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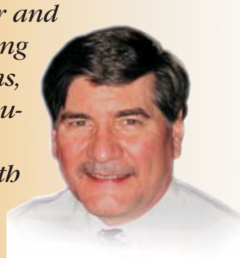
Pentek, Inc.
One Park Way, Upper Saddle River, NJ 07458
Tel: (201) 818-5900 • Fax: (201) 818-5904
email: pipeline@pentek.com
http://www.pentek.com

In This Issue

"The Model 7142 is a successor to our popular Model 7140 for customers who need more of everything. We see customers dealing with more complex waveforms, more channels in radar and beamforming applications, and communication systems with wider bandwidths."



Rodger Hosking, Pentek Vice President and Cofounder

Technical Resources

Download the new 5th edition of the *Digital Receiver Handbook:*
pentek.com/go/pipedrhb

Download the 2nd Edition of *FPGAs for Software Radio Handbook:*
pentek.com/go/pipefpgahb

Download the *Critical Techniques for High-Speed A/D Converters in Real-Time Systems Handbook:*
pentek.com/go/pipehshb

Taking another Look at Gravitational Waves

In the summer 2002 issue of The Pentek Pipeline, we reviewed the Laser Interferometer Gravitational-wave Observatory (LIGO) in the article *Looking at Gravitational Events of Cosmic Origin*. LIGO is aimed at searching for gravitational waves created by supernova collapses of stellar cores that form neutron stars and black holes, collisions and consolidations of such neutron stars and black holes, and the remnants of gravitational radiation created by the birth of the universe. To read the full article in that issue, please click here: **LIGO**.

The existence of these gravitational waves was predicted by Einstein's theory of general relativity. Gravitational waves are ripples that propagate through the universe. They are roughly analogous to electromagnetic waves, except what is "waving" is space time itself. Efforts to detect gravitational waves have been going on for roughly one-half century, but the measurements themselves are very difficult to make and no confirmed detections have been made yet.

LIGO Interferometry

As in the case of LIGO, most modern detection efforts use a technique known as interferometry: start with a laser beam, split it into two beams and send each of these two in a different direction. After some distance, reflect each beam with a mirror and return it to a central detector that's used to measure the distance to the mirror at the far end. A gravitational wave passing by will cause minute changes to the distances between the mirrors. Since space itself is stretching, the amount of displacement is directly proportional to the distance between the mirrors.

Scientists use the term "strain" to describe this change in length between mirrors divided by the original length. Typical expected strain amplitudes resulting from gravitational waves are in the order of 10^{-22}. Ground-based interferometers such as LIGO are approximately 4 km long. They must measure something with an amplitude spectral density on the order of 10^{-19} m/$\sqrt{\text{Hz}}$ at 1 kHz. This is about 1000 times smaller than the radius of a proton!

A Space Interferometer

NASA and the European Space Agency (ESA) are now in a partnership to build the Laser Interferometer Space Antenna, or LISA for short.

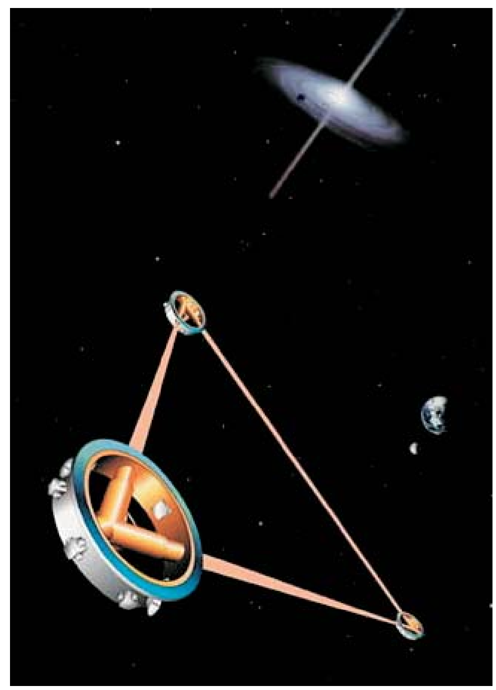


Figure 1. The LISA Space Interferometer (Courtesy of NASA/JPL-Caltech)

