

Addressing TEC Reliability for LiDAR Applications



LiDAR is a navigation solution that can:

- Capture topographical data on land
- Gather elevation and depth data over water
- Map out a clear path and help identify obstacles for autonomous vehicles

Build Reliability Into LiDAR Systems for Autonomous Vehicles

In order for autonomous vehicles to see widespread adoption in the coming years, both manufacturers and consumers will need assurance that safety is not only the utmost priority, but can actually be improved over conventional vehicles. Achieving peak reliability in Light Detection and Ranging (LiDAR) systems is a key piece of that.

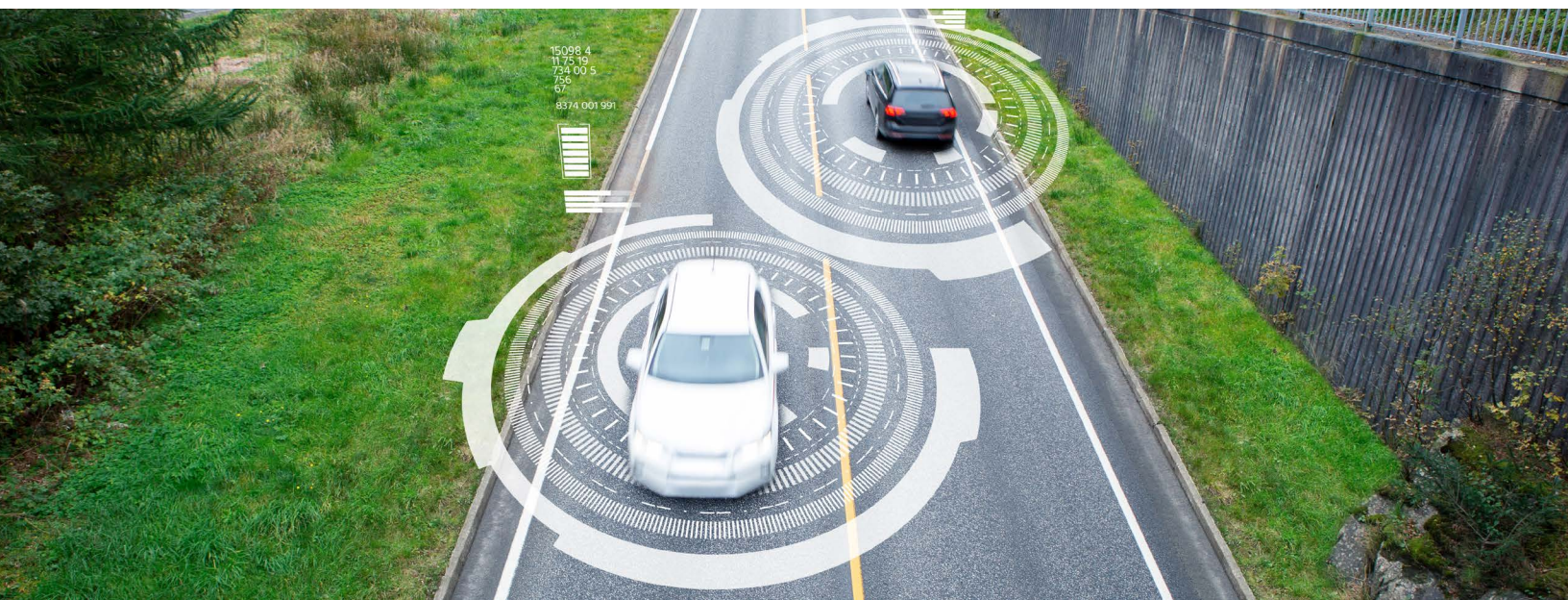
LiDAR is one common navigation method used in self-driving cars, drones and other autonomous vehicles. The technology relies on accurately measuring the time of flight of light pulses to map out the surrounding environment. By improving on this sensing accuracy and sensitivity, manufacturers will in turn improve the safety of their autonomous vehicles and prevent crashes from happening—perhaps achieving even greater safety than human drivers can deliver today.

Reliability needs to be built into the core of any LiDAR system in order to ensure a high level of accuracy for self-driving cars, even under challenging environmental conditions and at high speeds. But beyond that, these applications have extremely long lifespans that demand reliability. The average passenger car is more than a decade old, and cars are expected to perform well even after they've been driven more than 100,000 miles. Your LiDAR system will need to meet these tough consumer expectations.

