Digital Bandwidth Interleaving

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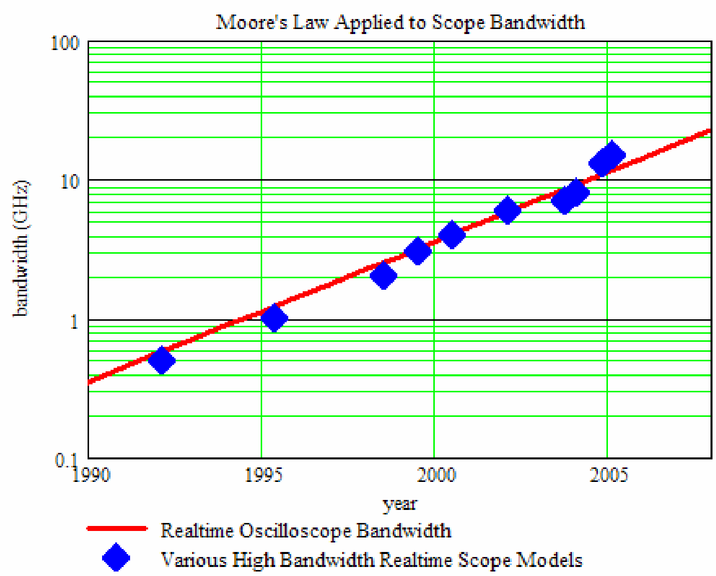
"The number of transistors on a chip doubles every 18 months."
- attributed to Gordon Moore
Co-founder Intel Corp.

Summary

Moore's Law[1] claims that transistor density doubles every 18 months. Since transistor speed is roughly proportional to linear density, it implies that transistor speeds double every three years. R&D engineers need real-time oscilloscopes that can keep up with the "bandwidth curve" in order to bring new designs to market.

Since the oscilloscope, while undergoing many changes during its long history, is still the primary tool used in the development of electronic instruments, Moore's law dictates that the oscilloscope bandwidth available must also double every three years in order to keep pace.

With regard to the real-time oscilloscopes (equivalent time, or sampling oscilloscopes have different rules), bandwidth increases of late have traditionally come through the utilization of higher speed processes in the design and development of oscilloscope front-end amplifiers, analog-to-digital converters (ADCs) and memories. Unfortunately for the oscilloscope manufacturers, this means the redesign of various custom ICs, with costs increasing at an exponential rate.[2] As the life-cycle of these high performance instruments continues to shrink, these costs are passed on to oscilloscope customers.

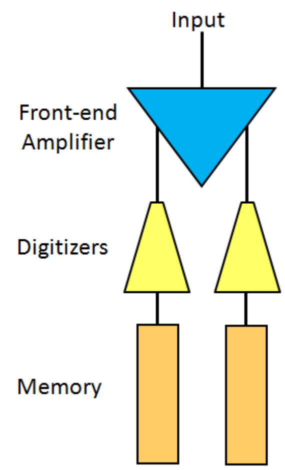


Historically, wise companies realize that the trends dictated by Moore's Law only perpetuate the problem. Oscilloscope manufacturers continue to march along the curve of inexorable bandwidth increases, bearing the pain of these increases. But throughout history, companies have occasionally found breakthrough innovations that change the so called rules. There are many examples of such feats. Perhaps one of the best examples is found by examining the history of the hard-disk drive and the invention of PRML, which enable densities that far exceeded the predictions of the governing trends.[3]

In the area of high bandwidth oscilloscope design, the major innovation that has been carrying the industry for the last two decades is that of *interleaving*. Interleaving is the combination of channel resources, namely the channel digitizers and memory, to create oscilloscopes with very high sample rates and memory lengths. This innovation relieves constraints on individual digitizer speeds that are far below the effective sample rates achieved. While interleaving has been highly successful, it does not address bandwidth, since interleaved digitizers are driven by a front-end amplifier which must be designed to accommodate the end bandwidth of the instrument.

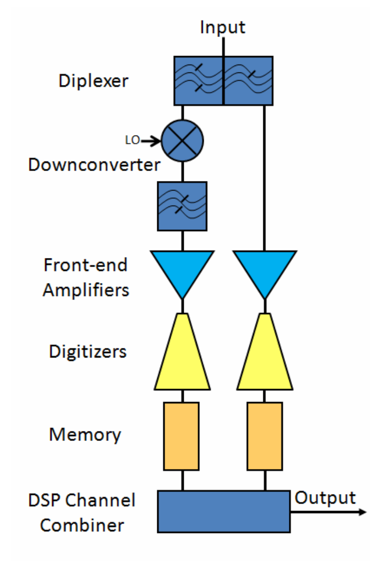
LeCroy has developed a new interleaving technique called *Digital Bandwidth Interleave* - or DBI - which provides the same benefits for increasing sample rate and memory length as traditional techniques, but allows for increasing bandwidth as well.

While traditional interleaving has certain hardware requirements of delivering signals and clocks to multiple paths, the problem is mainly calibration of the timing and gain/offset of the multiple paths. There are many ways to approach this calibration, and the algorithms for obtaining the best correction can be quite complex. However, the software which accomplishes the interleave is basically straightforward.



Traditional Interleave Topology

Digital bandwidth interleave, on the other hand, involves additional hardware, calibration and digital signal processing at the back end to recover the signal input by the oscilloscope user.



