Determining the Performance of Passive Radio Frequency Identification Tag Applications Using a Cost Effective Anechoic Chamber

Team 2

The Tycoons

Sponsor: M/A Com

Faculty Advisors: Professor Carl-Ernst Rousseau and Professor Bahram Nassersharif

Submitted: 5/12/08

Dan Dittman- Team Organizer
Dan Maruca- Team Designer
Harry Hosemann- Project Analyst
Aaron Hebenstreit- Research and Quality Control
Juan Quinchia- Testing and Programming

Abstract

The final design that was implemented for our Mechanical Engineering Capstone Design class was to successfully build an anechoic chamber that could be used for the testing of passive Radio Frequency Identification (RFID) tags. We were able to construct an extremely cost efficient self-contained testing chamber that fully blocked noise created by outside frequencies other than the testing antenna. Our goal was to be able to test a wide range of passive RFID tags in numerous testing variables to see the performance of passive tags in real life applications. This would enable a company to purchase our design project, along with a ThingMagic reader and antenna, in order to find the best applicable passive tag for whichever function the tag will be performing. Accompanying this testing apparatus is a protocol for testing, instructions for building, instructions for setting up the antenna and reader, and a Matlab code for easy analysis.

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List of Acronyms and Constants Used

RFID - Radio Frequency Identification

QFD - Quality Function Deployment

UTS – Ultimate Tensile Strength

L = length in mm (arbitrary length)
W = force in Newtons (arbitrary force)
E = Modulus of Elasticity in N/mm^2 (70,326.5 N/mm^2) (from 80/20 Inc.)
I = Moment of Inertia (6826 mm^4) (from 80/20 Inc.)
D = Maximum deflection of the beam in mm

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Introduction

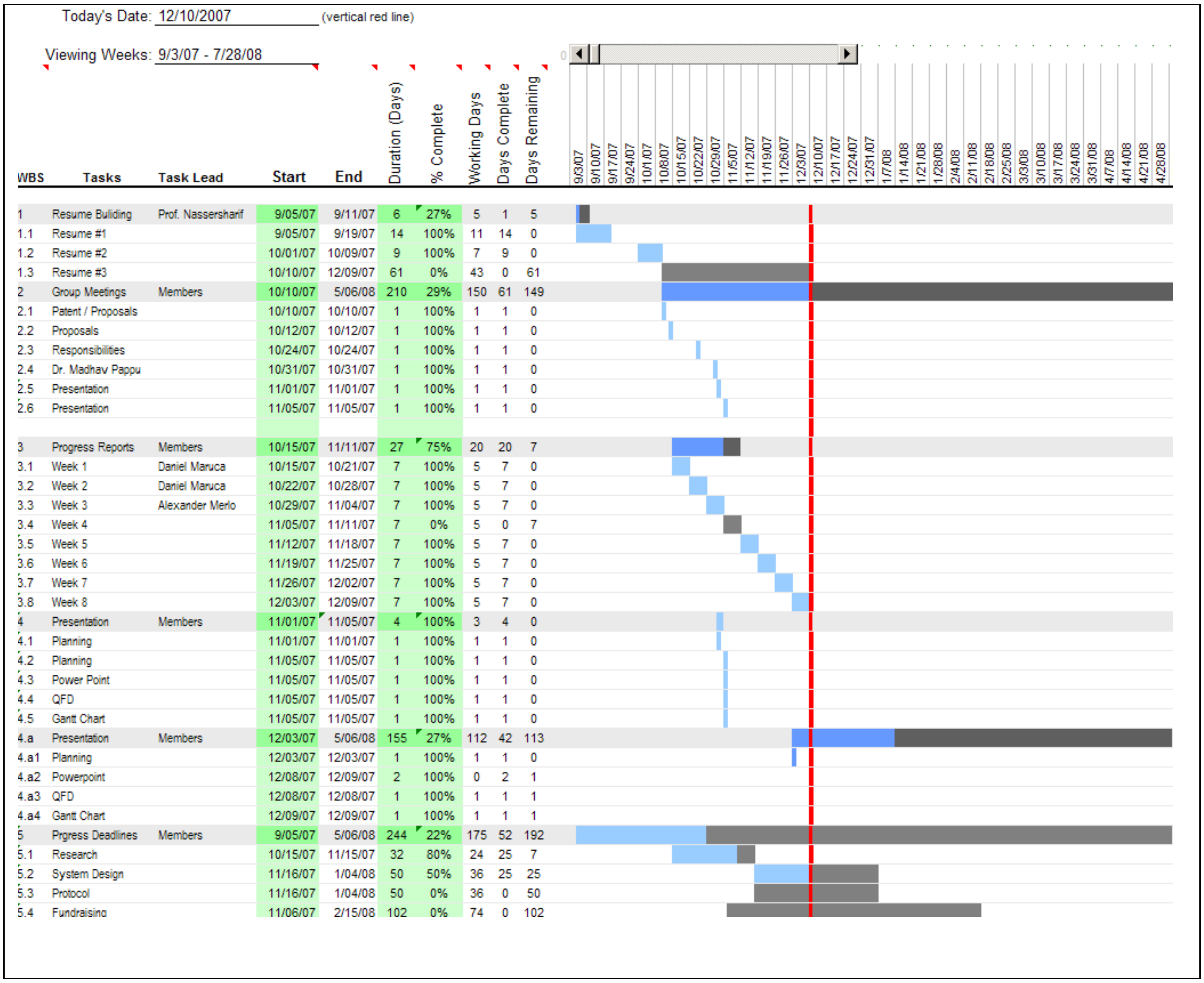
When we received our project assignment in the Fall 2007 semester, it was viewed as a very open-ended project. The main idea of the project was to test the performance of passive tags when they are put into applications used in the real world. The strength of an RFID tag is dependent upon its orientation to the reader, its distance from the reader, the amount of times it is read, and the material that the tag is mounted on. What we proposed was to create a way to test the performance of passive RFID tags by building a working anechoic chamber. An anechoic chamber is a shielded room designed to attenuate waves. Anechoic chambers were originally used in the context of acoustic echoes caused by reflections from the internal surfaces of the room, but more recently anechoic chambers have been used to provide a shielded environment for radio frequency and microwaves. A radio frequency anechoic chamber is designed to suppress the electromagnetic wave analogy of echoes, reflected electromagnetic waves, from the internal surfaces. Both types of chamber are constructed with echo suppression features and with effective isolation from the acoustic or radio frequency noise present in the external environment. In a well-designed acoustic or radio frequency anechoic chamber, the equipment under testing receives acoustic, mechanical or radio frequency signals from the signal source, not reflected from another part of the chamber. This ensures the integrity of the testing being conducted. Furthermore, the shielding of the chamber limits interference from equipment located outside of the chamber.

After erecting a fully operational anechoic chamber we made a protocol for testing so that companies will be able to mimic our testing methods to test the performance of the tags. The protocol informs the user on how to set up the reader and antenna, how to use the software, and what parameters may be tested for the tags. Accompanying the apparatus will be an instruction manual for constructing the frame and attaching the RFID shields. This will allow the consumer to purchase our device cheaply and save on building costs by eliminating outside contractors. Also, there will be a Matlab code that will make compiling the results from testing very easy for the user. This Matlab code, along with instructions on how to use it, will display graphs with the performance of each tag compared with the performance of a tag in optimal conditions.

Our design requirements were to make a working anechoic chamber. This chamber must be large enough to perform multiple tests, collapsible, moveable, and structurally sound to support the shields, reader, computer, and antenna. The chamber should also be made affordable to allow more companies to invest in our device. Commercial anechoic chambers generally tend to be extremely expensive, bulky, immobile, hard to build, and are limited on the amount of testing they can perform. We feel that our project eliminates all these unwanted characteristics while still being able to function as an RFID tag performance tester.

Project Planning

The Gantt charts below are dated and show the breakdown of our project as the semester progressed.



WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Resume Buliding	Prof. Nassersharif	9/05/07	9/11/07	6	27%	5	1	5
1.1	Resume #1		9/05/07	9/19/07	14	100%	11	14	0
1.2	Resume #2		10/01/07	10/09/07	9	100%	7	9	0
1.3	Resume #3		10/10/07	12/09/07	61	0%	43	0	61
2	Group Meetings	Members	10/10/07	5/06/08	210	29%	150	61	149
2.1	Patent / Proposals		10/10/07	10/10/07	1	100%	1	1	0
2.2	Proposals		10/12/07	10/12/07	1	100%	1	1	0
2.3	Responsibilities		10/24/07	10/24/07	1	100%	1	1	0
2.4	Dr. Madhav Pappu		10/31/07	10/31/07	1	100%	1	1	0
2.5	Presentation		11/01/07	11/01/07	1	100%	1	1	0
2.6	Presentation		11/05/07	11/05/07	1	100%	1	1	0
3	Progress Reports	Members	10/15/07	11/11/07	27	75%	20	20	7
3.1	Week 1	Daniel Maruca	10/15/07	10/21/07	7	100%	5	7	0
3.2	Week 2	Daniel Maruca	10/22/07	10/28/07	7	100%	5	7	0
3.3	Week 3	Alexander Merlo	10/29/07	11/04/07	7	100%	5	7	0
3.4	Week 4		11/05/07	11/11/07	7	0%	5	0	7
3.5	Week 5		11/12/07	11/18/07	7	100%	5	7	0
3.6	Week 6		11/19/07	11/25/07	7	100%	5	7	0
3.7	Week 7		11/26/07	12/02/07	7	100%	5	7	0
3.8	Week 8		12/03/07	12/09/07	7	100%	5	7	0
4	Presentation	Members	11/01/07	11/05/07	4	100%	3	4	0
4.1	Planning		11/01/07	11/01/07	1	100%	1	1	0
4.2	Planning		11/05/07	11/05/07	1	100%	1	1	0
4.3	Power Point		11/05/07	11/05/07	1	100%	1	1	0
4.4	QFD		11/05/07	11/05/07	1	100%	1	1	0
4.5	Gantt Chart		11/05/07	11/05/07	1	100%	1	1	0
4.a	Presentation	Members	12/03/07	5/06/08	155	27%	112	42	113
4.a1	Planning		12/03/07	12/03/07	1	100%	1	1	0
4.a2	Powerpoint		12/08/07	12/09/07	2	100%	0	2	1
4.a3	QFD		12/08/07	12/08/07	1	100%	1	1	1
4.a4	Gantt Chart		12/09/07	12/09/07	1	100%	1	1	1
5	Prgress Deadlines	Members	9/05/07	5/06/08	244	22%	175	52	192
5.1	Research		10/15/07	11/15/07	32	80%	24	25	7
5.2	System Design		11/16/07	1/04/08	50	50%	36	25	25
5.3	Protocol		11/16/07	1/04/08	50	0%	36	0	50
5.4	Fundraising		11/06/07	2/15/08	102	0%	74	0	102

Figure 1

RFID Tycoons

Project Name

Tyco RFID Performance
Material testing

Project Lead: Dr. Madhav Pappu

Today's Date: 12/20/2007 (vertical red line)

