



# Guide to PCBA Design for Manufacturing Excellence



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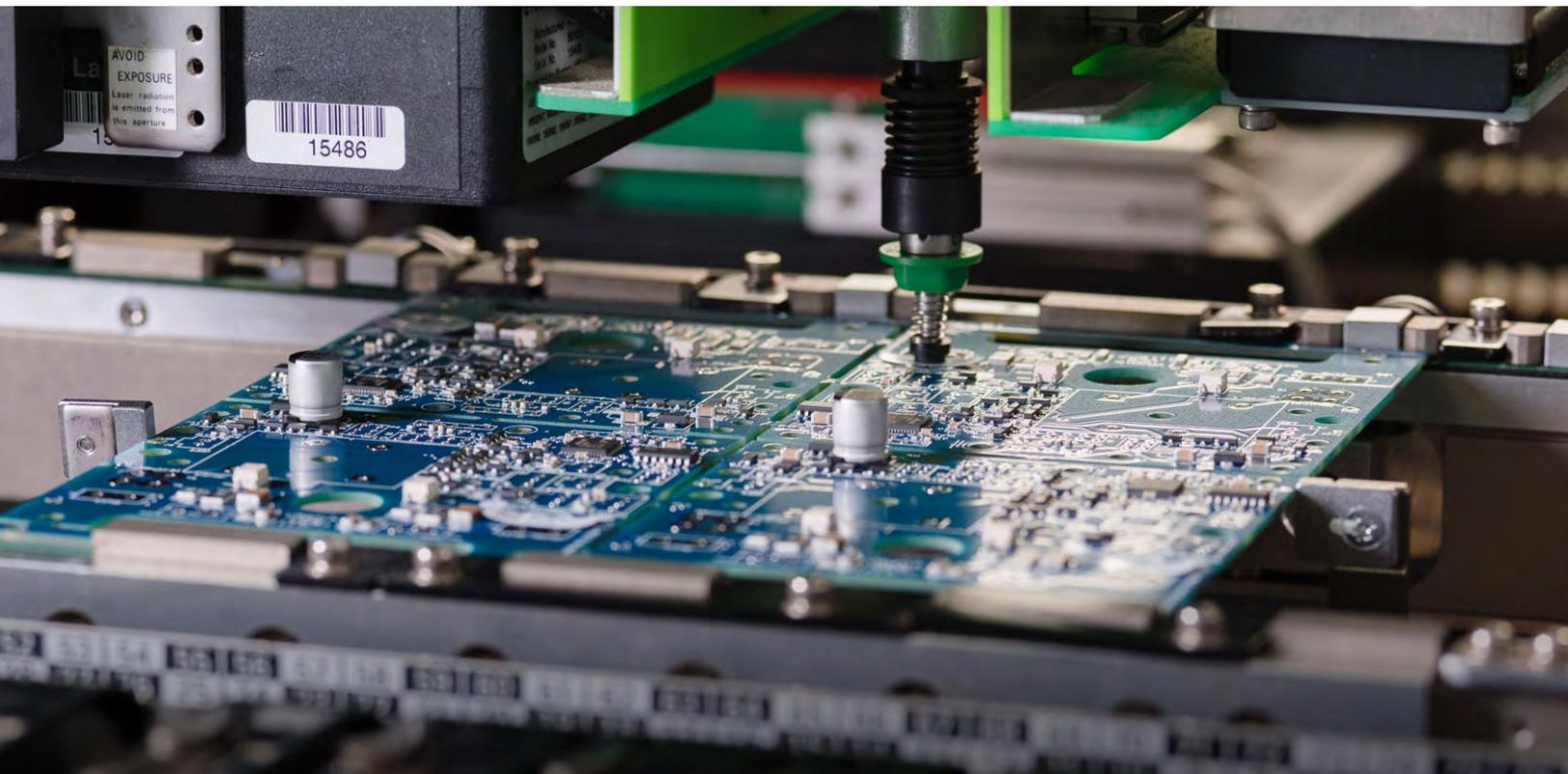
# PCBA DESIGN FOR MANUFACTURING EXCELLENCE

Printed-circuit boards (PCBs) and printed-circuit-board assemblies (PCBAs) lie at the heart of a vast number of devices as developers add intelligence and connectivity to consumer, healthcare, and many other products. Various industry verticals, from aerospace to medical electronics, are similarly packing more intelligence and connectivity into their products and systems. And the growing demand for increasingly connected and electrified automobiles is further driving the need for PCBs and PCBAs.