Putting an interferometer in space would allow one to overcome some of the noise sources that abound on earth, such as seismic vibrations and perturbations in the local gravitational field due to the motion of masses such as seas, clouds and moving trains. In addition, such an interferometer could be built with much longer arms to increase sensitivity at low frequencies. In this respect, LISA and LIGO are complementary since they look at different sources in different parts of the frequency spectrum.

As shown in Figure 1, LISA consists of three separate spacecraft in an equilateral triangle formation, 5 million kilometers on each side! LISA will be used to look for changes in interspacecraft distances to a level of 10 pm, where ➤

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1 pm = 10^{-12} m. Due to its size, LISA is unlike any existing interferometer. Among other interesting parameters, it takes light 16 seconds to travel from one spacecraft to the other! In order for it to succeed, it will have to implement some novel techniques that look good on paper but haven't been tested yet at the system level.

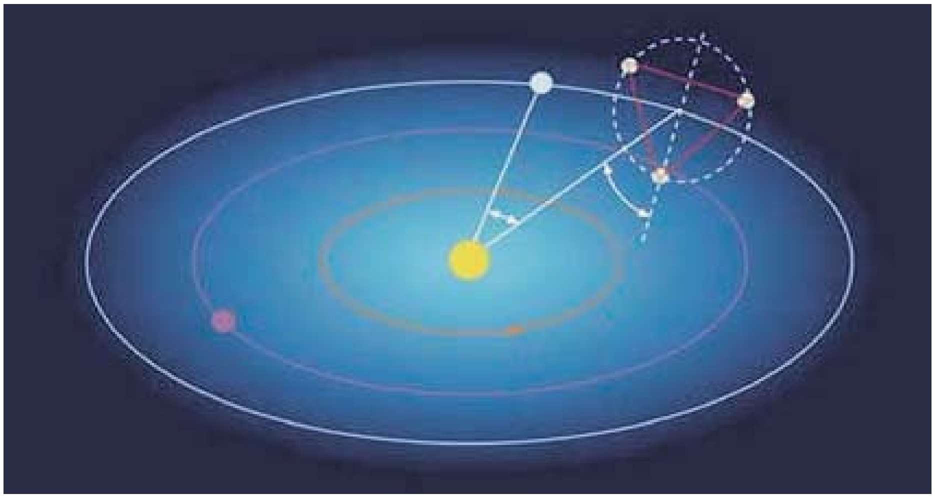

Figure 2. Orbit of the LISA Spacecraft 20 degrees behind Earth's Orbit around the Sun (Courtesy of NASA/JPL-Caltech)

Quick Facts about LISA

- Objective: Detect gravitational waves from galactic (within the Milky Way) binaries and extra-galactic (outside our galaxy) massive black holes.
- Planned Launch Date: 2015
- Mission Duration: 5 years nominal, 10 years extended.
- Orbit: 20 degrees behind Earth's orbit around the Sun at 1 AU (astronomical unit) from the Sun; orbit plane inclined 60 degrees to the ecliptic (Figure 2).
- Instrument: Identical in each of the three spacecraft, 40 cm (11.8 in.) telescope
- Power Supply: Solar array and lithium ion battery
- Spacecraft Attitude Control: star trackers and sun sensors
- Launch Vehicle: Delta IV

LISA Interferometry

LISA will not only be the world's largest interferometer, it will be the laser interferometer with the world's largest arm length difference. This arm length difference presents one of the most challenging problems of LISA. Fluctuations in the laser frequency in a standard Michelson interferometer, scale with the arm length difference and produce a noise background which could limit the sensitivity of the interferometer. A direct Michelson interferometer type measurement would require that the fractional frequency stability of the laser be less than or equal to the strain we are trying to measure. Taking all these parameters into account, the required laser frequency stability is on the order of a few $\mu Hz/\sqrt{Hz}$ at 1 mHz.

