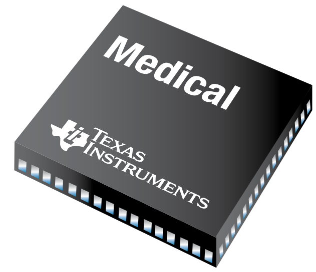
Medical Imaging Applications Guide



Texas Instruments

Ultrasound

Computed Tomography (CT) Scanners

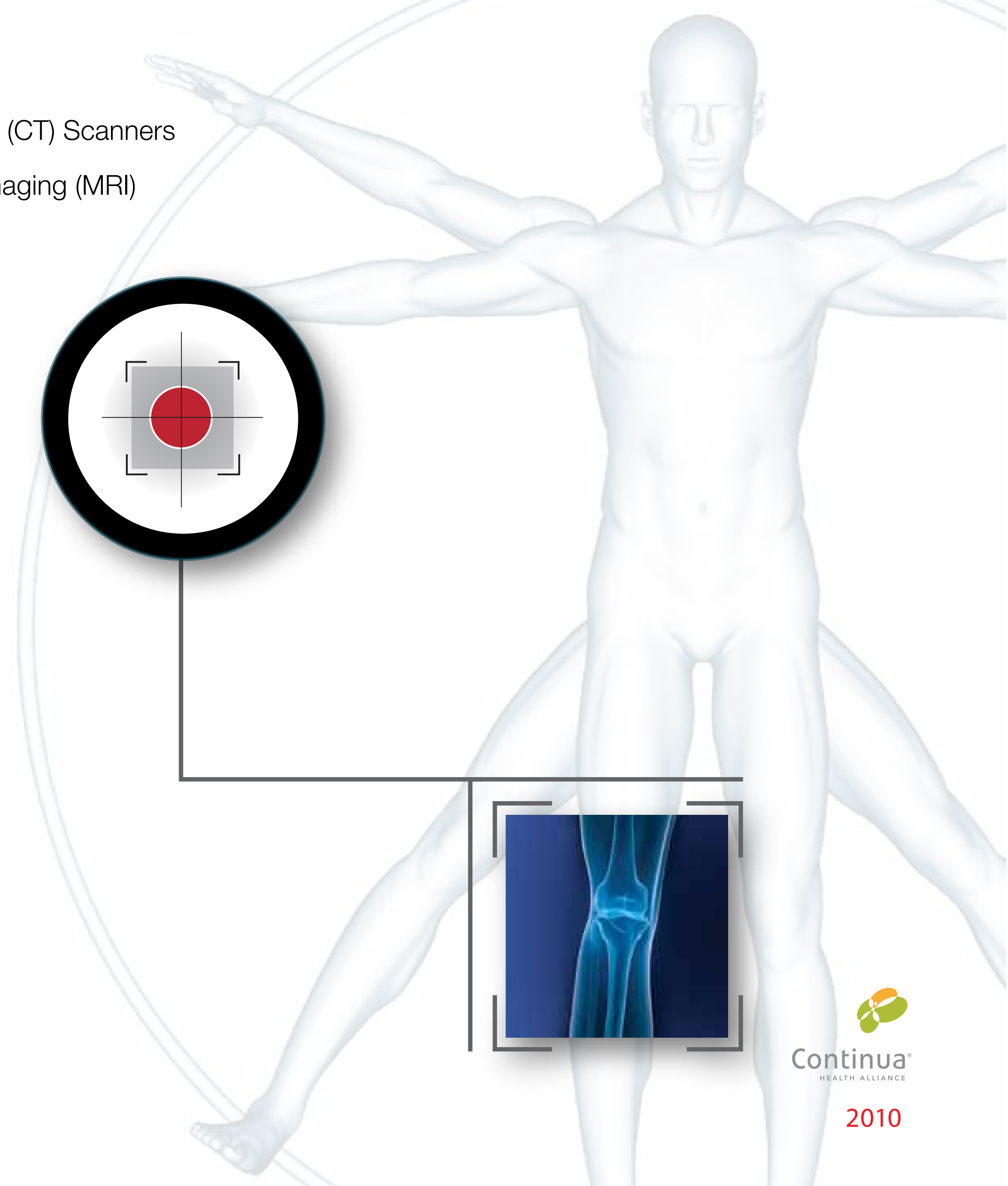
Magnetic Resonance Imaging (MRI)

Digital X-Ray

Positron Emission Tomography (PET) Scanners

Power Management for Medical Imaging

Connectivity Solutions



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HEALTH ALLIANCE

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Medical Imaging

Overview

Medical imaging technology is continually evolving and advancing, all with the goal of improving patient care. TI's complete analog signal chain, power management, interface and embedded processing portfolios empower innovation in medical imaging by:

- Enabling faster, more accurate diagnostic results.
- Increasing the speed of delivery and availability of medical care worldwide.
- Improving accessibility and affordability of end equipments.

