LeCroy

WHITE PAPER

Advances in Oscilloscope Technology

Introduction

In 2001, LeCroy introduced the first 5 GHz real time digital oscilloscope. This product was followed in 2002 by 6 GHz units from Tektronix, LeCroy and Agilent. All of these instruments provide new capabilities for debugging high frequency circuits. This article discusses the implementation adopted by LeCroy, and the advantages offered by this approach.

All digital scopes use the basic block diagram shown in Figure 1. The input signal passes through an amplifier/attenuator stage, then an ADC converts the time varying signal amplitude to a series of numbers which are stored in memory. The digital data from the acquisition memory is sent to a microprocessor.

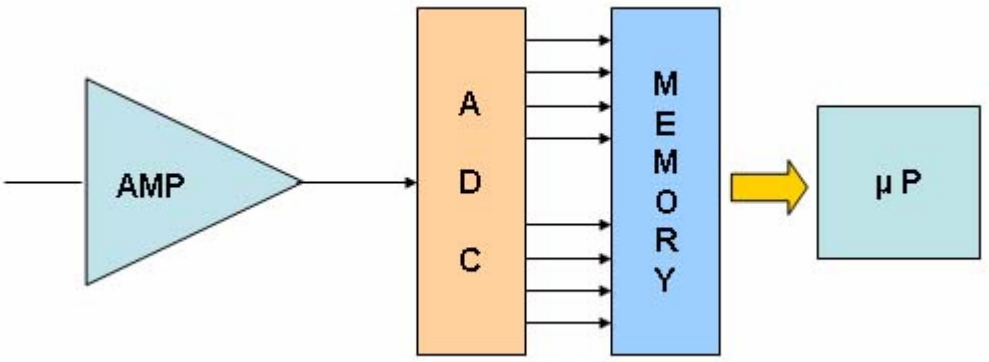

Figure 1 Block Diagram of a generic DSO

The Analog Signal Path

Constructing a 6 GHz path that can digitize signals in real time requires both careful design and specialized technology. In fact only LeCroy has a full speed path that can track an incoming signal with a 6 GHz bandwidth amplifier/attenuator, digitize it and transfer the data in real time into long memory.

Figure 1 shows the average frequency response (Bode plot) of 100 WaveMaster series 6 GHz scopes. LeCroy tests the bandwidth every unit using NIST traceable measurements and archives the data. The response is flat in the pass band and rolls off sharply beyond the rated bandwidth (see Figure 2). At 7 GHz, the response is down by more than 10 dB. This eliminates out-of-band noise, enabling the most precise timing and jitter

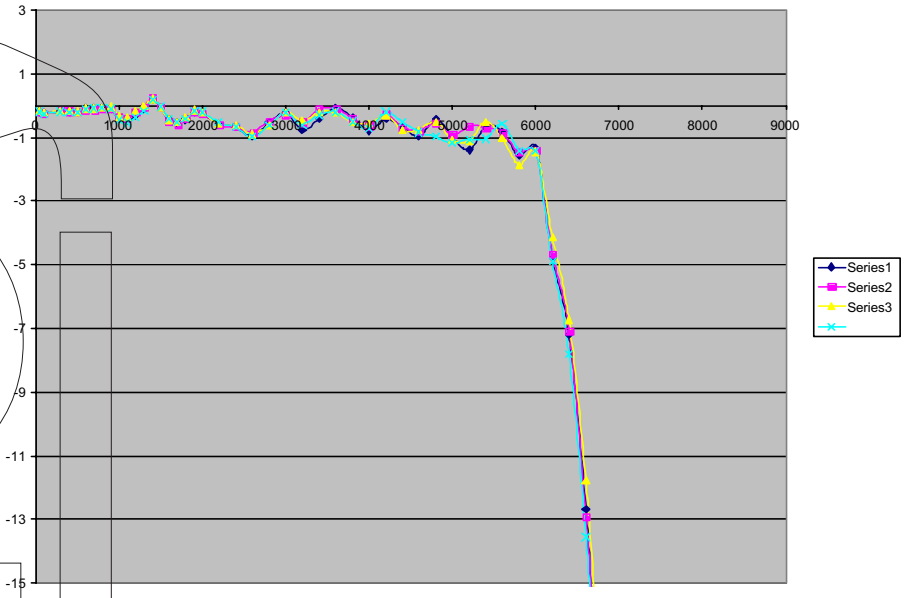

Figure 2 This Bode plot shows the average response of one hundred 6 GHz WaveMasters. Response is very flat in the pass band, and rolls off quickly above 6 GHz to preserve a low noise floor.

measurements. This rolloff is made possible by advanced digital filtering techniques , the subject of several patent applications.

