Final Project Report

Smart PCB Digital Factory Technical Publication	
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Table of Contents

1 Introduction

Electronic computer-aided design (ECAD) software used to design printed circuit boards (PCBs) continues to evolve and PCB manufacturing processes continue to advance, but the transfer of data between PCB designers and manufacturers has changed very little in the last 15 years. PCB build data today is comprised of a combination of electronic and paper documents spread across many files and multiple formats, (i.e. PDF, HPGL, JPEG, STEP, IGES, Excellon, ODB, ASCII, Gerber RS-274X, IPC-D-356, etc.). This “shopping cart” of files, shown in Figure 1-1, is unintelligently linked making data transfer and more importantly design intent difficult to communicate and interpret. As a result, today’s PCB manufacturers must review, translate and/or re-enter the data, causing their manufacturing processes to be labor intensive and prone to error.

The “Smart PCB Digital Factory”, sponsored by the Digital Manufacturing and Design Innovation Institute (DMDII), set out to eliminate the multiple file formats and the error-prone manual intervention required today by demonstrating that a single data file, IPC-2581 Rev B (or IPC-2581B), containing the ECAD, Mechanical Computer-Aided Design (MCAD) and Bill of Materials (BOM) information could be successfully used to manufacture a PCB from design through fabrication, assembly and test.

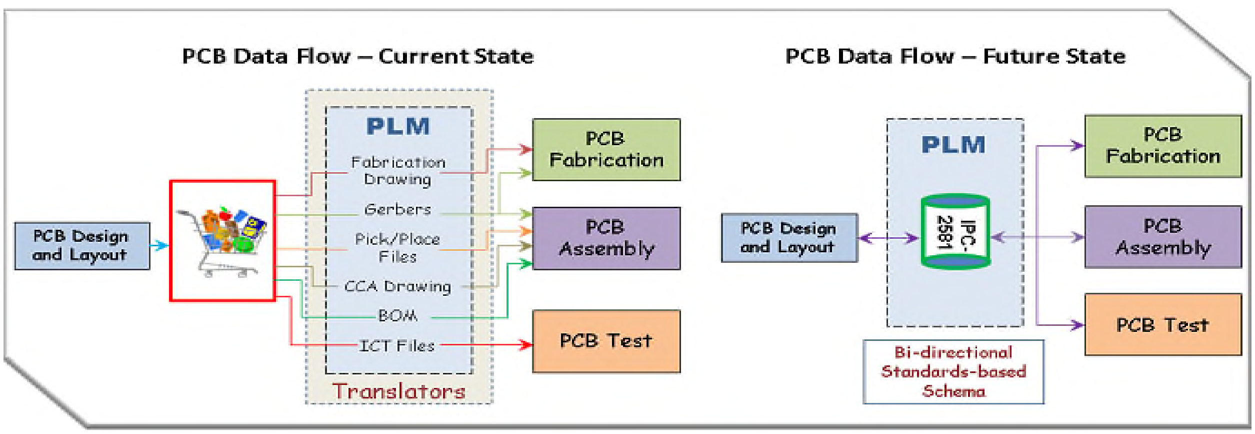


Figure 1-1: PCB Data Flow – Present-state vs. Future-state

In 2013, Fujitsu demonstrated that IPC-2581A could be used to fabricate a PCB. The Smart PCB Digital Factory team consisting of Lockheed Martin, Fujitsu, Sanmina, Siemens PLM, ZukenUSA, the Rochester Institute of Technology (RIT) and IPC, expanded upon that effort and used IPC-2581B to not only fabricate several PCBs but demonstrated that it could be used for assembly and test as well.

The following chapters chronicle the Smart PCB Digital Factory team’s journey.

1.1 Project Participants

A diverse team of industry leaders covering the PCB lifecycle was assembled for this effort:

- **ECAD Software**: ZukenUSA
- **PCB Design**: Fujitsu and Lockheed Martin (two Original Equipment Manufacturers)
- **PCB Fabrication**: Sanmina, Fujitsu and Lockheed Martin

- **PCB Assembly**: Sanmina, Fujitsu and Lockheed Martin
- **PCB Test**: Sanmina, Fujitsu and Lockheed Martin
- **Manufacturing Equipment Software**: Siemens PLM
- **Workforce Development & Training**: IPC and Rochester Institute of Technology

1.2 IPC – 2581

In 2012 the IPC consortium released IPC-2581 Rev A which defined the information needed to fabricate a PCB in an XML-schema file format. Their intent: to increase the efficiency and accuracy of data transfer from PCB designers to PBC manufacturers. The year after the standard was released, Fujitsu fabricated the first PCB using the new standard with three separate fabricators: Sanmina, Sierra Circuits, and TTM-OPC. That same year, the IPC consortium released Rev B of the standard which extended the XML-schema file to capture the information needed to assemble and test PCBs as well.

1.3 Problem Statement and DMDII Relevance

Printed circuit boards are found in nearly all electronic devices in use today across every conceivable industry including entertainment, medical, communication, personal, military and defense, aerospace, automotive and computing (Figure 1-2). As such, the successful demonstration of this project and the realization of its benefits could have a large impact on the United States electronics industry.

Figure 1-2: Examples of PCBs and products that can benefit from IPC-2581

The PCB lifecycle is shown in Figure 1-3. A PCB begins in design and is generated using ECAD software (SW). At design completion, the PCB designer, through the ECAD SW currently generates multiple output files to support the downstream PCB manufacturing processes as shown in Figure 1-3. Since the various output files are created as independent objects, they can become disconnected from the data source. This disconnect often results in inconsistencies and/or incomplete data packages delivered to PCB manufacturers.

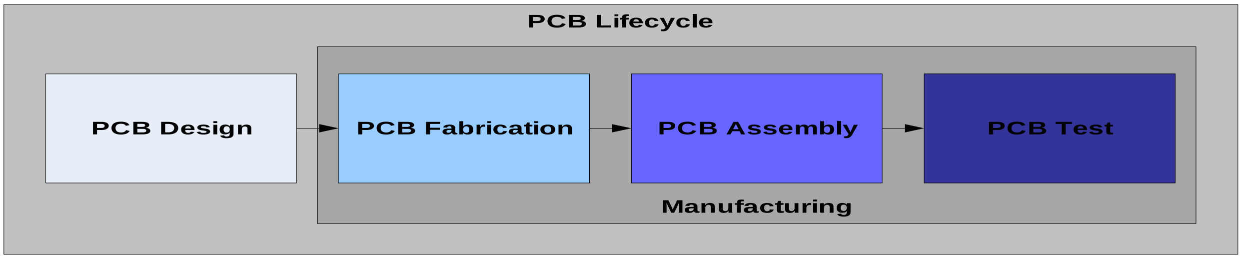


Figure 1-3: PCB Lifecycle

To ensure a successful build, PCB manufacturers today need to manually review, interpret, and translate the data. Because there are "humans in the loop", these steps are error-prone and can result in several iterations between the PCB manufacturers and the PCB designers. The manual processing steps and design/manufacturing iterations increase PCB production costs and push out PCB delivery dates to Original Equipment Manufacturers (OEMs).

The IPC-2581B standard supports the generation of a single digital output file by ECAD SW. This file contains all information needed by PCB manufacturers and eliminates the need for multiple outputs. In addition, whenever a change is made to the data source, that change is carried through the IPC-2581B data product eliminating inconsistencies. Manufacturers no longer need to interpret or translate multiple drawings and documents. This leads to more efficient manufacturing processes, lower production costs, fewer iterations between PCB designers and manufacturers, fewer errors and faster cycle times, allowing electronic equipment manufacturers to bring their product to market sooner.

Table 1 shows critical data that influenced the PCB fabrication, assembly and test steps in the five manufacturing facilities used on this project. Each column represents a specific step in the process. Both the equipment vendor and software vendor are identified where applicable. This project used an IPC-2581B file to manufacture a PCB through each of the steps highlighted in green. Steps highlighted in yellow or red do not currently support IPC-2581B.

1.4 Project Task Overview

The Smart PCB Digital Factory team chose to demonstrate the use of IPC-2581B using three PCB designs with varying degrees of complexity: two of the designs were from Fujitsu and one design was from Lockheed Martin. Both present-state and future-state (IPC-2581B) files were generated for the selected designs. For clarity, the definition of *present state* is: the files, tools, methods, and processes of each company or organization prior to working with IPC-2581. Similarly, *future state* is defined as: the fully-integrated use of IPC-2581 from design through fabrication, assembly and test.

Upon receiving the design data, the PCB fabricators performed data integrity analyses on both the present-state design files and the IPC-2581B design file. The fabricators reported:

1) the number of discrepancies, if any, between the present-state and IPC-2581B fabrication files,

2) the number of hours required to prepare for PCB fabrication using the present-state files,

3) the number of hours required to prepare for PCB fabrication using the IPC-2581B file,

4) any errors in the IPC-2581B file that required ECAD software changes, and

5) any issues with the build.

To minimize cost, each fabricator only manufactured a single PCB from the IPC-2581B file. Once built, each fabricator performed continuity and isolation testing on the PCB and reported any issues with the build resulting from the use of the IPC-2581B input.

Once fabricated, the PCBs were shipped to a PCB assembly vendor (in some cases the fabricator also provided assembly services) along with the components necessary to complete the assembly. Each assembly provider received the present-state files and the IPC-2581B file. Each assembler performed data integrity analyses on both sets of files and reported:

1) any discrepancies between the present-state and IPC-2581B files,
2) the hours required to prepare for PCB assembly using the present-state files,
3) the hours required to prepare for PCB assembly using the IPC-2581B file,
4) any errors in the IPC-2581B file that required ECAD software changes, and
5) any issues with the build.

To minimize cost, each assembly provider assembled a single PCB using the IPC-2581B file. When assembly was complete, each assembly provider reported any issues with the assembly resulting from the use of the IPC-2581B input.

Once built, the assembled PCBs were tested using flying probe (an electro-mechanically controlled probe to access components) or automated optical inspect (AOI) methods. Each test provider received the present-state flying probe or AOI test files and the IPC-2581B file. Each test provider performed data integrity analyses on both sets of files and reported:

1) any discrepancies between the present-state and IPC-2581B files,
2) the number of hours required to prepare for PCB test using the present-state files,
3) the number of hours required to prepare for PCB test using the IPC-2581B file,
4) any errors in the IPC-2581B file that required ECAD software changes, and
5) any issues with test.

Testing was only performed using the IPC-2581B input. When testing was complete, each test provider reported any resulting issues with test from the use of the IPC-2581B input.

1.5 Challenges, Goals & Objectives

The columns in Table 1-1 show the PCB fabrication, assembly and test steps demonstrated during this project. The rows indicate the facility, site and vender. The manufacturing equipment and software vendors are identified, where applicable. This project used IPC-2581B to manufacture a PCB through each step highlighted in green.

TABLE 1-1

Partner	Location	Mfg Flow	Design							Fabrication							Assembly				Test
			PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM	PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill	SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT X-Ray Inspection	Flying Probe / ICT
Fujitsu	Dallas, TX	Mfg Equipment Vendor		VISE, Valor	Polar Instruments	Frontline PCB Solutions	Cadence	Ansys		Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	FTC Assembly	Fuji, DEC	Vitrox (Agilent)	Vitrox	Agilent, Testronix
		SV Vendor	Cadence SPB v16	VISE VisualCAM, Valor NPI	Polar Speedstack	Frontline InStack	Cadence SPB v16	Ansys Designer, SI Circuit, HFSS	[illegible]	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Vize Stencil Tools	Fujitsu TEXCAM	Fujitsu TEXCAM	Fujitsu TEXCAM	Fujitsu TEXCAM
Lockheed Martin	MFC - Dallas, TX	Mfg Equipment Vendor		ADIVA & Frontline Valor	Polar Instruments		Cadence	Ansys		Valor Genesis 2000	Orbotech	Orbotech	MicroCraft EMMA	Excellon	Hitachi	Excellon Cobra	Stentech	MyData	Kho-Young		Acculogic
		SV Vendor	Cadence Allegro & Mentor Expedition	ADIVA_DRC v8.7 & Frontline Valor Genesis DRC	Polar Speedstack		Cadence SPB v16	Cadence Sigrity Mentor Hyperlynx	Oracle's Agile Product Lifecycle Management	Valor Frontline	Valor Frontline	Valor Frontline	MicroCraft 2 Software's	Valor Frontline	Valor Frontline	Valor Frontline	CAD/Gerber	MyCenter - Aegis (Unicam)	EPM SW by Smart Vision Corp.		Xmatic software (Unicam)
	MST - Owego, NY	Mfg Equipment Vendor		Valor	Polar Instruments		Zuken CR5000	Ansys		Valor Genesis 2000 *	Orbotech	Orbotech	Mania probot	Excellon	Pluratec	Excellon Cobra	Vendor - No MST capability	Universal Instruments	OMRON BT FINS		Takaya
		SV Vendor	Zuken CR5000	Valor Genesis DRC	Polar Speedstack		Zuken CR5000	Ansys HFSS		Valor Frontline *	Valor Frontline	Valor Frontline *	Parcam Ext & TFI converts netlist into Probot	Valor Frontline *	Valor Frontline	Valor Frontline *	Vendor - No MST capability	Universal UPS Editor	OMRON CT (Unicam)		Siemens Test Expert
	SSC - Denver, CO	Mfg Equipment Vendor		Adiva			Zuken CR5000	Zuken CR5000		Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	[illegible]	ASM Siplace	Koh Young Zenith		Takaya & Acculogic
		SV Vendor	Zuken CR5000	Adiva_DRC v8.7			Zuken Lightning	Zuken Lightning	PTC Windchill	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	(CAD/ Gerber) AOI can provide	Access Database (Unicam)	Access Database (Unicam)		Siemens Test Expert
Sanmina	San Jose, CA	Mfg Equipment Vendor				Frontline PCB Solutions	Frontline PCB Solutions			Linux Machines	Orbotech	Orbotech & CAM Tech	Everett Charles ATG	Excellon & Hitachi	Excellon	Hitachi	Cannot Disclose	AIMEX II AI to A3 modules	Nordson FII Optical Inspection		Takaya ATT 9411 SL Takaya
		SV Vendor				Frontline InStack	Frontline InStack			Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Frontline InPlan, InCAM, InSight,	Aegis	Aegis	Aegis/ Gencad		Odb++ FatF Pad (TestExpert)
Rochester IT	Rochester, NY	Mfg Equipment Vendor																ASM Siplace			
		SV Vendor																Siplace Pro Interface			

An audit was performed to identify opportunities for improvement to the design and manufacturing process at Fujitsu, Lockheed Martin, Sanmina, and RIT. These were documented and color-coded as follows:

- Green means IPC-2581B support status exists
- Yellow means IPC-2581B support status is unknown
- Red means IPC-2581B support status does not exist

Some workarounds or alternative, customized solutions were needed by some facilities that were not able to secure the required support from their equipment or software suppliers in the eighteen-month project timeline.

IPC and RIT examined the workforce development aspects associated with the introduction of IPC-2581B and have developed a Workforce Development Plan (WDP). The WDP outlines and provides the training needed for various organizations as they transition from using the “present-state” to “future-state” using IPC-2581 as their as PCB manufacturing standard.

2 Design

The design phase of the project focused on the selection of the designs to be used and the generation of the "present state" and IPC-2581B files for those designs Fujitsu selected two designs that together would complete a product assembly. LM-Space chose a simple design for its first attempt at using the new standard.

2.1 Fujitsu Design

2.1.1 Fujitsu Objective

Prior to this project, Fujitsu had fabricated bare boards using IPC-2581A. Their objective for this project was to fully validate the flow from design through assembly and test using IPC-2581B to ensure production readiness.

Fujitsu designs their PCBs in house. The selection criteria for their designs for this demonstration was:

- Design shall be reasonably complex with good rotation of parts on the board but not too expensive since they would not be sold to a customer
- At least one design shall have a minimum of one board rotated on the panel
- Design is currently being built or will be built within the next few months, so the additional part count can be readily procured
- Design shall have unit functional tests available

2.1.2 Design Details

Fujitsu selected two PCB designs for this demonstration project. The two designs were then assembled together to make a fully testable product unit. Four each of the two designs were built to make four operational product units. Following are some details of the two Fujitsu designs:

Fujitsu Design 1	
Board Details	**Requirement**
Layer Count	12
Board Thickness	1.69 mm [0.067 inches]
Drill Sizes	20
Hole Count/Plated Hole Count	1857/1593
Min Line Width/Spacing	0.1016/0.1 mm [0.0040/0.0039 inches]
Fabrication & Solder Mask Specs	Proprietary to Fujitsu
Impedance Control	Yes, Single Ended
Final Finish Type	Immersion Tin
Assembly Details	**Requirement**
SMT Part Number Count (Installed Components)	70
Total SMT Parts Installed	510
Assembly Specs	Proprietary to Fujitsu

Fujitsu Design 2	
Board Details	**Requirement**
Layer Count	12

Board Thickness	2.25 mm [0.089 inches]
Drill Sizes	17
Hole Count/Plated Hole Count	3805/3760
Min Line Width/Spacing	0.089/0.09 mm [0.0035/0.0035 inches]
Fabrication & Solder Mask Specs	Proprietary to Fujitsu
Impedance Control	Yes, Single Ended & Differential Pair
Final Finish Type	OSP
Assembly Details	**Requirement**
SMT Part Number Count (Installed Components)	121
Total SMT Parts Installed	939
Assembly Specs	Proprietary to Fujitsu

2.1.3 Fujitsu Tools and Design Flow

2.1.3.1 Fujitsu Initial Tools Assessment

Schematic capture and PCB layout were performed using Cadence's Silicon Package Board (SPB) suite of PCB tools. At the start of the project the Cadence version used in production was 16.5, which could support IPC-2581B export.

For the present-state DFX and CAM at Fujitsu, Valor NPI was used in production for panel creation and DFM checks.

Initially, the project scope included plans to evaluate and purchase a stack-up analysis tool. For Signal Integrity analysis, Cadence and Ansys tools were available however Ansys had not yet released support for IPC-2581B.

Partner ▼	Location ▼	Mfg Flow ▶	Design						
			PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM
Fujitsu	Dallas, TX	Mfg Equipment Vendor							
		SW Vendor	Cadence SPB v16.5	WISE VisualCAM, Valor NPI	Polar Speedstack	Frontline InStack	Cadence SPB v16.5	Ansys Designer, SI Circuit, HFSS	Dassault Enovia v2013x

Figure 2-1 Fujitsu Initial Tools Assessment

2.1.3.2 Fujitsu Final Tools Assessment

It was decided to move to Cadence version 17.2 for the project, in advance of production due to the improvements in stack-up property definition. (Now 17.2 is also used in production.)

The IPC-2581B interface to Enovia PLM enabled Fujitsu to perform several new functions enabled by IPC-2581.

VisualCAM from WISE was chosen to provide DFX and CAM capabilities. WISE provided enhanced features in v16.9 that were used to support fabrication and assembly on the project.

WISE developed a stack-up editor feature, per request, which displays and augments material and impedance properties as well as fab/assembly instructions, that are embedded in the IPC-2581B file.

SI (signal integrity) analysis was deemed out of scope of the project.

			Design						
Partner ▼	Location ▼	Mfg Flow ▶	PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM
Fujitsu	Dallas, TX	Mfg Equipment Vendor							
		SW Vendor	Cadence SPB v17.2	WISE VisualCAM v16.9	WISE VisualCAM v16.9	Frontline InStack	Cadence SPB v17.2	Ansys Designer, SI Circuit, HFSS	Dassault Enovia v2013x

Figure 2-2 Fujitsu Project Tools Assessment

2.1.4 Fujitsu Changes in Design Process to Support IPC-2581

Fujitsu used the Cadence Allegro tool suite for ECAD and chose WISE VisualCAM for PCB panel creation and DFM checking. For the PCB schematic designers, no changes were required to the design process to support IPC-2581B. The PCB layout designers, instead of generating 2 files for fabrication and assembly (ODB++ and GMF), now only need to export a single IPC-2581B file. Furthermore, additional library properties that were required for the present-state fab and assembly flows are no longer required.

In the present-state process several bare board fabrication requirements were passed to the manufacturing team using drawings and notes. This requires the fabricator to read, interpret, and associate these items to the appropriate digital data and manufacturing process step. A key objective of the smart PCB digital factory project was to eliminate as much of this manual intervention as possible.

WISE provided several enhancements to their VisualCAM product that allowed the PCB designer to include stack up requirements and impedance specifications in the design and transport these requirements to the fabricator using IPC-2581B schema placeholders. This eliminated the need to send separate drawings and notes that require manual manipulation in manufacturing. To prove this capability was possible, Sanmina agreed to use the WISE Viewer tools to extract this information during bare board fabrication.

To take advantage of the WISE VisualCAM capabilities, the layout designers had to adopt the following process changes:

- Learn to use the WISE VisualCAM tool/features. The VisualCAM process has now been automated through the use of scripts.
- Enter the stack up material properties in the PCB layout tools. Stack-up material properties are now a one-time entry that is preserved through panelization and provided to the fab vendor embedded in the IPC-2581B file.

The mechanical designers agreed to change their process for creating the board and panel outlines in their MCAD tool. By changing the v-score lines in the panel to very thin shapes and attaching properties to them, the v-scores could be exported in the .emn file used to automatically create the outlines in the ECAD tools. WISE VisualCAM then automatically detected and re-created the v-scores when importing the .emn file to make the panel, and added specifications to them (angle, web, etc.) that are then embedded in the IPC-2581B export.

Fujitsu went a step further and integrated IPC-2581 into their PLM system. They developed a custom interface to their PLM system used for configuration and lifecycle management. Fujitsu developed their own utilities based on the XSLT transform capability to edit the IPC-2581B file to:

- Automate PCB product structure creation in PLM and link it to part definitions, attributes, characteristics, and specifications managed in PLM
- Facilitate BOM management and BOM validation capabilities (part rank and part lifecycle checks, etc.)
- Augment BOM items with part properties available in the PLM system but not in the CAD system, i.e. merging internal part numbers, manufacturer part numbers, attributes, characteristics, and approved vendors, into IPC-2581B
- Merge an IPC-2581B based BOM imported from the MCAD tool with the ECAD BOM
- Augment associated firmware and software BOM items into IPC-2581B
- Augment programming specifications, test specifications, compliance specifications, etc. into IPC-2581B
- Insert custom Fujitsu CAD properties into XML schema that were not supported by Cadence at the time, e.g. fiducial definitions
- Augment part and assembly revision and lifecycle information into IPC-2581B
- Export fabrication and assembly mode IPC-2581B files on demand, which are sub-sets of the Function Mode “full” file vaulted in PLM. This restricts the intellectual property exposure to only provide the data subset which is required to complete the intended task (i.e. fabrication, assembly, etc.)

The following diagram summarizes Fujitsu's future-state tools and design process flow:

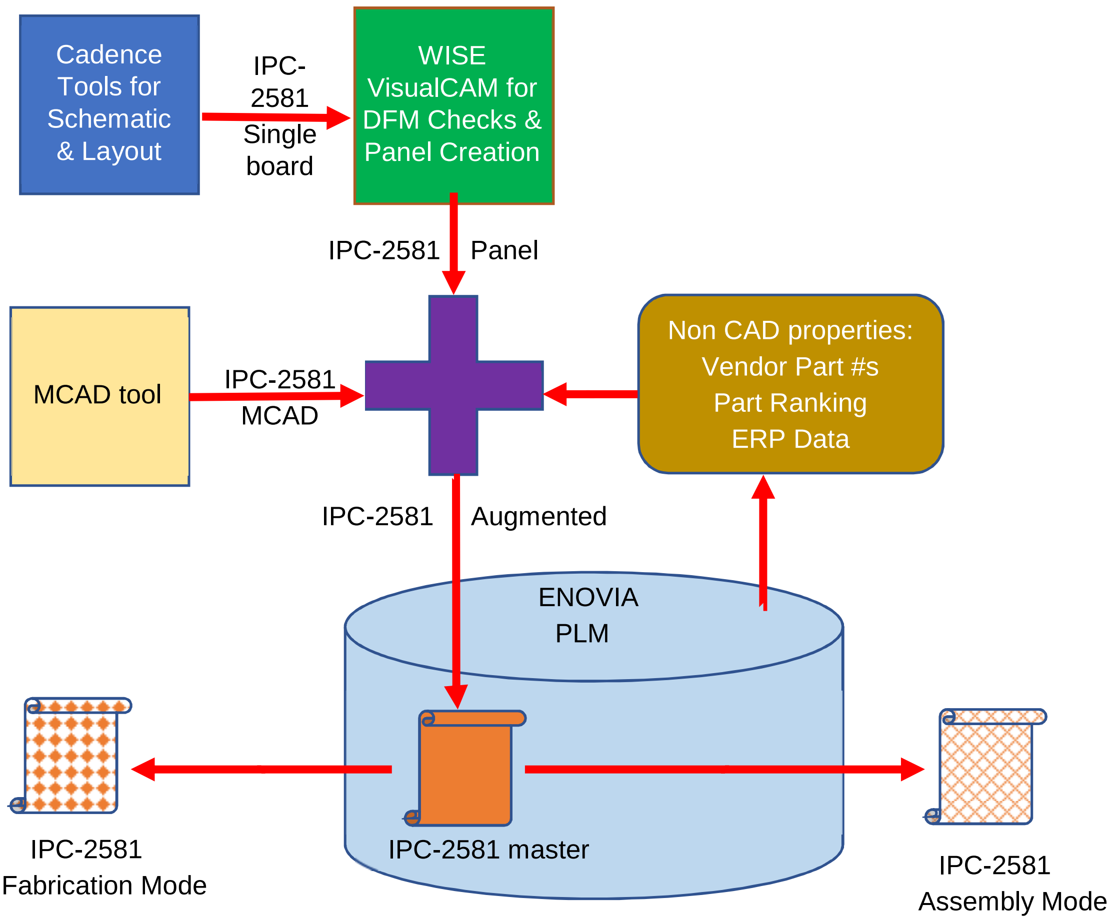


Figure 2-3. Fujitsu Design Flow in Support of IPC-2581

2.1.5 Fujitsu Design Validation Methodology

IPC-2581B files for the two designs were generated and vaulted using the above design flow. To validate the files, fabrication and assembly mode experts compared the IPC-2581B files against the present-state file formats for those operations. Fujitsu's present-state file format for fabrication was ODB++, exported from Valor NPI after panel creation. The time necessary to create the panel in Valor NPI and export ODB++ and the time needed to create the panel in WISE VisualCAM and export IPC-2581B were collected.

The fabrication data contained in the IPC 2581B file and the ODB++ files were read into WISE VisualCAM where each layer was graphically compared and validated.

Fujitsu's present-state assembly file format is a proprietary format called GMF (Global Manufacturing File). The amount of time needed to export a GMF file was compared to the amount of time needed to export the IPC-2581B file. The IPC-2581B assembly data was validated by the assembly group of Fujitsu in the U.S. by comparing part quantities, do-not-install, part placement location, orientation, and pick up points of the known good GMF file.

2.1.6 Fujitsu Design Data Observations

Data points were captured during this project as *Problem Reports* and *Metrics*. A listing of *Problem Reports* that pertain to the Fujitsu designs are listed below followed by the *Design Metrics*. Note that the numbering of the problem reports maps to the full listing in Section 8.

2.1.7 Problem Reports

2.1.7.1 Fujitsu Design Drafting Tool Problem Reports (1 Report)

Problem Report #15 (FUJ_PD032101): Drill data was not in the expected location for fabrication panel layout

Detailed Description:

Board fabrication data did not contain drill data in the single board step.

Resolution:

The macro used in the WISE VisualCAM tool to create the panel was putting all the drills in the panel step. WISE changed the macro to put the board drills in the board step.

2.1.7.2 Fujitsu Design IPC-2581 Committee Problem Reports (1 Report)

Problem Report #14 (FUJ_PD032001): <Profile> element(s) are not imported into Frontline tools

Detailed Description:

Frontline tools are not extracting <Profile> elements. The outline and routing data are missing.

Resolution:

For this project, 1) Fab house views the outline and routing data in the WISE Viewer. 2) Copy the outline and routing data to additional layers in the CAD and CAM tools so the Frontline tools to see those layers in the IPC-2581.

This negates the intent of the IPC-2581B schema however and needs to be addressed by the IPC-2581 technical committee.

2.1.8 **Metrics**

The project outlined three design metrics during the proposal of this effort with the plan to capture present-state and future-state process details. Those three metrics and their results are listed in the following section.

2.1.8.1 Time to generate ECAD output files (existing vs. IPC-2581B)

Present-state: Measure # hours required to generate existing files.

ODB++ .tgz file of single board step and panel step, generated by a script result:

Design 1 - 32 minutes

Design 2 - 25 minutes

Future-state: Measure # hours required to generate IPC-2581B.

IPC-2581B file of single board step and panel step, generated by a script result:

Design 1 - 6 minutes

Design 2 - 8 minutes

Project Goal: Reduction of >25% compared to present-state.

Design 1 - 81% reduction

Design 2 - 68% reduction

Comments: For both present and future-states a script is run in a CAM tool that generates the panel step from the imported board step and the MCAD panel definition. The script then prompts the user to input/choose stack-up, impedance, compliance requirements and design specific notes. In the present-state, the requirements and notes are written to a separate text file. This file and a PDF file of the profile are included in the ODB++ .tgz package. In the future-state, the requirements and notes, a dimensions layer that replaces the PDF, and a v-score layer are created automatically from the MCAD panel definition and are embedded in the IPC-2581B file. Note that the future-state CAM tool is different than the present-state CAM tool.

2.1.8.2 Number of ECAD SW changes (bugs) to correctly output IPC-2581

Present-state: Track number of Software changes required to correctly output existing PCB fab/assembly/ test files.

None - Based on SW stability of previous version.

Future-state: Track # SW changes required to correctly output IPC-2581B fab/assembly/test files.

1 Software Change refer to section 2.1.7.1 - Fujitsu Design Drafting Tool Problem Reports

Project Goal: Zero Software Changes

One software change (simple scripting error) was performed.

Comments:

Both present and future sate ECAD SW platforms are now stable.

2.1.8.3 PCB Design Changes

Present-state: Track # changes found and required by fab, assembly, and test vendors to fab/assemble/test PCB correctly with existing files.

None

Future-state: Track # changes required by fab, assembly, and test vendors to fab/assemble/test PCB correctly with IPC-2581B.

One Design Change was made post design release, refer to section 2.1.7.2 - Fujitsu Design IPC-2581 Committee Problem Reports. The IPC-2581 committee will review and determine if action can be taken to resolve in the schema.

Project Goal: Zero iterations between PCB designers and manufacturers. Design is correct when IPC-2581B output is generated.

present-state – 0 Changes
future-state – 1 Change

Note: The one design change that occurred after release was due to a limitation in the Fab vendor software.

Comments: The Fab vendor submitted an enhancement request to their SW vendor to be able to read the board and panel outlines directly from the <Profile> tags in the IPC-2581B file. Hopefully this will be fixed in their next SW release.

2.1.9 Fujitsu Results

The IPC-2581B design process resulted in an average of 75% savings in time over the two boards compared to the present-state process.

Fujitsu submitted two minor problem reports and the resolutions have been implemented.

Improvements have been seen not only in design data transfer but also in BOM processing. The integration with the PLM system worked smoothly and provided time savings by automatically merging ECAD and MCAD BOMs. Fujitsu also developed a process in the PLM system to export a hierarchical IPC-2581B BOM describing multiple boards that make up a product. This has yielded significant time savings when entering a product BOM into their ERP system as the former manual process can now be done automatically.

2.2 Lockheed Martin Design

2.2.1 Lockheed Martin Design Objective

Prior to this project, Lockheed Martin had no experience with IPC-2581. Given that this would be their first attempt at using the new standard, the Lockheed Martin design team used the following design selection criteria:

- Design shall already exist and have been fabricated previously
- Design shall be simplistic with a good variety of parts on the board
- Design shall be generally low cost to support builds at multiple locations
- Design shall exercise the fundamentals of fabrication, assembly and flying probe test

2.2.2 Design Details

Lockheed Martin chose a simple design that had a variety of component packages. The Table below provides details of the Lockheed Martin design:

Lockheed Martin Design	
Board Details	**Requirement**
Layer Count	4
Board Thickness	2.362 mm [0.093 inches]
Drill Sizes	11
Hole Count/Plated Hole Count	361/336
Min Line Width/Spacing	0.1524/0.1524 mm [0.006/0.006 inches]
Fabrication Spec	IPC-6012, Class 2
Impedance Control	None
Final Finish Type	Type X – Either Type S or T: S - Solder Coating T - Electrodeposited Tin-Lead (fused)
Assembly Details	**Requirement**
SMT Part Number Count (Installed Components**)**	30
Total SMT Parts Installed	107
Assembly Spec	J-STD-001, Class 2

2.2.3 Tools & Design Flow

The standard electronic computer aided design (ECAD) tool for Lockheed Martin Space is Zuken CR8000.

The standard drafting tool for Lockheed Martin Space is Downstream Technologies' BluePrint-PCB tool. This tool is used to add notes, drawing views and other drafting information needed by fabrication, assembly, and test vendors.

The Altova XML Spy tool was used to validate the Zuken CR8000 IPC-2581B output against the IPC-2581B standard. For DFM checks, Downstream's CAM350 tool was used.

The following diagram summaries the tools and design flow followed during this project:

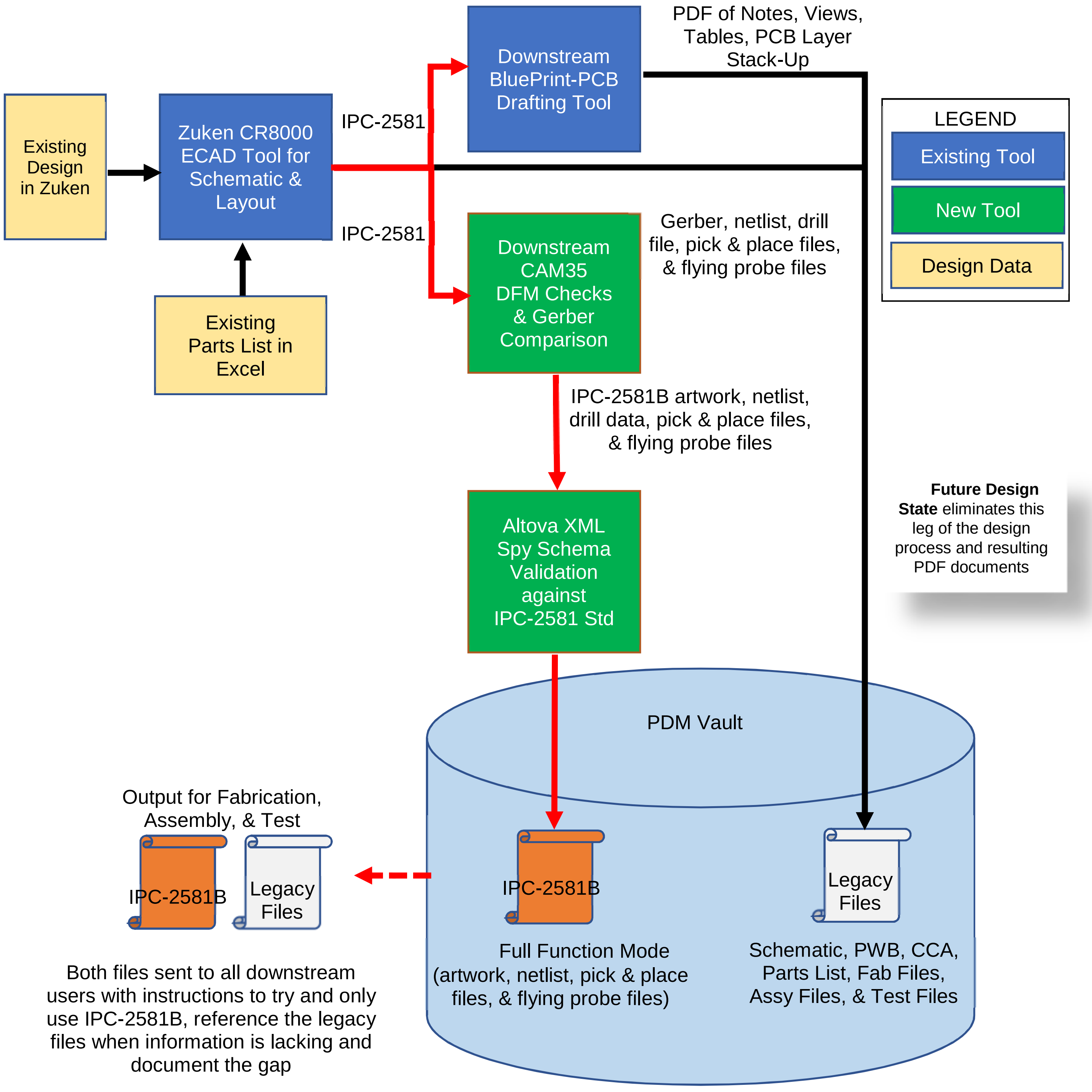


Figure 2-4 Lockheed Martin Space Design Flow in support of IPC-2581B

2.2.4 **Lockheed Martin Design Methodology**

Lockheed Martin Space selected the design, generated the present state and IPC-2581B output files, and compared them for differences. The design flow Figure 2-4 outlines the process used to create these files.

2.2.5 **Lockheed Martin Design Data Observations**

Data points were captured during this project as *Problem Reports* and *Metrics*. A listing of *Problem Reports* that pertain to Lockheed Martin design are listed below followed by the *Design Metrics*. Note that the numbering of the problem reports maps back to the full listing shown in Section 8.

2.2.6 **Problem Reports**

2.2.6.1 Lockheed Martin Design Problem Reports (2 Reports)

Problem Report #18 (SSC_PD051101): Gerber data missing connector holes

Detailed Description:

Prior to design release, connector in Gerber data was found to have missing mounting holes. IPC-2581B data reads this in correctly.

Resolution:

Designer needs to review settings in design to ensure all hole sizes are being output when generating Gerber files. Design has been reworked.

Problem Report #22 (SSC_CC092701): IPC-2581B Export from Zuken does not contain intelligent fiducials.

Detailed Description:

Programmer on assembly shop floor must manually identify the fiducial in the design to the assembly equipment.

Resolution:

Zuken will need to review 3.4.3 in IPC-2581B which identifies fiducial schema and implement this into their export function. On Zuken's plan for future release (post 2018). Plan to identify fiducials/fiducial classes. Must ensure design uses correct fiducials.

2.2.6.2 Lockheed Martin Design CAD Tool Problem Reports (13 Reports)

Problem Report #1 (SIE_PD120601): IPC file - Function Mode Design 1 does not contain info needed to map copper pins to their components.

Detailed Description:

Siemens PLM SW creates the shape outline from the outline of the package definition. The IPC-2581B file needs to include FUNCTIONMODE of FULL as the DESIGN Level output did not contain the information needed to map the copper for pins to their components.

Table 2-1 Zuken File Segmentation and Function Apportionment

Name	User Def	Design			Fabrication			Assembly			Test		
		1	2	3	1	2	3	1	2	3	1	2	3
Hierarchical layer/stack instance files	O	N	Y	N	N	N	N	N	N	N	N	N	N
Hierarchical conductor routing files	O	N	Y	N	N	N	N	N	N	N	N	N	N
BOM (Components and Materials)	O	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
AVL (Components and Materials)	O	N	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y
Component Packages	O	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
Land Patterns	O	N	Y	Y	N	N	Y	N	Y	Y	N	Y	Y
Device Descriptions	O	Y	Y	Y	N	N	N	N	N	Y	N	N	Y
Component Descriptions	O	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	Y
Soldermask; Solder Paste Legend Layers	O	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Drilling and Routing Layers	O	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Documentation Layers	O	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Net List	O	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N	Y
Outer Copper Layers	O	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Inner Layers	O	N	N	Y	Y	Y	Y	N	Y	Y	N	N	Y
Miscellaneous Image Layers	O	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
DFX Analysis	O	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

O = User Defined so Data is Optional N=Data is Not Included Y=Data is Included

Resolution:

Confirm Zuken CR8000 software in use is for Rev 2017 and generated an IPC file with FUNCTIONMODE = FULL so all information is available. Also, Siemens PLM made an update to their parser to recognize two methods for how ‘pin’ is defined in IPC-2581B.

