# APPLICATION NOTE
## GaGe CompuScope 14200-based Lightning Monitoring System

### Challenge

A customer needed to upgrade an older data acquisition unit for a real-time lightning monitoring system. Unlike many lightning detectors that measure the current pulse produced in a lightning rod that is actually struck by lightning, the customer's lightning detectors indirectly sense lightning pulses by detecting the burst of radio frequency (RF) electromagnetic radiation that is emitted by a lightning strike. The lightning monitoring system consists of an array of receiver antenna stations roughly arranged in a circle with a diameter of about 10 km. When a lightning strike occurs, the resultant RF burst is received by all eight antennas. Comparison of the relative arrival times of the RF pulses detected by each antenna allows the position of the lightning strike to be determined by triangulation. The intensity of the received RF pulses is a measure of the intensity of the lightning strike. A diagram of the lightning monitoring system is shown as Figure 1.

Pulses from each antenna station are transmitted through an analog radio channel to the master antenna station. The master station then transmits the pulse signals from all eight antenna stations to a remote analysis station using another radio channel. A Receiver/Demodulator unit demodulates the received radio transmission and recreates the eight analog RF lightning pulse signals. Calibration RF transmitters at known fixed positions emit pseudo-lightning bursts that are used to correct for differential propagation delays introduced to the lightning pulses by the radio transmission.

The eight analog signals from the Receiver/Demodulator unit are connected to an eight-channel analog acquisition analyzer unit where they are analyzed to provide the pulse amplitude and position of each of the eight pulses. The results are transmitted by Ethernet to a separate computer for interpretation and display. The customer was using an older home-made acquisition unit that provided only limited repetitive capture capability. The customer wished to update the system and replace the analyzer unit with a modern high-performance digitizer unit. Key requirements of the digitizing unit are listed below.

- The digitizer must have high 12 or 14-bit resolution in order to provide sensitivity to the high dynamic range of the lightning pulses, whose amplitude may vary widely with varying lightning strike intensities.

- A simultaneous 100 MS/s sampling rate is required on all eight channels in order to provide a timing resolution on the pulse position of 10 nanoseconds or better. Since the RF pulses travel at the speed of light, this sets the scale for the accuracy on the lightning strike position to be about of order 3 meters.

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*The GaGe solution is a system that consists of four CompuScope 14200s configured in Master/Slave mode for simultaneous triggering and sampling on eight channels and its eXpert™ Peak Detection firmware option.*