The 6GHz signal path is made possible by 3 Silicon Germanium Integrated Circuits designed by LeCroy and fabricated by IBM:

- The MFE441, an amplifier/attenuator, with >6 GHz bandwidth. This drives up to 2 ADC's (for channel interleaving) and the Trigger System.
- The MAD440 ADC with >6 GHz bandwidth and 10 GS/s maximum sample rate per chip.
- The MTT trigger chip with >5 GHz bandwidth, providing the world's fastest real time scope trigger.

This chipset provides capabilities unmatched by any other oscilloscope. In addition (see Figure 3) the signal path contains:

- A front panel connector whose core conductor is rated at 18 GHz.
- A 12GHz relay which switches a x1 or x10 attenuator into the signal

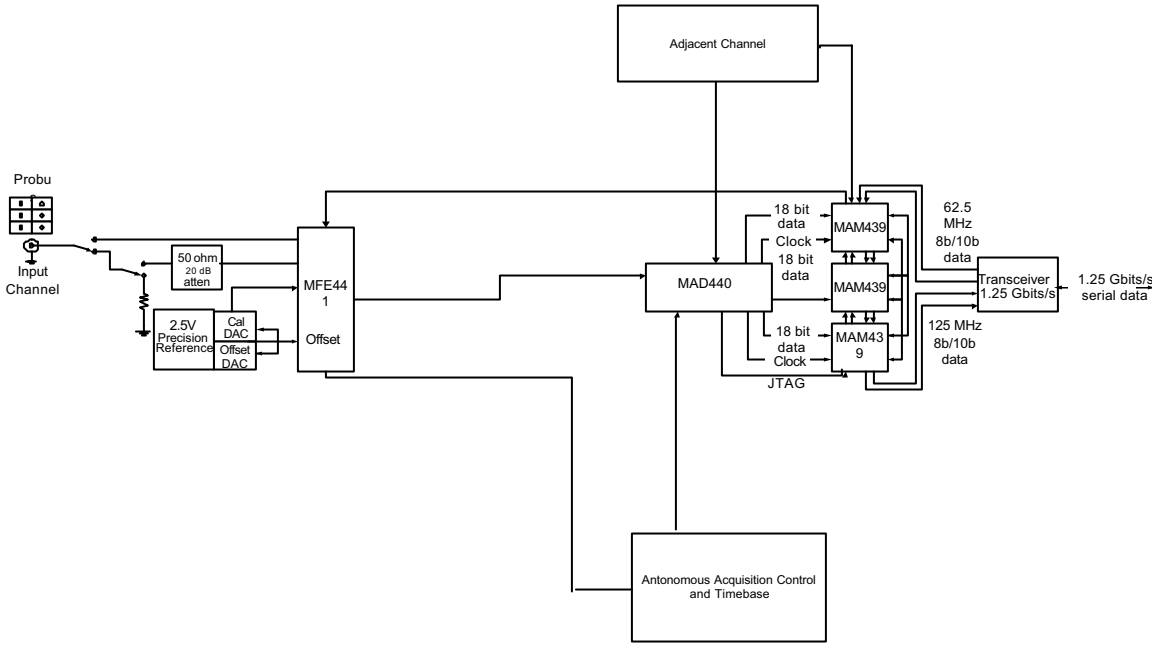

Figure 3 A WaveMaster front end. Simplicity is the key to obtaining a low noise, high bandwidth signal path. The MFE (monolithic Front End) and MAD (monolithic analog to digital converter) are both SiGe. The acquisition memory (MAM) is built using a high speed CMOS process.

