50 Gbps Automotive Optical Ethernet demo

Demonstrating 50 Gbps automotive Ethernet with datacom component leveraging

With the increase in *Advanced Driver-Assistance Systems* (ADAS), and the industry looking at autonomous vehicles on the horizon, the intelligent car needs growing bitrates to flow through its nervous system. Optical fibers have clear advantages as the nerves of this system; for example, the fact that no EMC problems will cause headaches to its implementers. This advantage becomes more critical with vehicle electrification, due to the noise immunity requirements demanded by the use of high power and efficient on-board power electronics.

Without doubt, the protocol of choice to implement the communication infrastructure in the car is *Ethernet*, and the 802.3 Working Group of the IEEE standardization organization is already paving the way to have multi-gigabit per second optical Ethernet in vehicles. A dedicated Study Group is already working on the future *IEEE 802.3cz* standard.

KDPOF is the leading company in the effort to build this new Ethernet standard. The purpose of this demo is to demonstrate that it is possible to implement 50 Gbps communication in automotive operating conditions, leveraging the components widely used for the datacom market.

Figure 1: KDPOF demo at Automotive Ethernet Congress, Munich, February 2020

VCSEL operation

A key component for this communication system is the light source. The *Vertical-Cavity Surface-Emitting Laser* (VCSEL) is the device that best fits the high speed and low-cost requirements of the application. The technology of the VCSEL device is well-known, mature and optimized, being heavily used in two killer applications: optical sensors for mobile phones and data center communications. The VCSELs used for this latter application can be leveraged for automotive communications, seizing on its already excellent cost and speed.

However, VCSELs used in data centers live a more comfortable life than they will in a car. Operating temperature ranges of 0ºC to 70ºC are normally supported, which is enough for many uses, considering that most of the time the optical transceivers enjoy air-conditioned spaces. However, the automotive industry cannot offer such a cozy environment for them, because reliable communication must be guaranteed in the extreme temperatures that the electronics in the car will be subjected to, from freezing cold when the car is started up in chilly weather, to suffocating hot in the inside of an already-running car. The objective is to support the range from -40ºC to +105ºC ambient temperature, which corresponds to the Grade 2 of the AEC-Q100 qualification standard used in the automotive industry. Trying to operate the datacom VCSELs at 105ºC ambient temperature will result in communication failure, because their performance is degraded and the system is not prepared for this degradation.

Successfully using the VCSEL in automotive conditions implies being able to compensate for its impairments at high temperature. The communication system must be designed to consider how the VCSEL will perform along the full range of operating temperature, from -40ºC to 105ºC ambient. The substrate of the VCSEL will reach an even higher temperature so, to have enough margin, we are considering a substrate temperature range of -40ºC to +125ºC. KDPOF's communication system implementation is able to support VCSEL operation in this range, also considering the possible technology process variations amongst the different VCSELs manufactured.

Automotive VCSELs are not only required to live in a harsh environment, they are also required to live longer. The fiber optic transceivers in data centers may fail after a few years and be replaced as part of regular maintenance operations, facilitated by the existence of redundant communication channels and fast resolution times guaranteed by *Service Level Agreements* (SLA) between the provider of the communication equipment and the company operating it. This is in no way acceptable for car operation. The automotive industry sets a very demanding objective for the reliability of electronic components, which can be summarized with a figure: 10 FIT (*Failures In Time*). This means that the failure rate expected for a component is at most 10 failures after one billion device-hours, which for example can be expressed saying that no more than 10 out of 1000 devices can fail after one million hours of operation.

Guaranteeing a reliability figure like this makes it necessary to operate the VCSEL in less stressful conditions. There is nothing to do about temperature, but at least we can make the VCSEL suffer less by making it deal with a lower current density. The lower the current density flowing through its structure, the longer the VCSEL will last. The current density is given by the operation current and the active area of the device. Therefore, we need to operate the VCSEL with the lowest possible current. The problem is that the optical output power from the laser is proportional to the current, so reducing the current results in less optical power at the receiving end of the communication. On top of that, reducing the current density also results in decreasing the bandwidth of the VCSEL and increasing the Relative Intensity Noise (RIN).

Again, we need a communication system designed to work with this lower current, a system that works perfectly in worse conditions than those in a normal datacom application. KDPOF's system deals with this, achieving error-free end to end communication with low current density in the VCSEL.

Setup used

The operation of the VCSEL is verified by using it as the light source of a data transmission whose correctness is checked.

The setup used to implement the transmission at a given VCSEL substrate temperature and the verification of the received signal is shown in the *Figure 2*.

