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A Flexible Fixturing System for In-Circuit Test of High Node Count Circuit Boards

Rob Jukna – Jabil, Inc.
Harry Jin – Checksum

Abstract
Large printed wiring assemblies (PWB) exceeding 7000 circuit nets create significant quality, cycle time and cost issues at structural test in the new product introduction (NPI) phase. Traditional in-circuit test and its requirement for expensive bed-of-nails (BoN) fixtures impose high tooling costs and long cycle times. While flying probers (FP) do not require test fixtures, thereby reducing those cost and time impediments, testing large board imposes extremely long test time and lower test coverage. We describe a "Flexible Fixturing System" which overcomes the cost and tooling cycle times inherent with traditional BoN fixtures while simultaneously providing the high throughput rates and test coverage of traditional in-circuit testers. Moreover, this is accomplished at an attractive capital cost.

Introduction
The "Holy Grail" of printed wiring board (PWB) structural test is to provide the highest test coverage and product throughput while minimizing test application tooling cycle time and cost. Traditionally, the means to accomplish this is in-circuit test (ICT) and a test application set designed for the particular PWB being tested. A test application set includes a bed-of-nails (BoN) test fixture designed and built to contact specific test points contained within the artwork of the board, together with a test program to examine the components and interconnections on the board.

Nowhere is achieving these frequently conflicting objectives for structural test more challenging than during the new product introduction (NPI) process. Releasing a test application set to production on time and on budget with maximum test coverage can be a challenging task even for relatively straightforward boards of just one or two thousand circuit nodes. But for large boards—those with more than 7000 circuit nodes and physical sizes exceeding 18" X 24"—the test application development process advances from the merely challenging to the positively risky.

Because of its ability to pinpoint defects precisely, ICT would be the preferred means for structural test in the NPI process. As in the case of production test, the BoN test fixture required for ICT remains the single greatest obstacle to achieving cycle time and cost goals. A single bed-of-nails fixture for a large board to be used on a traditional ICT system such as those from Agilent or Teradyne may cost upwards of $60,000 and require a fixture design, build and verification time of four to six weeks. A single test fixture released to production is costly enough. But the NPI process for large boards may involve up to five distinct board design and layout iterations before it is finally released to volume production. PWB layout or artwork changes can be extensive such that the next iteration of the prototype or pilot board requires a completely new BoN fixture. This reality leads to profoundly negative cost consequences that in some cases can be as large as $150 thousand dollars. Further, because of the BoN design, build and verification cycle, each new fixture may require four to six weeks to turn around. Multiply this cost and time by two, three, four or five and it is plain to see why a strategy using traditional ICT and its attendant BoN fixture becomes untenable.

The obvious first solution is to reduce fixture cost and delivery time. BoN fixture engineering and fabrication is a serial process involving numerous steps from CAD data import to drilling, loading probes, wiring, verifying proper wiring and documentation. Attempts to wring meaningful cost and time reduction out of what is effectively a custom product has defied the best efforts of many fixture and automatic test equipment vendors over the past thirty years. One solution that had appeared promising and was particularly applicable to large node count boards were wireless fixtures, which use a circuit board rather than hand wiring. However, they are really only cost effective when multiple identical fixtures are required. Production volumes of large boards are usually not great enough to require more than one fixture, thus negating the economics for wireless fixtures.

At this point the solution to excessive fixture cost and cycle times was to eliminate the bed-of-nails fixture altogether. Flying Probers (FP) appear to hold precisely that promise: adequate test coverage without the bother and expense of fixtures.

The Promise and Peril of Flying Probers
The goal of eliminating the recurring hardware cost of the fixtures, along with their lengthy delivery time suggests that the fixtureless test environment of a flying prober would be ideal for the NPI environment. Effectively, once the PWB is available for testing it can be placed immediately in the flying prober, requiring only test program development. Once this step that consumes about a day is complete, the boards would be ready to be tested. Most EMS providers have implemented a test strategy for NPI that use flying probers rather than traditional ICT.

