High-Burst-Rate Time Spectrometry...
from nanoseconds to milliseconds...
with 100-ps Precision

- **Time-of-Flight Mass Spectrometry**
  Exceptionally high data rates and superb digital resolution!

- **LIDAR**
  1.5-cm digital resolution for 0 to 1,000 km!

- **Fluorescence/Phosphorescence Lifetime Spectrometry**
  Measure lifetimes from ns to ms with one instrument!

All in a half-length PCI plug-in card . . .

complete with software for your PC
• 1-GHz Burst Rates: Multiple Stop capability with 1-ns pulse-pair resolving time
• Digital resolution selectable from 100 ps to 13 µs
• Time spans from 51.2 ns to 6.7 ms, (or to $\infty$ with customized roll-over monitoring)
• 512 to 67 M time bins
• Dead time correction function enables a factor of 10 higher event rates
• Half-length PCI card; up to 4 units in the same computer
• Histogramming, List, Trend, and Chromatograph Modes implemented in software
• Complete with data acquisition, control, display and analysis software running under Windows® 2000 and XP
• ActiveX™ controls provide an easy-to-use programmer’s toolkit
High Data Rates and High Resolution for the Most Demanding Applications

The Model 9353 100-ps Time Digitizer / MCS is a plug-in PCI card that functions as a time digitizer or a multichannel scaler. It measures the arrival times of Start pulses and multiple Stop pulses with a precision of 100 ps. Exceptional digitizing precision, speed and time span\(^2\) make it ideal for Electrospray Time-of-Flight Mass Spectrometry, Orthogonal-Acceleration MALDI TOF-MS, LIDAR, and Fluorescence/Phosphorescence Lifetime Spectrometry.

The Model 9353 measures the arrival times of multiple Stop pulses after the most recent Start pulse. Deep, cascaded FIFO buffers accommodate burst rates up to 1 GHz and sustained rates up to 10 MHz. The pulse-pair resolving time for Stop events is 1 ns. A dead time correction algorithm, implemented in software, permits increasing the Stop event rate by an order of magnitude, while keeping dead time distortions of the time spectrum insignificant.

Flexible Time Spans and Bin Widths to Suit any Application

The time span following each Start pulse can be as short as 51.2 ns or as long as 6.7 ms, with the selected span distributed over as few as 512 time bins, or as many as 67,000,000 bins. The maximum time span can be extended to infinity utilizing the auto roll-over monitoring with customized software. The width of each time bin can be adjusted from 0.1 ns to 13.1072 µs.

Minimize the Data File Size by Selecting List Mode or Histogramming Mode

The Time Digitizer / MCS can store the time information using either of two modes:

In the List Mode, the Start and Stop events are streamed to the supporting computer and onto hard disk as a list of 32-bit time stamps. This is a productive way to produce a compact file when the Stop event rates are low, and changes in the time spectrum occur over periods shorter than a few seconds. Each time stamp in the list marks the arrival time of a Start or Stop pulse with a precision of 0.1 ns. The time stamp for each Start pulse is referenced to the time at which the data acquisition commenced. For Stop pulses, the time stamp is referenced to the most recent Start pulse. The maximum value of the time stamp is approximately 6.7 ms for Stop pulses, and 125 hours for Start pulses. Either during or after acquisition, specific segments of the list can be selected and histogrammed by the software to display a time spectrum.

The Histogramming Mode produces a more compact file size when the data rates are high. In this mode, the software in the PC sorts and combines the Stop events following multiple Start pulses to form a spectrum of the number of Stop events versus their Start-to-Stop time. This spectrum is a histogram, because the horizontal axis is grouped into bins of 100-ps width. The resulting histogram is saved on hard disk. When the time digitizer is measuring the flight times of photons or charged particles over a fixed distance, this histogram is called the time-of-flight (TOF) spectrum.

More specifically, each Start pulse marks the beginning of a scan through the selected time span. The time stamps for the Stop pulses are expressed with zero time corresponding to the arrival of the prior Start pulse. The arrival time of a Stop pulse determines the appropriate bin in the histogram to which one count is added. This process of adding Stop events to the histogram is repeated for each scan until the desired number of scans has been completed. The resulting histogram is displayed as the number of Stop events (vertical axis) versus Start-to-Stop time (horizontal axis).