There are two prevalent trends in semiconductor innovation for the medical imaging market:

- Increased performance driven by the need for higher image quality.
- Decreased power consumption and size to allow equipment designs that are more portable, accessible and affordable.

TI's large portfolio of catalog and application-specific semiconductor products addresses major medical imaging modalities such as ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and digital X-ray, as well as newer innovative modalities such as hyperspectral imaging, optical coherence tomography (OCT), or not even yet envisioned imaging solutions.

Power continues to be a key concern for all of these modalities, as well as for medical applications overall, so we have dedicated a chapter to it towards the end of this section.

For more information on TI's offering for Medical Imaging, please visit *www.ti.com/medicalimaging*

Ultrasound

Ultrasound systems

As ultrasound equipment becomes more compact and portable, it heralds a variety of health care applications that illustrate how advances in medical technology are bringing care to patients instead of requiring them to travel. TI's embedded processors and analog products facilitate advanced ultrasound system designs with low power consumption and high performance, yielding portability with high-quality images.

Medical and industrial ultrasound systems use focal imaging techniques to achieve imaging performance far beyond a single-channel approach. By using an array of receivers, TI's latest products for ultrasound enable high definition images through time shifting, scaling and intelligently summing echo energy. This makes it possible to focus on a single point in the scan region; by subsequently focusing on other points, an image is assembled.

When initiating a scan, a pulse is generated and transmitted from each of the eight to 512 transducer elements. These pulses are timed and scaled to illuminate a specific region of the body. After transmitting, the transducer element immediately switches into receive mode. The pulse, now in the form of mechanical energy, propagates through the body as high-frequency sound waves, typically in the range of 1 to 15MHz. As it does, the signal weakens rapidly, falling off as the square of the distance traveled. As the signal travels, portions of the wavefront energy are reflected back to the transducer/receiver.

Limits on the amount of energy that can be put into the body require that the industry develop extremely sensitive receive electronics. At focal points close to the surface, the receive echoes are strong, requiring little if any amplification. This region is referred to as the near field. At focal points deep in the body, the receive echoes will be extremely weak and must be amplified by a factor of 1,000 or more. This region is referred to as the far field. These regions represent the two extremes in which the receive electronics must operate.

In the high-gain (far field) mode, the performance limit is the sum of all noise sources in the receive chain. The two largest contributors of receive noise are the transducer/cable assembly and the receive low-noise amplifier (LNA). In the low-gain mode (near field), the performance limit is defined by the magnitude of the input signal. The ratio between these two signals defines the system's dynamic range. Many receive chains integrate the LNA with a voltage-controlled attenuator (VCA) and a programmable gain amplifier (PGA).

then scan converted to the final output display form and size. For Doppler processing, velocity and turbulence are estimated in the color flow mode, and power is estimated in the power Doppler mode. These estimates are again scan converted to the final output display form and size.

An assignment of color to the estimates is also necessary for proper display. In spectral Doppler mode, a windowed and overlapped FFT is taken to estimate the spectrum. It is also customary to present the Doppler data, after separation of forward and reverse flow, in the form of audio. All of these intensive signal processing computations are well suited for DSPs.

Product portfolio for ultrasound

Analog application-specific signal chain products

- The main function of a digital front end in an ultrasound system is to focus at a given depth and direction. The AFE58xx family of fully integrated analog front ends offers parts 50 percent smaller than competitive solutions, with low power and low noise for superior image quality.
- The main function of T/R switches is to prevent high-voltage pulses from damaging the receive electronics.The TX810, an eight-channel integrated T/R switch, is designed to address designers' need to build smaller portable ultrasound systems while speeding time to market.
- The transmit beamformer, high-voltage (HV) pulser and HV multiplexer form the transmit path responsible for the pulse-excitation of transducer elements. The TX734 is an integrated, quad-channel, ±90-V pulser with active damping that reduces noise and minimizes size.

