APPLICATION NOTE

Meet Signal Integrity Challenges in Complex Medical Systems

Ensure efficacy, safety, and fast time to market

KEYSIGHT

High-Speed Digital Technology Enables Exciting Advances in Complex Medical Systems

The tremendous growth in both the number of complex medical systems and the increasing capabilities of those systems is enabling previously unimaginable applications. Medical imaging systems are enabling early detection of health conditions in orthopedics, obstetrics, gynecology, nephrology, neurology, cardiology, pulmonology, and more. Surgical robots, hospital facilities robots, and telehealth systems are helping medical practitioners detect and diagnose medical conditions and enhance care in ways that extend the lives of millions of patients. As we will see, all these capabilities are enabled by high-speed digital signals, which means that the signal integrity in these systems is more important than ever.

New applications enabled by software content

Much of the value in these complex medical systems comes from the intelligence provided by software capabilities. It is software that processes and removes noise from images, it is software that does edge computing, and it is software that produces the 3D images, and it is software that trains and uses the neural networks that segment and classify images.

More software means more high-speed digital hardware

Of course, the increased use of software enables the use of these complex medical systems in increasingly challenging applications, where reliability, speed, and low latency are essential for customer safety. This means that the digital hardware content of the devices must increase, faster data detection, acquisition, and signal processing, more and faster numeric processors and image shading processors, higher-speed memory, faster clock speeds, higher frame rates, faster interconnects, and advanced digital logic technologies, including PAM4, PAM8, PAM16, and non-return-to-zero (NRZ) logic. In addition, the increasing cybersecurity threat landscape and regulatory requirements for the privacy of patient information are driving the use of digital hardware for data obfuscation, encryption, and validity checking.

More high-speed digital hardware drives test challenges

The increasing use of high-speed digital hardware drives complex test challenges for several reasons:

- Faster clock speed and data rates mean that eye diagrams are less tolerant of signal noise and jitter.
- Increased amounts of data mean that even small bit error rates will lead to more errors.
- Increased density of components on the printed circuit board means that boards have less room for traces. This leads to more layers on the board.
- Increased component density also requires narrower traces, which are more likely to become unexpected opens than wide traces. Less space between traces makes the traces subject to crosstalk, either due to a magnetic field inducing a voltage on a trace or an electric field causing parasitic capacitance.
- More through-hole vias in multi-layer boards require more complex manufacturing processes, such as back-drilling, to improve signal integrity.
- Faster clock speeds and tighter board manufacturing tolerances mean that defects signal integrity issues such as reflections are more likely to occur.
- Advanced digital logic protocols such as PAM4, PAM8, PAM16, and NRZ are less tolerant to signal quality variations, thus amplifying the importance of solving the problems listed above.

Simulation before fabrication is no longer optional

For all the reasons listed above, it is critically important to reduce risk in your medical system by simulating board operation before you send the design to fabrication. While you may not be able to find every problem from a simulation, finding as many as possible will:

- Improve the actual performance of your board
- Decrease the number of hardware prototype versions required, saving both time and money
- Increase the speed at which you can successfully turn on prototypes
- Reduce the number of unplanned board modifications you need to make, test, and document
- Allow you to test firmware and software with fewer incorrect signals that may look like bugs

Keysight PathWave Advanced Design System (ADS) SIPro finds signal integrity problems before fabrication

The PathWave SIPro element of Keysight's PathWave ADS provides signal integrity analysis of complex high-speed PCBs. It lets you simultaneously characterize loss and coupling of signal and power nets with the PowerAware simulation engine. You can also extract and seamlessly transfer an accurate electromagnetic (EM) model for use in the ADS transient and channel simulators. The net-driven interface lets you go from layout to results in fewer than 20 clicks, delivering speed and accuracy. The SIPro element includes RapidScan Z0, which provides a quick check for trace impedance to save time before committing to an EM extraction. This lets you reduce the risk of errors in your patient's data or images.

