Using Bead Probes to Increase Test Access

Case Study

PRODRIVE

This case study discusses how Prodrive, a Netherlands-based electronics manufacturer, successfully implemented the Agilent Technologies *Medalist* Bead Probe Technology to complement their existing test strategies. It provides end-user insights towards decisions made on the selection of test and inspection methodologies in the highly complex manufacturing environment.

Introduction

The initial development of in-circuit test in the 1970's was driven by the cost, complexity, low fault coverage and poor maintainability of functional test systems within the manufacturing environment. The result was a shift in test strategy away from end-of-line functional test to in-circuit test. In the 1990's in-circuit test itself came under threat. Increased board performance and limited access meant that the coverage of in-circuit test decreased whilst the cost increased. The result was a further change in test strategy towards automated inspection, including solder paste, optical and X-ray inspection, followed by new functional test techniques using built-in test approaches such as boundary scan.

Now innovative probing techniques are causing the circle to turn again and allowing in-circuit test to once again become a dominant weapon in the test engineer's armoury. Test strategies are being re-written to downplay the complexity and cost of functional test and replace it with structural and electrical test regimes based on in-line automated inspection and in-circuit test.

To see the results of this move in action consider the example of Prodrive, a successful, innovative design and manufacturing company based in the Netherlands.

Prodrive was founded in 1993 with the aim of providing a range of design and manufacturing services to its clients. Its core expertise is digital signal processing and power electronics and since its inception the company has created many innovative products in these areas that include image processing, motion control and robotics. The company works with some of the major European companies involved in semiconductor, medical and industrial electronics.

The company now has over 250 employees and is structured into three distinct groups. The Digital Design Group continues to exploit the company's expertise in DSP, the Mixed Signal Design Group harnesses its power electronics expertise, and the Electronics Services Group provides manufacturing services for internal and contract applications.

Early in its history Prodrive made the decision to develop its own in-house manufacturing capability. Quality was a fundamental requirement and so from day one the company implemented a sophisticated statistical process control or SPC/Quality management regime using a proprietary quality management database. The test strategy employed reflected this with a combination of in-line automated inspection and functional test. The very first manufacturing line implemented included an Agilent *Medalist* SP50 high-speed solder paste inspection system; an Agilent SJ50 automated optical inspection system and an Agilent *Medalist* 5DX automated X-ray inspection system. These were followed by in-house functional test systems utilising the boundary scan capabilities built into the products by virtue of the company's DFM ethos.

This test strategy has served Prodrive well and as part of an integrated Quality Management methodology has allowed the company to achieve first pass yields of greater than 95% and process defects of less than 10 ppm. Since its first manufacturing line the company has grown significantly and now has three separate production lines each with its own Agilent in-line automated inspection systems.

Prodrive is very happy with its process test strategy. It was in the area of functional test that the challenges arose. They came to a head with a single board robotic controller that challenged the functional test approach. The board is physically large, greater than A3 in size, and combines digital processing with a full four-axis motion controller. The digital processing section incorporates high-speed processors, FPGAs and DSP. The motion controller section incorporates high power motor control circuits. With 14 separate edge connectors to connect and then disconnect just fixturing to the board under test during functional test was challenging. Functional test times were excessive and even with built-in-test that included boundary scan facilities, the fault coverage was less than required.

Tim Koene, Prodrive's Technology Manager in the Mixed Signal Group takes up the story, "There had been some concerns about the functional test approach for some time, due to its inherent complexity, cost and poor maintainability. However this board really challenged our test strategy."

Tim took the role of leading the search for an alternative test approach. He continues, "We had looked into in-circuit test already as an alternative electrical test platform. The problem was one of access. We needed much greater access than was currently available within our design in order to perform a comprehensive test."

In-circuit test relies on a bed-of-nails fixture that uses a matrix of probes to connect with internal points on the PCB. The conventional approach is to include test points or pads within the PCB layout and then use needle or chisel head probes in the fixture to contact with these. The sharp edged probes can usually penetrate any surface contaminants on the test pad and so should ensure a reliable connection. Once connected the in-circuit test system can apply parametric and/or analogue/ digital functional tests to assess whether the circuit is functioning correctly.

The provision of test pads within the PCB layout imposes an overhead. To ensure reliable connection the test pads have to be at least 0.89 mm in diameter, which equates to an area of around 0.62 sq mm. In itself this is a small area, however, test pads can only be located in the free space of the board, i.e., away from components. There also has to be a "keep out" area to ensure that the test probes contact with the test pad and not to adjacent components. This means that the area available for test pads is much less than the total area of the board and therefore finding the real estate to add multiple test pads can become a real challenge. It becomes a much greater challenge as packaging densities increase.