Embedded processors

- TMS320C6474 and TMS320C6455 high-performance DSPs are suitable for ultrasound processing such as B-mode imaging, color Doppler, speckle reduction, 3-D/4-D and other processing and filtering algorithms.
- OMAP35x SOCs are well suited to handle the operating system, connectivity and user interface require-ments in portable and hand-held ultrasound systems, while also being capable of handling processing algorithms like color scan conversion.

These products, along with TI's power management products, clocks and interfaces, provide a full signal chain portfolio of targeted integrated circuit solutions for ultrasound.

View the "Flexible Design, Low Power for Ultrasound Systems" video at: **www.ti.com/ultrasoundvideo**

TI's AFE5851 analog front end was named a best product in the 2009 Design News Golden Mousetrap awards.

Integrated 8- and 16-Channel Analog Front Ends
AFE5801, AFE5851

Get samples, datasheets and evaluation modules at: **www.ti.com/sc/device/AFE5801** or **www.ti.com/sc/device/AFE5851**

Key Features

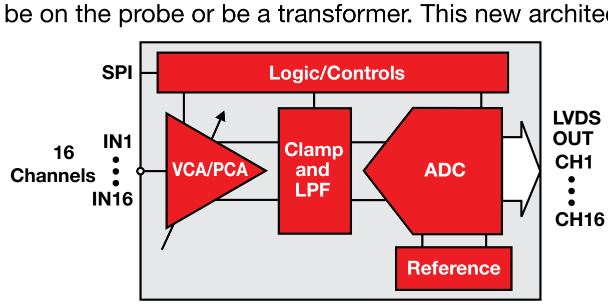
- Integrated VCA, PGA, LPF, 12-bit 65-MSPS ADC
- AFE5801:
  - 8 channels
  - 50mW per channel at 30MSPS 58mW per channel at 50MSPS
- AFE5851:
  - 16 channels
  - 39mW per channel at 32.5MSPS
- Digital gain control removes external DAC for smaller footprint and minimized noise
- Packaging: 9 x 9mm QFN

Applications

- Ultrasound

The AFE5851 is the first 16-channel AFE available for the ultrasound market. The device features 39mW/channel at 32.5MSPS and contains 16 variable-gain amplifiers (VGAs), followed by eight 12-bit, 65MSPS analog-to-digital converters (ADCs). Each ADC is shared between two VGAs and each VGA differential output is sampled at alternate clock cycles to optimize power dissipation. The ADC has scalable power consumption to enhance the lower power with lower sampling rates. The high channel count and low-power features of the AFE5851 allow for increased channel density in handheld ultrasound systems.

Both the AFE5851 and AFE5801 can be preceded by an off-chip low-noise amplifier (LNA), which can be on the probe or be a transformer. This new architecture enables customers to have more than 40 percent less power and a 70 percent smaller analog front-end footprint for hand-held ultrasound systems.



AFE5851 functional diagram.

CT Scanners

Computed Tomography

Computed tomography (CT) is a medical imaging technique that produces three-dimensional images of internal human body parts from a large series of two-dimensional X-ray images (called profiles) taken in a single-axis rotating structure called a gantry. When compared to a conventional X-ray radiograph, which is an image of many planes superimposed on each other, a CT image exhibits significantly improved contrast.

With the advent of diagnostic imaging systems like CT, where complex and intensive image processing is required, semiconductors play a very important role in developing systems with increased density, flexibility and high performance.

X-ray slice data is generated using an X-ray source that rotates around the object, with X-ray detectors positioned on the opposite side of the circle from the X-ray source. Many data scans are taken progressively as the object is gradually passed through the gantry. The newer helical or spiral CT machines that use faster computer systems and optimized software can continuously process the cross-section images while the object passes through the gantry at a constant speed.

