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The Interaction of Electrostatic Discharge and RFID

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1. Introduction

Electrostatic discharge, or ESD, is a common hazard in the electronics industry. Despite the fact that RFID has been in use for nearly forty years, there has been little to no discussion in the scholarly literature on how ESD interacts with RFID tags as a system. The intent of this chapter is to give the reader an overview of ESD and the aspects of RFID with which it interacts. Next, a view of ESD protections incorporated into RFID ICs is presented. A statistical examination of RFID tag susceptibility is summarized, and the chapter ends with a discussion of ESD issues that affect the RFID manufacturing environment. This document should, therefore, provide the reader with a comprehensive view of the interaction of RFID with ESD as well as a starting point for studying related areas.

2. Introduction to ESD

Electrostatic discharge (ESD) is the phenomena where a current passes from an object of high potential to one of low potential. For electronics, ESD is often an event which can be quickly but imperceptibly destructive. A device exposed to ESD can often be permanently damaged or destroyed with no obvious evidence as to the cause.

ESD is a multi-stage process that begins with the accumulation of charge on an object. Charge is often accumulated on a surface through a process called *triboelectric charging*. This process occurs when two materials come in contact. Materials have different affinity for electrons, so some materials may easily release electrons to the other material while others will take them. As the material is separated, the transferred electrons may or may not move back to the original material depending on, among other things, the rate of separation. Materials separated quickly will often leave a higher residual charge than those that are separated relatively slowly. Other factors which may impact charge accumulation are rubbing, surface cleanliness and smoothness as well as contact pressure and surface area.

The amount and rate of charge accumulation depends strongly on the types of materials involved. Charge accumulates when one insulator comes in contact with another. Two conductors will not leave residual charge because of the high electron mobility in both materials. When a charged insulator comes in contact with another insulator or conductor, it can transfer some or all of its charge. Beyond that, one must consider the material's affinity for triboelectric charging. A guide to estimate the likelihood of charge buildup in a fairly qualitative manner is the *triboelectric series*, shown in 1. The triboelectric series lists many common materials and their affinity for accumulating or rejecting electrical charge. The materials in the center of the chart are almost electrically neutral. Materials at one end (i.e., the ’negative’ end) will have a strong affinity for gathering negative charge, while those at the other end (i.e., the ’positive’ end) will easily release electrons, leaving a positive residual charge. When a material with a strong affinity for negative charge comes into contact with a material which prefers positive charge, charge accumulation on the material with a negative charge affinity is very likely. For example, human skin easily gives up electrons and teflon attracts electrons. When these come in contact, electrons will tend to move from human skin to the teflon, leaving the skin positively charged and the teflon negatively charged.

POSITIVE
Air
Human Skin
Asbestos
Glass
Mica
Human Hair
Nylon
Wool
Fur
Lead
Silk
Aluminum
Paper
Cotton
Wood
Steel
Sealing wax
Hard rubber
Mylar
Epoxy-glass
Nickel, copper
Brass, Silver
Gold, platinum
Polystyrene foam
Acrylic
Polyester
Celluloid
Orion
Polyurethane foam
Polyethylene
Polypopylene
Polyvinylchloride (PVC)
Silicon
Teflon
NEGATIVE

Table 1. Triboelectric Series Chart (Ott, 1988)

The second step in an ESD event involves transfer of charge from the insulator surface to a conductor. This can happen via direct conduction or induction. The conduction process occurs when a conducting body comes in direct contact with the charged insulator. The induction process occurs when the charge on the insulating material induces a charge redistribution in a nearby conductor. As an example, a negatively charged insulator will cause the side nearest the insulator to develop a positive charge resulting in a negative charge on the opposite side of the conductor. The net charge of the conducting object, however, is zero as there has not been a direct transfer of electrons. If the object comes in contact with ground, however, a net charge may result on the conductor as some of the charge from one side may be removed during contact.

The third step in the ESD process is discharge. Once charge has accumulated, it will generally be held on the object until it has dissipated or been discharged onto an object of lower potential. Dissipation is usually a preferable process: the static charge is released from the region slowly enough that the current is not harmful to electronics. This is the mechanism employed by several types of ESD mitigation techniques, such as wrist straps and ESD jackets. The material has a resistance that is low enough for current to flow and prevent electrostatic buildup. However, it is sufficiently high to prevent a large current should there be enough buildup. Discharge, however, usually is the result of a process where current flows relatively quickly from one object to another relatively unimpeded. The higher the speed, the larger the current and the more likely that damage to a device will occur.

An example of voltage levels for various ESD-generating events is given in 2. The current from a discharge event is calculated using

$$I = C\frac{dV}{dt}. \tag{1}$$

Discharge events are usually on the order of a nanosecond, and the capacitance will vary based on the type of discharge. The value used in the human body model, which will be discussed later, is 150 pF. Using these values, it is easy to see how even a small potential difference can result in currents on the order of 1A or more.

ESD damages electronics in two ways. First, the current can directly cause damage. Second, the discharge event creates strong localized fields that induce current on an object. High currents can damage electronics directly by heating or dielectric breakdown. The fields can cause damage such as overstress or an interruption in device function. When large enough, fields can also cause induced currents in nearby devices. These induced currents can cause damage in the same manner as an arc discharge current.

