ADI Positron Emission Tomography (PET) Solutions

PET System Theory and Typical Architecture

Positron emission tomography (PET) is a noninvasive imaging technology that generates 3D medical images by detecting gamma rays emitted when certain radioactively doped sugars are injected into a human body. A PET scan produces digital pictures that can, in many cases, identify the most common forms of cancer, including lung, breast, colorectal, lymphoma, and melanoma. Technically, PET is a medical imaging technology that images the biology of disorders at the molecular level before anatomical changes are visible. The gamma rays are generated when a positron emitted from the radioactive material collides with an electron in tissue. The resulting collision produces a pair of gamma ray photons that emanate from the collision site in opposite directions and are detected by gamma ray detectors arranged around the human body.

The PET system includes signal detection and processing, coincidence processing, line of response (LOR) memory, and image reconstruction. The detector is a ring located around the gantry bore, which is comprised of an array of thousands of scintillation crystals and hundreds of photomultiplier tubes (PMTs). The scintillation crystals convert the gamma radiation into light that is detected and amplified by the PMTs. The PMTs' current output signal is then converted to a voltage and amplified by a preamplifier, low noise amplifier (LNA), and then goes to a variable gain amplifier (VGA) to compensate for the variability of the PMTs. The output of the VGA is passed to two paths, one is the data path and the other is the timing path. In the data path, the VGA's output is filtered and offset compensated and then passed through to an analog-to-digital converter (ADC). A field programmable gate array (FPGA) is typically used to process the ADC output data for energy information. In the timing path, the signals from four or more of physically close channels are summed, and this combined signal is input to an ultrahigh speed comparator. A digital time stamp is generated using the comparator's output signal and an ultrahigh speed clock to get the timing information. The coincidence processor needs to find a matching singles event in an opposite detector block based on the energy and timing information. This is called the line of response. By analyzing tens of thousands of LORs, the back-end image signal processor can construct and display the collision activity as a 3D image.

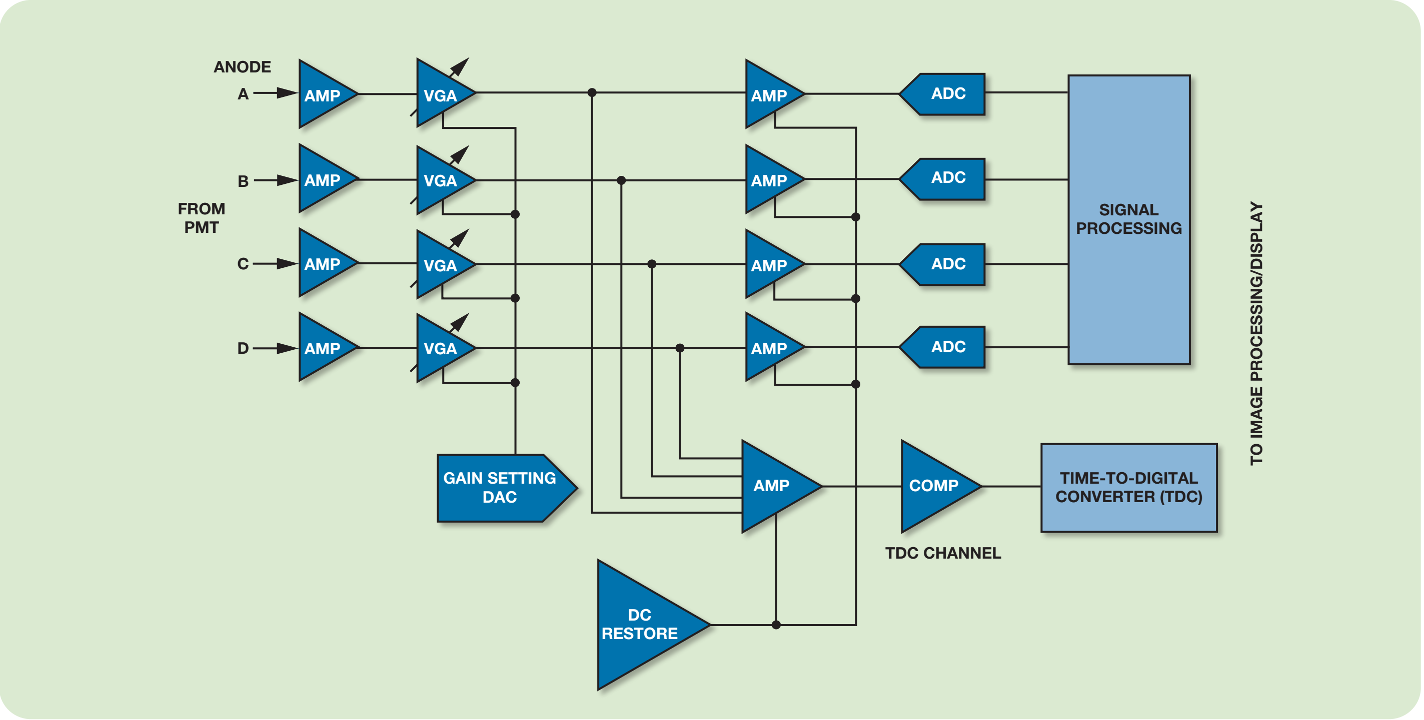
PET System Design Considerations and Major Challenges