Use of the best materials and stabilization control systems, can reduce the laser frequency noise into the $1Hz/\sqrt{Hz}$ range. It is expected that the temperature fluctuations on the LISA spacecraft will be in the same range and that the laser frequency noise in LISA will also reach the Hz range. The remaining noise would be about six orders of magnitude above the required noise level for a direct Michelson interferometer measurement.

Several solutions to reduce this noise further have been proposed. The most favored solution uses a technique called Time Delay Interferometry (TDI) to create an artificial equal arm length Michelson interferometer. It detects fluctuations in the two arms of the interferometer independently from each other and then forms linear combinations between the instantaneous signals and earlier measured (time delayed) signals. This linear combination will be insensitive to laser frequency noise, just like the interferometer signal of an equal arm length Michelson interferometer.

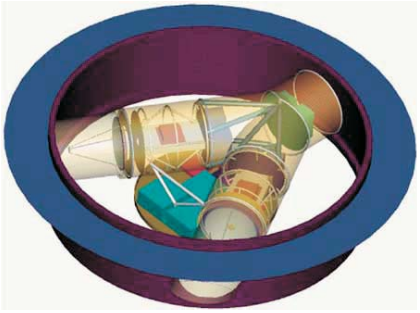

Figure 3. One of the LISA Spacecraft Showing the Optical Bench and the Telescope (Courtesy NASA/JPL-Caltech)

Arm locking is another solution. The idea is to use the arms of the LISA interferometer as the reference for the laser frequency and stabilize or lock the laser frequency to this reference. This elegant solution has the disadvantage that the long light travel times between the spacecraft, put severe constrains on the feedback loop and it is unlikely that the loop alone will have enough gain to suppress the entire laser frequency noise to the required level. However, a partial suppression of the laser frequency noise could significantly reduce the very tight requirements on TDI.

The LISA Simulator

A full test of TDI or arm locking depends on the capability to simulate the long light travel time between the LISA spacecraft. Until recently, it was assumed that this was impossible; that experimental tests could only be performed at the subsystem level; and that only simulations can bridge the gap to the final instrument. However, a group of scientists at the University of Florida (UF) succeeded in developing a light travel time simulator: the Electronic Phase Delay technique (EPD). They are now on their way to test TDI and arm locking in a realistic LISA-like interferometer configuration.

A model of one of the LISA spacecraft is shown in Figure 3. The central "Y tube" contains the payload, where each of the

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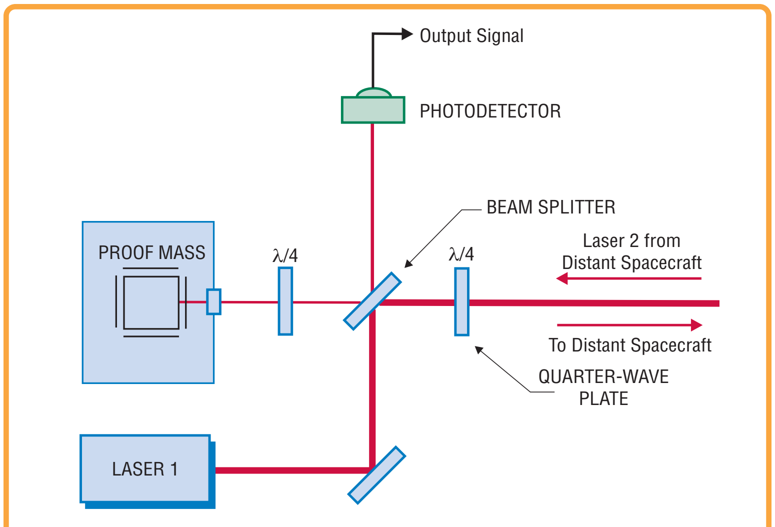


