Remote Monitoring of the Reflow Process

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Abstract

This paper will discuss:

- The process for continually and automatically capturing real-time data from the reflow and wave solder sections of the SMT production line.
- Tools for optimizing the reflow process.
- Distributing reflow data to remote locations via a corporate Intranet or the Internet.
- The effect distribution of soldering process data to remote locations has on production costs, quality control, and customer relations.

The installation of a real-time thermal management system on reflow and wave solder machines makes it possible to get real-time live data output from these processes; processes that have traditionally been difficult to monitor. The effect a thermal management system can have on process development and QC programs will be discussed in detail, as well as the applications for this system in fine-tuning thermal processes for new technologies (Ex: Lead-free electronics assembly) that require very precise thermal profiles.

The data produced by the thermal manager can be distributed internally via a LAN or an Intranet, helping manufacturers to maximize the value of scarce engineering and technical resources by allowing them to monitor multiple thermal processes from a single location. The method developed to distribute this data via the Internet will also be discussed. The ability to transmit data via the Internet was validated in February 1999, when real-time data from a remote location in the United States was transmitted to a major trade show in Anaheim, California. At APEX 2000, real-time data from three reflow ovens in separate locations will be transmitted to the show.

In today's competitive SMT manufacturing environment, having the ability to monitor the reflow process in real-time has become critical. Failure to obtain accurate process data can have a disastrous effect on yields--an unmonitored, out of control reflow process can cause defects on every board that passes through the oven. These failures may manifest themselves immediately, requiring expensive rework; or may only reveal themselves in the field, causing end-user and customer dissatisfaction. The ability to remotely monitor the thermal portions of the SMT process is significant to both Contract Manufacturing Companies and their clients. With the real-time manager, CMCs can provide real-time process statistics to their clients in any form required. This capability allows CMCs with well controlled processes to prove it in real-time to their clients, distinguishing themselves from competitors with less advanced processes and providing their clients with 24/7 peace of mind. The value of this advancement will be readily apparent to engineers, technicians, and managers involved in the electronics assembly industry.

Introduction: The Virtual Factory

One of the most significant trends of the past decade has been the emergence and evolution of a truly global marketplace. Many factors have contributed to this. The collapse of Communism opened up the previously closed markets in Eastern Europe and Asia. Trade agreements such as NAFTA have allowed companies to become truly international, with subsidiaries that were once nearly autonomous becoming integrated into a worldwide system of interdependent production facilities. While the political and economic events of the 1990's made the implementation of a global marketplace possible, it has been the huge advances in information technology that have made it work.

Few industries have been as heavily impacted by the growth of the global market place as the electronics industry. A further impact on the electronics industry has been the growth of contract manufacturing and outsourcing, a trend that has been accelerated by the growth of the global marketplace. While the rise of the global marketplace has offered obvious benefits and opportunities, the production of electronic assemblies in multiple, widely separated locations is not without pitfalls. Major electronics OEMs have as many as thirty facilities worldwide, and the largest Contract Manufacturers are approaching these numbers. The problem for these large companies is not only ensuring that each facility produces quality product, but also that each facility produces products of interchangeable quality. For a CMC, it is not acceptable to tell a client that the Mexican plant produces great quality parts, but that parts from the Brazilian plant are OK too. All products at all facilities must be of identical quality and reliability, and to achieve this, worldwide operations must act as one. One method for producing products of reliable quality at multiple locations is the Virtual Factory.

A Virtual Factory is defined as a facility that makes use of information technology such as activity based costing, design of experiment, and shop floor process control, to develop and share product, quality, and costing data with sister facilities and customers. Although the true Virtual Factory compiles and distributes data on all operations, including finance and accounting, this paper will be concerned solely with the process control and quality portions of the larger package. One of the essential tools for developing a Virtual Factory is computer-generated simulation of the production line. This is accomplished by a single or multiple software program(s) that extract(s) data from all significant process functions and then compares that data to a baseline history file to predict the line's ability to produce quality product at the given moment and in the future. Creating the Virtual Factory presents significant challenges. The first is reliably extracting pertinent data from all significant production processes. The second is networking the process data both internally in the plant, and externally, between all of a company's facilities worldwide. The third challenge is using the networked data in a manner that maximizes human resources and promotes more efficient production.

Electronics assemblers have had the ability to gather data on screen printers and pick and place machines for several years, but the reflow oven has remained a black box. Product goes in one end of the reflow oven and comes out the other; it either passes inspection and the in-circuit test or it does not. In order to implement the Virtual Factory, electronics assemblers must have the ability to gather data from all phases of production. Recent advances in thermal profiling further the implementation of the Virtual Factory by allowing users to track and document their thermal processes in real-time and transmit live data to facilities worldwide.

