Implementation of RFID in a Low Volume High Flexibility Assembly Plant: Module Component Tracking

by

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Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

Master of Engineering in Manufacturing

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2010

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Implementation of RFID in a Low Volume High Flexibility Assembly Plant: Item-Level Tagging

by

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Abstract

The purpose of this thesis is to help Varian Semiconductor Equipment Associates, Inc. (VSEA) to smooth the production and reduce the manufacturing cost. Without an efficient way to track on its high-value components, VSEA thereby spends hundreds of thousands of dollars to respond to customers' fraudulent claims and adds extra burdens to manufacturing teams.

RFID system is introduced to improve the traceability of high-value components. By physically applying a RFID tag on a component and associating the tag with necessary information of the component, VSEA is able to avoid accepting a fraudulent claim by providing reliable and accurate record for a particular component.

After testing different types of RFID tags and various checking system setups, the RFID system is verified feasible to be implemented in the high-value component tracking. Specially, a guideline of tag placements on different components is generated for reference in further implementation.

Thesis Supervisor: David E. Hardt
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Acknowledgements

First of all, I would like to thank my family and my fiancé for supporting me through the difficult times during this year, the most valuable period of my life. Without your love and support, I wouldn't be able to successfully finish my master degree and start my exciting career.

Thanks are also due to Mr. Scott Sherbondy and Mr. Daniel Martin for making this project in Varian Semiconductor Equipment Associates Inc. (VSEA) happen. With your courtesy, proficiency and support, I had experienced an exciting, formative and successful internship. I will miss the time at Varian and your sense of humor in the future.

Special thanks go to Norman Norton, Roger West, Debrework Legesse, Adam Mahoney and all other people in the flow line, in the clean room and at Varian. All of you were supportive and helpful; you generously shared your experience and patiently answered my copious questions. All of these make me happy working at Varian.

I would also like to thank my Advisor Prof. David Hardt for giving me the opportunity to study in my dream school. Your kind guidance and advice will be treasured in my life.

Last but not the least, I would like to thank my friends, classmates and colleagues Cyril Koniski and Yulei Sun. It's nice working with you and I learn a lot from you. I'm also appreciative of other two classmates and friends, Sivesh Selvakumar and Rodrigo Linares. Thanks for giving me your unconditional friendship.

Thanks again to all these people.

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Chapter 1 – Introduction

1.1 – Project Motivation

High complexity manufacturing plants with a broad production mix at low volumes are highly dependent on human labor. Typically, such facilities are viewed as unsuitable for task automation due the high degree of product customizability required. However, recent technology advances have made available solutions that enable efficient modification of processes to reduce production time by eliminating repetitive tasks.

As a manufacturer of high precision machines, Varian Semiconductor Equipment Associates (VSEA) must maintain strict quality requirements and offer its customer high flexibility, while consistently meeting delivery deadlines. As such, the company's operations are highly labor intensive and time consuming, resulting in long lead times and high production costs.

The project discussed in this thesis was undertaken by a team of three students enrolled in the Master in Engineering program at MIT and was sponsored by VSEA. Its objective is to assess the viability and technical feasibility of the implementation of an RFID-enabled system to trace parts throughout VSEA's factory, eliminating the need for labor-intensive inspections.

1.2 – Presentation of the Company

1.2.1 – Overview

Varian Semiconductor Equipment Associates, Inc. (VSEA) specializes in the design, manufacture, and servicing of ion implanters, a type of semiconductor processing equipment used in the fabrication of integrated circuits. Founded in 1971 in Peabody, MA as Extrion Corporation and acquired by Varian Associates in 1975, it was then spun off in 1999 as an independent company based in Gloucester, MA. Over the past 30 years, VSEA has managed to maintain a strong position as a supplier of ion implanters, adapting its product line to handle gradually increasing wafer sizes from the 1 in standard in 1980 to the current 300mm wafers. [1]

1.2.2 – Customers

VSEA's customers are semi-conductor manufacturers such as Intel, IBM or Samsung. VSEA is established worldwide and has a strong presence on the Asian market, with customers from Asia accounting for over three quarters of the company's revenue. The very high upfront investments (hundreds of millions of dollars) required to start a semi conductor production facility constitute a significant barrier to entry into the market, and therefore the few existing players have remained essentially the same over the years. As such, these customers have accumulated considerable buyer influence, enabling them to demand and obtain high customization and low lead time. VSEA has attempted to standardize some of the modules on the high current machine (e.g. beamline), but still often finds itself obligated to comply with customer wishes in terms of selects and options. The power of buyers in the semi-conductor industry, leading to low standardization and human-intensive production, is therefore one of the major causes for inefficiencies in the operations of VSEA and semi-conductor equipment manufacturers in general.

1.2.3 – Market Position

Over the past 8-10 years, VSEA has actively endeavored to widen the gap with its competition in the ion implanter market. It has grown from about 30% to over 70% of market share, and holds the top position as a manufacturer for all 4 lines of products it provides (High Current, Medium Current, High Energy and PLAD). In the High Current implanter market, VSEA has steadily broadened its customer base, supplying most of the top 20 (including the top 3) semi-conductor companies as ranked by the size of their capital expenditures.

1.2.4 – Product Offerings

Having become the most prevalent method for high-productivity doping of silicon wafers, ion implantation is a critical processing step of semiconductor device fabrication. VSEA specializes in the production of single-wafer, high productivity ion implanters, and offers a full suite of high current (HC), medium current (MC) and high energy (HE) models based on the common VIISta Platform, which includes a dual-magnet ribbon beam architecture, the VSEA's proprietary Varian Control System (VCS) and Varian Positioning System (VPS), as well as a single-wafer end station. Figure 1.1 shows the components of the VIISTA platform. [2]

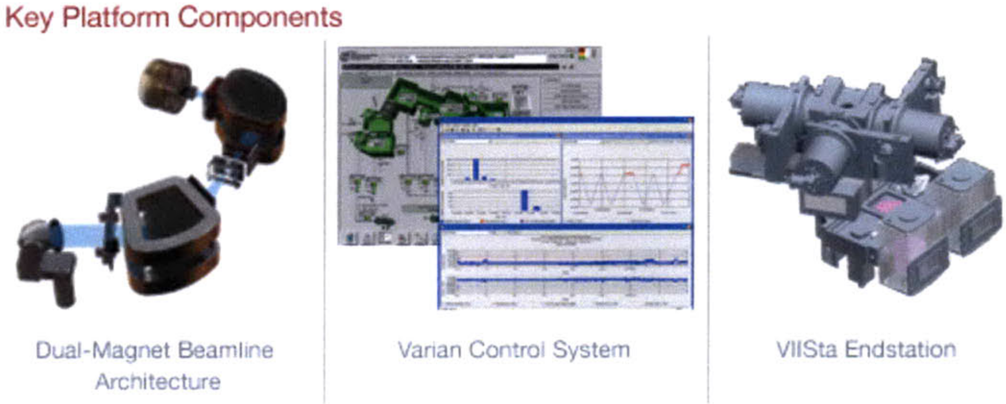


Fig. 1.1: Components of the VIISTA Platform

The main differences between these three product categories are the dose of ion used and the energy supplied for implantation. HC machines have higher dose which translates into higher ion concentrations on the wafer surface, while the MC and HE machines have higher energy, resulting in increased implantation depth. There are different types of machines under each category, designed to fit the particular 'recipes' produced at the customer's fab. They are shown below.

High current	Medium current	High Energy
VIISta HCS	VIISta 810XP	VIISta 3000XP
VIISta HCP	VIISta 810XEr	
VIISta HC	VIISta 900XP	

VSEA is also in the process of introducing its PLAD (Plasma Doping) line of implanters to accommodate ultra-high dose applications.

1.3 – Semiconductor Equipment Industry

The semiconductor industry where VSEA operates is a highly competitive and fast-paced one which represents a market of over $260 billion. Despite an average annual growth of 13% over the past 20 years, the market has also suffered from above-average market volatility, subjecting it to dramatic cyclical changes. [3]

A semiconductor fabrication plant can cost up to $4 billion to build, and consists of hundreds of high-precision equipment items, such as steppers, etching machines and ion implanters, which can cost upwards of $4 million each. [4]

In order to accommodate the fast pace of technological innovation in the field of semiconductor manufacturing, suppliers such as VSEA must constantly improve the performance of their devices while keeping prices constant. This leads to concern over operational efficiency and, in the case of VSEA, results in a push for lean production.

Having achieved significant reductions in lead time through the introduction of SmartShip (see Section 2.2) and other initiatives, VSEA shifted its focus to improving shipping operations. Accurate and on-time shipping is crucial to VSEA and its customers, as any delay may result in a halt of semiconductor fabrication at the client's site, potentially resulting in hundreds of thousands of dollars in lost revenue. As such, tracking of outgoing shipments is required, while total shipping time must be minimized.

1.4 – General RFID Introduction

After in-depth analysis of VSEA's current operations (which are detailed in Section 2 below), it was decided that the improvement which would benefit shipping operations and overall lead time most was the implementation of RFID tracking at VSEA's warehouse and in the company's shipping area. The remainder of this thesis will assess the technical feasibility of RFID for both high-level (large components and modules) and low-level (individual items or small sets of items) tracking of parts. It will also make concrete proposals about modifications to current operations that would make RFID implementation most effective.

RFID technology, which is described in details in section 3, allows for unique identification of products or parts without requiring line-of-sight reading, thus increasing depth of serialization and reducing the time spent counting inventory through simultaneous reading of several tags. [5]

In recent years, and following mandates by Wal-Mart and the US Department of Defense, RFID tagging for pallet tracking and high-level inventory management has become commonplace. [6] The technology is versatile, and can be adapted to numerous other applications, yet caution must be exercised in implementing it, as it is still incipient in some regards. Section 4 will discuss some of the specific challenges expected for our application in VSEA's industrial environment.

1.4 – Thesis Structure

In the next section, VSEA's operations are described in detail. The problem at hand is then clearly defined in section 3, both qualitatively and quantitatively, and the scope of the work narrowed. Review of theoretical background and previous work is summarized in section 4, while the methodology followed to study the problem is introduced in section 5. The results obtained are shown in section 6, and discussed in subsequent sections with the appropriate recommendations.

Chapter 2 – Description of Manufacturing Operations at VSEA

2.1 – Company-Specific Language

VSEA employees use company jargon to describe certain processes, internal transactions and record-keeping forms. A brief overview is presented here.

2.1.1 – Types of Orders

A *Machine Order* (or *Tool Order*) is the original order placed by VSEA's customer. These orders are collected by sales representatives and include different selects and options based on the customer's specific requirements. The machine order will include information about the agreed upon price, shipping date, terms and conditions.

A *Production Build Order* (PBO) is an expansion of a machine order. A PBO is a list of about a hundred *line items* representing all the assemblies (represented by their part codes) of the particular configuration ordered by the customer. A PBO is a dynamic document and can change upon customer request. In an effort to limit the disruptions caused by last minute requests, VSEA has instated a 10-day 'freeze' period prior to shipping, during which changes can no longer be made to the PBO.

A *Sales Order* is the order of spare or replacement parts by the customer for maintenance purposes. Internal orders to replenish 'material banks' (located all over the world to provide parts and support to customers) are also considered sales orders. Some sales orders may be assigned higher priority than others for various reasons (an *Emergency Order* or EMO represents the highest priority items).

A *Shop Order* (or *Work Order*) is issued to production workers to fulfill a single assembly or part collection task or perform machine testing. Shop orders have a multilevel hierarchical structure. For instance, at the highest level, a single shop order can be issued by a production manager for the assembly of the entire beamline module. At the lower levels, shop orders will be issued for each subassembly under the module shop order.

An *Engineering Change Order* (ECO) is used to document a design change to the current machine architecture. There are various reasons for having ECOs, including machine upgrade, bad part performance at customer site or discontinuation of the part by suppliers. Typically an ECO goes through a process of design, approval, testing and documentation before the change is applied to the machine.

2.1.2 – Kit Codes

Kit Codes are used in all aspects of VSEA's current operations. Originally, kit codes were meant to represent the breakdown of the machine into its multiple components and organize the production sequentially. For instance, 1LA stands for end station kit, 4V stands for beamline and terminal kit and AV stands for final assembly kit. It is interesting to note that under a single *kit code*, there may be several *kits* (coherent collections of parts and sub-assemblies serving a common function, or included in the same higher level subassembly), each containing a mix of parts and subassemblies purchased from suppliers and subassemblies produced in house. Production supervisors used to pull parts from stock by kit codes in a sequence, such as 1LA1, 1LA2 and then 1LA3, (Fig. 2.1, 1LA refers to kit codes pertaining to the end station module), but over time, new kit codes were created and existing ones were modified without regard to the original function, leading to gradual loss of the sequential order.

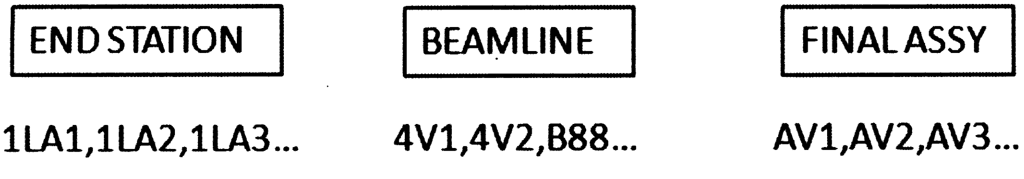


Fig. 2.1: General Structure of the Kit Codes

Currently, kit codes are all at the same level (no hierarchy) and based on a rough division of parts at the module level. This means production managers and engineers are forced to modify the contents of each kit code for each new machine order, depending on the desired configuration. The kit codes are then pulled onto the flow line by production coordinators and material handlers in a custom sequence dependent on previous experience.

2.1.3 – Bill of Materials

A *Bill of materials* (BOM) is a hierarchical list of all the components in a machine. A BOM goes from the entire machine down to the modules, major components, smaller subassemblies and single parts. It also keeps track of the quantities of each component that are required for the final assembly of the machine given the particular configuration ordered.

2.2 – Manufacturing Operations

'Manufacturing' at VSEA designates all assembly and testing operations. Assembly operations include production of subassemblies and assembly of modules whereas testing occurs at module-level or on the entire machine. The machines tested as a whole are known as *Full Build* orders, as opposed to *SmartShip* orders, which undergo more extensive module testing but bypass the final assembly and complete machine testing stage, thus reducing production time by about 100 hours. Currently 50% of production consists of SmartShip orders, with a target of 80% by 2012.

VSEA outsources all its parts from a large number of third-party suppliers. The company also outsources subassemblies that do not contain core technology and cannot be assembled in house at a lower cost.

The factory is divided into different areas. All the assembly and testing is done in the main building in which there are four main functional areas:

The factory is divided into different areas. All the assembly and testing is done in the main building in which there are four main functional areas:

- The *Supermarket* (SMKT) and the *source room* are the areas where subassemblies are produced. Parts inventory for the subassemblies are kept there.
- The *Flow Line* area is used for module assembly and testing
- The *Clean Room* is used for machine testing on full build orders, as well as for teardown tasks requiring a sterile environment.
- The remaining area is dedicated to shipping operations and includes an air shower area, as well as a packaging area where modules and parts are put into crates and loaded onto shipping trucks.

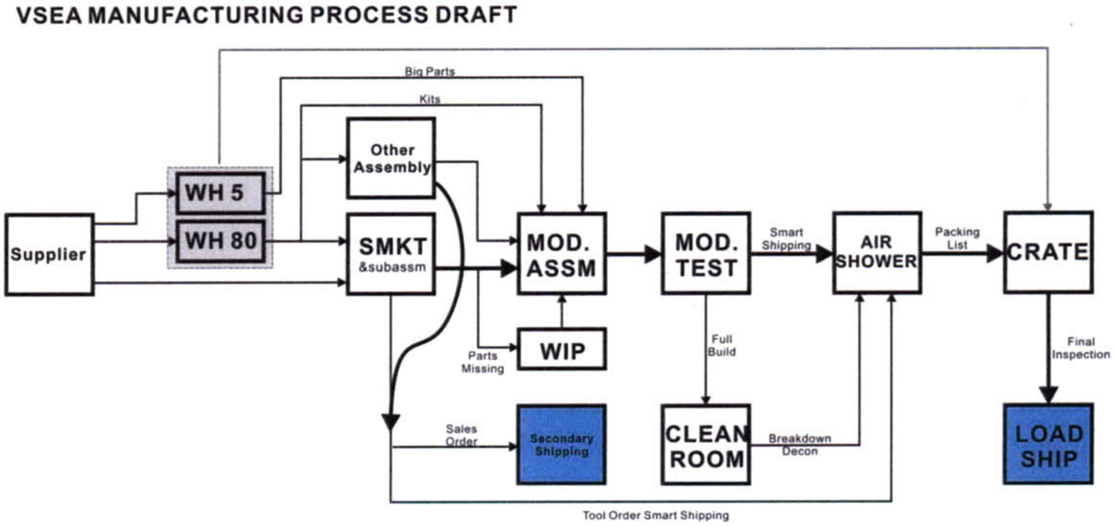


Fig. 2.2: Flow of Parts Through VSEA's Facility

With reference to Figure 2.2 above, the main operations at VSEA will be described in details in the rest of this section.

2.2.1 – Warehouses

There are two warehouses at VSEA: WH5 and WH80.

WH5 is mostly used to stock big parts such as the machine enclosure or the end station. Parts from WH5 will usually be sent to the main building's flow line and clean room (in the case of a full build order), or straight to shipping (for SmartShip orders).

WH80 is the main warehouse, accounting for parts supply in subassembly and flow line. Figure 2.3 below shows the general flow of parts within: parts from suppliers are delivered in the receiving area, and shipment receipt is confirmed into the SAP management system. The received parts may be inspected, then proceed to the 'sorting desk', where order accuracy is checked. The parts are then shelved in the stockroom. Upon receipt of a pull order (from the flow line, supermarket, kit room or any other internal department) or a sales order (from parts banks or directly from customers), a 'shopping list' is generated, and warehouse workers fulfill orders by picking the parts from the shelves.