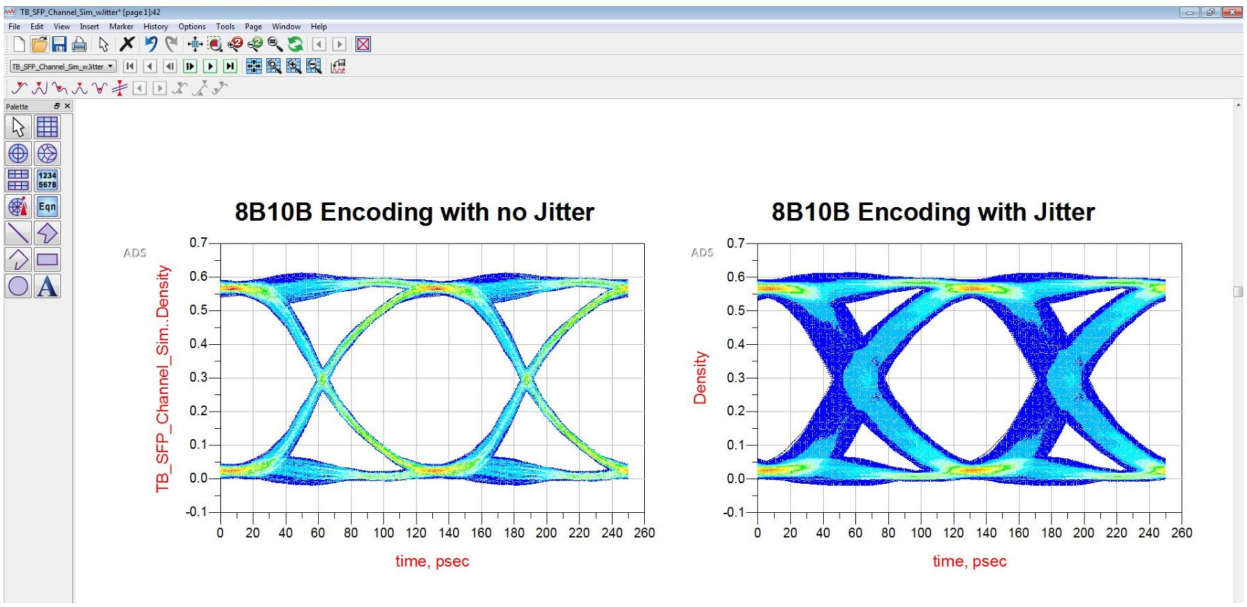

Figure 1. Keysight PathWave SIPro element analyzing the effects of jitter on an eye diagram

Possible solutions for signal integrity issues

There are several things that you can do at the design stage to improve signal integrity. For example, you can adjust the size of the copper annulus around a via. This is a bit of a balancing act, as you generally want a smaller annulus as the channel speeds increase. On the other hand, you want to allow a bit of margin to account for mechanical drill wander if you are not using laser-drilled holes. Similarly, you can increase pad sizes to allow for normal variation in the accuracy of surface mount technology (SMT) placement equipment. Finally, you should strive to keep vias away from via holes to let the solder mask do its job and prevent solder from getting into the via holes.

Use connectors that are appropriate for your application. The connector that worked well at one speed may no longer suffice when your system's data channels are running at a faster speed or with a more demanding digital signal protocol. Consider whether you may need to ask your bare board vendor to implement backdrilling to remove via stubs during the manufacturing process. Also consider whether you need to implement differential traces to improve noise immunity.

Why it is important to measure signal integrity after PCBA fabrication

Even if you run signal fabrication simulation software and take great care in laying out and fabricating your printed circuit board assembly (PCBA), you must still use an oscilloscope to measure your board's performance for signal integrity after it comes back from fabrication. There are several reasons for this.

