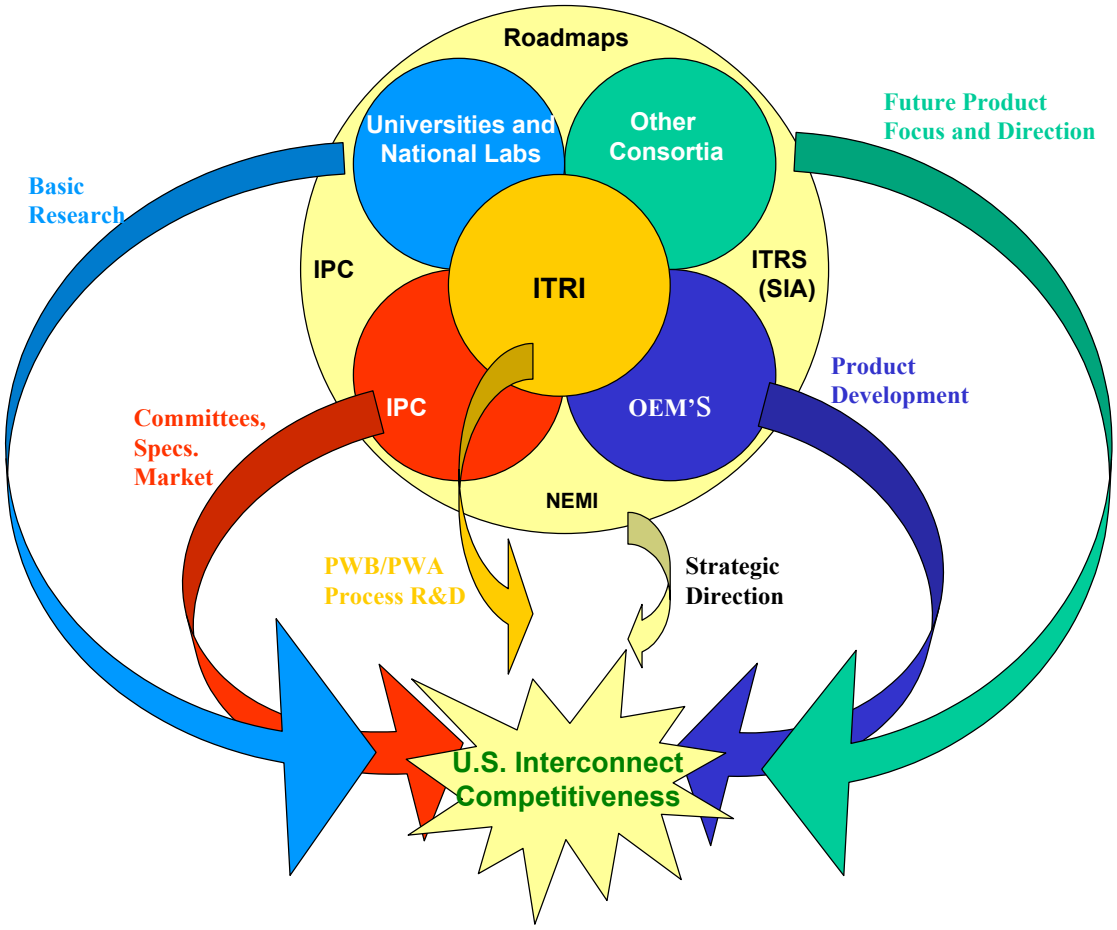
Interconnection Technology Research Institute



ITRI 50000

A White Paper on Domestic PWB Technology Hurdles and Barriers, and a Strategy to Overcome Those Obstacles

Authored by the ITRI Staff 1999

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ITRI
Interconnection Technology Research Institute

FORWARD

In early 1999, the ITRI Board of Directors requested that the ITRI staff prepare a report on the current technology issues facing the U.S. Interconnect industry, and to propose actions to address those issues. The purpose of this report was to identify specific steps that various industry segments could undertake to improve the competitiveness of the U.S. interconnect industry, and to recapture world market share. By suggesting specific actions, ITRI hopes to stimulate dialogue within the industry. Because the charter of ITRI is technology, this report is focused mainly on technical issues and actions. Business issues, financial issues, and business management issues are not addressed, except as they affect technology. They are left out not because they are unimportant, but because they are out of scope of the ITRI charter.

The ITRI Staff used several methods to gather the information included. Interviews and discussions were held with numerous people in the industry, from CEOs to manufacturing line workers. Surveys were sent to the ITRI Membership companies and to the ITRI Board. Ideas were formulated and reviewed with many of the industry leaders. In the end, however, the ideas and opinions expressed in this report are strictly those of the ITRI Staff.

The picture that emerged as this research was conducted, was one of great challenge, but also one of great reward to those who meet the challenge. As the large OEMs divest themselves of their internal manufacturing capability, the industry will be challenged to find ways to conduct the R&D formerly done by these big organizations. At the same time, the manufacturing volume that was done by these captive shops is now available for the independents to absorb. The rapid evolution of the Electronics industry and the products it makes is unprecedented in any other industry. This constant change requires that technology be quickly developed and integrated, replacing the old technology almost overnight. However, the technology turnover and new product introduction cycle is creating a demand for interconnection technology products that will reach double digit levels in many future years.

To capture this dichotomy, we prepared this report in two sections. The first section discusses the current status of the industry and the technical challenges we face. The strengths and weaknesses of the U.S. PWB fabricators are listed and discussed, and the status of research and development in the industry is reviewed. In the second section, specific recommendations are made for actions that need to be taken by each segment of the industry.

It is the intention of the ITRI staff that this be the first draft of a document that will be revised and updated periodically. The industry is too complex and the issues too volatile to be treated completely in one document. Furthermore, the rapid change in the industry will make any discussion of this type quickly out of date. Future revisions will be based on and will benefit from the feedback we receive from this first version.

Interconnection Technology Research Institute

A White Paper on Domestic PWB Technology Hurdles and Barriers and a Strategy to overcome these Obstacles

INTRODUCTION

The Printed Wiring Board (PWB) is the foundation of all electrical equipment. The PWB is a structural component that allows the intended physical function of the equipment to be accomplished, as well as an electrical component that interconnects all of the other electrical components. The importance of the PWB continues to increase as new equipment comes to market with increased functions, new packaging, and increased performance.

The PWB industry is primarily made up of hundreds of small to medium size companies and recently a small number of larger companies, many of them managed by classic entrepreneurs. In one instance, it is an industry very similar to the job-shop printing industry. In the printing industry technology and processes are widely available, orders are small, produced only with a purchase order, and are generally one of a kind. Industries that subscribe to this model are very tactical in their perspective and they lack strategic planning and execution. In the other instance, the PWB industry is driven by high technology influences, i.e. the semiconductor industry, the component packaging industry and OEM's seeking to increase market share. Management styles in this world are completely different. A new semiconductor fabrication facility can cost over $1 Billion and take several years to plan, build and qualify. Because of this, the predominate management style is very strategic and far-reaching. These two opposing models point out the conflicting signals that the PWB executives must face everyday.

U.S fabricators read about, see and hear about the astonishing changes taking place in today's workplace. The market is demanding faster, smaller products. This demand automatically increases PWB density. Because of investment constraints placed on them by the government and Wall Street, executives in the PWB industry look for an alternative solution. They hold back investment, hoping that today's technology can be stretched one more time. This strategy worked in the past where technology changes were slow and incremental. In today's world where technology changes are rapid and often revolutionary this "extend it one more time" idea is potentially a catastrophic error.

This white paper will attempt to discuss both sides of this situation. We will provide a strategic outlook for those companies that generally have a tactical perspective. We will identify issues and strategic activities that this large group of companies needs to prepare for the next millennium. We will also discuss the high technology needs of the OEM's and the packaging industry and discuss the impacts of high technology on the PWB industry and how the OEM's and PWB manufacturers must work together to increase effectiveness. Finally, we will outline a strategy for the development and implementation of PWB technology that if adopted, will enable the U.S. manufacturing infrastructure to maintain and recover market share.

Part I – Hurdles and Barriers

BUSINESS ENVIRONMENT

According to Prismark Partners, the worldwide electronic industries reached the $957 billion mark in 1997, and will exceed $1.3 trillion by the year 2002. The worldwide interconnect market needed to support the electronics industry in the year 2000, will be $35 billion. The United States portion of the $35 billion total is expected to be over $10 billion in the year 2000. If we add in the exploding silicon chip carrier market the $35 billion could grow to over $50–$55 billion.