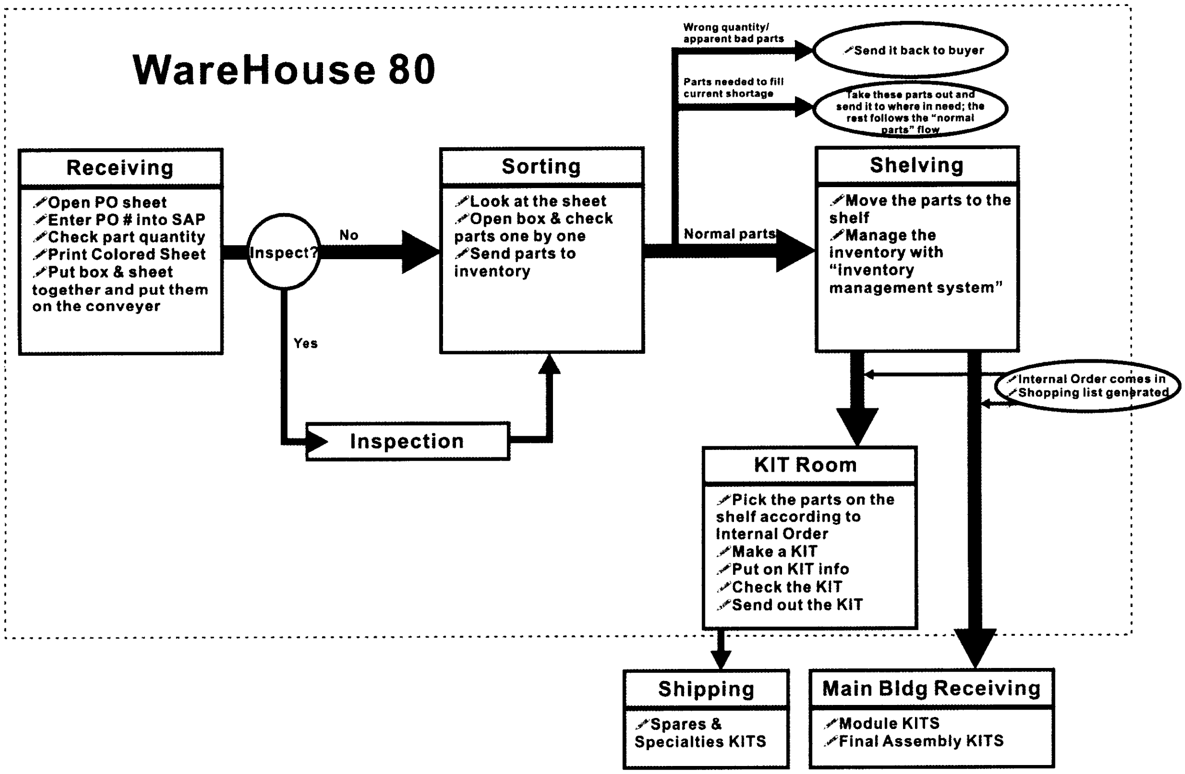


Fig. 2.3: Flow of Parts inside the Warehouse

2.2.2 – Kit Room operations

The 'Kit Room' is an area of the warehouse that essentially acts as an independent 'assembly' area, in that parts are pulled from the main warehouse stock room, and assembled into 'kits' (put in bins and bags and sent to different locations). The kit room mainly handles machine orders and sales orders, but may also ship kits to the flow line and clean room.

2.2.3 – Supermarket and Source Room

There are two areas for subassembly: the 'source room' and supermarket (SMKT). Workers in these two areas produce the subassemblies that feed module assembly on the flow line, as well as those which are shipped directly as spares or replacement parts.

Both areas also keep their inventory at hand and use one of several inventory management systems:

- 15% of the SMKT inventory is controlled by Kanban. In VSEA's implementation, all parts controlled by Kanban are placed in two identical bins, and workers are directed to deplete the inventory from the first bin before using the second. A Kanban ticket is given to the material handler once the first bin is empty, triggering replenishment of that part's inventory.
- Some parts inventory are designated as Vendor Managed Inventory, which means suppliers are responsible for ensuring enough parts are present.
- "Point of Use" parts have their inventory managed by the MRP system, and can be used by assemblers without restrictions.
- A transaction record is needed for the use of high value parts.

In addition to regular orders, SMKT produces subassemblies into a Kanban-managed buffer called “Golden Square” where a limited inventory of about 20 common subassemblies is kept for use as-needed.

2.2.4 – Main Building receiving

The main building receiving area serves as a parts distribution center. Its main function is to dispatch parts to the different areas within the main building.

In general, the receiving area receives parts from three main sources:

- The warehouse WH80 (daily truck delivery).
- Main suppliers. Some of the suppliers will send their parts directly to the receiving area instead of the warehouse. The parts are generally delivered by national freight carriers, such as UPS or DHL.
- Local suppliers. Some local vendors will deliver parts directly throughout the day.

Upon reception of a shipment, several tasks must be executed at the receiving area. Similar to the receiving procedure in the warehouse (section 2.2.1), shipment content is inspected and purchase order information is entered into the SAP management system, updating the part’s status and location. Around 90% of the parts which are packed in cardboard boxes then need to be de-trashed before being transferred to the assembly line on carts and pallets. There is a 3 to 5 hour lag between when the parts are marked as received and when they actually reach their destination within the main building. In order to relieve receiving area workers from the burden of de-trashing all parts, some local suppliers have been asked to deliver their parts directly in clear plastic bins.

Some functional but obsolete parts (or parts already available in surplus and occupying the limited inventory space of the main building) produced in the SMKT or in the source room are sent back to the warehouse for storage (*Credit to Order*). Also, parts requiring inspection will often be sent back to the inspection area at the main warehouse. Finally, the receiving area also handles so-called "offline orders", delivered directly to engineers for test or research.

2.2.5 – Flow Line

The flow line serves two functions: module assembly and module testing. Flow line assemblers pull parts from the subassembly areas (Section 2.2.3), warehouse (2.2.1) and suppliers (through the receiving area – 2.2.4). Some parts are also delivered by the suppliers directly to the flow line floor. Extensive module testing (e.g. wafer cycling, leak testing of the gas box or electronics testing) is done on the flow line for SmartShip machine orders, whereas only Full Build orders only undergo cursory testing at the flow line, most critical tests being conducted in the clean room on the complete machine (the distinction between SmartShip and Full Build orders was introduced at the beginning of section 2.2).

2.2.6 – Clean Room

Parts flow into the clean room for complete assembly and testing of the entire machine (Full Build orders). While modules from MC machines can be mounted on a slave enclosure, HC machines must go through the entire final assembly steps. Other slave parts, such as rough pumps, are used for testing. After testing, machines are taken apart to module level and sent to air shower for teardown.

2.2.7 – Air Shower

Most parts, including modules, sub-assemblies and miscellaneous parts pass through the air shower before shipping. In this area, modules are torn down (partially), drained, decontaminated, cleaned and bubble wrapped, while miscellaneous parts typically just pass through the air shower and get wrapped. Air shower workers are also responsible for final inspection of the components of the outgoing modules.

2.2.8 – Shipping Area

All outgoing parts are collected at the shipping area for final inspection, packaging and crating. The main modules, after teardown and inspection at the air shower, are placed directly into shipping crates. On the other hand, miscellaneous parts originating from the warehouse, clean room, flow line and subassembly area often require extra work, such as de-trashing, re-wrapping and extra assembly. This is particularly true for SmartShip orders, whereby all final assembly material must be processed by shipping workers:

Miscellaneous parts for the **Medium Current** machines are delivered directly to the shipping area. With reference to the diagram below, the flow of parts is as follows:

1- Parts are delivered from the warehouse to the packaging area in a truck containing cages (2-3 bins, the rest is loose parts)
2- 50% of parts need to get de-trashed, the rest goes to steps 3, 4 or 5 directly
3- About 10% parts need to get wrapped, this happens in the air shower
4- About 5% of parts require extra assembly
5- Parts are put in bins
6- Parts and bins are crated then shipped out

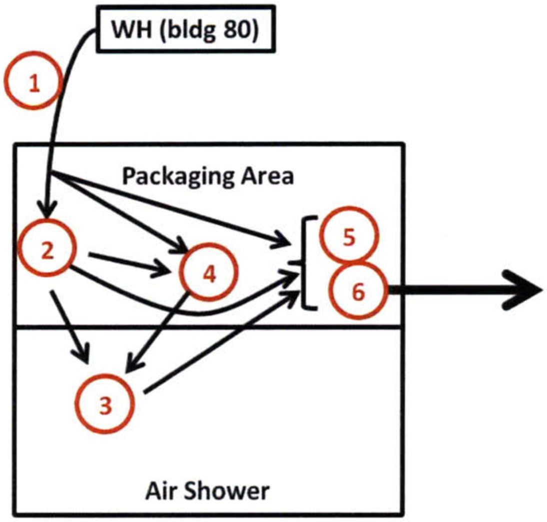


Fig.2.4: Flow of Miscellaneous Parts for the Medium Current SmartShip Orders

The steps are identical for the **High Current** machines, except they are carried out in different areas, as shown in the diagram below. It is noted that, since steps 3, 4 and 5 are conducted in the sterile environment of the clean room, the miscellaneous parts associated with High Current machines transit through the second air shower directly to the shipping area for crating (step 6).

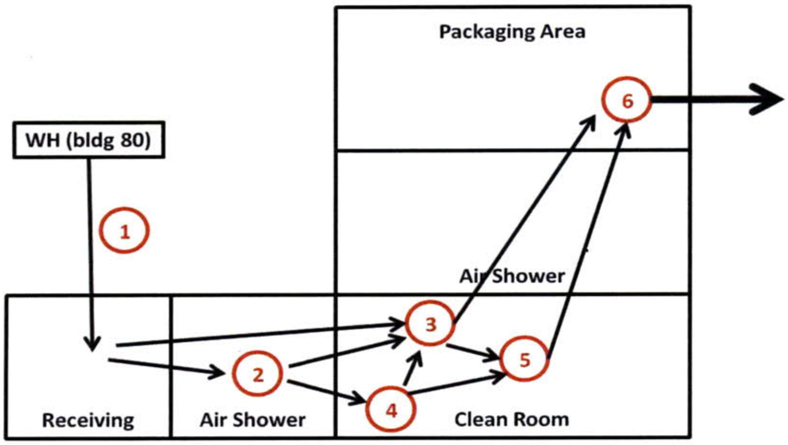


Fig. 2.5: Flow of Miscellaneous Parts for the High Current SmartShip Orders

Chapter 3 – Problem Statement

This section describes current problems within the manufacturing operations are identifies potential areas of improvement. Key factors considered include lead time reduction, waste elimination, and direct labor cost reduction. Thorough investigation of the internal parts flow directed the focus of this research towards four main issues:

1 – Long lead times in packing-shipping
2 – Inefficient part flow
3 – Concerns about warranty claims by customers
4 – Lack of traceability of parts throughout the facility

3.1 – Long Lead Time in Packing-Shipping

The current packing-shipping process at VSEA is time consuming and inefficient. It takes place in the air shower and the shipping area takes between 120 and 140 labor hours per machine for SmartShip orders, accounting for one-third of the total manufacturing labor time, which is considered to be a high proportion in manufacturing industry.

Several explanations were found to the long packing-shipping time. First, the workers count and check parts manually, which is labor intensive and time consuming. Poor standardization of tasks and varying parts flow also add to the lead time, while lack of communication results in problems of parts missing, leading to efficiency losses and increases in waiting time.

The examination of the operations in the air shower and the packaging area yields the breakdown of tasks performed in the shipping-packing process. The list of tasks, along with the reason each task is performed, are shown in Table 3.1.

Table 3.1: Tasks of Packing-Shipping Process

Area	Task	Reason
Air Shower	Module tear down (partial)	Facilitates shipping (crate configuration)
	Module parts drained, decontaminated, cleaned and bubble wrapped	Regulatory requirement
	Module checking and general inspection	Basic quality requirement
	Extra-wrapping (partial)	Regulation requirement (for parts directly from warehouse)
	Extra-assembly (partial)	Customer requirement
Shipping Area	Packing list generation	To sign out parts during crating For parts checking at customer site
	Parts received from several upstream processes	Parts that don't require further work go directly to shipping
	De-trash (partial)	Parts arriving from the warehouse need to be taken out of packing materials to avoid contamination
	Extra-wrapping (partial)	Safety requirement for fragile parts
	Part 'check-out' - Take the parts out of the WH bins -Count and check the parts -Put the parts into shipping bins -Sign out the packing list	Guarantee the correct parts are shipped Shipping process use its own new and clean bins which customers require Configure the bins/crates for easy installation Match the physical parts with the document
	Crating	Use crates for shipping
	Load crates on trucks	

The task of manually verifying the shipment contents in the shipping area (shown as 'parts check out' in Table 1) adds up to 10 hours to the process without adding value to the product.. Indeed, the contents of the various bins and cages received from the warehouse will have already been checked there, and the repetition of this visual verification merely serves as a means of extra precaution. A similar verification process also happens in the warehouse kitroom, as well as in the main building, where material carts are prepared.

3.2 – Inefficient Part Flow

Parts moving through VSEA's manufacturing facility can be thought of as following one of two distinct flows:

1. The *Module flow* consists of parts and subassemblies that will be assembled into large modules and shipped as a part of the assembled module.

2. The *Miscellaneous parts flow*, accounting for about 10% of the parts shipped out, consists of all the parts that will be shipped separately from the module (install kits, spares and replacement parts)

While the Module flow has been the object of much attention in recent years and has been thoroughly refined, the miscellaneous parts flow suffers from inconsistencies, resulting in efficiency losses and lead time increases. The latter will be described in this section.

First, the shipping area gets some individual subassemblies directly from the SMKT. These subassemblies are typically customized options requested by customers; they do not belong to the basic platform of the machine and as such don't require assembly and testing on the flow line. These parts need to be pulled by the shipping via SAP, then collected at the SMKT once they are completed. This process requires many extra labor hours for each machine.

Second, spares and specialties are transported directly from the warehouse directly to the shipping area in forms of bins and cages. At the shipping area, those parts will be reconfigured into other bins for reasons listed in Table 1.

Third, the parts sent from the warehouse as part of the 'final assembly' kits require some extra work performed by shipping workers. Final assembly kits represent for the parts that will only be used for on-site installation including doors, subfloors and walls, as well as some harnesses, cables and small subassemblies. As discussed in section 2.2.8, the miscellaneous parts (including the final assembly kits) will follow different paths depending on the machine they belong to.

The Figure 3.1 below (along with figures 2.4 and 2.5 from the previous section) shows the miscellaneous parts flow to shipping. The shaded zone represents some of the tasks in the shipping area. To summarize, the shipping area has many inputs; also it has several extra tasks that are not supposed to be the responsibility of the shipping process. There is a need to reorganize some of the parts flow, redesign the internal supply chain, redistribute the tasks of each process and keep the information flow smooth in an efficient way.

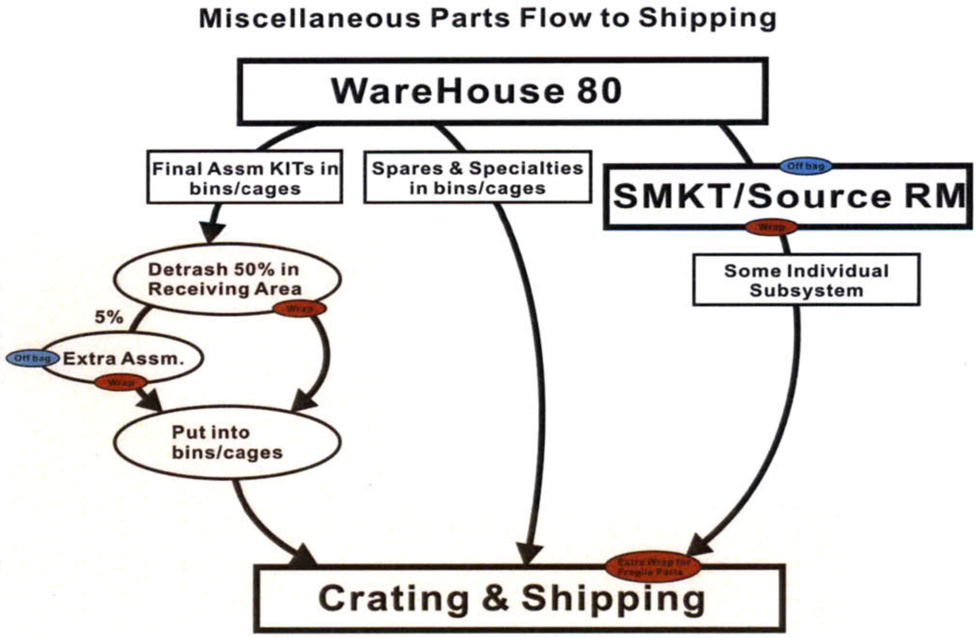


Fig. 3.1: Miscellaneous Parts Flow to Shipping

3.3 –Fraudulent Claims and Warranty Costs

VSEA products are expensive machines that are put to work in difficult environments at the client site. As such, failure of a machine component can cost VSEA customers several thousand dollars in replacement parts. Attempts to make fraudulent warranty claims have been witnessed, whereby a failed part from an old machine would be returned and claimed as new (from a more recent shipment still under warranty) in order to avoid purchasing replacement parts. With no reliable way to track a component to a given machine, VSEA has sometimes been unable and unwilling to debate these claims.

This type of fraudulent claims occur once a month on average at VSEA, and it has been estimated to cost VSEA about $100,000 per year on average, not counting time spent on investigation, troubleshooting and production of the replacement part.