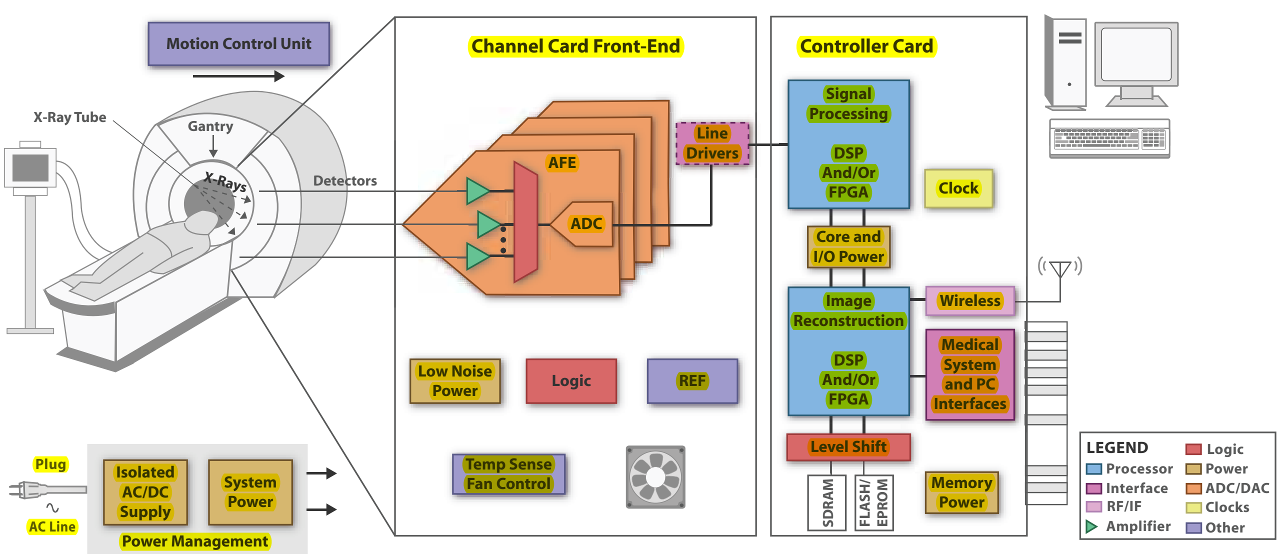
The detector system consists of a number of channel cards that have scintillator-photodiode solid state detectors. The X-rays interact with the scintillator and produce visible light, which is in turn converted into a current by the photodiode. The depth information along the direction of the X-ray beam that is lost in radiography is recovered by viewing the slide from many different directions.

The channel card has a front-end system where charge on the detectors are integrated, gained by amplifiers and converted to digital values by ADCs. The digital data from all channel cards is transferred by high-speed link to the controller card and onto the image conditioning cards. The image conditioning card is connected to the host computer where the CT images can be viewed. Here, the digital data are combined by the mathematical procedure known as tomographic reconstruction. Power supplies, clocks and clock distribution circuits, reference and reference buffers, logic, and interface products are some of the key blocks in the channel card subsystem.

Control cards can include DSPs and FPGAs, power supplies, clocks and clock distribution circuitry and interface blocks. DSPs can be used to provide accurate control of the gantry rotation, the movement of the table (up/down and in/out), tilting of the gantry for angled images, and other functions such as turning the X-ray beam on and off. Another important DSP control functionality is ECG gating used to reduce motion artifacts caused by heart movement. Here, the data acquisition is carefully synchronized with the heartbeat.

Product portfolio for CT scanners

- Channel card front end and control card subsystems, including data converters, processors, power management solutions and other analog products.
- Single-chip solutions for directly digitizing low-level currents from photodiode arrays in CT scanners.
- DSPs with TI's VelociTI™ VLIW architecture can provide accurate control of the gantry rotation, the movement of the table, the tilting of the gantry for angle images, and other real-time control and processing functions.
- Voltage supervisors, DC/DC converters, non-isolated power modules and low-dropout linear regulators to meet sequencing requirements.



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.

CT scanner system block diagram.

Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is a non-invasive diagnostic technology that produces physiologic images of the human body. Powerful magnets create a field that forces hydrogen atoms in the body into a particular alignment. Radio frequency (RF) energy distributed throughout the body is interrupted by body tissue. The disruptions correspond to varying return signals which, when processed, create the image.

Accurate signal processing is key to obtaining high-quality images. A key system consideration for the receive channel is high SNR. The return signals have narrow bandwidths, with an IF location dependent on the main magnet's strength. Some systems use high-speed pipeline ADCs with wide-band amplifiers to sample the IF, leaving large headroom for post-processing gain by a digital down converter or FPGA. Other systems mix the IF to baseband where lower speed, higher resolution SAR and delta-sigma ADCs can be used.