Viewing Weeks: 9/3/07 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Resume Building	Prof. Nassersharif	9/05/07	9/11/07	6	27%	5	1	5
1.1	Resume #1		9/05/07	9/19/07	14	100%	11	14	0
1.2	Resume #2		10/01/07	10/09/07	9	100%	7	9	0
1.3	Resume #3		10/10/07	12/09/07	61	0%	43	0	61
2	Group Meetings	Members	10/10/07	5/06/08	210	29%	150	61	149
2.1	Patent / Proposals		10/10/07	10/10/07	1	100%	1	1	0
2.2	Proposals		10/12/07	10/12/07	1	100%	1	1	0
2.3	Responsibilities		10/24/07	10/24/07	1	100%	1	1	0
2.4	Dr. Madhav Pappu		10/31/07	10/31/07	1	100%	1	1	0
2.5	Presentation		11/01/07	11/01/07	1	100%	1	1	0
2.6	Presentation		11/05/07	11/05/07	1	100%	1	1	0
3	Progress Reports	Members	10/15/07	11/11/07	27	75%	20	20	7
3.1	Week 1	Daniel Maruca	10/15/07	10/21/07	7	100%	5	7	0
3.2	Week 2	Daniel Maruca	10/22/07	10/28/07	7	100%	5	7	0
3.3	Week 3	Alexander Merlo	10/29/07	11/04/07	7	100%	5	7	0
3.4	Week 4		11/05/07	11/11/07	7	0%	5	0	7
4	Presentation	Members	11/01/07	11/05/07	4	100%	3	4	0
4.1	Planning		11/01/07	11/01/07	1	100%	1	1	0
4.2	Planning		11/05/07	11/05/07	1	100%	1	1	0
4.3	Power Point		11/05/07	11/05/07	1	100%	1	1	0
4.4	QFD		11/05/07	11/05/07	1	100%	1	1	0
4.5	Gantt Chart		11/05/07	11/05/07	1	100%	1	1	0
5	Prgress Deadlines	Members	9/05/07	5/06/08	244	48%	175	117	127
5.1	Research		10/15/07	11/15/07	32	80%	24	25	7
5.2	System Design		11/16/07	11/29/07	14	30%	10	4	10
5.3	Protocol		11/16/07	12/05/07	20	0%	14	0	20
5.4	Fundraising		11/06/07	2/15/08	102	50%	74	51	51

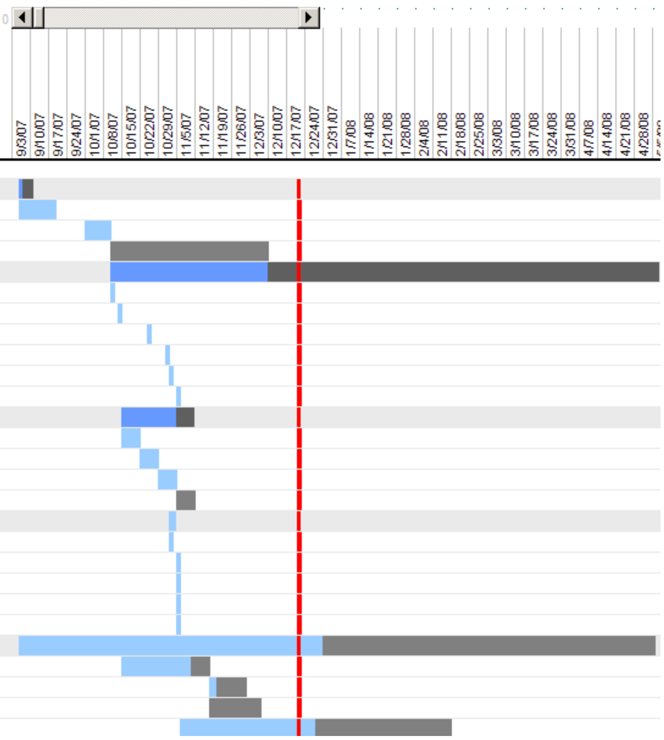


Figure 2

RFID Tycoons

Project Name

Tyco RFID Performance
Material testing

Project Lead: Profs. Nasersharif, Rouseau

Today's Date: 2/18/2008 (vertical red line)

Viewing Weeks: 9/3/07 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Resume Buliding	Prof. Nassersharif	9/05/07	9/11/07	6	27%	5	1	5
1.1	Resume #1		9/05/07	9/19/07	14	100%	11	14	0
1.2	Resume #2		10/01/07	10/09/07	9	100%	7	9	0
1.3	Resume #3		10/10/07	12/09/07	61	0%	43	0	61
2	Group Meetings	Members	1/28/08	8/24/08	210	72%	150	151	59
2.1	Group meeting 1		1/28/08	1/28/08	1	100%	1	1	0
2.2	Group meeting 2		2/04/08	2/04/08	1	100%	1	1	0
2.3	Group meeting 3		2/11/08	2/11/08	1	100%	1	1	0
2.4	Group meeting 4		2/14/08	2/14/08	1	100%	1	1	0
2.5	Group meeting 5		2/15/08	2/15/08	1	100%	1	1	0
2.6	Professor meeting		2/18/08	12/18/08	1	100%	1	1	0
3	Progress Reports	Members	1/28/08	2/17/08	20	100%	15	20	0
3.1	Week 1	Daniel Maruca	1/28/08	2/03/08	7	100%	5	7	0
3.2	Week 2	Daniel Maruca	2/04/08	2/10/08	7	100%	5	7	0
3.3	Week 3	Daniel Maruca	2/11/08	2/17/08	7	100%	5	7	0
5	Gantt Chart		11/05/07	2/18/08	90	100%	90	90	0
5.1	Prgress Deadlines	Members	9/05/07	5/06/08	244	50%	175	120	124
5.2	Research		10/15/07	11/15/07	32	100%	24	32	0
5.3	System Design		11/16/07	2/13/08	90	80%	64	72	18
5.3	Build device		3/03/08	3/16/08	14	0%	10	0	14
5.4	Testing		3/17/08	4/15/08	30	0%	22	0	30
5.3	Analysis		3/17/08	4/18/08	33	0%	25	0	33
5.4	Protocol		11/16/07	12/05/07	20	20%	14	4	16
5.6	Fundraising		11/06/07	2/15/08	102	50%	74	51	51

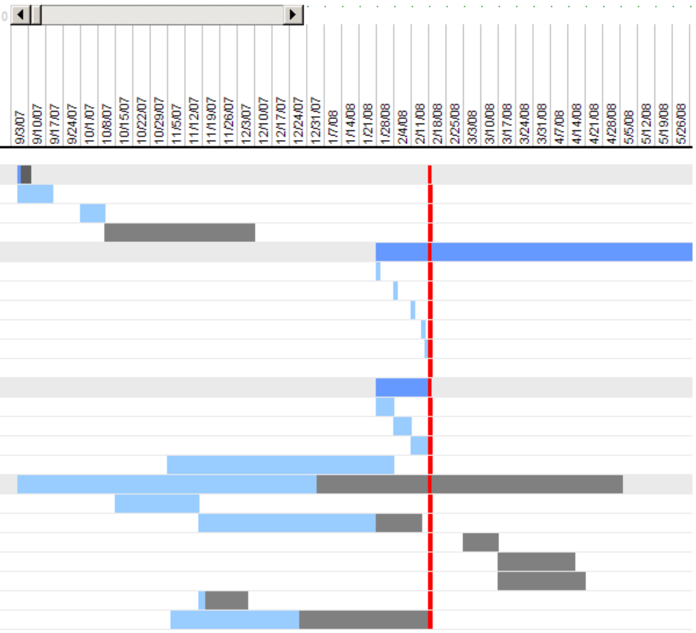


Figure 3

Material testing

Project Lead: Profs. Nassersharif, Rousseau

Today's Date: 3/11/2008 (vertical red line)

Viewing Weeks: 2/18/08 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
5.1	Daniel Maruca	Members	9/05/07	5/06/08	244	65%	175	159	85
5.2	Research		10/15/07	11/15/07	32	100%	24	32	0
5.3	System Design		11/16/07	3/09/08	115	90%	81	103	12
5.4	Build device		3/03/08	3/30/08	28	0%	20	0	28
5.5	Report Review		2/18/08	3/02/08	14	80%	10	11	3
5.6	Power Point		3/03/08	3/09/08	7	100%	5	7	0
5.7	Structure Analysis		2/24/08	3/27/08	33	15%	24	4	29
6.1	Daniel Dittman	Members	9/05/07	5/06/08	244	62%	175	150	94
6.2	Research		10/15/07	11/15/07	32	100%	24	32	0
6.3	System review		3/03/08	3/09/08	7	80%	5	5	2
6.4	Build device		3/03/08	3/30/08	28	0%	20	0	28
6.5	Power Point		3/03/08	3/09/08	7	100%	5	7	0
6.6	Report Review		2/18/08	3/02/08	14	80%	10	11	3
6.7	Final review		3/17/08	4/18/08	33	0%	25	0	33
7.1	Aaron Hebenstreit	Members	9/05/07	5/06/08	244	69%	175	168	76
7.2	Research		10/15/07	11/15/07	32	100%	24	32	0
7.3	Protocol		2/18/08	3/23/08	35	40%	25	14	21
7.4	Poster		3/03/08	3/09/08	7	100%	5	7	0
8.1	Juan Quinchia	Members	9/05/07	5/06/08	244	68%	175	167	77
8.2	Research		10/15/07	11/15/07	32	100%	24	32	0
8.3	Semester review		2/18/08	3/02/08	14	90%	10	12	2
8.4	Introductory Testing		2/18/08	3/16/08	28	75%	20	21	7
8.5	Final Testing		3/17/08	4/18/08	33	0%	25	0	33
9.1	Harald Hosemann	Members	9/05/07	5/06/08	244	72%	175	174	70
9.2	Research		10/15/07	11/15/07	32	100%	24	32	0
9.3	Protocol		2/18/08	3/23/08	35	40%	25	14	21
9.4	Poster		3/03/08	3/09/08	7	100%	5	7	0

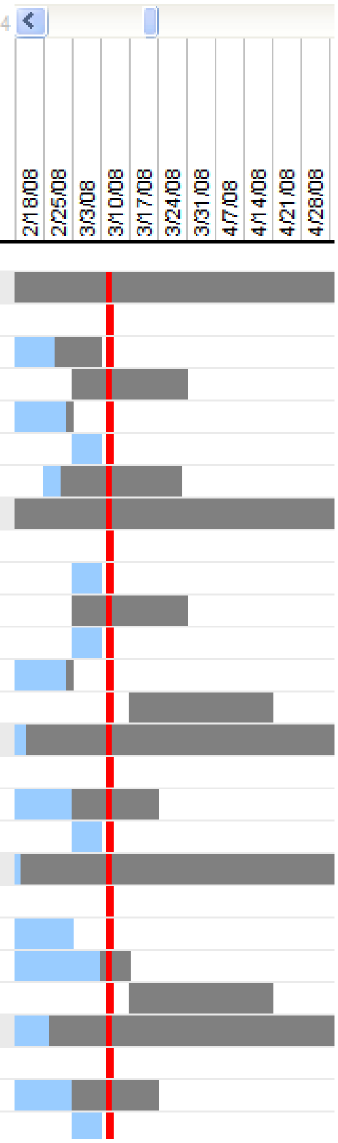


Figure 4

RFID Tycoons

Project Name

Tyco RFID Performance
Material testing

Project Lead: Profs. Nassersharif, Rousseau

Today's Date: 3/31/2008 (vertical red line)

