WIDE DYNAMIC RANGE ACQUISITION FOR ULTRASONIC SIGNALS

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Abstract. This paper describes our progress in the development of a novel technique of dynamic range expansion we call DRE. The resulting algorithms provide 16 effective bits and a spurious-free dynamic range of 96dB for most RF digitizers, even those collecting at 5GS/sec or higher. The recorded signals are linear and require no log amplifiers. Log amplifiers may provide acceptable dynamic range yet they introduce undesirable distortion and a significant loss of amplitude resolution.

Wide dynamic range collection has always been desirable but elusive. Without DRE, large signals such as interface echoes become saturated when gain is increased in order to view smaller echoes. The result is a loss in near surface resolution and severe distortion of the interface echoes. Gain constantly needs to be adjusted based on what you want to measure.

In this paper you will learn: About a new technique called DRE and how it digitizes signals with a very wide dynamic range (WDR). Dynamic Range – what it is, what it is not, how to achieve it, and how to make best use of it. Also, how wide dynamic range has been obtained in the past on systems that couldn't do without it.

INTRODUCING DYNAMIC RANGE EXPANSION (DRE)

DRE is a signal processing technique that improves the dynamic range of an NDE acquisition system. The biggest benefit of dynamic range is that measurements never need to suffer a loss of information due to signal saturation or quantization. DRE can provide 16 effective bits at virtually any digitization rate including 5 GS/sec and higher, taking full advantage of all bits, even the least significant bit (LSB).

essentially, $$DR(dB) = SNR(dB) = 20\log10(2n) = 6.02*n \qquad (1)$$

Therefore, when n represents a 16 bit result, DRE can provide a full 96 dB SNR, whereas a single 16 bit ADC cannot. This is because the lower bits of a single ADC are never completely noise free. Using dynamic range rather than gain opens up new opportunities for NDE. Front wall, back wall and flaws can be imaged in a single pass.

<u>What is Dynamic Range?</u>

Dynamic range is the ratio of the largest to the smallest signal that a system can handle without overflow or distortion. Dynamic range is expressed in dB. Dynamic range is one aspect of a signal's quality. Dynamic range is a product of the entire system, and as such, is often limited by the performance capabilities of one or more system components.

How does DRE work?

DRE is a compositing technique that uses two or more channels to achieve what one channel alone cannot. It is a modified form of sub-ranging that uses channels with near identical phase response and differing gains related by:

$$Offset_{DRE} = Av_1 - Av_2 \quad (2)$$

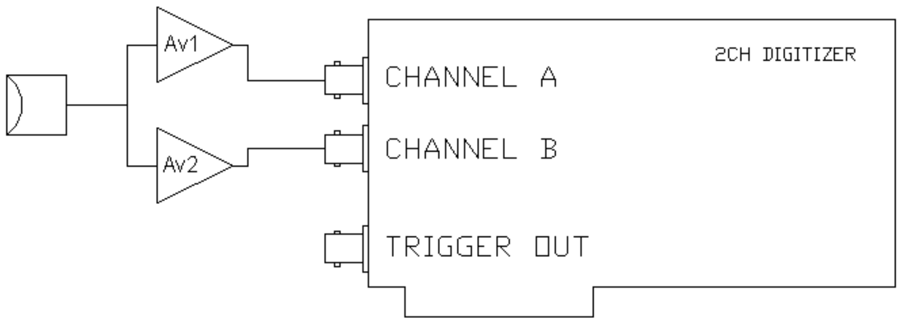


Figure 1. Schematic representation of DRE

DRE takes advantage of the fact that UT signals are nominally pulses, rather than continuous waves or DC. A composite signal is created when the unsaturated high gain channel is down scaled by $Offset_{DRE}$ and combined with the lower gain channel within a 16 bit numerical range. The exact methods used for combining the signals are proprietary.

