Impinj Enduro™ Technology

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Table of Contents

Overview

Impinj Enduro™ Technology, commonly called Enduro is Impinj's patented new high-performance attach technology to connect a Monza IC to an inlay antenna. Enduro replaces commonly used bumps with large, flat metal pads that are lithographically defined and form the connection between the IC and the antenna. The flat metal pads are formed on a thick repassivation layer overlaying the IC, and each covers nearly 50% of the IC area. When attached to an inlay, an Enduro IC offers a rugged connection with low resistivity, low RF parasitics, tight manufacturing tolerances, and a mechanically tough connection.

Figure 1 shows an Enduro-enabled Monza IC. Note the two large pads replacing the traditional bumps. Because Monza uses balanced rectifiers (i.e. there is no orientation preference with respect to which pad is (+) and which is (–)) either pad can be placed on either antenna connection.

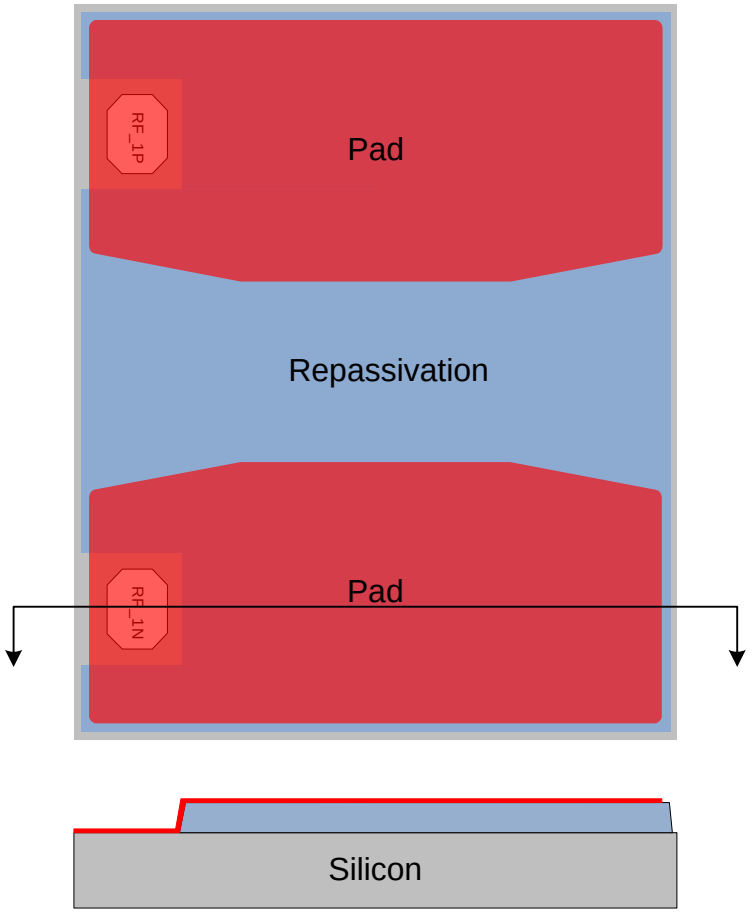

Figure 1: Enduro on a Monza IC: Pads (red); repassivation (blue); IC connection in a notch in the repassivation layer.

Summary of Benefits

Impinj tested Enduro extensively with its attachment partners Mühlbauer and DELO, using Monza 5 as a test bed. Impinj compared reliability, electrical performance, and mechanical ruggedness of Enduro to bump contacts. The data show that Enduro has substantial benefits in each of the areas tested. The key facts revealed by the tests were:

- The connection resistance to the inlay was significantly reduced compared to bumps, which improves inlay sensitivity and reduces sensitivity variability.
- Assembly can tolerate a wider range of assembly parameters, such as thermode force, and can be done faster with reduced inlay tuning variability.
- A much larger connection area allows for far more connection points between the IC and the inlay which improves reliability relative to a bumped IC.