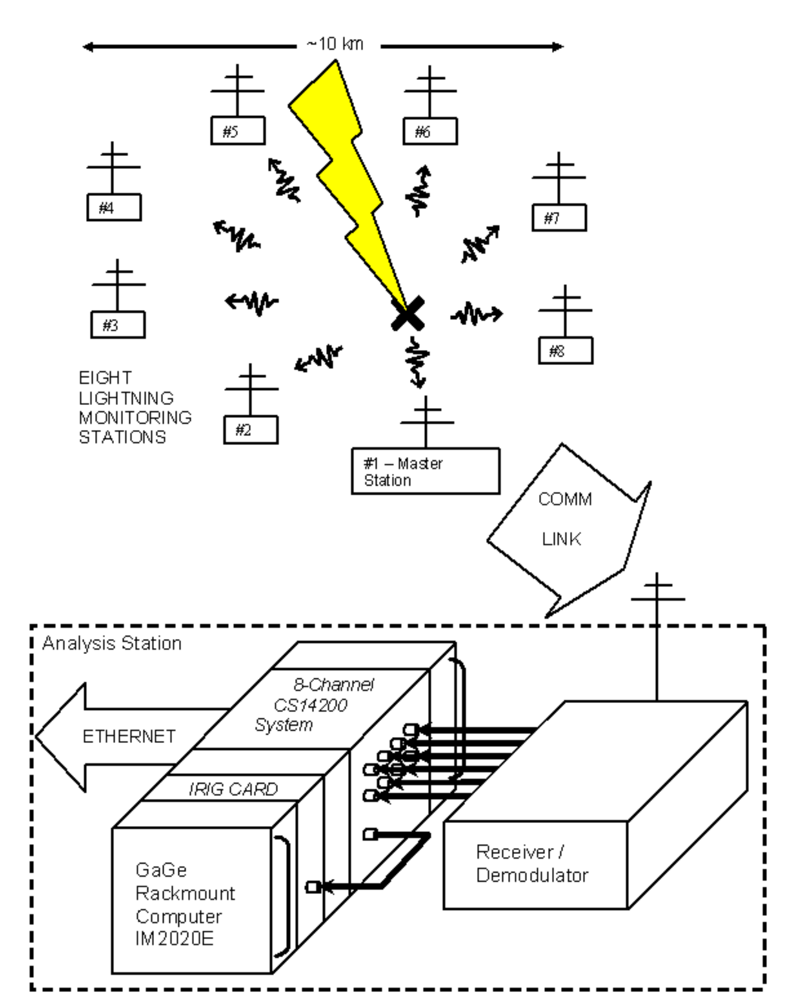


Figure 1: Illustration of lightning monitoring system

- Sampling and triggering on all eight channels must be simultaneous.
- One of the lightning pulse signals is highly amplified so that it is always larger than the signals from other channels. This pulse must be used as an internal trigger source for the digitizer unit.
- The acquisition time for each lightning pulse is about 100 microseconds. Although lightning strikes occur at random, they may occur in rapid succession. Consequently, the customer required that the system be capable of acquiring and analyzing pulses at a continuous rate of 9000 waveforms per second or better. The monitoring system will run continuously so that no temporary finite data buffer may be used to acquire data for post-processing.
- The digitizer system must provide an output trigger pulse that will be used to register an absolute Time-Stamp value on a PCI IRIG card. This card receives absolute timing signals from the atomic clock reference on-board satellites that are part of the Global Positioning System (GPS).
- The digitizer system must be provided with C source code so that the customer can integrate the digitizer hardware into the over-all lightning monitoring software.

## Solution

The GaGe solution is a GaGe Measurement System whose detailed specifications and testing regimen were prepared by GaGe application engineers in direct consultation with the customer. The system consists of four CompuScope 14200s configured in Master/Slave mode for simultaneous triggering and sampling on eight channels. The CS14200 provides 14 bits of vertical resolution and an impressive Signal-to-Noise Ratio (SNR) of 66 dB. Simultaneous sampling on all CS14200 input channels is possible at up to 200 MS/s.

The four CS14200s are housed within a GaGe Instrument Mainframe 2020E Industrial Computer with 16 available PCI slots. CS14200s are mechanically bracketed within the IM2020E for robustness during shipping and handling. Since the CS14200s only occupy four PCI slots, there are plenty of slots available for a commercial PCI IRIG card and other devices. The Windows/Intel-based IM2020E allows installation of low-cost commercially available hardware and software, such as storage media and Ethernet tools.

The standard Trigger Out output on the CS14200 produces a digital output pulse every time a trigger event occurs. This output may be connected directly to the customer's IRIG card so that the trigger time is logged with the absolute accuracy of an atomic clock.

The biggest challenge of the application was the acquisition and processing of waveform data at the required fast repetitive capture rate of 9 kHz. Initially, the approach of acquiring the raw waveform data and PCI transferring them to PC RAM for analysis by Windows software was considered. Although the PCI bus is extremely fast at up to a sustained data transfer rate of 200 MegaBytes/second, a quick calculation shows that this approach will not work. First, we calculate the number of samples required per 100 microsecond waveform:

Next, we calculate the amount of time required to PCI transfer all data from one waveform capture as:

The amount of time required to capture a 100 microsecond waveform and transfer the data to PC RAM is therefore 900 microseconds. This is far longer than the 1/9 kHz = 111 microseconds that are available and we have not even considered the time required for the peak detection analysis in software. Downloading waveforms one-by-one and processing them between triggers is not an option, therefore, for this requirement.