The lack of traceability of the components has also resulted in shortened supplier warranties, whereby a third-party supplier would offer warranty of a given component for a given period of time (e.g. one year) from the date of delivery to VSEA. VSEA, in turn, will offer (in this example) a one year warranty to the end customers, starting on the delivery date of the machine. This means the component in question is under warranty from the supplier while in VSEA's inventory, but not during the last few months of VSEA's warranty period to the customer. VSEA's yearly warranty liabilities are around $15 million, from which at least $1 million stem from such late-term warranty claims.

3.4 – Deficient Tracking Ability

Varian has a flexible assembly system for low volume and high diversity production. Although the machines are categorized into only three series and seven main types, each machine is customized for many reasons. For example, the power supply differs by country; some customer requires modification of machine configuration to fit for their on-site installation; others will select their own spares and specialties to realize specific functions. Moreover, a single part number may encompass different revisions and sizes. All these aspects require the manufacturing structure to guarantee the right flexibility.

Such a high flexibility leads to dedicated parts for each particular machine. Tracking a given part of a machine has been called for by different departments of the company.

3.4.1 – Lack of Reliable Tracking Method for Individual Parts

At present, VSEA has no reliable method to track information such as part type, part number, part revision, manufacturer, delivery date and warranty status. This type of information can be invaluable for the company. For instance, in the event of a machine component breakdown at the customer site, the company should have the capability to immediately define the broken part, find out the upstream supplier, and check the warranty status to see who will be responsible for fixing or replacing the part.

Poor traceability also prevents VSEA from tracking the performance of each type of parts – which parts always have problems, or which parts are robust enough. The company therefore has difficulties evaluating the suppliers based on the performance of their parts, making supply chain improvements slower.

3.4.2 – Redundant Machine Configuration Process

As stated before, all the machines are customized. The base platform of a machine consists of around 60% of total parts. The rest consists of customized parts, spares, and specialty items.

The different configurations are dictated by multiple reasons, including specific machine functionality, particulars of on-site installation, power difference in different countries and other customer preferences. In general, each customer will tend to order the same or similar configurations. At present, VSEA has no reliable way of keeping record of the configuration of outgoing machines, and therefore has to re-create a custom PBO (see section 2.1.1) each time a customer orders a new machine, regardless of how similar the machine is to the previous customer order.

3.4.3 – Parts Misplacement

In addition to the specific problems mentioned in the previous sections, VSEA experiences loss or misplacement of parts and delays attributed to:

1) Parts misplaced between process steps
2) Parts mistakenly taken for a different machine
3) Parts delivered to the wrong place
4) Parts shortages
5) Lag between SAP updates on part location and the actual physical location of the part.

These problems require the assembly workers to spend a large amount of time looking for parts, making phone calls or even placing new part orders.

Chapter 4 – Review of Theoretical Background and Previous Work

The findings of the previous chapter have made clear the need for an efficient parts tracking system at various levels of VSEA's facility. This chapter starts by underlining the versatility of RFID and presenting successful real-world application cases where the technology was used in contexts relevant to the project discussed here, warranting its use at VSEA. The remainder of this chapter presents an overview of the technology and the challenges it presents, as well as guidelines for the experiments to be performed.

4.1 – RFID Application Case

Because of RFID technology's unique characters, it has been widely used in different areas, including manufacturing industry, consumer industry, logistics, healthcare, security and public infrastructure. A selection of real-world application cases is presented in Table 4.1. Despite their diverging nature, these cases share the same results, in that they show RFID can help reduce complexity and operation time, eliminate errors and save labor costs. The applications with particular relevance to VSEA's operations are discussed further in sections 4.1.1-4.1.3.

Table 4.1: RFID Application Area (including pilots)

Area	Methodology	Company
Retail/ consumer	Automatic checkout, simplify transaction Inventory management. Storage control	Wal-Mart [7] METRO Group [8] Procter & Gamble [9]
Logistics	Track truck, pallets, containers in transportation	JR Freight [10] Sony logistics [11]
Manufacturing	Check parts in process Track key parts in use	Boeing [12] Volkswagen [13]

	Inventory management	Intel [14]
Pharmaceutical	Product Authentication and Drug Pedigree Packaging and logistics	AstraZeneca [15] Pfizer [16] Cephalon, Inc. [17]
Healthcare	Track patients to speed up check-ups	Apollo Hospital Chennai [18]
Security	Identity check	Bob Jones University (car entry) [19]; US department of Homeland Security [20]
Public sector	Identify individual persons, cars, or other assets	Highway "EZ-Pass" [21] Los Angeles Marathon [22]

4.1.1 – Boeing: Tracking of Key Components [12]

Boeing's 787 jets are assembled on a super-sized assembly line and comprise several hundred thousands of parts. After identifying 1,700 to 2,000 'mission-critical' parts (defined as parts that expensive or require frequent maintenance and replacement), Boeing chose RFID to track each of them during the assembly of its 787 jetliners,. Previous attempts to use barcodes for the purpose of tracking mission-critical parts failed due to some barcode label being unreachable by the scanner. In contrast, RFID supports "non-visual reads", allowing detection of tags without line of sight, thus enabling quick and reliable location of critical components.

Similar to Boeing, Varian's ion implanters are highly complex machines containing hundreds of high-value components often assembled in hard-to-reach positions. Tracking these critical parts in a convenient way is valuable for the purpose of maintenance and warranty, and can be done through RFID.

4.1.2 – Japan Rail Freight: Container Tracking [10]

JR Freight provides cargo transportation service by rail in Japan. At each stop, large steel containers are off-loaded from the railcars and stacked. Keeping track of several hundreds of containers previously involved tedious, time-consuming manual labor, whereby JRF operators had to walk along the terminal and log the containers' loading arrangement by hand. JRF's switch has automated this process: both containers and railcars are equipped with RFID tags, and they are paired together upon unloading, so as to easily keep an accurate and up-to-date record of the incoming and outgoing container configurations, and direct loading operations.

Such a linkage between individual parts and their parent assembly can help VSEA achieve instantaneous and complete module configuration logging. High-value components could be linked to the module they were assembled on, which in turn would be linked to the parent machine, and thus a complete configuration record could be kept for each customer.

4.1.3 – Stillage Tracking [23]

A European automotive OEM in the automotive industry uses specially designed stillages to carry different automobile parts produced by outside suppliers. To address stillage shortage, due to mishandling or misplacement by loaders, truck drivers or warehouse workers, the OEM chose an RFID-enabled solution, whereby each stillage, tagged by a unique RFID transponder, is checked both at the supplier site and upon receipt by the OEM. The gates of the warehouse are selected as the optimum places to read the tags and capture all stillage movements.

The concept of gate checking is a possible embodiment of RFID implementation at VSEA. Finished machine or parts container would be inventoried using such RFID-enabled 'gates' instead of being manually counted, with inventory information transmitted in real time to a central computer system for quick remedy to potential problems.

4.1.4 – Expected Benefits of RFID in Varian

In light of the preceding cases, RFID is deemed a suitable technology for VSEA's environment, and is expected to provide benefits at several levels:

Efficiency:
RFID technology can substitute manual counting with auto-checking at multiple stages wherever parts checking are required. Moreover, instead of scanning tags one by one such as what barcode system does, the RFID system is able to read hundreds of tags simultaneously in several seconds, which substantially expedites the part checking process.

Accuracy:
Varian's high value products which must be tracked by lot or unit make tracking particularly important. RFID provides an inventory tracking mechanism that is not dependent on human initiated scans. Transactions can be automatically recorded as product is moved within the supply chain. All physical moves could be systematically tracked without the need for an operator to record the transactions. Erroneous parts picking and overlooked mistakes could be eliminated.

Visibility:
The unique EPC code on each RFID tag can be associated with purchase orders for every single part, enabling supplier evaluation and early detection of frequently defective parts. This feature will make it possible to instantly know the history and location of every item in the supply chain.

Authentication:
Product authentication is another area that may prompt Varian to turn to RFID for high-value parts identification. If every object has a unique identifier and detailed information

on the object is stored in a server, Varian can validate the object's authenticity by interrogating its RFID tag.

4.2 – Components of a Typical RFID System

As shown in Figure 4.1, a typical RFID system consists of a tag, a reader, a host computer and a reader antenna. RFID systems work in the following way: the reader transmits a modulated signal through the antenna, which the tag antenna receives. The signal is processed by the tag's integrated circuit and a backscattered signal containing tag information (usually in the form of an Electronic Product Code – or EPC – which is unique to each tag) is emitted back to the reader, which demodulates the received signal and sends it to a host computer. The reader software in the host computer can then display the tag information and show the information about the tagged item by linking the tag to a relevant database. [24]

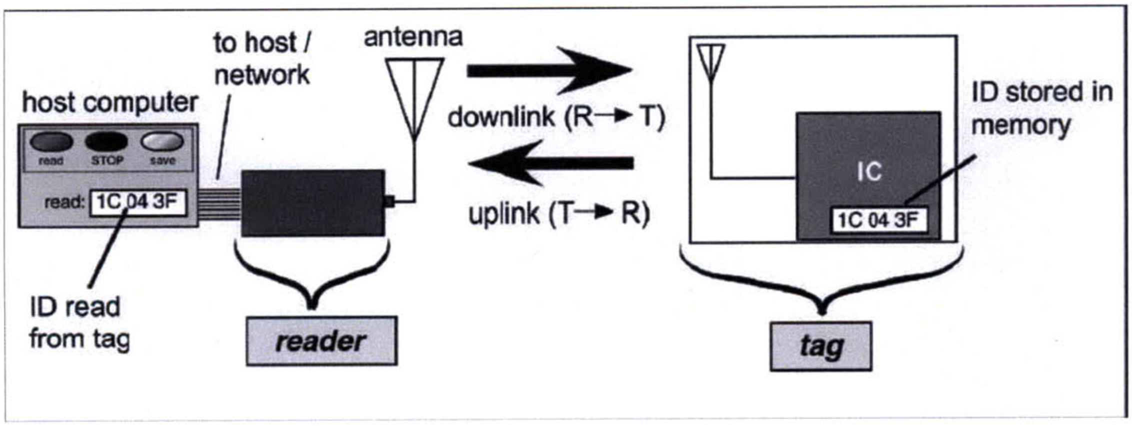


Fig. 4.1: Overview of a Typical RFID System [24]

The frequency of RFID systems varies from around 100 KHz to over 5 GHz, so from (1) (where λ is the wavelength, f is the frequency and c is a constant) we can calculate the corresponding wavelengths which are found to be as small as 10 cm and as large as 1 km.

(1)

$$\lambda = c/f$$

RFID systems can be categorized by whether the wavelength is comparable in size to the tag antenna, which can be as large as 1 m in diameter or as small as 1-4 cm. When the wavelength is much larger than the antenna, the systems are typically inductively coupled as all the available energy from the reader antenna is contained within a region near the reader antenna and the phase delay between transmitted signal and backscattered signal is much smaller than the time between peaks (the signal will travel 4ns to reach a tag at the distance of 1.5 m, or about 6% of the RF cycle at 13.56 MHz) making it hard to discriminate both signals. In contrast, high or ultra high frequency RFID systems usually use radiative coupling to communicate between the reader and tag. (Shown in Fig 4.2) [24]

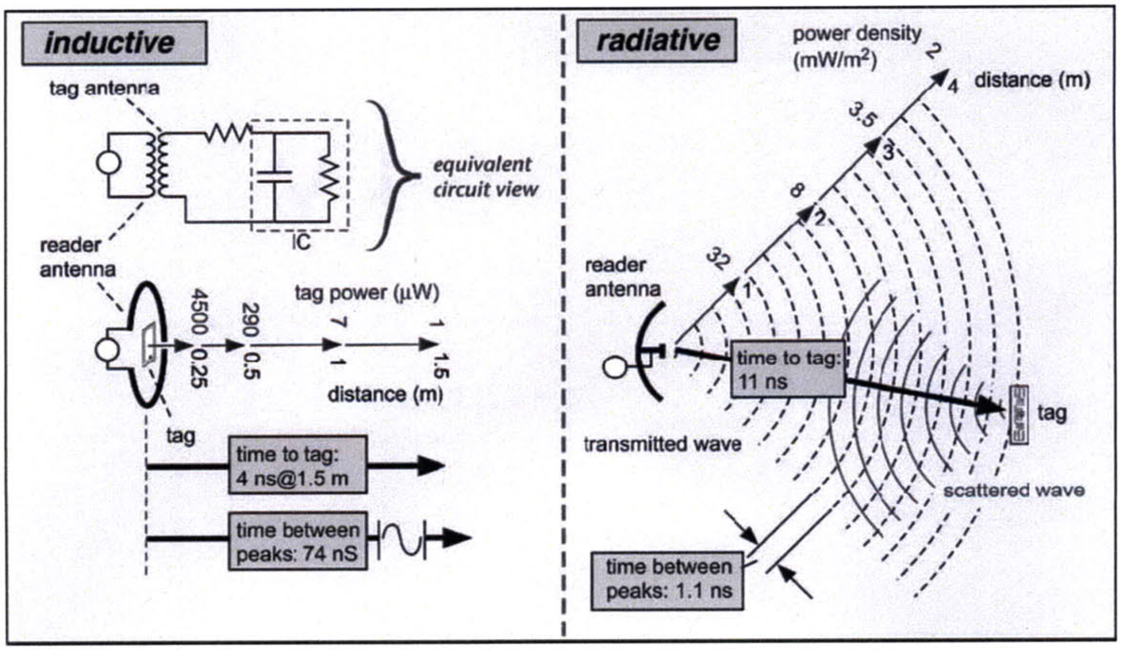


Fig. 4.2: Inductive Coupling (13.56 MHz, 50 cm diameter antenna) vs. Radiative Coupling (900 MHz), With Associated Power and Time Delays [24]

In the application discussed here, an Ultra High Frequency (UHF) RFID system was chosen to gain as wide a read zone as possible. However, the drawback is a complicated read zone. Because the power falls slowly with distance, and the wavelength is small compared to typical tag-reader distances, reflections from distant obstacles can propagate back into the region of interest and interfere with the waves launched by the reader antenna. As shown in Figure 4.3, even in a simple room with an RFID transmitter at the center, the energy distribution is not continuous and difficult to predict. With typical read energies (Energy required to activate the tag's IC and scatter the reader signal back) larger than -10 dB, the figure shows the existence of unreliable read zones between 2 to 4 m away from the reader antenna. The presence of multiple tags amplifies this problem.

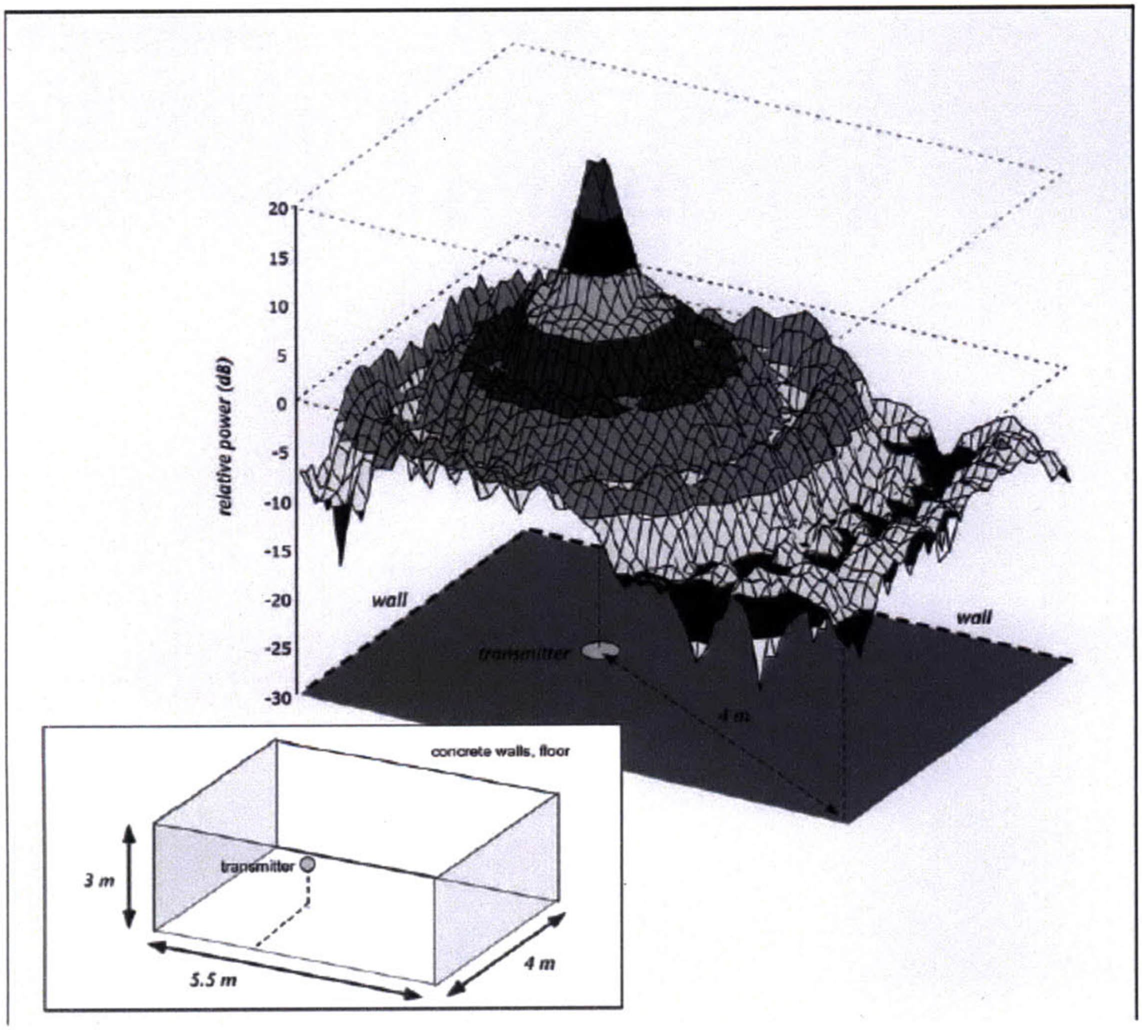


Fig. 4.3: Simple Model of Power Density in a Room with Partially Reflecting Walls and Floor [24]

When designing an RFID system, one must also be aware of skin depth, which indicates the ability of radio waves to penetrate obstacles such as metal and water. For instance, as evident from (2) and Table 4.2, the skin depth for metal is very small. Therefore even a thin piece of metal can cancel a radio wave. Therefore, when there are many metal parts in the read zone, the reliable read area is restricted and randomly located. The skin depth is given by

$$\delta = \sqrt{\frac{1}{\pi\mu\sigma f}} \qquad (2)$$

Where f is the wave frequency, σ is the conductivity and μ is the magnetic permeability.