Figure 4. Simplified Model of the LISA Optical Bench and Telescope

➤ two arms houses an optical bench and a telescope. Each telescope is directed at one of the far spacecraft. Each bench contains a Proof Mass and directional optics for the laser beams. The proof mass floats freely inside the spacecraft via a drag-free control system. Capacitive sensors measure the distance between the proof mass and the spacecraft, while thrusters steer the spacecraft around the proof mass. The interferometry between the spacecraft is designed to measure changes in the distance between proof masses on different spacecraft that are caused by gravitational waves.

A simplified design of the optical bench is shown in Figure 4. The majority of the beam from Laser 1 is reflected at a polarizing Beam Splitter and sent out to the far spacecraft. The same setup is located within the far spacecraft and directs another beam, from Laser 2, toward the bench of Laser 1. The telescope is used to gather the light of the diverged beam from Laser 2 and direct it onto the proof mass.

The Photodetector (PD) on the bench measures the beat signal between Lasers 1 and 2. The output signal will have a frequency equal to the difference frequency of the lasers, plus terms due to phase noise of the lasers and the travel time of light between the spacecraft.

Electronic Phase Delay

Any experimental verification of LISA interferometry requires a way to simulate the significant light travel time between the spacecraft. The EPD under development by the researches at UF, will delay signals in real time within an optical setup.

As shown in Figure 5, Laser 0 is used as a reference and beats with Lasers 1 and 2. The difference frequencies between the lasers seen by the photodetectors are in the range of 10–20 MHz and contain a large amount of frequency or phase noise, very similar to the expected noise in LISA. The signal from PD 2 is first filtered by an antialiasing low-pass filter and then digitized by one of the channels of a Pentek Model 6256 Four-Channel 14-bit, A/D Converter VIM module with dual Xilinx Virtex-II FPGAs.

The digital signal is then routed to one of the FPGAs, where a Phase Meter IP core is implemented. Here, the signal is mixed with both the I and Q quadratures of a sinusoidal signal generated onboard the FPGA by a Numerically-Controlled Oscillator (NCO). The two signals are then low-pass filtered to obtain the I and Q components of the input signal. This processing is required because the input phase noise is so large that it would wrap over many cycles. Consequently one of the quadratures is used as an error signal to adjust the phase of the NCO to keep the mixers in their linear ranges and remove any phase ambiguity from the signal.

The desired signal is the phase of the input signal which is obtained by properly combining the local oscillator signal to the NCO with the residual phase difference between the input and the NCO. This, along with the amplitude of the signal, is then downsampled to a lower rate and transmitted across the VIM-2 interface to the 4205 carrier board.

From the 4205, the data is streamed across the Ethernet interface to a PC for storage and analysis. In addition, the data is stored in the 4205 SDRAM to mimic the light travel time delay. The output of the SDRAM is then transmitted across the VIM interface to the Pentek 6228 Digital Upconverter and D/A VIM module, where an NCO core implemented in the FPGA upsamples the data and recreates the waveform with the delayed phase and amplitude of the original input signal. This analog output is then mixed and demodulated with the non-delayed beat signal between Laser 1 and 0. The demodulated signal is technically identical to a LISA optical bench signal.

