The Journey: Evolution of Printed Circuit Boards

In the past 50 years, the PCB technologies grow tremendously in different aspects and find wide applications in different areas. In the 2010 International Printed Circuit & Electronics Assembly Fair held at Shenzhen Convention & Exhibition Center on Dec 1-3, 2010, a specially designed pavilion showcased 44 pieces of printed circuit boards from 1950's to 2000's. It provided a good chance for visitors to take a close look at these rare boards and got to know the development history of PCB technologies. Below is the summary of the PCB characteristics at different decades.

1950's

Technology: Printed circuit board conductor width and spacing was 1⁄8 of an inch. Spacing on a connector was 5⁄32 of an inch (0.15625). Printed circuit boards were single sided cooper on paper-based phenolic substrates called XXXP. No plated through holes. Artwork for printed circuit boards was developed using black ink on cardboard or crepe tape on Mylar. Paste-down decals were used to define lands.

Industry Issues: Dimensions and tolerances. Discrete thru-hole components drove PCB performance.

1960's

Technology: Printed circuit board conductor width and spacing was 0.060 inches. Metal eyelets were used to connect the top and bottom of the printed circuit board creating a double sided PCB. Connector pitch was 1⁄8th of an inch (0.125). Research began on plated through holes and multilayer PCBs. Substrate was G10 epoxy and composite laminate. This decade marked the beginning of the IC industry.

Industry Issues: Semiconductor package and mounting. The reliability of plated through holes were questioned (etch back versus non etch back). Automated drilling was introduced making registration critical between the artwork and the drilled holes.

1970's

Technology: 0.100 inches became a standard measurement for the connector and component pins (dual in line package). As a result, printed circuit board conductor width and spacing was 0.100 inch pitch. Precision artwork was created using a mechanical photo plotter. Conductors ran mostly orthogonally – horizontal and vertical. For the first time, conductor routing was between lands on 0.100 inch centers.

The substrate used was FR4 glass epoxy. Glass polyimide substrates were used for military applications. Experimentation on multilayer boards and testing of multilayer and plated through holes continued in this decade. Standard layer count was 12 layers. In the late 70's, the pin grid array was introduced to increase performance and began to replace the dual-in-line package.

Industry Issues: Standardization of computer aided design artwork. Use of photo tools in manufacturing improved registration problems. However, high precision and complex designs required glass master artwork used to solve critical registration issues. It took the PCB manufacturer 4 weeks to produce a multilayer board. Customers were concerned about the throughput of multilayer board manufacturing.

1980's

Technology: Printed circuit board conductor width and spacing was .008". According to IPC data, a majority of PCB produced were split evenly between 3-4 layers or 5-8 layers. A JPCA report in March 1987 shows that 84% of the multilayers produced in Japan were 3-4 layers. Over 70% of the PCBs produced in the U.S. were either one or two conductors between lands on 0.100" centers. Liquid film solder mask in 1987 were used on nearly 70% of all printed circuit boards.

Surface mount applications for PCBs grew from 2% in 1984 to 30% in 1987. According to IPC statistics only 12% of the PCBs had surface mount parts on both sides.

The global market for PCBs in 1980, as estimated by the IPC, was $265 million. The regional break down was:

- North America: $146 million
- Europe: $30 million
- Asia and Australia: $75 million
- Rest of World: $14 million

Industry Issues: The difficulty and the cost of producing SMT PCBs. The shift in SMT dramatically shifts the hole sizes in PCBs with some estimating that 30% of all holes in PCBs 1986 will be .029" and under. As holes sizes decline, the cost of drilling goes up dramatically. In addition, reduced width of PCB traces require more sophisticated solder mask material and equipment.

1990's

Technology: The following table is reproduced from the IPC's "National Technology Roadmap for Electronic Interconnections" published in 1995.

ATTRIBUTE	**Conventional Technology (Production)**	**Threshold Technology (Limited Production)**	**Leading Edge/State-of-the-Art (Limits of Today's Technology)**
Line Width/Line Space (min.)	125 µm/125 µm	100 µm/100 µm	50 µm/50 µm

Plated Hole Diameter (minimum)	350 µm	250 µm	150 µm
Board Thickness @ 6 Layer	0.6 mm	0.4 mm	0.4 mm
Laminate Type	FR-4/Polyimide	C.E./Polyimide	Teflon
Surface Mount Pitch	0.5 mm	0.4 mm/0.3 mm	0.25 mm
Glass Transition Temperature	25°C	140-150°C	170-185°C

The world market for Rigid PCBs in 1995 according to the IPC was $24 billion. The regional break down was:

- Americas: $6.9 billion
- Japan: $6.5 billion
- Asia and Australia: $5.8 billion
- Europe: $4.4 billion
- Rest of World: $.4 billion

Industry Issues: Continued integration of surface mount technology. Elimination of CFCs prompted the industry to develop cleaning alternatives including "no clean" operations. Ball grid array (BGA) drives miniaturization and PCB density. Multichip modules and direct chip attachment were also developed to increase signal speed and reduce interconnection area.

