PCB Equipment Communication Standards Today and Tomorrow

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Abstract
All manufacturers in the printed circuit board (PCB) industry have experienced lack of reliability, maintenance, and performance problems with their machines. These challenges decrease manufacturing productivity and increase costs. Addressing these manufacturing challenges requires the right process information to be available to the engineering team. Currently, managers and process engineers either have insufficient or no data to measure the impact of these issues in order to make improvements. It is essential for the industry to use the adopted equipment communication standards that provide the basic framework to gather the data necessary to dramatically improve equipment utilization.

The industry has been using the Semiconductor Equipment Communication Standard/Generic Model for Communications and Control of SEMI Equipment (SECS/GEM) standards that allow manufacturers to gather data directly from the equipment. Several factories that have used SECS/GEM have published their remarkable process improvements. Experience demonstrates that SECS/GEM is most reliable when equipment suppliers use robust software products created by third party developers to implement the interface and provide it as a standard feature.

IPC is defining new communication standards for retrieving information from the equipment based on Extensible Markup Language (XML), a common and popular communication language. The new standards promise facilitated access to process information in order to increase equipment efficiency and reduce costs.

Equipment suppliers are already required to support the SECS/GEM standard for certain customers. Today, machine suppliers are on the verge of also supporting the IPC XML standards as manufacturers adopt the new standards. Suppliers and factories should avoid developing non-standard protocols to implement equipment communication interfaces and instead use the existing standards as a baseline and implement special messages to fulfill any additional requirements.

Introduction
Every year, new printed circuit board machines and models become increasingly more capable with a wide range software and hardware improvements. Too often these improvements neglect one of the most important features, the equipment communication interface. Many factory process engineers and managers fail to realize its tremendous value. With relatively few factory demands for equipment communication, machine suppliers focus on other features and improvements. Equipment interfaces are vastly underused, even though standard communication technology has been mature for many years. All hardware and software improvements in each machine should be matched by improvements and new features in the equipment communication interface.

Every factory wishes to optimize product quality and quantity. This is a constant goal that will never be satisfied. As soon as one plateau is reached, higher and more demanding numbers will be targeted. Continuous growth and improvement is essential to any factory. Production Engineers cannot effectively achieve this improvement without gathering ample information from each machine. This information is available through the equipment communication interface.

Today, there are two equipment communication standards, SEMI SECS/GEM and IPC XML that can both provide extensive functionality to enable factories to optimize machine utilization and diagnose problems. Many machines also provide non-standard equipment communication interfaces.

Equipment communication interfaces
An equipment communication interface is the machine supplier's software and hardware that enable the machine to send and receive information with host software running on another computer. A host computer is the factory's computer setup to

communicate with the machine. Although the host computer may be a stand-alone system, it typically is used to share information with other systems. One host computer may communicate with one or multiple equipment.

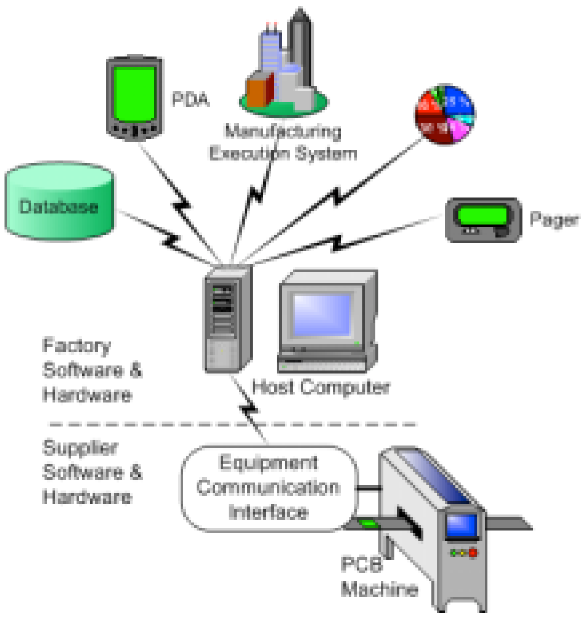

Figure 1 – Host Computer & Equipment Communications Interface

The communication interface software may run directly on the machine's main computer. Although less desirable, it may run on a separate, external computer provided by the supplier with the machine. The interface may be a standard or optional feature. In all cases, the machine supplier must provide documentation on how to use the interface.