One common misconception is that ESD only occurs when there is a path to ground. In reality, a path to ground potential is not necessary for current to flow. If there is any buildup of charge on an object and it comes in contact with a second object at a different potential, charge will flow from one object to another until the potential has been equalized. It is important to keep in mind that RFID tags, despite lacking a path to a ground potential, can still experience a discharge current if they come into contact with an object at a significantly different potential. Electronics should be handled in such a way that they are exposed to minimal amounts of static charge and are not put into contact with conducting surfaces. However, the level of static discharge that can be tolerated is device dependent. Electronics are generally classified into groups based on their tolerance to charge potentials. The class is determined by the model used to test the equipment. The models each have a different discharge current waveform which is supposed to incorporate representative impedance values for different scenarios.

Means of Static Generation	Electrostatic Voltage	
	10 to 20% Relative Humidity	65 to 90% Relative Humidity
Walking across carpet	35,000	1,500
Walking on vinyl floor	12,000	250
Worker moving at bench	6,000	100
Opening a vinyl envelope	7,000	600
Picking up a common polyethylene bag	20,000	1,200
Sitting on chair, padded with polyurethane foam	18,000	1,500

Table 2. Common Electrostatic Voltages (Ott, 1988)

More specifically, the human body model (HBM) and charged device model (CDM) use current waveforms which are representative of discharge currents from a human or to a metallic object by a charged device, respectively. There are other models, and thus corresponding waveforms, which can be used to test a device. Choice of the model is somewhat dependent on the circumstances which may confront the device during manufacture and use. The classification scheme is dependent on the testing model. HBM is generally the least stressful testing environment, so the voltage levels for each class are higher than for other models. Examples of the classifications for HBM and CDM models are shown in 3.

Human Body Model Sensitivity Classification	
Class	Voltage Range (V)
Class 0	< 250
Class 1A	250 to < 500
Class 1B	500 to < 1000
Class 1C	1000 to < 2000
Class 2	2000 to < 4000
Class 3A	4000 to < 8000
Class 3B	≥ 8000
Charged Device Model Classification	
Class	Voltage Range (V)
Class C1	< 125
Class C2	125 to < 250
Class C3	250 to < 500
Class C4	500 to < 1000
Class C5	1000 to < 1500
Class C6	1500 to < 2000
Class C7	≥ 2000

Table 3. HBM and CDM Classification

3. Introduction to RFID

Radio Frequency Identification (RFID) has become an the primary solution to most item tracking. RFID tags are used to track library books, livestock, and shipments of commercial goods. Recently, Walmart laid plans to use item-level tracking; that is, it plans to track individual items using RFID (Bustillo, 2010). Further, RFID is now being embedded in most countries' passports (Evers, 2006) and the US military has required all items from suppliers to be tagged (Ames, 2005). Because use of RFID is becoming pervasive, it is important to examine the reliability of such devices.

We will assume that the reader has a basic knowledge of most RFID systems. More comprehensive reviews can be found in (Dobkin, 2008; Finkenzeller, 2003; Glover & Bhatt, 2006). In this section, we intend to give an overview of how RFID systems work from an electromagnetics viewpoint. This overview is meant to be sufficient for the reader to understand the issue of ESD interaction with RFID and is by no means comprehensive. There are two components to most RFID systems: the reader and the tag (sometimes referred to as a transponder). The reader can be broken down further into a data storage device, a reader module, and an antenna. The tag is far more simple than the reader; we will regard it as an antenna and an integrated circuit (IC) or chip.

The reader antenna emits a radio-frequency (RF) signal which induces a current on the tag antenna. In a passive tag, i.e., one without batteries, the current must be large enough to power both circuitry and return communications. The IC will typically modulate its impedance, creating a change in the current on the antenna which generates a return signal. This return signal will couple with the reader antenna via magnetic induction or electrical field backscatter. Systems which operate in the LF (128 kHz) and HF (13.56 MHz) frequency ranges are more likely to use magnetic induction, while those in the UHF (860 - 960 MHz) and microwave (2.4 and 5.8 GHz) frequencies typically operate using backscatter (Finkenzeller, 2003; Glover & Bhatt, 2006).

The ESD research on RFID performed by the authors focused on passive tags, i.e., tags that have no battery to power either communications or circuitry. Thus, the presence of batteries may affect tag susceptibility but because there are no other scholarly studies of which the authors are aware, the extent is yet unknown. Additionally, this research has focused on UHF tags where backscatter is the primary means of information transfer.

4. Susceptibility of RFID integrated circuits

RFID ICs are designed to be low in cost and consequently must be manufactured in high volumes in order to be cost-effective (Dobkin, 2008). As mentioned in the previous section, a passive UHF tag is designed to be powered solely by the RF signal received from the RFID reader. In order to communicate with an RFID reader, the RFID IC must decode any commands sent by the reader and transmit responses back to the reader when required. Therefore, the RFID IC must contain at least three main components: i) a power supply circuit that takes incoming RF energy and converts it to a DC voltage which is suitable for powering the IC, ii) a logic section that interprets any received commands and generates appropriate responses, and iii) a method of transmitting information back to the RFID reader. Since most RFID ICs only have external pads or connections that are designed to mate with the antenna, only the power supply and the transmitting section of the RFID IC is exposed to the outside world and potential ESD damage.

