RFID for IBM Disk Drives

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Acknowledgements

Firstly, I would like to thank my advisor, Dean Arakaki, for his guidance and input throughout the course of this project. Thanks also to Dan Malone, for providing all of the parts needed for this project as well as the inspiration for it. Finally, thanks to the previous student developers of the anechoic chamber and RFID characterization methods. Without their work to build on I could not have completed the project.

I. Introduction

RFID is commonly used to accurately and efficiently track inventory and other assets. This project addresses the problem of using RFID to track IBM hard disk drives in a server rack environment. RFID tag size, type, and placement were optimized with the goal of maximizing performance in this difficult operating environment.

RFID tags placed directly on metal surfaces normally suffer from poor performance due to wave reflection at locations where incident waves encounter a metal surface. The reflected wave exhibits a 180° phase shift; thus, incident and reflected waves cancel.[1] This problem is addressed by placing a dielectric material between the tag and the disk drive.

In addition to the problem of metal surface field cancellation, metal in the surrounding environment can also pose blocking and interference problems. RF characteristics of tags on hard disks within a metal server rack were simulated in the anechoic chamber. Read distance and optimum tag configurations were determined.

II. System Description

RFID characterization in the anechoic chamber is setup as shown in Fig. 1.

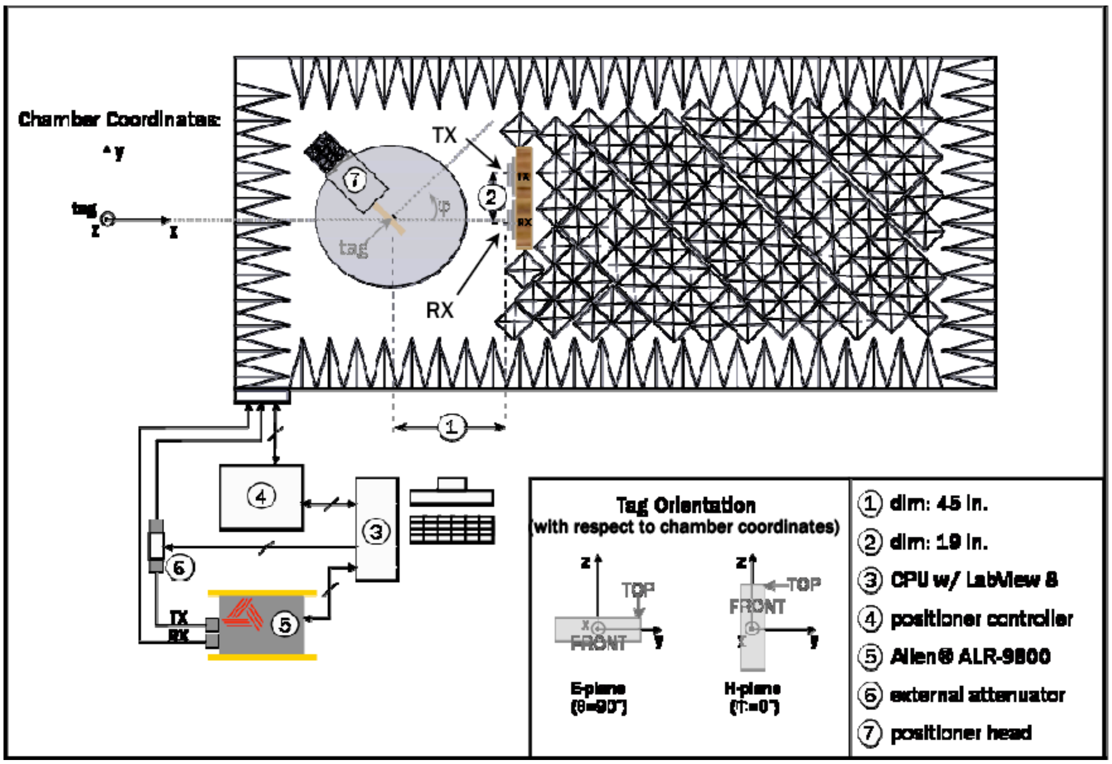


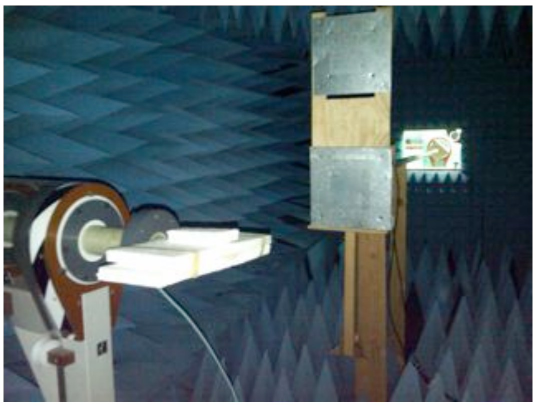
Figure 1: Anechoic Chamber Configuration for RFID Testing[2]

The RFID tags used for this project only operate in co-polarization, meaning that the tag is placed orthogonally to the patch antenna (one oriented vertically and the other horizontally. All possible test configurations are shown in Table 1. The ones in bold were performed for this project.

Table I: RFID Test Configurations[2]

Tag Orientation	Patch Antenna	Polarization	Plane
H	H	Cross-	E
H	**V**	**Co-**	**E**
V	**H**	**Co-**	**H**
V	V	Cross-	H

E-plane



H-plane

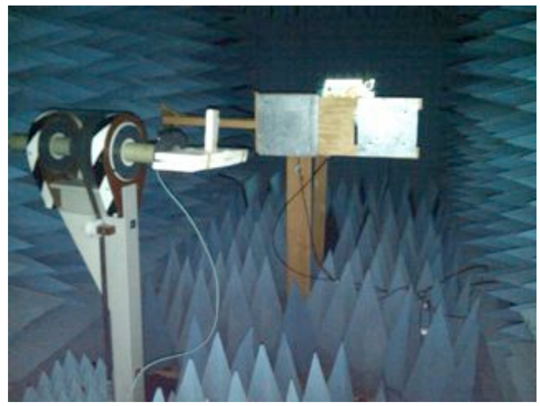


Figure 2: E-plane and H-plane Configurations

The Alien Technology "Squiggle" RFID tags were selected for this project for their dimensions. The tags are a suitable size for placement on the end of a hard drive.