- The Enduro surface is more mechanically robust and less likely to crack when stressed in printers, assembly, and converter machines, because the IC is flat

How to use Enduro

Enduro Monza ICs can be used in standard Mühlbauer assembly machines with no modifications. Enduro simplifies IC attachment in the following ways:

- Enduro reduces chip placement accuracy requirements by 2×, because Enduro eliminates the antenna tuning variations with the IC's x/y mounting location for conventional bumped IC placement accuracy and then only shows comparable variability beyond that.
- Enduro widens thermode pressure tolerances, so that the IC can be assembled over most of the thermode pressure adjustment range (1.2–4 N) without changing the antenna tuning, contact resistance or inlay reliability.
- Teaching the tag assembly machine to recognize an Enduro IC is easier than with a bumped IC, because the Enduro features are much larger.
- Enduro can also be used as an assembly process monitor. By rotating the IC 90º so that each pad shorts the antenna terminals, the contact resistance between the antenna and the Enduro pad can be directly monitored. This Enduro capability and how to employ it to monitor contact resistance are discussed further below.
- Enduro typically requires less adhesive than a bumped IC, while providing comparable shear strength.
- Enduro is compatible with a large number of adhesives, including DELO AC265 and AC268.
- Enduro's planar surface allows inlay assembly pick tools to be more effective. A pick tool removes an IC from a wafer using vacuum directed through a collet. Bumped parts introduce a ~20µm gap between the IC surface and the collet, losing vacuum and reducing collet pick force. Enduro's planar surface allows a higher vacuum force at the collet-IC interface, enabling ICs to be picked over a wider range of dicing-tape adhesive tackiness.
- Enduro relaxes the thermode constraints during adhesive curing. For bumped ICs, changes in thermode pressure change the IC-antenna spacing and with it the inlay tuning. Also, the rate at which thermode force is applied to the bumped IC changes the separation between antenna and chip edge, causing the chip to move laterally during adhesive curing and further changing the inlay tuning. Enduro eliminates these unwanted effects by controlling inlay tuning via repassivation thickness and pad shape, and provides a low-resistance and high reliability connection over a broad range of thermode pressures and pressure application rate.

Impinj has tested Enduro with typical inlay materials, including Al on PET, Al on paper, and Al/PET straps. All tests showed Enduro to provide superior connections, lower inlay variability, and improved inlay reliability than a comparable bumped IC. The net result is that inlays are more reliable and less expensive to assemble with Enduro.

Test results

Summary

	Bumped	Enduro	Enduro Results
Straps			
– Strap frequency tuning	✓	✓	tighter distribution
– Contact resistance	✓	✓	2-3x lower
– Shear	✓	✓	comparable
– Temperature-Humidity Test (THT)	✓	✓	NO fails
– Temperature-Cycling Test (TCT)	✓	✓	NO fails
– Bend	✓	✓	comparable
– Printer test **(24,000 tests)**	✓	✓	NO fails
Direct Chip-Attach on Inlays			
– Optimal tuning same design	✓	✓	comparable
– Contact resistance	✓	✓	2-3x lower
– THT	✓	✓	NO fails
– TCT	✓	✓	NO fails

Figure 2: Comparison of bumped and Enduro test results: Green check – superior performance, blue check – good performance in test results.

Lower contact resistance makes better inlays

Figure 3 shows the contact resistance of bumped versus Enduro IC's. Impinj performed this test at a 1.5N assembly pressure. The horizontal axis denotes the different designs (bumped and Enduro). The dots on the vertical for each design correspond to the contact resistance for each sample of that design. Notice that the bumped IC's had contact-resistance values from 50mΩ to more than 1.2Ω. The Enduro IC's, by contrast, had contact resistance values between 30mΩ and 100mΩ. The reason for the contact-resistance improvement is the difference in contact area. During assembly of bumped IC's, high pressure is exerted on a small number of ACP particles that lie within the small bump surface. During assembly of Enduro IC's, high pressure is exerted on a large number of ACP particles that lie within the large Enduro pad area. For bumped IC's, the bumps concentrate the assembly force. For the Enduro IC's, the ACP particles concentrate the assembly force. Although in both cases there is sufficient force to form a good contact, for the bumped IC's there are instances where few ACP particles make contact, resulting in a high-resistance connection. For Enduro, the larger number of captured ACP particles reduces both the mean and the standard deviation of the contact resistance. Enduro is clearly superior.