Problem Report #2(SSC_PD012301): IPC-2581B file does not contain electronic component values or tolerances.

Detailed Description:

Flying probe testers need electronic component values and tolerances to compare against actual test values.

Resolution:

Fixed in 2017 Zuken patch and incorporated in the March 2018 release.

Problem Report #3(SSC_PD012401): IPC-2581B file shows nodules that short the planes together

Detailed Description:

When reviewing the IPC-2581B output file, nodules were found that, if fabricated, would have shorted planes together. Nodules were not found in a layer by layer review of the source data.

Resolution:

1) *Simple Method* - When outputting the data, change the units to MM. This increases the accuracy enough to resolve the element issue from the internal layers. Then convert the data to INCH when reading into CAM350 and other tools.
2) *Complex Method* - Open a “Command Prompt” from the CR8000 Engineering Desktop tool. This is available under the right click tool options when set to Board Data file filter. Once the command prompt is open, navigate to the folder where your .dsgn file resides. Type the following command: ***DFipc2581out -p:decimal 8 -p:unit inch***. This

increases the accuracy enough to resolve the element issue. The default accuracy for the GUI command is 5 places, this command uses 8 decimal places.

Zuken incorporated in the March 2018 release.

Problem Report #8 (TWS_CC022303): Variant design flow or methodology for unpopulated/Do Not Install parts

Detailed Description:

Optional use of the "populate = true|false" element under RefDes is not in the Zuken output though several parts used in the design will not be populated during the assembly process.

Resolution:

Zuken generated a software patch and post-processed the file for the project to move forward. Zuken incorporated this in the March 2018 release.

Problem Report #7 (TWS_CC022302): Incorrect OEMDesignNumberRef and internal part number assignments in Zuken IPC-2581B file

Detailed Description:

Zuken CR8000:

- OEMDesignNumberRef contains a Lockheed Martin footprint name.
- internalPartNumber contains the engineering EBOM part number

Resolution:

Fixed in Zuken 2017 patch and incorporated into March 2018 release.

Problem Report #6 (TWS_PM022301): Extraneous layer data

Detailed Description:

IPC-2581B file contains layer entries that appear to be associated with Zuken internal functionality.

Resolution:

For this project, board fabrication shops ignored these layers by making them document layers. Zuken resolution being implemented in a future release.

Problem Report #9 (TWS_CC022304): Lockheed Martin design does not contain stack-up information in the IPC-2581B file

Detailed Description:

Zuken IPC-2581B export does not provide copper & dielectric materials required to manufacture the bare board as part of the current defined process. A subsequent drafting tool, currently Downstream Technologies BluePrint-PCB, generates this information and needs to be capable of exporting IPC-2581.

Resolution:

For this project, use of pdf drawings for this information is acceptable. The follow-on project to this effort will evaluate drafting tools that will define drawing information and select one that best supports IPC-2581B going forward for Lockheed Martin.

Zuken has resolved this issue in the CR-8000 2018 release.

Problem Report #11 (TWS_PM030602): Drill count discrepancies using Downsteam CAM350 (two drill layers with conflicting information)

Detailed Description:

Zuken exports drill information in two sections of the IPC-2581B file. In the Lockheed reference design, the drill information is represented in LayerRef "Hole1-4". When imported into Downstream CAM350 it also produces another layer "Drill_1_4". This is purported to be a result of the Zuken IPC-2581B export duplicating drill information in IPC-2581, a scenario presently supported by the current IPC-2581B specification and schema:

Method 1. LayerFeature -> Hole

Method 2. PadStack -> LayerHole

The "redundant" information contained in the "Drill_1_4" layer produced by the CAM tool when importing the Zuken data is missing 4 drills; mechanical mounting holes associated with connectors J13 and J22. The missing mechanical mounting holes issue was resolved with a setting in the design and is no longer a concern.

Resolution:

The duplicate data was ignored for this project. This issue is open and needs to be resolved by IPC-2581 Committee & Zuken.

Problem Report #12 (TWS_TE030601): Netlist compare fails in Downstream CAM350

Detailed Description:

Zuken exports drill information in two sections of the IPC-2581B file. In the Lockheed reference design, drill information is represented in LayerRef "Hole1-4". When imported into Downstream CAM350 it also produces another layer "Drill_1_4". This is purported to be a result of the Zuken IPC-2581B export duplicating drill information in IPC-2581, a scenario presently supported by the current IPC-2581B specification and schema:

Method 1. LayerFeature -> Hole

Method 2. PadStack -> LayerHole

Resolution:

Zuken is advised to not duplicate drill data (i.e. use only one of the methods to describe the Drill information). As it is presently represented in the Lockheed design, Hole1-4 contains the complete drill information required to correctly fabricate the design.

Zuken and other members of the IPC-2581 Standards committee need to come to an agreement how this issue should be addressed in future releases of the IPC-2581B Standard (i.e. Specify a single method in the IPC-2581B Standard and Schema and thus eliminate the redundant schema structure). Zuken will be incorporating into future release once path forward is defined.

Problem Report #16 (TWS_PR041901): Improper use of element OEMDesignNumberRef leads to improper and incomplete BomItem and AvlItem data structures creating several schema violations and the inability to link parts across BOM, AVL, and Assembly.

Detailed Description:

Zuken CR8000 2017 - Unique part attributes now differentiate parts, however the OEMDesignNumberRef contains footprint names that cause the BOM section to fail validation (duplicating footprint "Part Number" entries across different parts). The Avl is created with a single AvlItem using the shared footprint name. The Avl is missing all but one entry creating an improper one-to-many relationship to BOM and Assembly.

Resolution:

Fixed in 2017 Zuken patch and incorporated into March 2018 release.

Problem Report #17 (MFC_PM050901): IPC-2581B data has duplicated pads on almost all layers.

Detailed Description:

The extra data does not directly interfere with PWB manufacturing however it does add effort to CAM. The IPC-2581B data imports 240 layers into the CAM tool, most of which are empty or unrelated to printed wiring board manufacturing. Only 24 of these contained data. Twenty were classified as "board" layers and the remainder were categorized as miscellaneous. Only half of the "board" layers contained data.

Resolution:

Zuken will be incorporating into March 2019 release.

Problem Report #19 (MFC_PM062601): IPC-2581B read in a lot of layers on input (249), only 9 had board data.

Detailed Description:

IPC-2581B read in a lot of layers on input (249). Only 9 of the layers had actual board data on them. Layer data cleanup and manipulation would add time to CAM.

Resolution:

Zuken resolution being implemented in a future release.

Problem Report #21 (MFC_PM081601): IPC-2581B does not distinguish drills as plated or non-plated

Detailed Description:

When CAM is doing the tooling in Frontline Genesis there was no distinguishing if the drills were plated or non-plated.

Resolution:

Frontline Genesis can only separate out the NPTH from the PTH from the Cadence export and not the Zuken one.

2.2.6.3 Lockheed Martin Design Drafting Tool Problem Reports (2 Reports)

Problem Report #4 (SAN_PD013101): Lockheed Martin design does not contain fabrication drawing information in the IPC-2581B file

Detailed Description:

LM Space does not use Zuken to create board drawings. The drafting tool Downstream Technologies BluePrint-PCB generates this information; however, it is not capable of exporting IPC-2581B.

Resolution:

For this project, Lockeed Martin has used BluePrint-PCB to create pdf drawings. The follow-on project to this effort will evaluate options for capturing drawing information within the IPC-2581B schema.

Problem Report #13 (TWS_PD030701): Overly restrictive character set in Rev B schema produces numerous "false" validation errors since many of these characters are permitted by adopters of IPC-2581.

Detailed Description:

There exist several character restrictions in the IPC-2581B Schema definition. It appears many ECAD tools violate these character restrictions, and most downstream consumers of IPC-2581B ignore these restricted character violations.

The list of enumerated valid values for the character sets permitted in qualifiedNameType seem overly restrictive.

Zuken design data contained several Schema validation violations for elements using “qualifiedNameType” due to their use of “restricted characters”. Note: Most CAD/CAM tools seem to ignore the use of these characters.

Resolution:

A workaround to address these issues is to modify the IPC-2581B schema as follows:

```
<xsd:simpleType name="qualifiedNameType">
<xsd:restriction base="xsd:string">
<xsd:pattern
  value="([a-zA-Z0-9\p{Sc}\+\-][a-zA-Z0-9_\-#\.\(\)\{\}]*)(:[a-zA-Z][a-zA-Z0-9_\-
  #\.\(\)\{\}]*)*"/>
</xsd:restriction>
</xsd:simpleType>
```

These changes allow the use of the following symbols for those elements that use qualifiedNameType:

```
$  + - 0123456789      as the first character in a string
( ) { }                     anywhere in the string after the first character
```

It has been proposed to the Standards Committee to consider the relaxation of these constraints to better support what industry needs, uses, and accepts in current practice, eliminating most of restricted characters to allow maximum flexibility in support of existing CAD/CAM system operations. This needs to be handled by the IPC 2-16 Product Data Description standards committee.

2.2.6.4 Lockheed Martin Design IPC-2581 Committee Problem Reports (1 Report)

Problem Report #14 (FUJ_PD032001): <Profile> element(s) are not imported into Frontline tools

Detailed Description:

Frontline tools are not extracting <Profile> elements. The outline and routing data are missing.

Resolution:

For this project, 1) Board house views the outline and routing data in the WISE Viewer. 2) Copy the outline and routing data to additional layers in the CAD and CAM tools so the Frontline tools to see those layers in the IPC-2581.

This negates the intent of the IPC-2581B schema however and needs to be addressed by the IPC 2-16 standards committee. Frontline can address on their own and will need to follow IPC direction at next release.

2.2.7 **Metrics**

The project outlined three design metrics during the proposal of this effort with the plan to capture present-state and future-state process details. Those three metrics and their results are listed in the following section.

2.2.7.1 Time to generate ECAD output files (existing vs. IPC-2581B)

Present-state: Measure # hours required to generate existing files.

Gerber/Drills/etc. - 10 minutes
Gerber/Drills/etc. w/ scripting - 5 minutes

Future-state: Measure # hours required to generate IPC-2581B.

IPC-2581B - 1 minute

Project Goal: Reduction of >25% compared to present-state.

Gerber/Drills/etc. vs. IPC-2581B - 90% Reduction
Gerber/Drills/etc. w/ scripting vs. IPC-2581B - 80% Reduction

Comments: The set-up was minimal since the details of the output file were defined by IPC-2581B. The designer may parse the files using some of the output options shown in Table 2-1 however for the sake of this comparison the “FULL” function mode was used. The only manual intervention was renaming the file once it was generated.

The Gerber and drill files took some additional time to set up. Each exported artwork and drill file must define the database layers it contains. Each artwork layer and drill file must be given a unique name, unlike IPC-2581B where content and formats are predefined. Once the initial file structure is established, the designer can generate the files quickly. As the design changes over time, the set up must be reviewed to ensure it is aligned with the latest design parameters. To create the pick and place and flying probe files, the designer must enter manual commands in a terminal window. This takes several minutes, especially to someone new. This process is manual, done in a command window and is very prone to typing errors.

2.2.7.2 Number of ECAD SW changes (bugs) to correctly output IPC-2581

Present-state: Track number of Software changes required to correctly output existing PCB fab/assembly/ test files.

None - Based on SW stability of previous version.

Future-state: Track # SW changes required to correctly output IPC-2581B fab/assembly/test files.

13 Software Changes refer to section 2.2.6.2 – Lockheed Martin Design CAD Tool Problem Reports

Project Goal: Zero Software Changes

Thirteen software changes were performed.

Comments:

Existing ECAD SW platforms are stable.

2.2.7.3 PCB Design Changes

Present-state: Track # changes found and required by fab, assembly, and test vendors to fab/assemble/test PCB correctly with existing files.

No design changes were made to post design release for present-state files.

Future-state: Track # changes required by fab, assembly, and test vendors in order to fab/assemble/test PCB correctly with IPC-2581B.

One Design Change was made after design release due to lack of intelligent fiducials; refer to section 2.2.6.1 - Lockheed Martin Design Problem Reports

Project Goal: Zero iterations between PCB designers and manufacturers. Design is correct ***when IPC-2581B output is generated.***

Present-state – 0 Changes
Future-state – 1 Change

Comments: There were minimal design changes once the design was release. However, the lack of Fiducial data did cause a delay as all assembly and test tooling needed the fiducials for alignment.

2.2.8 Lockheed Martin Changes in Tools

2.2.8.1 Lockheed Martin Initial Tools Assessment:

During the proposal phase and initial tools assessment, Lockheed Martin was planning to use Zuken CR5000.

The Adiva tool was slated to support IPC-2581B during the project phase; however, it was not ready and a different tool was used in its place.

The Signal Integrity (SI) and Product Lifecycle Management (PLM) squares were deemed out of scope (i.e. not part of PCB fabrication, assembly, and test) for this project.

Figure 2-2 Lockheed Martin Initial Tools Assessment

Partner ▼	Location ▼	Mfg Flow ▶	Design						
			PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM
Lockheed Marti	SSC - Denver, CO	Mfg Equipment Vendor							
		SW Vendor	Zuken CR5000	Adiva_DRC v8.7			Zuken Lightning	Zuken Lightning	PTC Windchill

2.2.8.2 Lockheed Martin Project Tools Assessment

Lockheed Martin Space moved to Zuken CR8000 prior to the project start date and used that for the design phase of the project.

For DFx review Downstream Technologies CAM350 was used.

Figure 2-3 Lockheed Martin Project Tools Assessment

Partner ▼	Location ▼	Mfg Flow ▶	Design						
			PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM
Lockheed Marti	SSC - Denver, CO	Mfg Equipment Vendor							
		SW Vendor	Zuken CR8000	Downstream CAM 350			Zuken Lightning	Zuken Lightning	PTC Windchill

2.2.9 Lockheed Martin Changes in Processes

No changes were made to Lockheed Martin's design process as a result of this demonstration project, but changes may be required as Lockheed Martin works to transition IPC-2581 to production.

2.2.10 Lockheed Martin Design Results

The design-related metrics show an 80% reduction in the time needed to create the outputs necessary for PCB production. In addition, the Lockheed Martin design was successfully fabricated, assembled and tested at five different locations.

Additional efficiencies are expected in the future during the design verification phase as certain features will no longer be required to be checked. Also, design file configuration management concerns will be eliminated as there will only be one file containing all design information.

2.2.11 Lockheed Martin Design Conclusion

This project has demonstrated that Zuken CR8000 can output an IPC-2581B compliant file and that that file can be used successfully to manufacture a PCB. It was successful pathfinder, paving the way for IPC-2581 production roll-out.

3 Fabrication

The PCB industry has been using RS274X Gerber data as the fabrication data standard since the early 1980's. The amount of design content represented in Figure 1-1 depicts the difficulty encountered when attempting to effectively communicate this collection of information to the fabricator. The IPC-2581B file packages this data in a single file that encompasses all the required information into an intelligent form.

Three PCB designs were fabricated for this project. The two Fujitsu designs were fabricated at Sanmina. The Lockheed Martin design was fabricated at Sanmina, Lockheed Martin RMS (Owego, NY) and Lockheed Martin MFC (Grand Prairie, TX).

3.1 Lockheed Martin RMS - Owego

3.1.1 Objective

The objective was to compare the present-state and future-state files for the LM design for identical fabrication outcome, compare the time to process the present-state files and future-state file for fabrication, and fabricate the LM design using only the IPC-2581B data.

3.1.2 Materials

- Present-state fabrication files for the Lockheed Martin design
- IPC-2581 file for the Lockheed Martin design

3.1.3 Equipment

Equipment for this project refers to the software used to review, engineer, and build the bare printed wiring boards (PWB's) using the IPC-2851B file. Lockheed Martin's facility in Owego used:

- Present-state CAM tool: Infinite Graphics Inc.(IGI) ParCam with EXT version 8.60, build 4252, shell revision 12.52
- Future-state CAM tool: Frontline InCAM 3.0.1

3.1.4 **Tools**

Present-state

▼ Partner	▼ Location	Mfg Flow ►	Fabrication						
			PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
ed Martin	RMS - Owego, NY	Mfg Equipment Vendor	Orbotech	Orbotech	Orbotech	Mania probot	Excellon	Pluratec	Excellon Corbra
		SW Vendor	Infinite Graphics Inc.(IGI) ParCam	Infinite Graphics Inc.(IGI) ParCam	Infinite Graphics Inc.(IGI) ParCam	Parcam Ext & TFI converts netlist into Probot	Infinite Graphics Inc.(IGI) ParCam	Infinite Graphics Inc.(IGI) ParCam	Infinite Graphics Inc.(IGI) ParCam

Future-state:

▼ Partner	▼ Location	Mfg Flow ►	Fabrication						
			PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
ed Martin	RMS - Owego, NY	Mfg Equipment Vendor	Orbotech	Orbotech	Orbotech	Mania probot	Excellon	Pluratec	Excellon Corbra
		SW Vendor	Frontline InCAM v3.0.1	Frontline InCAM v3.0.1	Frontline InCAM v3.0.1	Parcam Ext & TFI converts netlist into Probot	Frontline InCAM v3.0.1	Frontline InCAM v3.0.1	Frontline InCAM v3.0.1

3.1.5 **Methodology**

The present-state fabrication process employs Gerber artwork layers in the RS274X format, nc-drill files, and an IPC-D-356A netlist file for PWB fabrication. The future-state employed IPC-2581B.

The fabrication process begins with the handoff of data from the PCB designer to the PCB fabricator. The fabricator first reviews and analyzes the design. The fabricator then generates a set of tooling consisting of panelized data, manufacturing drill/route files, imaging files for Automated Optical Inspection (AOI), and electrical test files.

3.1.6 **Present-state Process**

IGI ParCam was utilized for all present-state CAM operations at LM RMS - Owego. The full set of required process procedures, engineering specifications, and checklists were used by the front-end CAM and methods engineering teams to assist them in releasing new PWB's into LM RMS - Owego's PWB manufacturing line using Gerber data. The PWB process flow, associated tooling, and software are shown in Figure 3-1.

The major categories for this tooling are listed here:

- Importing the PWB data (Gerber artwork, nc-drill files, and netlist file) and editing the PWB data
- PWB Panelization and Coupon generation and placement
- Legend generation per the silkscreen artwork layer(s)

- Film tooling review
- Output of Legend Files
- Output of Film Files
- Output of Drill Files
- Output of Profile Route and Score Files
- Calculate Plating Area
- Output of AOI data
- Output of Solder Paste Stencil Data
- Export of Data for Electrical Test

Importing Gerber data is downloaded to the CAM workstation. The supplied data includes all elements needed to produce a new PWB:

- External artworks layers
- Internal artworks layers
- Drill files
- Profile/Score program(s)
- Solder mask artworks
- Nomenclature (Legend marking or silkscreen)
- Solder Paste Stencil (referenced in fabrication and used in assembly)
- IPC 356 netlist to verify the supplied data matches the design generated netlist.
- Fabrication drawing with performance and compliance standards
- Purchase order requirements that may supersede the drawing or fabrication specifications

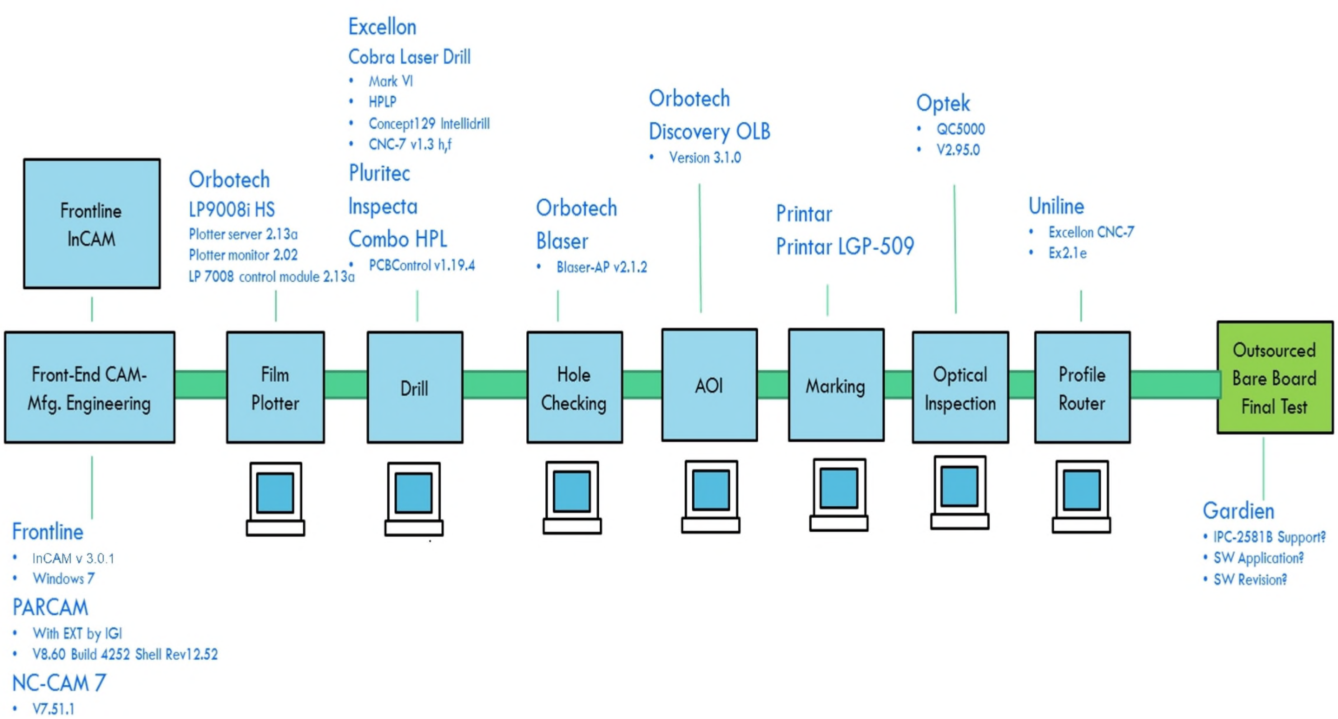


Figure 3-1: Lockheed Martin RMS PWB process flow

The actual editing of the PWB data in preparation for artwork generation included the following:

- CAM Checklist generation, construction of the panel layout and output of machine tools and programs, a netlist summary report for comparison, line sizes and copper to copper feature spacing. Other CAM enhancements to the data would include verification of drill sizes and annular ring requirements that directly impact PWB registration.
- Line sizes may need to be modified to achieve proper impedance values for controlled signals. The Polar impedance calculator tool is used to specify the correct line width and spacing.
- PWB manufacturing fiducial requirements and SMT assembly fiducials will be verified.
- Laminate and dielectric thicknesses are selected taking into consideration the press-out phases of the PWB build. Other key attributes like minimum annular ring are analyzed to meet PWB yield targets. Copper etch factors are assigned to each copper layer depending upon the starting copper weight and line widths, line to copper feature spacing, and whether the layer sees a copper plating cycle.

3.1.7 Future-state with IPC-2581B data

The present-state CAM application, Infinite Graphics (IGI) ParCam, did not support the future-state IPC-2581B data standard. To address this gap in capability LM RMS - Owego used the Frontline InCAM software tool for performing CAM with the IPC-2581B file. Initially there were many challenges that needed to be overcome with the InCAM software as well as other factors outside the control of this project. For example, the training for the Frontline InCAM tool was conducted in December 2016, however the actual CAM work for this design didn’t start until April 2017. Due to the long-time span in between training and project execution, the CAM technician had forgotten much of the basic set up and proper software menu selections. In addition, present-state scripts that automate many of the repetitive tasks for each new PWB design required modification.

3.1.8 Data Observation

PWB CAM Systems Used:

Lockheed Martin RMS used Infinite Graphics (IGI) to import Gerber data and Frontline InCAM to import IPC-2581B data. Both data sets were translated into separate jobs within the independent CAM systems.

1. A manual compare was performed on the buildups to determine layer count, type, and context.
2. A manual compare was performed on the drill tools using the tool within the CAM system. The discrepancies are noted below.
3. Manual Graphic layer compares for the PCB was performed using the two CAM tools. All common layers were compared between the two systems to insure the formats yielded the same results, including drills and masks. The discrepancies are noted below.
   - The IPC-2581B data contained many layers, most of which did not have any actual data.
   - None of the layer names between Gerber and IPC-2581B matched, making it difficult to pair them up.

The problems encountered performing PCB engineering and PCB fabrication are noted here:

- Since the Frontline InCAM software tool was new to LM RMS – Owego, they lacked experience using the tool and their ability to see some gains in efficiency using the IPC-2581B data were masked by the time required to learn the new tool.
- InCAM does not provide .dxf output. The RMS IMPEX via hole checker equipment requires

dxf data format. This .dxf data format is the only format the hole checking machine will accept. LM RMS - Owego plans to follow up with the machine fabricator to request support for the IPC-2581B data format in a future release of their application software. This was documented in Problem report #26, RMS-PM020601.

- InCAM Setup issues: The InCAM installation was initially incomplete and it was noted that the hook files were not edited to work with their computers. This was an Orbotech installation setup problem and was documented in Problem report #23, RMS-PM110201.
- There were changes required in InCAM to support the Orbotech LP 9008i Plotter; Output from InCAM was not compatible with the Orbotech Plotter LP 9008i. The problem was escalated and a field representative arrived on-site the following week to troubleshoot the issue. Changes were made to several plotter configuration files. The plotter was then able to plot the artwork layers correctly. This was documented in Problem report #24, RMS-PM112102.
- It was noted that that etch factor capabilities within InCAM were not available with the current license and a feature to support impedance coupon generation was not found. These issues will be addressed in the future as the project moves to the next phase.
- The Lockheed Martin design did not have assembly fiducials in the supplied data. We manually intervened and added assembly fiducials.
- There were some issues in the initial IPC-2581B file that was originally generated. Most notably, there were duplicated signal pads and a drill file that did not distinguish between plated and non-plated tooling holes. This was resolved in a later revision of InCAM provided by Frontline. There were also a set of duplicate layers with no data on them and a few missing features. This issue will be addressed by Zuken in a future release of CR8000.

Some of the major improvements with this new data format include:

- All copper layers are contained in one file, and the stack-up order is dictated in the schema which eliminates the need for the CAM technician to do layer naming and ordering.
- Excellon drill data is included in the IPC-2581B file, using a consistent format with the schema.

3.1.9 Metrics

Metric	Present -state	Future-state	Project Goal	Comment
PCB Fabrication				
Differences /discrepancies between existing fab files and IPC-2581B file	Present-state is baseline.	1. Duplicated pads 2. Drills weren't separated into plated and non-plated 3. Extra blank junk layers 4. Missing features	Zuken Design data run through DFM software with no errors: clean data	Team needed to be refreshed on InCAM software use. Expertise is needed with InCAM script writing to eliminate manual, repetitious CAM tasks. Lack of assembly fiducials identified in the design data. InCAM does not provide .dxf output: RMS hole checker (IMPEX machine) requires dxf. Additional support required to setup .dxf output capabilities, if possible. Purchase additional licensing required to allow for extra etch factor capabilities. Impedance coupons not generated. Need InStack for coupon design and impedance coupons.
PCB Fabrication Preparation	1 hour	1 hour	Reduction of 25% compared to present-state	Did not meet goals for time reduction.
# of PCB Manufacture SW vendor changes (bugs)	N/A present-state is baseline	Needed Orbotech on-site support with how to port data to the LP7008 artwork plotter machine.	0	Need to obtain the coupon generator module from Orbotech InCAM .

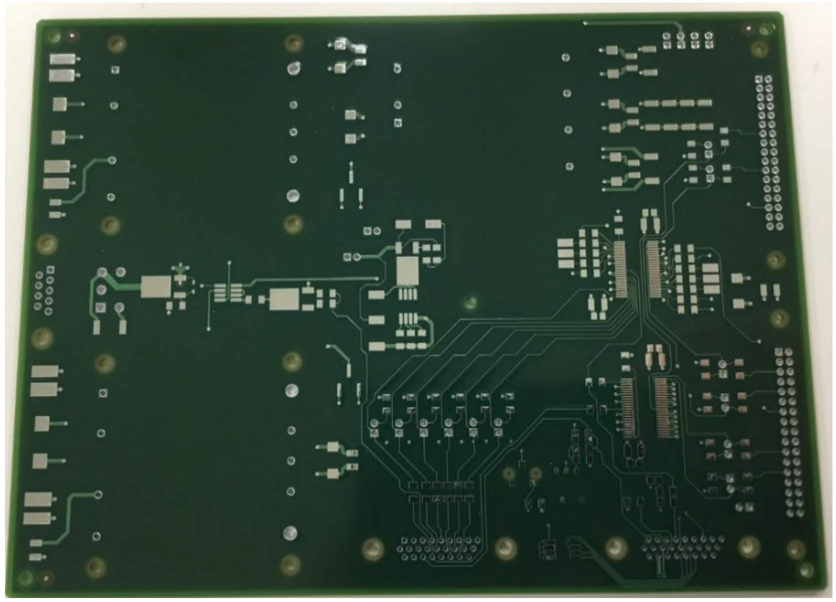


Figure 3-2: Lockheed Martin design top side

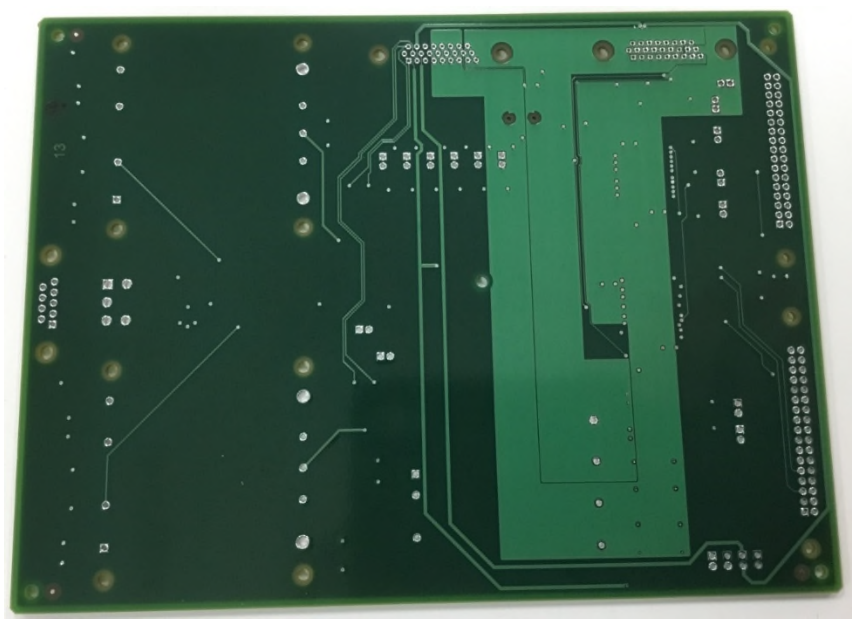


Figure 3-3 Lockheed Martin design PWB bottom side

3.1.10 **Summary**

Overall, the PCB CAM fabrication metric for a 25% reduction was not achieved. With additional experience and having already flushed out some of the issues, there will be efficiency gains in the future. This will be even more noticeable when new scripts can be written to take advantage of the intelligence contained in IPC-2581B data file.

3.2 Sanmina

3.2.1 Objective

The objective was to compare the present-state and future-state files for the Lockheed Martin design and the two Fujitsu designs to ensure identical fabrication outcome, compare the time to process the present-state files and future-state file for fabrication, and fabricate the three designs using only the IPC-2581B data.

3.2.2 Materials

Lockheed Martin design:

- Present-state data: zip file with Gerber 274x photoplots, IPC-356D netlist file, Excellon drill file, fabrication drawing with stackup definition, etc.
- Future-state data: IPC-2581B file

Fujitsu Network Communications designs:

- Two Printed Circuit Boards - HA380-2016-V920 Rev 01, HA380-2016-N040 Rev 01
- Present-state data: ODB++ tar archive (TGZ) with fabrication drawing, designer notes, stack-up definition
- Future-state data: IPC-2581B file containing all required information

3.2.3 Equipment

Equipment for this project refers to the software used to review, engineer, and build printed circuit boards with the IPC-2851 data format. Sanmina uses

- InSight PCB version 2.03
- Genesis 2000 version 10.3
- InCAM version and
- InPlan version 4.10
- Wise 2581 Viewer version 16.8

3.2.4 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ▶	Fabrication					
			PCB CAM	PCB LDI	PCB AOI	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
Sanmina	San Jose, CA	Mfg Equipment Vendor	Linux Machines	Orbotech	Orbotech & CAM Tech	Excellon & Hitachi	Excellon	Hitachi
		SW Vendor	Frontline InPlan, InCAM, Insight, Genesis 2000	Frontline InPlan, InCAM, Insight, Genesis 2000	Frontline InPlan, InCAM, Insight, Genesis 2000	Frontline InPlan, InCAM, Insight, Genesis 2000	Frontline InPlan, InCAM, Insight, Genesis 2000	Frontline InPlan, InCAM, Insight, Genesis 2000

Future-state:

▼ Partner	▼ Location	Mfg Flow ▶	Fabrication					
			PCB CAM	PCB LDI	PCB AOI	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
Sanmina	San Jose, CA	Mfg Equipment Vendor	Linux Machines	Orbotech	Orbotech & CAM Tech	Excellon & Hitachi	Excellon	Hitachi
		SW Vendor	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000	Frontline InPlan v4.1, InCAM v4.1, Insight v2.03, Genesis 2000

3.2.5 **Methodology**

When CAD data is presented to a fabricator there are several phases to producing the printed circuit board. The part will need to be quoted and the design data has a direct impact on the cost. The size, shape, materials, and special processing can be extracted from the data files. Often the question of if the part is manufacturable and/or requests to alter the design to make it manufacturable is requested by the OEM. This design review or DFM is performed by the fabricator.

The Pre CAM process is done once the order is received. We will first read the data into our system and then complete a cleanup of the data to prepare it for our CAM process.

The CAM process is to make minor adjustments to the design to prepare it for manufacturing. The design is replicated several times to create a panel and coupons, borders, targets, tooling holes, etc. are added for manufacturing.

The Engineering process will determine the BOM (build of materials), precise line widths to meet electrical requirements, the process route to create the desired board based on the design, the drawings, and specifications provided by the OEM.

The test file creation is an extraction of the electrical nets of the design. This netlist is used to program the test machines. Its purpose is to verify the boards manufactured represent the same electric nets as the design.

3.2.6 **Present-state**

Design review and/quoting

Sanmina used InSight PCB from Frontline for design review and metadata extraction of the CAD design to complete the quoting process. Drawings and attached documents are reviewed for additional manual inputs to the quoting process.

Pre CAM

Sanmina used Genesis and/or InCAM from Frontline for Pre CAM. This process is to read the CAD data into our system, contourizing drawn polygon shapes as a surface, adding attributes to features and running analysis to understand the if the data is manufacturable.

CAM

Sanmina used Genesis and/or InCAM from Frontline for creating the tooling files needed. This includes editing the one up circuit so that it meets the design intent and specifications, and creating the multi up panel with tooling holes, coupons, and borders for pressing and/or planting.

Engineering

Sanmina used Genesis InPlan from Frontline for creating the stack-up, impedance calculations, creating the process route, specifying the BOM, and adding work instructions for the manufacturing plant.

Test Files

Test files are generated as part of the CAM process.

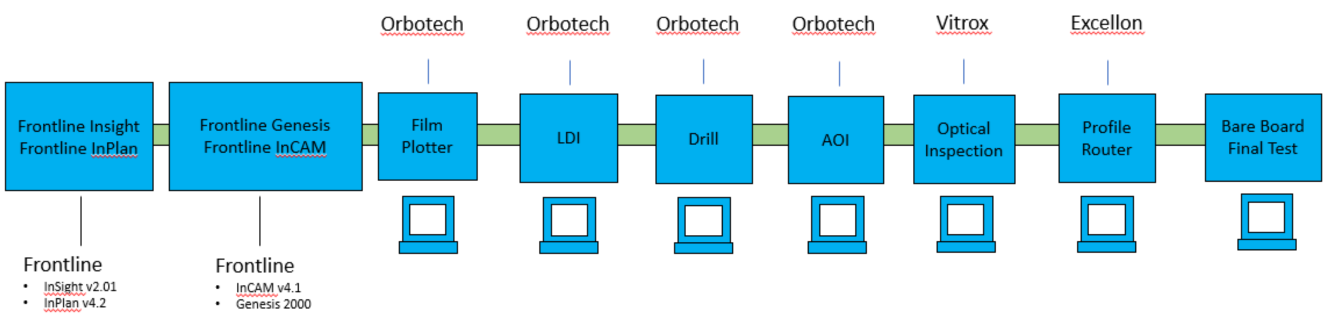


Figure 3-4: Sanmina PWB process flow

3.2.7 Future-state

Design review and/quoting

Sanmina will continue to use InSight PCB, but plans to write automation tools to extract additional data from the IPC-2581B file. Attributes like surface finish, materials, impedance constraints, and stack-up geometries can be extracted and sent directly to the quoting system saving both time and eliminating possible mistakes.

Pre CAM

Sanmina expects to eliminate this process step and use the data package as read in by InSight PCB. IPC-2581B eliminated many of the clean-up issues created by other data formats.

All layers are contained in one file, and layer stack-up order is enforced, so layer names are not important

Drill data is included in the IPC-2581B file, using a consistent schema.

All data is contained in the same file and is referenced to the same origin.

A board outline can be included in the same file as the artwork and other data.

No vector fills eliminating the need to “contourize” the data.

IPC-2581B does not have composite artwork layers. All artwork required for any given layer is included within a single layer definition.

Surface mount pads are features and not a composite of vectors,

CAM

No change expected.

Engineering

Sanmina will continue to use InPlan from Frontline for creating the stack-up, impedance calculations, creating the process route, specifying the BOM, and adding work instructions for the manufacturing plant.

Significant improvements are expected as the stack-up can be passed from the OEM to the fabricator as a readable file. This eliminates the need to type in material types, thickness constraints, and impedance constraints. The can be read in from the IPC-2581B file. Because dimensions, cutouts or routing, notes, material type, thickness, finish, etc., can all be embedded in the IPC-2581B file, Sanmina expects to eliminate the possibility for mistakes and be able to write automation rules to make the engineering process more efficient.

Test Files

No change expected.

3.2.8 Data Observation

Data Compare Results of the graphic differences found when comparing present-state and future-state data sets of the same design. In this case Gerber 274x and IPC-2581B.

First set of Files Compared:

- SK8606934_Rev2017.xml
- Gerber 274x and Excellon2:

Name	Size	Packed Size	Modified
ipc356.btd	63 652	8 845	2016-12-12 12:59
SK8606934_-_BRD.fph	227	122	2016-12-12 13:06
SK8606934_-_L01.fph	33 265	7 815	2016-12-12 13:06
SK8606934_-_L02.fph	46 365	9 150	2016-12-12 13:06
SK8606934_-_L03.fph	47 666	9 064	2016-12-12 13:06
SK8606934_-_L04.fph	24 553	5 781	2016-12-12 13:06
SK8606934_-_MAF.fph	128 654	35 222	2016-12-12 13:06
SK8606934_-_NCN.fdr	454	215	2017-03-23 15:47
SK8606934_-_NCP.fdr	4 848	1 308	2016-12-12 13:00
SK8606934_-_SMB.fph	13 689	2 228	2016-12-12 13:06
SK8606934_-_SMF.fph	22 489	4 184	2016-12-12 13:06
SK8606934_-_STF.fph	7 234	1 633	2016-12-12 13:06
SK8606935_REV_-_flying_probe.dsgf	2 479 549	216 113	2016-11-30 15:33
SK8606935_REV_-_flying_probe.ftf	606 421	61 588	2016-11-30 15:34
SK8606935_REV_-_picknplace.txt	21 608	2 443	2016-11-30 15:30

CAM Systems Used: Genesis 2000 and InCAM

Both data sets were translated into separate jobs within the CAM system.