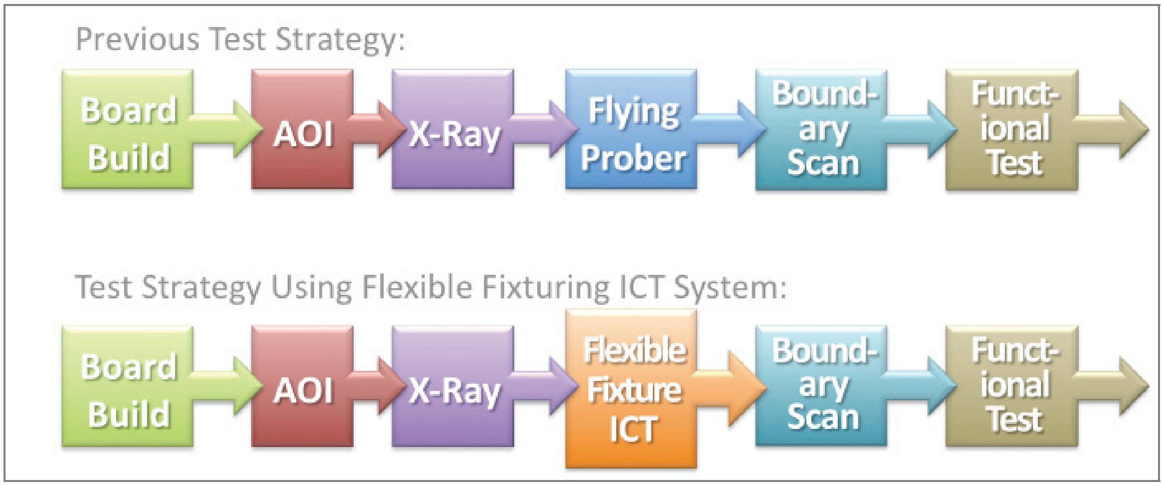

Figure 1: Evolution of the NPI Structural Test Strategy

However, the FP imposes significant limitations on NPI structural test strategy. The first limitation is reduced test resources compared to ICT: typically there are only two stimulus/measurement probes are available to "fly" to different areas of the PWB to perform 2-wire measurements. As well, there are four to six fixed probes for power and ground or developer-defined uses. The time required to execute a single test step, excluding handling time, consists of travel time for the probes to reach the designated pad on the board plus actual measurement time. Because travel time is mechanical, it is an order of magnitude slower than measurement time. In short, test step time is determined by mechanical travel time. Of course, ICT consists only of measurement time, so its overall test execution time for the sale set of test steps will be much faster. This reality becomes painfully obvious when testing large boards. One large board of approximately 7000 nodes, which took five-minutes to test on a traditional ICT, required three and one half hours to be tested on the flying prober. This meant that for a typical NPI production run of twenty boards, the total test time would have exceeded 70 hours, assuming perfect boards and no retest requirements.

Second, FP systems, being limited to two-wire measurements that, in general, are extremely difficult to be guarded, also suffer from lower test coverage than the same tests conducted on an ICT. Moreover, FP systems cannot check for shorts from one node to all other nodes simultaneously, requiring far more time-consuming shorts and continuity algorithms to identify interconnection failures. Finally, vectorless test (TestJet) cannot be used to identify opens around semiconductor packages.

Third, flying prober test program debug and validation proved to be arduous and time consuming. Physically large boards are subject to non-linear physical distortions caused by the PWB manufacturing process. These distortions are often sufficiently large that the test pad will no longer lie within the intended targeted position. Probe misses invariably result in the necessity for lengthy manual examination to determine the root cause of the problem—a tricky task where PWB expansion and contraction is involved. This situation in turn requires restarting the entire test validation step, which at up to three and a half hours means frustratingly long debugging sessions.

In the end, we found that the cost savings created by eliminating BoN fixtures were essentially offset by the added expense of lengthier test times, protracted test program validation times and reduced test coverage. This reality caused us to seek a more amenable solution that could combine the test coverage and test times of traditional ICT with the reduced development cycle times and lower variable cost promised by the flying prober. After searching the market for possible candidates and finding none, we decided to develop a solution in house.