Normally, for such fast repetitive acquisition requirements, GaGe would recommend CompuScope Multiple Record Mode, which allows acquired waveforms to be stacked in on-board memory. For instance, with 16 MegaSamples of memory per channel, the CS14200 can accumulate 16 MS / 10,000 = 1600 waveforms in its on-board memory. Between sequential acquisitions, Multiple Record Trigger circuitry is re-armed extremely rapidly in hardware with no software interaction required. After a Multiple Record acquisition sequence, however, all Multiple Records must be downloaded to the PC. Consequently, Multiple Record Mode is ideal for waveforms that come in bursts. The lightning monitoring system, however, must run continuously so that any finite Multiple Record target memory is insufficient.

Because of the potentially large data throughput requirement exceeds the capacity of the PCI bus, GaGe application engineers concluded that some sort of data reduction on the CompuScope hardware was required in order to reduce the PCI data traffic so that the waveform trigger rate could be correspondingly increased.

GaGe worked with the customer to design GaGe's eXpert™ Peak Detection firmware option. The only information that the customer required was five numerical values from the pulse waveform data. These values are the occurrence time of the trigger event, the maximum amplitude value within the waveform together with its position and the minimum amplitude value within the waveform together with its position. These values are illustrated in Figure 2.

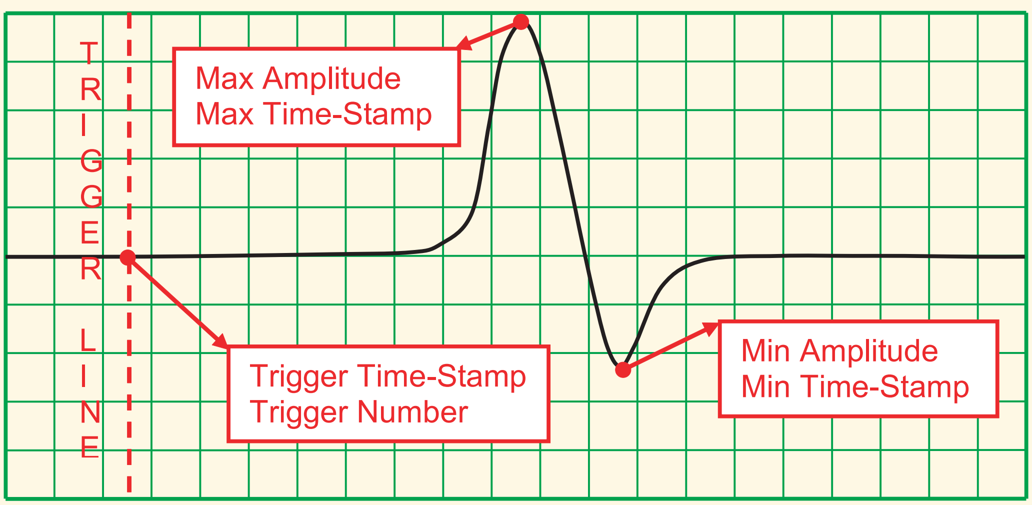



Figure 2: Peak Information Set parameters

Design of the eXpert Peak Detection firmware exploited empty space within the CS14200's on-board Field Programmable Gate Array (FPGA), which connects the ADC output data lines, the on-board CompuScope memory and the CS14200's PCI controller chip. Normally the FPGA is used to control CompuScope acquisitions and to mediate data flow amongst the three devices to which it is connected. For the customer's peak detection requirement, GaGe created a modified FPGA image that does peak detection analysis within the FPGA. A simplified schematic diagram that illustrates data flow using the eXpert Peak Detection firmware is shown in Figure 3.

Using the Peak Detection firmware, data are not passed directly from the ADC chips to on-board memory but are instead analyzed and reduced to the Peak Information parameters within the FPGA. Peak Information Sets are accumulated in a memory buffer within the FPGA. GaGe created special CompuScope driver functionality, which includes an autonomous Kernel-level process thread that periodically transfers available Peak Information Sets from the FGPA memory buffer to a RAM buffer within the host PC. This RAM buffer may be read by a Windows application-level program written in C.