PROBLEM: DYNAMIC RANGE IS EASILY MISUNDERSTOOD

Reason 1: Dynamic range is an abstract concept

Dynamic range is difficult to observe directly. Only when dynamic range is virtually nonexistent do we notice that something is wrong. We found 8 bits acceptable because it matched our human limitations and the limitations of our visual displays.

The images on the right may at first appear normal. Only on closer inspection can one see that the three bit image is made up of only four levels.

The eight bit image is at the limit of our ability to discern different shades of grey. If we had 96dB of dynamic range (65 thousand levels), how would we ever be able to tell?

Despite being almost impossible to experience directly, wide dynamic range remains a vital enabling tool for simplifying automated inspections.

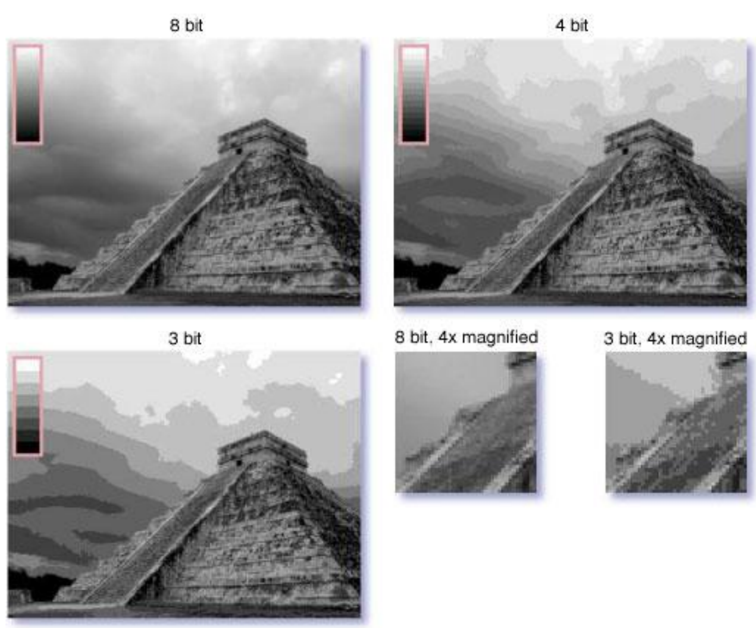


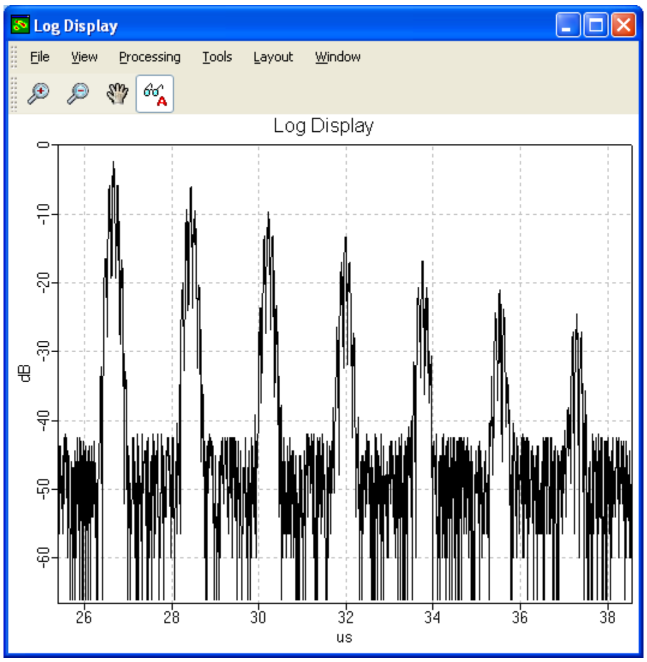
Figure 2. Image credit: Olympus Microscopy

Reason 2: Dynamic range has been incorrectly identified in the past

Dynamic Range is not the total gain control range of an instrument. Flaw detector manufacturers for a time hijacked the term dynamic range. Most digital flaw detectors have a useful dynamic range of only 32dB, despite some claiming 110dB in their specs.

