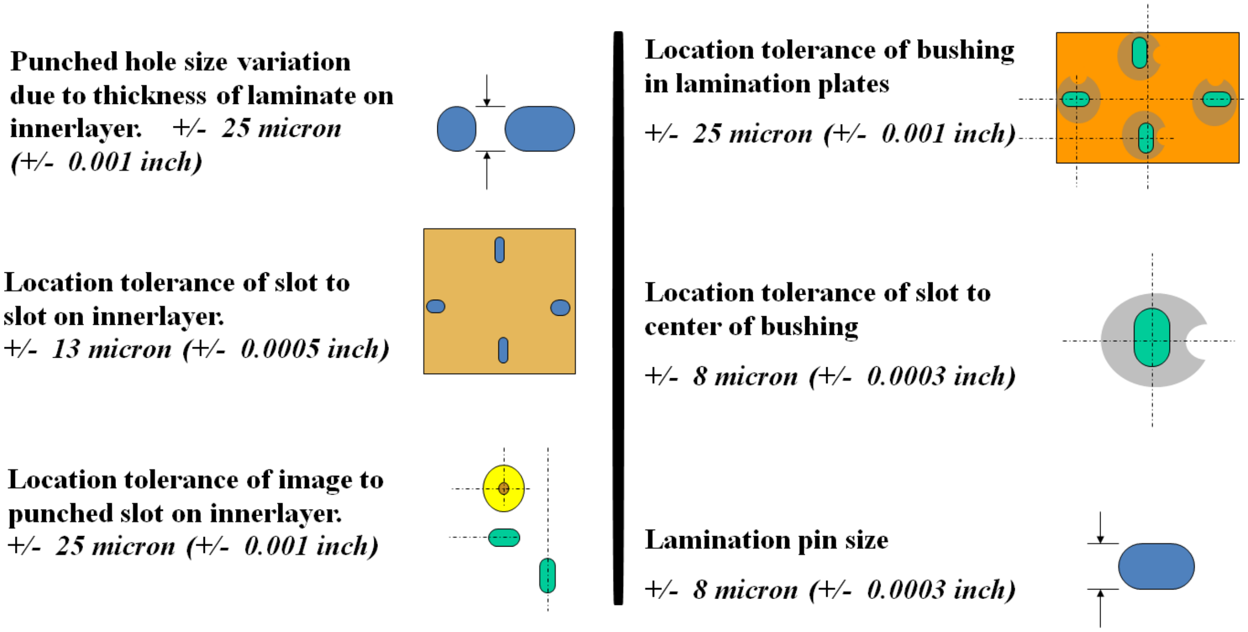
Optical layer-to-layer Alignment

Summary. *One of the biggest challenges in the production of PCBs has been layer-to-layer registration; current pinning processes make it difficult to meet today's PCB requirements. The introduction of optical alignment has now made it possible for many PCB manufacturers to move up the technology curve while lowering their production costs.*

Miniaturization is the creation of ever-smaller scales for mechanical, optical, and electronic products and devices. The continuing demand for miniaturization within many of the electronic devices that are used daily has pushed the electronic industry to consistently seek out improvements to the manufacturing process. Circuit Board shops have responded by continuously improving their processes to meet these needs. Over the last few years, due to miniaturization, the hole-to-copper tolerance expected from the industry has decreased from 8 mils to 5 mils, now some are requesting as tight as 3 mils. 8 mils was difficult enough for most shops, how many do we know that made extra boards due to yield loss. So what do you do now with those tight leading edge jobs? Make more boards to cover yield loss, or don't quote the job. This is the dilemma that most shops have. The introduction of LDI has improved the front to back registration. X-ray and conical drills optimize a drill pattern to each individual board. Predictive modeling software helps characterize a layer's expected movement. Unfortunately, while these efforts and expenditures have improved the multi-layer alignment situation, they do not get to the heart of the matter. The current layer-to-layer alignment processes available in the market *are* the limiting factor in meeting these new requirements.