Table 4.2: Skin Depth for Various Common Materials [24]

Material	**Skin Depth At**			
	125 kHz	**13.56 MHz**	**900 MHz**	**2.4 GHz**
Tap water	8 m	2 m	4 cm	8 mm
Animal tissue	2 m	60 cm	2 cm	8 mm
Aluminium	0.23 mm	71 μm	2.7 μm	1.6 μm
Copper	0.18 mm	55 μm	2.1 μm	1.3 μm

$1\,\mu\text{m} = 10^{-6}\,\text{m}$

4.3 - Metal Interference

The tag antenna is critical to signal exchange in an RFID system. However, the performance of the tag antenna is influenced by its immediate environment. For example, when a tag is attached on metal surface, it typically cannot receive or transmit signal. The impossibility to read RFID tags from a distance greater than a few centimeters in metal environments has partially limited the success of the technology and its application to supply chain. There are two main reasons for this behavior: eddy or mirror current in the metal surface and detuning. Eddy currents consume the energy from the radiation wave, so that the tag antenna cannot receive enough energy to work. The detuning involves energy drain caused by the electromagnetic "friction" from the metal. [25], [26]

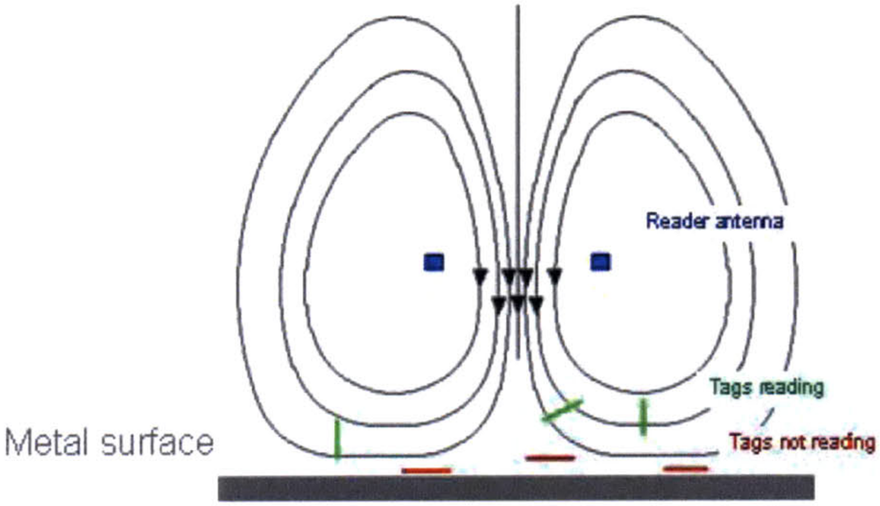


Fig. 4.4: The Perpendicular Magnetic Field's Effect [25]

As shown in Figure 4.4, metal causes eddy currents in the vicinity of the RFID reader antenna which absorb RF energy, thus reducing overall effectiveness of the RFID field. In addition to this, the eddy currents also create their own magnetic field that is perpendicular to the metal surface, cancelling the read field further.

Metal can also detune both reader and tag antenna, leading to added parasitic capacitance which reduces system performance.

Based on Adam's [25] and Deavours' [27] research on tags used in metal environment, several suggestions we found to enhance the performance of passive tags in such applications:

1. Design the correct tag antenna including ferrite-cored transponder coils. The high permeability of the ferrite core allows a small transponder to be energized by the weaker field that exists close to the metal surface. [25]
2. Pick the right frequency. The higher frequency could get the wider read zone, but suffers more energy loss due to eddy currents and parasitic capacitance. [25]
3. Increase the distance between tags and metal using a dielectric spacer. [27]

4.4 – Electromagnetic Interference

The presence of electromagnetic interference (EMI) will affect the detectability and read range of tags, especially in an environment with heavy electrical equipment. [28] The interference is significant when the RFID system is located in a similar electromagnetic radio frequency environment. For example, the authorized frequency band for UHF RFID in Europe is 868MHz, which is very close to the mobile network GSM 900 MHz-band. In some cases, the operation of a mobile network will greatly affects the read range of RFID system. [29]

In [28] Cheng suggests some feasible measures to alleviate problems stemming from EMI in RFID application:

1. Before implementing an RFID system, it is necessary to conduct an EMI investigation. Based on the mapping of the EMI environment, choosing suitable RFID equipment and placement will optimize tag detectability.
2. Attaching tags as far away from power sources as possible in manufacturing facilities can reduce the EMI effect.

4.5 – Design of Experiments

RFID is a highly versatile technology that can be adapted to many applications. However, factors specific to the implementation environment must be taken into account and a pilot project can detect problem areas ahead of full implementation. This section presents background relevant to the design and conduct of the pilot project under discussion, and the analysis of the results obtained from it.

4.5.1 – Arch Setup

The vision that was explored for the implementation of RFID in both the kit room at the warehouse and the shipping area in the main building relies on a check-in/check-out 'arch' setup where the contents of bins or cages of tagged items are checked for accuracy. Understanding the expected behavior of such arches in a theoretical RFID setup is critical to a successful implementation in real-world applications.

This theoretical behavior or a multiple reader portal is explored by Wang et al. in [30], where a simple setup with n antennas, which can take any of N potential positions, is considered. The 'tag space' is divided into a set of discrete positions, while the set of possible orientations of each tag is discretized using Rusin's algorithm [31] to approximate a uniform spherical distribution. Using Friis' equation to find the power received by the tag for each possible combination, the author builds $\alpha\%$ read zones, which are to be understood as delimiting the regions with an upper bound read accuracy of α %.

4.5.2 – DOE for tag and antenna placement

Beyond the general rules of thumb provided by the above, any field implementation of RFID must be preceded by extensive testing. The topic of Design of Experiments (DOE) for RFID applications is therefore currently the object of active research.

In [32], McCarthy at al. look at the various parameters, including inlay design, conveyor speed and reader type, as applied to the tracking of packaged meat. In [33], Hoong focuses on a 3 factor experiment (Power, bending diameter and tag orientation) to derive a linear model for read distance, while in [34] Ammu et al. explore how readability is affected by the tag-antenna distance as well as metal and electromagnetic interference.

4.4.3 – Tag Plane Array Effects and Tag Collision

In considering whether to tag individual parts, bags of parts or entire bins, one must consider the effect of tag collision and shadowing. In [35] Weigand and Dobkin present a theoretical discussion of tag plane array effects, showing multiple densely packed planes of RFID tags will exhibit significant interference effects.

In [25], several possible solutions are proposed to enhance reliability of tag readings in an environment where several tagged parts are packed in a dense fashion (such as in a shipping bin):

1. Having the parts in motion increases the chance for parts to be read
2. Optimizing the set of multiple reader antennas, such as the number, placement and angle of antennas, could increase the probability of all tags being read.
3. Applying multiple tags on a single part, filtering duplicate reads by software.

Chapter 5 – Methodology

In this chapter, the application of RFID to component-level tracking at VSEA is described. The main objective of this application is to enhance the traceability of some high-value components. As aforementioned, a module which comprises various components is a big portion of a whole machine. For example, a MC (Medium Current) machine usually consists of a beamline, a terminal and a UES (Universal End Station) module while a HC (High Current) machine is made up of a facility, a 70 degree, a 90 degree and a UES module. The high-value components on a module are usually some purchased and VSEA-build subassemblies.

After an overview of the RFID implementation vision, this section then describes the general methodology used to outline the implementation in VSEA's manufacturing operations and the specific methodologies applied in some steps of the pilot experiment process.

5.1 – Implementation Vision

5.1.1 – Problem Review

This thesis focuses on solving the problem of fraudulent warranty claims as discussed in section 3.3. Cyril Koniski's thesis [36] documents the proposals to implement the item-level RFID application as discussed in section 3.1 and Yulei Sun's thesis [37] proposes the flow redesign as described in section 3.2. These three together contribute to the solution to enhance the traceability of parts as mentioned in section 3.4.

Tracking of the high-value components is required by many departments, chief among them the Materials Quality and Manufacturing. The main problem of both departments is fraudulent warranty claims which cause extra assembly and testing work for

Manufacturing department and extra negotiations with suppliers for Materials Quality department.

5.1.2 – Objectives

As mentioned in section 3.3, fraudulent warranty claims can be avoided by fully implementing an RFID tracking system. With an RFID tag attached on a given component, it is uniquely identified by the EPC number. In the case of a fraudulent claim, VSEA could then obtain all the component information associated with the EPC number from its database, most importantly the data of manufacture and delivery, enabling it to dispute illegitimate claims.

The objective of this thesis is to assess the feasibility of component-level RFID implementation by generating a conceptual process modification and doing a pilot experiment.

5.1.3 – Integration with Current Operations

With the objective in mind, simply implementing the RFID system has little value without integration into the present tracking method as discussed below.

Currently, in order to negotiate warranty issues with suppliers and customers, VSEA uses serialization to keep a record of high-value components. Each component bought from suppliers has a serial number associated with manufacturing and warranty information, while the component built in the supermarket (SMKT) is given a VSEA generated serial number. In the event of a recall, the serial number is the only identification of a particular component. Similarly, upon receipt of a warranty claim on a failed part, VSEA will verify the warranty information of the part based on its serial number. Currently, since the supplier warranty period starts on the date of delivery of the component to VSEA, and VSEA's warranty to its customers begins upon shipment of the completed machine, there is up to a two to three month gap between the two. This time difference leads to unnecessary warranty costs when a claim comes within VSEA's warranty period but beyond the supplier's. The goal of serialization is to enable VSEA to negotiate with suppliers for the warranty period to start when VSEA ships out the components to customers, by providing them accurate and reliable information about component history, as enabled by tracking of the unique serial number. However, the current serialization process is flawed owing to a number of production constraints. For instance, the serial number is copied after module or machine testing because problematic components will get replaced after testing. As a result, some parts have to be disassembled if the serial numbers on them are invisible. It also takes long time to record serial numbers when they are not easily accessible on the module.

If well integrated into this system, RFID can greatly improve the process of serialization while the serialization system can expand the benefit of RFID.

5.2 – Implementation Overview

This section outlines the proposed component-level RFID implementation in VSEA as shown in Figure 5.1. The flow starts with a conceptual design in which the tagging procedure and the checking process were envisioned to realize the implementation. Equipment selection for a confirming experiment is then described. Before the experiment, a list of high-value components was determined aiming to test different components in various locations of the module. Then the factors of the experiment are discussed in the DOE (Design of Experiment) step.

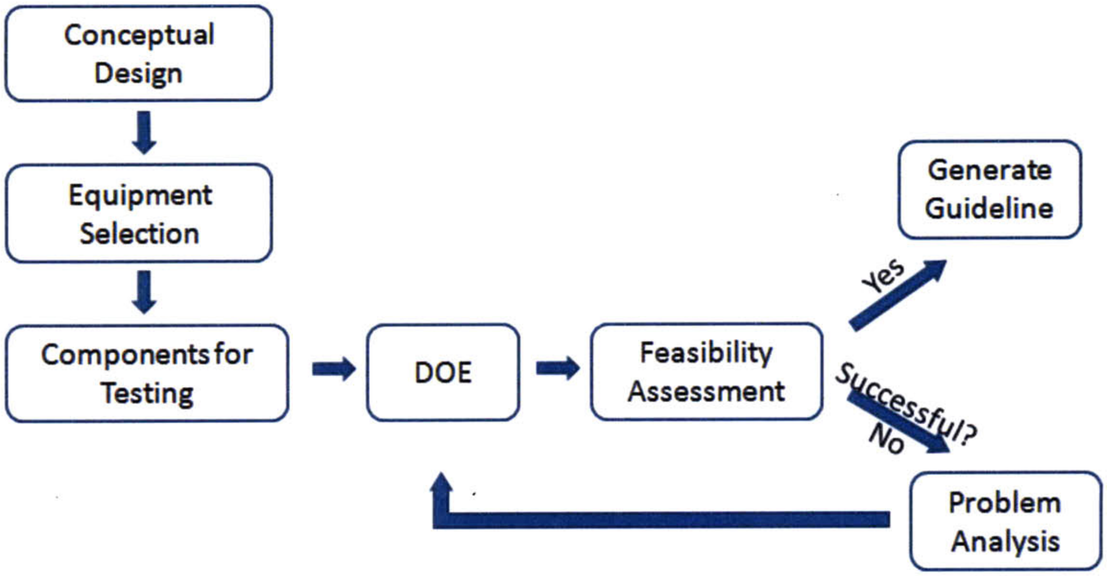


Fig. 5.1 RFID Implementation Overview

In the feasibility assessment step, the analysis of results obtained from the experiment are discussed in Chapter 6, leading to guidelines for tag placement on each specific component and the suggestion for tag type that can be used in future application discussed in Chapter 7. If the experiment is demonstrated unsuccessful, the components that were not read by the reader are analyzed in order to find reasons and then the related factors would be adjusted in the DOE step. Then more tests are conducted in the same way until getting a satisfactory result. More details are described in Chapter 6 and Chapter 7.

5.3 – Conceptual Design

Generally the operation of an RFID system consists of a tagging procedure in which RFID tags are physically attached on particular components and are associated with the component information and a checking process in which the tags are detected and the contained information is accessed. According to VSEA's operation, it was envisioned to locate a tagging process where the components are received or assembled followed by a checking process in the air shower right before shipping.

5.3.1 – Tagging Procedure and Checking Process

With reference to section 5.1.3, it is important that the current serialization method is coordinated with the RFID system. In addition, the internal supply chain also influences where to locate the tagging procedure. In the pilot experiment, RFID tags are applied by Varian as they are received, but in the long term, RFID tags should be provided by VSEA suppliers so that this process can be moved to the supplier site and they too can take advantage of the system.

To determine the locations of attaching tags and recording information, the current internal supply chain was analyzed. First of all, components that flow into module building come from three sources: the warehouse (WH), the supermarket (SMKT) and the receiving area marked as red arrows in Figure 5.2. Purchased subassemblies mostly come from the WH while some of them are stocked in the flow line and come from the receiving area. By comparison, VSEA self-build subassemblies come from the SMKT. In order to record the information of manufacturer, receiving date and warranty, which is based on the PO number and is accessible when components are received, there should be a tagging procedure in each of these areas. It is noted that the information for subassemblies built in the SMKT includes finishing date, warranty and revision version and so on, and it is not based on the PO number.

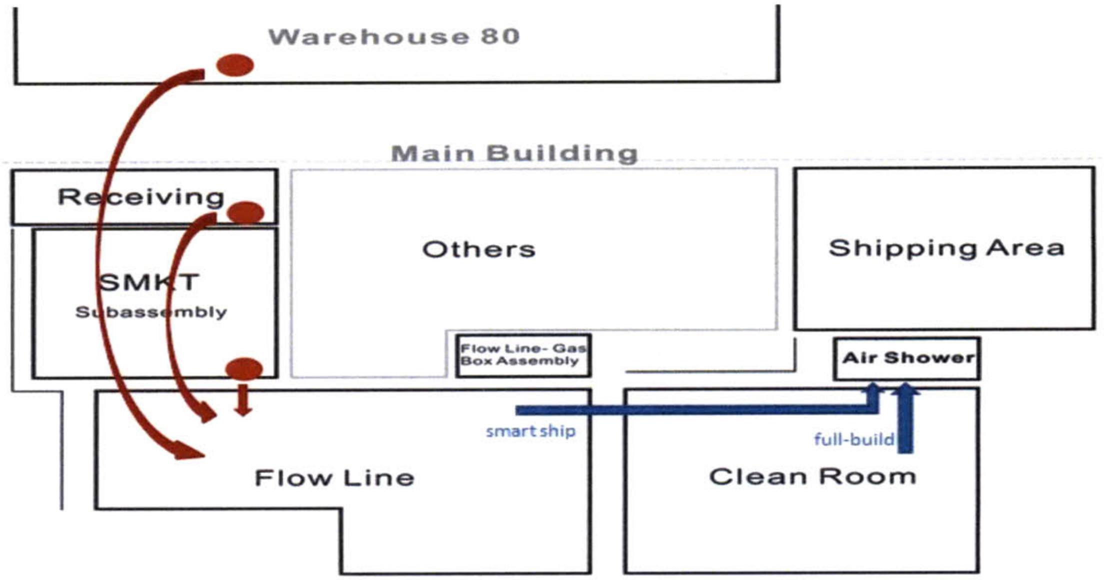


Fig. 5.2 Flow Line Layout

In addition to information on component production, information such as shipping date, machine order number must be recorded after module or machine testing because some components may be changed if they are fail in testing. This is true whether for both the smart ship and full-build order. (Flows of the two different orders are marked as blue arrows in Figure 5.2) As a result, the RFID checking process combines the process of recording information and the process of detecting the tags on components.

As shown in Figure 5.2, the RFID tagging procedures in three areas can ensure that all the components are tagged and the appropriate information is recorded, while the RFID checking process in the air shower can finish tags checking and extra information recording. More specific operations of tagging and related benefit analysis are described in section 7.2 of Yulei Sun's thesis [37].