Information from the machine may inform the host about the machine's processing status, performance, and errors. Once this information is transferred to the factory's host computer, many possibilities exist. For example, process engineers frequently consolidate selected information into a large database. The database in turn is used to analyze and react to the data. Making this data available to engineers allows them to detect issues quicker, resolve issues with improved efficiency, optimize machine utilization, and many other tasks.

An equipment communication interface benefits the factories and suppliers. Factories benefit because they gain the ability to monitor and log a machine's performance. In order for engineers to solve problems and make improvements, they must be able record what is happening inside and outside the machine. A communication interface provides this visibility. The machine becomes an open system. Suppliers benefit because an equipment interface empowers the factory to resolve and isolate many issues without any supplier assistance. If the interface is implemented to follow an industry standard, then all factories can use the same interface.

Features of Successful Implementation

An equipment communication interface is not guaranteed to be valuable. It must expose meaningful state and process information as well as thorough details. It must also be very robust.

Meaningful state and process information are essential. The host needs to know the status of the machine, product, and other components. Most host applications measure utilization using SEMI E10 or some similar technique. This information must be readily available to a host in the equipment interface.

Only thorough internal machine details can provide enough insight to resolve some issues. Factories need open systems with readily available information. The current feedback and state changes of all sensors, all machine and process setup values, all errors and warnings, and every step and sub-step in the process should be exposed to the host.

Factories develop very critical dependencies on equipment communication interfaces. One failed communication interface may indirectly affect other systems; therefore they must be extremely robust to run for months without any issues.

A powerful equipment interface reduces the need for cumbersome non-domain features in the operator interface. The supplier can create the operator interface to focus on the processing control allowing less focus on long-term machine analysis.

Sometimes equipment communication interfaces are used not only to monitor a machine, but also to control it. This includes downloading recipes, configuring various software controls, starting, and stopping the machine processing. A fully featured interface allows the host to completely setup and run the machine without any operator involvement. This in turn reduces human interaction and leads to better repeatability with total traceability and higher quality yields.

Local Operator Interface Comparison

Many machines provide status and diagnostics information in the local operator interface. This is a closed system. While this is useful for initially setting up and diagnosing a single machine, it does not allow engineers to manage the machine during production or perform serious process analysis. It requires an operator and technician to frequently visit the machine during production—the time when most machines should be left alone. It does not allow one machine activity to be compared to another one from the same or a different supplier. Instead of providing data, the local interface typically only shows limited analysis results. It does not provide the long-term or flexible data analysis. It does not allow engineers to analyze the entire process in the manufacturing line. In order to solve problems and make improvements, engineers require access to low-level machine information and require the ability to analyze the data in a variety of creative perspectives. This flexibility is only available when the data can be transferred off of the machine and into state of the art data analysis tools

Proprietary Communication Interfaces

Proprietary communication interfaces include all equipment interfaces that are not based on industry standards. These are typically developed to meets the particular needs of a one project or customer, but fail to address the general needs of all factories. Few provide extensibility to accommodate new features and technologies.

Before standards emerged over ten years ago, every machine supplier with equipment communication interfaces implemented a proprietary protocol and message scheme. Some of these are still maintained. In past years, implementations were based on a wide variety of technologies including serial communication, TCP/IP, SmallTalk, Telnet, and file-transfers based on FTP. Implementations today use new technologies like DCOM, ODBC, and CORBA.

Supplier Implementation

Initially, a proprietary equipment communication interface is easy for the machine supplier to develop. Typically it is developed to meet immediate demands of one or two key customers. Programmers can use any simple protocol and message format that suites the current machine's design. There are no rules or restrictions--total flexibility. Customers inevitably request new features that are difficult to implement, document, and maintain. Then over time, the proprietary interface becomes a burden and a costly expense. As in most software implementations, the maintenance costs far exceed the initial development cost. In the long run, the scope of the proprietary interface vastly exceeds the initial intent.

