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Step 1: Design for Manufacture

Design for Manufacture (DFM) is critical to ensure not only that a product or design actually can be made but also that it will be reliable, testable, reworkable or serviceable. When properly applied, DFM can be used to avoid designs that are not compatible with existing manufacturing processes or that may require extra steps or manual processes.

By Scott Buttars

The DFM document is the heart of another concept called Design for Excellence (DFX), which encompasses all processes from product inception through production release. When properly implemented, DFX will ensure ease of assembly and reduce the likelihood that a product will need subsequent design changes. A critical part of this process is a robust design review that should identify problems earlier in the design phase and assure compliance to DFM rules. Lack of a robust DFX capability and culture will, more than likely, result in a design for failure.

A key to the success of DFX is its acceptance and incorporation in the company culture. This must start with management and work its way down through all engineering functions and to the people actually assembling the product.

The DFM Document

All groups who use or are affected by DFM should be made to feel a part of the process and to contribute to its content. A team approach is the best method to accomplish this and to permit anyone to make change requests to the document. Finding or developing an outline of what information to include in a DFM document should be the first step taken by the team. An understanding of both design and manufacturing processes is required for filling in the details. Many times, studies will be required to obtain specific information as well as contributions from those with the most expertise. Starting with the basics and over time, the team can refine and expand the scope of the DFM. After implementation, it is a good idea to measure how well a new design follows the DFM guidelines. A metric for compliance can be developed and then correlated to factory yield, cycle time through the factory and product reliability data.

DFX Culture

When a company begins, typically only a few employees are involved with a product's design and manufacturing. The design rules at this time may not be written, making it necessary to rely on the skills and knowledge of the few individuals involved. As a company grows and more individuals come on board, however, it soon becomes necessary to document the rules for designing its products. By the time a company reaches a size that prevents those individuals from working directly with one another, it becomes essential to have a written DFM. The sooner this is begun and a culture established, the easier the job will be.

Starting and maintaining a DFM program will not be easy. Though it will take time and dedication, the results will be worth the effort. Goals must be defined clearly before a DFM program is started. Strategic guidelines, such as the following, are highly recommended:

- Be part of the corporate culture, i.e., management must provide support and encouragement.
- Be driven by customer needs.
- Include teamwork and creative thinking, e.g., management-supported teams and open thinking.
- Have measurable and justifiable goals. The key metrics of cost, yield, delivery, etc., must be defined.
- Be easy to use and apply, as assisted by documented methods and procedures.

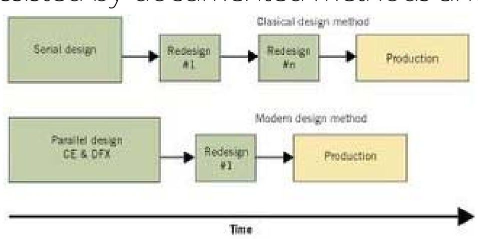

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Figure 1. A shorter time period is required for the design cycle in a DFM environment. Evaluation units as well as production quantities can be delivered sooner.

Stopping Defects Through Rules

When everything goes well during the design of a new product, fewer issues are encountered and the quality improves. Rules can be developed that will prevent defects associated with the design from making it to manufacturing. This will result in higher yields and less rework. Similarly, reducing rework will shorten the time to produce the product as well as the amount of scrap. When testability is designed into the product, more product function can be tested and a higher degree of product performance confidence can be achieved.

After each step in the process, the design should be verified against all DFM rules. This means that less time is spent on the debugging and repair of manufacturing issues before product evaluation and verification begins. Concurrent engineering and design verification may increase the length of the design phase slightly, but this effort can reduce both the number of design cycles required and the overall time to market or time until production release (Figure 1).

DFM requires a team approach to be successful, together with a DFM "champion" to set up the team and emphasize the benefits to management to be gleaned. In more fortunate scenarios, management may have mandated the establishment of a DFM program, in which case all are ahead of the game.

DFM Content

Even if a formal or written DFM guideline has not been created, much of what is needed to make up the documentation may already exist. In organizations that already are involved with the design process, CAD libraries and design rules created and used by the designers make a good beginning.

As stated, information from standards organizations are available. However, such data are general in nature and may not be specific sufficiently to cover the needs of individual manufacturing processes or customer requirements. The information available from the standard organization typically is given as a range. Thus, for consistancy, an organization may wish to establish a specific specification for each item or feature. Another source is from component suppliers who often provide data on recommended land patterns and other pertinent information. It always is important to ensure that all DFM guidelines meet recommended industry standards (i.e., fiducial targets).

The following is a list of items to be included in any DFM guideline as a minimum:

- General Design Criteria. It is important to identify the minimum and maximum board sizes that the company's equipment is capable of processing. Edge clearance requirements for conveyors and fixturing is critical as well. Board panelization techniques can be used to meet some of the board size and shape requirements. However, some board or panel sizes will be more economical to manufacture than others and must be taken into account.
- Component Selection Criteria. It is critical to select only components in the range of the placement equipment's capability, withstand the soldering temperatures, are machine placeable, and have leads or terminations with acceptable surface characteristics.
- Land Patterns. If the team has the resources required for creating its own land patterns it may either choose to do so or purchase a library of land patterns. Two possible sources for land patterns are SMT Plus (smtplus.com) and IPC-SM-782 (Figure 2). First, determine the length of the toe and heel fillets that are required. The formula for both length and gap are for a 0.015" fillet or a total of 0.030" for both toe and heel.
- Component Orientation. For ease of programming, machine efficiency and inspection, it is best for all components to be oriented in the same direction. Generally, this is not possible due to trace-routing requirements, but if parts rotation can be limited to two axes or have similar type components oriented the same way, it would be the next best solution. Wavesoldered components must have their leads or terminations on opposing sides of the body entering the wave simultaneously.

