The Circuit Centennial

By Ken Gilleo, Ph.D.
ET-Trends
gilleo@ieee.org

Introduction

1903 was an important milestone for technical innovation. The Wright Brothers demonstrated sustained flight at Kitty Hawk, NC. Guglio Marconi proved that wireless communication across the Atlantic Ocean was possible. There were many other achievements, but these two stand out. Yet there is an even more important technical milestone in 1903 and its ramifications have been profound. In fact, the invention we are about to discuss is the grand enabling technology of almost everything else including flight and communications. Without this invention, the all electronics including computers and PDAs, nearly all transportation, telecommunications, electricity and 10's of thousands of other products could not exist. In fact, if this key invention were to suddenly disappear, the world as we know it would end throwing us into catastrophic chaos.

The 19th Century Telecommunications Revolution

Dateline Dec. 31, 1899

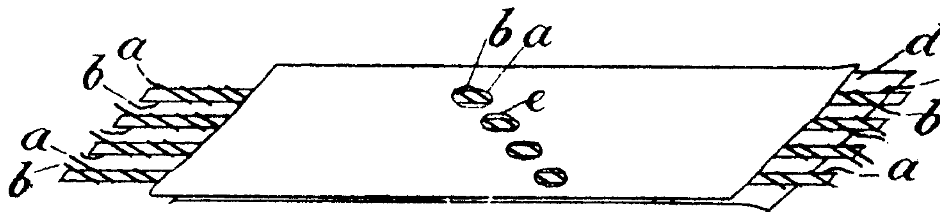
The Morse telegraph key had celebrated its 50th birthday and the Western Union Company had been in business for a half-century. Alexander Graham Bell had proven telephonic communication and the telephone and telegraph were now essential communication links in countries throughout the world. Marconi had already transmitted messages across the Atlantic, but it would still be a few years before Fleming would perfect the vacuum tube, the first diode (the Fleming Valve), and Lee De Forest would build the first triode amplifier (Audion) to fully enable wireless broadcasting. Marconi would later share the Nobel Prize for his wireless contributions. We had already entered the *Information Age*.

The embryonic electronics industry, consisting of telegraph, telephone and radio, was off to a strong start as we entered the new century. All of these communication industries were rapidly expanding, creating an immense need for circuitry - mass-produced circuitry! The telephone systems, with their hundreds of phone exchange lines, required manual switching units, or PBX consoles, that would allow operators to make line connections. The increasingly complex radio circuits needed an alternative to tedious and error-prone hand wiring if the technology was to become as wide-spread and far-reaching as that industry envisioned. The electronics industry sought circuit technology that could enable mass production and automation.

The Circuitry Concept

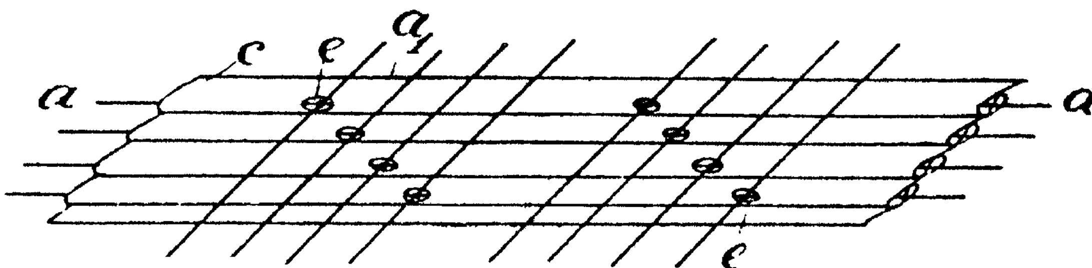
The year was 1903 when Albert Hanson, of Berlin, filed his "printed" wire patent in England. His invention was aimed at solving the telephone exchange need. The Hanson process, although not a true "printed circuit" method, did produce conductive metal patterns on dielectric substrate. Metal foil was first cut or stamped out into conductor patterns. The copper or brass traces were then adhesively bonded to paraffined paper and the like. This appears to be the first documented circuit invention. Figure 1 shows the basic concept scanned from the actual patent figures.

Figure 1 - Hanson Figures



But Hanson added some additional innovations that can still be considered “modern” circuit principles. This circuit inventor had already realized that high density would be of great importance and he therefore designed his circuits with conductors on both sides as can be seen in Figure 2. Also recognizing that inter-layer connections were critical, he added access holes to permit the top and bottom conductors to be selectively connected together. Although the connections were crude crimping and twisting, his 1903 invention clearly describes double-sided through-hole circuitry. Hanson also stated that conductors could be formed *in situ* by electrodeposition or by applying metal powder in a suitable medium (conductive ink). We find it remarkable that the first circuit patent touched on so many concepts that are considered to be of modern origin.