Nor is dynamic range the gain control range of a TVG or DAC circuit. TVG just fits a larger range of signals into the dynamic range that you already have.

Reason 3: Wide dynamic range displays have serious limitations



Log displays capable of showing WDR signals are not as useful as they need to be. Typical NDE tasks such as normalizing transducers, looking for small amplitude changes or making relative measurements are difficult to observe on a log display.

Log displays mask small amplitude changes and don't feel intuitive to those who are used to working with conventional linear A-scan displays.

For many, the log display looks noisier than a conventional A-scan display, despite both displaying exactly the same data. Something better is needed and will be proposed.

Figure 3. Log display showing noise below -40dB (1% FSH).

Reason 4: TVG is an imperfect attempt to measure over a wider range of amplitudes

Instrument-based TVG normalizes small signals so that they fit within the limited range of our displays. TVG makes equal sized reflectors appear the same size for flaw sizing purposes. This regrettably is not improved dynamic range. It is a corrupting single purpose use of the signal.

The original signal is altered based on where we had hoped the sound would be. Signals that take a different path than we had hoped will have meaningless amplitudes.

Once the original ultrasonic responses are distorted by TVG, they can never be retrieved for other quantitative purposes.

Wide dynamic range signals can overcome this limitation by allowing us to apply as many corrections as we wish to the original signal without losing the true responses from interfaces and indications.

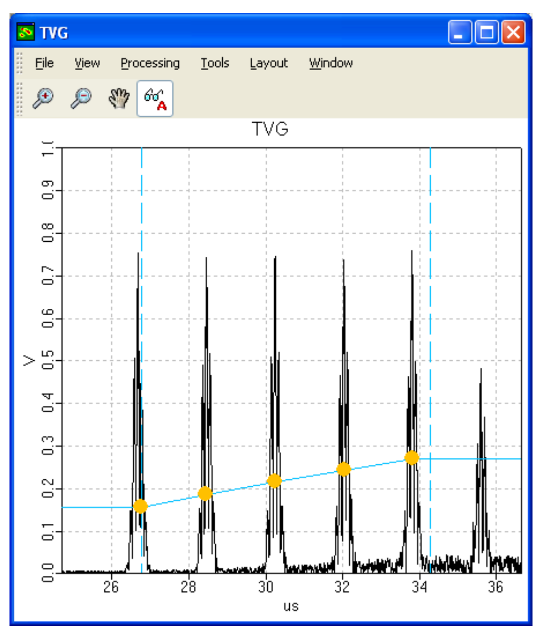
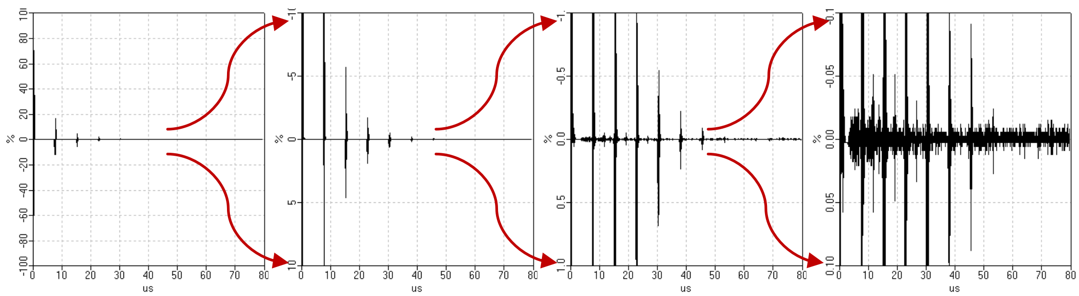


Figure 4. TVG distorting A-scan for one purpose.

WHAT DOES WIDE DYNAMIC RANGE LOOK LIKE?

Hint: Very, very quiet. Earlier, we learned how log displays can show the entire dynamic range yet they seem unintuitive. The following traditional A-scans are zoomed by a factor of ten, a total of three times. This represents a 1000x amplitude increase or +60dB. Note that we are not increasing the gain, just zooming in on the wide dynamic range 100% FSH signal. All of the interface echoes are available for coupling and alignment checks.