The "State of the Art" for aligning cores has been to use a four-slot post etch punch. The conventional wisdom was that more cameras on the post etch punch machine was the solution, and although in theory this sounds good, it really is not where the majority of the errors originate. Listed in Figure-A are the bulk of the tolerances, assuming the punching machine is in great shape, the punches are sharp and are sized correctly to core thickness being punched. The total on these tolerances alone is over +/- 4 mils. In manufacturing these tolerances don't usually stack in one direction, so the reality is that this comes in at 2-3 mils. Again, this is assuming that all is in perfect condition. This culminates in a difficulty of aligning layer to layer better than +/- 2 mils. Now we add on the material handling issues with a pin lamination system.

FIGURE A - Tolerances associated with pinning systems



When the pin lamination process was developed 40 years ago, 12 mil thick cores were considered thin core, now in some shops 12 mils is the thickness of a sub-lam panel. When an operator would lay-up a core that thick, they would gently place the core with two of the slots over two of the pins and carefully push the core down, then they would push down the other two slots and any misalignment would be self centered due to the stiffness of the core. This was the main benefit of a 4 slot system, the ease of lay-up, as opposed to lay-up up with round holes where wrinkling of the cores is difficult to control. That is okay with a 12 mil core, but not with a 2 or 4 mil core, the wall of the slot on the core is not rigid enough to allow the core to center itself. Now, when the operator places the core on pins, they cannot see if the core has shifted 2 mils or 10 mils. (See Figure-B) This is the biggest and most unpredictable tolerance that contributes to layer-to-layer misalignment.

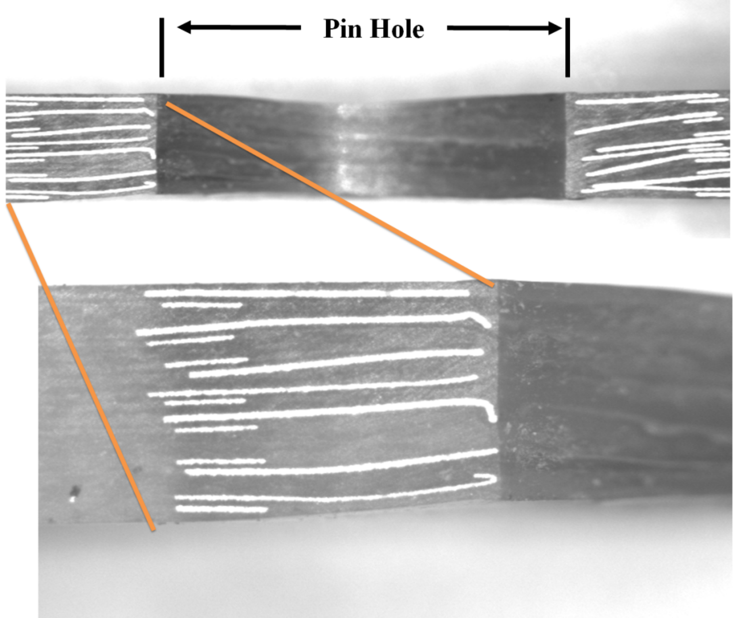
FIGURE B - Distortion of inner layer slots at lay up (thin cores)

The tendency for most operators is to wiggle the separator plates or the top lamination plate in order to place it over the four pins; this wiggle motion actually distorts the slots and will cause some misalignment. Material movement during the lamination cycle will also be a source of distortion. It is clear that after a lamination cycle, if the slots are cross sectioned, that the cores will show distortion caused by contacting the lamination pin.

There is no way to check registration using a pinning process prior to lamination; you can't put the complete book with lamination plates under the x-ray. Now some companies have gone to extremes to try to get better control of these tolerances and pinning problems by tightening the tooling tolerances. They have spent enormous amounts of money on new thicker lamination plates, and have gotten more expensive and tighter fitting pins and bushings. The lamination pins and bushings are checked after every cycle using dial indicators. This is time consuming and expensive since it requires experienced technicians to perform the checks.

Handling of the lamination book prior to the lamination cycle is critical. The assumption by most operators is that they are handling a solid block of steel and they don't see how they can cause any mis-registration, however, let's picture a book that is about 1.5" high and is now being moved from the lay-up area into the press. Often it is pushed down a roller conveyor into the lamination room and hits a stop. This causes the bottom plate to stop. The top plate wants to keep moving due to inertia, but its momentum is checked by the lamination pins. This impact just shifted the cores. Some companies have tried to address this by automating the book handling, and it does help to minimize this issue. Once again, these are adding more costs to the production line, both short and long term. As is shown in Figure-C, the evidence of these errors is easy to see.