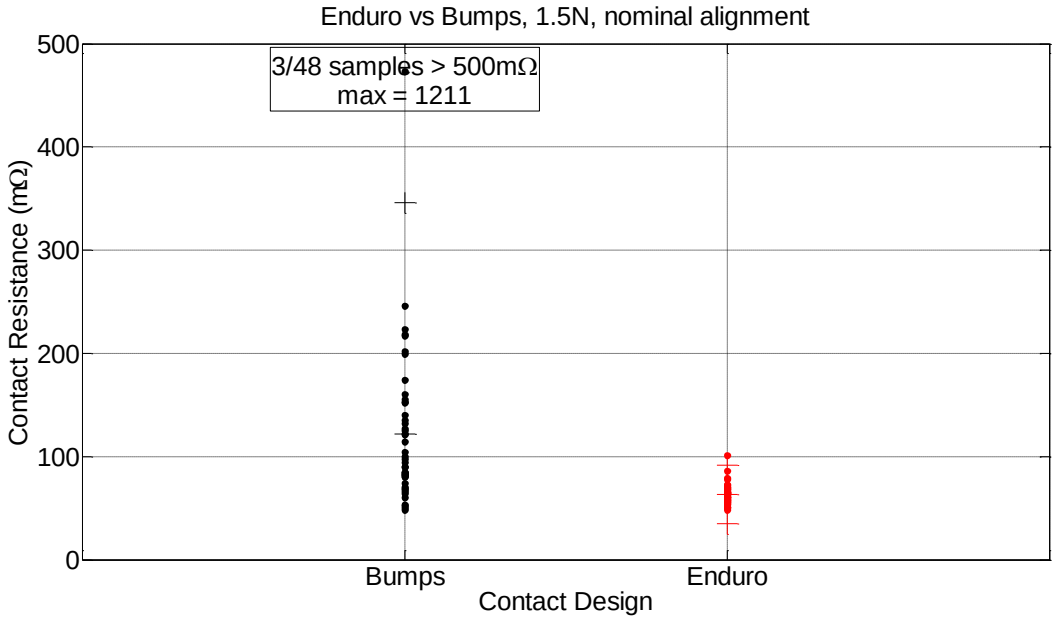

Figure 3: Contact-resistance comparison between bumps and Enduro

Figure 4 shows the relationship between inlay sensitivity and contact resistance. This relationship, when applied to the data from figure 3, shows that 5% of the bumped IC's will lose 0.3 – 0.6 dB of sensitivity due to contact resistance alone.

By contrast, the Enduro IC's will lose at most 0.05 dB. Impinj built all of these samples with DELO AC268, which is known to exhibit very good contact resistance, even for bumped IC's.