- Timing is everything in PET systems; both speed and noise are extremely important in the timing path. Anything contributing to timing jitter needs to be minimized.
- As in the timing path, the speed, noise, drive capability, and overload recovery are key specifications for the preamplifier, so an LNA with a few $nV/\sqrt{Hz}$ is required. Each anode needs its own gain control; the speed, gain range, and gain resolution are key specifications for the VGA. The combined LNA and VGA gain is approximately 40 dB with an adjustable gain range of about 20 dB. Adjustable precision of 10-bit to 12-bit resolution digital-to-analog converters (DACs) are used to control the gain of the VGAs if an analog VGA is selected.
- The timing channel summing amplifier rise time and noise are critical. The rise time, propagation delay, skew, and aperture jitter are important for a comparator. DC restore is usually necessary at this stage as the time stamp is dependent upon a constant dc level across all the channels. A precision operational amplifier with 1 mV offset is generally adequate.
- Unlike the timing path, the speed is not so stringent for a buffer/filter amplifier before the ADC. However, it is still fairly high speed and low noise since it must filter relatively short duration signals.
- The ADC selection is architecture dependent. High speed conversions dominates, as most PET systems are using a digital integrator which currently need higher sampling rates. A 10-bit to 12-bit ADC with higher than 40 MSPS can meet the requirement.

Total Solutions from ADI

ADI provides an extensive selection of amplifier, data conversion, signal processing, and power management solutions to maximize image quality and reduce power consumption and cost for PET equipment. In addition, ADI provides evaluation boards, simulation tools, and applications expertise to support customer design and development efforts.

Main Signal Chain



Notes: The signal chains above are representative of PET system. The technical requirements of the blocks vary, but the products listed in the table are representative of ADI solutions that meet some of those requirements.

Preamplifier	VGA	Gain Setting DAC	ADC Driver	ADC	Timing Path Summing Amplifier
AD8000/ADA4817-2/ ADA4857-2/ADA4897-2	AD8337/AD8331/ AD8335/AD8264	AD5381/AD5314/ AD5629R/AD5672R	ADA4927-2/ADA4937-2/ ADA4938-2/AD8138	AD9637/AD9228/ AD9212/AD9219	AD8099/ADA4899-1/ AD8045/ADA4857-1

Comparator	DC Restore Amplifier	DC Restore Switches	Voltage Reference	Clocking	Temperature Sensor	Power Management
ADCMP58x/ADCMP57x/ ADCMP56x/ADCMP55x	AD8608/ADA4077-4/ OP4177	ADG16xx/ADG14xx/ ADG12xx	ADR43x/ADR42x/ ADR45xx/ADR34xx	AD952x/AD951x/ ADCLK8xx/ADCLK9xx	ADT7310/ADT7410/ ADT7320/ADT7420	ADP2386/ADP2384/ ADP5052/ADP7102/ ADP7104/ADM7170/ ADM7171/ADM7172