FIGURE C **- Distortion of innerlayers at lamination pin locations**



Flexibility in tooling is almost nonexistent with a pin process; the panel sizes are typically limited due to the cost of different size lamination or separator plates as well as tooled foils, prepreg and lamination pads, etc. With the introduction of sub-lamination panels, shops realize another drawback with a pinning system. Some companies try to address this by starting with a larger panel, reducing the panel size or punch at different locations as they go through the process. These methods require more expensive tooling and are limited in the number of size and slot locations available.

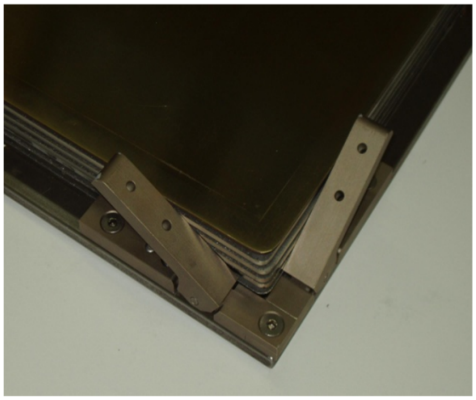
It is amazing that companies use the latest hi-tech system to produce circuit boards, such as LDI system for imaging, lasers for drilling and so on, but the current lay-up technique is an archaic process that has not yet arrived in this millennium (technologically speaking).

Optical alignment process delivers better registration accuracy by eliminating the mechanical tolerances of other processes. This process is to layer-to-layer alignment, as LDI has been to front-to-back registration. The process is exactly what the name implies, to optically align layers without the use of pins. Layers are aligned by a positioning system that holds each layer with the associated prepreg in alignment. Optical alignment has the advantage of viewing the alignment targets while holding the layers completely flat and clamping the layers in position. All of this happens with the targets in view of the cameras, unlike a punching system, where the cameras lose sight of the targets when punched.

In a straight build (no sub-laminations), all the internal cores are held in alignment and then the layers are tack welded together at four locations. For example: a 30 layer board will have layers 2 through 29 tack welded together; this inner layer package is then placed in the book at lay-up with prepreg and foil on the outside as layer 1 and 30. There are no pins at all required for optical alignment process. The book is held in place by four corner blocks, to ensure that the completed lay-up package, including the separator plates and top lamination plate, are held in position during transport into the press. They do not influence the registration of the circuit board; they are merely a method of holding the book in place. Typically these types of corner blocks are spring loaded, to accommodate a range of stack up heights.

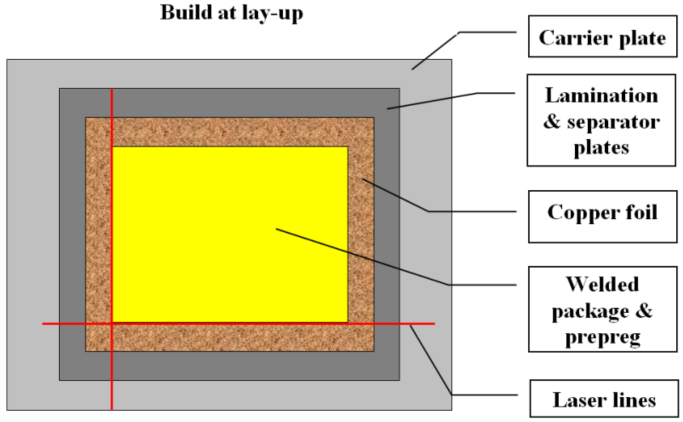
FIGURE D - Typical lay-up

Corner blocks



Used to hold book in position while tranfering to lamination press

Build at lay-up



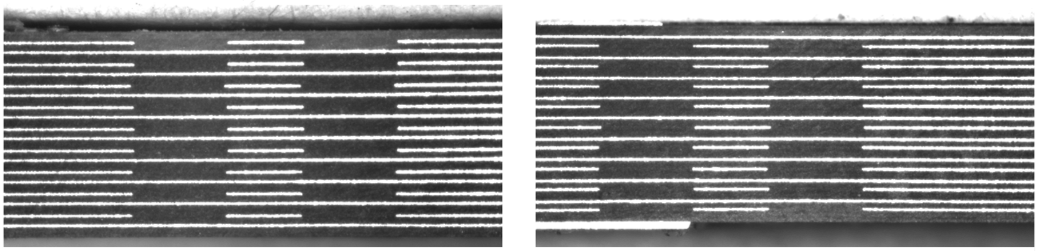
Laser lines used as guide to center the welded panel

