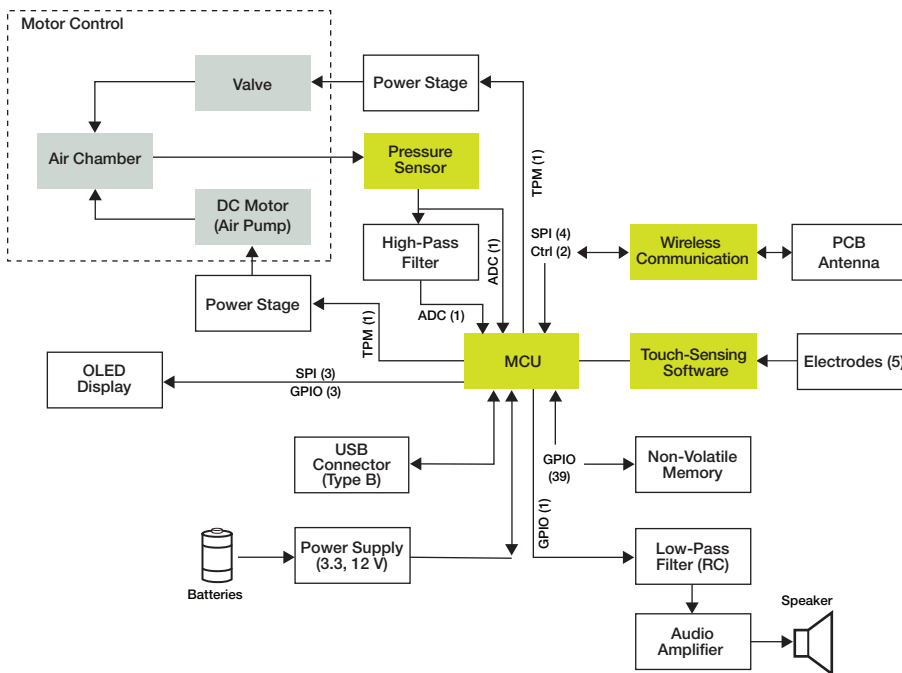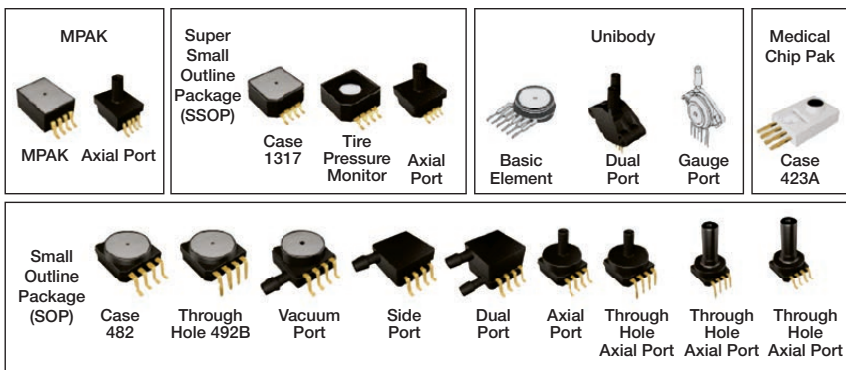### FIGURE 1-2e: MCU BLOOD PRESSURE MONITOR REFERENCE DESIGN BLOCK DIAGRAM

FIGURE 1-2f: NXP PRESSURE SENSORS

Blood pressure monitor reference design

For more information on how to build a blood pressure monitor, download the following PDF documents from **www.nxp.com**:

▸ Application note AN4328: *Blood Pressure Monitor Fundamentals and Design.* This application note describes the implementation of a basic blood pressure monitor using the MK53N512, medical oriented MCUs, pressure sensors, as well as the MED-BPM development board. Code is provided to speed development. The block diagram is shown in Figure 1-2H.

▸ Application note AN3500: *Blood Pressure Monitor Using Flexis QE128 and Pressure Sensors*

▸ Design reference manual DRM101: *Blood Pressure Monitor Using the Flexis QE128 Family and Pressure Sensors*

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

▸ For inertial sensors, see chapter on the Activity and Sports Monitor Application

▸ For wireless communication, power management, keypad and speaker implementation modules, see chapter on Telehealth Systems

▸ For LCD screen connection, see chapter on Blood Glucose Meter Introduction

▸ For pressure sensor implementation and motor control devices, see chapter on Ventilation and Spirometry Introduction

Kinetis KL2x USB MCUs

The Kinetis KL2 MCU family is pin, software and tool compatible with all other Kinetis L MCU families and adds a Full-Speed USB 2.0 On-The-Go controller with an integrated low-voltage regulator. The Kinetis KL2 MCU family is also compatible with the Kinetis K20 MCU family (based on the ARM® Cortex®-M4 processor), providing a migration path to higher performance and feature integration.

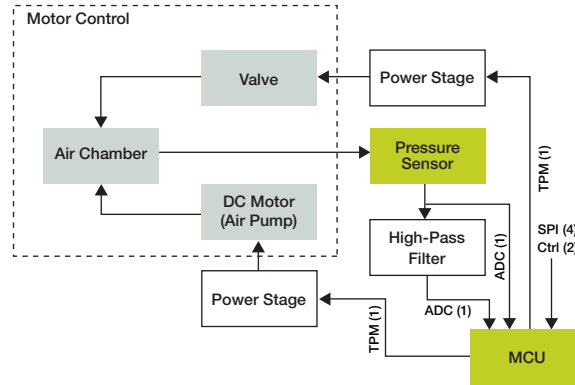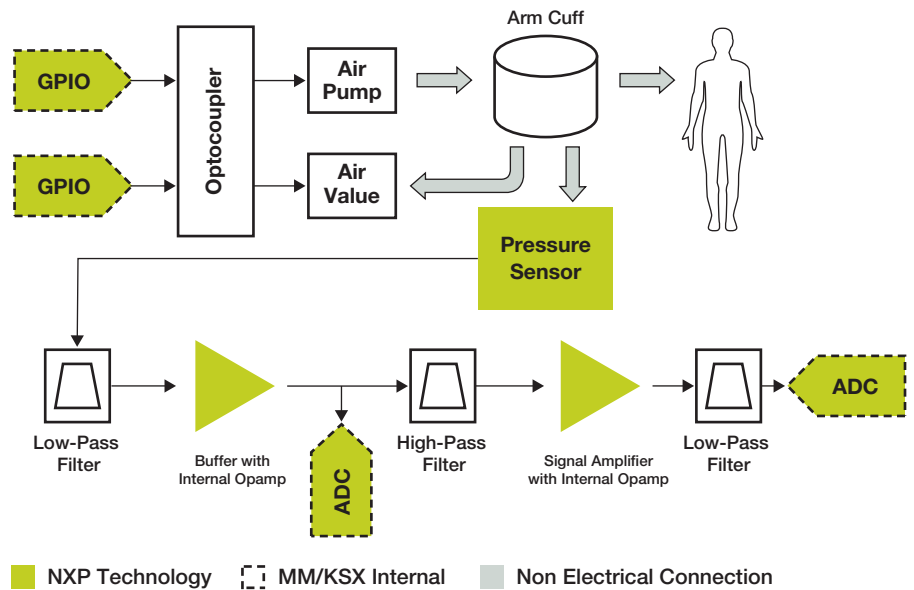## FIGURE 1-2g: PRESSURE GAUGE BLOCK DIAGRAM

FIGURE 1-2h: MED-BPM BLOCK DIAGRAM

Devices start from 32 KB of flash in a small-footprint 5 x 5 mm 32 QFN package extending up to 256 KB in a 121 MBGA package. Each combines ultra-low-power performance with a rich suite of analog, communication, timing and control peripherals.

Features

▸ ARM Cortex-M0+ core, 48 MHz core frequency over full voltage and temperature range (–40 °C to +105 °C)

▸ Up to 256 KB flash with 64 byte flash cache, up to 32 KB RAM

▸ Multiple flexible low power modes

▸ Up to 16-bit ADC with configurable resolution, sample time and conversion speed/power

▸ Capacitive touch sense interface supports up to 16 external electrodes and DMA data transfer

▸ USB 2.0 On-The-Go (Full-Speed) with integrated USB low-voltage regulator supplies up to 120 mA off chip at 3.3 volts to power external components from 5-volt input

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▸ Ultra-low-power operation
▸ 2 x opamp
▸ 2 x triamp
▸ 2 x 12-bit DAC
▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers
▸ Programmable delay block
▸ I²C
▸ USB connectivity
▸ ARM Cortex-M4 core with DSP instructions

FIGURE 1-2i: KINETIS K50 FAMILY BLOCK DIAGRAM
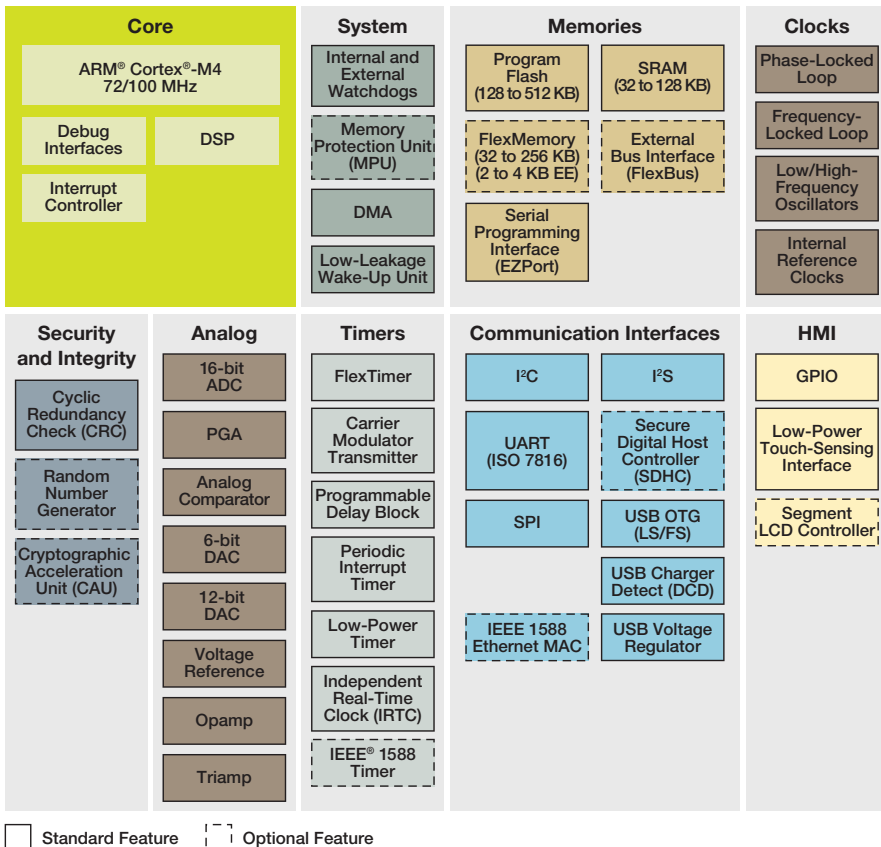
Telehealth System

1.3

Introduction

Telehealth is an example of a proactive and preventative approach to healthcare. These systems use technology to more effectively monitor people with chronic diseases, whether in the hospital, clinic or at home. In a clinical environment, systems must monitor all the patient's vitals on a single system that is easily accessed by healthcare professionals. The data captured by this system must be aggregated, analyzed and acted upon. Similarly, many patients need to continue this type of monitoring but can do so more comfortably in their own home. Physicians or home healthcare 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 relayed to the healthcare provider and caregivers to allow appropriate action to be taken.

Home health hub (HHH) reference platform

The HHH reference platform aids medical equipment manufacturers in quickly and easily creating remote-access devices that can collect, connect and securely share health data for improved healthcare management.

The changing dynamics of the aging global population are creating an increased demand for new technologies and tools that can offer peace of mind to the family members of seniors living at home. There's also a need to provide access to healthcare in remote and growing regions of the world to improve the quality of life for millions of people. The HHH reference platform is designed to simplify development of connected medical devices and help our customers more easily address these growing needs.

The HHH reference platform consists of an aggregator/gateway board based on the low-power i.MX28 applications processor (built on the ARM9™ processor) running various connectivity interfaces to healthcare end devices and wireless or wired connectivity for a remote user interface. Also included is a panic alarm sensor based on the our MC12311 sub-1 GHz radio, providing personal emergency response system (PERS) functionality. To complete the reference platform, software such as board support packages (Linux® and Windows® Embedded Compact 7) and example code are included. The HHH reference platform comes complete with the iDigi Telehealth Application Kit, and is available for purchase through Digi International at **digi.com/hhh**.

The iDigi Telehealth Application Kit enables the creation of secure, highly scalable cloud-connected healthcare gateway solutions right out of the box and brings wireless and wired connectivity to a wide array of healthcare devices and sensors. The iDigi Device Cloud™ provides remote management and secure data integration capabilities, allowing customers to build innovative and connected telehealth solutions for the medical and healthcare market.

The HHH reference platform, adhering to Continua device profiles, provides comprehensive functionality and can be used as the foundation for connected medical
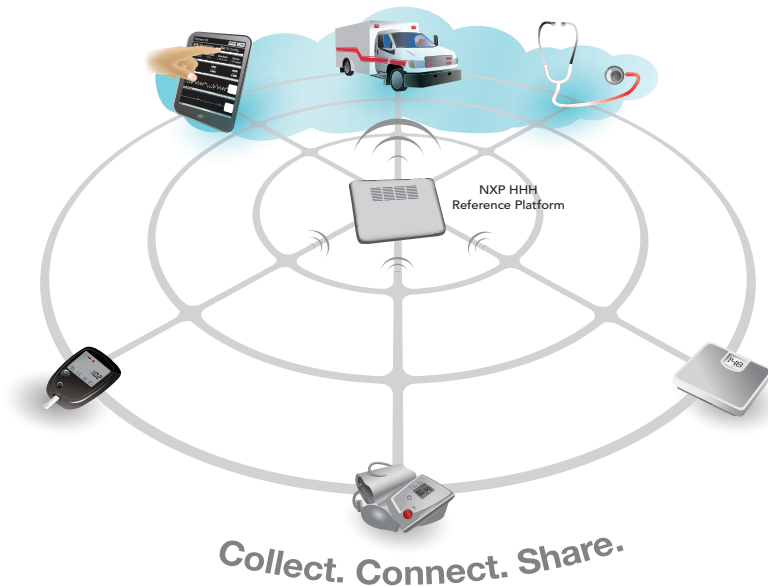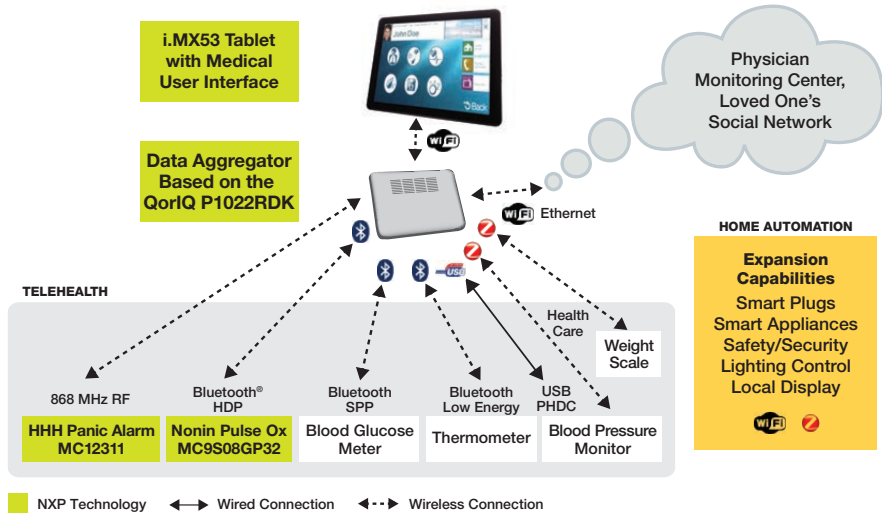
FIGURE 1.3a: HHH REFERENCE PLATFORM

NXP HHH Reference Platform

Collect. Connect. Share.

FIGURE 1-2h: MED-BPM BLOCK DIAGRAM

i.MX53 Tablet with Medical User Interface

Data Aggregator Based on the QorIQ P1022RDK

Physician Monitoring Center, Loved One's Social Network

HOME AUTOMATION

Expansion Capabilities
Smart Plugs
Smart Appliances
Safety/Security
Lighting Control
Local Display

WiFi Ethernet

TELEHEALTH

Health Care

Weight Scale

868 MHz RF | Bluetooth® HDP | Bluetooth SPP | Bluetooth Low Energy | USB PHDC

HHH Panic Alarm MC12311 | Nonin Pulse Ox MC9S08GP32 | Blood Glucose Meter | Thermometer | Blood Pressure Monitor

NXP Technology ◄──► Wired Connection ◄┄► Wireless Connection

product designs, giving developers a head start to help them get to market faster. The kit delivers hardware implementation and the necessary software components to provide pre-validated, secure connectivity for healthcare devices and user interfaces. The platform also enables connection to the Microsoft HealthVault, a privacy- and security-enhanced online data repository that lets users organize, store and share their health information.

The HHH reference platform was the Ultimate Products winner in the 2012 UBM Electronics ACE (Annual Creativity in Electronics) Awards in the Development Kits, Reference Designs and SBCs category.

ACE AWARDS EE Times EDN 2012 WINNER

MCIMX28: i.MX ARM9 applications processor

The i.MX28 family of applications processors is part of our portfolio of solutions built on the ARM9 core. The i.MX28 family integrates display, power management and connectivity features unmatched in ARM9-based devices, reducing system cost and complexity for cost-sensitive applications. The LCD controller with touch screen capability makes it possible to design creative and intuitive user interfaces required by many applications. The i.MX28 family reaches new levels of integration in ARM9™ devices and provides the enablement needed to help design differentiated medical, industrial, automotive and consumer products in less time.

Features

▸ 454 MHz ARM926EJ-S™ core

▸ 16 KB/32 KB I and D cache

▸ Power management unit (PMU) to power the device and drive external components supports li-ion batteries and direct connection to 5 V supplies

▸ Dual IEEE® 1588 10/100 Ethernet with RMII support and L2 switch (i.MX287)

▸ Single IEEE 1588 10/100 Ethernet with RMII or GMII support (i.MX280, i.MX283, i.MX286)

▸ Dual CAN interfaces (i.MX286, i.MX287)

▸ NAND support: SLC/MLC and eMMC 4.4 (managed NAND)

▸ Hardware BCH (up to 20-bit correction)

▸ 200 MHz 16-bit DDR2, LV-DDR2, mDDR external memory support

▸ Dual High-Speed USB with PHY

▸ Up to eight general-purpose 12-bit ADC channels

▸ Temperature sensor for thermal protection

▸ Multiple connectivity ports (UARTs, SSP, SDIO, SPI, I²C, I²S)

▸ Multiple family members support various feature sets based on above feature list

FIGURE 1.3c: I.MX28 FAMILY BLOCK DIAGRAM
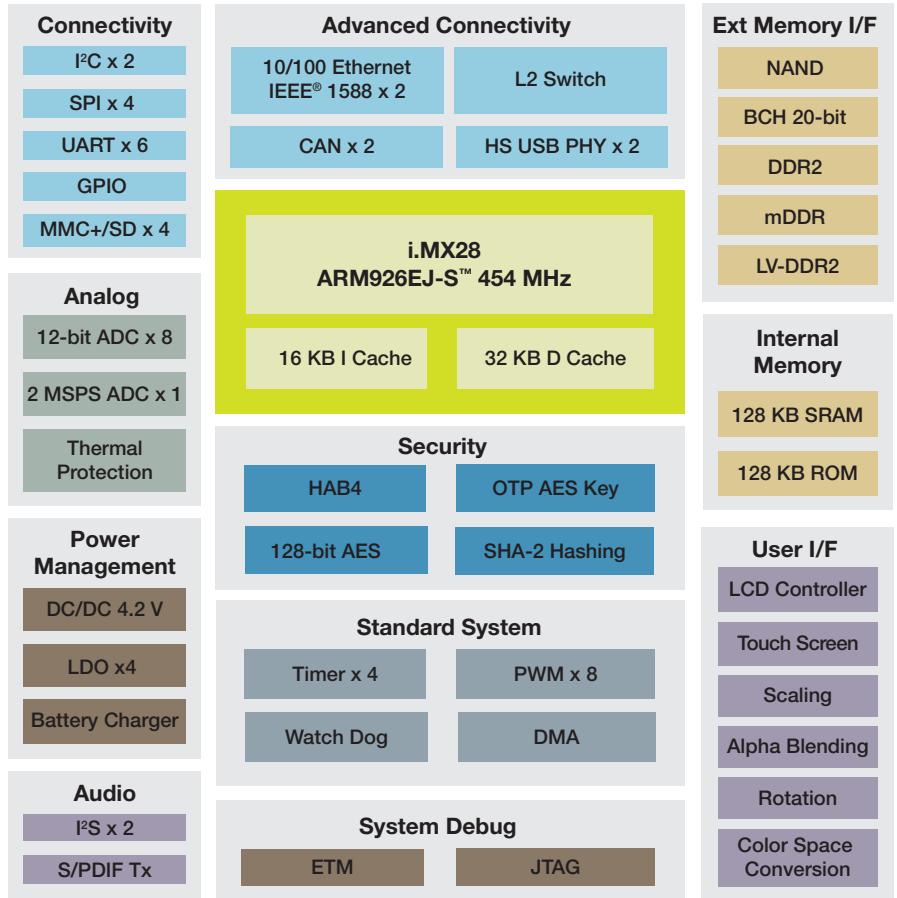
FIGURE 1.3d: BASIC TELEHEALTH GATEWAY
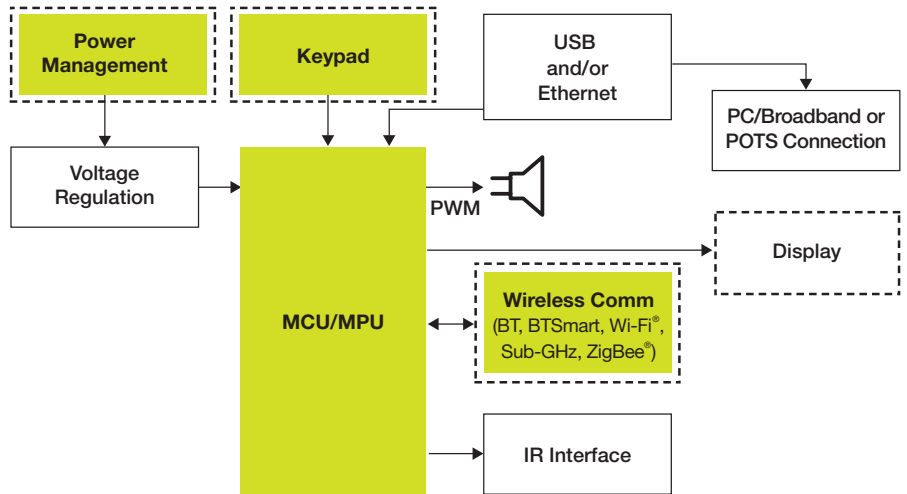
NXP Technology   Optional

Home health hub (HHH) Reference Platform

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. The 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 1.3e.

Features

▸ Integrated N-channel power MOSFET input voltage operating range from 3.0 to 6.0 V

▸ 1 percent accurate output voltage, ranging from 0.7 to 3.6 V

▸ 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

▸ Overcurrent limit and short-circuit protection

▸ Thermal shutdown

▸ Output overvoltage and undervoltage detection

▸ Active low power, good output signal

▸ Active low shutdown input

These regulators enable the use of multiple power sources such as batteries, chargers or AC adapters.

Voltage regulation

In systems where an MCU or DSP is 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 MC34704 power management device.

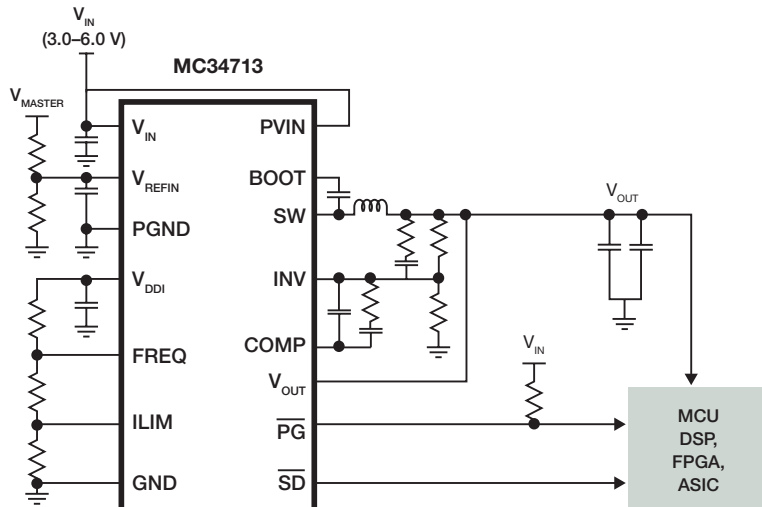**FIGURE 1.3e: MC34713 SIMPLIFIED APPLICATION DIAGRAM**
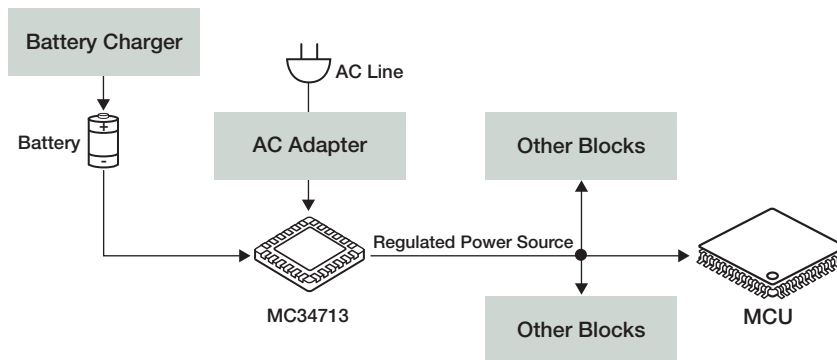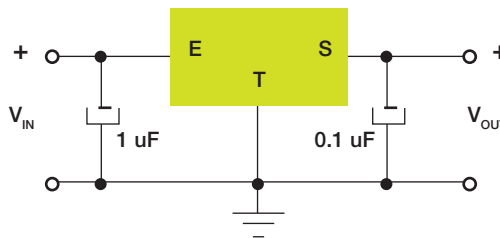

FIGURE 1.3f: BLOCK DIAGRAM USING POWER REGULATORS

**FIGURE 1.3g: LINEAR VOLTAGE REGULATOR**

MCIMX28: i.MX ARM9

The MC34704 is a multi-channel PMIC.

Features

▸ Eight DC/DC (34704A) or five DC/DC (34704B) switching regulators with up to ±2 percent output voltage accuracy

▸ Dynamic voltage scaling on all regulators

▸ Selectable voltage mode control or current mode control on REG8

▸ I²C programmability

▸ Output undervoltage and overvoltage detection for each regulator

▸ Overcurrent 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, 5.5 V VIN)

▸ True cutoff on all boost and buck-boost regulators

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

FIGURE 1.3h: SINGLE SYNCHRONOUS BUCK SWITCHING REGULATOR
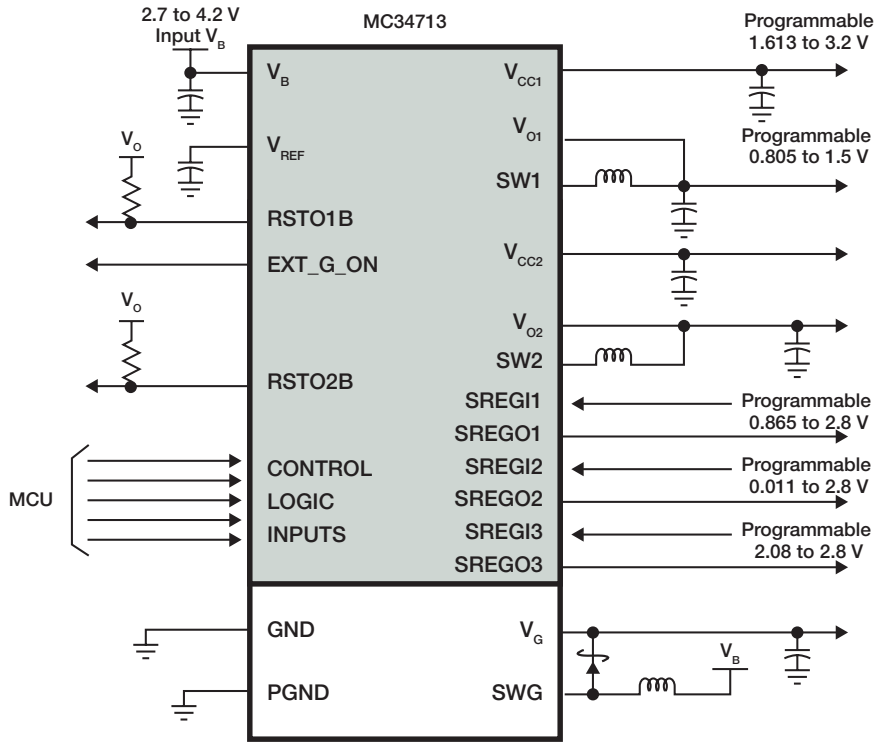
FIGURE 1.3i: MC34704 BLOCK DIAGRAM
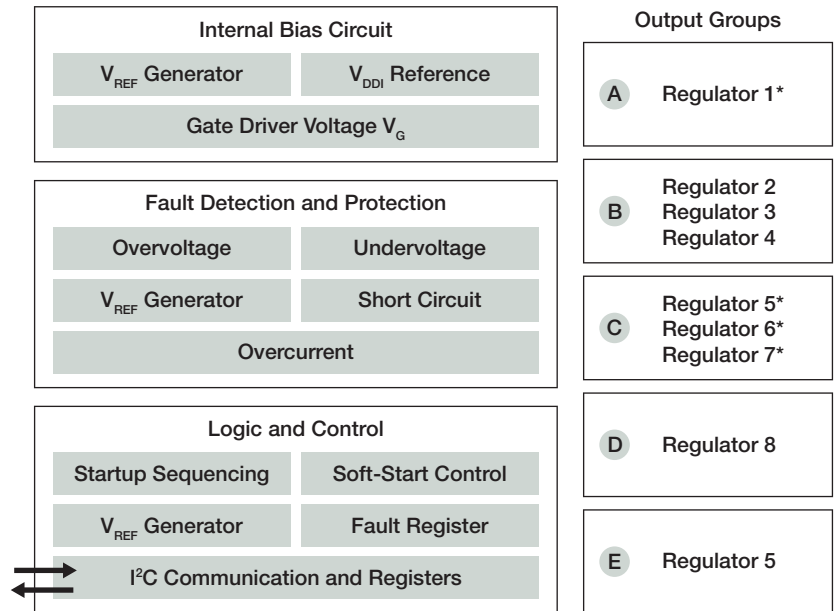
Keypad

Implementation of a touch-sensitive keypad provides advantages over classic button-based technology, including:

▸ Cost effectiveness
▸ Smaller design
▸ More durability due to lack of mechanical wear
▸ Easy to keep clean

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

These devices can be connected to an MCU through an I²C interface.

Touch-sensing software suite (TSS)

The TSS is a downloadable software package that enables a proprietary 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.

Features

▸ Intellectual property 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/less than 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

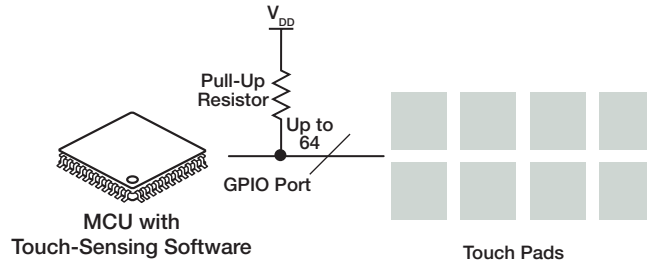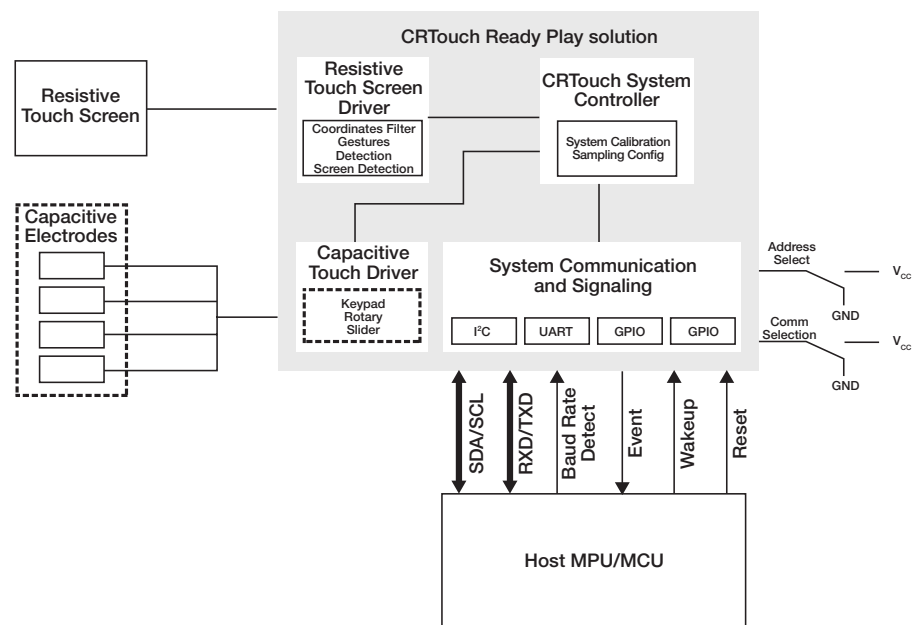### FIGURE 1.3j: KEYPAD IMPLEMENTATION USING TOUCH-SENSING SOFTWARE

FIGURE 1.3k: CAPACITIVE AND RESISTIVE TOUCH-SENSING PLATFORM

Capacitive and resistive touch sensing platform (CRTouch)

The CRTouch platform enables resistive touch screens to handle basic gesture recognition. CRTouch allows also the addition of up to four capacitive electrodes to a system, all packaged on a 5 x 5 mm lead-free 32-pin QFN. It supports 4- and 5-wire touch screens and communicates over UART and I²C communication protocols.

CRTouch is one of the industry's first devices that combine 4- and 5-wire resistive screen controller with basic gesture recognition and up to four capacitive touch-sensing electrodes, all encompassed in a single integrated circuit, allowing the implementation of both technologies for reduced space, software development cost and time to market.

How it works

External capacitance is charged and discharged continuously and depends on the sample configuration. While 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 measured. 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 contains 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, etc.)

▶ Output: Indicates touch detection both to the user and the application

Pulse width modulation (PWM) function for a speaker circuit

PWM can be implemented using a simple timer (in output compare mode) typically integrated in one of our 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 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 1-3n 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 1.3l: COMPONENTS OF A TOUCH-SENSING SYSTEM
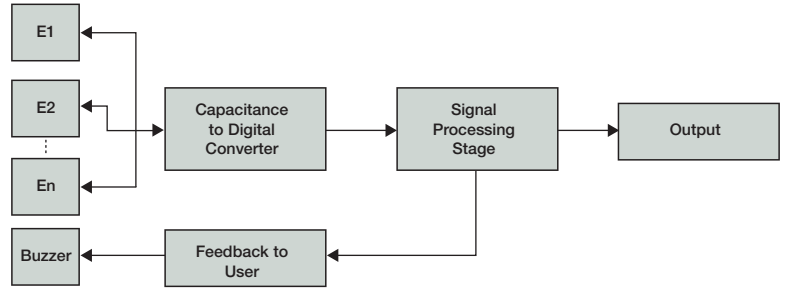
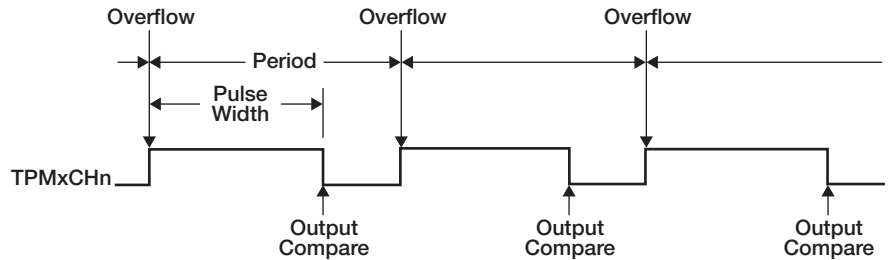### FIGURE 1.3m: TIMER OPERATION TO GENERATE PWM SIGNAL

Figure 1-3o 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.

Wireless communication

One technology that is expected to directly impact the trend of reduced healthcare costs and an increased level of patient care is wireless connectivity. We offer a broad portfolio of high- and low-power RF products, serving the wireless infrastructure, wireless subscriber, consumer and industrial markets. Our company was a pioneer in developing RF technology and continues to be a leader in the field by providing the quality, reliability and consistency required in today's healthcare designs.

Introduction to our technology

We offers a portfolio of low-power, cost-effective wireless solutions for embedded devices. These solutions address a number of monitoring and control applications, including consumer, smart energy, industrial and healthcare. We provide solutions for sub-1 GHz and 2.4 GHz bands, including IEEE 802.15.4 and ZigBee protocol stacks. Our solution is complete with development tools, reference designs and software designed to help ease wireless development and speed time to market.

ZigBee®/IEEE 802.15.4 applications in healthcare

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.

Our company has received ZigBee Certified product status for its ZigBee Healthcare 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 non-critical, low-acuity healthcare services.

Our proprietary 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.

Our proprietary 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
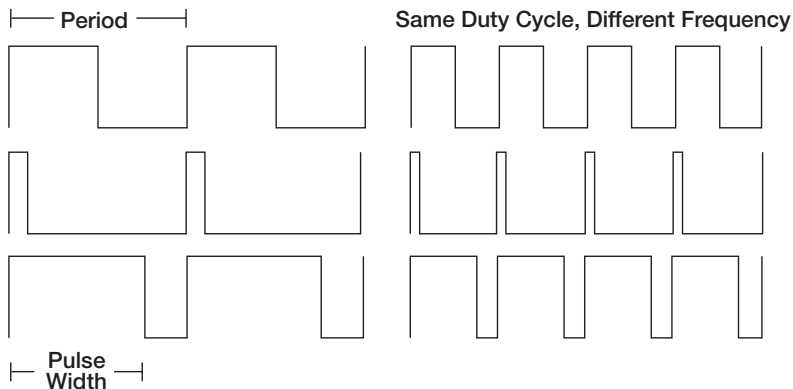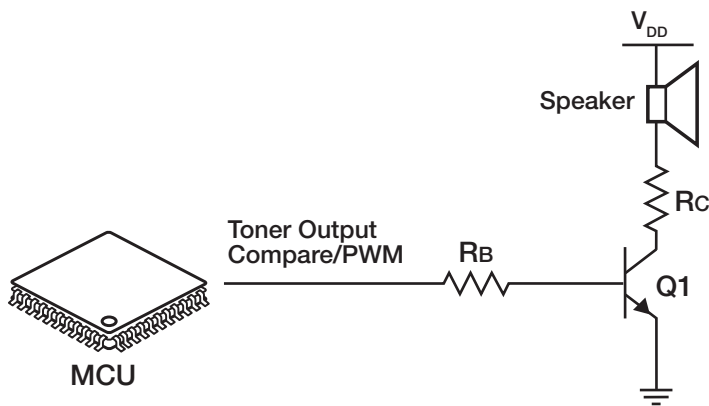
development. The BeeStack ZigBee-compliant stack with BeeKit wireless toolkit provides a simple software environment to configure network parameters. This tool allows customers to use a wizard and dropdown menus to help configure the ZigBee network parameters. To learn more about ZigBee technology, visit **www.nxp.com/ZigBee**.

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

FIGURE 1.3n: VARIATIONS IN PERIOD AND PULSE WIDTH

FIGURE 1.3o: IMPLEMENTATION EXAMPLE

Bluetooth Low Energy applications in healthcare

The recent introduction of Bluetooth® 4.0, more specifically, single-mode Bluetooth Low Energy, is driving the creation of a whole new class of wirelessly enabled devices that are connected to a smart mobile device. In addition to the connectivity to smartphones and tablets, Bluetooth Low Energy will allow devices equipped with the wireless technology to consume far less power than before. Bluetooth Low Energy capability is perfect for transmitting small amounts of data you might want to display on a watch, collect from a fitness machine or send to the cloud for analysis via a gateway like our HHH reference platform. It is predicted that there will be 50 billion connected devices in the world by the end of the decade, many of which will be healthcare specific.

Multi-mode radio products

The KW4x is an ultra-low-power, highly integrated single-chip device that enables Bluetooth low energy (BLE) or IEEE Std. 802.15.4/ZigBee RF connectivity for portable, extremely low-power embedded systems. Applications include portable health care devices, wearable sports and fitness devices, AV remote controls, computer keyboards and mice, gaming controllers, access control, security systems, smart energy and home area networks.

The KW4x SoC integrates a radio transceiver operating in the 2.36 GHz to 2.48 GHz range supporting a range of FSK/GFSK and O-QPSK modulations, an ARM Cortex-M0+ CPU, 160 KB Flash and 20 KB SRAM, BLE Link Layer hardware, 802.15.4 packet processor hardware and peripherals optimized to meet the requirements of the target applications.

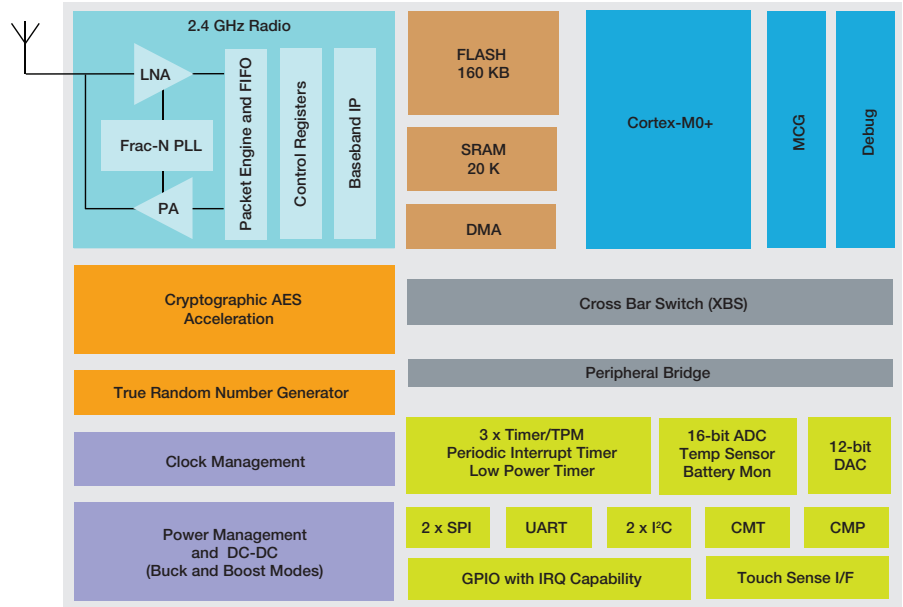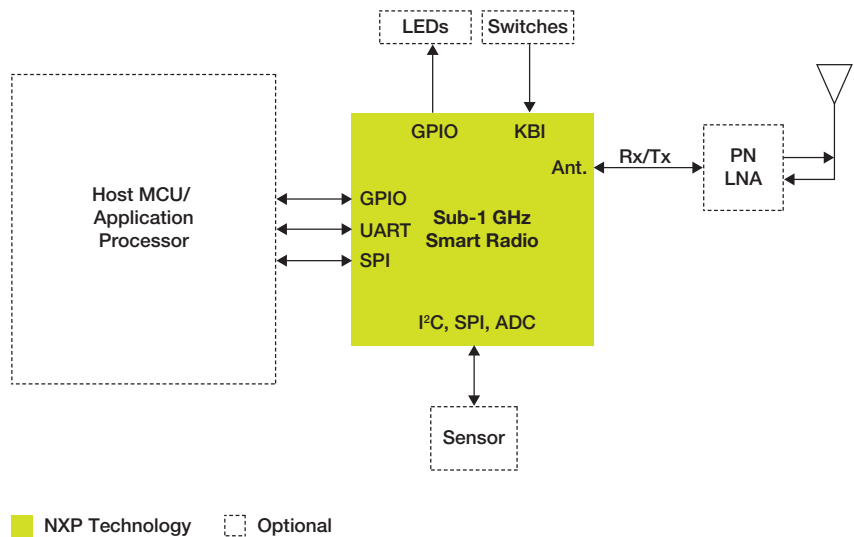FIGURE 1.3p: KINETIS KW40Z, KW30Z, KW20Z WIRELESS MCU FAMILY

FIGURE 1.3q: SUB-1 GHZ BLOCK DIAGRAM

Sub-1 GHz applications in healthcare

With the onset of the Internet of Things, wireless communication for embedded devices is becoming more pervasive. While 2.4 GHz is popular for wireless systems such as Wi-Fi®, Bluetooth and ZigBee, sub-GHz RF has been around for many years and is often preferred by industrial, commercial and healthcare applications due to its increased range and better propagation capabilities. In addition, new standards for sub-GHz radios including the recently released IEEE 802.15.4g as well as the move to Internet protocol with network components like 6LowPAN and IPv6 are driving up demand for sub-GHz wireless solutions. With options for 2.4 GHz and sub-GHz, developers now have the tools to design a wireless system that meets the needs of their application.

Sub-1 GHz products

KW01 family

The Kinetis KW01 ultra-low-power wireless MCU is an ARM® Cortex® core-based smart radio solution designed for sub-1 GHz (290–1020 MHz) wireless connectivity applications. Powered by the ultra-low-power 48 MHz 32-bit MCU built on the ARM Cortex-M0+ core, the MKW01 embeds a rich set of peripherals with a high-performance bi-directional sub-1 GHz radio, capable of operating over a wide frequency range including 315, 433, 470, 868, 915, 928 and 960 MHz in the license-free industrial, scientific and medical frequency bands.

Features

▸ Ultra-low-power 32-bit ARM Cortex-M0+ core.