A manual compare was performed on the buildups to determine layer count, type, and context. Discrepancies were noted.

A manual compare was performed on the drill tools using the “Drill Tool Manager” tool within the CAM system. Discrepancies were noted.

Graphic layer compares for the PCB was performed using the CAM tool “Layer Compare”. All common layers were compared between formats, including drills and masks. Discrepancies were noted.

Note: This procedure was followed once in InCAM and once in Genesis. The results were the same between CAM systems.

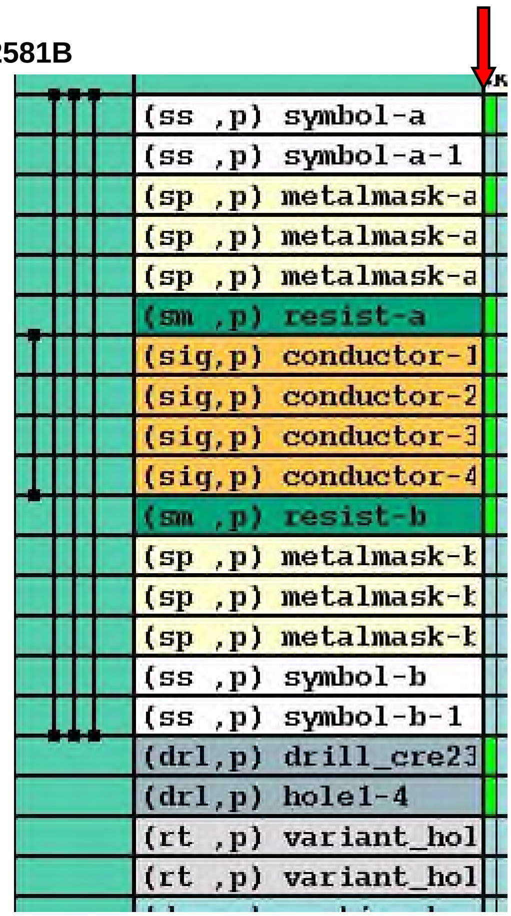
Gerber data contained SIPs (Self Intersecting Polygons), which are discouraged.

Buildup Compare

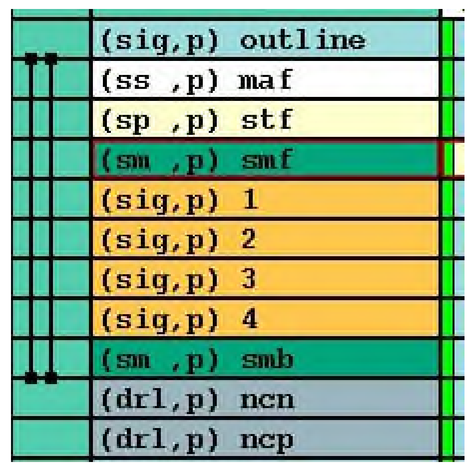
The IPC-2581B data has many layers, most of which did not have any actual data. None of the layer names between Gerber and IPC-2581B matched, making it a bit difficult to pair them up.

The column marked by the red arrow will be green if data exists on that layer.

IPC-2581B



Gerber



Full IPC-2581B Layer List:

Layer Name = Conductor-1	Layer Name = DXF_7	Layer Name = Layer_Back
Layer Name = Conductor-2	Layer Name = Fab_Dwg_8	Layer Name = Layer_Front
Layer Name = Conductor-3	Layer Name = Fab_Dwg_9	Layer Name = Layer_Inner
Layer Name = Conductor-4	Layer Name = Fab_Dwg_10	Layer Name = MISC_1
Layer Name = Symbol-A	Layer Name = Fab_Dwg_11	Layer Name = MISC_2
Layer Name = Resist-A	Layer Name = Fab_Dwg_12	Layer Name = MISC_3
Layer Name = MetalMask-A	Layer Name = Fab_Dwg_13	Layer Name = MountClear-A
Layer Name = HeightLimit-A	Layer Name = Fab_Dwg_14	Layer Name = MountClear-B
Layer Name = CompArea-A	Layer Name = Fab_Dwg_15	Layer Name = Place_Keepout_All
Layer Name = ThermalShape-A	Layer Name = Fab_Dwg_16	Layer Name = Place_Keepout_Back
Layer Name = Symbol-B	Layer Name = Fab_Dwg_17	Layer Name = Place_Keepout_Front
Layer Name = Resist-B	Layer Name = Fab_Dwg_18	Layer Name = Place_Keepout_Inn
Layer Name = MetalMask-B	Layer Name = Fab_Dwg_19	Layer Name = PlateMask
Layer Name = HeightLimit-B	Layer Name = Fab_Dwg_20	Layer Name = PlateMask_Back

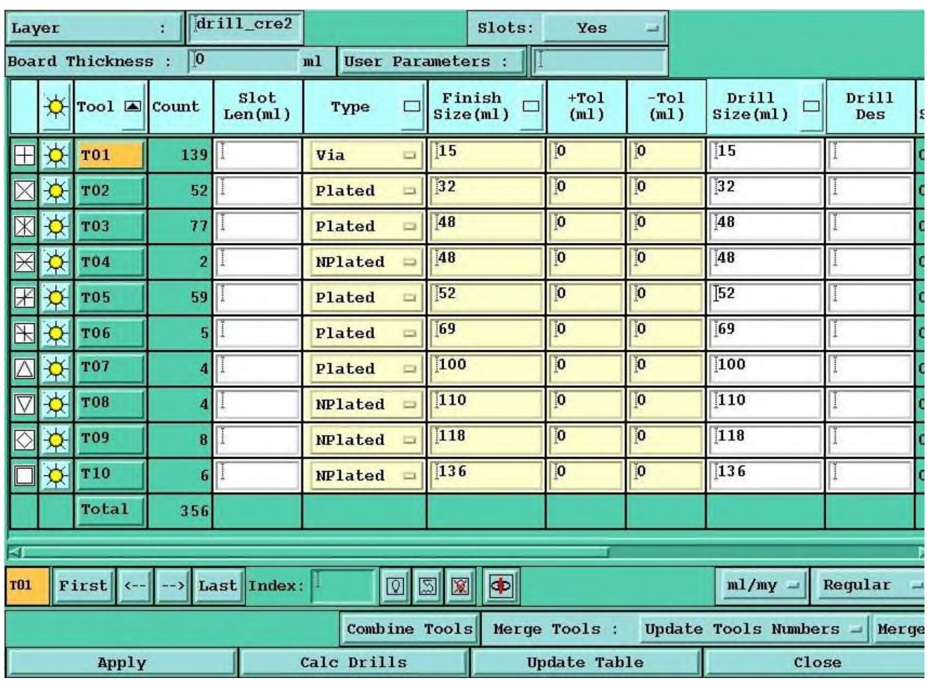
Layer Name = CompArea-B
Layer Name = ThermalShape-B
Layer Name = Symbol-A-1
Layer Name = Symbol-B-1
Layer Name = MetalMask-A-1
Layer Name = MetalMask-B-1
Layer Name = MetalMask-A-2
Layer Name = MetalMask-B-2
Layer Name = RulesByArea
Layer Name = Assembly
Layer Name = Assembly_Back
Layer Name = Assembly_Body-A
Layer Name = Assembly_Body-B
Layer Name = Assembly_Front
Layer Name = Assembly_Hole
Layer Name = Assy_Dwg_1
Layer Name = Assy_Dwg_2
Layer Name = Assy_Dwg_3
Layer Name = Assy_Dwg_4
Layer Name = Assy_Dwg_5
Layer Name = Assy_Dwg_6
Layer Name = Comp-buildupA
Layer Name = Comp-buildupB
Layer Name = Comp-buildupIN
Layer Name = Comp-compareaA
Layer Name = Comp-compareaB
Layer Name = Comp-core
Layer Name = Comp-coreIN
Layer Name = Comp-metalmask
Layer Name = Comp-resistA
Layer Name = Comp-resistB
Layer Name = CompHole
Layer Name = Comp_Area
Layer Name = Comp_Area_Back
Layer Name = Comp_Area_Front
Layer Name = Cond_Therm_Back
Layer Name = Cond_Therm_Front
Layer Name = Crosshair
Layer Name = Crosshatch
Layer Name = DXF_1
Layer Name = DXF_2
Layer Name = DXF_3
Layer Name = DXF_4
Layer Name = DXF_5
Layer Name = DXF_6
Layer Name = Template_3
Layer Name = Template_4
Layer Name = Template_5
Layer Name = Template_6
Layer Name = Template_7
Layer Name = Template_8
Layer Name = Template_9
Layer Name = Template_10
Layer Name = Template_11
Layer Name = Template_12
Layer Name = Trace_Keepout
Layer Name = Trace_Keepout_All
Layer Name = Trace_Keepout_Back
Layer Name = Trace_Keepout_Front
Layer Name = Trace_Keepout_Inn
Layer Name = Trace_Keepout_Outer_Adj
Layer Name = Patch_Back
Layer Name = Patch_Front
Layer Name = Template_13
Layer Name = Template_14
Layer Name = Fab_Dwg_21
Layer Name = Fab_Dwg_22
Layer Name = Fab_Dwg_23
Layer Name = Fab_Dwg_24
Layer Name = Fab_Dwg_25
Layer Name = Fab_Dwg_26
Layer Name = Fab_Dwg_27
Layer Name = Fab_Dwg_28
Layer Name = Fab_Dwg_29
Layer Name = Fab_Dwg_30
Layer Name = Fab_Dwg_31
Layer Name = Fab_Dwg_32
Layer Name = Fab_Dwg_33
Layer Name = Fab_Dwg_34
Layer Name = Fab_Dwg_35
Layer Name = Fab_Dwg_36
Layer Name = Fab_Dwg_37
Layer Name = Fab_Dwg_38
Layer Name = Fab_Dwg_39
Layer Name = Fab_Dwg_40
Layer Name = Format-Assy-Common
Layer Name = Format-PWB-Common
Layer Name = Format_Continuation
Layer Name = DXF_8
Layer Name = Documentation_1
Layer Name = Documentation_2
Layer Name = Documentation_3
Layer Name = Documentation_4
Layer Name = Fab_Dwg_1
Layer Name = Fab_Dwg_2
Layer Name = Fab_Dwg_3
Layer Name = Fab_Dwg_4
Layer Name = Fab_Dwg_5
Layer Name = Fab_Dwg_6
Layer Name = Fab_Dwg_7
Layer Name = Format_Title
Layer Name = Gerb_Bd_Outline
Layer Name = GlueMask
Layer Name = GlueMask_Back
Layer Name = GlueMask_Front
Layer Name = Hidden_Entities
Layer Name = IDF_1
Layer Name = IDF_2
Layer Name = IDF_3
Layer Name = Template_15
Layer Name = Template_16
Layer Name = Template_17
Layer Name = Template_18
Layer Name = Template_19
Layer Name = Template_20
Layer Name = TemplateShape1
Layer Name = TemplateShape2
Layer Name = TemplateShape3
Layer Name = TemplateShape4
Layer Name = TemplateShape5
Layer Name = TemplateShape6
Layer Name = TemplateShape7
Layer Name = TemplateShape8
Layer Name = TemplateShape9
Layer Name = Via_Keepout_All
Layer Name = Via_Keepout_Back
Layer Name = Via_Keepout_Front
Layer Name = Via_Keepout_Inn
Layer Name = hs_trunk_layer
Layer Name = Template_Shape
Layer Name = TemplateShape
Layer Name = Jumper_Back
Layer Name = PlateMask_Front
Layer Name = Routing_Keepout_2
Layer Name = Routing_Keepout_3
Layer Name = Routing_Keepout_4
Layer Name = Routing_Keepout_5
Layer Name = Routing_Keepout_6
Layer Name = Routing_Keepout_7
Layer Name = Routing_Keepout_8
Layer Name = Routing_Keepout_9
Layer Name = Routing_Keepout_10
Layer Name = Routing_Keepout_11
Layer Name = Routing_Keepout_12
Layer Name = Routing_Keepout_13
Layer Name = Routing_Keepout_14
Layer Name = Routing_Keepout_15
Layer Name = Routing_Keepout_16
Layer Name = Routing_Keepout_17
Layer Name = Routing_Keepout_18
Layer Name = Routing_Keepout_19
Layer Name = Routing_Keepout_20
Layer Name = Routing_Keepout_21
Layer Name = Routing_Keepout_22
Layer Name = Routing_Keepout_23
Layer Name = Routing_Keepout_24
Layer Name = Routing_Keepout_25
Layer Name = Routing_Keepout_26
Layer Name = Routing_Keepout_27
Layer Name = Routing_Keepout_28
Layer Name = Routing_Keepout_29
Layer Name = Routing_Keepout_All
Layer Name = Routing_Keepout_Back
Layer Name = Routing_Keepout_Front
Layer Name = Routing_Keepout_Inn
Layer Name = SilkScreen
Layer Name = SilkScreen_Back
Layer Name = SilkScreen_Front
Layer Name = Silkscreen_Outline
Layer Name = SolderMask
Layer Name = SolderMask_Back
Layer Name = SolderMask_Front
Layer Name = SolderStencil
Layer Name = SolderStencil_Back
Layer Name = SolderStencil_Front
Layer Name = Template_1
Layer Name = Template_2
Layer Name = Jumper_Front
Layer Name = TemplateShape10
Layer Name = TemplateShape11
Layer Name = TemplateShape12
Layer Name = TemplateShape13
Layer Name = TemplateShape14
Layer Name = TemplateShape15
Layer Name = TemplateShape16
Layer Name = TemplateShape17

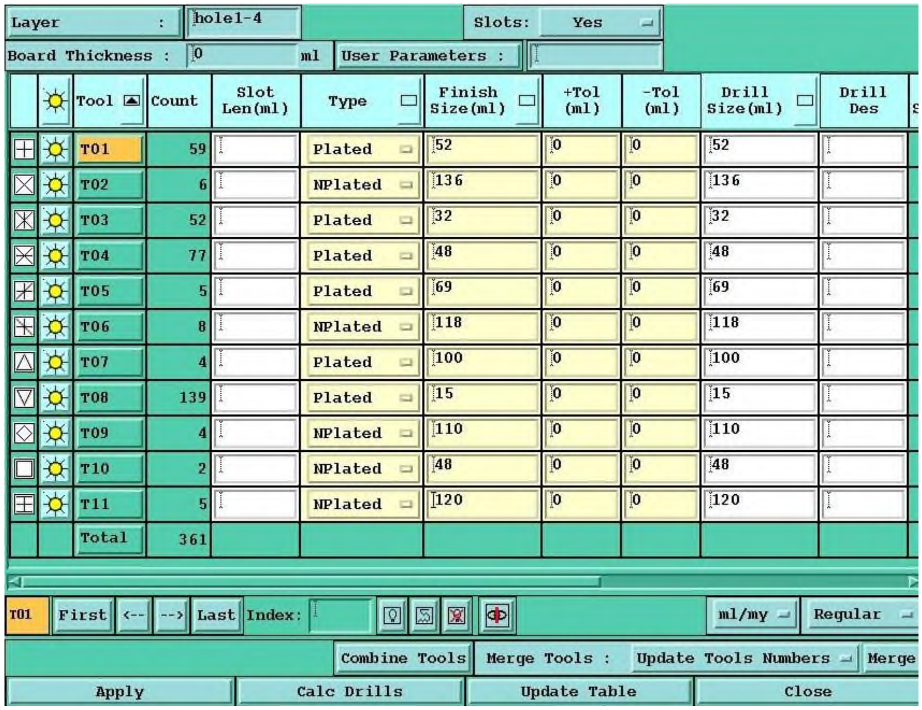
Note: While the IPC-2581B file contained route layers, the layers had no data.

Drill Tool Compare

```
Graphic Layer Compare – PCB Step
   IPC-2581B              Gerber
   symbol-a        →      maf                      Layers match
   metalmask-a     →      stf                      Layers match
   resist-a               smf                      Layers match
   conductor-1     →      1                        Layers match
   conductor-2     →      2                        Layers match
   conductor-3     →      3                        Layers match
   conductor-4     →      4                        Layers match
   resist-b               smb                      Layers match
Drill layers did not match!  See Tool Section below.
   drill-cre239           ncn
   hole1-4                ncp
```

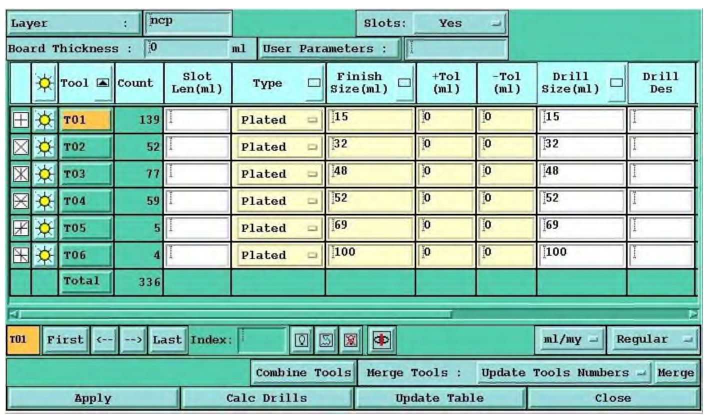
IPC-2581B: Missing tolerances. Drill programs contained duplicate hits when overlaid with one another (see problem report TWS_PM030602). It was not clear which one to use or which was correct. IPC-2581B layer hole1-4 had the same hole count as the 2 combined Excellon2 layers and the tools could be matched up.



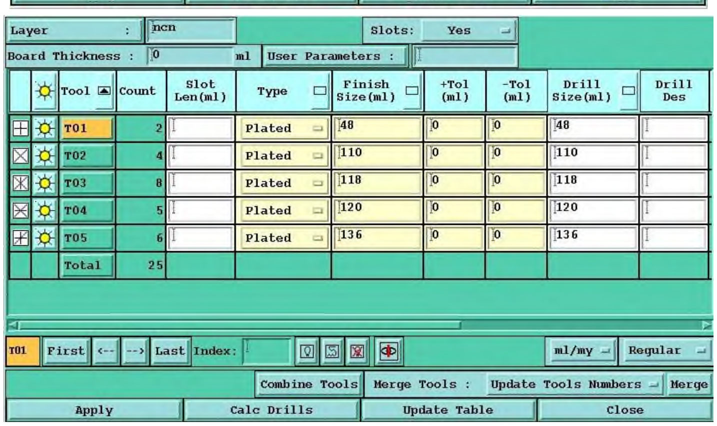


Tool	Count	Slot Len(ml)	Type	Finish Size(ml)	+Tol (ml)	-Tol (ml)	Drill Size(ml)	Drill Des
T01	59		Plated	52	0	0	52	
T02	6		NPlated	136	0	0	136	
T03	52		Plated	32	0	0	32	
T04	77		Plated	48	0	0	48	
T05	5		Plated	69	0	0	69	
T06	8		NPlated	118	0	0	118	
T07	4		Plated	100	0	0	100	
T08	139		Plated	15	0	0	15	
T09	4		NPlated	110	0	0	110	
T10	2		NPlated	48	0	0	48	
T11	5		NPlated	120	0	0	120	
Total	361							

Excellon2 : These appear correct (From the Gerber data) – 1 Plated (ncp) and 1 Nonplated (ncn). No duplicate hits.



Tool	Count	Slot Len(ml)	Type	Finish Size(ml)	+Tol (ml)	-Tol (ml)	Drill Size(ml)	Drill Des
T01	139		Plated	15	0	0	15	
T02	52		Plated	32	0	0	32	
T03	77		Plated	48	0	0	48	
T04	59		Plated	52	0	0	52	
T05	5		Plated	69	0	0	69	
T06	4		Plated	100	0	0	100	
Total	336							



Tool	Count	Slot Len(ml)	Type	Finish Size(ml)	+Tol (ml)	-Tol (ml)	Drill Size(ml)	Drill Des
T01	2		Plated	48	0	0	48	
T02	4		Plated	110	0	0	110	
T03	8		Plated	118	0	0	118	
T04	5		Plated	120	0	0	120	
T05	6		Plated	136	0	0	136	
Total	25							

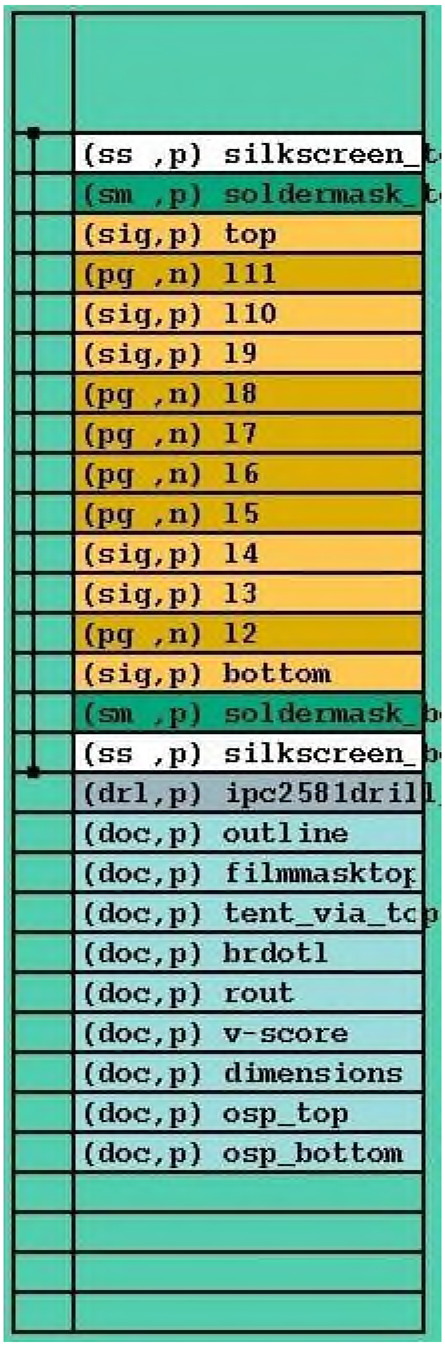
Corrections were made to the Zuken CAD system to resolve the extra layers and the drill that did not match up. Corrections were made to the Frontline CAM tools (InSight, Genesis, and InCAM) to bring in the drill tolerances once per drill hole size.

Second set of Files Compared:

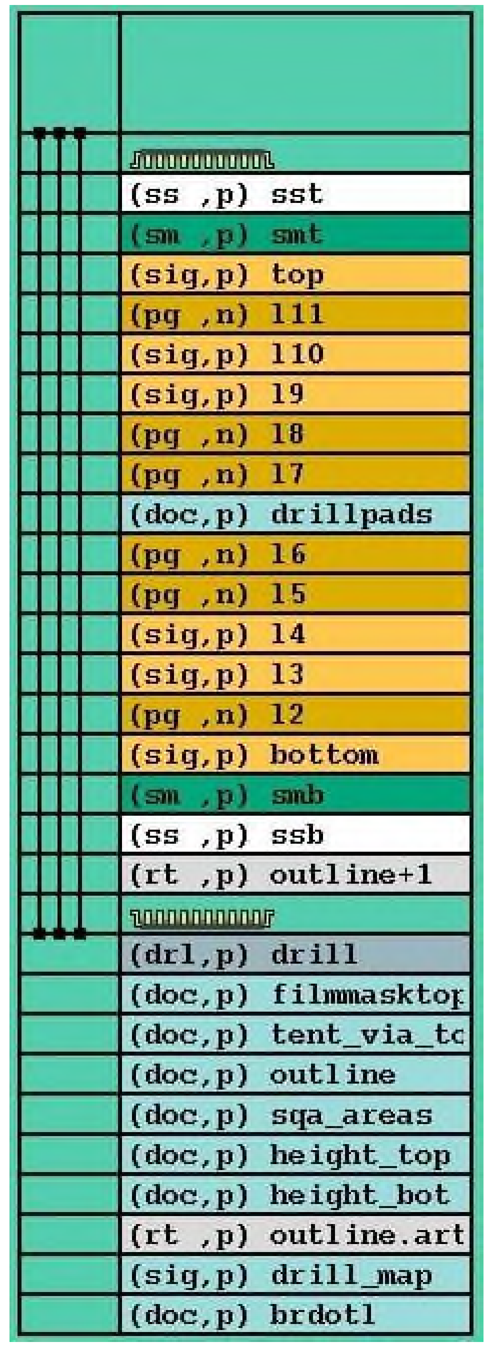
- HA380-2016-N040_01.xml
- HA380-2016-N040_01.tgz

Buildup Compare

IPC-2581B



TGZ



The ODB++ TGZ had the following layers that are not required for board fab. These did not appear in the IPC-2581B file. This is seen as a positive result as it reduces confusion and perhaps suppresses information not required for distribution.

Component Layers Top & Bot

drillpads

sqa_areas

height_top

height_bot

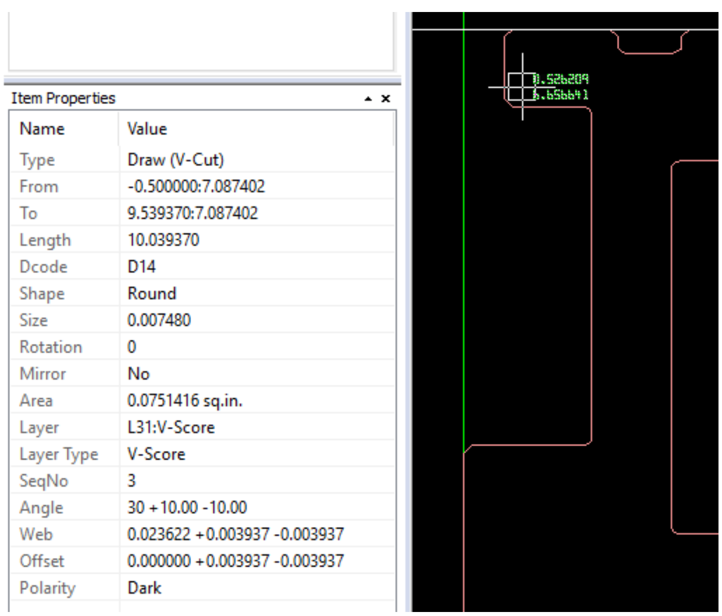
drill_map

outline.art

outline+1

The IPC-2581B included layers with additional requirements and specifications that the TGZ did not support. Typically, this information would be provided with a drawing that the fabricator would have print or plot. The product engineer would need to read, interrupt, and re-enter this information into their engineering system. Having this information represented in the IPC-2581 file added value to the fabrication process as there was no manual manipulation required.

Having this additional information embedded in IPC-2581B will save possible mistakes and time from data entry. For example, the v-score information can be directly imported from the job data. The same is true for impedance constraints. Having the surface finish as a layer in the data allows one to read this in directly. When this is a selective finish, having the area defined as a layer will save time for the fabricator.



There are times when some print notes need to be written and the IPC-2581B data supports this as displayed below using the WISE 2581 Viewer.

v-score

rout

dimensions

osp_top

osp_bottom

Stackup | Impedance | Designer Notes | Standard Notes | Board Information | Compliance

Name	Transimission Type	Structure	Impedance Ohms	Line Width MM	Differential Pair Spacing MM	Coplanar Spacing MM	Comr
E_MMCi100w0.287s0.246c0.23	EDGE_COUPLED	MICROSTRIP_MASK_COVERED	100 (+/- 10.00%)	0.287	0.246	0.23	100 ohm Diff CPW
E_Si100w0.089s0.114	EDGE_COUPLED	STRIPLINE	100 (+/- 10.00%)	0.089	0.114		100 ohm Diff
S_MMCi50w0.427c0.33	SINGLE_ENDED	MICROSTRIP_MASK_COVERED	50 (+/- 10.00%)	0.427		0.33	50 ohm SE CPW
S_Si40w0.16	SINGLE_ENDED	STRIPLINE	40 (+/- 10.00%)	0.16			40 ohm SE
S_Si50w0.108	SINGLE_ENDED	STRIPLINE	50 (+/- 10.00%)	0.108			50 ohm SE

Stackup | Impedance | Designer Notes | Standard Notes | Board Information | Compliance

Note
As viewed from the design data rotated image 8 degrees clockwise.
All line neck downs and changes to differential line width and space are of design intent.
Use artwork FILLED_VIA for holes that are to be filled with Peters 2795 or equivalent non-conductive resin. These are the plated COH Chip on hole or pad on via type vias to be plat...
The filled and plated over via is considered the most complex feature. The Fujitsu daisy chain coupon must contain the filled via feature.
Tent vias on top layer using artwork TENT_VIA_TOP.
For reference only, the down revision of this design is HA380-8006-V330_03.

Stackup | Impedance | Designer Notes | Standard Notes | Board Information | Compliance

Type	Property
INSTRUCTION	DF Standard 900/014 is the purchase specification that lists many of the requirements for this design. The specification also lists acceptable deviations that...
INSTRUCTION	It is acceptable to change the MADE IN USA text on the silkscreen layer to that of the actual country where the board is fabricated.
INSTRUCTION	The BRDOTL layer contains the rout data
INSTRUCTION	The V-Score layer contains the v-score data
INSTRUCTION	All holes are FHS. Drill sizes in the tables on HOLE_CHART layer(s) are for reference only

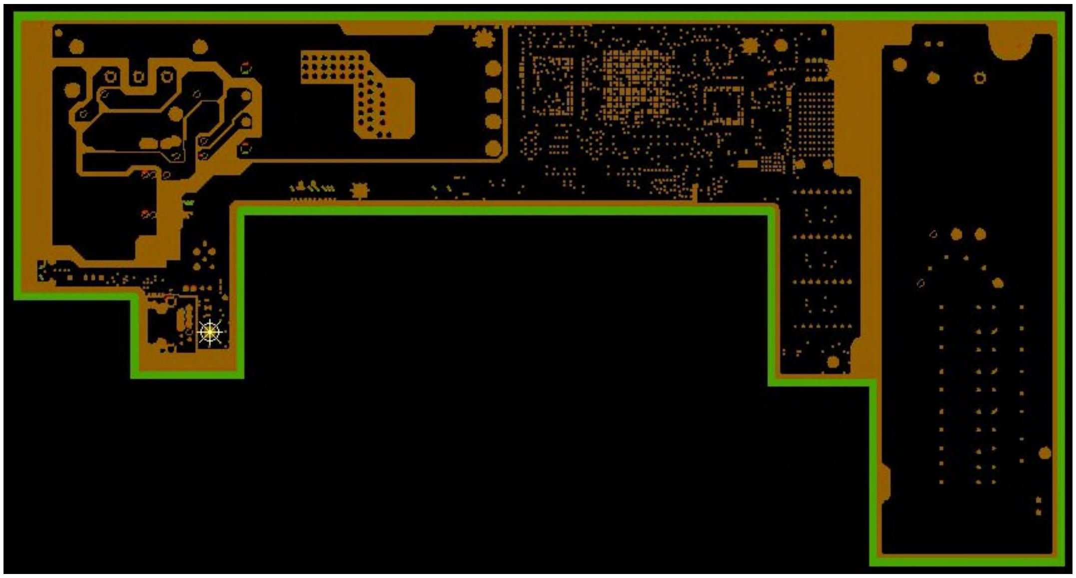
Graphic Layer Compare – PCB Step

Note: Layers contain surfaces, both formats.

IPC-2581B	TGZ	
Silkscreen_top	sst	Layers match
Soldermask_top	smt	Layers match
L11	L11	Discrepancies found*
L10	L10	Layers match
L9	L9	Layers match
L8	L8	Discrepancies found*
L7	L7	Discrepancies found*
L6	L6	Discrepancies found*
L5	L5	Discrepancies found*
L4	L4	Layers match
L3	L3	Layers match
L2	L2	Discrepancies found*
Bottom	Bottom	Layers match
Soldermask_bottom	smb	Layers match
Silkscreen_bottom	ssb	Layers match
Ipc2581drill_1-12	drill	Layers match with exception, see drill section
Outline	outline	Layers match
Filmmasktop	filmmasktop	Layers match with exception – TZG uses r0 feature size
Tent_via_top	tent_via_top	Layers match with exception – TZG uses r0 feature size
Brdot1	brdot1	Layers match
V_score		0 features
Dimensions		0 features
Osp_top		0 features
Ops_bottom		0 features

*Ground layers all have the following discrepancy: The TGZ data has a slightly larger rout clearance. Layers affected: l11-gnd, l8-gnd, l7-gnd, l6-pwr, l5-gnd, l2-gnd.

Note: Upon compare, the following layers from both formats are identical: rout, outline, outline+1, outline.art.



Above snapshot is an overlay of ground layers from each format. Green area around the outermost border is reported discrepancy.

Drill Tool Compare (PCB)

Drill Tool Discrepancies: Tool number, Drill Size and Drill Des and count.

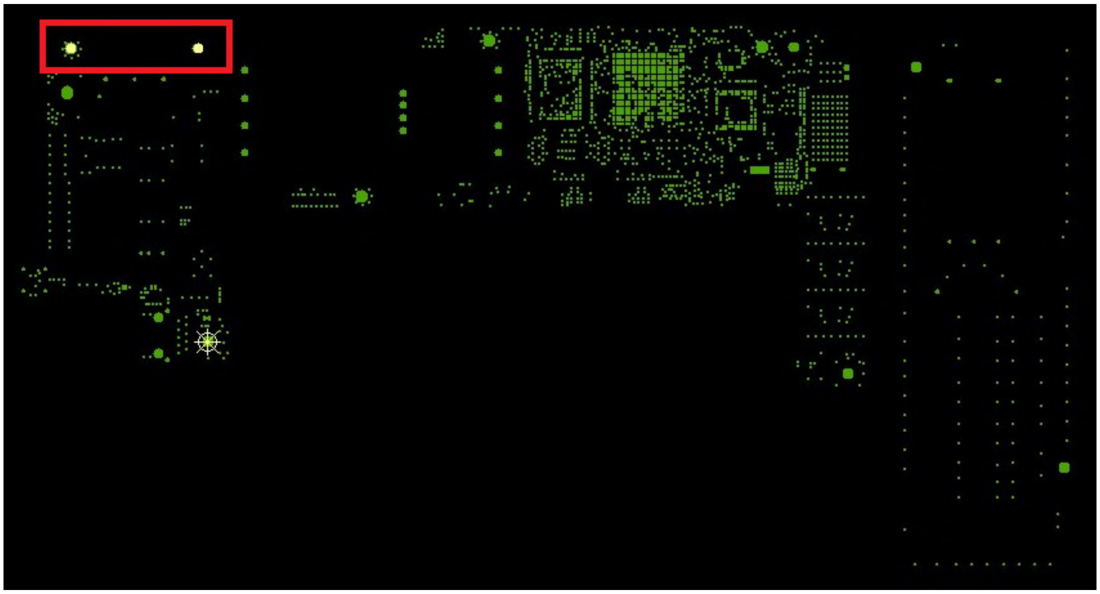
IPC-2581B

Tool	Count	Slot Len(ml)	Type	Finish Size(ml)	+Tol (ml)	-Tol (ml)	Drill Size(ml)
T01	1516		Via	5.906	3.15	5.906	5.906
T02	167		Via	11.811	3.15	11.811	11.811
T03	5		NPlated	165.354	3.15	3.15	165.354
T04	6		NPlated	141.732	3.15	3.15	141.732
T05	4		NPlated	62.992	3.15	3.15	62.992
T06	12		Plated	95.669	3.15	3.15	95.669
T07	10		Plated	47.244	3.15	3.15	47.244
T08	4		Plated	31.496	3.15	3.15	31.496
T09	42		Plated	35.433	3.15	3.15	35.433
T10	5		Plated	62.992	3.15	3.15	62.992
T11	2		NPlated	125.984	3.15	3.15	125.984
T12	8		Plated	40.354	3.15	3.15	40.354
T13	4		NPlated	47.244	3.15	3.15	47.244
T14	17		Plated	53.15	3.15	3.15	53.15
T15	4		NPlated	31.496	3.15	3.15	31.496
T16	28		Plated	11.811	3.15	11.811	11.811
T17	2		Plated	74.803	3.15	3.15	74.803
T18	4		Plated	51.181	3.15	3.15	51.181
T19	100		Plated	23.622	1.969	1.969	23.622
T20	2		NPlated	78.74	1.969	1.969	78.74
T21	2		NPlated	86.614	3.15	3.15	86.614
T22	2		NPlated	133.858	3.15	3.15	133.858
Total	1946						

TGZ

Tool	Count	Slot Len(ml)	Type	Finish Size(ml)	+Tol (ml)	-Tol (ml)	Drill Size(ml)	Drill Des
T01	1516		Via	5.906	3.15	5.906	9.843	1p018bg
T02	28		Plated	11.811	3.15	11.811	15.748	1p033rn
T03	167		Via	11.811	3.15	11.811	15.748	1p033rn
T04	100		Plated	23.622	1.969	1.969	27.559	1p060rn
T05	4		NPlated	31.496	3.15	3.15	31.496	1n080
T06	4		Plated	31.496	3.15	3.15	35.433	1p080rn
T07	42		Plated	35.433	3.15	3.15	39.37	1p090rn
T08	8		Plated	40.354	3.15	3.15	44.291	1p102rn
T09	4		NPlated	47.244	3.15	3.15	47.244	1n120
T10	10		Plated	47.244	3.15	3.15	51.181	1p120rn
T11	4		Plated	51.181	3.15	3.15	55.118	1p130rn
T12	17		Plated	53.15	3.15	3.15	57.087	1p135rn
T13	4		NPlated	62.992	3.15	3.15	62.992	1n160
T14	5		Plated	62.992	3.15	3.15	66.929	1p160rn
T15	2		Plated	74.803	3.15	3.15	78.74	1p190rn
T16	2		NPlated	78.74	1.969	1.969	78.74	1n200
T17	2		NPlated	86.614	3.15	3.15	86.614	1n220
T18	12		Plated	95.669	3.15	3.15	99.606	1p243rn
T19	2		NPlated	125.984	3.15	3.15	125.984	1n320
T21	6		NPlated	141.732	3.15	3.15	141.732	1n360
T22	5		NPlated	165.354	3.15	3.15	165.354	1n420
Total	1944							

IPC-2581B – ipc2581drill_1-12 has double hits, 2 large holeshighlighted (see (TWS_PM030602).



Graphic Layer Compare – Panel Step

See section 3.2.8 for layer compare list.

All layers of TGZ data have identification outside the panel profile, missing on IPC-2581B data.

Silkscreen Top/Bottom – IPC-2581B data missing corners and identification seen on TGZ data outside the panel profile.

Brdot1 layers match with exception – IPC-2581B uses r0 feature size.

Top and bottom layer identification on the panel, matches, but uses different fonts/size.

Panel Tooling Holes – minor variations noted.