The economic and strategic security of the U.S. depends on a strong electronics industry, which in turn depends on a strong interconnection industry. Printed wiring boards form the foundation both literally and figuratively for virtually all electronics in the world. Printed boards and electronic assemblies are the basic building blocks in all electronic systems, which in turn, support every other critical technology in the U.S., and drive productivity in almost every industry

Changing Nature of PWB Manufacturing

The PWB is the essential "glue" that molds individual components into today's advanced electronic systems. Increasingly sophisticated users are demanding light, highly portable systems that offer more functions but still keep the costs low. As a result, electronic manufacturing can no longer be partitioned into discreet market segments such as semiconductors, passive components, and PWB's which are designed and built independently and assembled into a system by yet another party. The new systems are requiring more functions per unit area, which drives more complexity into the interconnecting structure or PWB. The PWB itself is becoming an active part of the electronic circuit, as well as the structural support and package of the system. PWB design and manufacturing capability ultimately determines what and how electronic components can be used and the resulting system size and weight. Reliable portable systems are required in every industry. Consumer demand for hand held items seem insatiable. New markets for PWBs are opening with the rapidly expanding use of organic substrates in semiconductor device packaging components such as Ball Grid Arrays (BGA) and Chip Scale Packages (CSPs).

Emergence of EMSI the Middle Man

The Electronic Manufacturing Service Industry (EMSI) has grown rapidly over the last decade as the U.S. OEMs began selling off or closing down some of their captive assembly capability and outsourcing that work to independent assembly companies. In many cases, the independent assembly company has become the customer of the PWB manufacturer, rather than the OEM, as in the past. This puts another link in the already fragile communications chain. PWB manufacturers must find other ways to get the future OEM requirements necessary to properly focus their R&D.

Globalization of the Industry

The PWB industry, like most industries today, is no longer influenced only by local and national issues. The PWB manufacturer not only competes with the shop down the street, but must also compete with PWB manufacturers from all over the world. Electronic product OEMs are able to send designs anywhere for manufacturing, and they are choosing to send more and more of those designs to low cost PWB manufacturing facilities in other countries. Even companies who order prototypes in the U.S. often take the eventual large volume production orders offshore. The OEM does not want a different technology being used for prototype than used for production, or they would have to re-qualify, and in

many cases redesign the product. This means that U.S. PWB Manufacturers must either have offshore volume manufacturing capability, must partner with an offshore volume manufacturing company, or risk loosing even the prototype orders.

The U.S. PWB strategy from a global viewpoint has been one of incremental change, a slow methodical approach to increasing the customer base. Except for one or two specific cases, technology investment has not been a primary consideration. This approach has served the U.S. industry well, as long as product cycles were long. With the shortening of product cycles, the OEM does not have the luxury of waiting for fabricators to get better yields and install more capacity. They must hit the product window on its leading edge and have full manufacturing capability available. The U.S. strategy is significantly different from our two major competitors, Japan and Taiwan. Taiwan's strategy is to become the largest manufacturer of PWB's in the world. The shops in Taiwan are huge and getting bigger. They sell capacity at low prices. An OEM procuring PWBs in Taiwan knows that if his product is successful in the market, there is plenty of manufacturing capacity for supply. Previously the Taiwanese had not invested heavily in technology. They were very satisfied to become the volume supplier in conventional technology. This may be changing. Several Taiwanese PWB manufacturers seem to be making big investments in microvia technology. It is still too early to determine if this is an industry trend or just a few speculators.

The Japanese strategy is different from either the U.S. or Taiwan. The Japanese OEMs have always been the leaders in announcing new revolutionary products. The Japanese PWB manufacturers follow suit and strive to improve their technological capabilities rapidly and continuously so that PWB manufacturers in other countries cannot keep pace. The Japanese sell technology. This is consistent with their leadership in fine line technology over the past few years, along with their leadership in having the best yields in the industry.

Faced with these two challenges, the U.S PWB industry cannot afford to continue along the same path it has followed for the past few years. If we are to maintain or recover market share, the industry must adopt a strategy that will make us the world leaders in at least one competitive aspect of PWB manufacturing. The choices are limited. One must compete on cost, service, quality, turn-time, or technology. Each of these competitive differentiators has a business component: the investments, corporate culture, etc., and a technical component: the manufacturing methods, equipment, and materials, necessary to be successful. The current U.S. business climate is such that we can never expect to be the world leaders in low cost PWB manufacturing. However, there is no overwhelming business obstacle to our becoming world leaders in any or all of the remaining areas. The challenge there is a technical one. Can we as an industry adopt a strategy that will provide us the manufacturing technology advantage necessary to be world leaders in PWB service, quality, turn-time, and technology at a competitive cost?

Increasing Rate of Change of Technology

Many electronic products today have a cycle from concept to volume production of six months or less. This puts further pressure on PWB turn around time and a seamless transfer from prototype to production. Figure 1 illustrates the change that is taking place in today's markets. Previously products had a life of four, five or six years. Prototype and ramp up of a new product could take 12-15 months. After that, the OEM would often contract an additional fabricator or more to complete his full production schedule and then the product would go into its end of life period.

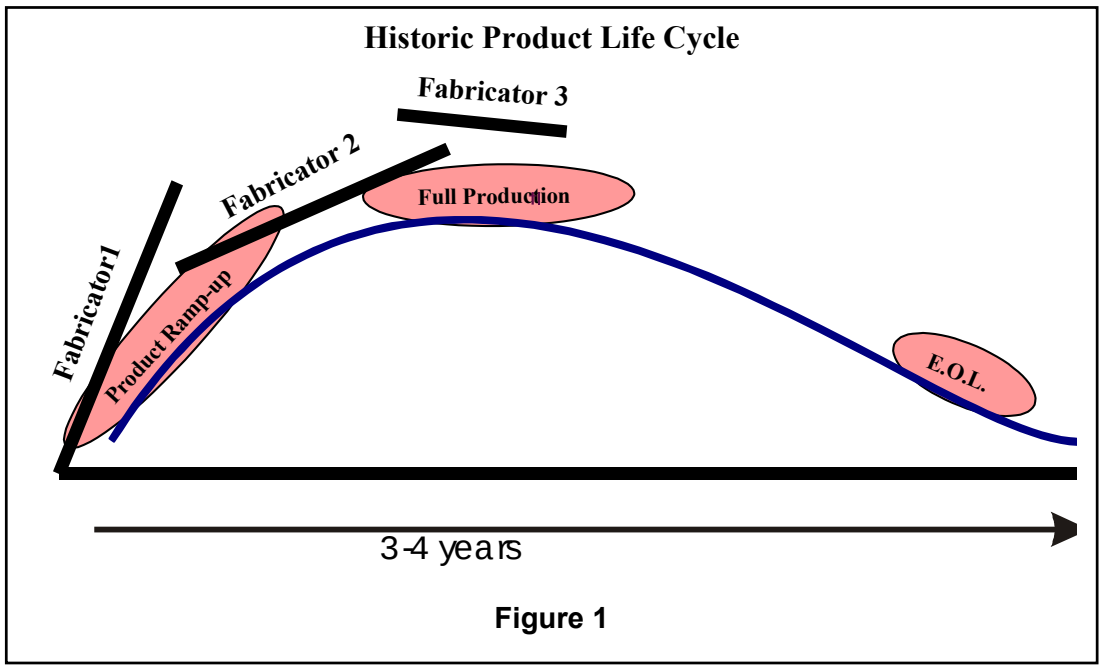

Figure 1

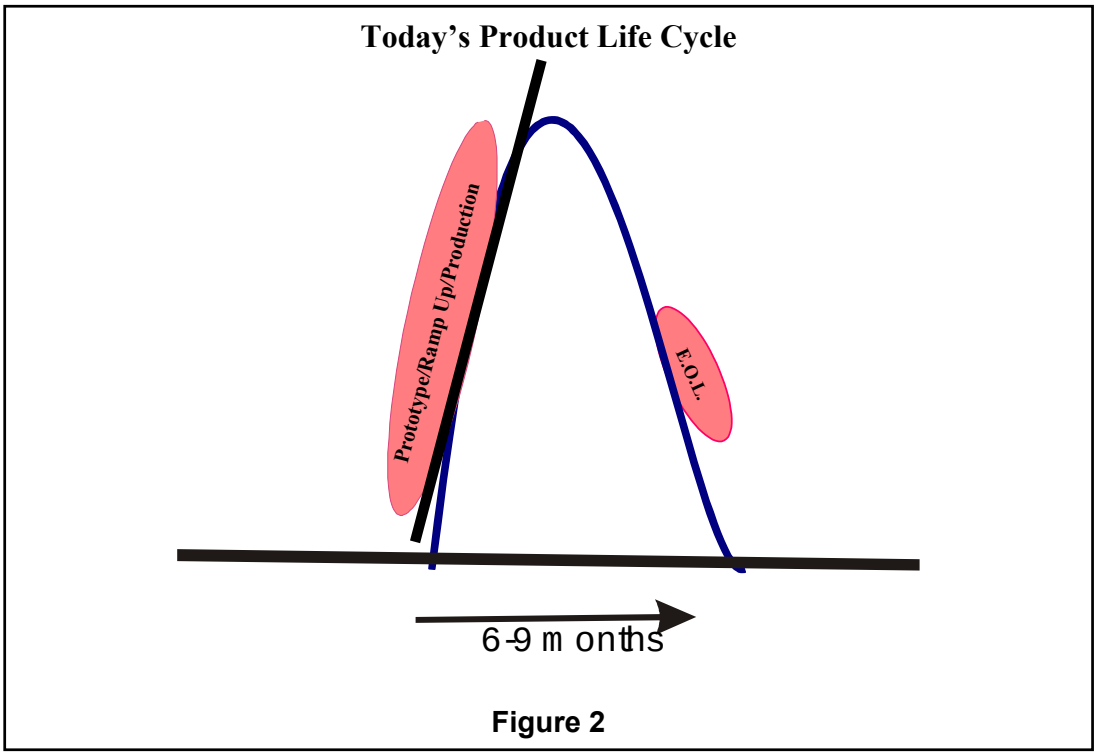

Figure 2

With today's very short product life cycles—sometimes six, eight, or nine months, prototype, ramp-up, and volume production are all done at the same time. If you don't do the prototype build, you can't do the full volume production.