Real-time Thermal Profiling

The installation of a real-time thermal management system on a reflow oven makes it possible to obtain real-time live data output from a processes that has traditionally been difficult to monitor. The current method of monitoring conveyorized thermal processes is to attach thermocouples to a product, and, using a data-logging or wireless device, run the device and the product through the oven to record the product thermal profile. This is called "profiling the oven," and is typically done on a regular basis—monthly, weekly, or as often as once a shift—to verify that the oven is working correctly. The oven must be verified regularly because it has been demonstrated that even in modern forced air convection ovens, there are times when the product thermal profile is no longer within specifications, even though the oven controller indicates that nothing has changed. Another instance when it becomes necessary to verify the oven by running a profile is when there is a problem on the production line. When there is a decrease in yield, the oven must be profiled to establish that it is not the source of the problem.

There are three problems with the current method of monitoring conveyorized processes:

1. Using a product profiler is time-consuming and often results in production downtime.
2. Each profile run is the equivalent of a snapshot taken with a still camera, and the oven user is forced to assume that the oven is not changing between "snapshots." These "snapshots" will rarely catch an intermittent problem in the oven.
3. If regular profiling uncovers a problem, there is no way to tell how much product has been affected. All production between the last good profile and the first bad profile becomes suspect.

Real-time thermal management systems can address all of these issues with advanced technology for monitoring conveyorized thermal processes and increasing productivity.

The real-time thermal manager continually monitors process temperature in the reflow oven. Thirty thermocouples embedded in two slim stainless steel probes are permanently mounted just above the conveyor. (See Figure 1) They are mounted close enough to the board to provide representative temperatures, but far enough from the oven rails so as not to be influenced by the thermal mass of the rails themselves. Though the system does not actually measure the board temperatures, it provides a detailed measurement of the process temperatures at the conveyor as the board passes through the reflow oven. This is a much more precise representation of the actual reflow process than the data provided by the oven controller thermocouples in the blower plenums. The creation of a baseline of these thirty data points during initial profiling can be used to monitor and accurately determine if the current profile differs from the baseline profile during actual production runs.

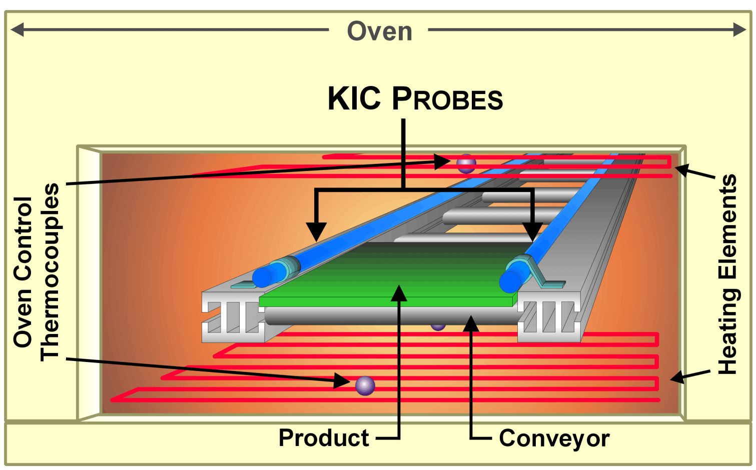
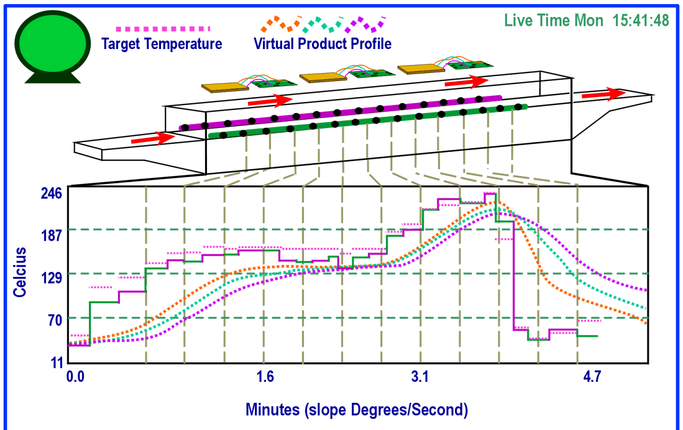


Figure 1 - Thermocouple Probe Placement

The probe thermocouples continuously monitor the process temperatures, taking readings as frequently as every five seconds. These temperatures are displayed as "Process Profiles" on the oven's PC screen. All data from each reading is recorded permanently to the hard drive, giving users the ability to review process data from any previous production date and time. Using this capability to 'turn back the clock' and view data from previous production runs in conjunction with a barcode-based, real-time quality control data collection system allows users to document the thermal profile of every board processed. This also provides assurance that the assembly or components were processed within their specified parameters when addressing component related assembly failures with component manufacturers. Another potential benefit of using the thermal manager with a barcode reader is total product traceability. This is especially significant for companies manufacturing products with high potential liability risks, like medical devices and automotive safety equipment.