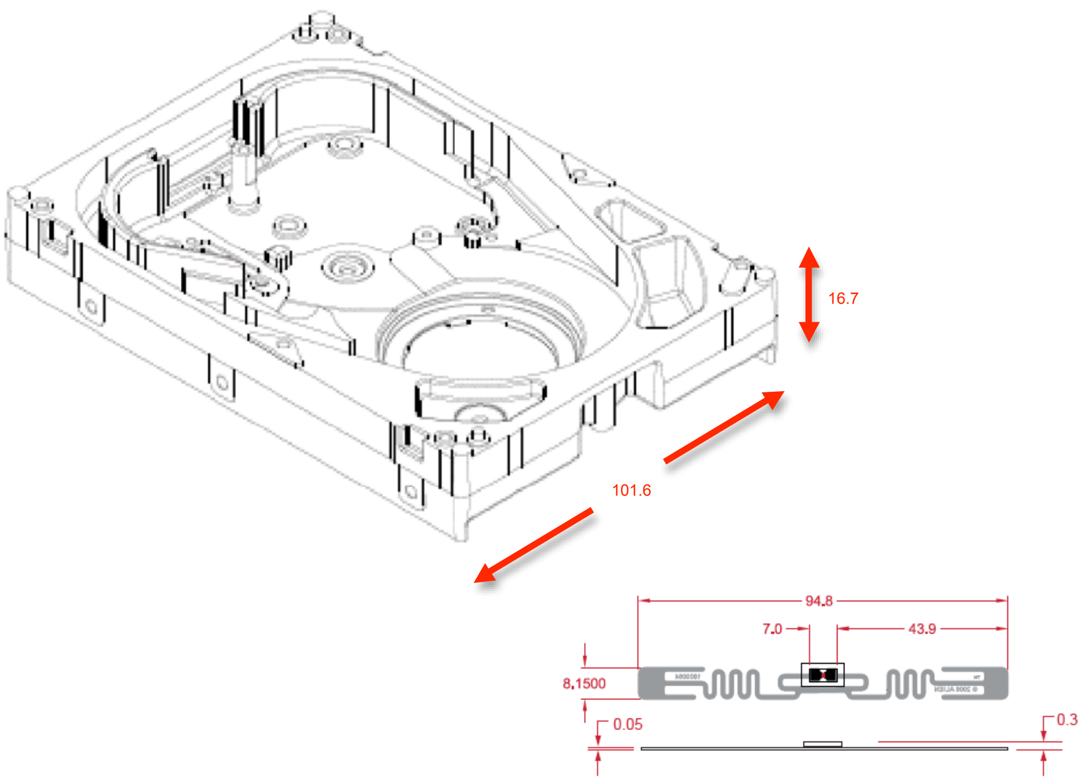


Figure 3: Hard Drive and Alien "Squiggle" Tag with Dimensions (mm)[3]

Tag Underlays

Ideally, a dielectric that provides spacing of $\lambda_d/4$ (λ_d =wavelength in dielectric) would be used. The quarter wavelength ($\lambda/4$) separation shifts the reflected wave an additional 180°, bringing it in phase with the incident wave.[1] Therefore, the presence of the reflected wave increases the amount of power available to the passive RFID chip. This can result in even better performance than could be achieved between an isolated tag and reader.

However, since the tags operate at 915 MHz, the signal has a free-space wavelength of 32.7 cm. In order to keep a low profile (5 mm or less) on the disk drive, a dielectric with very high relative permittivity (dielectric constant) needs to be used. The quarter wavelength in dielectric is calculated by dividing the free-space quarter wavelength by the square root of the dielectric constant. See table 2 for examples.

$$\frac{\lambda_d}{4} = \frac{\lambda}{4\sqrt{\varepsilon_r}} \quad [1]$$

Table II: Quarter Wavelength in Dielectric Examples

Dielectric Constant	λ/4 at 915 MHz (mm)
1	81.69
6.5	32.04
100	6.46
270	4.97

Another method is to use inexpensive foam spacing between the disk drive and tag. Performance limitations using this method will be discussed later in the report.

Disk Drives and Server Rack

The disk drives used are manufactured by Hitachi and adhere to the standard 3.5” form factor, with overall dimensions of 4” x 5.75” x 1.63”. The server rack below (Fig. 4) shows a typical application. The drives are placed in close proximity and surrounded by a metal case. Only one side of the hard drives

is exposed when the rack is opened. This corresponds to the right side of the drive as pictured in Figure 5.

Figure 4: EMC Symmetrix DMX1000 Server Rack

Top

Bottom

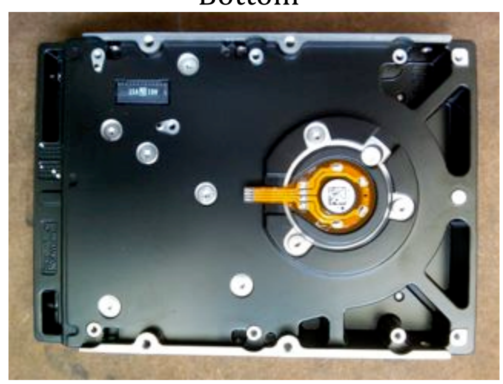


Figure 5: Hitachi V923H6 Disk Drive

To minimize the tag configuration profile, a cavity is formed on the exposed face to accommodate the tag. Using a micrometer, it was determined that the maximum thickness that can be removed to form a cavity is 0.105”. Mounting holes located at 0.115” impede the removal of any more material. Tolerance of 0.010” is left to prevent mounting hardware from interfering with the RFID tag substrate. The structural integrity of the drive housing is not significantly affected. Less than two percent of the overall depth is removed, and the only stress that the housing bears is the weight of the drive itself.

LabView[4]

LabView is a graphical programming tool that enables the creation of “virtual instruments.” A virtual instrument (VI) is a user-defined software measurement tool. It runs on a PC and is used to control several hardware devices and record data. In this project, LabView was used extensively for characterizing RFID tags. A VI was used to rotate RFID tags incrementally on an azimuthal plane and find the transmit attenuation needed to cause failure at each position. Previous anechoic chamber developers in the RFID testing area created the basis of the VI utilized.[2] However, due to problems encountered with the existing VI, major changes were implemented.

The existing VI for RFID measurements, ‘RFID Characterization’, referenced another VI called ‘RFID Single Read’ which handled communication with the reader, control of an external attenuator, and file output. The attenuator

was not being controlled at all, and file output showed a value of zero for each data point when this VI was used. Thus, the reference to this VI was elimated. The functionality was then programmed into the main 'RFID characterization' VI (Fig. 6). It was designed to operate in the following sequence:

1. User specifies start and stop azimuthal angles, incremental angle per data point, number of attempted and threshold reads, and a destination file.
2. After the user clicks on 'RUN TEST', the table inside of the anechoic chamber rotates to the specified start angle. It is controlled via GPIB connected to the positioner controller.
3. The reader is instructed to attempt the user-defined number of tag reads. The VI does this by sending text command strings from the PC to the IP address of the tag reader. They are both connected to the same network.
4. The response from the tag reader, which contains the number of successful reads, is a text string read from the same IP address. This is then converted to a decimal and compared to the user-defined number of threshold reads.
5. If the number of successful reads is below the threshold, the azimuthal angle is incremented, and the present attenuation is recorded. Otherwise, attenuation is increased by 0.5dB.
6. Repeat steps 3 through 5 until the stop angle is reached.

Attenuation is imposed at the transmit antenna port of the RFID reader. It is increased until transmitted power from the patch antenna is insufficient

to power the RFID tag; this is the maximum attenuation. From the maximum attenuation, read distance can be determined as a function of angle.

