A Whitepaper:

Boundary scan helps EMS companies cut test costs and increase revenues

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Richardson, Texas

Facing challenges at every turn

More and more original equipment manufacturers (OEMs) are turning to electronic manufacturing services (EMS) providers rather than making large investments in capital equipment and on-staff personnel training to set up their own manufacturing capabilities. This presents tremendous opportunities for skilled manufacturing firms, but the demands that OEMs place on EMS suppliers can be very challenging indeed.

Profit margins for EMS companies are often razor thin. And, in order to keep up with the hyper-pace of today's ever changing electronics marketplace, the production schedules that EMS firms must maintain are very demanding, sometimes unreasonably so. OEMs challenge their EMS suppliers to manage a complex process with extreme time pressures and still maintain a high level of product quality and workmanship.

OEMs depend on EMS companies to rapidly deploy their manufacturing strategies and shorten their time-to-market. To accomplish this, the EMS firm must maintain a high degree of flexibility in its processes. And, in the case of a global OEM, the EMS supplier must be able to repeat a high-quality, high-yield manufacturing process across multiple manufacturing plants located in the far corners of the globe.

Despite the constant demands of its customers, the successful EMS firm does not lose sight of its need to earn a profit through productive operations and, furthermore, to continually grow its business. For a service company, this often means making a concerted effort to differentiate itself and its services from its competitors as well as continually seeking new services to offer its customers and prospects.

Getting the Most from Test Technologies

The overriding goals of electronic test are maximum test coverage for minimum test cost. This will lead the EMS provider to examine all test technologies, including boundary scan, in-circuit test (ICT), automated optical inspection (AOI) and automated x-ray inspection (AXI), and to compare all of the various capabilities that each technology has to offer. Ultimately, the test strategy for each printed circuit board is unique, but the EMS firm that can deploy the right combination of these varied test technologies so as to maximize test coverage and minimize test cost will certainly enjoy a competitive advantage in the market and earn the respect of its customers.

Boundary scan (IEEE 1149.1/JTAG) features a set of electronic test and in-system programming capabilities that no other technology provides. Boundary scan doesn't need the physical access required by the probes and fixtures of ICT equipment, and yet it provides actual verification and diagnosis of physical connections that cannot be provided by technologies like AOI or AXI.

A discussion of the benefits of each test technology is beyond the scope of this document. Rather, following a short introduction to boundary scan technology, the remainder of this white paper will describe some of the many benefits that boundary scan holds for EMS firms at every stage in a product's life cycle, including the following:

- High-volume manufacturing
- High-mix manufacturing
- Functional test
- Field test

Some of the many benefits of boundary scan for EMS firms include:

- Lower test costs
- Improved manufacturing yields
- Better test coverage and product quality
- Faster time-to-market
- Increased revenues with boundary-scan test services
- Rapid return on investment in boundary-scan capabilities
- Greater manufacturing efficiencies

Boundary Scan: What Is It?

Boundary scan test techniques were first discussed in the late 1980s. At the time, experts believed that the move to surface-mount packaging would have a serious effect on an ICT system's ability to place a nail accurately on a test pad. In addition, the development of multi-layer boards compounded the problem of physical access for testing interconnects between devices on a PCB. Basically, many in the test industry predicted (mistakenly as it turns out) that the ability to physically probe the board with a bed-of-nails system would soon disappear.

As a result, a group of concerned test engineers banded together to address this problem. The group was called the Joint Test Action Group (JTAG). Its preferred solution was to access device pins by means of an internal serial shift register around the boundary of the device. In a boundary-scan device, each primary digital input signal and primary output signal is supplemented with a multi-purpose memory element called a boundary-scan cell. The collection of boundary scan cells on a board can be configured in various ways to achieve a parallel-in, parallel-out shift register that is used for testing and for on-board programming purposes.