IPC-2581B

Tool	Count	Slot Len(ml)	Type	Finish Size(ml)
T01	4		NPlated	102.362
T02	14		NPlated	165.354
T03	6		NPlated	141.732
Total	24			

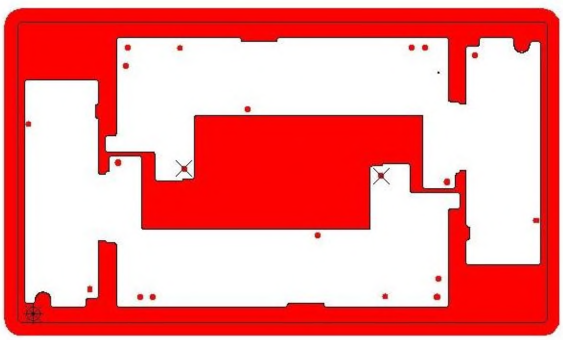
TGZ

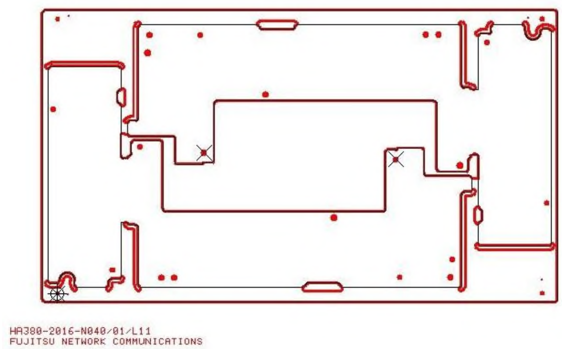
Tool	Count	Slot Len(ml)	Type	Finish Size(ml)
T01	4		NPlated	102.402
T02	6		NPlated	141.732
T03	14		NPlated	165.354
Total	24			

6. Power Ground Layers – All grounds show the same discrepancies around the PCB and Panel boarders. The data is not affected within the PCB itself.

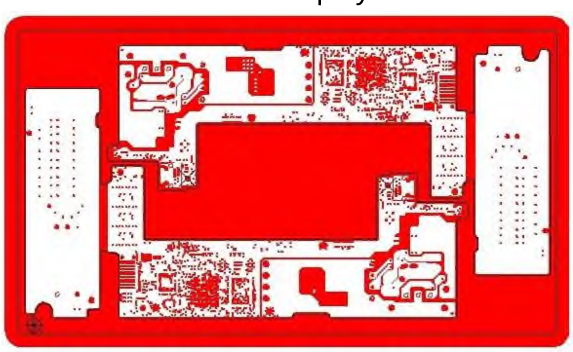
IPC-2581B TGZ

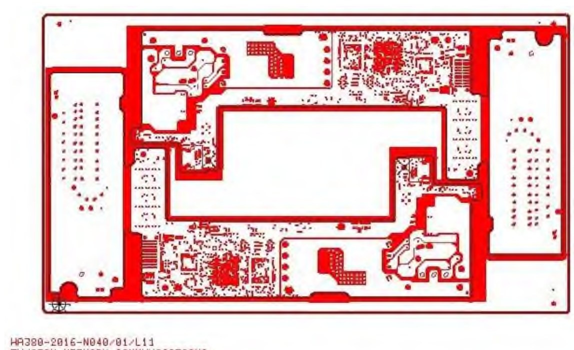
Panel without PCB data displayed





Panel with PCB data displayed





Note: From a CAM standpoint, the IPC-2581B data is correct and preferred, requiring little to no additional workup.

These discrepancies generated a technical query to the OEM. The results are as follows:

1. Layer by layer marking is a legacy practice as plotted layers needed to be identified.
2. Corner markings are a legacy practice and used for aligning plotted files on a light table.

3 & 4. Observations only, differences are noted

5. The OEM has a legacy process that was a work around for producing TGZ data that can now be eliminated.
6. The TGZ data is wrong and the IPC-2581B data is correct.

3.2.9 Discussion/Results/Summary

The future-state IPC-2581B file for the Lockheed Martin design was the first time Lockheed Martin had produced IPC-2581B data from Zuken, and the first time Sanmina had imported IPC-2581B data exported from Zuken. Though there were a number of discrepancies noted between the present-state Gerber and future-state IPC-2581B data, the bare-board fabrication of the Lockheed Martin design was successful with only minimal support from the present-state fabrication drawing.

The future-state IPC-2581B file from Fujitsu incorporated layers with additional requirements and specifications that Gerber and ODB++ TGZ does not support. The additional layers added value to the fabrication process. Typically, this information would be provided with a drawing that the fabricator would have print or plot. The product engineer would need to read, interpret, and re-enter this information into their engineering system.

Having this additional information embedded in IPC-2581B eliminates time associated with manual data entry, and the risk of introducing errors in interpretation. For example, the v-score information., impedance constraints, surface finish as areas defined on a layer, etc. can be directly imported from the job. This is a tremendous help to the fabricator.

The objective to reduce fabrication cycle time by 25% was achieved.

The value with IPC-2581B

- Reduced time to quote
- Reduced time for Pre-CAM
- Two-way format for Stackups
- Reduced Engineering time
- Standard format for first article and Inspection reports
- Cycle time reduction
- Elimination of mistakes
- Cost savings

3.2.10 Metrics

Metric	Present-state	Future-state	Project Goal	Comment
PCB Fabrication				
Differences/discrepancies between existing fab files and IPC-2581B file	Present-state is baseline.	1. Duplicated pads 2. Drills weren't separated into plated and non-plated 3. extra blank junk layers 4. Missing features		There is a direct dependency on the CAD software to produce the proper IPC-2581B file.
PCB Fabrication Preparation	4 hour	3 hour	Reduction of 25% compared to present-state	This future-state is dependent on InSight replacing Genesis for pre-CAM tool.
# of PCB Manufacture SW vendor changes (bugs)	N/A present-state is baseline	1. B-08080 Support input of drill tolerance from IPC2581B - InSight - Resolved - V2.0 2. CASE 00022486: IPC 2581B Translation Error - InSight - Resolved V2.02 3. CASE 00023035: unable to translate IPC-2581-B in InSight - Resolved V2.03 4. Case 00024772 : IPC2581B S&R Misaligned" was fixed in v2.03 - InSight - Resolved V2.03		Each bug was resolved as noted

3.3 Lockheed Martin - MFC Dallas

3.3.1 Objective

Receive present-state and future-state data for the Lockheed Martin Design, compare the time to process present-state file set and future-state file for fabrication, compare data sets for identical fabrication outcome, then fabricate the Lockheed Martin design using IPC-2581B data.

3.3.2 Materials

Design:

- Present-state data: zip file with Gerber 274x photoplots, IPC-356D netlist file, Excellon drill file, fabrication drawing with stackup definition, etc.
- Future-state data: IPC-2581B file
- Isola 370HR

Software:

- Present-state: Frontline Genesis version 10.02
- Future-state: Frontline InCAM version v4.00SP1

3.3.3 Tools

Present-state:

▼ Partner	▼ Location		Fabrication						
		Mfg Flow ▶	PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
	MFC - Dallas, TX	Mfg Equipment Vendor		Orbotech	Orbotech	MicroCraft EMMA	Excellon	Hitachi	Excellon Corbra
		SW Vendor	Frontline Genesis 2000 v10	Frontline Genesis 2000 v10	Frontline Genesis 2000 v10	MicroCraft 2 Software Apps	Frontline Genesis 2000 v10	Frontline Genesis 2000 v10	Frontline Genesis 2000 v10

Future-state:

▼ Partner	▼ Location		Fabrication						
		Mfg Flow ▶	PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill
	MFC - Dallas, TX	Mfg Equipment Vendor		Orbotech	Orbotech	MicroCraft EMMA	Excellon	Hitachi	Excellon Corbra
		SW Vendor	Frontline Genesis 2000 v10.3 InCAM v4.1	Frontline Genesis 2000 v10.3 InCAM v4.1	Frontline Genesis 2000 v10.3 InCAM v4.1	MicroCraft 2 Software Apps	Frontline Genesis 2000 v10.3 InCAM v4.1	Frontline Genesis 2000 v10.3 InCAM v4.1	Frontline Genesis 2000 v10.3 InCAM v4.1

3.3.4 **Methodology**

Frontline Genesis version 10.02 was the present-state CAM software tool in use at the beginning of the project. However, it only supported revision A of IPC-2581. The team wanted to utilize IPC-2581 revision B, so Frontline InCAM version v4.00SP1 was acquired to provide that capability.

The present-state at MFC Dallas utilizes the output of the Gerber RS 274X data from Cadence Allegro for PWB fabrication. The data is imported into InCAM to perform the various task to generate soft tooling programs which can communicate directly with the necessary shop equipment. This includes LDI (Laser Direct Imaging), CNC Drilling and Laser Drilling, CNC Profile routing, AOI (Automated Optical Inspection), Artwork for Solder Mask, Inkjet Nomenclature and Serialization and Electrical Test. The various outputs cover the major equipment sets required in printed board fabrication.

3.3.5 **Present-state**

Design Review Process

In the present-state process prior to the release of the fabrication drawing, the manufacturing CAM operator will perform a detailed drawing review and design for manufacturing (DFM) analysis in Frontline Genesis to feedback to the engineering design team. The following files are required as inputs:

- Gerber Files in 274X Format
- NC-Drill Files
- IPC-D-356A netlist file
- Fabrication Drawing in PDF format

Prior to performing the DFM analysis the CAM operator will perform the following steps in Frontline Genesis:

- Import into Genesis the Gerber Files and NC-Drill Files
- Rename the layers
- Assign layer types
- Assign drills to proper layers
- Delete off board geometries like the title block
- Drill compensation
- Etch compensation
- Setup DFM parameters per the fabrication requirements and manufacturing capabilities

After the initial setup in Frontline Genesis the CAM operator will run the analysis and do a fabrication drawing review. After the review a list of action items is generated and given to the designers in which they can accept or reject each line item of identified issues. For the case that an action item is rejected, the design engineers must take an exception to the identified problem with the understanding that the build is at risk because of the issues that were left unresolved. A DFM analysis and fabrication drawing review may be iterated as often as needed until design engineering and manufacturing engineering agree to proceed forward with the build.

CAM

In the present-state, after the release of the fabrication drawing and data, the manufacturing CAM operator will perform another round of reviewing the drawing and DFM analysis as detailed above in the Design Review Process.

After reviewing the data, the CAM operator will do the following steps during CAM:

- Run the coupon generation scripts

- Create impedance coupons
- Perform a netlist compare between the IPC-D-356A netlist and the Gerber Files
- Define the board Stackup
- Do panel layout setup
- Step and repeat the edited one-up to create the panel array
- Add features to the panel like tooling holes, vent patterns, coupons, etc.
- Output the manufacturing and test files

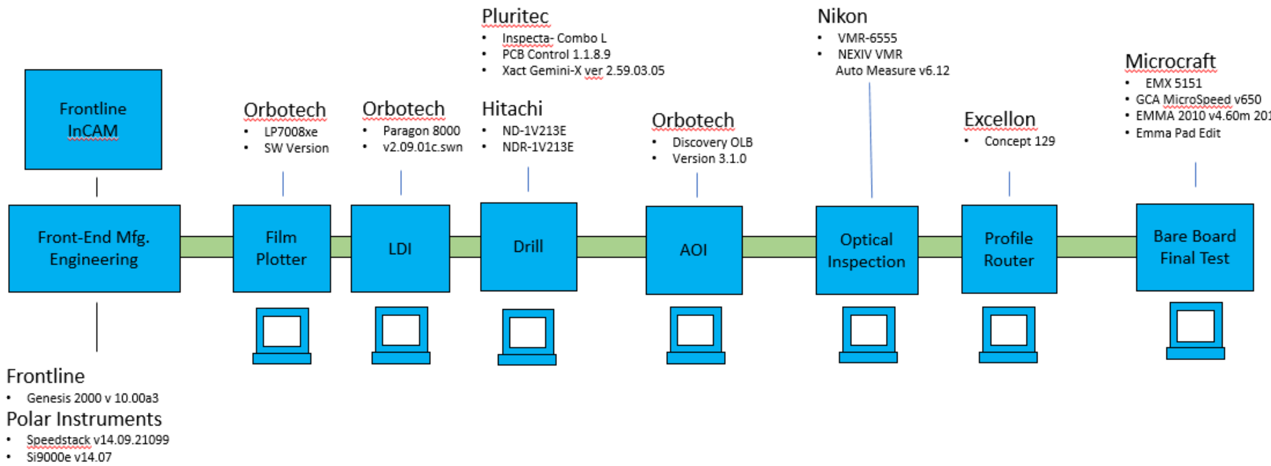


Figure 3-5: Lockheed Martin MFC PWB process flow

3.3.6 **Future-state**

<u>Design Review Process</u>

In the future-state process prior to the release of the fabrication drawing and data for fabrication, the manufacturing CAM operator will perform a detailed drawing review and design for manufacturing (DFM) analysis in Frontline Genesis and Frontline InCAM to feedback to the engineering design team. The following files are required as inputs:

- IPC-2581B file
- Fabrication Drawing in PDF format

Prior to performing the DFM analysis the CAM operator will perform the following steps in Frontline Genesis:

- Import into Genesis the IPC-2581B file
- Delete off board geometries like the title block
- Drill compensation
- Etch compensation
- Setup DFM parameters per the fabrication requirements and manufacturing capabilities

<u>CAM</u>

In the future-state, after the release of the fabrication drawing and data, the manufacturing CAM operator will perform another round of reviewing the drawing and DFM analysis as detailed above in the Design Review Process.

After reviewing the data, the CAM operator will do the following steps during CAM:

- Run the coupon generation scripts
- Create impedance coupons
- Perform a netlist compare between the IPC-2581B netlist and the design data in IPC-2581B
- Define the board Stackup
- Do panel layout setup
- Step and repeat the edited one-up to create the panel array
- Add features to the panel like tooling holes, vent patterns, coupons, etc.
- Output the manufacturing and test files

3.3.7 Data Observations

The CAM operator reported for following issues when working with IPC-2581B. Problem reports were submitted and noted below along with any resolutions.

1) Problem Report 19 (MFC_PM062601): IPC-2581B read in many layers on input (249). Only 9 of the layers had actual board data on them.
2) Data file size difference is minimal (366k vs. 278k). IPC-2581B is the smaller of the two.
3) Problem Report 21 (MFC_PM081601): Gerber data separated non-plated and plated drills in logical order. No logic or valid separation of IPC-2581B drill data. The issue was with the InCAM software and not the Zuken IPC-2581B file. The latest version of InCAM resolved this issue and InCAM can now separate the plated/non-plated holes.
4) Data appears to be visually identical between both formats
5) Problem Report 17 (MFC_PM050901): The IPC-2581B data had duplicate pads on top of each other. Below are the pad feature histories compare showing the duplicate pads.

```
a. Soldermask top        (Gerber=724,     IPC-2581B =1284)
b. Layer 1               (Gerber=1530,    IPC-2581B =2208)
c. Layer 2               (Gerber=806,     IPC-2581B =875)
d. Layer 3               (Gerber=971,     IPC-2581B =1064)
e. Layer 4               (Gerber=591,     IPC-2581B =853)
f. Soldermask bottom     (Gerber=370,     IPC-2581B =588)
g. Total CAM data features for all layers:
                         (Gerber =4992,   IPC-2581B =6872)
```

6) Problem Report 31 (MFC_PM091301): The pads read in with a feature attribute called “pad usage” and with the value of “toeprint”. This value doesn’t appear in the IPC-2581B and currently serves no purpose for fabrication.
7) Problem Report 32 (MFC_PM091302): On the soldermask layers the vias were defined as surfaces instead of pads. The data needed to be converted from surfaces to pads to enable easier editing if the via soldermask needed to be either grown or shrunk. For this project we had to select and group the vias in the project to globally edit them.

3.3.8 Discussion

Metrics, Time Comparison: Overview of working with IPC-2581B.

1) Read-in time (Gerber 274X) / (IPC-2581B) – No significant difference.
2) Problem Report 19 (MFC_PM062601): Layer organization in CAM after read-in – IPC-2581B data had 200+ more layers than Gerber. Needed to look at each layer to determine if it was needed to build job - 5-10 minutes longer for IPC-2581B.
3) Layer editing for manufacturability (extra editing required to use data - 20+ minutes.

4) Layer feature duplication was noticed.
5) Surface features used on standard via pad sizes.
6) Currently there doesn't exist bi-directional exchange with the stackup. InCAM doesn't currently support IPC-2581B export of stackup information.

3.3.9 Conclusion

- The IPC-2581B data and the Gerber 274X data set match to within .0002 inches. The variances are due to a difference in number of decimal places used (rounding) in each data set. The differences are not significant within normal PWB fabrication process tolerances.
- The IPC-2581B data has duplicated pads on almost all layers. The extra data does not directly interfere with PWB manufacturing. Zuken will correct this in a future release.
- The IPC-2581B data imports 240 layers into the CAM tool, most of which are empty or unrelated to printed wiring board manufacturing. Zuken will correct this in a future release.
- The issues above prevented LM-MFC from achieving its stated objective of reducing fabrication cycle time by 25%, however, once the issues with are corrected it is expected the objective will be achieved.
- The main benefit of IPC-2581B data is simplified data transfer and clearer communication of design intent which should result in reduction of errors and savings in fabrication cycle time

3.3.10 Metrics

Metric	Present-state	Future-state	Project Goal	Comment
PCB Fabrication				
Differences/discrepancies between existing fab files and IPC-2581B file	N/A Present-state is baseline.	1. Duplicated pads 2. Drills weren't separated into plated and non-plated 3. 249 extra blank junk layers	0	Need to address duplicate pads and extra layers. An upgrade to Frontline Genesis and InCAM resolved the PTH/NPTH issue.
PCB Fabrication Preparation	30 minutes	1 hour	Reduction of 25% compared to present-state	Did not meet goals for time reduction. However, once issues are resolved, it is anticipated that the goal will be met .
# of PCB Manufacture SW vendor changes (bugs)	N/A present-state is baseline	An upgrade to Frontline Genesis v10.3 required	0	Additional support and scripts unnecessary with upgrade

4 Assembly

Three PCBs were assembled for this project: two designs from Fujitsu and one from Lockheed Martin.

The Lockheed Martin design was categorized as easy with respect to assembly complexity with a total of 110 SMT components and the thru-hole parts were not populated on these PWBs. LM MFC-Dallas, LM Space-Denver, LM RMS-Owego, Rochester Institute of Technology and Sanmina each assembled the Lockheed Martin design. Fujitsu assembled their own designs which were significantly higher in assembly complexity then the Lockheed Marti design.

The Rochester Institute of Technology's (RIT) scope was to analyze assembly metrics along with the development of a college-level student lab for workforce training. RIT focused on generating an assembly program with IPC-2581B in Siemens PLM UniCam and ASM Siplace Pro software for their ASM SX2 pick-and-place machine. Their work included a comparison of assembly programming times for two different manufacturing engineers.

4.1 Objective

The purpose of the assembly phase was to compare present-state process required to generate SMT machine program files versus the future-state process when using the IPC-2581B data for machine program generation. The PWBs were then assembled using the programs generated using IPC-2581B data. Issues encountered during assembly were documented in problem reports.

Table 4-1 PCB Assembly Performance Improvement Metrics

Table 4-1: PCB Assembly Performance Improvement Metrics			
Metric	**Present-state**	**Future-state**	**Project Goal**
Difference/discrepancies between existing assembly files and IPC-2581B	N/A present-state is baseline	Track # of differences and discrepancies found	0
PCB Assembly Preparation	Track # of hours needed to setup for PCB assembly using existing files	Track # of hours needed to setup for PCB Assembly using IPC-2581B	Reduction of 25% compared to present-state
Assembly equipment SW vendor Changes	Track # SW changes required to correctly input/use existing files for PCB Assembly	Track # SW changes required to correctly input/use IPC-2581B for PCB assembly	0

4.2 LM MFC-Dallas

Detailed below are the materials, equipment and methodology used to assemble the Lockheed Martin design at LM MFC - Dallas. Included are the present-state and future-state assembly flows, the data collected from the assembly prep cycle-time for both the present-state and future-state flows, and a summary of the results.

4.2.1 Materials

- Lockheed Martin present-state files in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B format
- Siemen's UniCAM software v11

- Access database software
- Solder stencil
- Lockheed Martin design SMT components
- Aegis Circuit CAM v7.7.16.0

4.2.2 Equipment

- MyData Pick and Place Machine

4.2.3 Tools

Present-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
in	MFC - Dallas, TX	Mfg Equipment Vendor	Stentech	MyData	Kho-Young	
		SW Vendor	CAD/Gerber	MyCenter - Aegis v7.7.16.0	EPM SW by Smart Vision Corp. (Unicam)	

Future-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
in	MFC - Dallas, TX	Mfg Equipment Vendor	Stentech	MyData	Kho-Young	
		SW Vendor	Wise VisualCAM Stencils	Siemens Unicam v11.1 Aegis v7.7.16.0	Siemens Unicam v11.1 Aegis v7.7.16.0	

4.2.4 Methodology

The following methodology describes the process for generating machine files using present-state versus using UniCAM for the future-state to auto-generate files for pick and place.

4.2.5 Present-state

Traditionally the present-state SMT assembly preparation is performed using a script created by Aegis to translate Cadence Allegro design data to several CAD data files that can be used as input into the Aegis Circuit CAM software for assembly and test. The translated files contain symbol footprint geometries, BOM information, component rotation, component location, reference designation, netlist information, conductor traces, and pin pad information.

Stencil: The present-state stencils are created by using the solder paste Gerber file. The solder stencil openings in the solder paste layer of the Gerber file are one-to-one to the actual copper pin pad geometries so a new Gerber file with proper reduction of the stencil openings must be generated. The specification for solder stencil opening reduction has been predetermined and agreed upon by LM MFC- Dallas and its stencil vendor. The stencil vendor uses the LM MFC-Dallas solder paste Gerber layer and assembly drawing from the LM-MFC supplied input. The stencil vendor then applies the reduction formula, creates new solder stencil Gerber files, and creates the new stencil screen.

Aegis Circuit CAM Setup: Below are the step-by-step instructions for creating the Pick and Place files to be imported into the Mydata Pick and Place machine.

1. Get the circuit CAM file (ccam.cad) from PLM.
2. Get the Excel BOM from PLM.
3. Use the excel spreadsheet macro program to convert the excel BOM from PLM to contain only part numbers and reference designators. The excel BOM contains information not required for assembly and therefore must be removed before inputting it into the Aegis Circuit CAM software.

4. Save the converted BOM file as a text file.
5. Copy the CCAM.cad file and converted text BOM onto the computer connected to the pick and place machine.
6. The following steps are for doing setup on the Aegis Circuit CAM software:
7. Start new project
8. Import CAD file
9. Import Gerber layers “assembly top silkscreen”, “top assembly bottom” and “silkscreen bottom”
10. Manually delete thru-hole parts, CAD objects that are not components, and local fiducials
11. Setup/Import BOM
12. Flag the “do not install” parts since they exist on the board but not in the BOM.
13. Identify the DNI (do not install) parts and manually delete those parts in the edit components window.
14. Assign the origin of the board by using one fiducial. Generally, these are the bottom-left corner fiducials on the board.
15. Redefine fiducial properties from “component” to “fiducial”
16. Do this for both sides of the PCB. The first fiducial is the origin and subsequent fiducials are skew points.
17. Manually assign polarities to parts. The software only identifies pin 1 based on CAD data, however the CAD data could be wrong especially for components that have multiple pin numbering subsets, for diodes, and for tantalum capacitors. Manually review and match up according to the silkscreen which requires the designer to not make a mistake in placing the silkscreen manually on the board. Sometimes there is an issue if the assembly layer doesn’t contain polarity because it was instead in copper.
18. Next “Edit model point assignments”. This assigns parts to either the top or bottom of the circuit board (not long to do since it is already filtered per CAD data).
19. Check angle of the parts if they are at 0, 90, 180, 270, or other non-standard angles
20. Program machine to understand what orientation the component is within the reel
21. If mismatch between CAD and tape-reel, adjust the CAD data at the machine. This could be a potential issue on revisions, because revisions can overwrite the circuit CAM data such that orientation adjustments made on the machine regarding orientation are lost.
22. Assign the CCA part number to the layout field and the PCB field
23. Assign the fiducial geometry in Circuit CAM based upon previous history or manual measurement on the physical PWB.
24. Export the Pick and Place file from the Aegis Circuit CAM software to the MyData machine.

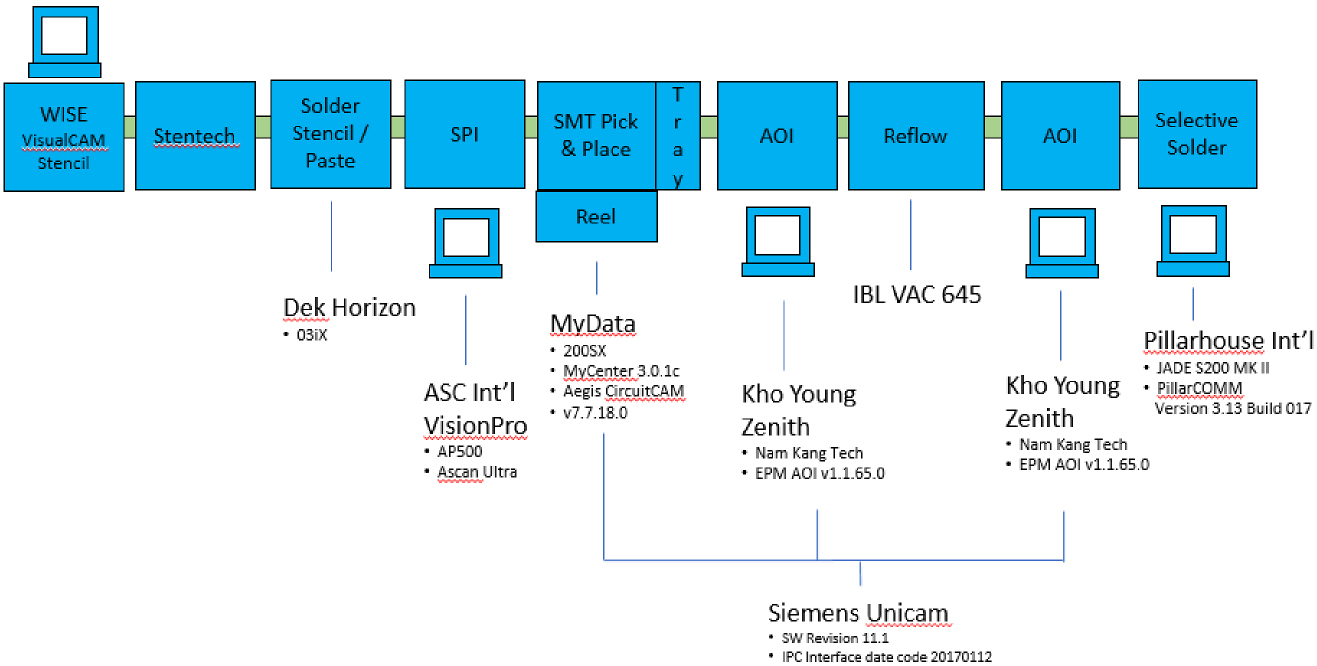


Figure 4-1: Lockheed Martin MFC PWB process flow

4.2.6 Future-state

For the future-state, Siemens PLM UniCAM software was used to generate the MyData Pick and Place machine files. Below are the step-by-step instructions for creating the MyData machine program.

Stencil: The stencil was created by sending the stencil vendor the IPC-2581B data. The stencil vendor already had the LM MFC- Dallas solder stencil opening reduction specification. The stencil vendor imported the IPC-2581 file into their Wise VisualCAM Stencils software application, optimized the stencil openings, and produced the solder stencil.

Siemens PLM UniCAM setup: Below are the step-by-step instructions for creating the Pick and Place files to be imported into the MyData Pick and Place machine.

1. Create a “New Job Base Directory” under “Global Profile”
2. Create a new “Job” and import in IPC-2581B data
3. Open View
4. Identify the fiducials. The fiducials were not identified properly in the IPC-2581B file and a work-around was required.
5. Setup the “insert class” for the components as either SMT or TH. The IPC-2581B data already properly identifies “Mounting technology” as either SMT or TH so setting up the insert class as either SMT or TH is extra effort that isn’t required for LM-MFC because we do not have multiple machine lines.
6. Test points are also identified as SMT, so we also need to set them as “do-not-install parts”.
7. Associate the correct MyData library shape to the CAD data library. This was a manual process and finding the correct MyData library shape can be difficult. Primary issue was that we were not able to connect the UniCAM software to the MyData machine. This presented many opportunities for error as will be discussed in the next section.
8. Export the MyData machine Pick and Place file.

4.2.7 Data Observation

LM MFC- Dallas Process: This demonstration project highlighted several opportunities for LM MFC – Dallas to review their current processes towards their goal of rolling IPC-2581 out to production.

Zuken: Fiducials were not uniquely identified in the IPC-2581B file as specified in the standard. This issue will be addressed in a future release of Zuken CR8000. Another issue was the component body outline. In the IPC-2581B file, the "CompArea-A" layer was used to outline the extent of the part including the component footprint area. The layer called "Assembly Front" layer should have been used instead. While this issue did not prevent LM-MFC from assembling the PCB, it did make it difficult for the UniCAM software to be tool agnostic since the current component body outline didn't exactly match the actual part.

UniCAM: Fewer steps were required in the future-state flow as compared to the present-state methodology. Since IPC-2581B already contains BOM information, the steps to convert and format the BOM were no longer required. This saved time and reduced the potential for introducing human error through manual manipulation. However, since this was the first time that LM-MFC had used the UniCAM software and IPC-2581B data, there was a learning curve. With time and training this will be overcome allowing the actual benefits and manufacturing cycle-time efficiencies to be fully quantified in terms of cost and schedule savings.

As mentioned above, the UniCAM software couldn't use the IPC-2581B data to create machine files that are machine agnostic due, in part, to the geometries exported by the ECAD software. IPC-2581B supports the information that is necessary to automatically create and/or associate the MyData library shape, but this relies on the ability to extract the right shape information and/or the specific part number and footprint name references. Once this process issue is resolved it will eliminate the manual step of associating the MyData library shape to the CAD library part.

Below are some examples of issues that were encountered during assembly that can be directly attributed to this manual step:

1. The TO-252 package had problems being placed by the pick and place machine. The nozzle would pick up the part, error out and then dump the component into a separate tray because it couldn't place it. When the MyData component packages were initially assigned to the UniCAM CAD layout, the process engineer manually tried to find the best fit. Unfortunately, in this case, the package that was picked wasn't correct. Considerable amount of time was spent on the MyData machine to try to find the best fit for the TO-252 package. It took 4 iterations of choosing existing packages in the MyData library before the MyData would place the component on the PWB. The process engineer also had to pull up the datasheet on his cell phone to use as a guide for finding the right MyData component part package. Reasons for failures on the MyData were the result of the component library part either having the wrong pitch, the wrong component height, or the wrong body to lead distance.
2. U3 (MOCD207R2M) is a standard S08 package, however it wasn't placed because the MyData library part that was picked for it had the wrong height information. We had to choose a different package from the MyData library that contained the right component height information.
3. Two parts had to be manually shifted by an operator after pick and place because they were placed off center (597D476X9050Z2T and the TO-252). Again, the originally chosen MyData library package didn't meet the IPC-2581B package data.

MyData Pick and Place Machine: Below are the part numbers of components that had to be hand placed due to geometry of the package not being conducive to the MyData pick and place:

- 84XR10KLFTR
- 450-1762-1-ND

- G3B15AP-S-YA
- MS12LNW03E-ND
- 563-1319-6-ND

4.3 LM Space-Denver

The Lockheed Martin design was assembled at the LM Space-Denver assembly shop. Detailed below are the materials that were used to assemble the design, the equipment in the assembly shop that was used, the methodology for assembling both the present-state and future-state files, the data that was collected from assembly both the present-state and future-state, and a summary of the results.

4.3.1 Materials

- Lockheed Martin present-state design files exported in CAD and ,csv format
- Lockheed Martin future -state design file in IPC-2581B format
- Siemen's UniCAM software
- Access database software
- Koh Young machine software
- Siemens PLM machine software
- Solder stencil
- Lockheed Martin design SMT components

4.3.2 Equipment

- Siemens PLM Siplace X2 pick and place machine, Speedline Momentum stencil printer

4.3.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ▶	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Lockheed Ma	SSC - Denver, CO	Mfg Equipment Vendor	Speedline MPM Momentum *Fineline	ASM Siplace	Koh Young Zenith	
Lockheed Ma	SSC - Denver, CO	SW Vendor	(CAD/ Gerber) AGI can provide solder stencil	Siemens Unicam v11.1	Siemens Unicam v11.1	

Future-state:

Partner ▼	Location ▼	Mfg Flow ▶	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Lockheed Ma	SSC - Denver, CO	Mfg Equipment Vendor	Stentech	ASM Siplace	Koh Young Zenith	
Lockheed Ma	SSC - Denver, CO	SW Vendor	Wise VisualCAM Stencils	Siemens Unicam v11.1	Siemens Unicam v11.1	

4.3.4 Methodology

The following sections describe the process for auto-generating machine files for the pick and Place machine using the present-state files and a proprietary tool compared to using UniCAM for the future-state file.

4.3.5 Present-state

The present-state process is performed using a proprietary Access database tool that converts a pick and place text file to an Excel placement list. This list is then modified to a format that can be imported into the Siemens PLM Siplace Pro Desk software to generate the placement file. The process is described in detail below.

Stencil: Stencil designs are created by the vendor, typically BlueRing Stencils. The stencil Gerber layers are obtained from the PWB data files. They are then sent to the vendor and a pdf of the layout and orientation is sent back for approval. The initial design apertures are one-to-one to the actual pad geometries. These are then reduced for the final design. This is typically a 5% reduction in size.

Placement File Generation: The following process is performed to convert the data provided by engineering into a placement file on the Siemens PLM Siplace X2 machine.

1. The pick and place text file containing reference designator, location, rotation, part number, package, installation side, and technology (PTH or SMT) is obtained from the assembly part number in EPDM.
2. The EBOM is downloaded from data warehouse in Excel format.
3. The pick and place file is uploaded into a proprietary Access database tool that converts the text file to a format usable by the SMT team to program the placement equipment.
4. Prior to use, the data is output to an Excel file and scrubbed to ensure it matches the EBOM. This is necessary as the CAD file is not revised every time the EBOM is updated. Corrections are made and then the Excel file is uploaded back into the Access tool.
5. The final Excel file is modified to match input format of the Siemens PLM Siplace Pro Desk software, including addition of alternates if applicable.
6. Find and add fiducials to SMT parts list.
7. Run BOM versus SMT PL (parts list) comparison.
8. Generate preforms parts list to append to SMT PL (if necessary)
9. Save file as tab delimited and transfer to SMT computer via portable USB device.
10. This file is imported to Siemens PLM ProDesk.
    a. Split SMT PL into top and bottom side files

11. Generate new PWB in ProDesk with PWB x, y, and z dimensions.
12. Attach stencil Gerber layer to PWB.
13. Attach each SMT PL (top and bottom) to the board.
14. Generate a job for assembly
    a. Attach each side of board to the job.
    b. Run optimization function. Optimization generates recipe and setup for each side of the board.

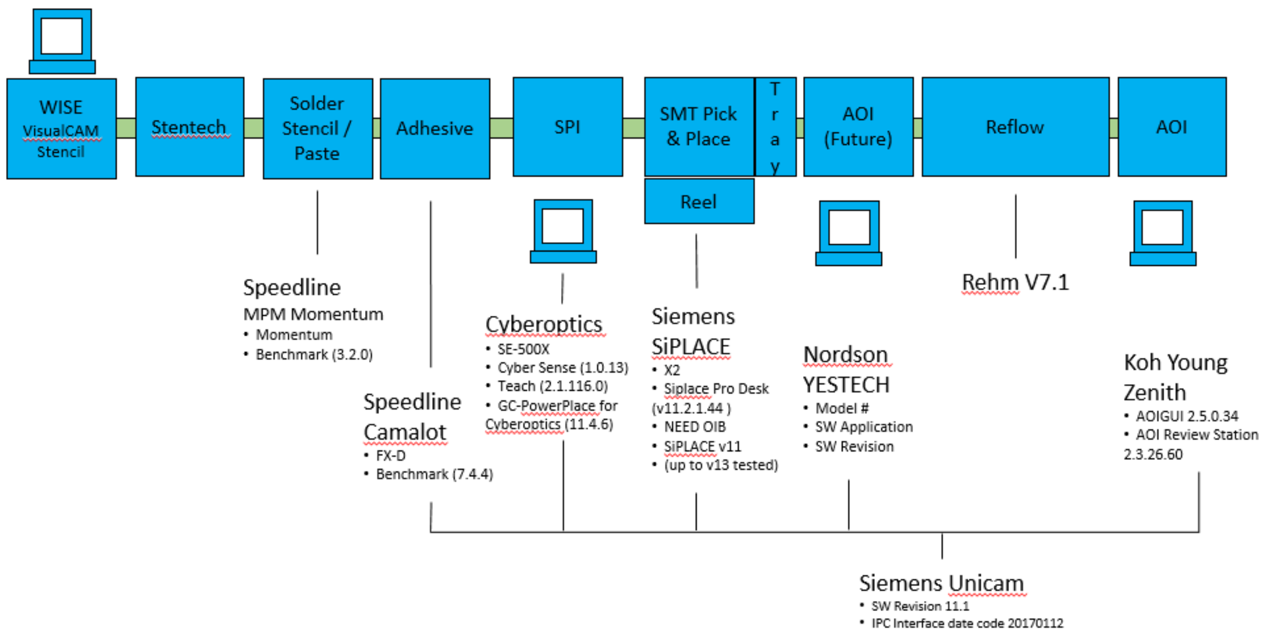


Figure 4-2: Lockheed Martin Space PWB process flow

4.3.6 Future-state

For the future-state, the Siemens PLM UniCAM software was used in to generate the Siemens PLM Siplace machine files. The step-by-step instructions for creating the Siplace machine program are as follows:

Stencil: The stencil was created by Stentech using the IPC-2581B file.

Siemens PLM UniCAM setup step-by-step instructions :

1. Create a “New Job Base Directory” under “Global Profile”
2. Create a new “Job” and import in IPC-2581B data
3. Open View
4. Identify the fiducials. As noted in the problem reports, Zuken CR8000 didn’t identify the fiducials and a workaround was needed. When this is fixed, we will need to check that the fiducials are “enabled” in the UniCAM software so that we can eliminate this manual step.
5. Setup the “insert class” for the components as either SMT or TH. The IPC-2581B file identifies the “Mounting technology” as either SMT or TH so setting up the insert class as either SMT or TH is extra effort that isn’t required for LM-Space as they do not have multiple machine lines.
6. Test points were also identified as SMT but the plan was not to install them, so they were set to be Do-Not-Install parts.

7. Associate the correct Siplace library shape to the CAD data library. This was a manual process and finding the correct Siplace library shape can be difficult. Primary issue is that we were not able to connect the UniCAM software to the Siplace machine. Shape names were copies of the package names. This created issues when exporting and importing the dataset to ProDesk as those shape names did not exist in the library.
8. Export the Siplace machine Pick and Place file(s). Since all components were only on the top of the PWB, a bottom pick and place file was not needed.
9. Import files to ProDesk and generate recipes and setup files.
   a. Components did not come in with shapes. Had to manually create/assign each shape.
   b. PL did not contain fiducials

The PL offset was different than PWB drawing and had to be manually accounted for.

4.3.7 Data Observation

LM-Space Process: Several LM-Space process steps were reduced because the IPC-2581B file contained the BOM and correct layer files. In addition, since the MBOM for the assembly matched the EBOM, no issues were encountered during the BOM import.

Zuken: Fiducials were not uniquely identified in the IPC-2581B file as specified in the standard. This issue will be addressed in a future release of Zuken CR8000. Another issue was found with the component body outline. In the IPC-2581B file, the “CompArea-A” layer was used to outline the extent of the part including the component footprint area. The layer called “Assembly Front” layer should have been used instead. While this issue did not prevent LM Space - Denver from assembling the PCB, it did make it difficult for Siemens PLM to make their UniCAM software tool agnostic since the current component body outline didn’t exactly match the actual part.