Future requirements for PCB were predicted to be:

- Silicon packaging determines PCB design.
- Finer and finer pitch would lead to finer and finer lines.
- High clock speed would drive electrically sound designs.
- Would totally dry processing of PCBs replace wet chemistry?

2000's

Technology: The Table represents the status of technology in the rigid board industry for 2010. Conductor (line) width and spacing of 40 µm on conventional FR-4 processes are available in limited production quantities; 35 µm lines and spaces are available only from very selected fabricators. Microvia technology is used on most of the package and module substrates; however, it is not used on conventional printed boards, because products in those markets, allow more liberal tolerances.

This fact is changing as designers find that they can reduce layer count by adding High Density Interconnect (HDI) layers. Microvias today show up in threshold and state of the art products, as exemplified by their use in high-end laptop computers and video recorders, and in special niche markets. These products are being produced with >75 µm lines and spaces.

	CONVENTIONAL Available from 85% of the industry fabricators		**LEADING-EDGE** (Limited Production) Available from 15% of the industry fabricators		**STATE OF THE ART** Available from less than 1% of industry fabricators	
	Rigid Board	**Microvia**	**Rigid Board**	**Microvia**	**Rigid Board**	**Microvia**
Conductor width/ Line space	75 µm /75µm	N/A	50 µm/60µm	40µm/45µm	35µm/35µm	30µm/30µm
PTH hole size (un-plated)	200-150 µm	N/A	150 µm	75 µm	100 µm	40 µm
Drill Capture Land Size	350 µm	N/A	250 µm	175 µm	150 µm	70 µm
Buried passive components	No	No	Very limited	Yes	Yes	Yes

For the first time in 2008, China/Hong Kong with $12 billion in production became the world's largest producer of PCBs surpassing Japan. China/Hong Kong continues to be the world's largest producer today. The world market/production for rigid PCBs in 2009 was $37.4 billion.

Industry Issues: The issues for rigid printed boards relate mainly to the conductor, spacing and plated hole geometries. In addition, environmental directives and regulations gain a prominent role in the PCB industry.

The Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment 2002/95/EC (Commonly referred to as the Restriction of Hazardous Substances Directive or RoHS) was adopted in February 2003 by the European Union. The RoHS directive took effect on 1 July 2006, and is required to be enforced and become law in each member state. This directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. The key impact of RoHS to the PCB and electronics assembly industry was/ is the ban on lead and its impact on electronic grade solder. The ban on lead forced the introduction of lead free solders as well as the development of new materials which can withstand the higher processing temperatures required by lead free soldering. Many in the electronic interconnection industry are still concerned about the performance of lead free solders in high reliability applications.

More and more materials and processes in the electronic interconnection industry will be impacted by environmental regulations and legislation.

行業進程：印製綫路板的發展之路

過去五十年，印製綫路板的發展一日千里，在不同的領域被廣泛使用。在去年 12 月 1 日至三日在深圳會展中心舉行的 2010 年度國際綫路板及電子組裝展覽會上，特別展出了 44 件從 1950 年代到 2000 年代生產的綫路板，讓觀衆有機會近距離欣賞這些難得一見的展品，回顧過去 50 年間綫路板技術的跳躍性發展。 以下是不同年代綫路板發展的特徵概要。

1950 年代

技術：綫路板導線寬度和間距爲 1 / 8 英寸。連接器間距爲 5 /32 英寸（即 0.15625 英寸）。綫路板爲紙基酚醛樹脂基板的單面板，稱爲 XXXP，無鍍通孔。最早是用墨水在卡板紙上或者用膠帶在聚酯膜上粘貼出線路板上的走線圖形，用不同形狀的貼紙粘貼在上面代表焊盤圖形

行業熱點話題：尺寸和公差。分立通孔器件的發展驅動著 PCB 性能的提升。

1960 年代

技術：綫路板導線寬度和間距爲 0.060 英寸。金屬扣眼用來連接綫路板的上面和下面從而生成了雙面板。連接器間距爲 1/8 英寸（即 0.125 英寸）。鍍通孔和多層板的研究開始起步。 基板採用 G10 的環氧樹脂及複合基材。這十年標誌著積體電路工業的開端。