At the device level, the boundary-scan elements contribute nothing to the functionality of the device. The boundary-scan path is independent of the function of any device or the board itself, but the scan path does provide virtual access to devices for test and programming. In fact, boundary-scan interconnect tests will verify the presence, orientation and correct bonding of devices -- the identical functionality that is provided by ICT but without the physical access needed by ICT. Essentially, boundary-scan cells

can be thought of as a set of virtual nails with the ability to set up and apply tests across the interconnect structures on a board.

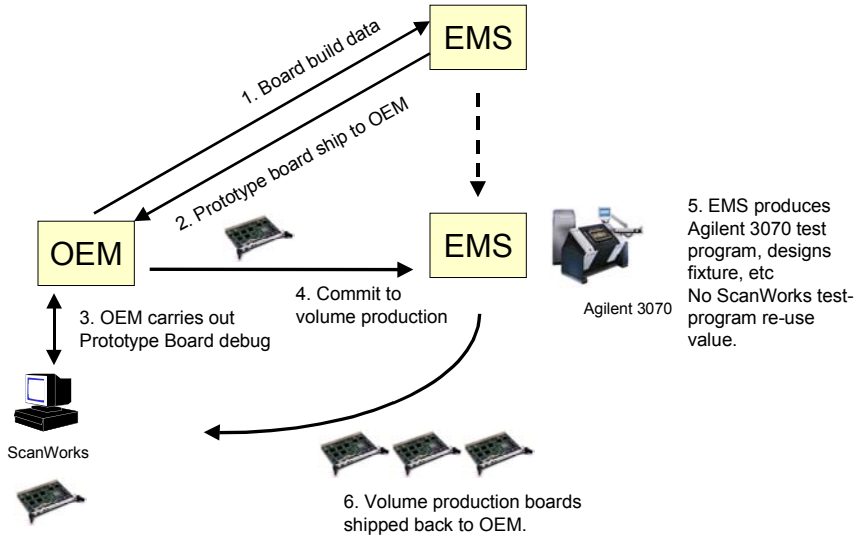
More and more manufacturers are finding that boundary scan can reduce costs and increase test and manufacturing efficiencies.

Boundary Scan in High-Volume Manufacturing

Before an EMS firm becomes involved with an OEM's product, boundary scan often is used by the OEM during the development phase to test prototype boards manufactured by the EMS provider. The OEM's development groups generate boundary scan tests to verify the structural integrity of prototype boards. Boundary scan also is used often to load software and firmware into flash and CPLDs that have already been soldered in place on the prototypes.

The most prevalent scenario among EMS firms today (Scenario 1 below) has the manufacturing company using ICT systems as a mainstay of its production test strategies.

