Modularised And Standardised PCB Manufacturing

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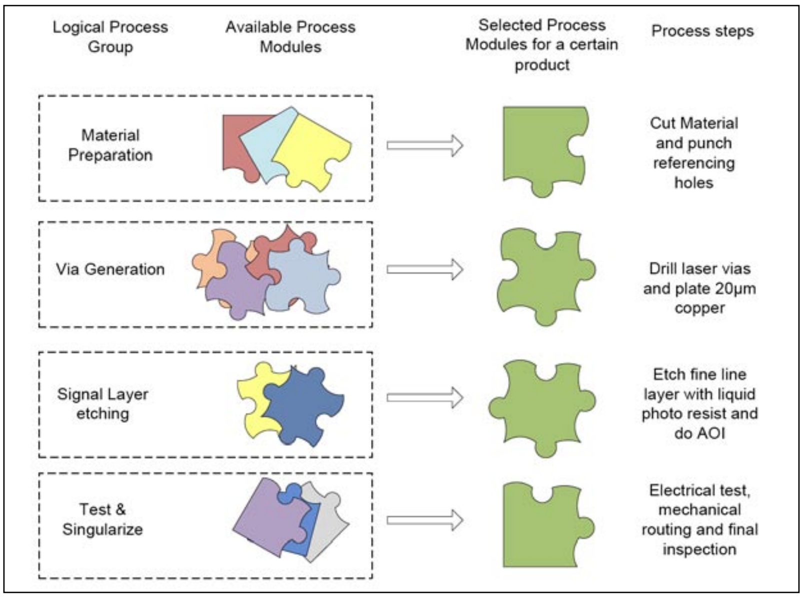
A modularised concept for the fabrication of printed circuit boards can deliver exceptional benefits. In addition to simplicity and ease of use for the engineer, modularisation inherently leads to standardisation of products because the same process modules are used over and over again. Most importantly, it reduces the effort necessary to optimise processes by allowing modules to be updated. In addition to streamlining the engineering process on the manufacturer's side, such a concept can also provide advantages for the customer such as process stability, good lead times and improved traceability.

Printed circuit boards are manufactured in a long chain of processes, each of which can have several parameter settings. A typical operation plan for a PCB consists of 50 to 300 single processes. Most processes are critical, meaning that they cannot be omitted without leading to a non-functional or lower quality PCB. A certain design does not lead to a unique process chain however. Optional processes or groups of processes as well as alternative process blocks always exist. Which of these alternatives is chosen may influence yield, costs and quality of the product. The requested quality level – e.g. the extent of AOI and visual inspections being planned – is primarily given by the customer (specification, IPC level) and the standards of the PCB manufacturer (defining that certain tests be carried out even if not requested by the customer). Optimisation of yield and costs is an essential key in gaining a competitive advantage, allowing lower target prices. Raising the yield of a product from 80% to 90% reduces its costs by 1/9. If this can be achieved by simplifying the operation plan, one can easily gain significant cost reductions without implementing new technologies or changing the build-up. Optimisation itself has its costs, since it usually involves engineering capacity. Dyconex manufactures around a hundred different PCBs at a time making it next to impossible to optimise the processes for each of these products.

Figure 1 – Principle of process modules



Automating the optimisation process

In order to automate the optimisation process, or better yet to start with a near optimum design and apply optimisations of one product also to other products, Dyconex has developed the PCB engineering software called Prisma. Compared to existing solutions on the market it allows for broad standardisation of the process flow while not imposing any restrictions on the design. It is a platform to specify the build-up, materials and the complete work instructions for PCBs. Engineers can use the system to transform the customer data into full manufacturing papers.

One of the key features of Prisma is its freely definable library of process modules. These modules always reflect the current capabilities and process settings. Existing products can be compared to the current state of the module library and be updated in a semi-automatic way. Build-up and operation plans are presented in an interactive graphical screen that allows the engineer to build the product and incorporate changes in an easy and intuitive way without the need to worry about detailed process specifications.

For PCB shops focusing on a certain type of products (like rigid multilayer only, or 2 layer flex only), process optimisation requires less engineering capacity per product. Prisma is designed for a manufacturer with a wide range of products (rigid, rigid-flex and flex boards), with a broad range of materials (polyimide, FR-4, LCP, molybdenum etc.) operating in a high-wage region (Switzerland).