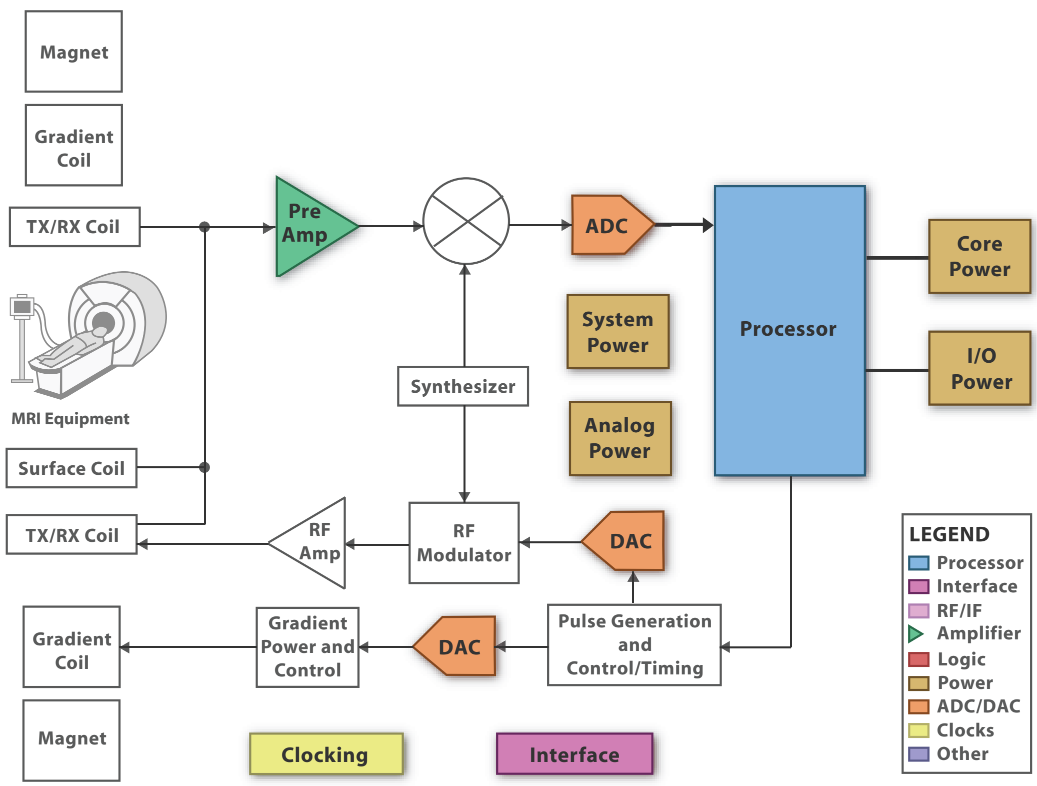
High-resolution, high-speed DACs are needed to control the magnetic and RF energy in the MRI. High resolution is required to accurately define the area of the patient to be scanned and high speed is needed to match the high IFs generated by the main magnet.

DSPs can be used to provide gradient processor control for properly controlling MRI system magnets. DSPs are also useful for implementing signal processing functionalities in MRI devices. MRI reconstruction is based mostly on 2-D Fourier transformation. In addition, functionalities like auto- and cross-correlation, curve fitting, combining sub-images and motion stabilization are required to pre- and post-process the image to reduce various artifacts.

Analog ICs and embedded processors are playing a key role in improving the delivery speed and crisp detail of magnetic resonance images, leading to more accurate diagnoses and effective treatments. Accurate signal processing is key to high-quality MRI images.

Product portfolio for MRIs

- Some systems use high-speed pipeline ADCs with wideband amplifiers to sample the intermediate frequency (IF) generated by the main magnet.
- Other systems mix the IF to baseband, allowing for the use of lower speed, higher resolution successive approximation registers (SARs) and delta-sigma ADCs.
- High-resolution DACs can control the magnetic and RF energy in an MRI.
- DSPs like the TMS320C6452 can provide gradient processor control for properly controlling the magnets and preprocess the signal before it reaches the image reconstruction engine.
- Other products for MRI systems and equipment manufacturers include operational amplifiers, clocking distribution, interface and power management devices.



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Magnetic resonance imaging (MRI) system block diagram.

Medical Imaging

Digital X-Ray

Digital X-rays – made possible because of technologies like digital signal processing – are revolutionizing diagnostic radiology and spurring innovative new applications, such as their use in surgical procedures. A key benefit of digital X-rays is the ability to store and transfer the digital images, allowing for the outsourcing of radiological services or easy access to remote and/or specialized analysis.