5.3.2 — Checking system Set-up

The experiment for the component-level RFID implementation mainly focuses on the checking process in the air shower. Both an archway system, which used the IMPINJ reader and fixed antennas to and a handheld reader system were tested. The archway system required less manual work, whereas the handheld reader system provided more flexibility and a greater possibility of detecting the tags.

5.3.2.1 – Archway System Set-up

The modules are usually oriented in the same way when they are moved into the air shower. As shown in Figure 5.3, fixing one antenna on each side as marked red was necessary because each side faced to multiple components attached with RFID tags. Since no tags are open to the bottom side and the fact that a metal fixture is mounted to the module when it is being moved, no antenna was fixed on the bottom side.

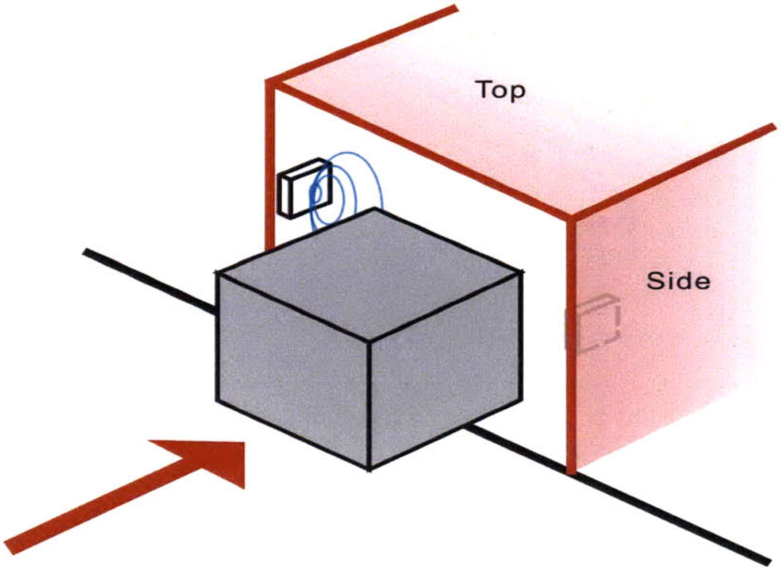


Fig. 5.3 Archway System Setup When Module Being Moved into the Air Shower

5.3.2.2 – Handheld System Set-up

The handheld reader system was tested when the module was laid down in the air shower. General rules were set in the experiment for the movement of handheld reader in the experiment. In Rule 1, the movement was based on knowing the placement of tags in advance, and therefore an operator looks for each tag by facing the antenna of handheld reader to tags. In Rule 2, as shown in figure 5.4, an operator not knowing the placement of tags, walks around the module with moving the handheld reader from top to bottom facing to the module by 5-10 inches away.

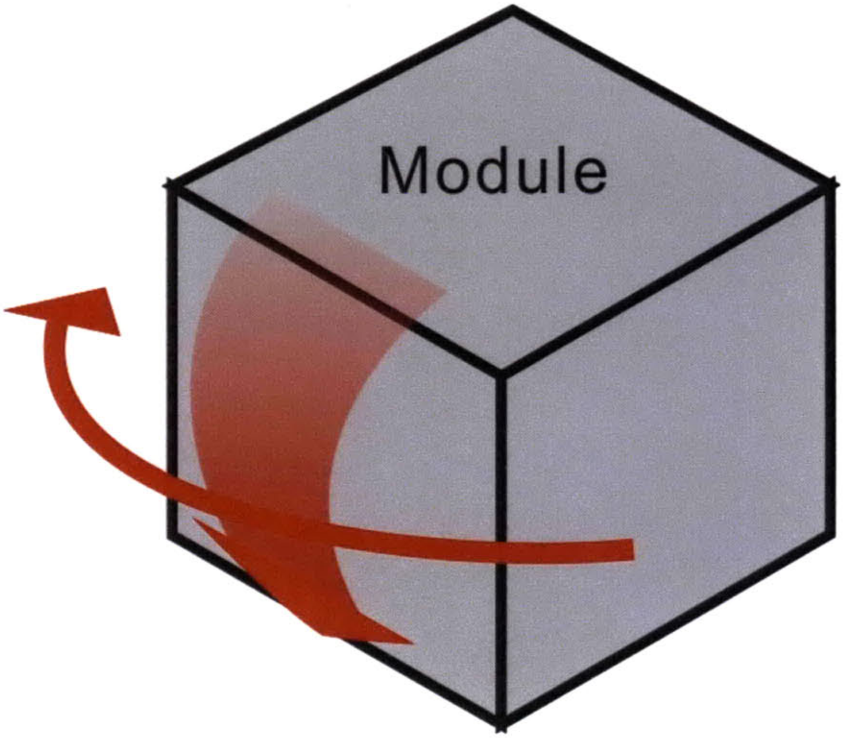


Fig. 5.4 Overview of the Rule 2 Movement of the Handheld Reader

5.4 – Equipment Selection

As discussed in section 4.2, a set of RFID equipment mainly includes readers and tags. In the scope of the pilot experiment, an IMPINJ reader evaluation kit, an ATID handheld reader and three types of metal mount tags were chosen. This section provides a short description of the equipment.

5.4.1 – RFID Reader

The IMPINJ reader kit consists of a Speedway reader, two Far-field antennas, a Brickyard antenna and a Mini Guardrail antenna. The Speedway reader can be powered over Ethernet or cellular modem and has 4 antenna port configurations. Reading and writing are controlled by software on the host computer.

The ATID handheld reader is integrated with software, reader and antenna into one, so it is portable but less powerful in transmitting signal.

More specifications of readers and antennas are shown in Figure 5.5.

	**IMPINJ Speedway R420 Reader**	
	Dimension(L x W x H)	7.5 x 6.9 x 1.2 in
	Transmit Power	+10.0 to +32.5 dBm
	**IMPINJ Brickyard Antenna**	
	Dimension	H:2.4 D:11.8 in
	Polarization	Circular
	**IMPINJ Mini Guardrail Antenna**	
	Dimension (L x W x H)	5.3 x 2.8 x 0.8 in
	Polarization	Linear
	**IMPINJ Farfield Antenna**	
	Dimension (L x W x H)	10.2 x 10.2 x 1.3 in
	Polarization	Circular
	**ATID Handheld Reader**	
	Dimension (L x W x H)	5.3 x 2.8 x 0.8 in
	Transmit Power	+5.0 to +28 dBm
	Polarization	Circular

Fig. 5.5 Specifications of RFID Reader and Antenna [38], [39], [40], [41], [42]

The transmitted signal of the Brickyard, Far-field and the handheld reader antennas is circularly polarized as opposed to that of the Mini Guardrail antenna which is linearly polarized. It was found in one simple test as shown in Figure 5.6 that circularly polarized antennas were more effective than linearly polarized ones, especially when applying RFID in high-value component tracking because tags will be differently oriented on the module. (The Mini Guardrail antenna and two non-metal mount tags of the same type were used in the test.)

The read range defined as the maximum range that the antenna can detect the tag was the output of the test. As seen from the result in Table 5.1, the read range in the case of orientation 1 and 2 was much more than that in orientation 3 and 4. In comparison, the read range of the same tags almost didn't change in orientation 1-4 when using the Far-field antenna as shown in Table 5.2. In order to maximize the possibility of tags being read, only circularly polarized antennas were used in the pilot experiment. It is noted that the read range in orientation 5 and 6 of both linear and circular antenna tests was much shorter than that in other orientations, because limited signal was received by tag antennas in such orientations. Based on this fact, a specific guideline of tag placement on some components is recommended in section 7.3.

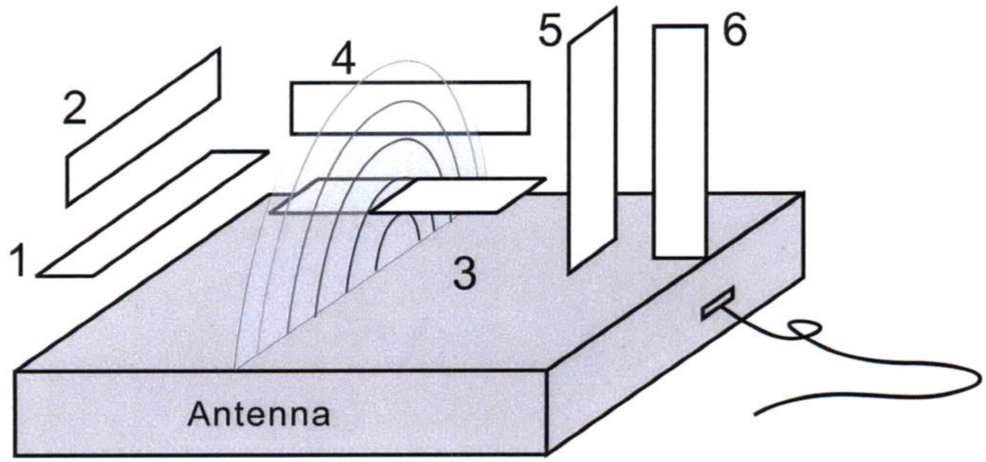


Fig. 5.6 Read Range Testing Process by Using Linear Antenna

Table 5.1 Read Range (Inch) of Different Orientations by Using Mini Guardrail

Tag Orientation	Squiggle 1	Squiggle 2
Orientation 1	12.5	11
Orientation 2	12	11.5
Orientation 3	4	4
Orientation 4	2.5	3.5
Orientation 5	1.1	1.2
Orientation 6	0.1	0.1

Table 5.2 Read Range (Inch) of Different Orientations by Using Far-field with Power set to +15dbm

Tag Orientation	Squiggle 1	Squiggle 2
Orientation 1	37.5	39
Orientation 2	38	38.5
Orientation 3	45	40
Orientation 4	39	39.5
Orientation 5	10	9
Orientation 6	9.5	9

5.4.2 – RFID Tag

Because of metal interference, 3 types of metal mount tags were chosen as shown in Figure 5.7. As shown in Table 5.3, the size of them is no bigger than the size of bar code tags that are currently used.

Table 5.3 Dimensions of Metal Mount Tags

Type	Dimension
Metal Tag Slim	3.0 x 0.625 x 0.06 in
Metal Tag Slim – F	1.4 x 0.625 x 0.12 in
Ghost	1 x 0.35 x 0.12 in

Fig. 5.7 Metal Mount Tags [43], [44], [45]

5.5 – Components for Testing

The high-value components are on different modules. In addition, tracing these components with a warranty given from VSEA to clients is important to Materials Quality department, whereas tracking of the parts which may not have a warranty but have different revisions or once had a failure report from customers is of great use to Manufacturing Engineering department. In general, a list of high-value components was generated for the experiment to include different types of components on different modules.

5.6 – Design of Experiments (DOE)

The DOE methodology helps obtain an objective result by providing a systematic way of varying inputs and using replicates to account for random behavior. In this particular RFID application, tag placement on the components was the most important factor in the feasibility testing. The way of defining the tag placement on different components was discussed in section 5.6.1. Each experiment was designed to have 3 or 4 replicates and different operators were involved to account for all sources of variation.

5.6.1 – Tag Placement

As mentioned in section 4.3, because of the complicated metal environment, a tag cannot be detected unless it is visible to the transmitted signal from the antenna. The tag placement is also restricted by the tag size because some components do not have a suitable spot. In addition, a tag cannot be attached to a part that is often taken apart from the component during assembly or testing, to avoid the possibility of mismatching a tag with another similar component. As a result, the tag placement needs to be well defined in the experiment.

As shown in Figure 5.8, a coordinate system was built on the antenna surface of the handheld reader. The tag placement was thereby defined three levels as follows:

Most visible placement (+1):

a. the placement was on the 'exterior' surface of the module (defined as the surface facing outwards once the entire machine is assembled) and was open to the signal
b. the placement was on the surface which was parallel to the YZ plane of the coordinate system when the handheld reader was visibly accessible to the tag
c. there was no difference between the tag placements on two different surfaces if they both satisfied rule a and b by adjusting the orientation of the handheld reader

Visible placement (0):

a. the placement was defined as same as the most visible placement in terms of rule b and c, but was inside the module and the tag was still visually accessible

Least visible placement (-1):

a. the placement was inside the module and the tag was still visually accessible
b. the placement was on the surfaces that were not parallel to the YZ plane of the coordinate system whatever the orientation of the reader was

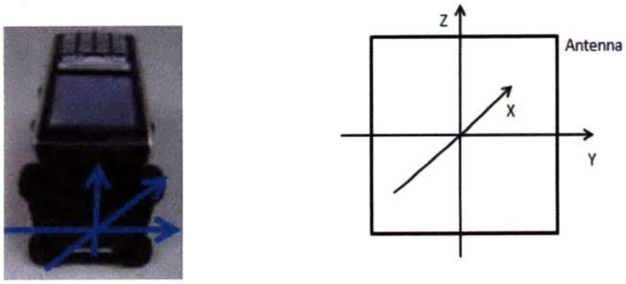
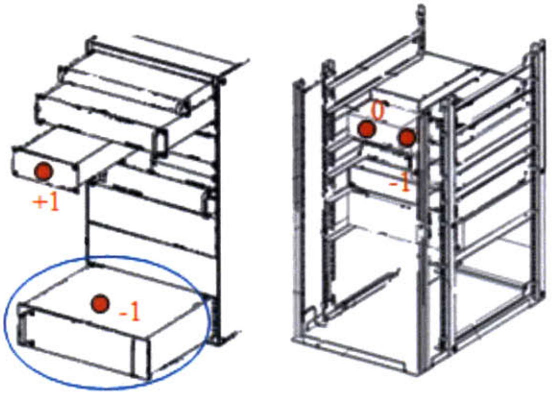


Fig. 5.8 the Coordinate System on the Antenna Surface

The definition of tag placement on components included most available possibilities. An example is shown in Figure 5.9, in which the most visible placement (marked as red +1) and the visible placement (marked as red 0) were on the front and back of the electronic equipment respectively. The least visible placement (marked as red -1) was on the side or on the top (if it was a full-size component such as the one in blue circle, the tag was on the top because of no space available on the side) of the electronic equipment which was surrounded by other equipments so that the YZ plane of the antenna could not face normally to the tag surface.



Front View Back View

Fig. 5.9 An Example of the Tag Placement

5.6.2 – Other Factors

The other factors in the experiment were the three types of the RFID tags used and the two checking systems (archway and handheld readers) used to detect the tags. These factors can lead to more thorough understanding of the performance of both tags and systems, contributing to the future application of the RFID system. There could be other factors such as the numbers of RFID tag on the same component or the combinations of different types of tags used in the same time. However, for feasibility testing, it was decided to start from the most important factors.

Chapter 6 – Results and Discussion

6.1 – Handheld reader testing on 90 degree module

This section describes the process and result of the experiment using a handheld reader checking system on a 90 degree module, whose primary function is to deflect the plasma beam by 90 degrees. Constrained by time, three or four replicates were taken in each different combination and different combinations of tag types and placements were tested. The transmitting power of the reader was set to the maximum +28 dbm.

6.1.1 – Module and Tag Placement Description

As shown in Figure 6.1, electronic racks circled in red contain similar high-value components such as ADIOs (Analog Digital Input Output), power supplies, monitors and so on. In the blue circle, the magnet, the power distribution box and the transformer (not shown) were chosen in the experiment. In total of 13 components of different types on different locations were chosen, which generally included most possible tag placements on this module.