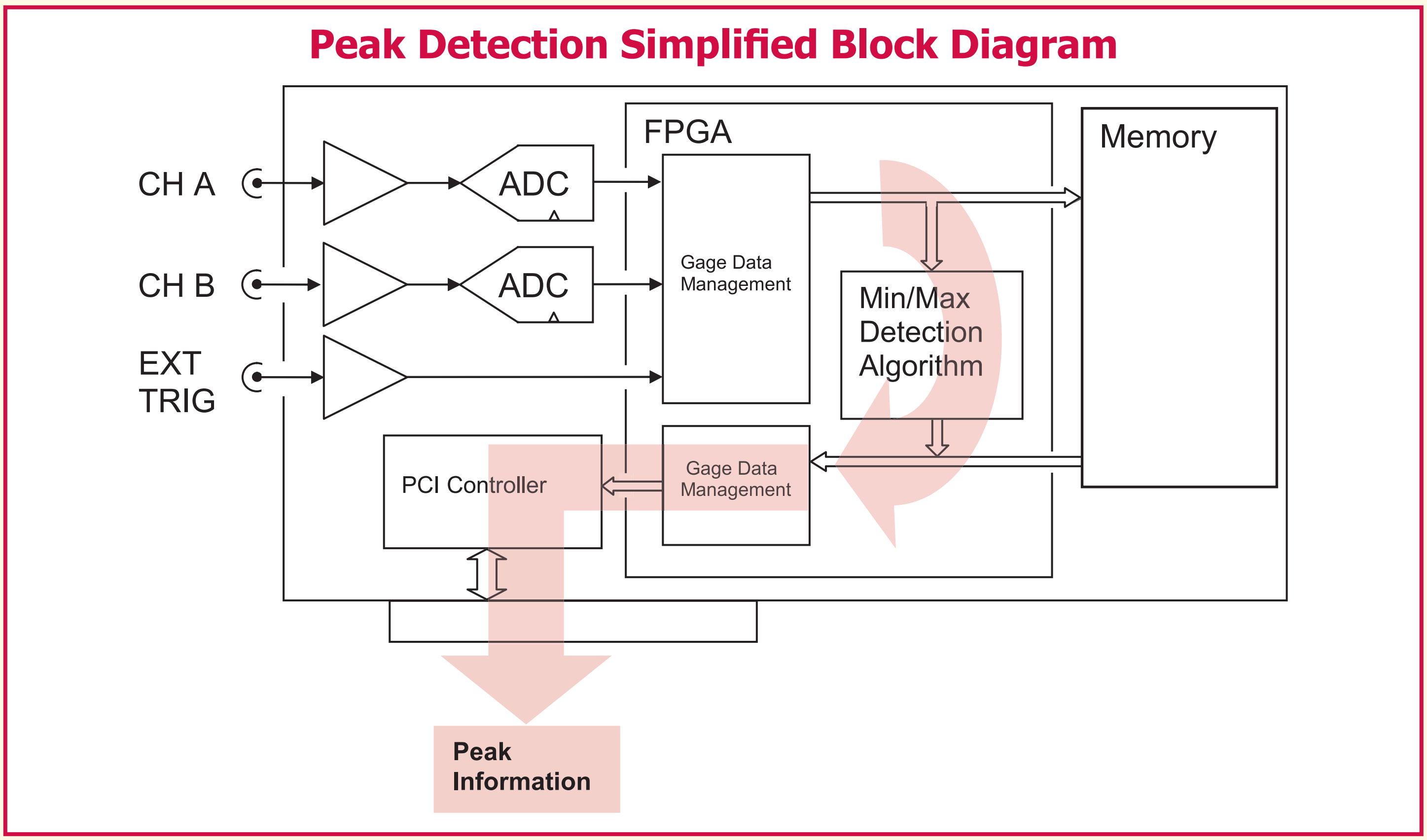



Figure 2: Peak Information Set parameters

The table in Figure 4 shows the contents of the Peak Information Set and its size in Bytes, which is equal to (# of Channel + 1) × 24 Bytes. For the customer's 8-channel system, therefore, the size of each Peak Information Set is 9 × 24 = 216 Bytes. The raw data volume is = 160 kiloBytes. The eXpert Peak Detection firmware, therefore, reduces the customer's data volume by a factor of almost 1000. The PCI data transfer time is correspondingly reduced from 800 µs to just a fraction of a microsecond. Furthermore, the eXpert drivers are capable of transferring Peak Information Sets in parallel with waveform acquisition so that no delays to repetitive acquisition are incurred due to data transfer. Also, trigger circuitry re-arming is effected in hardware with no software intervention required and occurs in well under a microsecond.

The net result is that the 8 channel CS14200 system equipped with eXpert Peak Detection firmware is able to continuously capture lightning pulses from all eight antenna stations. All lightning pulse triggers are captured and registered unless they occur within 1 microsecond of the end of the last acquisition. Provisions are even available to account for the rare occurrence of missed triggers, as will be described in the next section. GaGe knows of no other off-the-shelf solution that is capable of providing the performance required for this demanding application.

| PEAK INFORMATION SET (TOTAL SIZE = 8 BYTES + 16 BYTES + 24 BYTES × NUMBER OF CHANNELS) | | | | | |
|---|---|---|---|---|---|
| **NAME** | **DESCRIPTION** | **TYPE** | **SIZE** | **GROUP NAME** | **GROUP SIZE** |
| Structure Size | The size of the base structure for compatibility purposes | uInt32 | 4 Bytes | Header | 8 Bytes |
| Number of channels | The number of channel information sets | uInt32 | 4 Bytes | | |
| Trigger Number | The trigger count, which may be used to account for missed triggers, if any | uInt32 | 4 Bytes | Trigger information set | 16 Bytes |
| Reserved | | uInt32 | 4 Bytes | | |
| Trigger Time-Stamp | The Time-Stamp counter output that marks the occurrence time of the trigger event. | int64 | 8 Bytes | | |
| Max Amplitude | The maximum value that occurs within the waveform data set | int16 | 2 Bytes | Channel information set | 24 Bytes |