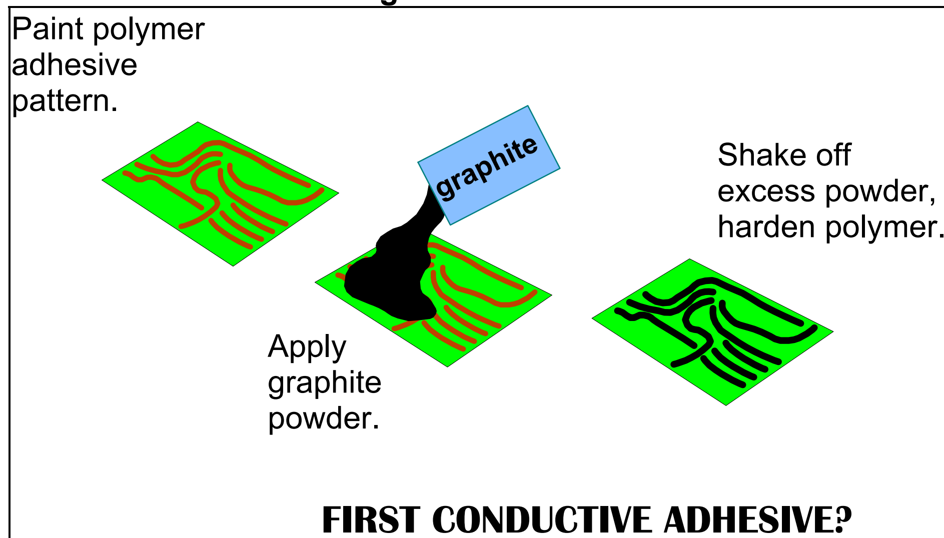
Figure 2 - Hanson Figures



Thomas Edison, who had recently commercialized the first incandescent electric light bulb, also tackled the printed wire problem. When asked by friend Frank Sprague, founder of Sprague Electric Co., how to “draw” conductive traces on paper, Edison offered several ideas in a written response. The approaches included (1) selectively applying glue (polymer adhesive) and dusting the wet

“ink” with conductive graphite or bronze powder, (2) patterning a dielectric with silver nitrate solution and reducing the salt to metal and (3) applying gold foil to the patterned adhesive. While Edison, in his short note, did not mention printing, the first two methods could be easily adapted to several printing processes. In fact, the concept (1) of using polymer-based adhesive with conductive particles, is the basis for today's Polymer Thick Film technology which continues to gain importance because of its low cost and intrinsically clean attributes. Figure 3 shows the Edison PTF concept that will be encountered dozens of times in later literature. Concept (2) is actually electroless plating, a method used today. Perhaps if Edison had worked the problem, he would have included copper plating and vacuum deposition since America’s most prolific inventor had already patented these processes[3]. We should note that Edison’s approaches are ADDITIVE.

Figure 3 - Edison



Several other ideas emerged over the next several decades as electronics continued to expand at an exciting pace. Radio soon became the most important driver for printed circuitry. Wireless was capturing the attention of the world. The first public radio station, KQW - San Jose, CA, had gone on the air in 1912. By the end of the second decade of the 20th century, radio had been introduced to most of the major countries. Ships now carried the Marconi radio system and the wireless was beginning to save lives. Soon, there could be a radio in every household as predicted by David Sarnoff who headed RCA and NBC. Electronics pioneers could see the immense market for mass-produced circuits and inventors were strongly motivated to answer the challenge of electronic interconnect.

Subtractive or Additive?

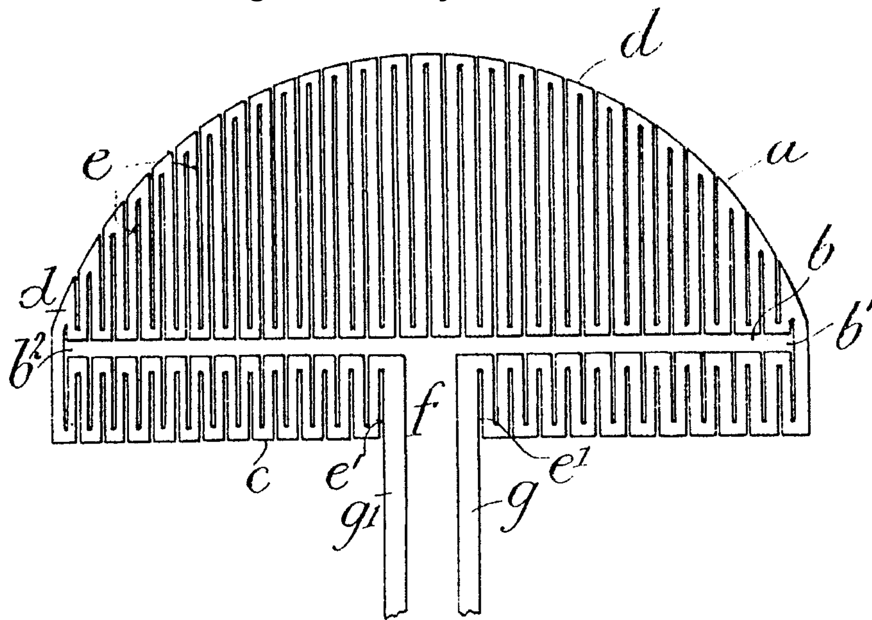
The earliest circuit principles were based on additive, or build-up methods. Conductors were deposited onto dielectric. This, of course, is the most straight-