The real-time thermal manager provides a product profile for every board processed by creating a mathematical correlation between product profile, as measured by a pass-through profiler, and process temperature, as measured by the real-time thermal manager thermocouple probes. This 'Virtual' product profile is calculated every 30 seconds, and Virtual Profile statistics, such as peak temperature, are also calculated and continuously updated.(See Figure 2) The real-time thermal manager can detect critical temperature variations that oven control thermocouples cannot, and immediately reveal these temperature drifts and their location. The instant a Virtual Profile falls outside of the pre-defined process window, an alarm will sound. This feature can also turn on an alarm light, or even shut down the oven input feed conveyor to prevent any further assemblies from being processed outside of specifications. Because it eliminates the potential for product defects due to thermal variation, the real-time thermal manager is an excellent tool for continuous monitoring of the reflow process.



	Peak	Min	Max Rising Slope	Max Falling Slope	Time Between 130/160	Total Time Above 183	Total Time Above 200
VP[01] U3B1	219.2	24.7	2.24	-1.99	134.63	57.36	33.42
VP[03] BOARD	266.4	25.2	2.96	-2.99	141.30	57.21	42.31
VP[05] U2G1	210.5	25.1	1.95	-1.20	118.10	59.70	27.06

Figure 2 – The Virtual Profile

Process Development

In 1989, the introduction of "Prediction" software revolutionized oven profiling. Before "Prediction", ovens were profiled by "trial and error". A process engineer ran a profile, made changes to the zone setpoints and/or conveyor speed according to his/her "best guess", and then ran another profile. The process was repeated until an adequate profile was found. This took hours, or even days in some cases. Prediction software allowed users to simulate oven profiles on their PC screens, make changes to oven setpoints and conveyor belt speeds on the computer, and quickly view the "predicted" effect of the changes on the profile. This software could evaluate a single change to an oven recipe in about five seconds—roughly the speed at which the operator could enter the change into their computer. This was a dramatic improvement over the conventional method of profiling thermal processes, but it was still a time-consuming "trial and error" method. Automated prediction software removes "trial and error" from the oven setup process by allowing users to define their process window by setting upper and lower limits on key process statistics such as Peak Temperature, Time Above a given temperature, and Maximum Rising and Falling Slope.

The automated prediction tool reviews thousands of possible oven recipes to achieve the desired results. It will then present them, ranked to provide the best results and widest process window. A ranking algorithm assures that the profile changes selected fall well within the center of a bell curve ranking. Upon reviewing the suggested changes, users choose the most appropriate profile based on ease of profile changeover from one product profile to another, faster throughput based on belt speed, or other possible needs specific to their process. After inputting the changes to the oven, a second pass of the board is performed to validate that the changes have resulted in the desired profile. This allows an optimum profile to be created rapidly, without tying up valuable equipment and engineering resources. In the majority of cases, two passes are all that is required to achieve an optimum profile.

Improved Automated Profile Prediction

One issue with the original automated profiling tool was that it required an expert operator. With a ten-zone oven, there are literally billions of possible combinations of zone setpoints and belt speed. To search all of these would take several days, so the operator was required know enough about thermal profiling to be able to tell the automated prediction tool which range of combinations of zone setpoint and belt speed to search in order to get a solution in a reasonable time. Furthermore, once an optimal oven recipe had been identified, it had to be manually transferred to the oven controller. This task could take a few minutes and there was always the possibility of transposition errors.

The latest release of the automated profiling tool offers several significant improvements. The KIC Navigator is an integrated software package that includes an automated prediction tool that is exponentially more powerful and accurate than any than any tool currently on the market. This improved automated prediction tool is capable of automatically searching the entire range of possible recipes in less than a minute, so operators no longer need to set search parameters. The software package also includes a comprehensive database of solder paste specifications, including specs for the new lead-free solder pastes from all major manufacturers. The operator selects the solder paste being used from a drop down menu, enters any non-solder paste-related process limits, runs a profile, starts the automated prediction tool, and in seconds has an optimal profile that is custom designed for both the oven and the product. A pass-through profile is run to confirm that the oven settings are correct and then the oven is ready for production. Because the improved automated prediction tool has searched the entire range of possible oven setups, users are assured of finding the best possible profile.