Market-research firm [Mordor Intelligence forecasts](#) that the worldwide PCB market **will grow at a CAGR of 1.53% through 2026 when it is projected to equal \$75.72 billion**. The firm cites North America as the largest market and Asia Pacific as the fastest-growing market.

These markets present a variety of challenges. Beyond the complexity of designing and manufacturing a sophisticated surface-mount-technology (SMT) or PCBA, market participants must deal with regulatory requirements and contend with supply chain management issues in a time of severe component shortages.

Whether you are new to PCBA manufacturing or an expert looking to expand capacity, you can work with a qualified electronics contract manufacturer (CM) to assist you in all aspects of the process—from circuit design and simulation to functional testing.





# WHY WORK WITH A CONTRACT MANUFACTURER

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You may be considering a CM for your electronic assemblies for many reasons.

Some original equipment manufacturers (OEMs) are deeply experienced with PCB and PCBA design and manufacturing. They have the latest schematic capture and layout software and proficient engineers who know how to use it. But they do not have the equipment necessary to produce PCBAs at scale. These makers need little input other than the CM's design rules.

Other OEMs may be experts in areas other than electronics. They may have mechanical engineering or software development expertise but lack specific knowledge of PCB and PCBA design. For example, a manufacturer with expertise in fluid flow may want to add electronic controls to a mechanical valve, an addition requiring a PCBA. Understandably, these engineers would lack the necessary electronics design and manufacturing expertise.

Likewise, an OEM's hardware platforms may lack the features and functionality to run the latest PCBA design software. A CM can offer engineering services to assist these customers.

The trend of product design for marketing departments rather than manufacturing can also present challenges. While this is ideal for the end-user customer, it's important that these OEMs work with a CM to help refine its designs into realistic, manufacturable PCBAs.



## DFX HOLDS THE KEY

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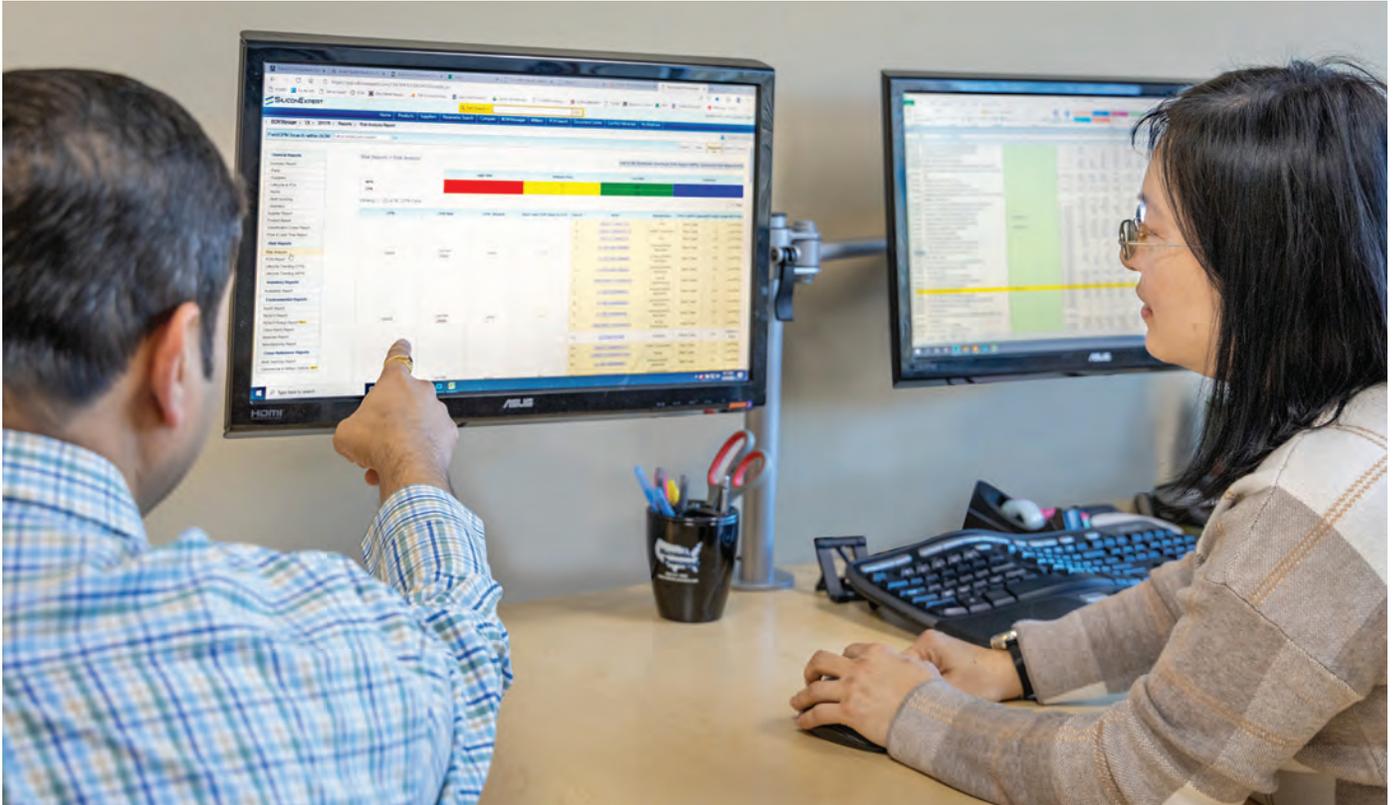
To successfully employ a CM to produce your PCBAs, you should follow design for manufacturing (DFM) best practices.

