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Printed Circuit Board Tracking with RFID: Speed, Efficiency and Productivity Made Simple

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Executive Summary

Tracking goods through manufacturing was originally accomplished with pencil, paper and human input. Barcodes introduced an automated, machine-readable tracking mechanism that streamlined all types of manufacturing. But modern printed circuit board (PCB) assemblies are running into limitations because of barcode labels. And though barcodes and RFID tags will co-exist, the relatively large barcode labels have to find increasingly scarce real estate on high density boards. Furthermore, flexible manufacturing processes that create dozens or hundreds of models derived from a base design, must be replaced with a barcode label in the final stages of product production which indicates that manufactures need to examine whether barcode tracking or RFID tracking is the better option for their business.

Radio frequency identification technology (RFID) RFID demonstrates a number of attributes which make it a natural fit for PCB tracking. RFID delivers accuracy, reliability, performance, durability in a variety of environmental conditions, and it is a secure technology that is easy to implement. It is those attributes, when applied into a PCB tracking environment, can streamline the manufacturing process. RFID is a proven technology and implementation for asset tracking in other industries has seen great improvements in both the operations and profitability metrics. RFID not only overcomes many of the problems associated

with barcodes including board real estate, automation, and human intervention, but it is reprogrammable and can be updated at any point in the manufacturing, stocking, or shipping process. Additionally, devices are now available that are among the smallest components produced. These benefits add flexibility, increase throughput, improve quality traceability, and reduce manufacturing costs. For example, should there be a problem at any point while assembling a product, RFID enables the manufacturer to isolate the problem, down to the exact point in the process, and readily identify those units that may have experienced the problem. It can be likened to finding a needle in a haystack, without disassembling the entire haystack. The benefits can extend beyond manufacturing to the entire lifecycle. In fact, service, warranty, and recall costs could all be reduced with RFID enabled circuitry.

Limitations of Barcodes

Barcodes have served electronics manufacturers well since the 1980's, but they have limitations and in many cases no longer meet the needs for tracking and managing manufactured goods. Perhaps more relevant is that technology, such as RFID, has evolved in parallel with business trends and requirements.

Some barcode proponents argue that standard linear barcode labels and scanners are simple and inexpensive. Unfortunately, their information density is low and it takes over 500 mm^2 to get approximately a dozen characters on a label. Therefore, placement flexibility is very low, and virtually every manufacturer has their own standard, label size and placement without the ability to change it for fear of missing reads or slowing down the production line.

The two-dimensional barcodes, or data matrices, which allow hundreds of bits of information to be placed in tens of square millimeters make an attempt to solve the density problem. However, this comes with a number of trade offs including high cost scanners, read reliability, and reduced flexibility. Typically, expensive, high-resolution cameras that require precise registration are needed to read a data matrix label. The high precision requires the assembly line cameras to be repositioned each time a new label position is processed and the background environment can change the accuracy of the reads. Read rates of 80-90% are typical for data matrix labels on high speed manufacturing lines.

Both types of barcodes require line of sight between the label and reader. This adds more restrictions on PCB component placement and many times the design and placement of large heat sinks or mounting brackets are affected by barcode restrictions. Another disadvantage of line of sight is that labels are unreadable once the PCB is in the final enclosure.

Neither type of barcode is reprogrammable, which is a major limitation for today's flexible manufacturing systems. Manufacturers generally create multiple versions of a basic product that differ by only a few components. These components are often installed after the device has been put in inventory or possibly even reworked from an existing finished stock. In these cases, the barcode has to be manually replaced to indicate the new, finished part number, serial number, etc. with little, if any, history saved for those units.

Barcode throughput is limited by scanners that only read one label at a time. If multiple, simultaneous reads are needed, multiple scanners must be installed. Even with inexpensive linear barcode scanners, multiple scanners represent an overhead and maintenance headache.

There are other problems with barcodes that may or may not apply to a given application:

- Oil, grease, or other chemicals on the label can render it unreadable
- Less physical durability mean labels can be burnt, torn or become unreadable
- Manual reading speeds are hindered if bar codes are difficult to find or at odd orientations.

