Commercial Circuit Design

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***Abstract*—This research paper aims to outline the process in which commercial PCB circuits are designed, manufactured, and made ready for marketing. Specifically, steps surrounding PCB class and type selection, inner layer assembly, outer layer assembly, solder-masking, relevant chemical processes, and surfacing of the PCB will be highlighted and elaborated on. This paper will also cover a brief overview of what PCBs are and common applications.**

***Index Terms*—PCBs**

Overview

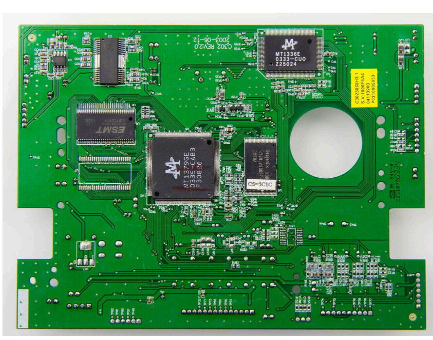

Fig. 1: Printed circuit board of a DVD Player
Source: [4]

A. Background Information

Printed Circuit Boards—or PCBs for short—are flat boards made of insulating material that can be etched with copper to form circuits. PCBs are etched through different printing and chemical processes as opposed to manually soldered circuits, hence the name "printed" [3]. In addition to the copper etched onto the board, electronic components such as capacitors, transistors, resistors, and integrated circuits—or ICs for short—can be connected on the surface of the PCB. Modern PCBs phased out manually soldered circuits for many reasons; their assembly process removed the possibility of human error through pre-determined wire pathways, they were much more compact, were much cheaper to produce, and, most importantly, were mass producible. Some of the leading manufacturers of PCBs include: Zhen Ding Tech. Group, based in China; Unimicron Technology Corporation, based in Taiwan and China; Viasion Technology Co., Ltd., based in China, and Suzhou Dongshan Precision Manufacturing Co., Ltd., based in China [13].

B. Components of a PCB

1) Capacitors

There are many components in a PCB. One of them is a capacitor. Capacitors are parts of the components found on a PCB, symbolized by the letter "C" or a capacitance number [25]. Capacitors are components that briefly store electrical energy and discharge the stored energy when needed. Capacitors retain electrical charge by accumulating opposite charges on two conductive layers, which are separated by an insulator [25]. Capacitors come in four major types, which are ceramic, electrolytic, film, and paper capacitors. The type of capacitor used on the PCB is dependent on the conductor and dielectric material employed. [25]. For example, electrolytic capacitors are used when they need high capacitance [25].

2) Fuse

Fuses are used to protect against current overload in the circuit. A fuse is symbolized by the letter "F." It has a glass casing, where the fuse wire can be seen, and metal caps on both sides of its ends [25].

3) Resistors

The primary function of a resistor is to resist the passage of electric current through it, as opposed to storing energy [25]. Additionally, resistors can be used to stop or block the flow of electricity into each linked element. It is rated in ohms and uses a resistance value [25]. They are used as the current is too high, while the usage for it, like a gate or LED in a PCB, has a lower voltage requirement. A resistor has many ratings depending on its usage and is color-coded so that Engineers know what the resistance is.

4) Inductors

Inductors store energy in the form of magnetic fields as the current flows through them [25]. Unlike capacitors that temporarily store energy, inductors store energy till the electronic circuits are broken [25]. Wire coils are the most common form of an inductor [25]. Inductors are symbolized with the letter "L" [25]. The magnetic field and resulting inductance increase proportionately to the number of coils in the wire [25]. Inductors are used to filter out or prevent certain signals [25].

5) Diodes

The primary role of a diode is to control the voltage [25]. The diodes are semiconductor devices that function as a circuit for current. The electrical signal goes out either through the anode or the cathode [25]. This feature can be used to prevent damage from electricity flowing in the incorrect direction [25]. A type of diode is the light-emitting diode, or LED, is the most common type of diode [25].