Histogramming improves the statistical precision of the data by summing the data from multiple scans. The precision improves in proportion to the square root of the number of scans summed. Histogramming can be performed on the data as it is being acquired, or on the list-mode data recalled from the hard disk.

\(^1\)All trademarks used herein are the property of their respective owners

\(^2\)US Patent Number 6,785,194
Perform Chromatograph/TOF-MS Acquisitions or Track Trends with the Chromatograph/Trend Mode

In the Chromatograph or Trend mode, the short-term changes in the Stop-pulse counting rate are tracked in a graph that displays the Trend or Chromatograph. Clicking on any point in this graph causes the TOF spectrum for that point to be displayed. The total number of Stop events in this TOF spectrum determines the ordinate for the corresponding point in the Chromatograph/Trend graph, while the first Start time stamp from the TOF spectrum specifies the abscissa. The TOF spectra from multiple points in the Trend graph can be summed and saved to improve the statistical precision.

Ready-to-Run Application Software and a Programmer’s Toolkit

The hardware comes complete with standard software for controlling data acquisition, display, manipulation, and storage on hard disk. The software runs under Windows 2000 and XP. In addition to the standard Windows features, the software provides:

- TOF X-axis calibration in user-defined units via least squares fitting to a linear, quadratic or cubic calibration curve.
- Post-acquisition dead time correction.
- Summing multiple TOF spectra to improve statistics
- 3-point and 5-point data smoothing to improve viewing statistics.
- Overlaying and comparing spectra.
- Exporting data in ASCII format.
- Copying display graphs to a file.
- Determining centroid, gross area and net area of a peak.

The software supports up to 4 Model 9353 cards operating simultaneously in the same computer.

ActiveX®, Controls provide a programmer’s toolkit to facilitate the writing of custom software. Custom software can take advantage of special combinations of the extensive hardware functions to add different features, or to integrate the 9353 into software controls for a larger system.

Supporting Electronics

Both the Start and Stop inputs of the 9353 include leading-edge timing discriminators capable of processing positive or negative detector pulses in the 50-mV to 5-V amplitude range, with widths as brief as 500 ps. Usually, the detector signal will need some amplification to optimize the timing performance with the 9353. Check the optional equipment list at the end of this brochure for suitable, fast amplifiers.

For applications where the desired time resolution is less than the rise time of the Stop pulse and the pulse amplitudes vary, a low-walk timing discriminator, such as the model 935, 9307 or 9327, must be inserted before the Stop input. See the section on optional equipment for further information.
SPECIFICATIONS

Hardware

PERFORMANCE

TIME-STAMP CLOCK FREQUENCY: 10 GHz; 100-ps digital time resolution, with no interpolator. Arrival of the input pulse leading edge captures the clock time. Accuracy: within 20 ppm from 0 to 50°C. Temperature sensitivity <1 ppm/°C.

TIMING JITTER: FWHM analog timing jitter is <200 ps +0.05 ppm of the Start-to-Stop time interval. (Typically <145 ps FWHM from 0 to 200 µs.)

INPUT DEAD TIME: 1-ns pulse-pair resolving time for the Stop Input. Dead time after the Start Input < 5 ns.

DIFFERENTIAL NON-LINEARITY*: For Start-to-Stop times >25 ns, bin widths are uniform within ±1% of the average bin width, or within ±2 ps, whichever is larger.

INTEGRAL NON-LINEARITY*: The time scale is linear from 0.25 µs to 200 µs within 20 ps rms (i.e., 0.1 ppm of 200 µs).

FIFO BUFFER MEMORIES: A fast FIFO handles bursts up to at least 256 input events at a maximum rate of 1 GHz (4 GB/s). The fast FIFO is drained at 78 M words/s into a 128-word FIFO, with Start events occupying 3 words and Stop events employing one word. The 128-word FIFO is drained at >15 M words/s into a slow FIFO having a depth of 8-M-words. The data is streamed from the slow FIFO to the computer through the PCI bus in a list mode at a maximum burst rate of 33 M words/s (132 MB/s). Note that the computer software or operating system can become the limiting bottleneck for extracting the data from the PCI bus. For a bus availability >50%, the time digitizer is capable of sustaining an average data transfer rate >10^7 Stop events per second. The maximum rate for Start events is 1/3 the maximum rate for Stop events.