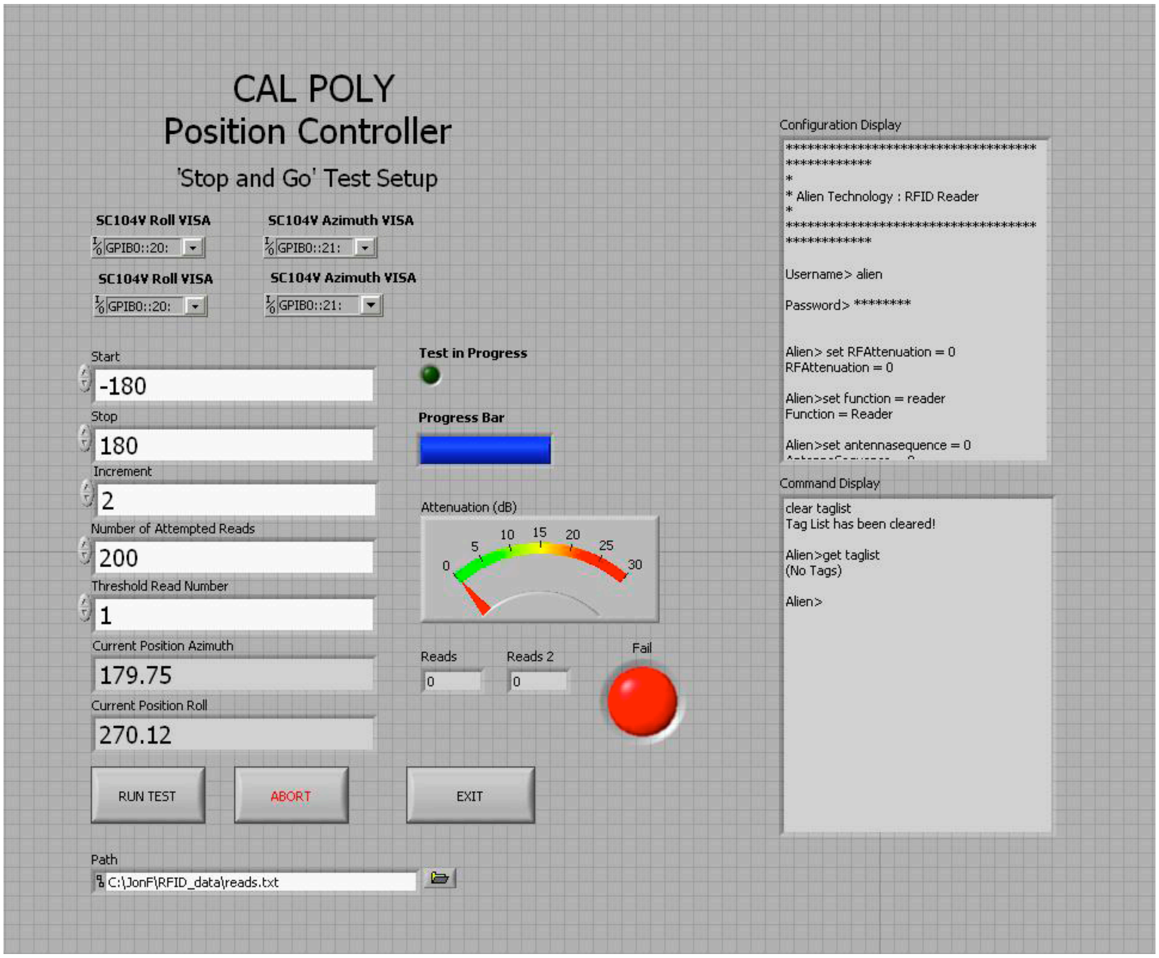


Figure 6: RFID Characterization User Interface

III. Simulated Results

Because of the affiliation with IBM/Hitachi, HFSS[5] could not be used to perform a antenna simulation. PCAAD[6] was used instead, but it can only provide a radiation pattern for the antenna itself without taking environmental conditions into account. Since the Alien tags use a bent dipole antenna design, they have been modeled as a half-wave dipole. The radiation pattern produced by PCAAD is the expected radiation pattern of isolated RFID tags.