Factory Implementation

Even initially, the factory makes a large investment to use a proprietary interface by writing unique software for one type of machine and working closely with the machine supplier to ensure that all of its requirements are satisfied. The supplier's documentation is typically adequate. Because the interface is proprietary, all of the investment is not reusable on other machines. The interface is highly subject to change, may lose functionality in future upgrades, and may be entirely dropped in a new version. If a different model from the same supplier is later used, some or all of the interface features may not be available. If a different supplier is later used to replace the machine, then all of the investment is lost.

Advantages

In the short term, a factory's requirements can be met using a proprietary equipment communication interface. The supplier's initial cost is relatively low. Industry standards do not restrict solutions.

Disadvantages

Over time, the cost is extremely high for both supplier and factory. It is typically very costly to implement new features at a future date. Both the supplier and factory are required to keep staff trained on how to debug connection problems and maintain the software. Time spent on how to improve throughput soon is replaced with training programs centered on understand all of the communication protocols that exist to make a line work (or worse how to locate the only person in the world who understands the proprietary protocol). If a supplier wishes to sell the same machine to a variety of factories, then a non-standard equipment communication interface is a very bad choice. At some point, a factory will demand compliance to an industry standard anyway. Then the machine will have to support both the proprietary protocol and industry standard. History has shown that a proprietary equipment communication interface will be discontinued.

SECS/GEM Equipment communication interfaces

The SECS/GEM standards include a set of standards that emerged from the Semiconductor Equipment and Materials International (SEMI) organization (www.semi.org) over ten years ago. Many factories around the world are using SECS/GEM today where it has become vital tool integral to the manufacturing process.

Messaging Overview

The SECS-II standard defines communication between one machine and one host. Either party may initiate a primary message. A primary message is typically followed by a secondary response message.

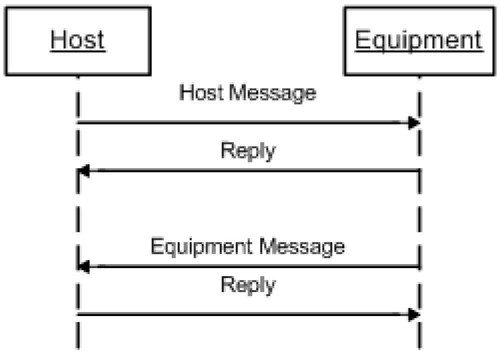

Figure 2 – SECS/GEM Messaging

Standard Overview

The set of SECS/GEM standards includes SECS-I (SEMI E4), SECS-II (SEMI E5), GEM (SEMI E30) and HSMS (SEMI E37). SECS-I and HSMS define standard implementations for RS-232 (serial) and TCP/IP (network) communication, respectively. The SECS-II standard defines the message content layer, basic rules of handshaking, and a set of message definitions. It also allows the definition of custom messages, but typically these are unnecessary. The GEM standard defines message scenarios and state machines to ensure predictable behavior from one machine to the next. The SECS/GEM standards provide a rich set of functionality that is widely applicable to any automated equipment, not just in the Semiconductor industry.

Alarm management and event notification enables the host to be notified when the machine performs various tasks and when state changes occur. The host enables the desired events/alarms and disables the undesired ones.

Several methods of data gathering allow a host to either query information or configure the machine to send data with events as the data becomes available. The machine supplier publishes a list of available data. The host only requests the data that is interesting and ignores other data.

Process program management functionality provides the hosts with tools to send recipes to and from the equipment. A factory can guarantee that the machines are setup correctly for the current product.

Remote Commands give the host power to start and stop the machine. They also allow the host to control the machine as dictated by the machine supplier.

The SECS/GEM standards are intentionally generalized so that they can be applied to any automated equipment. Although GEM specifies some data that must be available, the standard really focuses on providing message structure, not message content. Therefore the value of the SECS/GEM interface lies in the details of the implementation.

