ECG and EEG Applications

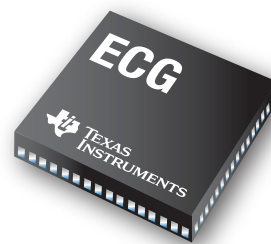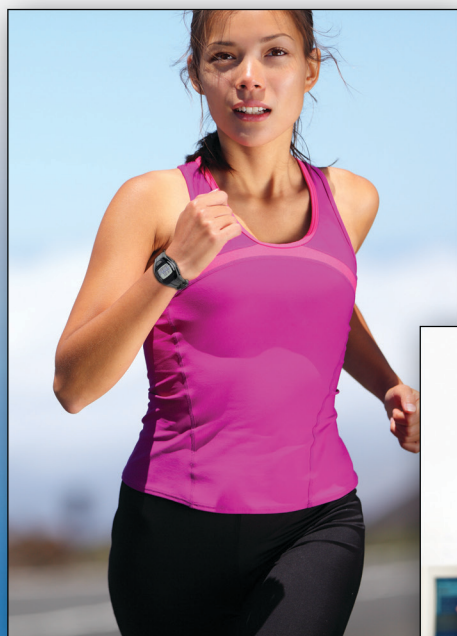**TEXAS INSTRUMENTS**

Quick Reference Guide

ECG and EEG Applications Quick Reference Guide

→ Overview

Biophysical Monitoring Overview

The human medical data acquisition system, in particular the patient monitoring system, presents the challenge to designers of measuring very small electrical signals in the presence of much larger common-mode voltages and noise. Front-end amplifiers perform the essential conditioning that complements downstream digital processing, which in turn refines the measurement and communicates with other systems. Biophysical measurements include electrical and mechanical signals for general monitoring, diagnostic and scientific purposes both in clinic and non-clinic environments. Successfully meeting the signal acquisition challenge requires system designers to have knowledge of the signal source, good design practice and ICs with appropriate characteristics, features and performance.

Signal Acquisition Challenges

The action potential created by heart wall contraction spreads electrical currents from the heart throughout the body. The spreading electrical currents create different potentials at different points on the body, which can be sensed by electrodes on the skin surface using biological transducers made of metals and salts. This electrical potential is an AC signal with bandwidth of 0.05Hz to 100Hz, sometimes up to 1kHz. It is generally around 1mV peak-to-peak in the presence of much larger external high frequency noise plus 50/60Hz interference normal-mode (mixed with the electrode signal) and common-mode voltages (common to all electrode signals).

The common-mode is comprised of two parts: 50Hz or 60Hz interference and DC electrode offset potential. Other noise or higher frequencies within the biophysical bandwidth come from movement artifacts that change the skin-electrode interface, muscle contraction or electromyographic

spikes, respiration (which may be rhythmic or sporadic), electromagnetic interference (EMI), and noise from other electronic components that couple into the input. Some of the noise can be cancelled with a high-input-impedance instrumentation amplifier (INA), like the INA333 or INA118, which removes the AC line noise common to both inputs and amplifies the remaining unequal signals present on the inputs; higher INA common-mode rejection (CMR) will result in greater rejection. Because they originate at different points on the body, the left-arm and right-arm ECG signals are at different voltage levels and are amplified by the INA. To further reject 50 and 60Hz noise, an operational amplifier deriving common-mode voltage is used to invert the common-mode signal and drive it back into the patient through the right leg using an amplifier. Only a few microamps or less are required to achieve significant CMR improvement and stay within the UL544 limit.

Supply Voltage

As in most other applications, the system supply voltage in biophysical monitoring continues the trend toward low, single-supply levels. While bipolar supplies are still used, 5V systems are now common and trending to single 3.3V supplies. This trend presents a significant challenge for the designer faced with at least a 300mV DC electrode potential and emphasizes the need for a precision signal-conditioning solution.

Frequency Response

Standard −3dB frequency bandwidth for patient monitoring is 0.05Hz to 30Hz, while diagnostic grade monitoring requires 0.05Hz to 100Hz or more. The analog front end must be AC coupled to remove artifacts from the electrode offset potential.

Instrumentation Amplifier Requirements

- Stability in low gain (Gain = 1 to 10)
- High common-mode rejection
- Low input bias current (I_B)
- Good swing to the output rail
- Very low offset and drift
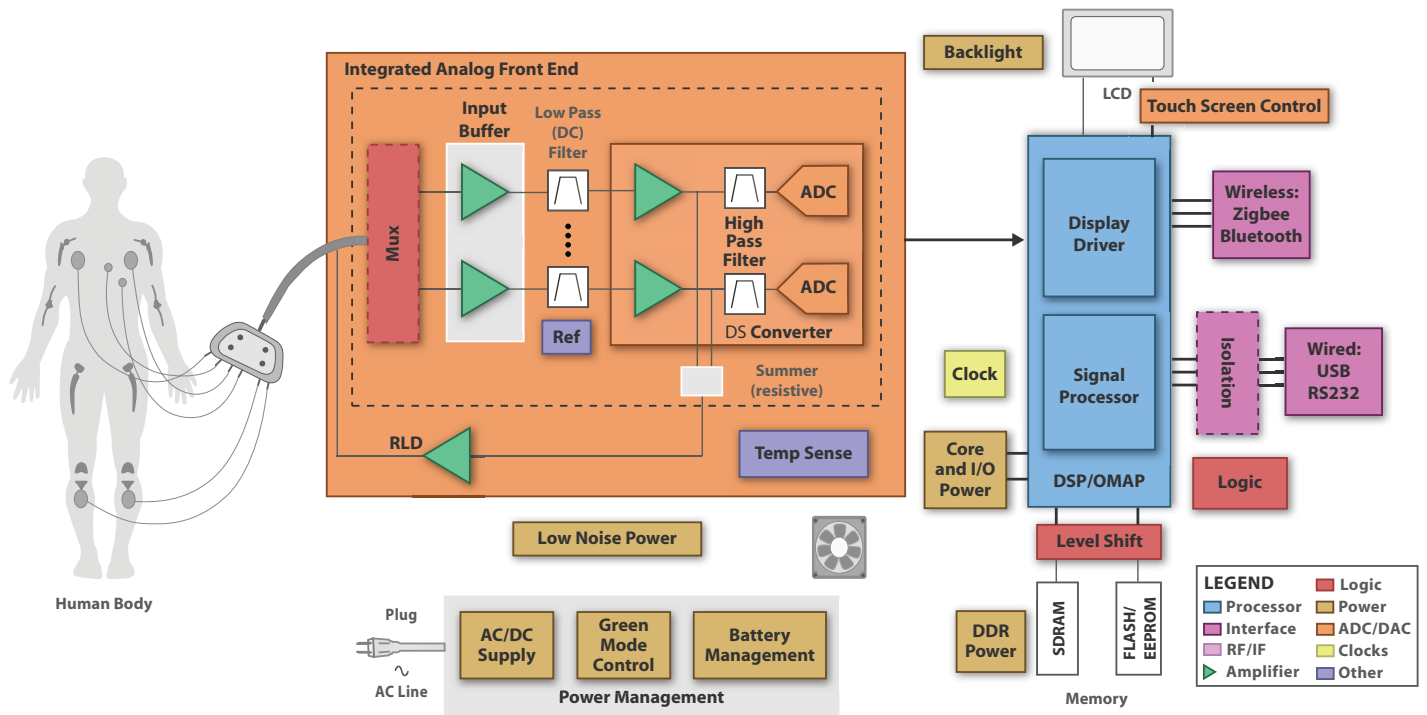
Operational Amplifier Requirements

- Low noise in high gain (Gain = 10 to 1000)
- Rail-to-rail output
- Very low offset and drift

Connectivity for ECG/EEG equipment has become of interest as caregivers require data to move from medical end equipment to data hubs such as the hospital/clinic IT infrastructure, computers or even mobile phones.

For more information, visit www.ti.com/ecg

ECG and EEG Applications Quick Reference Guide

→ Overview

Integrated Analog Front End

Input Buffer · Low Pass (DC) Filter · High Pass Filter · ADC · DS Converter · Summer (resistive) · Mux · Ref · RLD · Temp Sense

Human Body

Low Noise Power

Plug · AC Line · AC/DC Supply · Green Mode Control · Battery Management · **Power Management**

Backlight · LCD · Touch Screen Control · Display Driver · Wireless: Zigbee Bluetooth · Signal Processor · Isolation · Wired: USB RS232 · Clock · Core and I/O Power · DSP/OMAP · Logic · Level Shift · DDR Power · SDRAM · FLASH/EEPROM · Memory

LEGEND
Processor · Logic · Power · Interface · ADC/DAC · RF/IF · Clocks · Amplifier · Other

Three ECG electrodes connected to patient using CMOS components w/5V single supply. This circuit will operate on a 3.3V supply.