行業熱點話題：半導體封裝。鍍通孔的可靠性遭質疑（回蝕與非回蝕）。自動鑽孔被引入用於解決鑽孔和底片之間的精確對位問題。

1970 年代

技術：0.100 英寸成爲連接器和元件引腳（雙列直插封裝）的標準量度。因此，綫路板導線寬度和間距爲 0.100 英寸。採用機械成像繪圖器製作精密底片。導線主要以正交多導體爲主 – 水準及垂直。焊盤間印製導線最早的間距是 0.1 英寸。

基片使用 FR4 玻璃環氧樹脂板料。聚醯亞胺玻璃基板應用於軍事產品上。多層板和多層及鍍通孔測試的實驗在此十年間持續進行。多層板的標準層數爲 12 層。70 年代後期，針柵陣列被引入並開始取代雙列直插式封裝以提高電子產品性能。

行業熱點話題：電腦輔助設計底片標準化。製作工藝上採用照相的工具，以改進對位問題。然而，高精密和複雜的設計中需要原始玻璃底片來解決精確的對位問題。生產一塊多層綫路板需要 4 周時間。客戶關注的是多層板的生產量。

1980 年代

技術：綫路板導線寬度和間距爲 0.008 英寸。根據 IPC 資料，大多數綫路板是 3-4 層或 5-8 層板。據 JPCA 的 1987 年 3 月調查報告，日本生產的多層板有 84%爲 3-4 層板。美

國生產的綫路板有逾 70%是 0.100“中心的焊墊之間有一條或兩條導線。 1987 年將近 70%的印刷電路板採用液膜阻焊。

綫路板表面貼裝的應用也從 1984 年的 2%上升至 1987 年的 30%。根據 IPC 統計，只有 12%的綫路板兩面均採用表面貼裝。

據 IPC 估計，1980 年全球綫路板市場規模爲 2.65 億美元。地區產值分佈如下：

- 北美：1.46 億美元
- 歐洲：3 千萬美元
- 亞洲和澳大利亞：7500 萬美元
- 世界其他地區：1400 萬美元

產業熱點話題：綫路板表面貼裝生產中遇到的困難以及成本問題。表面貼裝製程出現明顯變化： 1986 年估計有 30%的綫路板孔徑爲 0.029 英寸及以下。隨著孔徑逐漸減小，鑽孔的成本大幅度上升。此外，由於 PCB 走線寬度減少，則需要更高級的阻焊材料和設備與之匹配。

1990 年代

技術：下表是轉載自 IPC1995 年出版的“國家電子互連技術路線圖”。

屬性	**傳統技術（生產）**	**門檻技術（限量生產）**	**尖端技術（當今最高技術）**
線寬/線距（最小）	125 微米/125 微米	100 微米/100 微米	50 微米/50 微米
鍍通孔直徑（最小）	350 微米	250 微米	150 微米
6 層板厚度	0.6 毫米	0.4 毫米	0.4 毫米
板材類型	FR-4/聚醯亞胺	C.E./聚醯亞胺	鐵氟龍
表面貼裝間距	0.5 毫米	0.4 毫米/0.3 毫米	0.25 毫米
玻璃轉化溫度	25°C	140-150°C	170-185°C

根據 IPC 資料，1995 年全球綫路板（硬板）市場的產值爲 240 億美元。地區產值分佈如下：

- 美洲：69 億美元
- 日本：65 億美元
- 亞洲及澳洲：58 億美元
- 歐洲：44 億美元
- 世界其他地區： 4 億美元

行業熱點話題：表面貼裝技術不斷整合。CFC（全氯氟烴）禁用促使行業發展清潔的替代品，包括“免清潔”行動。球柵陣列（BGA）封裝促使電子產品小型化及 PCB 綫路更密。多晶片模組和晶片直接附著的發展起到了提高信號速度和減少互連面積的作用。

預測未來綫路板要求將是：

- 矽包裝決定 PCB 設計。
- 精細，更細間距會導致線路越來越細。
- 高頻將驅動電聲設計誕生。
- 幹流程將完全取代化學濕流程？

2000 年代

技術：以下表格代表了 2010 年的硬板技術狀況。傳統的 FR － 4 工藝可在限量生產中實現 40 微米的導線寬度和間距; 只有很少的綫路板廠商可達到 35 微米的線寬和間距。大部分的模組基板和封裝採用微通孔技術，但是傳統綫路板因爲產品公差更大，所以沒有應用微孔技術。