Viewing Weeks: 2/18/08 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
5.1	Daniel Maruca	Members	9/05/07	5/06/08	244	68%	175	166	78
5.2	Research		10/15/07	11/15/07	32	100%	24	32	0
5.3	System Design		11/16/07	3/09/08	115	100%	81	115	0
5.4	Build device		3/03/08	3/30/08	28	0%	20	0	28
5.5	Report Review		2/18/08	3/02/08	14	100%	10	14	0
5.6	Power Point		3/03/08	3/09/08	7	100%	5	7	0
5.7	Ordering		3/03/08	4/04/08	33	70%	25	23	10
5.8	Structure Analysis		2/24/08	3/27/08	33	15%	24	4	29
6.1	Daniel Dittman	Members	9/05/07	5/06/08	244	61%	175	148	96
6.2	Research		10/15/07	11/15/07	32	100%	24	32	0
6.3	System review		3/03/08	3/09/08	7	80%	5	5	2
6.4	Build device		3/03/08	3/30/08	28	0%	20	0	28
6.5	Power Point		3/03/08	3/09/08	7	100%	5	7	0
6.6	Report Review		2/18/08	3/02/08	14	100%	10	14	0
6.7	Final review		3/17/08	4/18/08	33	0%	25	0	33
7.1	Aaron Hebenstreit	Members	9/05/07	5/06/08	244	67%	175	163	81
7.2	Research		10/15/07	11/15/07	32	100%	24	32	0
7.3	Protocol		2/18/08	4/02/08	45	40%	33	18	27
7.4	Poster		3/03/08	3/09/08	7	100%	5	7	0
8.1	Juan Quinchia	Members	9/05/07	5/06/08	244	67%	175	163	81
8.2	Research		10/15/07	11/15/07	32	100%	24	32	0
8.3	Semester review		2/18/08	3/02/08	14	90%	10	12	2
8.4	Introductory Testing		2/18/08	3/16/08	28	100%	20	28	0
8.5	Baseline Testing		3/17/08	4/06/08	21	50%	15	10	11
8.6	Final Testing		3/17/08	4/18/08	33	0%	25	0	33
9.1	Harald Hosemann	Members	9/05/07	5/06/08	244	68%	175	165	79
9.2	Research		10/15/07	11/15/07	32	100%	24	32	0
9.3	Protocol		2/18/08	4/02/08	45	40%	33	18	27
9.4	Poster		3/03/08	3/09/08	7	100%	5	7	0

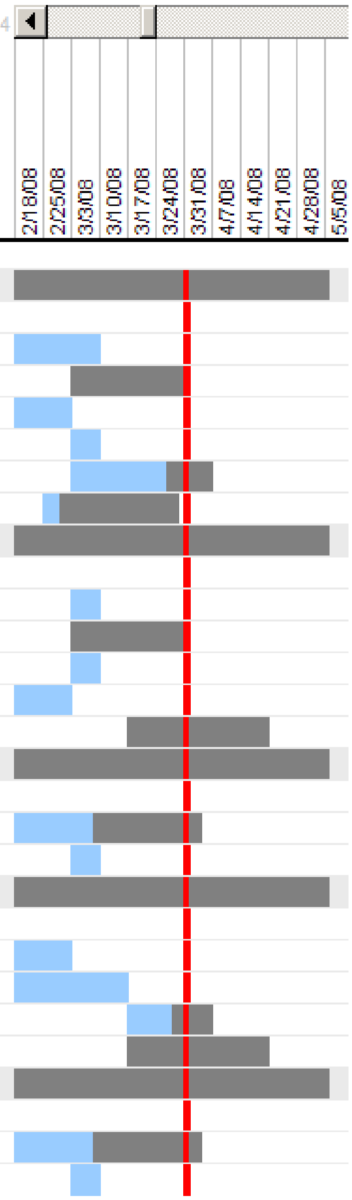
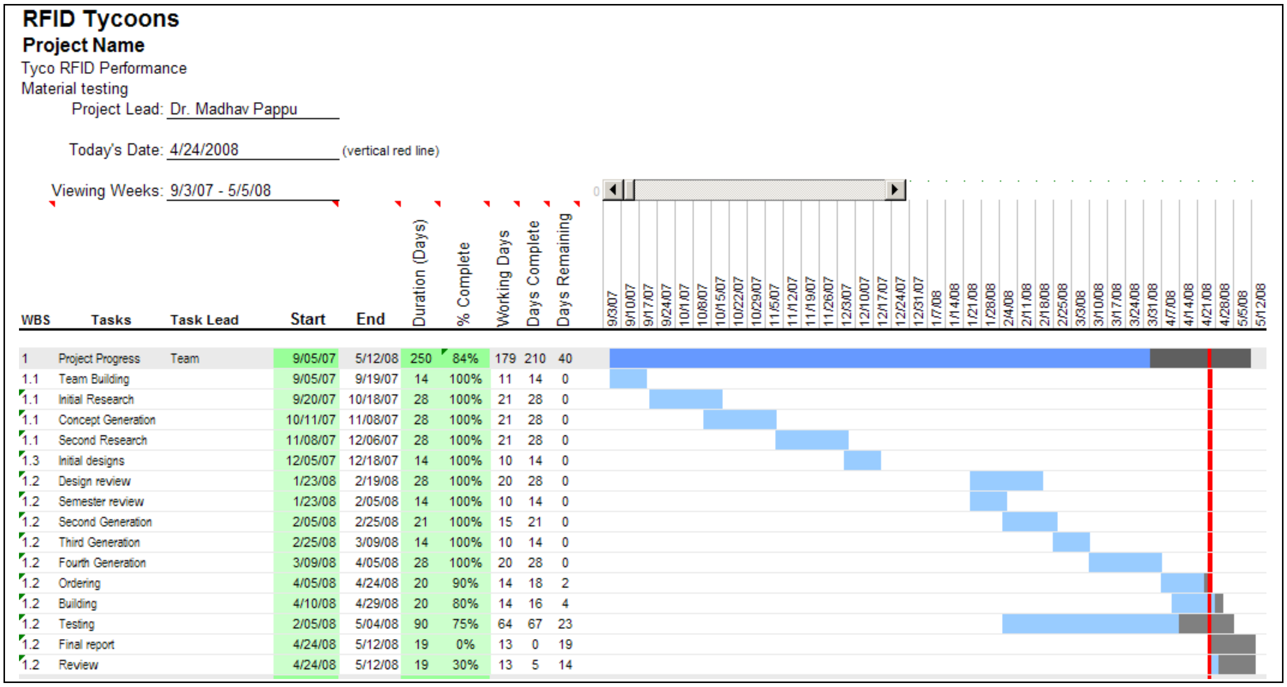


Figure 5



RFID Tycoons

Project Name

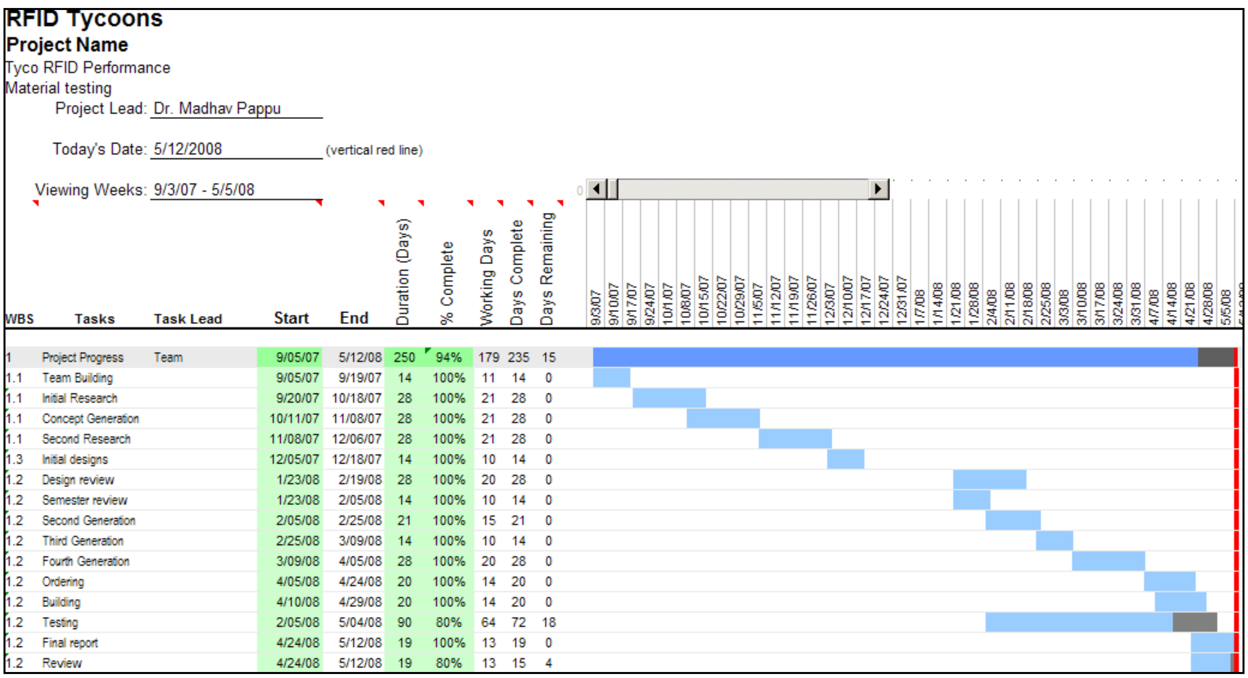
Tyco RFID Performance
Material testing

Project Lead: Dr. Madhav Pappu

Today's Date: 4/24/2008 (vertical red line)

Viewing Weeks: 9/3/07 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Project Progress	Team	9/05/07	5/12/08	250	84%	179	210	40
1.1	Team Building		9/05/07	9/19/07	14	100%	11	14	0
1.1	Initial Research		9/20/07	10/18/07	28	100%	21	28	0
1.1	Concept Generation		10/11/07	11/08/07	28	100%	21	28	0
1.1	Second Research		11/08/07	12/06/07	28	100%	21	28	0
1.3	Initial designs		12/05/07	12/18/07	14	100%	10	14	0
1.2	Design review		1/23/08	2/19/08	28	100%	20	28	0
1.2	Semester review		1/23/08	2/05/08	14	100%	10	14	0
1.2	Second Generation		2/05/08	2/25/08	21	100%	15	21	0
1.2	Third Generation		2/25/08	3/09/08	14	100%	10	14	0
1.2	Fourth Generation		3/09/08	4/05/08	28	100%	20	28	0
1.2	Ordering		4/05/08	4/24/08	20	90%	14	18	2
1.2	Building		4/10/08	4/29/08	20	80%	14	16	4
1.2	Testing		2/05/08	5/04/08	90	75%	64	67	23
1.2	Final report		4/24/08	5/12/08	19	0%	13	0	19
1.2	Review		4/24/08	5/12/08	19	30%	13	5	14



RFID Tycoons

Project Name

Tyco RFID Performance
Material testing

Project Lead: Dr. Madhav Pappu

Today's Date: 5/12/2008 (vertical red line)

Viewing Weeks: 9/3/07 - 5/5/08

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Project Progress	Team	9/05/07	5/12/08	250	94%	179	235	15
1.1	Team Building		9/05/07	9/19/07	14	100%	11	14	0
1.1	Initial Research		9/20/07	10/18/07	28	100%	21	28	0
1.1	Concept Generation		10/11/07	11/08/07	28	100%	21	28	0
1.1	Second Research		11/08/07	12/06/07	28	100%	21	28	0
1.3	Initial designs		12/05/07	12/18/07	14	100%	10	14	0
1.2	Design review		1/23/08	2/19/08	28	100%	20	28	0
1.2	Semester review		1/23/08	2/05/08	14	100%	10	14	0
1.2	Second Generation		2/05/08	2/25/08	21	100%	15	21	0
1.2	Third Generation		2/25/08	3/09/08	14	100%	10	14	0
1.2	Fourth Generation		3/09/08	4/05/08	28	100%	20	28	0
1.2	Ordering		4/05/08	4/24/08	20	100%	14	20	0
1.2	Building		4/10/08	4/29/08	20	100%	14	20	0
1.2	Testing		2/05/08	5/04/08	90	80%	64	72	18
1.2	Final report		4/24/08	5/12/08	19	100%	13	19	0
1.2	Review		4/24/08	5/12/08	19	80%	13	15	4

Figure 6

Preliminary Cost Analysis

In order to realize and construct our conceptual testing apparatus design, it was necessary to determine the material and accessories necessary to appropriately complete this task. For our frame, we selected extrusions from the McMaster Carr company. These extrusions provide the stability and strength necessary for the appropriate testing. For the assembly of the frame, we purchased Anchor Fasteners and T-Nuts from the same manufacturer and galvanized steel strap hinges from Home Depot. These accessories were carefully chosen, as it was essential to match all the dimensions of the frame itself. It was also necessary to purchase miscellaneous accessories to facilitate the construction of the apparatus. Some of these accessories include zip ties, paint, screws, wood and washers. The total amount required to complete the construction of the testing apparatus was calculated to be $678.76. This total cost represents a much more economical testing alternative than most of the devices currently available in the RFID testing market. A detailed list of the costs of construction is given below.

