A Fine Line To A Great Print Process

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"I want to greatly improve my circuit print process" – Really? Today, almost fifteen years after we developed a process to achieve accurate and consistent prints, yield in the high nineties, volumes in the 10s of thousands per week, I still see most ceramic companies using old techniques because they have not invested the Engineering dollars to achieve a real world-class Print Process.

I worked for a prominent Medical Company in the Phoenix area as the Manager of Equipment Engineering. I was there during one of those golden opportunities that only come around a couple of times in a lifetime. We had an infant HTCC process that was yielding in the 40s and producing a few hundred substrates a week. We had not even heard of Statistical Process Control. It was common place to lose an entire layer run or an entire lot at the back end because of a process problem with one of the layers or some other simple problem. This had to change if we were going to succeed in making all of our own substrates and have the most responsive ceramic facility in the world.

We had a commitment all the way from the top, to bring the process up in yield and volume through sound Engineering and dedication. This was essential to our success. Without the Commitment from top management backed up by the dollars to do real process engineering, to actually buy, modify or develop machines and processes, we would have never accomplished the amazing results in the timeframe allotted.

This story is about a few select processes that revolve around screen print and how a major shift in thinking can have profound effects on the overall operation.

Our layer counts were anywhere from 7-14 with via counts in the thousands per layer. Our normal product used 5 to 10 mil vias, 7 to 11 mil lines and 5 to 7 mil spaces. We manufactured our own ceramic tape, produced our own inks and via pastes. We had our own automatic gold plating line. Our process was as complete a process as was available anywhere, but infant and plagued with problems.

I will focus on the print process and screen manufacturing as two key areas where we made exceptional strides in yields, major reduction in setup time, orders of magnitude improvement in screen life and a major paradigm shift in the way we thought about inspection and acceptance. These accomplishments can be yours.

Now, what's the cost?

In round numbers…..$350 to $400K in equipment plus two good Engineers and less than 1 year.

This will give you:

- Complete screen making process ($150K) Includes: Screen Stretcher, Exposure System and Washout System, Artwork Alignment Fixture, plus peripherals.
- New specialized Measurement System that, not only automatically aligns your printers (up to four), but also can double as a via punch alignment verification tool ($85K).
- Artwork. You will need Fiducials and Registration Holes.
- Artwork control ($10K), Environmental Cabinet
- New screen frames ($20K): 200 Special Frames with alignment bushings.
- A highly specialized screen printer ($60K Retrofit of one (1) Printer).

Each additional printer would obviously be an additional outlay, but this gives you an idea what to budget the next time this subject burns to the top of the priority list. There's no sense in fooling yourself. If you want the results, you need to commit to the total process. Anything left out is just more variables blurring the Pareto Chart.

Still interested?

OK, let's describe the things that need to be done in detail so you fully understand their connection with the end result.

The Print Process is really a collection of several inter-related Processes that all must be engineered completely to have their respective effect on the whole.

MEASUREMENT SYSTEM

The key event that triggered a cascading of projects was our change from artwork as the "Last Word" to a "Standard" that could be used for several processes. By incorporating this "Standard" into a complete measurement system we had the tool necessary to help us begin the Process Control that we so desperately needed.

As you might expect the first and not necessarily the most obvious piece is a Measuring System that eliminates the use of artwork for any purpose except for exposing the prepared screen. There's nothing more frustrating than to have the production tech tell you that the via punch is out of alignment only to find out that he is using artwork to validate the via punching system. Talk about the tail wagging the dog. Artwork has only one use, to accurately put the print pattern on the screen emulsion. Any other use from a quality standpoint is non-existent.

I describe the Measurement System first primarily because it is both a major Paradigm shift and it has immediate positive effect on your process with minimal engineering. I have seen more tape layers remade because someone, using artwork as the Standard, was convinced that the Via Punch machine was out of alignment. Once you can get your people to buy into the concept of not using artwork for qualitative purposes, you will have resolved a lot of conflict.

The first truism or new concept is that our print alignment is to the "Registration Pins" not the vias.

The second truism with this concept is that the via-punch registration pattern is not necessarily accurate to the vias.

By aligning your processes to a common “Standard”, which is your registration pattern, you hold each process to a single target. This in effect cuts your total process alignment tolerance in half. If you align the punch to itself or do not align the punch at all you are hoping that all layers have the registration pattern punched exactly the same with respect to the vias. Then, when you align your print to the vias you are hoping that all layers will line up when stacked at lamination. I contend that via punch machines, like all machines, have tolerance that must be addressed. The measurement system allows you to verify where the punch is placing the vias with respect to the registration pattern. This information is used to invoke an offset in the punch program to correct the via pattern to the registration holes on a layer by layer basis.