| Min Amplitude | The minimum value that occurs within the waveform data set | int16 | 2 Bytes | | |
| Reserved | | uInt32 | 4 Bytes | | |
| Max Time-Stamp | The Time-Stamp counter output that marks the occurrence time of the maximum | int64 | 8 Bytes | | |
| Min Time-Stamp | The TimeStamp counter output that marks the occurrence time of the minimum | int64 | 8 Bytes | | |

Figure 4: Contents of Peak Information data set

## Results

In order to test the GaGe Measurement System, GaGe engineers created 8 simulated lightning pulse signals using a CompuGen 8150. The CompuGen 8150 is an 8-channel PCI-based waveform generator capable of generating waveforms at a clocking frequency of up to 150 MHz. Patterns may be seamlessly looped so that they repeat forever.

The CompuGen was used to generate pulse-like signals that simulated lightning pulses. The pulses were arranged to occur at a fixed repetition rate that allowed less than a 10 microsecond break between 100 microsecond acquisitions. The continuous trigger rate of the generated pulse is therefore greater than the 9 kHz requirement.

In order to allow differentiation between successively acquired waveforms, simulated lightning pulses were prepared so that seventeen different sequential pulses occurred. This pattern of seventeen pulses was endlessly repeated. The amplitude of the pulse for channel 1, which is used as the trigger channel, was gradually diminished over the seventeen generations. The amplitudes of the pulses for the remaining seven channels were as similarly diminished. In addition, the pulses for these seven channels were also increasingly delayed with respect to the channel 1 pulse over the seventeen generations.

The simulated lightning pulses are displayed in Figure 5, which shows acquisition under GageScope, the world's most powerful oscilloscope software. Persistence mode is used in which acquired waveforms are never erased so that all seventeen distinct waveforms are displayed. The diminishing amplitude of the pulse amplitude on channel 1 is clearly visible as the ribbon-like appearance of the pulse on channel 1. The diminishing amplitude and increasing delay of the pulses on the other seven channels is also clearly evident in Figure 5.