An even better approach is design for excellence (DFX). DFX encompasses all aspects of producing high-quality, cost-optimized products. The DFX framework includes DFM, design for test (DFT), and design for assembly (DFA) best practices. Additionally, an effective DFX strategy requires an understanding of the supply chain. While the DFA acronym is already taken, design for availability should also be top of mind. Designing for availability helps to set realistic expectations regarding ramping up from new product introduction (NPI) to pilot assemblies to full, high-volume production.

# CRITICAL PATH

## Engage your CM early...

The critical path for DFM starts at the beginning of your project, and you will want to engage your CM early. A CM familiar with your design can offer prompt feedback on both the PCB and the PCBA.



Focusing on DFM specifically, the first step to success requires knowledge of your CM's set of design rules to be followed to ensure your PCBA can be efficiently processed using the CM's equipment and systems. These rules center on concepts such as component pitch, component package type, component placement and orientation, component-to-PCB feature restrictions, and SMT process-direction issues.

Your CM will also likely impose keep-out zones due to mechanical or electrical constraints. These zones may be needed to provide sufficient clearance for a PCB-mounted switch or connector, to minimize issues between high-voltage and high-current components for safety, or to prevent electrical interference between sensitive high-speed ICs such as serial data transceivers and high-speed buses.

Depending on the size of the board, it may be cost-effective to use PCB panelization, in which multiple small PCBs are manufactured as a single large array, with depanelization occurring at the end of the manufacturing process. If you use that approach, your CM will have design rules for that, too.

# CRITICAL PATH (CONTINUED)

Finally, for DFT, your CM will have test-point placement and coverage rules, which can be taken into consideration as part of a comprehensive in-circuit-test (ICT) plan.

Learning all these rules early can eliminate the need for costly redesigns later. Before beginning your design, be sure to instill your CM's specific rules in your schematic-capture and PCB layout tools.

In general, CM rules are guidelines to optimize production and minimize costs. Although design rules are important, your design may have constraints that make following a specific, complete set of rules difficult or impossible. So, look to a CM that can offer some flexibility in its rules based on your application.

If your design requirements dictate that exceptions be made, you might face higher costs and lower throughput. On the other hand, if you don't have any special constraints, you could consider following DFM rules and guidelines that go beyond what the CM requires, thereby possibly reducing costs.