Optical alignment gives users the ability to measure panel accuracy prior to the lamination process. Welded panels can be measure on an x-ray machine to determine if the panels were aligned properly. This pre lamination data can be collected and added to a customers' predictive modeling software where the data can be used to evaluate what movements took place in the press allowing engineers to "dial in" the lamination press cycle. By analyzing the collected data, trends appear allowing you to make adjustments leading to repeatability. This would be difficult to control if the layer-to-layer alignment showed a random pattern. Up until now this has been mostly a trial and error method.

In Figure-E we see four cross sections of two panels; these 20 layer production boards processed using optical alignment. The two ends of each panel were cross sectioned along the long axis, and then the cross sections were book matched. The layers are aligned within 1mil total window. (See Figure-K "Cross-Section Analysis for Registration") This includes the alignment tolerance, material movement, scaling and lamination press cycle.

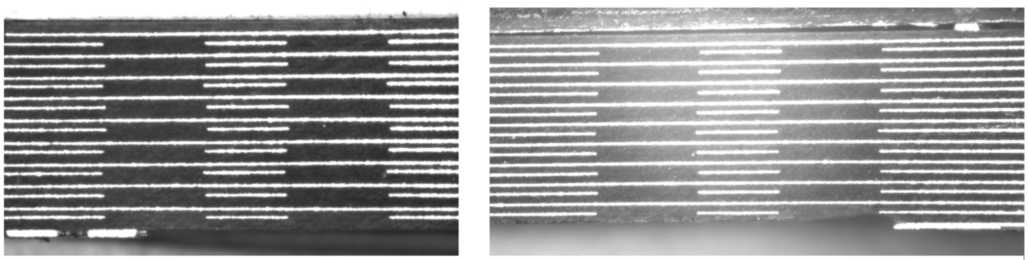
FIGURE E - Cross section of two 20 layer panels

20 LAYER PCB



CROSS SECTION OF OPTICAL TARGETS ON LONG AXIS

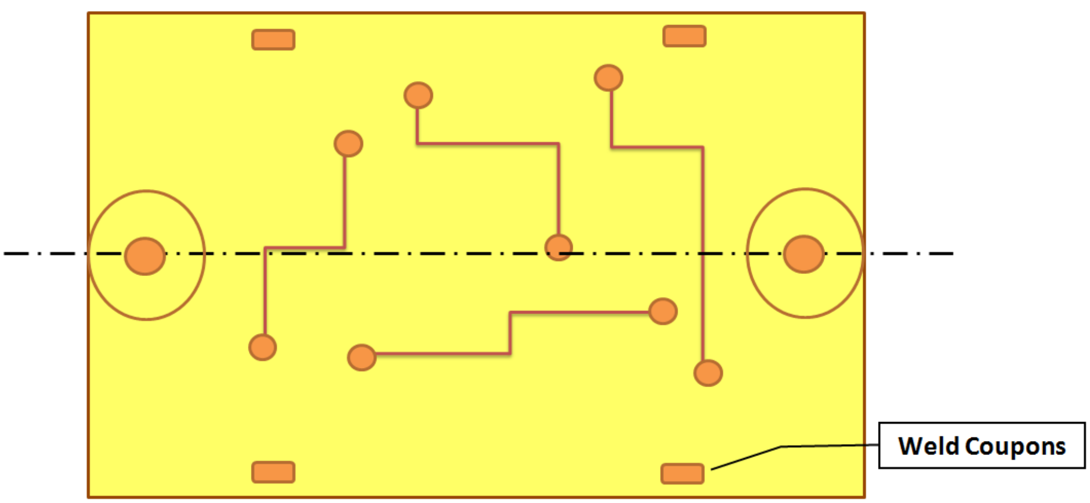
20 LAYER PCB



CROSS SECTION OF OPTICAL TARGETS ON LONG AXIS

The welding process is typically via an induction system. The internal package, whether it is layers 2-29 as in the example above or a mix of thin cores and sub-lamination panels is the same. Typically the panel is welded at several locations as seen in Figure-F.