- There are always variations within components, even if the components are within specifications. No signal integrity software can account for all variations.
- Components often have some inherent parasitic analog characteristics (impedance, capacitance, inductance) that are not specified.
- The SMT component placement process is subject to variability, and components may not always be centered on pads.
- The solder stencil process does not always produce perfect "bricks" of solder, and the solder depositions themselves tend to become smaller as the stencil is used between cleanings.
- The chemical composition and characteristics of solder change slightly the longer it sits out at ambient temperature and is exposed to oxidation and evaporation. This can affect the way the solder joints bond the copper pads to the SMT components.
- There is normal variation in the reflow oven that affects the way the solder reflows.
- Even joints that make an electrical connection may not be soldered well. For example, you may have a gull-wing part that lacks a heel fillet, a billboarded passive SMT resistor, or a head-in-pillow ball grid array (BGA) joint.

For these and many other reasons, it is critical to measure your signal integrity after board fabrication.

Infiniium MXR-Series oscilloscopes find signal integrity problems

The Keysight Infiniium MXR-Series oscilloscopes lets you measure up to eight channels simultaneously to quickly find signal integrity issues in your fabricated PCBA. To help you debug your board quickly, the MXR-Series has the capability of eight instruments in one. In addition to being an oscilloscope, it can do logic analysis, real-time spectral analysis (RTSA), serial protocol analysis, waveform generation, frequency response, and phase noise testing. It can also behave as a digital voltmeter and has triple counters with a 64-bit totalizer.

Figure 2. Keysight MXR-Series oscilloscope

Detect and diagnose crosstalk

Because the need for increased data communications speeds in medical systems has led to higher data rates and closely spaced parallel data lanes, electromagnetic coupling known as crosstalk is increasing. In addition, power supplies can create interference on the data lanes they drive in the form of noise and jitter, and they are susceptible to data-dependent noise such as simultaneous switching noise (SSN), which leads to ground bounce.

To address the problem of the detection and diagnosis of crosstalk, Keysight's Infiniium Series oscilloscopes can run Keysight's powerful and versatile D9020ASIA advanced signal integrity software. The application not only detects and quantifies the presence of crosstalk, but it can also determine which aggressors are primarily responsible. It can even remove the crosstalk from the victim to let you visually compare the original waveform and the clean waveform side-by-side directly on the scope display or by comparing the results from other scope analysis tools such as real-time eye diagrams or jitter analysis. This lets you quantify the amount of improvement you can expect by mitigating the various sources of crosstalk.

Figure 3. Keysight D9020ASIA advanced signal integrity software

Detect and diagnose jitter, vertical noise, and phase noise

To reduce risk in your high-speed digital medical device, you need to understand what is causing jitter, which includes random jitter (RJ), deterministic jitter (DJ), and data-dependent jitter (DDJ). Jitter is an effect observed in the time domain, and it is related to phase noise, which is observed in the frequency domain. Phase noise is one of the most important figures of merit of a signal generating device, and it can be a limiting factor in high-speed digital medical systems. Both jitter and phase noise are important because they tend to close an eye diagram in the horizontal direction. In addition to jitter and phase noise, you must measure vertical noise, which tends to close an eye diagram in the vertical direction.

Keysight's D9010JITA jitter, vertical, and phase noise analysis software helps you perform jitter, vertical, and phase noise analysis with Keysight's Infiniium oscilloscopes. By correlating jitter to the real-time signal in time you, the software helps you easily trace jitter components to their sources. The software also includes compliance views and a measurement setup wizard to simplify and automate RJ/DJ separation for testing against industry standards.

Figure 4. Keysight D9010JITA jitter, vertical, and phase noise analysis software

A modular solution to high-frequency signal integrity test

Many complex medical systems, especially imaging systems, rely on optical communications. While the concepts of jitter, phase noise, and vertical noise are similar the frequencies at which these optical signals operate are often much higher than the frequencies of electrical signals. To test such frequencies and to allow customers to flexibly configure cost-effective test solutions, Keysight has leveraged its digital communication analyzer (DCA) technology into a series of oscilloscopes. For example, the DCA-M sampling oscilloscopes can measure a wide range of data rates, from 1 Gb/s through 64 GBaud.