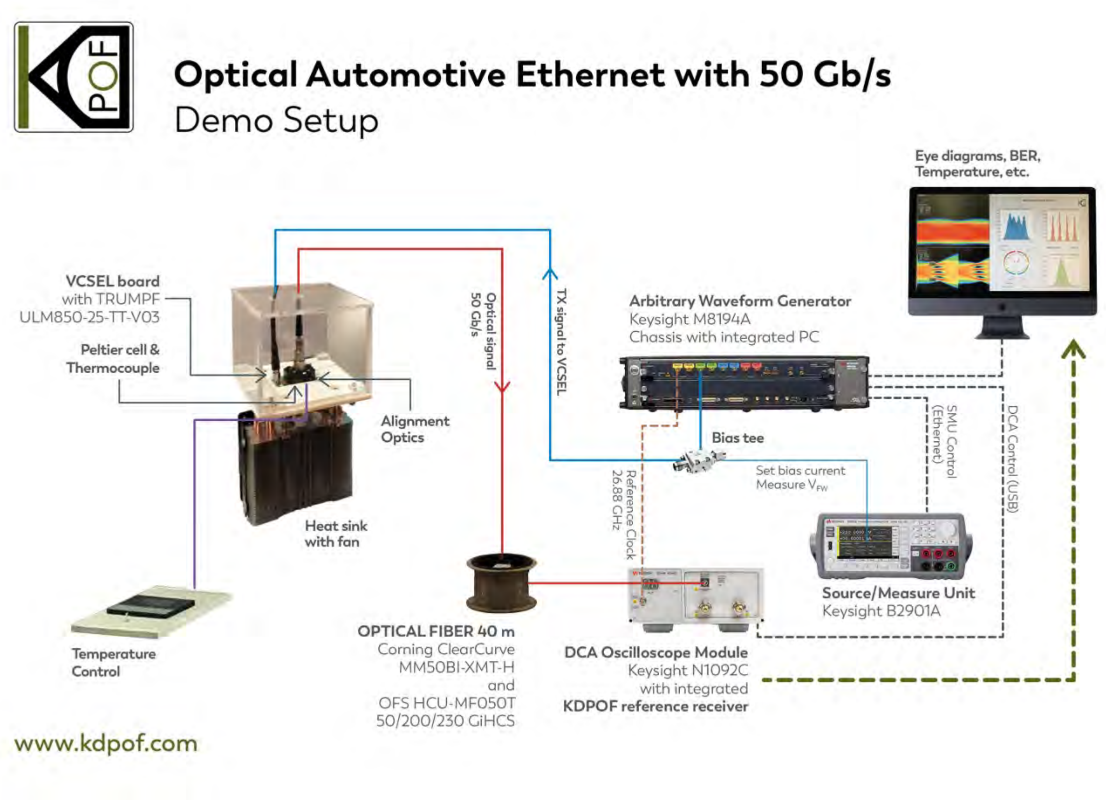

Figure 2: Diagram of the setup used for the demo

The test signal is sourced by an *Arbitrary Waveform Generator* (AWG), and it is checked on a *Digital Communication Analyzer* (DCA) sampling oscilloscope. The following models are used:

- AWG: *Keysight M8194A 120 GSa/s Arbitrary Waveform Generator*
- DCA: *Keysight N1092C DCA-M Sampling Oscilloscope*

The transmission is done in real time, at an actual speed of 50 Gbps. The reception, on the other hand, needs the implementation of a specialized receiver. This kind of receiver will be built in silicon in future KDPOF products, but for this demo it is implemented as a digital signal processing software module loaded in the DCA oscilloscope. Running this module in real-time is not possible, so the DCA creates a post-processing of the waveforms captured in memory. The module is implemented based on the user operator extension capability provided by Keysight *FlexDCA* software in the *Research and Development Package*.

The small signal output from Channel 2 of the AWG is provided to the VCSEL through a coaxial cable, together with a DC biasing. This one is generated with a precision *Source/Measure Unit* (SMU), the *Keysight B2901A*, and applied through a bias-tee (*Marki Microwave BTN-0040, 40 kHz to 40 GHz*). The SMU provides a controlled biasing current to the VCSEL in the same way as the future integrated circuit will do it. The same connection used to apply the current is also used to measure the voltage drop in the VCSEL.

The VCSEL has previously been characterized, and the relationship of the forward voltage drop versus the temperature for a given current is already known. This makes it possible to get real time data about the VCSEL's substrate temperature by measuring the forward voltage drop with the SMU. The junction temperature can also be calculated using the substrate to junction thermal resistance and the actual DC operating conditions.

The light from the VCSEL is coupled to an optical fiber terminated in an FC connector, through alignment optics. This optics stage is needed because the VCSEL is used as a simple semiconductor die, wire-bonded to a board, with no package providing optical coupling.