U.S. Industry Structure

The domestic interconnection industry is comprised of over 650 printed wiring board fabricators, 500 of which have sales less than $5 million. Ninety percent of these Fabricators are independent companies not affiliated with a specific OEM. By the year 2000, we expect that over 97% of the PWBs will be fabricated by independents. The industry is also made up of many equipment and material suppliers and contract assemblers.

In 1984, the U.S. owned 40% of the world's PWB market. By1990 that market share had dropped to 28% and the U.S. had lost the leadership position in the world. In 1994, the U.S. had regained its leadership role, but with a much smaller market share than the previous 40%. Once again, the U.S. is facing a loss of share, especially in the microvia market.

U.S. PWB manufacturing can be divided into three sectors by product type: Conventional PWB, HDI (non-microvia), and microvia. Generally, products in the conventional PWB sector are defined as boards with 125-micron lines and spaces or greater. One hundred percent of all PWB manufacturers can build this technology, and a very large percentage (>65%) build boards like this exclusively. The entire PWB industry is very cost conscious, but this segment focuses singularly on cost with little interest in new technology developments, except if they reduce cost. Because this is the largest PWB manufacturing segment, there is significant competition between U.S. manufacturers. However, this group is also competing directly with foreign manufacturers on a price basis. The U.S. fabricators have been fairly successful in competing in this sector, particularly for small and medium volume orders and when service and turn-time are a premium. This is mainly because significant portions of their customers are from the near regional area, where they have an advantage in service and turn-time. Prices on products in this sector are still decreasing. Prices dropped 3-5% during 1998 and 1999, slightly more than in the previous few years.

To reduce costs many of the large purchasers of low technology conventional PWBs have been buying boards from suppliers in the Far East. This trend is most noticeable in the desktop personal computer business where all of the top five producers of PCs in the U.S. bought from Taiwanese suppliers. Consequently, the U.S. lost market share and there was a strain on domestic fabricators. In the last five years, over 100 U.S. fabricators have gone out of business.

The second sector of manufacturing, HDI (non-microvia) is made up of fabricators that produce PWB's containing100 micron or smaller lines and spaces, but do not contain microvias. It is estimated that 10 – 15 % of the manufacturers can produce this technology. This is also a very cost conscious sector, but because there are far fewer U.S. fabricators making this product, it is possible to differentiate yourself from some of the competition with technology. This product is also manufactured by Far East competition, but again there are fewer capable suppliers. Domestic producers of high-density technology have succeeded fairly well in maintaining market share, although it has not been easy. They are continuously looking for new ways to reduce manufacturing costs.

Finally, there is the newly developing microvia business. This is a technology that only a handful of U.S. manufacturers has installed. Microvia technology is used in both standard PWB motherboards as well as in organic chip carriers for the semiconductor assembly and packaging industry. The U.S. status in this area is not good. There is a perception that North America is two years behind Japan in microvia technology. This is probably not true. Benchmarking has shown that the U.S. is equal to others in technology (materials, line width, hole size, etc). The U.S. is behind in manufacturing experience and installed capacity, and this is a significant factor to OEM's when they make corporate buying decisions. Product development cycles are short and getting shorter. OEM's feel they must pick a partner that has

installed capacity, otherwise they will miss the product introduction window. There are no significant technical choke points to U.S. microvia production. All equipment and processes are available worldwide. The primary reason for fabricator's lack of investment appears to be Wall Streets emphasis on "results today". This limits a PWB manufacturer's ability to invest in new technology without some form of confirmed orders. Additionally, government tax situations are significantly different in the U.S. than in other countries. This also limits PWB manufacturers' ability to invest. U.S. suppliers are not doing as well as they would like in this arena. There is a continuously increasing demand for hand held and portable products and that has been creating increased demand for microvia boards, but so far U.S. fabricators have not been able to successfully get volume orders from OEM's.

By dividing the industry in three sectors the authors are not trying to pigeon hole the fabricators into one of these sectors. We know that some manufacturers build boards in all three categories. We are simply trying to develop a strategy for each sector. Individual manufacturers can then make detailed plans based on the market(s) they serve.

Strengths and Weaknesses of the U.S. PWB Industry

The U.S. PWB industry has many strengths, but also is plagued by several significant weaknesses. In this section, we endeavor to identify these so that we may emphasize the strengths and work to reduce or eliminate the weaknesses.

U.S. Fabricator Strengths

- The ability to deliver conventional or commodity products in volume. There are over 600 fabricators capable of delivering this type of product.

- The U.S. PWB industry has complete self-sufficiency. The supply chain of materials, chemicals, equipment and process support allows the U.S. industry to operate completely independent of any foreign influence if it so desired.

- There is a very strong laminate materials technology industry. Besides standard laminates there are several world class manufacturers of specialty materials.

- The industry has full technical diversity; it is capable of manufacturing conventional, HDI, microvia, military high reliability and other products.

- Strong domestic electronics industry. The U.S continues to be a world leader in electronics manufacturing. U.S. PWB manufacturers have the advantage of close proximity to many of the leading electronics manufacturers.

- There is an abundance of niche manufacturers. Manufacturers that specialize in generally difficult to make products.

U.S. Fabricator Weaknesses

- A satisfaction with less than six sigma quality. Yields are not best-of-breed worldwide. The quality of U.S. materials is satisfactory, but not six sigma.

- The U.S. capital equipment industry is still selling tools, not solutions. This is very similar to the semiconductor industry prior to Sematech. Now the semiconductor capital suppliers are solution focused. The U.S. PWB capital-tooling suppliers would do well to study this history.

- Selling prices are marginally satisfactory. There is little room for improvement. There are two models evolving for cost reduction. The mega fabricators that will use economies of scale as a cost reduction mechanism and the pseudo vertical approach, where all phases of technology are in one large group. Design, Chip Manufacturing, Packaging, PWB, and Assembly.

- Automation is weak or non existent

- Fabricators are relatively small companies that do not have the resources to do the R&D all on their own.

- There is limited data on cost metrics associated with becoming a global industry. As one moves from a regional industry to a national industry to an international or global industry, the amount and type of cost information needed increases. Industry accepted cost metrics for defining the value of a PWB in relation to increasing density is required. Understanding the cost of the pipeline when OEMs purchase offshore is needed so that PWB manufacturers can present a case for OEMs doing business domestically. The PWB manufacturers need to understand the cost drivers of the EMSI industry and develop industry wide plans to help the growing EMSI companies lower their costs. Many of our fabricators are still using regional cost information in a global world.

- The industry does not have a conscious value item that it sells to buyers. Value items are things like price, quality, delivery, or technology. The U.S. tries to be satisfactory in all of them, and is not selling one or two of them as best in the world.

- There is a reluctance to cooperate with each other, even when there is no proprietary or confidential items on the agenda, and even when the real competition is offshore.

TECHNICAL ENVIRONMENT

Electronic packaging is a critical element of the electronics industry. Assembly of a complete system involves packaging at many different levels. First level packaging is generally thought to be the semiconductor packaging level. Second level is generally recognized as the printed circuit board fabrication and assembly level. The purpose of this level is to tie together, via printed copper wires, all of the first level packages and provide a connection to the next level of packaging, the third level or final box assembly. The major trends are the same for all levels of packaging: smaller, thinner, lighter, and cheaper.

Trends in First Level Packaging

Many low cost applications are packaged in single chip plastic packages, which will migrate to chip on board (COB) packages and possibly simple multi-chip modules. Ultimately “flip chip” technology may be implemented in this market. The most significant shift in packaging has been the introduction of array packages. These arrays come in many forms: BGA, CSP and Direct Attach Flip Chip, among others. This technology change is being driven by the technology changes in the semiconductor industry, and is in turn driving technology change in the second level interconnect industry.