Product Availability and Design Disclaimer – The system block diagram depicted above and the devices recommended are designed in this manner as a reference. Please contact your local TI sales office or distributor for system design specifics and product availability.
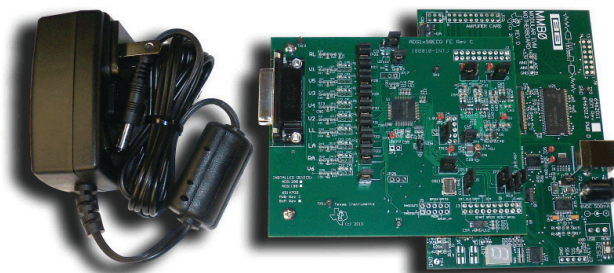
ADS1298ECG Front End Performance Demonstration Kit
ADS1298ECGFE-PDK

Get samples and datasheets at: **www.ti.com/sc/device/ADS1298ecgfe-pdk**

Key Features
- Easy-to-use evaluation software for Microsoft™ Windows XP
- Built-in analysis tools including oscilloscope, FFT, and histogram displays
- Flexible input configurations
- Optional external reference circuits
- Ability to export data in simple test files for post processing

The ADS1298ECG FE is a reference design for the ADS1298, a simultaneous sampling, 24-bit, delta-sigma ($\Delta\Sigma$) analog-to-digital converter (ADC) with a built-in programmable gain amplifier (PGA), internal reference, and an onboard oscillator. The ADS1298 incorporates all of the features that are commonly required in medical electrocardiogram (ECG) and electroencephalogram (EEG) applications. The ADS1298ECG FE can be used with a variety of patient simulators and allows the user to take advantage of the flexible input multiplexer which can be independently connected to the internally-generated signals for test, temperature, and lead-off detection.

ADS1298ECG front end performance demonstration kit.

3

ECG and EEG Applications Quick Reference Guide

→ Solutions

Low-Power, 8-Channel, 24-Bit Analog Front End for Biopotential Measurements
ADS1298

Get samples and datasheets at: **www.ti.com/sc/device/ADS1298**

Key Features
- Eight low-noise PGAs and eight high-resolution ADCs (ADS1298)
- Low power: 0.75mW/channel
- Input-referred noise: 4µVPP (150Hz BW, G = 6)
- Input bias current: 200pA (max)
- Data rate: 250SPS to 32kSPS
- CMRR: –115dB
- Programmable gain: 1, 2, 3, 4, 6, 8 or 12
- Built-in right leg drive amplifier, lead-off detection, WCT, test signals

Applications
- Medical instrumentation (ECG and EEG), including:
  - Patient monitoring; holter, event, stress, and vital signs ECG, AED, telemedicine, fetal ECG
  - Bispectral index (BIS), evoked audio potential (EAP), sleep study monitor
- High-precision, simultaneous, multichannel signal acquisition

The ADS1294/6/8 are a family of multichannel, simultaneous sampling, 24-bit, delta-sigma (ΔΣ) analog-to-digital converters (ADCs) with a built-in programmable gain amplifier (PGA), internal reference and onboard oscillator. The ADS1294/6/8 incorporate all of the features that are commonly required in medical electrocardiogram (ECG) and electroencephalogram (EEG) applications.

With its high levels of integration and exceptional performance, the ADS1294/6/8 family enables the creation of scalable medical instrumentation systems at significantly reduced size, power and overall cost.
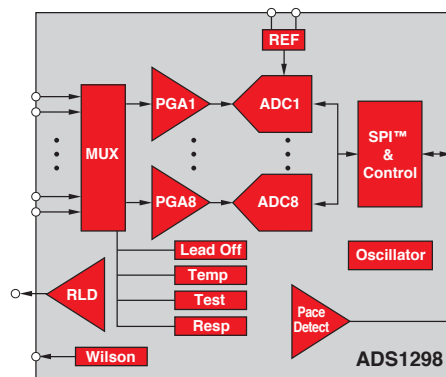
ADS1298 functional block diagram.

Biopotential Sensing (ECG/EEG) Delta-Sigma ADCs

Device	Res. (Bits)	Sample-Rate (kSPS)	Number of Input Channels	Interface	Input-Referred Noise (µVpp)	Common Mode Rejection (dB)	Power (mW)	HiRel Avail.	Package(s)	Price*
ADS1298	24	32	8 Diff	SPI	4	115	6	N	BGA-64, TQFP-64	23.95
ADS1298R	24	32	8 Diff	SPI	3	115	6	N	BGA-64	23.95
ADS1296	24	32	6 Diff	SPI	4	115	5.1	N	BGA-64, TQFP-64	17.95
ADS1294	24	32	4 Diff	SPI	4	115	3.6	N	BGA-64, TQFP-64	11.95
ADS1198	16	8	8 Diff	SPI	12	100	4.5	N	BGA-64, TQFP-64	8.00
ADS1196	16	8	6 Diff	SPI	12	100	3.9	N	BGA-64, TQFP-64	11.95
ADS1194	16	8	4 Diff	SPI	12	100	3	N	BGA-64, TQFP-64	15.95

Suggested resale price in U.S. dollars in quantities of 1,000.

*New products are listed in **bold red.***

ECG and EEG Applications Quick Reference Guide

➔ Solutions

2-Ch., 24-Bit Fully Integrated ADC for Medical Instrumentation and Sports and Fitness Applications
ADS1292

Get samples and datasheets at: **www.ti.com/sc/device/ADS1292**

Key Features

- Fully integrated ECG solution
- Optimized low noise PGA and 24-bit ADC
  - ADS1291: 1 channel
  - ADS1292: 2 channels
- Test signals, RLD amp, oscillator, reference
- Outstanding performance
  - Noise: less than 8µV p-p (150Hz BW, G=6)
  - CMRR: 105dB with G = 6
- Continuous lead off detection
- Low Power
  - Less than 350µW per channel
  - Standby mode: 160µW overall consumption

Applications

- Medical instrumentation:
  - 1- and 3-Lead ECG
  - Heart rate
  - AED
  - Holter
- Sports and fitness applications
  - Chest straps
  - Work-out equipment
  - Wrist watches

An ADS1292 solution takes up 92% less PCB space, consumes 94% less power, and uses 92% fewer components compared to a discrete implementation of a 2-channel Holter. Similarly, an ADS1291 solution takes up 52% less PCB space, 89% lower power consumption, and 75% fewer components over a discrete implementation.

Designers interested in creating a complete line of biopotential measurement products now have a family of devices to meet their needs from low lead count heart rate monitors (ADS1291) to 12-lead ECG systems (ADS1298).
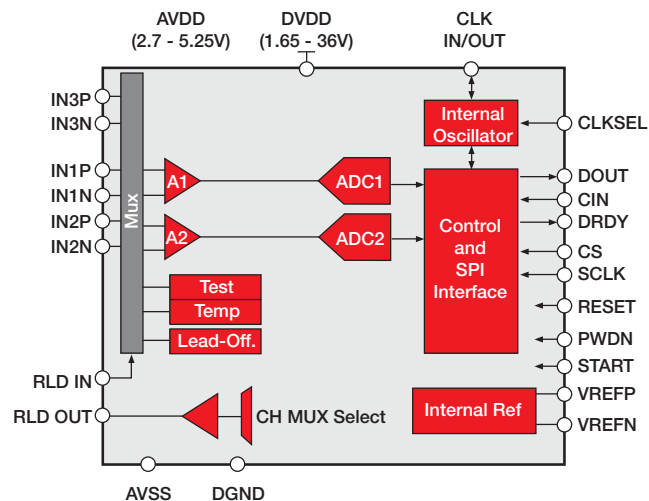
ADS1292 functional block diagram.