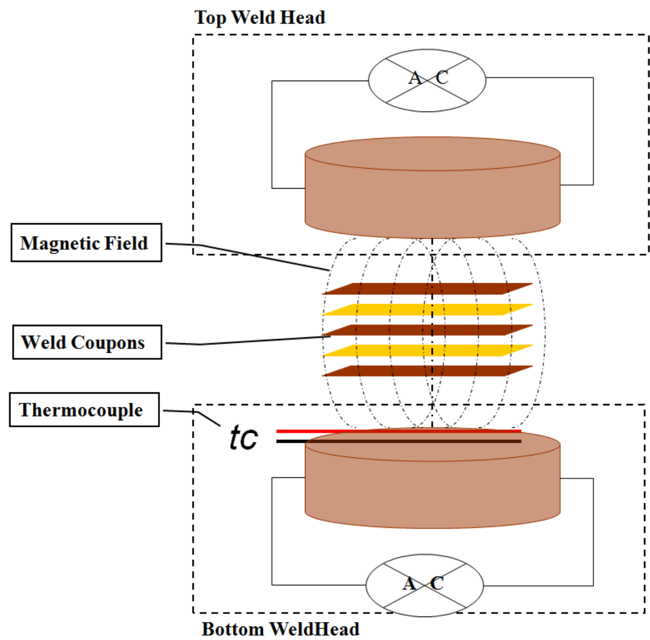
Figure F - Weld Coupons



Typical panel layout with 4 weld coupons and targets

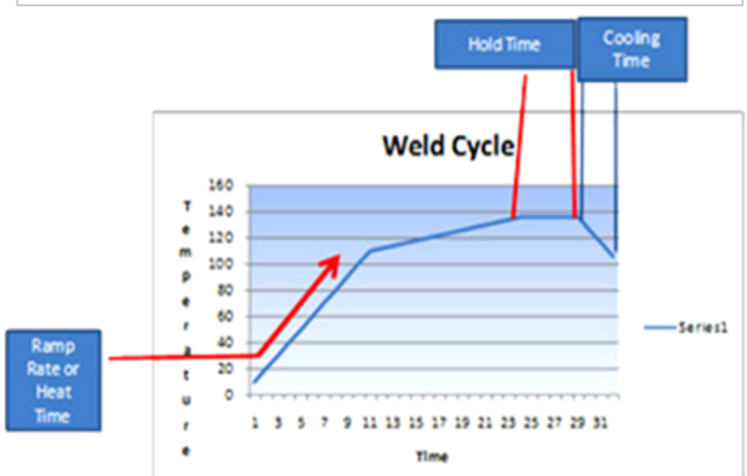
Once aligned, the panel is welded together utilizing a coupled induction system. The system consists of an upper and lower weld head per station as in Figure-G. As the magnetic field passes through the copper coupons on each layer it generates heat, thus the heating is in intimate contact with the prepreg and exactly where it is needed. Induction systems need metal to work, so as long as there is a weld coupon made of any metal, (copper or aluminum, etc) then heat will be generated. These systems are used with all types of laminates in the market today and the temperature range capability exceeds the highest temperatures required for lamination.

<u>Figure G</u> Coupled Induction Weld Head



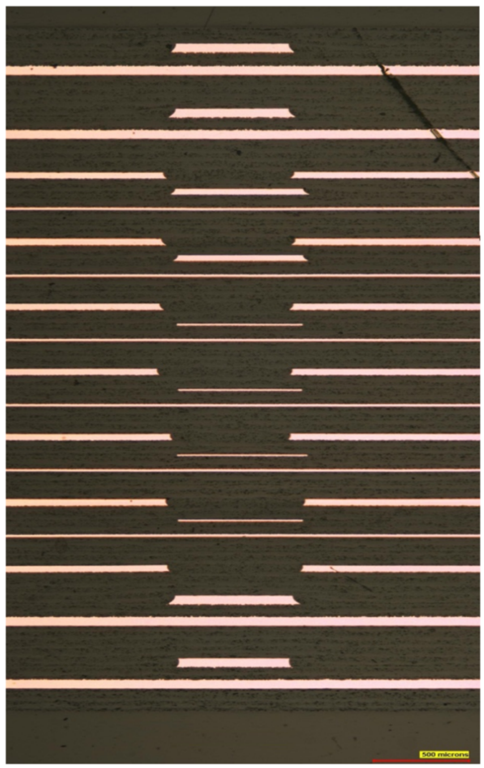
The complete weld cycle is controlled similar to a lamination press cycle. An imbedded feedback pad in the weld head monitors the temperature for the complete weld cycle. The different parameters are set, such as maximum temperature, temperature ramp rate, hold (soak) time, cooling time and pressure. (See Figure-H)