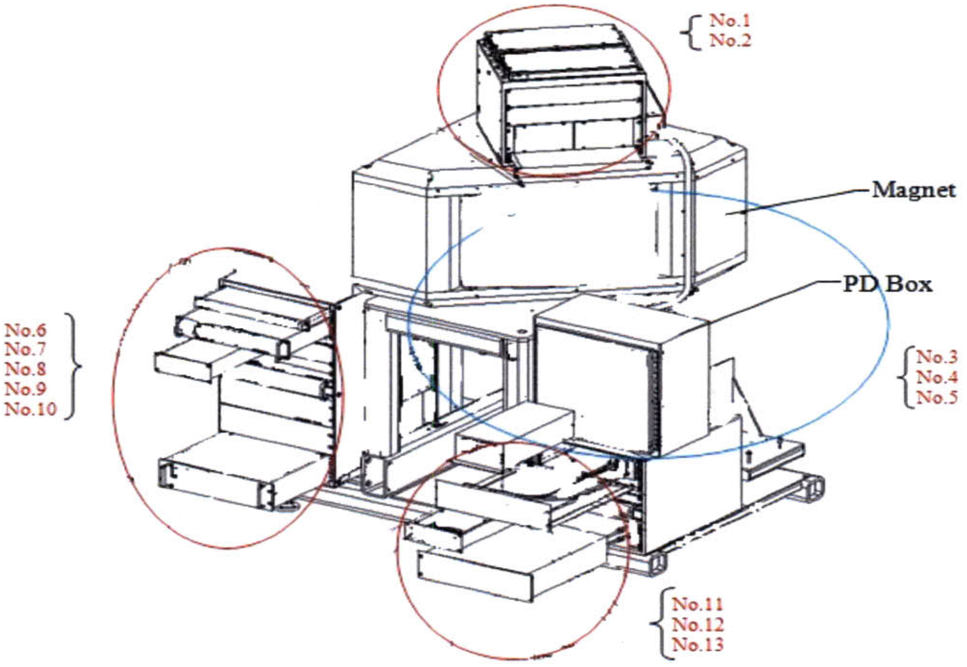
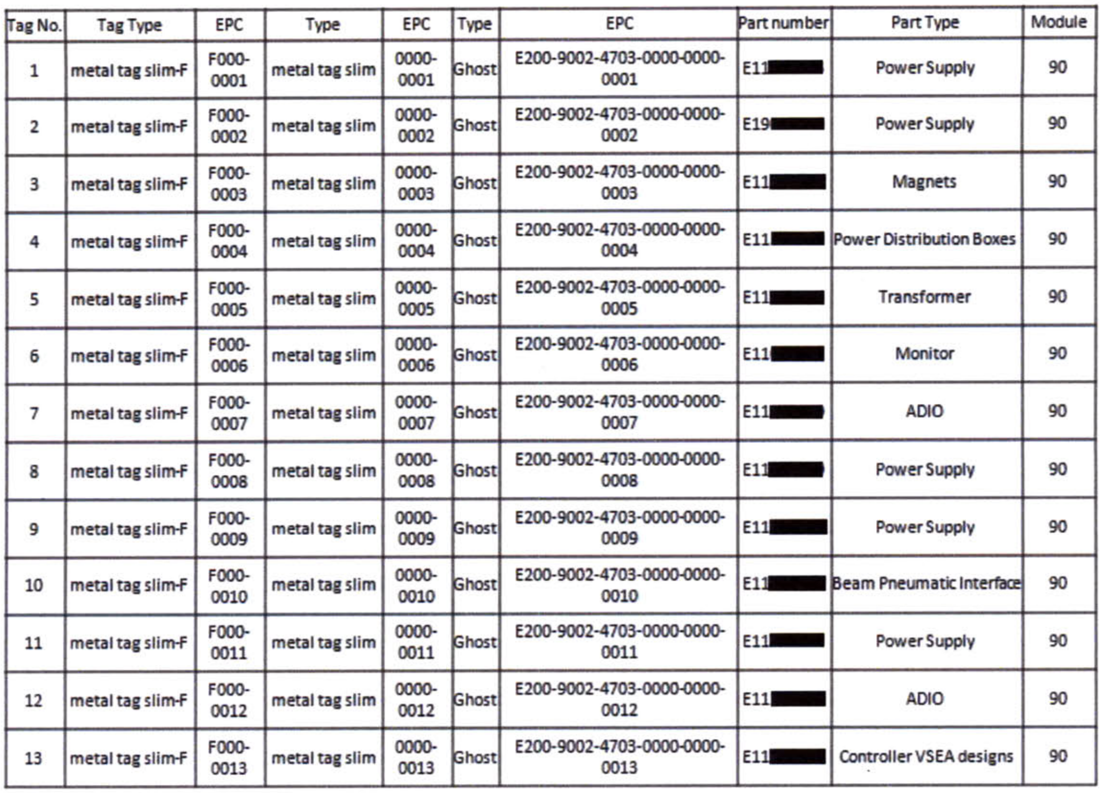


Fig. 6.1 Overview of 90 Degree Module and Locations of Components with Numbers Matched in Tag Registration Table

Before the experiment, all tags were registered to match the part number of these 13 components as shown in Table 6.1 below. As mentioned in section 5.2.2, three types of tags were tested. The tag placement had three levels as defined in section 5.6.1, strictly following the definition on most of components that are on electronic racks. However, the placement on big-size components such as the magnet, the power distribution box and the transformer did not follow the definition because all the exposed sides of such components can be considered as the most visible placement (+1). In order to be consistent with the electronic components, tags were attached on the front, top and back of such big-size components.

Table 6.1 RFID Tags Registration (90 degree module)



Tag No.	Tag Type	EPC	Type	EPC	Type	EPC	Part number	Part Type	Module
1	metal tag slim-F	F000-0001	metal tag slim	0000-0001	Ghost	E200-9002-4703-0000-0000-0001	E11[redacted]	Power Supply	90
2	metal tag slim-F	F000-0002	metal tag slim	0000-0002	Ghost	E200-9002-4703-0000-0000-0002	E19[redacted]	Power Supply	90
3	metal tag slim-F	F000-0003	metal tag slim	0000-0003	Ghost	E200-9002-4703-0000-0000-0003	E11[redacted]	Magnets	90
4	metal tag slim-F	F000-0004	metal tag slim	0000-0004	Ghost	E200-9002-4703-0000-0000-0004	E11[redacted]	Power Distribution Boxes	90
5	metal tag slim-F	F000-0005	metal tag slim	0000-0005	Ghost	E200-9002-4703-0000-0000-0005	E11[redacted]	Transformer	90
6	metal tag slim-F	F000-0006	metal tag slim	0000-0006	Ghost	E200-9002-4703-0000-0000-0006	E11[redacted]	Monitor	90
7	metal tag slim-F	F000-0007	metal tag slim	0000-0007	Ghost	E200-9002-4703-0000-0000-0007	E11[redacted]	ADIO	90
8	metal tag slim-F	F000-0008	metal tag slim	0000-0008	Ghost	E200-9002-4703-0000-0000-0008	E11[redacted]	Power Supply	90
9	metal tag slim-F	F000-0009	metal tag slim	0000-0009	Ghost	E200-9002-4703-0000-0000-0009	E11[redacted]	Power Supply	90
10	metal tag slim-F	F000-0010	metal tag slim	0000-0010	Ghost	E200-9002-4703-0000-0000-0010	E11[redacted]	Beam Pneumatic Interface	90
11	metal tag slim-F	F000-0011	metal tag slim	0000-0011	Ghost	E200-9002-4703-0000-0000-0011	E11[redacted]	Power Supply	90
12	metal tag slim-F	F000-0012	metal tag slim	0000-0012	Ghost	E200-9002-4703-0000-0000-0012	E11[redacted]	ADIO	90
13	metal tag slim-F	F000-0013	metal tag slim	0000-0013	Ghost	E200-9002-4703-0000-0000-0013	E11[redacted]	Controller VSEA designs	90

6.1.2 – Experiment Result

As shown in Table 6.2, tests under Replicate 1 and 2 were done by the author and those under Replicate 3 and 4 were done by Cyril Koniski and Yulei Sun respectively. With reference to section 5.3.2.2, the movement of handheld reader in Replicate 1, 3 and 4 followed Rule 1 while the movement followed Rule 2 in Replicate 2.

Table 6.2 Percentage of the Tags Being read (90 degree module)

Tag Type (level)	Replicate 1 (Rui Jia)	Replicate 2 (Rui Jia)	Replicate 3 (Cyril Koniski)	Replicate 4 (Yulei Sun)
Ghost (+1)	100% (13/13)	77% (10/13)	92% (No.5 missed)	
Ghost (0)	100%	62% (8/13)	92% (No.5	100%

			missed)	
Slim (+1)	100%	100%	100%	100%
Slim (0)	100%	77% (10/13)	100%	100%
Slim (-1)	100%	62% (8/13)	92% (No.12 missed)	100%
Slim-F (+1)	100%		100%	92% (No.5 missed)
Slim-F (0)	92% (No.9 missed)		85% (No.2&9 missed)	100%
Slim-F (-1)	100%		100%	100%

6.1.3 –Result Discussion

It is apparent that replicate 2, following movement rule 2, led to a large number of misreads. In replicates 1, 3 and 4 only seven misreads out of 23 overall tests were recorded, whereas in replicate 2 sixteen misreads out of four tests occurred. Rule 1 used in Replicate 1, 2 and 4 leads to almost 100% reads for all three types of tags and three levels of the tag placement, and is clearly more effective than Rule 2.

In those misreads of the tests that followed Rule 1, No.5 (the transformer) was misread three times. Two of the other four misreads are from No.9, the power supply and the rest two come from No.2, the power supply and No.12, the ADIO respectively. As shown in Figure 6.2, the transformer only offers two flat surfaces available for tagging, so the top of the transformer was applied in level +1 tests and the side was applied in level 0 and level -1 tests. Two out of total three misreads come from the top of the transformer and the other one is from the side. It seems the tag placement on the transformer requires a very specific location and attaching tags on the side makes them more likely to be read by the handheld reader than attaching them on the top. Since the No.2, No.9 and No.12 components are similarly structured and assembled on the racks, the missed reads from them can be treated as random errors.

Comparing the tag types in Replicate 1, 2 and 4, no evident difference of performance is noticed.

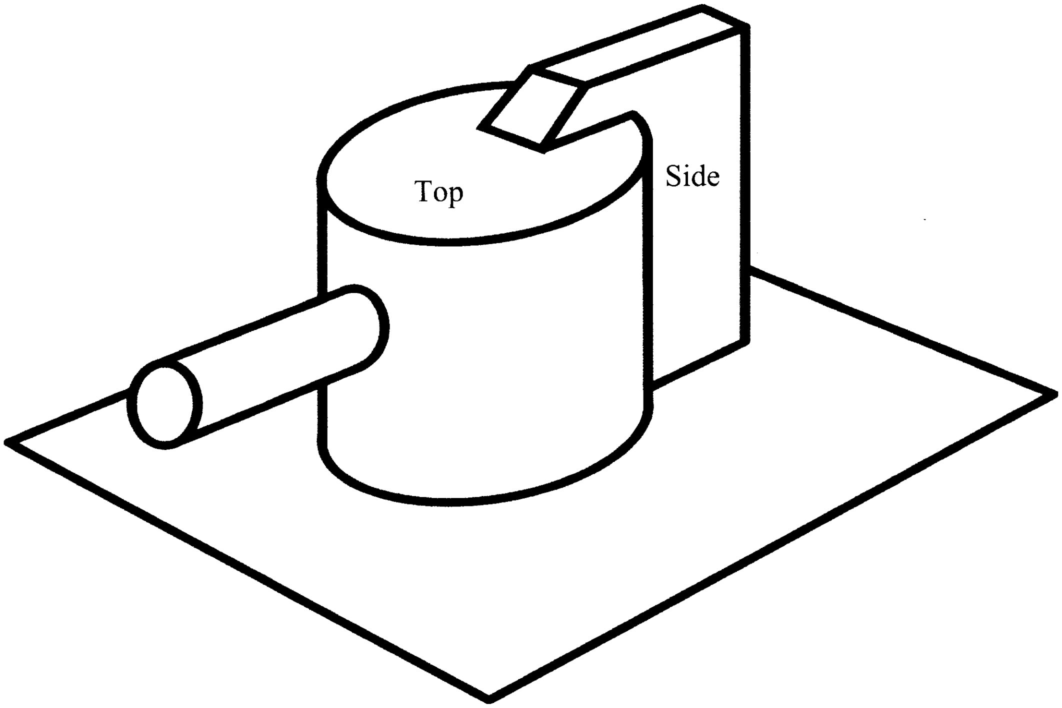


Fig. 6.2 Overview of the Transformer Showing the Only Two Flat Surfaces Availablefor Tagging

6.2 – Archway system testing on 70 degree module

This section discusses the process and result of an experiment using archway checking system done on 70 degree module. A three-replicate test was taken by moving and passing the module through the checking "arch" as shown in Figure 6.3. The arch consisted of two Far-field antennas on the side and one Brickyard antenna on the top, with the transmitting power of all the three antennas set to +30dbm.

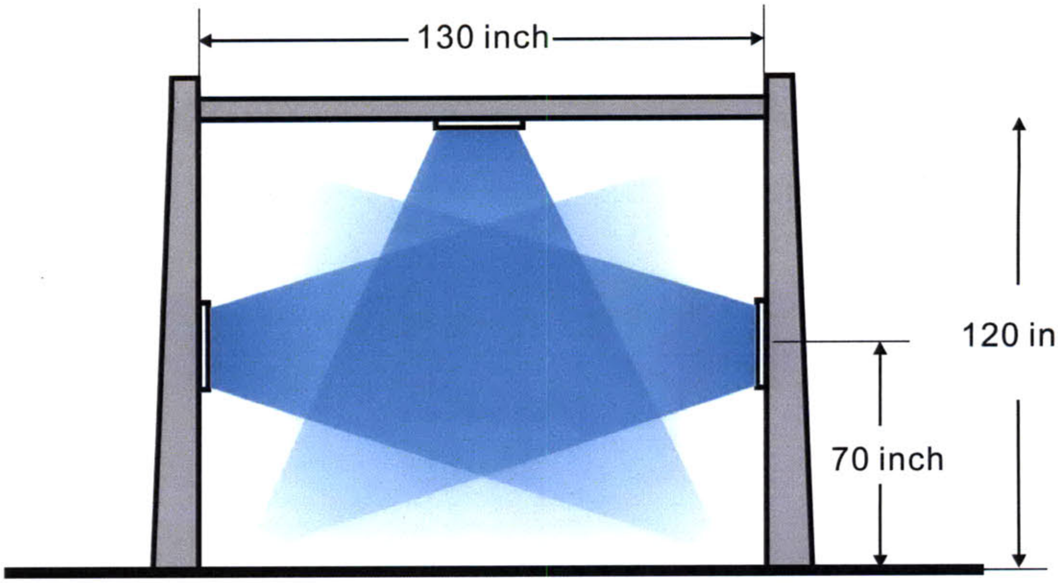


Fig. 6.3 Arch Setup with the Brickyard antenna at the top

6.2.1 – Module and Tag Placement Description

Similar to the 90 module mentioned in section 6.1.1, ten components chosen for testing were separated into two electronic equipment groups and one big-size component group. As circled red in Figure 6.4, the Rod Adjuster, the magnet, the power distribution box and the Rod Controller were selected as the big-size component group while all other electronic components were located in the two blue circles.

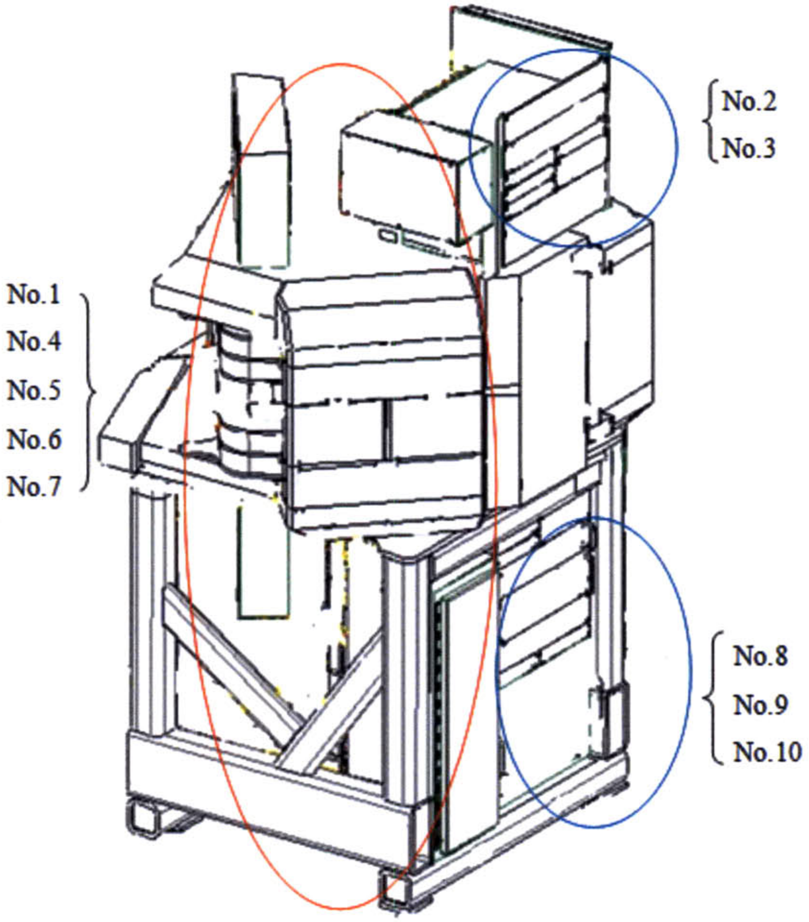


Fig. 6.4 Overview of 70 Degree Module and Locations of Components with Numbers Matched in Tag Registration Table

The tags were registered as shown in Table 6.3 before the experiment. The tags were placed similarly as discussed in section 6.1.1, the front, top and side of big-size components being level +1, 0, -1 respectively while the tag placement following the definition in section 5.6.1 on electronic components. Because of insufficiency of Slim and Slim-F tags, the placement of No.8-No.10 components of level -1 were not tagged.

Table 6.3 RFID Tags Registration (70 degree module)

Tag No.	Tag Type	EPC	Type	EPC	Type	EPC	Part No.	Part Type	Module
1	Ghost	E200-9002-4703-0000-0000-0001	metal tag slim	0000-0001	metal tag slim-F	F000-0001	E11[redacted]	Rod Controller	70
2	Ghost	E200-9002-4703-0000-0000-0002	metal tag slim	0000-0002	metal tag slim-F	F000-0002	E11[redacted]	Controller VSEA designs	70
3	Ghost	E200-9002-4703-0000-0000-0003	metal tag slim	0000-0003	metal tag slim-F	F000-0003	E11[redacted]	ADIO	70
4	Ghost	E200-9002-4703-0000-0000-0004	metal tag slim	0000-0004	metal tag slim-F	F000-0004	E11[redacted]	Adjuster	70
5	Ghost	E200-9002-4703-0000-0000-0005	metal tag slim	0000-0005	metal tag slim-F	F000-0005	E11[redacted]	Adjuster	70
6	Ghost	E200-9002-4703-0000-0000-0006	metal tag slim	0000-0006	metal tag slim-F	F000-0006	E11[redacted]	Magnets	70
7	Ghost	E200-9002-4703-0000-0000-0007	metal tag slim	0000-0007	metal tag slim-F	F000-0007	E11[redacted]	Power Distribution Boxes	70
8	Ghost	E200-9002-4703-0000-0000-0008	metal tag slim	0000-0008	metal tag slim-F	F000-0008	E11[redacted]	Controller VSEA designs	70
9	Ghost	E200-9002-4703-0000-0000-0009	metal tag slim	0000-0009	metal tag slim-F	F000-0009	E11[redacted]	ADIO	70
10	Ghost	E200-9002-4703-0000-0000-0010	metal tag slim	0000-0010	metal tag slim-F	F000-0010	E11[redacted]	Power Supply	70

6.2.2 – Experiment Result

The result is shown in Table 4. As mentioned in 6.2.1, no tags were applied on No.8, 9 and 10 components at the -1 level, so the percentage of reads in level -1 for Slim and Slim-F tags were based on a total number of seven components as shown in red in Table 6.4. Known from the experiment data (Appendix A), even two tests had same percentage, the missed components of each test might be different.