6) Transistors

A transistor is a miniature semiconductor that regulates or controls current or voltage flow in addition to amplifying and generating these electrical signals and acting as a switch or gate for them [26]. Transistors are the majority of PCB components used in modern electronics [25]. A single chip may contain many billions of transistors sliced into a semiconductor material [25]. In large numbers, transistors are used to create microprocessors where millions of transistors are embedded into a single integrated circuit [26].

C. Common Applications and Examples

PCBs are found in smartphones, computers, cars, factory equipment, and more, and typically serve as a pathway for electrical signals within a device that the device can use for communication and data exchanges [3]. They act as a physical “hub” for electrical signals to be transferred to different components of an electronic device. For example, the PCB in a computer is commonly referred to as the motherboard. For this reason, PCBs are essential components in virtually all modern electronics.

1) Biomedical Applications

One very useful technology that uses PCBs is surgical robots. Surgical robots are an essential tool when it comes to providing assistance to surgeons. Many benefits occur through the use of surgical robots, like the shortage of recovery time. Generally, surgical robots are meant to assist surgeons when performing surgery instead of taking their place. Surgical robots have come a long way in advancements, with the “da Vinci” surgical robot, introduced in 1999 being the most advanced right now. The “da Vinci” can perform naked-eye 3D imaging and can eliminate hand tremors [24]. Surgeons usually sit down as they perform surgery next to a console in order to assist the soreness of longer operating times. Surgeons can control robotic assistive devices remotely without any physical contact with the patient. The imaging system of the robot transmits images of the operative field to the surgeon next to the console in order to allow the surgeon to clearly view the anatomical position [24]. There is a probe attached to the imaging table which allows the surgeon to see a zoomed in version of the image. Overall, the advantages of surgical robots are that the surgeon can sit instead of stand, the surgical robot can remove hand tremors, a single person is needed for a surgery, the surgeon can see an enlarged view of the anatomical position of the patient, the incision size is small, and a shorter recuperation time [24]. Such surgical robots are powered and controlled by PCBs.

Design Process

The process of designing a PCB involves several key steps: deciding on a board class, deciding on a type of PCB, and pre-production engineering.

A. Board Class

Printed circuit boards have a variety of uses, and their classification determines their level of durability and tolerance [6]. Class 1 boards are for consumer use, electronics, and everyday products. They have a limited life and allow cosmetic defects [6,7]. Class 2 PCBs are for dedicated electronic products, such as phones and computers. They still can have cosmetic defects, but are more reliable and longer-lasting [6,7]. Class 3 PCB boards should always have continued high-end performance, and downtime can not be tolerated. The use environment can be harsh, and the product function is required. These boards are used in the medical, automotive, aerospace, and military industries [7].

B. Types of PCBs

There are 3 types of PCBs: rigid, flex, or metal core. Rigid boards are often the vast majority of the boards that we use. The layout of the board is contained within a rigid substrate created from a high-heat and pressure lamination process. They are commonly made of FR-4 [6]. Flexible boards are composed of a less rigid material that allows for far greater deflection. The material is like a film roll, and the board thickness is less than a standard rigid board [6]. Although there are fewer limitations than a standard rigid board, these boards have not gone up in popularity. A metal-core PCB came from rigid board designs, with an increased ability to dissipate heat throughout the board to protect sensitive circuitry [6]. This style can be an option for high-current designs to prevent thermal wear and failure [6].

C. Pre-production Engineering

In the pre-production engineering stage, an electrical circuit schematic is designed for the PCB in designer apps, such as Altium Designer. The PCB is designed in the schematic to serve its specific function within engineering constraints [1, 2]. A designer then provides the schematic files along with a Bill of Materials (BOM) for the PCB [8]. The schematic then undergoes DFM checks to identify errors [5]. Afterwards, the finished schematic files are then exported to computer-aided manufacturing (CAM) software that generates files that program multiple other steps involved in PCB fabrication and assembly [5].