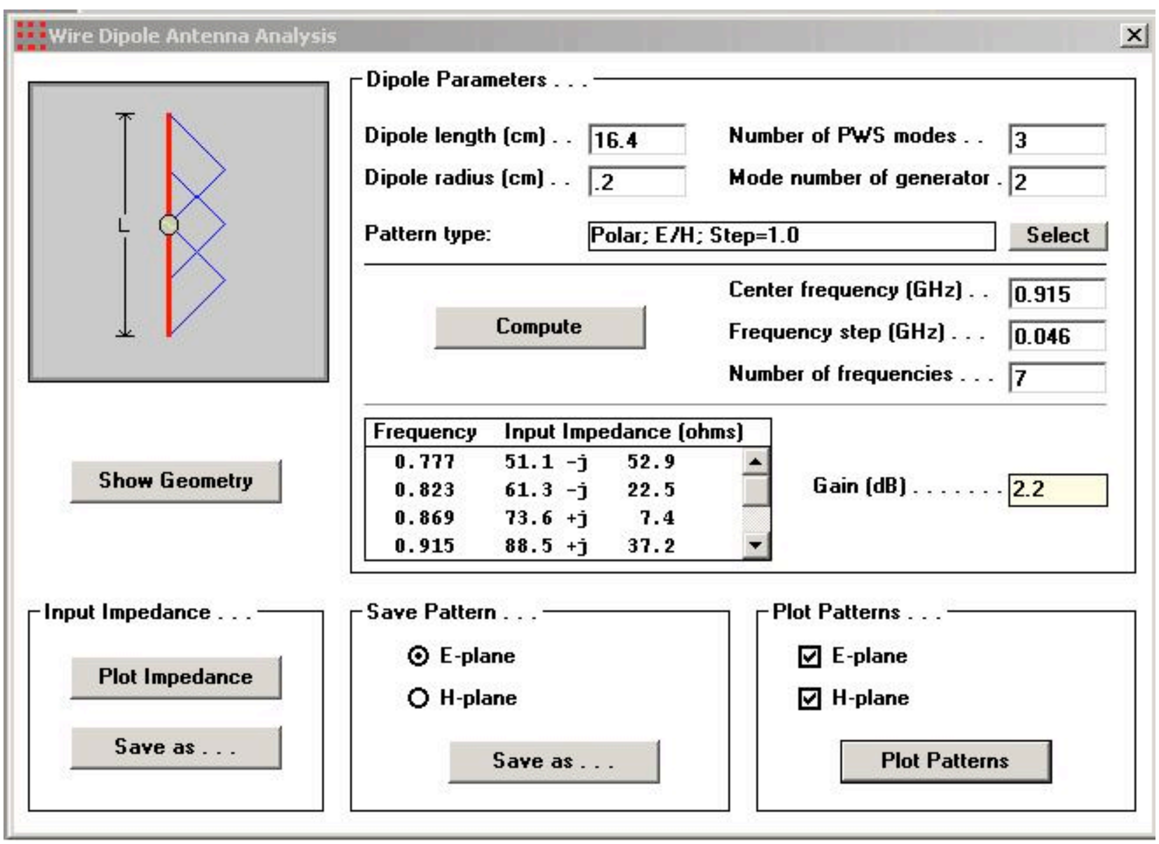


Figure 7: PCAAD Simulation Parameters

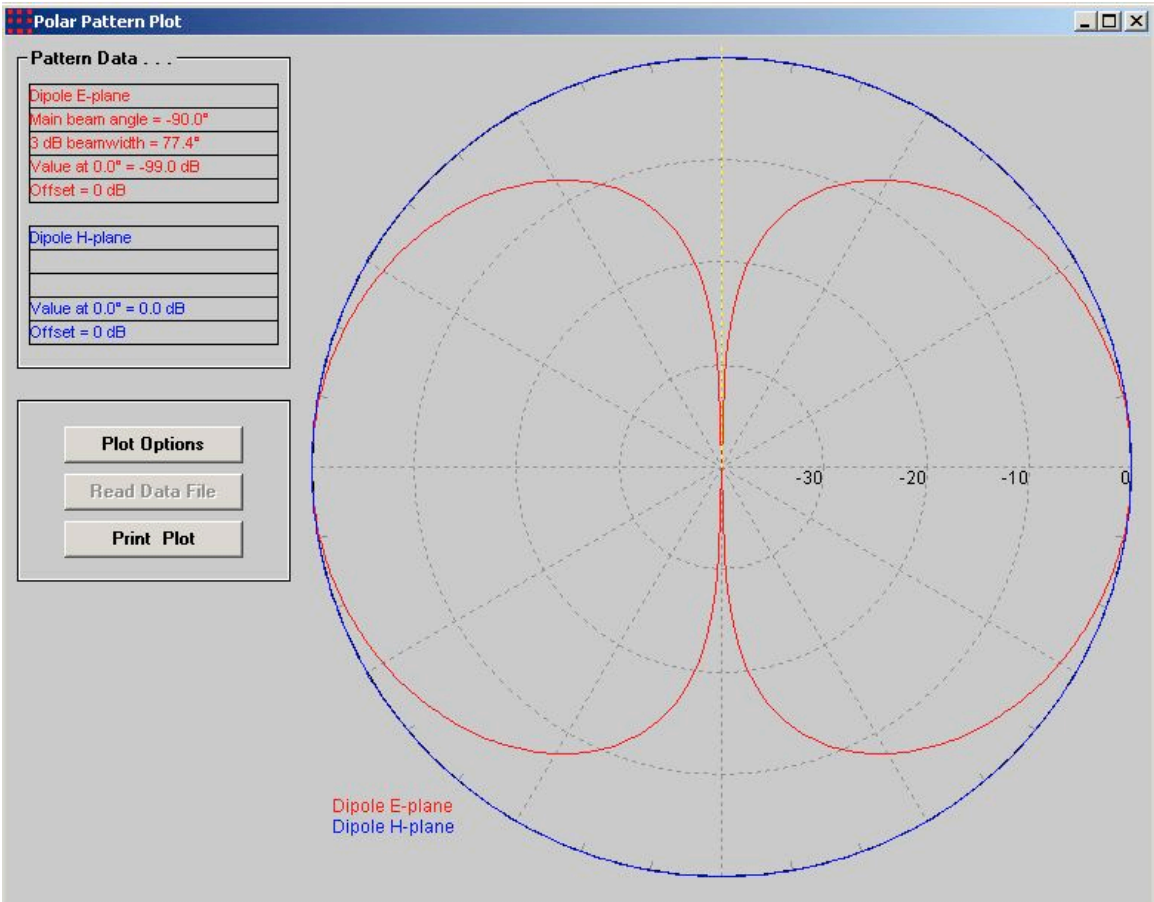


Figure 8: Simulated Dipole Radiation Pattern

IV. Construction and Design Tradeoffs

Environment Box

A "harsh" environment box was created to house the drives under test. A wooden box with dimensions 19" x 13" by 10" is covered with rectangular steel sheet metal sections to simulate an environment that is "harsh" for RFID operation. In addition to creating the harsh environment, the box can support the weight of at least eight drives; it can be used to simulate a server rack.

Figure 9: "Harsh" Environmental Enclosure

Dielectric

The original plan to use a quarter wavelength thick in dielectric did not meet design specifications. Ceramic dielectrics can be obtained that have a dielectric constant of 270, but the material costs exceed the potential benefit, and ceramics are difficult to cut to the correct size. A less expensive ceramic with a constant of 6.5 and thickness of 0.100" was acquired for testing, However, the Alien tag did not function at all when placed on top of this substrate. The company Pacific Ceramics offers a ceramic with relative permittivity of 270 at the quoted price of $84.05 per drive. At this price, implementing RFID is not cost effective. Thus, alternate solutions were sought.

It was determined with experimentation and testing that the tags can operate if just positioned at an adequate distance from the disk drive. Foam from a regular presentation board was chosen as spacing for its low dielectric constant ($\varepsilon_r \approx 1.03$), as it will be nearly transparent to RF. Two layer thicknesses were used: 0.116" and 0.174". The 0.116" option allows a low profile. After a 0.105" cavity is created for the tag, it extends only 0.011", or 0.28mm, past the original dimensions of the drive. The 0.174" option offers about double the performance in terms of maximum read distance and range of azimuthal angles for which it can be read. However, when placed in a 0.105" cavity it extends 0.069", or 1.75mm, farther than the drive alone. Complete test results can be found in Section V, Results.

Figure 10: RFID Tags with Spacers. 0.116” (white) and 0.174” (black)

Disk Modification

A cavity on the end of the disk drive was created for the tag/spacer combination to fit perfectly inside. The depth of this cavity was 0.105” +/- 0.005”. In practice, however, the tags could not be read in this configuration. Instead, the entire face was machined down to the same depth, leaving a drive of length 5.655” +/- 0.005”. Unless otherwise noted, all of the measurements were taken with the tags affixed to this flat, machined surface.

Figure 11: Material Removed Up to Red Line

Existing Solution

As the project was nearing completion, it was discovered that a solution for tracking IT assets for IBM had already been developed. The company Omni ID produces passive RFID tags that are specifically designed for use on metal surfaces. A sample set of these tags was acquired,[3] which were characterized and compared to the Alien tags.

The two tags shown below were tested. The smaller tag (Prox) has a thickness of 0.180" and will work only if placed on a metal surface. When placed inside a cavity of depth 0.100", however, the tag was unreadable. The added thickness is a tradeoff for having a smaller form factor.

The larger tag (Flex) has a thickness of 0.100”. When placed in a cavity of the same thickness, the tag still performed very well. It achieved a maximum read distance of 4m, and was operable at angles of up to 50° deviation from zero in the h-plane, and 70° deviation from zero in the e-plane. Performance results are given in Section V. Due to this capability, the tag is ideally suited for a situation in which a low tag profile is necessary.

