The Basics of PCB Design and Composition

Introduction: What is a PCB?

Printed circuit boards (PCBs) are devices that support and connect the electric components in almost all consumer and industrial electronics. The components are usually connected together using tracks and pads of conductive material (usually etched copper) that is then bonded to a piece of non-conductive substrate sheeting, usually fiberglass or epoxy. All of the components that connect to the PCB, such as resistors, capacitors or pieces of active circuitry, are usually soldered straight onto the board, though more advanced PCB designs may contain components that have been embedded right into the substrate sheeting.

The most common type of substrate sheeting in use today is FR-4 (flame retardant, grade 4) glass-reinforced epoxy laminate sheeting. Many times, the first building block of a simple PCB is just a piece of FR-4 sheeting laminated to a single side. The tracks, pads and other features are then etched out of the copper that has been laminated to the PCB board material.

There are three main types of PCBs in common use today, denoted simply by the number of layers a PCB has:

- single-layer or single-sided PCBs are a single piece of fiberglass/epoxy sheeting with a piece of copper foil laminated to one side. These boards are often used for hobby projects and simpler electronics.

- double-layer boards are a single piece of fiberglass or epoxy sheeting that has a piece of copper foil laminated to each side.

- multi-layer PCBs are a series of double-layer boards that have been sandwiched together and connected by a series of VIA (vertical interconnect access) connections that serve to connect different circuits between the boards.

The Composition of a PCB — Printed Circuit Board Components

So what exactly makes up a PCB? There are four different main components when it comes to the composition of a PCB: the substrate, the copper foil/sheeting, the solder mask and the silkscreen. Let’s start in the middle with the substrate and work our way outward.

The beginning piece of a PCB is almost always the base substrate material. As mentioned in the introduction, this is usually FR-4 fiberglass sheeting. Using a solid core material like fiberglass is what gives PCBs their rigidity and helps prevent damage like accidental snapping. However, there are also flexible PCBs (used in items that require electronics to curve) that are built out of flexible plastic that is also capable of resisting high temperatures.

Cheaper PCBs can be built out of perfboard, which is usually a piece of paper that has been laminated with a phenolic resin such as FR-2. In some cases, better-quality perfboard can even be laminated with FR-4.

The next layer after the substrate is a layer of copper foil, which is attached with an adhesive and then heat-fixed to the substrate. The most common type of printed circuit board, the double-sided board, has two layers of copper foil, one on each side. PCBs are often referred to by the number of layers that they have. So a 16-layer PCB is made up of 8 double-layer boards, each with two pieces of copper sheeting, one per side.

Between the copper foil/copper sheeting and the core layer there may be a layer of pre-impregnated resin, or prepreg. Prepreg is resin that has been impregnated with epoxy. It is then sandwiched between the core and the layer of copper foil, or between layers of copper foil. During the bonding process, heat and pressure are applied, sandwiching the prepreg down and activating the epoxy so that it bonds the core and the copper or the copper and the copper together. This is usually how multi-layer printed circuit boards are made.

The thickness of the copper used in PCB manufacture tends to vary by manufacture or use, but is generally specified in ounces per square foot. Most PCBs use one ounce of copper sheeting per square foot, but PCBs that handle exceptionally high power loads may use two or three ounces per square foot, with a regular ounce-per-square-foot sheet translating to a thickness of 34 micrometers.

Following the copper foil/copper sheeting is a layer of solder mask. The solder mask is what gives the PCB its color. Usually, PCB solder mask layers are green, but some manufacturers use different colors, such as red. Solder mask is used by the manufacturers to keep the copper tracks and pads insulated from other metal, pieces of solder, or other pieces of conductive material.

Solder mask is also used to help guide the user by showing them what areas of the board can be soldered to and demarcating the areas that can't be soldered to in a green (or other color) mask.

After the solder mask has been applied, the last layer is a silkscreen layer, usually in white ink. The silk screen is used to add information to the PCB that allows it to assembled more easily and be better understood by humans. Usually this information takes the form of numbers, letters and other symbols, such as function notations for the pins or LEDs.

The Functions of Printed Circuit Board Components

Attached to the copper traces (the pads and paths) of the printed circuit board are the components — these are the things that give the printed circuit board its purpose and are usually installed solely with that purpose in mind. If the substrate board is the skeleton and the copper traces are the musculature, then the components are the vital organs — they are what allow the PCB to function in its intended purpose.

There are many types of components that can be installed on a printed circuit board, but the eight most common ones are:

- batteries
- LEDs
- diodes
- switches
- inductors
- resistors
- transistors
- capacitors

The most common component is the battery. This is what is used to provide voltage, or charge, to the circuit. Once the charge on the battery wears out, the PCB may no longer work. The rest of the components on the list (LEDs, diodes, switches, etc) all take or store charge from the battery.