Digitizing the Data

After amplification and conditioning, the now-differential signal is passed to the ADC. Since normal PC board material has significant losses at 5 GHz, the WaveMaster uses a special Rogers 4003 low dielectric constant material. These traces have 0.18 dB loss per inch at 10 GHz. The ADC converts the signal into eight bit data, making one measurement every 100 picoseconds. The data bits are sent via six data ports to three LeCroy-designed embedded DRAM's. These high-speed CMOS chips can each accept data at a rate of 3.3333 gigabytes per second (total aggregate of 10 Gbytes/sec), making them possibly the world's fastest DRAM's. No other scope has technology capable of capturing data at 10 Gbytes per second (20 Gbytes/sec when using two channels) into long memory. This technology is key to maintaining high sample rate, thereby preserving signal integrity.

DSP in the Digital Oscilloscope

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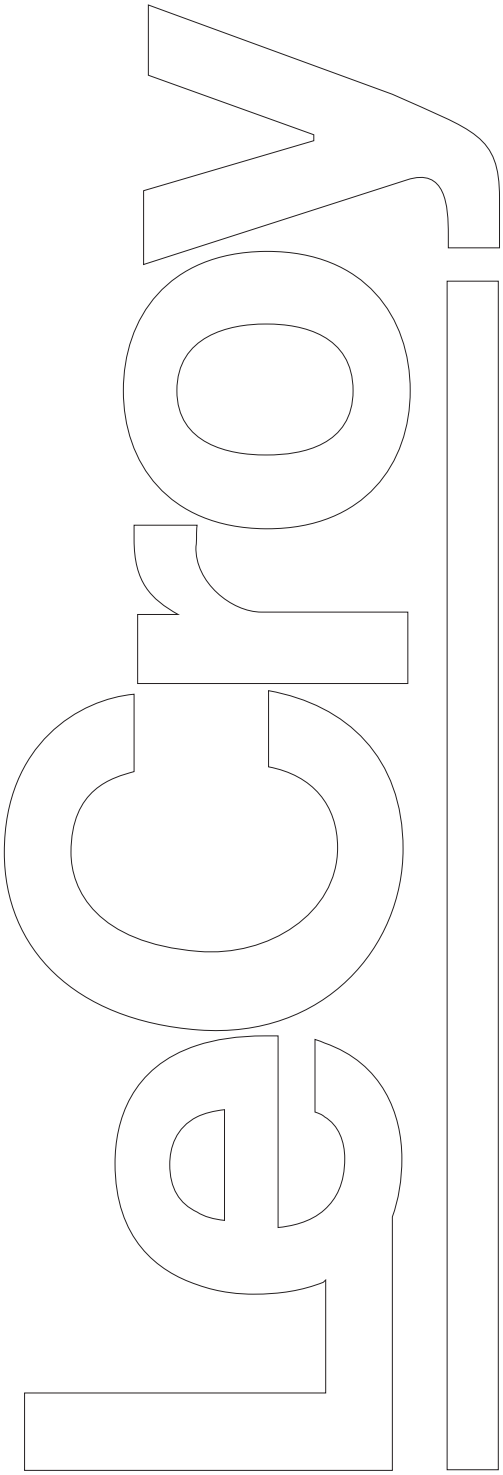
The oscilloscope has evolved into the most valuable tool utilized in the development of all forms of electronics equipment. This evolution is supported by many radical technology changes . These enable a DSO to reach previously-impossible performance in bandwidth, sample rate, memory length and signal fidelity. Critical technology enablers have included Silicon Germanium (SiGe), high-speed DRAM and high-speed processors. These technologies have been exploited by high-end scope manufacturers at the earliest opportunity.

In oscilloscopes, the primary need is to acquire complex, high-speed waveforms with high precision and to make accurate measurements of these waveforms. The aforementioned technologies have produced huge advances in the speed and duration of signal acquisition. LeCroy has focused on these capabilities, together with throughput—the speed at which waveforms can be processed. The convergence of speed, duration, and throughput enables LeCroy to acquire and analyze waveforms faster and more accurately than any other manufacturer. LeCroy has combined these capabilities to provide real-time digital signal processing in it's WaveMaster oscilloscopes

LeCroy has long recognized that together with the "banner" specifications, analog signal fidelity is of utmost importance. LeCroy uses its DSP technology to deliver higher signal fidelity than that achievable in hardware alone.