UniCAM: Since this was the first time that LM-Space had used the UniCAM software and IPC-2581B data, there was a learning curve. With time and training this will be overcome allowing the actual benefits and manufacturing cycle-time efficiencies to be fully quantified in terms of cost and schedule savings.

As previously mentioned, the UniCAM software couldn’t use the IPC-2581B data to create machine files that can be machine agnostic. If/when this problem is solved, this will eliminate the need to manually associate the Siplace library shape to the CAD library part. For this demonstration project, these shapes were manually created and assigned after the files were imported into ProDesk.

Siplace Pick and Place Machine:During assembly the tape did not peel properly; numerous mis-picks and pick errors were encountered. This was not related to the IPC-2581B file but did cause the placement process to be ineffective. As a result, most parts ended up being hand-placed.

4.4 Lockheed Martin RMS-Owego

The Lockheed Martin design was assembled at the Lockheed Martin RMS-Owego assembly shop. Detailed below are the materials that were used to assemble the Lockheed Martin design at this location, the equipment used during assembly, the methodology for assembling both the present-state and future-state, the data that was collected from assembling both the present-state and future-state processes, and a summary of the results.

4.4.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B format
- Siemen’s UniCAM software
- Access database software

- Solder stencil

4.4.2 Equipment

DEK Horizon 01i Screen Solder Printer, Machine software - v. 09 SP06 P01, Universal Instrument GSM pick and place machine, Machine software – UPS+ 6.8.0.4, Programming – DPO v. 9.1.1.2, Omron Automated Optical Inspection Machine, VT-RNS-6168 v. 7.40A

4.4.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ▶	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
d Martin	RMS - Owego, NY	Mfg Equipment Vendor	Vendor - No RMS capability	Universal Instruments	OMRON BT RNS	
		SW Vendor	Vendor - No RMS capability	Universal UPS Editor	Siemens Unicam v11.1	

Future-state:

Partner ▼	Location ▼	Mfg Flow ▶	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
d Martin	RMS - Owego, NY	Mfg Equipment Vendor	Stentech	Universal Instruments	OMRON BT RNS	
		SW Vendor	Wise VisualCAM Stencils	Siemens Unicam v11.1	Siemens Unicam v11.1	

4.4.4 Methodology

The following sections describe the process used to generate machine files for the pick and place machine using the present-state files compared to using UniCAM for the future-state file.

4.4.5 Present-state

The present-state generation of placement files for the Universal Instruments equipment involves the creation of a library component for each new device. This is followed by generating a placement program on the Universal Instruments pick and place machine. In addition, the electronic bill of material is translated into a manufacturing bill of material which includes additional component information that is relevant to the device for proper orientation and placement. It will also include any additional material that is required for the component such as gasket material, underfill, and adhesives that may not be included in the electronic bill of material.

During this process, the assembly engineer will request the solder stencil data from the PWB CAM operator to have a solder stencil created at an external vendor and use the engineering drawings to create a very detailed assembly routing for the card assembly.

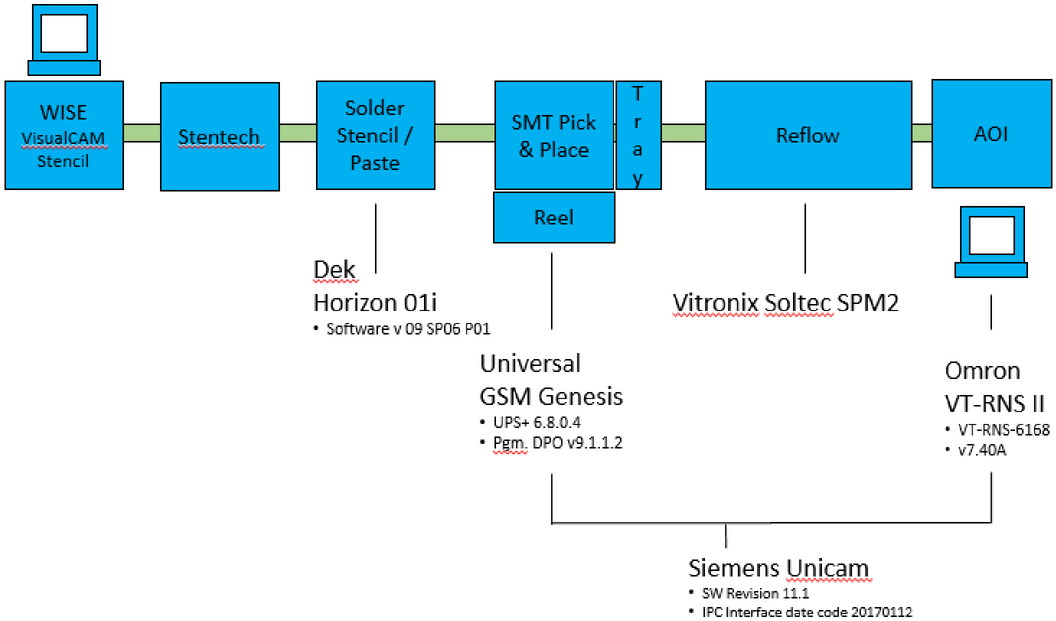


Figure 4-3: Lockheed Martin Space PWB process flow

4.4.6 Future-state

Solder Stencil: The stencil vendor generated the solder stencil with the IPC-2581B file. This resulted in a 33% reduction in time needed to create the stencil. Furthermore, the assembly engineer will have access to the stencil data within the IPC 2581B file so he will not need to rely on the CAM operator to supply the stencil data resulting in additional time saved.

Pick & Place: Because LM-RMS was using the Siemens PLM Unicam software for the first time on this project, there was a learning curve associated with executing the SMT assembly operations. The team was trained, but the several months had elapsed from the training to the actual use of Unicam on this project. The assembly ME read in the IPC-2581B data into the computer supporting the pick and place machine. Key improvement items noted were component orientation and proper x, y location on the PWB. This is key since this often takes up a good deal of time in the present-state process for the assembly engineer.

The Siemens PLM Unicam software setup and programming included the following steps:

1. Create new job directory and job name
2. Identify fiducials. This was done manually as the fiducials were not identified in the IPC-2581 file for this design. This will be resolved in a future release of Zuken CR8000.
3. Define location and orientation for all of the SMT components
4. Transfer program to the placement machine. The component reels were loaded onto the machine.
5. Check the placement machine for any possible interferences or safety concerns and begin our component placement.

4.4.7 Data Observation

Fiducials were not uniquely identified by in the IPC-2581B file as specified in the standard. This issue will be addressed in a future Zuken release.

Placement data for one IC device had to be rotated 90 degrees for proper orientation. The IPC-2581B data turned out to be correct. This issue was related to problems with the programming and placement information in the library file. These were updated for this component.

The creation and maintenance of component libraries that include not only the x and y dimensions, but the “z” height dimension and correct orientation would make placement machine programming more efficient. Additional thought and development with regard to corollary component material (adhesives, underfill, gaskets, etc.) required for successful assembly could be tied to the component library.

4.5 Sanmina

The Lockheed Martin design was assembled at the Sanmina assembly facility. Detailed below are the materials that were used to assemble the Lockheed Martin design, the equipment used during assembly, the methodology for assembling both the present-state and future-state, the data that was collected during assembly, and a summary of the results.

4.5.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B format
- Aegis v7.7.16.0
- Access database software
- Solder stencil
- Lockheed Martin SMT components

4.5.2 Equipment

Fuji AIMEXII

4.5.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Sanmina	San Jose, CA	Mfg Equipment Vendor	Cannot Disclose	AIMEX II AI to A3 modules	Nordson FX Optical Inspection	
		SW Vendor	Aegis v7.7.16.0	Aegis v7.7.16.0	Aegis v7.7.16.0/ Gencad	

Future-state:

Partner ▼	Location ▼	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Sanmina	San Jose, CA	Mfg Equipment Vendor	Cannot Disclose	AIMEX II AI to A3 modules	Nordson FX Optical Inspection	Vitrox
		SW Vendor	Downstream CAM 350	Aegis v7.7.16.0 Aegis Factory Logix 8.171.5	Aegis v7.7.16.0 Aegis Factory Logix 8.171.5	Demille research TestSight Translator

4.5.4 Methodology

The methodology will describe the process of auto-generating machine files for pick and place using the present-state files and Aegis v7.7.16.0 compared to using Aegis v7.7.16.0 for IPC-2581B for the future-state.

4.5.5 **Present-state:**

Stencil: Stencil procurement was outsourced to a qualified stencil vendor and they utilized Downstream CAM 350 software to import the present-state Gerber data and produce the stencils. Sanmina's vendors adjust the "Paste file" based on recommendations from our engineers, as required (i.e. special apertures).

Sanmina currently sends its stencil provider either Gerber files (solder mask, Paste, Silk, copper files) or ODB++. Sanmina's stencil provider has the capability of extracting paste files from ODB.

Input files for Stencils: Gerber package including at minimum (Solder Paste Layer, Solder Mask layer, Silkscreen, Bottom.art and Top.art_copper files, Drill files). Alternatively, Sanmina can also use ODB++.

Pick & Place:

- Input files for Pick and Place:
    - ODB++ and Excel BOM or
    - ASCII CAD files or
    - Gerber package + Centroid file + BOM

The advantage of ODB++ or CAD files is that the component layer is included and Sanmina's software can translate or generate library shape files faster. For Gerber + Centroid files, one must create shape and vision data files manually or directly teach the part on the machine.

Steps to create SMT machine program to feed into Fuji AIMEXII:

1. BOM cleanup and Excel BOM manipulation
   Time to BOM cleanup: Minimum 30 min. Max. 2hr Nominal: 1hr
   Time for Lockheed project: 30 min.
2. BOM and CAD merge/Reading in Centroid file + Gerber. Import BOM and ODB or .ASC cad file into Aegis. Instead of the ODB++ file, Gerbers and centroid files can be used. However, the output file will be missing component type/outline/pin data. For SMT programming not only is the centroid of the body needed; the number of pins, the outline dimension of the component and the centroid of each pin is also needed. In the absence of the component data, the SMT program will be transmitted to the line and every line item needs to be taught on the line.
   Time to import BOM/ODB++ (or equivalent) in Aegis + data manipulation
   Merge and verification: 10 min.
3. Fiducial identification: 5 min.
4. Export output of Aegis into Fuji Flexa
   Time to export output into Flexa: 15 min for Lockheed project
   A higher part count, more complex PCBA may take 30 min – 1 hr
5. Current state: Do not install parts
   Those locations which are do-not-install have no "Part number assignment" in the Fuji Flexa. We highlight those "No Loads" or "Without Part Number" in the program and setup sheet.
   Time: 5 min

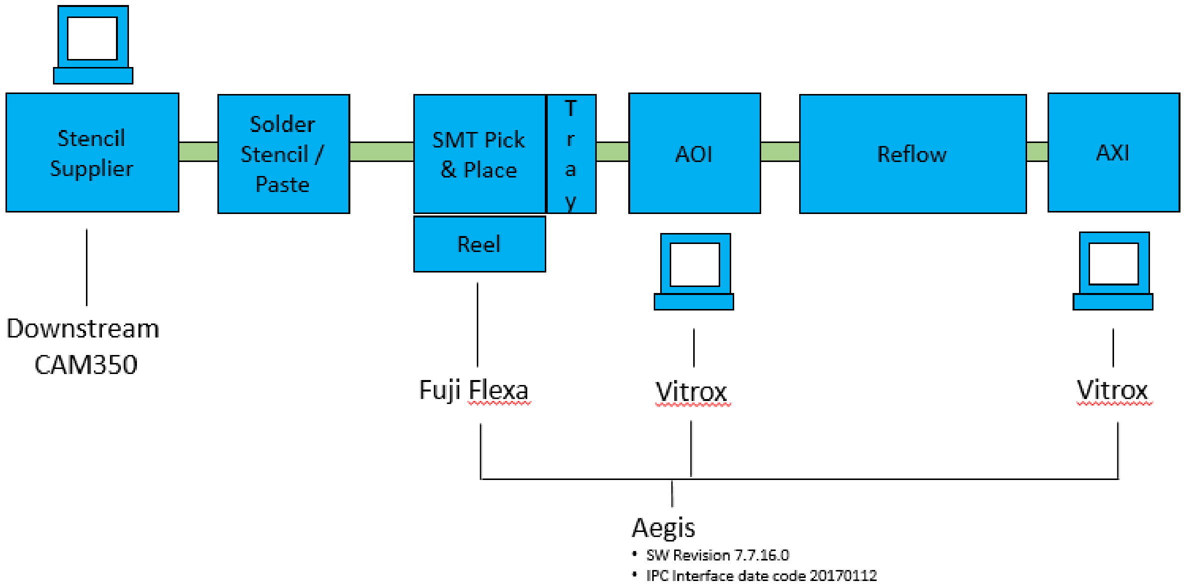


Figure 4-4: Sanmina PWB process flow

4.5.6 Future-state

Stencil: Sanmina's stencil vendor used the Downstream CAM 350 software to import the IPC-2581B file and produce the stencils. Sanmina's vendors have the ability to adjust the "Paste file" based on recommendations from Sanmina engineers as required (i.e. special apertures).

Input file: IPC-2581B

Pick & Place: In the current build, Sanmina used Aegis v7.7.16.0 and the Aegis and Fuji machine software(Fuji Flexa) for SMT program generation.

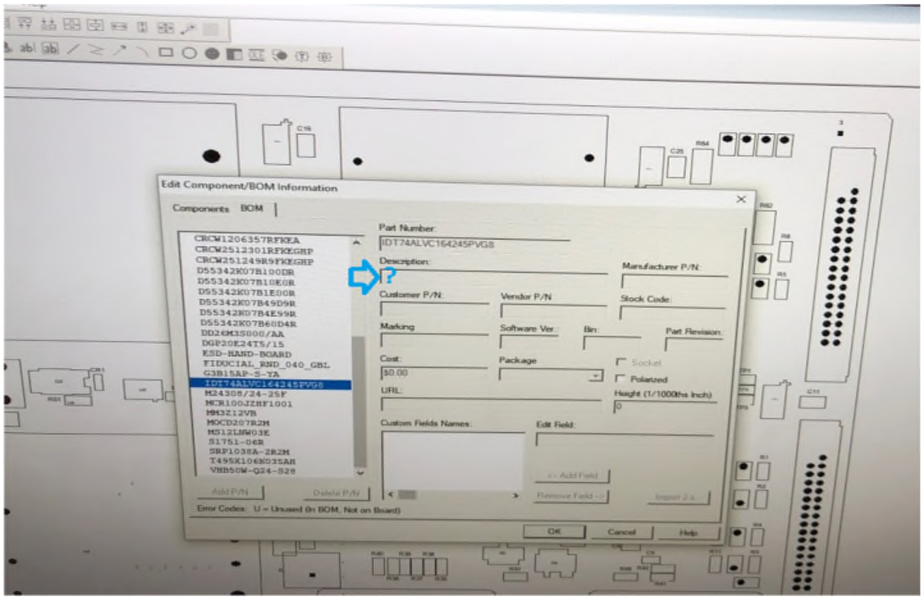
- Input files for Pick and Place
- Import IPC-2581B file

Steps to create SMT machine program to feed into Fuji AIMEXII:

1. BOM cleanup and Excel BOM manipulation

Same as above (30 min. current state).

The IPC-2581B import to Aegis yielded partial BOM information. The description field below was not populated automatically into Aegis as expected. Sanmina tested the IPC-2581B import into Aegis Factory Logix and the field was not populated there either. A problem report was generated with Aegis to investigate the missing "Description field".



Time: No change from current state.

2. The IPC-2581B was like the ODB++ file. If the designer included component data then there was no need to "teach" the components online.
   Time to import BOM/ODB++(or equivalent) in Aegis + data manipulation
   Merge and verification: 10 min.
3. Fiducial identification
   5 min. Same as above.
4. Export output of Aegis into Fuji Flexa
   Time to export output into Flexa: 15 min for Lockheed project
   A higher part count, more complex PCBA may take 30min. -1hr
5. IPC-2581B modification for Aegis Scripts for importing Aegis v7.7.16.0:
   Time to modify: 15 min
6. Future-state DNI: Do not install parts
   For this project the DNI parts were not correctly identified by Aegis. In Factory Logix there was a software feature update that has addressed this issue. Sanmina will need to verify that IPC-2581B "do-not-install" information is imported automatically into Factory Logix as advertised.

AXI: No change.

4.5.7 SUMMARY:

Sanmina saw no change in processing time for stencil creation, pick & place or AXI/AOI. Sanmina did need 15 minutes to update the file for electrical test. In the future, Sanmina can migrate to Factory Logix version 8.171.5. This is expected to eliminate the extra time required to manually setup electrical test.

4.6 Rochester Institute of Technology

The Lockheed Martin design was assembled at the RIT. Detailed below are the materials that were used to assemble the Lockheed Martin design, the equipment used during assembly, the methodology for assembling both the present-state and future-state, the data that was collected during assembly, and a summary of the results.

4.6.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B format
- Siemen's UniCAM software
- Access database
- Lockheed Martin design SMT components.

4.6.2 Equipment

- ASM Siplace SX2 SMT pick and place machine
- Siplace Pro Application Software

4.6.3 Tools

Present-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT X-Ray Inspection
Rochester IT	Rochester, NY	Mfg Equipment Vendor		ASM Siplace		
		SW Vendor		Siplace Pro Interface		

Future-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT X-Ray Inspection
Rochester IT	Rochester, NY	Mfg Equipment Vendor		ASM Siplace		
		SW Vendor		Siplace Pro Interface		

4.6.4 Methodology

The following sections describe the process for auto-generating pick and place machine files at the Rochester Institute of Technology using the present-state files compared to using UniCAM and the future-state file (IPC-2581).

4.6.5 Present-state

The following section outlines RIT's present-state methodology for generating a pick-and-place program for the ASM SX2 using the Siemens PLM Siplace Pro software. The present-state design-to-manufacturing process was described and demonstrated first in the lab to baseline the existing PCB production flow. The analysis starts using the scenario of a customer with a complete PCB design that they would like to have fabricated and assembled. This customer provides the PCB manufacturer a set of data files (i.e. the present state files). The data set is often spread across multiple folders as shown in the screen shot below (Figure 4-5).

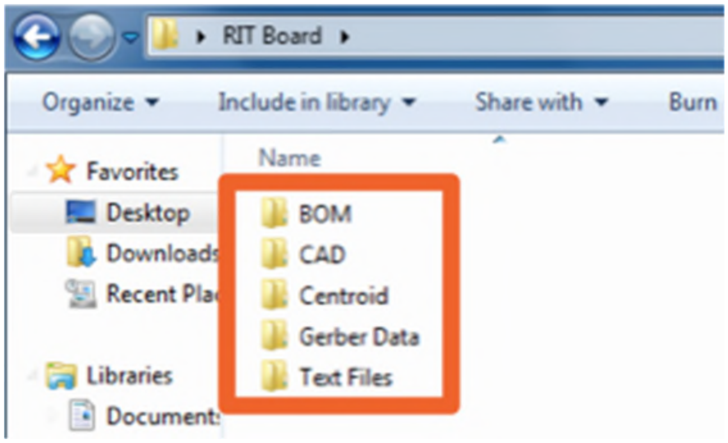


Figure 4-5

Figure 4-5 also shows that the folders include BOM, CAD, Centroid, Gerber Data and Text Files. Both the PCB designer and the PCB manufacturer expect these files to include all data necessary for the board to be produced.

Upon receiving the files, the PCB manufacturer first reviews the data. For this project, the Gerber data was imported into Cadence Allegro PCB Designer where the revision numbers and features like the board fiducials were checked. Next, the BOM was reviewed. The part numbers and number of parts were compared to the material in stock to ensure that there were no mismatches.

Finally, the centroid data file was opened and reviewed for formatting. Unnecessary information in this file needs to be removed manually either at this point or when the data is imported into the Siplace Import Wizard. Figure 4-6 shows an image of the received centroid data with the critical information beginning at row #6.

	A	B	C	D	E	F	G
1	| Export script for EAGLE to RIT CEMA Centroid.						
2	| Based on the Screaming Circuits Centroid export script.						
3	| Centroid Data for pc board: "untitled.brd" as of: 4/20/2017 9:08:21 PM						
4	| Measurements are in mils. Comma delimited						
5							
6	RefDes	Package	Part	LocationX	LocationY	Rotation	
7	FID1	FIDUCIAL	FIDUCIAL	300	412.5	0	
8	FID2	FIDUCIAL	FIDUCIAL	4337.5	1587.5	0	
9	FID3	FIDUCIAL	FIDUCIAL	900	1112.5	0	
10	AC1	C1206	PCC1880T	2500	1775	0	
11	AC2	C1206	PCC1880T	2750	1775	180	
12	AIC1	SOIC14	296-1981-	2500	1375	270	
13	ALED1	CHIPLED_	404-1034-	1925	937.5	270	
14	ALED2	CHIPLED_	404-1034-	3075	937.5	90	
15	AR1	R1206	RHM56ER	2250	225	180	
16	AR2	R1206	RHM56ER	2750	225	0	
17	AR3	R1206	RHM1.05I	2250	1775	180	
18	ASW1	JS102011!	401-1999-	4950	1562.5	90	
19	C3	D0603	D0603	4512.5	1600	90	

Figure 4-6

The Siplace Board Wizard uses a .txt file, so it was necessary to convert the centroid data spreadsheet into the required .txt file. A preview of the data after this conversion is shown in Figure 4-7 below. Unfortunately, the conversion introduced a misalignment of the placement data.

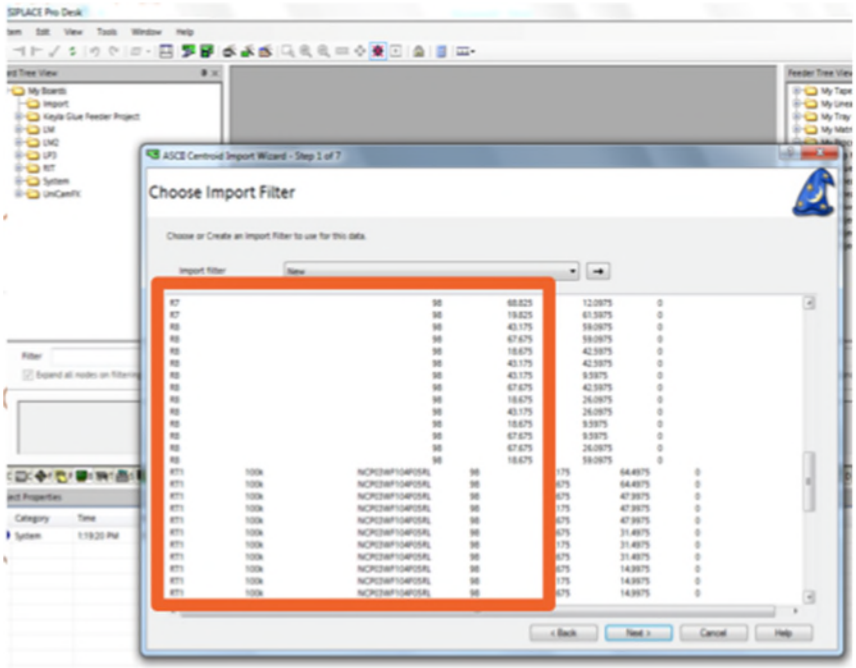


Figure 4-7

If this misalignment had not found, the placement data would not have been imported correctly. Additional space can be manually inserted between the columns to ensure alignment when the text file conversion is done. Properly formatted centroid data is not guaranteed as customers use a variety of tools with different outputs. Thus, it is important to check each one.

Figure 4-8 below shows properly formatted data.

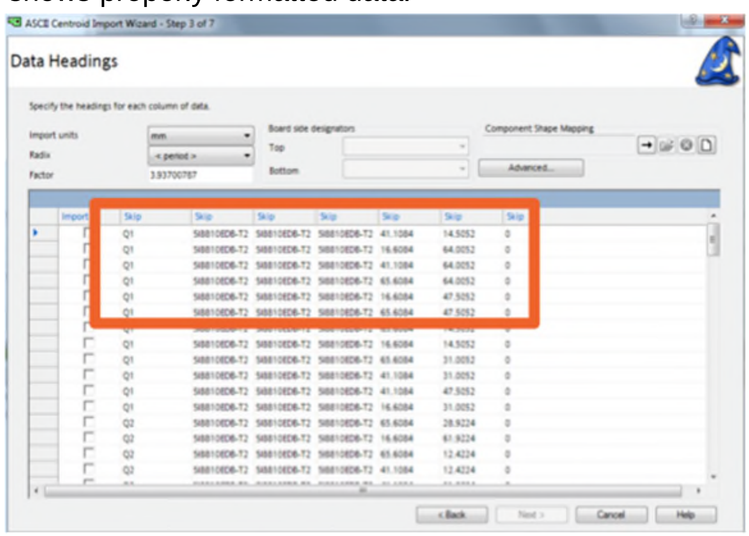


Figure 4-8

It is also important to check the units used for the centroid data. If the design software does not specify the units or the customer converts the units after exporting the centroid data, there could be errors. As shown in Figure 4-9, the units were not specified. This was determined after the process engineer completed the Siplace Board Wizard step and unfortunately that step had to be repeated.

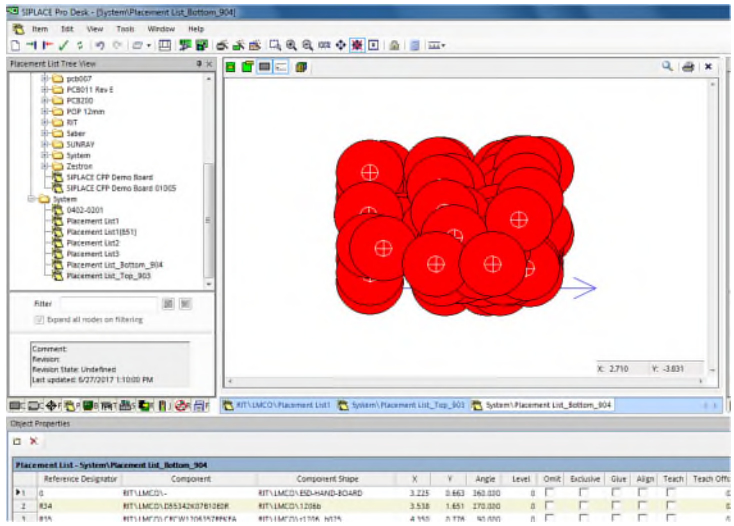


Figure 4-9

An error-free Siplace Wizard process results in a placement file with properly directed/found component shapes as shown in Figure 4-10.

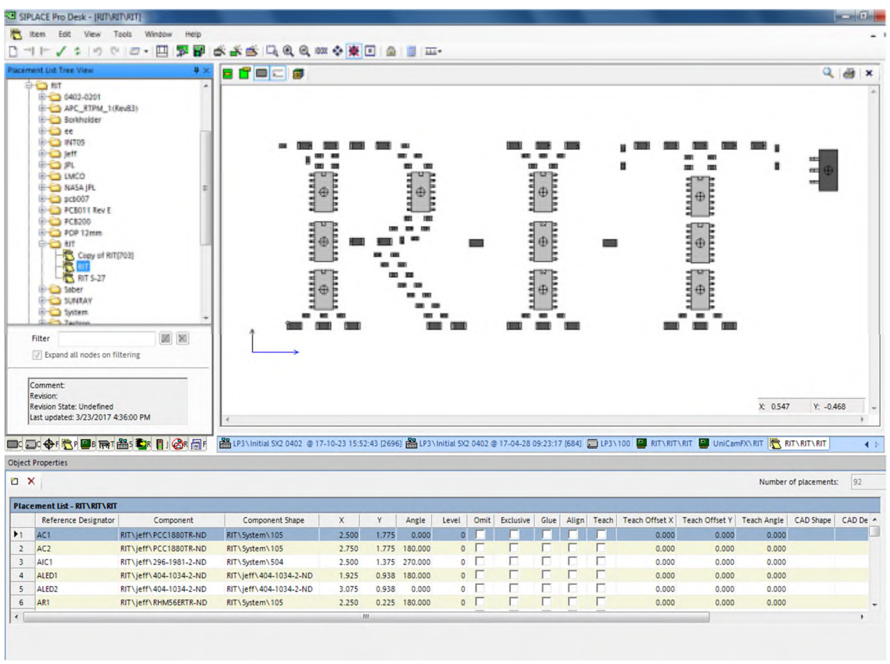


Figure 4-10

After the placement file is created, a few more steps are required to create a placement program. First, a board configuration needs to be generated to which the placement data will be linked. The data needed in this step is the length, width and thickness of the physical board along with the fiducial locations. The fiducial locations can be found within the centroid data file or one can use a Gerber viewer to manually measure the locations. Regardless of how the data is obtained, it is must be manually entered into the software. This can be an error-prone operation if the units are wrong, the conversion of units is not accurate, and/or if improper measurements are made. The outlined box in Figure 4-11 shows where the manual input of board data should be made. A completed board with placement data attached is shown in Figure 4-11.

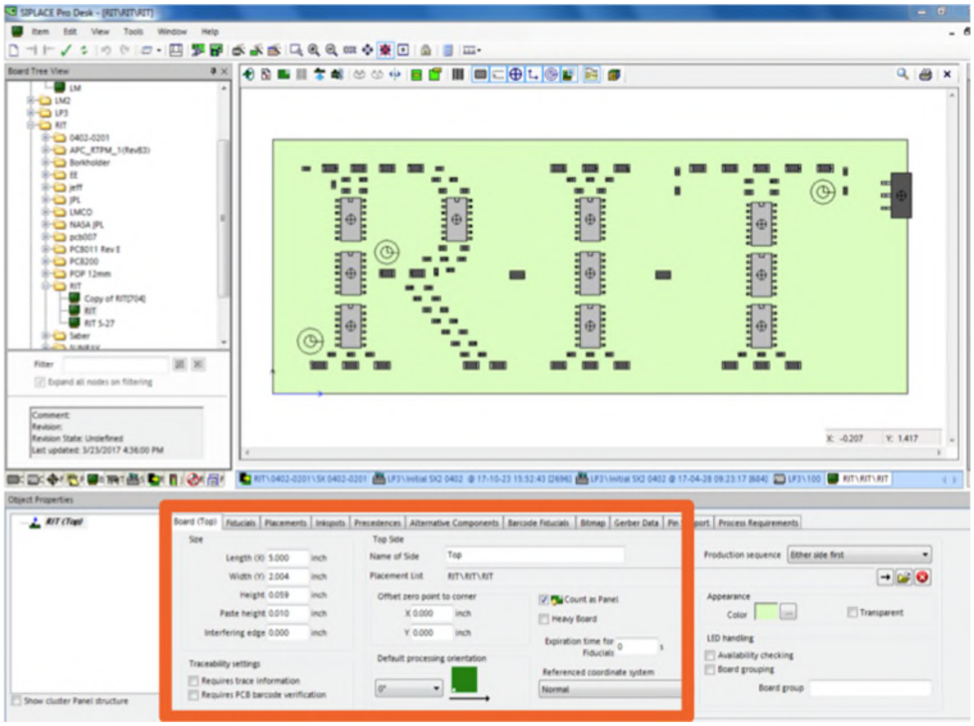


Figure 4-11

Once the board and placement data steps are complete, one must configure the line setup, generate a recipe file, and then compile all of this data into a job file/program to be sent to the machines. This completes the present-state process.

4.6.6 **Future-state**

The future-state design-to-manufacturing process includes a streamlined method of generating production programs for SMT equipment. The unique aspect of the future-state is that all the data needed for production is contained in a single file as shown in Figure 4-12.

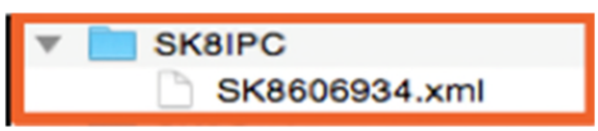


Figure 4-12

The IPC-2581 file is then imported into Siemens PLM UniCam as seen in Figure 4-13.

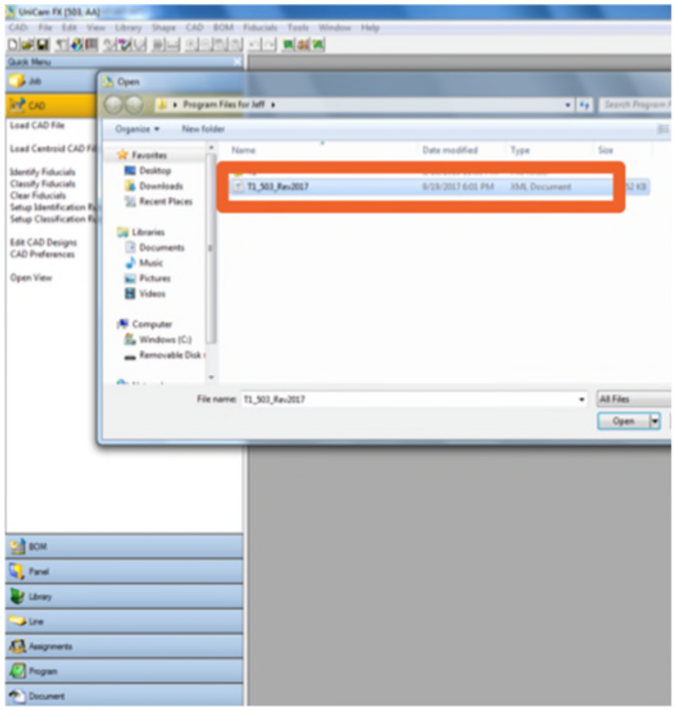


Figure 4-13

In the Open View, the full graphical representation of the design can be seen in Figure 4-14 including traces, pads, components, board outline details and features.

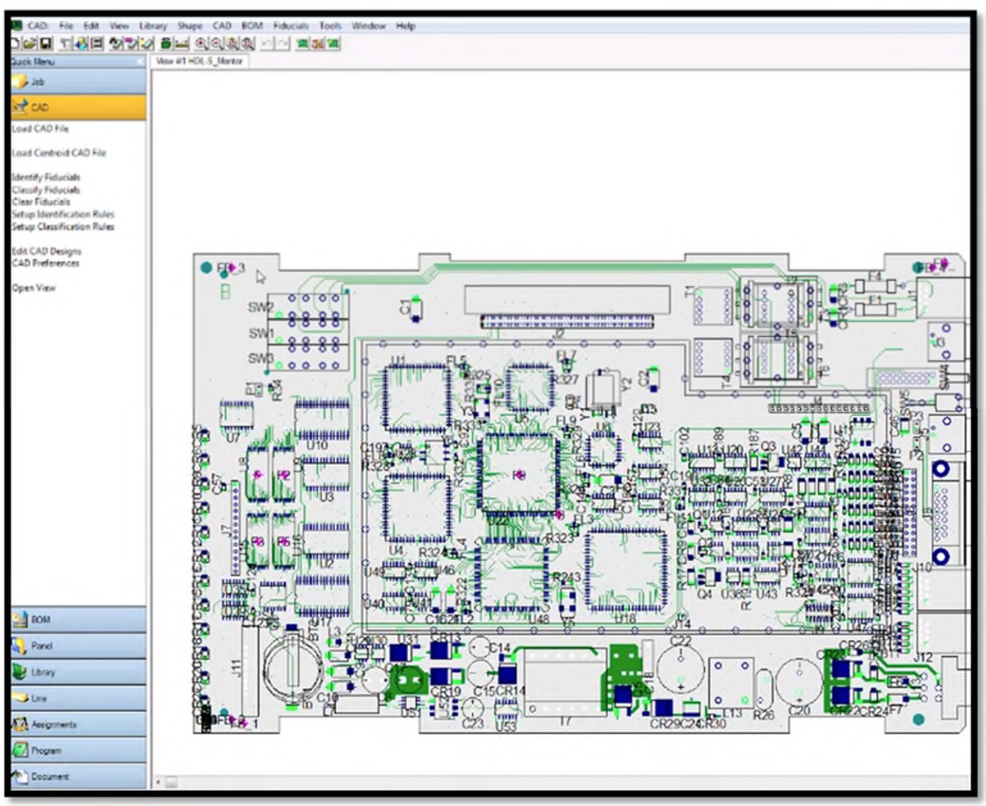


Figure 4-14 (UniCam Open View of IPC-2581B Design File)

The IPC-2581B file also contains component specifications including: reference designation, component shape, assembly type and other information as shown in the outlined areas in Figure 4-15 of the Job Data Editor.

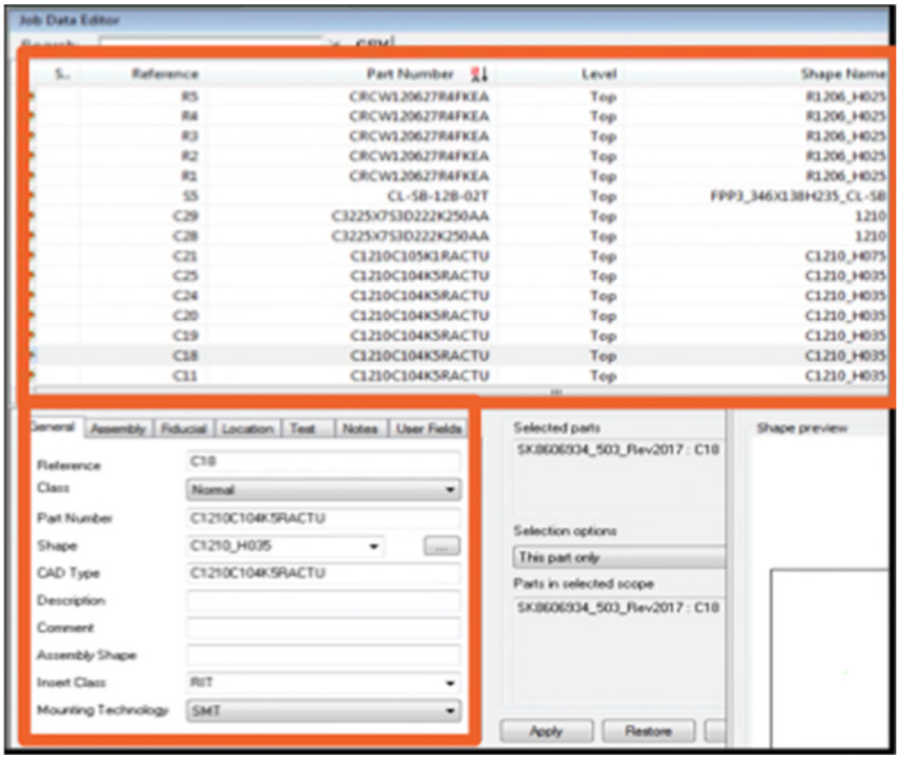


Figure 4-15 (UniCam Job Data Editor of IPC-2581B file)

Within the Job Data Editor, UniCam can verify and flag new components compared to its database. A common practice is to Update Library from Job with each new design to continuously add parts to the database. This step is typically done after the SMT Line is configured for the PCB manufacturer's equipment. For this demonstration, the ASM SX2 pick and place machine was the target. Figure 4-16 shows how this piece of equipment was selected.