The other rapidly developing half of the semiconductor industry is the high performance components. These include high performance microprocessors and Application Specific Integrated Circuits or ASICS. The driving factors for these products are higher clock speeds, increased lead counts and greater power dissipation. Packaging solutions for these components are Ball Grid Array (BGA), Chip Scale Packages

(CSP's), and Flip Chip. Most of these packages use array I/O configurations as opposed to the perimeter configuration.

The trend to area array package pin outs started several years ago with the introduction of the ball grid array package. This trend is continuing in BGA's and is growing with the emergence of many different chip scale package configurations, and will continue into the flip chip period. All of these packages impact the PWB, primarily by demanding finer features to escape the array. Chip scale and flip chip have the biggest impact. Because of the pitch and density of the I/O's on these packages, significant new technical advances are required to connect these components to other packages and to the system.

Effects of First Level Packaging

What this means to the interconnect industry is more solder joints per square inch, requiring finer wiring. It also means increased component counts. There are two opportunities here for the PWB industry. The first is the interconnect between these components (the conventional PWB), and the second is the substrate on which the semiconductor sits in the packaging modules (the chip carrier substrate). Traditionally, chip carrier substrates have not been a U.S. strategic business.

One measure of technology in this business is the wiring density of the copper conductors. To meet the requirements of these important, high technology products, second level packaging must increase it's wiring density from an average of 200 inches per square inch on state-of-the-art products today, to an average of over 400 inches per square inch in the year 2000. This 100% increase in density may not seem like much when compared to density increases in the semiconductor industry, but historically the second level packaging industry has increased density only 20 - 25 % for a five-year period.

Printed wiring boards are fabricated out of many different materials. The conductors are usually copper, but the insulating materials vary considerably. Glass transition temperature Tg and coefficient of thermal expansion (CTE), are just two material characteristics that determine material selection. Trends in materials are higher Tg and lower CTE to match the semiconductor devices.

Trends in Third Level Packaging

There are many trends in the marketplace, and they vary slightly depending on the final application of the product being designed. In general, all markets are looking for smaller, lighter, and increased function products. There is also a clearly identified cost/performance product sector and a high performance sector. Both of these sectors are viable and growing. It appears that the fastest growing segment of the interconnection industry is the hand held or portable market. Products in this market include telephones, calculators, personal digital assistants, laptops and a myriad of other equipment. Recent information indicates that this hand held and portable market will use 25 - 30 % of all multilayer PWBs produced in the world by the year 2000.

According to the recently published NEMI roadmap, OEM's in the Low Cost category, which includes Personal Digital Assistant (PDA), Cameras, Hand Held Calculators, and Modems, were looking for a 30% cost reduction in both PWB and PWA costs over the next five years. They are also looking at a 50% reduction in PWB cost in ten years. Component density on the PWB is also increasing. This directly affects the PWB technology. Component density will double on Hand Held products and triple on Cost Performance products over the next several years. Area array component pitch will decrease in the next ten years, with cost/performance products seeing the biggest changes. This also directly effects the PWB by reducing the line width and line space dimensions.

Changes in PWB Technology

Since the mid-90's the U.S. PWB industry has been going through several technology iterations. One of the most significant was, and still is, the introduction of microvia technology into the industry. Most people give IBM the credit for validating this technology with their development and introduction into manufacturing of the SLC^{R} photo via technology. Since then, numerous new types of microvia technologies have been put into production by OEMs and fabricators in Europe, the Far East and the U.S. ITRI has been very active in the analysis and promotion of all forms of microvias. Up to now, microvia technology has been looked upon as a high-density only technology, but this appears to be changing. Several fabricators are reporting significant activity in the use of microvias for only layer count reduction. If this continues, fabricators from all PWB manufacturing sectors will have to understand and manufacture microvias.

Another interesting development has been the introduction of daughter cards by Intel. These small, very dense cards usually plug into a larger motherboard. Because these boards are so dense in components, they are often confused with multichip modules or MCM's that were developed earlier. MCM's are generally regarded as components, and are tested to the more stringent component reliability requirements. Daughter cards, even though they may be smaller and more complex than MCM's, are considered product boards and are not subject to these more difficult reliability requirements.

The development of thin film technology as an alternative to organic PWB technology has also been an ongoing process for the past several years. To date it has been very successful in producing ultra fineline products, especially MCM's. However, the cost of this process has limited its opportunities. Thin film processes are very unique and it is not expected that they will become prevalent and replace standard technology in many PWB manufacturing lines. There will be some limited growth, but it will affect manufacturers that want to build the highest density boards for the high performance market.

PWB designers have long awaited the development of a cost affordable embedded passive technology. It appears that these new developments are getting closer. There are several organizations working on new processes. The NIST ATP Embedded Passives Project, in which ITRI is participating, is just one of these projects. The extent of the market and therefore the impact on the industry is still unknown. Some forecasts are very conservative; showing usage only in the discrete component-rich hand held telephone industry. Other forecasts are more aggressive and identify significant usage in laptops and servers. Another factor that could also impact the market is the environmental issue. If countries force the no-lead issue, buried passives may get a faster push.

RESEARCH AND DEVELOPMENT ENVIRONMENT

Declining Industry R&D Budgets

The printed wiring board industry has gone through a massive restructuring over the past few years. In 1979, captive fabricators within the major U.S. electronics companies served 60% of the market with significant R&D budgets and central research laboratories. Today, over 90% of the market is served by small, independent manufacturers with small revenues. This restructuring has had a major impact on R&D expenditures in the domestic PWB industry.

In the 60's, 70's and even into the early 80's the OEM's shouldered the majority of PWB R&D activities. Companies like IBM, AT&T, and DEC each had significant R&D laboratories specifically focused on Interconnect technology. These three companies alone spent over $100 million a year on PWB research

activities. The industry benefited greatly from their activity. Many of today's specifications and processes can be directly traced back to an OEM R&D project.

Current OEM research and development investment in the United States lags behind other countries and the OEM's overall R&D commitment continues to decline. For the past several years R&D investment, as a percentage of sales in the PWB industry, has been less than one percent. We can compare this to a 3 –5% investment by Japanese PWB manufacturers and a greater than 10% investment by semiconductor industry manufacturers. None of the small independent PWB manufacturers have the resources by themselves to replace the R&D investments formerly made by the large U.S. OEMs.

Declining Government Investment in R&D

The United States government role in research and development is also changing. In the late eighties and early nineties, the U.S. government spent millions of dollars funding technology research and development projects in industry. In the year 1994, The federal government funded $155 million of interconnect related R&D (see Table 1). This funding came primarily from DARPA (Defense Advanced Research Projects Agency), NIST (National Institutes of Standards and Technology), and DOE (Department of Energy). About three-quarters of this money went directly to the U.S. industry through contracts, grants, and other agreements.

Table 1

	FY 94 ($M)
NIST	6
DARPA	112
DoE	32
NASA	5
Total	$155

DARPA

The DARPA TRP (Technology Reinvestment Program) was the largest program providing funds to private industry for research and development. However in the past few years with the change of control in congress, a slow but continuous pattern of cutback in R&D expenditures has been occurring. In 1997, DARPA virtually curtailed all TRP spending. The last PWB related project sponsored by DARPA was the Low Cost, High Density, Sequential Build PWB Manufacturing Technology project. The participants of this project were Shipley Co., Advanced Circuits, Inc., AlliedSignal Aerospace, Delco Electronics Corporation, E.I. DuPont de Nemours & Co., Inc., ITRI, and Zycon Corp. The project had a government cost contribution of $6.9 million.

NIST

The only agency that is still supporting Interconnect R&D is NIST with its ATP program. The ATP is a unique partnership between government and private industry to accelerate the development of *high-risk technologies* that promise significant commercial payoffs and widespread benefits for the economy. The ATP encourages a change in how industry approaches R&D, providing a mechanism for industry to extend its technological reach and push out the envelope of what can be attempted. Major forces—globalization of markets and the pace of technology change—continue to drive private R&D to narrower, shorter-term investments to maximize returns to the company. Most private capital is reluctant to invest in anything less than a "sure thing" in terms of its own returns. In sharing the relatively high development risks of technologies that potentially enable a broad range of new commercial opportunities, possibly across several industries, the ATP fosters projects with a high payoff for the nation as a whole—in

addition to strong corporate rates of return. The nature of ATP projects, risky but broadly applicable, stimulates joint research ventures that link small suppliers with users, or link several firms together to solve a generic problem common to all. Figure 3 shows the change in NIST ATP funding over the last several years. Because of the nature of the ATP program, electronics and particularly interconnection technologies have not been major recipients of funding. Note that in 1994 only $6 million of the total $199.5 million was dedicated to interconnect technology R&D.