Figure 12: Omni ID RFID Tags; Prox (top) and Flex (bottom)

Figure 13: Flex Tag Configuration with Cavity

V. Test Results

Read Distance Calculation

The various tags and disk configurations tested for this project are compared by read distance at -180° to 180° for the isolated tags, and at -90° to 90° for the tags in a simulated sever rack environment (no reads were possible outside of this range due to steel backing of assembly). From the maximum attenuation value recorded in the LabView RFID characterization, the following relation and procedure were used to calculate the maximum read distance at each angle.

$$P_{tag} = \frac{(10^{\left[\frac{P_t[dBm]+G_r+G_t}{10}\right]}) \times \lambda^2}{16\pi^2 \times R^2} \quad [2]$$

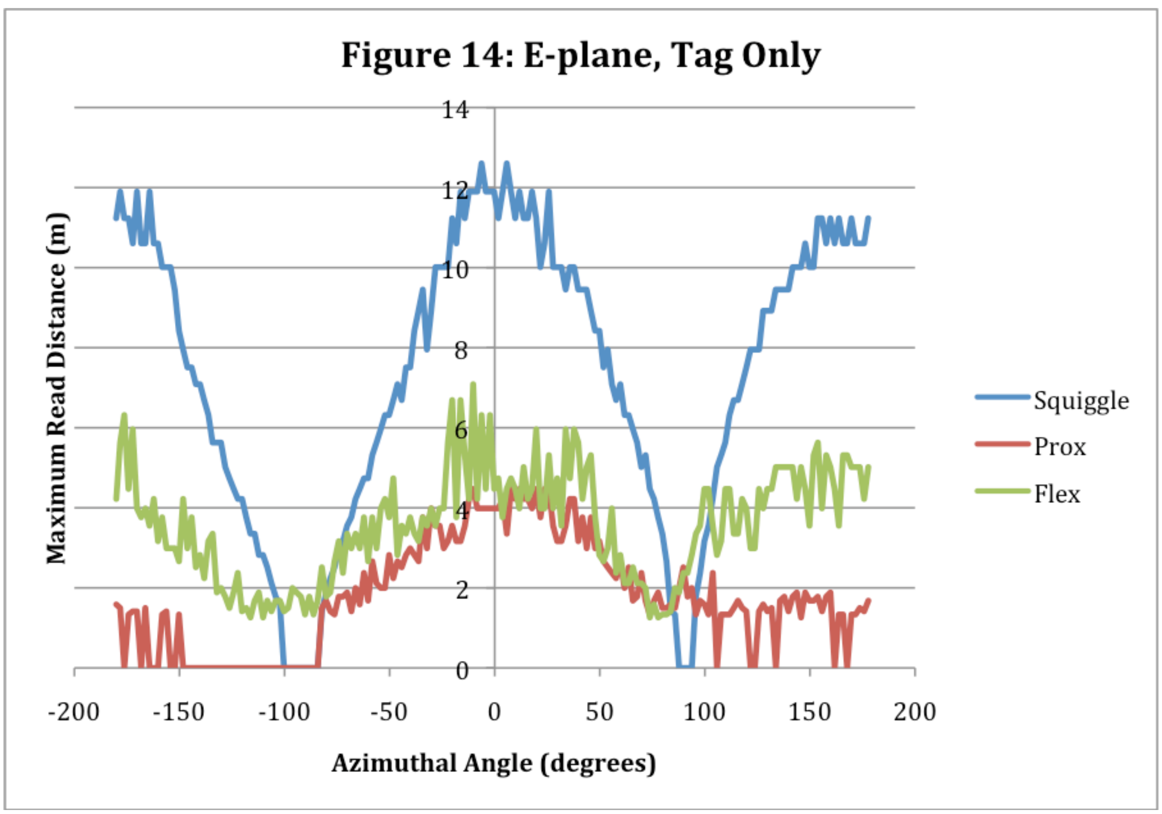
$$G_r + G_t \approx 10dB$$

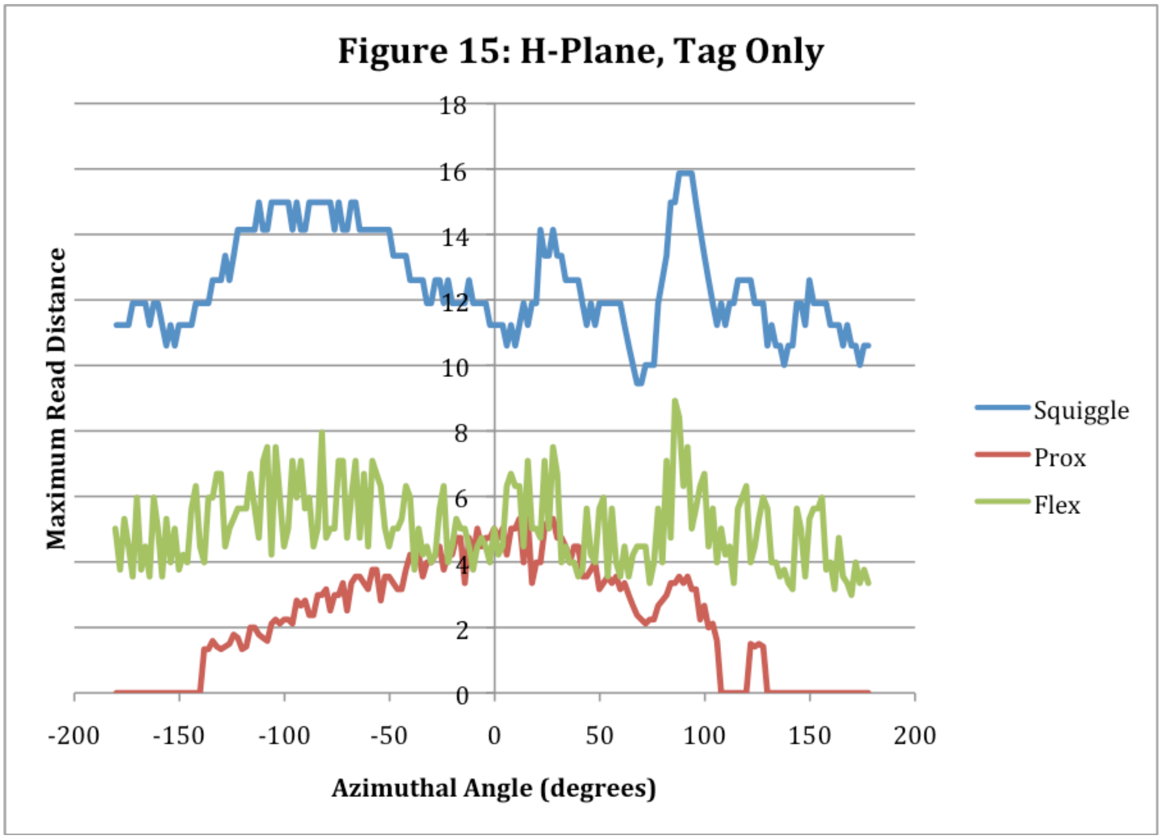
1. P_{tag} is calculated for P_t = (26.5dBm – attenuation[dB]), R = 1.19m (measured distance between tag and patch antenna during test). This is the minimum P_{tag} required for tag operation at a given azimuthal angle.
2. Using the P_{tag} value found in step one, and P_t = 26.5dBm (no attenuation), R was calculated. This is the maximum read distance without attenuation.