Table 6.4 Percentage of Tags Being Read (70 degree module)

Tag Type	Replicate1	Replicate 2	Replicate 3
Ghost (+1)	80% (8/10)	80% (8/10)	80% (8/10)
Ghost (0)	70% (7/10)	60% (6/10)	50% (5/10)
Ghost (-1)	40% (4/10)	50% (5/10)	30% (3/10)

Slim (+1)	50% (5/10)	60% (6/10)	60% (6/10)
Slim (0)	30% (3/10)	30% (3/10)	20% (2/10)
Slim (-1)	71% (5/7)	71% (5/7)	71% (5/7)
Slim-F (+1)	80% (8/10)	50% (5/10)	70% (7/10)
Slim-F (0)	40% (4/10)	20% (2/10)	30% (3/10)
Slim-F (-1)	43% (3/7)	43% (3/7)	43% (3/7)

6.2.3 – Result Discussion

As shown in Table 6.4, generally, tags in the placement of level +1 are more effective than those in level 0 while tags in level 0 are more effective than those in level -1. Ghost tags are more effective than the other two types, especially when the tag placement is level +1.

Further analysis has also shown that when tags are in the placement of level +1, No.1, the Rod Controller and No. 6, the magnet were not read in most of the combinations. This is probably because the front of these two components was facing the folk lift when the module was being moved, leading to signal blockage by the metal. Also, most of the electronic components on the bottom rack were not read when the tags are in the placement of level 0 and level -1. With reference to Figure 3, a possible reason may be that the Brickyard antenna provided a more intense read zone in the top area than that in the bottom area.

Chapter 7 – Recommendations

7.1 – Tag Type

The experiments show that there is no difference of the tag performance in the handheld reader system test. However, with the archway reader the Ghost tag is more effective than the other two tags. In addition, Ghost has an advantage in size, which is important when applying tags on some restricted spots of the components and it is esthetically pleasing. The cost of each tag is listed in Table 7.1, and Ghost tags are more expensive than the other two types, however, compared to the value of the module and the benefit gained from the RFID implementation, the price of Ghost is acceptable. Although Slim and Slim-F tags are customizable and may have same or even more advantageous performance and size in certain customization, Ghost tags are preferred at least for the initial RFID implementation.

Table 7.1 Unit Cost of Different Tags

Tag Type	Unit Cost ($)
Ghost	5.66
Metal Tag Slim	3.00
Metal Tag Slim-F	3.00

7.2 – Archway VS Handheld

The handheld reader system is recommended in this high-value component implementation mainly for three reasons:

1 – More effective in the complicated metal environment

By following the movement of Rule 1 as mentioned in section 5.3.2.2, the handheld reader obtained almost 100% of tags being read, much more effective than the archway reader in similar testing environment. Especially, the handheld reader is not restricted by different tag placements. With reference to Appendix A, all tag placements of three levels can be read. In comparison, the archway reader is not able to read most of the tags when they are in the placement of level 0 and level -1.

2 – Less expensive in obtaining same performance

It takes three minutes for the handheld reader to check a module by conservative estimation, so the value of time saving per machine by using the archway reader is trivial. In addition, the archway reader system needs a handheld reader or a portable antenna as a backup in case that some tags cannot be read by moving the module. As a result, a 4-antenna archway reader system is already more expensive than a handheld reader, regardless of the fact that the archway system could possibly obtain the same performance as the handheld reader system only when tags are in the placement of level +1.

3 – More flexible in real practice

The handheld reader system is more flexible in terms of the quantity. For example, one handheld reader can fit both two rooms of the air shower since the checking time is only about 3 minutes for each module, as opposed to the archway reader system which needs to be implemented in both rooms to avoid changing the material flow.

7.3 – Tag Placement

This section structures the guideline of tag placements on high-value components based on the result of the experiment.

7.3.1 – General Guideline

1 – The most visible tag placement first

As was shown from the archway system test, the most visible placement leads to the most possibility for the tags to be read by the outside signal. It also minimizes the effort to read the tags by using the handheld reader. Although all tag placements of three levels as defined in section 5.6.1 have similar performance when using the handheld reader in the experiment, it is recommended attaching tags on the most visible tag placement as possible.

2 – Close to the existing labels

Attaching tags close to the existing labels such as bar codes is recommended as a reference for tagging operators. Orientations of the tags are not specifically required as long as the tags fit and no esthetic concerns are involved.

3 – Uniform for similar types of components

Having a uniform placement for similar components is recommended for minimizing specific guidelines and increasing efficiency in tagging procedure.

7.3.2 – Specific Guidelines

This section discusses some specific guidelines recommended on some particular components.

1 – Big-size component guideline

In the case of big-size components, tag placement is not restricted by the available space. With following the general guideline, the tag placement on some components should be specifically assigned.

For example, as mentioned in section 6.1.3, the transformer missed three times in the experiment. Part of the reason may be the impedance of metal mount tag antenna circuits is designed for applying tags on metal, so when tags are on the top of the transformer where the material is plastic, the performance is worse than the case of metal. The reason of missing read on the side of the transformer where the material is metal may be the placement was on the corner where the movement of handheld reader is need to be more careful than in typical case. As a result, the tag placement on the transformer and similar components is recommended to be on the metal and to be as visible to handheld reader as possible.

2 – Electronic component guideline

The experiments have shown that all three levels of tag placement can be detected without problem and there is no obvious evidence indicating difference of performance. Nevertheless, when applying tags in the placement of level -1 which is either on the top or side of electronic components, the tag orientation is specially recommended. With reference to the simple test described in section 5.4.1, the tag orientation shown in Figure 7.1 matches the definition in Figure 5.6. The read range in orientation 2 and 4 is larger than that in orientation 5 and 6, leading to that RFID tags are recommended to be placed with long edge close to the edge of backside of electronic components.

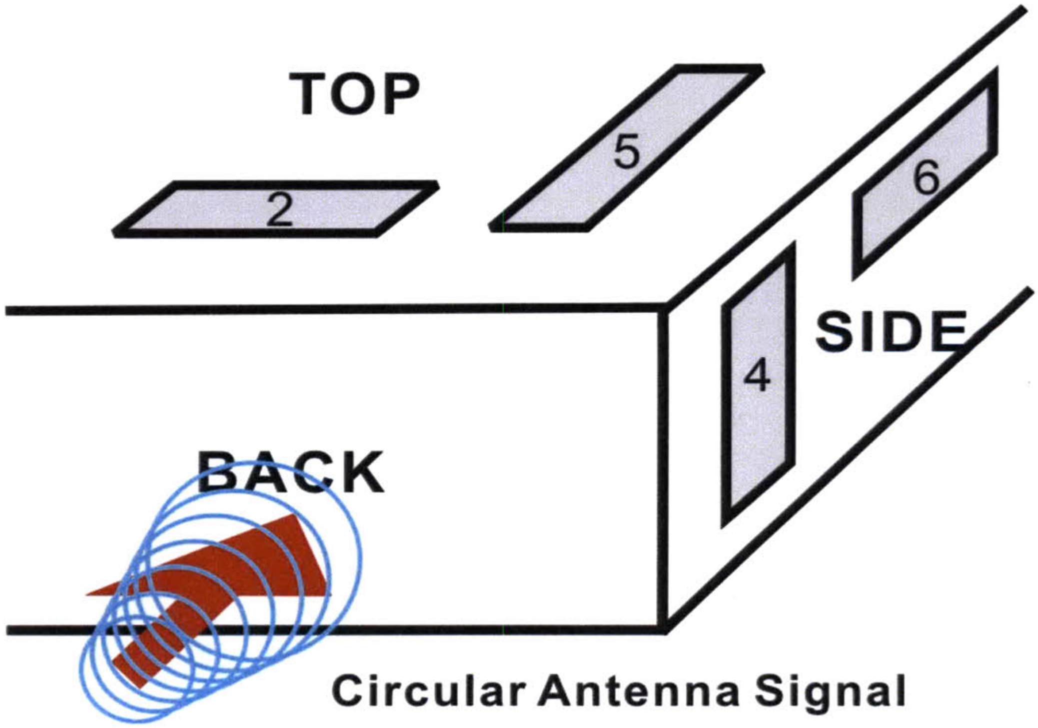


Fig. 7.1 Specific Guideline for RFID Tag in Level -1 Placement on Electronic Components

Chapter 8 – Conclusions and Future Work

8.1 – Project Summary

In conclusion, the pilot RFID project proved the suitability of the technology to VSEA's manufacturing environment. The results of experiments performed on high-value components attached to different machine modules suggested RFID tags could simplify and expand the serialization of such components, with immediate potential benefits on the type of warranty issues discussed in Section 3.3. A guideline of tag placement on components was proposed.

The analysis of the item-level tagging experiments revealed that the high read percentages necessary for successful implementation were indeed achievable, and a checkpoint 'arch' design was proposed. This work is documented in Cyril Koniski's thesis [36].

In Yulei Sun thesis [37], in-depth analysis of VSEA's operations is presented and several process modifications meant to enable RFID implementation and enhance its benefits are proposed. In addition, a flow line analysis model is proposed to evaluate the capacity and utilization of individual workstations under various conditions.

8.2 – Assumption and Limitation

As described in section 6.1 and section 6.2, two different checking systems were tested on two different modules respectively, so the results used to draw conclusions were assumed thoroughly representative of all other modules. Similarly, the components chosen were assumed to be representative of all components factory-wide. Also, the setup of the archway system used in the experiment was assumed to have little influence on the results.

One limitation discussed here is this thesis does not take into account the practical difficulties of process modifications to implement RFID. As mentioned in section 5.3.1, the add-on tagging procedures in three different areas require uniform discipline to train workers. If workers are unwilling to change or do not work collaboratively, the checking process after will be influenced and the benefit of RFID will be partially counteracted.

8.3 – Future Work

A complete feasibility of RFID on all modules is required to be established. Tag placement guidelines for each tracking component also need to be completed. Then a big challenge of the RFID application is to integrate with upcoming Enterprise Resource Planning system. Since it is a big cost to apply the RFID system, which also has an effect on suppliers and customers, a rigorous ROI analysis is required before its full-scale implementation.

References:

[1] Sherbondy, S., "Varian Semiconductor Equipment Associates Inc." MIT MEng in Manufacturing Project Presentations. 8-404, Cambridge, MA. Dec. 2009. Lecture.

[2] *VSEA - Products - VIISta Platform*. VSEA. Web. 20 June 2010. <http://vsea.com/products.nsf/docs/viistaplatform>.

[3] *Industry Factsheet*. SIA. Web. 19 June 2010. <http://www.sia-online.org/cs/industry_resources/industry_fact_sheet>.

[4] *Semiconductor Fabrication Plant*. Wikipedia. Web. 27 May 2010. <http://en.wikipedia.org/wiki/Semiconductor_fabrication_plant>.

[5] Impinj. *Getting Up to Speed: RFID Powered by Impinj*. Seattle, WA: Impinj, 2009. Print.

[6] Albright, B., "RFID Tag Placement." *Frontline Solutions* 5.6 (2004): 12-20. Print.

[7] *Wal-Mart and RFID: A Case Study.* <http://www.tutorialreports.com/wireless/rfid/walmart/case-study.php>

[8] *Metro Group Reaps Gains From RFID*. RFID Journal. Web. Jan. 24, 2005. < http://www.rfidjournal.com/article/view/1355/1/1>

[9] *P&G's Use of EPC in the Supply Chain*. RFID Journal. Web. <http://www.rfidjournal.com/article/articleview/482>

[10] *JR Freight Improves Operating Efficiencies with Intermec RFID Technology*. Intermec. Web. 10 June 2010 <http://www.intermec.com/learning/content_library/case_studies/cs1961.aspx>.

[11] *RFID/EPC™ in the EDC of Sony Europe.* http://www.mielooandalexander.com/download/reference_case/M&A_reference_case_sony_rfid_epc.pdf

[12] *Boeing Tracks Parts and Reduces Inventory with RFID Tags*. Intermec. Web. 10 June 2010 <http://www.intermec.com/learning/content_library/case_studies/cs2054.aspx>.

[13] *IBM brings RFID to Volkswagen's entire supply chain.* <http://www.tgdaily.com/trendwatch-features/41842-ibm-brings-rfid-to-volkswagens-entire-supply-chain>

[14] *RFID Improves Digital Supply Chain*. Intel, video. <http://video.intel.com/ ?fr_story=895a48fdda647fca392452d598010e921d7428dc&rf=sitemap>

[15] *AstraZeneca extends its RFID roll-out*. packagingnews.co.uk. <http:// www.packagingnews.co.uk/ news/642851/AstraZeneca-extends-its-RFID-roll-out/>

[16] *Pfizer Using RFID to Fight Fake Viagra*. RFID Journal. Web. Jan. 6., 2006. < http://www.rfidjournal.com/article/articleview/2075/1/1/>

[17] *RFID CASE STUDY*: Cephalon. Impin Inc. Print

[18] *Apollo Hospital Chennai Uses RFID to Speed Up Check-ups*. RFID Journal. Web. June 11, 2010. <http://www.rfidjournal.com/article/view/7659/>

[19] *Case study: Bob Jones University*. Intermec. Web. <http://www.intermec.com/public-files/case-studies/en/BobJones_cs_web.pdf>.

[20] *The use of RFID for Human Identification*. <http://www.dhs.gov/xlibrary/assets/privacy/privacy_advcom_rpt_rfid_draft.pdf >

[21] *RFID Drives Highway Traffic Reports*. RFID Journal. Web. Nov. 17, 2004. < http://www.rfidjournal.com/article/view/1243/1/1>

[22] *RFID CASE STUDY*: Los Angeles Marathon. Impinj Inc. Print

[23] *A Case Study to Track High Value Stillages using RFID for an Automobile OEM and its Supply Chain in the Manufacturing Industry*, P. Foster MSc, A. Sindhu, D. Blundell., IEEE Xplore.

[24] Dobkin, D., *The RF in RFID: Passive UHF RFID in Practice*. Amsterdam: Elsevier / Newnes, 2008. Print.

[25] Adams, D., "Read This': How RFID will work in metal Environments" Using RFID. April 2005.

[26] Deavours, D., *Improving the near-metal performance of UHF RFID tags*, 2010 IEEE International Conference on RFID

[27] Raumonen P. et al., *Folded Dipole Antenna near metal plate*, IEEE Antennas and Propagation Society International Symposium, Vol. 1, pp.848-851, 2003

[28] Cheng C., and Prabhu V., *Experimental Investigation of EMI on RFID in Manufacturing Facilities*, 5th Annual IEEE Conference on Automation Science and Engineering.

[29] Arnaud-Cormos, D., *Electromagnetic environment of RFID systems*, Proceedings of the 37th European Microwave Conference.

[30] Wang, L., "Placement of Multiple Rfid Reader Antennas to Maximize Portal Read Accuracy." *Int. J. Radio Frequency Identification Technology and Applications* 1.3 (2007): 260-77. Print.

[31] Rusin, D., "Topics on Sphere Distributions", Web. <http://www.math.nui.edu/rusin/known-math/95/sphere.faq>

[32] McCarthy, U., "Impact of reader antenna polarisation, distance, inlay design, conveyor speed, tag location and orientation on the coupling of UHF RFID as applied to modified atmosphere packaged meat", *Computers and Electronics in Agriculture* 69.2 (2009): 135-141. Print.

[33] Hoong, E., "Application of Paired *t*-test and DOE Methodologies on RFID Tag Placement Testing using Free Space Read Distance", 2010 IEEE International Conference on RFID

[34] Ammu, A. et al, "Effect of Factors on RFID Tag Readability – Statistical Analysis", IEEE International Conference on Electro/Information Technology, 2009.

[35] Dobkin, D., *The RF in RFID: Passive UHF RFID in Practice*. Amsterdam: Elsevier / Newnes, 2008. Print.

[36] Koniski, Cyril. "Implementation of RFID Tracking in a Low Volume High Flexibility Assembly Plant: Item-Level Tracking." Thesis. Massachusetts Institute of Technology, 2010. Print.

[37] Sun, Yulei. "Implementation of RFID Tracking in a Low Volume High Flexibility Assembly Plant: Process Redesign." Thesis. Massachusetts Institute of Technology, 2010. Print.

[38] *Speedway® Revolution*. Seattle, WA: Impinj, Inc, 2007. Print.

[39] *RFID Antenas*. Chesterfield, MO: Laird Technologies, Inc. Print.

[40] *CS-777 Brickyard*^{TM} *Near-Field Antenna*. Seattle, WA: Impinj, Inc, 2007. Print.

[41] *Mini-Guardrail ILT Antenna Datasheet*. Seattle, WA: Impinj, Inc, 2009. Print.

[42] *Mobile RFID Handheld.* Plano, TX: Venture Research, Inc, 2009. Print.

[43] *MetalTag^{TM} Slim.* Randolph, MA: Emerson & Cuming Microwave Products, Inc, 2010. Print.