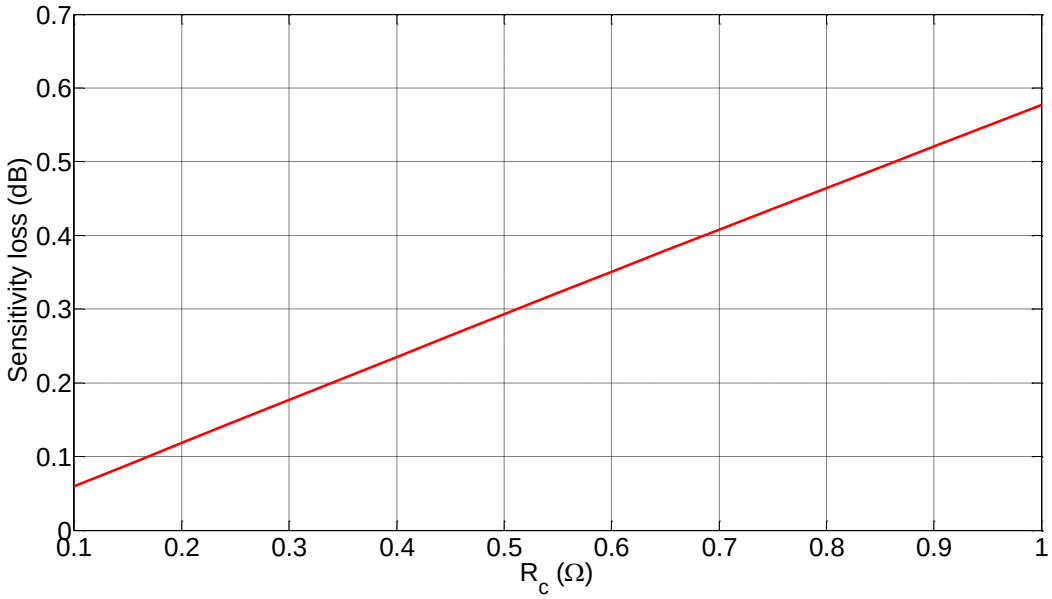

Figure 4: Sensitivity loss as a function of contact resistance R_c

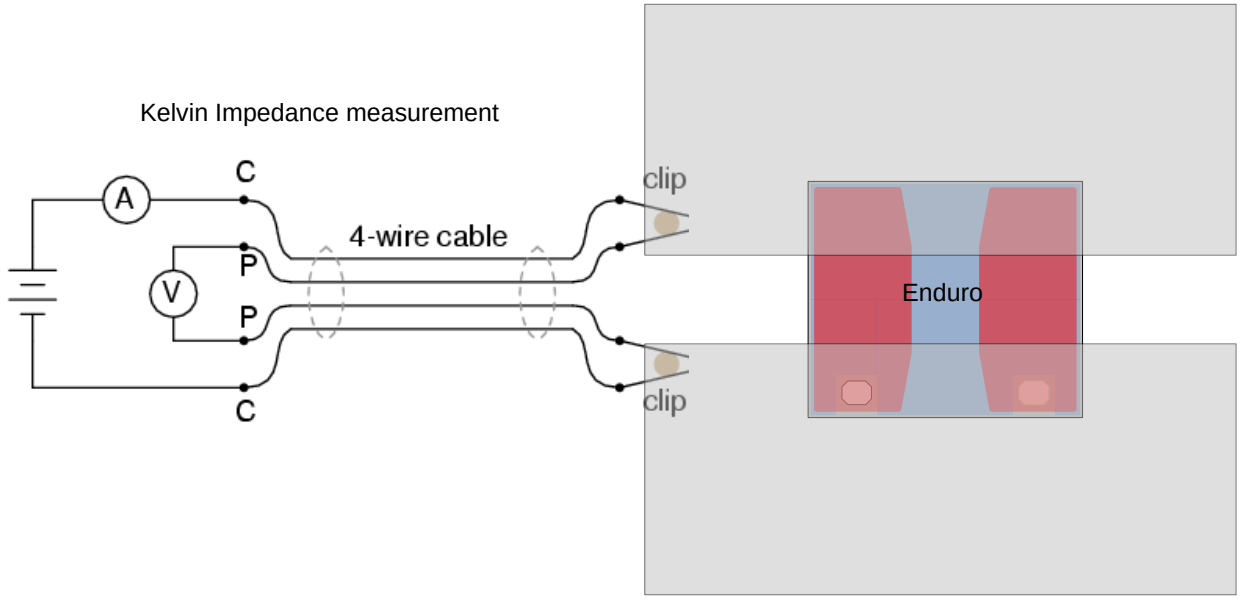

Figure 5: 4-point contact resistance measurement on rotated Enduro inlay

Whereas most bumped IC's don't provide a means to characterize or monitor contact resistance, Enduro does. Figure 5 shows a 4-point contact resistance measurement setup for a bumped Enduro inlay. To make this measurement, position the left RF1– contact pad and the right RF1– contact pad across the antenna gap. Because the resistance is generally very low (a few mΩ's), use a 4-point (Kelvin) resistance measurement setup which forces a current between the C (current) probes and measures the voltage between the P (potential) probes. This setup requires a 4-point resistance meter, for example the Fluke 8845. Another critical parameter for this measurement is the forcing current. This current must be limited to less than 1mA, to avoid damaging the IC during the measurement.