DFM is a key element to help you avoid costly redesigns, field failures, and lack of scalability. And keep in mind that DFM extends far beyond design rules. It also requires effective teamwork and management between you and the CM.

If you have a product already on the market but are planning to revise it to add features or design-out obsolete parts, talk to your CM before redoing your schematic, bill of materials (BoM), and layout. This will be the critical time where you can achieve the highest benefit of lowered costs at higher volume.



## But not too early...

Although you should engage your CM early, do not engage too early. If your concept exists only as a sketch on a napkin, it may be too early to talk to a CM. It will not be cost-effective for your CM to be closely involved in your year-long R&D project. Have a working breadboard, prototype, or other proof of concept when you approach your CM. **The sweet spot for CM involvement is when you anticipate running some volume in one to six months.**

# COST CONSIDERATIONS

Cost is proportional to the sum of all the product's features. The surest way to reduce the cost is to reduce the number of features and/or functionality. But note that cost is also proportional to quality— **if you require a high-quality product, do not attempt to save cost by reducing quality.**

Your CM may be able to help you optimize your cost of goods sold (CoGS) by suggesting component alternatives or adjustments to your PCB layout to improve manufacturability and increase test yields by focusing on the assembly.



## Make ten before you make 100 before you make 10,000

Successfully ramping up to high volume production requires the collaboration of capable DFX (including DFM, DFA, and DFT) teams. These teams will include your own design and manufacturing engineers, as well as those of your CM. Your collective purchasing and finance personnel should work together to ensure design for availability. And having your product managers work closely with your CM can help keep expectations in line.

You will understandably want to reach full volume production as soon as possible so you can ship products and make money. But it would be a mistake to rush this process. Get started by letting your CM run a small quantity on an NPI line to determine if the DFM built into your design meets the PCBA production goals. If not, take the time to determine what adjustments might be required before you attempt to scale. All changes will again be processed on the NPI line before moving to pilot production to build, for instance, 100 PCBAs.

Essentially, DFM is a gate confirming that a PCBA can readily move from NPI to a low-volume pilot production run and then on to successively higher volume runs. This gating function is important even for existing products being transferred to a new CM. Just because your former CM could produce thousands of your boards does not mean that your new CM can do so immediately due to potential documentation problems, such as a discrepancy between BoM and schematic, as well as differences in the two CMs' equipment and systems.

In all cases, starting with small quantities saves time and money in the long term by optimizing the manufacturing process for cost and quality while reducing any initial test fallout.

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# REGULATORY AND STANDARDS REQUIREMENTS



Regulatory issues are not strictly DFM issues, but there is no point in manufacturing a product you won't be able to sell because it fails required compliance tests. To help ensure regulatory compliance, choose a CM registered with UL in the United States, CSA in Canada, one of the TÜV organizations in Germany, or other relevant bodies depending on the regions in which you intend to market your products. (Note that many such organizations have a worldwide presence notwithstanding their country of origin.) If your end market is in Europe, you will want your products to comply with the European Union's Radio Equipment Directive (RED).

You should also determine the need for regulatory compliance based on your application vertical—for example, automotive, telecommunications, medical, or aerospace. And keep in mind that you or your customer may need to submit the end-product containing your PCBA to an independent laboratory for compliance tests with respect to emissions, safety, or other considerations.