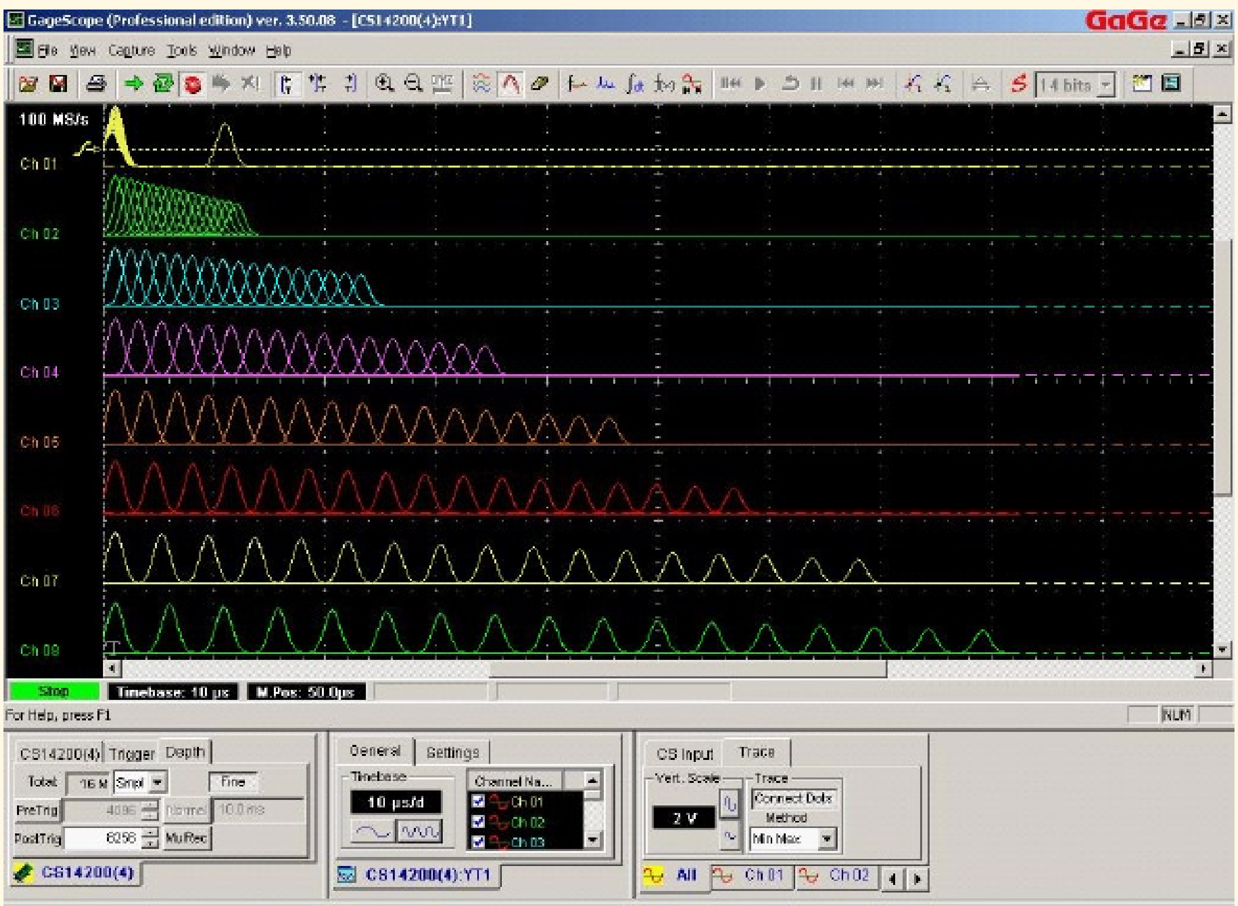



Figure 5: Acquisitions of simulated lightning pulses in GageScope

The customer was provided with a C sample program called MinMaxDetect, which is now provided with the CompuScope C/C# SDK. MinMaxDetect repetitively acquires waveforms using the eXpert Peak Detection firmware to reduce them to Peak Information Sets, which are accumulated and stored to an ASCII text file. With the simulated lightning signals of Figure 5 as sources, MinMaxDetect acquired tens of thousands of triggers so that any potential excessive latency would lead to data pile-up and eventual trigger loss.