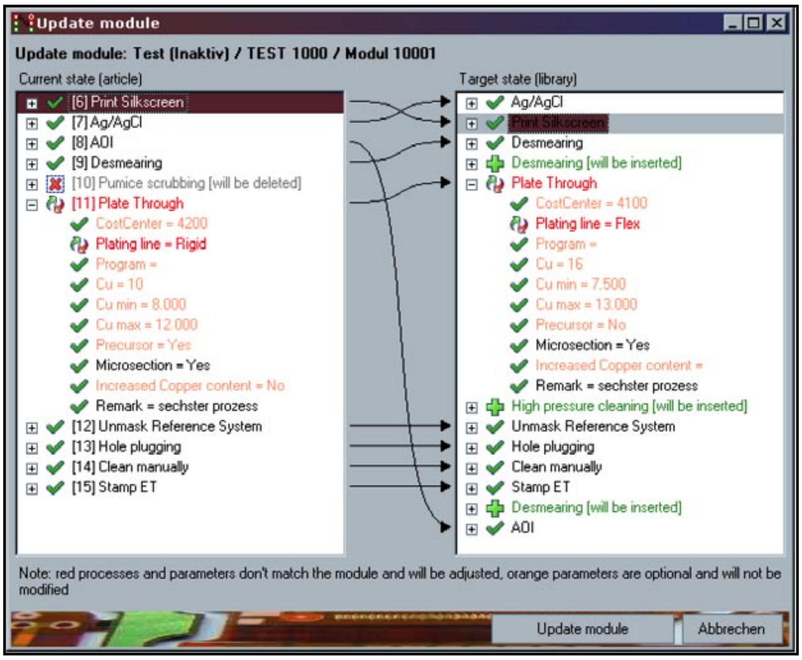


Figure 2 – Updating a process module: all processes of the selected module are shown. The icons indicate if the process will be updated (arrow icon), deleted (x-icon) or inserted (plus icon). For each process that is being updated all of its parameters are listed and each parameter is either updated or not, depending on its definition (note: this is an example and not a functional process module)

Concept

Modularity

It can be observed that process chains of very different PCB build-ups usually have similar groups of processes. The processes might use different recipes, but their topology is the same. An example is the signal layer etching that usually consists of the following processes:

Measure panel compensation > Plot films > Pretreatment > Apply photo resist > Punch reference holes > Expose > Develop > Etch > Strip > Automated optical inspection (AOI) > AOI Verification

For rigid and flex boards this flow is slightly different (no punching for rigid boards), but there is much less variance in the signal layer process than there is in the build-ups. We call these generic process flows 'process modules'. Once the process modules for all logical manufacturing steps have been identified (via creation, lamination, surface finish etc.) one can start building PCBs using these process modules like Lego bricks (Figure 1).

For the principle to work it is essential that the process modules be as universal as possible and have as little influence on each other as possible. There are two opposing tendencies: larger modules lead to a higher degree of standardisation and it is advantageous to not have too many modules in order to reduce searching and managing efforts. Large modules however tend to be too specialised to be uniformly used. One extreme would be to have a single process module for each PCB. On the other end of the scale, modules could contain only one process. Clearly, both cases render the use of modules unnecessary, as all the advantages vanish. The difficulty is to find the optimum module size that yields a manageable number of modules that can be used for many products while containing as much logic as possible. At Dyconex, 8 distinct top level categories for process modules were identified:

- Material preparation: includes steps like reference hole punching and initial copper thinning
- Via generation: combines drilling and plating
- Signal layer generation: creation and inspection of signal layers
- Contours: non-plated contours, holes and depth routing
- Inspection: all inspections that are not directly coupled to processes, like electrical testing
- Surface finish: solder mask, ENIG, silver etc.
- Lamination: includes pretreatment, drying and curing
- Auxiliary processes: short process steps like marking of panels that need not be part of the other modules.

Most products need modules from the first 7 categories. Each of these categories possesses a hierarchical sub-tree containing a total of 10-40 process modules.