Figure 5. Keysight DCA-M sampling oscilloscopes

High-speed digital medical systems continue to evolve. The test challenges and requirements you face tomorrow are likely to be greater than the ones you face today. In addition, the number of channels you want to test simultaneously is likely to increase. Therefore, you should consider another member of the DCA family, the Keysight DCA-X series of sampling oscilloscopes. These provide accurate and precise measurements of high-speed digital designs from 50 Mb/s to 224 Gb/s. You can configure the DCA-X mainframes with modules that perform precision optical, electrical, and time domain reflection / transmission (TDR / TDT) measurements with the bandwidth, filtering, and sensitivity to match your measurement needs on up to 16 channels.

Figure 6. Keysight DCA-X sampling oscilloscope

Software turns DCA measurements into crucial insights

The high-precision measurements of the DCA series are critically important to reducing patient risk and ensuring efficacy of your high-speed digital system. But to get to market quickly and deliver your system's value to patients and practitioners, you need actionable insights. Keysight's FlexDCA sampling oscilloscope software is much more than a friendly interface to control the DCA measurement hardware. It is also a visual output for simulation (such as Keysight's ADS and SystemVue products) and for remote access to supported DCA mainframes. Furthermore, it encompasses powerful tools that boost productivity and provide insights into root causes of issues with the signal or device under test.

It is well-suited and continues to evolve for applications such as:

- R&D verification of electrical transmitters (ASICs, FPGAs, PHYs)
- Research, development, and manufacturing of optical transmitters and transceivers
- Analysis of reflections and transmission characteristics of electrical components and channels
- General-purpose analysis of analog and digital signals

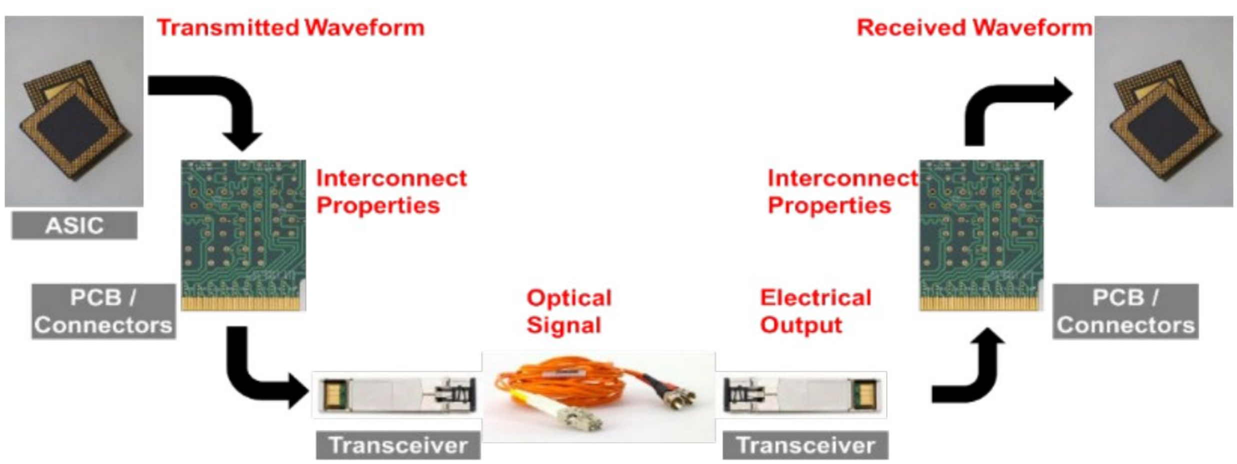

Figure 7. Typical use cases for Keysight FlexDCA sampling oscilloscope software

For even more powerful insights into signal integrity, the FlexDCA software has an optional N1010300A signal integrity package that adds powerful tools like Automatic Fixture Removal to measure impedances, transfer characteristics, and S-parameter calculations to the basic TDR/TDT measurements.