The other end of the fiber, which has a length of 40 meters, is connected to the optical input of the DCA oscilloscope.

A key part of the receiver implementation is the clock recovery. Clock phase recovery is implemented as part of the *user operator* loaded in the DCA. However, this is not possible for frequency recovery; it will be present in silicon, but here it would require the model to run in real time. Hence, it is necessary to provide a clock reference of the exact frequency to the DCA. This is done by generating a square signal with linear transitions in Channel 1 of the AWG and connecting this signal to the *Clock In* triggering input of the DCA. The frequency of the reference clock used is the same as the baud rate, 26.88 GHz.

In order to control the temperature of the VCSEL, a Peltier cell is attached to the board where it is assembled. A heat sink with a fan at the other side of the Peltier cell allows for heat exchange with the ambient temperature. A transparent methacrylate enclosure helps protect the VCSEL and keep the temperature constant in its surroundings.

Together with the Peltier cell, a thermocouple is also attached to the back side of the VCSEL board. A temperature controller drives the Peltier cell and uses the thermocouple to set up a stable temperature. This controller is programmed to reach a higher temperature than the one desired in the VCSEL, to account for the thermal resistance between the Peltier cell and the VCSEL's substrate. A temperature close to 145ºC is reached in order to obtain 125ºC at the VCSEL, and this last temperature is measured from the forward voltage drop, as commented above.

A computer, actually integrated in the same chassis as the AWG instrument, controls most of the setup. Through PCIe it controls the AWG to configure the test pattern generated, the modulation and the baud rate. By means of a USB cable it is connected to the DCA to set up the *user operator* for the post-processing and verify all the received data. An Ethernet connection is used to monitor the SMU, reading the voltage drop in the VCSEL.

A setup similar to this was used for the contributions presented in the IEEE 802.3cz Study Group, although in that case a professional thermal forcing system was employed.

Components used

Something to highlight is the fact that this demo does not use a special VCSEL, but one in common use in data centers. It is TRUMPF's 25 Gbps VCSEL model *ULM850-25-TT-V03*.

Two models of multimode graded index type glass fiber are used, OFS' *HCU-MF050T 50/200/230 GiHCS* and Corning's *ClearCurve Mid-Temperature Specialty Optical Fiber for Harsh Environments MM50BI-XMT-H*. These models have very similar optical performance to those used in data centers, but with a special coating to support high temperatures and mechanical stresses.

Transmitted signal and reception checking

The arbitrary waveform generator provides an electrical signal with pseudorandom data, using a PAM4 modulation with a baud rate of 26.88 Gigabauds. This signal is the one that drives the VCSEL, after adding the bias current to it.

The resulting optical signal in the fiber is received by the DCA oscilloscope through its optical input. After sampling it, the instrument shows to us two different eye diagrams, as shown in *Figure 3*.

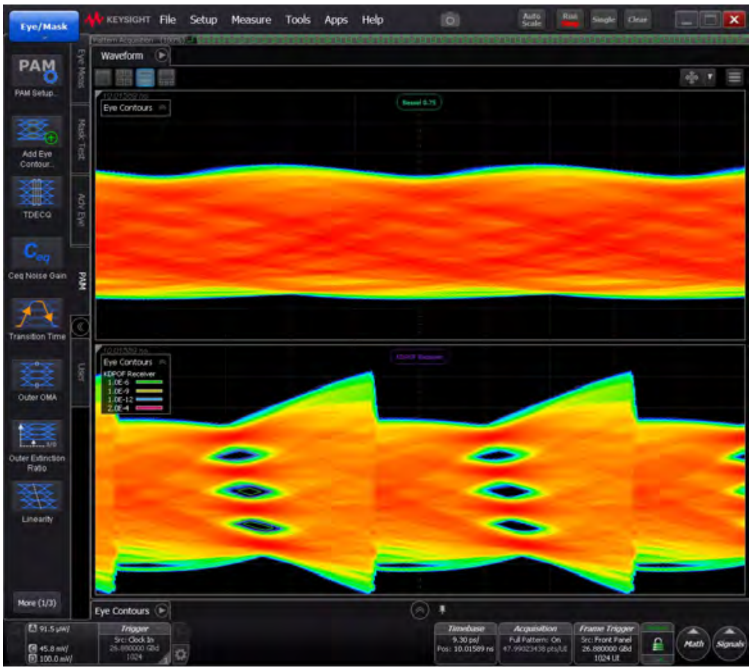

Figure 3: Eye diagrams: raw (top) and post-processed (bottom)

The first diagram is a representation of the signal samples as the instrument sees them at its input. Due to the very high speed and to the limited optical power resulting from operating the VCSEL at high temperature and low current, it can be seen that this received signal does not present an open eye, as it is impossible to distinguish the four levels of the PAM4 modulation.