DSP is not a new concept. Its origins lie as far back as the French mathematician Fourier. The bulk of the advancements that form the theoretical basis for its widespread use were made circa 1960. Decades ago, DSP was utilized only in military and intelligence applications that could afford the most powerful computers. Advanced DSP was impractical for most applications due to the extreme processing power required. The arrival of the microprocessor in the early 1970s began a revolution that continues to unlock the power of DSP for everyday applications. We have seen DSP permeate every aspect of everyday life, as evidenced by the following table:

Application	Pre-DSP	DSP-enabled
Audio Recording	Analog Tape	CD, MP3
Cellular Phones	Analog	GSM, CDMA, UMTS
Video Recording	VHS Tape	DVD
Television	NTSC, PAL, Secam	HDTV, DSB



DSP has been utilized sporadically in digital oscilloscopes, for example, the application of a sine x/x filter to interpolate the signal position in between ADC samples is one type of common DSP. But its full potential went untapped as the cost of dedicated DSP processors made them impractical. Recent developments in processor performance, however, are creating a technology shift toward DSP in the oscilloscope business. Like previous technology shifts (vacuum tubes to semiconductors, analog CRT's to digital oscilloscopes) these advances will be adopted at different rates by different vendors. But the advantages they provide make their ultimate adoption inevitable.

DSP is not magic, trickery, or a technique used to fool people. It has its roots in the mathematics of linear systems, differential equations, and the LaPlace and Fourier transforms. LeCroy uses DSP to improve signal fidelity beyond that provided by the raw hardware. This does not mean that LeCroy extends its scopes' bandwidth through DSP. If signals are not passed to the ADC at full bandwidth, no amount of DSP will cause missing details to reappear. But LeCroy's combination of 6 GHz signal acquisition AND advanced DSP provides benefits in the areas of flatness, phase response, and the removal of digitization artifacts. We will address these three areas in detail.

Due to imperfections in hardware components, no oscilloscope has a perfectly flat analog frequency response. At very high frequencies, transmission line effects make the job of providing a flat response very difficult. Previous compensation techniques involved tunable filters and components, usually employing trims or component selection. More recent techniques employ laser trimming of component characteristics either on the circuit board, hybrid, or the chip die itself. All oscilloscope manufacturers use some combination of these elements to enhance the flatness of their instruments. LeCroy uses a combination of on-die variable bandwidth adjustments and DSP filters to make the final flatness adjustments. This hardware/DSP combination replaces multiple hardware adjustments, and performs better than hardware only techniques. The result is enhanced signal integrity.

LeCroy Wavemaster 8600A oscilloscopes entering the adjustment phase of the manufacturing process have bandwidth in excess of 6 GHz. On-die variable bandwidth adjustments and custom digital filters then bring them to the desired flatness. The bandwidth adjustment filters are also used to reduce aliasing when lower sample rates are employed. The phase response of the scope is linearized through the use of digital filters to provide nearly constant group-delay characteristics.

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Customer and Product Support

Finally, digital filters are employed to tailor the frequency response to an approximate fourth order Bessel filter, with noise reduction filters introduced at around 6.5 GHz. These filters remove quantization noise which is an artifact of the digitization process.