Alternative Solutions

Device	Resolution	No. of Input Chs.	Respiration	Input-Referred Noise (μV_{pp})	Price*
ADS1298	24-bit	8	No	3	23.95
ADS1298R	24-bit	8	Yes	3	23.95
ADS1198	16-bit	8	No	12.2	14.35
ADS1296	24-bit	6	No	3	17.95
ADS1296R	24-bit	6	Yes	3	17.95
ADS1196	16-bit	6	No	12.2	11.35
ADS1294	24-bit	4	No	3	11.95
ADS1294R	24-bit	4	Yes	3	11.95
ADS1194	16-bit	4	No	12.2	7.80
ADS1292	24-bit	2	No	8	3.50
ADS1292R	24-bit	2	Yes	8	4.50
ADS1192	16-bit	2	No	24	2.50
ADS1291	24-bit	1	No	8	2.00
ADS1191	16-bit	1	No	24	1.50

Suggested resale price in U.S. dollars in quantities of 1,000.

*New products are listed in **bold red.***

ECG and EEG Applications Quick Reference Guide

→ Solutions

High-Performance, Low-Power, Fixed-Point Digital Signal Processor
TMS320C5515

Get datasheets, samples and technical documents at: **www.ti.com/sc/device/TMS320C5515**
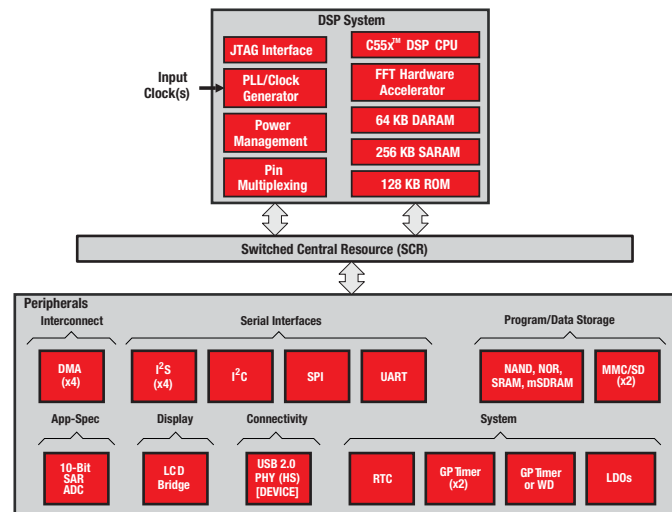
Key Features

- 320K bytes zero-wait state on-chip RAM, composed of:
  - 64K bytes of dual-access RAM (DARAM), 8 blocks of 4K × 16-bit
  - 256K bytes of single-access RAM (SARAM), 32 blocks of 4K × 16-bit
- 128K bytes of zero wait-state on-chip ROM (4 blocks of 16K × 16-bit)
- 4M × 16-bit maximum addressable external memory space (SDRAM/mSDRAM)
- 16-/8-bit external memory interface (EMIF)
- Direct memory access (DMA) controller

Applications

- Industrial controls
- Portable medical devices
- Wireless audio devices

The TMS320C5515 fixed-point DSP is based on the TMS320C55x™ DSP generation CPU processor core. The C55x™ DSP architecture achieves high performance and low power through increased parallelism and total focus on power savings. The CPU supports an internal bus structure that is composed of one program bus, one 32-bit data read bus and two 16-bit data read buses, two 16-bit data write buses, and additional buses dedicated to peripheral and DMA activity. These buses provide the ability to perform up to four 16-bit data reads and two 16-bit data writes in a single cycle.

TMS320C5515 block diagram.

ECG and EEG Applications Quick Reference Guide

➜ Solutions

C6-Integra™ DSP+Arm Processor
OMAP-L138

Get datasheets, samples and technical documents at: **www.ti.com/sc/device/omap-l138**
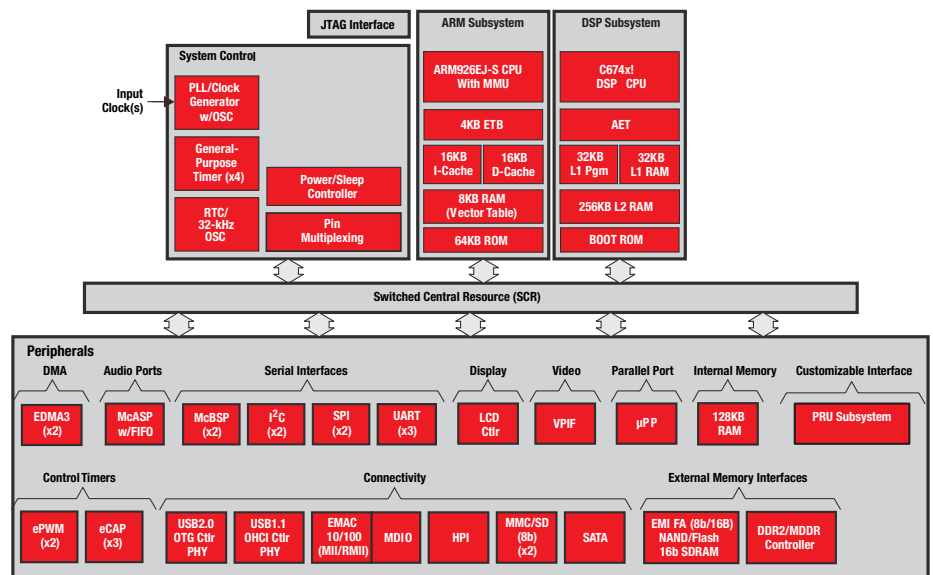
Key Features
- Dual core SoC
- Supports TI's basic secure boot
- Enhanced direct-memory-access controller (EDMA3)
- Serial ATA (SATA) controller
- DDR2/mobile DDR memory controller
- Two multimedia card (MMC)/secure digital (SD) card interface
- LCD controller
- Video port interface (VPIF)
- 10/100 Mb/s ethernet MAC (EMAC)
- Programmable real-time unit subsystem
- Three configurable UART modules
- USB 1.1 OHCI (Host) w/integrated PHY
- USB 2.0 OTG port with integrated PHY
- One multichannel audio serial port
- Two multichannel buffered serial ports

Applications
- Electrocardiogram (ECG)
- Pulse oximetry
- Software defined radio

The OMAP-L138 C6-Integra™ DSP+ARM processor is a low-power applications processor based on an ARM926EJ-S and a C674x DSP core. The dual-core architecture of the device provides benefits of both DSP and Reduced Instruction Set Computer (RISC) technologies, incorporating a high-performance TMS320C674x DSP core and an ARM926EJ-S core while providing significantly lower power than other members of the TMS320C6000™ platform of DSPs.

The device enables OEMs and ODMs to quickly bring to market devices featuring robust operating systems support, rich user interfaces, and high processing performance life through the maximum flexibility of a fully integrated mixed processor solution. It is capable of the highest level of diagnostic accuracy and enables wireless/wired transfer and 2D/3D display on large LCD screen with touch screen capabilities.

OMAP-L138 functional block diagram.

ECG and EEG Applications Quick Reference Guide

→ Solutions

Mixed-Signal Microcontroller
MSP430F6638

Get datasheets, samples and technical documents at: **www.ti.com/sc/device/MSP430F6638**

Key Features

- Low supply voltage range, 1.8V to 3.6V
- Ultra-low power consumption
- Wake-up from standby mode in < 5µs
- 16-bit RISC architecture, extended memory, up to 20-MHz system clock
- Flexible power management system
- Unified clock system
- 16-bit timer TA0, Timer_A with five capture/compare registers
- 16-bit timer TA1, Timer_A with three capture/compare registers

Applications

- Analog and digital sensor systems
- Digital timers
- Hand-held meters
- Thermostats

The Texas Instruments MSP430™ family of ultra-low-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low power modes is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 5µs.

The MSP430F663x series are microcontroller configurations with four 16-bit timers, a high performance 12-bit analog-to-digital (A/D) converter, 12-bit digital to analog (D/A) converter, two universal serial communication interfaces (USCI), hardware multiplier, DMA, real-time clock module with alarm capabilities, comparator and USB 2.

MSP430F6638 functional block diagram.

ECG and EEG Applications Quick Reference Guide

➜ Solutions

Sitara™ ARM Microprccesor
AM1802

Get datasheets, samples and technical documents at: **www.ti.com/sc/device/AM1802**

Key Features

- ARM9 memory architecture
- Enhanced direct-memory-access controller 3 (EDMA3)
- Two external memory interfaces
- Two serial peripheral interfaces (SPI)
- Three configurable 16550 type UART modules
- Multiamedia card (MMC)/secure digal (SD) card interface with secure data I/O (SDIO)
- One master/slave integrated circuit
- One multichannel audio serial port
- 10/100 Mb/s Ethernet MAC (EMAC)

Applications

- Electrocardiogram (ECG)
- Pulse oximetry

The device is a low-power applications processor based on ARM926EJ-S™. The ARM926EJ-S is a 32-bit RISC processor core that performs 32-bit or 16-bit instructions and processes 32-bit, 16-bit, or 8-bit data. The core uses pipelining so that all parts of the processor and memory system can operate continuously.