100% FSH 10% FSH 1% FSH 0.1% FSH

Figure 5. Vertical magnification of a wide dynamic range signal.

Even though an inspection procedure may have required that we start with 20dB more gain, everything that we need is in this signal. Using the wrong gain doesn't hurt us.

THE BENEFITS OF WIDE DYNAMIC RANGE IN NDE

Eliminate saturated signals

Problem: Traditionally, to display small signals you need to increase gain. Increased gain may cause large interface echoes to become saturated or clipped. Saturated signals deteriorate near surface resolution in most receivers because of overloading of the front-end amplifiers. Saturated signals are problematic for many types of signal processing such as peak picking, FFT, digital filters, etc. Turning up the gain ruins everything if you want to use these other echoes for inspection automation purposes.

Solution: Use little or no gain. Saturate nothing. Pull all of the signals you need out of the available dynamic range. Work with signals that are linear and contain no distortion from overloads at interfaces or from the application of TVG curves.

In the past some of these problems have been solved by using a back wall echo attenuator channel or by using a second gain function. Wide dynamic range eliminates the complexity of such solutions by offering one signal that contains all of the needed information. Modern software can extract the indications and measure them automatically.

How has wide dynamic range been achieved in the past?

Logarithmic Amplifiers: Log amps certainly offer a wide dynamic range but at the expense of amplitude resolution. This is called loss of amplitude granularity. Log amplifiers also lose important phase information needed by most NDT researchers.

Signal Averaging: Averaging improves the SNR but only up to the limit of the digitizer resolution. It is not changing the fundamental dynamic range of the system. Averaging is not suitable for C-scanning or rapid data collection as it reduces the amplitude of small indications and spatially smears the C-scan image.

Boeing AUSS: This clever approach uses as many as five cascaded channels of receivers and peak detector outputs and picks the signal from the first channel that isn't in saturation. This produces excellent wide dynamic range C-scan results but fails to produce a single A-scan that can be used for advanced signal processing.

Pulse Compression Techniques: These techniques include Chirp, Golay and other coding schemes. They do indeed offer improvements in dynamic range (+40dB) but at the expense of pulse resolution. These techniques can be combined with DRE for even better results bringing the total dynamic range to just under 140dB.

WHAT IS LIMITING OUR APPLICATION OF WDR SIGNALS IN NDE?

We are a big part of the problem

We are bags of mostly water with poor eyesight and quite frequently, bad attitudes. We stare at a screen with 35dB of useable dynamic range and twiddle knobs to make things fit. We never ask why we can't see all of the signal at the same time. Gain goes up, gain goes down, gain goes up…and so it goes.

Our experience becomes limited by our historical world view. We were trained in the use of our limited A-scan displays and we maintain an intuition that only what we see truly exists.

Image courtesy of Showcase

A lack of dynamic range forces behaviors that are unproductive

Constant gain adjustment is required to keep the signals of interest within a useful on-screen size, even if the original signals are perfectly useable by an automated system. This forces an unnecessary preoccupation with percent screen height. It causes scrapped scans due to %FSH calibration errors when it becomes clear that the base gain was "off by a bit". It also causes scrapped scans due to unanticipated signal saturation.

Furthermore, using gain adjustment to size flaws places unnecessarily tight calibration requirements on the instrument attenuator and amplifier controls. Proper calibration becomes critical to ensure meaningful measurements. Not that calibration isn't important, but it becomes less of a show stopper when inspecting with wide dynamic range instruments. All measurements can be made relative to each other at one gain setting. Only the amplifier linearity needs to be confirmed, and this can be built into the system.

Why has dynamic range been limited until now?

Existing digitizer technologies have limited our ability to use more than twelve bits, even if the analog dynamic range (SNR) was available. Also, pulser receivers that use attenuators with fixed-gain amplifiers inherently have a limited dynamic range of approximately 40dB because the amplifier is always at full gain generating noise.