Test pads can also have a detrimental effect on the performance of the board. This is particularly true of high-speed circuits. The data and clock rates encountered in today's boards can be very high to the point where high frequency design considerations such as transmission line theory have to be considered during the layout stage. The addition of a test pad on a high-speed trace can impact the performance of the circuit dramatically to the point where they can simply not be included. This is particularly unfortunate since it is in these areas of the board where additional access is often required for good fault coverage.

It is to overcome these problems that Agilent has pioneered the Bead Probe approach. Bead Probe inverts the probing paradigm. Rather than use a large test pad on the PCB and a sharp edged probe, the approach is to use a small test 'probe' on the PCB and a flat head target in the fixture. The Bead Probe fulfills the role of this small test 'probe'. It is a solder deposit on a PCB trace (Figures 1 and 2) that is the same width as the trace but with a given length (typically 3 to 5 times the width of the trace) and height (typically 4 mils). This approach addresses directly the two issues highlighted above. It consumes no extra surface area on the board so eliminates the real estate overhead. It does not degrade the signal path so eliminates the performance overhead.

Prodrive had already undertaken some investigation of the Bead Probe technique with good results and Tim Koene's own research concluded that it was an approach that could potentially be attractive for the single board controller.

A major advantage of the Bead Probe approach to Prodrive was that it could be applied retrospectively to the existing layout. This avoided a complete re-design of the PCB, which would have required a reiteration of the approval and sign-off procedure with the client.

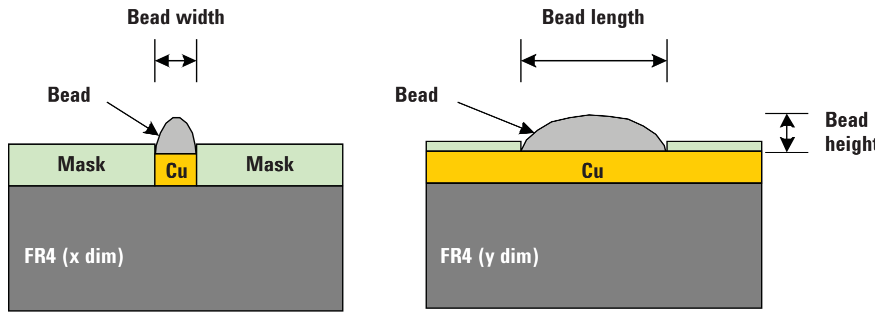

Figure 1. Diagram of Bead Probe

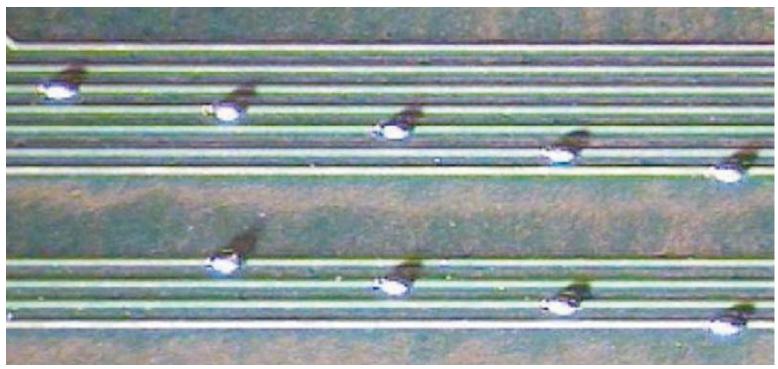

Figure 2. Image of Bead Probes

In implementing the Bead Probe technique Prodrive had to consider three aspects – the solder process, the CAD implementation and the test fixture. Sample boards using Bead Probes had been produced during the earlier investigation and the results achieved with these helped significantly in the single board controller project.

A Bead Probe is manufactured using the same steps as all other solder features. The solder mask is opened up over the trace where a bead is required. Then a new aperture in the paste stencil is opened over this solder mask hole. This aperture is deliberately oversized slightly to precisely control the amount of metal that forms a bead. Solder paste for beads is applied at the same time all other paste features are applied. During reflow, solder flows and is drawn to the copper trace due to the affinity of solder for copper versus its lack of affinity for the mask. Surface tension overcomes gravity causing the bead to have a curved surface and rise above the solder mask, where it solidifies into a Bead Probe. The opening in the solder mask defines the outside dimensions of the bead.

The height of the bead is controlled by two factors – the volume of the solder deposited and the solder stencil aperture. The solder mask hole is formed as a rectangle with rounded ends ('obround') with its width related to the width of the trace. The length runs in the same direction as the trace. The solder stencil hole is square, rotated 45 degrees to the trace and centred on the bead location. Figure 3 shows the board, solder mask and solder stencil stack-up for a Bead Probe.