The device enables OEMs and ODMs to quickly bring to market devices featuring robust operating systems support, rich user interfaces, and high processing performance life through the maximum flexibility of a fully integrated mixed processor solution.
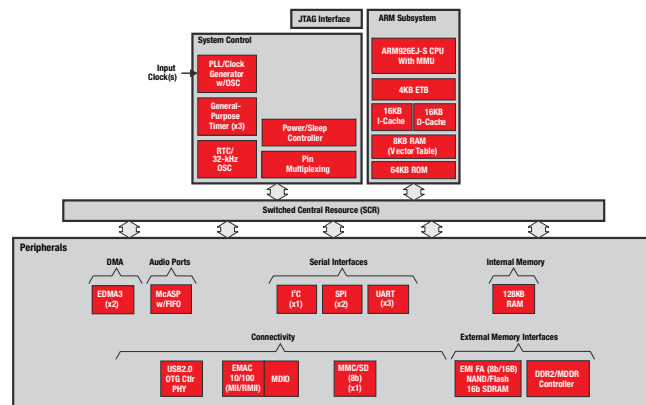
AM1802 functional block diagram.

Digital Media Processor
DM3730

Get datasheets, samples and technical documents at: **www.ti.com/sc/device/DM3730**

Key Features

- Compatible with OMAP™ 3 architecture
- ARM® microprocessor (MPU) subsystem
- High performance image, video, audio (IVA2.2™) accelerator subsystem
- Power SGX™ graphics accelerator

Applications

- Human interface
- Medical imaging
- Portable data terminals

The DM37x generation of high-performance, applications processors are based on the enhanced device architecture and are integrated on TI's advanced 45-nm process technology. This architecture is designed to provide best in class ARM and Graphics performance while delivering low power consumption. This balance of performance and power allow the device to support medical imaging, human interface and portable data terminal applications.
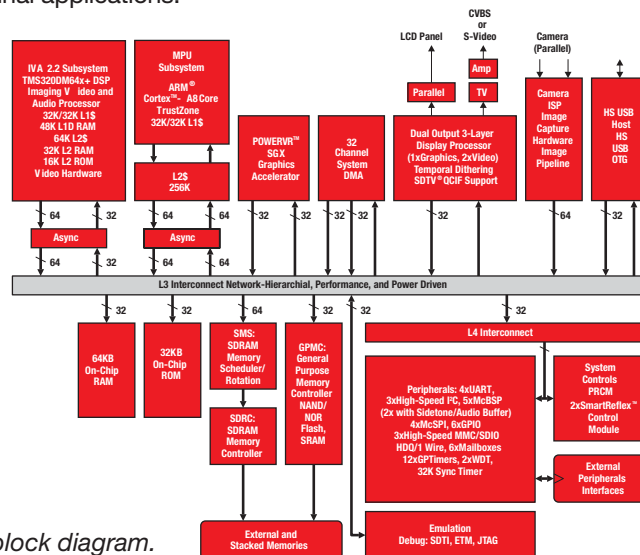
DM3730 functional block diagram.

ECG and EEG Applications Quick Reference Guide

→ Solutions

Zero-Drift, Low-Offset, Single-Supply Op Amps
OPA334, OPA335

Get samples, datasheets, evaluation modules and application reports at: **www.ti.com/sc/device/OPA334** or **www.ti.com/sc/device/OPA335**
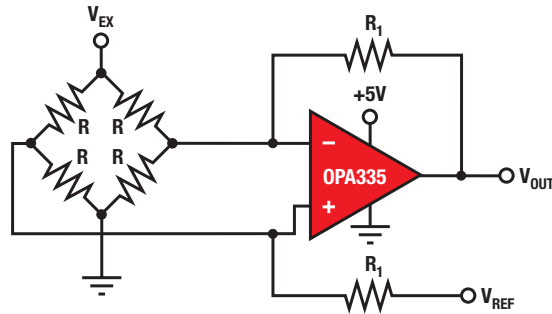
Key Features

- GBW: 2MHz
- Low offset voltage: 5µV (max)
- Zero drift: 0.05µV/°C (max)
- Quiescent current: 285µA
- EMI input filtered
- Shutdown available on OPA344
- Packaging: SOT23-5, SOT23-6, SO-8, MSOP-10 (dual)

Applications

- Transducer applications, such as pressure sensing
- Electronic weight scales
- Temperature measurement

The OPA334 and OPA335 CMOS op amps use auto-zeroing techniques to simultaneously provide very low offset voltage and near-zero drift over time and temperature. These high-precision amps offer high input impedance and rail-to-rail output swing.

OPA335 –5V supply bridge amplifier for high CMRR

Low Power, Precision Instrumentation Amplifier
INA333

Get samples, datasheets, evaluation modules and application reports at: **www.ti.com/sc/device/INA333**

Key Features

- Low offset voltage: 25µV (max), G ≥ 100
- Low drift: 0.1µV/°C, G ≥ 100
- Low noise: $50nV/\sqrt{Hz}$, G ≥ 100
- High CMRR: 100dB (min), G ≥ 10
- Low input bias current: 200pA(max)
- Supply range: +1.8V to +5.5V
- Input voltage: (V-) +0.1V to (V+) -0.1V
- Output range: (V-) +0.05V to (V+) -0.05V
- Low quiescent current: 50µA
- Operating temperature: -40°C to +125°C
- RFI filtered inputs
- MSOP-8 and DFN-8 packages

Applications

- ECG amplifiers
- Medical instrumentation
- Portable insrumentation
- Weigh scales

The INA333 is a low-power, precision instrumentation amplifier offering excellent accuracy. The versatile 3-op amp design, small size, and low power make it ideal for a wide range of portable applications.

The INA333 provides very low offset voltage, excellent offset voltage drift, and high common-mode rejection. It operates with power supplies as low as 1.8V (±0.9V), and quiescent current is only 50µA—ideal for battery-operated systems. Using autocalibration techniques to ensure excellent precision over the extended industrial temperature range, the INA333 also offers exceptionally low noise density (50 $nV/\sqrt{Hz}$) that extends down to dc.

$$G = 1 + \left[\frac{100k\,\Omega}{R_G}\right]$$
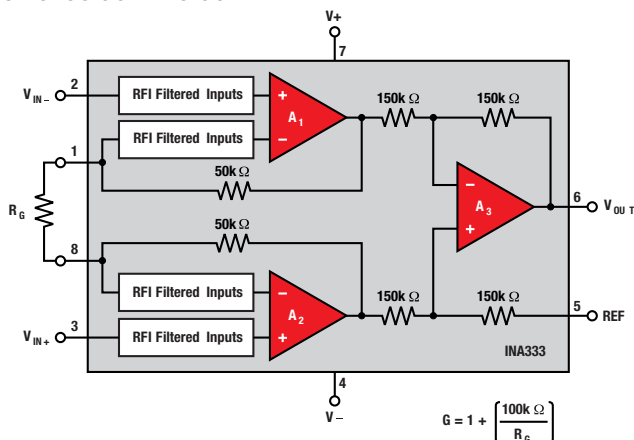
INA333 functional block diagram.

ECG and EEG Applications Quick Reference Guide

→ *Solutions*

3ppm/°C Drift, 0.05% Accurate, Low-Noise, Precision Series Voltage References
REF5020, REF5025, REF5030, REF5040, REF5045, REF5050, REF5010

Get samples, datasheets and app reports at: **www.ti.com/sc/device/PARTnumber** (Replace **PARTnumber** with **REF5020**, **REF5025**, **REF5030**, **REF5040**, **REF5045**, **REF5050** or **REF5010**)
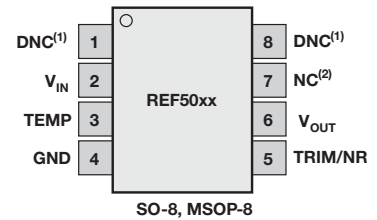
Key Features

- High accuracy: 0.05%
- Low temperature drift: 3ppm/°C (max)
- Very low noise: $3\mu V_{PP}/V$
- High output current: ±10mA
- Wide supply range: 2.7V to 18V
- Industrial temperature range: −40°C to +125°C
- Packaging: SO-8, MSOP coming soon

Applications

- Test and measurement
- 16-bit data acquisition systems
- Medical and patient monitoring
- Industrial process control

The REF50xx brings a new level of precision to the TI series voltage reference line. Offering 3ppm/°C (max) drift and 0.05% initial accuracy and very low noise, the REF50xx is designed for industrial, medical and test applications that require performance over temperature.