Introduction of Main Products for PET

Part Number	Description	Benefits
Preamplifier		
AD8000	1.5 GHz ultrahigh speed current feedback amplifier, with 4100 V/μs slew rate, 0.1% settling time: 12 ns, V_N RTI: 1.6 nV/√Hz, high output current: 100 mA	High speed, low noise, big output current is suitable for PET PMT output signal
ADA4817-2	Low noise, 1 GHz, *FastFET*™ op amp, with 870 V/μs slew rate, 0.1% settling time: 9 ns, V_N RTI: 4 nV/√Hz, high output current: 40 mA	High speed, low noise, big output current is suitable for PET PMT output signal
AD8099	Low noise, 700 MHz (G = 2), op amp, with 475 V/μs slew rate (G = 2), 0.1% settling time: 18 ns, V_N RTI: 0.95 nV/√Hz	High speed, low noise is suitable for PET PMT output signal

Introduction of Main Products for PET (Continued)

Part Number	Description	Benefits
VGA		
AD8337	280 MHz ultralow noise VGA with preamp, 0 dB to 20 dB gain range with 20 dB/V gain scaling; gain accuracy: ±0.1 dB, V_N RTI: 2.2 nV/√Hz	Excellent dc characteristics combined with high speed suited for PET system
AD8331	120 MHz dc-coupled VGA with preamp, 48 dB gain range with 50 dB/V gain scaling; gain accuracy: ±0.2 dB, V_N RTI: 0.74 nV/√Hz; dual-channel version: AD8332 and quad-channel version: AD8334	High speed, good linear in dB gain and ultralow noise makes it suited for PET application
AD8264	235 MHz quad dc-coupled VGA with preamp and differential output, 20 dB gain range with 20 dB/V gain scaling; gain accuracy: ±0.2dB, V_N RTI: 2.3 nV/√Hz	Excellent dc characteristics, high speed, low noise, and good linear dB gain
Gain Setting DAC		
AD5381	40-channel, 12-bit, output voltage settling time: 3 µs typ; parallel/serial/I²C interface, programmable internal 1.25 V/2.5 V, 10 ppm/°C reference	Programmable gain, dc offset, and all channels simultaneous update
AD5314	Quad, 10-bit, output voltage settling time: 7 µs typ; serial interface; pin-compatible with 12-bit version AD5324	Small offset and gain error, low power, and all channels simultaneous update
AD5629R	Octal, 12-bit, output voltage settling time: 2.5 µs typ; I²C interface; programmable internal 1.25 V/2.5 V, 5 ppm/°C reference	Small offset and gain error, low power, and all channels simultaneous update
AD5672R	Octal, 12-bit, output voltage settling time: 5 µs typ; SPI interface; internal 2.5 V, 2 ppm/°C reference; AD5671R is the I²C version	Small offset and gain error, low power, and all channels simultaneous update
ADC Driver		
ADA4937-2	1.9 GHz ultralow distortion differential ADC driver; V_N RTI: 2.2 nV/√Hz; HD2/HD3: –112 dBc/–102 dBc @ 10 MHz, –84 dBc/–91 dBc @ 70 MHz, –77 dBc/–84 dBc @ 100 MHz	Drives the highest performance high speed ADCs with CM adjust