Manufacturing Process

After the PCB has been designed, it is then manufactured and brought into fruition through multiple fabrication and assembly processes: inner layer assembly, outer layer assembly, and application of the solder mask.

A. Inner Layer Assembly

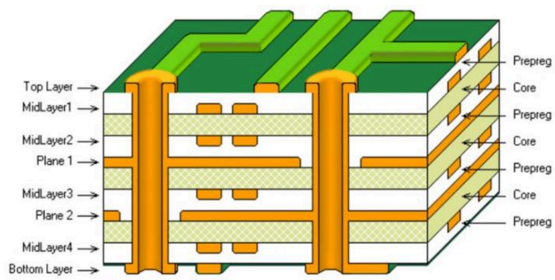

Fig. 2: Cross-sectional diagram of a PCB's multiple inner layers
Source: [9]

PCB boards are typically multilayer, meaning there is more than one layer of circuitry within the board. Inner layers initially start with three of their own layers: a photoresist layer made of photo-sensitive polymer film, a copper layer, and a laminate layer (ranked from surface level downwards) [5, 18].

1) LDI, Development, Etching, and Lamination

The first step in making a PCB board involves a photolithographic process known as laser direct imaging (LDI). Photolithography is the process of changing the solubility of a photo-sensitive polymer film, or photoresist, using UV light [20]. The polarity of the photoresist is important during this process, as a positive photoresist will decrease in solubility and harden under UV light, while a negative photoresist will undergo an opposite change [19]. LDI takes advantage of this by shining UV light on the PCB's positive photoresist layer in a way that traces the desired circuit pattern, altering the photoresist's solubility and causing the exposed photoresist to harden. Meanwhile, the unexposed and unhardened photoresist is chemically removed through a process called development [5, 17]. During development, a developer solution such as 1-methyl-2-pyrrolidone (NMP) dissolves the unhardened photoresist, exposing the copper layer underneath [16]. The copper surrounding the hardened photoresist is then chemically etched off with an etching solution—commonly ferric chloride or ammonium persulfate—revealing the laminate, while the copper protected by the photoresist remains [5, 16, 17]. The hardened photoresist is then also stripped away both chemically and through a high-pressure water rinse [5]. Afterwards, all the inner layers are stacked and combined in a process called lamination, which fuses the inner layers together through pressure and heat [5]. Prior to lamination, an optical punch machine precisely aligns the stacked PCB layers before the copper circuit is coated in an alternative oxide that encourages adhesion and protects the copper against rusting [5]. An X-ray drill controlled by a computer then drills holes into the layers.

2) Electroless Copper Deposition

After lamination, the walls of the drilled holes are made conductive through a process called electroless copper deposition [1, 2, 5]. The walls are submerged in an electroless copper bath mixed with a metal catalyst in the form of nanoparticles and then undergo an oxygen-reduction process where electrons are transferred to copper ions to reduce them into a thin copper sheathing that forms as substrates on the walls [15]. Common catalysts for reaction include palladium and tin. The process is also autocatalytic by nature, meaning that the reaction speeds up due to the products being catalytic to the reaction [14]. The chemical nature of this step is advantageous to PCB production, as it allows for a controlled chemical reaction that does not require external electricity to induce (for example, electrolytic reactions) [15]. The deposited copper metal forms a continuous and even surface typically 0.08 to 0.1 micrometers thick on the walls, allowing them to be conductive and connected to the rest of the PCB [5]. This is the final step in making the inner layers of the PCB.