Development Goals

Vendors of in-circuit testers have long recognized the cycle time and cost shortcomings of BoN fixtures. Through the years there has been much discussion and even occasional attempts at developing so-called universal fixtures, which would overcome these limitations. Ideally, a universal fixture would accommodate a wide variety PWB types while minimizing the customization that characterizes BoN fixtures. But the problem has really never been solved by commercial ATE vendors; hence our present dilemma. Our goals were less ambitious. We did not seek universality but flexibility instead. And even then, flexibility that was focused on the issues associated with in-circuit test of large boards in the NPI process. We established a list of design goals that are shown in Table 1:

Table 1: Flexible Fixture Design Goals

- Achieve test coverage at least the same as traditional analog only ICT.
- Reduce fixture cost at least 50% compared to a traditional wired BoN fixture.
- Reduce fixture design and build cycle time by at least 60%.
- ICT to handle boards with more than 10,000 test points.
- Reduce ICT capital cost by at least 20% compared to traditional ICT.

Results

Designed at Jabil Florida our development efforts over the period of about a year resulted in the Flexible Fixture System. It meets all of the design goals we laid out. The most significant project objective was obtain the advantages of a bed of nails fixture while eliminating the time and expense of custom wiring, which is the primary element of traditional BoN cost and tooling time. We replaced wiring with a pre-fabricated board that employs a standardized grid arrangement of test pads that are, in turn, connected to a common tester interface.

This system also eliminates the need for expensive custom-designed circuit boards that are required in a traditional wireless fixture. Software analyzes the existing test point locations and calculates the best possible positional alignment to the standardized grid arrangement. The current design of the Flexible Fixturing system can handle boards with up to 14,400 test points, although we envision future systems that will exceed 20,000 test points.

Figure 2: The Flexible Fixture System

Besides significantly reducing cost the other major benefit of eliminating fixture wiring is slash fixture design and build cycle time. The simplified fixture used in the flexible fixture system is designed and drilled based on the board's test point configuration. There is no theoretical upper limit on the number of test points that can be accommodated with this approach. While there is no wiring required for standard power-off in-circuit measurements, vectorless test sensors can be wired in as required. This new design approach resulted in fixture design and build together of five to seven days, including test program development. This is a reduction approaching 75 percent over the average fixture design and build cycle that averaged five weeks (25 days) for a traditional hand-wired BoN fixture. The fixture and test development process we now use is shown in Figure 3.