Supplier Implementation

Suppliers may choose to develop all aspects of the entire SECS/GEM interface software in-house, but this is highly discouraged. In-house solutions tend to be unreliable, incomplete, and over budget. Several SECS/GEM development products are readily available from third party companies. These products not only make it quite easy to implement a SECS/GEM interface, but also dramatically increase the interface robustness. The major product suppliers are found easily by searching on the Internet using the combination of keywords 'SECS' and 'GEM'.

The SECS/GEM standards are scalable to accommodate very simple and very complex implementations. Many features are optional so that simple machines are not unnecessarily burdened with useless features. Suppliers can easily provide simple interfaces initially, and then add more features later as requested.

Typically, the most difficult aspect of developing a SECS/GEM interface is in the design. The standard requires very few data and events. The value in the GEM interface is achieved only when a meaningful set of data and events are contrived. The supplier must work closely with factories to determine what information the process engineers might be interested. At some point the supplier generates a list of all events, data, alarms, remote commands, and equipment constants that will be supported. Since feedback is rarely provided until after the supplier delivers the first version, the software development must carefully anticipate needs for all customer factories. It is well worth the time to obtain consultation services from SECS/GEM experts to evaluate the design before beginning the software development.

There are a few other challenging tasks. Suppliers modify the operator interface to accommodate GEM features. They must also generate SECS/GEM documentation to publish the list of available events, data, alarms, and remote commands. The superior

SECS/GEM products on the market will include tools to simplify these tasks.

Many suppliers with different machine models make a strong effort to reuse SECS/GEM software between the different systems. As a result, the GEM interfaces for different models are very similar.

Many suppliers provide the SECS/GEM interface as an option that is installed only by request. Installation often takes place in the field. Field service engineers rarely have any knowledge of SECS/GEM; therefore the installation often goes poorly. Suppliers who provide SECS/GEM as a standard feature encounter much fewer problems.

Factory Implementation

Factories may develop entire SECS/GEM host software, although this is discouraged. Typically it is more cost effective and productive to purchase SECS/GEM software from a third party. Several products are available to factories from major software providers. Factories should use these products to write small or complex host applications.

The most difficult task is always in the design. In order to get value from a GEM interface, the factory must write software to do something with the SECS/GEM messages. SECS/GEM experts are available to provide education and consultation. Some software packages are publicly available that completely implement host applications using SECS/GEM.

The host dictates the amount of communication traffic. The same SECS/GEM interface in two different factories may generate vastly different network loads. Many host applications only use a few SECS/GEM messages.

Every supplier's GEM interface is vastly different, even if they produce machines with similar functionality. Even different models from the same supplier will have some small differences in the GEM interface. Therefore, the factory must either invest in configurable software that can be mapped to different GEM interfaces or develop custom software to handle each machine. Approaches vary as tremendously as the requirements.

Advantages

The SECS/GEM standards have been accepted and successfully implemented in many factories worldwide in several different industries. SECS/GEM standards have proven their ability to be adapted to very wide variety of machines in diverse factory situations. Currently available products make it easy and cost effective to implement for both the supplier and factory.

Disadvantages

Some are intimidated by the low-level details of the protocols. If a company intends to develop complete SECS/GEM software in-house, it can be difficult and time-consuming. This can be avoided by using available third-party development software.

Most SECS/GEM implementations are restricted to a single host connection. That means that once a host has occupied the SECS/GEM interface, then other host applications cannot use the interface. Some SECS/GEM products have overcome this limitation by providing multiple-host capability.

Suppliers are not required to provide very many particular events and data important to factories. Therefore GEM interface implementations vary tremendously. It is common for a factory to request to new events and data.

The price for a SECS/GEM interface varies widely. Some equipment suppliers charge a high price for the interface. However, over time the price has lowered to the point where at least once major supplier now includes the GEM interface as a standard feature at no additional charge.