The automated prediction tool is designed to center the profile in a process window defined by the solder paste specification and the user defined input process limits. This is done by ranking potential process profiles with a "Process Window Index" (PWI). The Process Window refers to how well a given profile "fits" the critical process statistics. A profile will process product without exceeding any of the critical process statistics is said to be inside the Process Window. Most profiling technology is capable of telling the user whether they are in or out of the Process Window (although it generally isn't capable of telling users how to get their profile into the process window.) The "Process Window Index" goes several steps beyond telling the user whether they are merely in or out of spec. The "Process Window Index" uses the input process limits to numerically rank profiles based on how well they fit the user-defined process window. A "Process Window Index" of 100 or more indicates that the profile will not process product in spec. A "Process Window Index" of 99 indicates that the profile will process product within spec, but it is running at the very edge of the Process Window. A "Process Window Index" of less than 99 indicates that the profile is in spec and tells users what percentage of the process window they are using: for example, a PWI of 70 indicates a profile that is using 70% of the process spec. (See Figure 3) The PWI tells users exactly how much of their process window a given profile uses, and thus how robust that profile is. The lower the PWI, the better the profile. A PWI of 99 is risky because it indicates that the process could easily drift out of control. Most users seek a PWI of below 80, and with the improved automated prediction tool, profiles with a Process Window Index between 50 and 60 are commonly achieved (if the oven is sufficiently flexible and efficient).

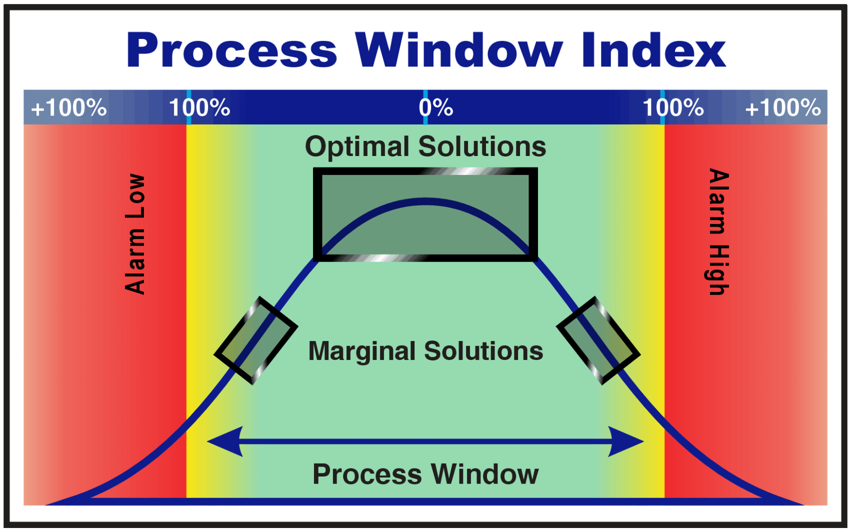


Figure 3 – Process Window Index

An example of a situation where the automated prediction tool is of great value is the reduced process windows lead-free solders will require. Currently available lead-free solders have a solidus/liquidous point about 20-50°C higher (depending on the alloy) than the leaded pastes currently in use. The current thermal process window is a wide one, with the lower limit set at 183°C (a lower limit of 200-205°C is the most common setting), the eutectic temperature of leaded solders, and the high limit at 235°C, which is the maximum temperature that some sensitive components can see. These high and low process limits provide a Delta of over 50°C—wide enough that a carefully monitored process can be expected to produce low defects and high yield with little fear of defects caused by process drift. With lead-free assemblies, the process window will shrink dramatically. The Bismuth alloys favored by Japanese assemblers (206-213°C liquidus) will shrink the window by half, to a Delta of 22-29°C. Using the more reliable Sn/Ag/Cu alloys (217°C liquidus), the window will be cut down by 65% to a Delta of 18°C. Given that few assemblers want to get within 5°C of their control limits, the true process window with Sn/Ag/Cu alloys will be approximately 8°C. This very narrow process window is the problem that will confront electronics assemblers making the shift to lead-free production, and the window is unlikely to open wider in the near future. The automated prediction tool will find a profile centered between the high and low limits, assuring the most robust process possible. With selected oven manufacturers, the profiling software can communicate with the oven controller. Zone setpoints and belt speed are automatically exchanged between the profiling software and the oven controller, eliminating any potential for data entry errors.

Companies with multiple manufacturing facilities can electronically share and compare the automated prediction tool's solution through e-mail. A data file viewer program allows anyone running Windows 3.1, Windows '95/98, or Windows NT to view the profile solution. This method can also be used by CMCs to send profiles to their clients for approval and to other facilities for immediate production line setup.

Quality Control

The real-time thermal manager offers significant advantages for quality control programs. When there is a problem on the line, typically the first thing that is done is to profile the oven. This is done whether or not the oven is suspected as the cause of the defects, because the oven is a black box and no one can say with certainty what is going on inside it. With the real-time thermal manager, users would already have been alerted if there was a problem with the oven.

SPC is a tool aimed at increasing profitability by controlling and monitoring production processes. Data is continuously charted and analyzed to detect trends and other information that may indicate whether the process is working at its optimum. SPC can provide early warning signals, allowing users to take corrective action to adjust the process before a single defect is produced. The real-time thermal manager features a live data output option for SPC, documentation, or other applications. Live Data Output continuously sends data collected by the 30 thermocouple probe sensors to a remote computer file or other programs. The data is output in ASCII format and may be accessed by a spreadsheet, SPC software, or other applications. The real-time thermal manager is also available with an integrated SPC package, which includes Control Charts, Histograms, Cpk Analysis, and a report generator for customized reports. It is extremely fast and easy to set up, and because all input data is controlled by the profiling software, any changes to product profiles are automatically transmitted to the SPC program as limits and other parameters. This option completely automates real-time data collection, management, and analysis of temperature measurements for SPC purposes.