Explicit details on the inner workings of commercial RFID ICs are not provided by manufacturers, though some information may be found on specific RFID ICs that have been reverse-engineered, c.f. (Torrance, 2009). However, there has been a fairly substantial body of work published in the literature on RFID IC designs, some of which will be highlighted below. Details provided in publications such as these allow us to make reasonable conclusions about the internal workings of commercial RFID ICs.
Since the RFID IC is powered by the RF signal transmitted by the reader, any RFID IC must have a way to convert the transmitted RFID signal to a DC voltage level high enough to power the digital state machine within the rest of the IC. This implies that two functions must be performed: *rectification* of the incoming signal, and a *potential step-up* to an acceptable level. Both of these functions are commonly implemented using a charge pump circuit. A charge pump consists of a bank of capacitors connected by diodes arranged in a fashion designed to facilitate flow of charge in one direction only. The simplest kind of charge pump, a voltage doubler, is shown in 1. The function of the circuit is to 'pump' charge from capacitor C1 on the left to capacitor C2 on the right, where it can be used to power any electronics connected across capacitor C2.

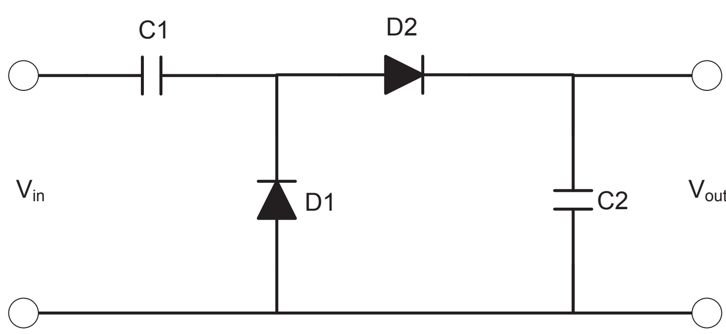


Fig. 1. Example Charge Pump

The operation of this circuit is fairly straighforward. When interrogating or waiting for a response from an RFID tag, the RFID reader will transmit an RF signal. When this signal is negative with respect to the input terminals, diode D1 will be forward biased, and capacitor C1 will begin to charge. If we represent the maximum peak voltage of the input as V_{pk} and the turn-on voltage of the diodes as V_{on}, when $V_{in} = -V_{pk}$, the voltage across capacitor C1 will be $-V_{pk} + V_{on}$, where we have assumed the positive terminal of the capacitor to be on the left side of the capacitor. As the input signal goes from negative to positive, diode D1 will turn off. Once the input voltage is positive enough, diode D2 will turn on, and the charge stored in capacitor C1 is transferred to C2. When $V_{in} = V_{pk}$, the voltage at the output will be

$$\begin{aligned} V_{out} &= V_{pk} - V_{C1} - V_{D2} \\ &= V_{pk} + V_{pk} - V_{on} - V_{on} \\ &= 2\left(V_{pk} - V_{on}\right) \end{aligned} \tag{2}$$

The input voltage available at V_{out} is roughly double that of V_{in}. Multiple diode-capacitor stages may be cascaded to produce higher input voltages, though there is a practical limit to the number of stages that can be added. This is due to the increasing voltage required to forward bias all the diodes in the circuit. The designs presented in (Barnett et al., 2006; Bergeret et al., 2006; Bo et al., 2009; Curty et al., 2005; Facen & Boni, 2006; Karthaus & Fischer, 2003) provide details on specific implementations of this type of circuit. It is worth noting that the designs in (Barnett et al., 2006; Facen & Boni, 2006) contain additional rectification circuitry in front of the charge pump circuitry.

As mentioned in the previous section, an RFID tag communicates with an RFID reader by modulating the RF signal transmitted by the RFID reader. In order to modulate the signal from the RFID reader, the RFID IC must have some method to change the input impedance presented to the antenna. Only two states are required in order to transmit data back to the RFID reader. One state is typically a matched state where the RFID IC is able to absorb the maximum amount of energy from the RF signal (Nikitin et al., 2005). There are several choices available for the second impedance state. In general, the second impedance state may be resistive, reactive, or both. As shown in (Dobkin, 2008), the choice of impedance has implications for the amount of energy scattered from the RFID tag antenna, the amount of power available to the RFID IC, and the modulation scheme (amplitude-shift-keying or phase-shift-keying). In the simple case where the input of the RFID IC is set to either an open or a short for one impedance state, no power can be absorbed by the RFID IC. Therefore, the RFID IC must be able to store enough energy during the matched impedance state to operate through the duration of the mismatched state. This is the approach taken in (Curty et al., 2005), where a simple two-transistor MOS switch is used to present either a matched impedance or a short-circuit to the antenna. This results in an amplitude-shift-key modulation of the RF signal transmitted by the RFID reader. In contrast, the design presented in (Karthaus & Fischer, 2003) implements a phase-shift-key modulation scheme by switching the input capacitance of the RFID IC using a MOS varactor. Using a reactive match allows this design to absorb some RF energy from the transmitted signal in both impedance states.