Future

Although the standards are already very mature, the Semiconductor industry continues to maintain and improve the standard as often as every quarter. The entire Semiconductor industry has generated new standards to use in its new 300 mm wafer factories. Some of these new standards including SEMI E39, SEMI E40, SEMI E87, SEMI E90, and SEMI E94 are all based on the SECS/GEM standards. This industry movement has surged new life and longevity into the SECS/GEM standards. SECS/GEM will assuredly continue to be used on many new machines and models for many years in the Semiconductor industry. In new 300 mm factories, the SECS/GEM standard is a required feature that undergoes exhaustive testing as part of machine acceptance.

In the printed circuit board industry, all of the major suppliers provide SECS/GEM interfaces at least as an optional feature. Some have even made this a standard feature on all machines at no additional charge.

IPC XML Equipment communication interfaces

IPC (www.ipc.org) has been working with printed circuit board industry representatives to develop new standards based on the popular (Extensible Markup Language) XML standard. These standards simplify equipment communication interface development by leveraging XML and all of its associated software tools and technology.

Messaging Overview

The messaging scheme is designed specifically for an internet/intranet environment. A web broker acts as a publish-subscribe intermediary for all messages. If a client wishes to receive messages from a machine, it must subscribe with the broker. For each message definition, the machine will send the message to the broker once if there is at least one subscriber. Then the web broker will save the message for each subscribed client until the client requests its messages. All of the current standards use this technique.

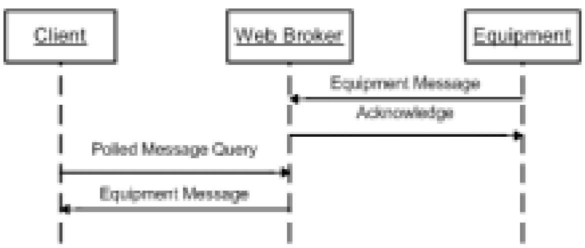

Figure 3 – IPC XML Communication

New standards under active development will allow a client to send a message to a machine and receive a reply. Thus clients will be able to download information to a machine and query information from the machine.

Standard Overview

IPC 2501 (Definition for Web Based Exchange of XML Data) defines the protocol, message headers, and rules of message exchange. This proposed standard (soon to be published) uses several Internet standards wherever possible including TCP/IP, HTTP, SOAP, and XML.

IPC has published several standards including IPC 2541 (Generic Requirements for Electronic Manufacturing Shop Floor Equipment Communication (CAMX)), IPC 2546 (Sectional Requirements for Specific Printed Circuit Board Assembly Equipment), and IPC 2547 (Sectional Requirements for Shop Floor Electronic Inspection and Test Equipment Communication). All of these depend on the IPC 2501 standard for message transfer.

The XML messages defined in the standard specify the required and optional data very explicitly. Therefore, all machines that implement a standard are sending the same messages with the same data structure. Additional data that is not part of the standard may be sent in supplier published XML messages or as an extension to a standard message.

IPC 2541 is a general standard applicable to many different types of printed circuit board equipment. It provides standard messages to keep track of the processing state, machine state, errors, warnings, and alarms. IPC 2546 and IPC 2547 are intended for very specific types of printed circuit board machines: assembly and test/inspection/rework, respectively. The messages and data were developed by consensus by experts in the respective areas. Therefore these messages include all of the data expected from such a machine.

Supplier Implementation

Suppliers must implement IPC 2501 and IPC 2541. This includes several security, configurations, and data integrity requirements as described in IPC 2501. If applicable, they must also implement IPC 2546 or IPC 2547. The XML message development can be accomplished by building the software using existing XML tools on the market. Additionally, multiple third party products are certain to emerge to facilitate IPC XML development. One company has already committed to provide an IPC XML development package as soon as a serious request is received.

Implementing these standards includes sending all of the appropriate XML messages at the correct time with the correct data to the message broker. The standards indicate the data structure for each message and explain when to send the messages.

Factory Implementation

Factories must first implement a web broker to communicate with the machines and with any interested web clients. In the near future, third party web broker software products will should available for general purchase. The web broker must follow the standard as described in IPC 2501. This includes implementing several configuration, security, and data integrity requirements.

Factories must develop XML applications to do something with the XML messages. The XML applications must register for interesting messages. Then the applications must continuously poll for any arriving messages.