Distribution of Data

The data file viewer has already been mentioned above as the simplest way to transmit profile data via email. Other methods of distributing and accessing data include the utilization of a Local Area Network (LAN), corporate Intranets, the Internet, and the use of server-based computing technology. The main problem with distributing thermal process data is obtaining adequate bandwidth. An optimal real-time network requires several megabytes of bandwidth, but there are methods of distributing data through a 56K Internet connection.

LAN distribution

The most effective method of distributing reflow process data at a single location is a Local Area Network. The extremely broad bandwidth a LAN provides makes it possible to run the thermal profiling software live on multiple oven controller PC's and at a central monitoring station. The data is also available to any engineer or manager connected to the LAN, so that a problem with the thermal process can be reviewed and remedied without anyone needing to leave their desk. At one major automotive electronics plant, the thermal manager is used in conjunction with a LAN to monitor 67 reflow ovens, curing ovens, and wave solder machines remotely and in real-time. (See Figure 4) Other users have utilized their network to send oven alarms to an auto-dialer, which then dials a pager to alert the person responsible for the process. This provides process engineers with 24/7 peace of mind that their process is in control and an instant alert when it is not.

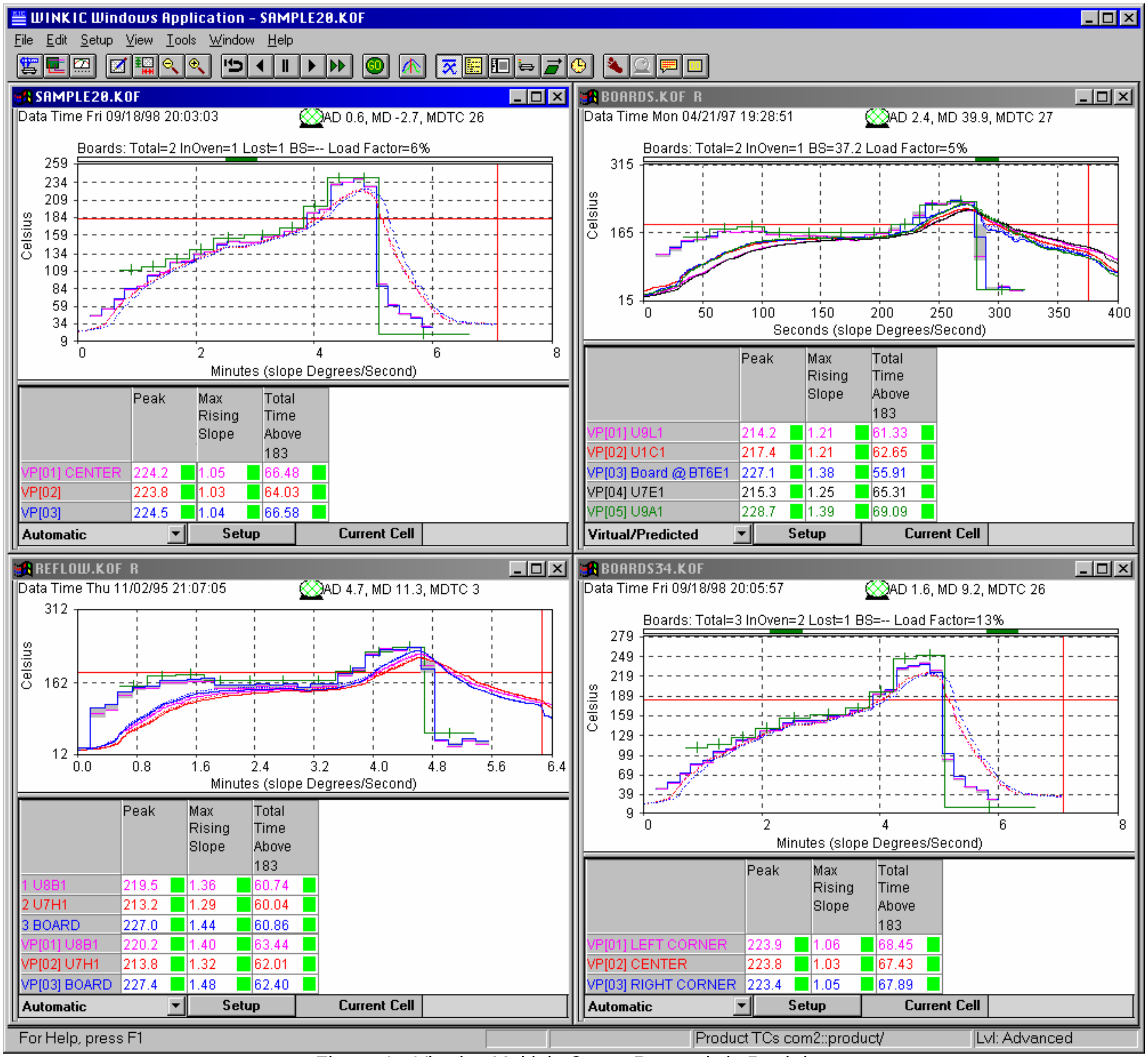


Figure 4 – Viewing Multiple Ovens Remotely in Real-time

Intranet & Internet Data Distribution

The data from the real-time thermal manager can be distributed to offsite locations via a corporate Intranet or the Internet. This is accomplished by capturing the thermal manager's real-time output at 15-second intervals with a third-party screen capture program at the oven controller PC. All of the thermal manager PCs are connected to an internal network, and at a pre-determined interval, the screen capture program exports the Virtual Profile image to a folder on a corporate server. The process data from this folder is retrieved and displayed by a web page on the network front end. The page is setup using a meta-command statement that allows the web page to go out to the folder, grab that image at an interval that matches the snapshots, and then automatically refresh the web page. As the data is captured by the screen capture program and placed in the folder, it automatically overwrites the previous image to avoid filling up the server hard drive. This system allows viewing data from either an individual oven or multiple ovens at any given time and has the capability to display multiple ovens on the production floor in a single snapshot window. (See Figure 4) The information from the output folder can also be accessed at the same interval from an Internet website.

The Internet website screen usually includes a header designating the line and oven type, as well as a snapshot of the live data output from the real-time thermal manager. The live data output captured is structured to display the oven footprint with zone temperatures and belt speed, along with average and maximum deviations. A statistics block