- 1" X 1" Square Extrusion, 8' Length – Purchased from McMaster Carr

  11 X $28.04 = $308.44

- Zinc Anchor Fastener W/Steel T-Nut for 1" SQ &1" X2", Packs of 1– Purchased from McMaster Carr

  25 X $3.69 = $92.25

- Double T-Nut W/Cap Screw for 1" SQ & 1" X2" Extrusion, Packs of 6 – Purchased from McMaster Carr

  5 x $7.25 = $36.25

- T-Nut W/Button Head Cap Screw for 1" SQ &1" X2", Packs of 4 – Purchased from McMaster Carr

  2 X $2.09 = $4.18

- RFI Shields– Purchased from TruProtect

  5 X $40.00 = $200.00

- Galvanized steel strap hinges – Purchased from Home Depot

  12 X $1.47 = $17.64

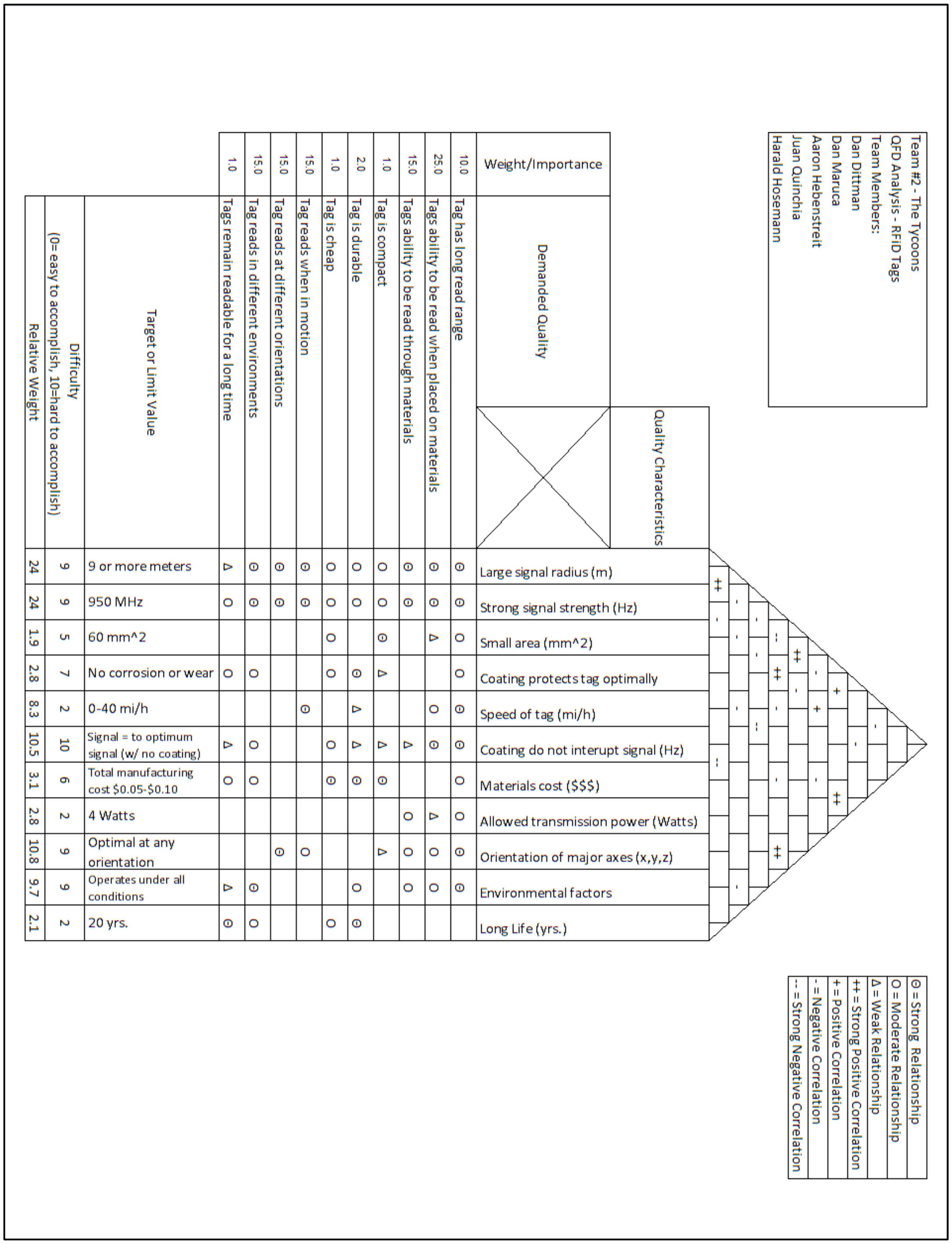
- Accessories (zip ties, paint, screws, wood, washers)

  1 X $20.00 = $20.00

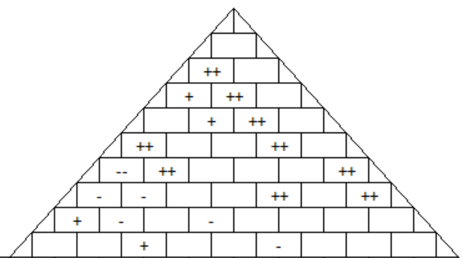
- Total = $678.76

QFD

The first chart is for passive tags and the second chart is for our product.



Team #2 - The Tycoons
QFD Analysis - RFiD Tags
Team Members:
Dan Dittman
Dan Maruca
Aaron Hebenstreit
Juan Quinchia
Harald Hosemann



Weight/Importance	Demanded Quality \ Quality Characteristics	Aluminum T-Slots	Wheels	Corner joints and bolts	Hinges	Foam sidings	Reads from grid close range	Reads far range	Housing: foam boards and appliances	Instructions for building device	Instructions for testing tags
10.0	Product must be affordable	Θ	Δ	Δ	Δ	Θ					
5.0	Product must be light weight	Θ				Θ					
10.0	Product must be compactable				Θ	O			O		
5.0	Product must be mobile		Θ								
10.0	Product must be easily assembled and disassembled	Θ	Θ	Θ	Θ	Θ				Θ	
15.0	Orientation of reader must be changeable	Θ					Θ	Θ			Θ
15.0	Outside frequencies should not interfere					Θ					
10.0	Product must house all appliances								Θ		
10.0	Product must be able to withstand weight of appliances	Θ		Θ	Θ						
10.0	Must contain easy directions to follow									Θ	Θ
	Target or Limit Value	9 or more meters	360° Rotation	Can hold 100 N force	Can withstand 100 Newtons	Block/absorbs all other radio	6 ft.	30+ ft.	4 Watts	Easy to follow	Easy to follow
	Difficulty (0= easy to accomplish, 10=hard to accomplish)	9	9	5	7	2	10	6	2	9	9
	Relative Weight	20	6.4	8.4	12.4	17.3	6	6	5.3	8	10

Θ = Strong Relationship
O = Moderate Relationship
Δ = Weak Relationship
++ = Strong Positive Correlation
+ = Positive Correlation
- = Negative Correlation
-- = Strong Negative Correlation

Figure 7
Figure 8

Patent Searches

Our project was modified after the initial patent search exercise in the fall semester. We had a significantly different objective in the spring semester, so our previous patent searches were rendered largely irrelevant. There are many different patents related to RFID design. However, we did not change the design – we simply tested a range of already-existing RFID tag products. There are also a number of patents related to processes and procedures for testing RFID tag technologies. Our most recent patent research reflects this. Important to note is that when companies in industry conduct testing on particular types of RFID that they use, they do so by their own parameters and under conditions specifically related to their designs and products, keeping all results and information confidential and proprietary in order not to leak results from their testing to market competitors.

After more searching through the online database of the United States Patent and Trademark Office, summaries of a number of patented processes and apparatuses are listed on the following pages along with their relevance to our project and how they were incorporated in our final process design for our particular RFID testing purposes.

United States Patent **7,306,162**

Forster **December 11, 2007**

RFID device tester and method

Abstract

Multiple ***RFID*** devices may be tested by moving a sheet, roll, or web of the devices in conjunction with a test apparatus having multiple ***RFID*** device testers, so that the ***RFID*** devices to be tested are each spatially static with regard to one of the ***RFID*** device testers for a period of time, during which testing may be performed. The device testers may be arrayed along the circumference of a circular test wheel or roller, or may be arrayed along the perimeter of a flexible belt. The coupling between the ***RFID*** devices and the ***RFID*** device testers may be capacitive. By utilizing short-range capacitive coupling, difficulties caused by simultaneous activation of multiple ***RFID*** devices may be reduced or avoided.

Inventors: **Forster; Ian J.** (Chelmsford, **GB**)

Assignee: **Avery Dennison Corporation** (Pasadena, CA)

Appl. No.: **11/136,124**

Filed: **May 24, 2005**

Related U.S. Patent Documents

Application Number	**Filing Date**	**Patent Number**	**Issue Date**<TD< TD>
10367515	Feb., 2003		<TD< TD>
PCT/US2004/004227	Feb., 2004	7225992	<TD< TD>

Current U.S. Class: **235/492** ; 235/382; 235/384; 235/451

Current International Class: G06K 19/06 (20060101)

Field of Search: 235/492,487,380,451 340/572.01,572.07

Analysis

This patent relates to the testing of multiple RFID tags at once, specifically in the form of a sheet or roll of tags passing through a testing apparatus by way of a conveyor belt or circular test wheel. This was an interesting concept, but was not employed for our purposes, since all the testing our group did was on one passive tag at a time.

United States Patent **7,298,343**

Forster , et al. **November 20, 2007**

RFID tag with enhanced readability

Abstract

A radio frequency identification (***RFID***) device includes a conductive antenna structure having an elongated slot therein. Parts of the antenna structure on both sides of one end of the elongated slot are coupled to a wireless communication device, such as an ***RFID*** chip or interposer. On the opposite end of the elongated slot, parts of the antenna structure at both sides of the elongated slot are electrically coupled together, for instance by being coupled together by other conductive parts of the antenna structure. All of the parts of the antenna structure may be parts of a continuous unitary layer of conductive material. The antenna structure with the elongated slot therein may facilitate increased readability of the ***RFID*** device, particularly in directions out from the edges of the ***RFID*** device.

Inventors: **Forster; Ian J.** (Chelmsford, **GB**)**, Puleston; David J.** (Duluth, GA)

Assignee: **Avery Dennison Corporation** (Pasadena, CA)

Appl. No.: **10/981,321**

Filed: **November 4, 2004**

Related U.S. Patent Documents

Application Number	Filing Date	Patent Number	Issue Date<TD< TD>
60517155	Nov., 2003		<TD< TD>

Current U.S. Class:	**343/767** ; 343/700MS; 343/795
Current International Class:	H01Q 13/10 (20060101)
Field of Search:	343/795,797,767,700MS,741,866,867,803,895

Analysis

This patent describes a process of developing passive tags. The most important part of the tag is the conductive antenna. The orientation of the enhancing slots can have a large effect on the performance of the tag. We wanted to see how the technology in this patent works in various *situations to determine guidelines for improved efficiency. The techniques in this application helped in determining proper tag orientations for good reading results.*

United States Patent **7,301,458**

Carrender , et al. **November 27, 2007**

Method and apparatus for testing ***RFID*** devices

Abstract

A method and apparatus for testing ***RFID*** straps. Arrays of ***RFID*** straps in a roll-to-roll process are coupled to an array of test elements. RF programming and interrogation signals are frequency and time multiplexed to the ***RFID*** array. Return signals are detected to determine sensitivity and programmability parameters of the ***RFID*** straps.

