ADVANCES IN DIGITIZER TECHNOLOGIES AND ULTRASONIC SCANNING ACOUSTIC MICROSCOPY (SAM)

Hari Polu, Geoff Shotts, Stephen McDonough, and Alyson Lipsett

Summary

Over the last 25 years, 'Digital' has replaced 'Analog' in scientific & engineering instrumentation. Advantages of digital are many: reproducibility at low cost, lossless long distance transmission, inexpensive storage, and extensive post processing, to name a few. With so many impressive gains to be made by going digital, one often tends to overlook the limitations of digital technologies. In this paper, we illustrate the benefits of digitizer technology, recent advances, and continuing limitations, when applied to Scanning Acoustic Microscopy (SAM). Analog signals generated by sensors such as ultrasonic transducers contain a wide range of content but cannot be stored, reproduced or transmitted; they must be utilized in real-time. Digitization of these analog signals aims at maintaining highest fidelity and content preservation while overcoming these limitations. Applying Nyquist Theory, and paying attention to aliasing and sampling errors, effective digital technology can be applied to Scanning Acoustic Microscopy. Oversampling reduces aliasing errors, improves resolution, and reduces noise.

As semiconductor packages become thinner, SAM technologies are pushed to their limits. Silicon, Dielectric, Under-fill, MUF, Stacked Dies, Copper Pillars are common technologies in most of the semiconductor devices. Inspecting these packages requires very high frequency transducers, ranging from 50 MHz to 300 MHz. Thinner layers and their interfaces require higher sampling rates and larger dynamic range digitizers to 'trap' the interface transition.

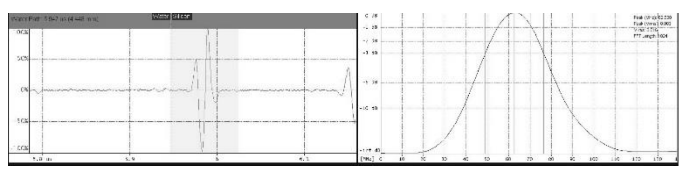
Digitizer Technology

Dynamic Range

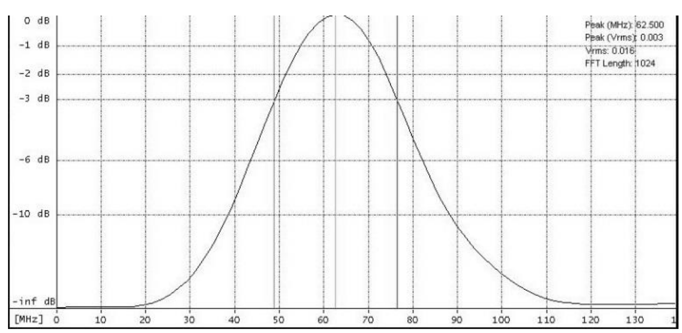
As packages get thinner, and defects smaller, the difference in analog signal between a 'good' area and a 'bad' area narrows. A standard digitizer with 8 bits has a dynamic range of 256 digital levels. Any signal change that falls under this threshold is not captured. However, advanced 10 bit digitizers have 1024 levels and 12 bit digitizers have 4096 levels, allowing capture of much smaller signal changes and the ability to resolve those finer defects. For a 1V peak to peak input analog signal, 8 bits can resolve up to 3.9mV, 10 bits up to 0.97mV, and 12 bits up to 0.24mV.

Sampling Rate

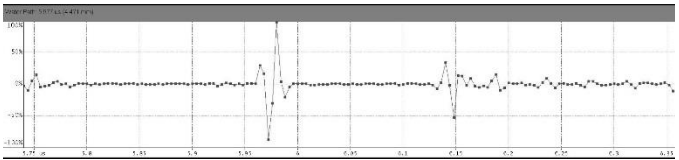
Higher frequency transducers require even higher sampling rate digitizers. To faithfully reproduce information contained in the ultrasonic signal generated by the transducers, high sampling rates and large dynamic ranges are required. Oversampling is required to avoid aliasing error; a typical number used by industry experts for ultrasonic applications is x10. A 100 MHz transducer often contains signals of interest in the higher ranges around 150 to 170 MHz, albeit at lower signal levels. To extract information at these frequencies, a 1.5 GHz digitizer is required. A 200 MHz transducer may have valuable information in the 300 MHz band. Only a 3 GHz digitizer can extract information from the higher frequency bands in this signal. Plots below illustrate the effect of sampling rate on an ultrasonic signal.