If any required data is unavailable in the existing standard XML messages, factories should request the data from the supplier either in a new XML message or as an extension to an existing message. If the data is generally applicable to various machines, then the factories should work with the IPC standards committees to enhance the standards.

Advantages

Because the IPC XML standards define messages in such detail, there is little or no customization for different types of equipment. Two machines from different suppliers will send the same XML messages, so factories enjoy tremendous software reuse.

Many software development tools provide extensive tools for developing XML messages in a variety of programming languages. Additionally, many XML developers exist throughout the software industry.

Disadvantages

The current IPC XML standards only define messages for the machine to broadcast. The standard does not define any messages that allow a web client to query information from the machines or send information to the machines. The current standards committee is working to develop standard IPC 2551 which will overcome this limitation. This is not a major issue for factories that simply monitor the equipment.

Although the XML technology is mature, the IPC XML standards are new and therefore lack maturity. Many tests and demonstrations have been completed successfully at various sites. However, maturity will come only after factories have proven the standard's value in production situations. To date, most suppliers have not offered the IPC XML standards yet as an available feature. This should change quickly as factories begin to recognize the value of equipment communication interfaces and these new standards.

Future

Over time the IPC XML standards will certainly become more refined and readily available. New standards development will bridge the gap of missing functionality for the advance applications. Suppliers and factories need to work to take advantage of these standards and use them to improve equipment management.

Case Study

Huntsville Electronics, located in Huntsville, Alabama, is a division of DaimlerChrysler. They use 59 surface mount (SMT) placement machines in manufacturing operations. The machines assemble printed circuit boards, transistors, integrated circuits, and other parts into the finished product components. SMT machines are designed to operate at the highest speed possible and to be self-correcting; that is, when a machine is unable to place a part, it will immediately discard the part and pick another part for placement. Operating inefficiencies caused excess parts waste and machine slowdowns - two items that directly affected the bottom line.

DaimlerChrysler realized that improved machine monitoring could solve these problems. Each placement machine was installed with an equipment communications interface. DaimlerChrysler installed host software on a Windows 2000 server and setup communication to the machines using a Novell LAN network. Since this system was put into place, DaimlerChrysler's Huntsville Electronics plant has increased machine throughput, reduced costs from parts losses, and improved inventory management. Machines spend reduced time in a malfunctioning state and have increased machine productivity. This led to lower manufacturing costs by cutting down on the number of parts wasted and by increasing the number of units produced per machine. In addition, the system enabled detailed information retrieval from the machines so that materials management can identify exactly which parts are being disposed of at unusual rates. Machines wasting more expensive parts are assigned higher maintenance priority and are repaired more quickly, resulting in significantly reduced costs by saving from parts that would normally be lost. Without the information provided through the equipment communication interface, this crucial data would not be available to determine when or where to apply maintenance.

Conclusions

Suppliers and factories both should stop spending resources developing and maintaining non-standard equipment communication interfaces. Instead, they should utilize the existing standards. Both existing standards, SECS/GEM and IPC XML, provide an extensible framework that allows custom data gathering. If for whatever reason, the existing standards cannot satisfy some requirements, then suppliers and factories should drive to enhance the standards by working with the committees from the SEMI and IPC standards organizations. In the long run, this will be much more effective and considerably less expensive.

Most suppliers already provide SECS/GEM interfaces. These interfaces must be maintained for at least several more years. SECS/GEM interfaces are also needed on new machines developed today. Suppliers need to implement IPC XML standards in addition to SECS/GEM. Both standards can coexist and even run simultaneously.

References

SEMI E5, SEMI Equipment Communications Standards 2, Message Content (SECS-II)

SEMI E30, Generic Model for Communications and Control of Manufacturing Equipment (GEM)

IPC 2501, Definition for Web Based Exchange of XML Data

IPC 2541, Generic Requirements for Electronic Manufacturing Shop Floor Equipment Communication (CAMX)

IPC 2546, Sectional Requirements for Specific Printed Circuit Board Assembly Equipment

IPC 2547, Sectional Requirements for Shop Floor Electronic Inspection and Test Equipment Communication