B. Outer Layer Assembly

Similar to the inner layers, the surface layer has a photoresist, copper, and laminate layer and also undergoes LDI to print the circuit pattern into the photoresist. The surfaces surrounding the drill holes are then plated; first with copper through controlled electroless copper deposition, and then with tin to temporarily protect the copper underneath [5]. The protection is required for the copper circuitry to be protected from an ammoniacal etchant that removes the excess surface copper on the PCB [18]. Finally, the photoresist layer is chemically removed, revealing the surface layer's laminate. The temporary tin plating is also chemically removed using concentrated nitric acid and ferric nitrate, leaving a clean, exposed, and undamaged copper circuit pattern [5, 22]. Ensuring the tin is removed cleanly is crucial to ___Afterwards, the outer layer of the PCB is complete.

C. Application of the Solder Mask

The solder mask of the step helps provide insulation resistance to the traces, distinguishes solderable areas, and provides protection against non-solderable areas with ink [5]. The application process uses a liquid photo imageable (LPI) mask that allows uniform coverage [5]. After the coating is applied, a UV light is used to harden the mask in transparent regions in the design. Then the unhardened and unexposed ink is chemically stripped from the board in another development process, leaving only the mask pattern. Then the mask is cured to chemically bond the ink with the dielectric material, allowing better adhesion [5]. Lastly, the board is baked in an oven or in infrared heat to dry and harden the solder mask. Overall, this process ensures that the resistive layer is accurately aligned and fully integrated with the circuit board structure [5].

D. Surface Finish

After the solder mask is the surface finish, which forms intermetallic joints between the bare copper of the solderable areas and its components [5]. This is very important because it prevents copper from corroding or oxidizing. Additionally, it enhances the shelf life of the board and prepares it for assembly [5]. There are many types of finishes, but most of the time, lead-free surfaces are used to comply with guidelines [5]. An example of a surface finish is hard gold, which is a thick gold plating with nickel used in high-wear areas like edge connectors [5]. In the end, the choice of the finish depends on many factors like cost, component, shelf life, and production volume.

E. Silk Screen

Next, the board is covered in a silk screen, which tells the user important information about the components of the board by labeling them. Inkjet projects use the image and the legends directly from the board's digital data [5]. The panels are then baked again to cure the ink [5]. Important data that is printed includes Component reference designators, polarity marking, pin 1 marking, component boundaries, warning symbols, logos, and more [11]. It is important to find the specifications for silkscreen printing for each board manufacturer as design parameters like size, clearances, and location of markings vary [11].

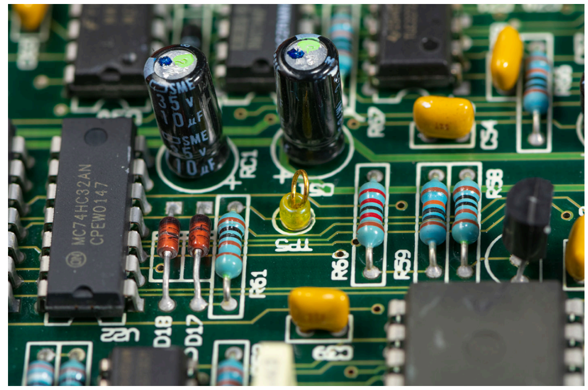

Fig. 3: PCB with white Silkscreen labeling
Source: [11]

POST-FABRICATION STEPS/MARKETING

A. Marketing Strategies

Starting with firm operations is essential. The marketing has to be professional, like being on time, or having the components working properly [10]. Digital marketing is preferable as it is modern. The marketing should be up to date. Publishing useful content can be a big factor in success in marketing [10]. Constant outreach can lead to success. Collaborations with designers to offer solutions can boost the level of marketing by a lot. The PCB industry is changing rapidly. Creating new products is key for competing in the market. Customizing PCB solutions are what make manufacturers unique [21]. The quality of the PCB and the affordability needs to be in check with each other in order to appeal to the customers. A strategy that can set PCB marketers steps ahead of other PCB marketers is going into international markets [21]. Creating trust with customers is crucial, and some ways to do this are providing products that either meet or excel the expectations given or keeping consistency in the quality. Going back to the use of online marketing, social media is a great way to target large audiences [21].

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