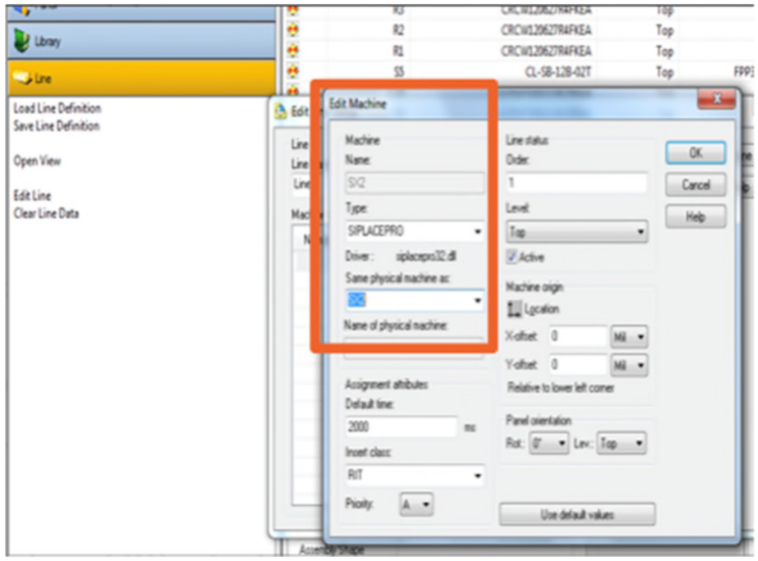


Figure 4-16 (Adding a Production Machine to the Line)

Figure 4-17 shows some of the Siplace configurations being set in Unicam.

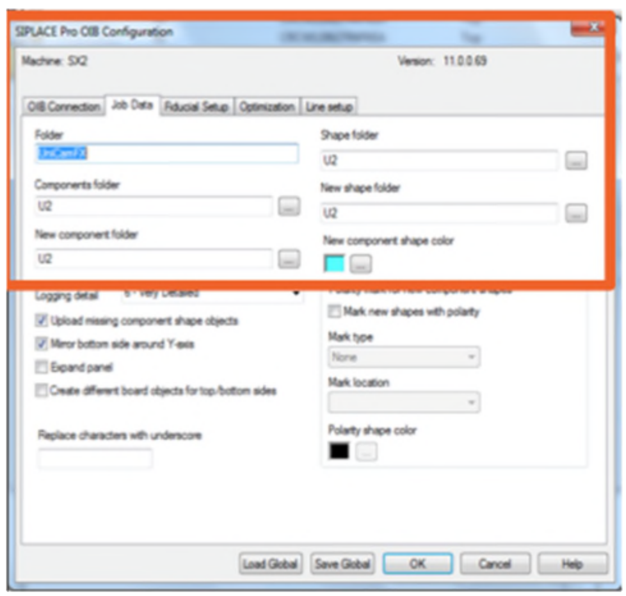


Figure 4-17 (Siplace Machine Configurations in UniCam)

After the equipment is configured, the Siplace Library should be updated from the Job Data to further ensure that the component data is transferred.

Lastly, the assignment of components to the machine should be made. This was done with a single click on Balance Line.

With those steps completed, UniCam can begin sending the production program to Siplace under the Program tab of the side bar menu. Once that step is complete, the placement, component and board data transferred into Siplace is ready to become a job for the pick-and-place machine as shown in Figure 4-18.

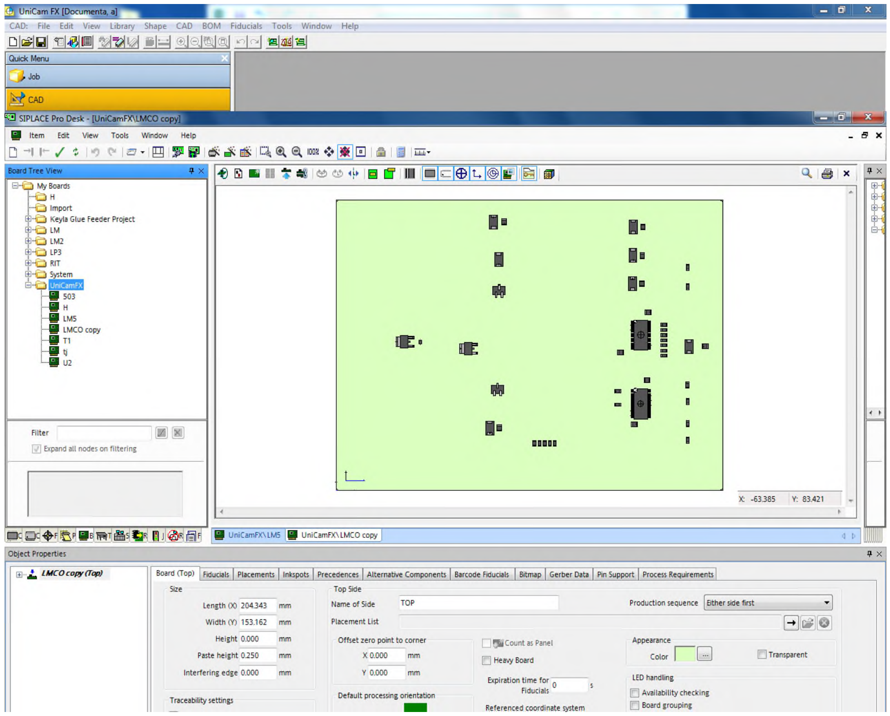


Figure 4-18 (Completed UniCam Program transferred to Siplace)

Above in Figure 4-18 is a screen shot a UniCam/IPC-2581B program that was transferred to Siplace Pro for an assembly program to be made.

4.6.7 Data Observation

To test the hypothesis that IPC-2581 will result in time savings, RIT designed an experiment to collect data using two factors: the present-state and future-state files and an experienced versus a relatively inexperienced assembly operator. Operator A had less than 5 years of experience and operator B had greater than 25 years of experience. A summary of RIT's experimental design results is shown in Table 4-3 below.

Table 4-3: RIT PCB Assembly Time Trial DOE		
Description	**Level 1**	**Level 2**
Assembly Data	Present-state	Future-state (IPC-2581B)
Operators	Operator A: Less than 5 years' experience	Operator B: Greater than 25 years' experience

4.6.8 Present-state

The present-state consisted of error-prone operations requiring manual manipulation by the operator, including taking time to review initial data and ensuring the data was compatible with Siplace Pro software. Practices that enforce specific data formatting can reduce errors and manual manipulation as noted with the centroid data formatting earlier.

Table 4-5 shows the breakdown of a time trial with the present-state design using Operator B with greater than 25 years' experience.

Table 4-5: RIT PCB Assembly Time Trial		
Present-state Time Break Down		
Action #	Description	Time (mm:ss)
1	Download/unzip production data	0:00
2	Find the centroid data	0:15
3	Open centroid data in Excel	0:45
4	Begin Reviewing the data and eliminating unnecessary data	1:45
5	Add in column spacing to avoid delimiter errors	2:30
6	Save file as .csv	3:00
7	Open .csv and copy and paste into Text Editor program	4:00
8	Review new .txt file and centroid data columns	4:45
9	In Siplace Pro begin ASCII Centroid Import Wizard	5:00
10	Select the .txt centroid data file	5:15
11	Review preview window of .txt centroid data file	5:30
12	Adjust imported centroid data accordingly, check treat consecutive deliminators as one	5:15
13	Review deliminated data	5:30
14	Proceed to adjust Data Headers (Ref des, X,Y, etc..)	7:00
15	Choose to create or map components and shape folders for the Siplace Library	7:45
16	Review new components imported	8:30
17*	Reference new components with component description then search Siplace Library to match component Shape	10:00
18	Create new board in Siplace and add dimensions	10:50

4.6.9 Future-state

Assigning components using the Job Data Editor was a meticulous manual effort and one that can be prone to errors. For RIT's portion of the PCB assembly, the IPC-2581B file that they received included incorrect components and as such, the manual effort to compare the BOM to the components received was inefficient.

Table 4-6 shows the breakdown of a time trial with the future-state design using Operator A with less than 5 years' experience and who was trained on UniCam.

Table 4-6: RIT PCB Assembly Time Trial		
Future-state Time Break Down		
Action #	Description	Time (mm:ss)
1	Download the PCB Assembly .xml file (IPC-2581)	0:00
2	Review the Open View of the board	0:15
3	Review the Job Data Editor of the board	1:00
4	Review the components that have Status of not existing in library	1:45
5	Update Library from Job	2:00
6	Add Machine to Line	3:00
7	Open Machine Configuration and map UniCam data to Siplace Pro	5:00
8	Assign components with balance line	5:30
9	Review number of Assigned components to match expected placement number/BOM	6:30
10	Begin Program/Data transfer to Siplace	6:45
11	Review Board created in Siplace	7:00
12*	Review any new components then search Siplace Library to match component Shape	7:50

Comparing the time trials, Operator A with less than 5 years' experience, using IPC-2581B was able to complete the production program quicker than Operator B with greater than 25 years' experience using the present state files.

4.7 Fujitsu

The present-state processes supporting SMT assembly operations & solder stencil generation, that use various data formats, were compared with the future-state process using only IPC-2581B data for two Fujitsu printed circuit board assemblies. The difference in manufacturing cycle times for solder stencil and assembly preparations were measured. Additional benefits the use of IPC-2581B files provided were noted.

4.7.1 Materials and equipment

Present-state GMF assembly data exported from Cadence Allegro v17.2 for two designs

Future-state IPC-2581B assembly data exported from Wise VisualCAM v16.9 for two designs

Wise VisualCAM Stencil tool v16.9

Bare board PWBs and parts for the 2 designs

Proprietary Fujitsu'TexCAM' software

TestSight translation software vX.X

Fuji pick and place machine
Vitrox AOI Machine
Vitrox X-Ray Machine

4.7.2 Tools

Present-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Fujitsu	Dallas, TX	Mfg Equipment Vendor	FTC Assembly	Fuji, DEC	Vitrox (Agilent)	Vitrox
		SW Vendor	Wise Stencil Tools	Fujitsu TEXCAM	Fujitsu TEXCAM	Fujitsu TEXCAM

Future-state:

▼ Partner	▼ Location	Mfg Flow ►	Assembly			
			SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT AXI
Fujitsu	Dallas, TX	Mfg Equipment Vendor	Blue Ring Stencils	Fuji, DEC	HP/Vitrox	Vitrox
		SW Vendor	Wise VisualCAM Stencils	Fujitsu TEXCAM	Demille Research TestSight Translator	Demille research TestSight Translator

4.7.3 Methodology

Present-state and future-state files were both imported into Fujitsu TexCAM and their content processed to prepare the Fuji SMT line for assembly. The contents of the present-state and future-state data sets were compared. The present and future-state files were imported and processed through Test Site application software to prepare the SMT AOI (Automatic Test Inspection) and X-Ray Inspection processes. Optimized solder stencil data was prepared using the present-state data (Gerber generation from GMF via TexCAM) and future-state (IPC-2581B from VisualCAM Stencils) were prepared. The solder stencils were ordered using only the IPC-2581B data. The two PCB assemblies were assembled using only IPC-2581B data.

4.7.4 Present-state

The present-state data was created using a custom SKILL script to export the required data from Cadence Allegro into a proprietary Global Manufacturing File (GMF) format, a specification created by Fujitsu.

The exported file contains information including footprint geometries, BOM information, component location and rotation, reference designation, netlist information, pin pad information, test point information, board and assembly pallet dimensions, board location(s) in pallet, and fiducial locations. The GMF file was submitted to our PLM system where it was configured into a release package (associated with drawings and fab data, etc.) and augmented with the revisions of all the other objects in the package.

Once reviewed the package was released, and the now complete GMF file was routed to our manufacturing group, where it was automatically loaded into TexCAM.

Stencil: The stencils were created by using a solder paste Gerber file created by and exported from TexCAM. Only limited reduction of the stencil openings can be done in TexCAM. CAM350 was used to review and do any further edits to the Gerber files before sending to Blue Ring Stencil, who then used them 'as is'.

AOI: The (component) data was exported from TexCAM using a custom script

X-Ray: The TestSight software was used to translate the data from the ODB++ package generated for fabrication

4.7.5 **Future-state**

The IPC-2581B process was initiated with custom (SKILL) script in Cadence Allegro which runs the out-of-the-box IPC-2581B export sandwiched between pre and post processing.

The pre-processing:

1. Adds an IPC-2581B default part orientation property to each part instance
2. Ensures that tear dropping has been performed

The post-processing:

1. Adds drill tolerances to all through-holes
2. Translates custom ECAD library properties to the correct IPC-2581B schema placeholders.
3. The exported IPC-2581B file is then imported into VisualCAM, checked for DFx errors, and if required, panelized into N up images
4. An IPC-2581B file was exported from VisualCAM and submitted to the PLM system.
5. At this time, further post processing takes place in PLM including:
    a. populating the Approved Vendor List (AVL) section of the IPC-2581B file for each part number in the BOM section, by extracting the corporate part number to vendor part number mappings from the PLM system. This is useful information for the Test Engineers.
    b. populating other non-CAD properties into the BOM section, such as FNC rank, RoHS status, humidity rank, and other attributes and characteristics.
    c. adding configuration data for the associated electrical, mechanical, firmware, and software content
    d. Adding mechanical parts to the BOM section, merging an IPC-2581B file exported from the mechanical design tool (PTC Creo)

Once reviewed the package was released, and the now complete IPC-2581B file was routed to our manufacturing group, where it was automatically loaded into TexCAM.

Stencil: The stencil was created using the Wise VisualCAM Stencil tool. The VisualCAM (.vcam) file of the board, or single piece board if part of a panel created for assembly and fabrication, was opened in the stencil tool. Solder stencil optimization was performed including home plating and window pane substitutions. We then exported the IPC-2581B file from the Stencil Tool to send to Blue Ring Stencil.

AOI & X-Ray: The TestSight software translated directly from IPC-2581B for both AOI & X-Ray

4.7.6 **Data Observation**

The metrics collected for the two designs show that the time taken to import the design data for SMT assembly was reduced from an average of 155 seconds using the present-state method to an average of 46 seconds using the future, IPC-2581B method, a 70% reduction.

Some other differences for SMT operations observed between using the present-state method and the IPC-2581B method are:

1. GMF files used the assembly outline shape in Cadence Allegro as the outline of parts whereas the IPC-2581B output from Allegro used the placebound shape as the outline. Both outlines can be made visible in VisualCAM, which was useful to be able to see the differences, although it took a few updates to VisualCAM before all the outlines were rendered correctly.
2. A property called CENTER in GMF was calculated as the centroid of the assembly outline, and a property called pickupPoint in IPC-2581B was calculated as the center of the placebound shape. The pick ‘n place machine used the CENTER or pickupPoint as the center of placement, and there were some differences seen between them for some parts. In general, the assembly outline used by GMF was less accurate, because there tends to be additional lines and text on

the assembly outline layer, which offset the centroid calculation, whereas the placebound shape is a basic shape only. But there were a few cases where the placebound shape did not yield the correct centroid. However, in Allegro you can explicitly set the pickupPoint location, as the center of a circle placed on the Body_Center subclass layer, which overrides the centroid calculation. This is very useful for asymmetric parts.

3. For Stencil generation the time taken was reduced from an average of 3.5 hours using the present-state method to an average of 2 hours, using the future, IPC-2581B method, a 43% cycle-time reduction on average. The stencil patterns per part type are saved to a library, and automatically selected the next time that part type is used, so only new part types need to be worked on. If the board is part of a panel then a script that Wise developed replicates the stencil patterns to each board location in the panel.
4. For the AOI machines there was no noticeable benefit observed by importing IPC-2581B via TestSight compared to importing directly from TexCAM, because the data required is simpler, and there is configuration required in TestSight
5. For the X-Ray machine, because both present and future-state methods use TestSight, there were benefits and time savings observed. The present-state source data is ODB++ which does not contain all the data required, so additional data has to be added manually. The future-state source data is IPC-2581B file contains all the required data.

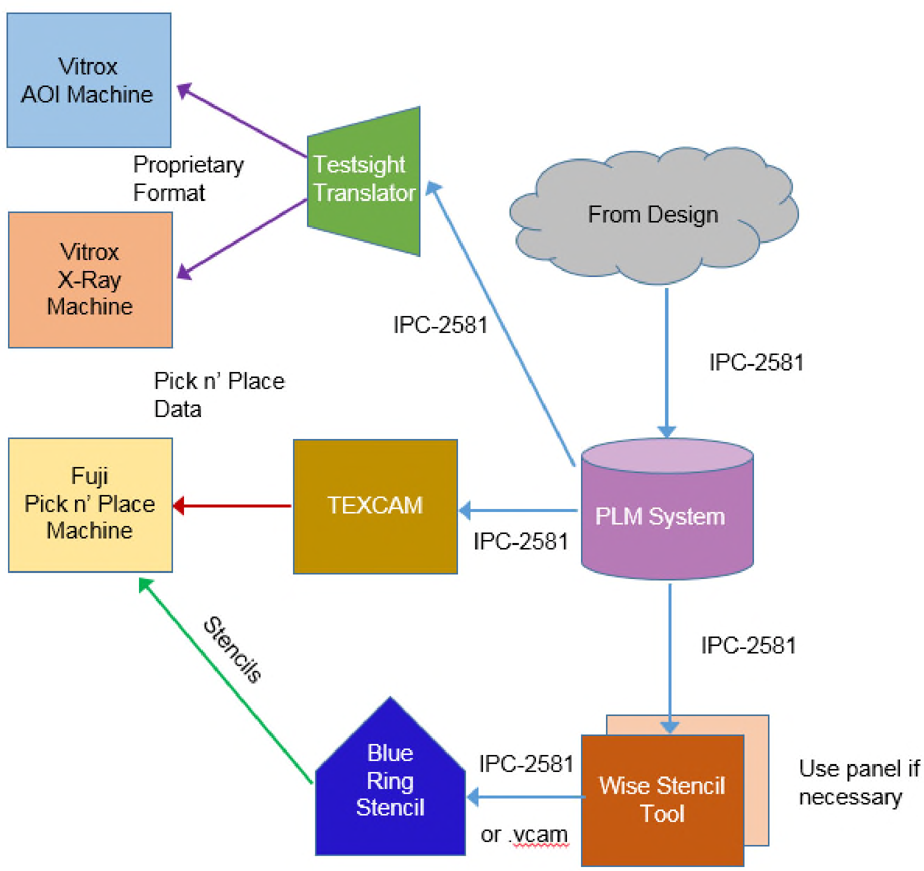


Figure 4-23: IPC-2581B Flow

4.7.7 **Conclusion**

SMT assembly benefited from the biggest percentage reduction, 70% compared to a 43% reduction for stencil generation. But the stencil generation benefited from a 1.5 hour savings compared to only a 109 second savings for SMT assembly. So, including the observable improvement in quality of the stencils, the stencil generation is considered to have the greatest benefit.

However, taking a broader perspective, there have been cases using the present-state method when the assembly data has not matched the fabricated bare board that it was supposed to be assembled on, because the fabrication data and assembly data versions were out sync. So, unless each bare board could be manually modified, which took extra time, they had to be scraped and reworked, costing much more money and time. With the Fujitsu IPC-2581B method this will never happen because the fabrication and assembly data is generated at the same instant in time, then stored in the PLM system as a single master file. The fabrication and assembly data are then subsets of the master file extracted on the fly and on demand.

The inclusion of the MCAD BOM into the IPC-2581B master file, and the generation of hierarchical product level BOMs in IPC-2581B format by the PLM system, are huge benefits for part procurement for assembly. For the present-state method the non ECAD BOM items must be manually entered into the ERP system. For the future-state all BOM data is automatically transferred from PLM to ERP systems.

4.8 Assembly Metrics

PCB Assembly Performance Improvement Results						
Metric	**Equipment**	**Metric**	**Present State**	**Future State**	**Percent Difference**	**Comment**
RIT	ASM SX2 pick-n-place	1	N/A Present state is baseline	0	0	
		2	0.5 hr (30.50 min)	0.45 hr (27.50 min)	9% Reduction	16% Difference from Goal
		3	0	0	0	Stencil created by outside vendor
LM SPACE-DENVER	ASM X2 pick-n-place	1	N/A Present state is baseline	0	0	
		2	1 hr	0.75 hr (45 min)	25% Reduction	Met 25% goal
		3	0	0	0	Stencil created by outside vendor
LM MFC-DALLAS	MYDATA pick-n-place	1	N/A Present state is baseline	0	0	
		2	0.75 hr	1.08 hr	31% Increase	Did not meet goal. The issues can be attributed to a learning curve for UniCAM and we had issues with directly writing to the Mydata machine from UniCAM. Direct connection between UniCAM and Mydata never worked and therefore we had to export the files on a USB drive to port over to the machine.
		3	0	0	0	Stencil created by outside vendor
LM RMS-OWEGO	DEK Horizon 01i	1	N/A Present state is baseline	0	0	
		2	1.2 hrs	0.9 hrs	25% Reduction	Met 25% goal
		3	3 hrs	2 hrs	33% Reducion	Met 25% goal
SANMINA		1	N/A Present state is baseline	0	0	
		2	1.08 hrs	1.33 hrs	23% Increase	Did not meet goal. Issues is attributed to Aegis software not importing in properly the BOM description, correctly identifying the fiducials, and identifying the DNI parts.
		3	0	0	0	Stencil created by outside vendor
FUJITSU	Fuji pick-n-place	1	N/A Present state is baseline	0	0	
		2	158 sec	47 sec	70% Reduction	45% Difference from Goal
		3	4 hrs	2 hrs	50% Reduction	25% Difference from Goal
FUJITSU	Fuji pick-n-place	1	N/A Present state is baseline	0	0	
		2	152 sec	45 sec	70% Reduction	45% Difference from Goal
		3	3 hrs	2 hrs	33% Reduction	25% Difference from Goal

5 Test

Flying probe, which is a manufacturing electrical confidence test, was performed for hardware assembled during this project as described in the Assembly section. Lockheed Martin Space, Lockheed Martin MFC, and Lockheed Martin RMS developed flying probe profiles using their present-state and IPC-2581B (future-state) files.

5.1 Objective

The purpose of the test phase was to compare present-state processes required to generate test machine program files versus the future-state processes when using the IPC-2581B format. After generation, the assemblies were tested to confirm no issues resulting from the IPC-2581B dataset.

5.2 Lockheed Martin Space-Denver

The Lockheed Martin design that was assembled at LM Space-Denver was also tested at the LM Space-Denver facility. Detailed below are the materials that were used to test the Lockheed Martin design, the equipment used in the test facility, the methodology for testing both the present-state and future-state, the data that was collected during test from both the present-state and future-state, and a summary of the results.

5.2.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B
- Siemen's Test Expert software v11

5.2.2 Equipment

- Takaya APT 9411SL software version 2.0-0B

5.2.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ▶	Test Flying Probe / ICT
Lockheed M	SSC - Denver, CO	Mfg Equipment Vendor	Takaya & Acculogic
		SW Vendor	Siemens Test Expert v11

Future-state:

Partner ▼	Location ▼	Mfg Flow ▶	Test Flying Probe / ICT
Lockheed M	SSC - Denver, CO	Mfg Equipment Vendor	Takaya & Acculogic
		SW Vendor	Siemens Test Expert v11

5.2.4 Present-state Process

The current process to generate flying probe program files utilizes Test Expert software, the .pcf and .ftf file outputs from Zuken, and an Excel parts list. The assembly drawing and schematics are also used during program generation. The following process is performed to generate the file outputs:

1. Gather the necessary files and documentation from EPDM.

2. Modify/format BOM for import into Test Expert
3. Import CAD Files and BOM into Siemens PLM Test Expert software to create FAZ file
    a. Overwrite the BOM that is in the CAD with the externally created BOM. Manually verify everything is correct.
        i. External BOM includes component values identified in part descriptions. Parts without values defined in description must be researched and manually updated.
    b. Adjust the shape of all components on the board so the tester can access points on the board.
    c. Adjust the probing location to be on the back 25% of pads
    d. Make sure the components are in the correct category (Resistor, capacitor, etc.)
    e. Set up type of test and determine fiducial points
    f. Determine the nail priorities
    g. Manually eliminate certain probes for components based on height – done by knowledge of programmer of component packages
    h. Generate program – FAZ file
4. Import FAZ file into flying probe software and generate flying probe program
5. Generate stimulus file and send to assembly CPE (certified principle engineer) for approval, if required by program
6. Optimize the flying probe program with the first article
    a. Load program onto flying probe machine
    b. Input actual references (Photos) for fiducial and make the board easy and repeatable to install
    c. Further reduce selection of probes based on component packages and board layout
    d. Debug test steps

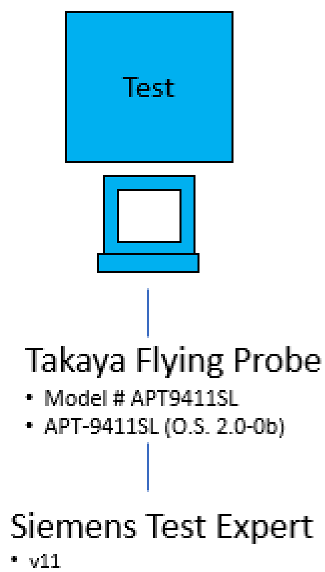


Figure 5-1: LM-S PWB process flow

5.2.5 **Future-state Process**

Test Expert software was used to generate the flying probe program files using the IPC-2581B dataset. The same process was used as the present-state process. Below are the differences noted between the different formats.

1. Siemens PLM released a patch that was able to populate the component level data, including values, tolerance, and units, when performing the BOM import from the IPC-2581B dataset. Prior to this patch being released, the existing Excel file import was used. The data was re-run after the patch to confirm this data was populated automatically from the IPC-2581B dataset.
2. During initial programming using the IPC-2581B dataset, the unpopulated components imported as populated and had to be manually corrected. Problem report #29, SSC-TE090601, was created. This was reviewed with Siemens and a new patch issued to correct this issue.
3. Certain probes were automatically eliminated as component height information is present in the IPC-2581B file. This reduced manually adjusting probes during debug of first article.

5.2.6 **Data Observations**

The BOM being incorporated into the IPC-2581B file format eliminated any manual formatting or editing of an external BOM prior to importing. This resulted in a time savings per assembly and reduced human error opportunities. The patch released by Siemens PLM to auto-import component data from the IPC-2581B dataset also reduced manual manipulation of the BOM prior to import or manually assigning those values in Test Expert.

Only having to get one file for data import also reduced setup time for programming versus retrieving several different file types. Also, since the BOM is part of the CAD at the variant level (-501, -502, etc.) versus having one CAD file for all variants, BOM cleanup/comparison is significantly reduced or eliminated.

The component height in the IPC-2581B dataset reduced manual selection/elimination of certain probes. This reduced the need of tribal knowledge of programmer of different component packages, maintaining some external documentation that identifies which probes can or cannot be used for certain packages, or manually verifying probes on physical assembly during first article build.

The automated BOM import in Test Expert using the IPC-2581B dataset did not handle non-populated components effectively. The issue identified was non-populated parts identified as “false” in the IPC-2581B dataset showed as populated. This was reviewed with Siemens PLM and a patch was released to correct the issue.

It should also be noted that LM Space-Denver did not process the assembly through flying probe. Due to issues related to the tape and reel packaging during assembly, numerous components were not placed. As a result, testing would have yielded a high number of failures due to missing parts. The main exercise of comparing the present-state to the future-state utilizing IPC-2581B for flying probe test, however, was completed successfully.

5.2.7 **Problem Reports**

5.2.7.1 LM-SSC Test Problem Reports (1 Reports)

Problem Report #28 (MFC_TE042601): Test Expert v11 BOM Import Error

Detailed Description:

When importing the IPC-2581B dataset into Test Expert v11 the parts identified in the IPC-2581B as “false” for populated were coming in as populated parts. These had to be manually changed to unpopulated.

Resolution:

Update to software. Siemens PLM released a patch to Test Expert that resolved the issue.

5.3 Lockheed Martin MFC-Dallas

The Lockheed Martin design that was assembled at LM MFC-Dallas was also tested at the LM MFC-Dallas facility. Detailed below are the materials that were used to test the Lockheed Martin design, the test equipment used, the methodology for testing for both the present-state and future-state, the data that was collected during test from both the present-state and future-state, and a summary of the results. The future-state programming was performed by LM Space-Denver using Test Expert.

5.3.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B
- Siemen's Test Expert software v11
- TestMatic software v11

5.3.2 Equipment

- Acculogic Flying Scorpion FLS980Dxi, software version is 6.4.7858

5.3.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ►	Test Flying Probe / ICT
in	MFC - Dallas, TX	Mfg Equipment Vendor	Acculogic
		SW Vendor	Siemens Test Expert v11

Future-state:

Partner ▼	Location ▼	Mfg Flow ►	Test Flying Probe / ICT
in	MFC - Dallas, TX	Mfg Equipment Vendor	Acculogic
		SW Vendor	Siemens Test Expert v11

5.3.4 Current State Process

The current process utilizes TestMatic software, CAD files from Cadence Allegro, and a parts list. The assembly drawing and schematics are also used during program generation. The following process is performed to generate the file outputs:

1. Import CAD file in the Cadence Allegro Database
2. Import a parts list that is formatted from PLM with the following required information
   a. Part number
   b. Values
   c. Tolerances
   d. Packages
   e. Types

f. X-Y location
g. Rotation
h. Side of the board

3. Perform the following through the database editor:
    a. Remove components that shouldn't be there like fiducials and tooling holes. Most can be removed by utilizing the clean button
    b. Afterwards go to the packages tab
        i. Assign the class (resistor, capacitor, etc.) for the components
        ii. Edit the package body dimensions if the CAD data is not accurate
        iii. Edit the keep-out region where the probe does not have access
        iv. Select the pins that you want to be probed. You'll also have to set the location as to where to probe. For example, for IC you need to offset it from the pin origin.
        v. Program the probe angle so that you don't have interferences
        vi. Define if the pin can be accessed from single or both sides
    c. Pin
        i. Choose the class like (IC, CAP, RES)
        ii. Edit the pin map (assign to Input, output, bidirectional, data, address, analog, vcc, ground, etc.)
4. Sometimes the CAD import does not place the origins correctly or the rotation is incorrect and therefore it must be adjusted
5. Specify board parameters such as the origin and rotation/orientation that the board will be in the test equipment
6. Specify the rules for the probes such as probe edge clearances, keep-outs, priority settings like caps first, ignore a component, etc.
7. Identify the nets that are power or ground
8. Output a .pba file from TestMatic and import into the machine software
9. Complete machine setup optimization
    a. Fiducial setup
    b. Test point optimizing
10. Adjust probes based on component packages and board layout

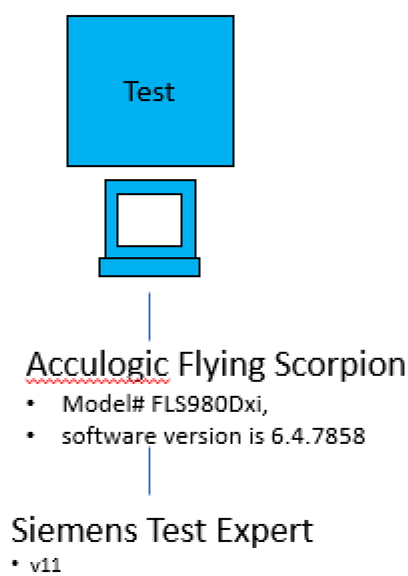


Figure 5-2: LM-MFC PWB process flow

5.3.5 Future-state Process

The Test Expert software was used in LM Space-Denver to generate the programming file for LM MFC-Dallas. Below is a comparison of the Test Expert processing using the IPC-2581B file versus the Cadence Allegro files and TestMatic.

1. During initial import into Test Expert using the IPC-2581B dataset, an issue was found where the BOM did not import properly. This was documented in problem report #28, MFC-TE042601, and corrected by Siemens. This resulted in automating the BOM import using the IPC-2581B dataset.
2. Unpopulated components did not require removal since the BOM and CAD are integrated in the IPC-2581B dataset.
3. Origins and rotations did not require modification.
4. Certain probes were automatically eliminated as component height information was present in the IPC-2581B file. This reduced manually adjusting probes during debug of first article.

5.3.6 Data Observations

The BOM being incorporated into the IPC-2581B file format eliminated any manual formatting or editing of an external BOM prior to importing. This resulted in a time savings per assembly and reduced human error opportunities. Only having one file for data import also reduced setup time for programming versus retrieving several different file types. Also, since the BOM is part of the CAD at the variant level (-501, -502, etc.) versus having one CAD file for all variants, BOM cleanup/comparison was significantly reduced or eliminated.

The component height in the IPC-2581B dataset reduced manual selection/elimination of certain probes. This reduced the need of tribal knowledge of programmer of different component packages, maintaining some external documentation that identifies which probes can or cannot be used for certain packages, or manually verifying probes on physical assembly during first article build.

The automated BOM import in Test Expert using the IPC-2581B dataset did not handle non-populated components effectively. The issue identified was non-populated parts identified as “false” in the IPC-2581B dataset showed as populated. This was reviewed with Siemens PLM and a patch was released to correct the issue.

The Lockheed Martin design assembly was processed through the Acculogic machine. One issue was found at LM MFC-Dallas where the locations of the probes on the physical machine did not match that shown on the CAD representation on the machine software. These probes had to be manually corrected for numerous locations during the debug of the program. The root cause of this anomaly was not determined but most likely cause is an issue with the export tool within Test Expert to generate the .pba file.

5.3.7 Problem Reports

5.3.7.1 LM-MFC Test Problem Reports (1 Reports)

Problem Report #27 (RMS_TE031301): Test Expert v11 will not import BOM

Detailed Description:

The IPC-2581B BOM information did not read in and we were forced to use the BOM converter step in Test Expert. This did not save time as we had to format the BOM and configuration file.

Resolution:

Update to software. Siemens PLM released a patch to Test Expert that resolved the issue.

5.4 Lockheed Martin RMS-Owego

The Lockheed Martin design that was assembled at Lockheed Martin RMS-Owego was also tested at the Lockheed Martin RMS-Owego facility. Detailed below are the materials that were used to test the Lockheed Martin design, the test equipment used, the methodology for testing for both the present-state and future-state, the data that was collected during test from both the present-state and future-state, and a summary of the results.

5.4.1 Materials

- Lockheed Martin present-state files exported in CAD and csv format
- Lockheed Martin future-state file in IPC-2581B
- Siemen's Test Expert software v11

5.4.2 Equipment

- Takaya APT 9401CJ software version 5.0
- Takaya APT 9411CE software version 2.1-1B

5.4.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ►	Test Flying Probe / ICT
d Martin	RMS - Owego, NY	Mfg Equipment Vendor	Takaya
		SW Vendor	Siemens Test Expert v11

Future-state:

Partner ▼	Location ▼	Mfg Flow ►	Test Flying Probe / ICT
d Martin	RMS - Owego, NY	Mfg Equipment Vendor	Takaya
		SW Vendor	Siemens Test Expert v11

5.4.4 Present-state Process

The current process to generate flying probe program files uses Test Expert software, CAD file from either Zuken, Mentor, or Cadence, and an Excel parts list. The assembly drawing and schematics are also used during program generation. The following process is performed to generate the file outputs.

1. Obtain all required input files (CAD, BOM, DWG, Schematic) from EPDM
2. Convert the BOM with external processors (Depending on source of the BOM)
3. Manually check the BOM that all of the parts were converted correctly
4. Load CAD into Test Expert suit
5. Overwrite the BOM that is in the CAD with the external created BOM.

6. Use Test Expert to finish developing the output for the tester.
    a. Make sure the correct BOM (Modified) is installed in Test Expert
    b. Adjust the shape of all components on the board so the tester can access points on the board location
    c. Make sure the components are in the correct category (resistor, capacitor, etc.)
    d. Adjust the probing to be on the back 25% of pads
    e. Set up type of tester and determine fiducial points
    f. Determine the nail priorities
    g. Adjust probe location after auto probe placement
    h. Generate program
7. Optimize program with the first article
    a. Load program onto flying probe machine
    b. Input actual references (Photos) for fiducial and make the board easy and repeatable to install
    c. Further reduce selection of probes based on component packages and board layout
    d. Debug test steps

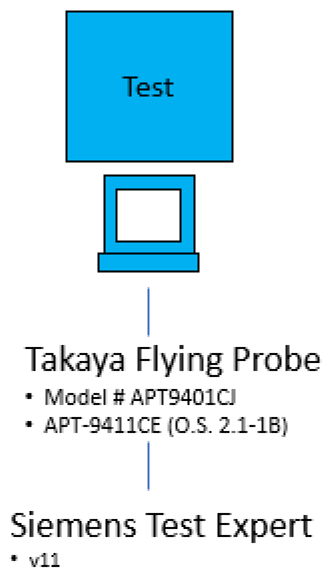


Figure 5-3: LM-RMS PWB process flow

5.4.5 Future-state Process

The Test Expert software was used to generate the flying probe program files using the future-state IPC-2581B dataset. The same process was used as the present-state process. Below are the differences between using the different formats.

1. During initial import into Test Expert using the IPC-2581B dataset, an issue was found where the BOM did not import properly. This was documented in problem report #27, RMS-TE031301, and corrected by Siemens. This resulted in automating the BOM import using the IPC-2581B dataset, eliminating steps 2, 3, and 5 of current process. This reduced the amount of time to generate the program and chances for human error.

2. During initial programming using the IPC-2581B dataset, the unpopulated components imported as populated and had to be manually corrected. This was reviewed with Siemens PLM and a new patch issued to correct this issue.
3. Certain probes were automatically eliminated as component height information is present in the IPC-2581B file. This reduced manually adjusting probes during debug of first article.

5.4.6 Data Observations

The BOM being incorporated into the IPC-2581B file format eliminated any manual formatting or editing of an external BOM prior to importing. This resulted in a time savings per assembly and reduced human error opportunities. Only having to get one file for data import also reduced setup time for programming versus retrieving several different file types. Also, since the BOM is part of the CAD at the variant level (-501, -502, etc.) versus having one CAD file for all variants, BOM cleanup/comparison is significantly reduced or eliminated.

The component height in the IPC-2581B dataset reduced manual selection/elimination of certain probes. This reduced the need of tribal knowledge of programmer of different component packages, maintaining some external documentation that identifies which probes can or cannot be used for certain packages, or manually verifying probes on physical assembly during first article build.

The automated BOM import in Test Expert using the IPC-2581B dataset did not handle non-populated components effectively. The issue identified was non-populated parts identified as “false” in the IPC-2581B dataset showed as populated. This was reviewed with Siemens PLM and a patch was released to correct the issue.

No issues were observed during processing of the assembly through the flying probe test at LM RMS - Owego.

5.4.7 Problem Reports

5.4.7.1 LM-RMS Test Problem Reports (1 Reports)

Problem Report #27 (RMS_TE031201): Test Expert v11 will not import BOM

Detailed Description:

The IPC-2581B BOM information did not read in and we were forced to use the BOM converter step in Test Expert. This did not save time as we had to format the BOM and configuration file.

Resolution:

Update to software. Siemens PLM released a patch to Test Expert that resolved the issue.

5.5 Sanmina

5.5.1 Materials

- Lockheed Martin present-state files exported in CAD and ,csv format
- Lockheed Martin future-state file in IPC-2581B
- Siemen’s Test Expert software v11

5.5.2 Equipment

- Analysis - FP Takaya APT 1400

5.5.3 Tools

Present-state:

Partner ▼	Location ▼	Mfg Flow ▶	Test Flying Probe / ICT
Sanmina	San Jose, CA	Mfg Equipment Vendor	Takaya ATT 9411 SL Takaya 8400
		SW Vendor	Siemens Test Expert v11

Future-state:

Partner ▼	Location ▼	Mfg Flow ▶	Test Flying Probe / ICT
Sanmina	San Jose, CA	Mfg Equipment Vendor	Takaya ATT 9411 SL Takaya 8400
		SW Vendor	Siemens Test Expert v11

5.5.4 Present-state Process

Sanmina's present-state process uses both the CAD file and an Excel parts list. These files are read into the Siemens PLM Test Expert software to generate the output file for the flying probe test machine. Additional references are made using drawings and schematics as needed.

The current process to generate flying probe program files utilizes Test Expert software,.pcf and .ftf file outputs from Zuken, and an Excel parts list. The assembly drawings and schematics are also used during program generation. The following process is performed to generate the file outputs.