forward approach and the most obvious process. However, the printing industry had long used subtractive methods for making plates. Initially, wood had been carved away to yield raised letters and graphics. Later, metal was cut and finally etch away to make printing plates. Acid etching had been known for centuries since acid was easily produced by natural processes including fermentation.

In 1913, Arthur Berry filed for a patent[4] which claimed a method of making circuits where metal was etched away. He described the process of coating metal with a resist, prior to etching, as an improvement over die cutting which left stress concentrator sharp corners. Berry appears to be the first to describe etched circuitry. Figure 4 shows his etched heater circuit. Later, Littledale[5] described a similar method.

Photolithography was well-know during the early days of circuit development, but the subtractive process was mostly ignored. Bassist[6] gave specific details of photoengraving including the use of photosensitive chromium salts. Although his patent dealt with print plate making, the process could easily be adapted for circuitry since Bassist described preparing compliant plates by electrodepositing copper foil onto dielectric laminate.

Figure 4 - Berry Heater Circuit



Early Commercial Circuit Processes

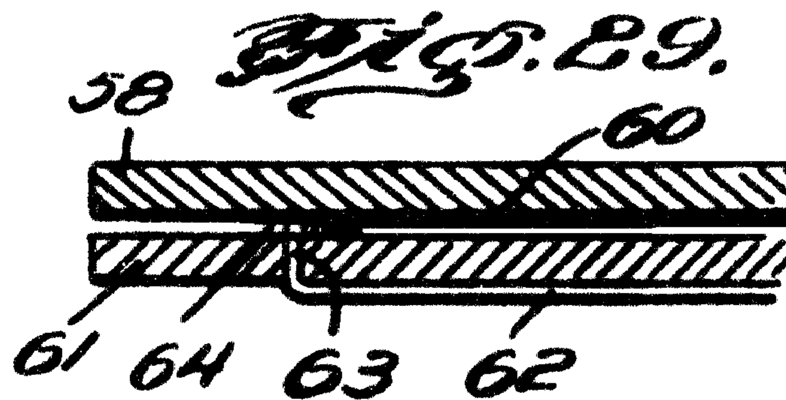
One successful inventor, Max Schoop, commercialized a metal flame spraying process that was used for many years. We need to keep in mind that early electronics was power hungry. Vacuum tubes required heated filaments and high voltages. The practical circuit of the vacuum tube era would need to carry substantial currents. The Schoop process, which could deposit thick patterns of

metal by flame spraying through a mask, produced the hefty and robust circuits that were required. Figure 5 shows the 1918 Schoop Process[7].

Figure 5 - Schoop Process

The Schoop flame spray approach had problems of cost and wasted metal and although subsequent inventors added improvements, a true printed circuit process was still needed. The next circuit inventor of note, was Charles Ducas[8], who described both etching and plated up conductors. One version involved electroplating a copper, silver or gold pattern onto a low temperature metal alloy through a contact mask. Heating allowed the conductor (typically a coil) to be separated from the fusible bus plate and mask. Another Ducas process involves forming grooves in dielectric such as wax and filling them with conductive paste (composition not disclosed). The paste is then electroplated. Conductive paste could also be printed, or stenciled onto dielectric and then electroplated. Both sides of the dielectric layer could be used for circuitry. In fact, Ducus goes on to describe multilayer circuits and a means of interconnection layers, “Two or more panels may be positioned adjacent to each other...”. “Figure 6 (patent Fig. 29) shows a method which may be employed for interconnecting the circuits of different planes. The electroplated metal forming conductor 62 extends through an aperture in a panel ... which in turn contacts with conductor 60 on panel 58”. Croot, of Paragon Rubber, also described filling grooves and electroplating[9].