<u>Figure H</u> - PC controlled welding cycle



One concern that often arises with any type of heat welding is the behavior of the layers with different scale factors in the lamination cycle. The misconception is that the weld point fixes the layers together that it holds the layer from moving in the press. The reality is that a layer will move and that the weld points or steel pins will not stop it. Some points to consider when panels are properly welded with an induction system; the weld point is not 100% cross linked; it should only be strong enough for handling at lay-up of the lamination book, the weld point is free to move within the separator plates above and below it, unlike a steel pin that is hard and fixed to a tooling plate. Figure-I is an excellent example of a 34 layer panel that has thin cores, thick cores and sub-laminated panels that have been welded together in an optical alignment system and then processed in lamination. The layer to layer alignment in this example is within a 1.25 mil window.

Figure I - Complex multilayer

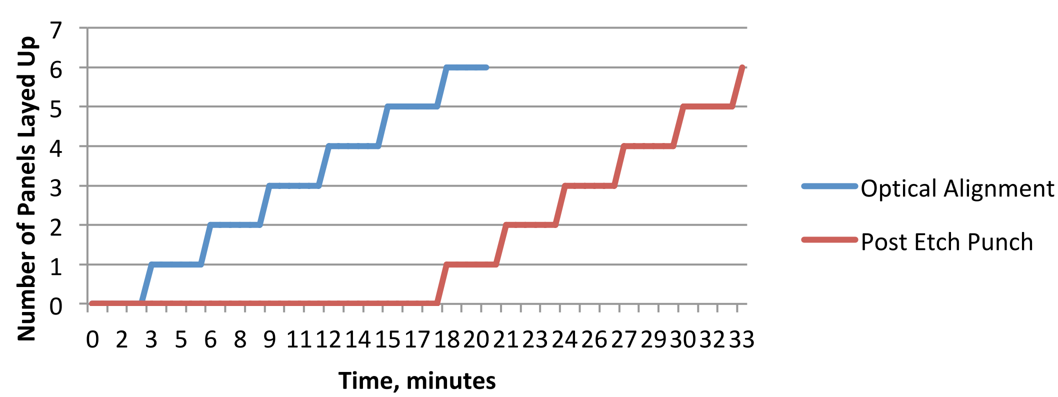


Cross section of a panel consisting of different thickness layers with different scale factors that were welded together

The key points that have been emphasized so far with optical alignment have been accuracy and repeatability. While these are the most important improvements, the introduction of optical alignment, this is just scratching the surface of the benefits of optical alignment. Unlike a post etch punching system, which is really a batch process, optical alignment is a continuous process, reducing layer handling and increasing productivity. In optical alignment as each panel is aligned and welded, it is then placed in the lamination book rather then having to be punched before the lay-up can begin.

Example: As seen in Figure-J, if processing 20 panels, 26 layers in a punch system, all layers 24/25 would be punched first, then 22/23 and so on until the complete batch is punched. Book lay-up would not be possible until all layers are punched. In optical alignment, 24/25 is aligned and clamped in position, and then 22/23 with the prepreg is loaded into the machine and aligned and so on. On average a 26 layer panel would be ready for book lay-up within 3 minutes. This means that by the time a punch machine had completed punching all of the cores, the optical alignment process will have had almost all of the panels completed, placed in the book and ready for lamination.

Figure J - Productivity Comparison of Job with 26 layers and 6 Panels



Conclusion:

In order to stay competitive, PCB shops need to keep up with technology that is demanded from the marketplace and still stay competitive. The attitude of “that’s the way we’ve always done it” will not keep companies in operation much longer. Investment in new proven technologies that move a company up in the technology curve while reducing operational costs must be considered. Optical alignment systems have now been in service for nearly a decade with pricing that is comparable or lower cost than a pinning system. When registration requirements are starting to chip away at a company’s bottom line, it is well worth considering this proven high tech alternative.