Scenario 1. EMS test strategy based on using Agilent 3070 ICT systems only

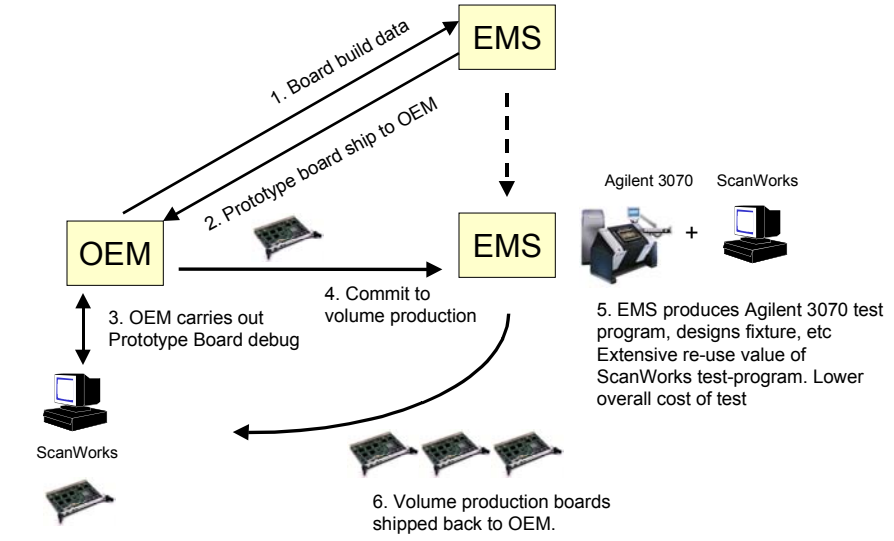


In this scenario, the OEM develops the prototype board debug test program on a standalone boundary scan system such as a ScanWorks Test Development Station from ASSET InterTech, but there is no test re-use value for the EMS firm because it has not deployed boundary scan test techniques in its high-volume manufacturing line, opting to rely solely on ICT systems. Until very recently when ASSET ScanWorks system was integrated into the Agilent 3070 series of ICT systems, most ICT systems had boundary scan tools, but they were unable to leverage the boundary scan tests that had been

generated for prototypes. If the EMS firm chose to implement boundary-scan test on its ICT systems, it often was replicating the test development work done by the OEM on standalone boundary scan test stations. EMS company can increase its productivity significantly and decrease its manufacturing costs if a seamless flow of boundary scan tests can be established from prototype development to volume manufacturing, eliminating any duplication of test development efforts. The increased test coverage that boundary scan offers will also increase the quality of the manufactured product and the yield of the manufacturing process.

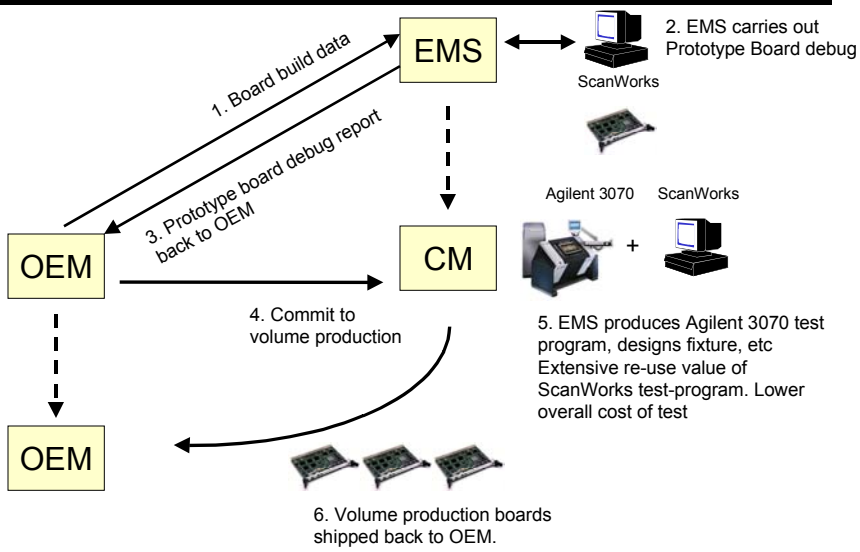
Another option to EMS companies is to integrate boundary scan and ICT, as ASSET and Agilent Technologies have accomplished with the ScanWorks/3070 solution (Scenario 2 below). Not only does the EMS firm reduce the OEM's time-to-market by saving valuable test development time by re-using the OEM's prototype board test developed on a ScanWorks station, but it also overcomes the physical access limitations of ICT and gains considerably in defect coverage. In addition, the cost of ICT fixturing is significantly reduced because the number of test points and associated wiring per fixture is reduced. Reducing the number of test points per board, reduces the number of test probes per ICT fixture. And because test probes simply wear out from repeated use, ICT fixtures require maintenance. Therefore, decreasing the number of test probes per fixture will reduce an EMS company's ICT fixture maintenance costs. Some manufacturers have estimated that fixture maintenance costs over the life of a fixture can run as much as 10 to 20 percent of the fixture's cost. For complex fixtures that easily cost upwards to $40,000, reducing fixture maintenance provides a significant cost savings.