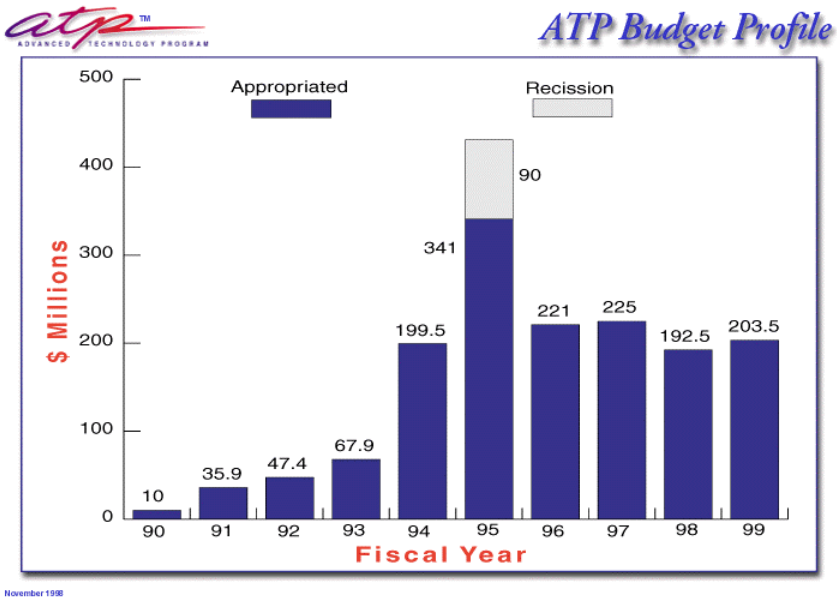

Figure 3

Formation of ITRI

In 1994, the I.P.C. Board of Directors approved the formation of the Interconnection Technology Research Institute (ITRI), a new and independent arm of the IPC. They wanted to create an organization that could pull together all companies involved in PWB manufacturing as well as suppliers and government agencies to do research in PWB and PWA processes and materials. The purpose of ITRI was to help fill the gap left with the decline of the OEM R&D efforts. ITRI's mission statement is "To enhance the global competitiveness of the North American electronic interconnection industry by enabling collaboration among its members to accelerate development and application of revolutionary and evolutionary technology."

ITRI has grown to over 60 Members and has 19 different technology projects underway. Eleven projects have been completed, and nine technical reports generated for external distribution. Close working relationships have been developed with all of the major Electronics Industry consortiums and organizations. Through this whitepaper, ITRI intends to further focus the R&D resources of the industry on those issues most critical to the competitiveness of the domestic industry, and provide increased value to the ITRI Membership. For this paper, competitiveness is defined as the ability to meet the test of international markets while at the same time maintaining or increasing revenues. Measures of competitiveness are market share, employment, productivity, and R&D outlays.

Industry Roadmaps

Technology roadmaps play a very significant role in the development of an industry R&D strategy. There are now numerous national roadmaps: the steel industry, the aluminum industry, and the forging and casting industries all have published technology roadmaps. In the electronics industry, there is also a large number of roadmaps: The National Electronics Manufacturing Initiative (NEMI) roadmap, The Association Connecting Electronic Industries (IPC) roadmap, The Semiconductor Industry Association (SIA) roadmap, and many others.

National technology roadmaps are not done for a particular product or market. Their purpose is to ensure that the industry is ready for the next technology. National Technology Roadmaps identify needs--they purposely don't try to supply solutions. For example, national technology roadmaps allow the materials industry to prepare materials with characteristics required for the next generation of technology. They also allow the capital equipment industry to prepare for the future. They provide links to national laboratories and to the academic research community.

Mr. Ray Kammer, Director National Institute of Standards and Technology, has this to say about roadmaps, "We at NIST love roadmaps…Roadmaps help us guide our investments and to allocate our resources in accordance with U.S. industry's priorities. And the more detailed the roadmaps the better…"

Bill Gray from Delphi Delco Electronics Systems says "Roadmaps provide foundations for competitive advantage, no matter where companies reside in the supply chain. Collaboration among industry stakeholders provides the forum for strong technical and business debates, which ultimately leads to better and faster solutions for our customers. The Roadmapping process ultimately provides consensus direction, with less individual risk and investment, yielding better solutions for our customers. "

ITRI plays a very responsible role in technology roadmaps. We use all of the interconnect roadmaps each year to help us produce our annual ITRI Technology Plan. A National Technology Roadmap Coordinating Committee meets periodically to discuss the future of roadmaps and to ensure that each has a link to another complementary roadmap. ITRI is a member of this committee.

Roadmaps provide the priorities for the research and development community. By reading and understanding roadmaps, researchers can understand the difficult challenges facing an industry in a general sense and then take the general issue down to a specific topic.

SUMMARY

The combination of declining resources for R&D and the demand for rapid changes in PWB technology are a formidable obstacle to overcome. Success will require an industry wide effort and new ways of working together for the advancement of all. Doing business the old way in this new environment will surely result in further declines of U.S. market share and individual company competitiveness.

Part II: A National Strategy for Interconnect Technology

INTRODUCTION

State of the art interconnect packaging technology is vitally important to the health of the overall electronics industry in the U.S. Although the U.S. does have leadership in some areas, there is cause for concern measured in terms of overall market share. Extreme cost pressure from offshore manufacturers with excess capacity means that market share for U.S. manufacturers cannot be maintained or regained by just reducing prices. Domestic PWB Fabricators must create value in their products, which exceeds that of the offshore manufacturers.

The commodity "build to print" nature of PWB manufacturing means that additional value cannot be created by just adding features. Increased value in PWB manufacturing comes from improved quality, faster turn time, improved service, and better technology. The solution to the Domestic PWB industry's competitive technical hurdles and obstacles is a coordinated strategy involving all of the industry sectors, that addresses significant improvements in these four value areas, while keeping costs low.

Research and development can provide the improved processes and materials, which will allow Domestic Fabricators to increase the value of their products. That R&D must be specifically directed at improving one or more of the four value areas, must address the industry's highest priority issues, and must have the support of all of the industry sectors. In the following sections, we identify those current industry highest priority technical issues, describe the existing or planned ITRI activities to address those issues, and discuss how the various industry "stakeholders" can help make that effort successful.

PWB INDUSTRY TECHNICAL PRIORITIES

ITRI's first step in identifying the technical issues to address was to ask the people involved in PWB manufacturing in the U.S. In 1996 and again in 1998, ITRI used the "National Technology Roadmap for Electronic Interconnections" and convened a group of OEM's, fabricators and consultants to identify several high-level priority areas for additional research and development. This focus allowed other research and development organizations like universities, national laboratories, and other consortia to easily identify areas that need increased activity in order for the U.S. to regain their lost market share. In 1999, ITRI took another approach. In addition to identifying high-level focus areas, the process was taken down one more level and specific focus activities were identified within the priority.

ITRI then surveyed their membership, as well as several other industry participants, and prepared the responses as shown in Table 2. This table lists those areas that these industry leaders have identified as their top technical needs. These areas are where they would like to see additional industry resources allocated. We believe that this is the first time that a table of this type, where specific activities have been identified by sector, has been published. It is one of the most important technical items in this report. This table should be a part of all ITRI/IPC/NEMI technical activity planning.

Table 2
Current PWB Industry Technical Needs by Manufacturing Sector

Conventional PWB Fabricators (5mil L/S min) Cost focus	HDI Non Microvia Fabricators (4&3 mil L/S) Cost and technology balance	Microvia (Vias less than 6 mils) **Technology Focus**	
		Microvia Motherboard	**Microvia Chip Carrier**
Technical Needs	Technical Needs	Technical Needs	Technical Needs
Surface Finishes / HASL Replacement	Fine Pitch Electrical Test	Fine Pitch Electrical Test	Fine Pitch Electrical Test
Direct Plating to reduce process steps	Fine Line Photo Processes	Improve Material Mechanical and Thermal Stability	Improve Material Parameters and Stability
Cost of Test Fixtures	Improve Registration for Fine Features	Fine Line Photo Processes	Fine Line Photo Processes
Oxide Replacement	Improve Material Mechanical and Thermal Stability	Improve Uniformity of Copper plating and etching	A.O.I. for fine Line
Improve Registration for yield	Improve Uniformity of Plating / Etching	Improve Registration for Fine Features	Specifications (JEDEC / IPC)
More accurate Scaling Factors for yield	Low Cost Imbedded Passives	A.O.I. for fine Line	
Improve Plating of Blind Vias	Improve Laminate Quality	Cad for microvia	
Improve Via Reliability	Reduce Warpage / Improve Flatness	Very thin Copper foils	
Other Concerns	***Other Concerns***	***Other Concerns***	***Other Concerns***
Better Material properties		Low Cost Embedded Passives	Improve Yield of Features Below 1 mil
Reduce the cost of making holes		Improve yield of Features below 1 Mil	

The organization of this table was discussed earlier in this paper under the "U.S. Industry Structure" heading on page 7. It is evident that there is a significantly different set of priorities in the industry depending on what is your company's target sector.