Figure 1: Linear Barcode and Data Matrix
From Wikimedia.org

RFID and Gen2 UHF

Radio Frequency Identification (RFID) is a technology that enables the contactless electronic identification of goods. The RFID "tags" are essentially rewritable memory chips with a radio. Tags that use a battery to boost the distance they communicate are called active tags. Passive tags harvest power from the reader's energy field and do not require a battery. There are many varieties of RFID tags with various levels of sophistication, memory size, read range, and security. This application lends itself well to one of the newest types of passive tags, EPCGlobal™Gen2 UHF.

The Gen 2 UHF specification, which was finalized in late 2004, is a simple, low cost protocol intended for high volume inventory control. It is now an ISO standard and operates in the 840~960MHz frequency band worldwide. Large corporate retailers in North America, Europe, and Asia are using Gen2 UHF to track products throughout their supply chain from their suppliers all the way to the store stock rooms. PCB manufacturers can benefit from the hardware and software developed for these retailers with the readily available building blocks that incorporate into their manufacturing systems.

Implementing RFID on PCBs

Using RFID for tracking electronics is not new; earlier versions used low frequency (LF) and High Frequency (HF) tags. Those trials either adhered a label-based tag to the PCB or etched an antenna that mounted directly to the RFID chip. Unfortunately, both HF and LF require a relatively large loop antennae, so those solutions required significant amounts of space. Ultra high frequency (UHF) tags, in contrast, need only a small dipole antenna which is a thin copper trace approximately 3-inches (75mm) long.

Historically, RFID solutions lacked a suitable package type that was compatible with surface mount manufacturing. To keep the device size small and the cost as low as possible, RFID makers typically used bare die assembled with flip chip techniques. However, this is impractical because the vast majority of manufacturing lines do not incorporate flip chip equipment. The advent of a very small, surface mount package that is compatible with conventional pick-and-place assembly lines is crucial. The surface mount technology (SMT) package for the UHF die can be less than 1.5 x 1mm (60x40 mil) which is similar in size to very small ceramic resistors and capacitors, and is ideal for high density electronics.

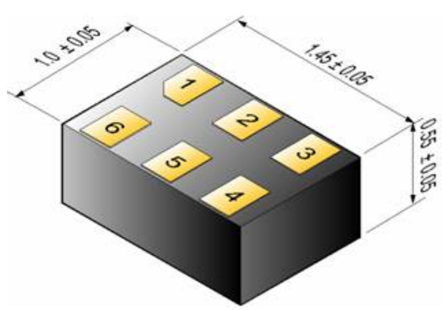

Figure 2: SMT RFID device

A major advantage for RFID is that it does not require a line of sight to read the tags. As long as the PCB is in the reader field it can be read. This means that as long as a reader antenna is set above the assembly line with sufficient transmit power, the position and orientation of the RFID chip is not critical. And as long as the PCB is not in a shielded enclosure or package, the tag may be readable.

Read ranges for Gen2 UHF tags can be as long as 10m (30ft). If too much read range is an issue, as it can be in certain cases, then it is an easy matter to reduce the range by changing the tag antenna design. The Gen 2 UHF specification requires that tags are disabled with a “kill” command; this renders the tags permanently inoperative if a manufacturer desires.

Benefits that the Gen2 UHF based chips bring:

- Low board real estate
- Rewritable data
- No line of sight required, can read through some packaging/enclosures
- Option to lock memory on the tags
- Password write protection
- Permanently disable tags with “Kill” command
- Read range is tunable
- SMT or Flip Chip mounting options
- As durable as standard SMT components
- Low cost with standard mfg operations
- Simultaneous high speed reads

The table below highlights many of the advantages RFID has over barcodes in PCB tracking applications.

	Barcode	Data Matrix	RFID
PCB area required (typical)	10x200mm (2000mm^2)	10x10mm (100mm^2)	35x1mm (35mm^2)
Placement Req.	Same position on all similar PCBs		Arbitrary
Line of Sight	Required		Not required, can read through non-conductive package
Rewritable	No		Yes
Read Range	35cm (1ft)	25cm (8 inch)	10~200cm 4inch~6ft
Simultaneous reads	Only with multiple scanners		Yes, 100+ per second
Reader/scanner placement flexibility	Moderate	Low	High
Scanner/Reader setup	Repositioning required if placement changes		Set and forget
Manual Scanning	Can be done in approx 130^o cone and the scanner must be turned roughly in line with barcode		virtually 360^o readability.
Smudge effects	Can render unreadable		No effect

Table 1: RFID vs. Barcode

Usage Example

While 96-bits, or 12Bytes, of information may not sound like enough memory for encoding, it is actually quite flexible. This amount of memory was selected to provide enough numbering space to give billions of products their model number and serial number. Ninety-six bits provides a total of 2^{96}, or $79x10^{27}$ unique numbers. While manufacturers will typically have their own method of encoding tags, a simplistic assignment method could use 32-bits each for a model number, serial number, and a set of manufacturing codes. Each 32-bit segment would have approximately 4.3 billion unique numbers available.