Scenario 2. EMS test strategy based on Agilent 3070 and ASSET ScanWorks



Another scenario involves an expansion of the EMS firm's business and service offering. In this case, the EMS provider has taken responsibility for the OEM's prototype debug program (Scenario 3 below). Using a standalone boundary scan system running on a PC, the EMS firm creates and applies the debug tests it has developed. It is then able to make immediate changes to the manufacturing process based on correctly diagnosing any defects on the prototype. This increases the manufacturer's yield and opens up a new business area, contract test programming. Another option, should the EMS firm not have the trained personnel needed to begin this new service offering immediately on its own, would be to partner with a third-party test development company. This gives the EMS firm the flexibility to test out a new business model while avoiding the fixed personnel costs that would be needed to deploy the service offering on its own. In support of this business model, ASSET InterTech has developed its Partner Provider program of third-party test development firms. For more information on this program, visit ASSET's web site at www.asset-intertech.com.

Scenario 3. EMS test strategy based on Agilent 3070 and ScanWorks (EMS owns ScanWorks.)

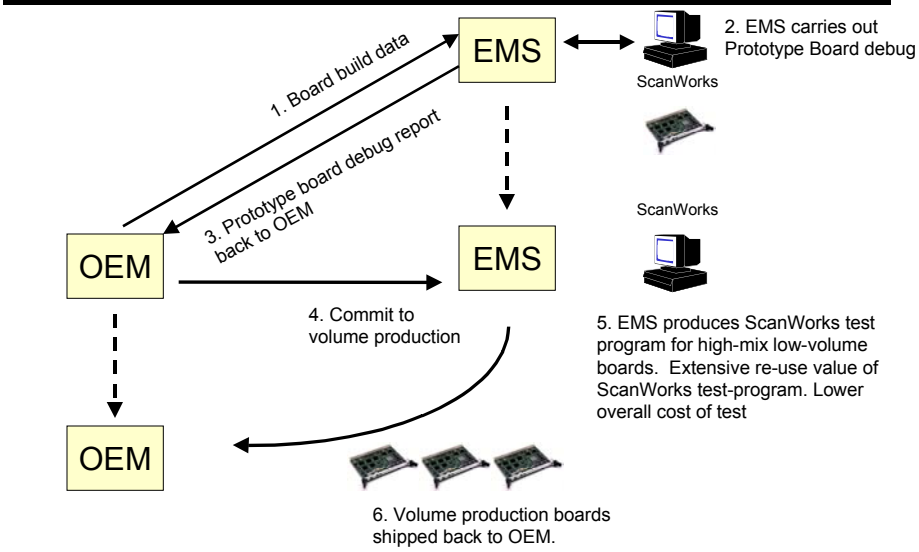


Boundary Scan in a High-Mix Manufacturing Environment

In a high-mix manufacturing environment, or an environment where a wide variety of boards are being manufactured in rapid succession, EMS companies must be able to rapidly alter the test strategies, processes and procedures as different boards come down the production line. For example, if a particular manufacturing line were expected to produce several different types of boards over the course of a day, delaying the implementation of a test suite for any one board for a prolonged period of time would be unacceptable. In this regard, the time required to change test fixtures and load new test software on ICT systems is closely scrutinized.

Boundary-scan technology presents three beneficial alternatives to the EMS firm that is coping with a high-mix manufacturing environment. One alternative would be for the EMS company to invest in boundary scan technology and use it exclusively to perform manufacturing tests (Scenario 4 below). A second option would be to combine boundary scan with a flying probe station. This alternative can reduce test time spent on the flying probe because boundary scan will test many of the nets on the board. A flying probe/boundary scan test station also provides an easy way to power up the board for boundary scan testing. And lastly, test diagnostics will be improved since the results of boundary scan routines can be shared with the flying probe tester and vise versa.

Scenario 4. EMS test strategy based on ScanWorks (EMS owns ScanWorks.)



The third alternative for the EMS firm would be to combine boundary scan and ICT test systems. This would ensure high throughput in manufacturing and, by using boundary scan to maximize test coverage, the number of test points needed by the ICT test fixture would be reduced, lowering the complexity of the test fixture and slashing its cost.