WORD LENGTH: 4 Bytes at the PCI bus. Each accepted Start pulse generates three, successive, 32-bit words. The first word incorporates the lower-order bits of the arrival time in bits 0 to 25. The second word contains the higher-order bits of the arrival time in bits 0 to 25. The third word contains the Start Pulse Number in bits 0 to 25. Each accepted Stop pulse generates one 32-bit word, with the arrival time in bits 0 to 25. A roll-over tracking word is automatically inserted in the data stream every 3.355443 ms, if there is no Start or Stop event within 12 ns of that time stamp. A data-padding word (contains no useful information) may be inserted occasionally to complete a desired array length. For all Stop and roll-over words, the arrival time is measured with respect to the preceding Start pulse (mod 6.710886 ms). For Start pulses, the time is measured relative to the most recent Reset before starting acquisition. Moving from the most significant bits (MSB) to the least significant bits (LSB), the bits in each word are reserved as follows:

* 31: Warning Flag. See FIFO Overflow Warnings.
* 30: Set to 1 for Start events. Set to 0 for Stop events, clock roll-over tracking words, and data padding words.
* 29 & 28: On Start words, these two bits reflect the TTL input tag bits that can be used to specify one of 4 external operating conditions. The TTL inputs are strobed by the Start pulse. Both bits are forced to zero on Stop events. On clock roll-over tracking words, bits 30 and 28 are set to 0, and bit 29 is set to 1. For data padding words, bit 30 is set to zero, while bits 29 and 28 are set to 1.
* 27 & 26: Identification of the three Start words. Bits 26 and 27 are both zero in the first Start word, which contains the lower-order bits of the time stamp in bits 0 through 25. Bit 26 is 1 and bit 27 is 0 for the second Start word, which incorporates the higher order bits of the time stamp in bits 0 through 25. Bits 26 and 27 are both 1 on the third Start word, which contains the sequential Start number in bits 0 through 25.
* 25 to 0: Used for capturing the arrival time from the 10-GHz clock on all Stop pulses, roll-over tracking words, data-padding words, and for the first two words of each Start pulse. With 26 bits, the clock rolls over at 6.710886 ms on Stop pulses, and at approximately 125 hours on Start pulses. On the third word for Start pulses, the information in bits 0 to 25 is replaced by the Start Pulse Number from the Start Pulse Counter.

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*Measured as a ± deviation of the counts per bin relative to the average counts per bin, using uncorrelated start and stop pulse generators, with sufficient counts to render the random error negligible compared to the inherent differential non-linearity.
*Measured with pulser peaks at 0.25-µs intervals by calculating the deviation of each peak’s centroid from a straight line drawn between the centroids of the peaks nominally at 0.25 µs and 200 µs.
START PULSE COUNTER: A counter records the sequential number of the Start pulse received at the Start Input. This counter runs continuously with a roll-over established by the 26 bits allocated in the Word Length above. Start pulses that arrive when the computer has disabled acquisition do not increment the counter. The value in this register is substituted for the time stamp in bits 25 to 0 in the third word from each Start pulse. The register can also be read and reset to zero by the computer.

TIME SPAN OF EACH SCAN: The hardware discards Stop events with time stamps larger than the selected limit. This can reduce data processing rates for the PC. With the standard software, the limit can be set from 51.2 ns to 6,700,000 ns in 0.1-ns steps. For customized software, this feature can be enabled or disabled by setting/resetting a bit in the control register. When the limit is disabled, the time interval between Start events determines the maximum Stop time.

STOP EVENT SUPPRESSION: The hardware discards Stop events with time stamps smaller than the selected limit. With the standard software, the limit can be set from 0 to 6,700,000 ns in 0.1-ns steps. But, the limit must be at least 512 bins less than the Time Span of Each Scan. This feature significantly reduces the data rates for the PC, and also minimizes the memory required for acquiring and saving the time spectrum, when only the last portion of the time span is of interest. For customized software, this feature can be enabled/disabled by setting/resetting a bit in the control register.