Cooling in LiDAR

A common challenge in LiDAR systems is temperature control, because the laser diodes that are critical to the technology also emit heat. A very attractive solution to this thermal management challenge is active cooling with thermoelectric coolers or TECs. TECs are very effective at maintaining the desired operating temperature and thus stabilizing the laser's wavelength; temperature control and wavelength stability go hand in hand.

Tight temperature control and sub-ambient cooling can also help improve sensitivity on the detector side of the LiDAR system, leading to higher sensitivity and range of the sensor. It is also critical for ensuring a good signal-to-noise ratio and range for picking up very low signals. For example, a blown-out tire on the road that is a good distance away is going to reflect much less light back towards the detector as compared to, say, a pedestrian or a light-colored car in the immediate vicinity. By improving the detector's sensitivity with active cooling and reducing thermal noise, manufacturers can ensure that their LiDAR system will be able to detect and map out every object, even those that reflect very little light.



Above all, your TEC can do three things for your LiDAR system:

1. Ensure wavelength stability
2. Improve pulse width and modulation frequency control
3. Increase detection sensitivity and ability to detect phase changes

Many LiDAR sensor developers are looking to actively cool their optical components with TECs to improve sensor range, sensitivity and reliability. Active cooling from a TEC can also allow for optics to be integrated more closely together, making the sensor more compact.

Reliability Testing for Your LiDAR's Cooling

Since the TEC is so integral to the LiDAR system's overall performance, it is also a single point of failure. If the TEC fails, the LiDAR sensor will be severely hampered and, depending on the design, it may not work at all, impacting the entire self-driving system. Any TEC that is designed into a LiDAR system needs to be exhaustively tested for reliability, so manufacturers can be confident that they will perform consistently out in the field.

Testing on TECs for LiDAR applications should include:



High-temperature storage: Stores the TEC at a specified ambient temperature to evaluate diffusion-based degradation mechanisms



Damp heat/UHAST: Exposes the TEC to high humidity to test moisture-related degradation mechanisms



Temperature cycling: Exposes the TEC to extreme temperature variations to test degradation related to thermomechanical stress



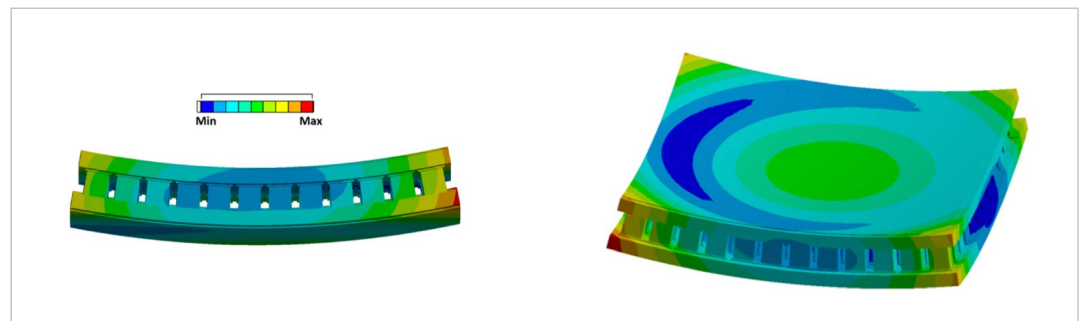
Mechanical shock & vibration: Subjects the TEC to sudden and extreme acceleration, deceleration and other conditions



Power cycling: Rapid on-off cycling with a large temperature gradient to test thermomechanical stress, the effect of high current and voltage, and high temperature operation

Power Cycling

Power cycling [PC] is one of the most stressful tests you can conduct on TECs. During PC testing, devices are rapidly cycled on and off. This results in a large temperature gradient [60°C or more] between the hot side and the cold side. Since materials naturally expand with increasing temperature and contract with decreasing temperature, this temperature gradient creates opposing mechanical stresses within the device that can result in mechanical deformation. In other words, the cold side of the device shrinks and the hot side expands. As a result, under aggressive conditions, the TEC deforms similarly to that shown in the finite element model below. It is typical to see the highest deformation in the corners of the thermoelectric module. See below:



Mechanical stress arising from the temperature gradient may cause TEC failure and needs to be thoroughly tested.

When selecting a TEC for LiDAR applications, here's what you should be looking for:

- **High heat-pumping capabilities** to maintain temperature control
- **Low power consumption** to stay within constraints for the total package
- **Excellent reliability and survivability** that is specifically tested for and meets real-world demands

The results of power cycling [PC] testing are used to determine the TEC's reliability and expected time to failure [TTF]. PC testing and other reliability tests are particularly important for LiDAR technology because of how often these systems will be in use. Autonomous vehicle use cases would see them driven daily, and probably multiple times per day. TECs used inside LiDAR systems may be electrically and thermally cycled multiple times per day as well.