Tim comments, "Implementing the solder process was surprisingly straightforward and the results were very impressive." In particular, Tim highlights the fact that the Bead Probes appeared to be self-correcting during the solder process. He elaborates, "We noticed after the fact that the solder mask applied to one of the boards was misaligned. Despite this the Bead Probes had been formed correctly." The assumption is that the effect of surface tension tends to draw the solder to the trace even if the mask is misaligned slightly.

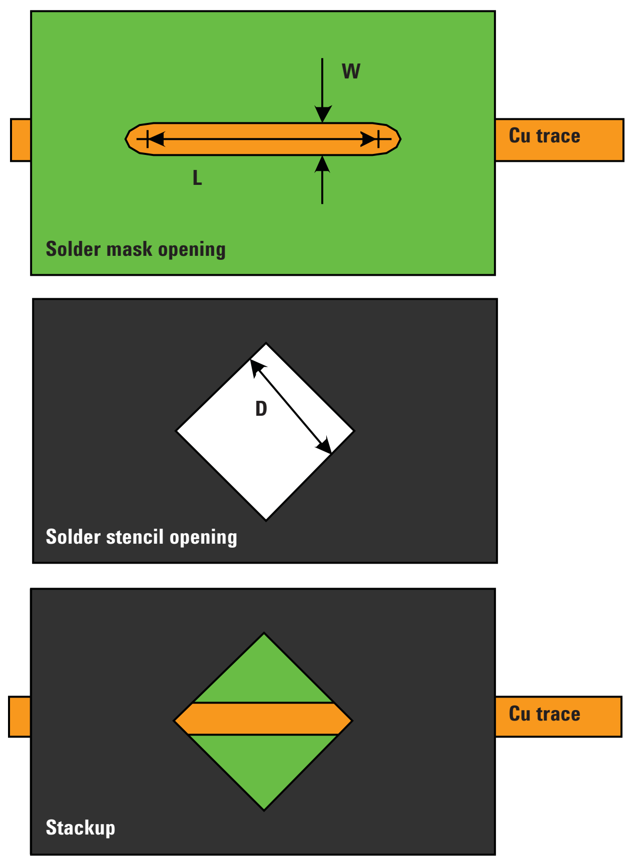

Figure 3. Board, mask, stencil stack-up

The Bead Probes have to be added to the layout of the board at the CAD stage. Bead Probes are built as CAD library elements to be placed either on the top or bottom of the board. They are similar to surface vias in their characteristics, however they differ in an important aspect. Vias have always been round so one library element can be used for all instances and there is no requirement to rotate them.

The Bead Probe in comparison is 'obround', and has a specified direction consistent with the direction of the trace. Library elements for standard Bead Probes had already been developed within the Prodrive's CAD system. Tim's team could very easily take these and apply them directly to their board.

When incorporating Bead Probe elements it is also essential to include targeting circles or 'keep out' areas that take account of the geometry of the flat head probe to be used. The aim is to ensure that the position of the Bead Probe does not include component bodies or device leads within the area. This avoids the possibility of the flat head probe hitting these higher profile elements rather than the Bead Probe. CAD tools can also be used for this.

Once these precautions are taken the addition of Bead Probes to a CAD layout is as straightforward as adding any other library element.

Since the concept of bead probing is no different from conventional bed-of-nails fixturing then the same design and production techniques can be used. There is a complication in that in most cases boards will use a mix of Bead Probes and conventional test pads. However, ultimately there is no reason why an entire board cannot be implemented with Bead Probes, which would eliminate this. In Prodrive's case Agilent constructed the bed of nails fixture using a combination of conventional and large flat head probes.

Tim mentions the reliability of the fixturing. Debug of the test program and fixture was conducted on a limited number of sample boards. As a result each of these was subjected to many activations of the fixture. The cycle counter recorded around 600 fixture activations in total, which implied 100 to 200 fixtures cycles per board. Throughout this the connectivity between the fixture and the board under test was maintained.

"The results that we achieved with the fixture were amazing", says Tim. "They bode very well for maintenance and repair where we could be testing boards that have been out in the field for a long time." One reason for these excellent results is believed to be the inherent nature of the Bead Probe approach. A needle probe is very aggressive and after just a few cycles can cause physical damage to the test pad. Indeed in extreme cases needle probes have been known to puncture the PCB itself. The flat head used with Bead Probes is not as aggressive. Although sufficient pressure has to be applied to break through any surface contaminants and this does cause a flattening of the top part of the bead (Figure 4) it does not result in the catastrophic damage that can be caused by conventional probing techniques.