SLOW FIFO OVERFLOW RECOVERY: When the 8-M-word slow FIFO is 7/8 full, the next Start event and all events following the next Start event are discarded. Once the FIFO is drained to less than half full, the FIFO resumes processing Start and Stop events, commencing with the next Start event. This process ensures that no partial scans are accepted when there is a slow FIFO overflow due to data blockage in the supporting computer, thus avoiding spectra distortion. To flag the missing scans, error bit 31 is set on the first Start event when processing resumes, and is automatically cleared immediately thereafter. The standard software displays a warning when a FIFO overflow has occurred.

INTERFACE TO PC: Packaged as a half-length PCI-bus plug-in card. The 8-MB FIFO buffer memory depth permits 4 time digitizers to be serviced simultaneously by the same PC at essentially the same total data rate that is possible with a single card.
INPUTS AND OUTPUTS

**START INPUT:** Rear-panel SMA connector with 50-Ω input impedance. Input comparator threshold adjustable from –2.5 V to +2.5 V in nominally 10-mV steps with a DAC under software control. Trigger polarity is selectable by software for positive or negative slope. Maximum linear input: ±5 V. Protected against overloads to ±5 V dc, and ±15 V for pulse widths <25 ns. Minimum pulse width at threshold: 0.5 ns.

**STOP INPUT:** Rear-panel SMA connector with 50-Ω input impedance. Input comparator threshold adjustable from –2.5 V to +2.5 V in nominally 10-mV steps with a DAC under software control. Trigger polarity is selectable by software for positive or negative slope. Maximum linear input: ±5 V. Protected against overloads to ±5 V dc, and ±15 V for pulse widths <25 ns. Minimum pulse width at threshold: 0.5 ns.

**ENABLE ACQUISITION GATE:** Rear-panel TTL input (SMA connector) provides a means of rejecting Start and Stop input signals by setting the gate input to the low TTL state. Input impedance is 5 kΩ to +3.3 V. Pulling the input low rejects Start and Stop pulses, commencing with the next Start pulse. Returning the input to the high state enables the collection of Start and Stop pulses, commencing with the next Start pulse. The gate pulse must precede the first Start pulse to be rejected by >50 ns and persist until >10 ns after the leading edge of the last Start pulse to be rejected.

**STOP INPUT GATE:** TTL input provides a means of rejecting Stop input signals by setting the gate input to the low TTL state. Input impedance is 5 kΩ to +3.3 V. This can be used to block Stop events in specific portions of the scan. The gate pulse must precede the first Stop pulse to be blocked by >50 ns and persist until >10 ns after the leading edge of the last Stop pulse to be blocked. The gate input is provided on the 9-pin D connector via signal and ground pins.

**TAG INPUTS:** Two pairs of signal and ground pins on the 9-pin D connector accept TTL tag signals to identify one of 4 external measurement conditions that applies to the current scan. Each Start pulse strobes and captures the state of the 2 tag inputs. Input impedance is 5 kΩ to ground. Protected to ±10 V. The Tag pulses must precede the Start pulse by >50 ns and persist until >10 ns after the leading edge of the Start pulse.

**PREAMPLIFIER POWER OUTPUT:** One set of pins on the 9-pin D connector provides +12 V power and ground for a 9326 Fast Preamplifier, a VT120 Fast-Timing Preamplifier, or a 9327 1-GHz Amplifier and Timing Discriminator.

**9-PIN D CONNECTOR:** Mounted on the rear panel of the PCI plug-in card. Provides access to the Stop Input Gate, the Enable Acquisition Gate, two Tag Inputs, and the preamplifier power. Pin assignments are:

<table>
<thead>
<tr>
<th>Pin Number</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preamplifier ground</td>
</tr>
<tr>
<td>2</td>
<td>Preamplifier ground</td>
</tr>
<tr>
<td>3</td>
<td>Logic signal ground</td>
</tr>
<tr>
<td>4</td>
<td>+12 V dc Preamplifier Power</td>
</tr>
<tr>
<td>5</td>
<td>Logic Signal ground</td>
</tr>
<tr>
<td>6</td>
<td>Stop Gate</td>
</tr>
<tr>
<td>7</td>
<td>Enable Acquisition Gate</td>
</tr>
<tr>
<td>8</td>
<td>Tag 0</td>
</tr>
<tr>
<td>9</td>
<td>Tag 1</td>
</tr>
</tbody>
</table>