The operating conditions utilized during the PC tests are highly accelerated relative to operating conditions experienced in normal applications. First, the hot side is operated at an elevated hot side temperature, increasing the rate of thermally-activated degradation processes, such as impurity diffusion. Second, the temperature gradient (ΔT) across the device is much larger than what is typically seen in cooling applications, so the thermal stresses, and therefore the potential deformation, are much larger. Finally, the devices are power cycled hundreds (even thousands) of times per day, whereas most applications will only require a handful of cycles per day. These accelerated conditions make PC testing the litmus test for determining thermoelectric reliability and time-to-failure [TTF].

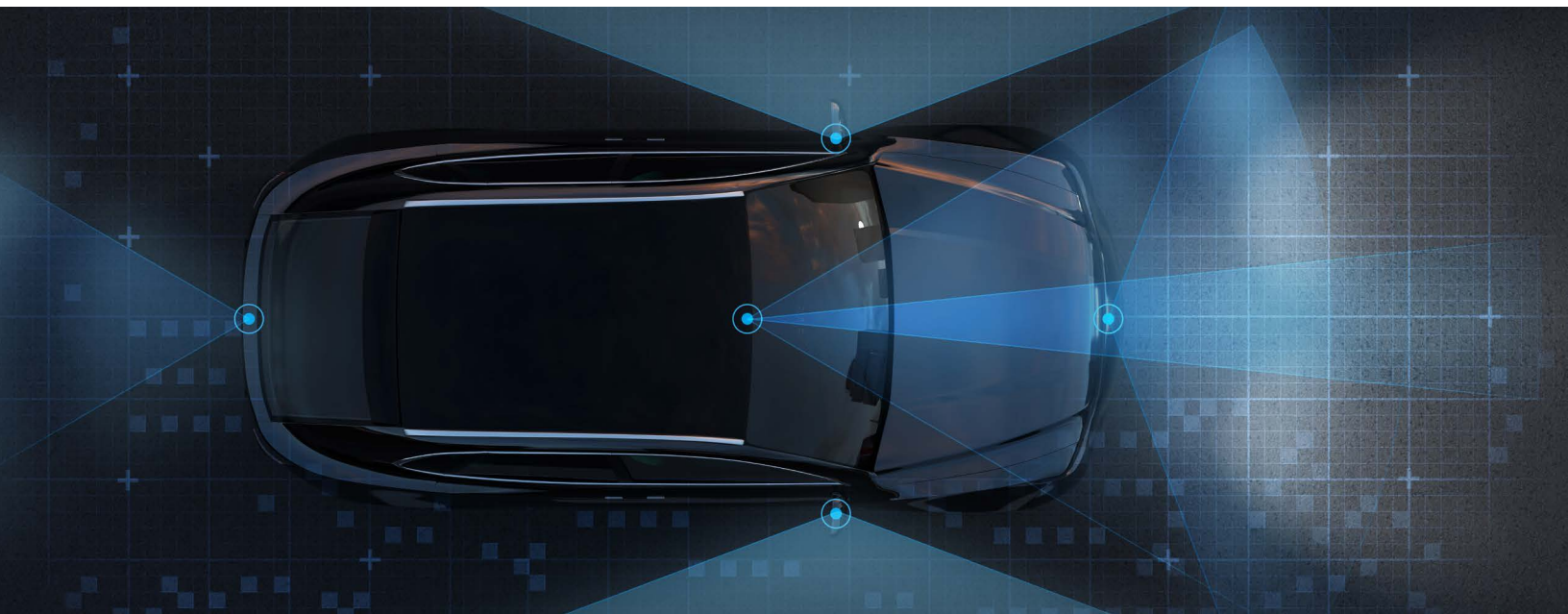
Reliability testing that is designed to put a TEC through these types of intense real-world conditions and performance demands helps ensure that they will not fail in everyday use.

What You Need to Look For In a TEC

To meet the range and sensitivity requirements for LiDAR sensors in autonomous vehicles, the laser diode inside the LiDAR system will need to emit high optical power. This means that the laser diode will consume several watts of electrical power and produce essentially that same amount of heat. Bulk TECs, or ceramic plate TECs, are sometimes the TEC solution of choice for LiDAR applications because they can pump several watts of heat.

The issue with most ceramic plate TECs is that they are not designed with reliability sufficient for the long life of passenger cars. They may be able to pump large amounts of heat, but they cannot withstand extreme conditions or thermal cycling, and they typically have a short overall lifespan. So when you're searching for a TEC solution for LiDAR, it's very important to take reliability into account, because it is often not specifically designed in.