Boundary Scan in Functional Test

Following assembly and manufacturing, printed circuit boards move into functional test where a key benefit of boundary scan is the re-use of tests for sub-assembly and backplane testing. These types of structural tests cannot be done on an ICT system because it is limited to only board test. But any boundary scan tests developed during prototype development for sub-assemblies or backplanes can be re-used at functional test even though they were not used at ICT test.

The flexibility that boundary scan gives manufacturers to re-program CPLDs, FPGAs, and flash memory is another benefit that EMS companies can take advantage of during

functional test. Many firms develop low-level functional diagnostic code that is loaded into programmable devices only to be replaced later replaced with operational software. Boundary scan simplifies this task significantly.

Another key benefit of boundary scan at functional test is its ability to identify certain manufacturing defects that may have been masked during other phases of the manufacturing process. For example, the vacuum pressure exerted by ICT test fixtures in manufacturing test can sometimes mask open-circuit structural faults. These failures can go unnoticed until the board reaches functional test where a simple boundary-scan test with pin-level diagnostics can save test engineers significant time and effort diagnosing the problem. In fact, boundary scan's excellent diagnostic capabilities can utilize layout and schematic data to pinpoint faults down to the pin level, drastically reducing the time and effort typically expended troubleshooting faults in functional test.

Another potential cause of failures on boards that have passed ICT test are the failures that are sometimes introduced by physically handling the boards. Applying previously generated boundary scan tests during functional test identifies these faults and eliminates the need to re-test a board on an ICT system.

Also during functional test, boundary scan can support microprocessor or DSP debug via emulation techniques. In general, emulation is based on an external controller such as a PC, which takes control of an on-board microprocessor (or DSP) and monitors what happens when the microprocessor executes certain instructions. In particular, the external emulator allows the functional test engineer to do the following:

- access historical instruction trace information to determine what happened and when it happened;
- retrieve information on data flow and understand which system resources created and accessed data; and
- assess whether embedded software is meeting the required performance criteria.

Emulation, sometimes called in-circuit emulation (ICE), has been used for years to test the functionality of processor-based boards. In the past, microprocessors usually were accessed either by a device clip-over or by removing the processor and inserting an umbilical cord into the device socket. Now though, access to the microprocessor is often achieved more simply through the microprocessor's serial boundary-scan port and special instructions which gain access to internal registers. This use of the boundary scan interface was pioneered by companies such as AMD and MIPS and is sometimes called extended JTAG (eJTAG). The external PC takes control of the on-board microprocessor and provides real-time run control to:

- query and modify all internal register and memory locations
- support hardware or software breakpoint or watch-point features
- provide memory substitution (memory emulation)