The print process is also aligned to the registration holes with the help of the measurement system. The print on the tape is measured with respect to the registration holes and correction offsets are uploaded to the printer. With this method you are using the measurement system to be the Correcting Agent to hold each of your processes to a single reference, your registration holes. If you align the printer to the vias then it is conceivable that some layers can be shifted in one direction while others are completely opposite thereby doubling the positional error that you actually see.

This Measurement System (See FIG 1) consists of a camera and telecentric lens, an XY Stage, a Computer, a Graphics Screen, a report printer and, the single most important item on the Measurement System, a built-in Glass Alignment Standard. This Standard becomes the Process Jewels for lack of a better analogy. This Glass Alignment Standard consists of a hardened frame with registration pins to match your registration pattern. Your tape layer goes on these registration pins and the system reads the Fiducials printed on the layer, calculates X,Y and Theta corrections and uploads alignment offsets to the printer automatically.

FIG 1 MEASUREMENT SYSTEM

Inside the frame is a highly accurate Glass Reticle that has a series of .004” diameter dots strategically and very accurately placed on it using Wafer Process Technology. The dots are used by the Measurement System to self correct its X and Y motions for orthogonality

and position. This keeps the Measurement System calibrated to the “Standard” and makes it the “Last Word” when it comes to measuring your via punch and printer accuracies.

The Measurement System has custom software, making it uniquely suitable for both validating your via punch system and semi-automatically aligning your printers. The Measurement system can recognize both Vias of different sizes and the Fiducials on your New artwork. Once a Printer is set up and the setup print created, the printed tape is placed on the Glass Alignment Standard of the System. The correct program corresponding to the specific Layer being built is loaded and the Measurement System sequentially moves to and reads each Fiducial and places a corresponding Fiducial Shaped graphic on the Graphics Screen within a Custom “Bulls-eye” Target to graphically show each Fiducial’s location with respect to “True” position. Once complete the System will calculate the “Centroid” and any XY or Theta (Rotational) error in the printed tape. It will then ask if you want the corrective coordinates to be uploaded to the specific printer. Once this is achieved the second print is usually in “Spec”. About the only thing that would prevent the System from accurately correcting the Printer would be a distorted image on the Screen Frame or remaining emulsion clogging up a Fiducial to make it unreadable. Usually careful Screen inspection prior to the Setup will prevent this from occurring.

ARTWORK

The next most important element is your new Artwork. NEW artwork looks like what you would expect, all of the individual circuits on it, however there are two new features that are essential: Fiducials and Registration Holes. The Fiducials are little distinguishing marks on the artwork, usually two per specific part, but if your parts are very small you could divide them in groups for each pair of Fiducials. These Fiducials are used primarily by the Measurement System to measure the **relative alignment of the print with respect to the registration holes** that are punched in the tape. Instead of aligning the print to the vias, we align the print to the “Standard”. This is how we get all layers to “Line-up” when stacking them for Lamination. These Fiducials can also be used down the line in your stacking and cutting and others processes.

This is the first project that needs to be funded. All of your artwork will need to be replaced with new artwork that has, not only Fiducials, but also punched registration holes that match your standard registration hole pattern. These holes are used in the screen making process to “Tool” the artwork to a very close tolerance to the Location Holes in your new screen frames (you will need to purchase these also). This places the image on the screen frame to within .005” of final position with the very first print (a setup print may be necessary). You can, by-the-way, use your Measurement System to validate your artwork because the artwork has all of the features necessary to act like a printed tape.

Once you’ve made the decision to redo your artwork, care must be taken to implement a humidity controlled environment (usually a specialized cabinet – a good project for your facilities people). Let’s face it, Artwork will change its size and shape over time and this is reflected in the actual circuit print created with the screen so it is imperative to protect your artwork and validate it from time to time to know when it is no longer in tolerance and

unable to create a usable screen. This is one area for which you will need to budget. Historically once you purchase artwork for a product, unless there is a change, the artwork lasts forever. You must come to the realization that Controlled Print Processes need Controlled and periodically validated Artwork.

SCREEN MANUFACTURING

Custom Screen Frames

You need several key elements from your screens if you hope to capture all of the process control you really desire.