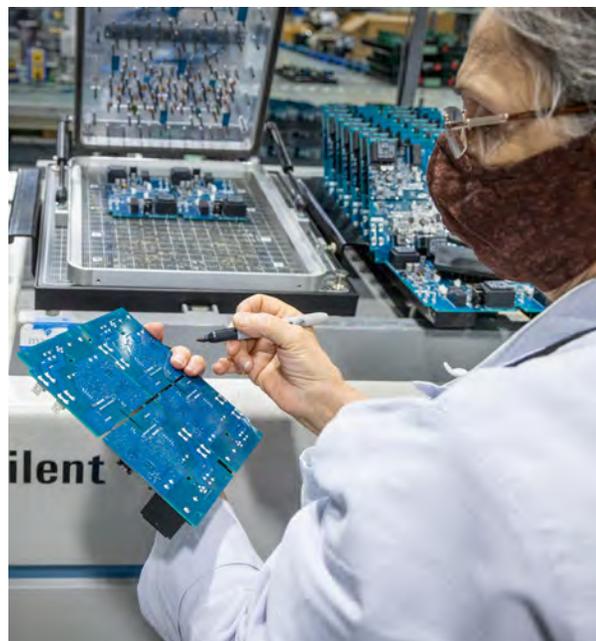
In addition to organizations such as UL and regulations like the RED directive, you should be aware of other organizations and standards when choosing a CM. One such organization is the International Organization for Standardization (which goes by the letters ISO), an independent, nongovernmental organization based in Geneva, Switzerland, with a membership of 167 national standards bodies. ISO standards relevant to PCB and PCBA manufacturing include:



**ISO 9001** specifies requirements for a quality management system (QMS) when an organization needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements.



**ISO 13485** specifies requirements for a QMS where an organization must demonstrate its ability to provide medical devices and related services that consistently meet customer and applicable regulatory requirements.



# REGULATORY AND STANDARDS REQUIREMENTS (CONTINUED)



If you are building a PCBA for a medical device, you may also want to choose a CM that is a U.S. Food and Drug Administration (FDA) Registered Facility, a requirement for businesses that are involved in the production and distribution of medical devices intended for use in the U.S.

If your products are used in aerospace applications, choose a CM certified to the AS9100 standard, which sets guidelines for implementing a QMS for aviation, space, and defense organizations. Promulgated by the International Aerospace Quality Group, AS9100 builds on ISO 9001 to enable companies to provide safe and reliable products in accordance with civil and military aviation requirements.

In addition, look for a CM who is certified to these key European Union requirements:

- ❑ The Restriction of Hazardous Substances (RoHS) directive, which bans specific hazardous substances such as lead, mercury, and cadmium from electronic products.
- ❑ The Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulation, which pertains to chemicals used in the production of electronic products.

Standards specific to PCB and PCBA manufacture come from the Institute for Interconnecting and Packaging Electronic Circuits (IPC). This nonprofit member-driven organization provides standards and training for OEMs, electronic manufacturing services (EMS) providers, and PCB manufacturers. Some relevant IPC standards include:

- ❑ IPC-A-610, “Acceptability of Electronics Assemblies,” which is a widely used PCBA inspection standard.
- ❑ IPC-J-STD-001H, “Requirements for Soldered Electrical and Electronic Assemblies,” which provides criteria on soldering processes and materials.
- ❑ IPC/WHMA-A-620, “Requirements and Acceptance for Cable and Wire Harness Assemblies,” which prescribes practices and requirements for the manufacture and test of cable, wire, and harness assemblies.



# SUPPLY CHAIN CONSIDERATIONS (DESIGN FOR AVAILABILITY)

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As a first step toward design for availability, determine whether you or the CM will purchase the components. In either case, avoid near-term supply chain problems. Don't choose components that are near end-of-life. Your CM can help by providing obsolescence forecasting. To deal with potential component shortages, consider qualifying alternate BoMs.

Another key aspect of DFM is design for traceability with associated documentation. Ensure your CM can meticulously record its manufacturing steps from receipt of raw materials to shipment of the final product. Your CM should also provide supply chain visibility to help you avoid counterfeit components.

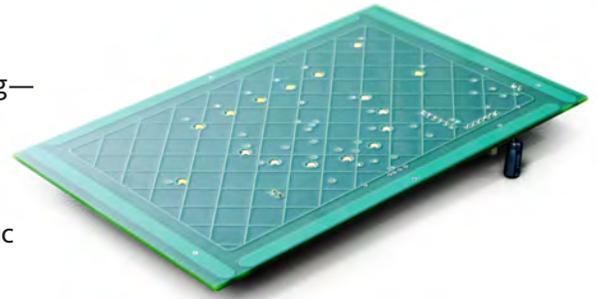
In addition, identify requirements for standards compliance for any components in your BoM. Most of the standards discussed in the previous section apply to the CM's QMS and the procedures it must follow. Some standards, though, like RoHS, also apply to the components you will choose. Another such standard is ISO 26262, which addresses functional safety for road vehicles. If you are serving the automotive industry, you may need to select components that comply with ISO 26262 as well as the Automotive Electronics Council's AEC-Q100, which requires that ICs for automotive applications pass specified stress tests.