**FAN-OUT CABLE (Optional):** Converts the 9-pin D connector to one standard ORTEC 9-pin D preamplifier power connector and 4 BNC connectors for the Stop Gate Input, Enable Acquisition Gate, and the Tag Inputs.
**COMPUTER CONTROLS AND INDICATORS**

**DATA ACQUISITION CONTROL:** ActiveX Controls provide the interface between the application software and the hardware, providing access to and control of all of the hardware features. Notably, the supporting computer can stop and start data acquisition at the input to the Fast FIFO. It can also clear the FIFOs, and clear any warning bits that are set in the status register. All FIFOs can feed their data to the PC until they are empty.

**FIFO OVERFLOW WARNINGS:** Bit 31 in the time-stamp word is set when any of the warning flags are set. Reading the status register will clarify the condition causing bit 31 to be set. The computer can read and clear these warning flags. The status register includes the following flags.

Slow FIFO Overflow: Set on the first accepted Start pulse after the slow FIFO has recovered from an overflow. Automatically reset otherwise.

Fast FIFO Overflow: An overflow sets this flag, and a reset command from the computer is required to clear it.

When an excessive, sustained data rate or a PC bottleneck has caused a FIFO overflow, the standard software uses the overflow flags to advise the operator.

**POWER AND PACKAGE**

**POWER SOURCE:** Nominally 1.7 A at +5 V plus the current drawn by any attached preamplifier from the +12-V supply. Power obtained from the PC power supply via the PCI bus connector.

**MECHANICAL PACKAGE:** Half-length PCI-bus plug-in card, 10.7 cm x 17.7 cm.

**WEIGHT:**
- Net: 0.14 kg (0.32 lb.)
- Shipping: 1 kg (2.3 lb.)

**AMBIENT OPERATING ENVIRONMENT:** 0 to 50°C at 0 to 80% non-condensing humidity.

**CE:** Conforms to CE standards for radiated and conducted emissions, susceptibility, and low-voltage power directives.

The Device Status Panel shows the state of all hardware communications registers.
Standard Application Software

The standard application software provided with the 9353 hardware runs under Windows® 2000 and XP with no programming required. The software provides control of all functions (see hardware specifications) plus data acquisition, display, and manipulation. Important controls and features are summarized below.

**TOF Mode:** Provides the ability to collect a single time-of-flight spectrum for a specified number of Start pulses. The data is histogrammed in software, and the updating results are displayed live during data acquisition. Number of Start pulses (scans) per spectrum is selectable from 1 to $10^6$.

**Chromatograph/Trend Mode:** Multiple time-of-flight spectra are acquired and saved on hard disk in rapid succession. The operator can select the number of Start pulses or scans per spectrum from 10 to $10^7$. The Chromatograph/Trend display shows the total Stop event count in each successive TOF spectrum versus the time stamp for the first Start pulse in each TOF spectrum. For chromatograph/TOF-MS applications this display is the total-ion chromatograph. Clicking on a point in the Chromatograph/Trend display causes the corresponding TOF spectrum to appear in the bottom portion of the display. The operator can choose a limit for the number of TOF spectra to be acquired (1 to 3,600,000). One of two methods for data storage on hard disk can be selected in the Chromatograph/Trend mode. The Software Histogramming Mode produces the most compact data storage file at high counting rates, whereas the List Mode yields a smaller file for low data rates.

**Software Histogramming Mode:** The incoming data is histogrammed in the PC memory for intervals determined by the number of Start pulses prescribed by the operator. The result is a sequence of histogrammed time-of-flight spectra that are stored in a common file on hard disk.

**List Mode:** The list of Start and Stop time stamps from the hardware are stored directly on hard disk without histogramming. The ordinate for each point in the Chromatograph/Trend display is generated by summing all the Stop counts for a prescribed number of sequential Start pulses. The time for each point is obtained from the first Start pulse in each summed sequence. Clicking on any chromatograph/trend point causes the software to histogram and display the corresponding TOF spectrum by recalling the appropriate segment of the list of time stamps from the hard disk.