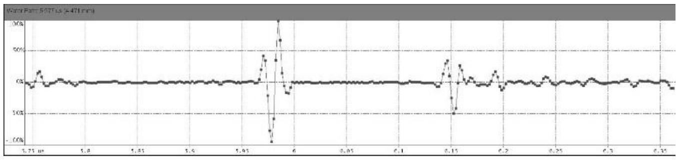
Ultrasonic Signal and Frequency Spectrum



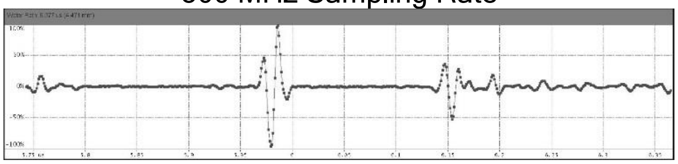
Frequency distribution of reflected signal from a 120 MHz transducer at 8 mm focal length, with center frequency of 60 MHz



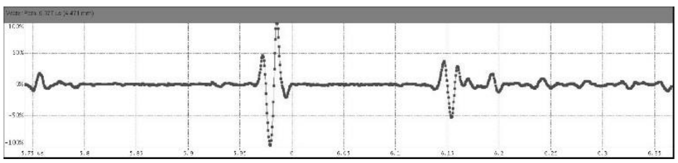
250 MHz Sampling Rate



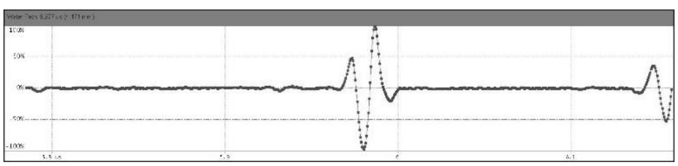
500 MHz Sampling Rate



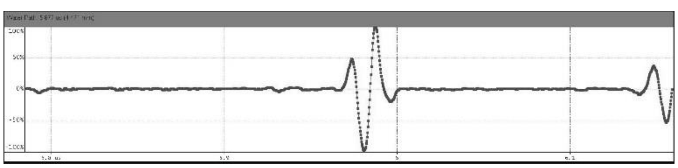
1 GHz Sampling Rate



2 GHz Sampling Rate



2 GHz Sampling Rate (zoomed in)



4 GHz Sampling Rate (zoomed in)

SAM applications plot peak amplitude from regions of interest to generate images for defect detection. As illustrated by the sampling rate plots above, the highest possible sampling rate is imperative for 'peak preservation.' Inadequate sampling rate will result in inaccurate peak measurement within the data gate, due to trigger jitter. Even 3% variability in peak amplitude measurement can cause erroneous imaging if the percentage difference between good and bad signals is in the same range.

Analog Bandwidth

In addition to high sampling rate and large dynamic range, the analog front-end must have enough bandwidth to capture all the analog information. A good ultrasonic digitizer should have at least 700 MHz bandwidth to capture signals from the highest frequency transducers.

A combination of high analog bandwidth, ultra high sampling rate, and a large dynamic range yields optimum digitizers for use in SAM. Recent advances have made such technologies possible. However, such high end instrumentation creates large amounts of data; a 3 GHz digitizer has a time resolution of 1/3rd of a nanosecond and generates 3 billion samples per second. Every microsecond of data results in 3000 samples. To effectively mine this data, digitizers must have on-board processing capability in hardware that is programmable via firmware. Separate DSP chips on a digitizer, while mathematically capable of processing, are unable to handle the rates of input and output transfer. On-board processing is implemented by designing custom firmware embedded into Field Programmable Gate Array (FPGA) devices.

Time Gain Correction (TGC)

Thinner packages and multiple interfaces demand higher frequency transducers. This poses a problem of signal attenuation. The higher the frequency the greater the attenuation in both water and semiconductor materials. A unique feature in digitizers called Time Gain Correction (TGC), alternatively known as Distance Amplitude Corrections (DAC), dynamically adjusts the gain of ultrasonic signal to compensate for the attenuation.

The best data is not always contained in the strongest signal. The often overlooked 'ringing' contains valuable information. However, the low amplitude of these signals requires digitization with large dynamic ranges to extract meaningful data, without saturating other portions of the signal.

Future

Transient signal recording capabilities are on the rise with a continuing trend of faster, lower power, and affordable discrete A/D components. A 5 GHz digitizer with 14 bits of dynamic range may be just a few years away.

You may send your comments on this technical article to:
OKOS SOLUTIONS, LLC
4429 Brookfield Corp. Dr., Suite 700
Chantilly, VA 20151, USA
Ph.: +1 703.880.3039 | Fx: +1 240.235.7277
Email: info@okos.com | www.okos.com