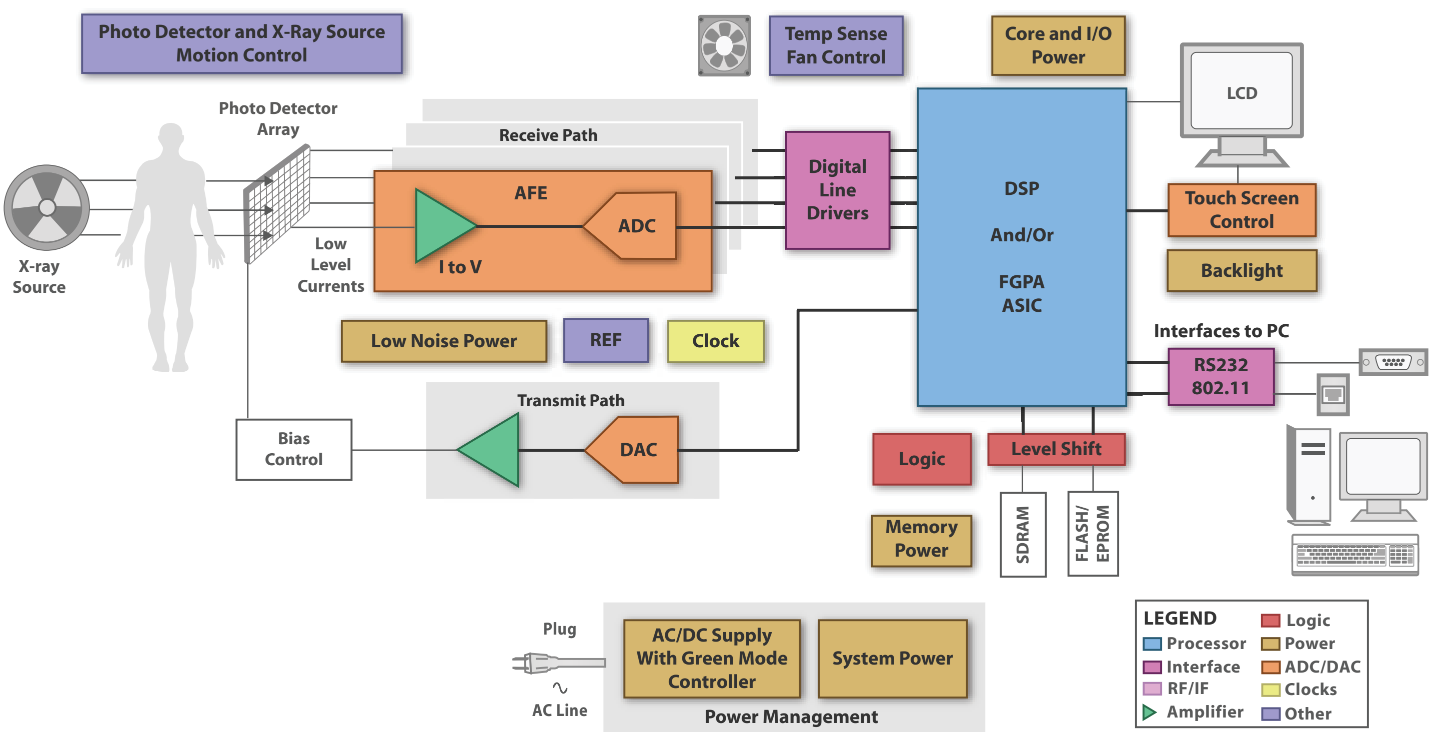
A conventional X-ray system, regardless of whether its individual components are optimized, captures less than 40 percent of the original image information. By adding a digital detector to digital X-ray imaging, it is possible to capture more than 80 percent of the original image information and use a wide range of post-processing tools to further improve the image.

Other digital X-ray technology advances made possible by semiconductor technology include:

- Faster diagnoses by eliminating photographic processing time and facilitating quick transmission over network connections.
- Reduced costs by eliminating photographic processing film and chemicals.
- Processing only the image data that highlights regions of interest, suppressing irrelevant information.
- Combining image data with other pertinent radiology information system (RIS) and hospital information system (HIS) records.
- Archiving all relevant information efficiently.

There are two different approaches to digital X-ray technology: computed radiology (CR) and digital radiography (DR). Computed radiology involves trapping electrons on an imaging plate (IP) containing photo-stimulated-phosphor (PSP) and exposing them to generate image data. The IP is then moved to a CR reader, where it is scanned using a laser beam.

The second approach, digital radiography, uses both direct and indirect conversion. In direct conversion, flat-panel selenium detectors absorb X-rays directly and convert them into individual pixel electric charges. In indirect conversion, X-ray signals are converted to light, and then converted to electric charges. Both tiled charge-coupled device (CCD) arrays and computed tomography use indirect conversion technology. Tiled CCD transitional technology employs multiple CCDs coupled to a scintillator plate via fiber optics.



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Digital X-ray system block diagram.