▸ 128 KB flash with 64 byte flash cache, 16 KB RAM

▸ 16-bit ADC with configurable resolution, sample time and conversion speed/power

▸ High-speed comparator with internal 6-bit DAC

▸ 12-bit DAC with DMA support

Software

▸ Simple media access controller (SMAC)
  – Simple communication and test apps based on drivers/PHY utilities available as source code
  – Small footprint (<10 KB)
  – Supports point-to-point and star networks with repeaters
  – Support for over-the-air programming

▸ Radio test tool
  – Run on PC connected through USB
  – Allow fast evaluation of the radio performance in a lab environment without need for writing software
  – Analysis of TX spectrum (output power, harmonics)
  – Modulation scheme impact (GFSK, BT, mod index) on spectrum
  – Help on matching network tuning
  – Analysis of RX sensitivity performance (RSSI, LNA input impedance, OOK threshold, AFC)
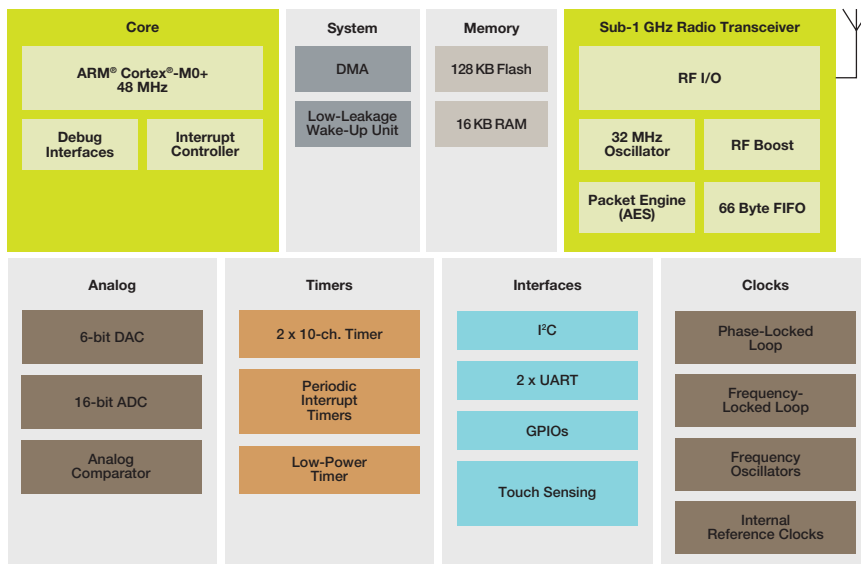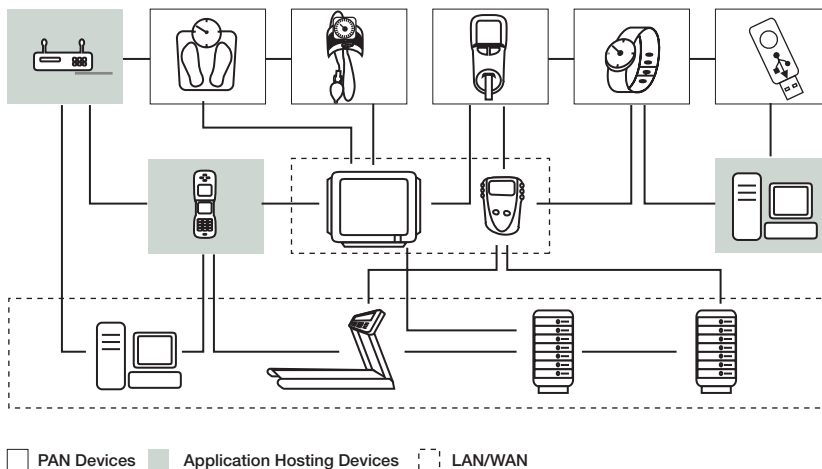
FIGURE 1.3r: MKW01 BLOCK DIAGRAM

FIGURE 1.3s: CONTINUA ECOSYSTEM TOPOLOGY

PAN Devices　　Application Hosting Devices　　LAN/WAN

PHDC USB library software

One of the biggest challenges for medical designers is medical standard compliances. The Continua Health Alliance (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 1.3s describes a medical device system topology.

We provide 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.

Standard medical USB communication

For USB communication, two main standards must be considered:

▶ IEEE 11073, which provides structure to the communication interface

▶ Personal healthcare 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 must be considered when selecting a particular USB connectivity software implementation for medical devices.

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.

FIGURE 1.3t: MEDICAL APPLICATIONS USB STACK
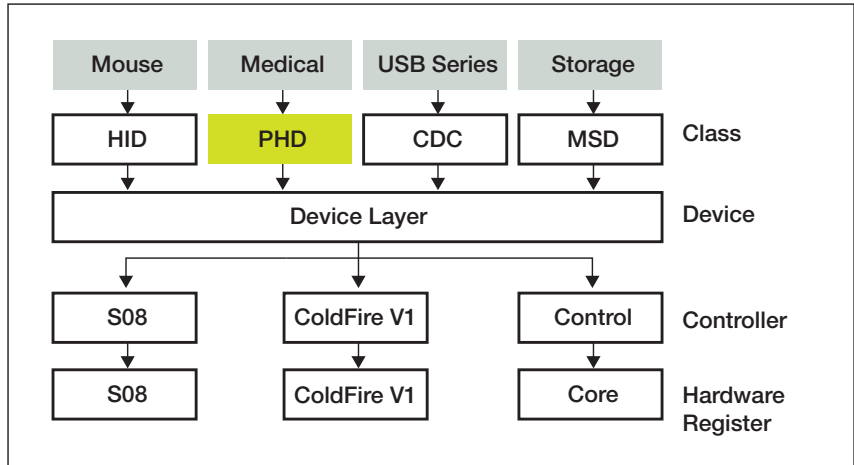
More information is available at **stonestreetone.com/singlemodemodule.cfm**.

FIGURE 1.3u: BROADBAND BLOCK DIAGRAM
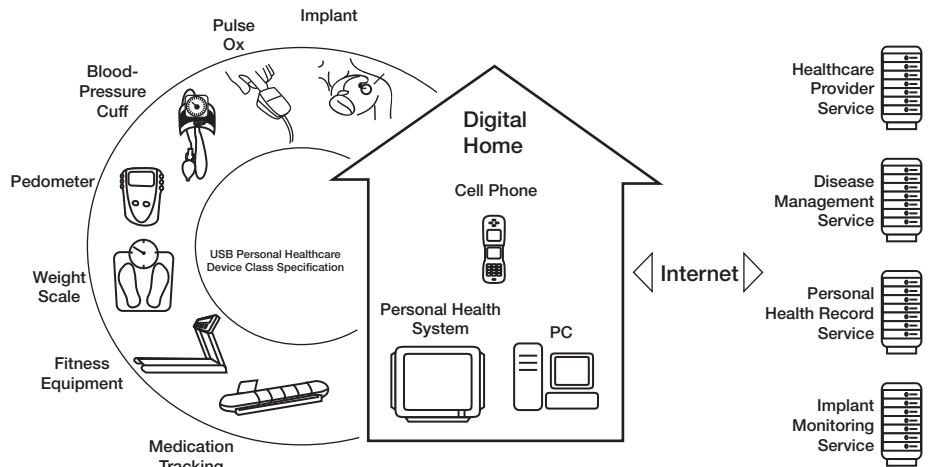
Software architecture helps to ensure code robustness, portability and reliability in embedded systems development.

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, 32-bit ColdFire and Kinetis devices and can be downloaded at **www.nxp.com**.
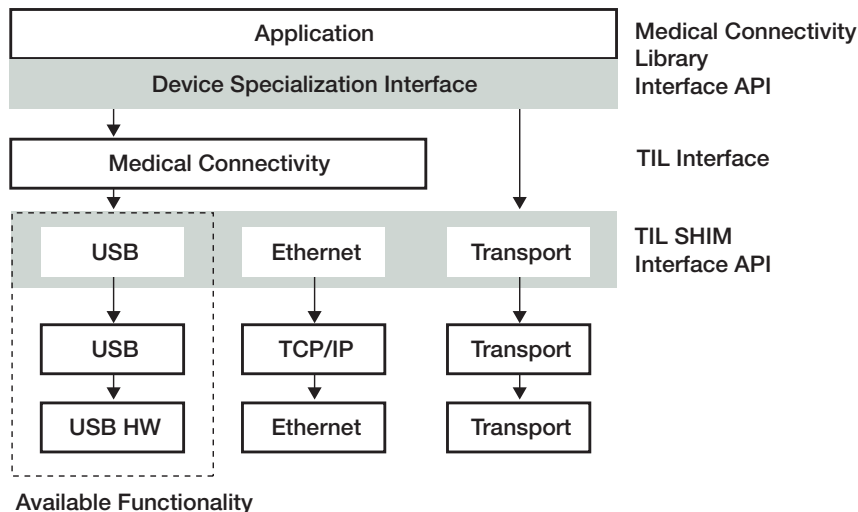
The USB protocol can be further broken into PHDC and low-level driver layers. The low-level driver abstracts USB IP to provide a generic interface to the class driver. The PHDC is a function-specific class layer.

Its responsibility is to hide transport-specific details from the data exchange protocol layer. Our company additionally provides a medical connectivity library that provides users with standard IEEE 11073 connectivity.

This library is transport-independent because of its transport independent layer. Therefore, protocols that may be used include serial, Bluetooth, USB and ZigBee. The library can be downloaded at **www.nxp.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. Other supported devices include, blood pressure monitors (IEEE 11073–10407), blood glucose monitors (IEEE11073-10417) and thermometers (IEEE11073–10408). Demo videos of these solutions are available at **www.nxp.com/healthcare**.
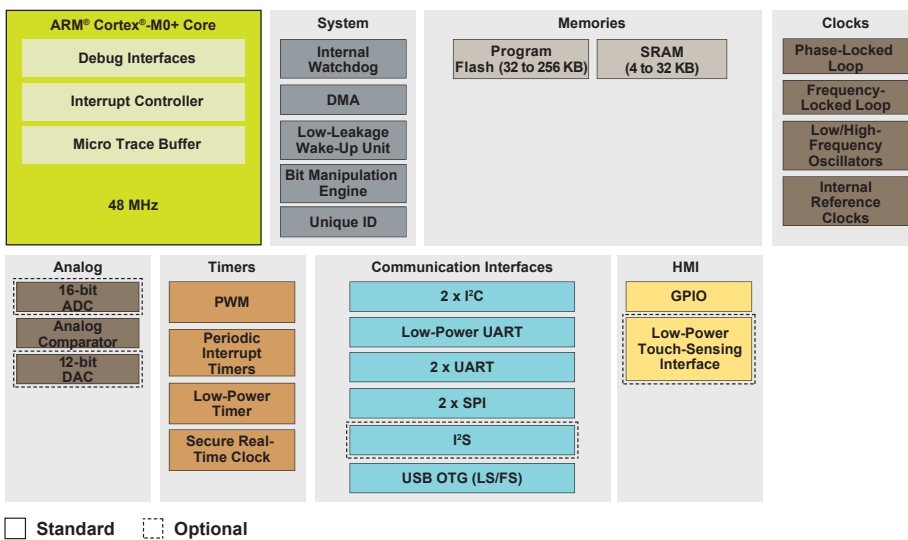
Kinetis KL2x family

The Kinetis KL2 MCU family is pin, software and tool compatible with all other Kinetis L MCU families and adds a Full-Speed USB 2.0 On-The-Go controller with an integrated low-voltage regulator. The Kinetis KL2 MCU family is also compatible with the Kinetis K20 MCU family (based on the ARM Cortex-M4 processor), providing a migration path to higher performance and feature integration.

Features

▸ Next-generation 32-bit ARM Cortex-M0+ core: 2x more CoreMark®/mA than the closest 8/16-bit architecture
  – Multiple flexible low power modes, including new compute clocking option which reduces dynamic power by placing peripherals in an asynchronous stop mode
▸ Up to 256 KB flash with 64 byte flash cache, up to 32 KB RAM
▸ USB 2.0 On-The-Go (Full-Speed) with integrated USB low-voltage regulator supplies up to 120 mA off chip at 3.3 volts to power external components from 5-volts input

FIGURE 1.3v: MEDICAL CONNECTIVITY LIBRARY (IEEE® 11073)

Available Functionality

FIGURE 1.3x: KINETIS KL2X FAMILY BLOCK DIAGRAM

▸ Two I²C with DMA support, up to 100 Kbit/s and compatible with SMBus V2 features
▸ One LPUART and two UART with DMA support
▸ Two SPI with DMA support
▸ Up to 16-bit ADC with configurable resolution, sample time and conversion speed/power
▸ Integrated temperature sensor
▸ High-speed comparator with internal 6-bit DAC
▸ 12-bit DAC with DMA support

Pulse Oximetry

1.4

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. When the light attenuated by body tissue is measured, DC components and AC components indicate artery absorption.

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.

Circuit design overview

This application starts with an optical sensor that is composed of two LEDs and a photodiode. The two LEDs must 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 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 (0.5–5 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]

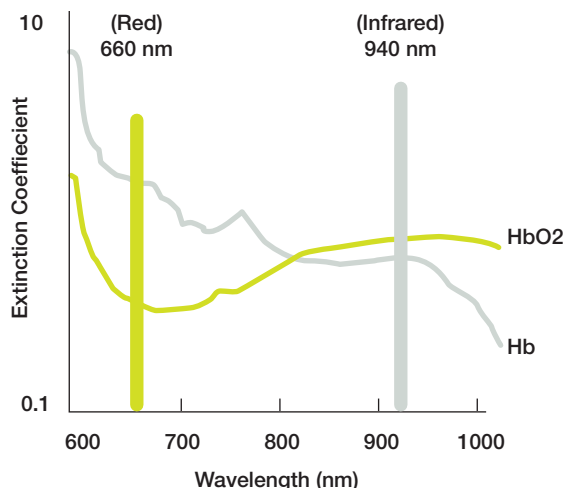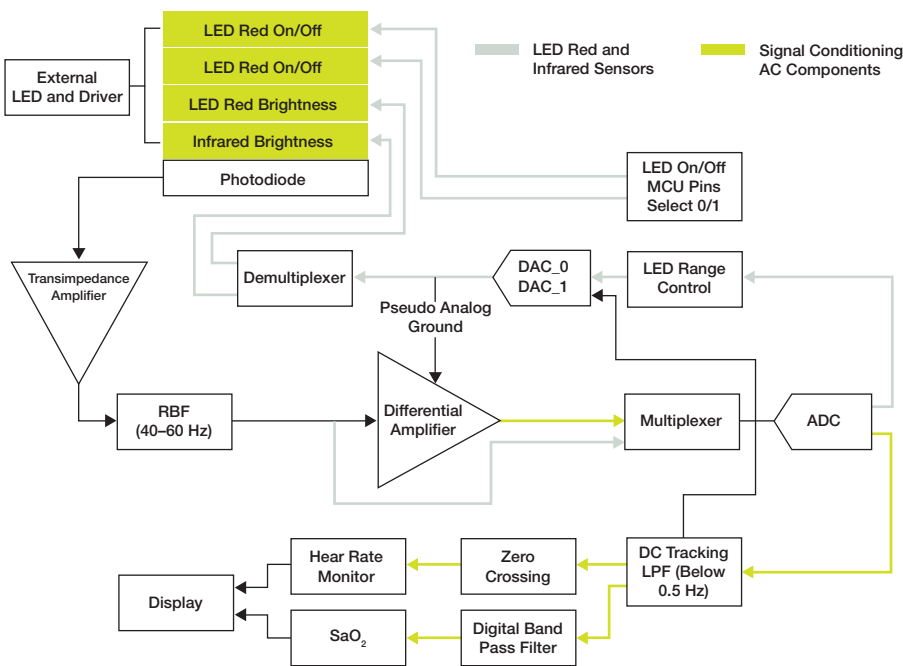### FIGURE 1.4a: SPECTRUM OF OXYHEMOGLOBIN AND DEOXYHEMOGLOBIN

FIGURE 1.4b: PULSE OXIMETRY ANALOG INTERFACE

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.

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 1 V for DC and 10 mV for AC. The Kinetis K50 MCUs have four integrated opamps. Both of the transimpedance and non-inverting amplifiers shown in figure 1.4e, as well as more active filters, can be developed using these MCUs. 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 the MC56F8006 DSC. The information can be shown on any kind of display.
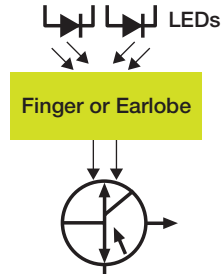
FIGURE 1.4c: OPTICAL SENSOR

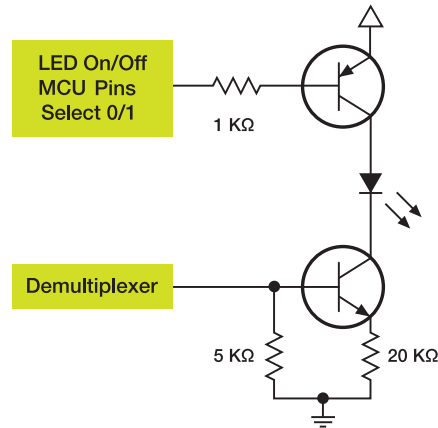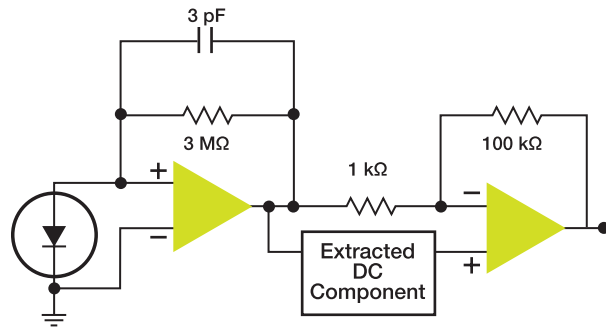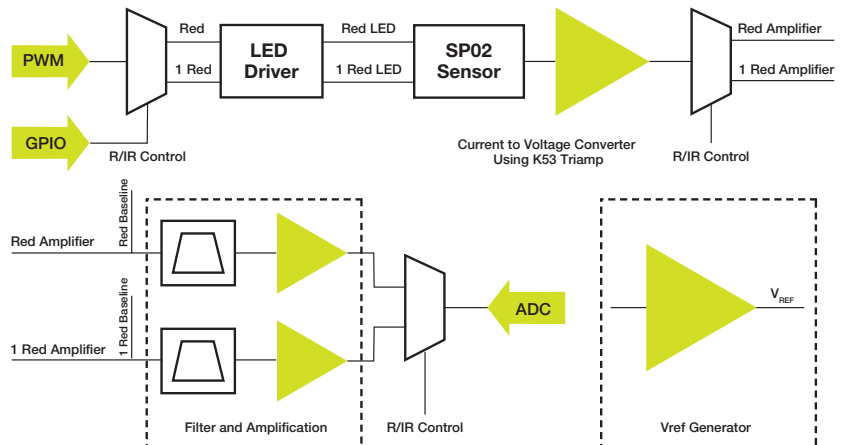## FIGURE 1.4d: LED DRIVE CIRCUIT

FIGURE 1.4e: DC/AC TRACKING

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

FIGURE 1.4f: MED-SP02 BLOCK DIAGRAM

AN4327 pulse oximeter fundamentals and design

This application note demonstrates the implementation of a pulse oximeter using the medical-oriented Kinetis K50 MCU together with the MED-SPO2 pulse oximeter development board. Basic principles of implantation and example code are included, enabling developers with an easy and effective pulse oximeter solution.

Kinetis K40 MCU

Kinetis K40 72 MHz MCUs are pin, peripheral and software compatible with the K10 MCU family, featuring Full-Speed USB 2.0 On-The-Go with device charge detect capability and a flexible low-power segment LCD controller supporting up to 288 segments.

Features

▸ 72 MHz, single cycle MAC, single instruction multiple data extensions

▸ 64–256 KB flash. Fast access, high reliability with 4-level security protection and 16–64 KB of SRAM

▸ USB 2.0 On-The-Go (Full-Speed). Device charge detect optimizes charging current/time for portable USB devices, enabling longer battery life. Low-voltage regulator supplies up to 120 mA off chip at 3.3 V to power external components from 5 V input

▸ Flexible low-power LCD controller with up to 288 segments (38 x 8 or 42 x 4). LCD blink mode enables low average power while remaining in low power mode. Segment fail detect guards against erroneous readouts and reduces LCD test costs

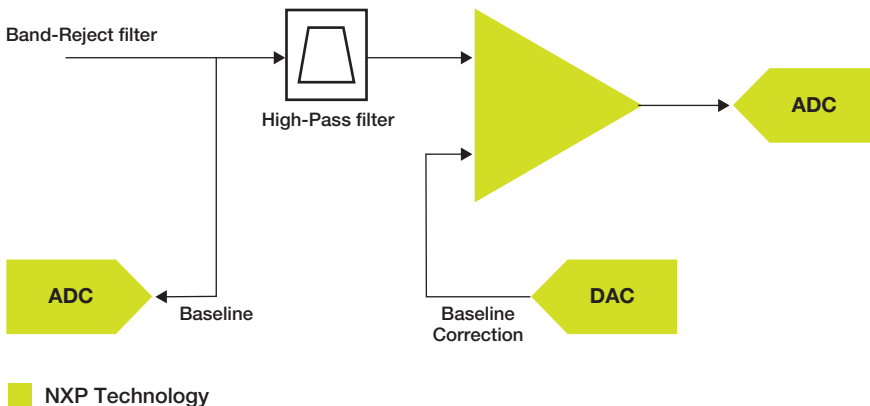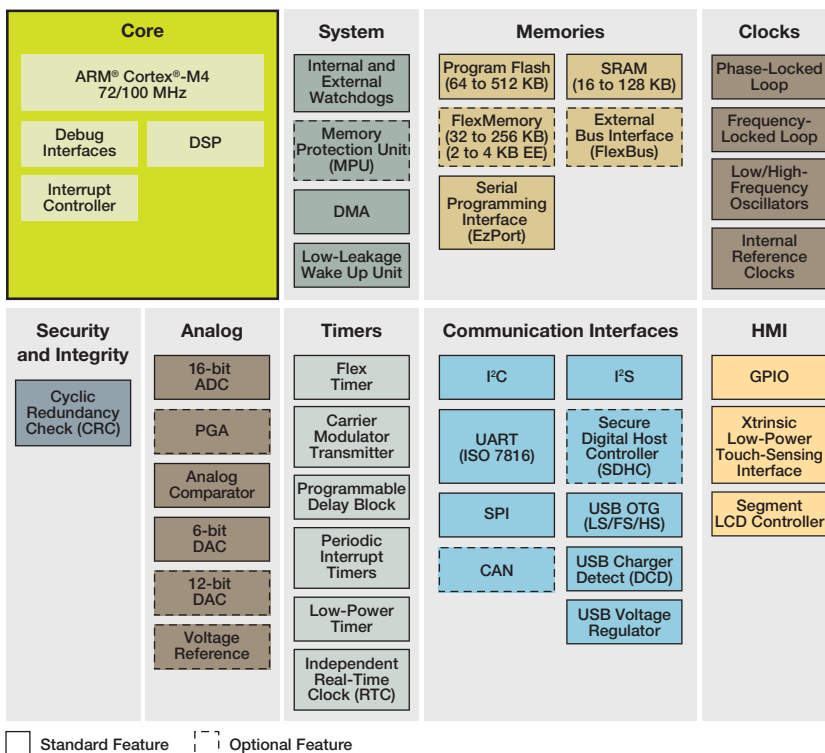**FIGURE 1.4g: PULSE OXIMETER BLOCK DIAGRAM**

FIGURE 1.4h: KINETIS K40 FAMILY BLOCK DIAGRAM

Heart Rate Monitor

1.5

Introduction

Heart rate monitors measure the heart rate during exercise or vigorous activity and gauge how hard the patient is working. Newer heart rate monitors consist of two main components: a signal acquisition sensor/transmitter and a receiver (wrist watch or smartphone). In some cases, the signal acquisition is integrated into fabric worn by the user or patient. MCUs analyze the ECG signal and determine the heart rate, making it possible to implement a simple heart rate monitor with an 8-bit MCU.

Heart signals overview

Figure 1.5a shows a typical heart signal in which 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. 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.

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 that 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.

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 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 to 60 Hz. Knowing this information, a circuit can be designed for amplification and filtration (see figures 1.5c, 1.5d, 1.5e and 1.5f for details).

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 0.1–150 Hz

‣ Band-pass filter

   Rl_p = 1 kΩ R_{hp} = 1.5 MΩ C_{lp} = C_{hp} = 1 uF

‣ AC line noise

   -3 dB frequency bandwidth of 40–60 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.
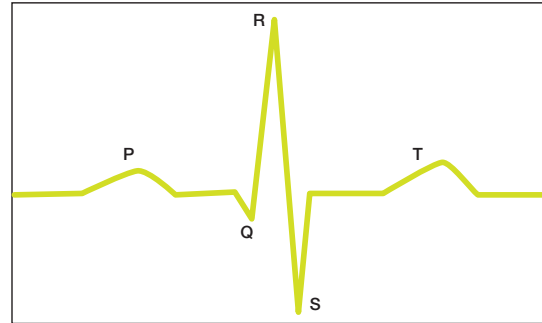
FIGURE 1.5a: TYPICAL HEART SIGNAL

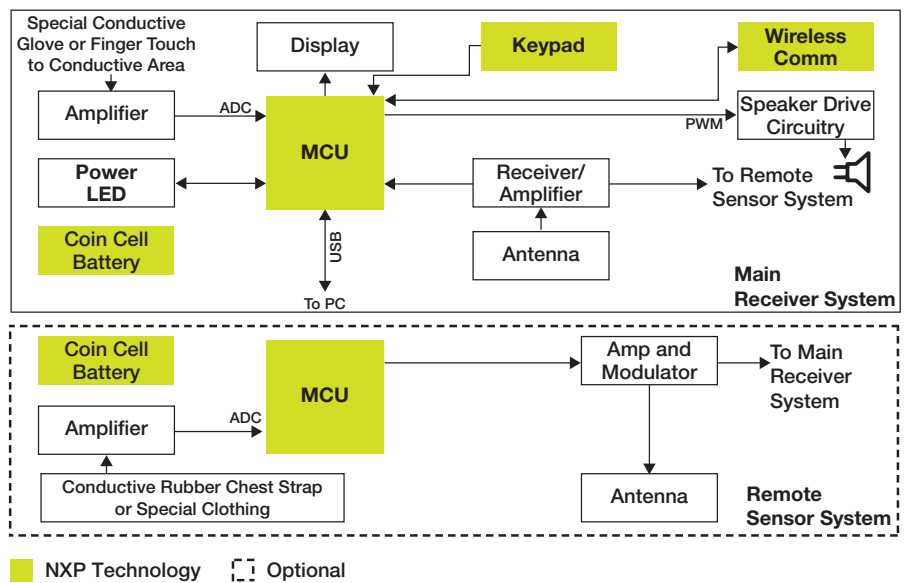FIGURE 1.5b: HEART RATE MONITOR (HRM) GENERAL BLOCK DIAGRAM

FIGURE 1.5c: SIGNAL CONDITIONING BLOCK DIAGRAM

Instrumentation amplifier requirements include:

▸ Low gain 10
▸ High common-mode rejection ratio
▸ 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

Obtaining QRS complexes

The QRS complex must 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 to 25 Hz to remove high-frequency noise and low-frequency drift. Filtering a derivation is then implemented and a threshold is taken to determine whether the data is part of the QRS signal.

Heart rate monitor design

For more information on how to design a heart rate monitor, refer to AN4323: *Solutions for Electrocardiograph and Heart Rate Monitor Applications.* This application note describes how to use the MED-EKG development board, a highly efficient board that can be connected to the Tower System to obtain an electrocardiogram signal and measure heart rate.

The application is implemented using either the MK53N512, MC9S08MM128 or MCF51MM256 MCUs.

FIGURE 1.5d: INSTRUMENT AMPLIFIER TO ACQUIRE HEART SIGNAL
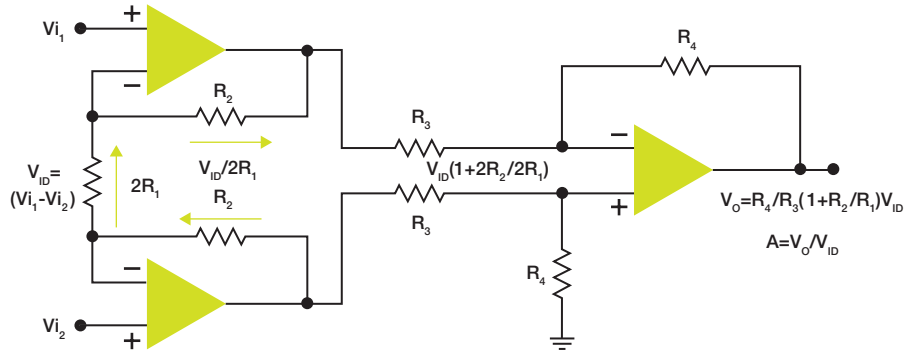

FIGURE 1.5e: PASSIVE BAND-PASS FILTER CIRCUIT OPERATING FREQUENCIES 0.1–150 HZ
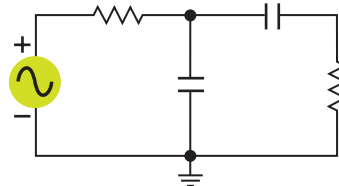

FIGURE 1.5f: ACTIVE BAND-PASS FILTER CIRCUIT OPERATING FREQUENCIES 0.1–150 HZ
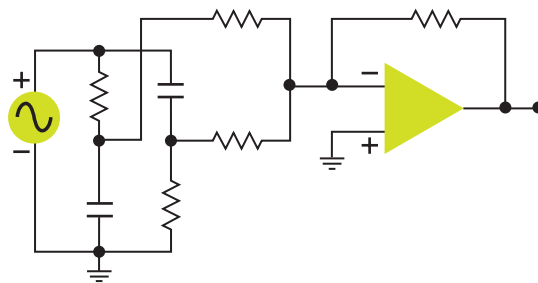
FIGURE 1.5g: DIGITAL SIGNAL PROCESSING TO OBTAIN THE QRS COMPLEX
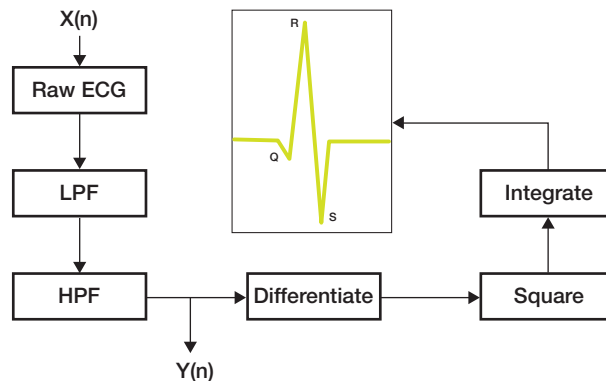
Blood Glucose Meter

1.6

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 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 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.

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 Kinetis K50 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 1.6d.

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

$C6H12O6 \rightarrow C6H10O6 + H2O2$
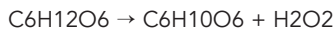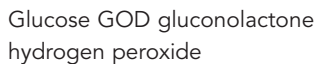
These strips are amperometric sensors that use a three-electrode design. This approach is useful when using amperometric sensors because of the reliability of measuring voltage and current in the same chemical reaction. The three-electrode model uses a working electrode (WE), reference electrode (RE) and counter electrode (CE).

FIGURE 1.6a: BLOOD GLUCOSE MONITOR GENERAL BLOCK DIAGRAM
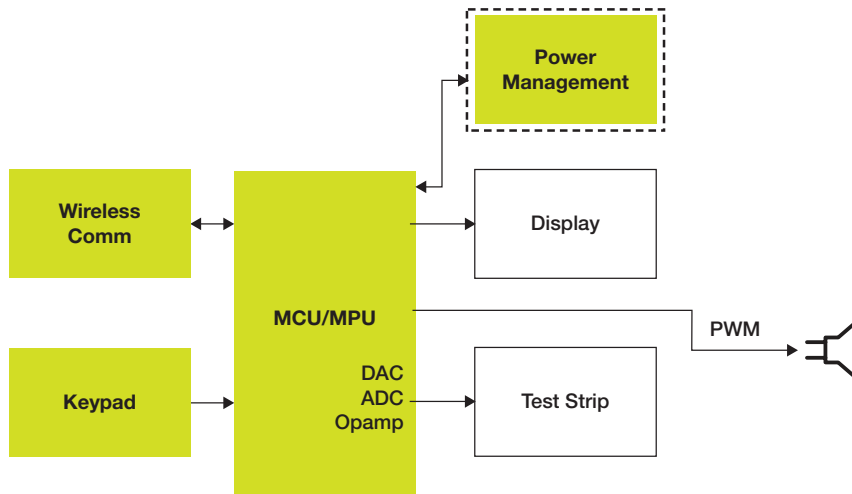
FIGURE 1.6b: EQUIVALENT CIRCUIT WITH RV EQUAL TO BLOOD CONDUCTIVITY

$$V_o = V_I \frac{Rv}{R+Rv}$$
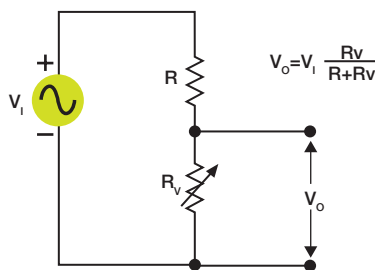
FIGURE 1.6d: TEST STRIP BASIC BLOCK DIAGRAM USING FLEXIS MM
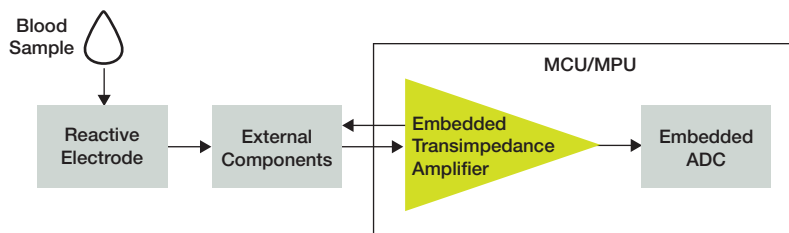
FIGURE 1.6e: CHIP SCHEMATIC

1) WE, 2) CE, 3) Ag/AgCl RE, 4) Conductive lines, 5) Pads
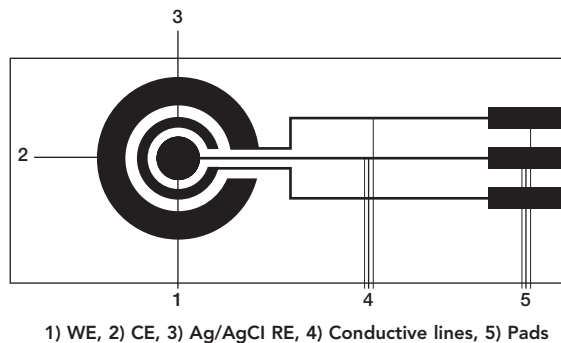
AN4364: glucose meter fundamentals and design

This application note shows a basic glucometer implementing K53, S08MM128 and MCF51MM MCUs. The application uses the MED-GLU board, which is a development board to enable the rapid prototyping of glucose meters by connecting it to the Tower System through the medical connector on medical-oriented MCU modules.

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▸ Ultra-low-power operation
▸ 2 x opamp
▸ 2 x triamp
▸ 2 x 12-bit DAC
▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers
▸ Programmable delay block
▸ I²C
▸ USB connectivity
▸ ARM Cortex-M4 core with DSP instructions

FIGURE 1.6h: MED GLU BLOCK DIAGRAM
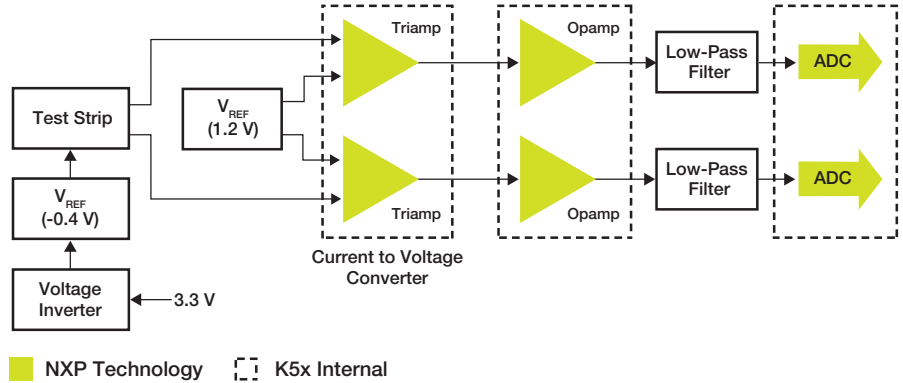
FIGURE 1.6e: KINETIS K50 FAMILY BLOCK DIAGRAM

Kinetis KL2x USB MCUs

The Kinetis KL2 MCU family is pin, software and tool compatible with all other Kinetis L MCU families and adds a Full-Speed USB 2.0 On-The-Go controller with an integrated low-voltage regulator. The Kinetis KL2 MCU family is also compatible with the Kinetis K20 MCU family (based on the ARM Cortex-M4 processor), providing a migration path to higher performance and feature integration.

Devices start from 32 KB of flash in a small-footprint 5 x 5 mm 32 QFN package extending up to 256 KB in a 121 MBGA package. Each combines ultra-low-power performance with a rich suite of analog, communication, timing and control peripherals.

Features

▸ ARM Cortex-M0+ core, 48 MHz core frequency over full voltage and temperature range (–40 °C to +105 °C)

▸ Up to 256 KB flash with 64 byte flash cache, up to 32 KB RAM

▸ Multiple flexible low power modes

▸ Up to 16-bit ADC with configurable resolution, sample time and conversion speed/power

▸ Capacitive touch sense interface supports up to 16 external electrodes and DMA data transfer

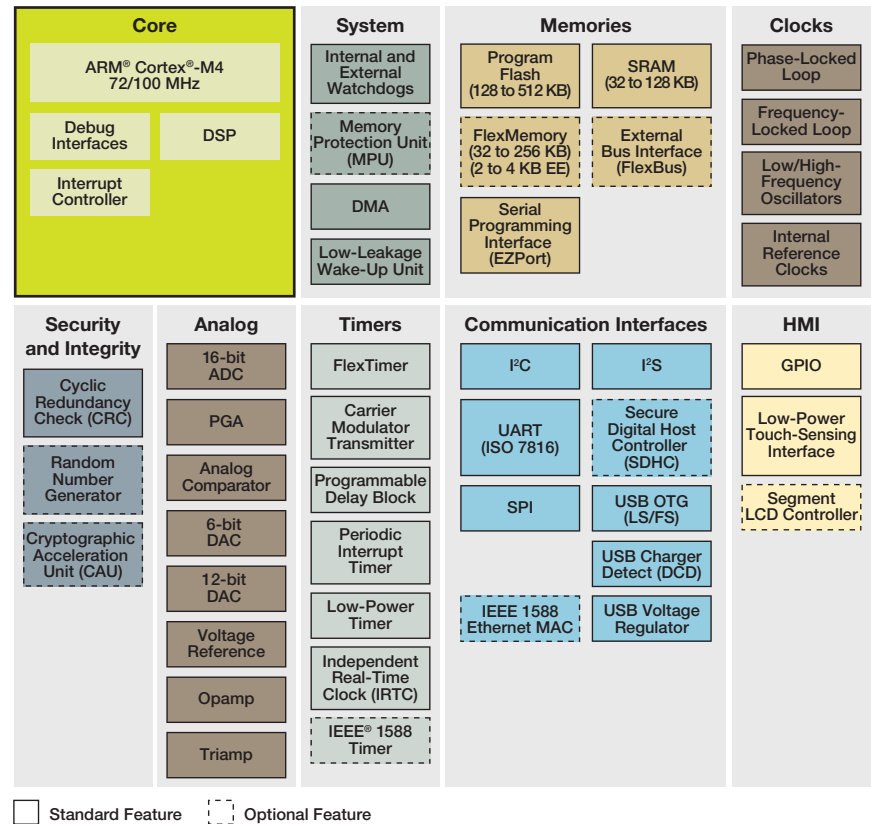▸ USB 2.0 On-The-Go (Full-Speed) with integrated USB low-voltage regulator supplies up to 120 mA off chip at 3.3 V to power external components from 5 V input

FIGURE 1.6f: KINETIS KL2X MCU FAMILY BLOCK DIAGRAM
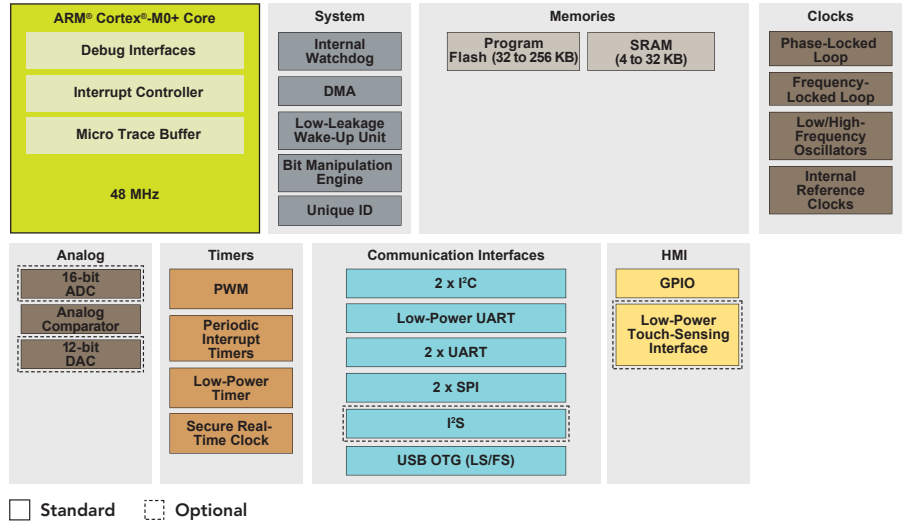
FIGURE 1.6i: EXAMPLE OF COMMUNICATION INTERFACE FOR BLOOD GLUCOSE MONITOR
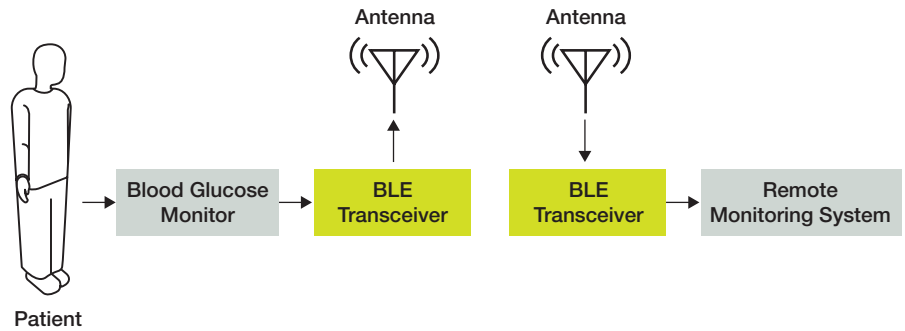
Wired and wireless communication

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

Our company offers several cost-effective, low-power MCUs with integrated USB interfaces for wired communication. For wireless options, we offers ZigBee solutions and Bluetooth Low Energy solutions. Figure 1.6i is an example of Bluetooth implementation.

Continuous Positive Airway Pressure (CPAP) Machine

1.7

Introduction

Obstructive sleep apnea (OSA) occurs when the back muscles of the throat relax while sleeping, causing the airway to narrow, resulting in snoring. These muscles could also completely block the flow of air to the lungs. When the brain detects a lack of oxygenation, it sends an impulse to the muscles forcing them to restart the breathing process. While this is a normal process that often happens to healthy people, patients with OSA may repeat this process hundreds of times during the night without being aware of this problem.

The most common treatment for sleep apnea is a method of pushing air through the airway called continuous positive airway pressure (CPAP). The main goal for this device is to provide constant positive pressure to the respiratory system in order to prevent muscles from obstructing the airway. Constant airflow pressure can be obtained by the continuous monitoring of the system pressure in conjunction with the ventilator motor control speed regulation.

CPAP design overview

The operating principle of a CPAP is to maintain a positive air pressure in the patient's airway. Figure 1.7a shows a flow diagram of this application.

An accurate pressure sensor is needed to monitor the airway. Single-supply, medical grade pressure sensors are recommended to facilitate the design implementation.

The pressure measurements are acquired using an ADC and processed by a microcontroller. Based on this information, the microcontroller performs the necessary motor control algorithms and manages the air pump functionality. The control signals from the microcontroller need to be power-amplified to be used. A 3-phase gate pre-driver is used to enable the power MOSFETs that will activate the air pump.

The CPAP counts with a humidifier chamber that increases the amount of vapor in the air to avoid drying out the airways or skin in the case of leakage in the mask. The most common humidifier for this application is the heater-humidifier. The humidifier chamber heater can be controlled through a GPIO with a 16-bit ADC channel measuring the temperature. Thus the humidity level can be adjusted by the patient.

The user interface needs to be as simple as possible, yet provide the physician with accurate feedback. The device must be robust and able to be used for extended periods of time. Touch keyboards are preferred due its ease of clean and lack of borders where the dust can accumulate.