Both the power supply and modulation circuitry contain ESD-sensitive PN junction devices, and therefore must be protected from damage by ESD events. ESD protection of RFID ICs includes additional challenges beyond those encountered in traditional ICs. Standard ESD protection techniques, such as those given in texts including (Amerasekera & Duvvury, 2002), can result in the addition of relatively high parasitic capacitances. As noted in (Glidden et al., 2004), these high capacitances can have a negative impact on the recifier conversion efficiency. This is of critical importance when the only power source for the RFID IC is the RF energy that can be received by the RFID tag antenna.

Also, the input impedance of the RFID IC will have an impact on the design of the tag antenna. A highly capacitive RFID IC will drive a requirement for the tag antenna to have an equally high inductance. This inductance is required to create an equal but opposite reactance in the operating frequency band compared to the reactance generated by the RFID IC input capacitance. Typical input impedances for commerical RFID ICs are on the order of 1500 ohms in parallel with 0.8 picofarads (AlienTech, 2008; Impinj, 2010), which results in an input impedance of $30.9 - 213j$ ohms at a frequency of 915 MHz.

The input capacitance of the RFID IC has implications on the overall Q of the circuit and the final operating bandwidth of the RFID tag, as noted in (Bo et al., 2009). Because of these issues, there has been at least one proposed RFID IC design that dispenses with ESD protection altogether (Curty et al., 2005). However, this practice not standard, and most RFID ICs will have ESD protection circuitry similar to that shown in (Facen & Boni, 2006).

5. Susceptibility of RFID tags

In theory, tag susceptibility to ESD events would be similar to that of individual IC chips. However, because tags are not simply composed of ICs, there are other factors which will affect susceptibility. There is little publicly available data on the interplay between these factors and ESD events. In 2004, an article in a paper industry publication claimed damage during use destroyed 1-30% of tags with typical rates being 5-6%. (Shaw, 2004) This data was provided by Appleton, a company which had developed dissipative coatings for RFID. As this data was fairly limited, giving no information on the types of tags tested and what factors altered the failure rate, the authors of this chapter tested and analyzed several commercially available tags and published the result in (Bauer-Reich et al., 2007). The results of that testing will also be summarized here. A further study performed accelerated stress testing on RFID tags (Sood et al., 2008). In that study, ESD was mentioned as a potential stress, but its effects on RFID tags were not explicitly examined.

There are several types of tags which are commercially available. It is reasonable to assume that some tags will be less susceptible than others, such as those encapsulated in plastics. However, many industries and government entities which ship or warehouse products, from clothing to pharmaceuticals to military supplies, are using variations on the passive, paper-label tags. These tags are used because they can have printing on the front, making it easier to visually identify the contents of crates and boxes. These tags are also the most likely to be physically touched by people. Because the IEC standard governing ESD testing (IEC61000-4-2, 2005) utilizes the human body model in its testing apparatus, this was the most appropriate choice of test.

Several factors were examined to see how they affected tag susceptibility: environment, potential difference, proximity to IC, IC type, antenna type, and covering material. Six different types of tags were chosen for testing. The characteristics of the tags are summarized in 4.

Two testing environments were utilized. The first environment was similar to IEC 61000-4-2 for ungrounded devices (IEC61000-4-2, 2005), while the other used a wooden table-top to more closely match similar to a warehouse environment. The discharge was created by a Schaffner NSG 432 Manual Discharge Device using the positive charge generator with the rounded-tip finger. Two hundred sixteen tags were tested in the presence of a ground plane. One hundred sixty-two tags were tested without a ground plane.

To measure the effects of the discharge, the change in minimum power required to activate the tag was measured using the procedure described in Bauer-Reich et al. (2007). The minimum power was measured before and after application of the discharge The discharge was applied when the tag was not operating. The normalized increase in minimum activation power was then calculated from the initial activation power $P_{initial}$ and the final activation power P_{final} using the following equation:

$$P_{normalized} = \frac{P_{initial} - P_{final}}{P_{Initial}} \tag{3}$$

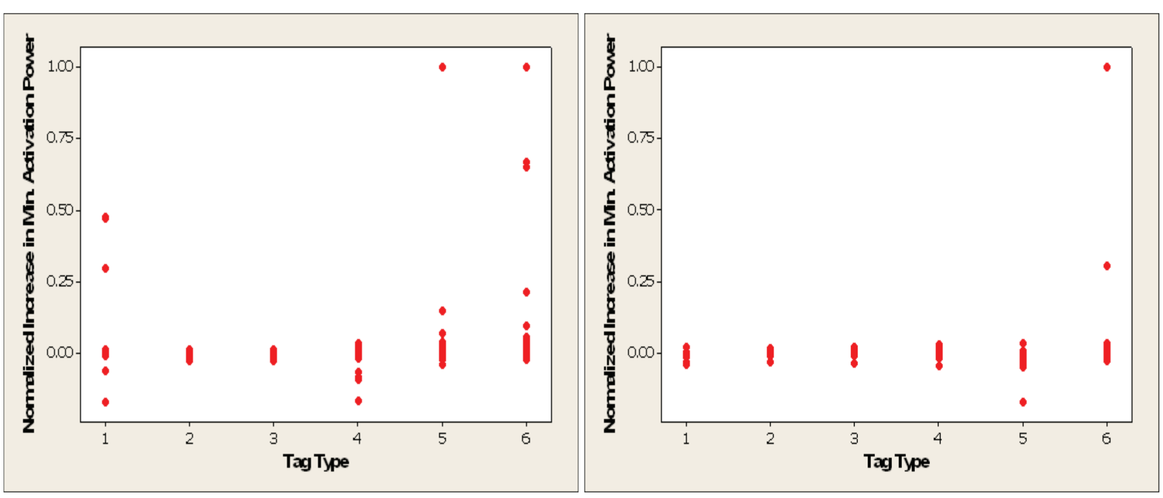
This formula implies that a tag that was unaffected and had the same activation power after the discharge would have a normalized increase in minimum activation power equal to zero. In the case where a tag completely failed and was unable to be read after discharge, $P_{normalized}$ would be equal to one.

It should be noted that in several of the tests, the normalized power of the tag is negative. It was hypothesized that this resulted from residual charge residing in the charge pump apparatus. Although no verification was performed, many of the tags were checked singificantly later and found to be functioning much closer to their original value. It appears that residual charge may reduce the amount of energy required to power the tag, thus making it easier for the tag to operate with less input from the reader antenna.

	Tag Characteristics		
Tag Type	Antenna	Label Covering Resistance (GΩ/mm)	IC
1	Patch-like	8	Gen 2
2	Dipole-like	17	Gen 2
3	Dipole-like	17	Gen 2
4	Dipole-like	17	Gen 2
5	Dipole-like	7	Gen 1
6	Patch-like	7	Gen 1

Table 4. Summary of Tag Characteristics (©2007 IEEE (Bauer-Reich et al., 2007))

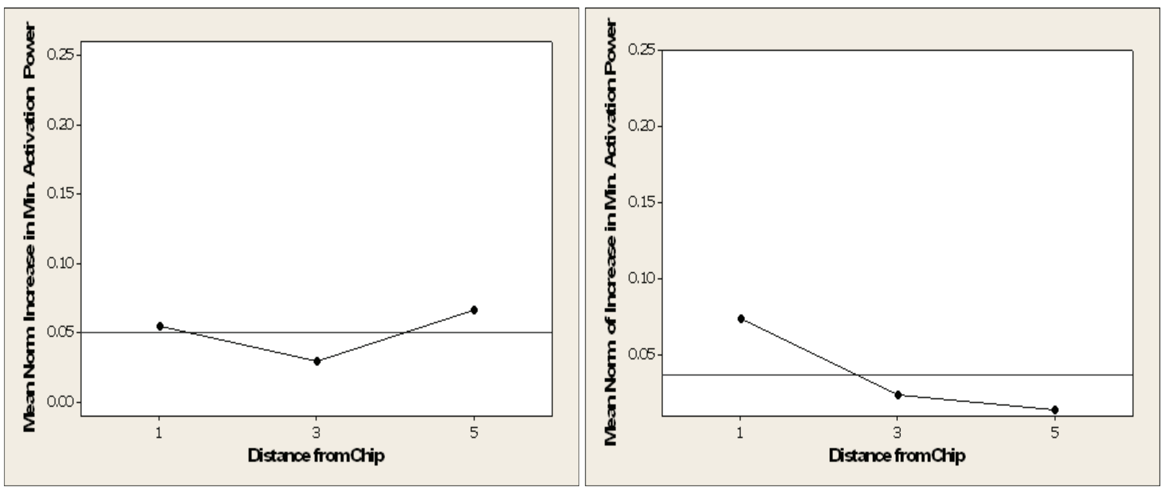
Of primary concern was how the presence of a ground plane, such as the one designated in the IEC standard, would change susceptibility. It has been suggested by (Greason, 1989) that the presence of a ground plane can increase the susceptibility of some devices. The overall results as shown in 2 indicate that a ground plane increases damage to tags. A larger percentage of tags were damaged when the ground plane was present than when not. However, the ground plane seemed to alter results when testing other factors. Therefore, the remainder of the results will be presented in the context of whether or not a ground plane was present.



(a) Testing with a ground plane. (b) Testing without a ground plane.

Fig. 2. The change in minimum activation power based on tag type. Two hundred sixteen tags were tested in the presence of a ground plane. One hundred sixty-two tags were tested without a ground plane. (©2007 IEEE (Bauer-Reich et al., 2007))

The next issue examined was the proximity of the discharge to the IC. The relationship was tested by placing discharges at distances of 1 cm, 3 cm, and 5 cm from the IC (3). When a ground plane was not present, there was a clear inverse relationship between the distance to the discharge and damage rates. The highest damage rates therefore corresponded to the closest distance. The lower damage rate at farther distances is likely due to additional inductance in the path to the IC with increasing distance. When the ground plane was present, the relationship was not as obvious. The farthest discharge point had the highest rate of failure, with the closest being slightly less. The intermediate point resulted in the lowest rate of damage.