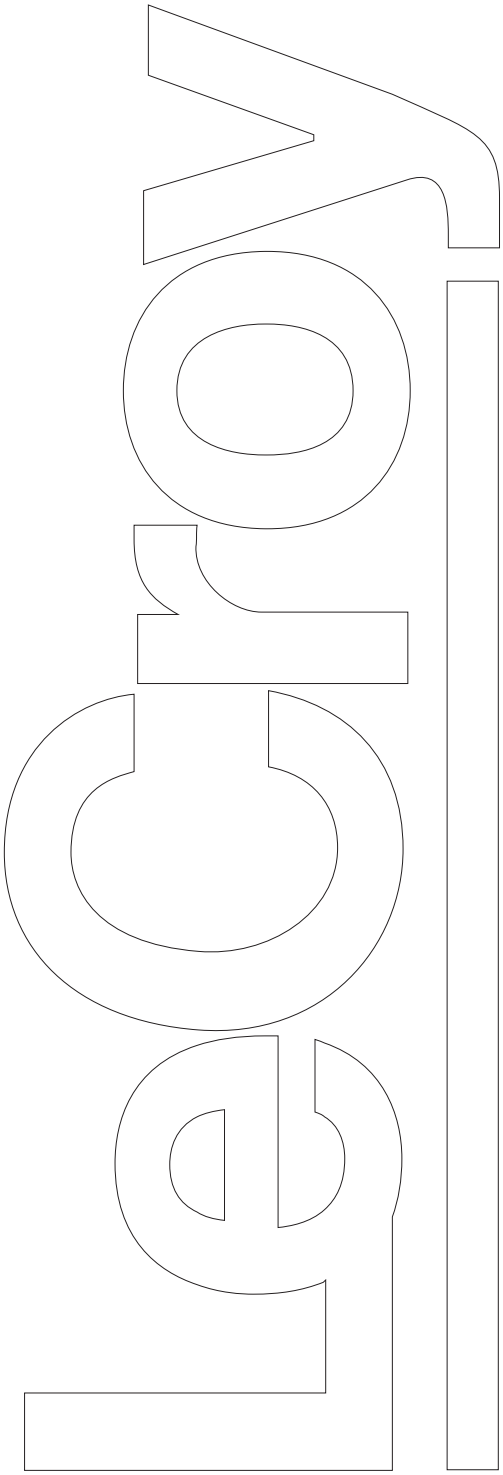
It is interesting to note that all of the DSP techniques utilized in the WaveMaster were originally developed for analog circuit design. These transfer functions would previously have been implemented with inductors, resistors and capacitors, and have simply been adapted for digital implementation which is more precise and repeatable than older analog methods.

Typical filters utilized within the WaveMaster DSO are 30 pole/zero IIR filters, calculated dynamically as required. The calculation of these filters is extremely complex and the refinement of this technology is the result of many years of investment into DSP technology. Because of the seamless integration of its acquisition system with the Wintel platform, LeCroy is able to digitally process the raw acquired data at a rate of one GFLOP (one billion floating point operations per second).

In summary, LeCroy has produced a DSO whose unmatched processing performance enables the use of DSP to enhance signal fidelity. LeCroy has long demonstrated a standing commitment to deliver the highest integrity measurement instruments available. The application of DSP technology to the DSOs is not an accident, but an example of that commitment. The result is faster and more accurate views and measurements of signals.

A comparison of the technical specifications of digital oscilloscope instruments is one way of determining value. A more complete comparison encompasses the overall experience a customer will have as a user of a particular piece of instrumentation. Factors such as an easy to use user interface, knowledgeable assistance, applications expertise and long term product support are all key aspects of the user's experience.

LeCroy prides itself on its commitment to service the products we sell, long after we have stopped manufacturing them. Our policy is to support (repair and calibrate) our instruments 7 years after we discontinue a product from general availability. We stand alone in the industry with this policy. This was not always the case; our primary competitors had these same customer support commitments at one time. Some have recently reduced their long-term product support, limiting the useful life of their instruments. The profits resulting from these decisions have come at the direct expense of their customers.



Similarly, the industry-standard oscilloscope warranty is 3 years. LeCroy maintains its 3-year warranties despite recent moves by others in the industry to shorten warranties and reduce long-term support.

LeCroy's direct and highly technical sales and applications engineering team are available on-site and around the world to assist our customers in getting the most out of our instruments. Unlike our competition, we have a singular focus on digital storage oscilloscopes. Our sales engineers devote all of their training efforts to these products, and are undistracted by widely diverse product lines. LeCroy sales and applications engineers "majored" in digital oscilloscope applications and their knowledge runs deep. Count on them to help you through your measurement applications.

Finally, we strive to ensure that LeCroy products can always be upgraded. When you purchase an instrument from LeCroy, you are assured of the ability to add any of the original options at any time, typically for the same price you would have paid at time of purchase. LeCroy always endeavors to make new features retrofittable into previous designs. This means that as LeCroy innovations are introduced, you can order them for your existing LeCroy scope, making it virtually obsolescence proof. Even the acquisition memory and processing RAM in most oscilloscopes can be upgraded.

LeCroy is proud of its 38 year heritage and devotion to signal fidelity, and customer support.