Up-to-date processes

One major advantage of using process modules is that it greatly simplifies the management of process flows. Typically, the number of variations of process flows in a range of products is reduced simply by the fact that process modules are being used. Reusing an existing module is easier and faster than creating a new module or composing the process flow using single processes. Due to the unique module identification, it is well known for which products a certain process module is used. If one such module is changed, one can decide if the products using this module should be updated as well. Generally this will not be done automatically, because the effect of a change might be different in different products. Even if the update is not done instantaneously, the product still 'knows' that one of its modules is not up to date and offers the user the possibility to update the module at any time (Figure 2).

Different levels of process parameters

The process module update feature transforms an existing process flow in an operation plan into the reference process flow of the process module. Each process can have several parameters however and it is not always desirable to update these parameters. An example for a parameter that should always be left

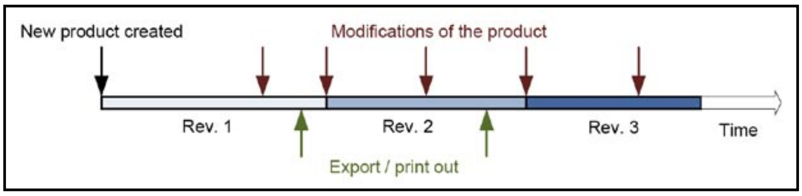


Figure 3 – Illustration of the automatic revision change. Each data export or print out freezes the current state and the first change afterwards leads to a revision increment

Figure 4 – Sample formula used to calculate the cycle time of one standard-sized lot for a horizontal processing equipment. Depending on the dimensions, the panels are either processed with the long or short edge in the machine direction, yielding different cycle times (speed is constant in this example)

```
DECLARE @Size FLOAT
DECLARE @Speed FLOAT
SET @Speed = 1.0*60*1000
IF $PanelWidth$ < 306
        SET @Size = $PanelWidth$
ELSE
        SET @Size = $PanelLength$
SELECT ($StdLot$*(@Size+100) / @Speed)
```

untouched by the update process is the 'remark' property that specifies additional unstructured product specific information. Other parameters like the equipment that must be used to complete a certain process are typically 'hard' parameters that must not be changed by the user and will be updated along with the process module.

Prisma defines three types of process parameters:

- Hard parameters: these are fully defined in the process modules and must not be changed by the user (e.g. the equipment to use for exposure)
- Soft parameters: these are fully defined in the process modules but can be changed if necessary by the user (e.g. the recipe of the plating process, which defines the amount of copper to be plated)
- Product specific parameters: these are not defined in the process modules at all. Their value is always product specific (e.g. the product ID of the needle bed adapter for electrical testing).

In real life, a system that handles modularised operation plans must also be able to handle non-standard operation plans, consisting of individual processes rather than process modules. This for two reasons:

- The system initially has to cope with an existing, 'chaotic' (non-modularised) product portfolio. Modularisation takes time, because it inevitably leads to processes changes in existing products. Each change must be checked for yield impacts and must possibly be released by the customer (e.g. for FDA approved customers)
- For prototypes, it is often necessary to quickly try a new materials and/or processes setting, which later may or may not result in a new process module. At least the first lot cannot be fully modularised.

The main challenge for a software supporting the standardisation process is to be very flexible for prototype and 'not-yet-standardised' products while enforcing the use of modules for all the other products. Prisma is based on the paradigm that the user will choose the fastest of several possible ways to work with the software. That means generally using the process modules and not single processes. In order to further boost the standardisation it is possible to limit the use of single processes to sample and prototype products and prohibit it for serial products. This approach allows for full flexibility and creativity in the prototype stage and forces the engineer to establish new technologies as official process modules once the series stage is reached. Other engineers hence automatically profit and can use the new technology in other products.

Revision management

Apart from the standard feature of having several parallel versions of a PCB (only one of which can be marked as active however), Prisma includes automatic revision management. To support traceability, it is important that any relevant change in the product specification (process or material) be tracked. First one has to define what the relevant changes are. The main feature of using a revision number is certainly to be able to compare two documents (either electronically or on paper). Equal revision numbers indicate that both documents are identical. Translating this to the software, it means that any operation plans and build-ups that have been printed out or exported to the ERP system must carry a revision number. If the user opens the PCB specification within the software and the revision number is the same as the one on paper, he must be safe in assuming that no changes whatsoever were made to the specification since the last export/print out was conducted. This could be achieved by simply increasing the revision number each time the user modifies the product. To prevent the unnecessary increase of the revisions, only a modification done directly after an export/print out triggers a revision increase (Figure 3).