Inventors: **Carrender; Curtis Lee** (Morgan Hill, CA)**, Hadley; Mark A.** (Newark, CA)

Assignee: **Alien Technology Corporation** (Morgan Hill, CA)

Appl. No.: **11/127,697**

Filed: **May 11, 2005**

Current U.S. Class:	**340/572.1** ; 235/438; 340/572.4
Current International Class:	G08B 13/14 (20060101); G06K 7/00 (20060101)
Field of Search:	340/572.1,572.4,572.7 324/667 235/492,437,438

Analysis

This procedure refers to testing of RFID tags that are mounted on "straps" and are fed through a testing apparatus from one roll to another, allowing for rapid testing rates. This could have been useful to us, if we were using procedures that called for testing tags in rapid succession. However, our test apparatus was designed for individual tag testing instead of straps of tags.

United States Patent **7,310,070**

Hardman , et al. **December 18, 2007**

Radio frequency identification shelf antenna with a distributed pattern for localized tag detection

Abstract

In accordance with the teachings described herein, an RFID antenna system is provided for detecting RFID tags on a display structure. The antenna system may include an antenna having an elongated conductor extending from a feeding point to a grounding point in a configuration that defines at least two loops and that has at least two conductor sections crossing each other at an intersection location between two adjacent loops, with a dielectric interposed between the conductor sections at the intersection location. The antenna may be attached to the display structure and may be located at a position on the display structure in relation to a reflective plane that allows the antenna to have a directional longitudinal radiation pattern that radiates into an area of the display structure that is configured to support a displayed item with an attached RFID tag.

Inventors: **Hardman; Gordon E.** (Boulder, CO)**, Pyne; John W.** (Erie, CO)**, Overhultz; Gary L.** (River Forest, IL)

Assignee: **Goliath Solutions, LLC** (Deerfield, IL)

Appl. No.: **11/508,466**

Filed: **August 23, 2006**

Current U.S. Class: **343/742** ; 340/10.1; 340/572.1; 343/867

Current International Class: H01Q 11/12 (20060101)

Field of Search: 343/742,867,700MS 340/572.1,10.1

Analysis

This apparatus is for mounting an RFID antenna reader on the same display structure as the products with the RFID tags themselves. There is a reflective panel near the display which radiates the antenna signals back onto the display it is mounted on, where they are received by the tags also mounted there. Our apparatus has a separate structure for the antenna and tag reader, and our testing was focused on normal tag reading with the tag and reader adjacent to each other rather than in a reflective setup.

United States Patent	**7,307,527**
Forster	**December 11, 2007**

RFID device preparation system and method

Abstract

An RFID device preparation system includes a printer combined with a short-range tester/reader. The tester/reader operatively couples to the RFID device using capacitive and/or magnetic coupling. By use of capacitive and/or magnetic coupling, good read characteristics may be obtained, while obtaining excellent discrimination between various RFID devices that may be in or near the tester/reader. Thus, RFID devices may be inexpensively and reliably tested one at a time, without appreciable interference or effect due to the presence of other RFID devices. The tester/reader may include electric-field and/or magnetic-field coupling elements that are configured to receive different signals, in order to test a variety of configurations of RFID devices. This may enable the device preparation system to accommodate various types and configurations of RFID devices, increasing versatility of the system.

Inventors: **Forster; Ian J.** (Chelmsford, **GB**)

Assignee: **Avery Dennison Corporation** (Pasadena, CA)

Appl. No.: **10/882,947**

Filed: **July 1, 2004**

Current U.S. Class:	**340/572.1** ; 235/449
Current International Class:	G08B 13/14 (20060101)

Field of Search: 340/572.1,572.7,572.8 235/449,450

Analysis

This patent describes a process for testing RFID tags of varying frequencies and characteristics simultaneously. This is made possible by a system of capacitive and magnetic coupling between the tags and the antenna that eliminates interference and other effects due to multiple RFID tags in the vicinity of each other. We were able to build on this idea in order to create our testing apparatus to be capable of testing a number of different RFID configurations, including mounting materials and environments, etc., which is what we were looking to do.

United States Patent **7,268,742**

Rahim **September 11, 2007**

Antenna arrangement

Abstract

An antenna arrangement including a first antenna module having a first antenna loop positioned in a plane for emitting a signal in a first spatial area, and at least one additional antenna loop positioned in substantially the same plane for emitting a signal in an additional spatial area. The arrangement includes at least one power source in communication with the first antenna module for providing current thereto. The first spatial area and the additional spatial area at least partially overlap, and the first antenna loop and the additional antenna loop are powered by the power source in a specified pattern. A method of identifying at least one item is also disclosed.

Inventors: **Rahim; Muhammad R.** (Monroeville, PA)

Assignee: **Mobile Aspects, Inc.** (Pittsburgh, PA)

Appl. No.: **11/378,001**

Filed: **March 17, 2006**

Related U.S. Patent Documents

Application Number	Filing Date	Patent Number	Issue Date<TD< TD>
60664166	Mar., 2005		<TD< TD>

Current U.S. Class: **343/867** ; 340/572.7; 343/742

Current International Class: H01Q 21/00 (20060101); G08B 13/14 (20060101); H01Q 11/12 (20060101)

Field of Search: 343/742,867,741,866 340/572.7

Analysis

This patent relates to testing RFID tags with two antennas. They are located in the same plane, overlap partially, and are powered by a single power source. There is then a greater chance of identifying the RFID tags or products without error. At the moment, our design apparatus is for testing with only one antenna, but this process could prove to be valuable for future improvements to the design, should the project adapt to include testing with more than one antenna reader.

United States Patent **6,104,291**
Beauvillier , et al. **August 15, 2000**

Method and apparatus for testing RFID tags

Abstract

The present invention provides a method and apparatus for testing RFID tags using wireless radio frequency (RF) communication. The method and apparatus allow RFID tags to be tested individually or in groups while they are in close proximity to each other (e.g., within the read range of the tag).

Inventors: **Beauvillier; Luc** (Richardson, TX)**, Brady; Michael John** (Brewster, NY)**, Duan; Dah-Weih** (Yorktown Heights, NY)**, Friedman; Daniel J.** (Tarrytown, NY)**, Moskowitz; Paul Andrew** (Yorktown Heights, NY)**, Murphy; Philip** (New Fairfield, CT)

Assignee: **Intermec IP Corp.** (Woodland Hills, CA)

Appl. No.: **09/167,026**

Filed: **October 6, 1998**

United States Patent	**7,161,489**
Sullivan , et al.	**January 9, 2007**

RFID system performance monitoring

Abstract

A system for monitoring and tracking performance of an RFID system collects information about parameters that may impact the performance of an RFID system. In various embodiments, the system may collect information from multiple nodes in the system. The system may perform statistical operations on the collected information to determine their impact on system performance. RFID system performance may be monitored at various nodes in the system, including, for example, individual reader units, environmental sensors, and programming stations. All collected information may be analyzed for the purpose of identifying parameters that contribute to reduced reliability of RFID system performance.

Inventors: **Sullivan; Michael S.** (Northborough, MA)**, Dubash; Jamshed H.** (Shrewsbury, MA)

Assignee: **The Gillette Company** (Boston, MA)

Appl. No.: **10/936,972**

Filed: **September 9, 2004**

United States Patent	**7,154,283**
Weakley , et al.	**December 26, 2006**

Method of determining performance of RFID devices

Abstract

A method of determining far-field performance of an RFID device, such as in or on a tag, label, package, film, carton, wrap, or a portion of any of these, includes performing near-field testing or measurement of the RFID device, and determining or predicting far-field performance based on the results of the near-field testing or measurement. The determining or predicting of far-field performance may involve calculating a measure of far-field performance based on near-field results or measurements. The predicted far-field performance may include any of a variety of performance factors, including range, sensitivity, frequency performance, read sensitivity, write sensitivity, peak operating frequency, and/or average sensitivity over a given frequency band. Using near-field testing results to predict far-field performance may allow use of compact testing facilities, in situ testing of RFID devices, and/or faster and/or less costly testing of RFID devices.

Inventors: **Weakley; T. Craig** (Simpsonville, SC)**, Forster; Ian J.** (Chelmsford, **GB**)

Assignee: **Avery Dennison Corporation** (Pasadena, CA)

Appl. No.: **11/359,669**

Filed: **February 22, 2006**

Evaluation of the Competition

In order to evaluate the competition, we must look at other anechoic chambers. The best shielding materials are copper, aluminum, steel, sintered ferrite, and geometric diffusers made of high density material. Metals tend to reflect the radio frequency waves along with other noise and do not diffuse them. This is not ideal for our application because the frequencies inside the apparatus will give inaccurate results. Metal shields are very expensive and would not make a cost efficient product. Proper geometries like the figures below would diffuse the frequencies; however, this type of shield is too large for our application.

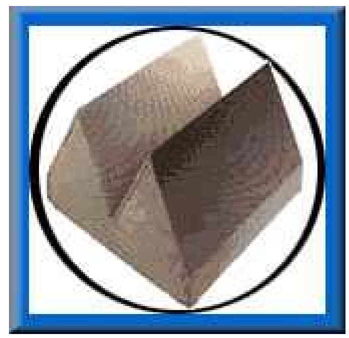


Figure 9

The shields chosen for our project are made by the TruProtect company. The shielding for diffusion of 1 GHz signals was chosen so that it would cover the frequency range of passive tags. This shield is rigid to add support to our frame and was made affordable due to support from Mr. Michael McDonald, the owner of TruProtect. Although our shields are made of aluminum, their multilayered design of cardboard and aluminum foil is designed to weaken the noise and trap it in between the layers acting as a diffuser. The specifications for the chosen shields can be found in the Appendix. The benefits of our shields are that they are affordable, absorb noise from both sides, do not reflect noise, and have thin geometry to allow for a spacious chamber for multiple testing.

When evaluating the competition we analyzed two companies, RA Mayes and Eckel. Both of these companies make anechoic chambers. These anechoic chambers like those shown below are extremely expensive, ranging from about $5000 to $7000. These chambers are not portable and require professional assembly, which will add more cost. They also have limited versatility, only allow near reads, are built specifically for one type of test, and have no software support.

ECKEL NOISE CONTROL TECHNOLOGIES

RA Mayes

Figure 10

We feel that our product, even with a limited budget, would gain market advantage due to the fact that it works as an anechoic chamber and that it is extremely cost efficient for companies. Our redesign of our project would add a slight increase in cost due to some higher quality parts, however, this increase would still place it far from the $5000 competition. Our strategy for marketing the product would be to market it together with the ThingMagic antenna and reader. This package would be very cost efficient, so that more companies would purchase it and perform their own tests on their specific tags. Due to the fact that it is collapsible, companies without much extra storage room would benefit from not having a large bulky anechoic chamber taking up space when it is only used on occasion.

Tyco Electronics

TRUPROTECT

Specifications Definitions

The customer requirements for our RFID system were first and foremost to be able to evaluate the performance of RFID tags. To achieve this, the data must be simple to gather and analyze in order to rate the performance of the tags accurately. The system must also be easy to operate and maintain. The test apparatus must be portable and operate safely. The entire unit must also be recyclable after its service life is over. For the apparatus to be moveable the frame sections and moveable joints must be able to withstand the rigors of moving the apparatus without the additional rigidity provided by the side, top, and bottom shields.