Proper testing is paramount to determining the survivability of your TEC in the real world, where extreme conditions may occur and lead to failure. With PC testing, you'll be able to tell whether or not your TEC can withstand daily operation for maximum reliability and lifetime in a wide range of thermal demands.



Time to Failure:

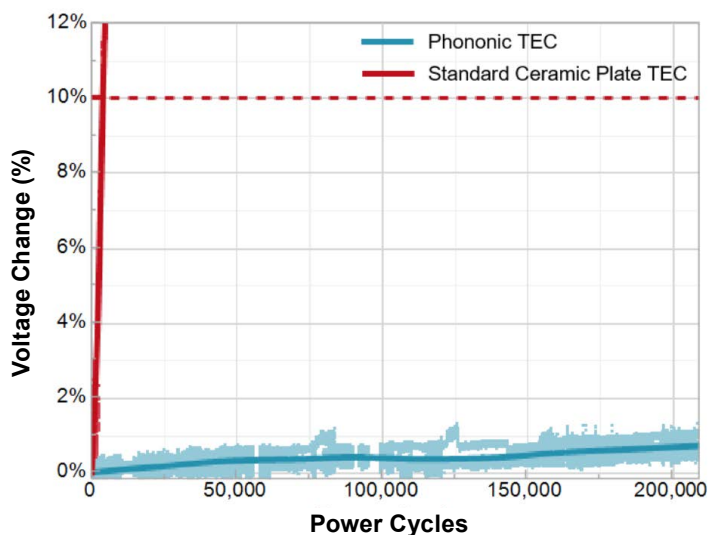
Standard ceramic plate TEC:
~4,500 power cycles

Phononic TEC:
>4,000,000 power cycles

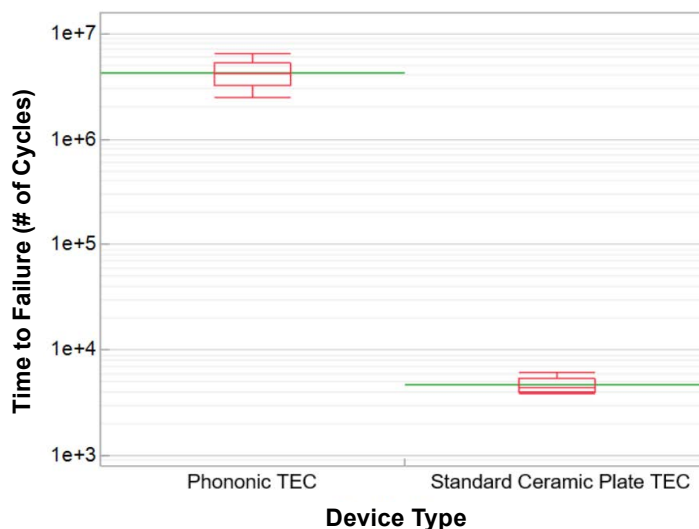
How Phononic's TECs Deliver Maximum Reliability

In our reliability testing, Phononic's TECs have demonstrated an almost 1000X improvement compared to traditional bulk TECs.

Phononic has designed, developed and built custom power cycling test equipment to ensure accurate reliability data collection. In our PC testing procedure, each device type is mounted to a heat exchanger system within the testing equipment. The devices receive a constant current power source to within 80% of I_{MAX} and the cycle is made long enough to develop a 50°C or higher temperature gradient from the hot side to the cold side. Throughout the testing process, both voltage and temperature delta (ΔT) are carefully and continuously monitored. Failure occurs when or if a device shows a change in voltage of >10% or a change in ΔT of >10°C. This testing is based on the standardized power cycling test specified by Telcordia GR-468 for TEC reliability in telecommunications applications.



Plot of voltage change v. power cycle count for a standard ceramic plate TEC and a Phononic TEC



Plot of Time to Failure [TTF] for standard TEC v. Phononic TEC

In the charts above, you can see that standard ceramic plate TECs exhibit a significantly larger increase in voltage to maintain constant current after just a few thousand cycles. Phononic's TECs, on the other hand, show a negligible voltage increase past several tens of thousands of cycles. Since standard ceramic plate TECs surpass 10% increase in voltage while under testing, it is straightforward to estimate the cycle TTF: roughly 4,500 cycles. Because Phononic TECs exhibit only a small increase in voltage, the data was extrapolated to determine the cycle count at which a 10% increase in voltage will be surpassed. For the Phononic TEC, the extrapolated time to failure is greater than 4,000,000 power cycles.