The Conventional sector on the chart is the cost focused sector. Industry experts estimate that there are approximately 400 PWB fabricators in the U.S. specializing in this sector. Looking at the priority list in this sector one can see that surface finishes, plating, and test are the main topics. These may be the most expensive operations in the factory. Replacement of Hot Air Solder Leveling, improved plating, and elimination of test fixtures are what these manufacturers want for tomorrow. The good news is that ITRI has current activities in both these areas. Manufacturers who work primarily in these sectors can participate in the ITRI projects and help steer them in the direction that serves them best.

In the HDI non-microvia sector, the top three priorities are: fine pitch electrical test, fine line photo processes, and registration. ITRI has current active projects in each of the areas in which manufacturers, suppliers, and OEMs can participate. The fine pitch electrical test problem for this group is different from the test problem in the conventional group. The issue with this group is a lack of capability, whereas the conventional manufacturers want mainly to eliminate the cost and bother of test fixtures. They are not interested in testing very high-density boards. The best technical solution may very well work for both groups.

For the HDI and microvia segments, fine pitch electrical test is the first priority along with new microvia structures and material sets that may be needed for performance enhancements. Embedded passives may be a path to leap ahead in interconnection technology. Also, most PWB manufacturers that focus on this sector are concerned about below 1-mil feature sizes, although it may be four or five years before they are needed by an OEM.

ITRI'S ROLE

As the only National Consortia focusing strictly on Interconnection R&D, ITRI must take a leadership role in focusing industry resources on the key issues identified above, and in enlisting the support of the other industry "stakeholders" in this endeavor. This begins with the ITRI Membership, for they are the ones that supply the project leaders and technical resources necessary to complete the projects. Each Member Company should identify the top technical issues that they are willing to support, and make a commitment to provide resources for a project addressing those issues. This is what has enabled ITRI to initiate and complete projects in the past, and that is how we can overcome the issues, which we will face in the future.

To continue to be successful, ITRI must have a clear picture of the different segmentation in its membership. The new segments identified in Table 2 above, is a start. These are not the only segments in the industry and ITRI must keep enhancing its knowledge in this area.

ITRI needs to identify and actively recruit receptors for its specific projects. General announcements are not enough; specific personal e-mails, teleconferences, and one-on-one meetings are required.

ITRI has to continue to reduce the risks of using its projects outputs. ITRI must also do a better job in maximizing rewards for its members. ITRI needs to clearly explain the value of its successful projects to its members.

Current ITRI Technical Activities

It is very important for ITRI to maintain a proportionate balance of activities in each of the industry manufacturing sectors. A proportionate balance does not necessarily mean equal, but does mean that members of ITRI who focus on one of these sectors, must receive sufficient return on their investment of resource. Figure 4 is a diagram of the current ITRI project activities. In Table 2 above, we have highlighted those focus areas in which ITRI has a current activity.

It is clear from this analysis that ITRI has good coverage in most areas, and reasonable attention to the four manufacturing sectors. The goal now must be to keep these activities moving at a reasonable pace, and to insure a successful conclusion of the existing projects. ITRI must put into place a process to ensure a continuing balance of activities across all sectors, so that the membership receives a return on investment no matter in which sector they do business.

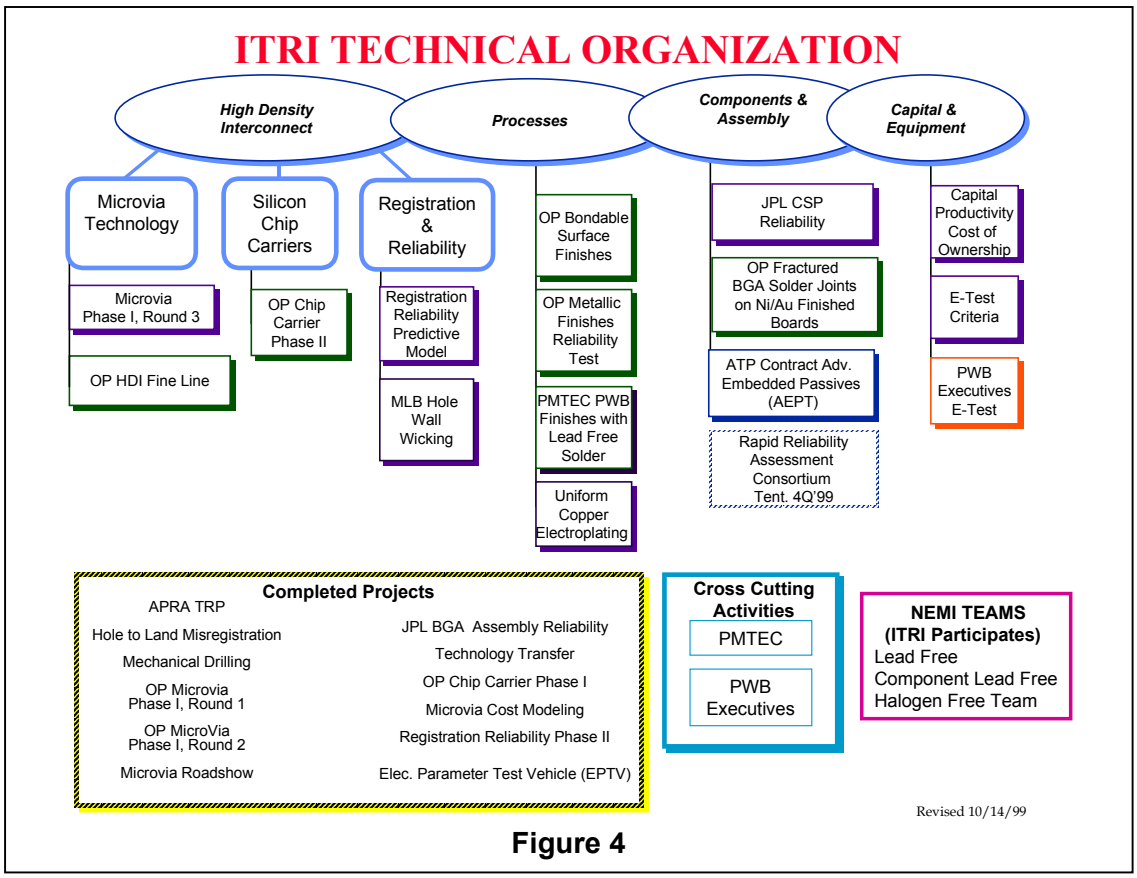

Figure 4

Proposed New ITRI Technical Activities

One area of need, which is apparent from the above table, and ITRI is not currently addressing, is material and laminate stability and performance. This issue appears at one level or another in every one of the industry sector's priority lists. The U.S. industry, by virtue of the fact that we have a very strong materials capability, should be a technical leader in this area. ITRI must bring together a group of fabricators and material and laminate suppliers to address the needs of each of the three industry sectors.

There are other activities, which do not appear in the table, the ITRI staff believe would have a significant impact on U.S. PWB manufacturing competitiveness if pursued. These activities involve general manufacturing yield and throughput improvements, and cost reduction. The first is the creation of a PWB Fabricator process improvement roundtable. The purpose of this group would be to share "Best of Class " process knowledge and experience, thereby increasing yield and reducing cost at all of the participating Fabricators. This group could be based on a model used at SEMATECH, where each Participant identifies the process step where they are "Best of Class", and then shares their know-how on this particular process step with the rest of the group. Participation in the discussion groups would be strictly limited to PWB manufacturing personnel only, and each Participant must share at least one process step. Participants in the SEMATECH exercise claim that this has been one of the most worthwhile outputs of SEMATECH. Although both ITRI and NEMI have activities in this area, more effort with a higher priority is required. ITRI should form this PWB Fabricators Process Improvement Roundtable and begin the process of mutual manufacturing improvement.

Within the PWB industry, continual process improvement, communication and mutual problem solving would be greatly enhanced by a set of standard manufacturing cost and performance metrics imbedded in a software toolset. Standard metrics would allow an individual manufacturer to assess his own performance and identify weak areas, as well as permit several manufacturers to identify best of breed manufacturing processes and accurately conduct manufacturing process trade-offs. These metrics would also provide a tool to measure the before and after impact of ITRI projects. Semiconductor fabricators currently have such a toolset, and the PWB fabricators could leverage off theirs. ITRI must form a team of fabricators to develop a PWB manufacturing process control toolset, and propose a series of manufacturing cost and performance metrics to the IPC for standardization.