The *user operator* embedded in the instrument thanks to its *R&D package* software makes it possible to post-process these raw samples with a model of KDPOF's reference receiver. In the same way as the future silicon will do, this receiver performs key DSP steps to interpret the received signal. This DSP processing involves clock phase recovery and channel equalization, resolving the impairments of limited bandwidth and high distortion and noise coming from VCSEL operation at low current and high temperature.

The result can be seen in the second eye diagram, where open eyes can be observed. Now it is possible to distinguish the four levels of PAM4 at the moment of data sampling.

Further DSP processing includes *Forward Error Correction* (FEC). This is also implemented in the receiver model, so bit error rate (BER) after FEC can be obtained. In *Figure 4*, a sample screen is shown, with the eye diagrams and a window with other interesting information from the receiver: the histograms of the oscilloscope samples before and after equalization, a histogram of the modulation error ratio (MER) and the BER after FEC. In the same window, the substrate and junction temperatures of the VCSEL are shown, together with the forward voltage measured and the bias current applied and its corresponding current density.

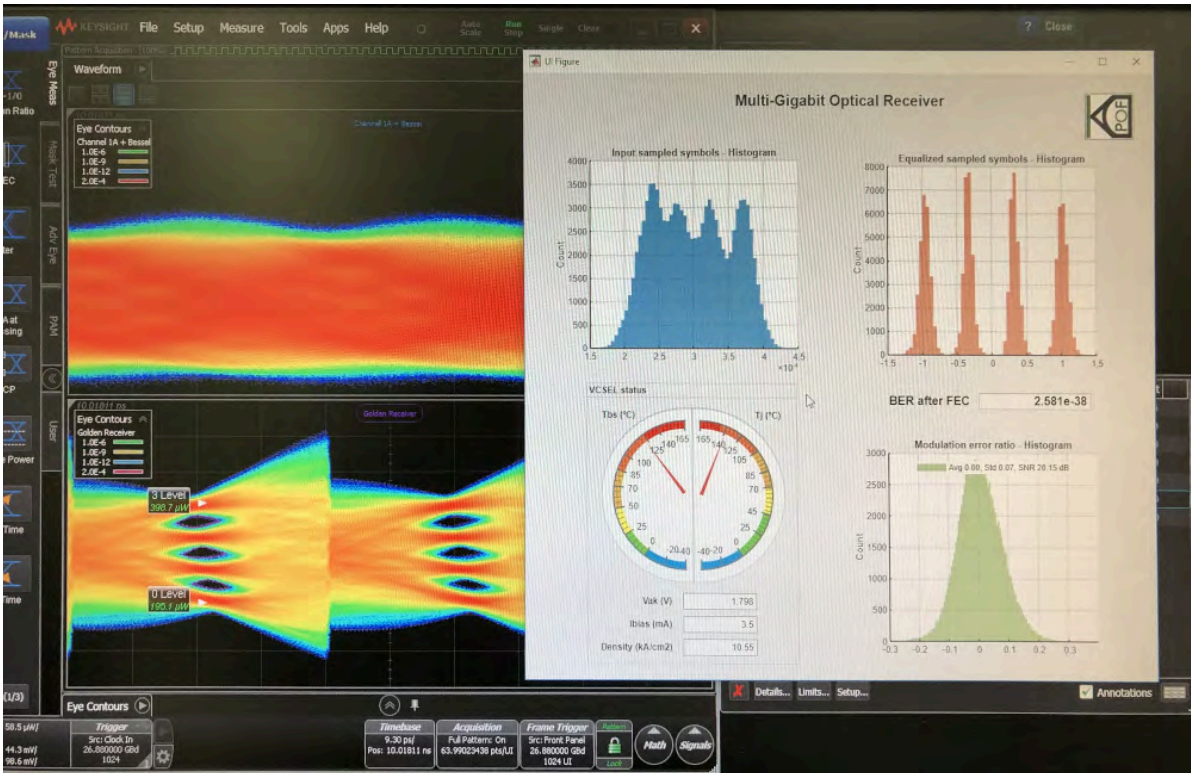

Figure 4: DCA screen showing eye diagrams, sampled symbols pre- and post-equalization, modulation error ratio, and BER after FEC and temperature

More information

For more information on the new *Multi Gigabit Automotive Optical PHY* Ethernet standard under development, visit the public area of the IEEE 802.3 Study Group: http://www.ieee802.org/3/OMEGA

For more information on KDPOF products, visit our web: https://www.kdpof.com/

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