1. Accumulate the necessary files and documentation .
2. Modify/format BOM for import into Test Expert. Approx. 15 to 30 mins if BOM already embedded into the IPC file
3. Imports CAD Files and BOM into Siemens PLM Test Expert software to create .CA9 File.
    a. Overwrite the BOM that is in the CAD with the external created BOM. Manually verify everything is correct.
    b. Adjust the shape of all components on the board so the tester can access points on the board.
    c. Adjust the probing location to be on the back 25% of pads.
    d. Make sure the components are in the correct category. (Resistor, capacitor, etc.)
    e. Set up type of test and determine fiducial points.
    f. Determine the nail priorities.
    g. Manually eliminate certain probes for components based on height – done by knowledge of programmer of component packages.
    h. Generate program – .CA9 file
4. Import .CA9 file into flying probe software and generates flying probe program.
5. Optimize program with the first article
    a. Load program onto flying probe machine
    b. Input actual references (Photos) for fiducial and make the board easy and repeatable to install.
    c. Further reduce selection of probes based on component packages and board layout.
    d. Debug test steps

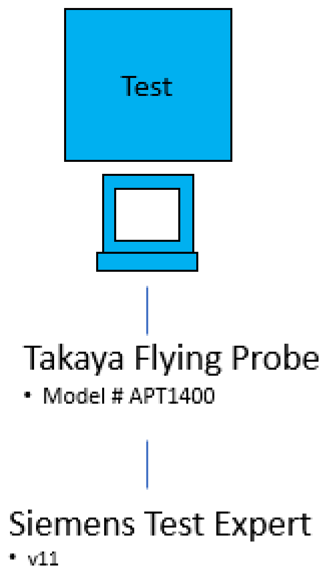


Figure 5-4: Sanmina PWB process flow

5.5.5 Future-state Process

The Test Expert software was used to generate the flying probe program files using the IPC-2581B dataset. The same process was used as the present-state process. Below are the differences between using the different formats.

1. Siemens PLM released a patch that was able to populate the component level data, including values, tolerance, and units, when performing the BOM import from the IPC-2581B dataset. Prior to this patch being released, the existing Excel file import was used. The data was re-run after the patch to confirm this data was populated automatically from the IPC-2581B dataset.
2. Certain probes were automatically eliminated as component height information is present in the IPC-2581B file. This reduced manually adjusting probes during debug of first article.

5.6 Discussion/Results/Summary

The data collected shows any issues using the file formats and resulting metrics (time savings using the IPC-2581B format). In addition, the gaps that exist with the IPC-2581 data, Lockheed Martin design practices, or Siemen's Test Expert software that prevented Sanmina from meeting the goals of automation with minimal human interaction are also documented.

The overall results of utilizing the IPC-2581B file showed a decrease in time required to generate programs for flying probe. Tables 5-1 and 5-2 show the PCB Flying Probe Performance Improvement Metrics.

Table 5-1: PCB Flying Probe Performance Improvement Metrics

Metric	Present-state	Future-state	Project Goal
1.) Difference/ discrepancies between existing assembly files and IPC-2581B	N/A present-state is baseline	Track # of differences and discrepancies found	0

2.) PCB Assembly Preparation	Track # of hours needed to setup for flying probe using existing files	Track # of hours needed to setup for flying probe using IPC-2581B	Reduction of 25% compared to present-state
3.) Assembly equipment SW vendor Changes	Track # SW changes required to correctly input/use existing files for flying probe	Track # SW changes required to correctly input/use IPC-2581B for flying probe	0

The following Tables show the results from each manufacturing site that performed flying probe.

Table 5-2: Denver Flying Probe Performance Improvement Metrics

Metric	Present-state	Future-state	Project Goal
1.) Difference/ discrepancies between existing assembly files and IPC-2581B	N/A present-state is baseline	0 – IPC-2581B dataset contained information to generate a usable program	0
2.) PCB Assembly Preparation	2 hours	1.5 hours	Reduction of 0.5 hours realized after re-running using BOM import with component details (values, tolerances, etc.)
3.) Assembly equipment SW vendor Changes	0	1 – Test Expert V11 script	0

Table 5-3: Dallas Flying Probe Performance Improvement Metrics			
Metric	**Present-state**	**Future-state**	**Project Goal**
1.) Difference/ discrepancies between existing assembly files and IPC-2581B	N/A present-state is baseline	0 – IPC-2581B dataset contained information to generate a usable program	0
2.) PCB Assembly Preparation	5 hours	2 hours	Reduction largely due to reduction of manual entry of component details in TestMatic
3.) Assembly equipment SW vendor Changes	0	1 – Test Expert V11 script	0

Table 5-4: Owego Flying Probe Performance Improvement Metrics			
Metric	**Present-state**	**Future-state**	**Project Goal**
1.) Difference/ discrepancies between existing assembly files and IPC-2581B	N/A present-state is baseline	0 – IPC-2581B dataset contained information to generate a usable program	0
2.) PCB Assembly Preparation	4 hours	2 hours	Reduction largely due to reduction of manual entry of component details in TestMatic
3.) Assembly equipment SW vendor Changes	0	1 – Test Expert V11 script	0

Table 5-5: Sanmina Test Performance Improvement Metrics			
Metric	**Present-state**	**Future-state**	**Project Goal**
1.) Difference/ discrepanc between existing test file and IPC-2581B	Gerber and/or ODB++ da	IPC-2581B data	N.A
2.) PCB Test Preparation	2 hours	2 hours	No significant reduction – usec Excel file for BOM to reduce manual entry of part level data
3.) Software	Test Expert V11 TestSigh V10.16.3	Test Expert V11 TestSigh V10.16.3	N/A

The times included in the metrics do not include debug time as this is highly sensitive to board complexity and not related to the dataset used to program the machines. The inclusion of component height in the dataset does reduce probe selection, which may reduce debug time.

When initially importing the IPC-2581B file into Test Expert, LM Space – Denver had to use the present-state BOM to import the BOM data (i.e. part numbers, attributes, and characteristics). Siemens provided a software patch that addressed this issue and the programming was performed again. A savings of 0.5 hours was observed.

The time savings realized by importing the component level data from the IPC-2581B data set compared to manually manipulating external BOM documents will be greater as the complexity of the assembly increases. The Lockheed Martin design used for this project was low complexity and did not require a large amount of time to manually generate the external BOM. For assemblies with hundreds of unique components, this time would be drastically increased. The data being automatically available is an enormous improvement in efficiency.

In summary, the IPC-2581B format resulted in time savings over existing present-state processes. While the overall process of creating a flying probe program using Test Expert did not change (reference Figure 5-5 below), the amount of work to prepare the data for use reduced significantly. The integration of the parts list data into the CAD yielded improvements in programming time. Additional data available in the IPC-2581B format, such as component height, also resulted in programming time reductions. The custom scripts required for importing PLM part data, to include information such as part values and tolerances, into the IPC-2581B dataset will result in unique solutions for each site. These unique solutions will have to be developed once and result in significant time savings and error-proofing over manually adding that data.

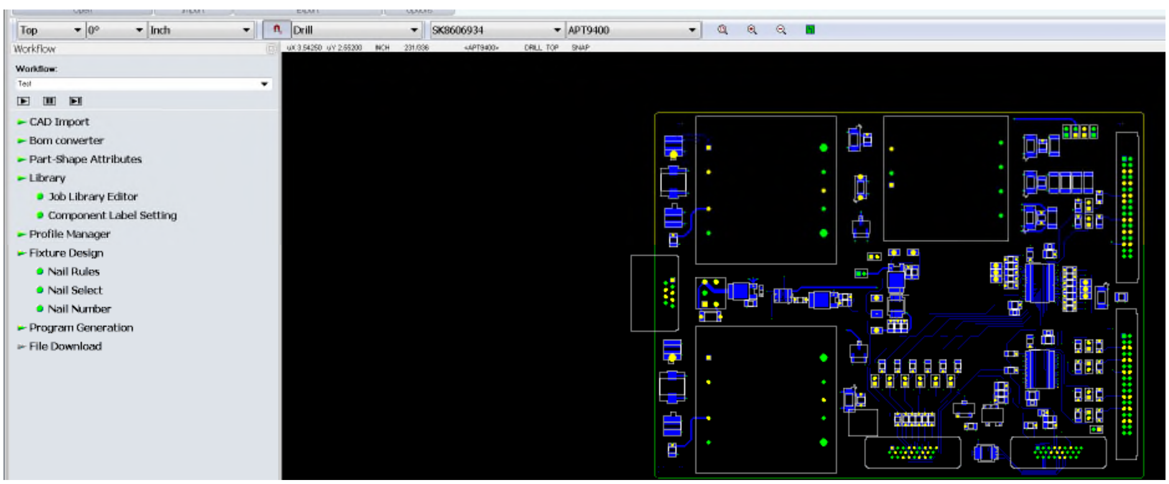


Figure 5-5. Test Expert Programming Screen

6 DMDII Project Conclusion

The success of the “Smart PCB Digital Factory” project hinged on receiving broad industry support for IPC’s standard, “PCB Product Data Description (Laminar View), also known as IPC-2581. First published in 2004, this standard began receiving significant attention in 2011 with the establishment of the IPC-2581 Consortium. The IPC-2581 Consortium members represent a broad cross-section of the PCB industry many of whom also support IPC standards development through committee participation. They recognize the value proposition IPC-2581B provides to the PCB industry.

The value of the DMDII “Smart PCB Digital Factory” project cannot be overstated. The DMDII umbrella enabled a diverse pool of talent from a variety of industry sectors to assemble and act as one cohesive team to test the merits of IPC-2581B. This project cultivated a synergy that enabled the team to openly collaborate and share expertise as they worked through decades-old present-state processes, explored future-state possibilities, and to thoroughly exercise newly developed software features, capabilities, and solutions to achieve the project objectives using IPC-2581B. Through these cooperative efforts many barriers were overcome and the root cause analysis of critical problems isolated. Solutions and work-arounds were provided in a timely manner allowing the project to proceed on schedule.

Though there were learning curves and issues encountered during the exercise, the majority of the team’s stated objectives aimed at enabling a digital thread for printed circuit board design and manufacture were realized during the execution of the DMDII “Smart PCB Digital Factory” project. The following summarizes the key achievements by each participant in the project.

6.1 Fujitsu

A comprehensive PCB process improvement initiative was undertaken by Fujitsu aimed at certifying the IPC-2581B dataset across its product development process. All major objectives within its control were achieved. Through this initiative Fujitsu has certified its digital PCB manufacturing “future-state” flow utilizing IPC-2581B and transitioned it to production use at its Richardson, Texas facility.

There are two software suppliers to Fujitsu depicted in the stoplight chart that were not able to supply solutions that include IPC-2581B support within the established DMDII project timeline. It should be noted that both software companies have indicated their intention to support IPC-2581B. This support will be incorporated in future releases of their respective software application suites.

6.1.1 Design process improvements:

- Regression testing of Cadence Allegro PCB Design v17.2 export of IPC-2581B for BOM, fabrication, assembly, test data.
- New authoring tool development, process automation development, and regression testing of Wise VisualCAM v16.9. VisualCAM now supports the authoring and export of IPC-2581B

data to support creation of assembly pallets and related features, impedance specifications, stack-up specifications, designer notes, and drill tolerance definitions.

- Internal tools to provide IPC-2581B export of PTC Creo Mechanical Assembly BOM were developed and implemented to support an IPC-2581B compliant BOM for the mechanical part content of the PCB assembly.
- Development, implementation, and validation of a streamlined revision control process for PCB products utilizing IPC-2581B in the product development lifecycle.
- New tools and methods were implemented to provide IPC-2581B support in Enovia PLM including:
    - PLM product structure creation of PCB and Mechanical assemblies,
    - Development of a comprehensive workflow supporting new part requests, new part qualification, links to related purchase specifications, and overall part lifecycle management
    - Tools and methods supporting BOM configuration, BOM validation, and BOM lifecycle management, “Where-Used” part searches, etc.
    - Tools to support unique IPC-2581B Function Mode exports for BOM, fabrication, assembly & test to protect intellectual property
    - ERP/MRP integration/interface supporting IPC-2581B transfer to Manufacturing Operations including Master Data Management, Procurement, and Production Control
    - Development and implementation of a new IPC-2581B driven preliminary BOM process supporting early procurement of long-lead items
    - Product Lifecycle Management and Release Management of PCB based products to facilitate configuration control of PCB products.
    - IPC-2581B data augmentation including the insertion of qualified suppliers, manufacturer part numbers, enterprise part attributes, firmware part numbers, and related lifecycle information to drive PCB Manufacturing
    - Enabled a streamlined administrative ECO procedure to accelerate the build order for NPI designs entering System Validation Test (gating First Customer Ship).
- Workforce training was developed and delivered to the Engineering team in support of the new tools, design practices, and process methodology that was introduced into the product development process.

Many incremental efficiency gains were made possible by having a complete product structure generated in PLM that provides visibility to every part of the PCB assembly including all components and part suppliers used and their corresponding lifecycle states, enabling traceability and enhancing sustainability of the product over its lifetime.

Both DMDII designs have been fabricated and assembled using only IPC-2581B, and when assembled together into a product, passed all tests with no issues. For Fujitsu the IPC-2581B process is considered a great success. Fujitsu met their objective of validating that their design and manufacturing process based on IPC-2581B is production ready. The IPC-2581B flow was placed into production for all future designs in the third quarter of 2018.

6.1.2 Fabrication process improvements

- Secured support from Sanmina to regress a fabrication data flow based upon IPC-2581B and certify it for production use.
- Introduction of intelligent specifications and layer features to convey requirements using intelligent, machine readable data in lieu of drawings, documents, and notes.
- Secured validation support from Sanmina to communicate the urgency of IPC-2581B support and build confidence with their CAM software providers that the standard is production ready for fabrication of Fujitsu designs.

6.1.3 Assembly process improvements

- Development, implementation, and regression test of a TexCAM parser supporting IPC-2581B import and machine program generation in Fujitsu's manufacturing facility.
- Acquisition, implementation, and regression testing of Wise VisualCAM Stencils v16.9 to streamline solder stencil creation and to export optimized IPC-2581B data destined for solder stencil suppliers.

6.1.4 Test process improvements

- Not performed at Fujitsu.

  Note: Though IPC-2581B contains everything required to support In-Circuit test this was not exercised by Fujitsu due to cost considerations. Functional test was used to verify the assembled product.

6.1.5 Inspection & Defect Analysis improvements

- Secured support from DeMille Research to facilitate the import IPC-2581B for Vitrox AOI and AXI equipment used for inspection and defect analysis at Fujitsu.

6.1.6 Other

- Several product development process improvements were prepared and exercised as the future-state process was developed around IPC-2581B. The visibility of intelligent data throughout the product development process enables Fujitsu to identify and eliminate unproductive, decades old practices and further streamline the product development workflow.

  One example of this gain in efficiency through design cycle-time compression was achieved at Fujitsu is demonstrated by how the design process was "left-shifted" to accelerate the "production release" objective. Leveraging visibility to key product lifecycle state information that is communicated through IPC-2581B throughout design and manufacturing Fujitsu is now able to issue the "production ready" build cycle with confidence that the design and manufacturing package has been thoroughly validated. Key enablers for this include:

- IPC-2581B data builds the product structure created in PLM linking all relevant part, spec, and characteristic, and attribute information. This data drives ERP and MRP operations for the PCB product.
- Component lifecycle states are known and visible throughout the product development workflow from prototype through production ready
- Production part number assignments are the norm including those assigned to "Prototype" parts and designs – the lifecycle is tracked as a "state" of that object
- Timely delivery of all required part, product, quality, and compliance information is a continual focus. The objective is to move all component lifecycle states in the BOM to the "production-ready" state as early as possible
- PCB assembly test results from last "prototype" build is fed back from Manufacturing and Engineering reviews of the build. This gates a "Go/No-Go" decision point. This "Go/No-Go" is the final item that gates the "production-ready" lifecycle state transition of the PCB assembly
- Upon successful tests of an assembly containing production ready parts, production lot builds destined for System Validation Test are triggered by an administrative ECO

Leveraging the intelligent information from Design through Manufacturing and accelerating the delivery of key work items enabled Fujitsu to eliminate a complete cycle back through CAD, reducing the production build cycle times an average of 10 to as many as 14 calendar days per design. First Customer Ship (FCS) dates for new products occur sooner as a result.

6.1.7 Next Steps

For Fujitsu this is not the end of the road, but the opening of a door into a new world of possibilities. Some of the following plans are already underway:

- Use IPC-2581B as the data transfer format between remote sites (using different CAD tools), 3rd party developers, and external customers of our assembly facilities
- Enhance CAD libraries to improve support of IPC-2581B properties
- Make use of the structures that IPC-2581B supports, such as slots, cavities, edge chamfers, etc.
- Continue to work with the IPC-2581B Technical Committee on introducing enhancements in future revisions of IPC-2581, such as support for flex designs, coins, links to external object such as 3D models or specifications, etc.
- Use IPC-2581B based data as the payload for machine to machine communication

Change is never easy, but the benefits now seen with IPC-2581B and the potential it provides for the future have made the change worthwhile.

6.2 Lockheed Martin

Lockheed Martin engaged in the DMDII "Smart PCB Digital Factory" as a part of their corporate "Digital Tapestry" initiative. This was Lockheed Martin's first examination of IPC-2581B in the PCB product development process. Lockheed Martin's primary objective was to gain sufficient understanding and experience to determine if the application of IPC-2581B at Lockheed facilities was feasible. Thorough evaluations were conducted at three Lockheed Martin facilities: LM MFC-Dallas, Texas, LM Space-Littleton, Colorado, and LM RMS-Owego, New York. Lockheed Martin's design was successfully fabricated, assembled and tested at five different locations using IPC-2581B.

Through this initiative Lockheed Martin has concluded that IPC-2581B is a good fit for its digital PCB manufacturing "future-state" goals and objectives. Through the partnership formed to support the Smart PCB Digital Factory project, this project showed that a Lockheed Martin design can be designed, fabricated, assembled and tested across multiple locations. This demonstration now supports further investment in changing the upfront processes for circuit and layout designers to fully integrate IPC-2581B into their business practices and PDM tool.

The metrics show a significant reduction in the time that it takes to create a design file. Additional efficiencies are expected to be seen during design verification as certain manual, labor intensive and error-prone steps are eliminated. Also, design file configuration management concerns will be eliminated as there will only be one file that contains all design information. These are the benefits that the Lockheed Martin Space design team sees going forward and understands that the efforts put in upfront to ensure the accuracy of the design will set the stage for seamless processing and automation downstream.

There was one software supplier to Lockheed Martin depicted in the stoplight chart that was not able to supply a solution that included IPC-2581B support within the established DMDII project timeline. It should be noted that this software supplier has indicated intent to support IPC-2581B. This support will be incorporated in a future release of their software application suite.

New tool learning curves, the lack of automation scripts, and several application software deficiencies impacted metrics collected at several locations. These unavoidable initial experiences will be overcome with time as the tools improve, automation is developed, and operators gain experience.

The BOM for the Lockheed Martin design contained a small number of components. As the part count increases it is expected that the overall time savings the IPC-2581B future-state process contributes over present-state methods will be much greater.

6.2.1 **Design process improvements**

Lockheed Martin Space thoroughly exercised the Zuken CR8000 PCB design tools and ECAD library capabilities with respect to IPC-2581B support. All major issues were addressed through workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8.

6.2.2 **Fabrication process improvements**

The project team thoroughly exercised the Frontline Genesis (Lockheed Martin) and Frontline InCAM (Lockheed Martin and Sanmina) CAM tools and abilities with respect to PCB fabrication using IPC-2581B. All major issues were addressed through workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8. Some of the major improvements with this new data format include:

- All copper layers are contained in one file, and the stack-up order is dictated in the schema which eliminates the need for the CAM technician to do layer naming and ordering
- Excellon drill data is included in the IPC-2581B file, using a consistent format with the schema

Overall, the PCB CAM fabrication metric for a 25% reduction was not achieved but it is believed that with additional experience and having flushed out some of the bugs in the software and tool systems having exercised the new IPC-2581B data standard, there can be efficiency gains in the future. This gain in efficiency will continue to improve when new scripts are written to take advantage of the intelligence contained in IPC-2581B future-state data to automate many redundant data manipulation tasks performed by the CAM technician on the present-state data.

The relatively young and evolving IPC-2581B standard is an intelligent format for delivering all the data needed to automate PCB manufacturing in one file. The IPC-2581B standard is open to implementation by anyone desiring to fabricate PWB's with no license required. This future-state format is expected to reduce PWB Pre-CAM cycle-time to a few minutes and minimize the common mistakes and line-stopping technical queries that often occur during the CAM "clean up" process using present-state files.

6.2.3 Assembly process improvements

The project team thoroughly exercised the Siemens Unicam software at three locations as well as Aegis (Sanmina) CAM tool abilities with respect to PCB assembly using IPC-2581B. All identified issues were addressed. All major issues were addressed to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8.

After assembling the Lockheed Martin design, the team believes that the time saved using the IPC-2581B data depends a good deal on the complexity of the PWB assembly.

From this project we can conclude that the IPC-2581B has the potential to save significant amounts of time and reduce mistakes in assembly due to manual data manipulations. While the project showed some mixed results, we are confident that with further software improvements, OEM process development, and continued IPC-2581B schema enhancements, full assembly factory automation will no longer be a dream but a reality.

6.2.4 Test process improvements

Lockheed Martin thoroughly exercised the Siemens Test Expert CAM tool abilities to support Flying Probe test using IPC-2581B at four locations. All identified issues were addressed. All major issues were addressed through workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8. Enhanced capabilities and future opportunities for improvement in Test are summarized below:

- The inclusion of component height in the dataset does reduce probe selection, which may reduce debug time.
- When initially importing the IPC-2581B file into Test Expert, LM Space – Denver had to use the present-state BOM to import the BOM data (i.e. part numbers, attributes, and characteristics). Siemens provided a software patch that addressed this issue and the programming was performed again. A savings of 0.5 hours was observed.
- The time savings realized by importing the component level data from the IPC-2581B data set over manually manipulating external BOM documents will be greater as the complexity of the assembly increases. The Lockheed Martin design used for this project was low complexity and did not require a large amount of time to manually generate the external BOM. For assemblies with hundreds of unique components, this time would be drastically increased. The data being automatically available is an enormous improvement in efficiency.

- It is important to note that the values, units, and tolerances are in textual characteristics in the electrical category of the dataset. There are property placeholders within the IPC-2581B schema for these values, but they are left blank due to the CAD software not properly loading them. Custom scripts and web services need to be developed at each site to integrate part data from the PLM system that is being utilized. Siemens generated a custom script to allow for these values to be imported into Test Expert from the IPC-2581B dataset. This is an interim solution and the direct import of PLM part data to the IPC-2581B fields is a more robust solution for future improvement.

In summary, the IPC-2581B format resulted in time savings over existing present-state processes. While the overall process of creating a flying probe program using Test Expert did not change the amount of work to prepare the data for use reduced significantly. The integration of the parts list data into the CAD yielded improvements in programming time. Additional data available in the IPC-2581B format, such as component height, also resulted in programming time reductions. The custom scripts required for importing PLM part data, to include information such as part values and tolerances, into the IPC-2581B dataset will result in unique solutions for each site. These unique solutions will have to be developed once and result in significant time savings and error-proofing over manually adding that data.

6.2.5 Next Steps

This was the first evaluation of IPC-2581B in Lockheed Martin's PCB product development process. It was also an initial readiness review of two of their CAD and CAM software application suppliers, Zuken and Siemens, as well as one of their contract manufacturers, Sanmina, for assembly and test. Though issues were identified, there were no insurmountable barriers encountered. The high-level expectations were achieved successfully.

Lockheed Martin will continue to develop its Digital Tapestry vision and work closely with its CAD and CAM software and equipment suppliers to enhance support for the IPC-2581 standards. Future project phases will examine how Lockheed Martin reconciles the engineering BOM and manufacturing BOM within the IPC-2581B and address other concerns such as paperless manufacturing, traceability of requirements, and other opportunities that will improve efficiency.

6.3 Sanmina

6.3.1 Fabrication process improvements

Frontline InCAM was exercised using Fujitsu's IPC-2581B WAM1 exports from Cadence Design Systems SPB 17.2 ECAD and Wise VisualCAM v16.9 CAM applications.

Frontline InCAM was exercised using Lockheed Martin's IPC-2581B export from Zuken's CR-8000 ECAD application.

All major issues were addressed through workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8.

6.3.2 Assembly process improvements

Aegis version 7.7.16.0 was exercised in the assembly process. All major issues were addressed through workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented. In Section 8.

Sanmina used the Aegis software and encountered issues with Aegis correctly importing in data from the IPC-2581B. A total of 55 min could have been saved had the Aegis software successfully imported in the BOM description information, fiducials, and do-not-install part information, and when Aegis software can read in IPC-2581B files directly without needing to edit the primitive names.

6.3.3 Summary

Sanmina believes the PCB industry is looking at an inflection point very similar to when it moved away from hand-taped circuit designs and converted to computer-generated artwork. Specifically, the manufacturers spend too much engineering time rearranging the layout for each customer. When they provide their “standard” pdf file they are often told other suppliers are more advanced because they use Excel. This is certainly true for stack-up. Today Sanmina uses pdf, image files like jpeg or png, and Excel. The Excel format is most troublesome as each OEM wants a different layout of the file because they are looking to automate the import back into their systems. Hence the need for an open standard method like IPC-2581B advocates. IPC-2581B is considered “intelligent data” because it is attributed, revision controlled, and validated, often through automated processes, before it is released from the OEM. This enables new efficiencies through open, collaborative design and manufacturing.

A single file format that can be exchanged between CAD and CAM is a benefit to OEMs, PCB fabricators, and contract manufacturers. The use of a single, intelligent file that facilitates the exchange of intelligent data in both directions and be saved and revision controlled enables a coherent exchange of information.

In summary the value proposition for IPC-2581B for fabrication, assembly and test includes:

- Reduced time to quote
- Reduced time for Pre-CAM
- Bi-directional exchange format for Stack-ups
- Reduced Engineering time
- BOM and AVL data including attributes and specifications for materials, components, etc.
- Standard format for first article, compliance, and inspection reports
- Cycle time reduction
- Elimination of mistakes
- Cost savings

6.4 Zuken

CR-8000 v2017 was thoroughly exercised by Lockheed Martin. All major issues were addressed through bugfixes and workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional requested enhancements are documented in Section 8.

6.5 Siemens

6.5.1 Assembly (UniCAM)

Unicam version 11 was thoroughly exercised by Lockheed Martin. All major issues were addressed through bugfixes and workarounds in to complete the stated objectives of the project in a timely manner. A list of problem reports with additional enhancement requests are documented in Section 8.

6.5.2 **Test (Test Expert)**

Test Expert version 11 was thoroughly exercised by Lockheed Martin. All major issues were addressed through bugfixes and workarounds to complete the stated objectives of the project in a timely manner. A list of problem reports with additional enhancement requests are documented in Section 8.

While RIT did see time reduction, they did not achieve the 25% goal because they did not assemble all the components. More time would have been saved had the design been fully populated.

6.6 **RIT**

6.6.1 **Assembly process development**

Through RIT's future-state lab experiments using IPC-2581B it was concluded that the intelligent part attributes lead to streamlined production programs, eliminating present-state inefficiencies. Accurate definition of part centroid data is one example of this improvement.

Data transfer inefficiencies that may still occur stem from the component libraries that may not be able to transfer the component shape data correctly requiring component engineering to manually correct the component shape for the assembly programs. This problem will be explored and addressed by the IPC 2-16 Product Data Description and subject matter experts from the PCB industry to develop short-term and long-term solutions to address this concern in the IPC-2581 schema.

6.6.2 **Workforce Development**

RIT collaborated with the DMDII project team to develop an industry framework for workforce development as a part of the DMDII project. RIT created a lab to introduce IPC-2581B into the coursework at its Center for Electronics Manufacturing and Assembly (CEMA) facilities. IPC-2581B data from the Lockheed Martin design was used to prove out the flow in the CEMA lab. Through a hands-on lab, RIT's students learned the benefits the IPC-2581B standard provides over the present-state file set utilized in the PCB industry today. The results tell a compelling story of how the implementation of the IPC-2581B can be integrated with engineers with 25 plus years' experience in SMT and those engineers with less than five years, all with minimal training.

6.7 IPC

6.7.1 IPC-2581B Standard

IPC-2581B (Lockheed Martin) and IPC-2581B WAM1 (Fujitsu) standards and related schema were thoroughly exercised in performing the Smart PCB Digital Factory project. No major barriers were encountered in the fabrication, assembly, or test of the three designs. Several suggestions for feature enhancements to the schema were captured and will be explored in the next revision of the standard. These include the following:

Proposal	Description	Group	Target Revision	Target Date for Spec	Comments
Relaxed restrictions for shortName and qualifiedNameType	set to the pattern to ([^:\s]+)(:[^:\s]+)?	2-16	C	12/1/2018	To be re-addressed in "C"
Confirm Legacy PhyNet Exposure is based upon the existence or absence of soldermask. Review the use/purpose of IPC-2581 LayerNameRef and NetNode as described in the Spec.	What purpose does LayerNameRef serve? How would one describe PhyNetPoints on inner layer vias - assume soldermask isn't a consideration?	2-16	C	12/1/2018	Embedded Designs, Cavities, and Flex champions are required
PCB Stackup Exchange has multiple methods allowed. Cadence, Zuken, Wise, Polar, Frontline all have different implementations that often are incongruent.	layer-spec relationship needs to be examined	2-16	C	12/1/2018	Need to convene a meeting to discuss.
Drill Data can be represented using multiple methods in the current specification. (C. Shaw has a proposal?)	LayerFeature -> Hole, PadStack -> LayerHole	2-16	C	12/1/2018	To be re-addressed in "C"
The present specification supports multiple methods for defining Pads (May have been addressed in RevB WAM1?)	Need to confirm if this is a schema issue or a developer issue.	2-16	C	12/1/2018	May need to re-examine problem statement and review their data.
The present schema only provides a single placeholder for the package definition.	The present schema only provides a single placeholder for the package definition. DFx wants placebound, SMT Ops wants accurate package geometry. IPC-2581 needs to provide both.	2-16	C	12/1/2018	Placebound (DRC), Assembly view (Drawing), 2D Package Definition (DFx, SMT)
Support for GD&T dimensioning on a drawing layer is required	Need to consider how Z-axis geometry is handled in the schema	2-16	C	12/1/2018	Need 2-40 team to start this work.
Sectionals supporting Software Developers, OEMs, Fabricators, Contract Manufacturers, Assemblers, Testers, etc. are needed.	IPC-2581 Adoption support: Guidelines and best practices to provide a technical reference guide for each discipline.	2-16 & 2-40	C	12/1/2018	Need industry support for this. Can IPC/IPC Consortium Marketing team solicit industry participation ?

6.7.2 **Workforce Development**

IPC has developed a framework to assist industry through the IPC-2581 adoption process. This plan outlines a strategy for those interested in pursuing IPC-2581B adoption including:

- Overview of the Industry
- Roles and Profiles
- Methodology for Dissemination
- Preparing the Future Workforce
- Adoption
- Sustainability
- Marketing and Communication Strategy

See "*Workforce Development Plan, Printed Circuit Board Factory 4.0, Design to factory data transfer*" DMDII Project, May 2018, Submitted by IPC

A need for several new IPC sectional standards was identified to support workforce development and industry adoption. These new sectionals will provide guidance to industry adopters of IPC-2581B including Software Suppliers and Developers, OEMs, Fabricators, Contract Manufacturers, and other suppliers to the PCB industry.

6.8 Metrics Summary

6.8.1 Fujitsu Design and Manufacturing Metrics Summary

Fujitsu Network Communications							
Action	**Location**	**Goal**	**Actual**	**Design Iterations**	**Tool Updates**	**Manual Work-arounds**	**Comments**
Design 1	**FNC**	**25%**	**81%**	1	1	0	Fix drill location
Fab 1	**Sanmina**	**25%**	**25%**	0	0	1	Used Wise 2581 Free Viewer to extract intelligent information CAM tool does not support
Stencil 1	**FNC**	**25%**	**25%**	0	0	0	
Assy 1	**FNC**	**25%**	**70%**	0	0	0	
AXI 1	**FNC**	**25%**	**72%**	0	0	0	
Test 1	**FNC**	**25%**	**N/A**	N/A	N/A	N/A	Functional test was performed
Design 2	**FNC**	**25%**	**68%**	0	0	0	
Fab 2	**Sanmina**	**25%**	**25%**	0	0	1	Use Wise 2581 Free Viewer to extract intelligent information CAM tool does not support
Stencil 2	**FNC**	**25%**	**33%**	0	0	0	
Assy 2	**FNC**	**25%**	**50%**	0	0	0	
AXI 2	**FNC**	**25%**	**61%**	0	0	0	
Test 2	**FNC**	**25%**	**N/A**	N/A	N/A	N/A	Functional Test

6.8.2 Lockheed Martin Design and Manufacturing Metrics Summary

Lockheed Martin Corporation							
	Location	Goal	Actual	Design Iterations	Tool Updates	Manual Work-arounds	Comments
Design 1	**LM-S**	**25%**	**80%**	2	2	1	Zuken CR8000: Adjust precision, configure BOM attributes, add fiducials, fix drills, patches for OEMDesignNumberRef, do-not-install parts
Fab 1	**Sanmina**	**25%**	**25%**	0	1	1	Reference fabrication drawing information
Assy 1	**LM-S**	**25%**	**25%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes
Test 1	**LM-S**	**25%**	**25%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes
Fab 1	**Sanmina**	**25%**	**25%**	0	0	1	Reference fabrication drawing information
Assy 1a	**Sanmina**	**25%**	**23%**	0	0	2	Aegis import does not read BOM, DNI attributes. Use present-state Excel BOM and manually adjust do-not-install parts
Test 1a	**Sanmina**	**25%**	**0%**	0	0	1	Did not receive Siemens Test Expert patches for BOM and do-not-install parts attributes
Fab 2	**LM-RMS**	**25%**	**0%**	0	2	1	Reference fabrication drawing information, Correct Frontline InCAM installation, Correct Orbotech plotter configuration
Assy 2	**LM-RMS**	**25%**	**38%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes
Test 2	**LM-RMS**	**25%**	**50%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes
Fab 3	**LM-MFC**	**25%**	**0%**	0	1	1	Reference fabrication drawing information
Assy 3	**LM-MFC**	**25%**	**31%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes
Test 3	**LM-MFC**	**25%**	**60%**	0	0	0	LM-S provided machine programs for MFC Test
Assy 1b	**RIT**	**25%**	**9%**	0	1	0	Patches to Siemens Unicam BOM attributes and do-not-install attributes

7 Definitions and Acronyms

7.1 Definitions

Legacy: The term “legacy” is used when referring to older tools that are still used in the present-state or as ‘heritage’ tools.

“Siemens” herein only refers to Siemens Product Lifecycle Management Software Inc (Siemens PLM Software).

7.2 Acronyms

The following acronym list defines most acronyms used in this document. Some acronyms are defined in the location where they are used. Acronyms which are specific product names are not included below. Acronyms such as XML and JPG, JPEG, TIFF, and BMP are not included below.

IPC
DMDII............................Digital Manufacturing and Design Innovation Institute
LDI................................Laser Direct Imaging
MFC ....Missiles and Fire Control (Lockheed Martin)
RMS ....Rotary Mission Systems (Lockheed Martin)
AOI ....Automated Optical Inspection
PTH ....Plated Through Hole
RIT ....Rochester Institute of Technology
PWA..............................Printed Wiring Assembly (same as CCA)
SI...................................Signal Integrity
SMT...............................Surface Mount Technology
LM ....Lockheed Martin
CCA...............................Circuit Card Assembly (same as PWA)
PCB...............................Printed Circuit Board
BOM ....Bill of Material (Parts List)
EBOM............................Electronics Bill of Materials
MBOM ....Mechanical Bill of Materials
PWB ....Printed Wiring Board (same as PCA)
ECAD ....Electronic computer-aided design
MCAD............................Mechanical computer-aided design
CAD...............................Computer Aided Design
CAM ....Computer Aided Manufacturing
DFM ....Design for Manufacturing
DFx................................Design for…
DNI ....Do Not Install
SPDF.............................Smart PCB Digital Factory (the name of this DMDII project)
PLM...............................Product Lifecycle Management
ERP...............................Enterprise Resource Planning
MRP ....Material Requirements Planning
OEM ....Original Equipment Manufacturer
AVL ....Approved Vendor List
SW ....Software
PL..................................Parts List

8 Problem Reports

8.1 Naming Convention

When the decision was made to capture problems as they were encountered, a PDF form was created to capture key details. Each problem report contains:

- Company / team member creating the report
- Author & date
- Process phase (design, fab, assy, test)
- Brief Title/ Summary
- Details of issue
- Proposed Resolution / Recommendation/ Action Taken
- Additional page(s) required/ attached? (y/n) *[additional pages are not included herein]*

8.2 Full Problem Report List

Information exchange between individuals/companies is shown as resolutions were explored and defined. For the purposes of this report, interactions are shown as:

LM-Space = Lockheed Martin Space (Denver, CO facility)

LM-MFC = Lockheed Martin Missile & Fire Control (Dallas, TX facility)

LM-RMS= Lockheed Martin Rotary Mission Systems (Owego, NY facility)

TWS = Thing Weaver Solutions

Siemens refers to “Siemens Product Lifecycle Management Software Inc” (Siemens PLM)

Fujitsu refers to Fujitsu Network Communications, Inc.

The full problem report listing is provided to demonstrate the actions taken to successfully complete the project. Statements shown in these problem reports do not represent commitments by team members.

8.2.1 IPC file issue - need more than Design level files

No.	ID/FileName	Author	Date	Title/ Summary
1	SIE_PD120601	Siemens	12/6/2016	IPC file issue - need more than Design level files

Details of Issue: Summary: Component CAM1 appears differently from WISE in Siemens software. Siemens creates the shape outline from the outline of the package definition. WISE does not display this information. It just displays layers. It would also be better to be testing with a file that has a FUNCTIONMODE of FULL because DESIGN level files are missing the information that allows Siemens software to map the copper for pins to their components.

WISE: Triangle is on CompArea-A. No way to display Package -> Outline

FX: Triangle comes from Package -> Outline

TE: triangle comes from Package -> Outline, smaller triangle can be seen when turning on layer CompArea-A

FX shape outline matches Package -> Outline. See polygon definition in bottom status bar:

FX shape CAM1 outline from the Zuken file

see- FX shape CAM1 outline from the Zuken file

Produce an IPC file that has a FUNCTIONMODE of FULL because DESIGN level files are missing the information that allows Siemens software to map the copper for pins to their components.

12/13 - ZukenUSA asked LM-Space to confirm version of software in use is Rev 2017. LM is using CR-8000 Design Force 2015 (Release 2015.120). LM-Space has been given a license for 2016 for testing purposes; Check with LM-Space to produce the FULL IPC-2581B output.

12/14 – LM-Space posted new files. Siemens team analyzed the files and found data missing for the pins (Simply - layer feature pads should reference a component pin combination as required by the spec).

12/16 - TWS: "Unfortunately there are two methods 'pin' can be defined in IPC-2581B. It is a known issue … meaning this is not the first time the issue has come up. Though this is not an ideal situation the Standards Development Committee voiced concern that declaring a single "best" method might impact existing implementations thus the duplicate method has not(yet) been deprecated."

12/21 - TWS, ZukenUSA, and Siemens discussed, resulting in a change to the Siemens PLM parser.

Resolved:

1/13 - Received confirmation from Dawn that Siemens PLM has no issues with the design files and that the data missing for the pins has been resolved by making changes to their parser.