For more information on LISA, click here: **lisa.nasa.gov** . ❑

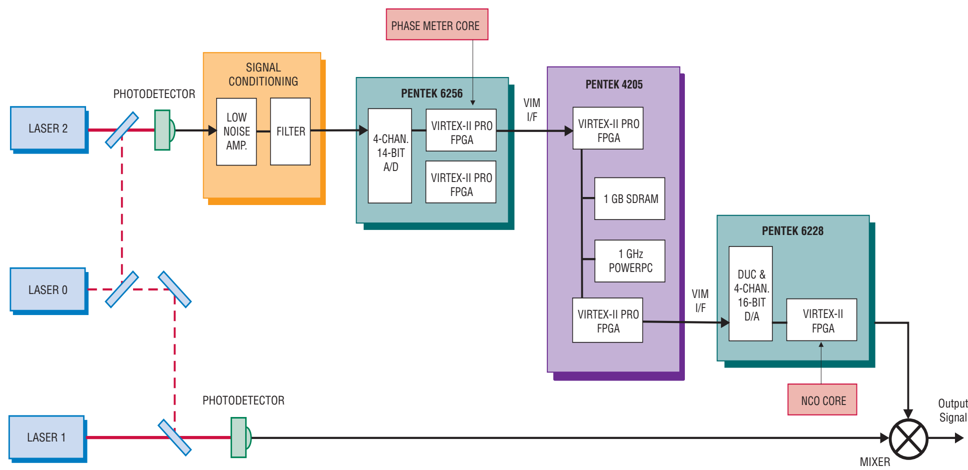


Figure 5. LISA Simulation Electronic Phase Delay Block Diagram

Model 7142 PMC/XMC Multichannel Transceiver Boosts FPGA, Memory and A/D Resources

Product Focus

Model 7142

The Model 7142 PMC/XMC module provides complete software radio transceiver functions suitable for IF or RF communication systems and offers increased capabilities. These include dual Virtex-4 FPGAs, four A/D converters, an upconverter with D/A and large SDRAM memory.

The Model 7142 is also available in a variety of form factors including PCI (Model 7642), 6U and 3U cPCI (Models 7242 and 7342), as well as ruggedized and conduction-cooled versions.

This Model is also available in 6U and 3U cPCI and PCI formats. The products are also available in ruggedized and conduction-cooled versions.

GateFlow ReadyFlow Board Support Libraries

Features

- Dual Virtex-4 FPGAs provide configurable DSP and high-speed I/O
- Four 14-bit A/Ds operate at 125 MHz maximum sampling rate
- XMC I/O delivers data streams over Gigabit serial fabrics
- 768 MB memory to buffer data for digital delay and transient capture
- Built-in sync bus enables multiple board synchronization

A/D Converters

The front end accepts four full scale analog HF or IF inputs at +4 dBm into 50 ohms with transformer coupling into Linear Technology 14-bit 125 MHz A/D converters.

The digital outputs are delivered into the Virtex-4 FPGA for signal processing or for routing to other module resources.

Upconverter and D/A Converter

A TI DAC5686 digital upconverter (DUC) and D/A accepts a baseband real or complex data stream from the FPGA with signal bandwidths up to 40 MHz.

When operating as an upconverter, it interpolates and translates real or complex baseband input signals to any IF center frequency between DC and 160 MHz. It delivers real or quadrature (I+Q) analog outputs at up to 320 MHz to the 16-bit D/A converter. Analog output is at +4 dBm into 50 ohms.

If translation is disabled, the DAC5686 acts as an interpolating 16-bit D/A with output sampling rates up to 500 MHz.