Model	Voltage Out
REF5020	2.048V
REF5025	2.5V
REF5030	3.0V
REF5040	4.096V
REF5045	4.5V
REF5050	5V
REF5010	10V

REF50xx package diagram

2.95V to 6V Input, 2W, Isolated DC/DC Converter with Integrated FETS
TPS55010

Get samples, datasheets, evaluation modules and application reports at: **www.ti.com/sc/device/TPS55010**

Key Features

- Isolated fly-buck topology
- Primary side feedback
- 100kHz to 2000kHz switching frequency
- Synchronizes to external clock
- Adjustable slow start
- Adjustable input voltage UVLO
- Open-drain fault output
- Cycle-by-cycle current limit
- Thermal shutdown protection
- 3 mm x 3 mm 16-pin QFN package

Applications

- Noise immunity in PLCs, data acquisition and measurement equipment
- Isolated RS-232 and RS-485 communication channels
- Powers line drivers, ISO amplifiers, sensors, CAN transceivers
- Floating supplies for IGBT gate drivers
- Promotes safety in medical equipment

The TPS55010 is a transformer driver designed to provide isolated power for isolated interfaces, such as RS-485 and RS-232, from 3.3V or 5V input supply. The device uses fixed frequency current mode control and half bridge power stage with primary side feedback to regulate the output voltage for power levels up to 2W. The switching frequency is adjustable from 100kHz to 2000kHz so solution size, efficiency and noise can be optimized. The switching frequency is set with a resistor or is synchronized to external clock using the RT/CLK pin. To minimize inrush currents, a small capacitor can be connected to the SS pin. The EN pin can be used as an enable pin or to increase the default input UVLO voltage from 2.6V.
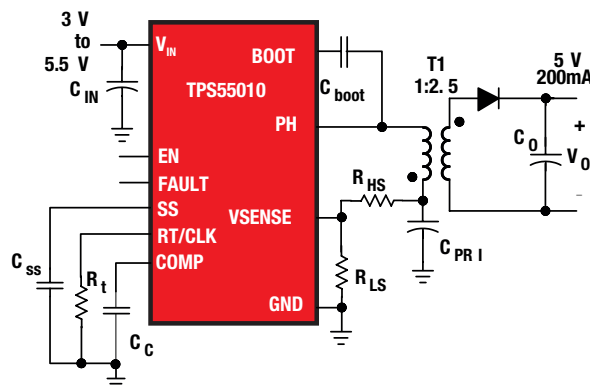
TPS55010 functional block diagram.

ECG and EEG Applications Quick Reference Guide

➡️ *Solutions*

60mA Charge Pump Voltage Inverter with Fixed 250kHz Operation
TPS60403

Get samples, datasheets, evaluation modules and application reports at: **www.ti.com/sc/device/TPS60403**
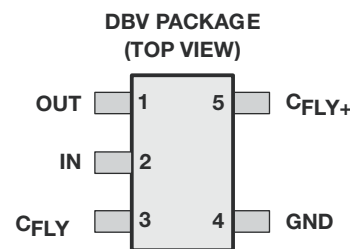
Key Features
- Inverts input supply voltage
- Up to 60-mA output current
- Only three small 1-µF ceramic capacitors needed
- Input voltage range from 1.6V to 5.5V
- PowerSave-mode for improved efficiency at low output currents (TPS60400)
- Device quiescent current typical 65µA
- Integrated active Schottky-diode for start-up into load
- Small 5-pin SOT23 package

Applications
- Battery-operated equipment
- LCD bias
- Medical instruments
- Sensor supply in portable instruments

The TPS6040x is a family of devices that generate an unregulated negative output voltage from an input voltage ranging from 1.6V to 5.5V. The devices are typically supplied by a preregulated supply rail of 5V or 3.3V. Due to its wide input voltage range, two or three NiCd, NiMH, or alkaline battery cells, as well as one Li-Ion cell can also power them.

Only three external 1-µF capacitors are required to build a complete dc/dc charge pump inverter. Assembled in a 5-pin SOT23 package, the complete converter can be built on a 50mm2 board area. Additional board area and component count reduction is achieved by replacing the Schottky diode that is typically needed for start-up into load by integrated circuitry.

DBV PACKAGE (TOP VIEW)

TPS60403 package.

Bluetooth® v2.1 + EDR (Enhanced Data Rate) Transceiver
CC2560-PAN1325

NEW

Get samples, datasheets and app reports at: **www.ti.com/cc2560-pan1325**

Key Features
- Fully qualified *Bluetooth®* v2.1 + EDR (enhanced data rate)
- +10dBm Tx power with transmit power control
- -93dBm receiver sensitivity
- Support for *Bluetooth®* power saving modes
- Integrated antenna (PAN1315 available without antenna)
- HW and SW pre-integration with TI's MSP430 and Stellaris platforms
- *Bluetooth®*, FCC, CE, IC certified
- Dimensions: 9 mm x 9.5 mm x 1.8 mm
- *Bluetooth®* + ANT, and *Bluetooth®*

Applications
- Cable replacement
- Wireless sensors
- Medical devices
- Computer peripherals
- Industrial control
- Consumer devices

The CC2560-PAN1325 is a highly-integrated class 2 HCI module with increased output power capabilities offered by Panasonic utilizing TI's CC2560 *Bluetooth®* 2.1 + EDR Transceiver. Based on TI's 7th generation *Bluetooth®* technology, the solution provides best-in-class *Bluetooth®* RF performance of +10dBm Tx power and -93 dBm receiver sensitivity. This solution is provided as a module to help customers reduce development time, lower manufacturing costs, save board space, ease certification, and minimize RF expertise required. For evaluation and development, various platforms are available which integrate the Panasonic module, *Bluetooth®* stack, Profiles (SPP for MSP430™, SPP + A2DP for Stellaris™), and sample source applications running on a TI host controller (MSP430, Stellaris).
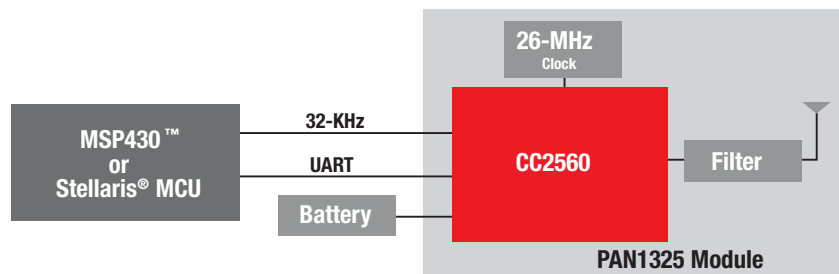
CC2560-PAN1325 *Bluetooth®* **system**

CC2560-PAN1325 system block diagram.

ECG and EEG Applications Quick Reference Guide

→ *Solutions*

Second Generation System-on-Chip Solution for 2.4 GHz IEEE 802.15.4 / RF4CE / ZigBee®
CC2530