This flexibility can be extremely useful for contract manufacturers (CM) as they face special problems trying to interface with dozens or hundreds of disparate customer systems and methods. In their own factories, they can use the encoding system that works best for them, and then simply reprogram the tags when shipping to their OEM customers. If a CM has a customer that does not want RFID-enabled tracking, the device can either be “killed” or mounted to the scrap portion of the PCB and taken off before shipping.

Table 2 below lists a possible manufacturing line flow and the information that could be programmed at various steps and logged in the manufacturing database. The method below uses the memory allocation mentioned above with 32-bits each for model number, serial number, and manufacturing code bits (MCB). The flexibility of this type of system is invaluable because manufacturers can realize the additional benefits from the real-time data collected via RFID. This enables management decisions in real-time improving the efficiencies of the process. Providing quality information and being able to react quickly to customer’s changing demands is especially important in today’s competitive market and the ability to quickly reconfigure a unit from one model number to another and log the unit’s entire history is a valuable tool as noted above.

Manufacturing Operations	Info programmed
Load Bare PCB and components on line	n/a
Populate bottom side components, including RFID device	n/a
Reflow oven- RFID operational at this point	Model number and serial number MCB*- Pick and place station, oven used
Populate top side	MCB- Pick and place station
Reflow oven	MCB- oven used
Mechanical assembly #1	MCB- Assembly station
Functional test	MCB- Test pass/fail
Rework if necessary	MCB- Rework flag
Final mechanical assembly	MCB- Assembly station
Burn in station	MCB- Burn-in test results
Move to inventory	MCB- stocking date
Pull from inventory and rework to new version or model no.	Reprogram model and serial no.'s MCB- flag as reworked from previous version
Ship to customer	Log model and serial no., lock device to prevent data tampering.

*MCB= Manufacturing code bits section of memory

Table 2: Example manufacturing flow of PCB tag

The benefit of programming the manufacturing codes into the tag is that now factory staff and systems will not need to have access to an online database in order to determine a unit's history. Business rules can be pushed out to the floor and machinery and personnel can react quickly, without worrying about network speed or even connection reliability. This offline readability can be leveraged for greater manufacturing flexibility and efficiency.

Conclusion

The need for high quality manufacturing, outsourcing, flexibility, and legal requirements are pushing the traceability of manufacturing assemblies to the limit. Many companies face significant warranty, safety, and liability costs if they do not have a highly accurate, comprehensive view into their manufacturing data. Imagine, instead of recalling an entire lot of products, if a manufacturer could identify only those serial numbers made on the specific machine, at a specific date that caused the problem. The savings in recall, warranty, and possible litigation costs would go straight to that company's bottom line.

The total number of units produced by a PCB assembly line is easily tracked today. However, the number of units in process, their location, status, and the time metrics are not readily available with the accuracy needed to manage the production process in today's high volume factories. Every unit needs to be tracked individually for quality, traceability and assembly line efficiency. Today's highly automated environment also requires as little human intervention as possible. Finally, the rapid adoption of the EPCGlobal™ Gen2 spec (aka ISO 18000-6C) means there is a standards based approach with readily available infrastructure for both reader hardware and software. This standards based method provides manufacturing ROI for improved efficiencies, real-time data, and accurate tracking of PC boards and assemblies. These new devices provide a space saving, highly flexible method of automated identification to make assembly line operation and setup more efficient. RFID technology can take manufacturers to the next level of sophistication.

About the Authors

Chris Cook is an application specialist for Texas Instruments, Inc. In this role, he works with contactless payment customers to provide application advice, testing, and technical assistance. With more than 12 years of experience in electronics, Chris leverages his expertise in designing and managing electronics packaging solutions in support of TI's contactless payment business.

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