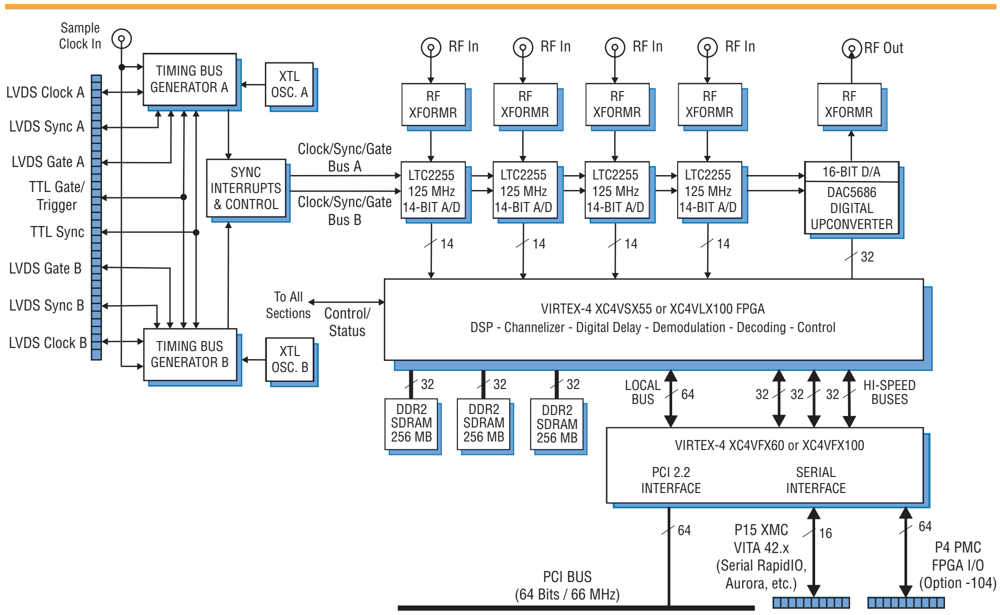
Virtex-4 FPGAs

The Model 7142 architecture includes two Virtex-4 FPGAs. All of the board's data and control paths are accessible by the FPGAs, enabling factory installed functions including data multiplexing, channel selection, data packing, gating, triggering and SDRAM memory control.

The Xilinx XC4VSX55 features 512 DSP slices and is ideal for demodulation/modulation, decoding/encoding, decryption/encryption, digital delay and channelization of the signals between reception and transmission.

For applications requiring more FPGA logic cells, the Model 7142 can be optionally configured with an XC4VLX100 in place of the XC2VSX55 for 110,592 logic cells.

A second Virtex-4 FPGA provides board interfaces including PCI and serial I/O. The XC4VFX60 FPGA also includes two PowerPC cores which can be used as local microcontrollers to create complete application engines.



Clocking and Synchronization

Two independent internal timing buses can provide either a single clock or two different clock rates for the input and output signal paths. Each timing bus includes a clock, a sync, and a gate or trigger signal. Signals from either Timing Bus A or B can be selected as the timing source for the A/Ds and the upconverter and the D/A. Two internal crystal oscillators and a front panel reference input or LVDS bus can drive the timing buses.

A front panel 26-pin LVDS Clock/Sync connector allows multiple modules to be synchronized.

Memory Resources

Three independent 256 MB banks of DDR2 SDRAM are available to the FPGA. Built-in memory functions include an A/D data transient capture mode with pre- and post-triggering and a D/A waveform generator mode. All memory banks can be easily read or written to through the PCI interface.

For more information on the Model 7142 Multichannel Transceiver, click here:
www.pentek.com/go/pipe7142 ❑

Product Focus

System RTS 2504

Real Time Multiband Transceiver System Handles Recording & Playback

The Pentek RTS 2504 is a recording system that contains all the hardware and tools needed for acquiring, downconverting, processing, analyzing, recording, upconverting and playing back wideband signals. Integrating recently introduced A/D and D/A converters, digital downconverters and upconverters, FPGAs and signal processors, this system allows the design engineer to take advantage of the latest technology for signal processing.

The combination of data recording and playback capabilities in a single unit makes the RTS 2504 especially valuable for developers. Instead of using simulated signals and signal analysis tools during system development of radar or communication systems, engineers can take the RTS system into the field to capture and generate real-world, real-time signals for direct validation of both signal-processing algorithms and system hardware.

Scalable from two to 40 transceiver channels in a single 6U VMEbus enclosure, the RTS 2504 serves equally well for advanced research projects and proof-of-concept prototypes, or as a cost-effective strategy for deploying high-performance multichannel embedded systems.

