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TUTORIAL 4680

# Introduction to Positron Emission Tomography (PET) Imaging

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*Abstract: This tutorial explains how positron emission tomography (PET) imaging systems generate 3-D medical images. The article details how the PET system detects gamma-rays produced when injected doped sugars react differently to affected tissue. The article also discusses how competing electrical noise in the environment affects imaging, and why it is important to accurately detect photon timing and movement so the signal generated within the patient can be localized. A functional block diagram shows the IC components typically found in a PET system.*

## Overview

Positron emission tomography (PET) imaging systems construct 3-D medical images by detecting gamma rays emitted when certain radioactively doped sugars are injected into a patient. Once ingested, these doped sugars are absorbed by tissues with higher levels of activity/metabolism (e.g., active tumors) than the rest of the body.

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 patient. Unlike anatomical imaging techniques like computed tomography (CT), X-ray, and ultrasound, PET imaging provides "functional" information about the human body.



*Photo by Jens Langner*

CT and PET systems can be combined to provide both excellent anatomical detail and functional information.

## Detecting a Photon

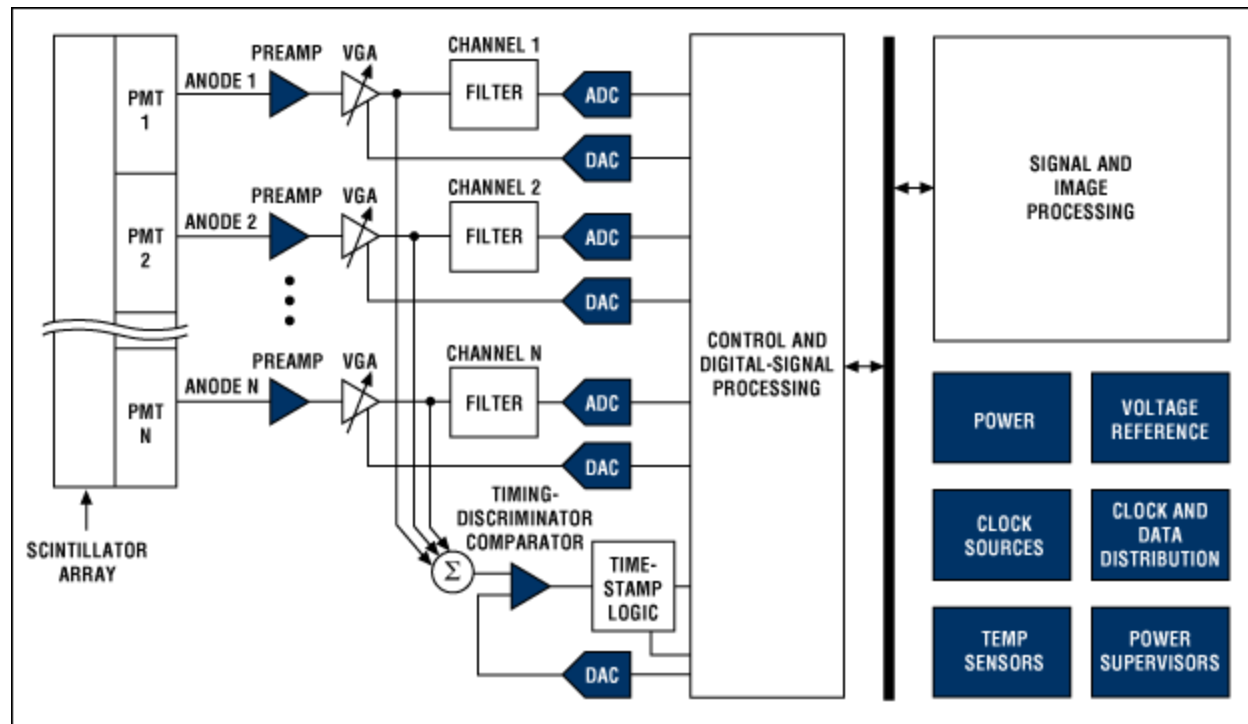
The PET detector is comprised of an array of thousands of scintillation crystals and hundreds of photomultiplier tubes (PMTs) arranged in a circular pattern around the patient. The scintillation crystals convert the gamma radiation into light which is detected and amplified by the PMTs.

## Signal versus Random Photon "Noise"

The manufacturers of PET imaging equipment continue to improve the diagnostic performance of these systems. Their focus has been on increasing the timing accuracy and the localization of gamma-ray photon detection.