The first requirement is precise alignment of the circuit pattern with respect to the Screen Frame alignment Bushings. We achieve this by providing two alignment bushings that are used not only in the printer, but also in the exposure process. Remember the registration holes in the artwork. We use them in conjunction with the alignment bushings in the screen frames by incorporating a custom Polycarbonate alignment fixture that precisely locates the artwork with respect to the alignment bushings in the screen frame during the exposure of the emulsion on the screen (See FIG 2). This precise alignment guarantees that when you place a new screen on the printer it will be within .005" of final location. This insures minimal setup time and perfect alignment after the first print.

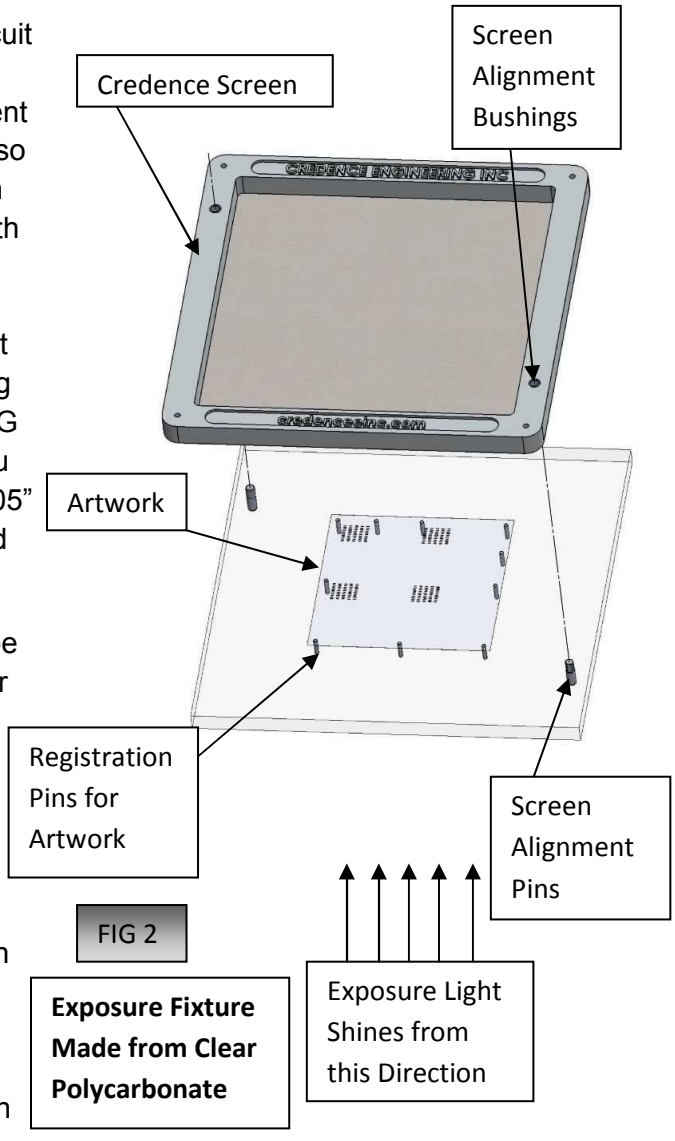
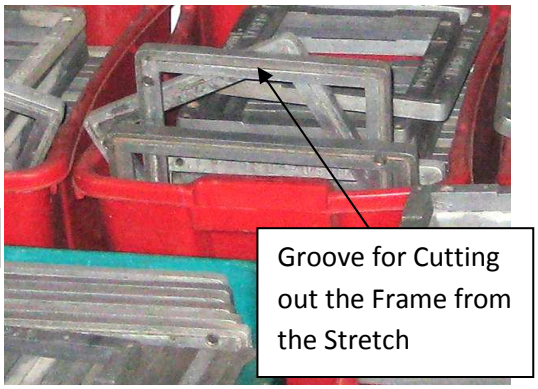


FIG 2

You also need the bottom surface of the screen to be perfectly flat. This plays an important part when your printer is transformed because the key variable that we eliminate in the Print Process is the "Snap-Off" adjustment. The snap-off is a fixed distance determined by your Process Engineer and is firmly set through careful Engineering of your Printing Machine. We can only achieve this if the screen frame locates in the Printer X and Y with the location bushings, but equally importantly in the Z direction with the bottom surface (or emulsion surface) locating in a downward direction thereby eliminating the effects from any variation in the individual screen frames. All thickness variation in the frames is of no consequence since the frame locates on its bottom surface.

Your frames also need to be generally flat. Any twist in the frame carries with it a corresponding variation in tension when the frame is forced flat in the Printer. We achieve this flatness during the mesh gluing process.