Figure 6 Ducas-29

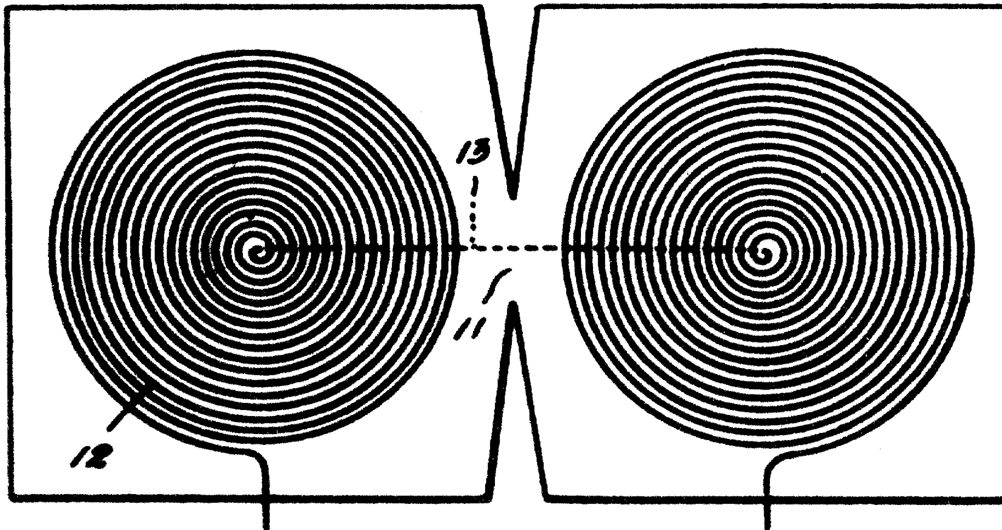


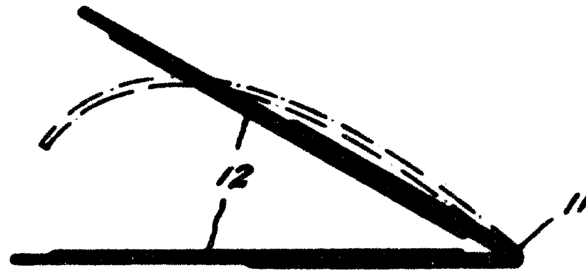
A year later, Frenchman Cesar Parolini came up with improvements in the field of additive plating[10]. He patented the printing of patterns with adhesive onto dielectric followed by applying copper powder to the wet ink. The excess copper particles were shaken off and the ink hardened with heat. This is the basic Edison concept and one of the Ducas methods, but Parolini reduced it to practice and added one more concept - jumpers or cross-overs. “U” shaped metal wires were imbedded into the wet conductive ink which was then hardened. Electroplating forms continuous metal over the copper ink and also plates the jumpers to the conductors. Figure 7 shows the Parolini Process complete with a jumper.

Figure 7 - Parolini Circuit with Jumper

Other inventors of that era also employed print & plate methods for circuitry. Seymour[11], used printed graphite paste to make the platable patterns. But this inventor was already moving into the flexible circuit niche. Seymour described “...pathways along or across which impulses may be conveyed, transmitted or regulated...” on “...flexible, relatively thin, pliable body...capable of being made to assume various forms...” He used waxed paper and gutta percha as the dielectric and graphite, lead and copper conductive pastes. Copper plating was the final step. Figure 8 shows this 1923 flexible circuit used as a radio tuner.

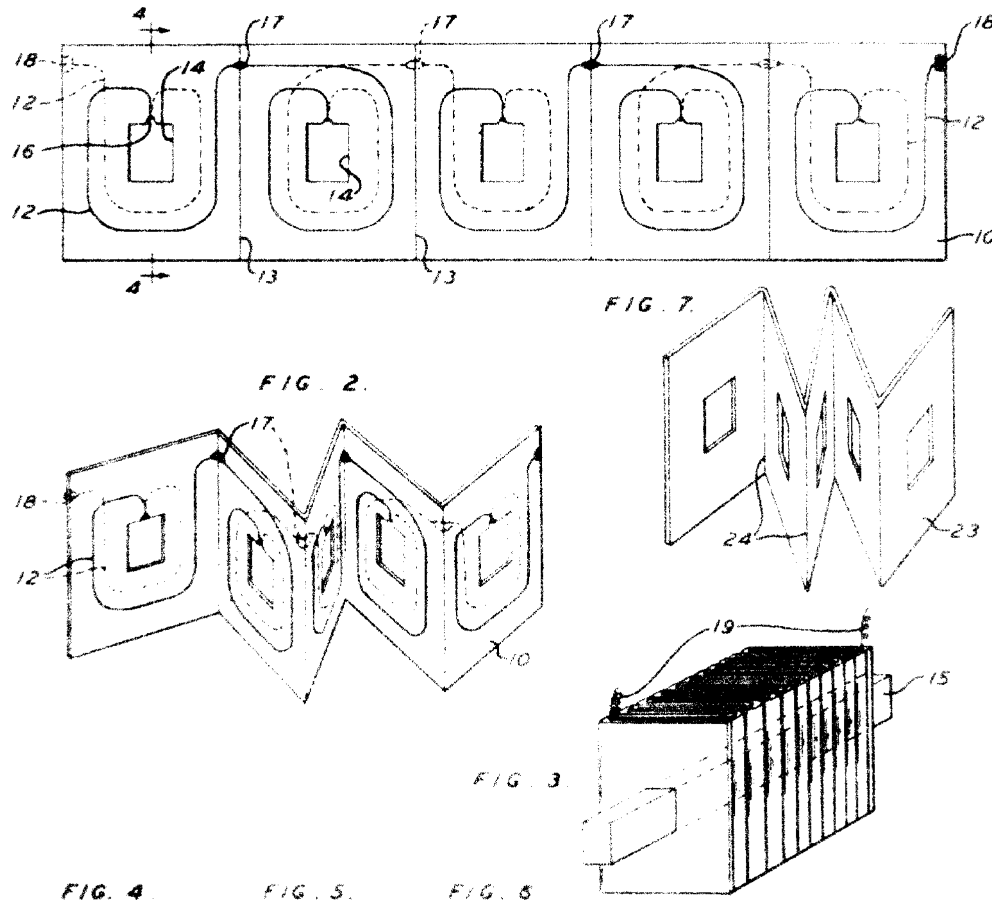
Figure 8 - Seymour (Fig.1,2)