Therapy results can be shared with the physician to determine the condition of the patient. Information can be transmitted using wireless technologies such as Bluetooth® and ZigBee® or wired using USB.
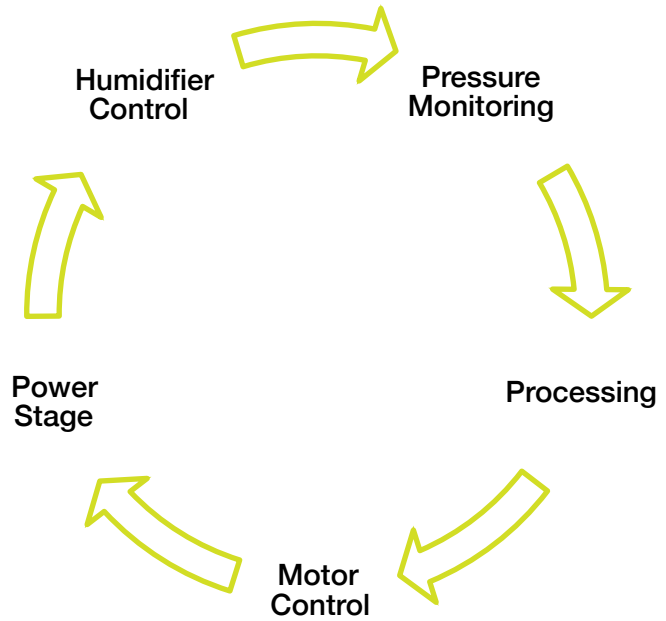
FIGURE 1.7a: CPAP OPERATING PRINCIPLE

FIGURE 1.7b: CPAP BLOCK DIAGRAM

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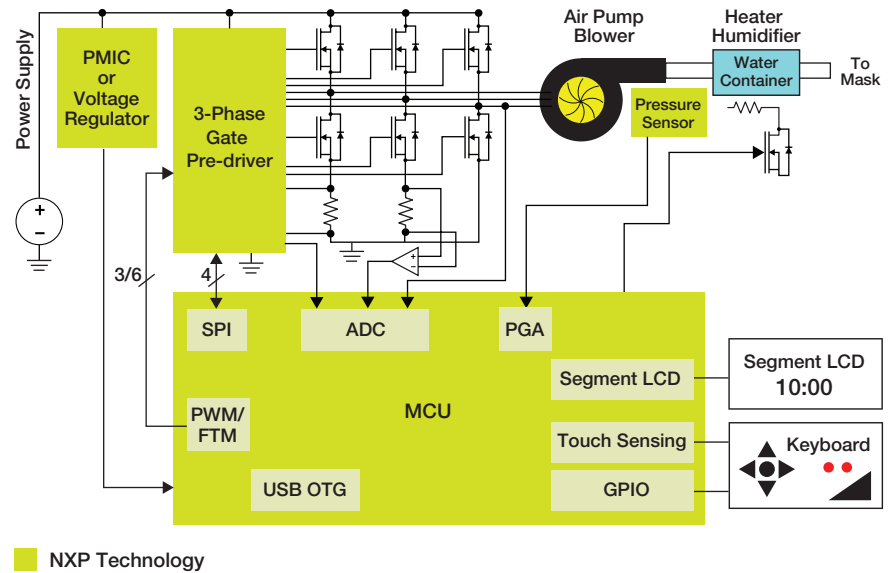
Recommended solutions

Kinetis K4x

The K4x MCU family is pin-peripheral and software-compatible with the K1x MCU family and adds full-speed USB 2.0 On-The-Go with device charge detect capability and a flexible low-power segment LCD controller with support for up to 320 segments.

Devices start from 64 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package with a rich suite of analog, communication, timing and control peripherals.

Kinetis KL4x

The Kinetis KL4x family is pin, peripheral and software compatible with all other Kinetis L series families and combines a full-speed USB 2.0 On-The-Go(OTG) controller with integrated low-voltage regulator and a flexible, low-power segment LCD controller with support for up to 376 segments.

The Kinetis KL4x family is also compatible with the Kinetis K40 (ARM® Cortex®-M4 core) family, providing a migration path to higher performance and feature integration. Devices start from 128 KB of flash in a 64 LQFP package extending up to 256 KB in a 100 LQFP/121 MAPBGA package and combine ultra-low-power performance with a rich suite of analog, communication, timing and control peripherals. These features make the KL4x family well suited to display-based applications like electronic scales, thermostats, flow meters and smart meters.

MPXV7025DP pressure sensor

The MPXV7025 series piezoresistive transducer in the small outline package (SOP) is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

FIGURE 1.7c: KINETIS K40 FAMILY BLOCK DIAGRAM
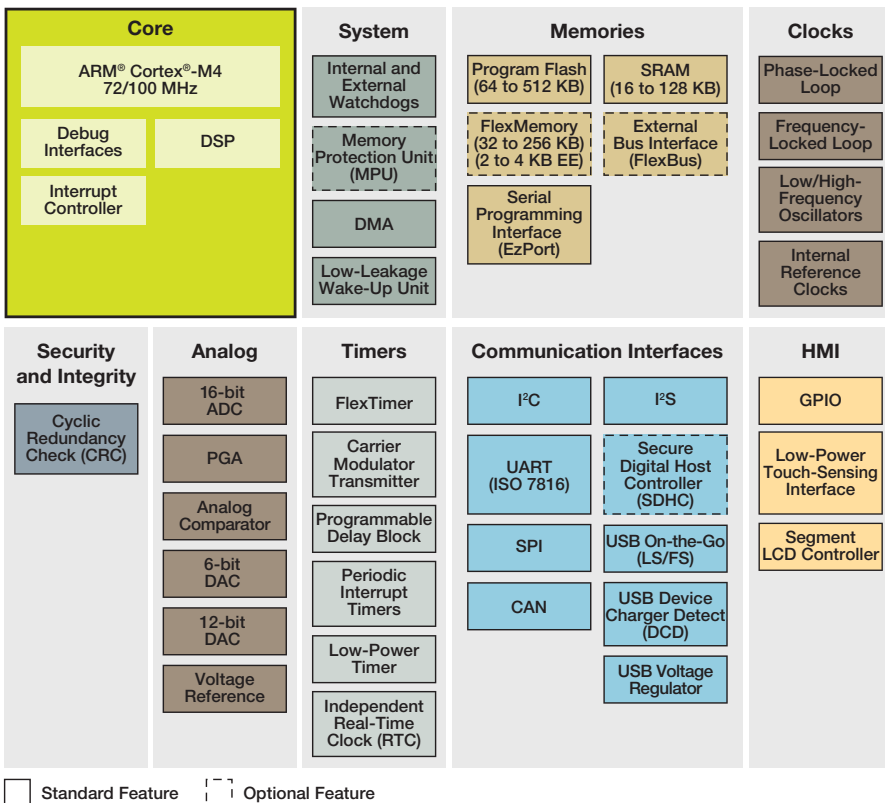
FIGURE 1.7d: KINETIS KL4X FAMILY BLOCK DIAGRAM
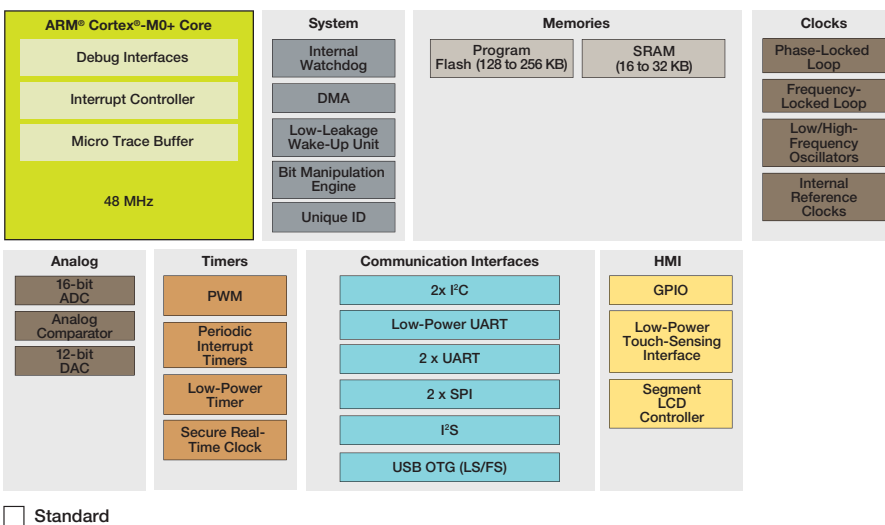
The MPXV7025 is designed to measure positive and negative pressure. In addition, with an offset specifically at 2.5V instead of the conventional 0V, this new series allows to measure pressure up to 25kPa through each port for pressure sensing but also for vacuum sensing.

MC34937 three-phase field effect transistor pre-driver

The 34937A is a field effect transistor (FET) pre-driver designed for three-phase motor control and similar applications. The integrated circuit (IC) uses SMARTMOS technology. The IC contains three high side FET pre-drivers and three low side FET pre-drivers. Three external bootstrap capacitors provide gate charge to the high side FETs. The IC interfaces to a MCU via six direct input control signals, an SPI port for device setup and fault detection, an asynchronous reset, an interrupt and two enable signals. Both 5.0 and 3.0 V logic level inputs are accepted and 5.0 V logic level outputs are provided.

Motor control box

The motor control development toolbox provides an integrated development environment and tool chain for configuring and generating all of the necessary software (including initialization routines, device drivers and a real-time scheduler) to execute motor control algorithms on our proprietary MCUs. The toolbox includes the math and motor control library set developed by our Motor Control Center of Excellence. It includes dozens of blocks optimized for fast execution on our MCUs with bit-accurate results compared to Simulink® simulation. There is also built-in support for software- and processor-in-the-loop (SIL and PIL) which enables automated comparison and plotting of numerical results.

FIGURE 1.7e: MC34937 SIMPLIFIED APPLICATION DIAGRAM
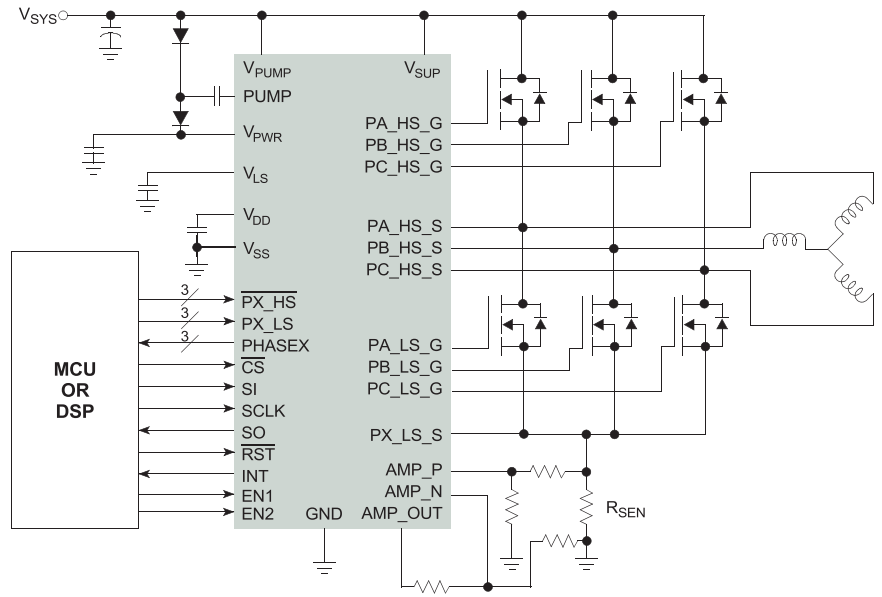
Inhalers (Pulmonary Drug Delivery)

1.8

Introduction

In a landscape that has been plagued by increasing development costs, diminishing financial performance and the pressure to cut drug prices, pharmaceutical companies are looking for new ways to appeal to customers. No longer able to rely on the old blockbuster model, it must now focus on getting more out of existing drugs and creating new products to address unmet medical needs.

New and innovative drug-delivery solutions have been part of the answer, as pharmaceutical businesses look for ways to increase R&D productivity, improve drugs, extend product life cycles and strengthen their offerings. Providers of drug-delivery solutions are fast becoming strategic partners rather than mere contract development organizations.

The growth of drug-delivery solutions is one of increasing importance to pharmaceutical companies, and has resulted in significant changes in the drug-delivery landscape. Volumes and future growth projections for these devices are increasing, causing a number of innovative drug-delivery systems to be introduced each year. This has created a significant amount of competition, forcing companies to differentiate their drug delivery devices to differentiate themselves.

One area of drug delivery that is poised for significant growth is the inhaled (pulmonary) segment of the market. Inhaled drug therapy is an appealing option for patients because of its painless and flexible administration compared to injections. Compared to oral administration, it has the advantage of a more rapid onset of action, lower dosing, avoidance of first pass metabolism and potentially fewer side-effects. This trend is reflected in global market research showing that the pulmonary drug delivery market is growing rapidly and is expected to reach US $37.7 billion within the next five years with the US and Europe accounting for 75% share. The inhalation route is a fast and effective way of delivering medication locally to the lungs and also for the systemic administration of certain agents. Inhalation drug therapy is used extensively to treat respiratory conditions such as asthma and Chronic Obstructive Pulmonary Disease (COPD). Recently, it has been shown that pulmonary drug delivery could also be an effective route to deliver drugs to the systemic circulation thanks to the large surface area of the lungs.

Types of inhalers

The Metered Dose Inhaler (MDI) is the original and most widely used device to deliver inhalation therapies. It uses pressurized gas to release its dose when activated by the patient. More recently, the Dry Powder Inhaler (DPI) has been gaining popularity because it does not rely on propellant to deliver the medication and patients find it convenient and easy to use. When developing a new product, researchers can select either a standard inhaler device or decide to develop a customized solution that is more tailored to the requirements of their product and the particular disease area.

Whatever solution is chosen, the effectiveness of the technology will also depend on the patient's ability to administer his or her own medication, making it essential that the device is designed using a patient-centered approach. Patients express preference for devices that are small, portable and easy to use and safe, ensuring that an accurate dose is dispensed.

FIGURE 1.8a: SIMPLIFIED ELECTRONIC INHALED DRUG DELIVERY BLOCK DIAGRAM

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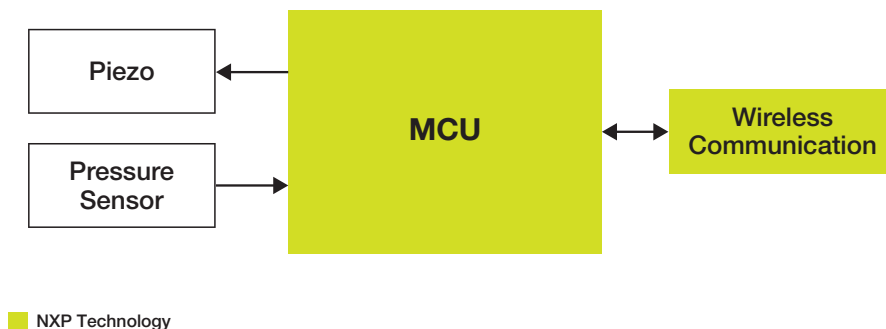
FIGURE 1.8b: ELECTRONIC INHALED DRUG DELIVERY WITH INTEGRATED CONNECTIVITY
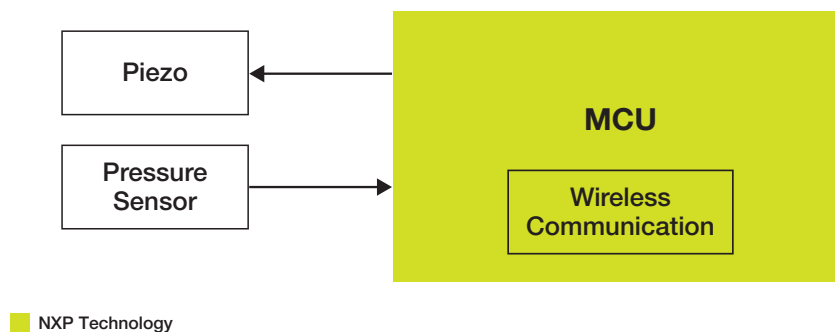
■ NXP Technology

Design considerations

Regard less of the inhaler type chosen, all have very similar requirements: they must be cost effective, optimized for minimal power consumption, portable and have some form of internet connectivity. Technology providers like our company are delivering key advances in these strategic areas that are needed to enable pharmaceutical companies the ability to easily optimize their products. A simplified block diagram of an electronic inhaled drug delivery device is shown in Figure 1.8a.

In this diagram you will notice 4 basic components: a low power microcontroller, a pressure sensor, a piezo and a wireless communication device. As the user inhales, the pressure sensor will wake up the microcontroller to drive the piezo which precisely vibrates the medication to assure maximum absorption. Following the dose, the wireless device will then communicate to a home gateway or a smart mobile device where the data will be sent via a cellular or wired network to the cloud. This data can then be accessed by the user/patient as well at their caregiver/doctor. A connected, sensor driven system like you see here has the ability to increase drug absorption, thus lowering dosages and increase patient compliance, lowering overall healthcare costs.

Ultra-low-power performance

Ultra-low power performance is important for many reasons in an inhaled drug delivery device, the most significant being battery life and battery size. Device designers need to evaluate microcontrollers that use innovative technology to achieve the absolute lowest power, such as our Kinetis product portfolio of ultra low power microcontrollers. All of the devices in this portfolio contain the four main features that are the foundation of low-power micro controller operation: a low-power crystal oscillator, low-power modes of operation, a flexible clock source and peripheral clock gating.

The crystal oscillator intellectual property used in our devices has been optimized to drive crystals at low power, with options for low or high-gain modes. This peripheral consumes less than 500nA for a 32.768kHz crystal when in a low-power mode, and can keep accurate time while the microcontroller unit is in standby mode. This is especially important and can significantly increase your battery life.

Kinetis microcontrollers have multiple modes of low-power operation, each of which is tailored to a specific level of functionality to allow the most efficient performance/power consumption trade-offs. These products support power consumption as low as 150nA in a stop mode and 25uA/MHz in low power run mode. In order to reduce 'run' mode power consumption further, each of the peripherals on the low-power platform can be clock gated, which shuts down the clock signal that is routed to the peripheral. When disabling clocks to all peripherals, it has been measured to reduce run-mode power consumption by almost a third.

Two products that offer cost effective performance and low power operation in a small form factor are the Kinetis MKL1x family of microcontrollers and the MPL3115 family of pressure sensors. Block diagrams for these parts are located in Figures 1.8b and 1.8c respectively.

FIGURE 1.8c: MPL3115A2 BLOCK DIAGRAM
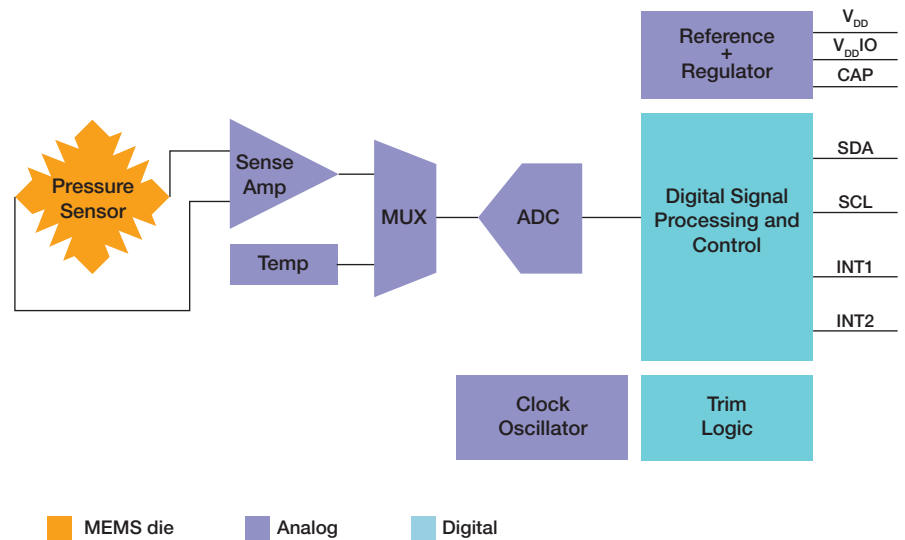
FIGURE 1.8d: KINETIS KL1X MCU FAMILY BLOCK DIAGRAM
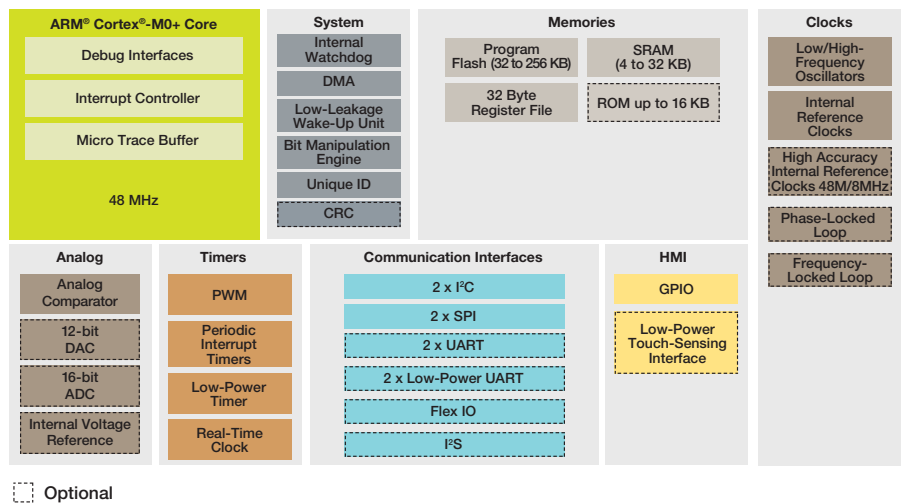
Key features of MKL1x

▶ ARM® Cortex®-M0+ core up to 48 MHz

▶ Up to 256 KB flash with 64 byte flash cache, up to 32 KB RAM

▶ Up to 4-ch. DMA for peripheral and memory servicing with reduced CPU loading

▶ Independent-clocked COP guards against clock skew or code runaway for fail-safe applications

▶ Security circuitry to prevent unauthorized access to RAM and flash contents

▶ 16 KB ROM and built-in boot loader

▶ 16-bit ADC with configurable resolution, sample time and conversion speed/power

▶ Integrated temperature sensor

▶ High-speed comparator with internal 6-bit DAC

▶ 12-bit DAC with DMA support

▶ Capacitive touch sense interface supports up to 16 external electrodes and DMA data transfer

▶ Two I²C with DMA support, up to 1Mbps and compatible with SMBus V2 features

▶ One LPUART and two UART with DMA support

▶ Two SPI with DMA support

Key Features of MPL3115

▸ 1.95 V to 3.6 V Supply Voltage, internally regulated by LDO

▸ 1.6 V to 3.6 V Digital Interface Supply Voltage

▸ Fully Compensated internally

▸ Direct Reading, Compensated
  – Pressure: 20-bit measurement (Pascals)
  – Altitude: 20-bit measurement (meters)
  – Temperature: 12-bit measurement (degrees Celsius)

▸ Programmable Events

▸ Autonomous Data Acquisition

▸ Resolution down to 0.1 m

▸ 32-Sample FIFO

▸ Ability to log data up to 12 days using the FIFO

▸ 1 second to 9 hour data acquisition rate

▸ I²C digital output interface (operates up to 400 kHz)

FIGURE 1.8e: KINETIS KW40Z, KW30Z, KW20Z WIRELESS MCU FAMILY

Connectivity

Next generation drug delivery devices will need to have the ability to transfer information to the cloud for additional analysis, to create an electronic medical record, or to view data via an app on a smart mobile device or a PC. Bluetooth and ZigBee technology became the first wireless standards adopted by the Co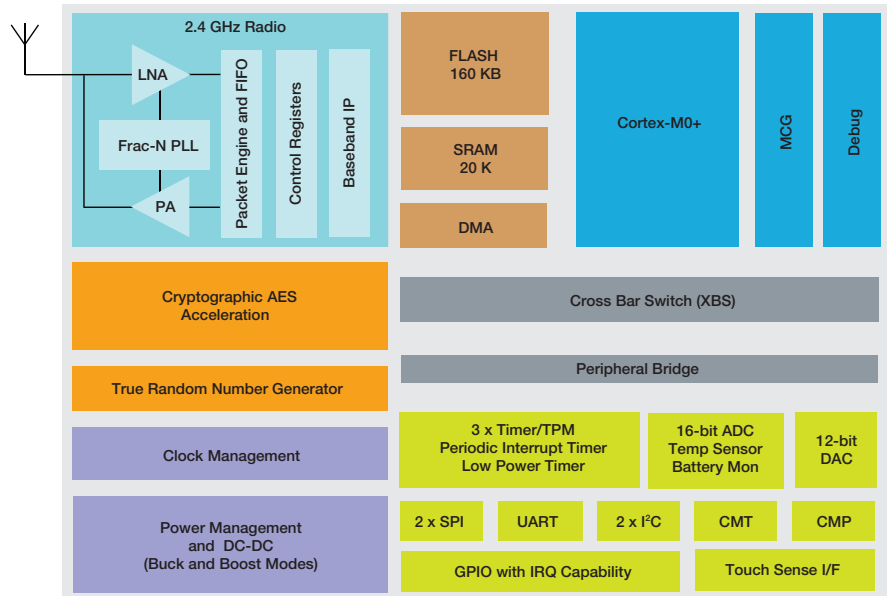ntinua Health Alliance, a consortium consisting of more than 200 member companies from the technology and the medical device markets focused on developing a standard system of connected personal medical solutions. In 2010, Bluetooth Low Energy (BLE) was added to the list of approved standards and has since taken a firm hold of the market due to the adoption of BLE into smart mobile devices. In most portable healthcare application, inhaled drug delivery included, a smart mobile device will likely be the preferred gateway to the cloud, using BLE to connect to the smart mobile device and cellular to connect to the cloud.

Device designers have a couple system design options when looking at adding connectivity. An architecture as shown in Figure 1.8d at the beginning of this chapter can be uses, where you separate your application code and your wireless software stacks in separate microcontrollers. A second option involves combining your application code and your wireless stack onto a single low power microcontroller with integrated wireless connectivity. This method is generally the lowest power and most cost effective option.

The Kinetis MKW3x product family is a perfect fit for designing the lowest power, most cost effective and smallest form factor connected solution. This low power, highly integrated microcontroller can be connected to an MKL1x device via SPI if using a multichip architecture or can used as a single MCU if using an architecture as shown in Figure 1.8d.

Key features of MKW3x

MCU and memories

▸ Up to 48 MHz ARM® Cortex-M0+ core
▸ On-chip 512KB Flash memory
▸ On-chip 128KB SRAM

Multi-standard radio

▸ 2.4 GHz Bluetooth Low Energy version 4.1 compliant
▸ IEEE Standard 802.15.4 2006 compliant
▸ Typical Receiver Sensitivity (BLE) = -94dBm
▸ Typical Receiver Sensitivity (802.15.4) = -102dBm
▸ Programmable Transmitter Output Power: -20dBm to +5dBm
▸ Low external component counts for low cost application

Low power consumption

▸ Typical Rx Current: 6.2 mA (DCDC in buck mode, 3.3 V supply)
▸ Typical Tx Current: 6.2 mA (DCDC in buck mode, 3.3 V supply) for a 0 dBm output
▸ Low Power Mode (VLLS0) Current: 180 nA

Body Composition Meter

1.9

Introduction

Body composition meters are a really useful tool for people to keep on track of their overall weight and healthy limits of percentage of body fat and skeletal muscle. Some of the chronic degenerative diseases like diabetes type 2, are linked to the increase of body fat, and some risks of acute complications like heart arrest are linked to the ratio of visceral fat the person has.

Segmental body composition, or the distribution of fat is essential also for people who are interest in fitness performance, and this information could help fitness enthusiasts and professionals to improve their control and monitor their overall improvements by segmental distribution (upper segment, middle segment and lower segment).

Usually the body composition meters are based on vendor's own algorithms and tables, so the importance of certain parameters and their relationship to the algorithms is key. The accuracy of the bioimpedance sensor and how to process the signal is the most important part of the data acquisition but it is the proprietary tables and correlations that will make the accuracy of the device.

Types of body composition meters

There are three main types of body composition meters.

▸ Hand to hand: used to measure the upper part of the body

▸ Foot to Foot: lower portion of the body is measured.

▸ Hands to Feet: takes whole body into account and is a more accurate measurement than the previous two.

The key for a standard measurement is being consistent in the time, day and method taken.

Bioelectrical impedance

▸ Is considered one of the most accurate and accessible methods of screening body fat.

▸ Send a weak electrical current (0.5 mA / 50kHz) through the body, that should not be felt during the operation.

▸ Body fat uses a formula that factors: electrical resistance, height, weight, age and gender.

The basic of bioelectrical impedance is the signal generation of a 0.5 mA/50 kHz electrical current that is generated using a DAC that is included in the MK5x microcontroller, and the measurement of the signal that is received after being transmitted over the body of the user. This signal is then compared to the original signal and the impedance is calculated.

The signal that is received goes directly to the op amps of the MK5x that includes 2 op amps and two trans impedance amplifiers, that can be configured by software to rectify and amplify the signal, and then send it to the MCU high precision ADC and processes by its floating point ARM Cortex-M4 core.

The result is then compared with the vendor's tables of healthy individuals, it is important to mention that usually the tables used are only for people with average body compositions in terms of muscle and fat, it is not useful for body builders or high performance athletes.

FIGURE 1.9a: BIOELECTRICAL IMPEDANCE BLOCK DIAGRAM
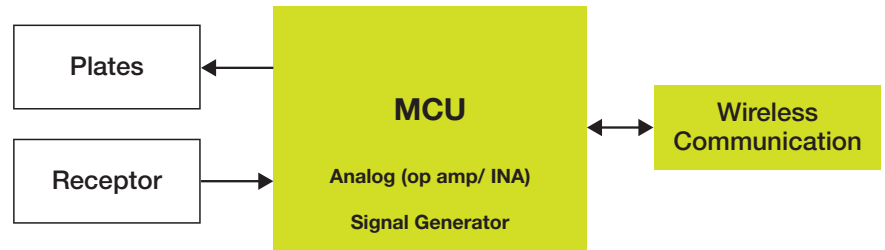
NXP Technology

High-precision analog and floating point MCU

The MK5x processor family built on ARM Cortex-M4 MCUs is ideal for this types of applications due to the integrated measurement engine that allows to avoid the high costs of external analogs while reducing the necessary steps to avoid noise in the measurement.

Measurement engine functions

▸ Static and Dynamic Biasing

▸ Signal Conditioning

▸ Accurate Measurements

Measurement engine contains

▸ 16-bit analog-digital converter
  – SAR type; typical 13.5b accuracy

▸ 12-bit digital-analog converter
  – 1ms settling time (min)

▸ Programmable delay block
  – Synchronizes ADC and DAC operations

▸ 1.2 V trimmable voltage reference
  – 33 ppm/C variation (design target)

▸ General-purpose operational amplifier
  – Customizable functio—filter, PGA

▸ Trans-impedance amplifier
  – 300 pA input bias current operation

▸ Analog comparator with prog. reference
  – low-power wakeup on analog threshold

Measurement microcontrollers based on Cortex-M4 core

The Kinetis K5x MCU family is pin-, peripheral- and software-compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE® 1588 Ethernet and hardware encryption, full-speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin LQFP packages extending up to 512 KB in a 144-pin MAPBGA package.
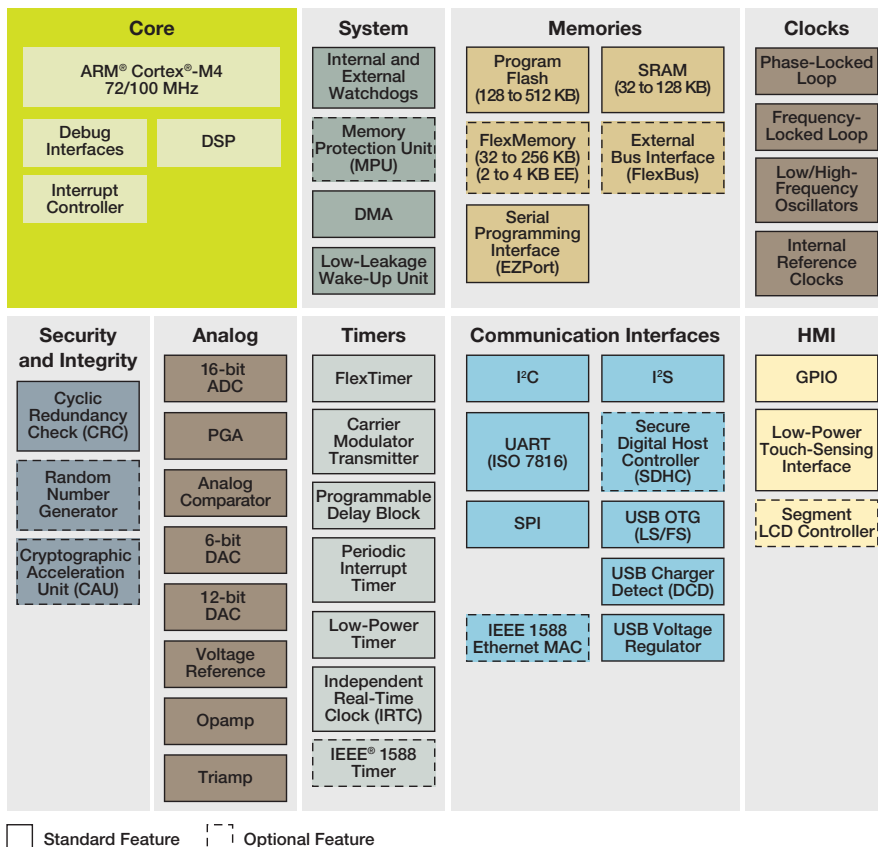
Kinetis M Series: metrology microcontrollers based on ARM Cortex-M0+ core

Kinetis M series MCUs are based upon the low-power ARM® Cortex®-M0+ core and are designed for single-chip 1, 2 and 3 -phase electricity meters as well as flow meter and other precision measurement applications.

Kinetis M Series MCUs include a powerful analog front end consisting of multiple 24-bit Sigma Delta ADCs, Programmable Gain Amplifiers, voltage reference with low drift over temperature and a phase shift compensator. A large range of security features including a memory protection unit, external tamper detection pins, iRTC with tamper detect and a random number generator provide protection of supplier/user data within the MCU and from the MCU to the power grid. A low power segment LCD controller support up to 288 segments and 8 backplanes.

FIGURE 1.9b: KINETIS K50 FAMILY BLOCK DIAGRAM

Core	System	Memories	Clocks
ARM® Cortex®-M4 72/100 MHz	Internal and External Watchdogs	Program Flash (128 to 512 KB) / SRAM (32 to 128 KB)	Phase-Locked Loop
Debug Interfaces / DSP	Memory Protection Unit (MPU)	FlexMemory (32 to 256 KB) (2 to 4 KB EE) / External Bus Interface (FlexBus)	Frequency-Locked Loop
Interrupt Controller	DMA	Serial Programming Interface (EZPort)	Low/High-Frequency Oscillators
	Low-Leakage Wake-Up Unit		Internal Reference Clocks

Security and Integrity	Analog	Timers	Communication Interfaces	HMI
Cyclic Redundancy Check (CRC)	16-bit ADC	FlexTimer	I²C / I²S	GPIO
Random Number Generator	PGA	Carrier Modulator Transmitter	UART (ISO 7816) / Secure Digital Host Controller (SDHC)	Low-Power Touch-Sensing Interface
Cryptographic Acceleration Unit (CAU)	Analog Comparator	Programmable Delay Block	SPI / USB OTG (LS/FS)	Segment LCD Controller
	6-bit DAC	Periodic Interrupt Timer	USB Charger Detect (DCD)	
	12-bit DAC	Low-Power Timer	IEEE 1588 Ethernet MAC / USB Voltage Regulator	
	Voltage Reference	Independent Real-Time Clock (IRTC)		
	Opamp	IEEE® 1588 Timer		
	Triamp			

☐ Standard Feature   ⌐⌐ Optional Feature

Sleep Monitor

1.10

Introduction

Traditionally, sleep monitoring has been instrumental in the identification of sleep disorders. For example, a polysomnography, is considered the best way to rule out obstructive sleep apnea in cases of unrefreshing sleep or daytime sleepiness. In home sleep monitors can be designed to address the over 70 million Americans who suffer from a form of sleep disorder. An in-home sleep monitor can assess an individual's sleep environment and measure parameters such as temperature, humidity, ambient noise, tossing and turning, heart rate and ambient light. With this information,

an individual can improve their sleep and reduce their likelihood of developing symptoms often associated with poor sleep such as weight gain, headaches, high blood pressure, diabetes, depression, and an impaired immune system.

A vendors' algorithm could take the above collected data and recommend ways to improve an individual's sleep cycles and improve time in deep sleep.

Types of sleep monitors

There are four types of different sleep studies:

▸ Simple sleep study – sleep study conducted within the home premises

▸ Polysomnogram (PSG) – sleep study that involves recording of brain activity, eye movement, oxygen and carbon dioxide blood levels, heart rate and rhythm, breathing rate and rhythm, flow of air through the mouth and nose, snoring, body muscle movements, and chest and abdomen movement

▸ Multiple sleep latency test (MSLT) – sleep study that measures how long it takes an individual to fall asleep by several naps in one day

▸ Maintenance of wakefulness test (MWT) – a test to measure whether an individual can stay awake during a period of time he or she would normally be awake

The scope of the recommended solution below is designed to cater to the simple sleep study that can be done in the home.

The block diagram (Figure 1.10a) can be used to implement a multiple functionality, high performance sleep monitor. The secondary MCU in the block diagram is a Cortex M0 who is responsible for collecting data from all the sensors, play an alarm through a speaker, record audio if necessary. This microcontroller will wake up and then package all the data it is receiving and send the information over USB to the main MCU, a Cortex M4F with floating point. This architecture allows for the lowest power consumption, while still providing the ability to run complex algorithms on the data. The secondary board is powered over USB from the primary board. All the information is processed before being sent over Bluetooth low energy to a remote client such as a phone or tablet.

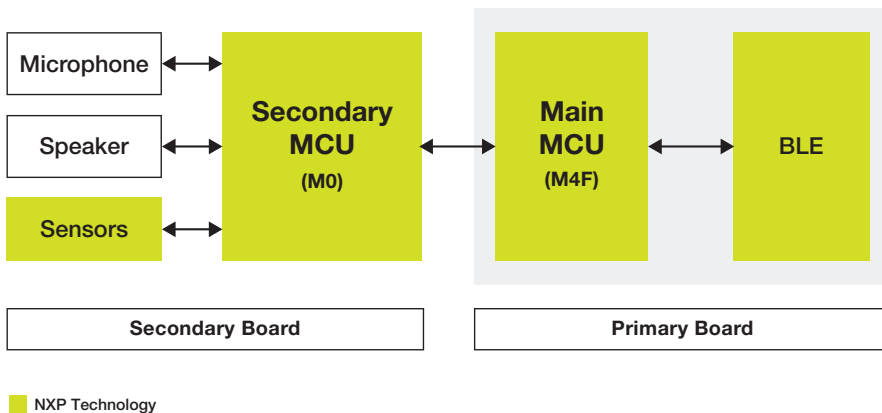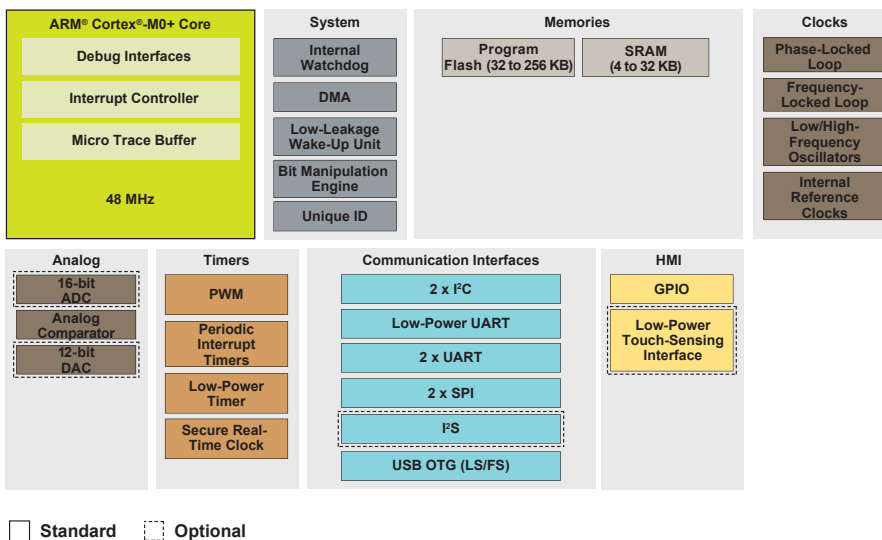**FIGURE 1.10a: SLEEP MONITOR BLOCK DIAGRAM**

FIGURE 1.10b: KL26 BLOCK DIAGRAM

Recommendations

KL26

The KL26 is a great secondary MCU for sensor aggregation as it can be set to have a 50 µA/MHz run current in its low power mode. Other features include:

Performance

▸ 48 MHz ARM® Cortex®-M0+ core

Memories and memory interfaces

▸ Up to 256 KB program flash memory

▸ Up to 32 KB SRAM

System peripherals

▸ Nine low-power modes to provide power optimization based on application requirements

▸ COP Software watchdog

▸ 4-channel DMA controller, supporting up to 63 request sources

▸ Low-leakage wakeup unit

▸ SWD debug interface and Micro Trace Buffer

▸ Bit Manipulation Engine

Clocks

▸ 32 kHz to 40 kHz or 3 MHz to 32 MHz crystal oscillator

▸ Multi-purpose clock source

K22F

The K22F is a great primary microcontroller as it provides floating point capability, advanced security, while, maintaining a low power footprint. Run power consumption can be as low as 156 µA/MHz. The K22F also provides a USB LS/FS OTG 2.0 with embedded 3.3 V, 120 mA LDO voltage regulator. In addition, the USB FS device provides crystal-less functionality. Other features include:

FIGURE 1.10c: K22F BLOCK DIAGRAM
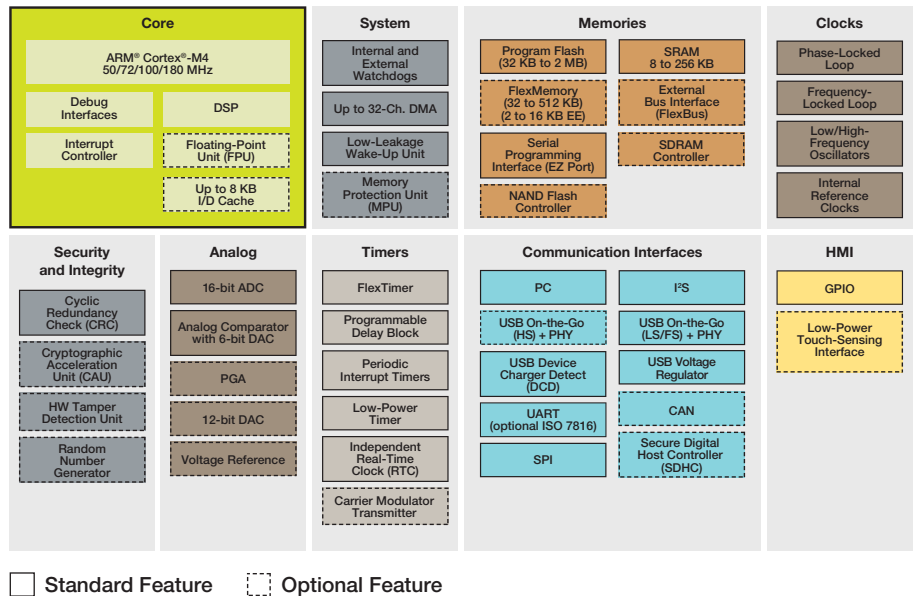
Performance

▸ 120 MHz ARM Cortex-M4 core with DSP instructions delivering 1.25 Dhrystone MIPS per MHz

Memories and memory interfaces

▸ 512 KB of embedded flash and 128 KB of RAM

▸ FlexBus external bus interface

▸ Serial programming interface (EzPort)

▸ Preprogrammed Kinetis flashloader for one-time, in-system factory programming

System peripherals

▸ Flexible low-power modes, multiple wake-up sources

▸ 16-channel DMA controller

▸ Independent external and software watchdog monitor clocks

▸ Two crystal oscillators: 32 kHz (RTC) and 32-40 kHz or 3-32 MHz

▸ Three internal oscillators: 32 kHz, 4 MHz, and 48 MHz

▸ Multipurpose clock generator with PLL and FLL

Security and integrity modules

▸ Hardware CRC module

▸ 128-bit unique identification (ID) number per chip

▸ Hardware random-number generator

▸ Flash access control to protect proprietary software Human-machine interface

▸ Up to 81 general-purpose I/O (GPIO)

MKW4x

The MKW4x part provides a dual mode radio that provides a ZigBee and BLE radio. This part provides a Cortex-M0+ microcontroller to control either radio on board. Other features include:

Core/Memory/System

▸ Cortex-M0+ running up to 48 MHz

▸ 160 KB, 20 KB SRAM

▸ Four independently programmable DMA controller channels

Multi-Protocol Radio

▸ Support for BLE v4.1, 802.15.4-2006

▸ -94 dBm in BLE mode, -102 dBm in 802.15.4 mode

▸ -20 to +5 dBm programmable output power

▸ 13 mA Rx & Tx (0dBm) current target (DC-DC bypass) (confirm with FTF launch material)

▸ <7 mA Rx & Tx (0dBm) current target (DC-DC enabled)) (confirm with FTF launch material)

▸ <2µA low power current

Communications/HMI/Timers

▸ 2 x SPI, LP-UART, 2xI2C, CMT, TSI, GPIO with IRQ capability (KBI)

▸ 3 x FlexTimer (TPM) with PWM and quadrature decode support

▸ Low Power (LPTMR), Programmable Interrupt (PIT) and RTC timers

Analog

▸ 16-bit ADC with integrated temperature sensor and battery monitor

▸ 12-bit DAC and 6-bit High-speed Comparator

FIGURE 1.10d: KINETIS KW40Z, KW30Z, KW20Z WIRELESS MCU FAMILY
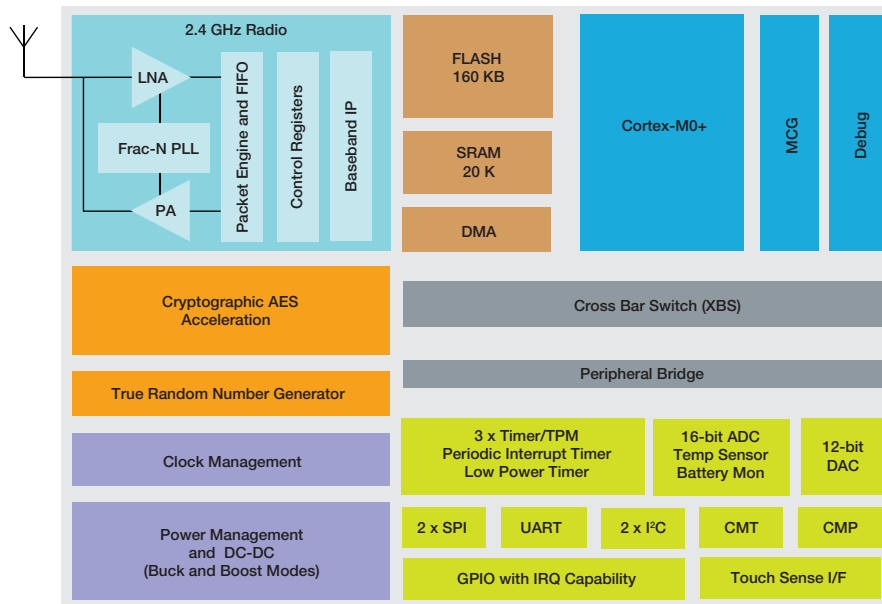
Security

▸ AES Accelerator and True Random Number Generator

Integrated DC-DC Converter

▸ Normal: 1.71 V to 3.6 V

▸ Buck : 1.8 V to 4.2 V for coin cell operation

▸ Boost : 0.9 V to 1.795 V for single alkaline battery operation

Unique identifiers

▸ 80-bit device ID programmed at factory

▸ 40-bit MAC address programmed at factory, for BLE and 802.15.4 MAC addresses.

