An Introduction to the Many Types of Printed Circuit Boards (PCBs)

What is a Printed Circuit Board?

Printed circuit boards (PCBs) are the boards that are used as the base in most electronics, both as a physical support piece and as the wiring area for the surface-mounted and socketed components. PCBs are most commonly made out of fiberglass, composite epoxy, or another composite material.

Most PCBs for simple electronics are also simple, being only a single layer. However, more complex hardware such as computer graphics cards or motherboards, can have multiple layers, sometimes up to 12.

Even though PCBs are most often associated with computers, they can be found in a multitude of other electronic devices, such as:

- TVs
- Radios
- Digital cameras
- Cell phones

In addition to their use in consumer electronics and computers, different types of PCBs are used in a variety of other fields, including:

- Medical devices. Since electronics have become more dense and consume less power than previous generations, new and exciting medical technology is able to be built and tested. Most medical devices make use of a special type of PCB known as a high-density PCB, which is used to create the smallest and densest design possible, helping to alleviate some of the special constraints inherent in designing devices for the medical field. PCBs have found their way into everything from small devices, such as pacemakers, to much larger devices like x-ray equipment or CAT machines.

- Industrial machinery. PCBs are commonly used in high-powered industrial machinery. In places where current once-ounce copper PCBs do not fit the requirements, thick copper PCBs can be used instead. Examples of situations where thicker copper PCBs would be of great benefit include motor controllers, high-current battery chargers and industrial load testers.

- Lighting. As LED-based lighting solutions catch on in popularity because of their low power consumption and high levels of efficiency, so too do aluminum-backed PCBs, which serve as heat sinks and allow for higher levels of heat transfer than a normal PCB. These same aluminum-backed PCBs form the basis for both high-lumen LED applications and low-cost solutions.

- The automotive and aerospace industries. Both the automotive and aerospace industries make use of flexible PCBs, which are designed to withstand the high-vibration environments that are common in both industries. The other thing that makes flexible PCBs a perfect fit for the automotive and aerospace industries is the fact that depending on specifications and design, they can be very lightweight and are able to conform to the tight spaces that might be present in aerospace and automotive applications, such as inside instrument panels or behind the instrument gauge on a dashboard.

In addition to the different types of PCB boards mentioned above, there are are several different overarching types of PCB boards, each with their own manufacturing specifications, material types and usages.

Types of Printed Circuit Boards

- Single-layer PCBs
- Double-layer PCBs
- Multi-layer PCBs
- Rigid PCBs
- Flexible PCBs
- Rigid-Flex PCBs
- High-frequency PCBs
- Aluminum-backed PCBs

Single-layer PCBs

A single-layer or single-sided PCB is one that is made out of a single layer of base material or substrate. One side of the base material is coated in a thin layer of metal, with copper being the most common due to how well it functions as an electrical conductor. Once the copper base plating is applied, a protective solder mask is usually applied, followed by a last silk-screen to mark out all of the elements on the board.

Since single-layer/single-side PCBs only have their various circuits and electrical components soldered onto the one side, they are easy to design and manufacture. The general manufacture of single-layer PCBs are easily understood by most PCB fabricators, making them both common and popular.

This popularity means that they can be had for low-cost, specifically for high-volume orders, which makes them common in a large number of applications, such as calculators, cameras, radio and stereo equipment, solid state drives, printers and power supplies.

In addition to their use in simple electronics, single-layer PCBs are also an excellent starting point for someone doing any kind of electrical engineering as a hobby, since they can be easily put together using commonly-acquired materials.

Double-layer PCBs

Double-layer or double-sided PCBs are boards of base material which have a thin layer of conductive metal, like copper, applied to both sides of the board. Holes drilled through the board allow circuits on one side of the board connect to circuits on the other.

The circuits and components of a double-layer PCB board are usually connected in one of two ways: either by means of a through-hole or with the use of a surface-mount. A through-hole connection means that small wires,

known as leads, are fed through the holes, with each end of the lead then soldered to the correct component. Surface mounts don't utilize wires.