Through rigorous testing, Phononic's TECs are proven to meet the most demanding thermal management requirements for LiDAR systems in autonomous vehicles. They also provide the long-term reliability that these applications demand.

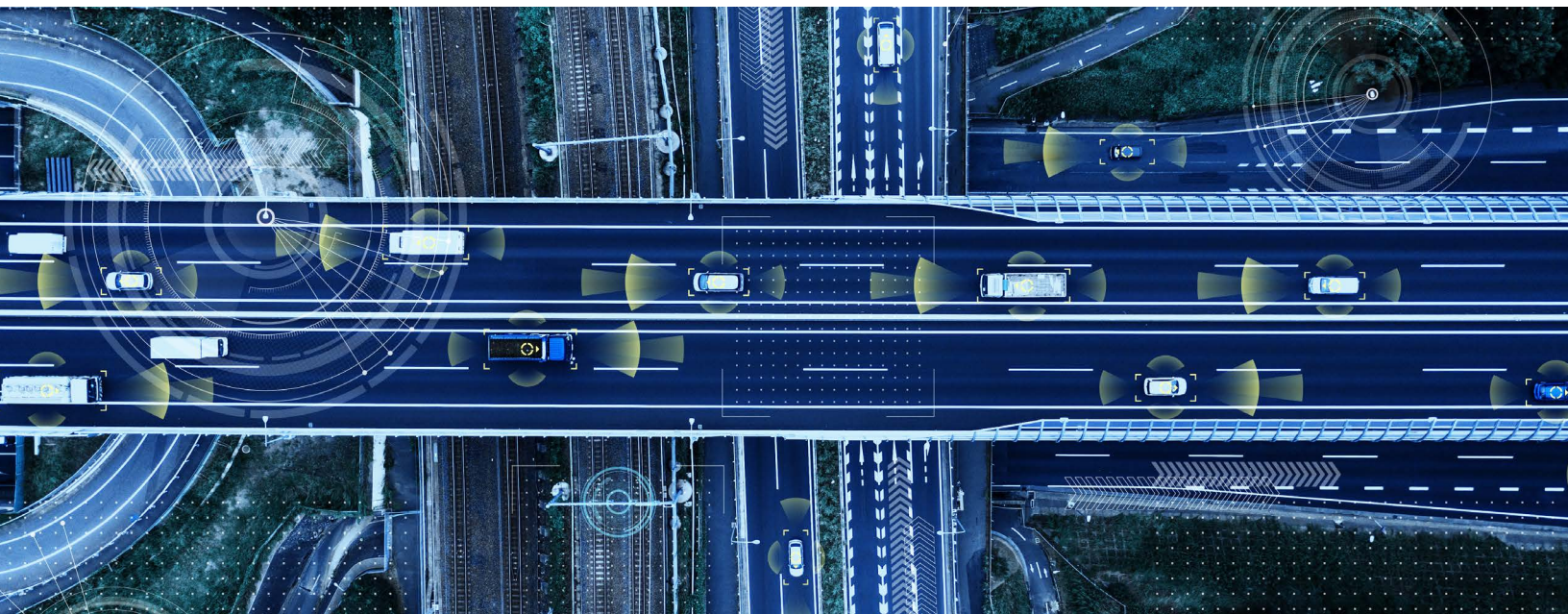
Extreme Reliability and Dramatically Long Lifespans

Reliability remains one of the most critical factors limiting the adoption of LiDAR-based autonomous vehicles and other LiDAR applications. As shown in this paper, our TECs have demonstrated a 1000X improvement in reliability as compared to alternative TEC solutions.

Power cycling is the harshest reliability test available, and our TECs do more than just pass: they excel. In typical use, devices are cycled only a few times per day. But, even when an application requires 50 full thermal cycles per day every single day, our TECs are proven to last for more than 25 years.

As you've seen, Phononic TECs directly address concerns around both operational reliability and usable lifespan. As such, our technology may just end up being the most reliable component in your LiDAR system.

Contact us to learn more about how Phononic can deliver superior reliability, and how our TECs can be designed into your LiDAR system for autonomous vehicle applications.



Phononic is reimagining cooling and heating in ways never thought possible. Its breakthrough solid-state technology is transforming industries and creating new markets with innovative solutions that disrupt antiquated business models and incumbent technologies. Phononic is the critical element of innovation needed to radically change what it means to be efficient, effective and sustainable. The company has been named to the 2016, 2017 and 2019 CNBC Disruptor 50 lists, received the US EPA's 2017 Emerging Tech Award, R&D 100 Award and more.