Table 1.11: Technologies for Home Portable Medical

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Blood Glucose Monitors				
Microprocessors	i.MX6S	i.MX ARM Cortex A9 MPU	Cortex A9 up to 1 GHz, Ethernet, 2D and 3D Multimedia	i.MX6SX, i.MX28, i.MX6UL
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL46, KL33,KL26, K22F
Inertial Sensors	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 µA-165 µA current consumption	
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	TSSMCU
Power Management	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	MC34712, MC34713, MC34717
Wireless Communications	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48M Hz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x, NT3H1101
Blood Pressure Monitors				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL46, KL33,KL26, K22F, LPC8xx
Inertial Sensors	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 µA-16 5µA current consumption	
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	TSSMCU
Pressure Sensors	MPL3115A2	50 to 110kPa, Absolute Digital Pressure Sensor	Provides highly precise pressure and altitude data	MPXx5050, MPXx2050
Power Management	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	MC34712, MC34713, MC34717
DC Brush Motor Control	MPC17C724	H-Bridge, Motor Driver, 2.7-5.5 V, 0.8 A, 200kHz	H-Bridge, Motor Driver, 2.7-5.5 V, 0.8 A, 200kHz	
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x, NT3H1101
Body Composition Analyzer				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL46, KL33,KL26, K22F
CPAP Machines				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL46, KL33,KL26, K22F, K4x
Pressure Sensor	MPXV7002	-2 to 2kPa, Vacuum Pressure Sensor	Integrated Pressure Sensor	MPXx5004
PMIC/Voltage Regulator	MC34700	Switching Power Supply	9-18 V four output, multi-purpose switching power supply	
3-Phase Gate Driver	MC34937	Three Phase Field Effect Transistor Pre-driver	3 high/3 low side FET pre-drivers, 3.0 V/5.0 V logic inputs, 5.0 V logic outputs	
Heart Rate Monitors				
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	Add K2x, LPC541xx
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	
Power Management	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	MC34712, MC34713, MC34717
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48M Hz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x, NT3H1101
Inhalers				
Microcontrollers	MKM1x	Kinetis ARM Cortex-M0+ Measurement MCU	50 MHz Cortex M0+, 24-bit SD ADC, 16-bit SAR ADC w/PGA	KL46, KL33,KL26, K22F
Pressure Sensor	MPL3115A2	50 to 110kPa, Absolute Digital Pressure Sensor	Provides highly precise pressure and altitude data	
Wireless Communications	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x

Table 1.11: Technologies for Home Portable Medical (continued)

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Portable Electrocardiograph				
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	KL46, KL33,KL26, K22F, K4x, K5x
Microprocessors	i.MX6S	i.MX ARM Cortex-A9 MPU	Cortex-A9 up to 1 GHz, Ethernet, 2D and 3D Multimedia	i.MX28, i.MX515, VF5xx
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200, PF3000
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x, NT3H1101
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	TSSMCU
Pulse Oximtery				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL46, KL33,KL26, K22F, K4x
Finger Detection	MPR03x	Touch Sensor	2- or 3-pad touch sensors	
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	
Power Management	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5A, 3.3 V)	MC34712, MC34713, MC34717
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x, NT3H1101
Sleep Monitor				
Microcontrollers	K2x	Kinetis ARM Cortex-M4 Measurement MCU	Low-power Cortex®-M4 up to 120 Mhz, up to 1 MB Flash, Crystal-less USB OTG, Touch Sensing interface	
Microprocessors	i.MX6SX	I.MX Heterogeneous ARM Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	
Motion Detection	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 μA-165 μA current consumption	
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN902x
Telehealth System				
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	KL46, KL33,KL26, K22F, K2x, K5x
Microprocessors	i.MX6D	i.MX Dual Core ARM Cortex A9 MPU	ARM® Cortex® -A9, dual-core, up to 1.2 GHZ, display, 64-bit memory bus, graphics, video, 10/100/1000 ETH, CAN, PCIe, PMU	i.MX6DL, i.MX6S, i.MX28, i.MX233, i.MX537, VF3xx, VF5xx, VF6xx
Keypad or Touch Screen	CRTOUCH	Touch Sensing for MCU's	Touch Sensing Software	TSSMCU
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200, MC13233
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	QN 902x, NT3H1101

Diagnostic and Therapy Devices

2.1

Introduction

Reliability and accuracy are key considerations for diagnostics and therapy devices. These devices are used in critical situations when physiological events need to be recognized quickly and addressed appropriately. These medical devices need a processing core that is powerful enough to acquire, process and interpret several parameters at once.

NXP offers a full spectrum of 32-bit processors that offer the performance and integration needed to power the next generation of diagnostic and therapy devices. Integrated wired and wireless communication interfaces facilitate convenient data transfer from a device to a PC, smart mobile device, or embedded gateway for processing or long-term storage in the cloud. LCD interfaces of varying resolutions are common across NXP's ARM-based product portfolios providing clinicians and patients a meaningful way to visualize clinical data in real time.

Electrocardiograph

2.2

Introduction

An electrocardiogram (ECG or EKG) is a graph produced by recording the electrical activity of the heart over time. This allows healthcare providers to diagnose a wide range of heart conditions.

A portable ECG is a device that 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.

QRS complex

A typical ECG period consists of P, Q, R, S and T waves. 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, 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 obtain 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.

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. 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 2.2c shows a basic implementation circuit that detects the electrical currents through the electrodes.

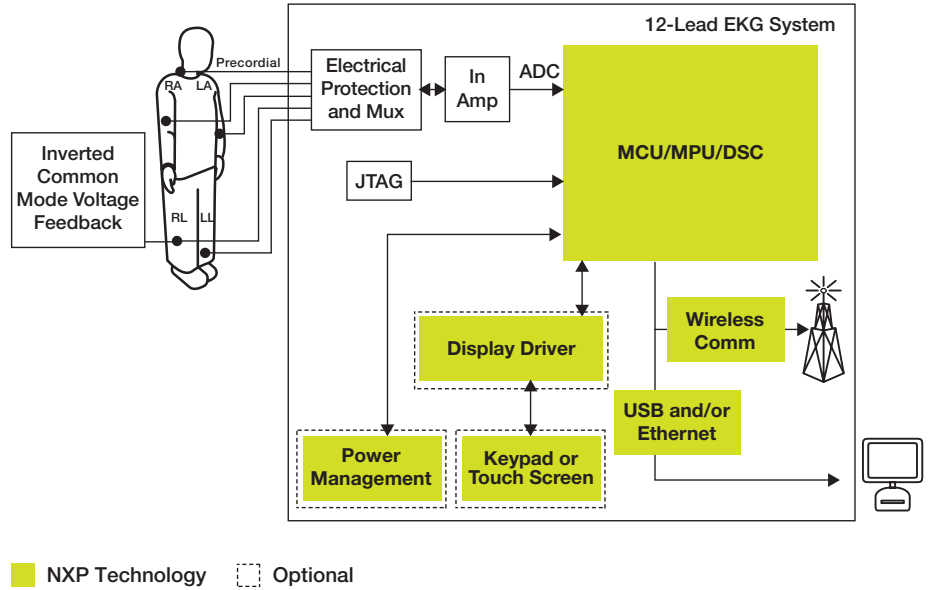### FIGURE 2.2a: ELECTROCARDIOGRAPH BLOCK DIAGRAM

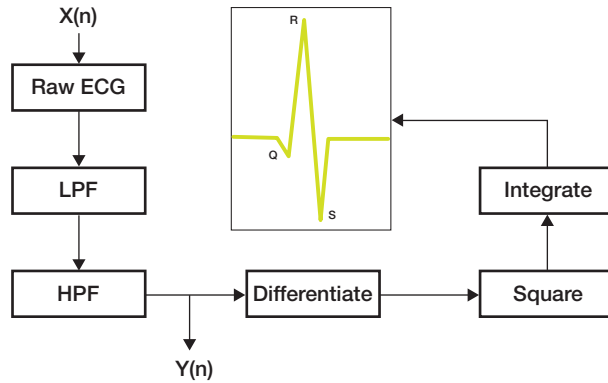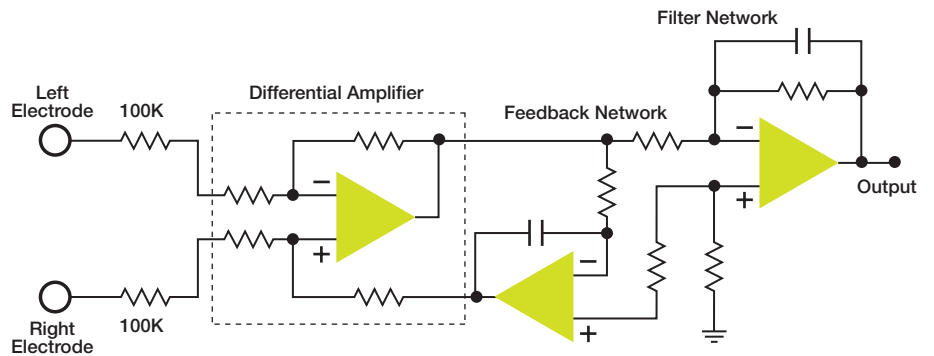### FIGURE 2.2b: DIGITAL SIGNAL PROCESSING TO OBTAIN THE QRS COMPLEX

FIGURE 2.2c: ECG ANALOG FRONT END

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 slightly amplified. 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 that 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.

AN4323: Solutions for electrocardiograph and heart rate monitor applications

This application note describes how to use the MED-EKG development board, a highly efficient board that can be connected to the Tower System to obtain an electrocardiogram signal and measure heart rate.

The application is implemented using the MK53N512.

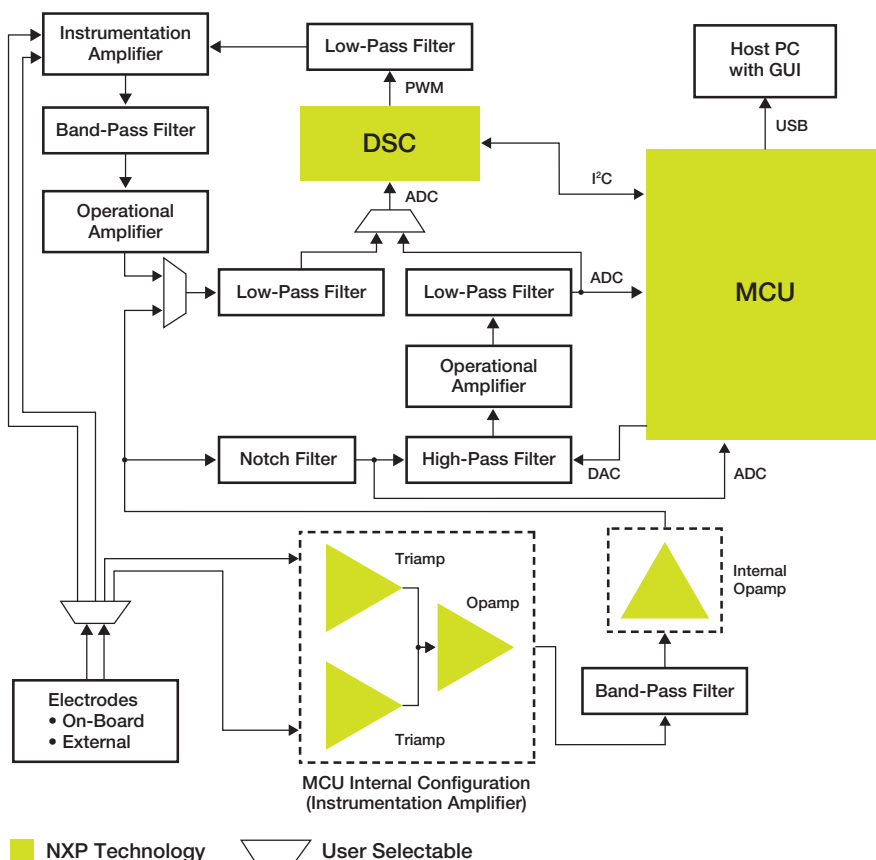### FIGURE 2.2d: ELECTRODES CONNECTION CIRCUIT AND SIGNAL CONDITIONING
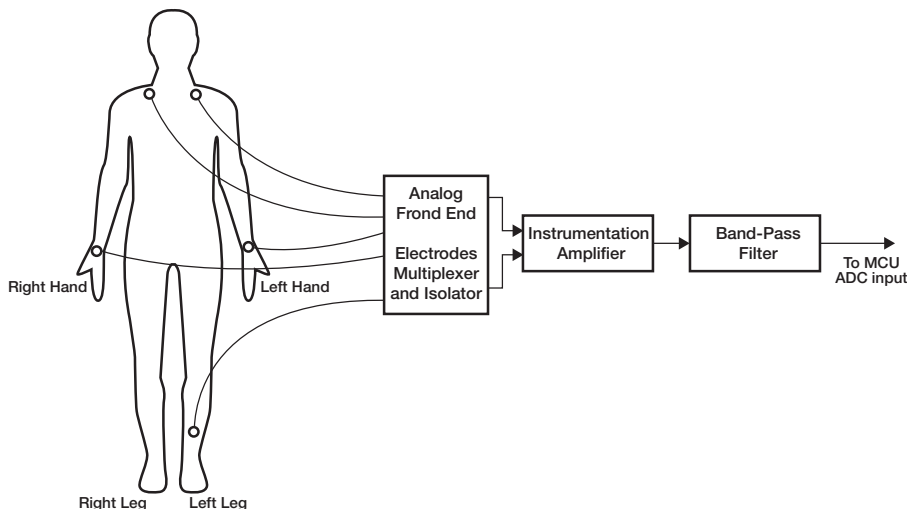
FIGURE 2.2e: MED EKG BLOCK DIAGRAM

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▸ Ultra-low-power operation
▸ 2 x opamp
▸ 2 x triamp
▸ 2 x 12-bit DAC
▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers
▸ Programmable delay block
▸ I²C
▸ USB connectivity
▸ ARM Cortex-M4 core with DSP instructions

VF6xx: Vybrid VF6xx Dual Heterogeneous Core Solution with XGA Display, Dual USB, Dual Ethernet and L2 Switch

Features

▸ Dual heterogeneous core: ARM Cortex-A5 and ARM Cortex-M4
▸ Dual USB 2.0 OTG with integrated PHY
▸ Dual Ethernet 10/100 MAC with L2 switch
▸ Video/camera interface unit with optional OpenVG accelerator
▸ Display controller supporting resolutions up to XGA (1024 x 768)
▸ High-assurance boot with crypto acceleration
▸ Up to 1.5 MB on-chip SRAM and dual SDIO

FIGURE 2.2f: KINETIS K50 FAMILY BLOCK DIAGRAM

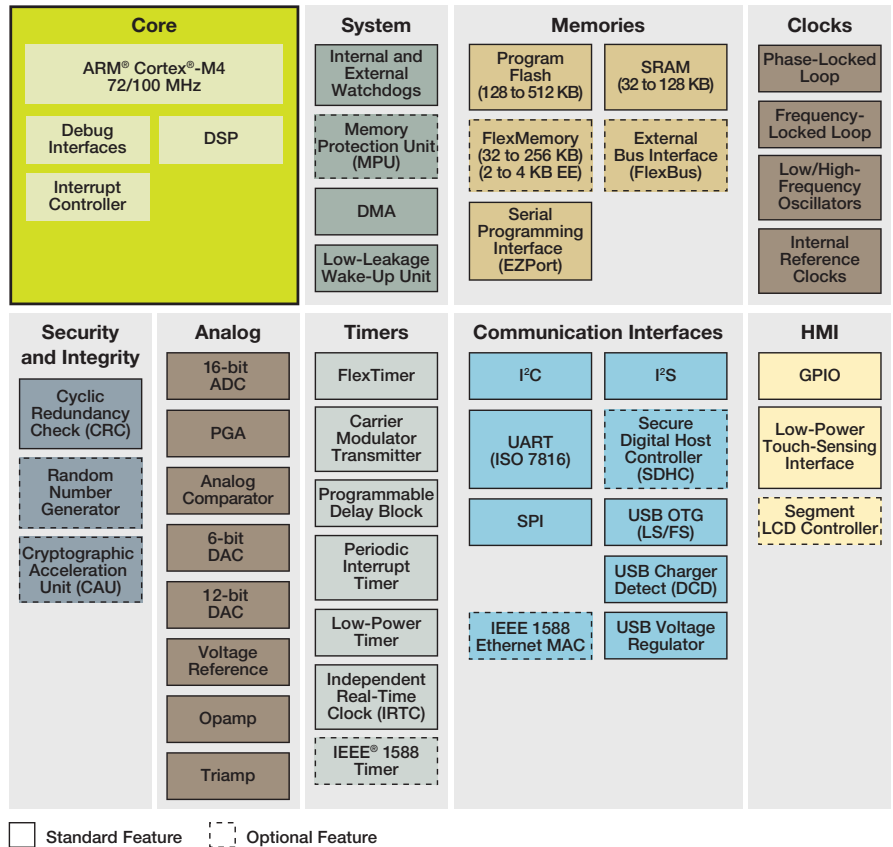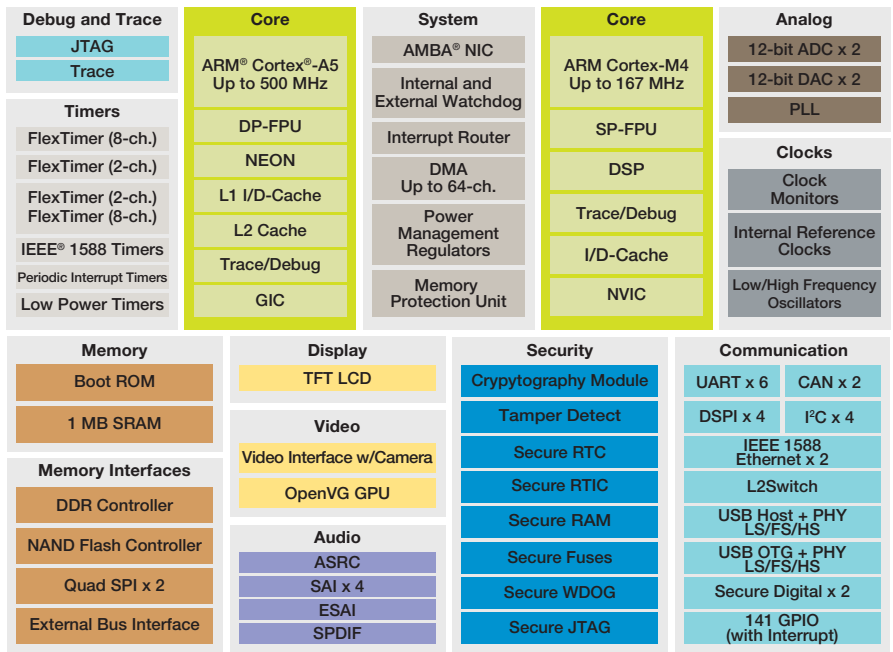**FIGURE 2.2g: VYBRID VF6XX BLOCK DIAGRAM**

▶ 800 MHz DDR3 and LPDDR2 support

▶ NAND flash controller and dual quad SPI with eXecute-In-Place (XIP)

▶ Dual 12-bit ADC and DAC

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

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 Vybrid VF6xx controller solution is shown in Figure 2.2h.

For more information about these connections, see the Vybrid VF6xx reference manual and application notes about touch screens and LCD memory, available at **www.nxp.com**.

Enhanced multiply-accumulate (eMAC) module

One of our 32-bit MCUs 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 of embedded code while supporting the integer multiply instructions of the baseline 32-bit architecture.

Our company 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.

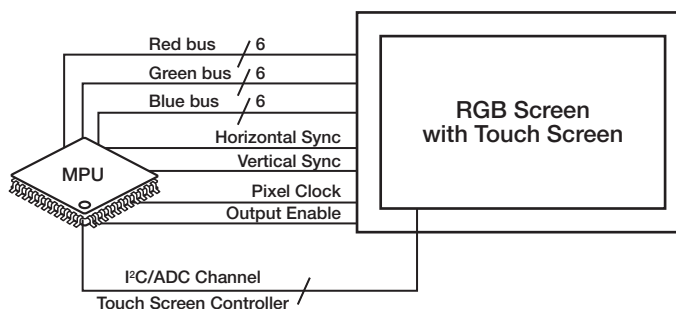**FIGURE 2.2h: SCREEN CONNECTION ON VYBRID VF6XX CONTROLLER SOLUTION**
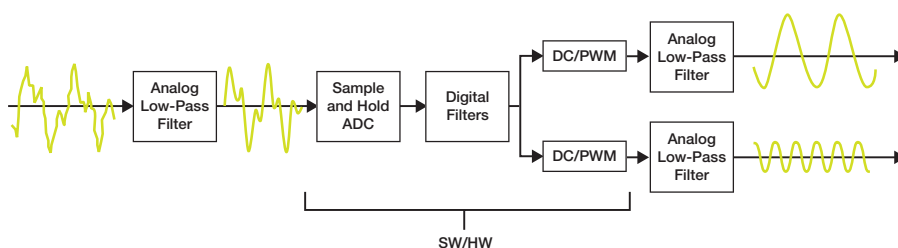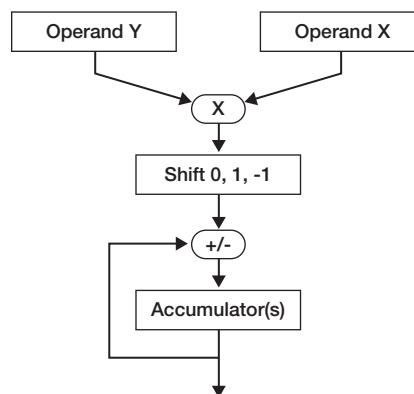

FIGURE 2.2i: TYPICAL DSP CHAIN

FIGURE 2.2j: MULTIPLY-ACCUMULATE FUNCTIONALITY DIAGRAM

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.

MPUs 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.
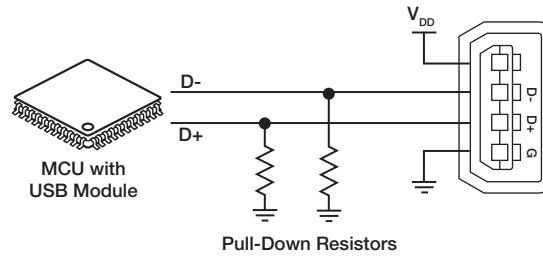
USB connection

The USB connection allows the ECG 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 found in many of our products.
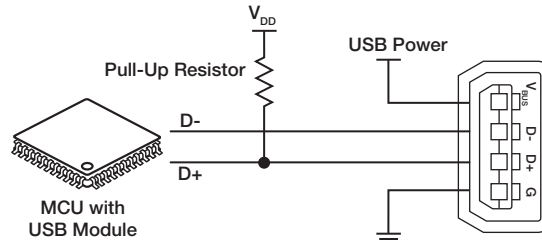
FIGURE 2.2k: DSP LIBRARY STRUCTURE
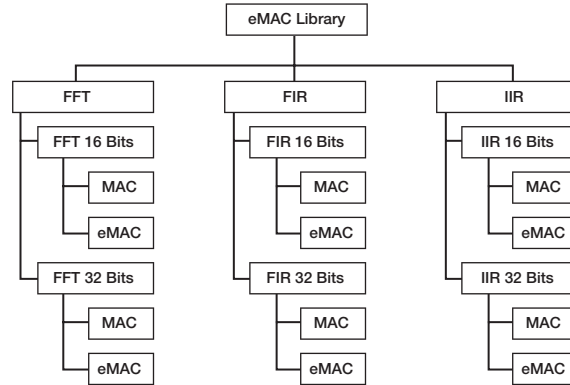
FIGURE 2.2l: HARDWARE CONFIGURATION IN HOST MODE

FIGURE 2.2m: HARDWARE CONFIGURATION IN DEVICE MODE

Multi-Parameter Patient Monitor

2.3

Introduction

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

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

Measuring temperature

The S08QG family includes a temperature with an output connected to an ADC analog channel input. The approximate transfer function of the temperature sensor can be expressed by this equation:

$$Temp = 25 - ((V_{TEMP} - V_{TEMP25})/m)$$

For more information about the temperature sensor, see the document MC9S08QG8/QG4 Device Data Sheet, available at **www.nxp.com**.

ADC module features

▸ 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 I²C Bus Using MC9S08QG8* (document AN3048), available at **www.nxp.com**.

ECG monitoring

An ECG is a graph produced by recording the electrical activity of the heart over time. This allows healthcare providers to diagnose a wide range of heart conditions.

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 and restrictive pulmonary disease.

Table 2-3. S08QG MCU Family

| FEATURES	S08QG
Core	HCS08
Flash	8/4 KB
RAM	512/257 KB
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
I²C	1
Operational voltage	1.8 to 3.6 V

FIGURE 2.3a: MULTI-PARAMETER PATIENT MONITOR GENERAL BLOCK DIAGRAM
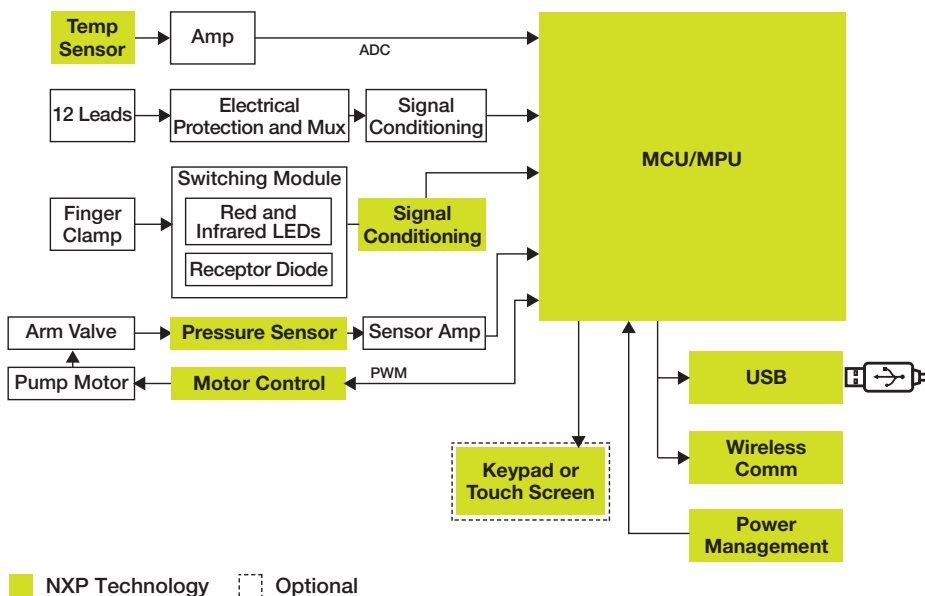
FIGURE 2.3b: GENERAL OVERVIEW OF TEMPERATURE MEASUREMENT

FIGURE 2.3c: SIGNAL CONDITIONING TO ECG MONITORING
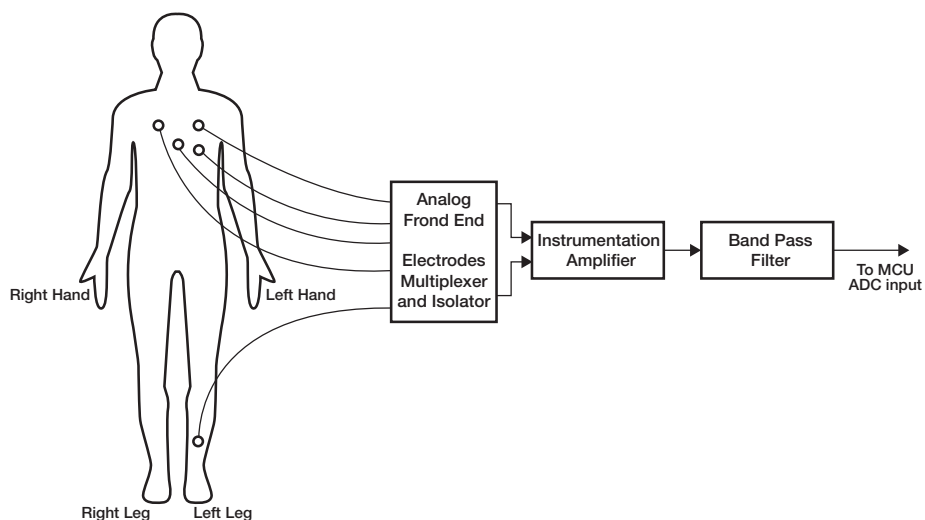
Blood pressure monitoring

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

Motor control with NXP devices

The 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)

Applications processor

Multi-parameter patient monitors require a versatile platform for multimedia and display applications. i.MX processors based on ARM technology deliver an optimal balance of power, performance and integration to enable next-generation smart devices.

The i.MX 6 series unleashes the industry's first truly scalable multicore platform that includes single-, dual- and quad-core families based on the ARM Cortex-A9 architecture. Together with a robust ecosystem, i.MX 6 series provides the ideal platform to develop a portfolio of end devices based on a single hardware design.

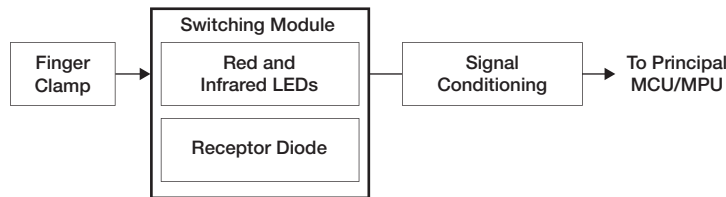### FIGURE 2.3d: GENERAL OVERVIEW OF PULSE OXIMETRY MONITORING

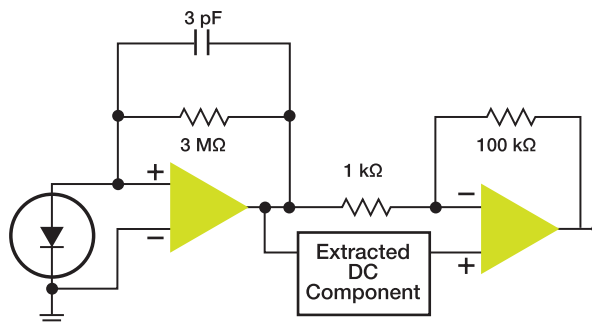### FIGURE 2.3e: SIGNAL CONDITIONING FOR PULSE OXIMETRY MONITORING

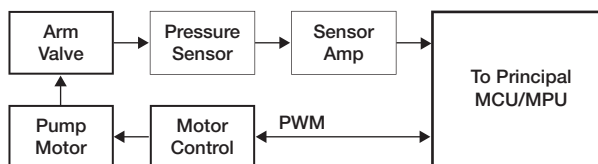### FIGURE 2.3f: GENERAL OVERVIEW OF PRESSURE MONITORING

FIGURE 2.3g: I.MX 6 BLOCK DIAGRAM

Digital Stethoscope

2.4

Introduction

A digital stethoscope is a device that uses ultrasound waves to detect different types of tissue and movements within the body, such as those produced by heart contractions and relaxation or even blood flow through the arteries via an ultrasonic probe.

This functionality is based on the Doppler effect, which consists of the wavelength variation sent or received by a moving object.

With a digital stethoscope, a source sends acoustic waves to the heart. While a portion of the energy bounces back, the heartbeat changes the frequency of the returning waves via the Doppler effect. Simple algorithms are then used to detect and measure the patient's heartbeat via these returning signals.

Ultrasonic probe

The ultrasonic probe may consist of an oscillator (X1 in Figure 2.4b) that generates an ultrasound frequency (for these applications, the range is 1–3 MHz) followed by an amplifier (U2 in Figure 2.4b) 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.

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 2.4c) 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.

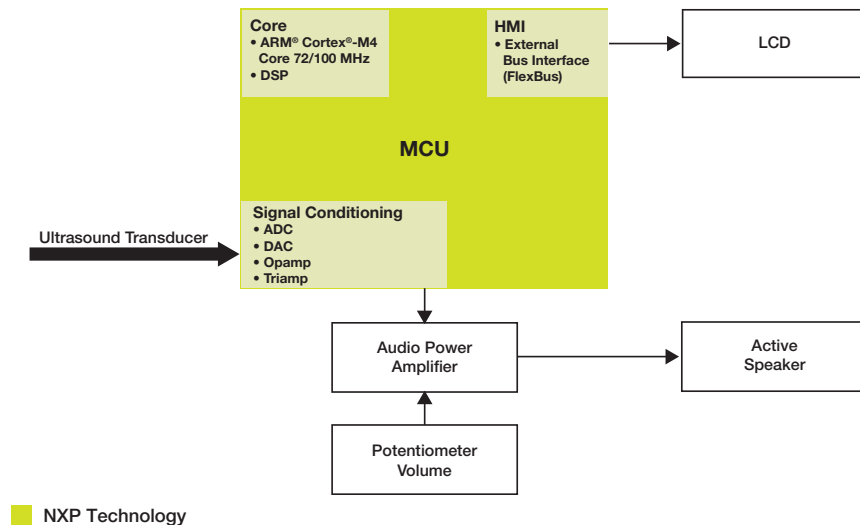**FIGURE 2.4a: DIGITAL STETHOSCOPE GENERAL BLOCK DIAGRAM**

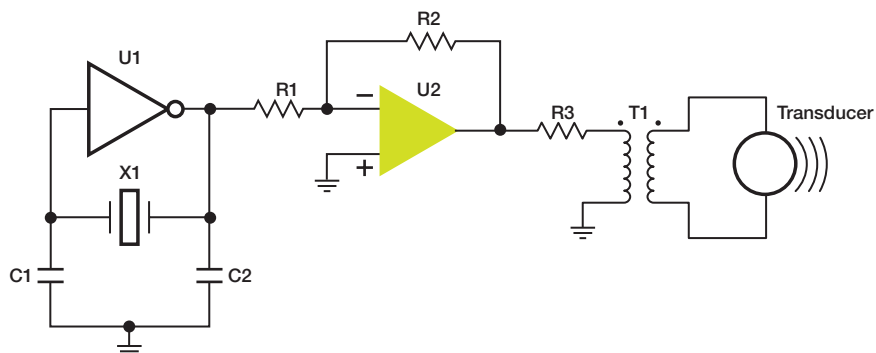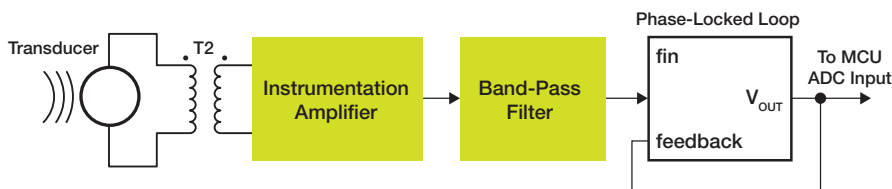**FIGURE 2.4b: TRANSMITTER ULTRASONIC PROBE EXAMPLE**

FIGURE 2.4c: RECEIVER ULTRASONIC PROBE EXAMPLE

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 ADC embedded on the MCU.

LCD display

The MCU is responsible for processing the information acquired according to an algorithm and displaying the data on an LCD screen. We provide a wide range of MCUs with embedded LCD controllers. Ultra-low-power MCUs with segment LCD drivers can be found in the Kinetis L series. We also offer segment LCD and graphical display options in the Kinetis K series of MCUs.

For more information about LCD devices and connections, see Section 1.5, Blood Glucose Meter.

For information about a digital stethoscope reference design, download DRM132 *Medical Stethoscope Design Reference Manual.*

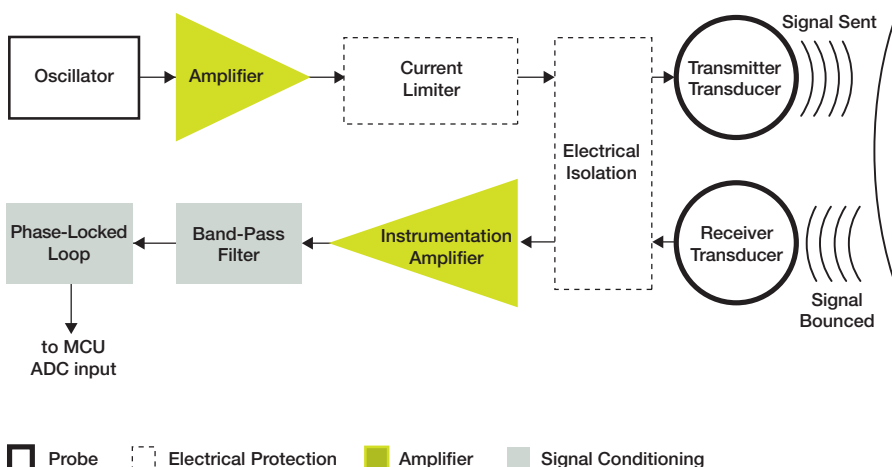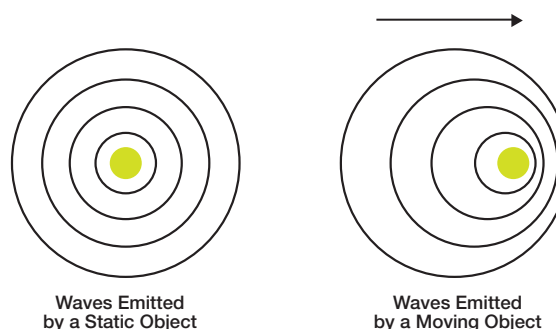### FIGURE 2.4d: ULTRASONIC PROBE ELEMENTS BLOCK DIAGRAM

FIGURE 2.4e: DOPPLER EFFECT EXAMPLE

Waves Emitted by a Static Object

Waves Emitted by a Moving Object

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment.

LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

The Kinetis K50 MCU has the next features and peripherals in its integrated measurement engine:

▸ Ultra-low-power operation
▸ 2 x opamp
▸ 2 x triamp
▸ 2 x 12-bit DAC
▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers
▸ Programmable delay block
▸ I²C
▸ USB connectivity
▸ ARM Cortex-M4 core with DSP instructions

Fetal heart rate monitor

A fetal heart rate monitor is a target application of digital stethoscopes. It provides an audible simulation of the heartbeat of a fetus inside the mother's womb and displays the number of beats per minute. Fetal heart rate monitors are increasingly being used in the home, allowing parents to listen to their baby's heartbeat.

Figure 2.4g shows the basic block diagram of a fetal heart rate monitor.

FIGURE 2.4f: KINETIS K50 FAMILY BLOCK DIAGRAM
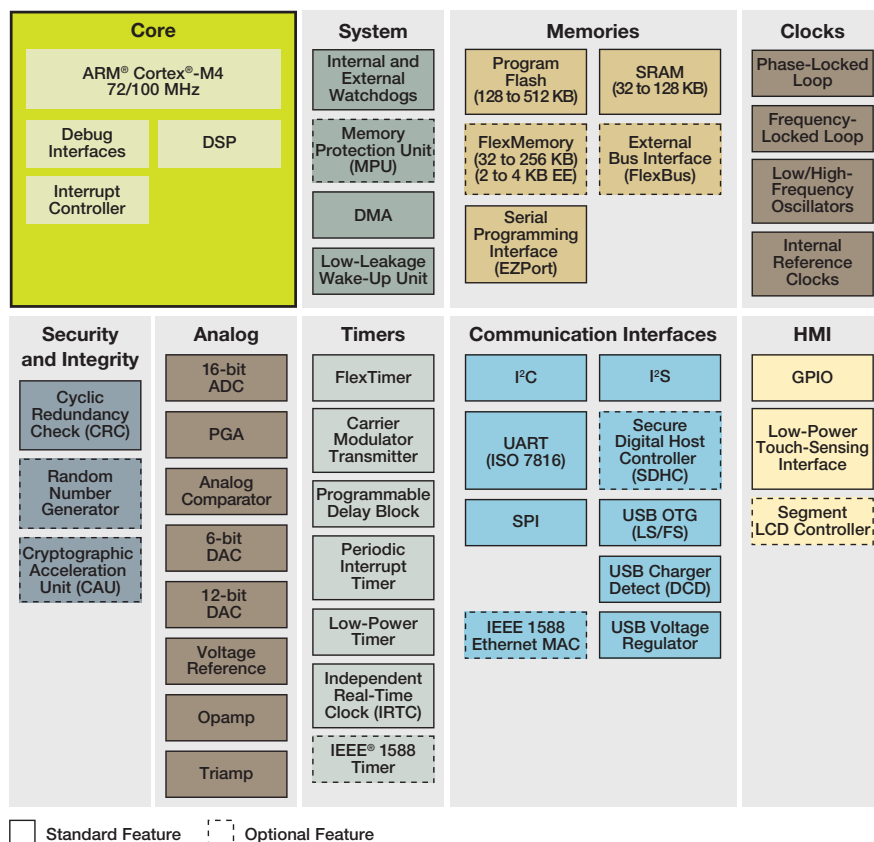
FIGURE 2.4g: FETAL HEART RATE MONITOR GENERAL BLOCK DIAGRAM
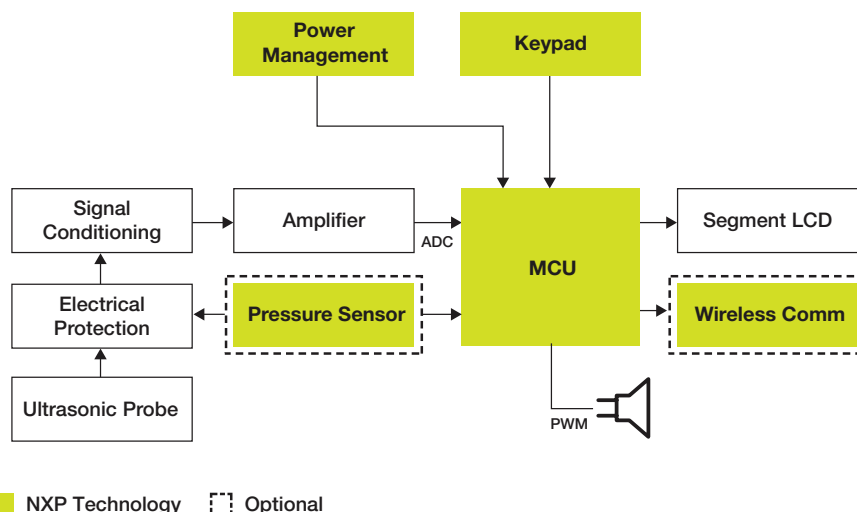
Infusion Pumps

2.5

Overview

An infusion pump is a device that dispenses fluids such as medication or nutrients to a patient through the circulatory system. These devices are programmed to deliver a predetermined quantity of a substance in specific timing intervals or volumes. This allows better medication control with patients that require this kind of care.

Circuit design overview

An infusion pump is formed by three principal blocks; human machine interface, dose control and power management.

Human machine interface

A small control panel is used to determine the correct parameters for a specific fluid during the infusion. Touch sensing interfaces are preferred as the input method due its ease of clean and lack of borders that can accumulate dirt. A segment LCD screen can be used to show the selected parameters and a section with LEDs can indicate alarm conditions. Sound alarms may be included using a buzzer and a PWM channel to control the sound frequency. Next Generation infusion pumps are implementing touch screen displays that contain both patient information and user interface. These type of applications use a product similar to an i.MX6SX.

Dose control

Dose control is maybe the most critical part of the device. It is in charge of control the delivering of the fluids and the operation must be precise and safe. A fluid pump, a motor moving a syringe or an occlusion mechanism for an IV catheter can be used to control the flow and volume applied. Motor control algorithms help to achieve precise movement of these mechanisms. Proper motor drivers must be used allowing the microcontroller to activate the mechanisms using GPIO.

A pressure sensor must be used to monitor the flow and pressure in the line. An air inline sensor allows determining if there is air in the fluid line that can cause an embolism. If air is detected, the infusion pump stops delivering and sends an alert to the physician.

Power management

Infusion pumps are usually powered by the hospital power line. A circuit for conditioning the input power to proper levels must be developed. Also, patient protection circuitry must be included in the design.

These devices must have battery power autonomy of at least 2 hours. PMIC ease the battery management and can increase the battery life.