**CHANGING DISPLAY LABELS AND FORMAT:** The displays can be customized to suit the application. Right-clicking on the TOF or Chromatograph/Trend display opens a menu that permits the operator to change most aspects of the graphical display. This includes changing the text used for the titles and the X- and Y-axes labels, choosing the symbols for the points, selecting a logarithmic or linear Y axis, and altering the colors for the titles, labels, axes, lines, grids and symbols.
**TOF HORIZONTAL SCALE CALIBRATION:** The TOF X-axis can be accurately calibrated in appropriate units for the application. A choice of linear, quadratic or cubic function is offered for least squares fitting of a calibration curve in user-specified units for the horizontal axis.

**DEAD TIME CORRECTION ALGORITHM:** A software dead time correction algorithm\(^5\) offers post-acquisition corrections of any TOF spectrum for the known value of extending dead time in the system. This permits a factor of 10 higher data acquisition rates with negligible dead time distortion of the time spectrum.

**DISPLAYED TIME RESOLUTION:** Software selectable from 0.1 ns per bin to 13.1072 µs per bin in a 1, 2, 4, 8, .... binary sequence.

**TIME SPAN:** 51.2 ns minimum to 6.7 ms maximum.

Minimum number of bins: 512. Maximum number of bins\(^6\): 67,000,000.

**STOP EVENT SUPPRESSION:** Software selectable limit from zero up to the selected time span minus 512 bins. Stop events with time stamps less than this limit are discarded before the slow FIFO in the hardware to reduce data rates and the size of allocated memory. Useful when measuring a small time interval near the end of a long flight time.

**TOF INFO AND C/TREND INFO:** Peak centroid, gross area, and net area above background are displayed when a peak region is marked in either the TOF or the Chromatograph/Trend display.

**TOOLBAR:** Buttons provide controls for magnifying and contracting the displayed regions of the spectra, performing a 3-point or 5-point smooth on the data to reduce statistical noise, plus the normal Windows functions.

**ADDITIONAL FUNCTIONS** are available from menus or by right-clicking the mouse to:

- perform dead time corrections
- toggle between uncorrected and corrected spectra
- implement horizontal scale calibration
- toggle between calibrated and uncalibrated scales
- overlay and compare spectra
- sum multiple TOF spectra to achieve better statistics
- save spectra
- export data to file in an ASCII format
- copy the graphs to a file
- view or set the instrument operating properties

**PROGRAMMER’S TOOLKIT** with ActiveX\(^3\) controls is provided along with the standard data acquisition, control, display and manipulation software to facilitate development of custom software.

\(^5\)ORTEC Application Note AN57 Dealing with Dead Time Distortion in a Time Digitizer, February 2001.

\(^6\)Each data point requires 16 Bytes of free PC RAM beyond that required for software programs. For 67,000,000 time bins at least 1.072 GB of free RAM is required for the TOF spectrum.
COMPUTER PREREQUISITES

Hardware
IBM-compatible PC with:
- One available PCI-bus slot with space for a 17.7-cm card length,
- >200 MHz CPU,
- At least 500 MB of memory
- 20-GB Hard drive or larger,
- CD-ROM (Software is supplied on a CD.)

Software
Windows® 2000 or XP

OPTIONAL AND RELATED EQUIPMENT

Typically, the signal from the detector must be amplified before presentation to the Stop Input of the 9353. The following models should be considered for that purpose:

- VT120 Fast Timing Preamplifier
- 9305 Fast Preamplifier
- 9306 1-GHz Preamplifier
- 9326 Fast Preamplifier

For detector signals exhibiting substantial variations in pulse amplitude, inserting a timing discriminator between the amplifier output and the 9353 Stop Input can reduce the resolution broadening caused by varying amplitudes. This is important when the desired time resolution is less than the rise time of the Stop pulses. Consider the following models:

- 935 Quad, 200-MHz, Constant-Fraction Discriminator
- 9307 pico-TIMING™ Discriminator
- 9327 1-GHz Amplifier and Timing Discriminator

Because of space and rise time considerations, the 9353 uses SMA connectors for some signals. SMA-to-BNC adaptors may be needed depending on the connectors on the supporting electronics. For 50-Ω coaxial cables, cable adapters, and other options, consult the catalog.

ORDERING INFORMATION

To order, specify:

- 9353 Time Digitizer / MCS (includes 9353-B32 software and instruction manual)
- 9353-FANOUT Fan-Out Cable (optional)