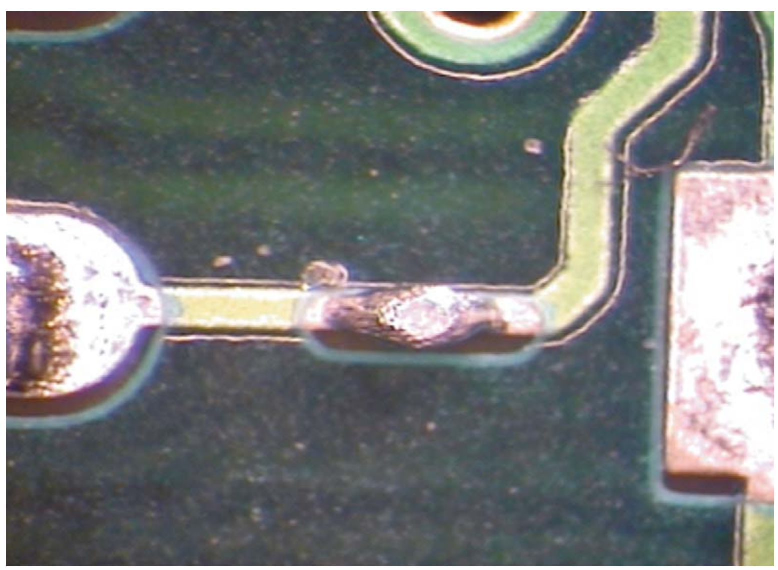

Figure 4. Flattening of top of bead

As a result of the project the decision was made to revise the test strategy used for the single board controller. End-of-line functional testing of the controller board no longer takes place. All structural and electrical testing now takes place in-line using the Agilent automated inspection and in-circuit test systems. Each of Prodrive's three production lines is now fully equipped with the suite of Agilent inspection systems and in-circuit testers. Environmental and functional testing continues to take place at sub-assembly stage.

The effect on test time reduction was very significant. The functional test of the controller board was taking 15 minutes. The in-circuit test took 90 seconds. As a result of this, over the next six to 12 months Prodrive anticipates that a further 60 boards will use its new in-circuit test philosophy.

Having led the successful project to optimise the testing of the controller board Tim is enthusiastic for the future of bead probing. "Bead probing gives us another option and releases our dependency on end-of-line functional testing of PCBs. We can now use in-circuit testing effectively on our most complex boards without incurring the overheads associated with conventional test pads."

The controller board used Bead Probes only where necessary. Where space allowed conventional test pads were used. However, Tim Koene sees this as a transitionary stage only. "In-circuit test can do so many things that functional test cannot, the issue has been access. Bead Probes can help solve this. The implementation of Bead Probe can be easily accommodated in our CAD, solder and test processes so why not use 100% Bead Probes?"

In-circuit test took the test world by storm in the mid 1970's and was the prevalent test methodology for two decades. The innovation of bead probing now looks set to turn the circle and make in-circuit test the test method of choice once again.

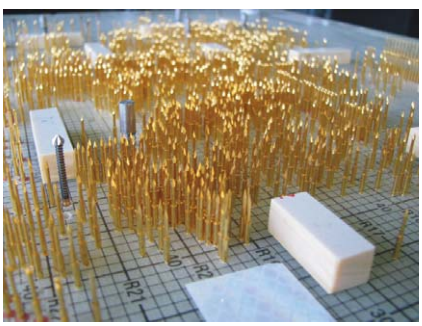

Figure 5. A sea of test probes

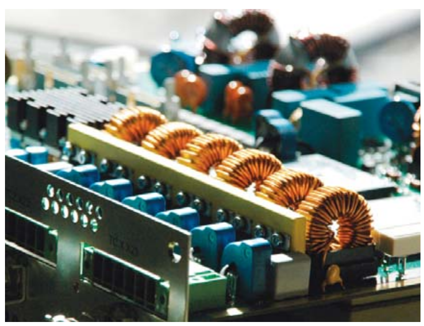

Figure 6. Prodrive managed to successfully implement Bead Probes as part of their in-circuit test strategy for complex electronics products.

Figure 7. Prodrive's manufacturing facility in Son, The Netherlands.

Conclusion

The in-circuit tester continues to be a strong tool for testing printed circuit boards during the manufacturing process. Even though the complexity of boards are increasing year over year, new technologies used at the in-circuit test stage help manufacturers keep up with the continued battle for test access. The Agilent *Medalist* Bead Probe Technology is one of the solutions that have been developed to enable continued access to complex PCBAs. This case study shows that Bead Probes can be inserted in new designs but also can be an important addition to existing designs helping the EMS industry to increase OEM design test coverage and therefore, product quality.

Cost efficiency drives new ways of looking at complex problems. Functional test has always been seen as viable solutions towards limited access but the cost for limited coverage and analysis at functional test is high. New technologies like Bead Probe Technology enable electronics manufacturers to re-look at their test strategy and make changes that decrease manufacturing cost and increase product quality.

References

[1] K. P. Parker and D. DeMille, "A Bead Probe CAD Strategy for In-Circuit Test", *Proceedings, International Test Conference,* Paper 18.2, Santa Clara CA, Oct 2007

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