FIG 3



Your screen frames need a groove in the bottom surface that is used to cut the individual frames out of the stretch once the glue is cured (See FIG 3).

Your screen frames need to be durable. We chose a custom sand casting and then had them precision double disc ground for flatness and thickness consistency. We then had them precision machined for the location bushings. That's it. They are actually very reasonable in price considering everything they accomplish.

Screen Stretcher

I have searched the world over for a screen stretcher that would produce a "Stretch" with tension variation less than 1%. After a long exhaustive search we decided to build our own screen stretcher. This Screen Stretcher takes into consideration everything that is important in the Printing Process. If you can achieve **uniform** highly **accurate** tension, you can double the life of your screens. It works like this; the total tension of the screen is made up of all of the singular tensions of all of the wires in the mesh. When every microscopic wire tensions uniformly, then, when the screen starts to relax (under use), the image does not migrate laterally or change shape. The number one cause of screen failure (or no longer production worthy) is the image begins to distort or migrate.

Your screen stretcher needs to provide:

- Truly uniform (<1% variation) tension across the entire stretch.
- Your screen stretcher needs a very flat surface on which to place a sheet of Mylar for gluing the frames to the mesh. We used a granite surface plate in its own support stand.
- Your stretcher needs the ability to raise and lower the stretched mesh so that you can precisely place the stretched mesh down on the flat curing surface so as to not invoke any stray tension variation when you lay the glued frames onto the mesh. We used a manually controlled electro-hydraulic system to accomplish this.
- The center flat surface should be, but this is icing on the cake, heated to the curing temperature of the epoxy used to fasten the frames to the mesh. We accomplished this by incorporating 15kw of heaters on the bottom surface of the granite surface plate. Once it was brought up to temperature it was rarely turned off. The controller that we used provided a PID temperature control that held the temperature to within 1 degree C all year round.

By meeting all of these requirements we created a truly unique screen stretcher that has proven to be State-of-the-Art even today and it was built 17 years ago.

This Screen Stretcher has two banks of specialized clamps that clamp the mesh and hold it while the tension is applied. Most screen stretchers out there have two fixed beams of clamps that are opposed with two movable beams of clamps. Imagine that one corner of the mesh is fixed with both adjacent edges being fixed while the opposite corner is movable with its two adjacent edges being movable. Each of the clamps is on rollers which allow the clamp to move laterally as the mesh is pulled. The entire “Bank” of clamps is moved with a jack mechanism with ratchet until the desired tension is achieved. The problem with the whole bank moving at once is simple. The mesh is hand-placed into the clamps and it is impossible to get the same pre-tension of the mesh in each clamp. When the jack mechanism is actuated the wires that are pre-tensioned the most will come to final tension first and then be over-tensioned while the “whole” tension is being met. We improved upon this concept and made each clamp its own “Jack” or pulling device as opposed to the whole bank moving in unison. This eliminated the problem associated with manual pretension as the mesh is clamped into the jaws. Any variation in pretension is eradicated when each pulling clamp is able to pull independently from all others. All pulling clamps pull to the exact same force regardless of distance.

We incorporated special jaws in each clamp mechanism that swivel allowing the individual wires to equalize while being tensioned. Each jaw has a rubber face with special interlocking grooves to prevent slippage once clamped and maintain their grip once tension is achieved. These jaws are also designed in such a way so that they naturally overlap preventing any stray mesh wires from being tensioned. There are no gaps between clamp jaws. All clamps on a side of the stretcher are actuated with a single lever valve (4 total) and all pulling (stretching) cylinders on a side are actuated with a single lever valve (2 total). To clean up the appearance of all of the tubes (2 per clamp and 2 per pull cylinder), the entire outer frame assembly is actually a multi-cored air manifold so each clamp and cylinder only needs a short tube from the pneumatic device to just down to the frame below (See FIG 4).