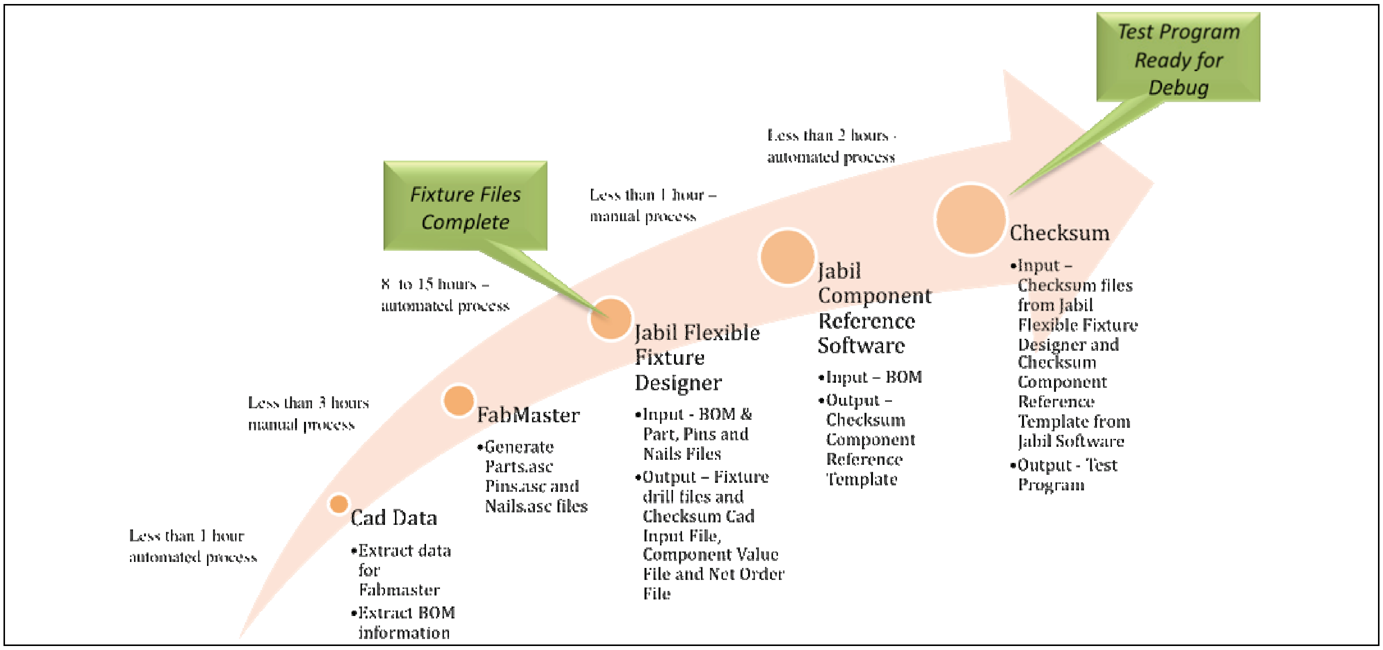

Figure 3: The Flexible Fixture system development process for fixture and test program

Cost reduction results have been equally impressive, with an estimated savings of exceeding 50% for a five thousand pin fixture compared to equivalent wired or wireless BoN fixtures that would be used on an Agilent 3070-series tester, as illustrated below in Figure 4. We estimate the savings would approach 60% over an equally sized BoN fixture for a Teradyne 2287L.

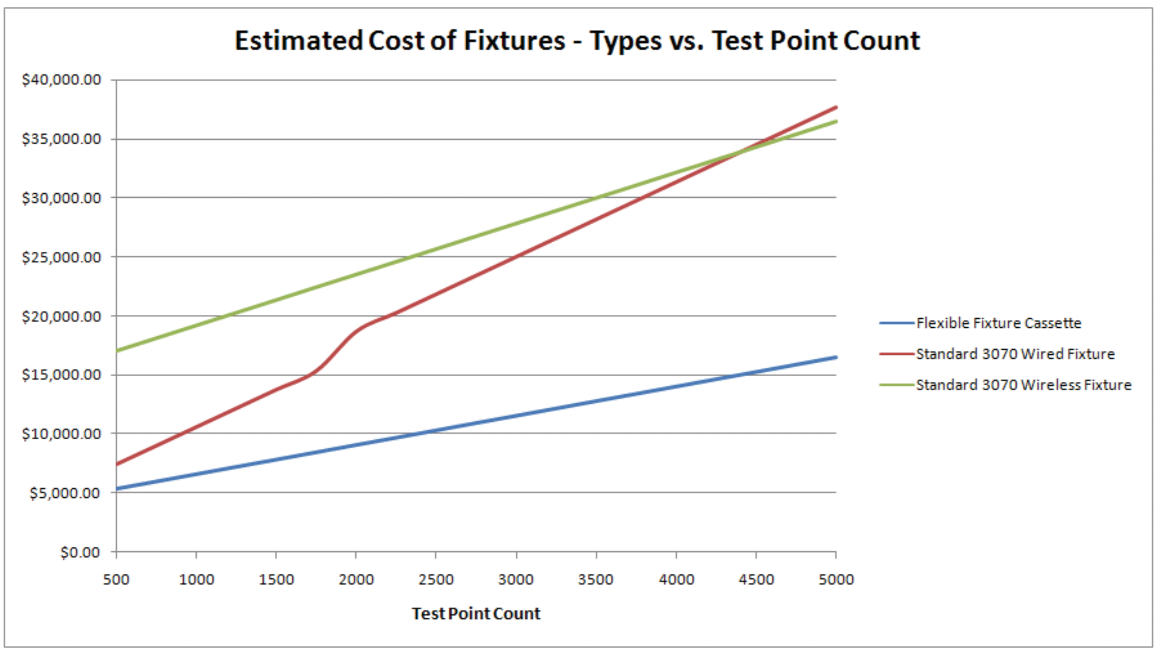

Figure 4: Estimated Cost Savings for the Flexible Fixture system compared to fixtures used on an Agilent 3070-series system.