To meet these design specifications, we used an all-aluminum frame. The use of aluminum for the frame gives us a strong frame, but still makes the apparatus light enough to be easily movable. The MATLAB program to collect and analyze the data is easy to operate. For our system to operate as safely as possible, we choose an antenna and electronics that operate in the bandwidth of 902 - 928 MHz. In this range, if a person is exposed to RF radiation, that exposure can be time-averaged and, with no immediate re-exposure, any damaging effect will be reversible. To limit as much as possible any exposure to RF radiation emitted by the antenna, shields made of aluminum foil and cardboard laminate that are manufactured by TruProtect were installed to form a simple and economically feasible anechoic chamber. Our unit comes with a complete preventative maintenance protocol to ensure appropriate upkeep of the anechoic chamber and to ensure safe operation over its life cycle. When our system is no longer in operation, every component will be recyclable. The aluminum frame can be totally recycled, and the shields made of aluminum foil and the cardboard can also be totally recycled. The antenna and electronics must be recycled because of the pollution they can cause, but the materials they contain are too valuable not to be recycled anyway.

With our design specifications and choice of electronics and material, we believe we have meet and surpassed the customer's requirements for a safe, simple to operate, easy to maintain, and economically practical RFID system.

CUSTOMER REQUIREMENTS	DESIGN SPECIFICATIONS
COST	LESS THAN $1000.00
LIGHT WEIGHT	FRAME IS LESS THAN 20 LBS.
STRONG , DURABLE AND MOVEABLE	AT LEAST 350 N.
MAINTENANCE	COMPLETE MAINTENANCE PROTOCOL

SAFETY	TruProtect SHIELDS

Conceptual Design

Conceptual Design

Throughout the project, there were a number of phases of concept generation and design. Included in this section is a separation of areas where we came together to create options for the paths that our project would follow. It was necessary to generate concepts for our testing apparatus, testing procedures, and evaluation of the data we received.

Major concepts were generated in the following categories.

Testing apparatus:

Structure that would house the reader and antenna

Be large enough to perform testing inside

Must have the ability to read tags in near and long range

Have a grid table to use a reference while doing short range testing

Have a means of measuring the table height and distance from the reader

Have the cage insulated with shields to control RF noise in the area

Must be easy to store

Must be easy to build

Portable

Use recyclable materials

Be safe for operation mechanically and protect user from extended RF exposure

Testing procedure:

Test orientation in relation to the face of the antenna

Test on material samples

Test for baseline to determine optimum performance

Observe number of reads per a set unit of time

Stagger in predetermined distances for the unit of time in long range testing

Use motion in testing, to simulate packages or products on conveyors

Test the capabilities of the antenna

Procedure for setting up the equipment and using the Yagi program

Data evaluation:

Create a data logging program to sync with the reader program

Create a data logging format for operator

Create a program for comparing performance decreases

Program plot performance for easy comparison to baseline performance

Concept Evaluations

Testing apparatus:

For the frame, we worked in as many concepts as possible to make the device versatile, effective, and user-friendly.

The structure houses the antenna, reader, and computer all together. This feature allows for easy operation and an organized working space. This also allows for fast operation, as there does not need to be a large amount of time dedicated to setting up all of the equipment. That time would take away from productive work and would be a waste for the operator. The table height for the reader and computer are set comfortably at forty-two inches.

The frame has an internal space of 6 x 4 x 4 feet with a volume of 96 cubic feet. This space allows the user to place a large array of other testing devices in the cage to utilize the chamber's ability to block out RF noise.

The ability of the apparatus to read at long and short ranges is the most important feature that provides such versatility. The antenna and reader can operate inside of the completely sealed chamber for short range reading without interference. The antenna can also be mounted horizontally to read in the long range. With the shield parallel to the antenna, the area in which the antenna can read is larger. This focus of the antenna's read range limits the ability of the antenna and reader to recognize tags in the vicinity of the test.

The use of the grid table was decided to be unnecessary for the apparatus. As our understanding of the tags increased, we discovered that the capabilities of the tag and the antenna's performance would not vary significantly within the confines of the grid when all other variables remain constant.

A measuring tape is required to keep the long and short range distances accurate. The key to measuring is keeping standard distances in the tests. If possible, the long range distances can be marked on the floor in the direction of the read.

The insulating shields are a very important part of the apparatus. The shields are manufactured by TruProtect and are made of varying layers of aluminum and cardboard. The RFI shields block out the existing radio frequency noise present in the area from affecting the tests within the chamber. By keeping the noise out, the antenna within the apparatus will only observe the tags that are desired to be read. The shields also absorb waves. This causes the scatter of radio frequency waves within the chamber to be diminished and allows for consistent testing.

We were able to create a design to make the device easy to store. When folded into a non-operating state, the device takes up a foot print of only 2.5 x 4 feet. The frame stores the antenna reader and all of the shields together.

The build portion had to be simple enough to only require two people to complete the assembly. It is necessary for the customer to build the frame to keep the price affordable. If the device were to be prebuilt, the cost would rise substantially and the costs of shipping would rise as well. The instructions included are clear and easy to follow. The most complicated steps in construction are screwing in the bolts and zip tying the wires in place.

We wanted to make the apparatus portable by using casters. Unfortunately the casters had to be removed from our order to keep our expenses down. Our final product would include the casters so that the device can be moved when setup or in collapsed form.

The entire frame is made of recyclable aluminum. The panels contain aluminum sheeting and cardboard that would need a proper disposal.

The structure is very secure and safe. The frame contains no dangerous materials or harmful components. The shields protect the user from any harmful exposure to radio frequencies and allow for no restrictions on the person performing the testing.

Testing procedure:

Test orientation in relation to the face of the antenna is the major consideration in testing. This is worked into the testing procedure in evaluating the performance of each tag. Optimal performance of a tag comes when the tag is parallel to the antenna exposing the entire cross-section of the tag's antenna. Adjusting the orientation causes the performance to drop considerably.

Testing on material samples was the goal of our project. Our program evaluates through comparison the optimum performance of a tag through testing with the performance of a tag through the same tests while mounted to a certain material sample.

Testing for a baseline optimum performance is crucial to the previous concept. To understand the degradation of the performance in a certain operating situation, the user must know the potential of the tag. The program we created holds the values of performance in the testing and can compare drops in performance when applied to products.

As a part of our test, we understood that the equipment had limited capabilities. The reader and antenna can only detect whether a tag is being read or not. We then decided that we would observe the number of reads per unit of time. The antenna and reader read at a certain rate but as interfering materials or distance changes, the number of reads decreases in that amount of time.

While testing and observing reads per unit of time, the tests must be done at certain length intervals. Depending on the user's interests or parameters they are searching for, the distances will change. The key is that during testing, to understand degradation of performance, the testing distances must be uniform.

We had a desire to test tags in motion to emulate packages and products in motion while being read. Due to a limit of resources we were not able to fully evaluate the possibility of installing a system to create motion of the tag and material to which it is mounted.

As a standard, it is important to understand the capabilities of the reader and antenna included in the system. We implemented a testing standard and evaluation system in our program to know how an antenna can operate under ideal situations. This is important because stronger antennas will produce different results when testing and it is not feasible to compare testing results from one antenna to results from another.

A procedure for setting up the equipment and using the Yagi program was created as a user guide. In addition to building the apparatus, we intended to provide instructions for operation. The guide covers setting up the electronic equipment and operating the reader program.

Data evaluation:

We were unable to create a data logging program to sync with the reader program. The online tool used to operate the reader is a standalone program. It was not possible for us, given our limited programming knowledge, to create a program that would analyze the data automatically.

We were able to create a data logging format for an operator using Microsoft Excel. This allowed the user to manually take down the information from the reader program. Depending on the test, the format will specify read distances and an area to log the number of reads.

We were also able to create a program for comparing performance decreases. The program stores optimal performance operation of a tag and can compare that information to any other tests performed. This set up is very easy for a user to operate and creates clear outputs in graphical form of the tag degradation.

Detailed Product Design

Detailed product design

Alpha design phase:

The first design phase was a realization of concepts. The drawing designs only encapsulated our desires but did not include true specifications. We had our design set with the following features.

-6' x 6' x 4' cage

-RFI shielding

-Ability to test at short and long ranges

-Table grid to view placement and orientation

-Measuring system on the frame to observe read distance

This preliminary design had many flaws. There was minimal adjustment available to the apparatus. The cage was also difficult to store when not in use. The design did not take into consideration the building materials or their requirements. Shown below is our Alpha design.

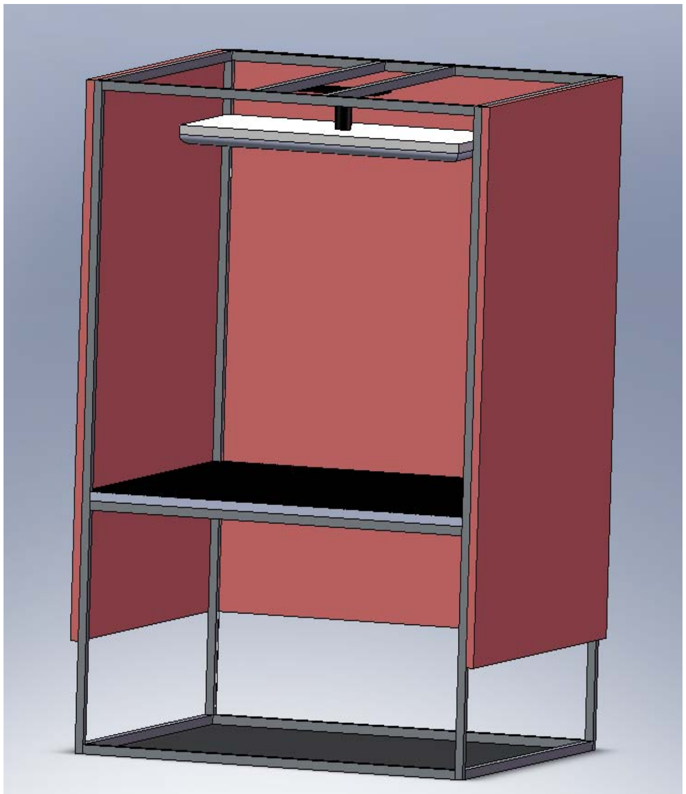


Figure 11

Beta design phase:

This second design phase encapsulated all of our desired concepts. In the second phase we considered build option materials, strength, and versatility. The Beta design had the following features.

-Ability to collapse for storage

-Strong joints with supports

-Made of aluminum t-slot extrusions

-Has the ability to house all of the electronic components

-Portable with casters

The less impressive part of the second design phase was the cost. Due to funding restrictions and creating a product that would be affordable, another design phase would be necessary. The joint supports, casters, and hardware were far too expensive. The Beta design phase is shown below.

Figure 12

Gamma design phase:

This is the final design phase that includes the concepts we decided to be the most important. This phase of design had the largest impact from the materials we chose. We decided to use the aluminum T-slot extrusions for the frame. To attach the joints, we decided on an anchor system from McMaster Carr. This decision resulted in the requirement of countersinks in some of the members. This phase also included the shielding that we decided to use. With the support of TruProtect we obtained the ½ inch 1 GHz shields. The shields are composed mainly of aluminum and cardboard. The shields reflect and absorb the RF noise that would affect our tests and are the main factor in creating an effective anechoic chamber. The following features are included.

-Easy to store due to collapsible design

-Houses all instrumentation

-Blocks out RF noise in the testing vicinity for short range testing

-Focuses the antenna's read range for long range testing

-Strong joints due to anchors

-User-friendly workspace

-Includes user interface for testing analysis (see Appendix)

-Includes building instructions (see Appendix)

-Includes instructions for setting up the electronic hardware (see Appendix)

All of the extrusion and shield components in the design are described in the appendix. Shown below is the finished frame with all of the shield components attached.