(a) Testing with a ground plane. (b) Testing without a ground plane.

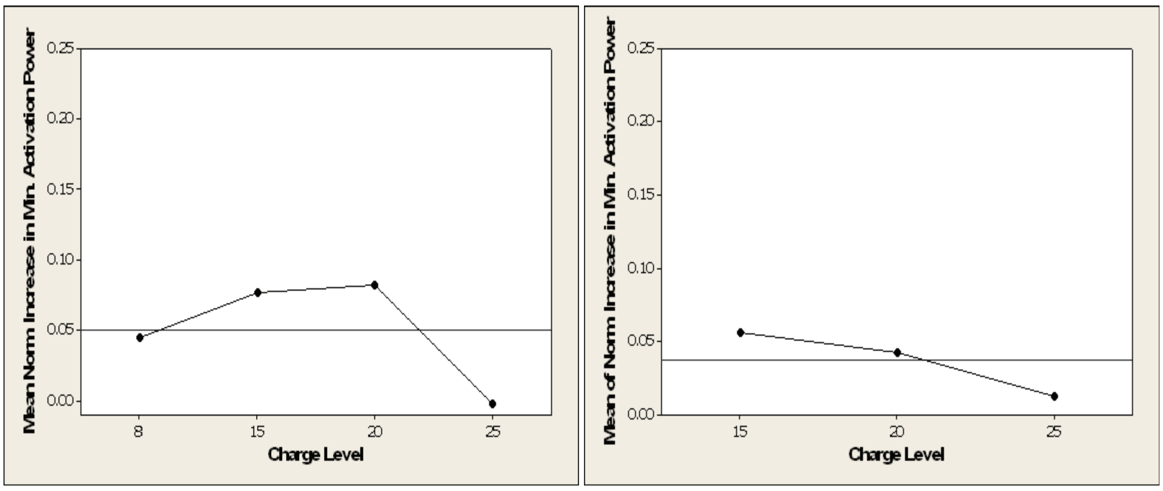
Fig. 3. The effect of dischange distance from the RFID tag IC on minimum activation power. (©2007 IEEE (Bauer-Reich et al., 2007))

It was postulated that the potential level would have a direct relationship with tag damage. The potential levels tested were 8 kV, 15 kV, 20 kV, and 25 kV (4). When the ground plane was present, it appeared that the larger discharges caused greater damage until one reached the 25 kV level. At 25 kV, the damage caused appeared to be less than the other three levels. Possible explanations are that there was sufficient arcing that the tag was bypassed (an event which was observed), there may have been multiple smaller discharges, or that the current waveform changed with the larger potential value. When the ground plane was removed, tag damage had an inverse relationship with charge level, decreasing with higher potentials.

When producing RFID tags, there are several factors affecting susceptibility which are under the direct control of the manufacturer. There were three such issues examined in the study: antenna type, IC, and tag covering or label material. The resistance of the label material seemed to play an important role: materials with higher resistivities covered tags that had lower damage levels. Proper selection of label material, therefore, seems to be an important way to decrease the likelihood of damage.

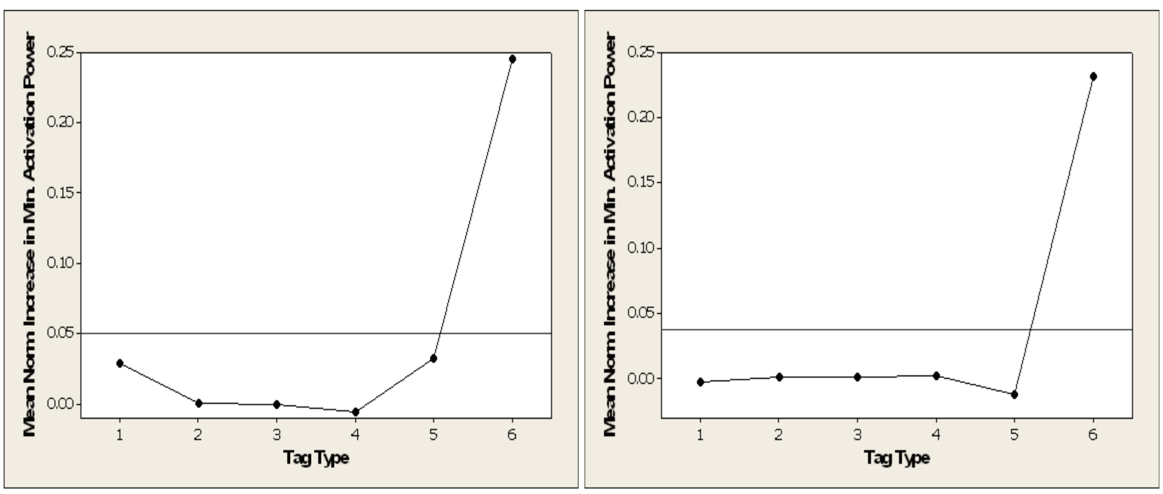
A second factor was the tag antenna. The antennas were grouped into two types: a dipole and a ”patch-like” antenna. The patch-like antenna would be more accurately described as a fat dipole. The dipole antennas fared better in testing, indicating that a fat dipole may not be an ideal choice 5. However, testing did not illuminate what factors caused higher susceptibility for fat dipoles. It was also noted that, because an electromagnetic analysis of each antenna was not performed, it is likely that antenna type may have also played a role in some of the unexpected results for other factors.