Records in the database are generally only modified or deleted if no revision change is pending. Modifications of the product after an export or print out lead to insertion of new records while the original records are left unmodified. The date of each record modification as well as the user ID is stored in the database. This system guarantees full traceability of all changes down to the date and user while minimising the amount of stored data. Only the last revision can be edited, all previous revisions are read-only.

Process times and cost calculation

Prisma requires a full description of PCBs on the process level and stores all data in a structured way in the database. This prepares the ground for advanced features such as the calculation of realistic process times and costs based on the processes and the process parameter settings. A formula editor provides the framework to define setup times, cycle times (cost relevant) and total process times (relevant for production planning). The formulas can make use of all technical parameters of the current process that the software knows of, as well as all general parameters of the PCB such as the dimensions, the IPC level or the number of layers. Based on the setup and process times the ERP system is able to calculate a realistic cost expectation that can be used to set the price of the PCB. The total cycle time is an absolute necessity for an accurate production planning (part of the ERP system as well). To illustrate this concept, a sample formula is shown in Figure 4.

The syntax of the formulas is TSQL and Prisma does not have its own parser but uses the SQL Server to evaluate the results. The sum of setup and cycle time can be multiplied by the cost rate of the process to get a cost estimate. Different calculation schemes are possible, e.g. not using time but technical quantities such as the number of panels processed.

Copper thickness calculations

Copper thickness is often an issue in designing the manufacturing process of a PCB, especially when using a panel plating process. Minimum copper on the surface is desired for signal layers etching while a safe amount of copper plating is needed to guarantee the minimum copper thickness inside the vias. Many cleaning steps reduce the copper thickness (e.g. the treatment before applying photo resist, solder mask, cleaning before lamination, etc.). For complex products it can become very time-consuming to manually add up all positive and negative effects on the copper thickness for each layer, always respecting the minimum and the maximum tolerances. Prisma does just that for the user. Each process has a predefined or parameter dependent min/max effect on the copper thickness that is applied to the copper layers the process has been linked to (see also Figure 5, the column 'Cu+Met' shows the average base copper plus plated copper on each layer after final processing). A plating process has a positive effect (adding copper) and cleaning or etching processes have negative effects.

Benefits for the customer

Process excellence

PCB manufacturers sell their process capability to customers. Prisma manages process flows and helps to establish standards. The key attributes customers expect from a good PCB manufacturer in addition to low prices are reliability (constant and good quality), predictability (constant yield, no unexpected technical problems) and short lead times.

Prisma helps achieve improvements in all categories. Reliability is enhanced by the fact that elements of a library consisting of tested process modules are used to build new products. This reduces the risk of design defects, neglected process steps and unconscious introduction of new and untested process flows. Since inspections are reflected in process modules, the amount of testing done during the fabrication is standardised as well. Quality is a result of stable, tested processes and an adequate level of inspection.

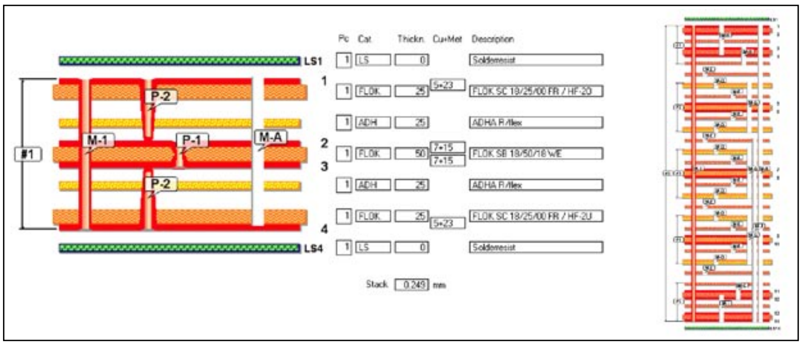
Predictability is partly guaranteed by the fact that changes to existing products are tightly controlled. Series products can only by changed by modifying existing process modules or introducing new ones. In both cases the procedure must be released by a committee (Prisma only limits such modifications to super users, release procedures are part of business processes and not the software). As a result, sudden yield losses or technical problems leading to supply problems are minimised. Customers can be confident that there will be no surprises when ordering products based on existing technology.