OEM'S ROLE

OEM's by design want a market place that continuously creates new business opportunities. A product line with continuous upgrades in features, capabilities or concepts is the lifeline of an OEM. The PWB industry needs to understand that to accomplish this, the OEM needs access to superior manufacturing technology, especially technology that reduces size, weight, or increases functionality.

Most PWB manufacturers in the world would say that the U.S. OEM's have been cutthroat in their approach to buying PWB's. This is especially true in the computer and communications market sectors. In other words, the commercial OEM's treat all PWB manufacturers as commodity suppliers. There appears to be a better long-term relationship between OEM and PWB fabricator in the military and automotive high-reliability market segments than in the commercial segment.

There are several areas where OEM's, PWB manufacturers and the industry support organizations can work together to insure that a new technology is developed and deployed in such a manner that both OEM and fabricator can achieve simultaneous benefits. They are:

- OEM technical requirements need to be translated into supplier deliverables. Technology roadmaps need to be translated into expected costs, feature sets, quality levels, yields and performance levels for market segments. The market segments need to have projected volumes and associated requirements.

- There is a need to accelerate technology convergence of the supply chain to meet target product needs. OEMs need to provide more detail on features, densities, and prototype cycle times, production cycle times and demand. The OEM's have a unique insight on what is occurring in PWB plants around the world. This benchmarking needs to be shared often in order for U.S. fabricators to understand global competitiveness.

- Industry metrics needs to be improved. Product density requirements and associated cost targets need to be developed so that both fabricator and OEM are working from the same page. The OEMs need to develop better metrics for price expectations with time and product requirements.

- Innovations from both the OEMs and PCB suppliers are necessary if we are to achieve a competitive position in the marketplace. Process simplification is needed to meet projected yield and price targets in all segments of the industry.

There are several things U.S. PWB manufacturers should expect from OEMs, if the OEMs expect the manufacturers to invest in new technology. They include:

- The OEMs need to provide technology, cost, and business roadmaps. To protect the OEMs proprietary data there may have to be some new semi-private communication mechanisms developed.

- The OEMs also need to provide success criteria, indicators, and requirements for PWB manufacturers and then stand by them. If a PWB manufacturer is successful in meeting the requirements, he should have some expectation of continuing business.

- The OEMs should provide the "best known methods" to U.S. manufacturers for development, manufacturing and cost reduction to improve communication, expedite certification and cost reduction

In the past, the OEM's had their own PWB manufacturing shops. The OEM's were in control of their own interconnect destiny. Communications mechanisms in the vertically structured OEM's were informal. Information on product roadmaps and future technology market analysis reports were passed to other employees informally, individual to individual. This informality worked well inside the corporation. Today the OEM's have outsourced their PWB manufacturing shops and are in the process of outsourcing assembly. The problem is that the OEM's have not outsourced their information process. They still maintain tight control of information given to the outside. Some of the tightness is understandable due to the competitive nature of the marketplace, but if the OEM wants the independent entrepreneur to invest, they must supply sufficient information. The same information they freely shared with their internal PWB shop managers.

Today's customer supplier relationships are largely commodity based. This means that sourcing decisions are generally based on price and availability. There is very little interest on the part of the OEM to share advanced knowledge of future needs with suppliers. Advanced product roadmaps and technology roadmaps are marked confidential. However, the long-term health of both OEM and supplier depends on continuous detailed two-way discussion of future product manufacturing technology needs. The success of the PWB industry in the future requires that we find a way for OEM's to share their new product needs at a detail level that defines new technology opportunities and requirements, and in some manner demonstrates potential market size.

The OEMs often talk of their interest in developing "partnerships" with PWB manufacturers. If they are truly interested in a partnership, a relationship where both companies want each others business revenues to grow proportionally, then the OEMs must find a way around their commodity based "vendor type" approach.

EMSI'S ROLE

The OEM's use of contract assemblers presents a unique situation to the communications problem. When the OEM out-sources their assembly activity, the sourcing of the raw card is often left up to the contract assembler. The assembler becomes the customer of the PWB manufacturer. This put another link in the already fragile communications chain. In these days of limited R&D, the PWB manufacturer is very dependent on the OEM for technical direction and often process upgrade information. The contract assembler often takes the position that they are the order placer and the fabricator doesn't need to know anything else. This shortsighted attitude by the contract assembler only hurts every one in the supply chain. If the EMSI provider is going to assume the PWB specifying role of the OEM, then he must also

assume the role of providing technology direction to the PWB Manufacturer by making dollars available for interconnect technology R&D.

PWB MANUFACTURERS ROLE

The U.S. PWB manufacturers have a major responsibility in returning the U.S. to its previous level of competitiveness. Paradigm shift in new technology development needs to occur in the U.S. PWB manufacturing industry. The industry needs to understand more of the semiconductor manufacturing methodology with emphasis on cost of ownership**,** clean rooms, high yield and quality with continuous improvement and certified process and change procedures.

There are several things that OEM's should be able to expect from U.S. PWB fabricators:

- A position on commitment to new technology development. This is something the OEM gets from foreign manufacturers especially in Japan (plans,…,schedule,…investment).

- A commitment to become a long-range technology and business strategy partner (reuse of suppliers by OEM to reduce the development cost).

- Commitment to become a leader in technology development, manufacturing, and cost reduction to meet EMSI/OEM roadmap.

There needs to be significantly improved vertical (OEM, Fabricator, and Supplier) and Horizontal (Fabricator/Fabricator) communications across the industry to understand needs, capabilities, supplier chain and to increase fabricators competitiveness. This goes beyond industry seminars and conferences. These meetings need to be small executive level groups where semi private and private agreements can be made face to face by individuals who represent their company.

SUPPLIER'S ROLE

The IPC Suppliers Council has been in existence for several years and has made some significant contributions to IPC and to the industry at large. The annual IPC PWB Expo is just one example of this group's contributions. The Suppliers Council also has on-going activities like the Trade Committee.

For the purposes of this paper there are additional activities that we believe the Suppliers Council could undertake in partnership with ITRI and IPC.

As the PWB industry goes through the massive changes that it is experiencing in loss of R&D: consolidation of manufacturers, price reductions etc.; the industry capital suppliers and fabricators are finding it harder and harder to fund the development of new capital equipment. The fabricators have limited capital that they can risk in working with a single selected supplier to develop new equipment; and the suppliers are hesitant to risk investment in a very high technology piece of equipment that serves only a small portion of the industry. ITRI recently proposed a new model/method for developing capital equipment in the PWB industry that may be the model of the future. A team of five PWB manufacturers wrote a common criteria specification, and committed financial support for the development of the equipment. The specification was sent to numerous industry capital suppliers and a down selection was made. Semi-finalists were visited by the ITRI team and a finalist was selected. This new unique process has several advantages for all parties:

- The specification is a group effort and the capital supplier knows that it is not just one company's wish list. It also gives him the confidence that there is potentially more than one buyer.

- The specification is essentially a statement of future equipment needs and therefore no PWB manufacturer is giving up their proprietary processes or business plans to other partners or the capital supplier.

- The manufacturers, by telling the capital supplier up front that they will financially support the project, minimize the suppliers risk. The participating companies may be able to negotiate advantages on future equipment purchases that non-participants will not have.

- If the development process is successful, other PWB manufacturers will be able to purchase the tool at a later date; therefore, the entire industry benefits.

ITRI believes that this process can become an industry asset in the future, and that the Supplies Council can assist in promoting and enhancing it.

The development and implementation of a "Cost of Ownership" model has proven to be very successful in the capital decision making process in other industries. ITRI has several members who are interested in working on a project related to "Cost of Ownership". The Suppliers Council could add significant value to this activity if they would also adopt it as a project.

The IPC publishes a national technology roadmap every two years. It would be valuable to the industry if the Suppliers Council published a short response to the roadmap showing the suppliers capability and potential for meeting the targets set in the roadmap. This approach greatly enhances the activities for researchers at Universities and Government Labs. They will be better advised as to where to apply their resource.

ASSOCIATION/CONSORTIA ROLE

Associations and Consortia will play a very significant role in the success of the PWB manufacturing industry in the next few years. Consortia in the United States have been around since the 1970's. Many people give the electric power industry the credit for creating the first consortia in the U.S. It was formed in 1973, and was, and still is called the Electric Power Research Institute (EPRI).

An interesting fact that has been proven several times is that consortia are generally formed by corporate executives that have the authority to commit corporate resource. These executives are strategic in their thinking and visionary in their ideas. They initiate the consortia with a long-term payback mentality. After the consortia is formed membership activities are passed down to more tactical operatives. These people want results quicker and the projects quickly move to closer in activities.