Aside from the battery, possibly the second most common component, at least when it comes to hobby projects, is a light-emitting diode, or LED. LEDs simply take the charge or current from the battery or the capacitor, which is then used to power the light portion of the LED.

Diodes are much like LEDs in that they take charge and current. Unlike LEDs, simple diodes don't make anything light up. Instead, they simply take the current and pass it along to other components in the chain, but in one direction only — the diode "blocks off" the other direction.

Switches, as their name implies, allow you to "switch" current on or off. When the switch is "on," it is open, which means that current can pass through it. When it is closed and "off," then current cannot pass through it.

An inductor is almost like a half-switch. Essentially, it allows certain currents to flow through it while resisting or stopping other currents. If you attempt to pass direct current (DC) through an inductor, it will go through just fine. However, when you try to pass alternating current (AC) through an inductor, it will be stopped cold by the change in voltage to the inductor's magnetic field.

Much like inductors create resistance when you attempt to pass alternating current through them, resistors are passive components that are used to create resistance in the flow of electrical current as goes through the circuit. The resistance that is generated on an electrical current is measured in ohms, which are derived using a mathematical equation known as Ohm's Law, which looks like this:

$$I = \frac{V}{R}$$

Essentially, one ohm is the resistance that is generated when a 1-amp current passes through a 1-volt resistor, with the current being proportional to the voltage.

So why might you use a resistor? There are several reasons, but the most known are probably for heat generation or the matching and loading of other circuits with electrical energy — by using a resistor, you can cause the current from one circuit to match that of another, making it easier for electricity to flow between them.

Unlike resistors, which are used to hamper the current and charge in circuits, transistors are used to amplify the current in a circuit. Instead of having an "on" state and an "off" state, like most electrical components, transistors can be set to a number of states — anywhere from "fully on" to "fully off". Then a "control current" is passed through the transistor. Once the "control current" flows through the transistor, a larger "main current" flows through it depending on which state it is in. This way, a transistor can be used to amplify a current.

While many of the previous components on the list are used to transfer electrical current in some form or another, capacitors do the opposite. Like batteries, they are used to store electrical charge or harbor electrical current. However, where a battery stores electrical energy, capacitors store electrical energy. A capacitor is made from two or more metal plates that sandwich a dielectric between them.

When electrical current flows through the capacitor's terminal, the positive and negative portions get stuck on each of the plates. The current on the plates wants to come together, but is stopped by the dielectric sitting between each portion. The positive and negative charges pushing against the dielectric is what causes the electrical charge that capacitors store.

Once a path through the circuit is created, the charges in the capacitor can find another way to each other — they don't have to keep trying to go through the dielectric. In this way, the capacitor can be discharged.

Does a PCB's Assembly Matter?

Does the way a PCB is assembled matter when it comes to function? In short, yes. There are things that multi-layer boards can do that single and even double-layer boards can't even come close to. Multi-layer PCBs allow for more circuits to be connected on a single "board" than do single or double-layer boards, which means that they are capable of supporting electronics that are not only much more complex, but much more power-hungry, as well.

There's also the fact that the type of board used in a PCB can alter what it is used for entirely. While fiberglass-cored rigid PCBs are the most common PCBs on the market, they cannot and should not be used for every application out there — and there's some that they just can't be used for. This is where other types of board, such as flexible and metal-cored boards, come into play. Flexible PCBs tend to be made out of bendable plastic that is capable of withstanding high (or in some cases low) temperatures, which makes it perfect for uses where PCBs and their components need to bend.

The third type of board, and the one most commonly used as an alternative to the standard FR-4 board, is a metal-cored board, usually made out aluminum or another metal that is capable of conducting heat well. The heat-conductive properties of metal-cored boards mean that they spread heat more efficiently and more readily than a fiberglass-cored board would. This helps protect other, more sensitive components because the board can dissipate heat away from those components just that much quicker.

The way the components are mounted to the board can also make a difference in how the PCB’s assembly affects its function. There are two different ways that components can be mounted to the board: through-hole and surface-mount.

When a component is mounted using a through-hole, the component is actually plugged in through holes in the board itself, with the component’s leads punched through the PCB to the other side. The lead is then soldered on the other side of the board. This makes it perfect for larger components like capacitors.

Surface-mount technology, on the other hand, is used for smaller, sensitive components like resistors, diodes and the like. Because they are mounted straight to the board, as opposed to through it, the use of smaller components frees up portions of the board that might otherwise have been taken up by leads and solder from larger components.

Depending on what kinds of PCBs you need made, it might be hard to figure all of this out — especially if you need a PCB for a high-value piece of electronic equipment. If you need to get PCBs made, it’s best to contract the work out to a PCB manufacturing company, or, if you’re able to do the manufacturing in-house, at least consult with one to avoid hiccups.