Random gamma rays exist in the environment and the PET imaging system must differentiate a random photon from photon pairs generated within the body. To do this, the system must detect a time-correlated photon pair or, more simply stated, the presence of two photons generated at the same time and traveling in opposite directions. The system accomplishes this by analyzing the location of the photon pairs striking

the circular detector array to ensure that they are traveling in opposite directions. The system must also accurately measure when the photon pair strike the detector to ensure that they were generated at approximately the same time. Using this information, the PET system can discriminate random photon noise from the desired signal.



Block diagram of a PET system. This diagram shows one of multiple receiver groups that share a common time discriminator. For a list of Maxim's recommended PET solutions, please go to: [www.maximintegrated.com/pet](http://www.maximintegrated.com/pet).

## Detecting Photon Signal Strength for Event Localization

To reduce cost and complexity, most modern PET systems have many more scintillating crystals than PMTs. Given the disparity between the number of crystals and PMTs, the system must determine which of the many scintillating crystals was struck by a photon. It does this by analyzing the signal strength from the output of the PMTs in the vicinity of the crystal of interest.

The current signal from each PMT output is converted to a voltage and amplified by a low-noise amplifier (LNA). The signal generated by the PMT is a pulse with a fast attack and slow decay. The signal strength from each PMT is determined by digitally integrating the area under this time-domain pulse. The system uses a variable-gain amplifier (VGA) after the LNA to compensate for variability in the sensitivity of the PMTs.

The combined LNA and VGA gain is approximately 40dB with a gain range of about 20dB. The amplifiers used typically have noise of a few  $nV/\sqrt{Hz}$  or less, with bandwidths in the 100kHz to 1GHz range. Current-feedback amplifiers are sometimes used to provide high speed while minimizing power. High-density digital-to-analog converters (DACs) with 10-bit to 12-bit resolution are used to control the gain of the VGAs.

The VGA's output is passed through a lowpass filter, offset compensated, and then converted to a digital

signal by a 10-bit to 12-bit analog-to-digital converter (ADC) sampling at a 50Msps to 100Msps rate.

The ADC samples are typically processed by a field-programmable gate array (FPGA) discriminator which can process multiple ADC outputs. As such, ADCs with serial LVDS outputs or dual ADCs with multiplexed CMOS output buses can be useful in some cases to reduce both interconnect complexity and digital noise. As noted above, the digital-signal information from multiple PMTs is used to calculate the location of a particular photon strike.

## Detecting the Timing of a Photon Strike

The timing resolution of the digitized receiver output is, unfortunately, not adequate enough to determine precise time-of-flight information for enhanced imaging or even the approximate coincidence of two photon strikes. For this reason, the PET system utilizes ultra-high-speed comparators.

The signals from a number (typically four or more) of physically close PMTs are summed, and this combined signal drives the input of an ultra-high-speed comparator. A DAC generates the comparator's reference voltage to compensate for DC offsets. Extremely high accuracy is required to calculate time of flight, so a digital timestamp is generated using the comparator's output signal and an ultra-high-speed clock. In this way, timing information can be compared for multiple PMTs that are physically separated by a significant distance.

## Generating an Image

The photon pair defines a line on which the collision took place. This is called the line of response (LOR). By analyzing tens of thousands of LORs, the backend image signal processor can display the collision activity as a 3-D image. In some PET systems, the timestamp of two photon-strike events is used solely to determine if two strikes were close enough in time to be counted by the system as a valid signal. Verifying this LOR is challenging and requires a timing accuracy of a few nano-seconds.

Newer, higher performance PET systems are now using the time-stamps of the two photon-strike events to determine the approximate location of the collision site on the LOR. This technique improves image quality. These PET systems calculate the location of the collision to within ~10cm by computing the time of flight for each photon to within 100ps. This calculation places significantly greater demand on the timing accuracy of the system.

## Power and Integration Density Considerations

Power dissipation is a significant issue in a PET system, given the large number of system channels and signal-processing speeds. Consequently, manufacturers want lower power and more highly integrated solutions. In the future, PET systems will evolve away from PMTs and begin to utilize solid-state photo-detectors with much higher channel counts. When this happens, channel counts could increase from hundreds to tens of thousands of channels. This evolution will put significant pressure on IC solution providers to reduce power and increase integration density even further.

Related Parts		
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<a href="#">MAX19517</a>	Dual-Channel, 10-Bit, 130Msps ADC	<a href="#">Free Samples</a>
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