Instead, many little leads are soldered directly to the board, meaning that the board itself is used as a wiring surface for the different components. This allows circuits to be completed using less space, which frees up space to allow the board to complete more functions, usually at faster speeds and with less weight than a through-hole board would allow.
Double-sided PCBs are usually used in applications which require an intermediate level of circuit complexity, such as:

- Industrial controls
- Power supplies
- Instrumentation
- HVAC systems
- LED lighting
- Automotive dashboards
- Amplifiers
- Vending machines

Multi-layer PCBs

Multi-layer PCBs are a series of three or more double-layered PCBs that are secured together with a specialized glue and sandwiched between pieces of insulation to ensure that excess heat doesn't melt any of the components on any of the boards. Multi-layer PCBs come in a variety of sizes, going as small as four layers or as large as 10 or 12, though the largest multi-layer PCB ever built was 50 layers deep.

With the extra accessibility afforded by many layers of printed circuit boards, designers are able to make very thick, complicated designs suitable for a wide range of tasks where incredibly complex networks of circuits would be required. Applications where multi-layer PCBs would be a boon include file servers, data storage, GPS technology, satellite systems, weather analysis and a wide variety of medical equipment, like heart monitors.

Rigid PCBs

Rigid PCBs are printed circuit boards that are made out of a solid substrate material that prevents the board from twisting. Possibly the most common example of a rigid PCB is a computer motherboard, which is a multi-layer PCB designed to allocate power from the power supply while simultaneously allowing communication between all of the many parts of the computer, such as the CPU, GPU and RAM.

However, rigid PCBs are not just used for computer motherboards: in fact, rigid PCBs are used anywhere that there is a need for the PCB itself to be set up in one shape and remain that way for the remainder of the device's

lifespan. Rigid PCBs can be anything from a simple single-layer PCB all the way up to an 8 or 10-layer multi-layer PCB.

Rigid PCBs make up perhaps the largest number of PCBs manufactured, with the entire worldwide PCB industry coming in at an estimated $58.2 billion dollars in 2016.

Since rigid PCBs are also the same overarching type as most PCBs (e.g. single-layer, double-layer and multi-layer), they have the same uses, so rigid PCBs can be used in much the same way a single-layer, double-layer or multi-layer board can, since it is the exact same thing.

Flexible PCBs

Unlike rigid PCBs, which use unmoving materials such as fiberglass, flexible PCBs are made of materials that can flex and move, such as plastic. The use of flexible materials means that a flexible PCB can turn or shift during the course of normal use without doing unrepairable damage to the components or connections that make up the board.

Much like rigid PCBs, flexible PCBs come in single, double or multi-layer formats. However, because they need to be printed on a flexible material, they tend to cost more for fabrication.

Still, flexible PCBs offer a number of advantages over their rigid cousins, the most prominent being the fact that they can flex, meaning they can be folded over edges or wrapped around corners.

That same flexibility offers cost and weight savings since a single flexible PCB can be used to cover areas that might take multiple rigid PCBs. Flexible PCBs can also be used in areas that might be subject to environmental hazards. To do so, they are are simply built using materials that might be waterproof, shockproof, corrosion-resistant or resistant to high-temperature oils — an option that traditional rigid PCBs, with their fiberglass construction, may not have.

Rigid-Flex PCBs

Rigid-flex PCBs combine the best of both worlds when it comes to the two main overarching types of PCB boards. Rigid-flex boards consist of numerous layers of flexible PCBs attached to a corresponding number of rigid PCB layers. The flexible boards are designed to be in a constant state of flex or bend, e.g. bent around a corner.

Rigid-flex PCBs have many advantages over just using rigid or flexible PCBs to wire up certain applications. For one, rigid-flex boards have a lower parts count than traditional rigid or flexible boards because the wiring options for both can be combined into a single board. The combination of rigid and flexible boards into a single rigid-flex board also allows for a more streamlined design, reducing the overall board size and package weight.

Since rigid-flex PCBs are designed to save on space and weight, they are most often found in applications where space or weight are premium concerns, including:

- Cell phones
- Digital cameras
- Pacemakers

- Testing equipment
- Automobiles

High-frequency PCBs

High-frequency PCBs refer not necessary to a type of PCB construction, as the previous types do, but instead a general PCB design element: that is, high-frequency PCBs are circuit boards that are designed to transmit signals over 1 gigahertz.