The Peak Information Sets created by MinMaxDetect were analyzed and compared against the known generated signals. Differences between the measured peak positions in time for each channel and the known peak positions are shown in Figure 6 for the last 100 triggers of a 10,000 trigger acquisition sequence using MinMaxDetect.

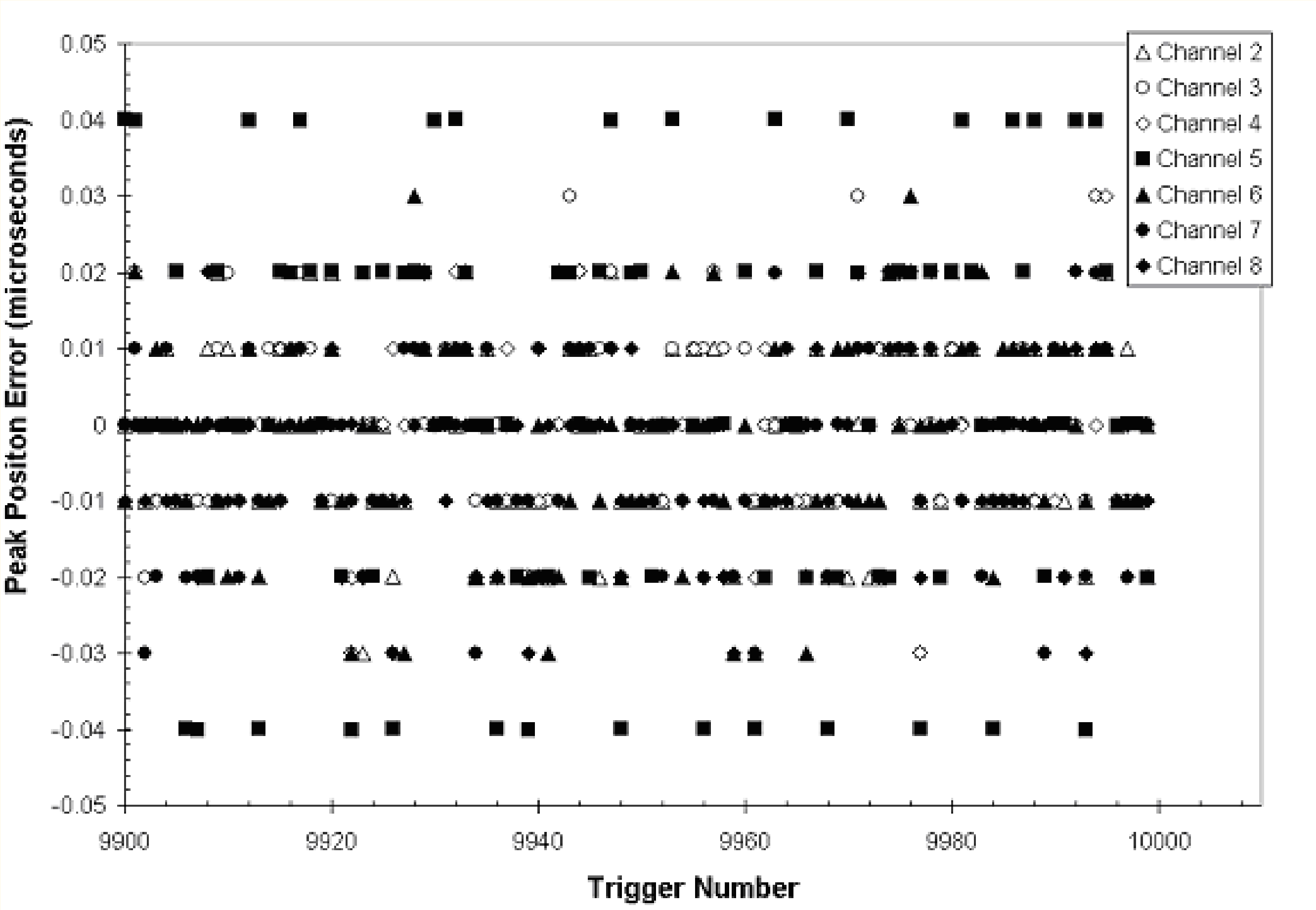



Figure 5: Acquisitions of simulated lightning pulses in GageScope

First of all, the excellent agreement shown in Figure 6 between measured and known peak positions immediately indicates that no triggers were missed by the system. Any missed trigger would cause the measured peak positions to fall out of synchronization with the known seventeen waveform peak position sequence and would lead to huge errors in Figure 6. Consequently, this test has rigorously demonstrated that the system can acquire and analyze waveforms at a continuous rate of over 9000 waveforms per second without missing any triggers.

In fact, the residual 20~30 nanosecond measurement error shown in Figure 6 occurs primarily because of the relatively large simulated pulse width and not because of any failing of the Peak Detection firmware. Measured pulse amplitudes were also compared against expected values and also showed excellent agreement.

The rapid re-arm and data reduction afforded by the CompuScope eXpert Peak Detection firmware reduces the possibility of missed lightning signal trigger to the minimum possible value. However, it is still possible for a lightning pulse to occur while a previous pulse is being acquired or during the sub-microsecond trigger re-arm time. Such missed triggers would, however, be detected by other instruments in the overall lightning monitoring system. This discrepancy would lead to misalignment between corresponding lightning strike data from the GaGe system and from the other instruments.

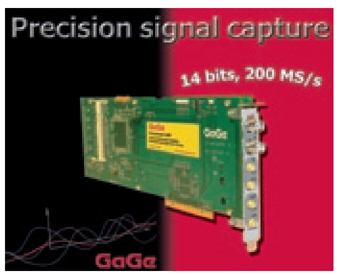
In order to resolve this problem, the eXpert Peak Detection ensures that all trigger events are counted, even if some triggers are missed. The eXpert Peak Detection firmware provides a Trigger Number value within the Peak Information Set, as shown in Figure 4. If triggers are missed then the Trigger Number for sequentially acquired Peak Information Sets will be found to increase by more than 1.