這一事實正在改變，因爲設計師發現通過加入高密度互連（HDI）層可以減少多層板層數。今天微孔作爲一個技術門檻出現在尖端產品中，例如高端筆記型電腦及錄影機的應用以及特殊的利基市場的產品應用。線寬與綫距在這些產品中大於 75 微米。

	傳統技術 85%PCB 製造商可達到		**先進技術** （限量生產）15%PCB 製造商可達到		**目前最先進** 小於 1%的 PCB 製造商可達到	
	硬板	微孔	硬板	微孔	硬板	微孔
綫寬/ 綫距	75 微米/75 微米	N/A	50 微米 /60 微米	40 微米/45 微米	35 微米/35 微米	30 微米/30 微米
鍍通孔孔徑（無鍍銅）	200-150 微米	N/A	150 微米	75 微米	100 微米	40 微米
鑽孔連接盤尺寸	350 微米	N/A	250 微米	175 微米	150 微米	70 微米
嵌入的被動元件	無	無	非常有限	是	是	是

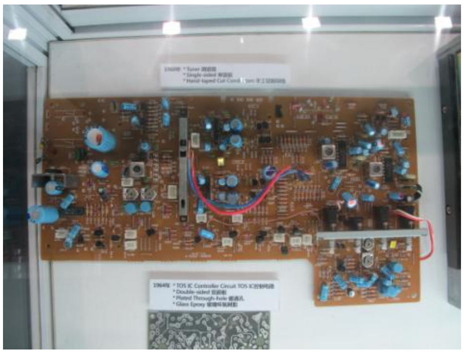
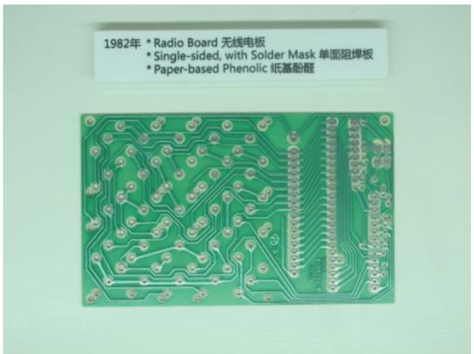
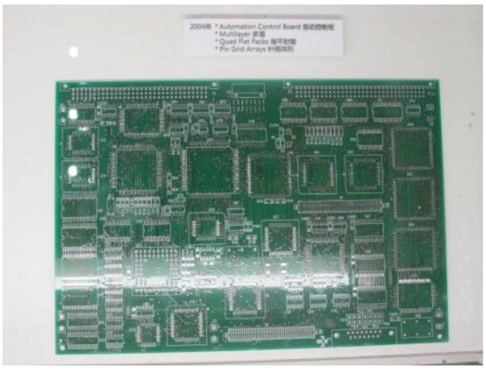
2008 年，中國（包括香港）綫路板產值以 12 億美元首次超過日本成爲世界最大綫路板生產國。今天中國（包括香港）仍是世界最大綫路板生產國。2009 年全球 PCB 硬板產值爲 374 億美元。

行業熱點話題：硬板的問題主要涉及導線，間距和金屬化孔的幾何形狀。此外，環保指令和法規對 PCB 行業有重要影響。

2003 年 2 月歐盟通過對“電器及電子設備使用某些有害物質的限制 2002/95/EC”限制指令（通常稱爲 RoHS 或有害物質限制指令）。 RoHS 指令已於 2006 年 7 月 1 日生效並執

行，已經成爲歐盟各成員國的法律。該指令限制在各類電子和電氣設備製造中使用六種有害材料。RoHS 指令對綫路板和電子組裝行業的重大衝擊是鉛的禁用和給電子焊料帶來了極大的影響。鉛的禁用迫使無鉛焊料的引進以及發展能承受要求較高加工溫度的新材料。電子互連行業許多人士現今仍然擔心在高可靠性應用中的無鉛焊料的性能。

電子互連行業中將有越來越多的材料和工藝受到環境法規和法律的影響。

 Single-sided, hand-taped cut conductors board for Tuner (1960) 調諧器之手工切割導線單面板（1960）	 Single-sided, with solder mask; paper-based phenolic radio board (1982) 單面阻焊紙基酚醛無線電板（1982）
 Video Card Assembly (2005) 視訊卡組件（2005）	 Pin Grid Arrays， Quad Flat Packs， Multilayer Automation Control Board (2004) 針柵陣列扁平封裝自動控制多層板（2004）