Digital X-Ray

Computed tomography involves trapping electrons on photo-stimulated plates and exposing them to generate image data. In both approaches, charges proportional to X-ray intensity seen by the pixel are stored in the thin film transistor (TFT) storage cap. A number of such pixels form the flat detector panel (FDP). The charges are deciphered by read-out electronics from the FDP and transformed into digital data.

The block diagram shows the readout electronics required for direct imaging to convert the charge in the FDP to digital data. It has two chains: the acquisition and the biasing chain. At the beginning of the acquisition chain, an analog front-end is capable of multiplexing the charges on different FDP (channels) storage caps and converting those charges into voltage. The biasing chain generates bias voltages for the TFT array through intermediate bias-and-gate control circuitry. Digital control and data conditioning are controlled by a DSP, an FPGA, an ASIC or a combination of these. These processors also manage high-speed serial communications with the external image processing unit through a high-speed interface (serialized, LVDS, optical).

Temperature sensors, DACs, amplifiers and high-input voltage-capable switching regulators are other key system blocks. Each block must have an enable pin and synchronize frequencies to avoid crosstalk with other blocks in the acquisition chain. The number of FDP pixels determines the number of ADC channels versus ADC speed. Static or dynamic acquisition also determines ADC speed. While static acquisition means a single image in less than 1 s, dynamic means an image is refreshed at 30 Hz for more specific cardiovascular, fluoroscopic or related applications that require much faster data conversion with the same number of channels. An ADC in the range of 2 MSPS or more with excellent DC performance will work well.

For indirect conversion, the CCD output requires correlated double sampling (CDS). The signal level's reset voltages and image signal level are converted to digital data by an analog front end (AFE). The AFE's sampling speed is determined by the number of pixels in the CCD array and the frame rate. In addition, the AFE corrects sensor errors such as dark current correction, offset voltages and defective pixels. Depending on the signal level, the presence of programmable gain amplifiers (PGAs), the linearity of the PGAs and the range of gains available may also be important. During digitization, the number of bits determines image contrast. Typically, digitizing the initial data with two to four bits more precision than desired in the final image is recommended. For example, if 8 bits of final image data are required, initially digitize to 10 bits to allow for rounding errors during image processing.

The main metric for image quality is detection quantum efficiency (DQE), a combination of contrast and SNR expressed in percentage. The higher the contrast and lower the noise, the higher the DQE. Contrast is the number of shades of gray determined by the ADC's output resolution. Generally, 14 or 16 bits are suitable for the application.

SNR indicates not only SNR from the ADC, but system SNR impact from X-ray dose, pixel size and all electronic components. SNR can be improved by increasing X-ray dose and photodiode spacing and decreasing electronics noise. Increasing the X-ray dose is not suitable for patients or operators. Increasing photodiode spacing may not be suitable because this decreases spatial resolution. Decreasing the noise from the system's electronics is the main challenge.

Total system noise is the root-square-sum of all noise contributions over the signal chain, assuming all are uncorrelated. This means all parts have to be ultra-low-noise or heavily filtered, when applicable, including ADCs, op amps and references. Stability over temperature is another important challenge. Internal temperature increases, due to power dissipation, may offset gray levels and distort an image, especially during dynamic acquisitions. Therefore, temperature stability of ADCs, op amps and references should be high.

The digital X-ray data undergoes several processing steps before it is presented to the display for viewing. The first step, called shading, is where the non-idealities in the detector pixels are corrected. Next, the unexposed area is determined in the detector so that it is not used in subsequent processing. Histogram equalization is then carried out on the useful data. Finally, several image enhancement techniques are used for noise reduction, contrast improvement and edge enhancement.

Product portfolio for digital X-rays

- High-performance DSPs for control functions and signal conditioning to acquire and improve the clarity of the image.
- Analog front ends (AFEs) capable of multiplexing the charges on different flat detector panels (FDPs), storage caps (channels) and converting these charges into voltage for direct conversion X-rays. AFEs also convert the signal level and its reset voltages to digital data and correct sensor errors in indirect conversion X-rays.
- Temperature sensors, DACs, amplifiers and high-input voltage-capable switching regulators are other key system blocks.
- Power management and other analog products.

Positron Emission Tomography (PET) Scanners

Positron emission tomography (PET) is a non-invasive diagnostic technology. Used to identify growing cancer cells, for example, a PET scan uses radiation emissions from the body (generated by radioactive chemical elements consumed by the patient) to produce physiologic images of specific organs or tissues.