ADA4927-2	2.3 GHz ultralow distortion current feedback differential amplifier; V_N RTI: 1.4 nV/√Hz; HD2/HD3: –105 dBc/–103 dBc @ 10 MHz, –91 dBc/–98 dBc @ 70 MHz, –87 dBc/–89 dBc @ 100 MHz	Wideband, low noise, low distortion with CM adjustable is suitable for differential ADC driver
ADA4938-2	1.0 GHz ultralow distortion differential ADC driver; V_N RTI: 2.6 nV/√Hz; HD2/HD3: –106 dBc/–109 dBc @ 10 MHz, –82 dBc/–82 dBc @ 50 MHz	Drives the highest performance high speed ADCs with CM adjust
ADA4940-2	260 MHz ultralow distortion differential ADC driver; V_N RTI: 3.9 nV/√Hz; HD2/HD3: –102 dBc/–96 dBc @ 1 MHz	Drives the highest performance high speed ADCs
ADC		
AD9637	Octal 12-bit, 40 MSPS/80 MSPS serial LVDS 1.8 V ADC; SNR = 72 dB @ 19.7 MHz (2 V p-p input), SFDR = 92 dBc (to Nyquist), 650 MHz full power analog bandwidth	High performance, combined with low cost, small size, and ease of use
AD9228	Quad, 12-bit, 40 MSPS/65 MSPS serial LVDS 1.8 V ADC; SNR = 70.2 dB @ 19.7 MHz (2 V p-p input) and 40 MSPS data rate; SFDR = 82 dBc (to Nyquist); pin-compatible with 10-bit version AD9219	High performance, combined with low cost, small size, and pin-compatible resolution family, ease of use
AD9212	Octal, 10-bit, 40 MSPS/65 MSPS serial LVDS 1.8 V ADC; SNR = 61.2 dB @ 19.7 MHz (2 V p-p input) and 40 MSPS data rate; SFDR = 80 dBc (to Nyquist); pin-compatible with 12-bit version AD9222	High performance, combined with low cost, small size, and pin-compatible resolution family, ease of use
Timing Path Summing Amplifiers		
AD8099	Ultralow distortion, high speed, low noise op amp with 1350 V/µs slew rate; 700 MHz to 450 MHz (G = 2 to G = 10); V_N RTI: 0.95 nV/√Hz, HD2/HD3: –84 dBc/–92 dBc @ 10 MHz @ G = 10, offset voltage: 100 µV typ, low input bias current: 6 µA typ	High speed, low noise, low distortion is suitable for PET timing path
ADA4899-1	Unity gain stable, ultralow distortion, high speed, low noise op amp with 310 V/µs slew rate; bandwidth: 600 MHz (G = 1); V_N RTI: 1 nV/√Hz, HD2/HD3: –80 dBc/–86 dBc @ 10 MHz, offset voltage: 35 µV typ, low input bias current: 6 µA typ	High speed, low noise, low distortion, and input bias current cancellation function
ADA4857-1	Low power, ultralow distortion, high speed, low noise op amp with 2800 V/µs slew rate; bandwidth: 850 MHz (G = 1); V_N RTI: 4.4 nV/√Hz, HD2/HD3: –88 dBc/–93 dBc @ 10 MHz, low input bias current: 2 µA typ	High speed, low noise, low distortion, and low power
Comparator		
ADCMP58x	Ultrafast SiGe voltage comparators with 180 ps propagation delay; 37 ps typical output rise/fall, 10 ps deterministic jitter (DJ), 200 fs random jitter (RJ)	Small propagation delay, fast rise time, and low jitter suited for PET system
ADCMP57x	Ultrafast SiGe voltage comparators with 150 ps propagation delay; 35 ps typical output rise/fall, 10 ps deterministic jitter (DJ), 200 fs random jitter (RJ)	Small propagation delay, fast rise time, and low jitter suited for PET system