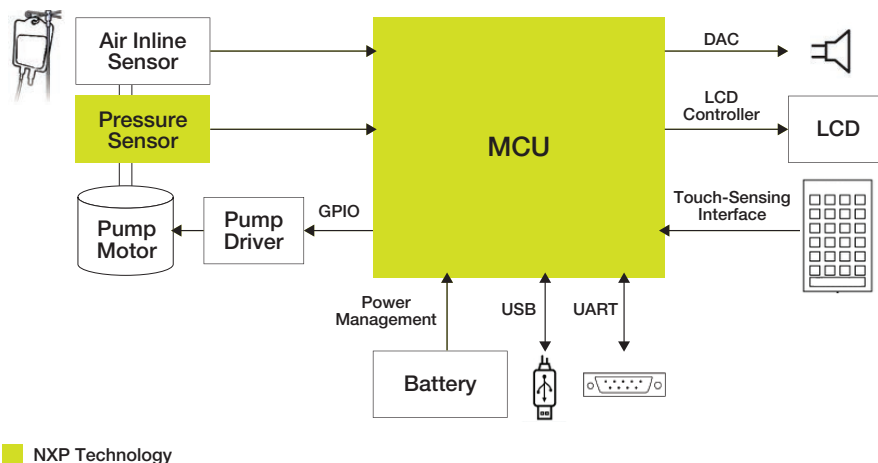### FIGURE 2.5a: INFUSION PUMP BLOCK DIAGRAM

FIGURE 2.5b: i.MX 6SOLOX MULTIMEDIA PROCESSOR BLOCK DIAGRAM
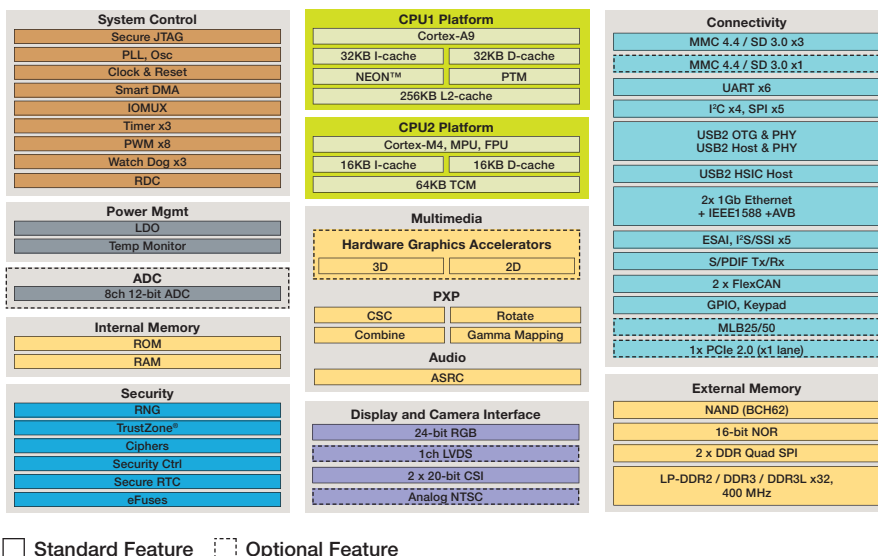
Recommended solutions

Kinetis K3x Family

The K3x MCU family is pin, peripheral and software compatible with the K1x MCU family and adds a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 80-pin LQFP packages extending up to 512 KB in a 144-pin MAPBGA package with a rich suite of analog, communication, timing and control peripherals.

MC34931: 5.0A H-Bridge

The MC34931 is a monolithic thermally efficient 28V/5A H-Bridge DC motor driver featuring real-time load current monitoring and automatic thermal back-off ensuring high availability operation in demanding high-current, high-temperature industrial applications. It is designed primarily for DC brushed and servo motor driver applications within the current and voltage limits stated in this specification. This device is powered by SMARTMOS technology.

MPXx4006: 0 to 6kPa, 5.0v, differential and gauge silicon pressure sensor

The MPxx4006 family (MPVZ4006G and MPXV4006G series) are state-of-the-art monolithic silicon pressure sensors. The series combines advanced micromachining techniques, thin-film metallization and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure.

FIGURE 2.5c: KINETIS K3X FAMILY BLOCK DIAGRAM
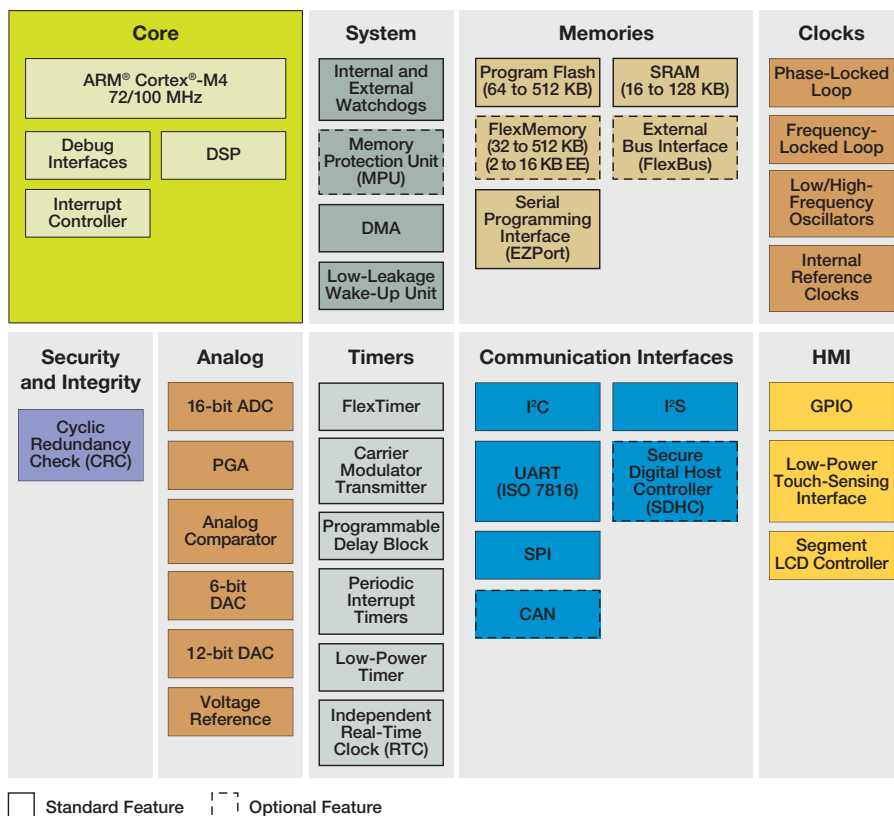
Defibrillator

2.6

Automated external defibrillator (AED)

An 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 medical emergency occurs mainly due to ventricular fibrillation.

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, as a victim's chance of surviving drops by seven to 10 percent for every minute a normal heartbeat is not restored.

An MCU or MPU 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.

Circuit for capacitive discharge defibrillators

In Figure 2.6b, 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 τ (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 10 seconds.

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 2.6b 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 2.6a: DEFIBRILLATORS GENERAL BLOCK DIAGRAM
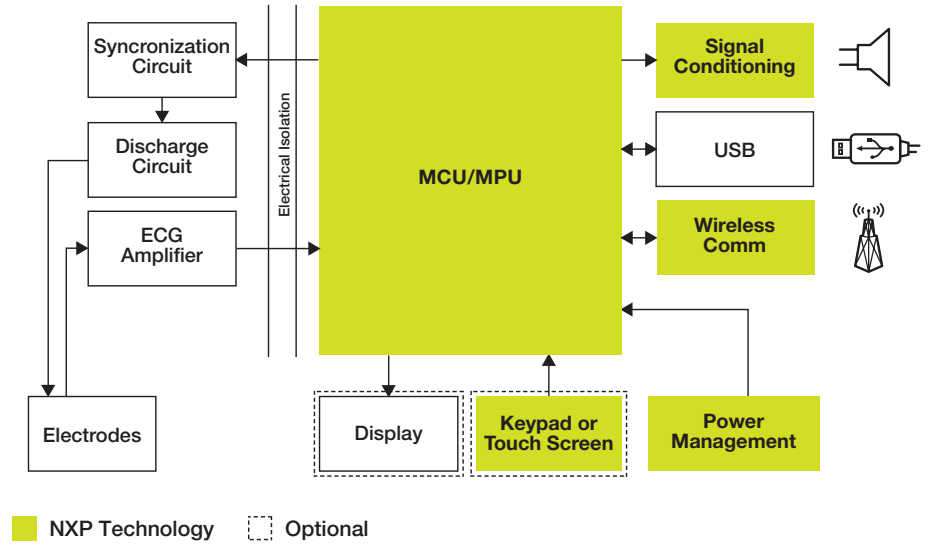
FIGURE 2.6b: BASIC CIRCUIT DIAGRAM FOR A CAPACITIVE DISCHARGE DEFIBRILLATOR
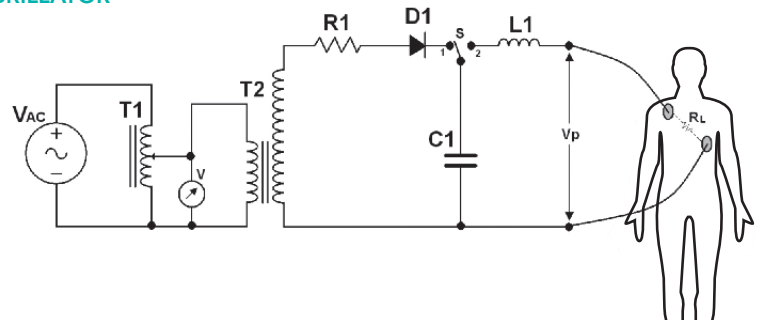
FIGURE 2.6c: BLOCK DIAGRAM FOR A RECTANGULAR WAVE DEFIBRILLATOR
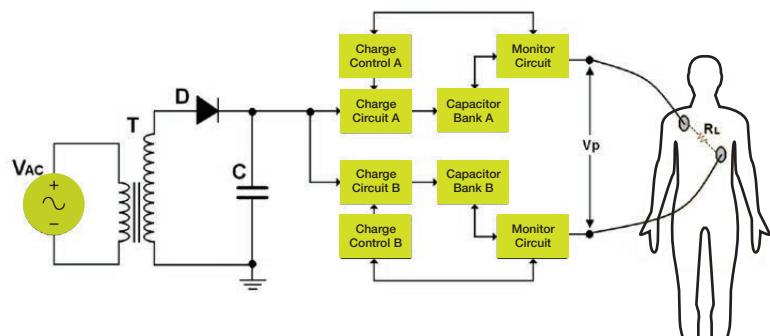
FIGURE 2.6d: UNIPOLAR AND BIPOLAR DEFIBRILLATOR WAVEFORMS
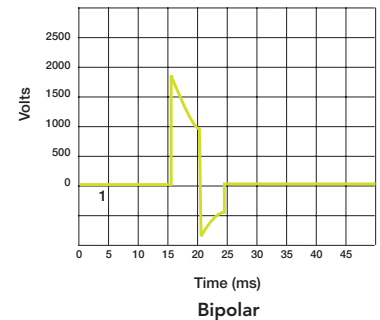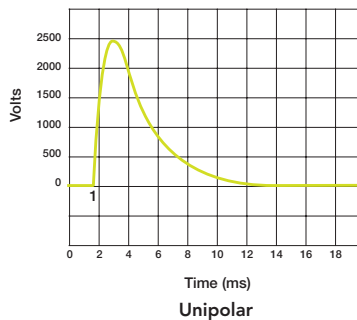
Ventilator and Respirator

2.7

Introduction

A ventilator is a machine designed to mechanically move air in and out of the lungs to intermittently, 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/MPU. This MCU/MPU receives information from the airways, lungs and chest wall through the sensors and decides how the ventilator pump responds.

System sensors

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

Our company 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 NXP pressure sensors, including the **MPX2300DT1, MPX2301DT1, MPXC2011DT1, MPXC2012DT1, MPX2050 and MPX5050**.

Spirometer

Spirometers measure static pulmonary volumes, except the functional residual capacity and total pulmonary capacity. 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 2.7b illustrates how to configure a spirometer using a pressure sensor. The next two figures observe the different volumes of lungs.

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)

FIGURE 2.7a: VENTILATION/RESPIRATION GENERAL BLOCK DIAGRAM
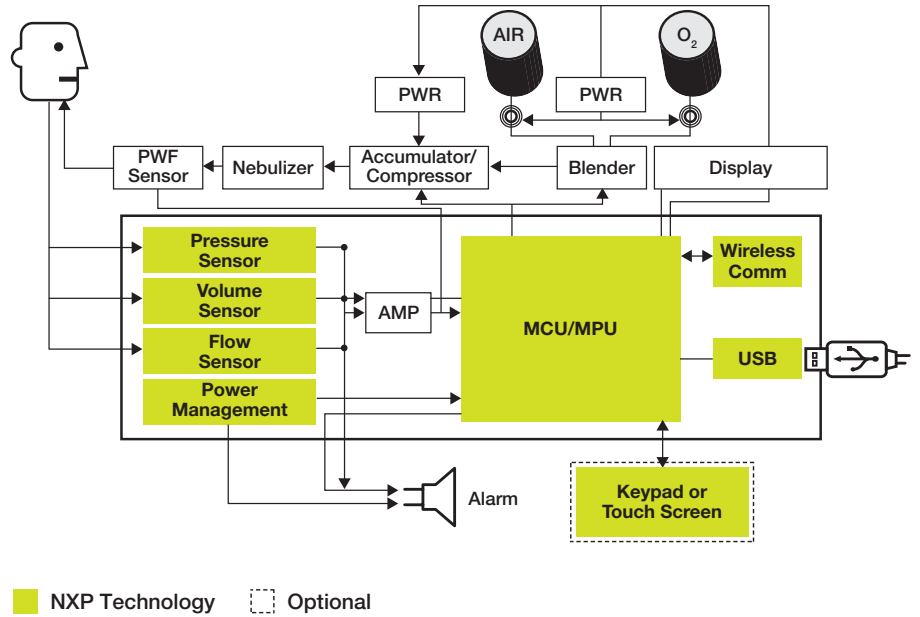
FIGURE 2.7b: SPIROMETER
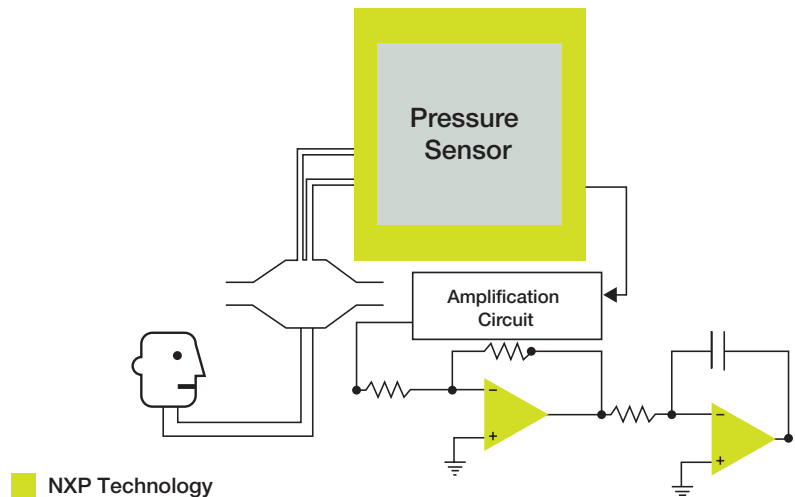
▶ Expiratory reserve volume (ERV)—The maximum volume of additional air that can be expired at the end of a normal expiration (1500 ml)

▶ 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)

AN4325: spirometer demo with NXP MCUs

The contents of this application note show how it is possible to use the Kinetis K50 with the Tower System to implement a device capable to quantify human respiration capacities by measuring volumes and flow rates. It uses the MED-SPI development board, which is an analog front end designed to enable the prototyping of spirometry devices.

Graphic LCD MPU

Our company offers the following devices that generate graphics. These devices can be used to illustrate lung volume.

▸ **Kinetis MCUs**

The Kinetis K70 MCU family includes 512 KB to 1 MB of flash memory, a single precision floating point unit and a graphic LCD controller that supports color QVGA displays as single chip or up to 24-bit SVGA displays using external memory. Supported by the Portable Embedded GUI (PEG) Library with simple WindowBuilder interface for powerful GUI development.

▸ **Vybrid controller solutions**

Part of the Vybrid platform, the VF7xx family of devices includes dual heterogeneous core SoCs meant for solutions that want to concurrently run Linux® or Android™ on the ARM Cortex-A class core and an RTOS like our proprietary MQX solution on the ARM Cortex-M class core optimized power-performance core with very high integration. VF7xx devices have been designed to replace at least the MPU and MCU products on a system that requires rich HMI and real-time control simultaneously.

▸ **i.MX processors**

The most versatile platform for multimedia and display applications, ARM-based i.MX processors deliver an optimal balance of power, performance and integration to enable next-generation smart devices. i.MX solutions include processors based on ARM9, ARM11™, ARM Cortex®-A8 and ARM Cortex-A9 core technologies, and are powering applications across a rapidly growing number of consumer, automotive and industrial markets. These solutions bring interactivity to a whole

new world of products. The i.MX 6 series is a truly scalable multicore platform of devices based on the ARM Cortex-A9 core for flexibility in design and re-use of a platform across multiple tiers of products or different products.

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.

FIGURE 2.7c: MED SPI BLOCK DIAGRAM

☐ NXP Technology

FIGURE 2.7d: NORMAL SPIROMETER

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.

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.

For more information on how to build a ventilator/respirator, download *Ventilator/ Respirator Hardware and Software Design Specification* (document DRM127) from **www.nxp.com**.

FIGURE 2.7e: NORMAL LUNG VOLUME
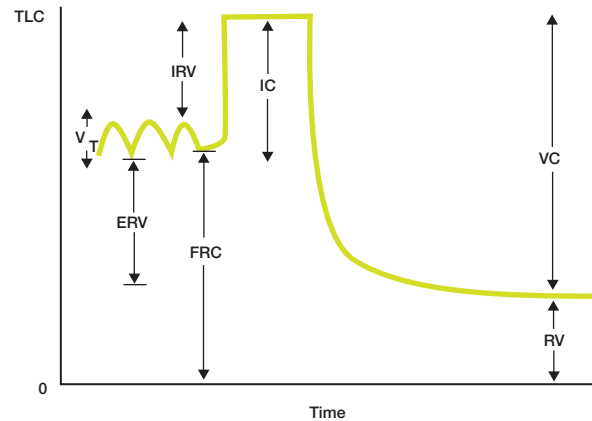
FIGURE 2.7f: BLENDER CONFIGURATION
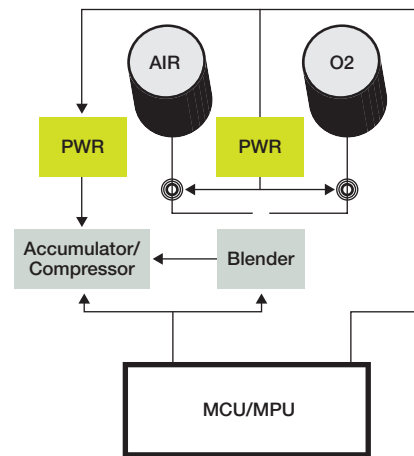
Kinetis K20 MCUs

The K20 MCU family is pin, peripheral and software compatible with the K10 MCU family and adds Full-Speed USB 2.0 On-The-Go with device charge detect capability. Devices start from 128 KB of flash in 80-pin LQFP packages extending up to 512 KB in a 144-pin MAPBGA package with a rich suite of analog, communication, timing and control peripherals.

Features

▸ ARM Cortex-M4 core with DSP, 100 MHz clock, single cycle MAC, and single instruction multiple data extensions

▸ 128–512 KB flash. Fast access, high reliability with four-level security protection

▸ Hardware touch-sensing interface with up to 16 inputs. Operates in all low power modes (minimum current adder when enabled). Hardware implementation avoids software polling method. High sensitivity level allows use of overlay surfaces up to 5 mm thick

▸ Memory protection unit provides memory protection for all masters on the cross bar switch, increasing software reliability

▸ Cyclic redundancy check engine validates memory contents and communication data, increasing system reliability

MPX230xDT1: high volume pressure sensor

Features

▸ Cost effectiveness

▸ Integrated temperature compensation and calibration

▸ Ratiometric to supply voltage

▸ Polysulfone case material (ISO 10993)

▸ Provided in tape and reel

MPL3115A2: smart pressure sensor

Features

▸ Less than 1 foot/0.3 m resolution

▸ Pressure range: 20–110 kPa

▸ Compensated, direct reading (software is not needed):
   – 20-bit pressure measurement (Pascals)
   – 20-bit altitude measurement (meters)

▸ 12-bit temperature measurement

▸ On-board intelligence

▸ Flexible sampling rate up to 128 Hz

MPXx5050: –50 to 0 kPa and 0 to 50 kPa integrated silicon pressure sensor, on-chip signal conditioned, temperature compensated and calibrated

Features

▸ 2.5% maximum error over 0 °C to 85 °C

▸ Ideally suited for MPU- or MCU-based systems

▸ Temperature compensated from over –40 °C to +125 °C

▸ Patented silicon shear stress strain gauge

MPXx2050: 50 kPa pressure sensor, On-Chip signal conditioned

Features

▸ 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 2.7g: KINETIS K20 BLOCK DIAGRAM
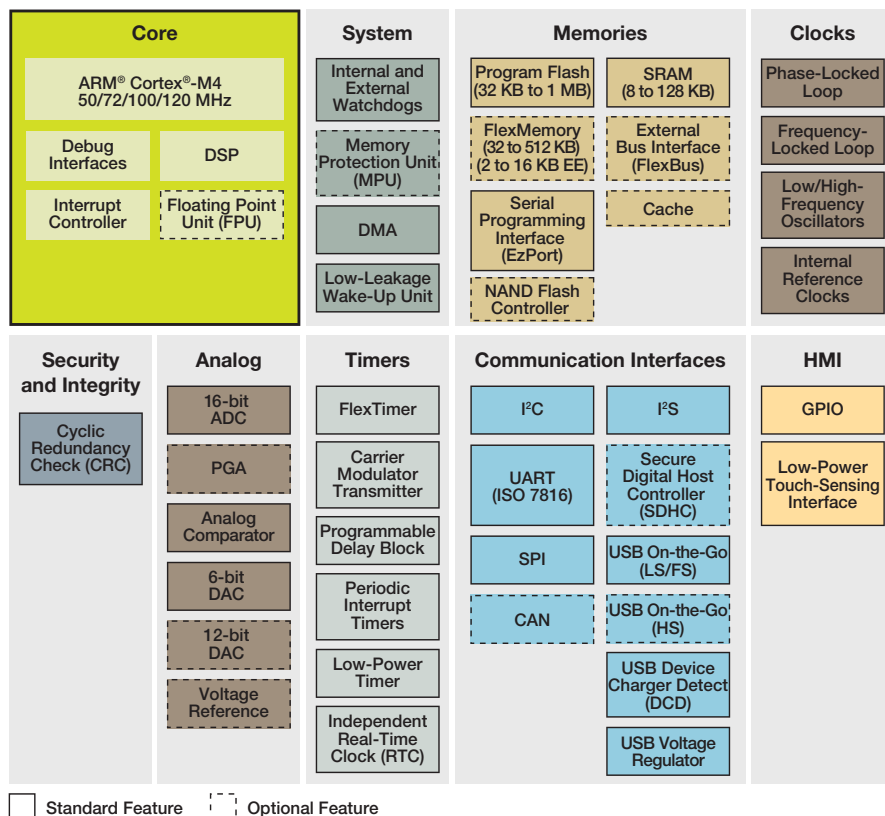
Table 2.7: MPXx2050 Packaging Information

DEVICE TYPE	PACKING OPTIONS	CASE
MPX2050D	Differential	344
MPX2050DP	Differential, Dual Port	423 A
MPX2050GP	Gauge	344B
MPX2050GSX	Gauge Axial PC Mount	344F

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

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▸ Ultra-low-power operation

▸ 2 x opamp

▸ 2 x triamp

▸ 2 x 12-bit DAC

▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers

▸ Programmable delay block

▸ I²C

▸ USB connectivity

▸ ARM Cortex-M4 core with DSP instructions

FIGURE 2.7h: KINETIS K50 FAMILY BLOCK DIAGRAM
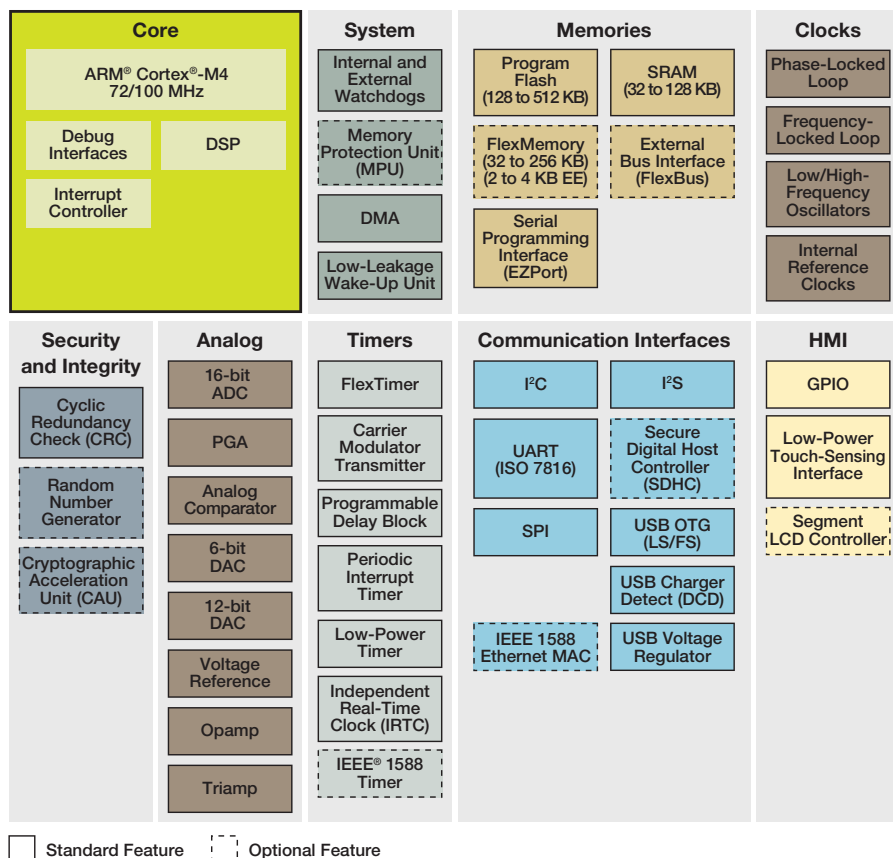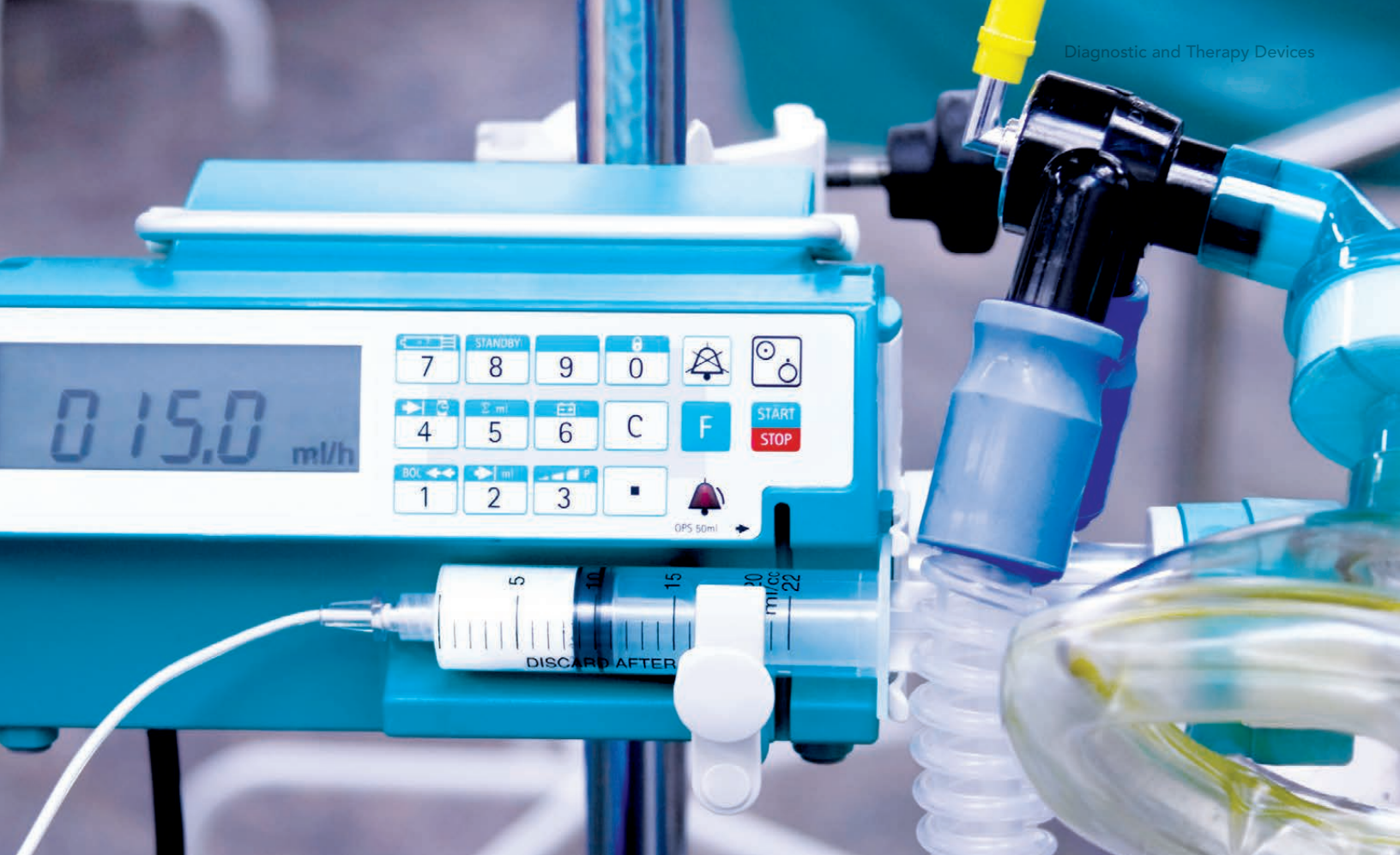
Anesthesia Monitor

2.8

Introduction

An anesthesia monitor is a machine that administers anesthesia to patients intravenously or via inhaled gas.

It exchanges respiratory gases and administers anesthetic gases, maintaining a balance of gases through the respiratory and cardiovascular system. During a surgical intervention, an anesthesiologist administers the infusion of anesthetics based on drug models and drug distribution over time.

The basic design of an anesthesia machine is as follows: pressurized gases are supplied by cylinders or pipelines to the machine, which controls the flow of gases before passing them through a vaporizer and delivering the resulting mixture to the patient via the breathing circuit.

Brief theory

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 (Halothane, O_2, and N_2O) system. Here, the O_2 and the N_2O are mixed to 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 (Halothane, O_2, and N_2O).

Pressure sensor

This sensor helps the principal MCU take the pressure of the O_2 and N_2O. 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 our portfolio, see Chapter 12, Ventilation and Spirometry.

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.

Principal MCU

The remainder of the process occurs in the vaporizer (there is a special apparatus to make this). Here, Halothane, O_2 and N_2O are mixed. These substances must be vaporized to provide the necessary anesthesia. Therefore the principal MCU must control the rate by adjusting 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 Kinetis MCUs are recommended for this application.

FIGURE 2.8a: ANESTHESIA UNIT MONITOR
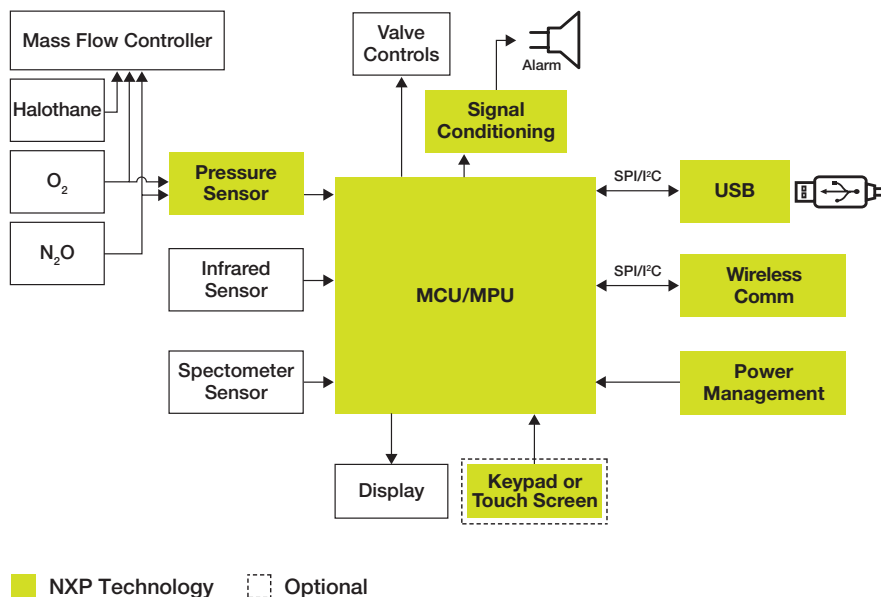
FIGURE 2.8b: ANESTHESIA APPLICATION GENERAL OVERVIEW
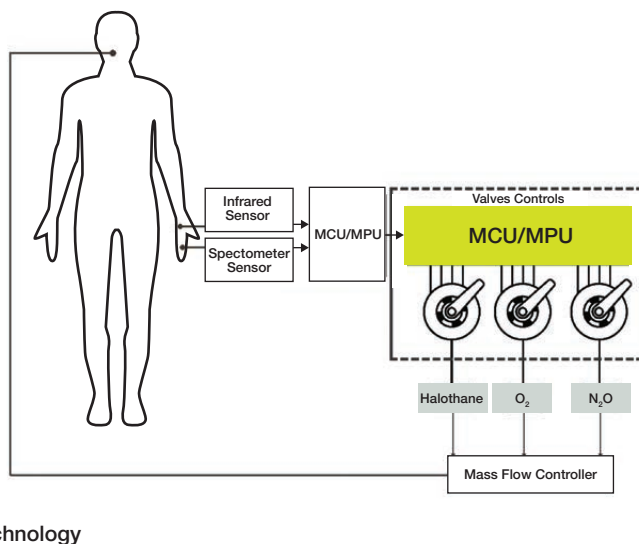
Kinetis K60 MCUs

The Kinetis K60 MCU family includes 512 KB–1 MB of flash memory, a single precision floating point unit, IEEE 1588 Ethernet, Full- and High-Speed USB 2.0 On-The-Go with device charge detect, hardware encryption, tamper detection capabilities and a NAND flash controller. 256-pin devices include a DRAM controller for system expansion. The Kinetis K60 family is available in 144 LQFP, 144 MAPBGA and 256-pin MAPBGA packages.

Features

▸ ARM Cortex-M4 core + DSP. 120–150 MHz, single cycle MAC, single instruction multiple data (SIMD) extensions, single precision floating point unit

▸ 512 KB–1 MB flash. Fast access, high reliability with four-level security protection

▸ Up to four high-speed 16-bit analog-to-digital converter with configurable resolution. Single or differential output mode operation for improved noise rejection. 500 ns conversion time achievable with programmable delay block triggering

▸ System security and tamper detect with secure real-time clock with independent battery supply. Secure key storage with internal/external tamper detect for unsecure flash, temperature, clock and supply voltage variations and physical attack detection

FIGURE 2.8c: KINETIS K60 FAMILY BLOCK DIAGRAM
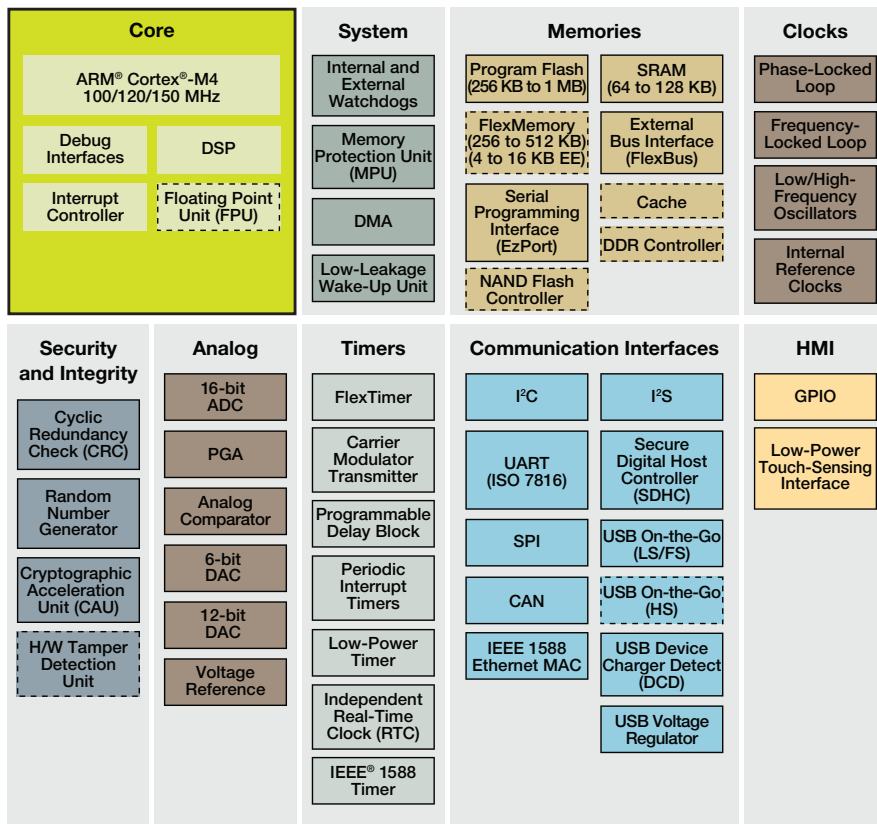
Hospital Admission Machine

2.9

Introduction

With the increasing prevalance of technology in the medical market, administrators are open to infusing that technology into hospitals to help increase the quality of service.

Automated hospital admission machines, tracking devices/ bracelets and automatic inventory control are just some of the solutions our healthcare team is developing. By leveraging our strengths in embedded control and wireless communications our company strives to bring connected intelligence to hospitals.

Hospital admission machine

A hospital admission machine helps patients and doctors increase the efficiency of a hospital through automating procedures that require time from 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 integrated MCUs such as the Kinetis MK53N512—allows the designer to achieve portability for touch-sensing interfaces and medical-grade communication (following Continua Health Alliance™ guidelines) with libraries that are downloadable from **www.nxp.com/healthcare**. These elements enable solutions focused on preventive medicine, which ultimately reduce a patient's 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 reduce 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 use, as a machine with mechanical buttons 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.

FIGURE 2.9a: HOSPITAL ADMISSION MACHINE GENERAL BLOCK DIAGRAM

■ NXP Technology   ⸽⸽⸽ Optional
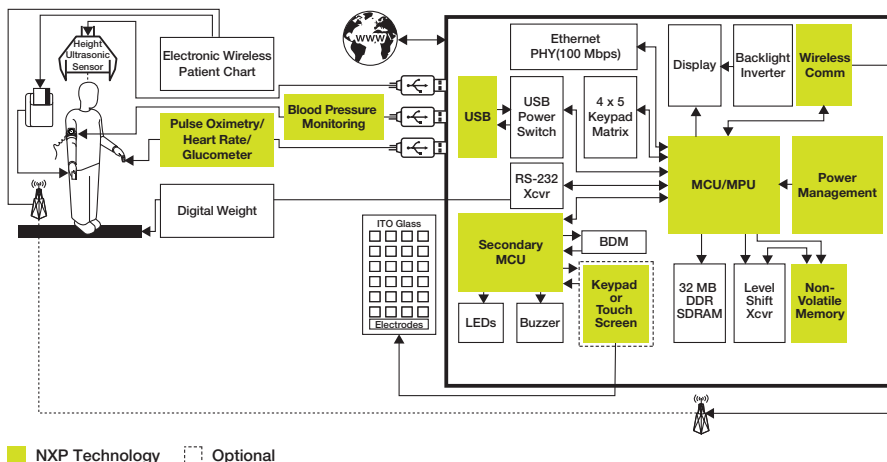
FIGURE 2.9b: ANALOG CONFIGURATION FOR LEDS AND BUZZER
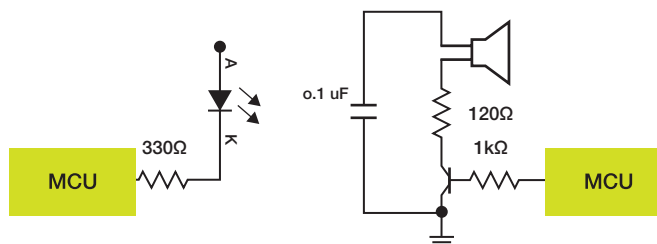
‣ Non-pathological personal history: Blood type, alcohol and tobacco use, drug abuse, allergies, etc.

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 (SaO_2)

‣ Maximum expiratory and inspiratory flow peak

‣ Inspiratory and expiratory lung volume

After this information is entered, 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.

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

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

Patient height and weight

The patient's height is taken by an ultrasonic sensor that 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 MCU to be processed and then passed by RS-232 or USB to the principal MPU. The general block diagram shows that the weight of the patient is passed through RS-232, although you can transmit by USB (optional). If RS-232 is used, it is necessary to add a MAX232 device according to the protocol (see Figure 2.9e).

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 MCU, such as those in the Kinetis L series.

FIGURE 2.9c: PORTABLE MONITORING SYSTEM
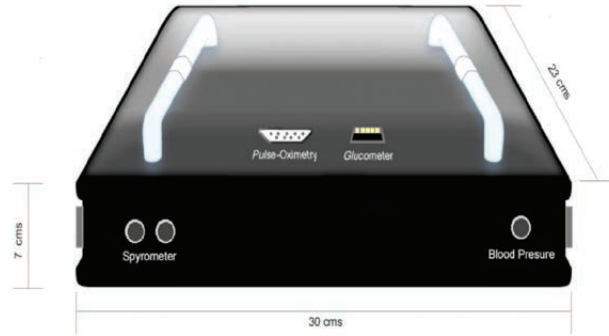
FIGURE 2.9d: MEASURING PATIENT HEIGHT
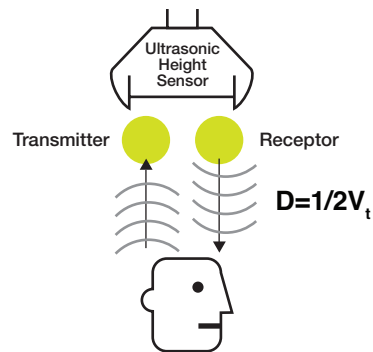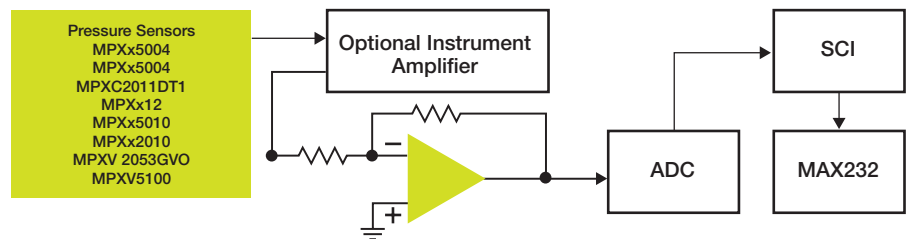

$$D=1/2V_t$$

FIGURE 2.9e: CONFIGURATION TO MEASURE PATIENT WEIGHT

Pressure Sensors
MPXx5004
MPXx5004
MPXC2011DT1
MPXx12
MPXx5010
MPXx2010
MPXV 2053GVO
MPXV5100

Optional Instrument Amplifier

SCI

ADC

MAX232

▮ NXP Technology

Communication interface

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, the devices are powered on and the principal MPU starts the communication as host.

The USB port is implemented in a regulator (MC33730) that provides 5 V at 2 A out. However, the devices only support 500 mA. Therefore, it is necessary to add a 500 mA fuse to limit 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 MPUs recommended for this application integrate two or more hosts, allowing more than one USB device without using a hub. For a list of recommended MPUs, visit **www.nxp.com/healthcare**.

Serial communications interface (SCI)

SCI 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 simultaneously). SCI uses either an 8- or 9-bit data format, with data sent using non-return-to-zero. 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 that allows the integration of RS232, RS422 and RS485 serial transceivers.

Data can be sent as 8- or 9-bit words (a least significant bit). A START bit marks the beginning of the frame and is active low. Figure 2.9h 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 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.

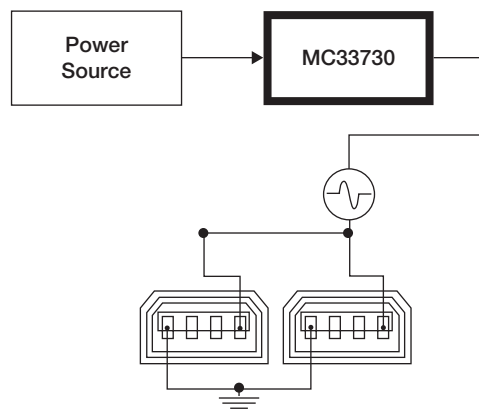FIGURE 2.9f: USB PORT CONNECTIONS

FIGURE 2.9g: USB GENERAL CONFIGURATION
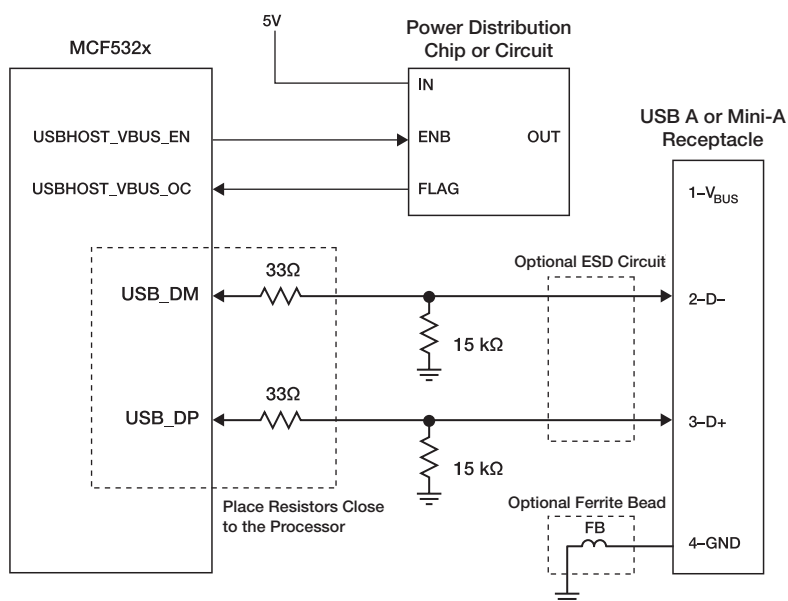
FIGURE 2.9h: SCI TRAM
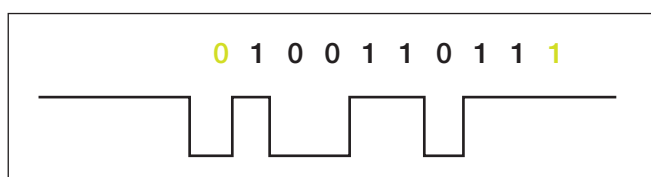
The odd parity bit will be high if there are an odd number of ones/zeros in the data field. A stop bit will normally follow the data field. The stop bit is used to bring the signal rests at logic high following the end of the frame, so when the next start bit arrives it will bring the bus from high to low. Idle characters are sent as all ones with no start or stop bits. Our MCUs provide 13-bit baud. The SCI modules can operate in low power modes.