Read distance was calculated at each data point for all configurations using Excel. The performance of different configurations is compared using graphical results.

Tag-Only Comparison

Each tag was initially characterized by itself, without the metal enclosure or any disk drives. From this baseline measure of tag performance, it is possible to assess the effects of the disk drive or metal structure surroundings. Figure 14 shows the maximum read distance in the e-plane for each tag: Omni ID Prox, Omni ID Flex, and Alien Squiggle. Fig. 15 shows maximum read distances for the same tags in the h-plane.





From Figs. 14 and 15 above, the Alien Squiggle tag clearly outperforms the Omni ID tags when metal surfaces are not present in the system under test. The Squiggle and Flex tags follow a very similar pattern, which matches expectations from the PCAAD simulation. Since the Prox tag requires placement on a metal surface, its performance peaks at zero degrees (directly facing the patch antenna). It does not perform as well as the other two tags beyond 90 degrees in either direction because the metal mounting plate blocks the path to the patch antenna.

Server Rack Characterization

To simulate a server rack environment, drives were stacked together, without any spacing between them, inside a metal "harsh environment" enclosure.

H-plane E-plane

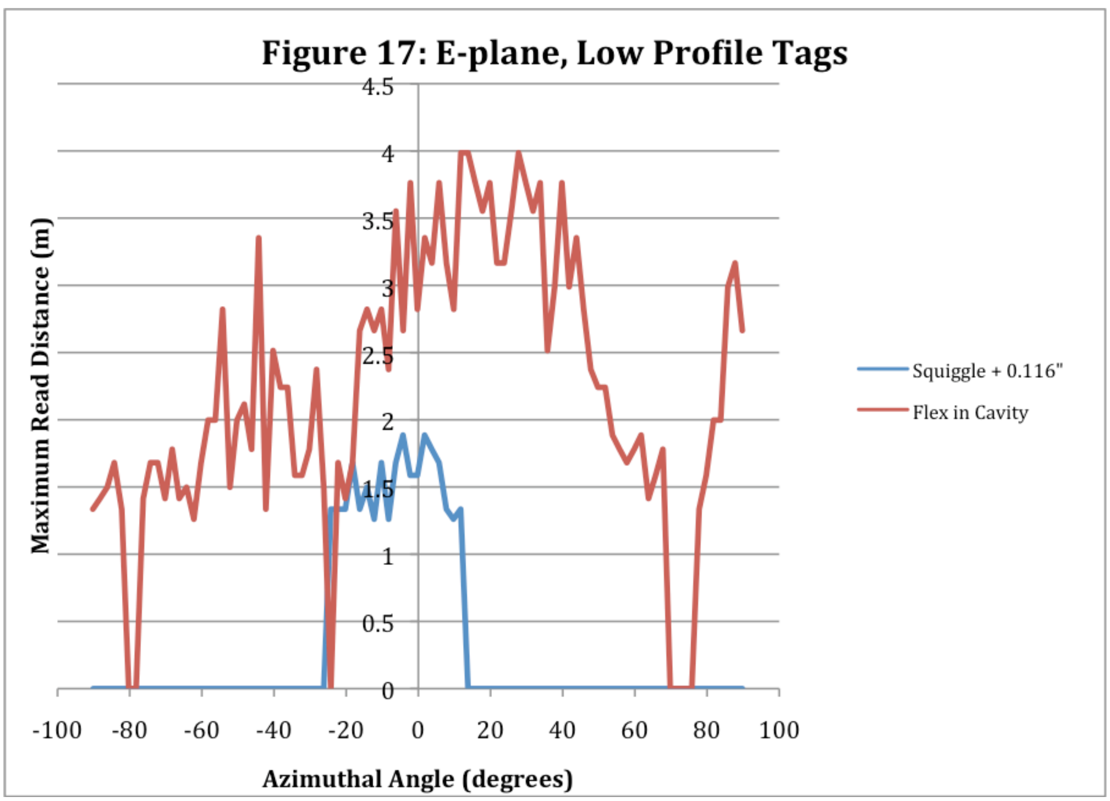
Figure 16: Server Rack Simulation

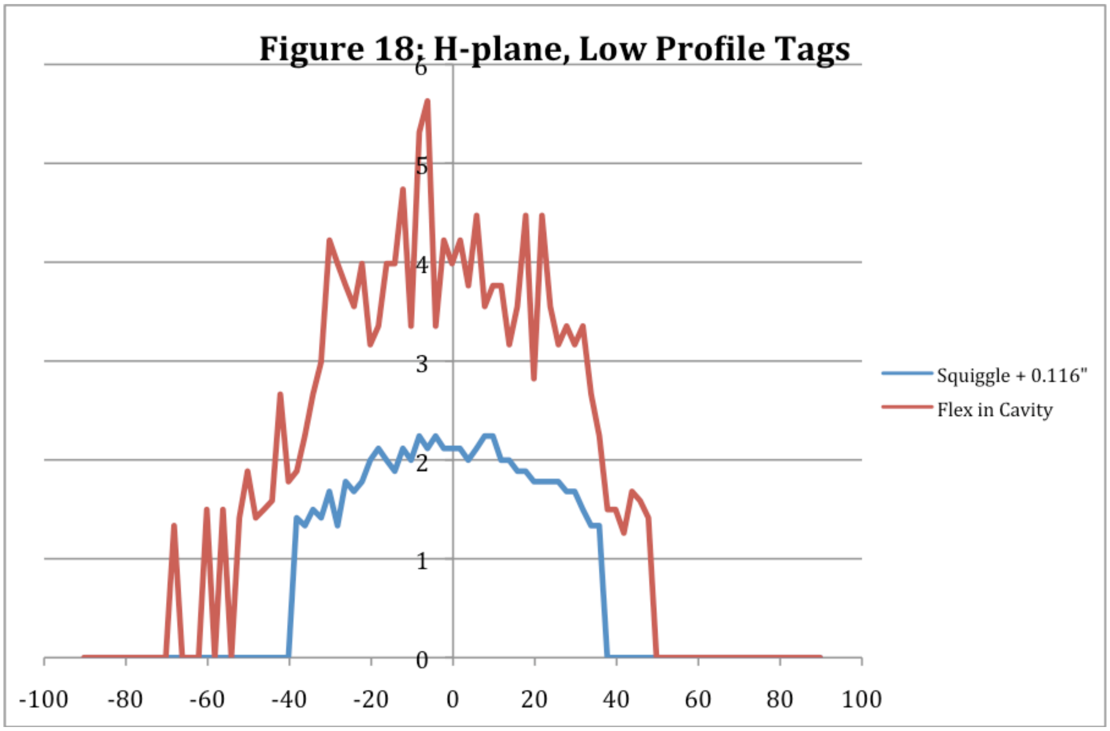
Four different configurations were tested in the server rack environment, divided into two categories: low profile and high performance. The low profile setups include the Alien Squiggle tag with 0.116" spacing and the Omni ID Flex tag placed in a recessed cavity. Each of these configurations adds 0.011" or less extra size to the disk drives. The high performance category is comprised of the Alien Squiggle Tag with 0.174" spacing and the Omni ID Prox tag placed directly on the drive. The footprint of each tag configuration is also taken considered.