Get samples, datasheets and evaluation modules at: **www.ti.com/CC2530**
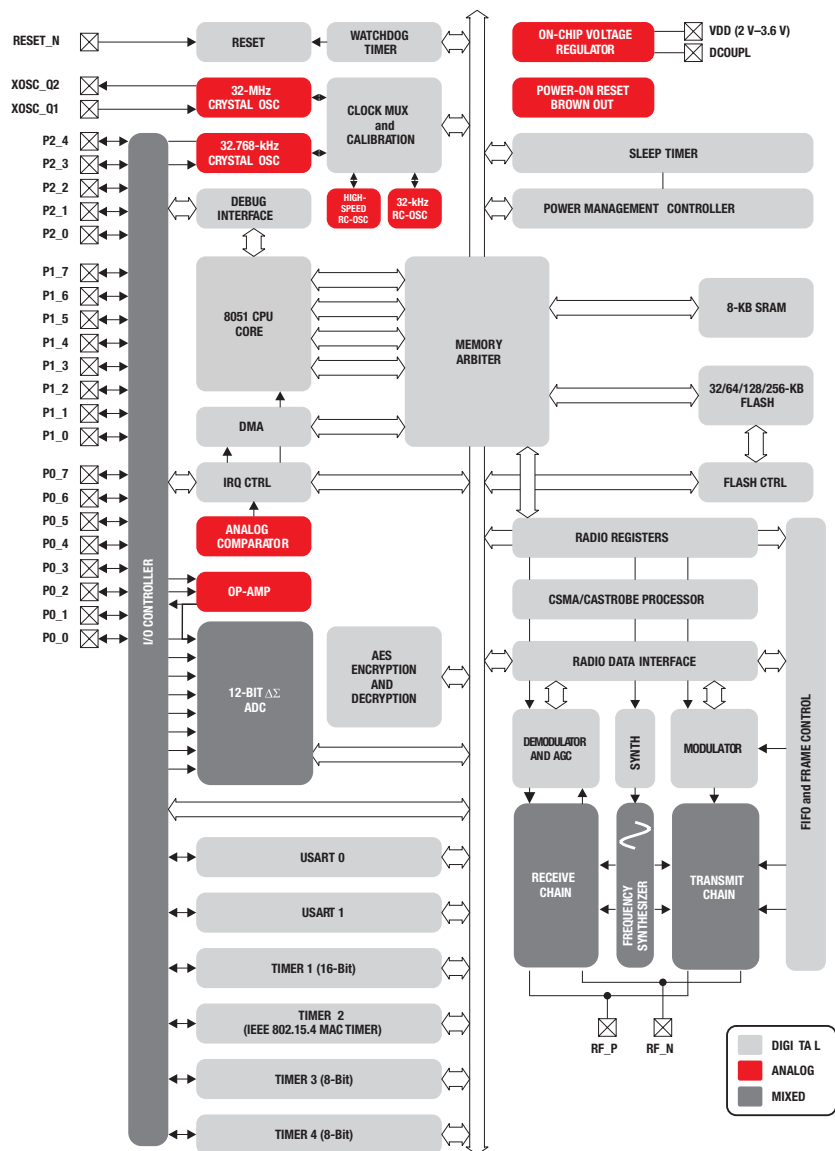
Key Features
- 2.4-GHz IEEE 802.15.4 compliant RF transceiver
- Excellent receiver sensitivity and robustness to interference
- Programmable output power up to 4.5dBm
- Very few external components
- Only a single crystal needed for asynchronous networks
- Wide supply-voltage range (2V–3.6V)

Applications
- 2.4-GHz IEEE 802.15.4 systems
- Consumer electronics
- Low-power wireless sensing networks
- Health care
- ZigBee® systems (256-KB flash)

The CC2530 is a true system-on-chip (SoC) solution for IEEE 802.15.4, Zigbee® and RF4CE applications. It enables robust network nodes to be built with very low total bill-of-material costs. The CC2530 combines the excellent performance of a leading RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and many other powerful features. The CC2530 comes in four different flash versions: CC2530F32/64/128/256, with 32/64/128/256KB of flash memory, respectively. The CC2530 has various operating modes, making it highly suited for systems where ultralow power consumption is required. Short transition times between operating modes further ensure low energy consumption.

CC2530 block diagram.

ECG and EEG Applications Quick Reference Guide

→ **Selection Table**

Component Recommendations

Component	Description	Key Features	Benefits	Other TI Solutions
Amplifiers				
INA118	Instrumentation Amp	110dB CMRR, 5nA (max) bias current, 50μV (max) offset	Wide BW at high gain, ±1.35V to ±18V supply	INA128, INA121
INA121	Instrumentation Amp	106dB CMRR, 4pA (max) bias current, 200μV (max) offset	Low input bias current	INA126
INA126	Instrumentation Amp	175μA/ch supply, 3μV/°C (max) drift, 250μV (max) offset	Precision low power, ±1.35V to ±18V supply	INA2126
INA128	Instrumentation Amp	120dB CMRR, 5nA (max) bias current, 50μV (max) offset	High CMRR, wide BW at high gain, ±2.25V to ±18V supply	INA129
OPA277	Op Amp	10μV offset, ±0.1μV/°C drift, 134dB open-loop gain	High precision, low drift, low power	OPA2277 (dual) OPA4277 (quad)
INA326	Instrumentation Amp	120dB CMRR (G = 100), 100μV (max) offset, 0.4μV/°C (max) drift	High CMRR, low cost, +2.7V to +5.5V	INA321, INA333
INA333 *Page 10*	Instrumentation Amp	25μV (max) offset, 50nV/°C drift, 50μA (typ) Iq	Best offset/noise combination, supply down to 1.8V, low power	INA326, INA321
OPA130	FET-Input Amplifier	20pA (max) bias current, 90dB (min) CMRR, 1MHz BW	Precision, low input bias, low power	OPA131, OPA137
OPA333	Precision Op Amp	1.8V min supply, 0.017mA/ch (max), 10μV offset (max), 0.05μV/°C drift (max)	Zero drift, high precision, low power, EMI input	OPA335, OPA378, **OPA330**
OPA334/5 *Page 10*	Op Amp	2MHz, 5μV (max) offset, 0.05μV/°C (max) drift, 285μA	Provides very low offset voltage and near-zero drift over time and temperature; SOT23	OPA735, OPA333, OPA334
OPA336	Op Amp	125μV (max) offset, 1.5μV/°C drift, 20μA supply	micoPower, SOT23 package	OPA379
OPA378	Low Noise Precision Op Amp	0.1μV/°C Vos drift, 125μA, 900kHz, 0.4μV$_{PP}$ (0.1Hz to 10Hz) 0.4μ V$_{pp}$ (0.1Hz to 10Hz), 0.9MHz	Lowest noise, power, price, precision zero-drift option	**OPA330**, OPA333
OPA2378	Precision Op Amp	2.2V to 5.5V supply, 20μV voltage, 0.1μV/°C drift, 125μA quiescent current	Has excellent PSRR which makes it an ideal choice for applications that run direct from batteries without regulation	
THS4521/22/24	Low Power FDA	1.14mA quiescent current (typ), 4.6nV/$\sqrt{Hz}$ voltage noise, 2.5V to 5.5V supply	Low power, low noise enables high accuracy	
Data Converters				
ADS1258	Delta-Sigma ADC	16-channel, 24-bit, 125kSPS, 23.7kSPS/channel	Fastest multi-channel, delta-sigma ADC, measures all 16 inputs in <675μs	ADS1256, ADS1255, ADS8344
ADS1271/74/78	Delta-Sigma ADC	24-bit, 128kSPS, 8-channel, 111dB SNR	Simultaneous measurement, onboard decimation filter	
ADS1298 *Page 4*	ECG/EEG AFE	24-bit, 8 PGA, 8 ADC, plus RLD and RESP	Complete front end, reduction in power and size, increase reliability	**ADS1294, ADS1296, ADS1198,** ADS1258
ADS8317	SAR ADC	16-bit, 250kSPS, 2.7V to 5.5V supply, ±1.5 LSB (max) INL, differential input	Low power, small package, and wide supply range	ADS8326
ADS8326	Low-Power ADC	16-bit, 250kSPS, 2.7V to 5.5V supply, ±1.5 LSB (max) INL	Small package, wide supply range	
ADS8331/32	SAR ADC	16-bit, 500kSPS, 4/8 channels, with serial interface	Mux out feature can be used to reduce system part count and overall cost	ADS8342
ADS8341/2/3/4/5	Serial Output ADC	16-bit, 4-/8-channel single-ended or 2-channel differential input, 2.7V to 5V single supply ADC	Easy to use	
ADS8519	High Volt. SAR ADC	16-bit, 250kSPS, 1.5LSB (max) INL, 92dB SNR	Single supply, high voltage inputs	ADS8515
DDC112	Charge-Digitizing ADC	Dual current input, 20-bit ADC, ±0.005% INL reading ±0.5ppm FSR	High precision, true integrating function	DDC114, DDC118, DDC232
References				
REF02	Precision V$_{REF}$	0.2% (max) initial accuracy, 10ppm/°C (max) drift, 1.4mA (max)	Excellent line/load regulation, low noise	REF5050
REF102	10V, Ultra Precision	0.05% (max) initial accuracy, 2.5ppm/°C (max) drift, 1.4mA (max)	Excellent stability and line/load regulation	REF5010
REF30xx	Low-Power, Low-Drift Ref.	50μA, 0.2% initial accuracy, 50ppm/°C max drift, ±25mA output, 1.25V, 2.048V, 2.5V, 3.0V, 3.3V, 4.096V		REF31xx, REF33xx, REF29xx
REF32xx	Ultra-Low-Drift Series Reference	100μA, 0.2% initial accuracy, 7ppm/°C max drift, ±10mA output, 1.25V, 2.048V, 2.5V, 3.0V, 3.3V, 4.096V	Improves system accuracy	
REF33xx	Very Low-Power Series Reference	5μA, 0.15% initial accuracy, 30ppm/°C max drift, ±5mA output, 1.25V, 1.8V, 2.048V, 2.5V, 3.0V, 3.3V	Preserves battery life, fits into physically constrained systems	REF30xx, REF31xx, REF29xx
REF5010	10V, High-Precision, Very Low-Drift Series Reference	0.05% initial accuracy, 3ppm/°C max drift, ±10mA output, 10V	Improves system accuracy	REF102
REF50xx *Page 11*	High-Precision, Very Low-Drift Series Reference	0.05% initial accuracy, 3ppm/°C max drift, ±10mA output, 2.048V, 2.5V, 3.0V, 4.096V, 4.5V, 5.0V	Improves system accuracy	REF02