Ethernet PHY (100 Mbit/s)

An Ethernet communication interface may be implemented to connect the MCU to the Internet or to control the system remotely. This requires coupling impedance for the RJ-45 connection.

Backlight inverter

A backlight is a form of illumination used in LCDs to illuminate the side or back of the display panel, unlike front lights, which are placed in front of the LCD.

Multimedia applications with the i.MX 6 Series

The i.MX 6 series of applications processors unleashes a scalable multicore platform that includes single-, dual- and quad-core families based on the ARM Cortex-A9 architecture for next-generation consumer, industrial and automotive applications. By combining the power-efficient processing capabilities of the ARM Cortex-A9 architecture with bleeding edge 3D and 2D graphics, as well as high-definition video, the i.MX 6 series provides a new level of multimedia performance to enable an unbounded next-generation user experience.

The market for intelligent, multimedia-centric, touch-based devices is increasing exponentially. Tomorrow's battery-powered smart devices need to present data and user interface choices to the end user primarily through rich sound, video, voice, pictures and touch, rather than keyboards and mice. The need for manufacturers to quickly provide multiple devices to fit specific market segments or niches and provide their customers with a broader range of choices is increasing just as quickly.

FIGURE 2.9i: SERIAL COMMUNICATION INTERFACE GENERAL CONFIGURATION
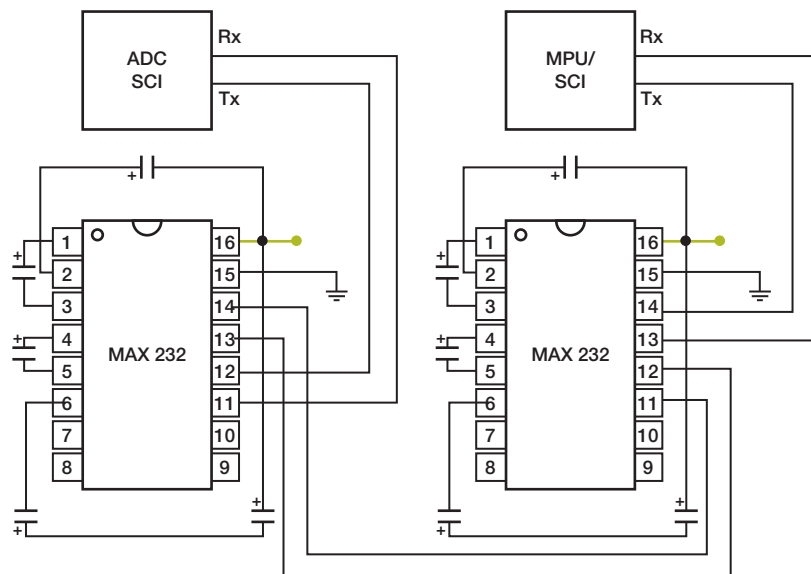
FIGURE 2.9j: ETHERNET INTERFACE CIRCUITRY
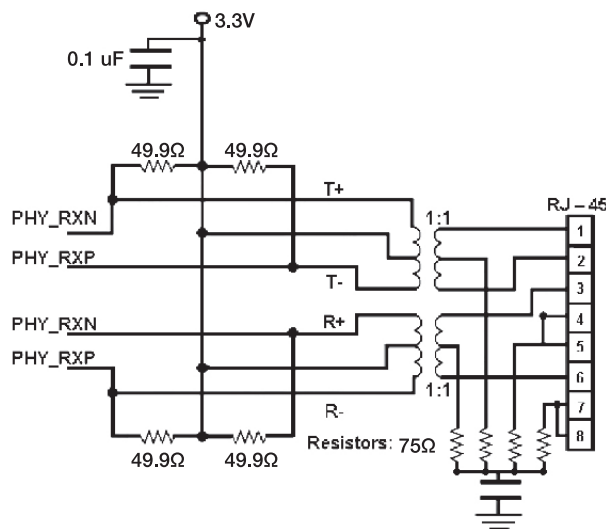
The i.MX 6 series was designed specifically to enable this new market by bringing together high-performance scalable multimedia processing, a software-compatible family of five processors and pin-compatible (i.MX 6SoloLite is not pin compatible) processor solutions with integrated power management that allow manufacturers to deploy a full portfolio of products with a single hardware design.

Features

▸ Scalable single-, dual- and quad-core offerings based on ARM Cortex-A9 up to 1.2 GHz, with ARMv7™, Neon™, VFPv3 and TrustZone® support

▸ 32 KB instruction and data L1 caches and 256 KB to 1 MB of L2 cache

▸ Multi-stream-capable HD video engine delivering 1080p60 decode, 1080p30 encode and 3D video playback in HD in high-performance families

▸ Exceptional 3D graphics performance with up to quad shaders performing 200 Mt/s and OpenCL support

▸ Separate 2D and/or Vertex acceleration engines for an optimal user interface experience

▸ Stereoscopic image sensor support for 3D imaging

▸ Integrated market-specific I/Os, which may include HDMI v1.4 with integrated PHY, SD3.0, multiple USB 2.0 ports with integrated PHY, Gigabit Ethernet with integrated PHY, SATA-II with integrated PHY, PCI Express® with integrated PHY, MIPI CSI, MIPI DSI, MIPI HSI and FlexCAN

▸ Comprehensive security features include cryptographic accelerators, high-assurance boot and tamper protection

▸ Optional integration of an EPD display controller for e-readers and similar applications

FIGURE 2.9k: I.MX 6 SERIES BLOCK DIAGRAM
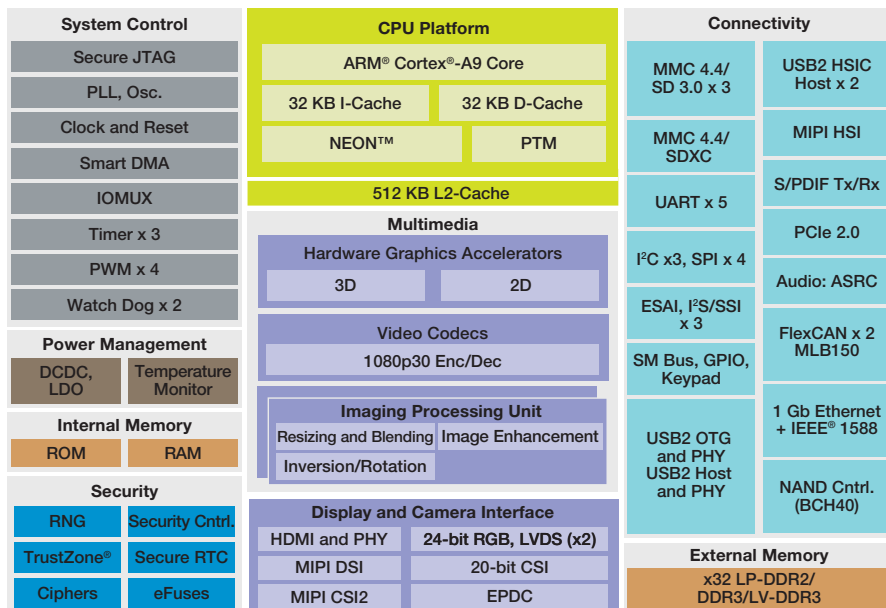
Benefits

▸ Pin- and software-compatible single-, dual- and quad-core families enable easy design of a broad portfolio of next-generation products

▸ Ultra-realistic and richer user interfaces enabled by an integrated 3D graphics engine in high-performance families

▸ Aggressive power management enables HD multi-stream video playback in high performance families

▸ Highly integrated family with a broad range of integrated I/Os to reduce design complexity and time to market

Powered Patient Bed

2.10

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. The result is a more comfortable bed and one that is easier for healthcare professionals to move and adjust.

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 the result of 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 while electric motors allow 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 adjust the height of the bed and provide movement to the bed's wheels. A typical system containing an MCU, an H bridge and a motor is shown in Figure 2.10b.

The requirements for an MCU vary based on the size of the motor and the required efficiency. Most patient bed applications require 32 to 100 MHz, 16 to 156 KB of flash memory, 2 to 64 KB of SRAM, a highly accurate timer and the ability to synchronize the timer with the 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.

Our company offers a wide variety of products specifically for motor control systems ranging from DSCs to MCUs and H bridges. An ideal MCU and H bridge solution for a bed is a Kinetis K series MCU paired with the flexible, low-power MC33926. In some cases, depending on the complexity of the motor system, a single DSC may be sufficient to control the motor. The MC56F8xxx family is an alternative cost-optimized solution for real-time motor control.

FIGURE 2.10a: POWERED PATIENT BED GENERAL BLOCK DIAGRAM
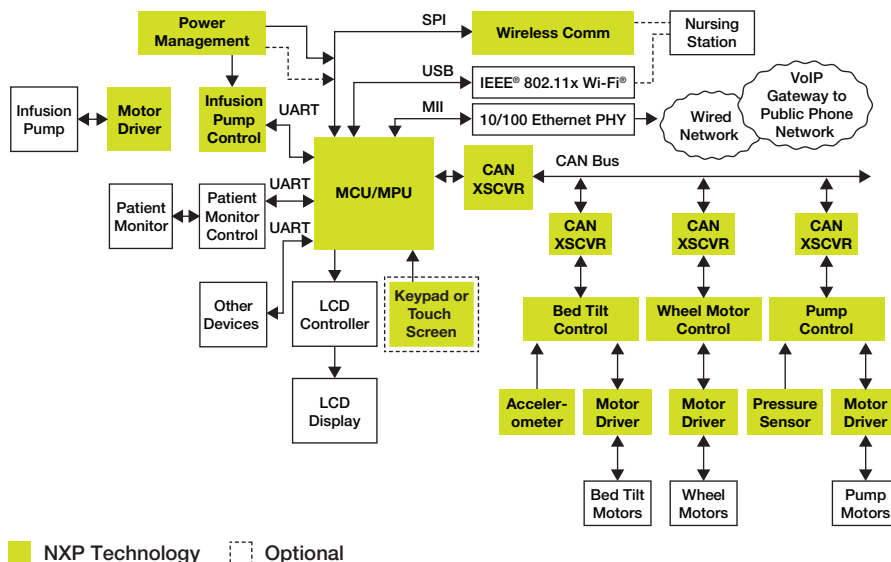
Integrated real-time patient monitoring

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, ECG, blood glucose meters and an infusion pump.

The modules shown in Figure 2.10a provide extra features allowing healthcare providers and 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.

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 must remain paramount. 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 most often used to position the patient in the bed at the ideal angle for the patient's comfort.

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 MMA845xQ series accelerometers are ideal solutions for XY and XYZ tilt sensing.

A simple tilt application can be implemented using an MCU 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 power 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.

Integrated intercom using VoIP

VoIP intercom applications can improve communication 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 additional switching equipment is required to

FIGURE 2.10b: ELECTRONIC MOTOR SYSTEM
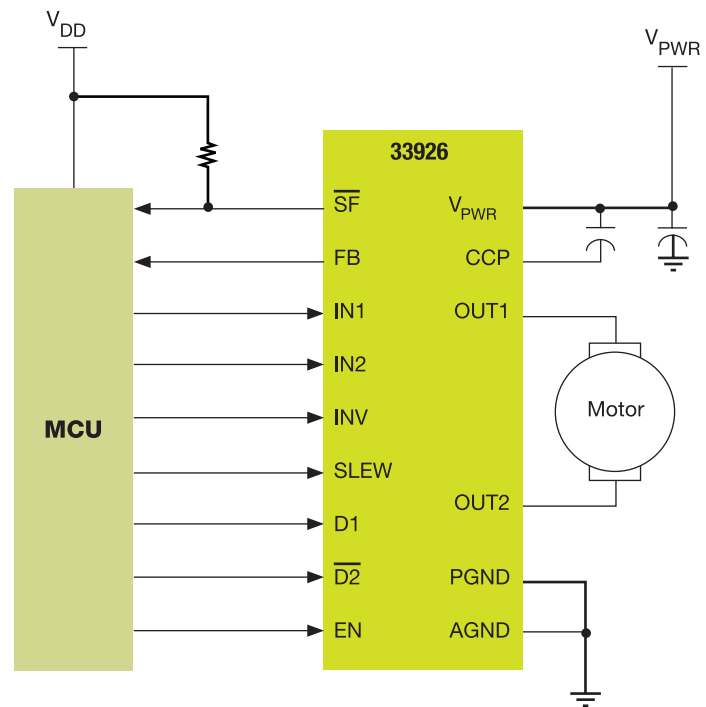
implement these systems across an existing network. To meet these needs, the system MPU must feature a high level of integration to simplify a design for seamless video, voice and network connectivity. It must have enough processing performance and network bandwidth to simultaneously transfer data from many sources, including a keypad, touch screen display panel and voice inputs and outputs.

Our company offers a comprehensive hardware and software solution for commercial VoIP applications that meet these specific requirements. The i.MX product family contains processors up to 800 MHz with the proper mix of memory and peripherals for creating the VoIP solution.

Table 2.11: Technologies for Diagnostic and Therapy

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Anesthesia Monitor				
Processors	i.MX6SX	I.MX Heterogeneous ARM® Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	i.MX6S, i.MX28, VF3xx, VF5xx, VF6xx
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	K2x, LPC541xx
Signal Conditioning	MKM1x	Kinetis ARM Cortex-M0+ Measurement MCU	50 MHz Cortex M0+, 24-bit SD ADC, 16-bit SAR ADC w/PGA	MKM3, MK5x
Keypad or Touch Screen	CRTOUCH	Capacitive and Resistive Touch-Sensing Platform	Capacitive and resistive touch sensing with gesture recognition to allow zoom and rotation	TSSMCU
Pressure Sensors	MPL3115A2	50 to 110kPa, Absolute Digital Pressure Sensor	Provides highly precise pressure and altitude data	MPL115A, MPxx5004
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200
Wireless Communications	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN902x, NT3H1101
Defibrillators				
Processors	i.MX6SX	I.MX Heterogeneous ARM Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	i.MX6S, i.MX257, i.MX28
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	LPC541xx
Signal Conditioning	MKM1x	Kinetis ARM Cortex-M0+ Measurement MCU	50 MHz Cortex M0+, 24-bit SD ADC, 16-bit SAR ADC w/PGA	MKM3, MK5x
Keypad or Touch Screen	CRTOUCH	Capacitive and Resistive Touch-Sensing Platform	Capacitive and resistive touch sensing with gesture recognition to allow zoom and rotation	TSSMCU
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200
Wireless Communications	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN902x
Digital Stethoscope				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	K1x, K3x, K4x, KL1x, KL3x, KL4x
Electrocardiograph				
Processors	i.MX6S	I.MX ARM Cortex A9 MPU	Cortex A9 up to 1 GHz, Ethernet, 2D and 3D Multimedia	i.MX257, i.MX28, i.MX537, VF5xx, VF6xx
Microcontrollers	K6x	Kinetis ARM Cortex-M4 MCU	150 MHz, 1 MB flash, Ethernet, floating point, and security	K2x, K5x, LPC541xx
Display Driver	MC34844	10 Channel LED Backlight Driver with Power Supply	10ch, 10-27" display	
Keypad or Touch Screen	CRTOUCH	Touch-Sensing for MCUs	Touch-Sensing software,	TSSMCU
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200
Wireless Communication	MKW3x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN 902x, NT3H1101
Hospital Admission Machine				
Processors	i.MX6SX	I.MX Heterogeneous ARM Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	i.MX28, i.MX6S, VF3xx
Microcontrollers	MKL1x	Kinetis ARM Cortex-M0+ Measurement MCU	50 MHz Cortex M0+, 24-bit SD ADC, 16-bit SAR ADC w/PGA	MKM3, MK5x
Keypad or Touch Screen	CRTOUCH	Touch-Sensing for MCUs	Touch-Sensing software,	TSSMCU
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200
Wireless Communication	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN902x, NT3H1101
Infusion Pumps				
Processors	i.MX6SX	I.MX Heterogeneous ARM Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	i.MX6S
Microcontrollers	MKV4x	150 MHz, ARM Cortex®-M4, Real-Time Control, Motor and Power Control, High-Performance Microcontroller	150 MHz Cortex-M4 core with DSP, floating point unit, eFlexPWM module with 312ps resolution and dual FlexCAN	K5x, KV3x, LPC541xx
Motor Drive	MC34932	H-Bridge, Brushed DC Motor Driver, 5-36V, 5 A, 11kHz/20kHz	H-Bridge Brushed DC/Stepper Motor Driver, 5-28 V, 5 A, 11kHz	MC34931, MPC17510
Pressure Sensors	MPL3115A2	50 to 110kPa, Absolute Digital Pressure Sensor	Provides highly precise pressure and altitude data	MPxx4006

Table 2.11: Technologies for Diagnostic and Therapy (continued)

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Multi-Parameter Patient Monitor				
Processors	i.MX6S	I.MX ARM® Cortex® A9 MPU	Cortex A9 up to 1 GHz, Ethernet, 2D and 3D Multimedia	i.MX28
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	K2x, K6x, LPC541xx
Signal Conditioning	MKM1x	Kinetis ARM Cortex-M0+ Measurement MCU	50 MHz Cortex M0+, 24-bit SD ADC, 16-bit SAR ADC w/PGA	MKM3, MK5x
Keypad or Touch Screen	CRTOUCH	Touch-Sensing for MCUs	Touch-Sensing software,	TSSMCU
Pressure Sensors	MPXx5050	-50 to 50kPa, Differential and Gauge Pressure Sensor	0 to 50 kPa (0 to 7.25 psi), on-chip signal conditioned, compensated and calibrated pressure sensor	
Temperature Sensors	S08QG	8-bit Small Package QG MCUs	8-bit MCU, Temperature Sensor	
Motor Control	MPC17C724	H-Bridge, Motor Driver, 2.7-5.5 V, 0.8 A, 200kHz	H-Bridge Brushed DC/Stepper Motor Driver, 2.7-5.5 V, 0.8A, 200kHz	
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MC34704, MMPF0200
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x
Powered Patient Bed				
Processors	i.MX6SX	I.MX Heterogeneous ARM Cortex-A9 and ARM Cortex-M4 MPU	Cortex A9 up to 1 GHz, Cortex M4 up to 200 MHz, Ethernet, 2D and 3D Media	i.MX6S, i.MX257
Bed Tilt Control	MKV4x	Kinetis ARM Cortex-M4 Motor Control Microcontroller	150 MHz Cortex-M4 core with DSP, floating point unit, eFlexPWM module with 312ps resolution and dual FlexCAN	MKV3x, MKV1x
Infusion Pump Control	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	MKV4x, KV3x
Pump Control	MKV4x	Kinetis ARM Cortex-M4 Motor Control Microcontroller	150 MHz Cortex-M4 core with DSP, floating point unit, eFlexPWM module with 312ps resolution and dual FlexCAN	MKV3x, MKV1x
Wheel Motor Control	MKV4x	Kinetis ARM Cortex-M4 Motor Control Microcontroller	150 MHz Cortex-M4 core with DSP, floating point unit, eFlexPWM module with 312ps resolution and dual FlexCAN	MKV3x, MKV1x
Accelerometers	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 µA-165 µA current consumption	MMA8450Q, MMA955xL
Pressure Sensors	MPxx5050	-50 to 50kPa, Differential and Gauge Pressure Sensor	0 to 50 kPa (0 to 7.25 psi), on-chip signal conditioned, compensated and calibrated pressure sensor	
Keypad or Touch Screen	CRTOUCH	Touch-Sensing for MCUs	Touch-Sensing software,	TSSMCU
Controller Area Network	MC33897	Single-Wire Can Transceiver	CAN I/F	MC33742
Motor Driver	MC34932	H-Bridge, Brushed DC Motor Driver, 5-36 V, 5A, 11kHz/20kHz	H-Bridge Brushed DC/Stepper Motor Driver, 5-28 V, 5A, 11kHz	MC34931, MC3388, MC33886, MC33887
Power Management	MC34717	5.0 A 1.0MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	
Wireless Communication	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN902x
Ventilator and Respirator				
Processors	i.MX6S	I.MX ARM Cortex A9 MPU	Cortex A9 up to 1 GHz, Ethernet, 2D and 3D Multimedia	i.MX28
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	K6x, LPC541xx
Flow Sensors	MPXV7002	Integrated Pressure Sensor	Integrated Pressure Sensor	
Keypad or Touch Screen	CRTOUCH	-2 to 2kPa, Vacuum Pressure Sensor	Touch-Sensing software,	TSSMCU
Pressure Sensors	MPL3115A2	50 to 110kPa, Absolute Digital Pressure Sensor	Provides highly precise pressure and altitude data	MPxx5004, MPL115A
Volume Sensors	MPXV7002	-2 to 2kPa, Vacuum Pressure Sensor	Integrated Pressure Sensor	
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	MMPF0200, MC34704
Wireless Communications	MKW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	MKW3x, MKW2x, QN902x, NT3H1101

Medical Imaging

3.1

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 the performance limits for advanced integrated I/O, rigorous data processing, powerful display capabilities and high levels of connectivity. Many of these needs are addressed by our portfolio of Power Architecture-based multicore processors, StarCore DSPs and high-power RF devices.

The Power Architecture-based processor family is designed for applications that require a rich user interface with complex displays and connectivity options with various standard protocols. StarCore DSPs offer unprecedented high-processing capacity to support data-intensive applications, such as medical imaging reconstruction. Our RF power amplifiers provide the high output power required to achieve the desired frequency of resonance.

Ultrasound

3.2

Introduction

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 a successful pregnancy.

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 = ρv. The fraction of energy R refracted at the normal interface of two different tissue types is:

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

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 Section 2.4, 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 ranges from 5 to 8 MHz.

The blocks needed for signal conditioning/ pulse generator blocks are shown in Figure 3.2b.

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 for use as receivers. Multiplexing reduces the number of connections needed, because the transducers array can range from eight to more than 256.

FIGURE 3.2a: ULTRASOUND GENERAL BLOCK DIAGRAM

FIGURE 3.2b: ULTRASOUND TRANSDUCER DIAGRAM

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 3.2d shows the behavior of this element.

Figure 3.2a 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.
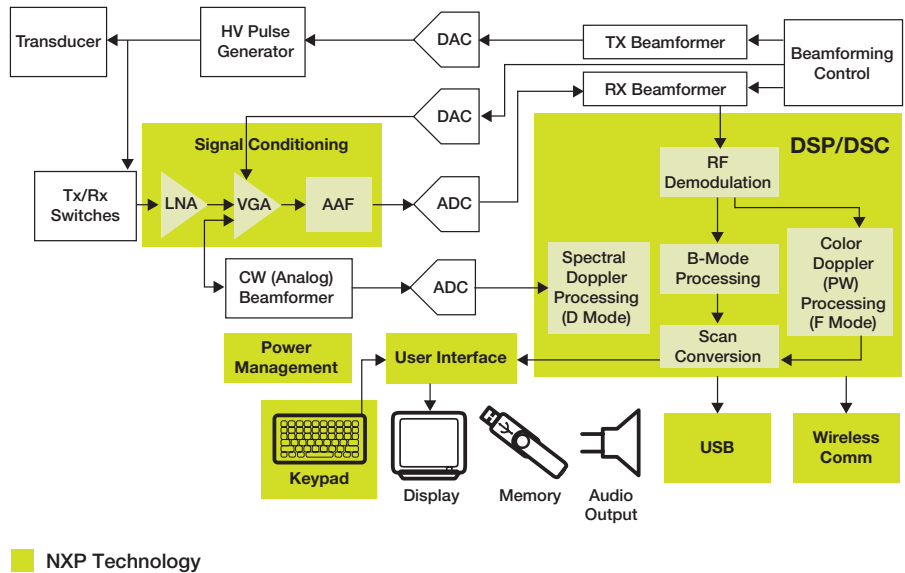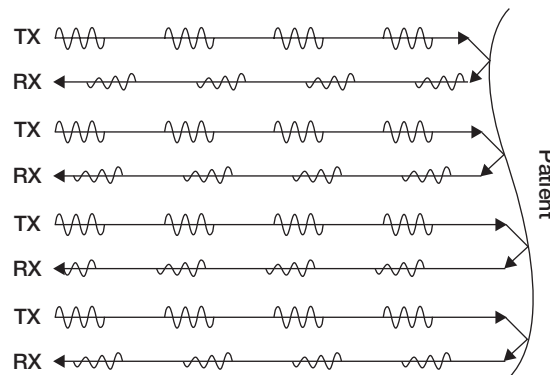
Beamformer

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 3.2c is a diagram of the direction of propagation of waves controlled by a beamformer.

Ultrasound software library

The ultrasound software library produces an ultrasound image from a beamforming signal. The beam is stored in the memory and passes through the ultrasound library algorithms to generate an output image with the specified height and width.

The depth in color used in the final image runs from 0 to 255, where 0 represents the brightest point and 255 represents the darkest. The output image from the MSC8156 DSP is stored in the DDR0 memory.

The MSC8156 DSP is used throughout the document because the library adapts perfectly to it. This library is suitable to develop embedded software for the MSC8156 DSP that involves working with a beamforming signal or grayscale output images. Knowledge in CW IDE and C programming language is necessary.

The library uses different algorithms to generate the final output image:

▶ FIR filter
▶ Envelope detection
▶ Log compression
▶ Histogram equalization
▶ Speckle noise reduction
▶ Scan conversion
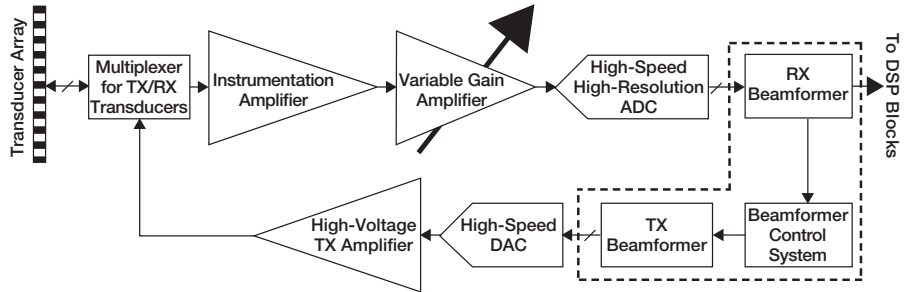
FIGURE 3.2c: ULTRASOUND PROBE BLOCK DIAGRAM

FIGURE 3.2d: VARIABLE GAIN AMPLIFIER FUNCTION

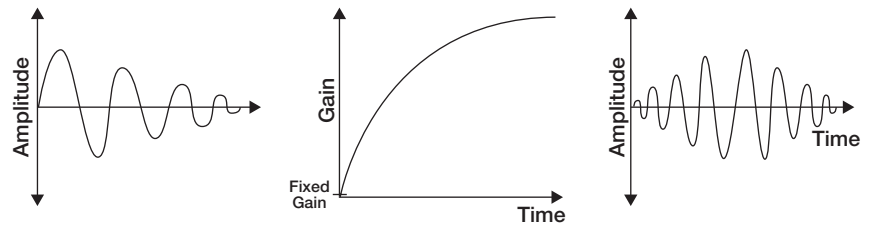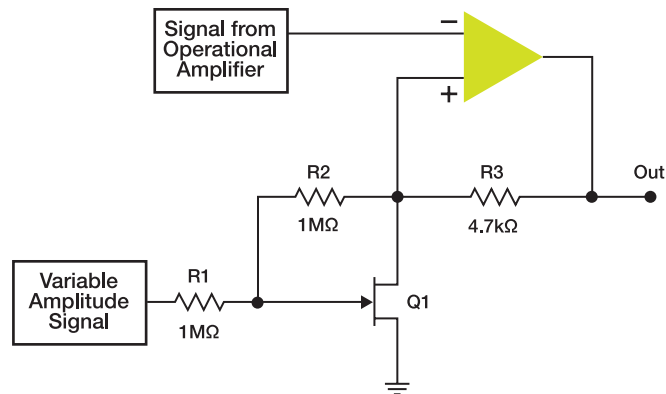### FIGURE 3.2e: ANALOG IMPLEMENTATION OF VARIABLE GAIN AMPLIFIER

Target Applications

▶ Digital stethoscope

▶ Medical ultrasonography

▶ Ultrasonic lithotripsy

Ultrasound Software Library Reference Design

For more information on how to use the Ultrasound Software Library, download Ultrasound Software Library (document MEDIMGLIBUG) from **www.nxp.com**.

MPUs

i.MX 6 Series

The i.MX 6 series unleashes the industry's first truly scalable multicore platform that includes single-, dual- and quad-core families based on the ARM Cortex-A9 architecture. Together with a robust ecosystem, i.MX 6 series provides the ideal platform to develop a portfolio of end devices based on a single hardware design.

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

FIGURE 3.2f: I.MX 6 BLOCK DIAGRAM
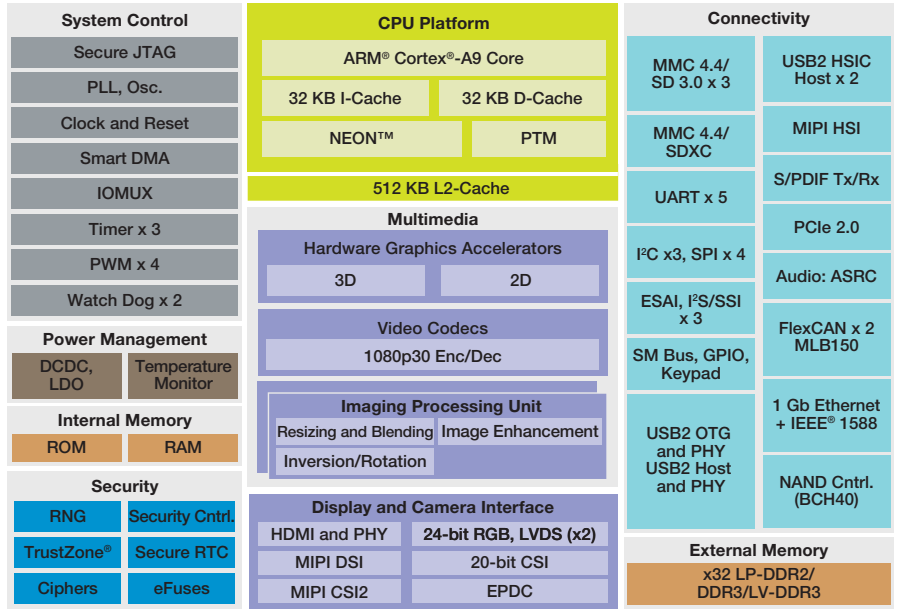
Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▶ Ultra-low-power operation

▶ 2 x opamp

▶ 2 x triamp

▶ 2 x 12-bit DAC

▶ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers

▶ Programmable delay block

▶ I²C

▶ USB connectivity

▶ ARM Cortex-M4 core with DSP instructions

Table 3.2

STARCORE SC3850-BASED DSPS	
MSC8151	Single-core DSP, 8 GMAC, FFT/DFT accelerator
MSC8152	Dual-core DSP, 16 GMAC, FFT/DFT accelerator
MSC8154	Quad-core DSP, 32 GMAC, FFT/DFT accelerator
MSC8156	Six-core DSP, 48 GMAC, FFT/DFT accelerator
MSC8251	Single-core DSP, 8 GMAC, PCIe, <3W
MSC8252	Dual-core DSP, 16 GMAC, PCIe, <4W
MSC8254	Quad-core DSP, 32 GMAC, SRIO, PCIe
MSC8256	Six-core DSP, 48 GMAC, SRIO, PCIe

DSPs

Image reconstruction and processing can be best realized on our proprietary single- or multicore DSPs. These devices are capable of performing the data-intensive B mode image reconstruction and the different modes of Doppler processing, all of which are integral parts of any ultrasound system. In addition, these DSPs are ideal for running other signal processing functions, such as filtering, demodulation and scan conversion, to achieve the desired output image.

MSC815x and MSC825x StarCore-based, DSP families feature the SC3850 core running at 1 GHz and delivering up to 48 GMACs per device. All the devices featured are pin compatible, allowing system scalability from one to six cores.

Our multicore DSP devices offer unprecedented I/O and memory bandwidth with the ability to combine Serial RapidIO®, Gigabit Ethernet and/or PCI Express typically used for high bandwidth FPGA connectivity. One or two 64-bit DDR2/3 interfaces will support the most data-intensive applications, such as medical image reconstruction.

MSC815x device family also features a dedicated DFT/FFT hardware accelerator capable of running up to 350 Mega samples/ sec. Offloading these functions from the cores leaves ample processing headroom for additional system requirements or enables the use of single- or dual-core devices (MSC8151 and MSC8152).
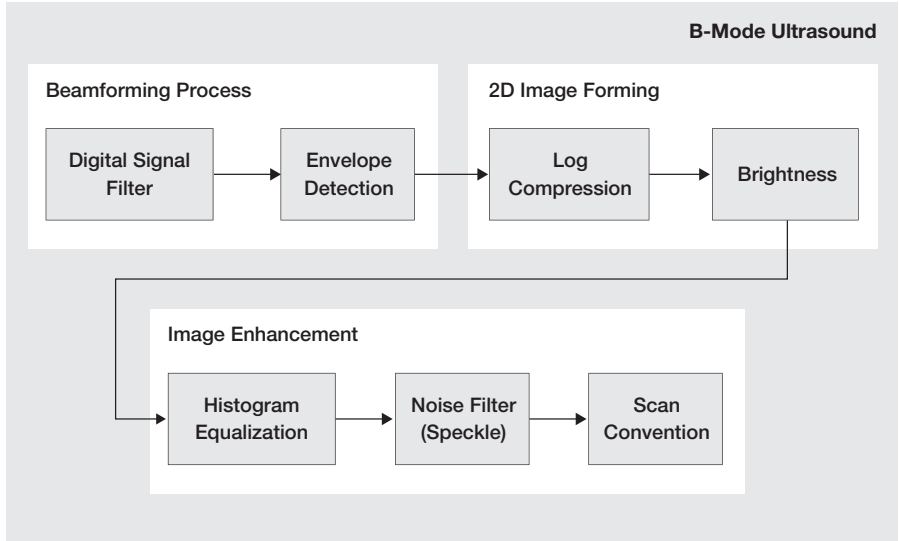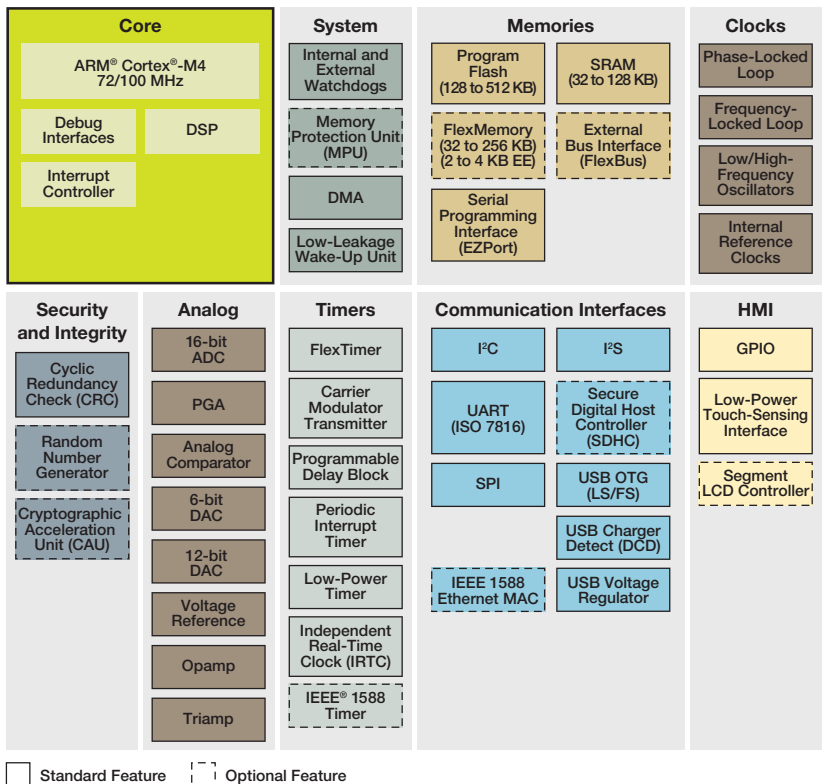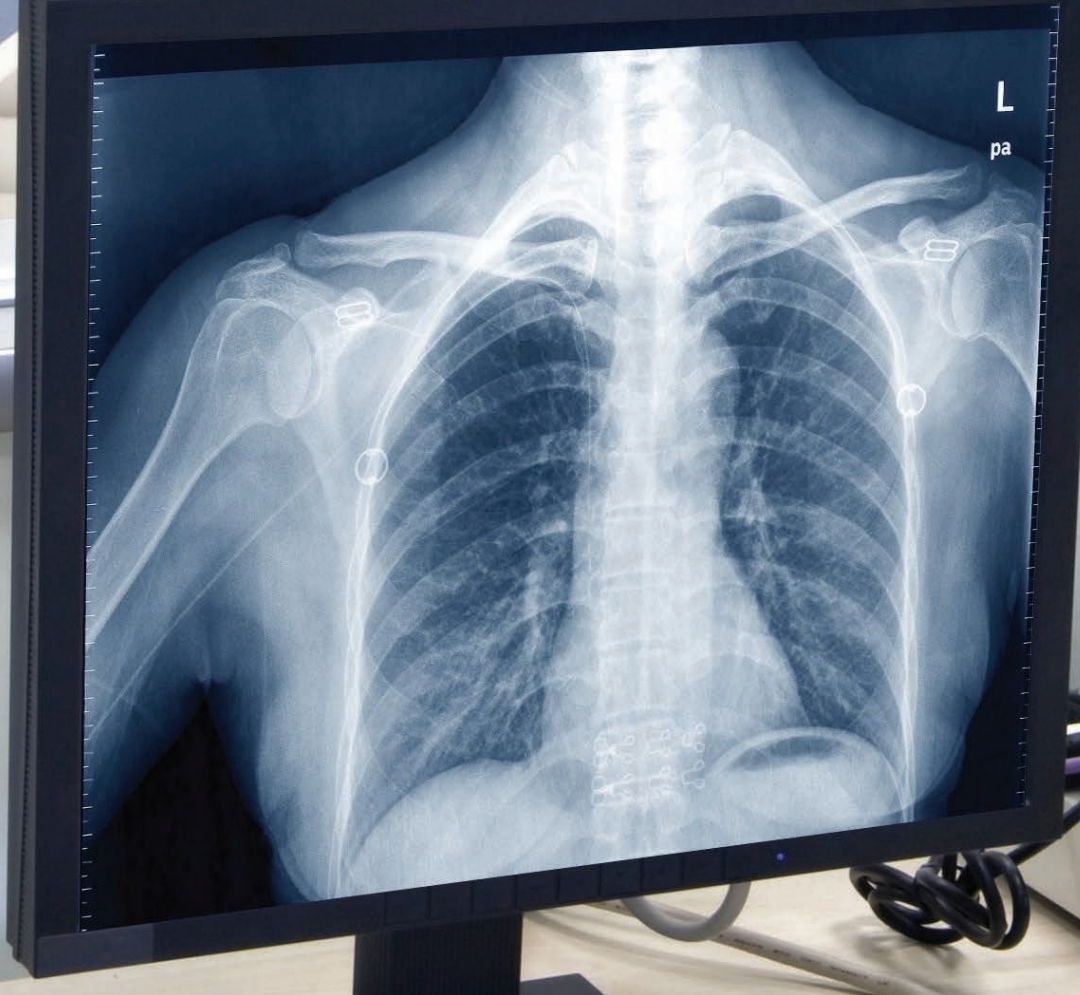
FIGURE 3.2g: ULTRASOUND LIBRARY FLOW

FIGURE 3.2h: KINETIS K50 FAMILY BLOCK DIAGRAM

Digital X-Ray

3.3

Introduction

Digital X-ray is a form of X-ray imaging where digital sensors are used instead of traditional photographic film. It revolutionized the classical X-ray by providing more information, reducing diagnostic time, lowering cost and opening access to a broader range of post-processing tools.

Our proprietary DSPs with high-processing capacity of up to 48 GMACS, built-in FFT HW accelerators, low power consumption and competitive pricing provide a realistic solution for replacing FPGAs and ASICs. Combined with the i.MX ARM-based MPU family and 2D/3D built-in accelerators and rich connectivity, they are the perfect combination for your next-generation design.

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

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.

Signal processing

The signal processing and conditioning technology required to generate radiography typically involves the transformation of signals from spatial domain to frequency domain by use of Fourier Transform, performing convolutions on the transformed data and inverse transform back to spatial domain. The MSC815x StarCore-based DSP family with the dedicated DFT/FFT hardware accelerator is ideal for implementing these functions and other image processing techniques used in X-ray applications.

These devices are based on the SC3850 core running at 1 GHz and delivering up to 48 GMACs per device.

All the devices featured are pin compatible, allowing system scalability from one to six cores.

Our multicore DSP devices offer unprecedented I/O and memory bandwidth with the ability to combine Serial RapidIO, Gigabit Ethernet and/or PCI Express, typically used for high bandwidth FPGA connectivity. One or two 64-bit DDR2/3 interfaces will support the most data-intensive applications, such as medical image reconstruction.

The MSC815x device family features the MAPLE hardware accelerator with dedicated DFT/FFT functions capable of running up to 350 Mega samples/sec. Offloading these functions from the cores leaves ample processing headroom for additional system requirements or enables the use of single- or dual-core devices (such as the MSC8151 and MSC8152 DSPs).
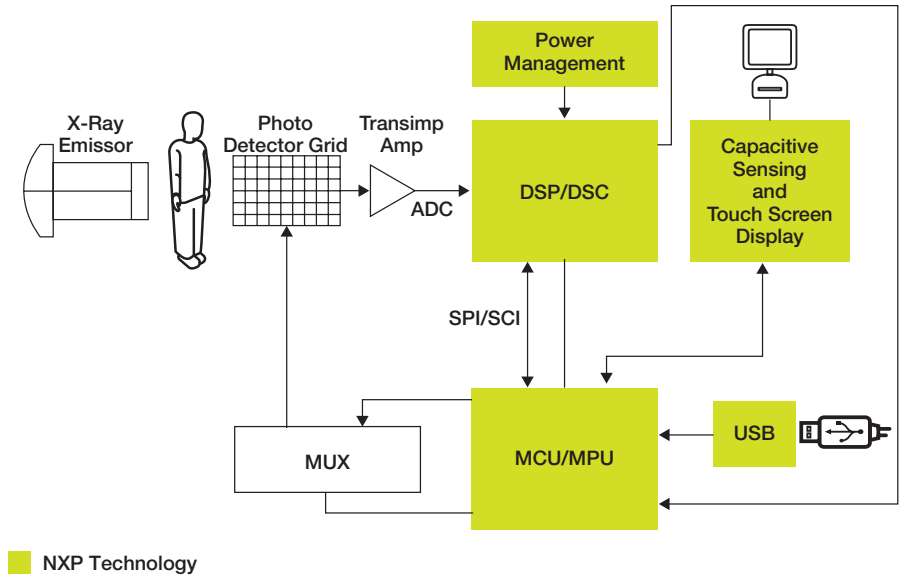
FIGURE 3.3a: DIGITAL X-RAY GENERAL BLOCK DIAGRAM
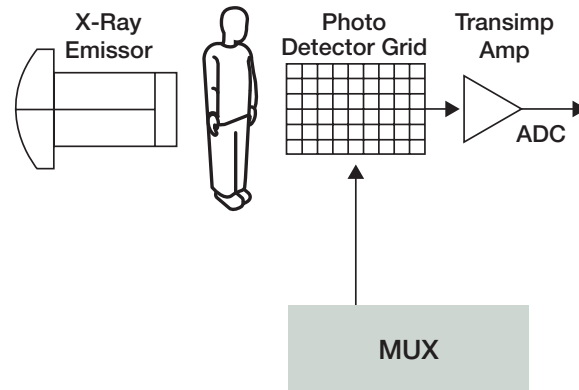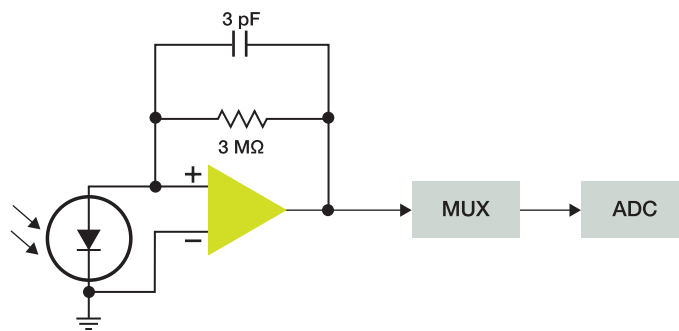

FIGURE 3.3b: GENERAL ANALOG CONFIGURATION

FIGURE 3.3c: PHOTO DETECTOR CONFIGURATION

The MSC825x family features one to six DSP SC3850 cores without the hardware accelerator for maximum flexibility in algorithm implementation and improved power efficiency.

DSP 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

▸ MC56F81xx/83xx
▸ MC56F80xx

DSCs

▸ 56800/E
▸ MC56F82xx
▸ MC56F84xx

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 that 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 an 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.nxp.com**.