Figure K

Cross-Section Analysis for Registration

There are two ways to cross-section targets. They are shown below for reference. Cross-sections must always be done through the optical targets that are used by the Direct Optical Registration system or cross-section targets that are next to optical targets.

Pick the cross-section type that will provide you with the data in the axis that you are more concerned with if you are cross-sectioning optical targets. Type L cross-section has samples that are cut along the long axis of the PC board.

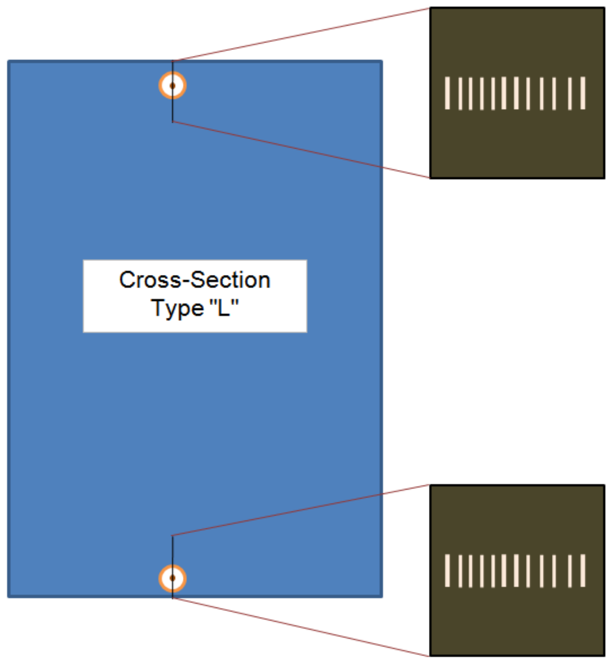


Figure 1, Cross-Section along the long axis of board

Type S cross-section has samples that are cut along the short axis of the PC board.

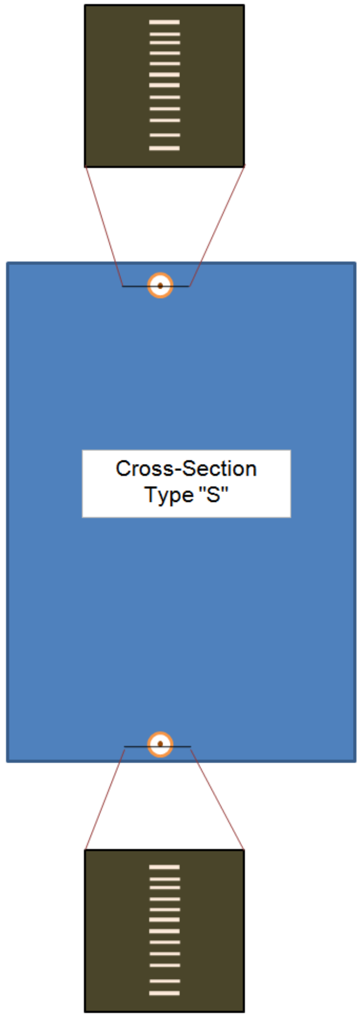


Figure 2, Cross-Section along the short axis of the board

When analyzing cross-sections be sure to mark each sample with at least the following information and be sure that this information stays with the sample at all times:

- Job number
- Panel number
- Which end of the board that the sample was taken from
- Cross-section direction (L or S)
- Which side is layer 1

Next identify which layers are the even numbered layers. If the targets are placed only on the even numbered layers this will be easy to do. If it was an atypical construction identify the layers that the camera saw during the layup and alignment process in the PRS machine.

When looking at a cross-section under high magnification using a digital image measurement system, set the sample so that it is level on the screen. See figure 4. Draw a horizontal line across the screen and line up the drawn line with the foil layer, if available, or the surface of the laminate sample. Next identify the layers that you are interested in measuring. Draw a vertical line perpendicular to the first pad that extends through all of the other lines. This will be your reference line. Measure from the center point of each of the lines representing the pad width horizontally to the vertical reference line record the distance and direction.