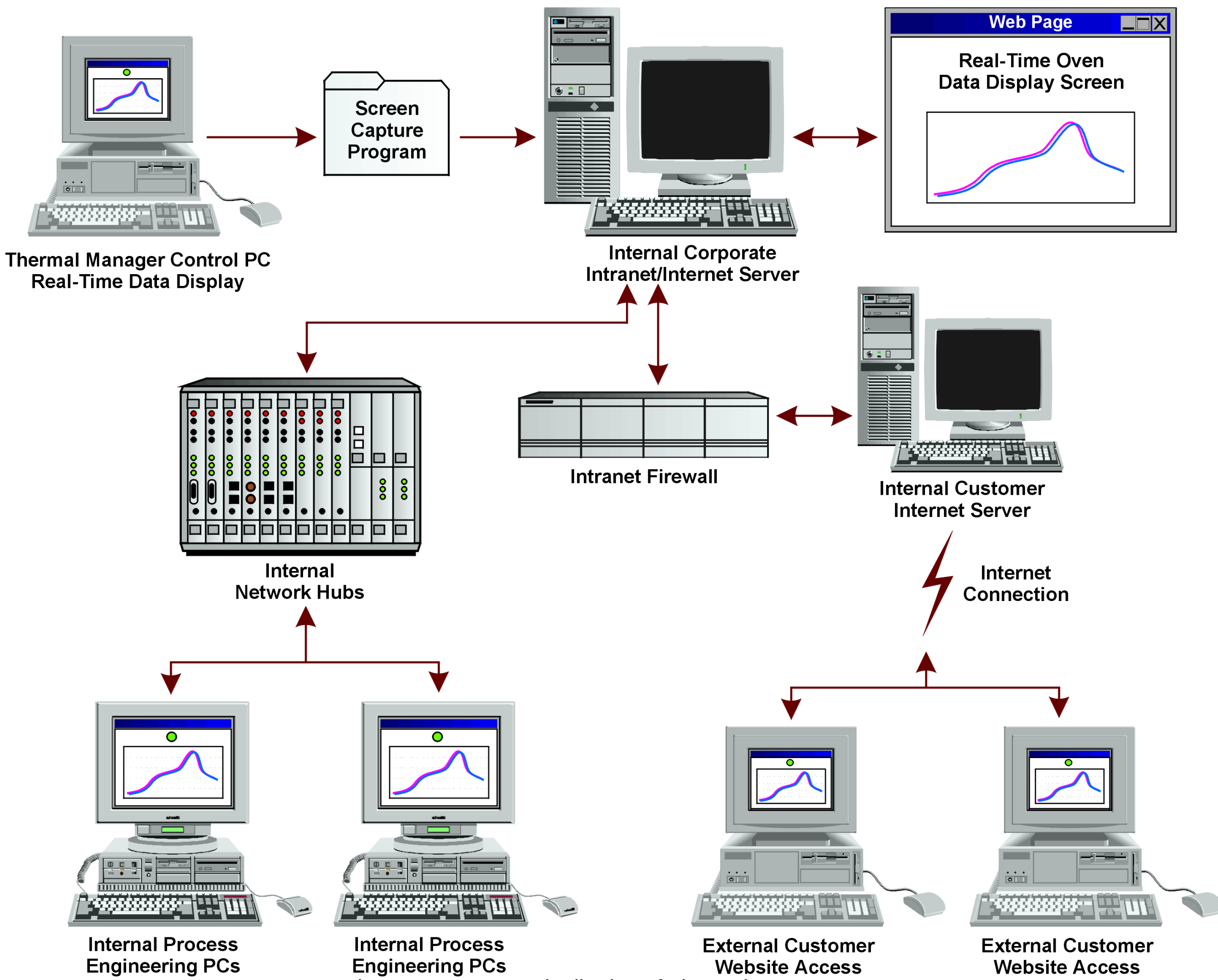


Figure 5 – Internet Distribution of Thermal Process Data

showing ramp rates, soak time/temperature, time above liquidus and peak temperature can also be included. Also seen is the Virtual Profile 'crystal ball' icon, indicating green, yellow or red for whether or not the process is running in control. The main concern with the output of data via the Internet versus a corporate Intranet is that the refresh response time increases due to the transmission routing delays inherent to Internet connections. In February 1999, an experiment was developed and conducted to validate the feasibility of ongoing Internet transmissions. Using a 128k ISDN connection, real-time thermal data was transmitted from a contract manufacturing facility in Texas to a major industry trade show in Southern California. The data was viewable in real-time the entire length of the show, with good image quality and refresh response rates. More recently, acceptable external data refresh rates have been achieved utilizing a standard 56k dial-up connection. At Apex 2000, a more ambitious experiment will be performed, with three reflow ovens at multiple United States locations being monitored live on the convention floor. (See Figure 5)

Server-based Technology Distribution — The Next Step

While the current method of Internet distribution offers users many advantages, there is still more work to be done. The current method allows users to view a selected process status screen from anywhere in the world, but it does not allow them to interact with the thermal profiling software. For example, the current system is capable of letting a user know that the process is stable, or that there is a problem with the process. The current method of Internet data distribution does not allow the use of the thermal profiling software's event browser to access history files for further information on the product status.

It appears possible to allow users to exercise remote control read-only access to complete thermal process data utilizing server-based computing technology such as MetaFrame™. Use of this architecture would require the installation of a MetaFrame-type application server on the oven controller/thermal manager PC. Users logging into the