Features

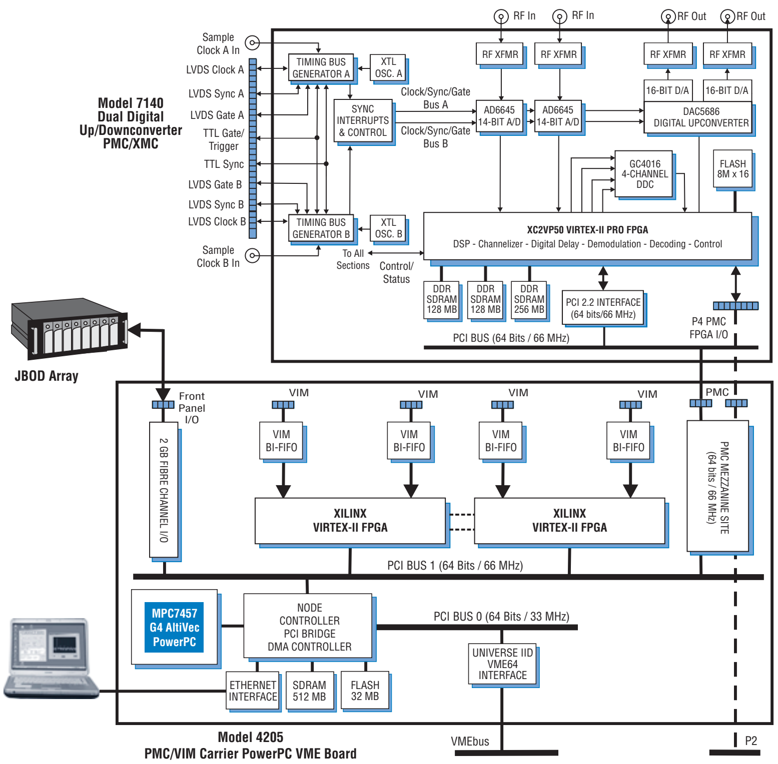
- Highly scalable recording system from two to 40 transceiver channels
- System includes 14-bit 105 MHz A/Ds, 16-bit 500 MHz D/As, 1 GHz PowerPC processor
- Multiple Xilinx Virtex-II and Virtex-II Pro FPGAs
- Digital downconverters and upconverters for complete software radio applications
- SystemFlow® Recording Software
- Optional GateFlow® FPGA Design Kit and IP cores
- Ideal for radar, wireless, SIGINT, telecom and satcom

Inside the RTS 2504

The Model 7140 high-performance dual channel transceiver PMC/XMC module digitizes HF or IF input signals using a pair of 14-bit, 105 MHz A/D converters and generates output signals with two 16-bit, 500 MHz D/A converters. A Virtex-II Pro FPGA serves as a control and status engine with data and programming interfaces to each of the many onboard resources. These include a two-channel digital downconverter, a two-channel digital upconverter and a very versatile clocking and synchronization system.

The FPGA is supported with 512 MB DDR SDRAM for built-in buffering functions, such as data capture and delay. A 64-bit 66 MHz PCI interface includes a nine-channel DMA controller to boost PCI transfer speeds.

The 7140 transceiver is installed as a PMC peripheral on a Pentek Model 4205 I/O PowerPC processor. The processor features a 1 GHz MPC7457 PowerPC, 1 GB SDRAM and two Xilinx Virtex-II FPGAs. It acts both as an executive for managing data transfer tasks and performing signal processing and data formatting functions.



SystemFlow Recording Software

SystemFlow Recording Software provides a rich set of function libraries and tools for controlling and building Pentek's RTS real-time recording and data acquisition systems. SystemFlow allows developers to configure and customize the system's interfaces and behavior. It includes code not only for the real-time data acquisition, recording and playback functionality, but also for the user-control software running on the host PC including the GUI.

For more information, click here: **www.pentek.com/go/pipe2504**. ❑