Each panel that is to be cross-sectioned must have both targets cross-sectioned in the same way. They must both be type S or both be type L. In the long axis of the PC board, the PRS vision system will position each core so that the core's center point is always the same. After lamination some cores may be longer and some will be shorter. You will not be able to determine the long axis accuracy without looking at both cross-sections. They should be mirror image of each other or "book matched" as shown below.

Figure 3, This is what a type L cross-section would look like if you could see both targets.

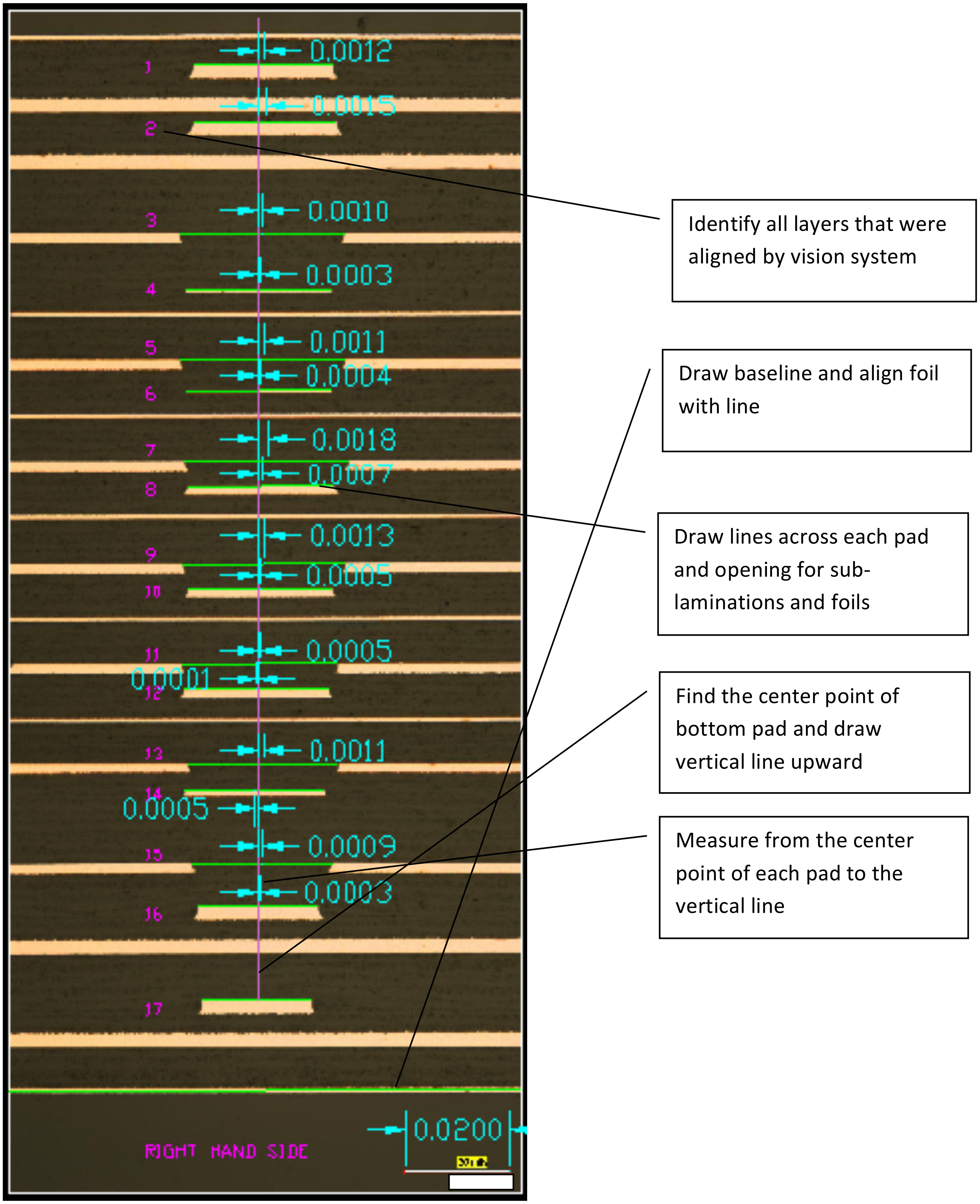


Figure 4, Cross-section for analysis