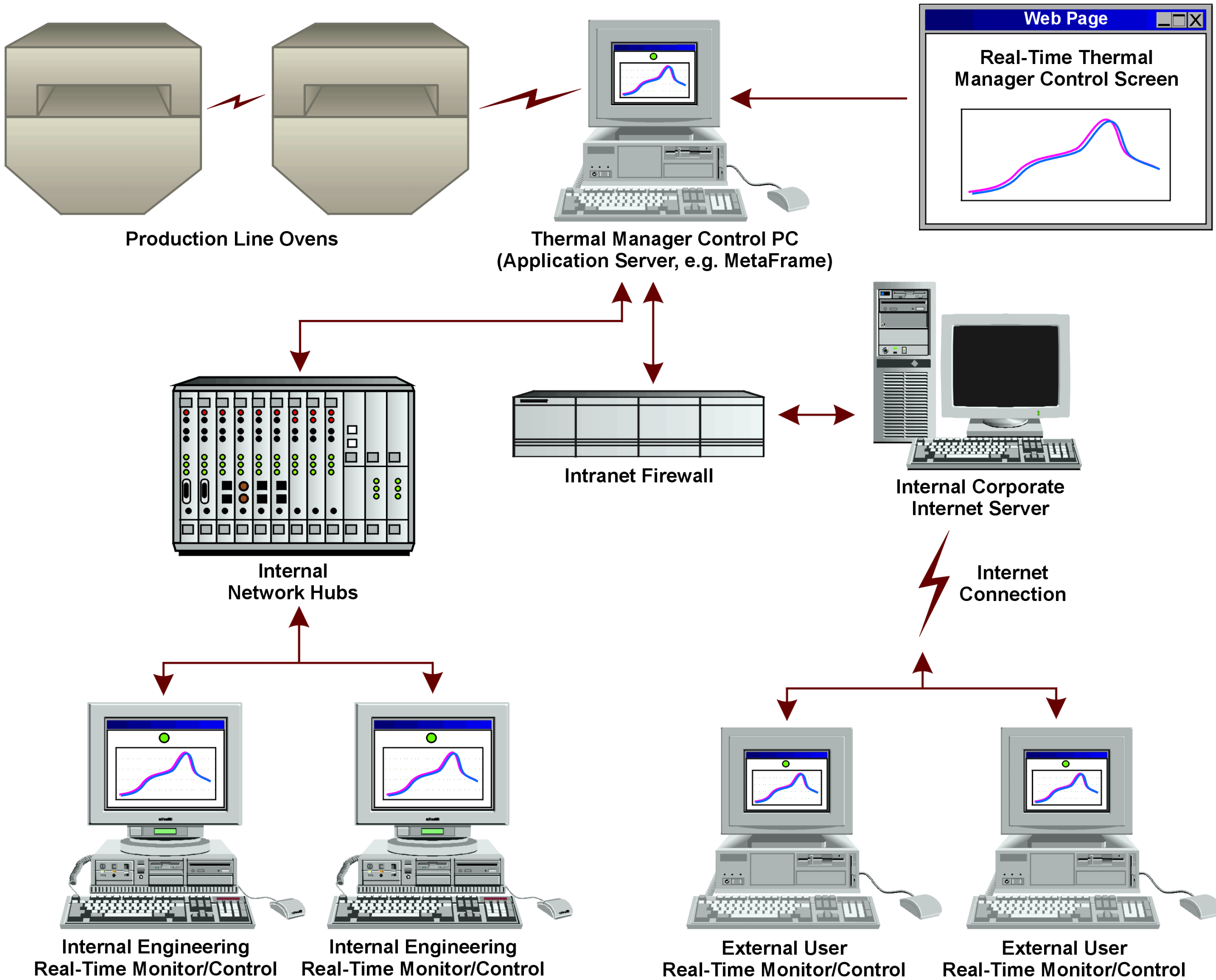


Figure 6 – Server Based Technology Remote Control of the Thermal Process

application server via a secure web page would be able to take full advantage of the real-time thermal manager's features from anywhere in the world with nothing more than a standard 56K Internet connection. (See Figure 6) This technology has not been tested but is technically feasible. Once it has been tested and the appropriate procedures developed, users will be able to control their thermal process from offsite locations.

Effects and Advantages of Real-time Thermal Process Data Distribution

The effect that internal distribution of thermal process data over a local network has on production costs and quality control is significant. With qualified engineering staff difficult to come by, many companies are running lean on engineering and support staff. Being able to access data remotely eliminates the engineer's need to constantly jump up and go out to the shop floor to view each process, and allows companies to maximize the value of scarce engineering resources. Time spent efficiently by engineers means a better bottom-line for any facility.

Further benefits can be realized by companies running production at multiple facilities. Comparative SPC data from each plant allows management to quickly evaluate plant performance. With thermal process data transmitted over the Internet, a worldwide company has real-time access to all of their thermal processes, making comparisons between facilities simple. If one facility has better throughput and higher quality, or if they can see one facility getting higher quality from an oven that has been standardized, the oven can be monitored remotely in real-time and the data can be used to improve the processes at other facilities. A further benefit of gathering this data is that it points to a concrete dedication to quality and process improvement that both OEMs and CMCs can show to their customers.

The external distribution of the thermal process data to CMC clients via the Internet offers an opportunity to further increase customer satisfaction and demonstrate cutting-edge technology. Customers can be given individual web sites on a corporate Intranet that they can access through the firewall with a personal password. Within their sites, customers are able to view work in process and real-time quality data