- Spacing Requirements ("Keep Out" Zones). Component spacing is a critical aspect of manufacturability. Manufacturing will want as much space around the components as is practical while design and layout will, in many cases, need the minimum spacing to satisfy design requirements. Minimum spacings must satisfy the manufacturing requirements for placement, soldering, testing, inspection and rework. While diffrent components will have different spacing requirements, similar components often will feature the same requirements, permitting them to be combined into a single category.Once the component spacing requirements and categories have been determined, a matrix is a simple way to show the minimum spacings between components of various categories. This matrix was created for a reflow process; a wavesolder process will require different spacing to prevent bridging.

- Soldering Considerations. Different soldering processes require different design considerations. As stated, orientation and spacing will have different requirements for reflow than for wave soldering. The types of components that can be wave soldered must be limited. Typically chip resistors and capacitors along with small-outline integrated circuit (SOIC) packages are the only parts that are wave soldered. Capacitors that are wave soldered must be X7R type to avoid cracking, and wave soldering SOIC components without some bridging may be difficult.
- Testability Requirements. The board must be designed so that it is compatible with all test equipment. Items that reduce the cost of the test equipment also should be included. Test pads, required when using automated test equipment, must be accessible with their size and shape specified. For full test coverage, a test pad for each node is required; however, this may not be practical due to real-estate constraints. Minimum test coverage requirements also must be specified.

- Fabrication Specifications. The following list is for items that must be covered in any fabrication specification all vary according to the design requirements. This portion of the DFM, used by the board designers, also can be sent to the board supplier. It includes base material stack-up, finished PCB thickness, surface finish, number of layers, and minimum line width and spacing. Other data used includes via spacing and pad stack, soldermask requirements, and impedance requirements.
- Applicable Industry Specificatons. It is a good idea to list all the industry standards the designer must adhere to and that can be referenced while writing the DFM.

The DFM Document

DFM documents should be covered by document-control procedures. A history of revisions should be included to show when changes were made and what information was affected. Companies certified by the International Standards Institute (ISO) must meet associated requirements.

The traditional method of using paper documents will not ensure that recent updates are included, which may pose a risk in keeping it secure. Such problems only become worse when multiple design and manufacturing sites or geographic locations are involved. Today, most companies have an intranet or access to the Internet, i.e., using a Web site for the DFM will ensure that when the guidelines are updated all will have instant access to the new information.

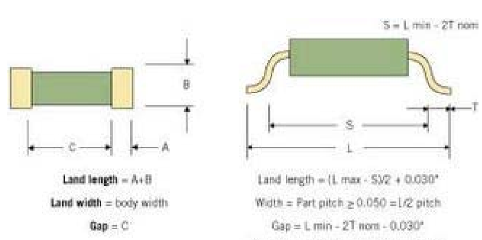

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Figure 2. Some basic rules for land pattern design. The information in the bottom portion can be used for both gull wing and J-lead components.

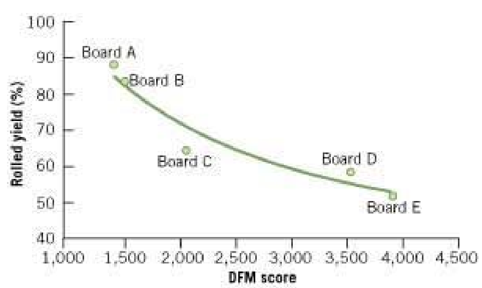
Continuous Improvement

How long will it take to complete a DFM document? The answer is it will never be completed as long as technology advances, requiring new rules and some old rules to change. After all the basic requirements have been captured in the DFM there still will be questions and issues that arise, and as they are answered, the solutions can be incorporated.

Experimentation and process development may be required to determine if the processes and equipment are capable of producing the new design. Sometimes new equipment will be necessary and will need justification based on return on investment (ROI). This becomes easier if the design will be used on future products and is included in a technology roadmap. Improvements are always possible and continuous improvement should be the team's goal.

DFM Index

An index can be developed to measure how well a design meets the requirements of each section of the DFM. The index also can be designed as a predictor of how well a board can be expected to do in the factory. Factors such as cycle time, process steps required and expected yield can be taken into account to make this determination. It is possible for an index to take into account board complexity, although that should not be the primary objective. More complex boards will be more challenging to the factory and should be reflected by a higher score.



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The following are some items that can be included in a DFM index. However, one must determine the impact of each item on the manufacturing process and weigh each factor accordingly. Some items will be given a small point value while others with a large impact should receive a comparatively large number. Points are given:

- For each process step used and, depending on its difficulty or impact on a particular process, will vary. Pick-and-place is the lowest and selective soldering and ECO wires are

the highest values.
- For each SMT component, part number used and hand-added component.
- For more difficult components such as fine-pitch and ball grid array (BGA). Additional points are added for components that require off-line preparation.
- For each square inch of board size.
- For each violation (major and minor) of the DFM.

After developing a DFM index, the score for each new board design can be correlated against how well it does in the factory. Correlation can be against first-past yields, defects per million opportunities (DPMO) or cycle time through the factory. Figure 3 shows an actual correlation study comparing the DFM score to factory yield data.

Summary

To establish a successful DFM program, a corporate DFX culture will need to be in place. This will include support of management to ensure that all participants work together to meet DFM requirements. The DFM document is the heart of any DFX program and a team approach is the best method to create the DFM. The basic outline for any DFM may be somewhat standard but the actual contents must be specific for the equipment on hand and the processes and design technology used. DFM documents are a work in progress and should be updated continuously for improvements and to keep up with technology changes. Finally, it is important to have a way to measure how well a design follows the DFM and how well it can be expected to perform in actual production. SMT

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