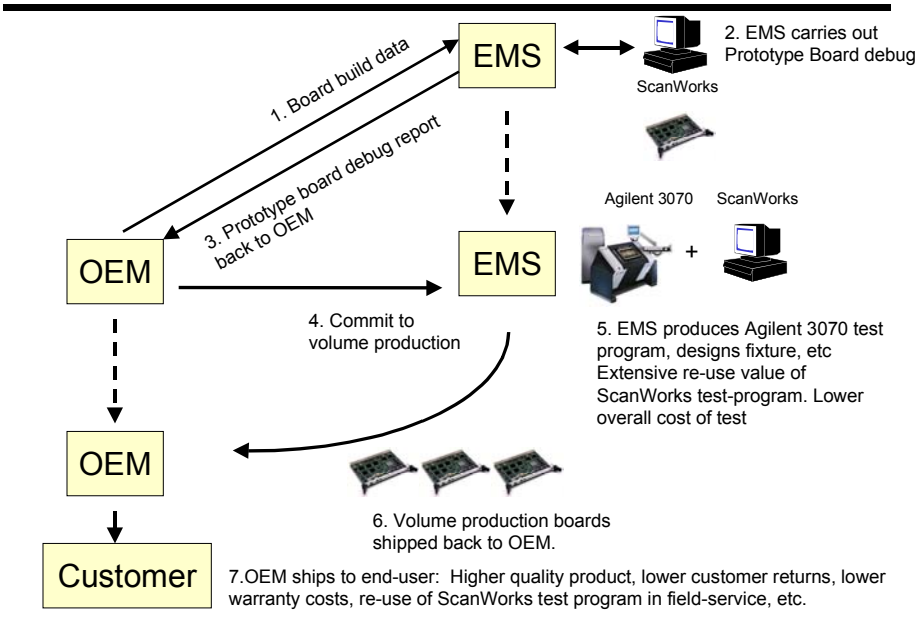
Boundary Scan in Field Service

Completing the product life-cycle, boundary scan tests can become an integral part of a test suite used in the field once systems have been installed. The same or slightly modified tests that were generated at the beginning of product development can be deployed as part of preventive maintenance routines or as another tool which technicians can use for troubleshooting purposes.

In addition, boundary scan can be used to program or re-program a product that has reached the market. After systems have been introduced, software sometimes is modified to enhance the product. Engineering change orders (ECOs) are issued and software in the field must be replaced, supplemented or enhanced. Boundary scan's ability to program devices in-system or on-board simplifies this process immensely.

Scenario 5 shows a scenario where the boundary scan tests first developed on a ScanWorks Test Station for prototype debug are subsequently re-used in volume manufacturing, functional test and field service. Re-using boundary scan throughout a product's lifecycle provides significant benefits to the OEM's customers in terms of higher quality products. And the OEM and EMS company will experience lower field returns and warranty costs. In addition, the original ScanWorks boundary scan tests can be used as part of a system test suite, assuming a suitable backplane test bus and test bus master have been implemented.

Scenario 5. Bigger picture: Benefits to the OEM's customers



In addition, field service could expand the business opportunities for enterprising EMS firms. The EMS company could capitalize on the expertise it has built up by continually testing a system throughout development and manufacturing, and contract with the OEM

to perform field service on the system. Or, if the OEM prefers to retain control over field service, the EMS firm could sell or license its boundary scan test suite for use by the OEM's field service personnel.

Rapid Boundary Scan ROI

Calculating a definitive return-on-investment (ROI) figure for boundary scan is notoriously difficult because the technology can affect so many aspects of an EMS firm's business and so many phases of a product's life cycle. In addition, each EMS company will deploy boundary scan differently. Some will make the most of the technology, while others, for whatever reason, will only derive some of the benefits the technology has to offer. Assuming an optimum deployment of boundary scan, the following are some important aspects of boundary scan's ROI.

- Time-to-Market

In highly competitive markets, time-to-market is a matter of survival. When the EMS firm can reduce the time it takes to test an OEM's products, the OEM will not only be very satisfied with the work of the EMS, but it will probably ask the EMS to shoulder more responsibility for test. Boundary scan can reduce a system's time-to-market during every phase of the life-cycle, beginning with prototype test and continuing in manufacturing, functional and environmental test.

A prominent OEM user of ASSET's ScanWorks boundary-scan test system, Cisco Systems, found that boundary scan helps it get to market faster by shortening removing many of the bumps in its design cycle.

> *"During the prototype process, board design is not stable enough to warrant fixturing for in-circuit test…Board design is also not stable enough in functionality and operation for a designer to understand whether a non-working board is due to a design fault or a bad build. With boundary scan, our design engineers get higher yields, boards come up faster, the design cycle goes more smoothly and is therefore less costly." -- Manager of Embedded Test Technology at Cisco Systems, as quoted in EP&P Magazine, July 2002.*

- Generating New Business

Because of the relative low cost of boundary scan test systems vis-a-vis ICT test systems, any new test business that the EMS firm receives will very quickly surpass the firm's investment in boundary scan test equipment.

