TLA7SA00 One-click Calibration

Efficiently Tuning the Tektronix Logic Protocol Analyzer

PCI Express® Gen 3.0 introduces several new physical layer changes designed to improve the flexibility and operating efficiency of the link endpoints. One such change is in lane equalization. With this major shift in the physical layer design, protocol analyzers must now dynamically calibrate to lanes that may have as many as 128 different equalization values.

Adding to the challenge of acquiring signals with as few errors as possible is the location of the probe: mid-bus probes see a very different signal from probes at either end of the link. How does the Tektronix Logic Protocol Analyzer overcome these significant challenges and also provide an efficient, easy to use calibration mechanism? The paper introduces the new One-click Calibration GUI, an automated calibration system that keeps the engineer in control with a minimum of effort.

Introduction

If you are debugging PCI Express® links operating at Gen 1 (2.5GT/s) (Giga-Transfers / second) or Gen 2 (5.0 GT/s), the factory default settings for the Tektronix Logic Protocol Analyzer (LPA) are usually sufficient to operate the instrument with an approximate BER of 10^{-12}. But when the link is operating at Gen 3.0 rates (8.0 GT/s), calibration is almost guaranteed to be required even for BERs as high as 10^{-9}. Several changes in the PCIE Gen 3.0 specification contribute to the need, most notably the introduction of dynamic equalization between the link endpoints. The number of possible equalization settings has increased from 2 *static* values to 2^7 possible *dynamic* values. In Gen 3.0 links, each side of the link negotiates on a specific equalization profile. The LPA doesn't participate in this negotiation; instead, it has to identify the best operating conditions with as little impact on the link's signals as possible.

The problem is made more challenging by the variety of probe options available to the engineer. The LPA provides one of several probe types: slot interposer, mid-bus or solder down. While slot interposer is the most convenient to the engineer (and is likely to calibrate more easily than the other choices), it is also the most intrusive: in spite of all effort to reduce its impact on the link, the very presence of the interposer will change the equalization negotiation between the endpoints.

Mid-bus probes are the least intrusive choice, but require planning ahead to provide a header for the probes. In addition, the signals at the mid-bus location are not anything like they are at the end points, nor can the engineer anticipate the signal characteristics at the mid-point probe location. Instead, the LPA's calibration process must tease open the eye.

Solder-down probes may be necessary in some circumstances; here again the engineer will be hard pressed to define the signal characteristics at the probe points.

The LPA needs to anticipate the possibilities of any given link's equalization design per the PCIE Gen 3.0 specification, probe location and the like. But even if two links are designed with the same scheme, for example two identical circuit boards, their operating conditions may vary enough to require a different calibration in the LPA. As a result, when the LPA is attached to a new link, calibration is usually necessary.

The LPA uses two variables: Gain and EQ to adjust the signal characteristics it acquires. Gain is applied to the entire probe; EQ is applied on a lane by lane basis.

Bit Error Rate

Theoretically, we all want our instruments to operate without introducing any errors, but in the real world instruments themselves can introduce errors. Similarly, in theory we all want the most error-free operating conditions in our circuits. But again, in the real world, depending on the nature of our investigation and time pressures, we are willing to accept a certain number of errors.

For example, we may know that our link is not operating error-free, but we don't want to hold up our investigation just because the link won't calibrate to a 10^{-9} (or better) error rate (see sidebar). Instead, we may want to capture something and begin our analysis, saving the error-free acquisitions for later.

The LPA One-click calibration has been designed to efficiently identify the best possible operating conditions for the LPA through a combination of human-managed variables and automation.

The engineer is always in control of the calibration process by identifying the desired target BER. Because this one value has the greatest impact on the length of time required to calibrate, the engineer is best able to make the tradeoff between calibration time and BER.

How does the BER selection affect calibration times?

Bit Error Rate values are based on statistical analyses of data streams. To achieve a specific BER, the data stream must run without errors for a minimum amount of time. But that doesn't guarantee a BER for that data stream; during a subsequent acquisition, the stream may contain more errors than the target BER.

BERs are calculated based on a "confidence level." That is, any arbitrary data stream with a BER of 10^{-9} may still have errors – it depends on the confidence level of the BER analysis. The confidence level is determined by the size of the time window: the longer the time window, the greater the confidence.

The LPA calculates BER by analyzing the link for a time period with approximately 93% confidence for Gen 3.0 links (Gen1/2 links are almost 100% because error detection is much simpler in those links).

Decreasing a BER from 10^{-9} to10^{-12} means increasing the time window by 1000. For a x16 link with one or two troublesome lanes (in which all EQ and Gain values have to be tested), this makes the difference between a 32 minute operation and 22 days.

These are worst case and unlikely.

The system automatically tests thousands of possible combinations of operating parameters against the data flowing across the probes for the minimum amount of time required to achieve the engineer's specified BER.