Finally, the IC was examined. Four of the six tags utilized ICs that conformed to the EPCglobal Class 1 Generation 2 standard (EPCglobalGen2, 2008), while the remaining two tags utilized ICs that conformed to the EPCglobal Class 1 Generation 1 standard (EPCglobalGen1, 2002).



(a) Testing with a ground plane. (b) Testing without a ground plane.

Fig. 4. The mean change in the minimum activiation power as a function of the magnitude of the discharge. (©2007 IEEE (Bauer-Reich et al., 2007))



(a) Testing with a ground plane. (b) Testing without a ground plane.

Fig. 5. The mean change in the minimum activiation power as a function of the tag type. (©2007 IEEE (Bauer-Reich et al., 2007))

In brief, the EPCglobal Class 1 Gen 1 standard was one of the first UHF RFID standards to see a significant deployment in terms of numbers of tags. The EPCglobal Class 1 Gen 2 standard (also incorporated as the ISO standard ISO 18000-6C) was developed in order to address a number of shortcomings in previous first generation protocols, including the EPCglobal Class 1 Generation 1 protocol. A more readable description of both protocols than that found in the applicable standards documents is given in (Dobkin, 2008).

It was found that the tags conforming to the EPCglobal Class 1 Gen 2 standard had a lower failure rate (6). In order to examine the issue, tag inlays, i.e., tags without the label covering, were tested. The inlays had the same antenna but some had EPCglobal Class 1 Generation 1 ICs while the rest had EPCglobal Class 1 Generation 2 ICs. The result is that there was significantly more variability in the EPCglobal Class 1 Generation 1 ICs after discharge. It appears that the EPCglobal Class 1 Generation 2 tags may have incorporated better ESD protections on chip.

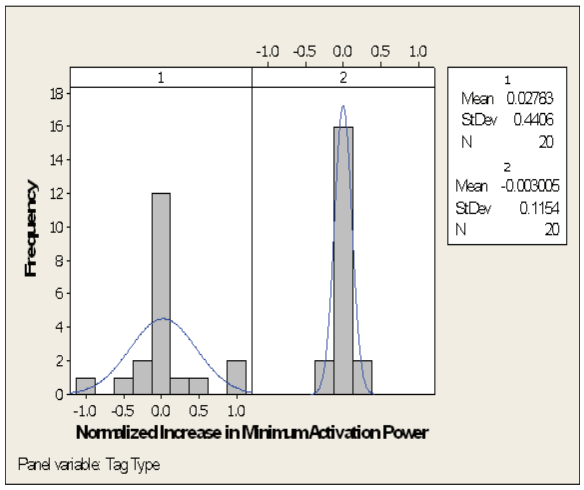


Fig. 6. The distribution of the change in normalized minimum activation power for Generation 1 ICs (left) compared with Generation 2 ICs (right). (©2007 IEEE (Bauer-Reich et al., 2007))

Overall results indicate that RFID tags could have failure rates as high as 4%. The failure rates, however, are dependent on several factors such as the environment, proximity of discharge to the IC, and type of IC utilized. Significantly, this is the failure level when the tag is not in the presence of an ambient field, such as that created by a reader antenna. It seems reasonable to expect that this level would be higher if an ESD event were to occur when a tag is actively communicating.

The results of this study were necessarily narrow; they did not address any type of tag beyond adhesive-paper label tags that operate at UHF frequencies. They also were limited to two ICs. Since this paper was published, there have been many new types of tags and ICs introduced into the marketplace. There are also tags that are manufactured for considerably different uses. The authors are unaware of any additional studies dealing with the interaction between RFID and ESD, indicating that there are many areas where this behavior is still unquantified.

6. Minimizing ESD in the RFID manufacturing and testing environment

In any electronics manufacturing environment, there are certain precautions which should be taken to prevent damage to the product. Fairly universal solutions should include static dissipative counter-tops and floors, ESD-safe office equipment, and use of static dissipative clothing for personnel. Indeed, precautions such as these are called out by an RFID IC manufacturer in Impinj (2005).

In RFID processing, however, there are additional issues which need to be taken into consideration (Blitshteyn, 2005). Processing tags into their final form, such as label conversion, is one area where ESD creates signficant product loss. RFID tags that are used in label form must be tested, converted to labels, and retested. All of these processes provide multiple opportunities for tags to fall victim to ESD.

