Measuring Deterministic Jitter—With a ‘Scope!

Jitter measurements for Ethernet and Fibre Channel components have long been confined to grossly expensive systems. Not any more.

By John Quirk

Accurate jitter measurement is a challenge for Ethernet and Fibre Channel components. While test equipment designed specifically for jitter measurement is available from multiple sources, the equipment can be cost-prohibitive or just too specialized for some applications. However, by using a probe and a regular off-the-shelf digital sampling oscilloscope, designers can accurately make reasonably fast deterministic-jitter measurements, with nowhere near the financial outlay that designers have come to expect. Here, we offer step-by-step instructions on how this can be done for relatively short patterns.

Jitter can be grouped into two types: random (or unbounded) and deterministic (or bounded). Deterministic jitter (DJ) includes all jitter that can be reproduced by controlled conditions. Some subsets of deterministic jitter are periodic jitter (PJ), pattern-dependent jitter (PDJ), duty-cycle distortion (DCD) and bounded uncorrelated jitter.

The main causes of DJ are:
- **Baseline wander,** caused by the presence of a low-frequency cutoff in the system. This effect creates jitter near long consecutive identical digits (CIDs).
- **Insufficient system bandwidth,** which can prevent some pulses from reaching a steady-state level. This causes jitter on isolated pulses (.01.. or ..10.. data sequences).
- **Amplifier offsets,** causing pulse-width distortion (sometimes called duty-cycle distortion) on every data transition.
- **Nonlinear amplifier effects,** have unpredictable jitter effects but often cause jitter after long CIDs.
- **Power-supply noise and crosstalk** are effects that can result in jitter that is not related to the data input (sometimes called bounded uncorrelated jitter).

In a fiber-optic communications system, jitter accumulates at each component. At the receiver, a clock and data recovery circuit (CDR) analyzes the data and extracts the serial rate clock. At the CDR, jitter appears as small frequency changes in the clock rate. Slow changes (low-frequency jitter) can be tracked easily. Fast changes (high-frequency jitter) cannot be easily tracked. If too much high-frequency jitter is present at the receiver, the clock cannot be extracted, and data communications will contain excessive errors.

**Balance the jitter budget**

To prevent that situation, systems designers use a jitter budget. Note that deterministic jitter accumulates linearly (all sources are added together in a worst-case situation), whereas random jitter, or RJ, accumulates geometrically (the square root of the sum of the squares). This assumes that the noise sources causing random jitter are independent and uncorrelated. Separating those jitter components allows the individual components to generate more random jitter and has several benefits, including longer link distance or lower-cost components.

Note that a DJ measurement error always makes a component’s DJ appear larger and is subtracted directly out of the budget. An RJ measurement error is not as severe. This provides additional incentive to measure DJ accurately.

Measurement of deterministic jitter
requires a known data pattern. K28.5 is a pattern commonly specified for jitter measurement in Fibre Channel and Ethernet systems operating between 1 Gbit/second and 3.125 Gbits/s. This pattern is a special character in the 8B/10B-coding table and often marks the beginning or end of a frame. A repeating K28.5 sequence (composed of alternating K28.5+ and K28.5-) contains the symbols 0011111010110000010. This pattern contains five consecutive 1’s and five consecutive 0’s, (the longest consecutive identical digits found in 8B/10B coded data). It also contains an isolated 1—010—and an isolated 0—101.

A repeating K28.5 pattern has a 50 percent transition density and a 50 percent mark density, making this pattern useful for measuring deterministic jitter caused by baseline wander, low bandwidth and offset. Other patterns may be more appropriate for measuring jitter that results from nonlinear effects.

**Jitter measurement**

Three common methods for measuring DJ with an oscilloscope are the eye diagram, the averaged eye diagram and the averaged crossing measurement. Fig. 1 compares their properties.

With eye diagrams, multiple waveform crossings are displayed simultaneously, giving a quick view of total jitter (deterministic and random jitter combined). The primary advantages of the eye diagram are speed and ease of setup. A typical setup showing the test equipment and device under test (DUT) is shown in Fig. 2. But the eye diagram does not allow separation of random and deterministic jitter, nor does it allow removal of jitter caused by the test system.

When using eye diagrams, be aware that the triggering method can hide much of the DJ. For example, suppose that a pattern generator provides a trigger on every 10th clock cycle. If the pattern length is even, the oscilloscope will never trigger on an odd bit, and that effectively will hide some of the transitions. Using an odd-length pattern or triggering on the pattern generator clock output will avoid that problem.

If the device under test includes a time-regenerating circuit (clock recovery or retimer), a golden phase-locked loop should be used to recover a clock for oscilloscope triggering. The properties of a golden PLL are protocol-specific. Also, if the DUT includes optical components, it will be necessary to add appropriate optical transducers (optical-to-electrical or electrical-to-optical converters). For simplicity, it is assumed that optical converters or golden PLLs are included in the test equipment if needed.

Some oscilloscopes provide an averaging mode that removes random jitter in eye diagram mode. This mode provides more accuracy and repeatability than a basic eye diagram, but the same cautions about triggering apply.