In order to verify the functionality of the Trigger Number value, a single spurious trailing pulse was added to the simulated lightning signal for channel 1. The trailing pulse was added only for the ninth distinct waveform in the seventeen-waveform sequence. The lone trailing pulse is visible on the signal for channel 1 in Figure 5. The system cannot possibly trigger on this trailing pulse since it occurs while the waveform for the main pulse is being acquired. Examination of the Trigger Number data provided by MinMaxDetect showed that the Trigger Number did indeed increase by 2 during the ninth waveform acquisition within every seventeen-waveform sequence, exactly as expected.

After thorough testing, the GaGe Measurement System was shipped to the customer, who was able to integrate the hardware and software into his complete lightning monitoring system within a couple of weeks. The firmware developed specifically for the customer's application is now available as the eXpert Peak Detection firmware option, together with complete accompanying documentation and the MinMaxDetect software. This complex, high-performance solution exemplifies how GaGe is able to modify catalog GaGe hardware to provide a complete turn-key GaGe Measurement System that exactly meets the requirement of the customer application.

## CompuScope 14200

CompuScope 14200 can sample two analog input at speeds up to 200 MS/s with 14-bit resolution and store the data in the very deep on-board memory.




**Features**

- 200 MS/s sampling on 2 synchronous channels
- 14 bit resolution
- Now available with up to 2 GigaSamples of on-board acquisition memory!
- Up to 100 MHz bandwidth
- 32 bits, 66 MHz PCI featuring 200 MB/s transfer to PC memory
- Full-featured, software-controlled front-end
- Programming-free operation with GageScope oscilloscope software
- Software Development Kits for C/C#, MATLAB, LabVIEW under Windows



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