Navini Networks, an OEM user of ASSET's ScanWorks, found that the low investment in ScanWorks was quickly recouped when its test coverage shot up from less than 50 percent to over 90 percent.

> *"Functional tests would give us a list of faults that might be causing the problem, but it still took a lot of time to investigate all of those possibilities. With ScanWorks and its Memory Interconnect Test capabilities we knew exactly where the fault was. That saves us a lot of time and effort," said Michael Hinz, digital hardware design engineer at Navini Networks. Hinz estimated that ScanWorks paid for itself after testing 10 to 20 boards.*

- Prototype Testing

During the prototype phase, designs typically are not stable enough for the OEM to invest in ICT fixtures, but if the manufacturer can perform boundary-scan tests and verify the structural integrity of the design, the OEM's prototype engineers will be able to bring up boards faster, with higher yields and at less cost. Again, this is a new business opportunity for many EMS companies.

One OEM user of ASSET's ScanWorks found that, much to the delight of the firm's design group, boundary scan reduced the time of prototype test significantly.

> *Rick Harper, senior test engineer at Vivace Networks said: "ScanWorks helps us bring up tests very quickly so that the design engineers don't have to wait long to see how a new design is going to function. ScanWorks has shaved as much as three or four weeks off of the prototype verification process for each board. This has really won over the design group."*

- Volume Production Testing

Since many EMS companies already have ICT test systems, complementing ICT with boundary-scan test will increase test coverage, reduce the cost of ICT fixtures because fewer test points will be needed as a result of boundary scan taking on more of the test load, and improve the overall quality and yield of the EMS firm's manufactured boards. Increased customer satisfaction can lead to increased business. Boundary scan in manufacturing test can reduce costs and increase the throughput of the EMS company's production lines. When this happens, the ROI on boundary scan is short indeed.

> *Vivace Networks' director of manufacturing engineering, Dan Howley, found huge cost savings by eliminating ICT test points. "We started to sort through our designs to identify everything that could be tested by boundary scan and we discovered that we would be able to eliminate more than two-thirds of all the test points on our typical boards," Howley said. "And if you compare the cost of producing an ICT test fixture with all of the possible test points and the cost of a fixture with two-thirds fewer test points, you'd see that the cost difference is very significant. You save approximately $40,000 to $60,000 per fixture."*

In another instance, an EMS firm, SMT Unlimited L. P., found that the complementary nature of boundary scan and ICT are needed to ensure high yields from its manufacturing line.

> *"We use ICT equipment extensively, but for some boards, we just don't have the access that an ICT system needs," Hom-Ming Chang, Vice President of Test Engineering and Information Systems for SMT explained. "That's when we turn to boundary scan. We use ICT and boundary scan as complements to each other and that has worked very well for us." SMT used boundary scan on several very densely populated boards and its manufacturing yields have increased significantly.*

- Functional Test

Catching ICT escapes with boundary scan will reduce the time spent in functional test because diagnosing a structural failure with boundary scan prior to functional test is much easier than after functional tests have been applied to the board. Motherboard/daughtercard assemblies also can be tested with boundary scan for structural faults before they reach functional test. In addition, accessing on-board processors for emulation purposes through boundary scan reduces the time boards spend in functional test and lowers the possibility of introducing faults from the added physical handling that other methods of processor access require.

In addition, the diagnostic abilities of boundary-scan test environments can quickly isolate faults down to the level of a particular pin. For troubleshooting a board in functional test, engineers can use the design's layout and schematic data to isolate and quickly resolve problems.

This increased quality and shorter time-to-test creates good will with OEMs and the EMS firm is perceived as responsive to the needs of its customers. By streamlining the functional test process, the EMS will deliver product to its OEMs faster and generate revenues sooner. In the end, using boundary scan in functional test will shorten the ROI considerably.

An OEM customer of ASSET, ADC Telecom, recently required that its EMS firm test its boards with ScanWorks. The results have been soaring yields in ADC's functional test area.