More importantly, inspection specifications are written based on the technology available at the time and therefore don't address WDR acquisition. There has been no champion for wide dynamic range acquisition because few thought that it was possible.

We are committed to changing this, firstly by offering DRE enabled instruments, and secondly by offering software that can work with WDR signals. The goal is to expect more from UT signals. The *more* in our case is a dedication to inspection automation.

NOVEL DISPLAYS

Rather than being limited to only linear or log A-scans, how about both? The hybrid display shown in Figure 6. is linear from 100% FSH down to 5% FSH (-26dB). Below 5% FSH the display is logarithmic starting at -26dB and ending at -96dB.

Gates can be used that make relative measurements between signals that could not normally be seen simultaneously. Computers don't have our poor eyesight.

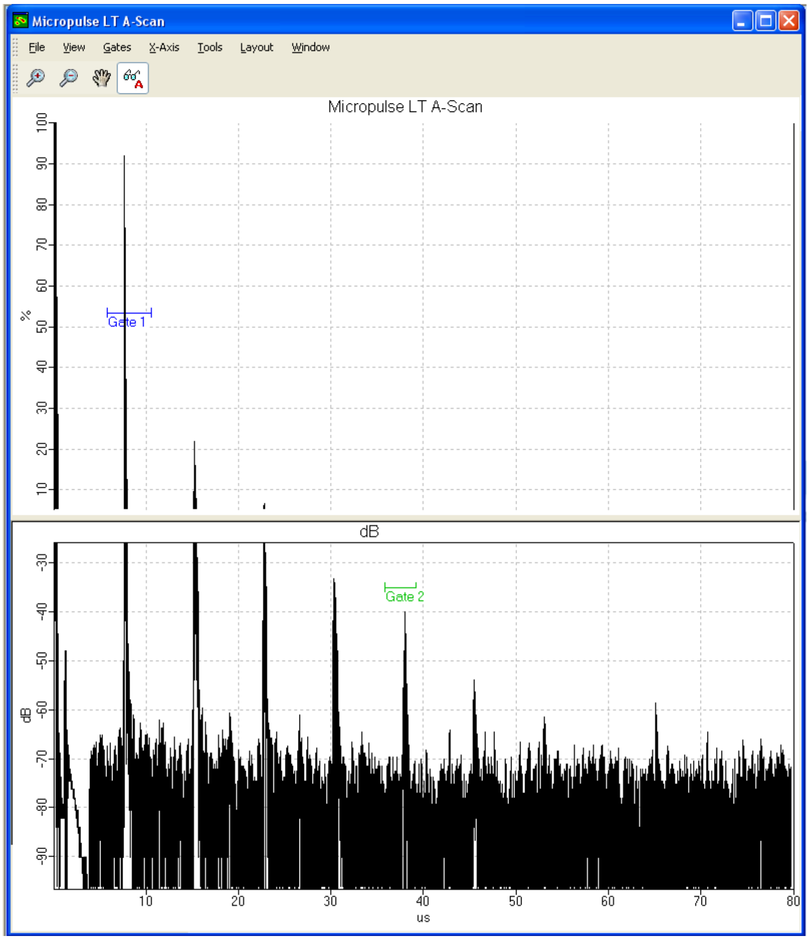


Figure 6. A hybrid display showing both linear and log plots.

CONCLUSION

New techniques become possible

NDT has fallen behind the rest of factory automation for reasons discussed in this paper. Once the problems associated with limited dynamic range are dealt with, the human limitations go away as well. New ways of doing things become possible. Consider that most NDT departments currently have manually configured systems with humans interpreting the results, either A-scans or C-scans.

Humans are better at planning, process design and subjective analysis. Machines are better at operating faster, being repeatable, making measurements and reporting their own errors. Inspection automation requires DRE and other technologies in order to catch up with the rest of factory automation and gain the benefits that automation provides.

In our next paper we will be presenting the other enabling technologies.