Also, design with the end-product operating life (three years, five years, or perhaps ten years) in mind and choose BoM components accordingly. Identify any requirements for accelerated life testing (temperature, humidity, vibration, etc.) and determine if and when you will need to engage an outside laboratory to perform these tests. Even if you don't need testing at an outside laboratory, your CM will need to test your products during the assembly process, so determine who provides the necessary test programs and fixtures. And finally, determine whether your CM should ship your products directly to your customer.



# THE SMT PROCESS

You do not need to know all the details of SMT PCBA manufacturing—from solder-paste printing to functional test—to implement an effective DFM strategy and have your PCBs and PCBA built. That is why you are paying the CM to make the product. Nevertheless, understanding the basics can help you determine whether a specific CM has all the necessary equipment to handle your project.



SMT manufacturing is a multi-step process. An early-stage is solder-paste inspection (SPI), which verifies that the paste has printed properly. SPI is followed by component placement, followed in turn by automated optical inspection (AOI), which verifies that components have been placed properly and are correctly oriented. The next step is solder reflow, which can be followed by another AOI step to look for solder quality and any damage that may have occurred during the reflow process. At this point, x-ray inspection may also be used to examine solder joints not visible to AOI—joints under a ball grid array (BGA), for example. The final steps include in-circuit testing, functional testing, or both.

The entire process may seem complex, repetitive, and overly expensive, especially the multiple inspection steps. However, you will not save money by omitting SPI or post pick-and-place AOI. The goal is to tune the process and find defects as soon as possible. Waiting until after reflow to fix a problem due to solder printing defects or component misalignment can cost orders of magnitude more than fixing it before reflow.

## **Choose a CM that offers the full complement of production, inspection, rework, and test equipment.**

The CM can determine how best to deploy its equipment depending on the complexity of your product.



# CO-AX CAPABILITIES

For more than 25 years, CO-AX Technology Inc. has specialized in designing and manufacturing electronic assemblies, including PCBAs, cable and wire harnesses, and complete box builds. The company's PCB design engineering team can work with you and assist with circuit-simulation software, schematic capture, and PCB layout software. They can also help with embedded system and software design and perform through-hole (TH) to SMT component conversion. With the design complete, CO-AX can produce prototypes using its dedicated NPI line and rapid prototyping service. Commonality between CO-AX's NPI and production equipment ensures a smooth transition to full-scale production.

CO-AX deploys the following equipment to help build your products quickly and cost-effectively while ensuring the highest levels of quality:

- ❑ Juki SMT lines
- ❑ Siemens/ASM high-speed SMT line
- ❑ No-clean wave soldering
- ❑ Programmable selective soldering
- ❑ Finetech BGA rework station
- ❑ 3D AOI and SPI machines
- ❑ X-ray inspection station
- ❑ In-circuit and functional testers

And finally, CO-AX has achieved many quality certifications:

- ❑ ISO 9001
- ❑ ISO 13485
- ❑ FDA Registered Facility
- ❑ UL Certified
- ❑ AS9100 (expected in 2023)
- ❑ RoHS
- ❑ REACH
- ❑ IPC-A-610
- ❑ IPC-J-STD-001H
- ❑ IPC/WHMA-A-620

## Design for Manufacturing Excellence

So now you know— DFM is just one of the many “design for...” abbreviations representing critically important aspects of the design and manufacturing process. Design for test, design for assembly, and design for availability all fit under the design for excellence umbrella.

At CO-AX Technology Inc., we embrace DFX, which extends from the design process through sourcing, assembly, test, and the entire end-product lifecycle.

For help with your next project, contact the CO-AX DFX experts at [coaxinc.com](http://coaxinc.com) or 1-440-914-9200.



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