Each squiggle configuration has a 100mm x 15mm footprint. The Prox tag covers an area of 35mm x 10mm, and the Flex tag covers 77mm x 15mm.

Low Profile

The Alien Squiggle tag with 0.116" thick foam substrate is compared with the Omni ID Flex tag. With 0.105" removed from the drive, the Squiggle tag extends 0.011" past the original dimensions. The Flex tag is placed inside of a cavity with depth 0.100", making it even with the disk drive face.





Higher Performance

The Alien Squiggle tag with 0.174” thick foam substrate is compared to the Omni ID Prox tag. Each of these configurations extend farther beyond the disk drive than the previous “low profile” configurations, but they have improved read distance and can operate at a greater angle with respect to zero (normal) in both the e-plane and h-plane. With 0.105” removed from the drive the Squiggle tag extends 0.069” beyond the drive. The Prox tag cannot operate inside a cavity, and is placed directly on the drive, adding a thickness of 0.180”. Although the Prox tag extends farther than the Squiggle configuration, it has the benefit of a smaller footprint.

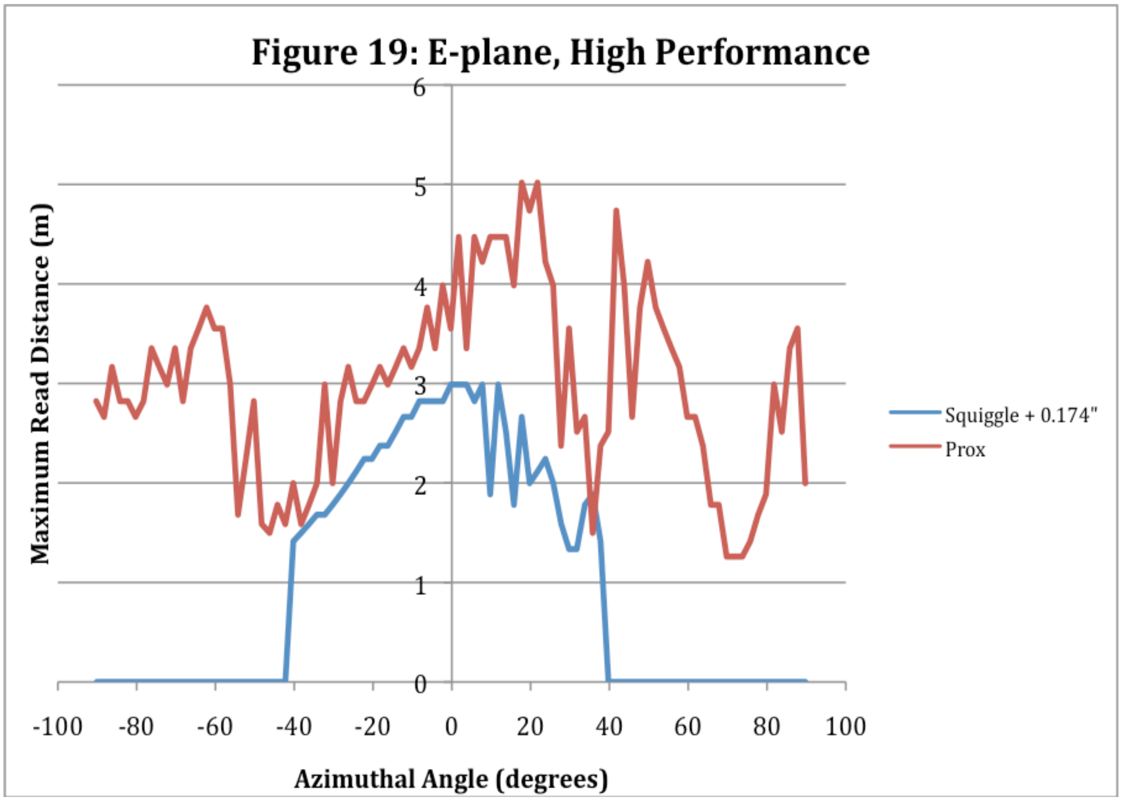


Figure 19: E-plane, High Performance
Maximum Read Distance (m)
Azimuthal Angle (degrees)
Squiggle + 0.174"
Prox
0
1
2
3
4
5
6
-100
-80
-60
-40
-20
0
20
40
60
80
100

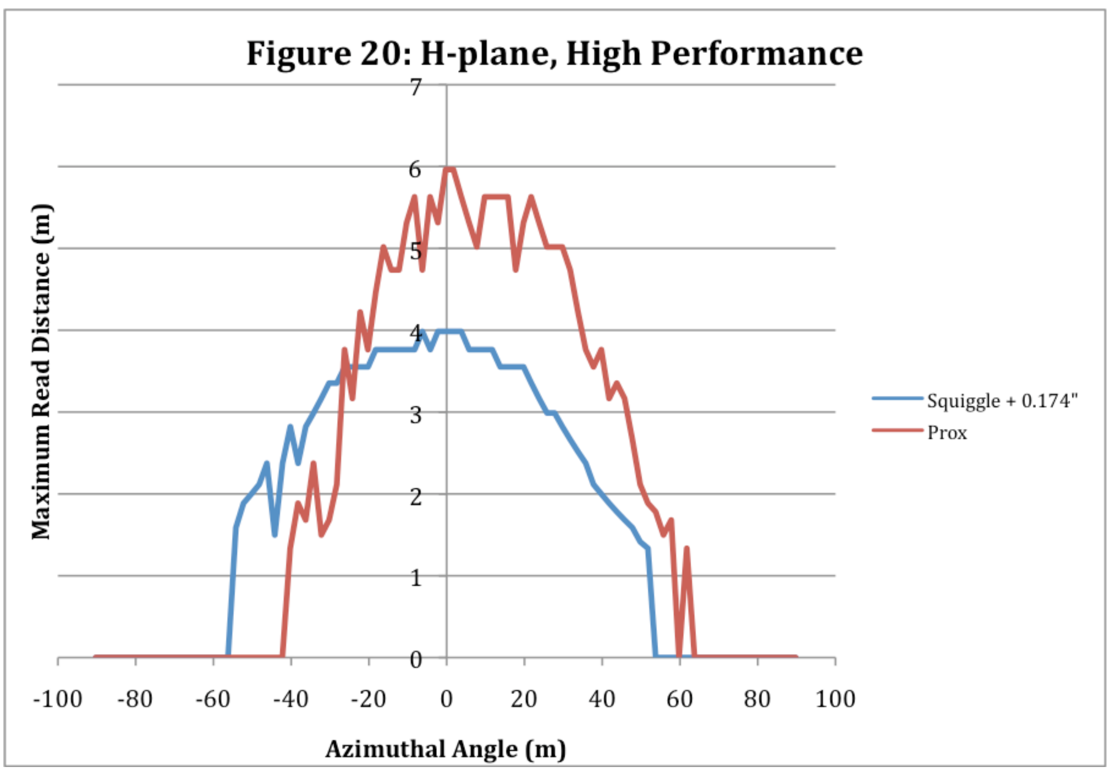


Figure 20: H-plane, High Performance
Maximum Read Distance (m)
Azimuthal Angle (m)
Squiggle + 0.174"
Prox
0
1
2
3
4
5
6
7
-100
-80
-60
-40
-20
0
20
40
60
80
100