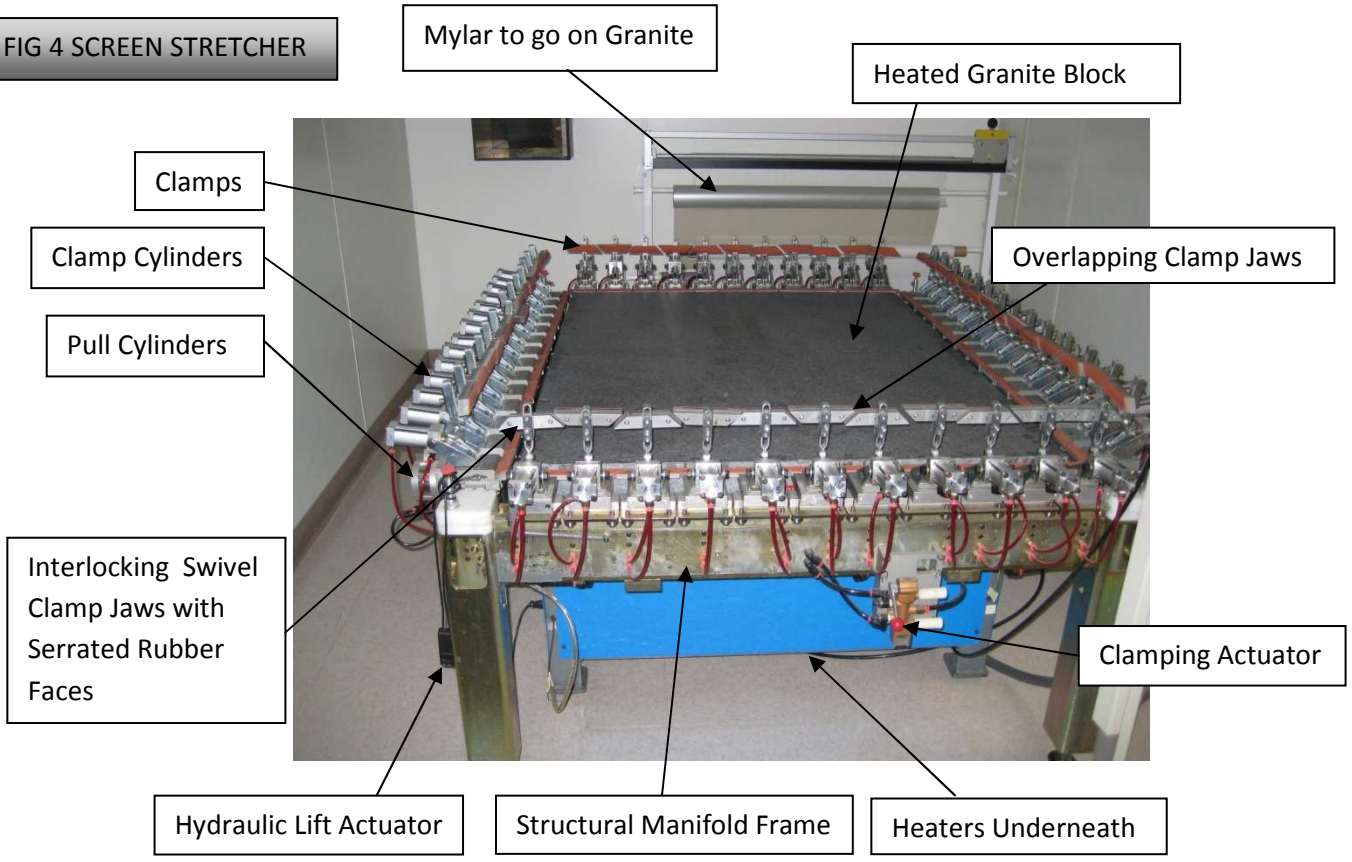
These features made a huge difference in the stretcher performance.

We did not stop there however. For the next major change we took into consideration the need to have the frame glued to the mesh in a completely flat arrangement. To accomplish this we put a granite block in the center of the clamp assemblies on which to set the stretched mesh while gluing the frames. There are not many things flatter than a granite surface plate and surface plates are relatively inexpensive. This not only creates a flat bottom surface on the screen. It also compensates for any twist there might be in the screen frame by filling the small variations with Epoxy while leaving the screen mesh as the bottom locating surface of the screen.

We incorporated a hydraulic foot lift system that hydraulically raises and lowers the stretched mesh from several inches above the granite to flat on the granite surface. This allows the operator to raise the glued stretch (collection of glued frames) once the glue is cured and easily remove the glued stretch from the stretcher.

We wanted to improve the throughput of the system and so we added 15 KW heaters to the bottom of the granite block to heat it to the epoxy curing temperature. Now, all we do is put a sheet of Mylar on the granite block, set the stretched mesh down on the Mylar. Set the pre-glued screen frames on the mesh (glue side down) (which produces a super smooth and flat bottom surface which we use to locate the screen in the Printer), wait for the Epoxy to cure, release the tension cylinders, release the clamps, turn the stretch over, and cut out the frames from the stretch. Several cycles can be produced in a shift.