A parade of other inventors quickly followed, but most proposed variations on the themes that had been disclosed by predecessors as is typically the case today. For example, Franz[12], in 1933, added conductive particles to the polymer ink. He made a printing paste with carbon filler that could be screen printed or stenciled onto cellophane or similar lamina. The hardened ink, although stable, had high resistance compared to metal. Franz, perhaps aware of the Parolini Process that was disclosed 7 years earlier, added a copper electroplating step. Once again, this concept has been used by modern circuit makers. Figure 9 shows a clever "accordion" circuit that Franz described in his patent. This is clearly a 3-D flex circuit principle. Surprisingly, the flex circuit industry has not yet fully utilized 3-D flex concepts. And what was the purpose of the accordion circuit? The Franz folding circuit was a replacement for windings in transformers as can be seen in Figure 9. Since the Franz invention, several modern circuit practitioners have attempted to re-invent the printed winding concept. While not all circuit inventions have yet been made, a search of early patents can be a humbling experience for the would-be inventor.

Figure 9 - Franz Accordion



The War Effort and Hybrid Circuits

World War II brought on circuit developments that took a different twist. The need for extremely robust microelectronics for military ordnance spurred development of ceramics. Secret projects developed highly reliable ceramic substrate and conductive inks, call cermets; ceramic-metal. This process, now widely practiced in the ceramic hybrid industry, involved screen printing or stenciling circuit inks, followed by high temperature firing. The process was used to produce tens of thousands of various ordnance electronic fuses and is discussed in great detail by Cadenhead and DeCoursey[2]. The war efforts resulted in both the development and optimization of high volume thick film printed circuit manufacturing. Note that the hybrid process and most of the earlier inventions are additive methods.

After the war, printed circuit technology was disseminated by the US government under the auspices of the National Bureau of Standards (NBS). Conferences were held and publications resulted that described virtually all of the circuit making concepts, including subtractive etching[13].

The US Government Defines Circuit Processes

[Note that we just got these gov't docuemnts and more will be added to this section, ken]

Now that the war was over, it was time to move printed circuit technology into the commercial sector. A Circuit Symposium, sponsored by the US Aeronautical Board and the National Bureau of Standards was held in Washington, DC in October 1947. Dozens of speakers and hundreds of attendees interacted in this unusually well attended conference. The more than two dozen processes were distilled down to six methods with a seventh included as an alternate step in some of these. The government settled on the following categories:

1) Painting (really Printing): Metal-filled inks are applied and cured or fired. This method includes Ceramic Thick Film (CTF) and Polymer Thick Film (PTF) and it remains a key method today. Application methods included, brushing, coating, pen writing, stenciling, printing and dipping. CTF and PTF utilized screen printing almost exclusively although conductive adhesives for component assembly are often stenciled. Printing is expected to remain an important process in the thick film circuit area for some time to come.

2) Spraying: Molten metal or composite conductor material is sprayed through a mask or stencil. The mask can be a resist applied to the substrate. Metal flame spraying was first described by Schoop[7] in 1918 and later by several others. The method achieved only limited commercial success because of high cost and waste. One alternative was to spray the entire substrate and then selectively etch away metal to form the circuit pattern. Spraying is an obsolete circuit process today.

3) Chemical Deposition: Electroless and electrolytic plating are included here. Dozens of early patents described electroless, electrolytic and combination plating. Chemical deposition remains an important process in many circuit making schemes. Electroless deposition of copper was patented[14] over a century ago, however. Thomas Edison's circuit concept of 1904 was to selectively apply electroless silver[2]. Chemical deposition methods can be expected to increase as additive, semi-additive and build up processes become more prevalent.