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ECG and EEG Applications Quick Reference Guide

➜ Selection Table

Component Recommendations (Continued)

Component	Description	Key Features	Benefits	Other TI Solutions
Processors				
AM1802 *Page 9*	Sitara™ ARM Microprccesor	ARM9 memory architecture, EDMA3, two external memory interfaces and two SPI	The device enables OEMs and ODMs to quickly bring to market devices featuring robust operating systems support, rich user interfaces, and high processing performance.	
DM3730 *Page 9*	Digital Media Processor	Compatible with OMAP™ 3 architecture, ARM® microprocessor (MPU) subsystem, high performance image, video, audio (IVA2.2™) accelerator subsystem, power SGX™ graphics accelerator	Designed to provide best in class ARM and Graphics performance while delivering low power consumption.	
MSP430F20xx	Ultra-Low-Power 16-bit MCU	1KB/2KB Flash, 128B RAM, SPI+I²C 16-bit MCU	8 ch. 12-bit ADC or 4 ch. 16-bit SD ADC, 4 x 4mm package	
MSP430F22x4	Ultra-Low-Power 16-bit MCU	8 to 32KB Flash, 512B/1KB RAM, SPI + I²C + UART/LIN + IrDA	12 ch. 10-bit ADC, 2 operational amplifiers	
MSP430F23x0	Ultra-Low-Power 16-bit MCU	8 to 32KB Flash, 1KB/2KB RAM, SPI + I²C + UART/LIN + IrDA	Analog comparator, HW multiplier	
MSP430F41x	Ultra-Low-Power 16-bit MCU	4 to 32KB Flash, 256B to 1KB RAM, SVS, 96 segment LCD	Analog comparator	
MSP430F42x	Ultra-Low-Power 16-bit MCU	8 to 32KB Flash, 256B to 1KB RAM, SPI + UART, SVS, 128 segment LCD	3 x 16-bit SD ADC	
MSP430F42x0	Ultra-Low-Power 16-bit MCU	16 to 32KB Flash, 256B RAM, 56 segment LCD	5 ch. 16-bit SD ADC, 12-bit DAC	
MSP430F43x	Ultra-Low-Power 16-bit MCU	16 to 32KB Flash, 512B/1KB RAM, SPI + UART, SVS, 160 segment LCD	8 ch. 12-bit ADC, analog comparator	
MSP430F44x	Ultra-Low-Power 16-bit MCU	32 to 60KB Flash, 1KB/2KB RAM, 2x SPI + UART, SVS, 160 segment LCD	8 ch. 12-bit ADC, HW multiplier	
MSP430F47xx	Ultra-Low-Power 16-bit MCU	60KB Flash, 256B RAM, (4) USCI, 160 segment LCD	(4) SD16 ADC, HW multiplier, temp. sensor, analog comparator	
MSP430F241x	Ultra-Low-Power 16-bit MCU	120KB Flash, 8KB RAM, (4) USCI, SVS, temp. sensor	8 ch. 12-bit ADC, analog comparator, HW multiplier	
MSP430F261x	Ultra-Low-Power 16-bit MCU	120KB Flash, 8KB RAM, (4) USCI, SVS, DMA, temp. sensor	Analog comparator, 2 ch. 12-bit DAC, 8 ch. 12-bit ADC, HW multiplier	
MSP430F471xx	Ultra-Low-Power 16-bit MCU	120KB Flash, 8KB RAM, (4) USCI, DMA 160 segment LCD	(7) SD16 ADC, HW multiplier, temp. sensor, analog comparator	
MSP430F54xxA	Ultra-Low-Power 16-bit MCU	128 to 256KB Flash, 16KB RAM, (4) USCI, PMM, DMA, temp. sensor	16 ch. 12-bit ADC, analog comparator, RTC, internal voltage regulator for power optimization	
MSP430F6638 *Page 8*	Ultra-Low-Power 16-bit MCU	1.8V to 3.6V low supply voltage range, wake-up from standby mode in > 5µs, unified clock system	This device is optimized to achieve extended battery life in portable measurement applications.	
MSP430FG42x0	Ultra-Low-Power 16-bit MCU	16 to 32KB Flash, 256B RAM, 56 segment LCD	5 ch. 16-bit SD ADC, 12-bit DAC, 2 integrated op amps	
MSP430FG43x	Ultra-Low-Power 16-bit MCU	32 to 60KB Flash, 1KB/2KB RAM, SPI + UART, SVS, 128 segment LCD	12 ch. 12-bit ADC, 2 ch. 12-bit DAC, DMA, 3 op amps	
MSP430FG461x	Ultra-Low-Power 16-bit MCU	92 to 120KB Flash, 4KB/8KB RAM, SPI + I²C + UART/LIN + IrDA, 160 LCD	12 ch. 12-bit ADC, 2 ch.12-bit DAC, A-comp, 3 op amp, HW multiplier	
MSP430FG47x	Ultra-Low-Power 16-bit MCU	32 to 60KB Flash, 2KB RAM, SPI + I²C + UART/LIN + IrDA, 128 LCD controller	5 ch. 16-bit SD ADC, 2 ch. 12-bit DAC, comparator_A, 2 op amps	
OMAP3530	Applications Processor	ARM® Cortex-A8, C64x+™, graphics accelerator, video accelerators	Laptop-like performance at handheld power levels	OMAP3503, OMAP3515, OMAP3525
OMAP-L138 *Page 7*	C6-Integra™ DSP+Arm Processor	Dual core SOC, EDMA3, LCD controller, 10/100 Mb/s EMAC, DDR2/mobile DDR memory controller	The device enables OEMs and ODMs to quickly bring to market devices featuring robust operating systems support, rich user interfaces, and high processing performance life.	OMAP-L137
TMS320C5000™	DSP	Power efficient, high performance		
TMS320F28x™	32-Bit MCU	32-bit architecture, fixed- or floating-point code, up to 225MIPS operation	Microcontroller integration, real-time control performance	TMS320F2823x, TMS320F2833x
TMS320F2802x/3x Piccolo™	32-Bit Microcontroller	Up to 60MHz C28x™ core with optional control law accelerator. Up to 128KB Flash, high resolution (150ps) PWMs, 4.6MSPS ADC, CAN/LIN, QEP.	With dedicated, high precision peripherals, Piccolo microcontrollers are the ultimate combination of performance, integration, size, and low cost. Ideal for precision sensing and control applications.	TMS320F283x Delfino, TMS320F280x
TMS320F283x Delfino™	32-Bit Floating-point Microcontroller	Up to 300MHz C28x™ core. Up to 512KB Flash, high resolution (150ps) PWMs, 12MSPS ADC, CAN/LIN, QEP, external memory bus, DMA.	Delfino brings floating point and unparalleled performance to MCUs. Native floating point brings increased performance and quicker development. Ideal for precision sensing and control applications.	TMS320F2802x/3x Piccolo, TMS320F280x

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*New products are listed in **bold red***

→ Selection Table

Component Recommendations (Continued)