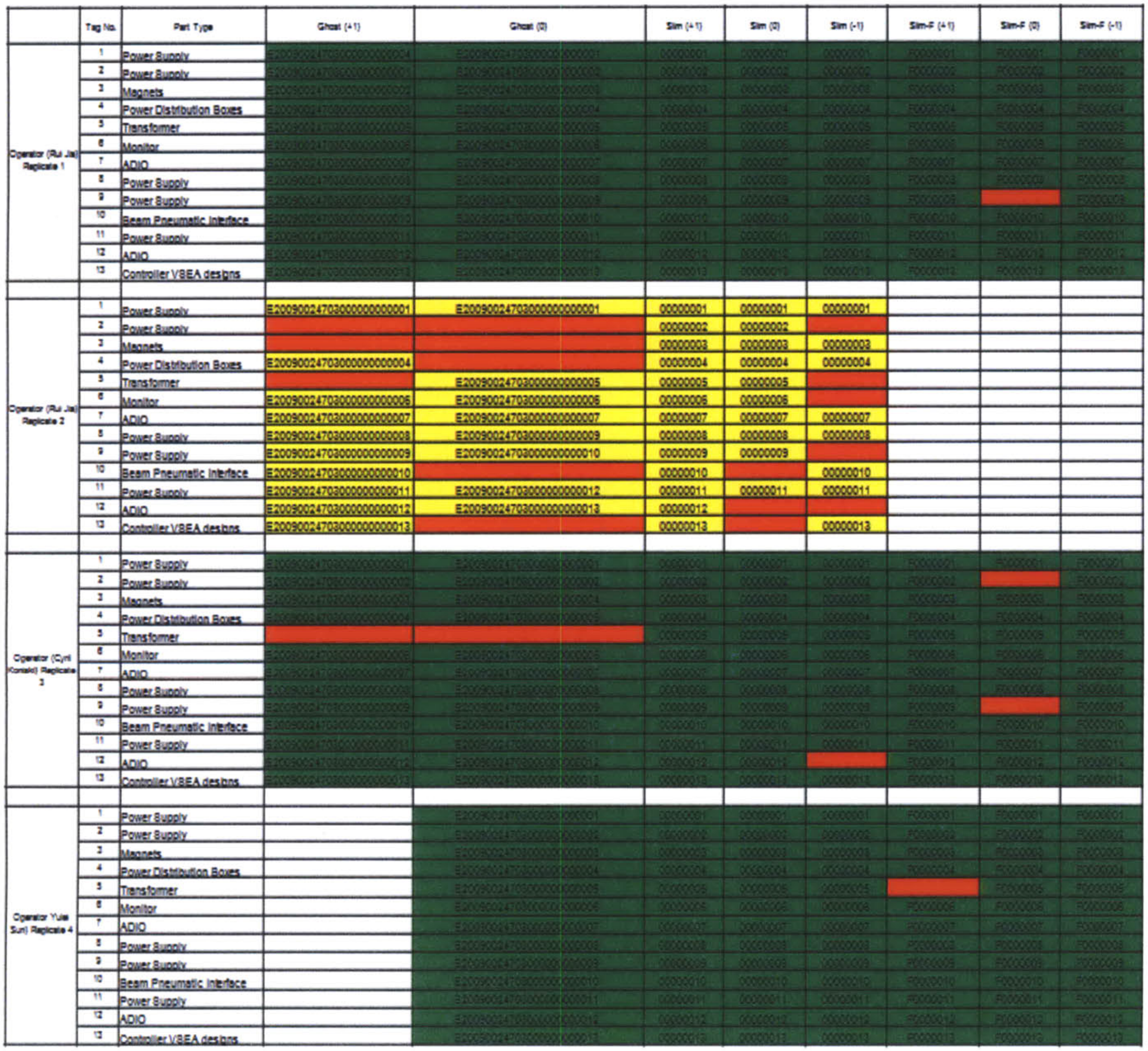
[44] *MetalTag^{TM} Slim-F.* Randolph, MA: Emerson & Cuming Microwave Products, Inc, 2010. Print.

[45] Atlas RFID – RFID Tags – "Ghost" Metal-Mount RFID Tag. Atalas. Web. 23 July 2010. <http://atlasrfidstore.com./Ghost_Metal_Mount_RFID_Tag_p>

Appendix A

Experiment Data of Test of RFID Handheld Reader Checking System on 90 Degree Module

Note: reads in Rule 1are marked green, reads in Rule 2 yellow and misreads red.

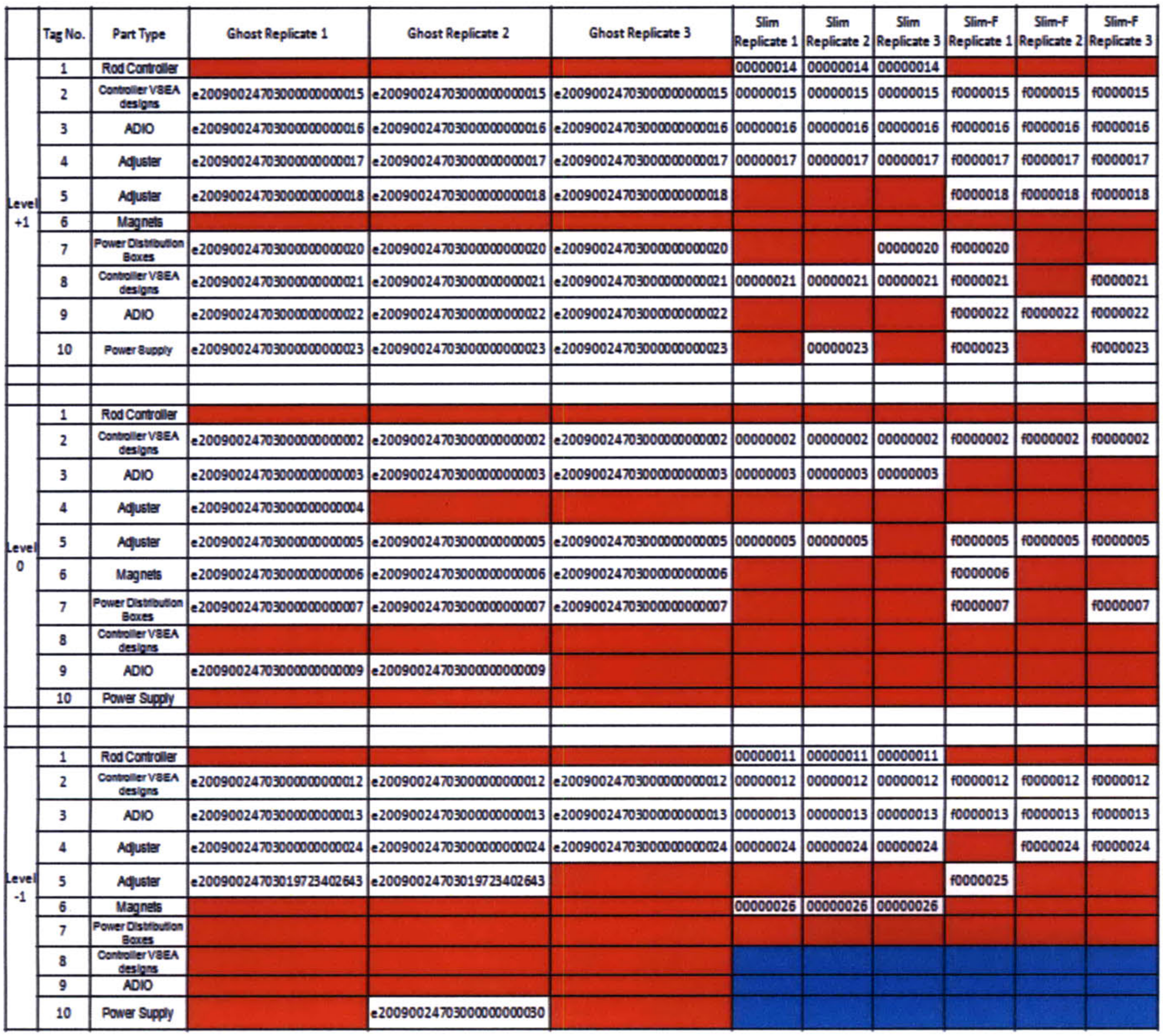


	Tag No.	Part Type	Ghost (+1)	Ghost (0)	Sim (+1)	Sim (0)	Sim (-1)	Sim-F (+1)	Sim-F (0)	Sim-F (-1)
Operator (Rui Jia) Replicate 1	1	Power Supply	E20090024703000000000004	E20090024703000000000001	00000001	00000001	00000001	F0000001	F0000001	F0000001
	2	Power Supply	E20090024703000000000001	E20090024703000000000002	00000002	00000002	00000002	F0000002	F0000002	F0000002
	3	Magnets	E20090024703000000000002	E20090024703000000000003	00000003	00000003	00000003	F0000003	F0000003	F0000003
	4	Power Distribution Boxes	E20090024703000000000003	E20090024703000000000004	00000004	00000004	00000004	F0000004	F0000004	F0000004
	5	Transformer	E20090024703000000000005	E20090024703000000000005	00000005	00000005	00000005	F0000005	F0000005	F0000005
	6	Monitor	E20090024703000000000006	E20090024703000000000006	00000006	00000006	00000006	F0000006	F0000006	F0000006
	7	ADIO	E20090024703000000000007	E20090024703000000000007	00000007	00000007	00000007	F0000007	F0000007	F0000007
	8	Power Supply	E20090024703000000000008	E20090024703000000000008	00000008	00000008	00000008	F0000008	F0000008	F0000008
	9	Power Supply	E20090024703000000000009	E20090024703000000000009	00000009	00000009	00000009	F0000009	🟥	F0000009
	10	Beam Pneumatic Interface	E20090024703000000000010	E20090024703000000000010	00000010	00000010	00000010	F0000010	F0000010	F0000010
	11	Power Supply	E20090024703000000000011	E20090024703000000000011	00000011	00000011	00000011	F0000011	F0000011	F0000011
	12	ADIO	E20090024703000000000012	E20090024703000000000012	00000012	00000012	00000012	F0000012	F0000012	F0000012
	13	Controller VSEA designs	E20090024703000000000013	E20090024703000000000013	00000013	00000013	00000013	F0000012	F0000013	F0000013
Operator (Rui Jia) Replicate 2	1	Power Supply	E20090024703000000000001	E20090024703000000000001	00000001	00000001	00000001			
	2	Power Supply	🟥	🟥	00000002	00000002	🟥			
	3	Magnets	🟥	🟥	00000003	00000003	00000003			
	4	Power Distribution Boxes	E20090024703000000000004	🟥	00000004	00000004	00000004			
	5	Transformer	🟥	E20090024703000000000005	00000005	00000005	🟥			
	6	Monitor	E20090024703000000000006	E20090024703000000000006	00000006	00000006	🟥			
	7	ADIO	E20090024703000000000007	E20090024703000000000007	00000007	00000007	00000007			
	8	Power Supply	E20090024703000000000008	E20090024703000000000009	00000008	00000008	00000008			
	9	Power Supply	E20090024703000000000009	E20090024703000000000010	00000009	00000009	🟥			
	10	Beam Pneumatic Interface	E20090024703000000000010	🟥	00000010	🟥	00000010			
	11	Power Supply	E20090024703000000000011	E20090024703000000000012	00000011	00000011	00000011			
	12	ADIO	E20090024703000000000012	E20090024703000000000013	00000012	🟥	🟥			
	13	Controller VSEA designs	E20090024703000000000013	🟥	00000013	🟥	00000013			
Operator (Cyril Konski) Replicate 3	1	Power Supply	E20090024703000000000001	E20090024703000000000001	00000001	00000001	00000001	F0000001	F0000001	F0000001
	2	Power Supply	E20090024703000000000002	E20090024703000000000002	00000002	00000002	00000002	F0000002	🟥	F0000002
	3	Magnets	E20090024703000000000003	E20090024703000000000004	00000003	00000003	00000003	F0000003	F0000003	F0000003
	4	Power Distribution Boxes	E20090024703000000000004	E20090024703000000000005	00000004	00000004	00000004	F0000004	F0000004	F0000004
	5	Transformer	🟥	🟥	00000005	00000005	00000005	F0000005	F0000005	F0000005
	6	Monitor	E20090024703000000000006	E20090024703000000000006	00000006	00000006	00000006	F0000006	F0000006	F0000006
	7	ADIO	E20090024703000000000007	E20090024703000000000007	00000007	00000007	00000007	F0000007	F0000007	F0000007
	8	Power Supply	E20090024703000000000008	E20090024703000000000008	00000008	00000008	00000008	F0000008	F0000008	F0000008
	9	Power Supply	E20090024703000000000009	E20090024703000000000009	00000009	00000009	00000009	F0000009	🟥	F0000009
	10	Beam Pneumatic Interface	E20090024703000000000010	E20090024703000000000010	00000010	00000010	00000010	F0000010	F0000010	F0000010
	11	Power Supply	E20090024703000000000011	E20090024703000000000011	00000011	00000011	00000011	F0000011	F0000011	F0000011
	12	ADIO	E20090024703000000000012	E20090024703000000000012	00000012	00000012	🟥	F0000012	F0000012	F0000012
	13	Controller VSEA designs	E20090024703000000000013	E20090024703000000000013	00000013	00000013	00000013	F0000013	F0000013	F0000013
Operator Yule Sun) Replicate 4	1	Power Supply		E20090024703000000000001	00000001	00000001	00000001	F0000001	F0000001	F0000001
	2	Power Supply		E20090024703000000000002	00000002	00000002	00000002	F0000002	F0000002	F0000002
	3	Magnets		E20090024703000000000003	00000003	00000003	00000003	F0000003	F0000003	F0000003
	4	Power Distribution Boxes		E20090024703000000000004	00000004	00000004	00000004	F0000004	F0000004	F0000004
	5	Transformer		E20090024703000000000005	00000005	00000005	00000005	🟥	F0000005	F0000005
	6	Monitor		E20090024703000000000006	00000006	00000006	00000006	F0000006	F0000006	F0000006
	7	ADIO		E20090024703000000000007	00000007	00000007	00000007	F0000007	F0000007	F0000007
	8	Power Supply		E20090024703000000000008	00000008	00000008	00000008	F0000008	F0000008	F0000008
	9	Power Supply		E20090024703000000000009	00000009	00000009	00000009	F0000009	F0000009	F0000009
	10	Beam Pneumatic Interface		E20090024703000000000010	00000010	00000010	00000010	F0000010	F0000010	F0000010
	11	Power Supply		E20090024703000000000011	00000011	00000011	00000011	F0000011	F0000011	F0000011
	12	ADIO		E20090024703000000000012	00000012	00000012	00000012	F0000012	F0000012	F0000012
	13	Controller VSEA designs		E20090024703000000000013	00000013	00000013	00000013	F0000013	F0000013	F0000013

Appendix B

Experiment Data of Test of RFID Archway Checking System on 70 Degree Module

Note: misreads are marked red and untagged parts are marked blue.



	Tag No.	Part Type	Ghost Replicate 1	Ghost Replicate 2	Ghost Replicate 3	Slim Replicate 1	Slim Replicate 2	Slim Replicate 3	Slim-F Replicate 1	Slim-F Replicate 2	Slim-F Replicate 3
Level +1	1	Rod Controller	🟥	🟥	🟥	00000014	00000014	00000014	🟥	🟥	🟥
	2	Controller VSEA designs	e20090024703000000000015	e20090024703000000000015	e20090024703000000000015	00000015	00000015	00000015	f0000015	f0000015	f0000015
	3	ADIO	e20090024703000000000016	e20090024703000000000016	e20090024703000000000016	00000016	00000016	00000016	f0000016	f0000016	f0000016
	4	Adjuster	e20090024703000000000017	e20090024703000000000017	e20090024703000000000017	00000017	00000017	00000017	f0000017	f0000017	f0000017
	5	Adjuster	e20090024703000000000018	e20090024703000000000018	e20090024703000000000018	🟥	🟥	🟥	f0000018	f0000018	f0000018
	6	Magnets	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	7	Power Distribution Boxes	e20090024703000000000020	e20090024703000000000020	e20090024703000000000020	🟥	🟥	00000020	f0000020	🟥	🟥
	8	Controller VSEA designs	e20090024703000000000021	e20090024703000000000021	e20090024703000000000021	00000021	00000021	00000021	f0000021	🟥	f0000021
	9	ADIO	e20090024703000000000022	e20090024703000000000022	e20090024703000000000022	🟥	🟥	🟥	f0000022	f0000022	f0000022
	10	Power Supply	e20090024703000000000023	e20090024703000000000023	e20090024703000000000023	🟥	00000023	🟥	f0000023	🟥	f0000023
Level 0	1	Rod Controller	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	2	Controller VSEA designs	e20090024703000000000002	e20090024703000000000002	e20090024703000000000002	00000002	00000002	00000002	f0000002	f0000002	f0000002
	3	ADIO	e20090024703000000000003	e20090024703000000000003	e20090024703000000000003	00000003	00000003	00000003	🟥	🟥	🟥
	4	Adjuster	e20090024703000000000004	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	5	Adjuster	e20090024703000000000005	e20090024703000000000005	e20090024703000000000005	00000005	00000005	🟥	f0000005	f0000005	f0000005
	6	Magnets	e20090024703000000000006	e20090024703000000000006	e20090024703000000000006	🟥	🟥	🟥	f0000006	🟥	🟥
	7	Power Distribution Boxes	e20090024703000000000007	e20090024703000000000007	e20090024703000000000007	🟥	🟥	🟥	f0000007	🟥	f0000007
	8	Controller VSEA designs	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	9	ADIO	e20090024703000000000009	e20090024703000000000009	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	10	Power Supply	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Level -1	1	Rod Controller	🟥	🟥	🟥	00000011	00000011	00000011	🟥	🟥	🟥
	2	Controller VSEA designs	e20090024703000000000012	e20090024703000000000012	e20090024703000000000012	00000012	00000012	00000012	f0000012	f0000012	f0000012
	3	ADIO	e20090024703000000000013	e20090024703000000000013	e20090024703000000000013	00000013	00000013	00000013	f0000013	f0000013	f0000013
	4	Adjuster	e20090024703000000000024	e20090024703000000000024	e20090024703000000000024	00000024	00000024	00000024	🟥	f0000024	f0000024
	5	Adjuster	e20090024703019723402643	e20090024703019723402643	🟥	🟥	🟥	🟥	f0000025	🟥	🟥
	6	Magnets	🟥	🟥	🟥	00000026	00000026	00000026	🟥	🟥	🟥
	7	Power Distribution Boxes	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	8	Controller VSEA designs	🟥	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦
	9	ADIO	🟥	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦
	10	Power Supply	🟥	e20090024703000000000030	🟥	🟦	🟦	🟦	🟦	🟦	🟦