4) Vacuum Deposition: Sputtering and evaporation through a mask are the key processes mentioned. Thin film circuits are made by vacuum depositing copper, gold and other metals. Modern thin film processes involve applying the mask, or photoresist, directly to the substrate and removing after coating with metal. Although sputtering is gaining popularity today for producing adhesiveless flexible circuit substrate, Thomas Edison patented a metal vacuum deposition apparatus and process over 100 years ago[3].

5) Die Stamping: Many of the early patents claimed cutting and die stamping as the process for patterning conductors. More modern methods simultaneously bonded the weakly adhered metal foil to the substrate during the die cutting

process. This was accomplished by using B-staged adhesive and a heated die bed. The method, although low cost and environmentally friendly, is diminishing in use as tolerances become tighter and density demands increase. The major market for die stamping has been automotive instrument cluster circuits. General Motor's Packard Electric Division, used die stamping to produce hundreds of millions of automotive circuits. The process was abandoned in the 1980's as high tool costs and long changeovers, combined with higher density requirements, diminished the value of the process. The die stamping circuit process is still used today for very high volume runs of low density circuits.

6) Dusting (conductive powder over tacky ink): Application of graphite or metal powder over wet ink or adhesive is one of the earliest processes reported. Thomas Edison was apparently the first to suggest dusting graphite over pattern adhesive. As mentioned earlier, a dozen or more patents used the basic dusting concept, but with various improvements like electroplating. The dusting idea still seems to intrigue the modern circuit technologist as evidenced by recent patents. Some of the later patents apply solder to the dusted conductors[15]. However, Parolini in 1927, patented all the important elements of the process including overplating with copper.

Extra) We should note that the conference did not give subtractive chemical etching its own category. The majority of processes covered in the conference and in much of the early patent literature dealt only with additive circuit processes. The idea of applying metal to the substrate only to remove most of it in a later step, apparently did not appeal to the pioneers. The conference considered etching as an obvious auxiliary process that could be used, if really needed, with some other processes.

One more method mentioned, but not separated out, is "groove and fill", or channel circuitry. This involves forming grooves or recesses in the substrate, and filling them with conductive material. The two basic subdivisions are: doctor blading conductive paste into the grooves and using a fusible alloy (solder) that will flow off the board surface into the grooves. The groove and fill concept, mentioned by early inventors, still seems to attract modern technologists[16, 17]. The method has never been an important circuit manufacturing technique. However, over the past several years, circuit interposers (multilayer interconnects) have been made by doctoring conductive materials into holes in dielectric.

The Rise and Fall of the Father of the Printed Circuit

Paul Eisler began developing circuit manufacturing processes during the war era and perhaps as early as 1936 when he moved to England, although

documentation is lacking on his earliest claim. The goal of this Austrian was to develop a low cost, mass production circuit process. Eisler eventually obtained several British patents[18,19,20] dealing with the etching process. The method ultimately became the well-known photo etching process which is the most popular method now in use. The process steps are shown in Figure 10.

Figure 10 - Photo Etching Process

The printing industry had used etching for print plate making well before there was even a need for circuitry. Printing technologists had already perfected the copper etching process which initially used an etch resist that was mechanically patterned by scraping away with a sharp tool. During the 1800's, photo-sensitive coatings were discovered and perfected that enabled the widespread use of photoengraving. Eisler appears to have borrowed this well-established technology and imported it to the electronics industry, but was he really the first as he claimed?

The primary difference in the photoengraving process and Eisler's circuit-making method is the substrate construction. The printers used relatively thick copper plates while Eisler used copper foil laminated to dielectric, although some printing plates were made of copper laminate[6]. The thick copper plates were engraved by the etchant to a depth of several mills and copper typically remained at the base. Eisler's thinner copper was etched all the way through so that the patterns were isolated from one another. The Eisler patent referenced the print plate making technology and did not actually describe the etching chemistry. The phrase, "as used in the printing industry", is found throughout the Eisler circuitry patents.

Several years later, Eisler received several US patents[21,22,23] by referencing his British patents. There were a number of irregularities in the proceedings and the US patents were held up for about 4 years. Initially, the US Patent Office rejected all of the Eisler claims because of prior art, much of which, was covered in the earlier sections. After meetings and appeals, most of the patent claims were allowed, but there is no explanation by the patent office. A patent’s “file wrapper” normally contains all of the written communication as well as summaries of meetings. The patent examiner simply allowed the patent without explaining what had transpired in the meeting and why he had decided to ignore the substantial prior art that would seem to invalidate Eisler’s claims.