Fixed contact area reduces inlay variability

Figure 6 shows measured tuning variability for bumped versus Enduro IC's. Enduro IC's show 44% less tuning variability when compared with bumped IC's.

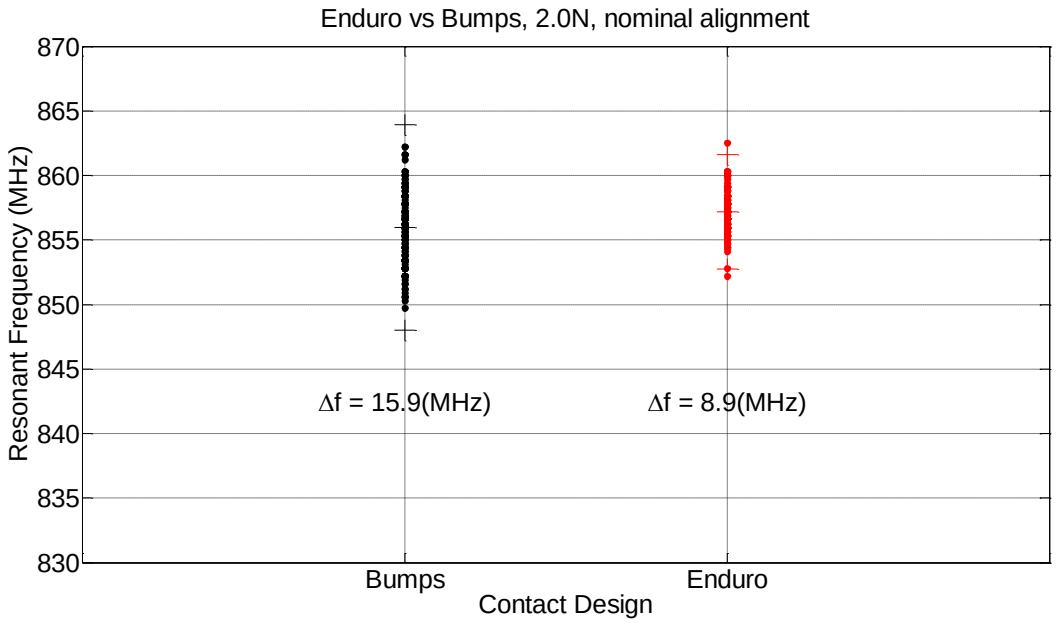

Figure 6: Comparison of tuning variability for bumped and Enduro

Figure 7 shows measured sensitivity versus frequency for an inlay assembled with a bumped and an Enduro IC using the same inlay design. The data show that Enduro has similar parasitics compared to a mounted bumped- IC. The data also show that the Enduro inlay has ~0.25dB better sensitivity, most likely due to lower contact resistance.