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

FIGURE 3.3d: MC56F84XX DSC
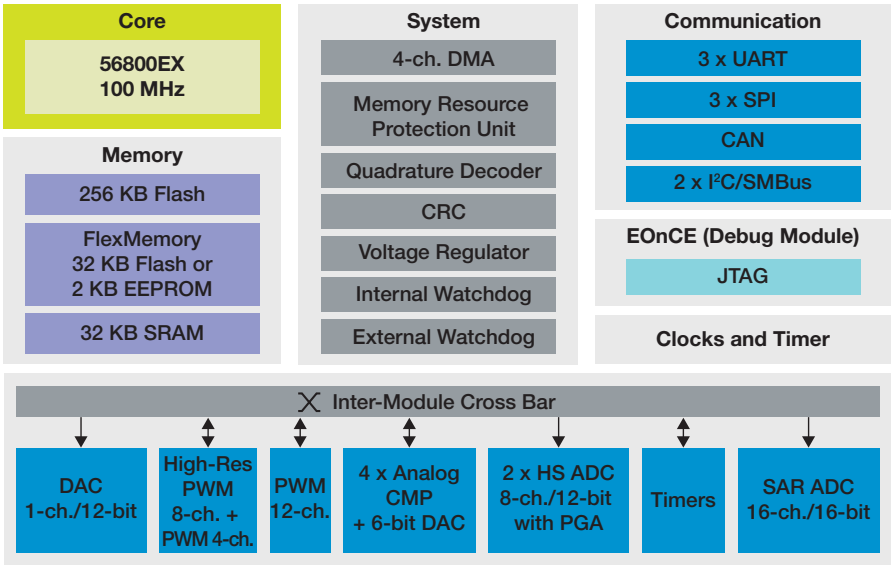
Table 3.3a: FFT/DFT Hardware Accelerator Features

STANDARD COMPLIANCE	DATA RATES	COMMENTS
FFT sizes: 128, 256, 512, 1024, 2048 points	FFT2048: Up to 280 Mega samples/sec FFT1024: Up to 350 Mega samples/sec	Advanced scaling options Guard bands insertion in iFFT
DFT sizes: Variable lengths DFT/IDFT processing of the form $2^k \cdot 3^m \cdot 5^n \cdot 12$, up to 1536 points	DFT: Up to 175 Mega samples/sec	

Table 3.3b: MSC815x and MSC825x Family Comparison Chart

DEVICE	8156	8154	8152	8151	8256	8254	8252	8251
SC8350 DSP cores	6	4	2	1	6	4	2	1
Core speed (MHz)	1 GHz	1 GHz	1 GHz	1 GHz	1 GHz 800 MHz	1 GHz 800 MHz	1 GHz	1 GHz
Core performance (16-bit MMACs)	Up to 48000	Up to 32000	Up to 16000	Up to 8000	Up to 48000	Up to 32000	Up to 16000	Up to 8000
Shared M3 memory	1 MB				1 MB			
I cache (per core)	32 KB				32 KB			
D cache (per core)	32 KB				32 KB			
L2 I cache (per core)	512 KB				512 KB			
DDR2/3	2 (800 MHz)				2 (800 MHz)			
PCIe	1				1			
GEMAC (RGMII, SGMII)	2				2			
sRIO	2				2			
TDM	4				4			
SPI	1				1			
UART	1				1			
I²C	1				1			
FFT/DFT accelerators	1							
Proc. tech.	45 nm SOI				45 nm SOI			
Package	783 Ball FC-PBGA				783 Ball FC-PBGA			

Table 3.3c: Technologies for Medical Imaging

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Ultrasound Imaging				
Processors	i.MX6Solo	ARM9™ Applications Processor	Single core, up to 1 GHz, DDR3 display, graphics, video, 10/100/1000 Ethernet, USB PHY, x2, CAN, PCIe	i.MX28x, i.MX 6DualLite, i.MX6Dual
Signal Conditioning	MSC8156	Six-Core High Performance DSP	DSC built on multicore StarCore DSP	MSC8154, MSC8152
Touch Screen	MPR03x	Touch Sensor	2 or 3-Pad touch sensors	Touch-Sensing Software
Wireless Communications	MC13224V	2.4 GHz RF Transceiver	Platform in a Package	MC13213
Digital X-Ray				
Processors	i.MX6Solo	ARM9™ Applications Processor	Single core, up to 1 GHz, DDR3 display, graphics, video, 10/100/1000 Ethernet, USB PHY, x2, CAN, PCIe	i.MX28x, i.MX 6DualLite, i.MX6Dual
Signal Conditioning	MSC8156	Six-Core High Performance DSP	DSC built on multicore StarCore DSP	MSC8154, MSC8152
Touch Screen	MPR03x	Touch Sensor	2 or 3-Pad touch sensors	Touch-Sensing Software
Wireless Communications	MC13224V	2.4 GHz RF Transceiver	Platform in a Package	MC13213

Wearables

4.1

Introduction

Wearable technology, a key driver of the IoT, is prevalent in the consumer, entertainment, sports and fitness markets. Wearable devices must be small, very low powered to enable long battery life and able to seamlessly connect to a hub or gateway device for access to the internet or cloud. Our company offers the market's broadest and best-enabled portfolio of solutions ideal for designing into wearable products. Our scalable MCU and MPU families range from small ultra-low-power Kinetis MCUs, such as the KL03 chip-scale package (CSP) the world's smallest ARM Powered® MCU, to i.MX applications processors with hardware acceleration to enable designs with higher level operating systems, such as Linux® and Android™.

Hearing Aid

4.2

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 batteryoperated hearing aids to reduce the environmental noise so that only the desired signals are amplified and sent to the speaker. An inertial sensor can be used for gesture recognition in high-end units where a shake motion could turn the hearing aid on or change volume.

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 ADC.

The ADC converter transforms the continuous audio signal into digital samples to be processed and filtered by a DSP.

Class D amplifier

There are several available technologies for audio amplification applications. 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 that allows more audio channels and higher wattage in smaller form factors.

MC56F825x devices offer a combination of peripherals and software to enable Class D amplifiers to operate at peak performance.

MC56F825x Architecture

The architecture of the MC56F825x device combines, on a single chip, DSP processing power and MCU functionality with a flexible set of peripherals:

‣ eFlexPWM with up to nine channels, including six channels with high-resolution NanoEdge placement

‣ Two 8-channel, 12-bit ADCs with dynamic x2 and x4 programmable amplifier

‣ Two 16-bit quad timers (2 x 4 16-bit timers)

‣ On-chip relaxation oscillator: 8 MHz (400 kHz at standby mode)

‣ Three analog comparators with integrated 5-bit DAC references

‣ On-board power conversion and management

‣ JTAG/OnCE debug programming interface

FIGURE 4.2a: HEARING AID GENERAL BLOCK DIAGRAM

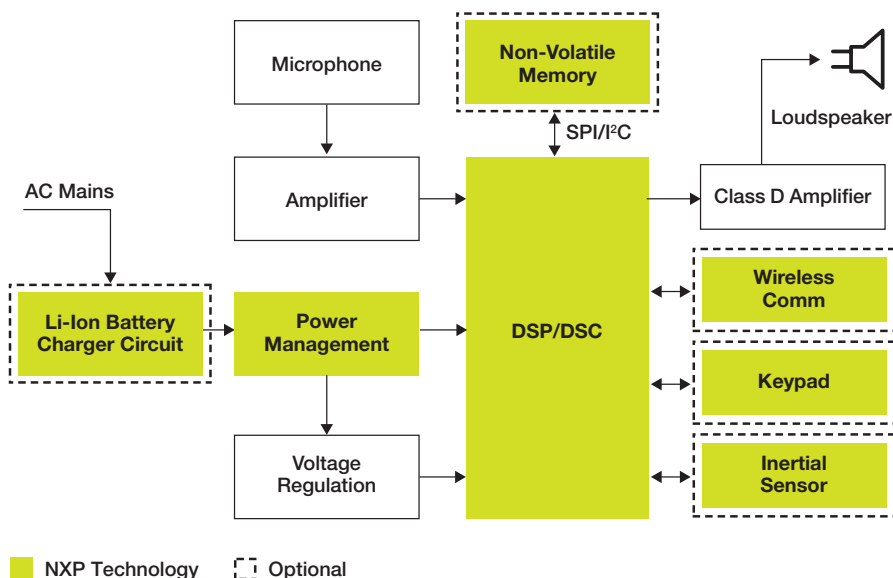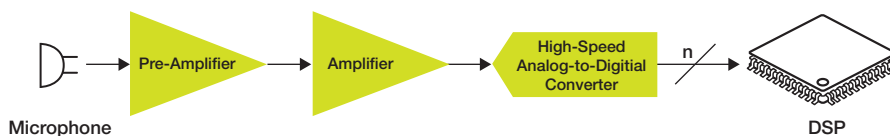

FIGURE 4.2b: SIGNAL ACQUISITION BLOCK DIAGRAM
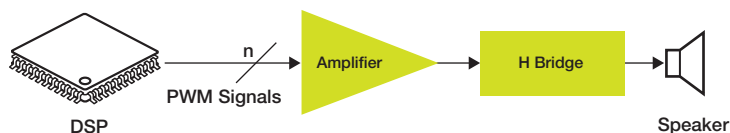

FIGURE 4.2c: GENERAL DIAGRAM OF CLASS D AMPLIFIER IMPLEMENTATION

DSP

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.

The MC56F84xx DSC can take the place of an amplifier, ADC and PWM/timers. 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 MC56F84xx DSC provides the following features:

▸ 100 MHz/100 MIPS 32-bit DSP core
▸ Programmable gain amplifier connected to ADC inputs
▸ 2 x 12-bit High-Speed ADCs with 3.3 Ms/s resolution
▸ Up to 24 channel high-res PWMs with 312 pico-second resolution
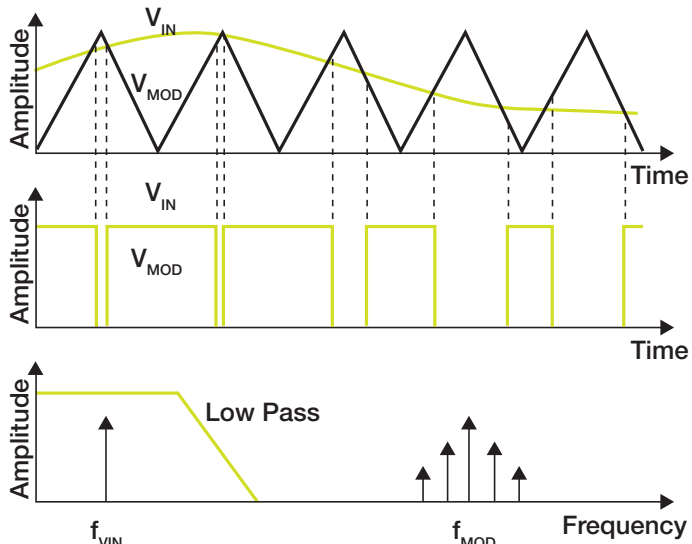
FIGURE 4.2d: PRINCIPLE OF PWM MODULATION
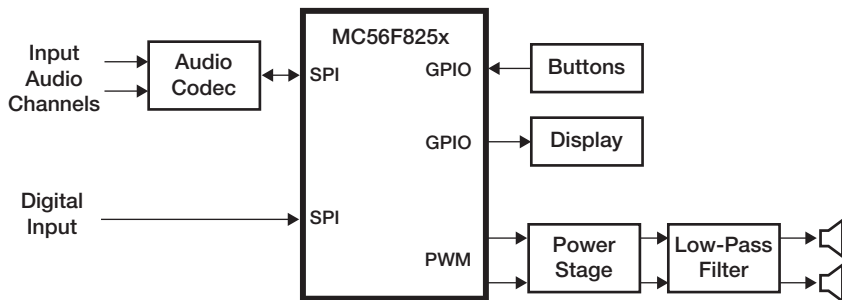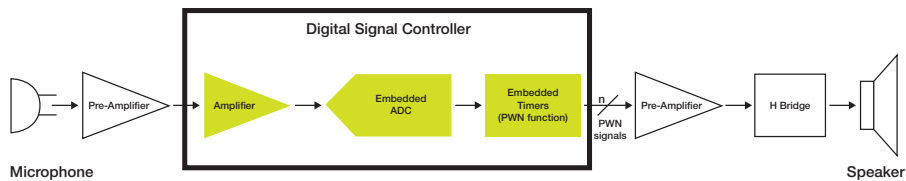

FIGURE 4.2e: DSP AUDIO APPLICATION

FIGURE 4.2f: SIMPLIFIED APPLICATION USING A DSC

MC56F800x: MC56F8006 and MCF56F8002 DSCs

Features of these DSCs include:

▸ Single-cycle 16 × 16-bit parallel multiplier-accumulator

▸ Four 36-bit accumulators including extension bits

▸ Two 2x-16x programmable gain amplifiers

▸ 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)

Application Notes

▸ *Static Serial Bootloader for MC56F800x/801x/802x/803x* (document AN3814)

FIGURE 4.2g: MC56F84XX BLOCK DIAGRAM
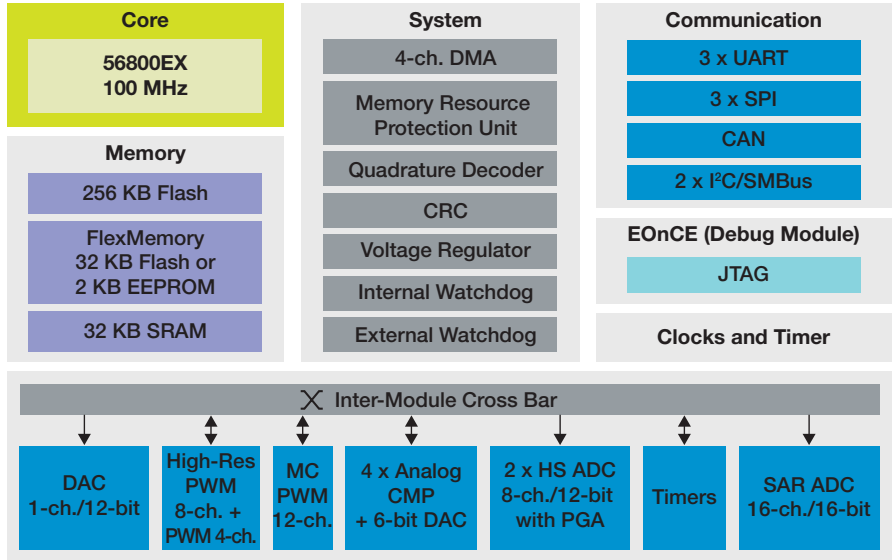
FIGURE 4.2h: MC56F800X BLOCK DIAGRAM

Activity and Wellness Monitor
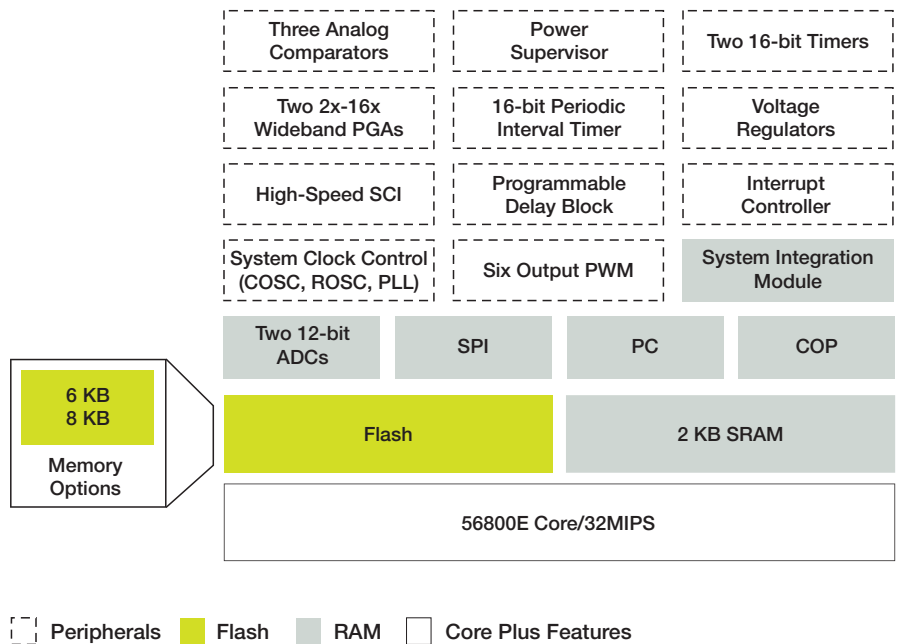
4.3

Introduction

An activity monitor is an auxiliary device for the management of sports and fitness activities. It keeps a record of the user activities, calories burned, energy consumed in food as well as other useful features for diet control and exercise performance.

An activity monitor registers heart rate for improved management of exercise efficacy. It also monitors physical performance using auxiliary modules such as a pedometer, timer and chronometer. A personal data record including age, height and weight provides a more accurate calculation of caloric consumption.

By monitoring individual parameters of the user, a health and fitness ecosystem can be built online so data can be utilized for individual performance. This goes beyond simply tracking calories and other data to create more personalization and behavior modification.

The information is often stored in a microSD memory card and may be transferred to a computer via a wired or wireless connection.

Electrocardiography (ECG) acquisition

The heart rate calculation is performed using the ECG signal. The heartbeat frequency is determined by measuring the time between QRS complex intervals. The ECG signal is acquired using two finger sensors, one on each side of the device. The first takes the signal from the left index finger. The second is divided in two parts: one takes the signal from the right index finger, the other works as reference.

The signal is amplified using an instrumentation amplifier built by using the internal opamps of the Kinetis K50 MCU, which has a high common-mode rejection ratio that allows it to work as an initial filter. Then, the signal must go through a 0.1–150 Hz band-pass filter to remove environmental noise. A second filter must be applied. In this case, a 50–60 Hz notch filter, depending on the country's electrical service frequency. This second filter is intended to remove the power line noise, which equals 50 Hz or 60 Hz, depending on the region. Finally, the signal must be acquired by an MCU using an ADC. Optionally, the MCU can perform digital filtering algorithms for a more reliable signal.

Pedometer

The pedometer counts the quantity of steps taken by the user while the activity monitor is activated. Accelerometers can be used to determine the overall activity level of the user. This module uses an accelerometer to determine device movement and it must be able to detect when a step has been taken or whether the user starts running. The acceleration measurements recorded by the accelerometer are sent to an MCU either by using analog voltages to represent the movement, or by using digital methods such as I²C to send previously processed signals.

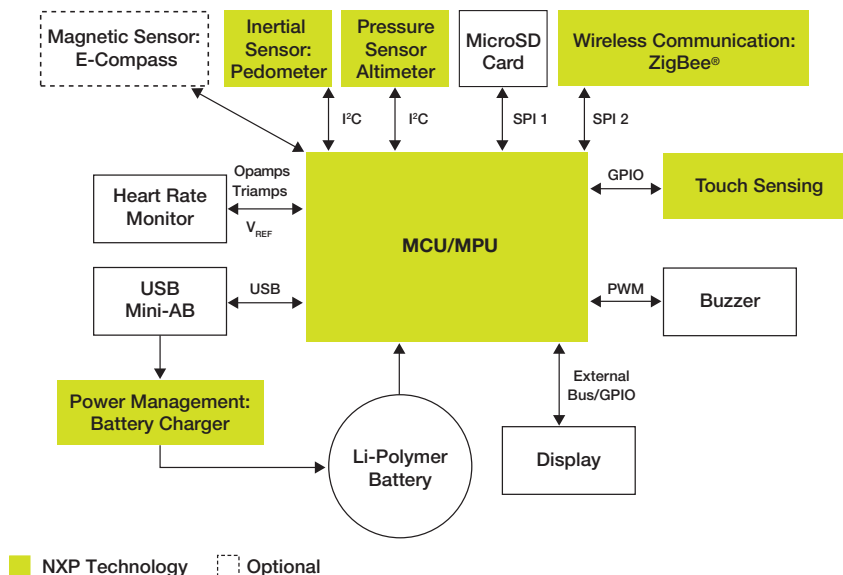**FIGURE 4.3a: ACTIVITY MONITOR BLOCK DIAGRAM**

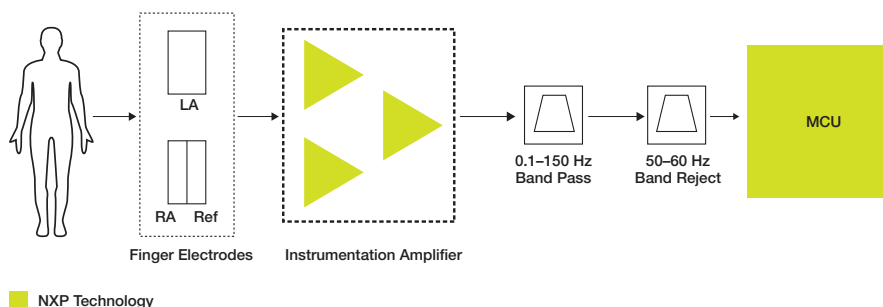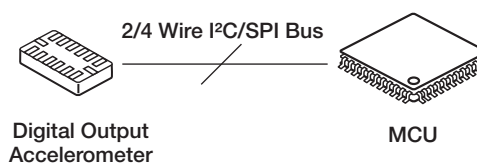**FIGURE 4.3b: ECG ACQUISITION BLOCK DIAGRAM**

FIGURE 4.3c: IMPLEMENTATION OF THE DIGITAL ACCELEROMETER

MMA845xQ accelerometers

The MMA845xQ accelerometer family offers extremely low power and pin compatibility with a broad range of resolution (14-, 12- and 10-bit) and embedded features for configurable, accurate motion analysis. To operate with extremely low power, the MMA845xQ accelerometers have six user-configurable sample rates that can be set over a wide range of 1.5 to 800 Hz. The power scheme contains four different power modes from high resolution to lower power, offering best-in-class savings in supply current and extremely high resolution for very small motion detection.

Features

▶ Low power current consumption
  – Off mode: 50 nA
  – Standby mode: 2 uA
  – Active mode: 6–166 uA

▶ Low-voltage operation: 1.95–3.6 volts

▶ Embedded features include:
  – Freefall detection
  – Orientation detection
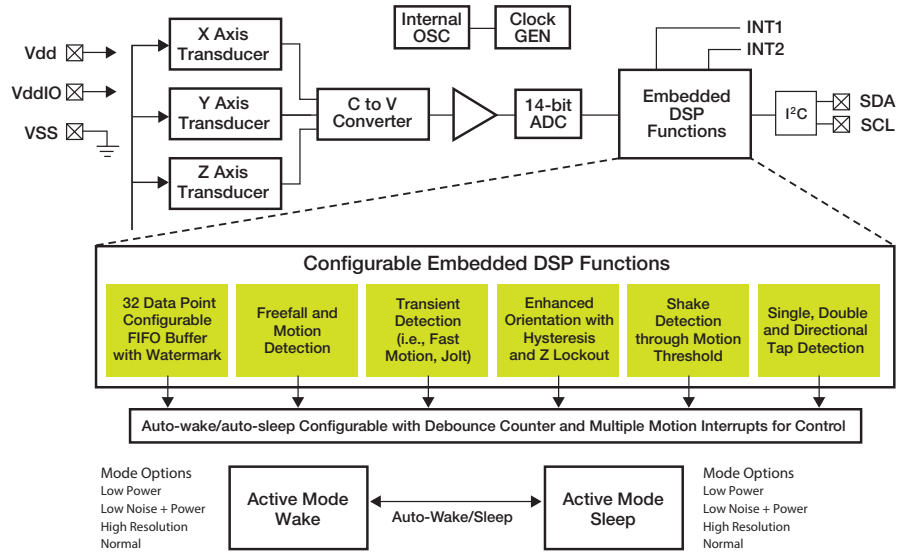 – Tap detect
  – Shake detect
  – Auto-wake sleep

MMA9553L intelligent motion-sensing platform

The MMA9550L intelligent motion-sensing platform is an industry first with integration of a MEMS accelerometer, a 32-bit embedded ColdFire MCU, flash memory and a dedicated architecture to manage other sensors. We've expanded the MMA9550L offering with the MMA9553L to enable pedometer functionality. The MMA9553L intelligent motion-sensing platform performs activity monitoring beyond step counting. This entails recognition of motion such as rest, walking, jogging and running.

Features

▶ Communication protocols: I²C/SPI

▶ Low-voltage operation: 1.71–1.89 V

▶ Embedded smart FIFO for data processing while apps processor is asleep

FIGURE 4.3d: MMA845XQ BLOCK DIAGRAM

▶ Configurable sample rate: 1–1024 samples/sec

▶ Auto-wake monitors change in activity/position

▶ Embedded features include:
  – Orientation detection
  – Single, double and directional tap detect
  – Single, double and directional shake
  – Threshold detection
  – Linear and rotational freefall
  – Flick detection
  – Tilt angle

User interface

The user interface is an essential part in the activity monitor development. It must be simple, intuitive and attractive for the user. The use of graphic displays makes the activity monitor easier and more intuitive to use, and it also adds aesthetics to the design. MCUs with external bus interface reduce the processor's load, allowing for improved graphics with reduced processor intervention.

The touch-sensing interfaces (TSI) make the design an attractive and functional application by removing the need for mechanic buttons. In addition, the TSI is easier to clean and more hygienic.

Touch-sensing software

Touch-sensing software (TSS) transforms any standard MCU into a touch sensor with the ability to manage multiple configurations of touchpads, sliders, rotary positions and mechanical keys, all while maintaining standard MCU functionality.

Reference designs

We provide ready-to-develop applications intended to reduce development time, time to market and cost. The following documents include useful information on the development of activity monitor applications:

▸ DRM125 *Activity Monitor*

▸ AN4323 *Solutions for Electrocardiograph and Heart Rate Monitor Applications*

▸ AN4519 *Data Manipulation and Basic Settings of the MPL3115A2 Command Line Interface Driver Code*

Kinetis K50 measurement MCUs

The K50 MCU family is pin, peripheral and software compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE 1588 Ethernet and hardware encryption, Full-Speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin QFN packages extending up to 512 KB in a 144-pin MAPBGA package.

Features

Kinetis K50 MCU features and peripherals in the integrated measurement engine:

▸ Ultra-low-power operation

▸ 2 x opamp

▸ 2 x triamp

▸ 2 x 12-bit DAC

▸ 2 x 16-bit SAR ADC, up to 31 channels with programmable gain amplifiers

▸ Programmable delay block

▸ I²C

▸ USB connectivity

▸ ARM Cortex-M4 core with DSP instructions

FIGURE 4.3e: XTRINSIC MMA9553L INTELLIGENT MOTION-SENSING BLOCK DIAGRAM
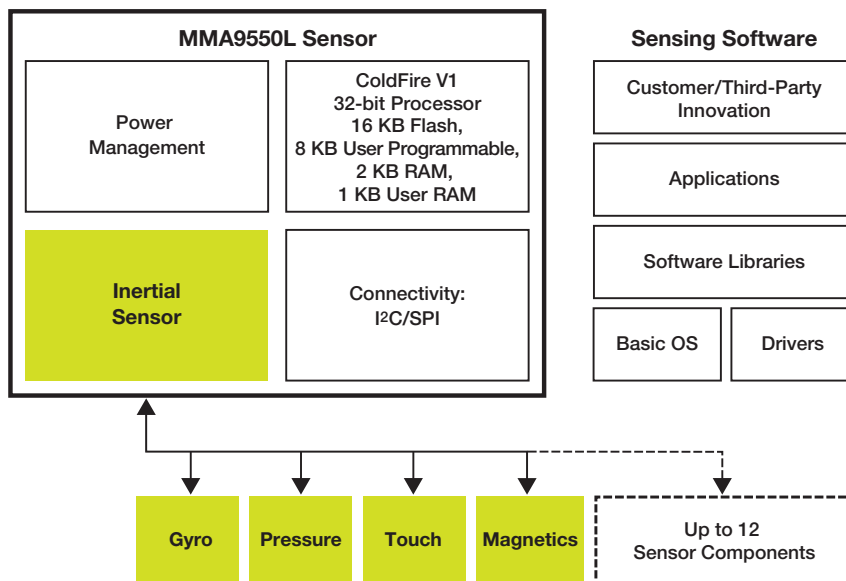
FIGURE 4.3f: KINETIS K50 FAMILY BLOCK DIAGRAM
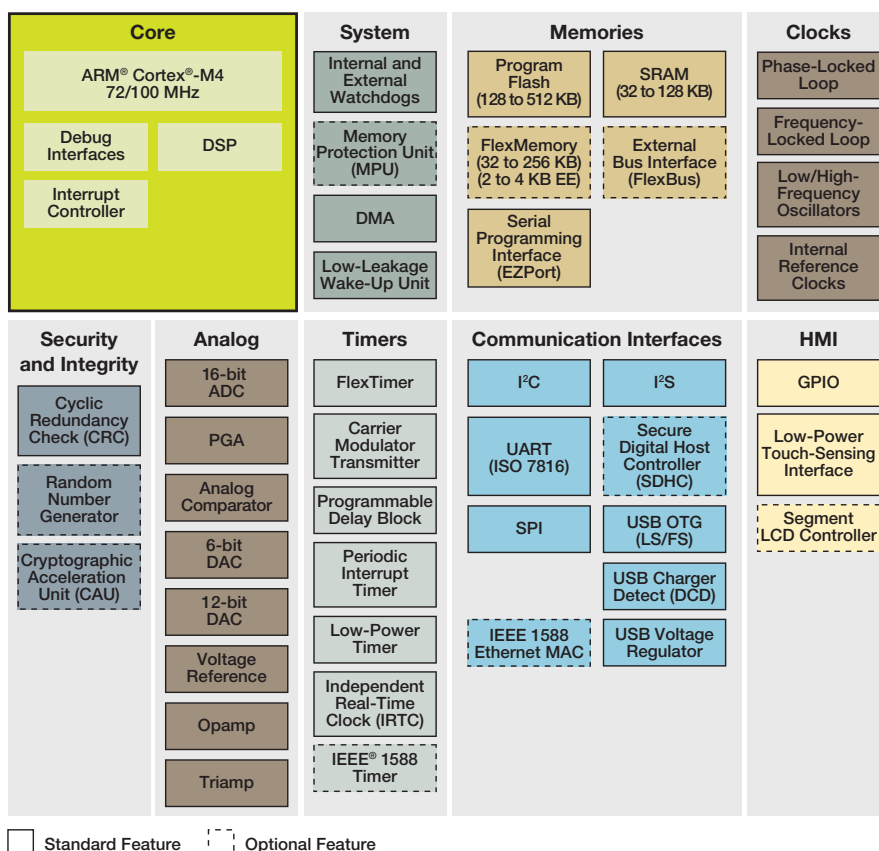
Continuous Glucose Monitor

4.4

Introduction

A continuous glucose monitor (CGM) measures the amount of glucose in the blood stream of people with Type 1 and Type 2 diabetes in real time. Continuous monitoring allows for more frequent adjustments, mobile device notifications, wireless connectivity to the medical cloud and more accurate insulin regulation. It provides the user with an easy-to-use, painless way to capture real-time blood glucose readings.

The continuous blood glucose meter allows real time wireless communication with other devices such as tablets, smartphones, insulin dispensers or calorimeters, useful for telehealth applications and remote patient monitoring.

Circuit design overview

The glucose sensor is a disposable unit that is placed on the skin to continuously monitor the glucose levels. This electrochemical sensor generates a current proportional to the glucose concentration. This current is passed through a current-to-voltage converter to obtain a signal that can be acquired by an ADC.

The acquired signal is processed and transmitted wirelessly to a master device such as a smartphone. Wireless technologies such as Bluetooth® or ZigBee® are used with this purpose.

Since it is a small disposable device, the selected microcontroller must have a small footprint and a low cost. High analog module integration can help to significantly reduce the sensor size and reduce the power consumption caused by external analog devices. Low power consumption is also an important feature that allows the continuous sensor to reach the necessary battery life for this kind of devices.

Recommended solutions

K5x measurement MCUs

The K5x MCU family is pin-, peripheral- and software-compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE® 1588 Ethernet and hardware encryption, full-speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin LQFP packages extending up to 512 KB in a 144-pin MAPBGA package. The K5x Measurement MCUs are Energy-Efficient Product Solutions.

FIGURE 4.4a: CONTINUOUS GLUCOSE MONITOR BLOCK DIAGRAM

FIGURE 4.4b: KINETIS K50 FAMILY BLOCK DIAGRAM

MC34671: 600 mA battery charger

The MC34671 is a cost-effective fully integrated battery charger for Li-Ion or Li-Polymer batteries. It tolerates an input voltage up to 28 V, which eliminates the input over-voltage protection circuit required in handheld devices. A charge cycle includes trickle, constant-current (CC) and constant-voltage (CV) charge modes.

The constant-current (CC) is programmable up to 600 mA, with an external resistor. The constant voltage is fixed at 4.2 V. The trickle charge current is preset to 20% of the CC current when the battery voltage is lower than the trickle-charge threshold. The end-of-charge (EOC) current threshold is preset to 10% of the CC current to save board space and cost. A charge-current thermal foldback feature limits the charge current when the IC internal temperature rises to a preset threshold.

The MC34671 has a 2.6 V falling power-on-reset (POR) threshold, making it perfect to work with current-limited power supplies. Three indication pins (PPR, CHG, and FAST) can be simply interfaced to a microprocessor or LEDs. When no power supply is connected, or when disabled, the charger draws less than 1.0 µA leakage current from the battery.

MC13202: 2.4 GHz RF transceiver for 802.15.4

The MC13202 is the 2nd generation 2.4 GHz band transceiver designed for wireless sensing and control applications. The MC13202 includes a complete packet modem capable of formatting data into packets with 125 byte payload. It has an over the air data rate of 250 kbps using O-QPSK modulation and Direct Sequence Spread Spectrum (DSSS) coding. It builds on the first generation product by integrating a Transmit/receive switch that lowers the overall component count, size and cost of the solution.

FIGURE 4.4c: MC34671 FUNCTIONAL BLOCK DIAGRAM
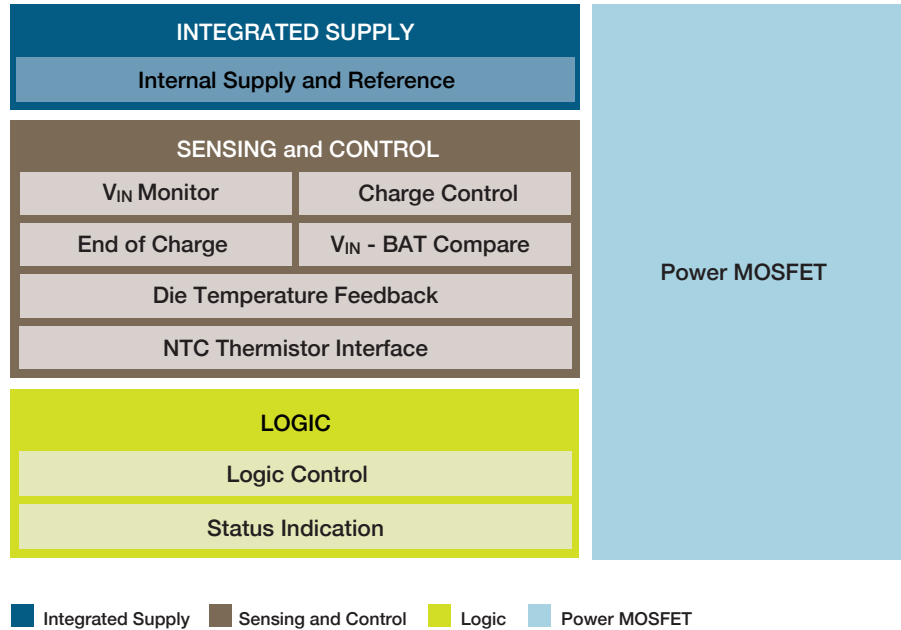
The four wire serial peripheral interface (SPI) allows interface to a variety of processors, providing developers to tailor the solution to meet their needs. We offer a variety of MCUs that range from 8 to 32bit that easily connect to the MC13202. The software and processor can be scaled to fit applications ranging from simple point-to-point systems, through complete ZigBee® networking. The 13202 supports the SMAC software, IEEE 802.15.4 PHY/MAC and 3rd party ZigBee stacks.

Wearable Wireless Healthcare Patch

4.5

Introduction

Healthcare patches are small devices that are fastened to the body surface to obtain physiological parameters. Patch type healthcare products increase patient mobility and comfort and can wirelessly upload vital signs data to the cloud for real time analysis or long term record keeping.

The patch can consist of several sensors to detect the required parameters. Data acquisition across such sensors can be pointto-point or multipoint-to-point, depending on specific applications. Data transaction may be also real-time or non-real-time. Although the patient monitoring type of applications requires real-time packet routing, monitoring an athlete's physiological data can be collected offline for processing and analysis purposes.

As an indispensible part of the system, the power supply for these components should be small-sized, lightweight, environmentallyfriendly and long lasting as well. The processor must be an embedded system, including the most number of peripherals required for the application, everything in a small footprint and with low power consumption.

K5x measurement MCUs

The K5x MCU family is pin-, peripheral- and software-compatible with other Kinetis MCUs and provides designers with an analog measurement engine consisting of integrated operational and transimpedance amplifiers and high-resolution ADC and DAC modules.

The family also features IEEE® 1588 Ethernet and hardware encryption, full-speed USB 2.0 On-The-Go with device charger detect capability and a flexible low-power segment LCD controller with support for up to 320 segments. Devices start from 128 KB of flash in 64-pin LQFP packages extending up to 512 KB in a 144-pin MAPBGA package. The K5x Measurement MCUs are Energy-Efficient Product Solutions.

MPL3115A2: 50 to 110kPa, 2.5v, absolute SmartPressure sensor

MPL3115A2 provides highly precise pressure and altitude data with variable sampling rate capability. It has very low-power consumption, smart features and requires zero data processing for mobile devices, medical and security applications.

The MPL3115A2 pressure sensor smart features include digital output, two interrupts for auto-wake, minimum/maximum threshold detection and autonomous data acquisition. MCU usage can be limited since the MPL3115A2 pressure sensor can process sensor data locally, reducing communications required with the host processor.

KL0: Kinetis KL0 entry-level MCUs

The Kinetis KL0 family is the entry point into the Kinetis L Series MCUs based on the ARM® Cortex®-M0+ processor. The Kinetis KL0 family provides a bridge for 8-bit customers migrating into the Kinetis portfolio and is software and tool compatible with all other Kinetis L families Devices start from 8 KB of flash in a small-footprint 4 x 4 mm 24 QFN package extending up to 32 KB in a 48 LQFP package. Each combines ultra-low-power performance with a rich suite of analog, communication, timing and control peripherals.

FIGURE 4.5a: KINETIS K50 FAMILY BLOCK DIAGRAM
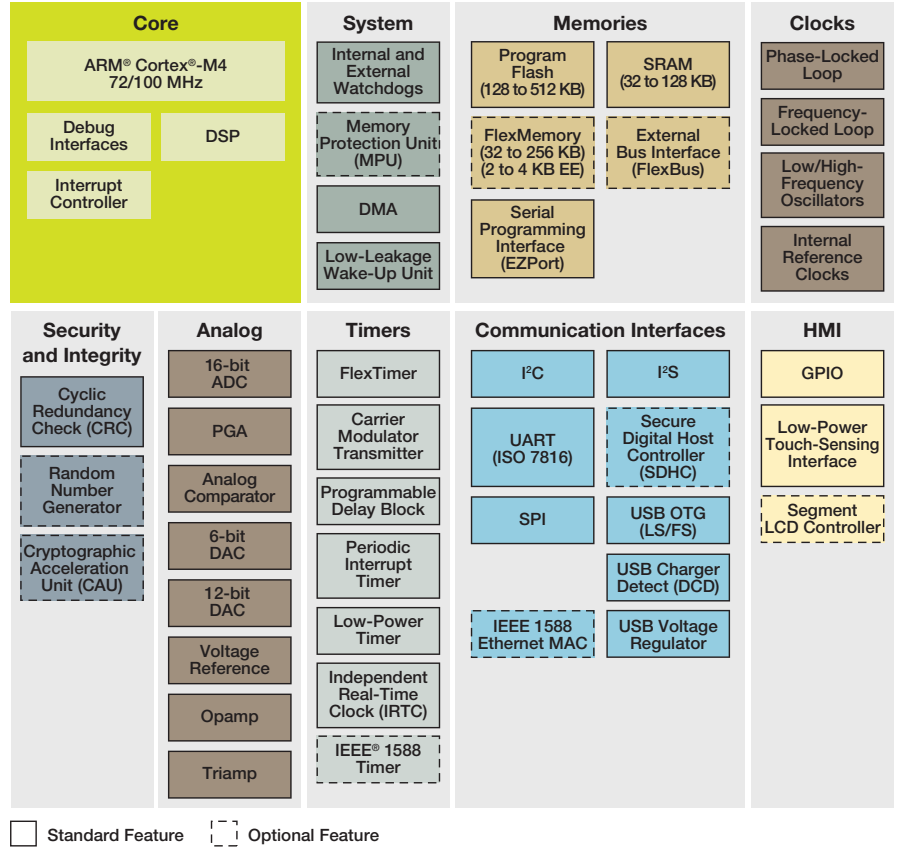
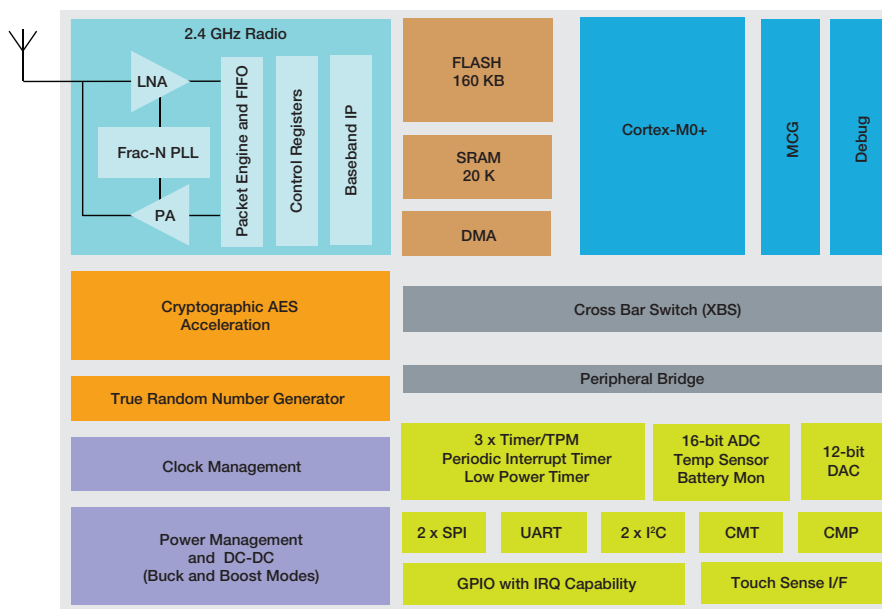**FIGURE 4.5b: KINETIS KL0X MCU FAMILY BLOCK DIAGRAM**
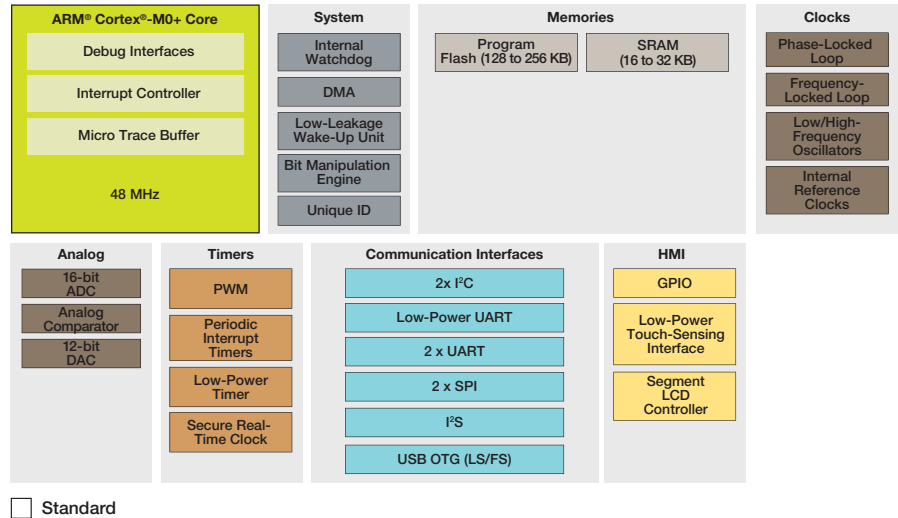
KW2x: 2.4GHz RF MCUs

The KW2x is a low power, compact integrated device consisting of a high-performance 2.4 GHz IEEE 802.15.4 compliant radio transceiver and a powerful ARM® Cortex®-M4 MCU system with connectivity and precision mixed signal analog peripherals.

Part of the large Kinetis MCU portfolio, the KW2x family of devices are used to easily enable connectivity based on the IEEE® 802.15.4 family of protocols including ZigBee Pro network stack and application profiles for Smart Energy 1.x, Home Automation, Healthcare, and RF4CE, as well as the ZigBee IP network stack and the Smart Energy 2.0 application profile. Typical applications include Home Area Networks consisting of meters, gateways, in-home displays, and connected appliances, and also networked Building Control and Home Automation applications with lighting control, HVAC, and security.

Recommended solutions

The ADC converter transforms the continuous audio signal into digital samples to be processed and filtered by a DSP.

MMA8653FC: 2g/4g/8g, 3-axis, 10-bit digital accelerometer

The MMA8653FC 10-bit accelerometer has industry leading performance in a small 2 x 2 x 1 mm DFN package. This accelerometer is packed with embedded functions that include flexible user-programmable options and two configurable interrupt pins. Overall power savings is achieved through inertial wake-up interrupt signals that monitor events and remain in a low-power mode during periods of inactivity.