Now armed with US and British patents, Eisler commercialized circuit making under Technographic Printed Circuits, Ltd. All appears to have gone well for the company until it sought to limit competition by lawsuit. Technograph, through its US counterpart, Technograph Printed Electronics, Inc., sued The Bendix

Corporation that was producing printed circuits by an etching process in the US. The case came to trial in a lengthy process that essentially reviewed the entire history of printed circuitry *ad nosium*, as was pointed out by the weary judge. Eisler was not able to substantiate claims of earlier work and could not produce his “book of circuit samples”. His prime exhibit, a 3-tube radio receiver, never worked throughout the long months of trial.

Bendix, the defendant, countered with an overwhelming amount of prior patent art and asked that the patents be declared invalid. They pointed out that many, including, Spaulding[24] and Miller[24B], as well as Stevens and Dallas[25], had used photoetching to make circuits before 1940. Others, such as O’Connell[26], had used print and etch. But a key point argued in the trial was that Eisler had maintained claims in the US patents that had already been rejected in the earlier British patent filings. In other words, he was attempting to get US coverage by referencing non-existent documentation. Another important defense was that Eisler had simply patented well understood photolithography that had long been used by the printing industry. Certainly, Eisler’s own statements in his patents, supported this accusation.

On May 27, 1963, the case was decided, “Action by Technograph Printed Circuits, Ltd. and Technograph Printed Electronics, Inc. against The Bendix Corporation for patent infringement. Complaint dismissed.”[27] Eisler had been defeated and dethroned as the father of printed circuitry. Until the day he died, Eisler felt that he had been wronged by the system, but it is clear from the vast amount of prior art that he was not first. The printed circuit was not invented by a single person, but by many inventors who contributed to the total concept.

The Industry Today

Subtractive photolithography, borrowed from the ancient printing industry, still remains the workhorse circuit making method. While one may argue that today’s circuit making is akin to using the eraser end of the pencil instead of the point, the process has survived because it works and has reasonably good economics. The backwards process has been assaulted for decades by matter-of-fact technologists that want to set circuit making right - make it additive. However, fully additive processes have not delivered enough on their promises and have garnered only a small niche. The etching process has also weathered many storms brewed by environmentalists as better waste recovery methods evolved. However, subtractive etching is now under the most serious attack yet.

The demands of *faster-smaller-cheaper* and the responses have propelled the electronics industry into a revolution. Perpetual progress by the semiconductor industry brought more power and more problems. Chips with millions of transistors needed 1000-plus connections to the outside world. Consumers demanded portability for converging technologies. Something had to give and it would be the interface between the IC and circuit board. The IC could no longer

be housed in a body that was more than an order of magnitude larger than the brain. The electronic package was under severe pressure to shed girth.

The ever downsizing package was quickly running out of real estate with its peripheral wiring scheme and micro-pitch leads were becoming an assembler's nightmare. We were already feeling the strangle hold of Perimeter Paralysis Packaging. The salvation was The Packaging Revolution, that was launched when area array designs, like the Ball Grid Array (BGA), became a major focus. Chip on Board (COB), Flip Chip on organic circuits and new Chip Scale Packages (CSP) also became part of the shrinking landscape. But the Packaging Revolution puts extraordinary demands on the circuit industry for higher and higher density. And that pulls us right into the next stage of the domino affect, the Printed Circuit Revolution.

The two areas for circuit densification are conductor line widths/spaces and vertical interconnect. Both areas are receiving considerable attention, with impressive government and industrial funding. ARPA has funded development in both areas and significant progress has resulted that will likely change the circuit industry. One important trend is emphasis on semi-additive processing. Let's take a closer look.

The flexible circuit industry is noted for very fine pitch, high density products. Flex has had a long association with products that require intense miniaturization. This includes packaging like TAB (Tape Automated Bonding - a flex-based package), disk drives, watches and hearing aids. More recently, flex has become the choice for many new packages, including the elegant μBGA. So it is no mystery that the flex circuit industry has been striving for high density and is the recipient of much of the ARPA money.

Density attributes begin with flex materials that lend themselves to fine pitch and micro vias. The substrate is very thin and smooth with no reinforcement that could interfere with hole fabrication. But flex materials have been undergoing dramatic changes that can enable new circuit processes. Flex substrate producers have been steadily replacing foil lamination with direct metal deposit processes. Vacuum deposition will likely become the main process for producing adhesiveless laminate (actually, the correct term is clad since no adhesive is used). Although the newer materials are superior, because the weak link adhesive has been eliminated, a more important feature is thinness of the copper. Flex material is now available in very thin configurations, all the way down to a few microns of copper. This has important ramifications for the circuit industry.