Introduction of Main Products for PET (Continued)

Part Number	Description	Benefits
DC Restore Amplifier		
ADA4077-4	Low offset and drift, high precision amplifiers; offset voltage: 15 μV and 0.4 μV/°C typ, V_N RTI: 7 nV/√Hz	Low dc offset voltage and drift is suitable for the dc restore circuits
AD8608	Precision, low noise, CMOS, rail-to-rail, input/output op amps; offset voltage: 20 μV and 1.5 μV/°C typ, V_N RTI: 8 nV/√Hz	Low dc offset voltage and drift is suitable for the dc restore circuits
OP4177	Precision low noise, low input bias current op amps; offset voltage: 25 μV and 0.3 μV/°C typ, V_N RTI: 7.9 nV/√Hz	Low dc offset voltage and drift is suitable for the dc restore circuits
DC Restore Switch		
ADG1608	8-channel multiplexers; on-resistance: 4.5 Ω typ, 1 Ω flatness; up to 470 mA continuous current, –64 dB typical off isolation at 1 MHz	Low on-resistance, high continuous current, robust to power sequencing
ADG1411	Quad SPST switches; on-resistance: 1.5 Ω typ, 0.3 Ω flatness; up to 250 mA continuous current, –80 dB typical off isolation at 100 KHz	Low on-resistance, high continuous current, robust to power sequencing
Voltage Reference		
ADR43x	Ultralow noise, voltage references with current sink and source; 0.15% accuracy and 10 ppm/°C for A grade	Low drift and high accuracy benefit ADC and DAC SNR performance
ADR34xx	Micropower, high accuracy voltage references; 0.1% accuracy and 8 ppm/°C	Low drift and high accuracy
Clocking		
ADCLK8xx/ ADCLK9xx	Multioutput fan out buffer optimized for low jitter and low power operation; additive broadband jitter less than 500 fs	Well suited for low jitter PET clock distribution
AD951x/ AD952x	Multioutput clock distribution functions with subpicosecond jitter performance, along with an on-chip PLL and VCO	Well suited for low jitter PET clock divide and distribution
Temperature Sensor		
ADT7420	Digital I²C temperature sensor with ±0.25°C accuracy from –20°C to +105°C, 16-bit resolution (0.0078°C), ADT7320 is the SPI interface version	No calibration required, over/under temperature interrupt
ADT7410	Digital I²C temperature sensor with ±0.5°C accuracy from –20°C to +105°C, 16-bit resolution (0.0078°C), ADT7310 is the SPI interface version	No calibration required, over/under temperature interrupt
Power Management		
ADP2384	4.5 V to 20 V input, 4 A output current, synchronous step-down dc-to-dc regulator; pin-to-pin compatible with 6 A version: ADP2386	High efficiency, accurate current limit allow the use of smaller inductor
ADP7102	3.3 V to 20 V input, 300 mA output current, 200 mV dropout voltage LDO with low noise performance, 15 μV rms for fixed voltage output, high PSRR 60 dB @ 10 kHz, reverse current protection; pin-to-pin compatible with 500 mA version: ADP7104	Improves performance of noise sensitive loads and low dropout
ADP7112	2.7 V to 20 V input, 200 mA output current, 200 mV dropout voltage LDO with low noise performance, 11 μV rms for fixed voltage output, high PSRR 88 dB @ 10 kHz	Improves performance of noise sensitive loads and low dropout
ADP150	2.2 V to 5.5 V input, 150 mA output current, 105 mV low dropout voltage LDO with low noise performance, 9 μV rms independent voltage output, high PSRR 60 dB at 100 kHz; pin-to-pin compatible with 200 mA version: ADP151	Improves performance of noise sensitive loads and low dropout
ADP5052	4.5 V to 15 V input, 1-channel, 2-channel: programmable 1.2 A/2.5 A/4 A sync buck regulators with low-side FET driver; 3-channel, 4-channel: 1.2 A sync buck regulators; channel-5: 200 mA low dropout LDO	5-channels integrated power solution reduces the design difficulty and also the board size
ADM7170	2.3 V to 6.5 V input, 500 mA output current, 105 mV low dropout voltage LDO with low noise performance, 6 μV rms independent voltage output, high PSRR 70 dB at 10 kHz; pin-to-pin compatible with 1 A version: ADM7171, 2 A version: ADM7172	Improves performance of noise sensitive loads and low dropout

Design Resources

Circuits from the Lab®

- *Interfacing the High Frequency AD8331 VGA to the AD9215 10-Bit, 65 MSPS/80 MSPS/105 MSPS ADC* (CN0096)—*www.analog.com/CN0096*

Application Notes and Articles

- *AN-737 Application Note, How ADIsimADC™ Models an ADC—www.analog.com/an_737*
- *AN-756 Application Note, Sampled Systems and the Effects of Clock Phase Noise and Jitter—www.analog.com/an_756*
- *AN-1224 Application Note, 40 Channels of Programmable Voltage with Excellent Temperature Drift Performance Using the AD5381 DAC —www.analog.com/an-1224*

Design Tools and Forums

- ADC
  - High speed ADC evaluation board with schematic and PCB layout gerber file
  - High speed FPGA-based data capture board (HSC-ADC-EVALCZ)—*www.analog.com/fifo*
  - VisualAnalog® software—*www.analog.com/VisualAnalog*
  - ADC SPI interface software (SPIController)
  - ADIsimADC™ modeling tool—*www.analog.com/ADIsimADC*
- Clocking and PLL
  - ADIsimCLK™ modeling tool—*www.analog.com/ADIsimCLK*
  - AD951x/952x evaluation software and board
- Amplifier
  - ADIsimOpAmp™: amplifier parametric evaluation tool—*www.analog.com/ADIsimOpAmp*
  - DiffAmpCalc™: differential amplifier calculator—*www.analog.com/diffampcalc*
- PMP
  - ADIsimPower™: power design tools—*www.analog.com/ADIsimPower*
  - Evaluation board

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