The PCB board types most often used in a high-frequency PCB include FR4-grade glass-reinforced epoxy laminate, polyphenylene oxide (PPO) resin and Teflon, with Teflon being one of the most expensive options because of its small and stable dielectric constant, small amounts of dielectric loss and overall low water absorption.

There are several characteristics that need to be considered when choosing the PCB boards and the types of PCB connectors that go best with them:

- dielectric constant (Dk)
- dissipation
- loss
- dielectric thickness

The most important of these is the Dk of the material in question. Materials with high probability for change of dielectric constant often have changes in impedance, which can disrupt the harmonics that make up a digital signal and cause an overall loss in digital signal integrity — one of the things that high-frequency PCBs are designed to prevent.

Other things to consider when choosing the boards and PC connector types to use when designing a high-frequency PCB are:

- dielectric loss (DF), which affects the quality of the signal transmission. A smaller amount of dielectric loss could make an accordingly small amount of signal wastage.
- Thermal expansion. If the thermal expansion rates of the materials used build the PCB, such as copper foil, are not the same, then materials could separate from each other due to changes in temperature.
- Water absorption. High amounts of water absorption will affect the dielectric constant and dielectric loss of the PCB in question, especially if it is used in wet environments.
- Other resistances. The materials used in the construction of a high-frequency PCB should be rated highly for heat resistance, impact endurance and resistance to hazardous chemicals, as necessary.

Aluminum-backed PCBs

Aluminum-backed PCBs are designed in much the same way as their copper-backed cousins. However, instead of the usual fiberglass used in most PCB board types, aluminum-backed PCBs instead make use of an aluminum or copper substrate board.

The aluminum backing is then lined with thermally insulating material that is designed to have a low thermal resistance, meaning that less heat is transferred from the insulating material to the backing. Once the insulation is applied, a circuit layer of copper, ranging in thickness from one ounce to ten, is applied.

Aluminum-backed PCBs have many advantages over PCBs with fiberglass backing, including:

- Low cost. Aluminum is one of the most abundant metals in the Earth's crust, making up 8.23 percent by weight. This means that it can be found in a variety of climates, making it easy to mine and cutting costs related to the mining process. This in turn cuts costs on the manufacturing process, meaning that manufacturing products with aluminum is less expensive, as well.

- Environmentally friendly. Aluminum is non-toxic and easily recyclable. Additionally, due to its ease of assembly, manufacturing printed circuit boards out of aluminum is a good way to conserve energy.

- Heat dissipation. Aluminum is one of the better materials out there in terms of dissipating heat away from the crucial components of a circuit board. Instead of dissipating the heat out into the rest of the board, aluminum actually dissipates heat out into the open air. An aluminum PCB will cool faster than an equivalent-sized copper PCB, which will stay hotter longer because it does not dissipate heat into the open air as well.

- Material durability. Aluminum is much more durable than materials like fiberglass or ceramic, especially in regards to drop tests or shattering. The use of sturdier base materials helps reduce damage during manufacture, shipping and installation.

All of these advantages make aluminum-backed PCBs a great choice for applications that require high outputs of power within very tight tolerances, including:

- Traffic lights

- Automotive lighting

- Power supplies

- Motor controllers

- High-current circuitry

In addition to these major areas of use, aluminum-backed PCBs can also be used in applications that require a high degree of mechanical stability or where the PCB might be subject to high levels of mechanical stress. They are less subject to thermal expansion than a fiberglass-based board, meaning that the other materials on the board, such as the copper foil and insulation, will be less likely to peel away, further lengthening the lifetime of the product.

Throughout the years, PCBs have evolved, from the simple single-layer PCBs used in things like calculators to more involved, more recent designs, such as a high-frequency Teflon design. PCBs have found their way into almost every industry on the planet, from simple things like lighting solutions all the way up to more complex applications like medical technology or the aerospace industry.

The evolution of PCBs has also pushed an evolution in PCB building materials: no longer are PCBs built solely out of fiberglass-backed copper foil. New building materials include aluminum, Teflon and others, such as bendable plastics. Bendable plastics and aluminum in particular have spurred the creation of products like rigid-flex and aluminum-backed PCBs in order to address the inherent shortcomings in things like regular fiberglass-backed or rigid PCBs for certain applications, such as the aerospace industry or satellite technology.