In addition to cost and cycle time savings, we were able to meet the goals of the third arm of the "tester Holy Grail:" achieving equivalent test coverage for interconnect, power-off analog and vectorless tests with this system compared to traditional ICT. Table 2 lists the in-circuit tests we are able to conduct using the Flexible Fixture system.

Table 2: In-Circuit tests performed by the Flexible Fixture System

Interconnection (Shorts/Opens)	
Resistors	Capacitors
Transistors	Inductors
Diodes	Zeners
LEDs	Opto-Isolators
Relays	Transformers
IC Presence/ Orientation	Vectorless (TestJet)

The Flexible Fixture system also met our throughput goals. We are once again able to benefit from the fast test throughput times associated with in-circuit test. For one large PWB, the flying prober required a test time exceeding 90 minutes. The test time for the same board on the Flexible Fixture System required just slightly less than seven and one half minutes, more than a ten-fold improvement in test throughput.

In-Circuit Test Subsystem

Because of its high point count, the Flexible Fixture System cannot be mated with a traditional ICT system. We went to the marketplace seeking what in essence was a greatly expandable in-circuit measurement and switching subsystem, including its own operating software. We chose a Checksum Analyst low-cost in-circuit test system as the "test engine" used in the Flexible Fixture system. This rack-mounted system met our design goals by offering the essentially unlimited test point expansion capability we needed at a reasonable capital cost. While the tester electronics can perform the power-off and power-on modes of typical general-purpose in-circuit testers our test strategy required only its interconnection, analog power-off and vectorless test modes. The in-circuit measurement and switching subsystem is mounted in a separate bay, which is connected to Flexible Fixture hardware via ribbon cable. Software provided by the in-circuit system vendor offsets residual resistance and capacitance of the ribbon cable and fixture assembly.

The in-circuit subsystem met our goal of significantly reducing capital cost compared to traditional ICT. An Agilent 3070-series tester equipped with a 5100-point capacity costs in excess of $300,000, roughly $60 per test point. A Teradyne 2287L equipped for 7000 test points costs around $750,000, about $107 per test point. The complete Checksum subsystem cost around $230,000 for its 14,400-point capability, or about $16 per test point. On a test point basis we were able to reduce capital costs by more than 70 percent compared to the Agilent system. In fact, the capital cost of the low-cost in-circuit tester even came in at less than the flying prober's $280,000 cost.

Conclusion

Notwithstanding numerous predictions over the years of its imminent demise, in-circuit bed-of-nails structural test still remains the best means of achieving the "Holy Grail" mix of cost, time and quality than any alternative structural test method for PWBs. We have proved this truism again with the Flexible Fixture System, albeit with several significant changes compared to traditional ICT and traditional custom-wired BoN fixtures.

We accomplished this by being able to abandon both traditional wired and wireless fixtures, which have proven inefficient at best an inappropriate at worst in the large board new product release process. We have been able to demonstrate with actual boards in an actual NPI process that the Flexible Fixture System is a fresh approach to the in-circuit paradigm.
First, we have achieved the promise of radically reduced fixture costs for the NPI process without the time and coverage shortcomings of flying probers.

Second, we have dramatically reduced fixture and test program development and verification cycle time compared to both traditional ICT and flying probers by steering a "third course" between the expense and tooling time of traditional BoN fixtures and the lengthy test times and inadequate test coverage of fixtureless test.

Third, we have achieved power-off test coverage equal to—and in some cases—exceeding that of traditional ICT at far lower cost and substantially less fixture development time.

So, even as other test organizations try to write yet another obituary for in-circuit test, creative thinking and adroit execution by Jabil and its in-circuit test electronics and software partner has again pushed the boundaries of technical feasibility and compelling economics to enable manufacturers to again produce and structurally test extremely large and complex PWBs at higher coverage on time and on budget.