Resolution Owner LM-Space & ZukenUSA

8.2.2 IPC-2581B file does not contain component values or tolerances

No.	ID/FileName	Author	Date	Title/ Summary
2	SSC_PD012301	LM-S	1/23/2017	IPC-2581B LM D1 file does not contain electronic component values or tolerances.

Details Of Issue: Flying probe testers need electronic component values and tolerances to compare actual test values against.

Proposed Resolution/ Recommended Action

Workaround, if necessary: use a separate BOM with this information and import this data for testing.

ZukenUSA will need to update the IPC-2581B file output to include this information.

ZukenUSA: Believe this issue is fixed in Design Force 2017. This upcoming version will have the ability to include user-defined properties such as value, tolerance, LMC part number and so on. I should be able to test this version around the end of February and we should be able to deliver a released version to LMC around the end of March or early April. In short, I hope we can resolve this issue soon, but for right now a separate BOM may be needed. As soon as I can get my hands on the beta version of 2017, I'll generate a test file for review.

Status: Resolved. This issue was resolved by ZukenUSA

Resolution Owner ZukenUSA

8.2.3 File compare: Gerber and IPC-2581B using the CAM350 tool

No.	ID/FileName	Author	Date	Title/ Summary
3	SSC_PD012401	LM-S	1/24/2017	Performing the file compare between Gerber and IPC-2581B using the CAM350 tool, additional nodules appeared that shorted the planes together.

Details Of Issue: The designer (LM-S) went through the artwork layer by layer looking for the origin of the nodules but cannot find anything in the source data.

Proposed Resolution/ Recommended Action

Need to engage Zuken regarding the IPC-2581B Zuken output.

Need to find contact at CAM350 about a netlist check with the IPC-2581.

Confirmed that this issue was not only seen in the CAM350 tool. TWS also saw it in the WISE tool.

1/22/2017: A second design was evaluated and confirmed to have differences between IPC-2581B and Gerber that could not be resolved in the database. See attachment 2

ZukenUSA to get development time starting on 2/27.

3/3/2017: [ZukenUSA] There is a way to output the IPC-2581B data without creating the phantom objects on the internal layers. These were a problem because they would've caused shorts in fabrication. The other main issue is that with Cam350 and our data, the netlist checker shows issues related to surface mount pads. Apparently, we are defining these surface mount pads as "through" pads, but the geometry is really only appearing on the correct layer. So Cam350 is reading the definition and that's over riding the physical definition. I'm working with dev to identify the cause of the definition and see if we can fix it on our end. So I feel that we may be able to proceed with the current data, (of course this is up to you). If needed I can provide LM-Space with the command line needed to generate the same data as I provided for test.

Resolved:

3/6/2017 There are two options:

1) (Simple method) When outputting the data as you've done in the past, just change the units to MM. This bumps up the accuracy enough to resolve the element issue from the internal layers. Then convert the data to Inch when reading into Cam350 and other tools.

2) (More complex method) Open a "Command Prompt" from the CR-8000 Engineering Desktop tool. This is available under the right click tool options when set to Board Data file filter. Once the command prompt is open, navigate to the folder where your .dsgn file resides. Type the following command: DFipc2581out -p:decimal 8 -p:unit inch

This increases the accuracy enough to resolve the element issue. The default accuracy for the GUI command is 5 places, this command uses 8 decimal places.

3/6/2017 [LM-Space] It doesn't take the command DFipc2581out.

3/8/2017 [LM-Space] I was able to generate the file. Today I verified the anomaly did not exist, however, I cannot recreate the anomaly with the old file, I have a new revision of CAM350, and maybe that has something to do with it. Now that the new file is loaded I can have TWS look at it with Wise and verify the old to the new file as a sanity check.

Resolution Owner ZukenUSA

8.2.4 LM-S design does not contain fab drawing info in IPC 2581B file.

No	ID/FileName	Author	Date	Title/ Summary
4	SAN_PD013101	Sanmina	1/31/2017	LM design does not contain fabrication drawing information in the IPC 2581B file. Comparison between LM Design and Fujitsu Design has been provided.

Details Of Issue: Clear definition of Stack-Up, Impedance, Designer Notes, Standard Notes, Board Information, and Compliance Information is not contained within the LM Design IPC-2581B file.

Proposed Resolution/ Recommended Action

Workaround was to use present-state PDF drawings for required fabrication information.

Status: Future solution is TBD. LM needs a tool that will support this. (Blueprint/Wise) Preference for Blueprint to export layer into IPC-2581B file. Potentially common issue (with different solutions) for LM-RMS & LM-MFC

Resolution Owner Lockheed Martin

8.2.5 Drill data support in IPC-2581B

No.	ID/FileName	Author	Date	Title/ Summary
5	TWS_PM020101	TWS	2/1/2017	Drill data support in IPC-2581B

Details Of Issue: Drill information described by the elements Hole (8.2.3.12.4) and LayerHole (8.2.3.2.1) contain dimensional tolerance attributes plusTol and minusTol.

Proposed Resolution/ Recommended Action

This information must be authored and/or managed by CAD and CAM applications that produce and consume Lockheed Martin design data (e.g. ZukenUSA, Cadence, Mentor, Downstream, Wise, and Frontline). For the purposes of this project, ZukenUSA, Downstream, and Frontline are critical.

LM workaround: fabricator must manually apply a tolerance attribute to all drill information in the existing design.

Sanmina Problem: With Fujitsu design data, to which tolerance data was already present in the IPC-2581B file, Sanmina's challenge was that IPC-2581B allows you to have a tolerance per each drill location. Frontline did not take in all the instances of tolerance since this was a significant amount of data - it was left blank. Frontline agreed to use the tightest tolerance for each drill size and worked this into their program. This has been tested and software is now working at Sanmina (Insight, InCAM, and Genesis).

Status: Used workaround for Lockheed Martin design and fully solved for Sanmina with Fujitsu IPC-2581B design files. Future: Does/will Zuken CR-8000 IPC-2581B output contain tolerance information?

Resolution Owner ZukenUSA

8.2.6 Extraneous Layer data in Zuken Export

No.	ID/FileName	Author	Date	Title/ Summary
6	TWS_PM022301	TWS	2/23/2017	Extraneous Layer data in Zuken IPC-2581B Export

Details of Issue: IPC-2581B file contains extra layers

Proposed Resolution/ Recommended Action

Workaround is for the board fabrication shops to ignore these layers by making them document layers.

IPC-2581B output contained numerous layers of which only a small subset contained fabrication data required by the PCB manufacturers. The extraneous layers should be suppressed from the IPC-2581B export.

Zuken resolution being implemented in a future release.

Resolution Owner ZukenUSA

8.2.7 Incorrect Part Data in Zuken IPC-2581B Export

No.	ID/FileName	Author	Date	Title/ Summary
7	TWS_CC022302	TWS	2/23/2017	Incorrect OEMDesignNumberRef and internalPartNumber assignments in Zuken IPC-2581B Export

Details of Issue: In the Feb 2017 IPC-2581B file exported from Zuken CR-8000:

- OEMDesignNumberRef* contains a Lockheed Martin footprint name.
- internalPartNumber contains the engineering EBOM part number

This is not the correct use of these elements.

Proposed Resolution/ Recommended Action

OEMDesignNumberRef should be populated with an engineering EBOM part number associated with the part specification document containing all qualified "fit-form-function" equivalent manufacturer part numbers from approved suppliers.

*internalPartNumber should be populated with the manufacturing part number associated with the OEMDesignNumberRef. This typically includes a suffix to the OEMDesignNumberRef or a cross reference to another MBOM part number that includes packaging specific requirements (i.e. Tape & Reel specification, Tray specification, or other packaging specifications and the associated labeling specifications)

Status: Resolved by ZukenUSA.

Resolution Owner ZukenUSA

8.2.8 Variant design flow or methodology for do-not-install components

No.	ID/FileName	Author	Date	Title/ Summary
8	TWS_CC022303	TWS	2/23/2017	Variant design flow or methodology for do-not-install components

Details Of Issue: Optional use of the "populate = true|false" element under RefDes is not seen in the Zuken output though a number of parts used in the schematic and layout are not to be populated during the assembly process.

A related issue was also revealed: Siemens PLM Test Expert did not properly interpret the do-not-install flags.

Proposed Resolution/ Recommended Action

Workaround is for Assembly & Test to manually manipulate.

We need to know how this should/could have been handled in Zuken CR-8000. Designer should be able to annotate these settings in the schematic. This is a process adjustment; previously "populate = true" has been the desired setting.

Two different variants of design have been suggested for the DMDII project. All facilities will be building to -501 except RIT will be building to -503. IPC-2581B does not support variants at this time. Design will try to incorporate unpopulated part information for -501 configuration only using CR8000 Design Force (CR5000 Design Gateway previously accommodated this).

Status: Zuken has resolved this issue (incorporated in the March 2018 release). Siemens PLM (August 10, 2018) patch solved Test Expert side of this issue (in future releases of Test Expert).

Resolution Owner ZukenUSA, Siemens PLM

8.2.9 Zuken IPC-2581B export does not include the material stackup definition

No.	ID/FileName	Author	Date	Title/ Summary
9	TWS_CC022304	TWS	2/23/2017	Zuken IPC-2581B export fails to provide the material stackup definition

Details Of Issue: Zuken IPC-2581B export does not include the material stackup definition (i.e. the copper & dielectric materials required to manufacture the bare board).

Proposed Resolution/ Recommended Action

Workaround was to use PDF drawings for information.

Status: Zuken has resolved this issue in the CR-8000 2018 release.

Resolution Owner ZukenUSA

8.2.10 Project Scope Limitations

No.	ID/FileName	Author	Date	Title/ Summary
10	TWS_CC022305	TWS	2/23/2017	The Smart PCB Digital Factory proof of concept effort does not facilitate the authoring of drawings, specifications, designer notes, standard notes, and other specification information to facilitate paperless manufacture using IPC-2581B.

Details of Issue: There are opportunities to eliminate external documentation, drawings, and specifications that presently exist in paper form and are used in the manufacturing process. The present scope of DMDII SPDF did not specifically address the flow necessary to perform and evaluate these opportunities, however, there may be features/functions in Zuken CR-8000 or other tools that could be employed to become truly paperless.

Proposed Resolution/ Recommended Action

Workaround is to use pdf drawings for information.

Getting to this full implementation level for LM was out of scope for this project.

Resolution Owner Lockheed Martin

8.2.11 Drill count anomalies using Downstream CAM350

No.	ID/FileName	Author	Date	Title/ Summary
11	TWS_PM030602	TWS	3/6/2017	LM-Space reported drill count anomalies using Downstream CAM350 (Two drill layers with conflicting information)

Details of Issue: Drill information was exported in two sections of the IPC-2581B file. In the Lockheed Martin design, drill information was represented in LayerRef "Hole1-4". When imported into Downstream CAM350, another layer "Drill_1_4" was produced. This scenario is presently supported by the current IPC-2581B specification and schema:

Method 1. LayerFeature -> Hole

Method 2. PadStack -> LayerHole

The redundant information contained in the "Drill_1_4" layer produced by the CAM tool when importing the IPC-2581B data was missing 4 drills, which were mechanical mounting holes associated with connectors J13 and J22. The missing mechanical mounting hole issue was resolved with a setting in the design and is no longer a concern.

Proposed Resolution/ Recommended Action

Workaround is to ignore unwanted drills and use the LayerRef Hole1-4.

Ideally ECAD vendors should not duplicate the drill data (i.e. use only one of the methods to describe the Drill information. As it is presently represented in the Lockheed design, Hole1-4 contains the complete drill information required to correctly fabricate the design).

Members of the IPC-2581 Standards Committee need to come to an agreement how this issue should be addressed in future releases of the IPC-2581 standard (i.e. specify a single method in the IPC-2581B standard and schema).

Status: This issue is open and needs to be resolved by IPC-2581 Standards Committee.

Resolution Owner IPC-2581 Standards Committee

8.2.12 LM-S reported Netlist Compare fails in Downstream CAM350

No.	ID/FileName	Author	Date	Title/ Summary
12	TWS_TE030601	TWS	3/6/2017	LM-Space reported netlist compare fails in Downstream CAM350

Details of Issue: Surface mount pads are instantiated with the wrong “exposure” attribute for test.

CAM tools can/will produce “false” net short conditions where “exposure” is incorrectly instantiated.

In IPC-2581B, PhyNet makes use of the following convention*:

- EXPOSED = PhyNet is accessible on Top & Bottom
- COVERED_PRIMARY = PhyNet is not accessible on Top. (Accessible on the Bottom)
- COVERED_SECONDARY = PhyNet is not accessible on the Bottom. (Accessible on the Top)
- COVERED = PhyNet is not accessible

* This convention is inherited from the ODB++ Specification (Reference: Version 7, 2010).

Proposed Resolution/ Recommended Action

Workaround is for PWB fabricator to create their netlist from artwork and compare to ref netlist provided with design. Use exposed pad side.

Zuken IPC-2581B export needs to use the appropriate "exposure" attribute on surface mount pads.

Status: Resolved by Zuken.

Resolution Owner ZukenUSA & IPC-2581 Committee

8.2.13 Overly restrictive character set in IPC-2581 Rev B schema

No.	ID/FileName	Author	Date	Title/ Summary
13	TWS_PD030701	TWS	3/7/2017	Overly restrictive character set in IPC-2581 Rev B schema produces numerous "false" validation errors since many characters are permitted by adopters of IPC-2581. Several character restrictions exist in the IPC-2581B schema definition. It appears many ECAD tools violate these character restrictions, and most downstream consumers of IPC-2581B ignore these restricted character violations.

Details of Issue: The enumerated list of valid values for the character sets permitted in qualifiedNameType seem overly restrictive.

In reviewing recent design data from Zuken, there were Schema validation violations for elements using “qualifiedNameType” due to their use of “restricted characters”. Despite the stated schema constraints, most CAD/CAM tools seem to ignore the use of these characters. (Not a good practice, however, this is ubiquitous behavior across many toolsets.)

Proposed Resolution/ Recommended Action

Standards Committee should consider the relaxation of these constraints to better support what industry needs, uses, and accepts in current practice. Consider eliminating majority of restricted characters to allow maximum flexibility in support of existing CAD/CAM system operations. This needs to be handled by the IPC 2-16 Product Data Description standards committee.

Status: Open with ‘IPC 2-16 Standards Committee’

Resolution Owner IPC-2581 Committee

8.2.14 <Profile> element(s) in IPC-2581B not imported into Frontline tools

No.	ID/FileName	Author	Date	Title/ Summary
14	FUJ_PD032001	Fujitsu	3/20/2017	<Profile> element(s) in IPC-2581B are not imported into Frontline tools

Details of Issue: It appears that the Frontline tools are not extracting <Profile> elements during an IPC-2581B import, because Sanmina is reporting that the outline and routing data is missing.

Proposed Resolution/ Recommended Action

Workarounds are 1) Sanmina can view the outline and routing data in the Wise Viewer. 2) we copy the outline and routing data to additional layers in the CAD and CAM tools, so the Frontline tools see those layers in the IPC-2581.

However, this negates the intent of the IPC-2581B schema. Sanmina has reported the incident to Frontline.

Status: The IPC standards committee will attempt to find a solution that satisfies Frontline expectations.

Resolution Owner Frontline & IPC-2581 Committee

8.2.15 Drill data was missing in the Frontline tools

No.	ID/FileName	Author	Date	Title/ Summary
15	FUJ_PD032101	Fujitsu	3/21/2017	Drill data was missing in the Frontline tools

Details of Issue: Sanmina reported that they didn't see any drill data in the single board step. It took Sanmina a while to realize that the macro used in VisualCAM to create the panel was putting all the drills in the panel step.

Proposed Resolution/ Recommended Action

Ask Wise to change their macro to put the board drills in the board step.

Status: Resolved. This problem was resolved by Wise Software Solutions.

Resolution Owner Wise

8.2.16 Improper use of element OEMDesignNumberRef

No.	ID/FileName	Author	Date	Title/ Summary
16	TWS_PR041901	TWS	4/19/2017	Improper use of element OEMDesignNumberRef leads to improper and incomplete BomItem and AvlItem data structures creating several violations and the inability to link parts across BOM, AVL, and Assembly.

Details Of Issue: Recent export of IPC-2581B data from Zuken CR8000 2017 including part attributes and characteristics was examined. The addition of unique part attributes in the new BOM now differentiates parts, however the OEMDesignNumberRef contains footprint names and causes the BOM section to fail validation (duplicate footprint "Part Number" entries across different parts). The AVL is created with a single AvlItem using the shared footprint name. The AVL is missing all but one entry creating an improper one-to-many relationship to BOM and Assembly.

1. internalPartNumber is populated with the corporate part number that belongs in OEMDesignNumberRef. Note: The internalPartNumber(s) may not be known to the Zuken ECAD Library Management system. A void entry is acceptable.
2. OEMDesignNumberRef is incorrectly populated with ECAD footprint names. The causes several unique part numbers to "rollup" under the shared Footprint "part number" entered in OEMDesignNumberRef.
3. The OEMDesignNumber in the AVL section is created using the same footprint name in OEMDesignNumberRef, thus all the unique part numbers are not properly represented and linkage to the BOM, AVL, and Assembly sections is not possible.

Proposed Resolution/ Recommended Action

Zuken IPC-2581B export needs to export corporate Part Number information into BomItem OEMDesignNumberRef and AvlItem OEMDesignNumber elements. internalPartNumber should be filled in, if known, or left void.

Status: This issue was resolved by ZukenUSA.

Resolution Owner ZukenUSA

8.2.17 MFC Data Review in PWB Fab Shop

No.	ID/FileName	Author	Date	Title/ Summary
17	MFC_PM050901	LM-MFC	5/9/2017	MFC Data Review in PWB Fab Shop

Details Of Issue: 1) The IPC-2581B data has duplicated pads on almost all layers. The extra data does not directly interfere with PWB manufacturing. It is an anomaly that should be investigated and eliminated in the future.

2) The IPC-2581B data imports 240 layers into the CAM tool, most of which are empty or unrelated to printed wiring board manufacturing. Only 24 of these contained data. Twenty were classified as "board" layers and the remainder were categorized as miscellaneous. Only half of the "board" layers contained data.

Proposed Resolution/ Recommended Action

No impact to PWB fabrication. Workaround with InCAM and Genesis was used.

Status: To be addressed in a future Zuken release.

Resolution Owner ZukenUSA

8.2.18 Gerber data missing connector holes

No.	ID/FileName	Author	Date	Title/ Summary
18	SSC_PD051101	LM-S	5/11/2017	Gerber data missing connector holes

Details of Issue: Connector in Gerber data is missing mounting holes. IPC-2581B data reads this in correctly.

Designer needs to review settings in design to ensure all hole sizes are being output when generating Gerber files. Design was reworked.

Status: Closed.

Resolution Owner LM-Space

8.2.19 Frontline Genesis CAM Tool Issues with IPC-2581B Data

No.	ID/FileName	Author	Date	Title/ Summary
19	MFC_PM062601	LM-MFC	6/26/2017	Dallas fabrication shop IPC-2581B database review using the Frontline Genesis CAM tool. Issues with the IPC-2581B database and a comparison to the normal Gerber file process is detailed in this report.

Issues:

1. IPC-2581B read in a lot of layers on input (249). Only 9 of the layers had actual board data on them. Layer data cleanup and manipulation would add time to CAM.
2. The IPC-2581B data has duplicate pads on top of each other. Histogram of comparison shown below. This will add time to CAM to cleanup.
   a. Soldermask top (gerber=724, IPC-2581B =1284)
   b. Layer 1 (gerber=1530, IPC-2581B =2208)
   c. Layer 2 (gerber=806, IPC-2581B =875)
   d. Layer 3 (gerber=971, IPC-2581B =1064)
   e. Layer 4 (gerber=591, IPC-2581B =853)
   f. Soldermask bottom (gerber=370, IPC-2581B =588)
   g. Total CAM data features for all layers (gerber=4992, IPC-2581B =6872)
3. With the IPC-2581B database the soldermask layer is seen as surfaces instead of features with unique D-Code. Will cause problems with growing feature sizes since now you must manually select each surface item that you want to grow.

Observations:

1. Data file size difference is minimal (366k to 278k), IPC-2581B being the smaller of the two.
2. Gerber data separated non-plated and plated drills in logical order. There appeared to be no separation of IPC-2581B plated and non-plated holes in the drill data. However, this problem could not be reproduced.
3. Data appears to be visually identical between both formats.
4. Pads read in with feature attribute data defined, but the attributes are not useful to building the job better in any way (no value added).

Proposed Resolution/ Recommended Action

Work with Zuken to fix the IPC-2581B export for problems 1 and 2.

For problem #3 we will export an IPC-2581B database from Cadence and see if that problem still exists. If so, then we will reach out to Frontline. If not, we need to work with ZukenUSA to correct their export.

Sanmina turns extra layers into documentation layers, then they are ignored.

Status: To be addressed in a future Zuken release.

Note that this Problem Report resulted from a detailed look at the differences between IPC-2581B data and Gerber data; this provides a more detailed look at the layers issue also covered in other problem reports.

Resolution Owner ZukenUSA

8.2.20 UniCam Machine Library

No.	ID/FileName	Author	Date	Title/ Summary
20	RIT_CC72701	RIT	7/27/2017	UniCam Machine Library

Details Of Issue: The UniCam software enables users to define the SMT Line and add specific machine brands to be programmed. The drop-down menu that is installed does not include the full list that was accessible during the UniCam training, which included the ASM XS machine that RIT currently uses.

Proposed Resolution/ Recommended Action

UniCam trainer was emailed as he had to fix this problem during the training and enabled everyone in the class to then have access to the machine list.

Status: This issue was resolved by Siemens PLM

Resolution Owner Siemens PLM

8.2.21 Zuken IPC-2581B data doesn't distinguish plated or non-plated drills

No.	ID/FileName	Author	Date	Title/ Summary
21	MFC_PM081601	LM-MFC	8/16/2017	The Zuken IPC-2581B output doesn't distinguish if the drills are plated or non-plated

Details Of Issue: When CAM is doing the tooling in Frontline Genesis there was no distinguishing if the drills were plated or non-plated. CAM needed to use the paper fabrication drawing to identify where the non-plated drills were and then manually manipulated the data to distinguish those drills. The Zuken IPC-2581B output contains the data.

Proposed Resolution/ Recommended Action

LM-MFC investigated further by comparing the Cadence export to the Zuken export of the IPC-2581B. They do handle the exporting of NPTH and PTH differently, however when the IPC-2581B file was imported into Frontline InCAM, LM-MFC didn't have any issues separating the NPTH from the PTH. Frontline Genesis, though, can only separate out the NPTH from the PTH from the Cadence export and not the Zuken export. Frontline Genesis currently does not accommodate both methods. Per the IPC-2581B schema both methods are valid.

Status: This issue was closed. There are two valid methods to export PTH and NPTH data per the IPC-2581B standard. Zuken IPC-2581B export is representing the information correctly.

Resolution Owner Frontline Genesis

8.2.22 Zuken IPC-2581B Export lacks fiducial information

No.	ID/FileName	Author	Date	Title/ Summary
22	SSC_CC092701	LM-S	9/27/2017	IPC-2581B export from Zuken does not contain intelligent fiducials.

Details of Issue: Programmer on assembly shop floor must manually identify the fiducial in the design to the assembly equipment.

Proposed Resolution/ Recommended Action

Zuken will need to implement section 3.4.3 of the IPC-2581B standard which identifies fiducial schema in a future release.

Status: To be addressed in a future Zuken release.

Resolution Owner ZukenUSA

8.2.23 InCAM Setup

No	ID/FileName	Author	Date	Title/ Summary
23	RMS_PM110201	LM-RMS	11/2/2017	InCAM Setup

Details of Issue: InCAM installation was incomplete. The hook files were not edited to work with LM-RMS computers.

Proposed Resolution/ Recommended Action

Orbotech tech support was called and a ticket was issued.

Status: This was resolved by Orbotech Field Support (an installation setting).

Resolution Owner Orbotech/LM-RMS

8.2.24 Changes made to InCAM and Orbotech Plotter

No.	ID/FileName	Author	Date	Title/ Summary
24	RMS-PM112102	LM-RMS	11/21/2017	Changes made to InCAM and Orbotech Plotter

Details Of Issue: Output files generated by the InCAM software were producing an error when placed into the plot queue of the Orbotech Plotter LP 9008i. Orbotech onsite support was required.

Proposed Resolution/ Recommended Action

Orbotech tech support was called.

Status: This was resolved by Orbotech Field Support (change within program controlling the plotter).

Resolution Owner Orbotech/LM-RMS

8.2.25 InCAM - Missing Features

No.	ID/FileName	Author	Date	Title/ Summary
25	RMS-PM112101	LM-RMS	11/21/2017	InCAM - Missing Features

Details Of Issue: InCAM does not provide etch-back capability with LM-RMS SW license. Also, there is no capability to generate impedance coupons with InCAM.

Proposed Resolution/ Recommended Action

LM-RMS will need to add these capabilities by purchasing the necessary license(s) and/ or services.

Status: Workaround was used. Future resolution needed for LM-RMS.

Resolution Owner LM-RMS

8.2.26 InCAM missing .DXF output for IMPEX and Netlist creation

No.	ID/FileName	Author	Date	Title/ Summary
26	RMS_PM020601	LM-RMS	2/6/2018	InCAM missing .DXF output for use with IMPEX machine and Netlist creation for vendor test.

Details of Issue: InCAM does not provide a .dxf file output usable by the IMPEX machine at RMS-Owego. Also, the option for Netlist creation was not purchased with our current license.

Proposed Resolution/ Recommended Action

Additional training/support. Purchase Netlist creation option license. Explore possibility of having IMPEX (post hole drill inspection) read IPC-2581B directly. Function mode export?

Status: To be resolved by LM-RMS.

Resolution Owner LM-RMS

8.2.27 Test Expert v11 will not import BOM

No	ID/FileName	Author	Date	Title/ Summary
27	RMS_TE031301	LM-RMS	3/13/2018	Test Expert v11 will not import BOM

Details of Issue: Have to manually enter the BOM because the way the IPC-2581B file is laid out is not per the way Test Expert is expecting the data. All of the data that is needed is on multiple levels in the IPC-2581B file.

Proposed Resolution/ Recommended Action

Update the Test Expert Importer to parse the required data from the 2581B file created to the IPC-2581B specification and schema.

Status: This issue was resolved by Siemens PLM

Resolution Owner Siemens PLM

8.2.28 IPC-2581B BOM didn’t read into Test Expert

No.	ID/FileName	Author	Date	Title/ Summary
28	MFC_TE042601	LM-MFC	4/26/2018	IPC-2581B BOM didn’t read into Test Expert

Details of Issue: The BOM information did not read in and we were forced to use the BOM converter step in Test Expert. LM-MFC had to format the BOM (from present-state data & configuration methods).

Proposed Resolution/ Recommended Action

Test Expert should be able to automatically import in the BOM from the IPC-2581B file.

Status: This issue was resolved by Siemens PLM

Resolution Owner Siemens PLM

8.2.29 Non-populated parts show in Test Expert as populated

No.	ID/FileName	Author	Date	Title/ Summary
29	SSC_TE090601	LM-S	9/6/2018	Non-populated parts show in Test Expert as populated

Details of Issue: When importing the IPC-2581B dataset into Test Expert v11, the parts identified in the IPC-2581B file as "false" for being populated were coming in as populated parts. These had to be manually changed to unpopulated.

Proposed Resolution/ Recommended Action

Siemens PLM released patch that resolved the issue. Future release also to include this updated capability.

Status: This issue was resolved by Siemens PLM

Resolution Owner Siemens PLM

8.2.30 Zuken CR8000 doesn't export the correct component body to IPC-2581B file

No.	ID/FileName	Author	Date	Title/ Summary
30	MFC_PD091201	LM-MFC	9/12/2018	Component body

Details of Issue: Currently the CR8000 tool uses the CompArea layer as the component body to be used in IPC-2581. However, the Assembly Front layer should be used as the component body. This caused issues in both assembly and test because without an accurate component body we were prevented from doing software enhancements that could make use of such data to more automate the machines.

Proposed Resolution/ Recommended Action

Zuken should make the assembly front layer the layer that needs to be exported and consider enhancing their library creation such that the true pin land pattern can be added to the component pin padstack. This will enable real DFA analysis and create better manufacturing software that requires accurate component dimensions.

Status: This opportunity has been communicated to ZukenUSA for consideration.

Resolution Owner ZukenUSA

8.2.31 InCAM "Pad Usage" attribute with the "toeprint" value

No.	ID/FileName	Author	Date	Title/ Summary
31	MFC_PM091301	LM-MFC	9/13/2018	InCAM "Pad Usage" attribute with the "toeprint" value

Details of Issue: The IPC-2581B doesn't have the value toeprint so that means InCAM is adding this value to the project.

Proposed Resolution/ Recommended Action

InCAM will have to investigate where the “toeprint” value is coming from and purge it from the fabrication project.

Status: This issue has been communicated to InCAM

Resolution Owner InCAM

8.2.32 Zuken soldermask for vias are surfaces instead of pads

No.	ID/FileName	Author	Date	Title/ Summary
32	MFC_PM091302	LM-MFC	9/13/2018	Soldermask for vias are surfaces instead of pads

Details of Issue: On the soldermask layers the vias were defined as surfaces instead of pads. The data needed to be converted from surfaces to pads to enable easier editing if the via soldermask needed to be either grown or shrunk. For this project we had to select and group the vias in the project to be able do a globally edit them.

Proposed Resolution/ Recommended Action

Need to review Zuken implementation of the soldermask for the vias and determine if it meets the IPC-2581 standard. If so, then we need to review what InCAM currently supports and see if they can support that definition for vias as well.

Status: This issue has been communicated to ZukenUSA.

Resolution Owner ZukenUSA

9 StopLight Chart

9.1 Before and After State of Diagram

Project Start

Partner	Location	Mfg Flow	Design: PCB Design	Design: PCB DFx, Assy Pallet	Design: PCB Material Stackup	Design: PCB Material Stackup	Design: PCB SI	Design: PCB SI (High Speed)	Design: PLM
Fujitsu	Dallas, TX	Mfg Equipment Vendor		VISE, Valor	Polar Instruments	Frontline PCB Solutions	Cadence	Ansys	
Fujitsu	Dallas, TX	SW Vendor	Cadence SPB v16	VISE VisualCAM, Valor NPI	Polar Speedstack	Frontline InStack	Cadence SPB v16	Ansys Designer, SI Circuit, HFSS	[illegible] PLM Programmable Content, JTAG, Physical Inventory, [illegible]
Lockheed Martin	MFC - Dallas, TX	Mfg Equipment Vendor		ADIVA & Frontline Valor	Polar Instruments		Cadence	Ansys	
Lockheed Martin	MFC - Dallas, TX	SW Vendor	Cadence Allegro & Mentor Expedition	ADIVA_DRC v8.7 & Frontline Valor Genesis DRC	Polar Speedstack		Cadence SPB v16	Cadence Sigrity Mentor Hyperlynx	Oracle's Agile Product Lifecycle Management
Lockheed Martin	MST - Owego, NY	Mfg Equipment Vendor		Valor	Polar Instruments		Zuken CR5000	Ansys	
Lockheed Martin	MST - Owego, NY	SW Vendor	Zuken CR5000	Valor Genesis DRC	Polar Speedstack		Zuken CR5000	Ansys HFSS	
Lockheed Martin	SSC - Denver, CO	Mfg Equipment Vendor		Adiva			Zuken CR5000	Zuken CR5000	
Lockheed Martin	SSC - Denver, CO	SW Vendor	Zuken CR5000	Adiva_DRC v8.7			Zuken Lightning	Zuken Lightning	PTC Windchill
Sanmina	San Jose, CA	Mfg Equipment Vendor				Frontline PCB Solutions	Frontline PCB Solutions		
Sanmina	San Jose, CA	SW Vendor				Frontline InStack	Frontline InStack		
Rochester IT	Rochester, NY	Mfg Equipment Vendor							
Rochester IT	Rochester, NY	SW Vendor							

Partner	Location	Mfg Flow	Fabrication: PCB CAM	Fabrication: PCB LDI	Fabrication: PCB AOI	Fabrication: PCB Flying Probe	Fabrication: PCB CNC Drill	Fabrication: PCB CNC Drill	Fabrication: PCB Laser Drill	Assembly: SMT Solder Stencil	Assembly: SMT Pick and Place	Assembly: SMT AOI	Assembly: SMT X-Ray Inspection	Test: Flying Probe / ICT
Fujitsu	Dallas, TX	Mfg Equipment Vendor	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	FTC Assembly	Fuji, DEC	Vitrox (Agilent)	Vitrox	Agilent, Testronix
Fujitsu	Dallas, TX	SW Vendor	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Wise Stencil Tools	Fujitsu TEXCAM	Fujitsu TEXCAM	Fujitsu TEXCAM	Fujitsu TEXCAM
Lockheed Martin	MFC - Dallas, TX	Mfg Equipment Vendor	Valor Genesis 2000	Orbotech	Orbotech	MicroCraft EMMA	Excellon	Hitachi	Excellon Corbra	Stentech	MyData	Kho-Young		Acculogic
Lockheed Martin	MFC - Dallas, TX	SW Vendor	Valor Frontline	Valor Frontline	Valor Frontline	MicroCraft 2 Software's	Valor Frontline	Valor Frontline	Valor Frontline	CAD/Gerber	MyCenter - Aegis (Unicam)	EPM SW by Smart Vision Corp.		Xmatic software (Unicam)
Lockheed Martin	MST - Owego, NY	Mfg Equipment Vendor	Valor Genesis 2000 *	Orbotech	Orbotech	Mania probot	Excellon	Plurateo	Excellon Corbra	Vendor - No MST capability	Universal Instruments	OMRON BT RNS		Takaya
Lockheed Martin	MST - Owego, NY	SW Vendor	Valor Frontline *	Valor Frontline	Valor Frontline *	Parcam Ext & TFI converts netlist into Probot	Valor Frontline *	Valor Frontline	Valor Frontline *	Vendor - No MST capability	Universal UPS Editor	OMRON CT (Unicam)		Siemens Test Expert
Lockheed Martin	SSC - Denver, CO	Mfg Equipment Vendor	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	[illegible]	ASM Siplace	Koh Young Zenith		Takaya & Acculogic
Lockheed Martin	SSC - Denver, CO	SW Vendor	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	(CAD/ Gerber) AGI can provide	Access Database (Unicam)	Access Database (Unicam)		Siemens Test Expert
Sanmina	San Jose, CA	Mfg Equipment Vendor	Linux Machines	Orbotech	Orbotech & CAM Tech	Everett Charles ATG	Excellon & Hitachi	Excellon	Hitachi	Cannot Disclose	AIMEX II AI to A3 modules	Nordson FX Optical Inspection		Takaya ATT 9411 SL Takaya
Sanmina	San Jose, CA	SW Vendor	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Aegis	Aegis	Aegis/ Gencad		.Odb++ FatF Pad (TestExpert
Rochester IT	Rochester, NY	Mfg Equipment Vendor									ASM Siplace			
Rochester IT	Rochester, NY	SW Vendor									Siplace Pro Interface			

* Contingent on new Valor Genesis software provided to MST Owego

Supports IPC-2581

To be determined

Does not support IPC-2581

Future scope

Not Applicable

Project Completion

Partner	Location	Mfg Flow	Design							Fabrication							Assembly				Test
			PCB Design	PCB DFx, Assy Pallet	PCB Material Stackup	PCB Material Stackup	PCB SI	PCB SI (High Speed)	PLM	PCB CAM	PCB LDI	PCB AOI	PCB Flying Probe	PCB CNC Drill	PCB CNC Drill	PCB Laser Drill	SMT Solder Stencil	SMT Pick and Place	SMT AOI	SMT X-Ray Inspection	Flying Probe / ICT
Fujitsu	Dallas, TX	Mfg Equipment Vendor								Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Blue Ring Stencil	Fuji, DEC	HP/Vitrox	Vitrox	N/A
Fujitsu	Dallas, TX	SW Vendor	Cadence SPB v17.2	WISE VisualCAM, Valor NPI	VisualCAM	~~Frontline InStack~~	Cadence SPB v17.2	Ansys Designer, SI Circuit, HFSS	EnoviaPLM Programmable Content, JTAG, Physical Inventory, other specs, etc.	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Wise Stencil Tools	Fujitsu TEXCAM	Demille Research TestSight Translator	Demille research TestSight Translator	N/A
Lockheed Martin	MFC - Dallas, TX	Mfg Equipment Vendor									Orbotech	Orbotech	MicroCraft EMMA	Excellon	Hitachi	Excellon Corbra	Stentech	MyData	Kho-Young		Acculogic
Lockheed Martin	MFC - Dallas, TX	SW Vendor	Cadence Allegro & Mentor Expedition	ADIVA_DRC v8.7 & Mentor Valor	Polar Speedstack		Cadence SPB v17	Cadence Sigrity & Mentro Hyperlynx	Oracle's Agile Product Lifecycle Management	Frontline Genesis 2000	Frontline Genesis 2000	Frontline Genesis 2000	MicroCraft 2 Software's	Frontline Genesis 2000	Frontline Genesis 2000	Frontline Genesis 2000	Wise VisualCAM	MyCenter & Unicam	EPM SW by Smart Vision Corp. & Unicam		Xmatic software & Unicam
Lockheed Martin	RMS - Owego, NY	Mfg Equipment Vendor								Orbotech	Orbotech	Orbotech	Mania probot	Excellon	Pluratec	Excellon Corbra	Stentech	Universal Instruments	OMRON BT RNS		Takaya
Lockheed Martin	RMS - Owego, NY	SW Vendor	Zuken CR5000	Valor Genesis DRC	Polar Speedstack		Zuken CR5000	Ansys HFSS		INCAM	Orbotech	Orbotech	Parcam Ext & TFI converts netlist into Probot**	Excellon drill file	Pluratec drill file	Excellon Corbra	Stentech	Universal UPS Editor	OMRON CT (Unicam)		Siemens Test Expert
Lockheed Martin	SSC - Denver, CO	Mfg Equipment Vendor								Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Speedline MPM Momentum *StenTech Solder Stencil Fab	ASM Siplace	Koh Young Zenith		Takaya & Acculogic
Lockheed Martin	SSC - Denver, CO	SW Vendor	Zuken ~~CR5000~~ CR8000	~~Adiva_DRC v8.7~~ Downstream Technologies			Zuken Lightning	Zuken Lightning	PTC Windchill	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	Sanmina (see below)	(CAD/ Gerber) StenTech can provide solder stencil	Access Database (Unicam)	Access Database (Unicam)		Siemens Test Expert
Sanmina	San Jose, CA	Mfg Equipment Vendor								Linux Machines	Orbotech	Orbotech & CAM Tech	Everett Charles ATG	Excellon & Hitachi	Excellon	Hitachi	Cannot Disclose	AIMEX II AI to A3 modules	Nordson FX Optical Inspection		Takaya ATT 9411 SL Takaya
Sanmina	San Jose, CA	SW Vendor				Frontline InStack	Frontline InStack			Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Frontline InPlan, InCAM, Insight,	Aegis	Aegis	Aegis/ Gencad		Odb++ FatF Pad (TestExpert)
Rochester IT	Rochester, NY	Mfg Equipment Vendor																ASM Siplace			
Rochester IT	Rochester, NY	SW Vendor																Siplace Pro Interface			

* Contingent on new Valor Genesis software provided to RMS Owego	
** PWB flying probe testing path exists, but not exercised due to schedule constraints	
(green) Supports IPC-2581	
(yellow) To be determined	(light grey) Future scope
(red) Does not support IPC-2581	(crossed box) Not Applicable