Bandwidth Interleave Topology

A simplified diagram of the hardware topology of DBI is shown. Basically, the input signal is split with a diplexer. A diplexer is a microwave filter designed to split incoming signals into multiple frequency bands. In the case of a two channel, bandwidth doubling arrangement, the low frequency band is delivered from the diplexer directly into one front-end. The cutoff of the low frequency path from the diplexer has been designed to pass an entire frequency band which meets the bandwidth capabilities of the oscilloscope front-end. The high frequency band enters a downconverter. The downconverter is realized utilizing a wide-band mixer. The downconverter mixes a predetermined local oscillator with the incoming high frequency band and produces two image bands – one at the difference frequency and the other at the sum frequency.

The difference frequency is an image of the high frequency band passed to the mixer, but is now within a band that can be handled by the oscilloscope front-end. Therefore, the high frequency band has been shifted in its entirety to a lower frequency band. This uses the same basic concept as a radio receiver. In essence, both the low and high frequency bands are acquired by the oscilloscope, with the low band in its original location and the high band "moved" to a different (lower) frequency location.

Once acquired, each band undergoes signal processing. The main effect of the processing is to remix the high frequency band with a digitally synthesized replica of the local oscillator to move the band into the correct frequency locations. It also digitally rejects the new image created by the mixing action. Finally, the two bands are recombined forming an acquisition that is almost double the bandwidth of an acquisition utilizing a single oscilloscope channel.

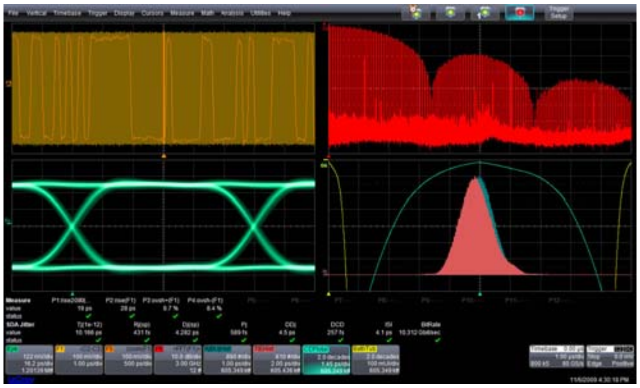
A key point to remember about DBI is that each frequency band is within the bandwidth capability of the acquisition channel which will acquire it. The digital signal processing is used to recombine the waveforms, but is not being used to "extend" the bandwidth of a channel. Thus, the problems with the bandwidth extension, such as increased noise, are not introduced in a DBI based oscilloscope.

DBI technology is enabled by two key elements: The first is the recent improvements in the performance of microwave and RF technologies. A new generation of wide bandwidth amplifiers, mixers, attenuators, filters, etc. can achieve the amplitude accuracies required for use in the input signal path of a real time oscilloscope.

The second enabler is the speed of digital signal processing within, at first, Intel Pentium processor based instruments and continuing with Intel multi-core processors. While not generally thought of as a "signal processor", these processors perform extremely fast, floating digital signal processing.[4]

With the available raw processing power, LeCroy mastered the digital signal processing techniques for the compensation of analog signal paths. The final challenge was devising and implementing the complex routines used in the automated test systems which calibrate the instrument. The result is a solution that operates with incredible performance.

DBI is a technology that shifts the limitations on real time oscilloscope bandwidth from cost, design effort and speed limitations of IC design processes available to limitations dictated by speeds of RF and microwave design technology. As applied in the current 30 GHz WaveMaster 830Zi, DBI lifts the bar by at least a factor of two (and as much as three in previous designs).



A 10.3125 Gb/s serial data signal evaluated on a LeCroy 830Zi oscilloscope that uses DBI technology. Note the signal fidelity in the capture and the eye, and the bandwidth in the FFT display.

LeCroy's WaveMaster 830Zi oscilloscope using DBI technology to combined four 16 GHz channels. Note the high bandwidth connectors for the 30 GHz input on the bottom row of oscilloscope inputs.

As such, DBI is an innovation that provides a discontinuity or disruption in the oscilloscope bandwidth trend. Initially, DBI was a retrofit technology for a previously designed oscilloscope platform. With the launch of the WaveMaster 8Zi Series of oscilloscopes, DBI was built-in at the beginning of the design cycle, enabling an upgrade path from as low as 4 GHz up to 30 GHz.

The resulting DBI enabled oscilloscope performs the same as an instrument implemented with traditional technology. Parameters such as accuracy and noise are essentially the same. Frequency response accuracy and return loss, parameters of particular importance for accurately reproducing eye diagrams of serial data signals, have actually improved in the first instrument designed with DBI.

The author is Vice President & Principal Technologist at LeCroy and a co-inventor of the Digital Bandwidth Interleave technology. He has held a variety of titles during his ten year career at LeCroy including digital signal processing engineer and product marketing manager for high performance oscilloscopes. He holds a BSEE from Rutgers University and is a member of Tau Beta Pi, Eta Kappa Nu and the IEEE communications and signal processing societies. He holds several patents in the area of the application of digital signal processing to measurement instruments.

[1]Gordon E. Moore, "Cramming more components onto integrated circuits", Electronics, Volume 38, Number 8, April 19, 1965

[2]Simon Young, "The Risk/Reward Realities of Chip Development", TechOnLine Publication, Nov. 7, 2002

[3] Clayton M. Christensen, "The Innovator's Dilemma", Harvard Business School Press, 1997

[4] BDTImark2000TM Scores, Berkeley Design Technology, Inc., June 2001