> *"In the past, we would frequently receive boards and expect to have multiple problems on each board to troubleshoot and fix," John Howard, Manufacturing Test Manager at ADC, explained. "Now, we often don't have a single problem on a board because the contract manufacturer has already tested them with (boundary scan) test programs generated by (ASSET's service division) Ensure DFT. Using Ensure DFT to advise us and generate our tests and using the ASSET boundary-scan test system to run the tests at our contractor has reduced the number of variables we*

have to deal with. And that has simplified our lives significantly." ADC's yields at functional test rose from a range of 10 to 60 percent before boundary scan was implemented by its EMS firm to over 90 percent on a recent lot of manufactured boards.

- Environmental

Boundary scan can be used in environmental test chambers to perform tests that were not possible before. Typically, environmental chambers are small and the units under test (UUT) are subjected to large swings in temperature and voltage. A boundary scan system outside the test chamber can be connected via data cables to the boards undergoing environmental test. In this way, test technicians can monitor the UUTs and capture important information at the time of failure. This kind of environmental test procedure can reduce the diagnostic time required to determine the cause of failures, accelerating fixes and delivering higher quality product to the market sooner. Higher quality and more reliable boards will generate more business for the OEM, and shorter environmental test cycles will bring product to market faster. These factors yield a rapid ROI on boundary scan capabilities.

- Field Service

For EMS firms involved in field service, boundary scan tests can be quite useful. Many of the same boundary scan test programs that the EMS firm developed for prototype and manufacturing test can be re-used in the field as a critical part of a troubleshooting suite. The additional revenue generated from field service will accelerate the EMS firm's ROI on its boundary scan expenditures.

Ericsson first deployed ASSET's ScanWorks by combining boundary-scan interconnect test with functional test. Since then, the company has implemented a ScanWorks manufacturing station in its repair center to diagnose and troubleshoot boards that have been returned from the field.

"The ASSET software is just superior. And the graphical user interface lets us support our remote functional test and production test operations with minimal effort and training," said Samuel Messian, test manager and senior test engineer for Ericsson.

Other Potential Cost Savings for the EMS Firm

EMS suppliers can expect to accrue other various cost savings from boundary scan test and in-system programming. These include the following:

- More efficient engineering change orders (ECO)

An ECO typically is easier and less costly to carry out when it pertains to a boundary-scan chain on a PCB as opposed to an area of the board that is tested by ICT. If the ECO

effects a change in an ICT fixture with many probes, changing the configuration of the mass of wires in the fixture can be very time consuming and costly. If the ECO calls for a change on a boundary-scan chain, this will have little effect on the ICT fixture as long as the probes for boundary scan's test access port (TAP) are not affected. In addition, the in-system programming capabilities of boundary scan can be used to efficiently execute firmware ECOs. In fact, these ECOs can be done in real-time on the manufacturing floor through boundary scan.

- More efficient manufacturing processes

With boundary scan forming a basis for the entire manufacturing process, synergistic efficiencies can be brought about by the fact that all personnel understand and appreciate the benefits of boundary scan technology. In addition, work load leveling can take place when more boundary scan resources are in place and more people across the organization understand boundary scan.

- Improving ICT results

Boundary scan test can actually make ICT test more efficient and cut board repair costs for the EMS firm. By using boundary scan test strategies on a PCB, the number of ICT test pads on the board can be reduced because less of the board is being tested by ICT. Fewer pads means that those that are needed can be larger and this improves the reliability and repeatability of the probe's contact with the pad. ICT will then be able to identify a greater number of faults, reducing the time spent repairing boards.

Conclusions

In short, boundary scan can have an advantageous effect on both sides of an EMS firm's balance sheet. On the expense side, boundary scan will reduce costs by speeding up the test process, ensuring higher yields from manufacturing, reducing field returns and many other cost-saving measures. On the income side, boundary scan can generate additional revenues for the EMS company by expanding its business into new areas of test services such as functional test, field service and others. When both sides of the equation are affected positively, the ROI on a boundary scan investment will be short indeed.