The semi-additive circuit process requires a thin conductor layer, or "seed" metal that can serve as a removable plating bus. A typical process involves applying a photoresist over the thin metal, followed by imaging, developing, electroplating, stripping resist and etching away the thin seed layer. Although etching is still

involved, the process does not define the conductor shape and very little metal is removed. The semi-additive process is starting to gain momentum since it can produce very fine lines (<25 microns), build straight-wall conductors (no etch factor) and produce minimal waste. The flex-based package industry has already adopted semi-additive circuit making to produce the down to 1 mil wide conductors needed. TAB and μBGAs are now produced by plating up conductors.

Vertical connection processes are also undergoing changes. The original plated through-hole process, launched in 1953 by Motorola (Placir Process), is being replaced by more efficient structures and processes. Drilling is being replaced by lasing and plasma etching. The plated through-hole is replaced by direct plating through micro vias. Build-up multilayer methods have become commercial where holes are photodefined. Interposer methods, where anisotropic conductive adhesives mate circuit pairs together, are also enjoying success[28-30]. The future high density circuits will likely be plated up instead of etched.

Summary

The printed circuit has a long and fascinating history. Many parents have helped the child grow up. In fact, the electronics community raised the circuitry child who often seemed an orphan. The industry began with additive processes, but borrowed from the ancient printing industry to step back to subtractive etching. Although the industry has been very slow to adopt different processes, the Packaging Revolution appears to be the force that will bring about major changes in circuit making at least in some sectors. Availability of thin copper substrate and the need for much higher density, are moving semi-additive processing into the mainstream. Build-up and interposer multilayer designs appear ready to replace the 40 year old plated through-hole processes. So get ready for the Printed Circuit Revolution where opportunities await you.

REFERENCES

1. Hanson, A., British Patent 4,681, 1903.

2. Cadenhead R. and DeCoursey D., "The History of Microelectronics - Part One", The International Journal of Microelectronics, Vol. 8, No. 3, pp. 14-30, Sept., 1985.

3. Edison, T., US Patent 395, 963, Jan. 1889.

4. Berry, A., British Patent 14,699, 1913.

5. Littledale, British Patent 327,356, April 1930.

6. Bassist, E., “Halftone Plate Process and Process of Producing Same”, US Patent 1,525,531, Feb. 1925.

7. Schoop, M., US Patent 1,256,599, 1918.

8. Ducas, C., “Electrical Apparatus and Method of Manufacturing the Same”, US Patent 1,563,731, Dec. 1925.

9. Croot, W., “Improvements in Wireless and Other Electrical Apparatus”, British Patent 267,172, Mar. 1927.

10. Parolini, C., British Patent 269,729, 1926.

11. Seymour, F., “Variable Pathways”, US Patent 1,647,474, Nov. 1927.

12. Franz, E., “Article”, US Patent 2,014,524, Sept. 1935.

13. Proceedings of the First Technical Symposium on Printed Circuits, Washington DC, Oct., 1947 (NBS Publication # 192, 1948).

14. Von Liebig, J., “Improvements in Electroplating with Copper and Other Metals the Silvered Surfaces of Mirrors and Other Articles”, US Patent 33,721, Nov. 1891.

15. DesMarais Jr., R., US Patent 4,421,944, Dec. 1983.

16. Stepan, W., US Patent 4,508, 753, Apr. 1985.

17. Elarde, V. , US Patent 4,532, 152, July 1985.

18. Eisler, P., British Patent 639,111, published June 1950
19 Eisler, P., British Patent 639,178 published June 1950.

20. Eisler, P., British Patent 639,179 published June 1950.

21. Eisler, P., US Patent 2,441,960, May 1948.

22. Eisler, P., US Patent 2,706,697, Feb. 1948.

23. Eisler, P., US Patent 2,587,568, Frb. 1952; reissue Re 24,165.

24. Spalding, A., “Halftone Photomechanical Printing Plate and Method for Producing the Same”, US Patent 1,709,327, April 1929.

24B. Miller, F., “Process for Reproducing Designs in Metal”, US Patent 1,804,021, May 1931.

25. Stevens and Dallas, US Patent 2,219,494, Oct. 1940.

26. O’Connell, ?., “Method of Making Electrostatic Shields”, US Patent 2,288,735, July 1942.

27. “Technograph Printed Circuits, Ltd. et al v. The Bendix Corporation”, 137 USPQ, No. 11421, p.725, May 1963.

28. Barnwell, P. G., “Alternative Interconnection Technologies - A Personal View”, 5th European Hybrid Microelectronics Conference Proceedings, Stresa, Italy, May 22-24, 1985.

29. Gilleo, K., "A Simplified Version of the Multilayer Process", Electronic Packaging & Production, pp. 134-137, Feb. 1989.

30. Gilleo, K., "A New Multilayer Concept Based on Anisotropicity", Proceedings, NEPCON WEST, Anaheim, CA , Feb. 26, 1990.