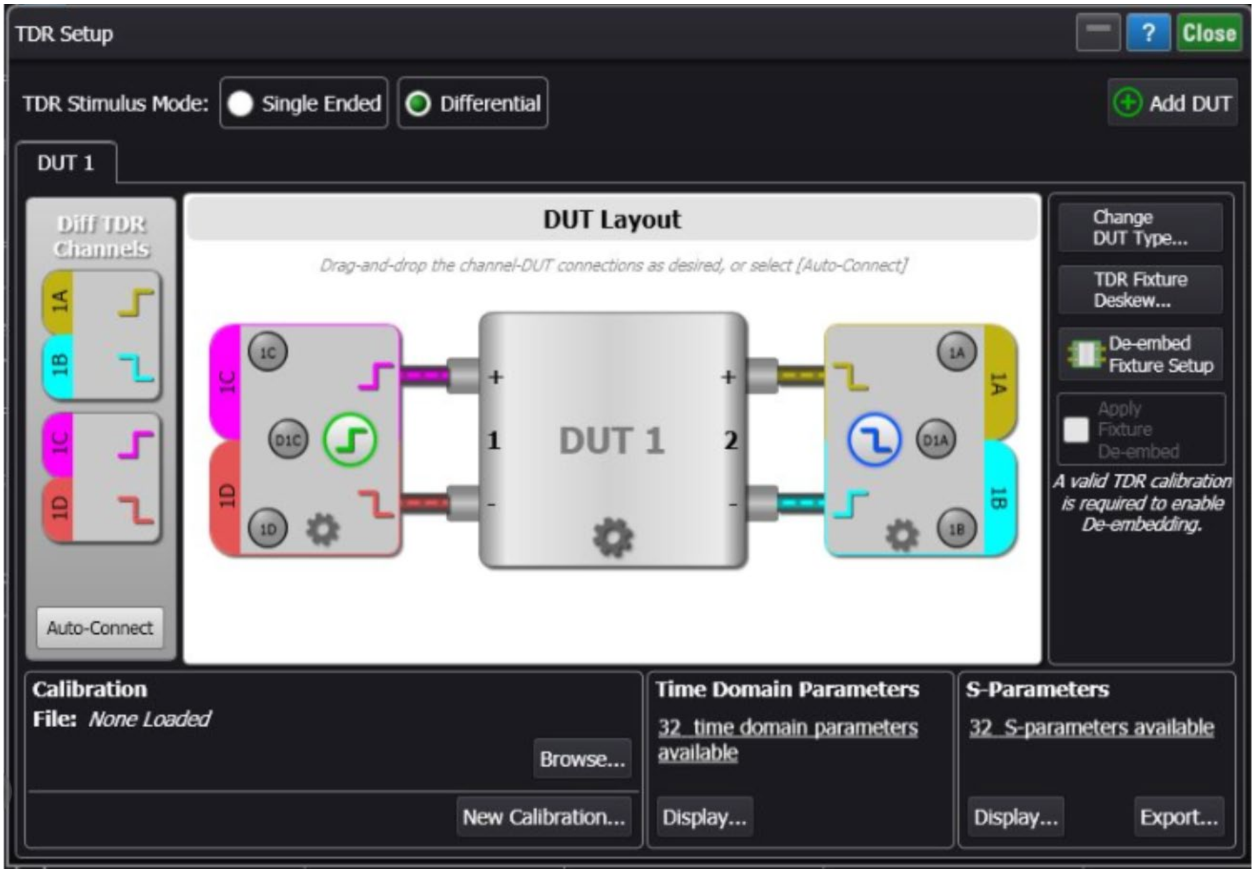

Figure 8. N1010300A signal integrity package for Keysight FlexDCA sampling oscilloscope software

Conclusion

Delivering high-speed digital medical systems has always been challenging, and with faster data rates, higher resolution imaging, and more edge computing embedded into the system, the challenges associated with maintaining excellent signal integrity appropriate to the application continue to increase. By using simulation software before PCB fabrication and oscilloscopes with powerful software after fabrication, you can reduce risk to patients and get your life-changing products to market with the efficacy and safety that patients and medical professionals require and deserve.