FIGURE 4.5c: KINETIS KW40Z, KW30Z, KW20Z WIRELESS MCU FAMILY

FIGURE 4.5d: WEARABLE WIRELESS HEALTHCARE PATCH BLOCK DIAGRAM
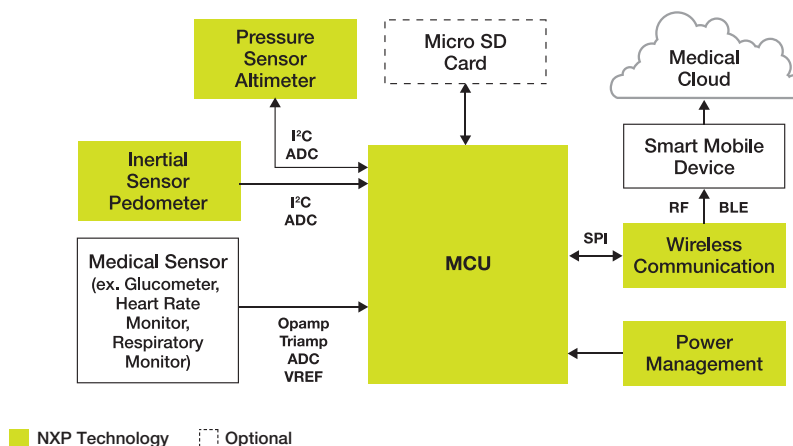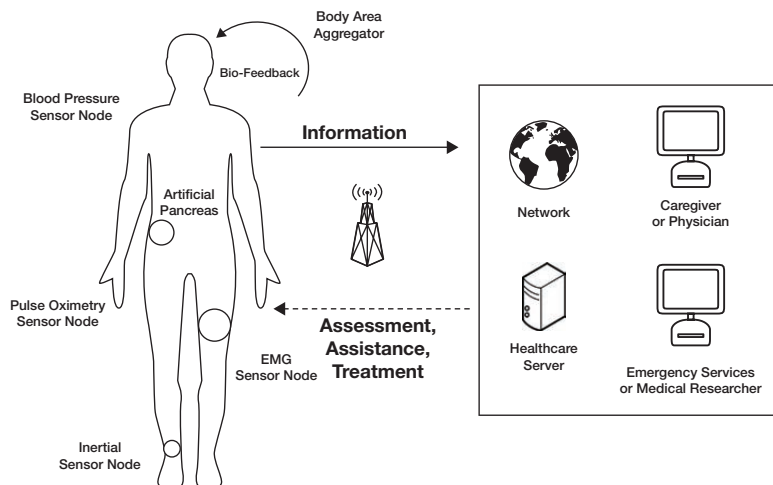

FIGURE 4.5e: WIRELESS PATCH SYSTEM

Wireless Insulin Pump

4.6

Introduction

An insulin pump is a medical device used to deliver insulin as part of a diabetes mellitus treatment. Wireless insulin pumps use RF connectivity to connect a disposable insulin delivery patch to a handheld control interface. The handheld control interface can be used to regulate blood glucose, recommend the required insulin dosage, provide dietary support with a food library and upload data to a medical cloud where it can be shared and analyzed.

Diabetes is a very common health concern in today's world. However, with tight glycemic control and early diagnosis, the number and severity of medical complications and medical costs can be greatly reduced. The major objective of glycemic control is to maintain a person's blood glucose level within a physiologically acceptable range. An ideal treatment of diabetes requires a closed-loop insulin delivery system. Such a system, which comprises a glucose sensing component and an insulin pump, acts as an artificial pancreas. This requires miniaturization and coordination of three components, namely a safe and reliable insulin infusion device, an accurate and stable glucose sensor, and a control system that regulates insulin delivery according to blood glucose variations assessed by the glucose sensor. The continuous delivery of insulin based on the obtained glucose data is the key function an insulin pump. The blood glucose data is sent to a microcontroller unit, whose function is to compute the proper amount of insulin based on the measured glucose level and control the administration of insulin.

Recommended solutions

KW0x: Kinetis sub-1 Ghz radio and ARM Cortex –M0+ MCU

Our new Kinetis KW01 ultra-low-power wireless MCU is an ARM® Cortex®-based smart radio solution designed for sub-1 GHz (290-1020 MHz) wireless connectivity applications. Powered by the ultra-low-power 48 MHz ARM Cortex-M0+ 32-bit MCU, the MKW01 embeds a rich set of peripherals with a high-performance bi-directional sub-1 GHz radio, capable of operating over a wide frequency range including 315, 433, 470, 868, 915, 928 and 960 MHz in the license free industrial, scientific and medical (ISM) frequency bands.
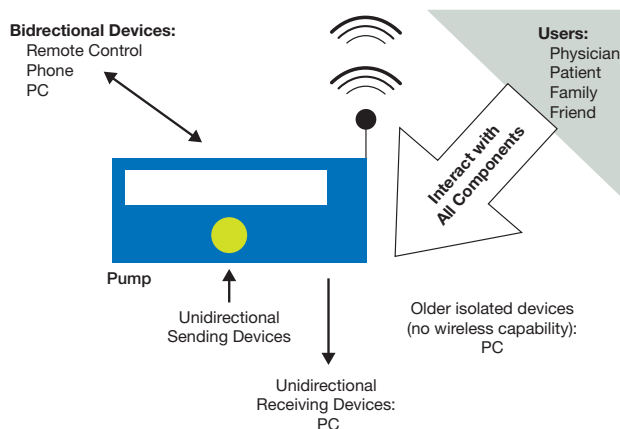
FIGURE 4.6a: WIRELESS INSULIN PUMP OVERVIEW

FIGURE 4.6b: WIRELESS INSULIN PUMP BLOCK DIAGRAM
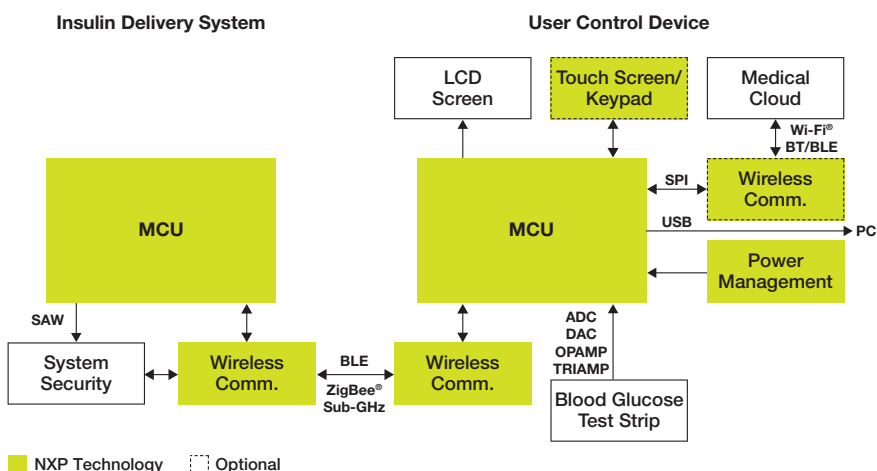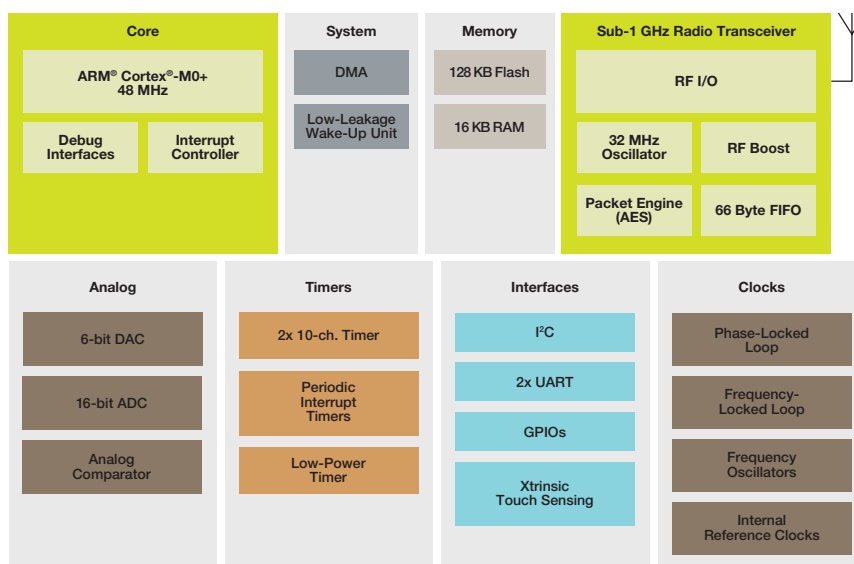

FIGURE 4.6c: KINETIS KW0X MCU FAMILY BLOCK DIAGRAM

Smart Watches

4.7

Introduction

Smart watches are connected platforms used for interacting with smart phones and other connected devices to complete a variety of tasks. These tasks can include retrieving SMS messages, streaming music or displaying information from healthcare monitoring devices (heart rate monitors, glucose meters, among others).

The information is shown on a small display (usually 1" to 1.5"). The device can include some sensors to collect data that can be processed in the same device and provide useful information to the user. This information can include environment temperature, pedometer data or free fall detection. This information can be retrieved from external gadgets or be transmitted to other devices wirelessly. Common wireless communication technologies used are Bluetooth®, ZigBee® or WiFi.

When selecting a processor for this application, the size restrictions and battery life are two aspects that need to be considered. An appropriate processor must have a small footprint, and preferably, embed other required modules such as a graphic display controller. Low power consumption will help to increase the battery life and significantly reduce the period between charge cycles.

Recommended solutions

i.MX 6 SoloLite

The i.MX 6SoloLite family introduces a single core running up to 1.0 GHz with 256 KB of L2 cache and 32-bit DDR3/LPDDR2 support. Targeted integration of EPD controller and an LCD controller makes the i.MX 6SoloLite ideal for next-generation e-readers and smart devices.

MMA7660FC: 3-axis, digital accelerometer

The MMA7660FC is a digital output I²C, very low-power, low-profile capacitive micro-machined accelerometer featuring a low pass filter, compensation for zero-g offset and gain errors and conversion to six-bit digital values at a user configurable output data rate. The device can be used for sensor data changes, product orientation and gesture detection through an interrupt pin (INT). The device is housed in an extremely small 3 mm x 3 mm x 0.9 mm DFN package.

FXOS8700CQ: 6-axis 3D accelerometer + 3D magnetometer

Our FXOS8700CQ 6-axis sensor combines industry leading accelerometer and magnetometer sensors in a small 3 x 3 x 1.2 mm QFN plastic package. The 14-bit accelerometer and 16-bit magnetometer are combined with a high-performance ASIC to enable an eCompass solution capable of a typical orientation resolution of 0.1 degrees and sub 5 degree compass heading accuracy for most applications.

Applications include eCompass, enhanced user interface, augmented reality, and location based services (static geographic heading). Target products include smartphones, tablets, personal navigation devices, remote controls for smart TV's, watches, gaming controllers, robotics, and unmanned air vehicles (UAVs).
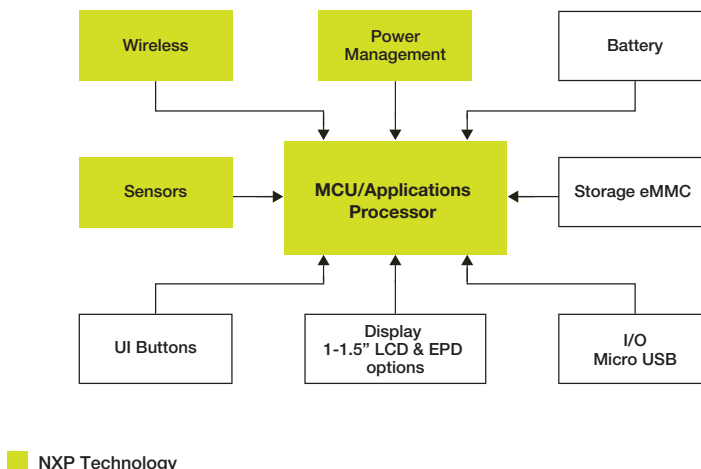
FIGURE 4.7a: SMART WATCH BLOCK DIAGRAM

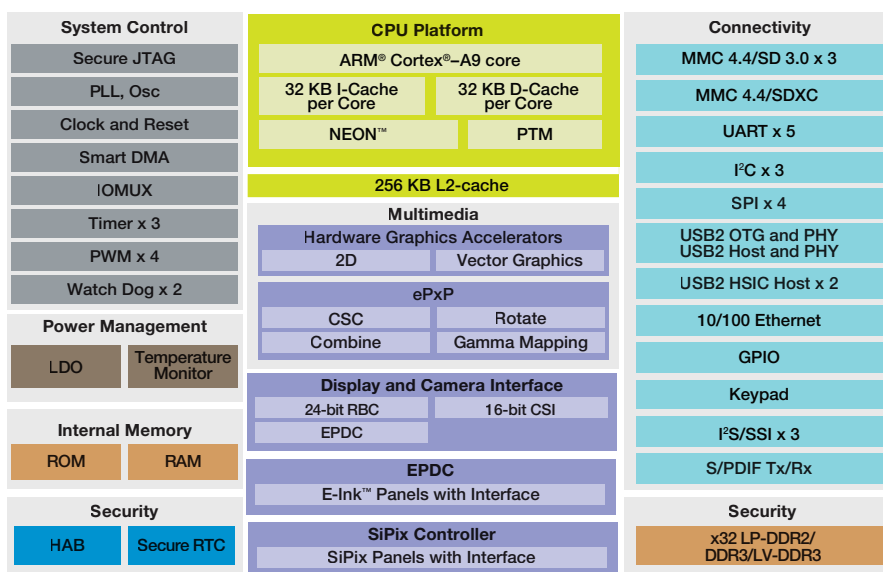FIGURE 4.7b: i.MX 6 SOLOLITE MULTIMEDIA PROCESSOR BLOCK DIAGRAM

Table 4.8: Technologies for Wearables

ROLE	DEVICE	DESCRIPTION	FEATURES	ALTERNATE OPTIONS
Activity and Wellness Monitor				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL2x, KL3x, KL4x, K2x
Microprocessors	i.MX6SL	i.MX ARM Cortex A9 MPU	Cortex®-A9 up to 1 GHz, 2D/3D graphics	i.MX28, VF6xx
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	
Touch Sensing	MPR121	Proximity Capacitive Touch Sensor Controller	1.71-3.6 V, 29 µA supply current, Continuous independent auto-calibration	TSSMCU, eGUI
Inertial Sensor	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 µA-165 µA current consumption	MMA955xL
Pressure Sensors	MPL3115A2	50 to 110kPa, Absolu te Digital Pressure Sensor	Provides highly precise pressure and altitude data	
Power Management	MC34673	1.2 A Single-Cell Li-Ion/Li-Polymer Battery Charger	Li-Ion or Li-Polymer battery charger	
Continuos Glucose Monitor				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL2x, KL3x, KL4x, K2x
Microprocessors	i.MX6SL	i.MX ARM Cortex A9 MPU	Cortex®-A9 up to 1 GHz, 2D/3D graphics	i.MX21, i.MX21S, i.MX28
Power Management	MC34712	3.0 A 1.0 MHz Integrated DDR Switch-Mode Power Supply	Li-ion Battery Charger	
Touch Screen	MPR121	Proximity Capacitive Touch Sensor Controller	1.71-3.6 V, 29 µA supply current, Continuous independent auto-calibration	TSSMCU
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	
Hearing Aids				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL2x, KL3x, KL4x, K2x
Inertial Sensor	MMA8451Q	±2g/±4g/±8g, low g, 14-bit Digital Accelerometer	1.6-3.6 V, 6 µA-165 µA current consumption	MMA9555L, MMA8450Q
Battery Charger	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	MC34712, MC34713, MC34717
Power Management	MC34716	3.0/5.0 A 1.0 MHz Integrated Dual Switch-Mode Power Supply	Li-Ion battery charger, dual switch-mode power supply (5 A, 3.3 V)	MC34712, MC34713, MC34717
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	
Smart Watch				
Microprocessors	i.MX6SL	i.MX ARM Cortex A9 MPU	Cortex®-A9 up to 1 GHz, 2D/3D graphics	
Microcontrollers	K2x	Kinetis ARM Cortex-M4 Measurement MCU	Low-power Cortex®-M4 up to 120 Mhz, up to 1MB Flash, Crystal-less USB OTG, Touch Sensing interface	KL2x, KL3x, KL4x, K5x
Sensors	FXOS8700CQ	Accelerometer (±2g/±4g/±8g) + 3D Magnetometer	3x3 mm, two-combo: three-axis accelerometer + three-axis magnetometer	MPL3115A2, MMA955xL
Power Management	MMPF0100	14 Channel Configurable Power Management IC	I.MX power management IC (PMIC)	
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	
Wearable Wireless Healthcare Patch				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL2x, KL3x, KL4x, K2x
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	
Power Management	MC34712	3.0 A 1.0MHz Integrated DDR Switch-Mode Power Supply	Li-ion Battery Charger	
Wireless Insulin Pump				
Microcontrollers	K5x	Kinetis ARM Cortex-M4 Measurement MCU	100 MHz Cortex M4, Integrated opamps, triamps, ADC, USB, Ethernet and segment LCD	KL2x, KL3x, KL4x, K2x
Microprocessors	i.MX6SL	i.MX ARM Cortex A9 MPU	Cortex®-A9 up to 1 GHz, 2D/3D graphics	i.MX21, i.MX28, i.MX21S
Power Management	MC34712	3.0A 1.0 MHz Integrated DDR Switch-Mode Power Supply	Li-ion Battery Charger	
Touch Screen	MPR121	Proximity Capacitive Touch Sensor Controller	1.71-3.6V, 29µA supply current, Continuous independent auto-calibration	TSSMCU
Wireless Communications	KW4x	Kinetis ARM Cortex-M4 Low Power Wireless MCU	48 MHz Cortex M0+, 160k Flash, 20k SRAM, 2.4 GHz RF (802.15.4, BLE, ZigBee, Thread)	

Summary

APPLICATIONS	OUR PRODUCTS	OUR DIFFERENTIATORS
Home Portable		

• Blood Pressure Monitor
• Diabetes Care (Blood Glucose Monitor and Insulin Pumps)
• Digital Scale
• Digital Thermometer
• Heart Rate Monitor
• Pulse Oximetry
• Telehealth/Telemonitoring
	• **Kinetis ARM® Cortex®-M0+ family:** MKL10, MKL20, MKL30, MKL40
	• **Kinetis ARM Cortex®-M4 family:** MK10, MK20, MK40, MK50
	• **i.MX series** (ARM core, 32-bit)
	  - i.MX 6 series: Multicore, display(s), graphics, video, USB, 10/100/1000 Ethernet, power management
	  - i.MX28x: Power management, LCD controller with touch screen, USB, Ethernet
	• **Wireless:** MC1322x (IEEE® 802.15.4/ZigBee® technology)
	• **Pressure sensors:** MPL3115A2, MPX2300DT1, MPXV5050GC6, MPXM2053GS (blood pressure monitoring)
	• **Touch sensors:** MPR03x, MPR121QR2, touch-sensing software IP
	• **Accelerometers:** MMA8451Q, MMA8452Q, MMA8453Q (arm angle detection for blood pressure monitoring), MMA8451Q, MMA8452Q, MMA8453Q (portrait/landscape)
	• **Power management:** MC34671, MC34673, MC34674, MC34704, MC13892
	• **Motor drivers (H bridge):** MC33887, MPC17C724, MC33931, MC33932, MC33926
	• **LED backlight:** MC34844
		Product differentiators
		• Highest quality standards
		• Product life: 15-year longevity
		• Connectivity: USB, ZigBee
		• Pressure sensors: Packaged specifically for medical applications
		• High-end MPUs 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

Diagnostics and Therapy		

• Ablation Laser
• Anesthesia Unit Monitors
• Clinical Patient Monitoring
• Clinical/Surgical Equipment
• Defibrillators/AEDS
• Dialysis Equipment
• Electrocardiogram
• Electromyograph
• Fetal Heart Rate Monitor
• Fitness/Wellness
• Hospital Admission Machines
• Implantable Devices
• Infusion Pumps
• RF Ablation
• Ventilator/Respirators
• Wound Management
	• **DSCs:** MC56F82xx, MC56F84xx
	• **Kinetis ARM Cortex M4 family:** MK40, MK50, MK60
	• **i.MX 6 series:** Multicore, display(s), graphics, video, camera, USB, 10/100/1000 Ethernet, power management
	• **i.MX series** (ARM core, 32-bit)
	  - i.MX287: power management, LCD controller with touch screen, USB, Dual Ethernet
	• **High-performance 32-bit MPUs:** MPC5121e, MPC8377, MPC8641, MPC8535, P1022, P1013
	• **Wireless:** MC1322x (IEEE 802.15.4/ZigBee technology)
	• **Pressure sensors:** MPXx5050, MPX2300DT1, MPX2301DT1, MPXC2011DT1, MPXC2012DT1, MPX2050
	• **Touch sensors:** MPR03x, MPR121QR2
	• **Accelerometers:** MMA8451Q, MMA8452Q, MMA8453Q
	• **Power management:** MC13892, MC34712, MC34713, MC34716, MC34717
	• **Motor drivers (H bridge):** MC33887, MPC17C724
	• **LED backlight:** MC34844
	• **Radio frequency (RF) LDMOS power transistors:** MRF6VP41KH, MRF6S24140H, MRF6P24190H
	• **E series high-power enhanced ruggedness RF amplifiers:** MRFE6VP100H, MRFE6VS25N, MRFE6VP5600H, MRFE6VP6300H, MRFE6VP61K25H, MRF6VP8600H
		Product differentiators
		• Highest quality standards
		• Product life: 15-year longevity
		• Breadth and scalability of portfolio
		• Low-power solutions
		• i.MX series: High level of integration
		  - Connectivity (USB and Ethernet)
		  - LCD control (graphic and segment)
		  - Internal memory
		  - High precision analog
		• i.MX series: Video and graphics acceleration
		• Strong/comprehensive RF power LDMOS portfolio
		  - Best ruggedness in the market
		  - Broadest line of enhanced ruggedness devices
		  - Exceptional efficiency
		  - Highest gain
		
		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

Imaging		

• Bone Densitometer
• Computed Tomography
• Fluoroscopy, Angiography
• Magnetic Resonance Imaging
• Positron Emission Tomographer
• Ultrasound
• X-Ray and Related Applications
	• **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.MX 6 series: Multicore, display(s), graphics, video, camera, USB, 10/100/1000 Ethernet, power management
	  - i.MX53: 32-bit, video, graphics, Ethernet, LCD with touch screen, USB
	• **Wireless:** MC132xx ZigBee technology
	• **Accelerometers:** MMA8451Q, MMA8452Q, MMA8453Q (vibration sensing)
	• **Touch sensors:** MPR03x, MPR121QR2
	• **Power management:** MC13892, MC34704, MC34712, MC34713, MC34716, MC34717
	• **LED backlight:** MC34844
	• **General-purpose amplifiers**
	• **High-power RF amplifiers:** MRF6VP41KH, MRF6S24140H, MRF6P24190H
	• **E series high-power enhanced ruggedness RF amplifiers:** MRFE6VP100H, MRFE6VS25N, MRFE6VP5600H, MRFE6VP6300H, MRFE6VP61K25H, MRF6VP8600H
		Product differentiators
		• Highest quality standards
		• Product life: 15-year longevity
		• Breadth and scalability of portfolio
		• Low-power solutions
		• i.MX series: High level of integration
		  - Connectivity (USB and Ethernet)
		  - LCD control
		  - Internal memory
		  - High precision analog
		• i.MX series: video and graphics acceleration
		• Strong/comprehensive RF power LDMOS portfolio
		  - Best ruggedness in the market
		  - Broadest line of enhanced ruggedness devices
		  - Highest gain
		  - Exceptional efficiency
		• High-performance processors: PCI Express® support and Serial ATA 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

Application Notes

APPLICATION NOTES

AN2975: IEEE 802.15.4 and ZigBee Applications

AN3231: SMAC Based Demonstration Applications

AN3761: Devices for Contactless Touch Applications

AN3583: Using Low-Power Mode on the MPR083 and MPR084

AN3796: LCD Driver Specification

AN4223: Connecting Low-Cost External Electrodes to MED-EKG

AN4115: IrDA Driver and SD Card File System on the MM/JE Flexis Families

AN3460: Low Power Enabled by QE128 (S08 and MCF51)

AN3465: Migrating within the Controller Continuum

AN1326: Barometric Pressure Measurement Using Semiconductor Pressure Sensors

AN1097: Calibration-Free Pressure Sensor System

AN3870: Developing an Application for the i.MX Devices on Linux

AN3552: Analog Comparator Tips and Tricks

AN4153: Using eGUI with TWR-LCD on MCF51MM Family

ANPERIPHQRUG: Quick Reference User Guide for Analog Peripherals on the MM and JE Family

AN3827: Differences Between Controller Continuum ADC Modules

AN3412: Dynamic LCD Driver Using GPIO Pins

AN3949: ADC16 Calibration Procedure and Programmable Delay Block Synchronization

AN2731: Compact Integrated Antennas

AN4318: Histogram Equalization

AN4323: Solutions for Electrocardiograph and Heart Rate Monitor Applications

AN4325: Spirometer Demo with NXP MCUs

AN4327: Pulse Oximeter Fundamentals and Design

AN4328: Blood Pressure Monitor Fundamentals and Design

AN4364: Glucose Meter Fundamentals and Design

AN4496: Pulse Oximeter Using USB PHDC

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 that meets the specifications.
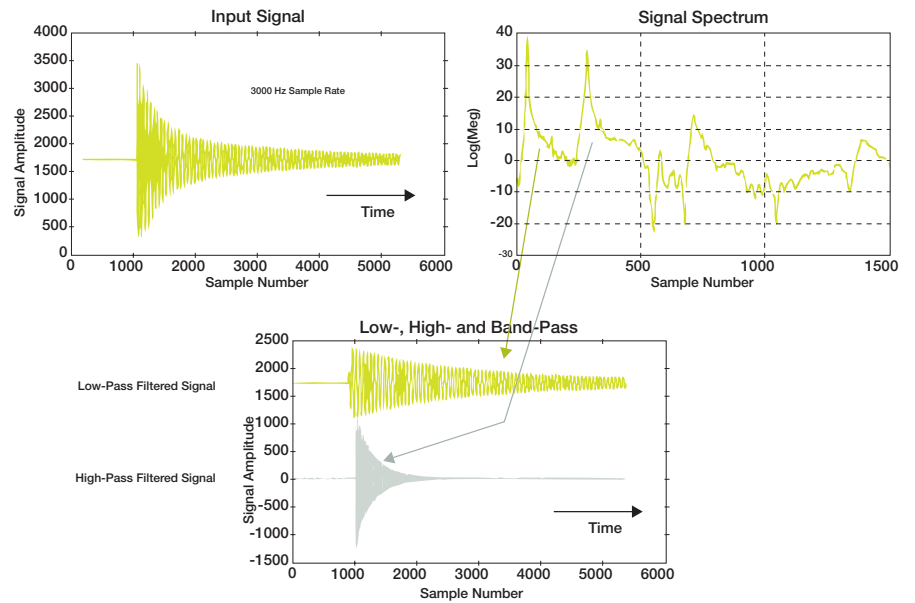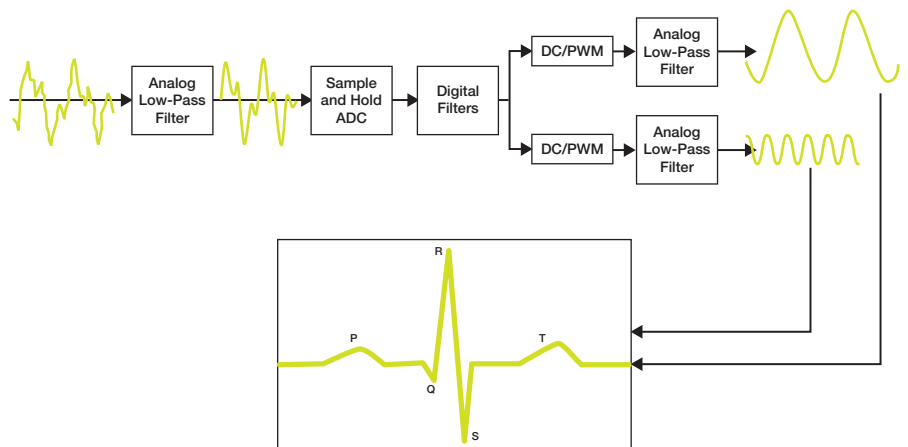
FIGURE A-2: SIGNAL PROCESSING FOR HRM AND PULSE OXIMETRY

FIGURE A-2: SIGNAL PROCESSING FOR HRM AND PULSE OXIMETRY

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, 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.

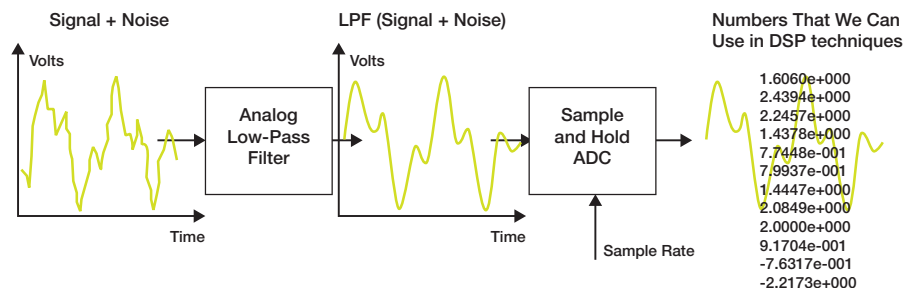### FIGURE A-3: ANTI-ALIASING FILTER AND SAMPLING

FIGURE A-4: LOW- AND HIGH-PASS FILTERS

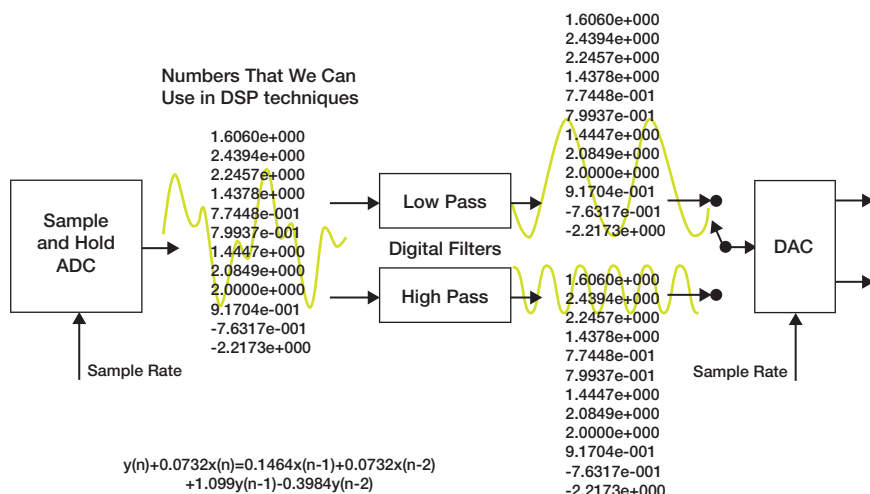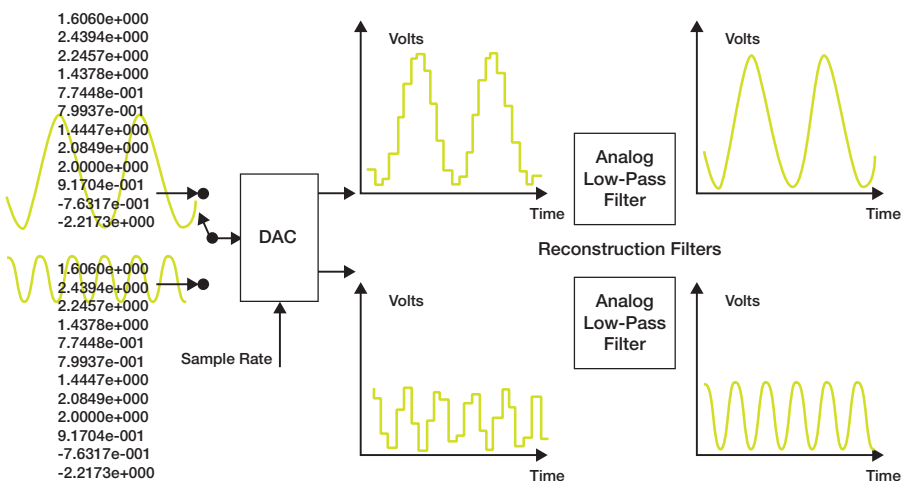$$y(n)+0.0732x(n)=0.1464x(n-1)+0.0732x(n-2)+1.099y(n-1)-0.3984y(n-2)$$

FIGURE A-5: SIGNAL RECONSTRUCTION

Our 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 **www.nxp.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 common-mode rejection ratio, is often used. This device can be built with discrete elements or can be obtained pre-built. The amplifier obtains the differential between the signal and amplifier depending on the gain, which determines the signal amplitude.

The gain recommended for medical applications is 1000 because the signal oscillates around 1 mV, and with this gain the signal can be amplified up to 1 V. 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.
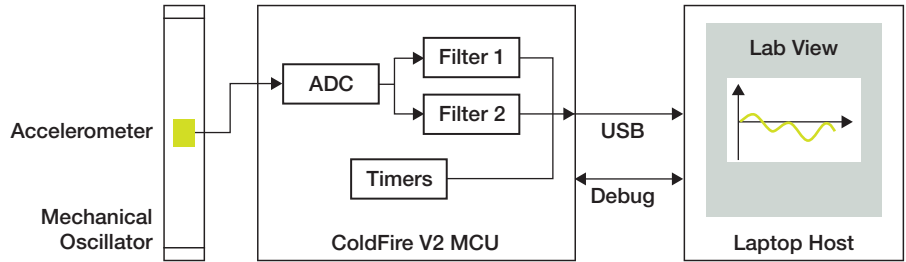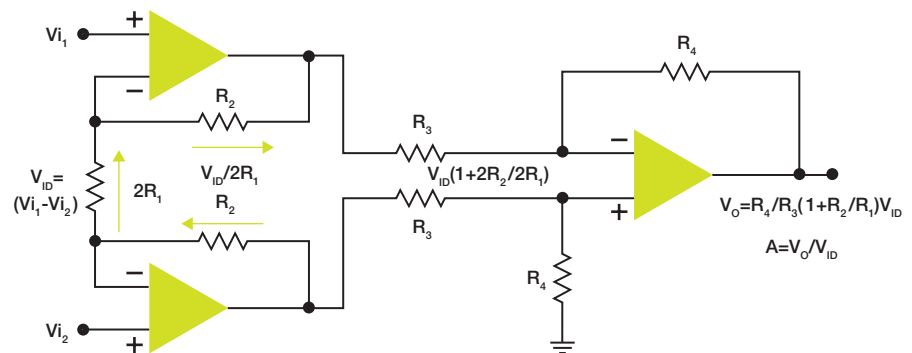
FIGURE A-6: COLDFIRE DEMO BOARD (M52221 DEMO)

FIGURE A-7: INSTRUMENTATION AMPLIFIER DESIGN DIAGRAM

$$A_1 = 1 + \frac{R_2}{R_1}$$

$$A_1 = \frac{R_1 + R_2}{R_1}$$

$$R_2 = (A_1 R_1) - R_1$$

$$A_2 = \frac{R_4}{R_3}$$

$$R_4 = A_2 R_3$$

$$A_1 = A_1 A_2$$

Values to obtain a signal around 1 V: Low gain: 10, high gain: 100, total gain: 1000

Analog measurement engine

Some of the analog modules are commonly used in most of the medical applications. Therefore, it is necessary to add them in the design separately, which increases the PCB size and increases the cost. NXP medical-oriented solutions embed these modules—reducing PCB size, cost and increasing the design performance. Modules included in the analog measurement engine are opamp, triamp, ADC, DAC, ACMP, VREF and PDB. These modules are explained below.

Opamp

Opamps have several purposes. They can be configured as simple as a buffer circuit or as complex as an N order filter, opamps have a huge application field in the medical industry.

Our medical-oriented MCUs integrate opamps on chip. These opamps can be configured to work as general-purpose opamps, buffer circuit or configurable gain inverting and non-inverting amplifiers.

Triamps

Triamps are special general-purpose opamps with reduced input offset voltage and bias current, ideal for applications that require low amounts of voltage and current. Triamps can be also used as general-purpose opamps to reduce BOM and PCB size.

Analog comparators (ACMP)

ACMP compare two analog inputs and generate a high or low state depending on the input values. Output is high when the positive input is greater than the negative input and low when the negative input is greater than the positive input. Analog comparators can constantly check the value of both inputs and generate an interrupt when a change occurs.

FIGURE A-8: TEST STRIP BASIC BLOCK DIAGRAM USING FLEXIS MM
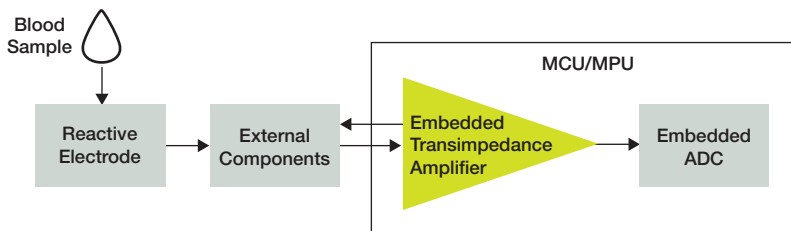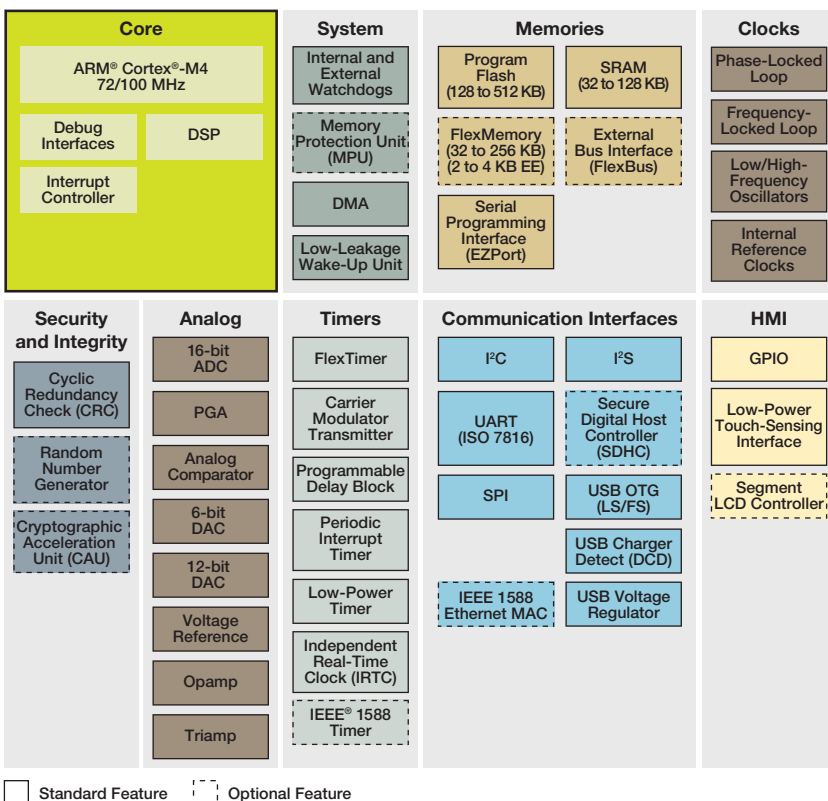

FIGURE A-9: KINETIS K50 FAMILY BLOCK DIAGRAM

Kinetis K50 family MCUs can provide up to 31 16-bit ADC channels

Analog-to-digital converter (ADC)

ADCs are one of the most important modules in the medical and overall electronics field. This module allows the conversion of an analog input into a digital value that can be processed by an MCU or MPU. ADCs output a bit value as a result of the conversion, and can significantly offset the PCB size. Embedded ADCs reduce PCB size and processing efforts, reducing the access time to the result value.

Digital-to-analog converter (DAC)

The DAC generates an analog voltage depending on the value of its input register and the module resolution. DACs are useful in the generation of reference voltages or as waveform generators. Electrocardiography uses DACs for ECG baseline adjustment.
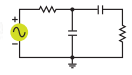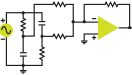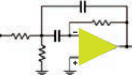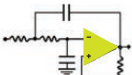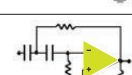
Programmable delay block (PDB)

The PDB provides controllable delays from either an internal or an external trigger, or a programmable interval tick, to the hardware trigger inputs of ADCs or generates the interval triggers to DACs, so that the precise timing between ADC conversions and/or DAC updates can be achieved. The PDB can optionally provide pulse outputs (pulse-outs) that are used as the sample window in the analog comparator.

VREF

The VREF module generates a static voltage that can be used as a reference on an opamp, DAC, ACMP or other application without the need for external regulators. Embedded VREF modules are programmable and can reduce the amount of external components on a PCB, eliminating the need for external regulators or voltage dividers for VREF applications.
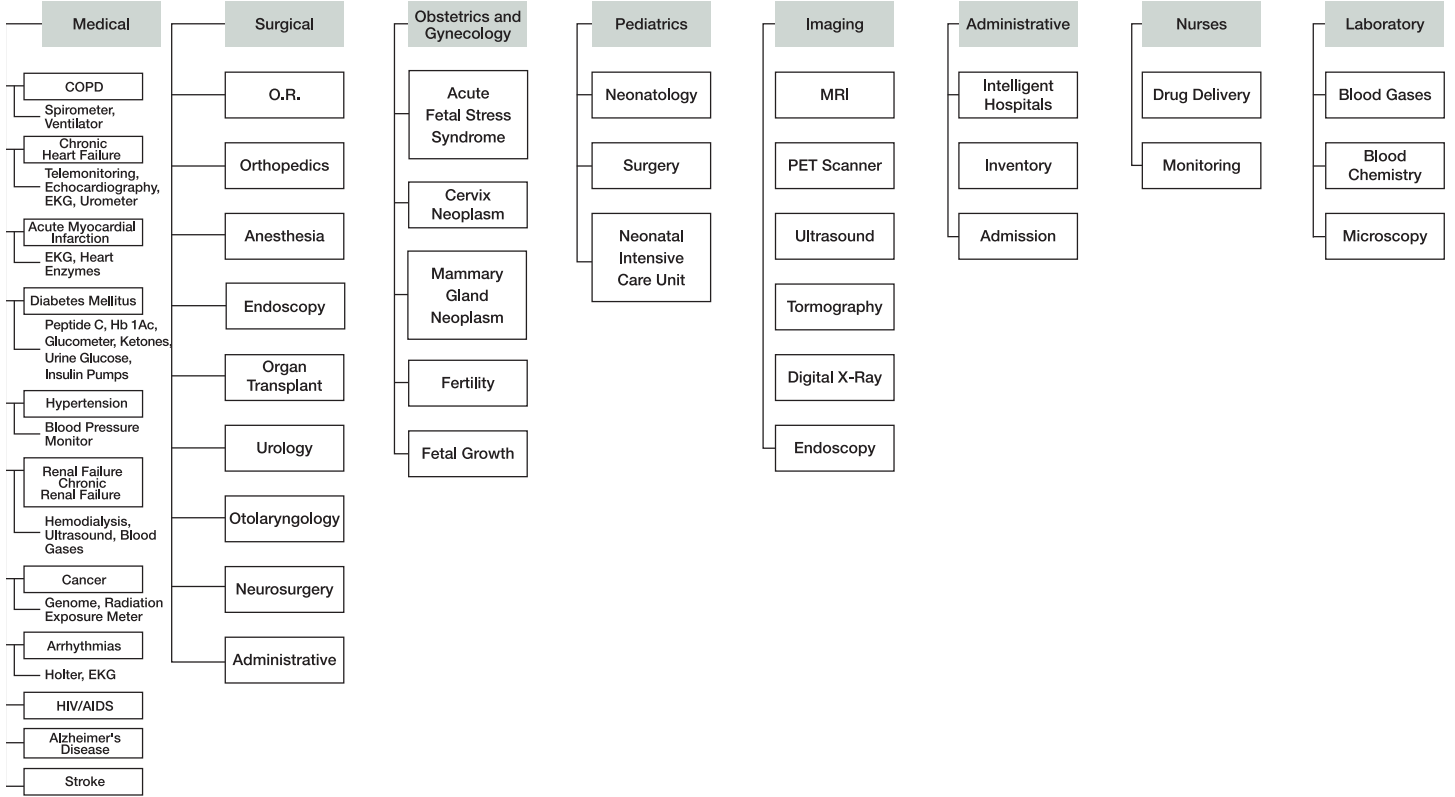
TABLE A-1: FILTERS FOR MEDICAL APPLICATIONS

Type	Circuit	Cut frequency	Equation
Band-pass passive		0.1–150 Hz Heart operating range	$f_0 = \dfrac{1}{2\pi RC}$
Reject-band passive		40–60 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	$f_0 = \dfrac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$

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 to attain a more accurate diagnosis. These filters can be built with passives or actives (opamps) depending on the application, although active filters are more effective at rejecting noise. Passive filters are more suitable in some cases due to their cost effectiveness. An MCU does not always have a DAC. This can be built by the PWM module and external low-pass filter to convert digital data to analog data.

FIGURE A-10: APPLICATIONS BASED ON MEDICAL SPECIALTIES

Medical	Surgical	Obstetrics and Gynecology	Pediatrics	Imaging	Administrative	Nurses	Laboratory
COPD	O.R.	Acute Fetal Stress Syndrome	Neonatology	MRI	Intelligent Hospitals	Drug Delivery	Blood Gases
Spirometer, Ventilator	Orthopedics	Cervix Neoplasm	Surgery	PET Scanner	Inventory	Monitoring	Blood Chemistry
Chronic Heart Failure	Anesthesia	Mammary Gland Neoplasm	Neonatal Intensive Care Unit	Ultrasound	Admission		Microscopy
Telemonitoring, Echocardiography, EKG, Urometer	Endoscopy	Fertility		Tormography			
Acute Myocardial Infarction	Organ Transplant	Fetal Growth		Digital X-Ray			
EKG, Heart Enzymes	Urology			Endoscopy			
Diabetes Mellitus	Otolaryngology						
Peptide C, Hb 1Ac, Glucometer, Ketones, Urine Glucose, Insulin Pumps	Neurosurgery						
Hypertension	Administrative						
Blood Pressure Monitor							
Renal Failure Chronic Renal Failure							
Hemodialysis, Ultrasound, Blood Gases							
Cancer							
Genome, Radiation Exposure Meter							
Arrhythmias							
Holter, EKG							
HIV/AIDS							
Alzheimer's Disease							
Stroke							

NOTES

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