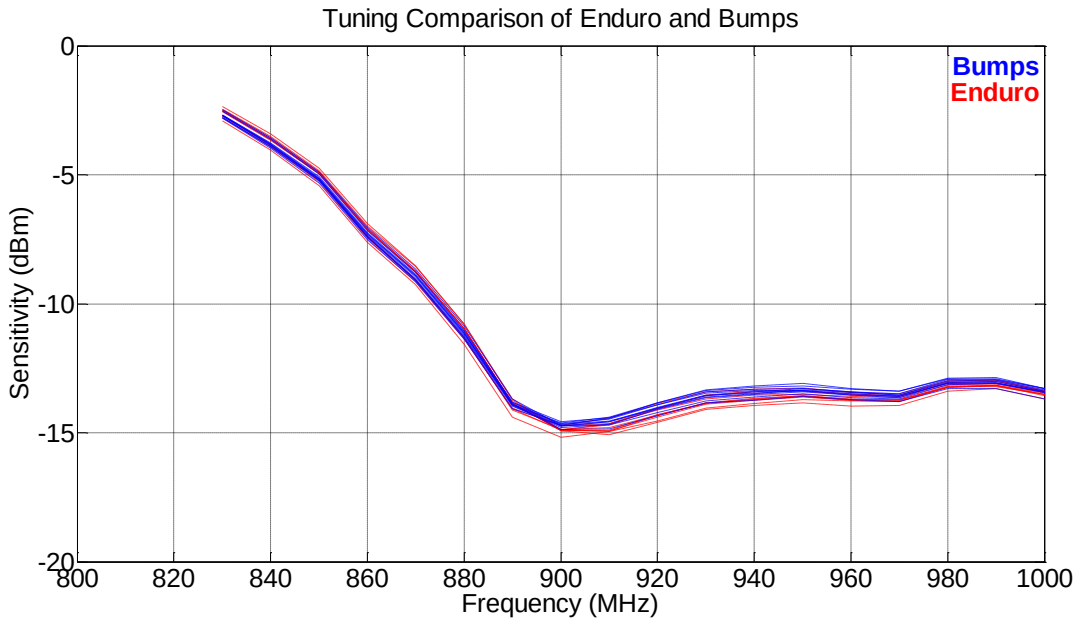

Figure 7: Comparison of tuning performance of bumped and Enduro on the same inlay design.

Large contact pads make reliable inlays

Impinj has performed extensive reliability testing on Enduro. Figure 8 shows a typical Temperature-Humidity-Test (THT) at 168hrs for inlays built with bumped and Enduro IC's. The data show that inlays built with bumped IC's had about 6-7% failure rate in THT testing with some of the inlays nearly nonfunctional (97% performance degradation). However, all inlays built with Enduro passed the 168hr THT test.