FIG 4 SCREEN STRETCHER



All of this is relatively easy once your people are properly trained. These processes should not need much engineering support once all of the training is accomplished.

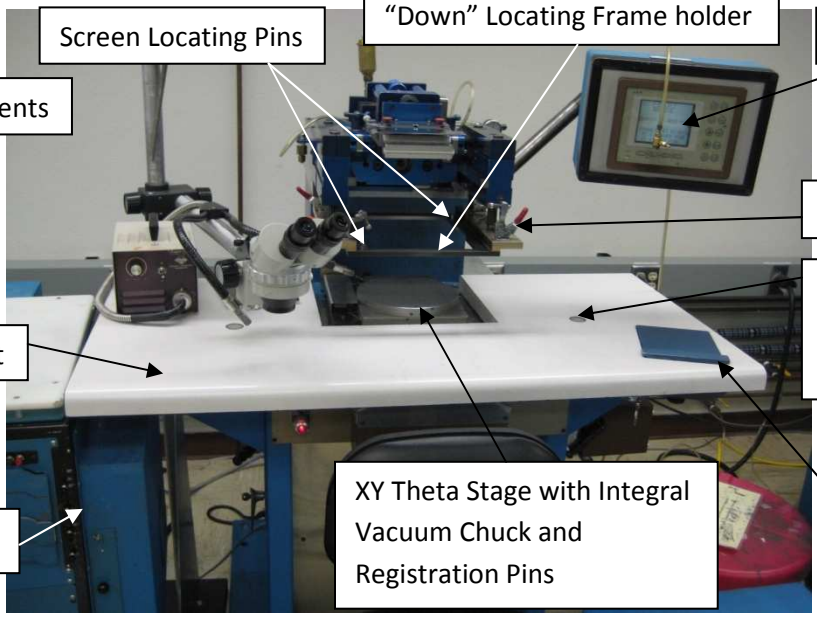
SCREEN PRINTER

Now to the Printer. We chose Autoroll as our Printing Machine. This is what we had and it seemed like a robust system so why not make what we have work better. The original Autoroll printer looked like the printer in FIG 5. It had all of the typical controls, too many as far as we were concerned. In order for this printer to do what we wanted we first did an extensive Design-of-Experiments to understand all of the specific features we wanted in a Printer. We determined squeegee angle, squeegee speed, Snap-Off distance, Flood

Blade position etc. etc. etc. Once the Process Engineer completed the DOE we had our work cut out for us. We not only needed to transform this Printer into one that had all of its variables fixed, but we also had to integrate an XY Theta Motorized Motion of the stage and then have the measurement system upload corrections to be able to take the print alignment adjustment out of the hands of the operator. The System had to be accurate, safe, easy to set up and it had to look good. Without going into all of the details here I have included an "after" photo with some of the new features pointed out (FIG 5).

FIG 5 "Before"

FIG 6 "After"



So, what did we accomplish?

- Screens with the most uniform tension available.
- Double screen life across all product lines.
- Totally flat bottom surface on all screens that eliminate any twist in the frames.
- Elimination of all printer adjustments including Snap-Off adjustment.
- Setup times in the 5 to 10 minute range.
- Higher yields.
- Greater throughput.
- Reduced Maintenance of the Printer

In conclusion, it is possible to achieve “unheard of” Print quality results on HTCC of LTCC tape layers. Is it easy? It wasn’t 17 years ago, but having done it all, it will be a lot easier today. There are also a lot of newer technologies available today that will make the process even better and even more State-of-the-Art in particular CTS which eliminates artwork entirely by ink-jet printing the image onto the emulsion instead of using a sheet of artwork. Also, most currently available Semi-Automatic Printers today will require only minor modifications and most have an interface for a measurement system.

It all starts with a commitment and the willingness to see it through.

What about Screen Print Via Filling vs. Via Fill Machine?

How can a change in thinking result in major via punch throughput?

How can the Hot Cut Machine be made to compensate for movement during lamination?

Many more…….

Stay tuned……..

Jim Ellis is President of Credence Engineering, Tempe, AZ, http://credenceeinc.com, an equipment company offering machines for the manufacture of LTCC and related green ceramic products. He has > 25 years of experience in designing and building equipment and consulting on process improvement. He was Equipment Engineering Manager (14 years) at Medtronic, Tempe, AZ, their high fire pacemaker manufacturing operations, Engineering Director for Pacific Trinetics (PTC), San Diego, CA, where he developed their via punch and several other equipment designs and Started Credence Engineering in 1999.