VI. Conclusion

In each case, the Omni ID tags performed better on a metal surface than the Alien tags with spacing. Due to the combination of better performance and easier implementation, IBM should use the Omni ID tags to address their needs. The choice between Prox or Flex depends on the end user's requirements. If the user desires a configuration that will not extend past the regular disk drive dimensions, he or she should use the Flex tag with a cavity of 0.100" depth. However, if the user does not require such a low profile, the Prox tag should be used. It performs slightly better and has a smaller footprint.

VII. Further Development

Different approaches to solving the problem of RFID tags mounted on metal surfaces should be investigated. One possible solution that was not examined in this project is the use of Electromagnetic Band Gap substrates between the antenna and metal surface. This method has been used before, and it resulted in better performance in an RFID antenna.[7,8] It would be interesting to see this applied and compared to other solutions for this problem.

Other common uses of RFID can be tested for as well. RFID is often used for tracking inventory during manufacturing processes, and performance inside packaging and shipping containers could be investigated. Initially, that was a goal for this project, but ultimately there was not enough time to complete a shipping container characterization. Preliminary tests were done with the setup show below.

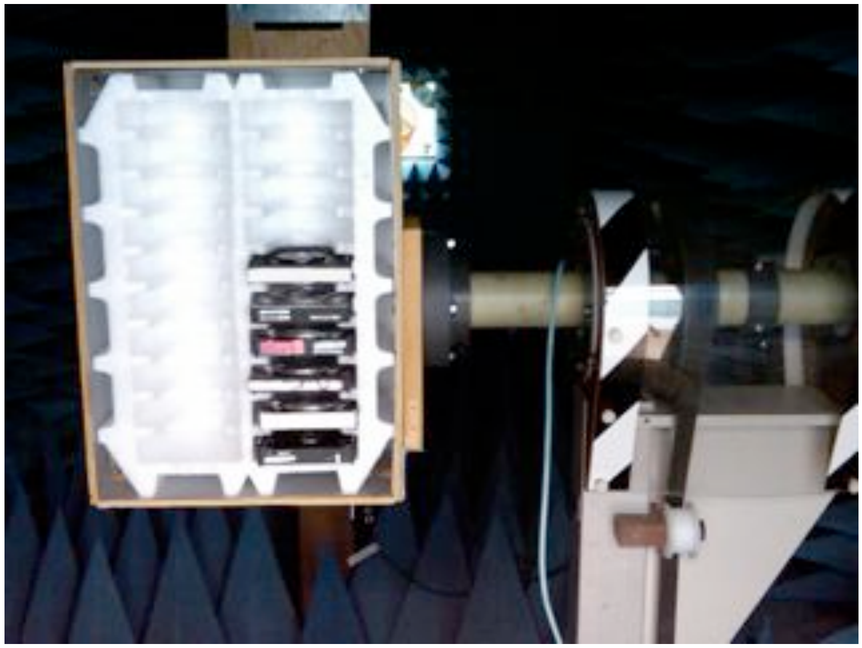


Figure 21: Shipping Container Assembly

Changes to this assembly are required to create a more realistic simulation; the hard drive shipping box and packaging are a good place to start.

VI. References

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Appendices

A. Derivation of Formulas

1. Quarter-wavelength in dielectric

$$\lambda = \frac{c}{v}$$

$$\lambda_d = \frac{\lambda}{\sqrt{\varepsilon_r}}$$

$$\frac{\lambda_d}{4} = \frac{\lambda}{4\sqrt{\varepsilon_r}}$$

λ = Wavelength in free space

c = Speed of light in free space

v = Frequency

λ_d = Wavelength in dielectric

ε_r = Relative permittivity or dielectric constant

2. RFID tag power

$$\omega_r = \frac{P_t G_t}{4\pi R^2}\left[\frac{\omega}{m^2}\right]$$

$$A_e = \frac{G_r \lambda^2}{4\pi}\left[m^2\right]$$

$$P_{tag} = A_e \times \omega_r = \frac{P_t G_t G_r \lambda^2}{16\pi^2 \times R^2}$$

$$P_t G_t G_r = 10^{\left[\frac{P_t[dBm]+G_r[dB]+G_t[dB]}{10}\right]}$$

$$P_{tag} = \frac{10^{\left[\frac{P_t[dBm]+G_r[dB]+G_t[dB]}{10}\right]} \times \lambda^2}{16\pi^2 \times R^2}$$

P_t = Transmitted power

G_r = Receive gain (RFID tag antenna gain)

G_t = Transmit gain (patch antenna gain)

λ = Wavelength in free space

R = Distance between patch antenna and RFID tag

B. Parts List

Number	Description	Quantity	Price
1	Hitachi V923H6 Hard Drive	8	Donated
2	High-Alumina Ceramic Sheet	1	$12.99
3	Steel Sheet Metal	1	$20.00 est.
4	Hardware (Nuts, Bolts, Braces)	8	$5.00 est.
5	Alien RFID Tag Sample Pack	1	Donated
6	Omni ID RFID Tag Evaluation Pack	1	Donated
7	0.116" Thick Presentation Board	1	$5.99
8	0.174" Thick Presentation Board	1	$5.99
Total			**$49.97**

C. Schedule

ID	Task	Duration	Start Date	End Date
1	Research	3wks	3/23/09	4/12/09
2	Software Simulation	1wks	4/6/09	4/12/09
3	Order or Procure Supplies	4wks	4/13/09	5/03/09
4	LabView Programming	4wks	4/13/09	5/03/09
5	Build Server Rack	1wk	5/04/09	5/10/09
6	Characterize Isolated Disk Drive	1wk	5/04/09	5/10/09
7	Modify and Improve RFID Cutout	1wk	5/11/09	5/16/09
8	Characterize Server Rack	3wks	5/11/09	5/31/09
9	Find Best Placement and Orientation	2wks	5/17/09	5/31/09
10	Analyze Data	1wk	5/25/09	5/31/09
11	Write Report	2wks	6/01/09	6/12/09