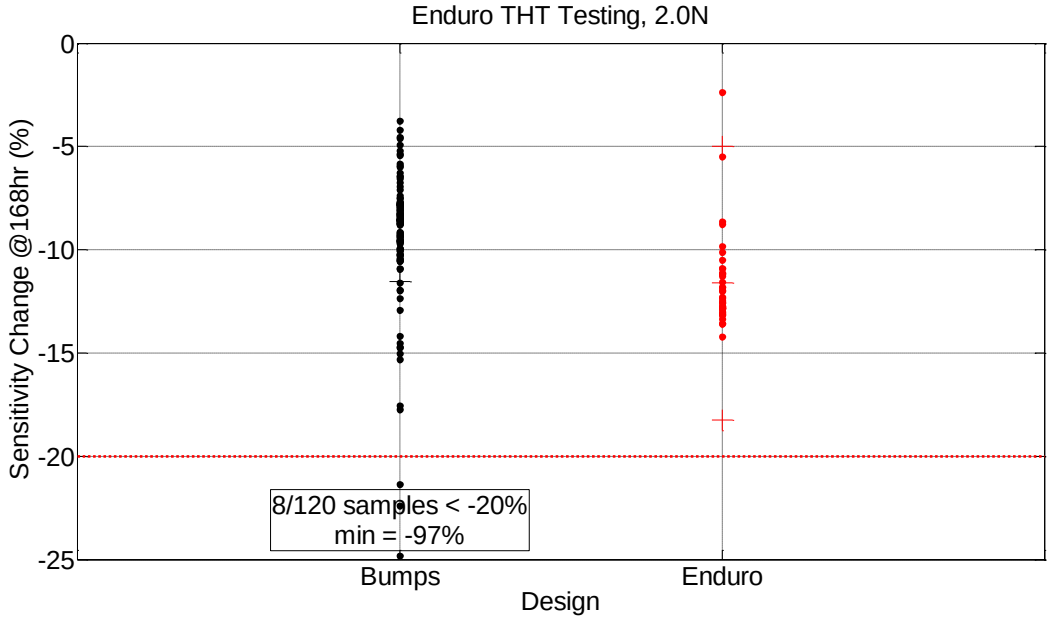

Figure 8: Comparison of THT between bumped and Enduro

We have done further THT testing to 1000hrs on Enduro inlays with our partner DELO. The data showed that Enduro-enabled inlays using DELO AC268 survived 1000hr THT with negligible performance degradation. These inlays used 2.0N thermode pressure, but data over the full range of 1.2 – 4.0N thermode pressure show similar results. These THT Enduro results far exceed any results we have seen for inlays using bumped IC's.

Figure 9 shows a histogram of the sensitivity degradation on the Enduro inlays tested at DELO. All samples at 4 different frequencies (800, 830, 910, and 1000 MHz) had less than 20% sensitivity degradation, which is the typically used THT pass/fail limit. Recall from figure 8 that >6% of bumped parts, with the same adhesive, failed the test at 168hrs.

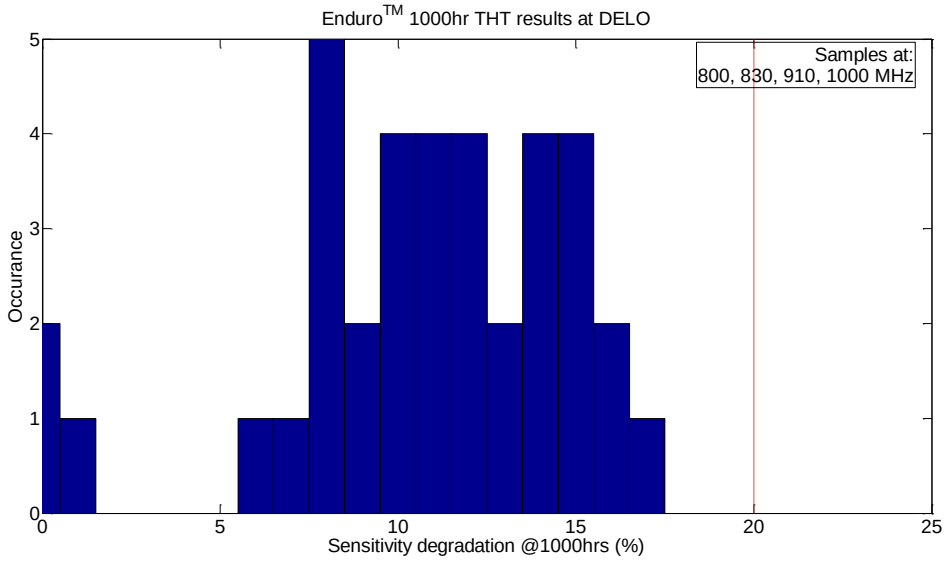

Figure 9: Histogram of sensitivity degradation of Enduro inlays at 1000hrs THT testing

Figure 10 shows a Temperature-Cycling-Test (TCT) for inlays built with bumped and Enduro IC's. The data show that the inlays built with Enduro IC's passed the TCT test, while those built with bumped IC's showed 1–2% failure rate.