collection showing both in-process inspection and test yields. The ability to "dial-in and check-out" a particular product at any time from anywhere assures customers that they are getting a quality product that is built to their specifications. This technology also gives OEMs the opportunity to monitor outsourced production by requiring their contractors make thermal process data available over the Internet. Further, the Virtual Factory allows customers to be confident that whether a product is made in Mexico or the United States or Taiwan, the product quality will be exactly the same. Running the same machines in all facilities and sharing real-time information worldwide is the next step in process control. By assuring that quality is consistent in all facilities worldwide, production costs can be reduced by building boards where they're needed without having to worry about issues of varying production.

Conclusions

Accessing thermal process data via the Internet has set a new standard for Quality Control. Real-time thermal profiling provides electronics assemblers with the opportunity to make significant process improvements in terms of both quality and efficiency. Making thermal process data available over the web is a significant steps towards monitoring the entire process remotely and in real-time—the first step towards implementing the Virtual Factory. Installation of the real-time thermal manager on reflow ovens and wave solder machines can greatly improve processes by reducing defects, increasing yield, and significantly reducing the labor costs and downtime associated with manual process verification. Implementation of the latest in thermal profiling—the improved automated prediction tool or the self-profiling oven, will yield even greater process improvements. A further benefit of distributing real-time thermal process data over the Internet is increased efficiency of global operations, allowing CMC's to prove their processes are in specification 24/7, and giving OEM's peace of mind regarding their outsourced production. The key to successful thermal processing in the twenty-first century lies in the real-time thermal manager's ability to provide quick and easy access to the process status, which makes it simple and convenient to determine whether the process is in or out of control at any time.

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