A consortia in any industry generally has three attributes:

- They are attractive to firms that are interested in, and benefit from a broad R&D agenda like the larger PWB manufacturers. These companies have greater resource for implementing consortia research activities.

- Consortia will focus on low – risk activities with near term horizons. This means that consortia focus more on development than research. Since their members want returns for their investment, development benefits come sooner. Development also is more product focused than research is, and products provide revenue. Also consensus – driven decisions favor low – risk, near term projects.

- Successful projects will occur in areas in which standardization offers greater benefits than differentiation.

If consortia like ITRI, NEMI or PMTEC are to be successful, they must design projects that have appeal across all of their membership, PWB manufacturer, EMSI member, supplier, large company, small company, etc.

Like ITRI, NEMI has a mixed membership of manufacturers, suppliers and OEM's, but NEMI is focused on a different level of activity than ITRI. ITRI's primary focus is on PWB / PWA manufacturing and the activities on the manufacturing floor. NEMI stands back and takes a higher level view. They focus on the final product and all of the different components of product management. Displays, data Storage, Modeling and Simulation, Floor Control are as much of a NEMI focus as is interconnect technology. This different view is good for the interconnect industry and we would do well to help NEMI grow and continue their role. Jack Fisher is a member of NEMI's Technical Committee and helps to set the NEMI technical plan for the future. Jack is also a NEMI TWG chairman and he chairs the NEMI Organic Interconnect Technology chapter in the NEMI roadmap. Thom Dammrich and David Bergman are also active in NEMI meetings and this activity should continue.

PMTEC is a new consortium and is still developing their model. PMTEC is associated with the U.S. Army Aviation and Missile Command, and will always have a military focus. This is one of the methods by which the U.S. Government can partner with and support Interconnect Industry R&D. ITRI and PMTEC have developed a close relationship, and the IPC and ITRI must continue to support the PMTEC concept.

Other consortia and organizations which have an interest in the Interconnect Industry are: SEMATECH, The Georgia Tech Packaging Research Center, The High Density Packaging Users Group, NCMS, EMPF, The Integrated Electronics Engineering Center of the State University of New York (SUNY), and Auburn University. ITRI has a close working relationship with all of these organizations. This relationship needs to continue to insure that our resources are focused on the highest priority issues, and that duplication is avoided.

GOVERNMENT'S ROLE

Research and Development in the U.S. has changed significantly over the past 10 years. New paradigms for R&D have begun to emerge in the public as well as the private sector. The leading supporter of U.S. R&D, the federal government, is very unclear as to the magnitude of it's future support.

International economics, balanced budgets, and a call to end corporate welfare all effect the congressional R&D policy. Federal support for R&D has been an on-again off-again matter. In the past, the portion of federal R&D support that has been devoted to interconnect technology has been very small. Complacency or resignation to this position is a losing position for the industry, and we can change the status quo. Efforts by ITRI, the IPC, and the member companies resulted in a focused Interconnect Technology area within the Advanced Technology Program (ATP), and the funding of PMTEC. We, the interconnect industry, must continue to lobby for federal R&D. We must develop our relationships with

the academic R&D world, and, most of all, we must have a documented plan that addresses the interconnect industries position today and provides a clear path to tomorrow. This plan should be developed through the industry roadmap activities, and will guide our future efforts for Government R&D support.

UNIVERSITY ROLE

The PWB industry has not been extremely successful to date in tapping into the university research base. There are a few universities who do research in PWB technology, but it is very limited. It appears that Georgia Institute of Technology (Georgia Tech) has the biggest interconnect budget. Others that have some interconnect technology activities include Auburn University, Cornell, Binghamton University, Florida International, R.I.T., and Univ. of Maryland. NEMI recently published a list of 19 universities doing research in some form of packaging.
The authors believe that the industry needs to form a PWB Interconnect Research Council, which includes members of University and Government Research organizations. This group should meet at least once a year to listen to current activity reports and to strategize together where the PWB research dollar should be spent. To make this large scale activity successful and ongoing, the IPC, NEMI and ITRI should jointly sponsor the activity.

The IPC sponsors two annual events for PWB and PWA manufacturers, the IPC Printed Circuits Expo and the IPC/SMEMA APEX Conference. University representatives have always been a part of these conferences, but they have been spread throughout the conference agenda generally discussing the university's role in an existing activity. One new suggestion is to have specific session on far reaching university research giving the universities a chance to showcase their research activities. The session leader should be a recognized university or government lab researcher.

SUMMARY

The underlying theme of this paper is that the Domestic Electronics Interconnection industry needs to change if it is to remain competitive. The authors have discussed change with many different segments of the industry on numerous occasions. Generally everyone agrees that change is needed, however most of them first point to another segment of the industry when making suggestions for change.

This paper was written with a total industry perspective. Everyone associated with the industry needs to change. We have made recommendations to OEM's, PWB manufacturers, suppliers and to consortia such as ITRI. We did not consider a segment's size, past history of contributions, or other status. Taken incrementally, some of the recommendations may seem trivial. However, as a whole, where each and every segment of the business participates in doing their part, these recommendations will make the U.S. interconnect industry more competitive. The authors recognize that there are other things that need attention, but for the sake of brevity, we have selected those things that we feel are a priority. ITRI hopes that this paper will be a living document and continue to evolve.

ITRI has changed since its inception. Some of our projects have been very successful, some not so successful. Our membership has changed. Some of the small fabricators that joined ITRI in 1994 are now part of a much larger corporation. The small corporation and the large corporation have different needs and we must accommodate both of them.

The PWB industry will continue to consolidate, and to transform. OEMs will continue to outsource and evolve toward becoming "system integrators" instead of manufacturers. The large EMSI companies will

become more like pseudo or virtual OEMs. Some PWB manufacturers will continue to be profitable while others will not and will disappear.

Implementing these recommendations will not stop the OEM from becoming a non-manufacturing entity. Implementing these recommendation will not stop the EMSI corporation from continuing to grow and become more like OEMs. Implementing these recommendations will assist the well managed PWB manufacturer in becoming more competitive and gain back lost market share for the U.S.

The following is a summary by industry segment of the recommendation made in this report:

ITRI

- Continue to identify the different sectors in the industry (large/small, HDI/Non-HDI, high volume/ prototype, etc.) and ensure that Members from each sector get a return on their investment in ITRI.
- Actively recruit receptors for all ITRI projects
- Provide a better explanation of the benefits of ITRI projects to all ITRI members.
- Develop projects on laminate electrical, mechanical and environmental performance improvement.
- Implement an industry fabricator process improvement roundtable.
- Develop a software toolset for manufacturing control of cost and performance metrics.

OEM's

- Translate product technical requirements into supplier deliverables.
- Provide detail on features, densities, lead times, and demand.
- Provide world wide benchmarking insight to U.S. manufacturers.
- Provide data to the industry on expected cost per feature vs. feature density increases.
- Provide technology, cost, and business roadmaps to the industry.
- Develop and commit to success criteria factors such that fabricators who meet those criteria can expect a continuing business relationship.

EMSI

- Understand their unique position as a communication bridge between the OEM and PWB fabricator. Technical problem solving, new product information, design and specification understanding and tradeoffs are all part of the daily business.
- The EMSI provider must accept the responsibility to obtain the necessary information and provide that information to the PWB manufacturer.

PWB Manufacturer

- Make a commitment to technology development. Document your technology roadmaps, manufacturing capacity, and investment plans, and share them with the customer. Demonstrate your commitment to yields and quality improvement by collecting and sharing actual line performance improvement over time. Most of all, show a commitment to the customer by having a corporate manufacturing executive personally deliver and explain the above data.
- Make a commitment to participate in cross industry activities, such as the proposed fabricator process improvement roundtable, that are designed to share best of breed and benchmarking information between suppliers.

Suppliers

- Actively promote the development of leading edge capital equipment, using processes like the ITRI electrical tester project. Encourage PWB manufacturers to work together to develop common specifications that meet both supplier and user needs.
- Actively promote and participate in the development of a "Cost of Ownership" model that is structured similar to the Sematech version.
- Publish a supplier's technology roadmap that is designed to be a response to the IPC technology roadmap, in which the suppliers technology capabilities and plans are shown.

IPC

- Form an Interconnect Technology Research Council that meets periodically to discuss research and development needs in the industry.
- Provide the academic community with a specific forum at Expo and Apex so those researchers have a place to showcase their long-range research activities in interconnect technology.

The future of the interconnect industry in the U.S. has many challenges, but it also has many opportunities. Those manufacturers who put on blinders and continue with "business as usual" in this fast changing environment, will have difficulty profiting from the new opportunities. Those manufacturers who embrace the changes, and utilize the tools and resources available from all of the industry segments, will take advantage of what the future has to offer. This document has attempted to define the industry segments, and suggest actions that can be taken by each one to meet the challenges. Now the hard work of implementing those changes must begin.

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