Component	Description	Key Features	Benefits	Other TI Solutions
TMS320VC5506	DSP	200MHz, dual MAC, very low stand-by power of 0.12mW	Supported by eXpressDSP™ and many other software packages and tools	TMS320V5509A, TMS320V5502
TMS320C5515 *Page 6*	DSP	320K bytes zero-wait state on-chip RAM	High performance and low power	
Power Management				
bq20z90-V110	Battery Fuel Gauge	Instant accuracy better than 1% error over lifetime of the battery	Automatically adjusts for battery aging, battery self discharge and temperature inefficiencies	bq20z70, bq20z80
bq24703	Battery Charger	0V operation, ±0.4% charge voltage accuracy, integrated PWM	Dynamic power management, multichemistry	bq24702, bq24705
bq24721C	Battery Charge Management	Multi-chemistry and multi-cell sync switch-mode charger	High efficiency, pack and system protection functions	
bq29330	Battery Safety	Battery pack full-protection analog front end	Provides individual cell voltages and battery voltage to battery management host	
DCH010505D	Galvanic Isolated, DC/DC Conv.	1W, 3kV isolation, minimal external components	Safety isolation, removal of ground loops	DCH010512/15 DCR021205
TPS22902	Load Switch with Controller Turn-On	Low on resistance, controlled turn-on, ultra small 0.64mm^2 package, quick output discharge	Ultra-small, fully integrated solution	TPS22901, TPS22922, TPS22924C, TPS22960
TPS22946	Current Limited Load Switch	Configurable current limit, ultra-small package, 1μA quiescent current at 1.8V	Ultra-small, low quiescent current current limited switch	TPS22949, TPS22945
TPS3808Gxx	Voltage Supervisor	Low quiescent current, programmable-delay	Circuit initialization and timing supervision	TPS310x
TPS54350	DC/DC Converter	4.5 to 20V$_{IN}$ 3A DC/DC w/integrated switch FET, sync pin, enable	Eliminate beat noise/ceramic caps/FPGA/integration	TPS54550
TPS55010 *Page 11*	Isolated DC/DC Converter with Integrated FETS	2.95V to 6V input, 2W, Isolated fly-buck topology, primary side feedback, 100kHz to 2000kHz switching frequency	The TPS55010 is a transformer driver designed to provide isolated power for isolated interfaces, such as RS-485 and RS-232, from 3.3V or 5V input supply	
TPS60403 *Page 12*	Charge Pump Voltage Inverter	Fixed 250kHz operation, up to 60-mA output current, only three small 1-μF ceramic capacitors needed, Input voltage range from 1.6V to 5.5V	PowerSave-mode for improved efficiency	
TPS61097-33	Boost Converter with Bypass Switch	Highly efficient, operates down to 0.3V; bypass switch; 5nA shutdown current; SOT-23	Supper efficient boost, works over entire battery range, low quiescent current, integrate the bypass switch, small package	
TPS62110	Step-Down Converter	3.1V to 17V V$_{IN}$, 1.5A conversion, synchronization pin, low battery indicator, power save mode	Very low noise/high efficiency	TPS62050
TPS62230	Step-Down Conv.	Up to 90dB PSRR, excellent AC and transient load regulation	Low noise regulation, 12mm^2 solution size	TPS62260
TPS62400	Dual Output Step-Down Conv.	180° out of phase operation, serial interface	Flexible voltage adjustment for processors and MCUs	TPS62410
TPS63030	Buck-Boost Converter	1A switch, automatic transition between step down and boost mode	Extending application run time, small solution	TPS61020
TPS65130	Boost Converter	800mA switch, adjustable, dual output, positive/negative boost	Two supplies from one switcher	
TPS717xx	Single-Channel LDO	Very high rejection of power-source noise	Low-noise power rails for sensitive analog components	TPS795xx, TPS799xx
TPS718xx-yy	Dual-Channel LDO	Very high rejection of power-source noise	Low-noise power rails for sensitive analog components	TPS719xx-yy
TPS780xx	LDO with DVS	Dynamic voltage scaling (DVS) with low I$_Q$ 500nA	DVS voltage designed to operate with MSP430 to increase power savings	TPS781
TPS79901	Single Channel LDO	Very high rejection of power-source noise	Low-noise power rails for sensitive analog components	TPS79501, TPS74301
RF ICs				
RF Transceivers				
CC1101	Sub-1GHz RF Transceiver	Wake-on-radio functionality; integrated packet handling with 64B data FIFOs; high RF flexibility: FSK, MSK, OOK, 1.2 to 500kbps; extremely fast PLL turn-on/hop time	Ideal for low-power systems; any low-end MCU can be used; backwards compatible with existing systems; suitable for fast frequency-hopping systems	CC2500
CC2520	2.4GHz ZigBee®/ IEEE 802.15.4 RF Transceiver	Best-in-class coexistence and selectivity properties; excellent link budget (103dBm); extended temperature range; AES-128 security module	Reliable RF link with interference present; 400m line-of-sight range with the development kit; ideal for industrial applications; no external processor needed for secure communication	CC2530
RF Systems-on-Chip				
CC2560-PAN1325 *Page 12*	*Bluetooth*® v2.1 + EDR Transceiver	+10dBm Tx power with transmit power control, -93dBm receiver sensitivity, support for *Bluetooth*® power saving modes, Integrated antenna	This solution is provided as a module to help customers reduce development time, lower manufacturing costs, save board space, ease certification, and minimize RF expertise required.	
CC1110/11	Sub-1GHz System-on-Chip	MCU, Flash and RAM in one package; four flexible power modes for reduced power consumption; includes CC1101 transceiver frequency synthesizer; built-in AES-128 encryption coprocessor	Complete low-cost solution on single chip; ideal for low-power battery-operated systems; robust and secure link with good noise immunity; no external processor needed for secure communication	CC2510, CC2511
CC2530/CC2531 *Page 13*	Second Gen. System-on-Chip 2.4GHz IEEE 802.15.4/RF4CE/ ZigBee	Excellent RX sensitivity, low power, easy to use development tools	RF design System-on-Chip for quick time to market. Provides a robust and complete ZigBee USB dongle or firmware-upgradable network node	CC2590/91, CC2530ZNP

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ECG and EEG Applications Quick Reference Guide

→ Selection Table

Component Recommendations (Continued)

Component	Description	Key Features	Benefits	Other TI Solutions
RF ICs (Continued)				
RF Systems-on-Chip (Continued)				
CC2540	2.4GHz *Bluetooth*® Low Energy Compliant RF System-on-Chip	Excellent link budget enabling long range applications without external frontend, receiver sensitivity, selectivity and blocking performance	Fast-to-market *Bluetooth*® low energy compliant solution	
WL1271	2.4GHz 802.11b/g/n and *Bluetooth*® 2.1 Chipset	Single-chip 802.11b/g/n WLAN and *Bluetooth*® solution using TI's digital radio processor technology using a single antenna.	Sophisticated low-power technology ideal for battery operated solutions; coexistence features enable simultaneous WLAN and *Bluetooth*® operations; supports ANT+ standard.	WL1273
WL1273	2.4/5GHz 802.11a/b/g/n and *Bluetooth*® 2.1 Chipset	Single-chip 802.11a/b/g/n WLAN and *Bluetooth*® solution using TI's digital radio processor technology using a single antenna.	Sophisticated low-power technology ideal for battery operated solutions; coexistence features enable simultaneous WLAN and *Bluetooth*® operations; supports ANT+ standard.	WL1271
RF Network Processor				
CC2530ZNP	Second Generation Z-Stack™ Network Processor	ZigBee stack and radio in one chip; implements ZigBee certified stack; configurable device type and network settings; excellent selectivity and blocking performance	Add CC2530ZNP and your system is ZigBee enabled; ideal for battery operated systems; excellent coexistence with *Bluetooth*® technology and Wi-Fi.	
Toolkits				
ADS1298ECGFE-PDK **Page 3*	Reference design for the ADS1298	Easy-to-use evaluation software, built-in analysis tools including oscilloscope, FFT, and histogram displays, flexible input configurations, optional external reference circuits	The ADS1298ECG FE can be used with a variety of patient simulators and allows the user to take advantage of the flexible input multiplexer which can be independently connected to the internally-generated signals for test, temperature, and lead-off detection.	

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	Fax	+1(972)927-6377
	Internet	support.ti.com/sc/pic/americas.htm

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Phone

European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
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Fax	+49 (0) 8161 80 2045
Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

Phone	Domestic	0120-92-3326
Fax	International	+81-3-3344-5317
	Domestic	0120-81-0036

Internet
International	support.ti.com/sc/pic/japan.htm
Domestic	www.tij.co.jp/pic

Asia

Phone
International	+91-80-41381665
Domestic	Toll-Free Number

Note: Toll-free numbers do not support mobile and IP phones.

Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	1-800-425-7888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010
Fax	+8621-23073686
Email	tiasia@ti.com or ti-china@ti.com
Internet	support.ti.com/sc/pic/asia.htm

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