Lead times are reduced for two reasons. First, the engineering time is cut down because working with blocks of processes is faster than reinventing the same technology again and again. This latter procedure is also more error prone than copying existing products because each process module must be deliberately chosen and checked. Second, a smaller number of variants in the process flows leads to more clarity and less errors during the fabrication.

Traceability

As described in the revision management section, any change in the specification of a PCB such as the material, process, process parameter or even a remark in the operation plan is tracked if a revision increment is pending. Based on this system it is possible to reopen the product in the software for each production lot at any time. The clear work instructions automatically generated by Prisma from the operation plan increase the certainty that each process step is done in the same way each time (in contrast to a system where everyone has the

Figure 5 – Left: build-up of a 4-layer flex board with plasma drilled micro-vias. Further information is printed in the table next to the illustration: number of material sheets (Pc), material category (Cat.), base material thickness (Thickn.), copper thickness (Cu+Met) and material name (Description). Right: 14-layer rigid flex board (table with details omitted)



freedom to influence the wording and formatting of the work instructions).

Visualisation

Especially for complex PCB build-ups with multiple lamination steps and various interconnection levels a visual representation of a cross section can be helpful. In a simplified way, a build-up of a PCB can be characterised through the following features: materials, interconnections, routings, and laminations.

Prisma supports a graphical interface that allows the user to quickly sketch a product from scratch using a library of generic materials and processes. The generic material library only defines the category of material (polyimide, FR-4, adhesive, etc.) and the processes distinguish vias (mechanical, laser and plasma, either plated or non-plated), routings and laminations. Especially in the initial inquiry phase when different technical solutions for the customer's design are being discussed, visual representations help establish a mutual level of comprehension between customer and supplier. Examples of graphical build-ups are shown in the following section.

Sample PCBs

To illustrate the potential of the presented concepts, two examples of actual PCBs implemented with Prisma are shown. The first is a fairly simple construction of a fully flexible PCB built with polyimide and acrylic adhesive. Micro vias connect layers 2-3, 1-2 and 3-4 and are drilled in a plasma process. Additionally, layers 1 and 4 are connected by mechanical holes. Solder mask is applied on both side and the final separation is done in a mechanical routing step (Figure 5).

This product was assembled using 11 process modules from the standard library yielding a total of 90 processes. The sequence of the process modules is the following:

Prepare material > Drill & plate vias 2-3 > Signal layers 2 & 3 > Laminate > Drill and blind vias and through holes 1-4 > Signal layers 1 & 4 > Apply solder mask > Mechanical routing > Surface finish > Electrical test > Final inspection

It is easy to modify this product, e.g. replace the plasma drilling process by a laser process. In that case the substitution of the two drilling modules would be sufficient. Similarly, the modification of the surface finish could be achieved by replacing only one module and possibly placing it after the electrical testing if necessary (e.g. for surfaces like OSP that could be damaged by the electrical testing). An extract of the operation plan (Figure 6).

In order to illustrate the power of the concept, an example of a 14-layer rigid flex board is also shown in Figure 5. The bendable area consists of 3 double layers flex areas, copper being protected by pre-routed coverlay sheets. Two 4-layer rigid cores made of glass reinforced polyimide provide the stiffness. 105 processes and 25 modules were used to build this product.

Future enhancements to the system

After about one year's use of Prisma, many ideas exist to further extend the modularisation concept and the software in general. One improvement would be a compatibility check that prevents the user from specifying adjacent modules which are incompatible, or even better an expert system that suggest possible process modules based on the precedent module and the build-up. Such a system would require meta data on the process module level that allows the software to understands its function. Currently only human readable descriptions can be defined. Another approach to promoting modularisation could be an automated module recognition / optimisation procedure that converts a given operation plan into one with a minimum number of process modules from the current library. This would allow the user to easily update prototype products that were initially built with single processes rather than process modules.

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Figure 6 – Section showing a few processes of an operation plan. The left side holds a visual representation of the operation plan consisting of processes that are grouped into process modules. Each process may have several parameters that can be modified in the parameter editor. On the right, the conversion of the operation plan in to work instructions can be seen