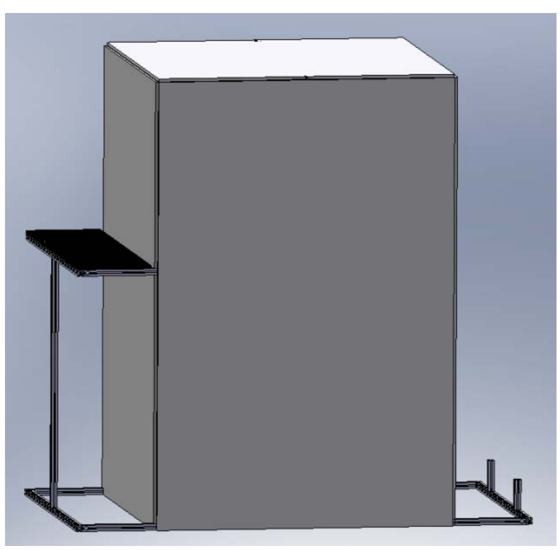


Figure 13

Engineering Analysis

An effort was made to use the Instron testing machine in order to test the tensile strength of the anchors we purchased. Due to lack of equipment for the Instron machine, we were not able to accurately test the anchor strength. We did not have the appropriate clamps to clamp the T-slot extrusions so we jerry-rigged them to the best of our ability. The screw was able to withstand 3500 Newtons of tensile force before the clamps began to slip. The weak point of the zinc anchors were the ¼ inch 20 low carbon steel bolts. The minimum ultimate tensile strength (UTS) of the bolt is 9,310.74 N, with a yield strength of 5,605.44 N.

When a one-foot T-slot extrusion bar was loaded with 200 lbs. and supported at each end, the maximum deflection was only 1 mm. This is a far greater load than the frame will need to handle during normal operation. From the equations, a distributed load of 200 lbs. would produce an even smaller deflection. The worst-case scenario would be a simply supported beam as shown in the third figure. Even with a concentrated load of 200 lbs. on the end, the beam would still only deflect 17 mm. This is a very small deflection for such a large weight. Also, none of our T-slots are set up to take a load in this fashion. Given this information, it is claimed that the frame of our apparatus will be able to endure the loads of all attachments.

$$\frac{L^3 * W}{48 * E * I} = D$$

$$\frac{L^3 * W}{304 * E * I} = D$$

$$\frac{L^3 * W}{3 * E * I} = D$$

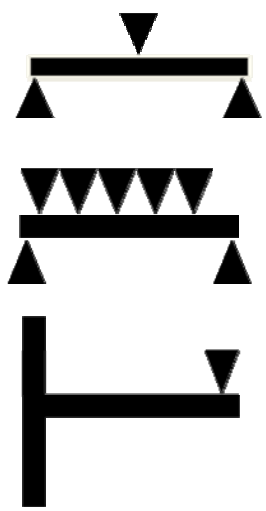


Figure 14

Where

L = Length in mm (arbitrary length)
W = Force in Newtons (arbitrary force)
E = Modulus of Elasticity in N/mm^2 (70,326.5 N/mm^2) (from 80/20 Inc.)
I = Moment of Inertia (6826 mm^4) (from 80/20 Inc.)
D = Maximum deflection of the beam in mm

A finite element analysis on the T-slot extrusions was also desired. We simulated what would happen if the beams were fixed on each end and loaded with weight across the member. The member was 23 inches long, simulating the collapsible bars, and loaded with 1150 lbs. The correct Young's Modulus of 10,000,000 psi and a Poisson's Ratio of 0.33 were used. Although Figure 15 looks like it is deflected a lot, this is simply due to the exaggerated view rendered by the Abaqus FEA program. The actual maximum deflection of the center of the beam was 0.0723 inches.

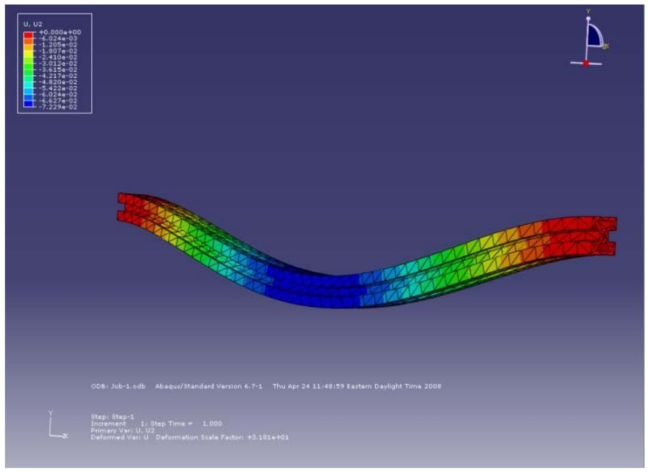


Figure 15

Next, we analyzed how the stresses would look if the bar were compressed axially on one end and fixed on the other. The 42-inch bar was loaded with 1000 pounds of force. This bar represents the bar supporting the table. The results in Figure 16 show that the bar would deflect 1 inch in either the x- or y-direction. This bar will never have to withstand 1000 pounds of axially loaded force. This test proves that the frame for our apparatus is sturdy enough to hold all of its intended contents.

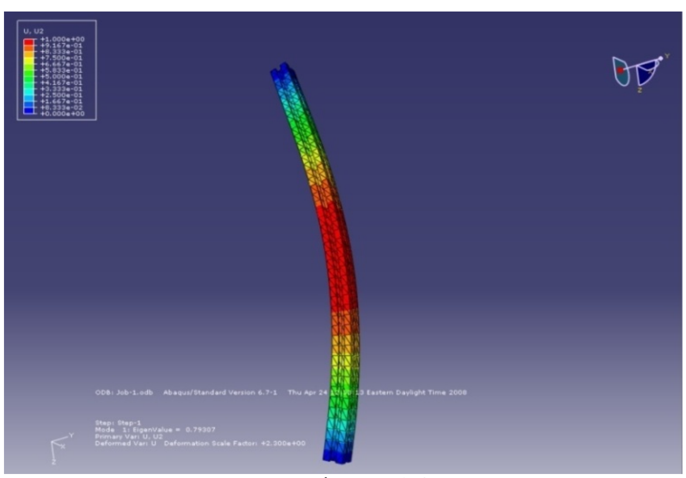


Figure 16

Manufacturability

Although our product is made up of numerous parts, the manufacturing process will be very inexpensive, require a short time to complete, and will need only simple machining. Many of our purchased items fit together and require no manufacturing whatsoever. The T-slot extrusions had to be cut to the correct lengths and counter-bored so that the zinc anchors could fit into the T-slots. The hinges needed to be bored to allow them to be screwed into the frame. The shields were cut to appropriate lengths and then notched out to fit snugly to the frame. A ¼ inch piece of plywood was cut to 1 x 4 ft, painted black to make it more appealing to the eye, and then drilled to allow it to be attached to the frame. The remaining manufacturing steps consisted of the assembly of the anechoic chamber. Everything needed to be screwed in using ¼ inch 20 screws. This took the most time. Sealing the chamber through use of aluminum tape is also necessary. The user must determine how the chamber will be used – for long or short range testing – to decide which shields are going to be used.

If we were to redesign our project, a lot of the manufacturing would be unnecessary. We could use more efficient T-slot connectors and thus not have to bore holes for the anchors. Manufacturing for production would be limited to simply cutting the proper length of each extrusion and marking the bars to coincide with the instructions. While production would decrease, the number of hardware components would increase, and build time for the customer would increase as well. The hardware could be obtained in high volume to keep our and the customers costs as low as possible. With these improvements, our product would be able to be mass produced very easily. We would probably not need to mass produce this product, however, if all major companies that use RFID tags wanted to purchase our anechoic chamber we would be able to accommodate for them.

Manufacturing our project

1. Cut 8-foot extrusion members to lengths of 6 ft, 4 ft, 2 ft, 1 ft, 6 inch, and 23 inch.
2. 3/8 inch holes were bored at the ends of the extrusions to fit the zinc anchors.
3. Drilled ¼ inch holes into the hinges to enable them to fit to our frame.
4. Cut and painted wooden table top.
5. Drilled holes to attach table top to frame.
6. Cut 8 foot shields to lengths of 6 ft and 4 ft.
7. Drilled out holes to attach shields to frame.
8. Cut out corners of shields to fit the frame snugly.
9. Color code and label all parts for easy assembly.

Future manufacturing plans

1. Cut 8 foot extrusion members to lengths of 6 ft, 4 ft, 2 ft, 1 ft, 6 inch, and 23 inch.

2. Cut the nylon sheets to 1 x 4 ft and drill appropriate holes to attach to the frame.
3. Cut 8 foot shields to lengths of 6 ft and 4 ft.
4. Color code and label all parts for easy assembly.

Testing

Below are the instructions for installing the antenna and reader, connecting the reader to a computer, and setting up the computer. Included in the Appendix is a PowerPoint presentation created by Alex Merlo to show each step of the instruction (Appendix)

Instructions

Installing the antenna and reader

1. Plug in the 24V AC adapter to the back of the reader
2. Connect the coaxial cable to R-1 on the back of the Mercury4 reader
3. Connect the other end to the antenna
4. Connect the coaxial cable to T-1 on the back of the Mercury4 reader
5. Connect the other end to the remaining port on the antenna

Connecting a PC to the reader

1. Connect the Ethernet crossover cable to the PC and to the reader

The PC's TCP/IP Setup for Windows XP

1. Click on the Start Menu, then on Control Panel.
2. Double-Click the Network Connections icon.
3. Disable the PC's Wireless Connection.
4. Double-Click the Local Area Connection icon. The local Area Connection Status window appears.
5. Click the Properties Button.
6. Scroll down to the bottom of the list and select the Internet Protocol (TCP/IP) item.
7. Click on the Properties Button.
8. The Internet Protocol (TCP/IP) Properties window appears.
9. Select the radio button labeled "use the following IP address."
10. Enter the following settings:
    IP address: 10.0.0.102
    Subnet Mask: 255.255.255.0
    Default Gateway: 10.0.0.1
11. Click OK to save and exit the window
12. Click OK at the Local Area Connection Properties Window

Preliminary testing

Abstract

This experiment was performed to help aid students who are to perform similar tests in the future. More specifically, it was designed to find a testing procedure that is user-friendly and capable of generating reproducible results. Another function is to inform the students of the results themselves. It is hoped that with this knowledge, students will be able to quickly and efficiently setup a testing structure of their own without any time lost due to trial and error mistakes.

A number of procedures were carried out, varying several parameters in an attempt to inform and educate students on which factors had an impact on the test results. These factors were identified and are discussed in detail in the report. A graph of Signal Power vs. Range was produced for three tag orientations from the test data. This can guide them on how to choose a power setting for a given distance and also serve as independent data to which the students can refer and compare. As a final result, a procedure was developed that the students can follow. It contains areas of potential risk that could produce inefficient experiments with poor quality data.

List of Equipment

Before any testing could begin, certain equipment needed to be procured. The list of required tools is as follows.

1. (1) Laptop Computer
2. (1) RFID reader (ThingMagic's Mercury4)
3. (1) RFID antenna (Tyco Electronics / MA-COM 902-928 MHz)
4. (1) Ethernet cable (At least 4 ft)
5. (1) RFID tag (NXP Gen 2 tag)
6. (1) 24V AC converter
7. (2) Coaxial cables
8. (1) Distance measuring device
9. (1) Spacious room (Gilbreth classroom at URI)
10. (1) Assistant

Setup Procedure

Once all of the necessary equipment is at hand, the following procedure is used to set up and begin using the testing software.

1. Find a large, spacious room. The room should have at least 30 feet of testing space without any obstructions (especially metal)
2. Place all of the equipment at one end of the room near an electrical wall socket
3. Take a coaxial cable and attach one end to the female connection on the back of the antenna and the other end to R-1 on the reader
4. Take the other coaxial cable and attach one end to the other female connection on the back of the antenna and the other end to T-1 on the reader
5. Plug the AC adapter into the socket and reader
6. Start up the computer and attach the Ethernet cable to it and the reader
7. Setup the computer to interface with the MercuryOS software and ensure the antenna is connected properly (Yagi .ppt)
8. Position the antenna so that it faces down range of the test room, right side up
9. Run the Yagi software to ensure the reader can identify the tags (Yagi PPT)
10. Run a measuring device from the antenna to the end of the room (should be at least 30 feet)

Testing Procedure

Below is the procedure that was used in this experiment. It does not need to be followed explicitly to perform other tests, but contains useful information to do so.