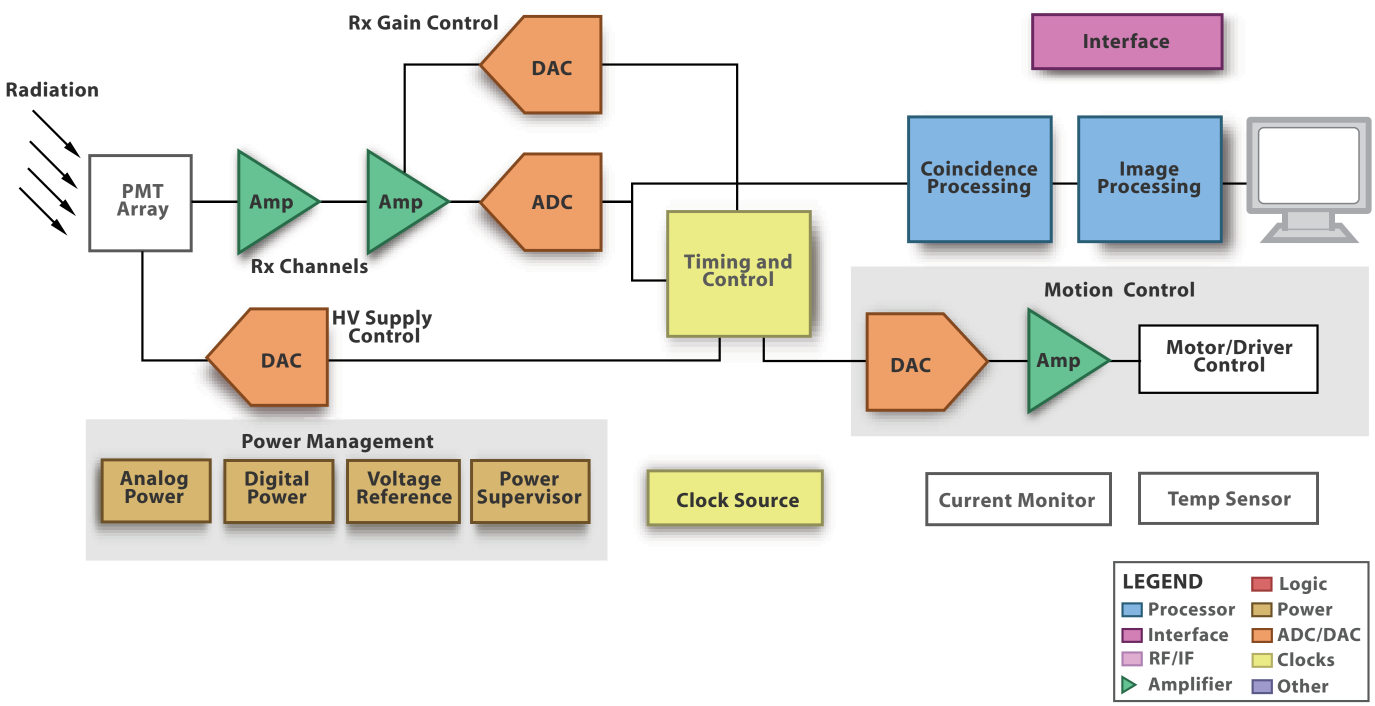
The radioactive emissions are converted to light via a scintillation crystal detector and are amplified and converted to an output current by a photomultiplier tube (PMT). The PMT's current output is then converted to a voltage that is amplified and filtered before being converted to a digital signal by an ADC.

Signal processing is needed for detector signal processing of the receive channels and for a number of control functions. DSPs, microcontrollers and digital-to-analog converters are used in this application for functions such as varying input amplifier gain, controlling the PMT high-voltage power supply, and motion control for the detector ring assembly and patient entry/exit.

DSPs can be used for PET scanner control and signal processing units. Filtered back-projection algorithms can be used in image reconstruction. Several iterative techniques have also been proposed for PET image reconstruction. Additional signal pre-conditioning may be necessary to correct various artifacts like attenuation variations, detector geometry and efficiency variations, random and scatter coincidences, etc.

Product portfolio for PET scanners

- Amplifiers, power management products and other analog parts are suitable for converting radioactive emissions to light and reconstruct and correct images.
- DSPs such as the TMS320C6455 can handle tasks such as varying input amplifier gain and controlling the photomultiplier tube (PMT) high-voltage power supply and motion control for detector ring assembly and patient entry/exit. DSPs are also suitable for PET scanner control and signal processing units.



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PET scanner system block diagram.