The averaged-crossing measurement method provides an accurate measurement of most sources of deterministic jitter on a K28.5 pattern. The procedure is as follows:

- Connect the device under test as shown in Fig. 2. Trigger the oscilloscope on the pattern.
- Display the entire K28.5 pattern on the oscilloscope screen.
- Calculate the expected crossing times for each transition on the screen (ideally, they are one unit interval apart, skipping unit intervals where no transition occurs).
- Average heavily.
- Tabulate the crossings and calculate the jitter. For the repeating K28.5 pattern (0011111010110000010), there are 10 crossings; see Fig. 3.
- Ensure that the signal fills at least 2/3 of the vertical area available. This optimizes the digitizing capabilities of the oscilloscope.
- Set the main position of the scope as small as possible (keep the delay from trigger to display as short as possible, to reduce trigger jitter).
- Use maximum horizontal resolution (many horizontal points).
- Use heavy averaging (64 to 1,000 averages) to reduce random jitter.

Note that periodic jitter and bounded uncorrelated jitter are not captured with an averaged oscilloscope waveform. Other methods should be used to measure those types of jitter. The averaged-crossing measurement is appropriate when it can safely be assumed that the DUT does not generate significant amounts of those types of jitter.

This technique may end up proving difficult to apply to systems employing scramblers because the test patterns for...
(acknowledged packets) to NACKs (not acknowledged packets). The algorithm then attempts to estimate the performance of the link. The transmitted packet type is then modified, as it would be with CQDDR, although nothing can be done for inbound data streams.

**Simple—but effective**

Despite the simplistic nature of this algorithm, it has proven highly effective in practice, particularly in saving a link that has been using DH packets and then experiences increased interference. If the link were to stay on DH packets without the algorithm, eventually an increasing BER would decrease the probability of getting a DH5 packet through until it is essentially zero, and the link would time-out.

Given the current level of support for CQDDR, the practical advice for product developers lies first in being aware of the problem, and what CQDDR can do about it. From there, the next level of advice and precaution is to make the baseband mechanism the subject of close investigation, to understand its packet-selection algorithms and any proprietary techniques employed to optimize bandwidth.

For projects in progress, it is possible to provide some level of bandwidth protection at the application level, albeit with a much higher time overhead. Commands are available at the HCI level to get information on link quality, but developers need to be aware that the information is provided not as hard data but as a number ranging from 0 to 255 (the lower the number, the poorer the quality). Again, this number also depends on the baseband implementation of the silicon in question.

As more chip sets reach maturity, they will include CQDDR and reliable BER measurement schemes. Gradually, application developers will need to worry less about packet type choices and will leave the hard work to the baseband, regardless of the chip set vendor.

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David McCall (david.mcall@csr.com) is a senior applications engineer for CSR. He has a MSEE from Edinburgh University, with a focus on IC engineering. He is also a contributing author to the book Bluetooth Application Developer’s Guide, edited by Jennifer Bray.

**MPLS Router Design Strategies**

Find that these protocols usually consist of the following software blocks, as indicated in Fig. 6: a timer-triggered event generator, a peer-discovery (Hello messaging) mechanism, an information database, a protocol message parser and possibly a policy manager.

The LDP uses UDP port number 646 to send Hello messages periodically in a multicast IP address to all routers in the subnet to indicate the existence of an LER/LSR. After verifying the Hello messages, two neighboring routers establish a TCP session in TCP port 646 for further reliable message exchange. The first message is usually an initialization message from both sides. After that, both sides are ready to start the label advertisement messages.

Meanwhile, routing protocols such as OSPF also start up by multicasting Hello messages to establish adjacencies. Adjacent routers exchange database description messages, and send link-state requests and updates to synchronize routing tables.

In topology-driven LSP establishment, the LDP requests a label for each route entry in the routing table to the next-hop MPLS-peer router. The next-hop (downstream) router allocates the label from its label space. In case the router is running in an independent label-distribution mode, the LDP sends a label-mapping message back to distribute the label to the requesting (upstream) router. The upstream router then updates its label-forwarding information database and the LSP is then considered established.

A clear understanding of the steps involved in the design process of MPLS routers, as described above, will go a long way toward the development of a solid end product.

Chaoping Wu (chaopingw@attbi.com) is a senior engineer at Vpacket Communications. As an experienced designer of routers over the past decade, Chaoping has worked at senior engineer positions in companies such as Nortel and AccessLan Communications. He received an MS degree from the University of Arkansas and a BS from Shanghai Jiao Tong University in China.

**Attacking jitter, with scope**

Those protocols tend to be longer. For example, the 223-1 pseudorandom binary-sequence pattern—commonly used to test scrambled data systems—is over 8 million bits in length. The averaged-crossing measurement would be slow and inaccurate on such a long pattern.

**Enhanced accuracy**

Many modern components have deterministic jitter that is comparable to or less than the jitter of pattern generators and oscilloscopes. Accurately determining the jitter of those components requires determining the jitter introduced by the test system and then adjusting the measurement. The error of the measurement system can be measured by removing the DUT from the measurement setup and determining the jitter on each transition of the data pattern. When the DUT is replaced in the measurement system and jitter values are measured again, the jitter contribution of the DUT can be determined mathematically.

The averaged-crossing measurement method described here is well-suited for measuring deterministic jitter of Ethernet and Fibre Channel components in systems using 8B/10B coding. The technique uses commonly available test equipment to produce accurate and repeatable jitter measurements.

Further jitter measurement enhancements are found in the full text of this article at http://img.commsdesign.com/commssdesign/csd/measurejitter.pdf.

John Quirk (jquirk@mxim.com) is a senior member of the technical staff at Maxim Integrated products. He holds an MSEE from Washington State University.

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