Finally, the One-click Calibration GUI provides feedback before, during and after completing the calibration process to keep the engineer informed of the need to calibrate, the success or failure of the calibration, and most importantly, the level of BER achieved as a result of the calibration. The advantages of this approach are discussed in detail in the white paper *The Tektronix Logic Protocol Analyzer Setup Window: A "Soft" Front Panel for Diagnosing Link Health.*

To Manually Calibrate the LPA:

1. Set the Gain for the probe
2. Set an EQ value for all of the lanes
3. Construct a trigger to count errors for a pre-defined period of time (based on a desired BER) – and stop when the number of errors exceeds a threshold.
4. Take an acquisition
5. Inspect each lane and manually count the number of errors
6. Rinse and repeat until the best combination of Gain and EQ has been found

Performing this process manually not only could take days to complete, the engineer would likely fatigue before getting through many of the settings.

One-click Calibration:

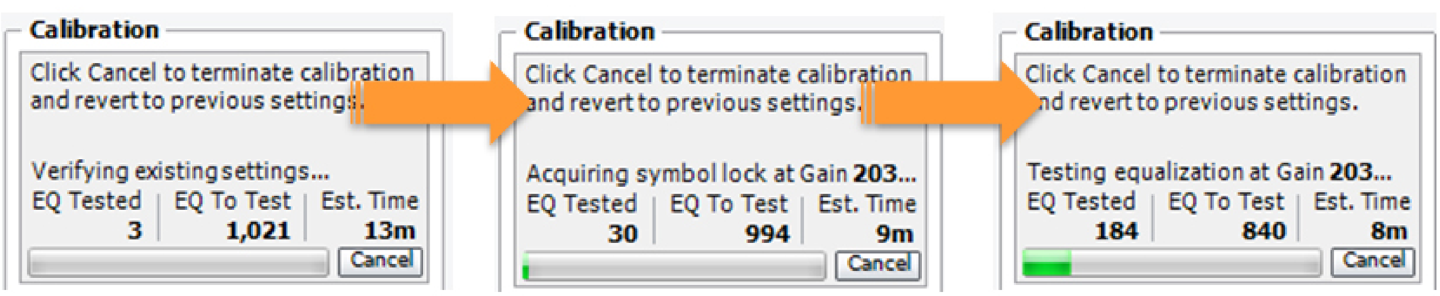

Figure 1. Calibration progress indicators provide constant updates of the process.

1. Verify whether the current settings for Gain and EQ (whether factory default or the most recent settings) achieve the desired BER. If so, calibration is done. This should take about one minute.
2. If the initial verification step doesn't succeed, begin walking through the Gain/EQ values for each of the lanes mapped to the LPA. Obviously, more lanes require longer times to calibrate.
3. For each lane, sample the symbols for a period of time prescribed by the target BER. For example, if the engineer has targeted 10^{-9}, the dwell time is substantially shorter (3 orders of magnitude to be exact) than for 10^{-12}.

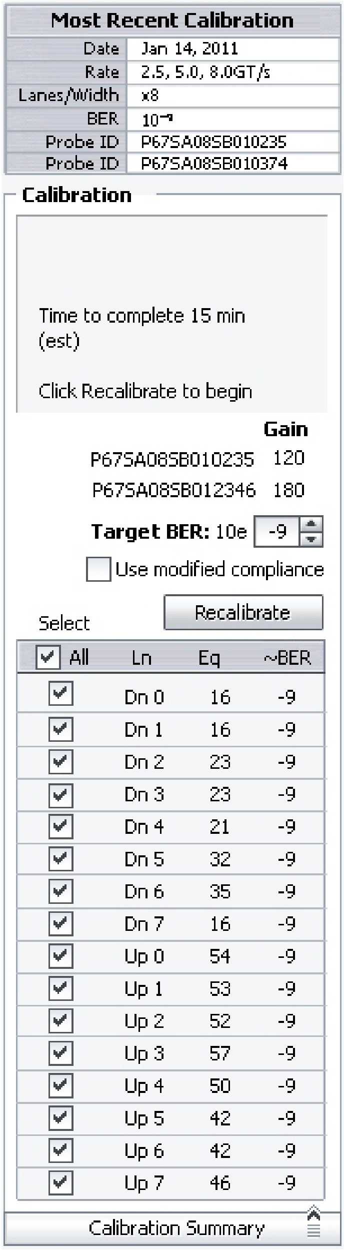

Figure 2. Completed calibration values.

4. After reviewing all of the possible combinations that don't fail, identify the settings that best achieve the desired BER.

5. As calibration proceeds, the system updates the amount of time required to complete. The time required to calibrate is highly variable, dependent on the link health, target BER, and number of lanes. For links that have few problems, calibration completes quickly. For links that have substantial problems (bad lanes, signal integrity issues and the like), calibration also completes quickly. In the cases of links that have moderately good behavior on some lanes and poor behavior on others, calibration times will stretch out because the algorithms are forced to try every possible combination on every lane.

6. When calibration completes, it posts the Gain value for each probe and the EQ and BER values for each lane (see Figure 2).

The link should remain out of recovery for the time period required to sample the lanes at each Gain/EQ value for the targeted BER. Calibration can be successful even if the SUT goes into and out of recovery, as long as the frequency is fairly low. In the event the SUT cannot remain sufficiently stable during this period, the LPA provides an alternative mechanism, Modified Compliance. (Modified Compliance is the same as the basic Compliance Pattern sequence with the addition of two error status Symbols followed by two K28.5.)