One consideration is that roll-to-roll processes are used for manufacture and testing of RFID. These processes involve unrolling and re-rolling the product through several rollers. Both the machinery and local environment of these processes should be evaluated regularly for factors which may increase susceptibility, especially to inlays. The machinery for the process should, of course, include a static dissipative coating on all surfaces that come into contact with tags. However, this static-dissipative coating should not be assumed to eliminate all possibilities of ESD. Coatings will prevent discharge from occurring if the static build-up on the device is not too large.

RFID tag antennas tend to be printed on materials such as polymers which are very prone to triboelectric charging. When this material is placed on a roll-to-roll device, large amounts of static can be accumulated and transferred from rollers and testing devices despite the presence of static dissipative surfaces. Sometimes this static can build up faster than it can be removed safely from the equipment.

The reader should note that a large number of synthetic materials have a strong affinity for negative charge, as shown on Table 1. There are also specialized triboelectric series to deal with such materials. A series of guidelines was published in (Diaz & Felix-Navarro, 2004), suggesting that nitrogen containing polymers generated a strong positive charge, halogenated polymers resulted in strong positive charge, and hydrocarbon-based polymers were nearly neutral. Although considerations such as cost play into selection of materials for manufacturing, the probability of triboelectric charging should be one consideration when choosing materials which will be used in manufacturing electronics.

ESD events in the manufacturing environment are likely to affect neighboring tags through field induction. Because tags are often placed closely together, a large ESD event may be sufficient to damage not only the tag directly affected but nearby tags, as well. Therefore preventing a single ESD event may prevent damage on several tags.

There are several ways to deal with ESD in manufacturing. One of the most effective methods is to reduce the speed of the process. Triboelectric charging increases as the rate of separation increases, so keeping the rate low will reduce charging. Another possibility, although more difficult to implement, is changing the substrate of the RFID tags to one that is not as prone to generating charge, such as a hydrocarbon-based polymer. Increasing humidity near the process is another way to dissipate charge. It is important in any electronics manufacturing environment to make sure that humidity levels are sufficiently high, but a second step is to make sure that the humidity level is constant throughout the area. A process which is placed a long way from a humidifier and perhaps near a window that may contribute to temperature swings will be more likely to have ESD issues than a process in a well-controlled area. The use of ionizers is also popular, but their placement should be carefully determined as improper positioning will cause more problems than it solves. For instance, an ionizer which neutralizes charge at one point in the process may adversely affect the process if the roll threads through an area underneath the ionizer where remnant charge may fall. Finally, keeping other equipment away from the process is often necessary. To monitor processes, display screens and other computer equipment may be placed near or integrated into the process. However, this equipment can often generate an electromagnetic field and, when not properly shielded, can create areas of large static build-up despite all other preventative measures.

One method of monitoring processes is through the use of a field meter, such as (StaticSolutions, n.d.). Field meters can detect an ambient electromagnetic field created by accumulation of static electricity. Areas where ESD events are likely to occur to transfer charge that may later be involved in an ESD event can be identified with a field meter and then neutralized. A field meter is meant to be used as a preventative measure as it cannot detect actual ESD events.

Another way to identify problem areas is an ESD event detector or monitor. These sensors detect discharge events above a user-defined threshhold. Devices can be connected to a computer to record data or hand-held devices. The devices cannot detect the exact location where ESD is occuring but are useful in locating problem areas. These are able to detect events and therefore not useful as a preventative measure. They also cannot determine whether damage has occurred, therefore making it difficult to assess whether a specified level of event is an issue of concern. Finally, these may be useful in determining the relationship between ESD activity and process speed. If one wishes to avoid events above a specified level, ESD monitors may be used to assess the speed at which event levels are unacceptably high.
Through the combined use of equipment designed to prevent and detect ESD and regular monitoring, ESD in the manufacturing and testing environment can be minimized. Each company will have to determine what rate of loss is acceptable and choose their materials and equipment accordingly.

7. Conclusion

Dealing with ESD in the RFID industry is a challenge which can be approached from several perspectives. Care should be taken in the manufacturing environment, but reducing ESD susceptibility of relevant circuitry is also useful. Based on studies performed by the authors, however, it appears that these challenges are still present in the manufacturing and usage environment. Given up to 4% of tags the tags tested failed, the prevalence of RFID technology in the current economy could imply significant losses. Therefore, it is necessary to understand the factors which can cause tag failure and try to find a means to prevent it.

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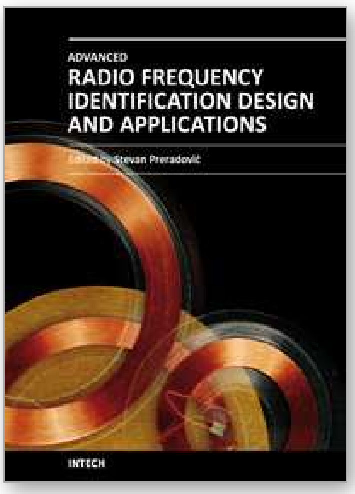

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Radio Frequency Identification (RFID) is a modern wireless data transmission and reception technique for applications including automatic identification, asset tracking and security surveillance. This book focuses on the advances in RFID tag antenna and ASIC design, novel chipless RFID tag design, security protocol enhancements along with some novel applications of RFID.