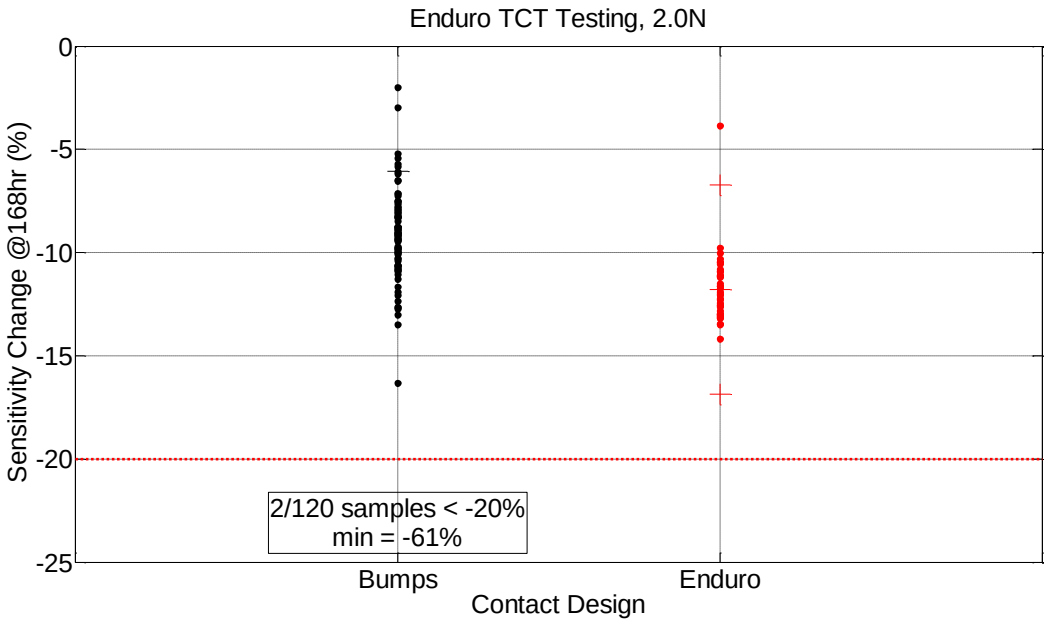

Figure 10: Comparison of TCT results for bumped and Enduro

Figure11 shows a comparison of the Bend Test results for inlays built with bumped and Enduro IC's. In this test, inlays with both the bumped and Enduro IC's passed the test with acceptable levels of sensitivity change.

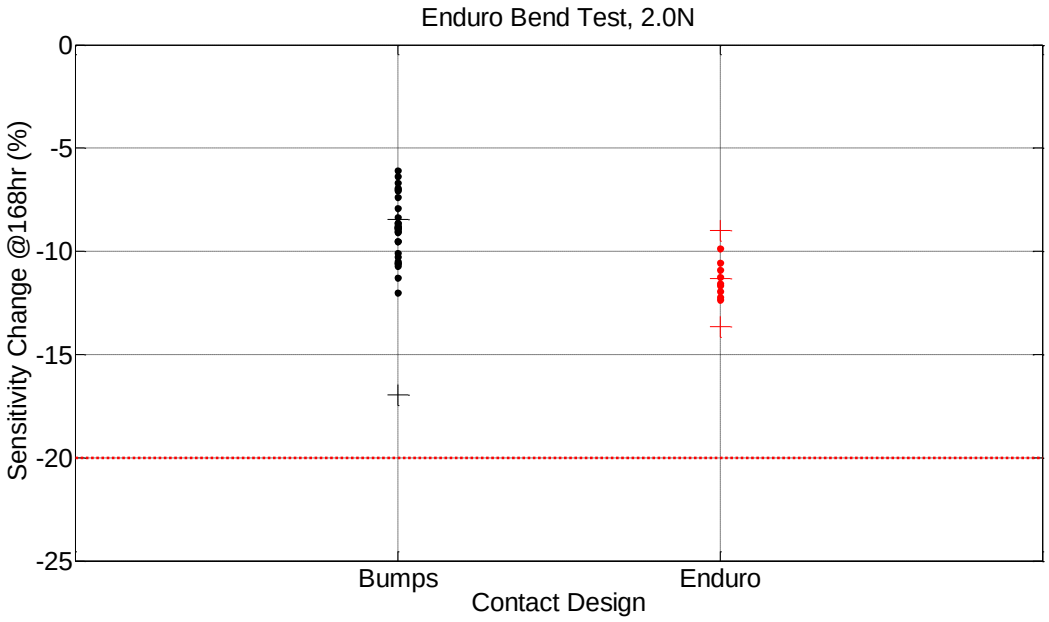

Figure 11: Comparison of bend test results for bumped and Enduro

Intellectual Property

Enduro is covered by U.S. Pat. Nos. 8,188,927, 8,511,569, and 8,614,506. Multiple additional patent applications are pending.

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