To use Modified Compliance to calibrate the LPA, the engineer needs to do two things: set the SUT into Modified Compliance operation (how to do this varies based on the configuration of the agents on the link) and check the Modified Compliance checkbox in the Calibration Details GUI.

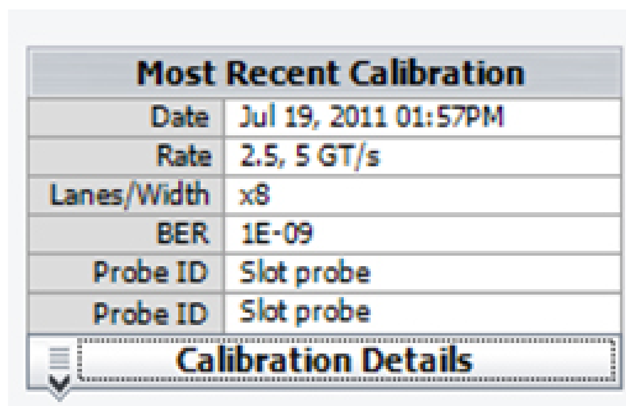

Figure 3. Calibration Dashboard providing at-a-glance confirmation of most recent calibration

After finishing calibration, the system provides Information about the calibration in the Calibration Dashboard, visible at a glance from the module's Setup window. If the calibration was successful, the dashboard data, including the date, rate, width and BER values are rendered in a normal color as Figure 3 displays.

When Calibration Isn't Perfect

In those cases when calibration encounters a problem, it reports the issue in the dashboard as well, highlighting the item. In addition to the summary information, the system reports the best BER achieved on a lane by lane basis. By seeing BER results, the engineer is in control about what to do next: continue to debug with a sub-optimal system or attempt to improve the link characteristics and re-calibrate. Even here, the LPA has been designed to reduce work: the engineer can "cherry-pick" the lanes to be re-calibrated using the associated checkbox. The LPA will only recalibrate lanes that are checked (see Figure 4).

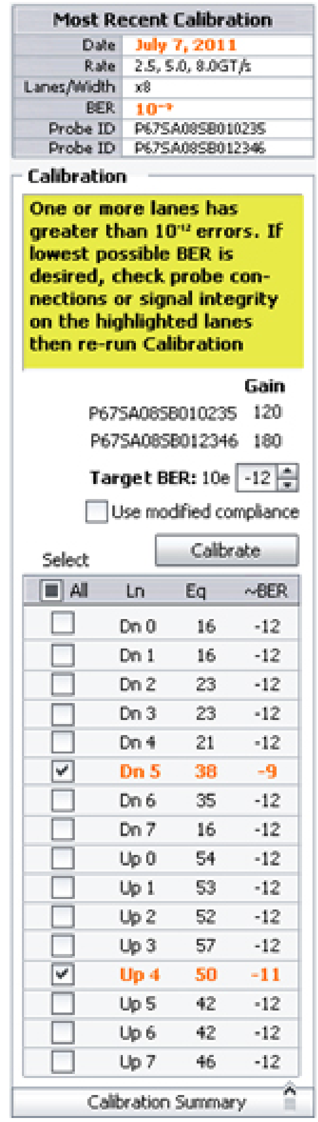

Figure 4. After an unsuccessful calibration the system displays the results of its analysis.

Beyond making it easy to identify what needs to be calibrated, the exception indicators returned by the calibration results provide insights into what the problems might be with the SUT. For example, if the results return "?," the lane failed to achieve symbol lock. This could be the result of a poorly configured module (polarity inversion, e.g.), a badly seated probe, or poor signal integrity on the SUT.

If the results return a BER greater than 10^{-9}, say 10^{-5}, this would suggest a problem with the module's configuration – for example reversed polarity or a mis-mapped lane. The engineer can quickly evaluate the situation by glancing at the adjacent read-outs in the Setup window.

In some cases, a SUT cannot remain out of recovery for the required time period, and Modified Compliance is not an option. In these cases, the automated calibration procedures may throw away correct EQ values and fail to provide accurate results. The LPA provides the engineer with a completely manual method of controlling the Gain and EQ values, a topic beyond the scope of this paper.

Conclusion

The Tektronix LPA has been designed to reduce the time it takes for an engineer to calibrate the instrument to a desired level of BER. The One-click Calibration process combines the capabilities of the LPA's acquisition hardware and trigger engine with the engineer's unique knowledge (of desired accuracy, of the SUT's operating conditions, etc.), to efficiently identify the best possible operating parameters for the LPA.

Rather than forcing the engineer to spend time configuring the system, acquiring and analyzing data just to figure out if the instrument is acquiring data with the least number of errors, the LPA One-click Calibration performs all of these tasks automatically. Taking advantage of automation to reduce the engineer's workload and providing clear visual feedback when there's a problem, significantly reduces the time and effort required to configure the LPA.

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