1. Set the signal power to maximum (Yagi .ppt)
2. Walk backwards until the reader can no longer identify the tag. While testing a tag at any signal power and efficiency, make sure that:
    a. An assistant can tell you when the reader loses the signal from the RFID tag
    b. The tag position is directly in front of the antenna at all times
    c. The tag retains the same orientation that is being tested
    d. There are no obstructions between the reader and the tag. Avoid covering the tag with a hand while holding it and also holding the tag close to the tester's body.
3. Measure and record the distance.
4. Walk forwards slowly until the tag is read at 100% efficiency (Yagi .ppt)
5. Measure and record the distance.
6. Slowly begin to walk backwards until the tag is read at an efficiency between 0-100%
    a. Have the assistant count the amount of times the tag is read out of ten total cycles (Yagi .ppt)
7. Measure and record the distance.
8. Change the tag orientation and repeat Steps 1-7 until all orientations have been tested.
9. Change the signal power and repeat Steps 1-8.

Results

After conducting the RFID tag testing, the tag's performance exhibited certain behavior. Graphs 1-6 were created in such a manner that these characteristics are easily viewed and compared with each other. The first three graphs show the difference in performance of the three tag orientations. Each orientation graph shows the distance* versus the read efficiency from the reader at three different signal power settings.

The higher signal power settings exhibited predominantly larger read ranges throughout these tests. However, the 24 dB signal gave a larger range than the 32.5 dB signal at Orientation B. This is discussed later in the report.

*All measurements taken to the nearest ¼ foot.

Figure 17 – Orientation A

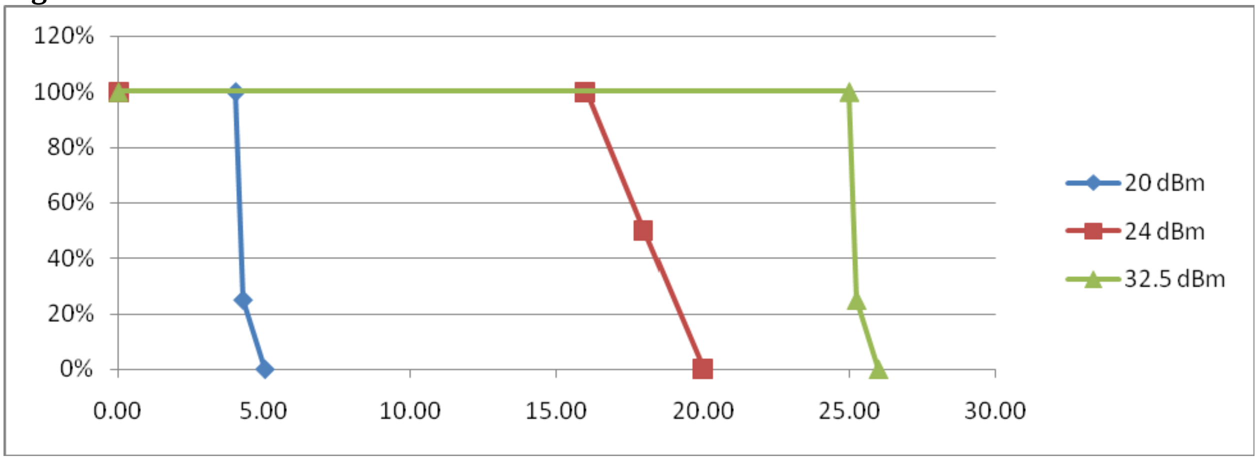


Figure 18 – Orientation B

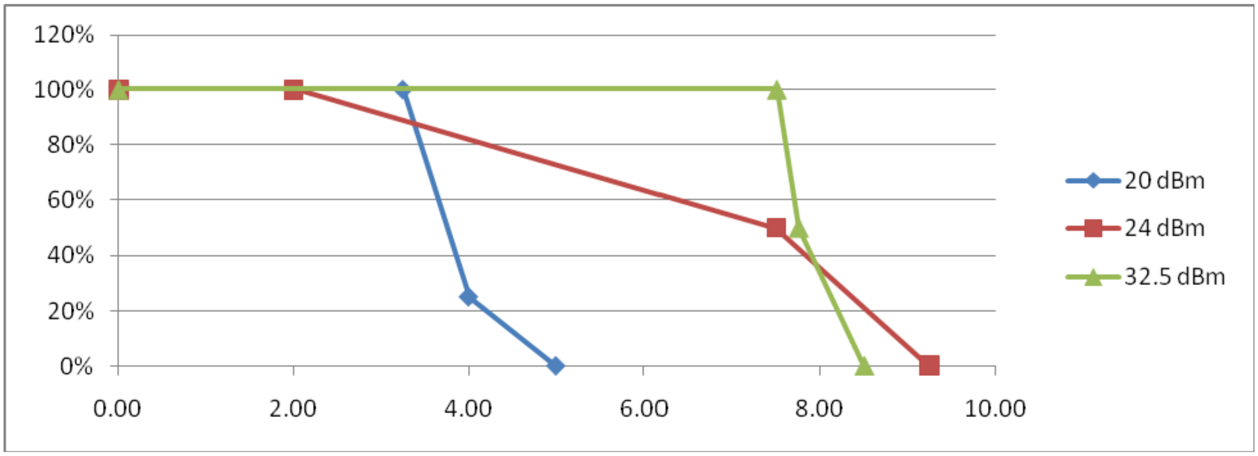
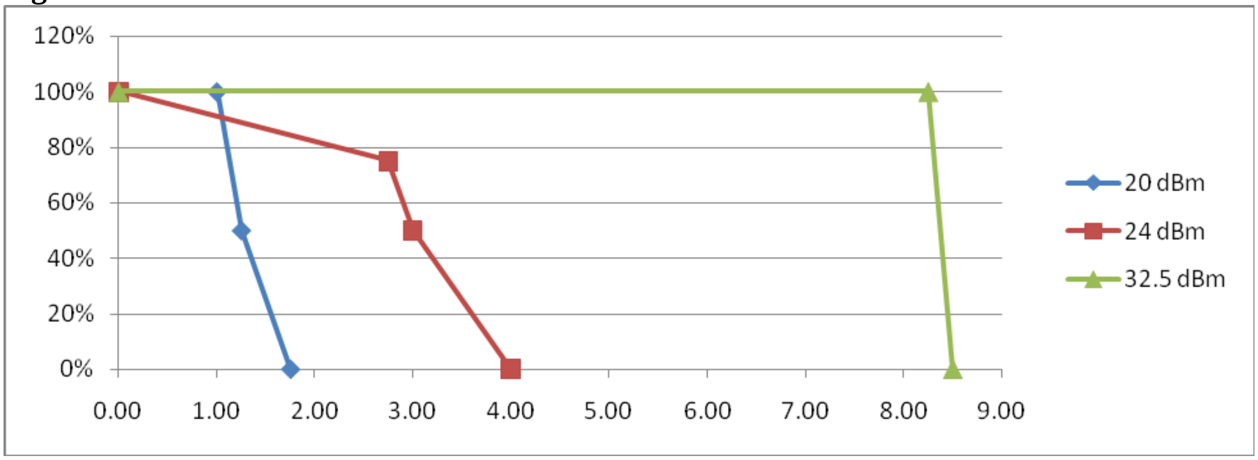


Figure 19 – Orientation C



This second set of graphs shows the difference in performance of the three orientations at the same signal power setting. They do this by showing read range versus the read efficiency from the reader while the signal power remains constant instead of the tag orientation.

The results show that the orientations with the greater cross sections perpendicular to the signal had the larger ranges. This gap seemed to narrow down as the signal power was lowered. Orientations A and B gave the same maximum read range for the 20 dB signal setting.

Figure 20 – Signal Power 20 dB

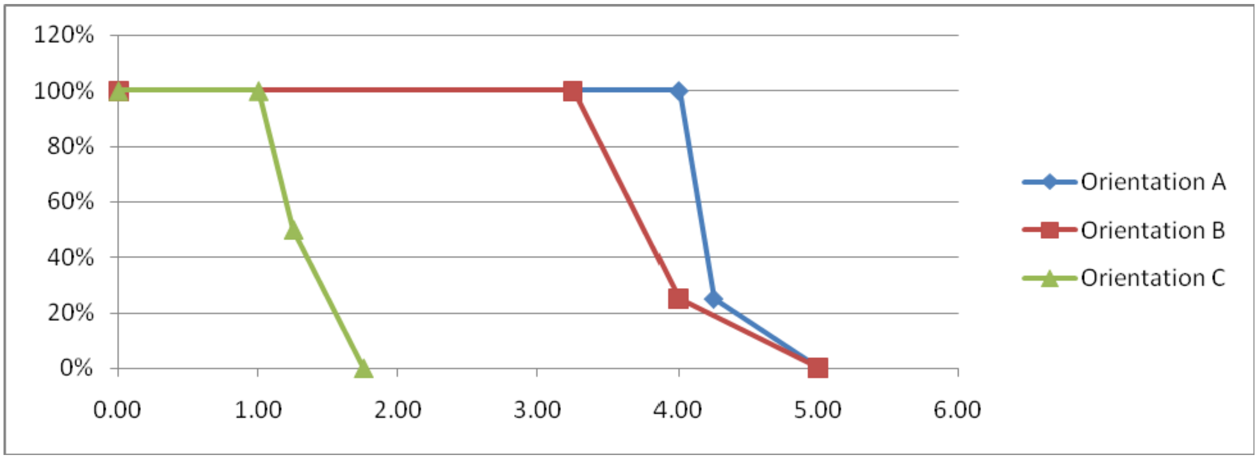


Figure 21 – Signal Power: 24 dB

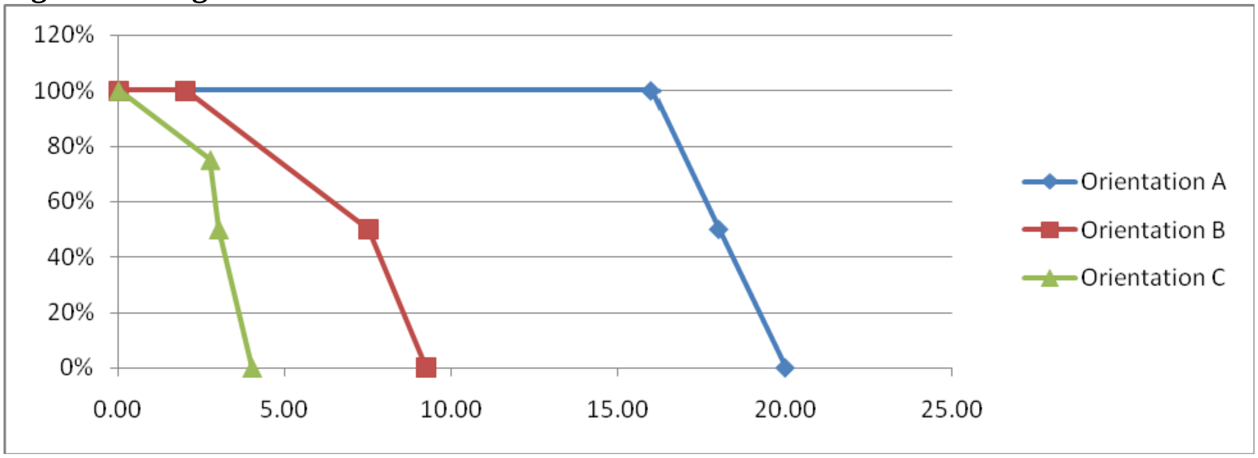
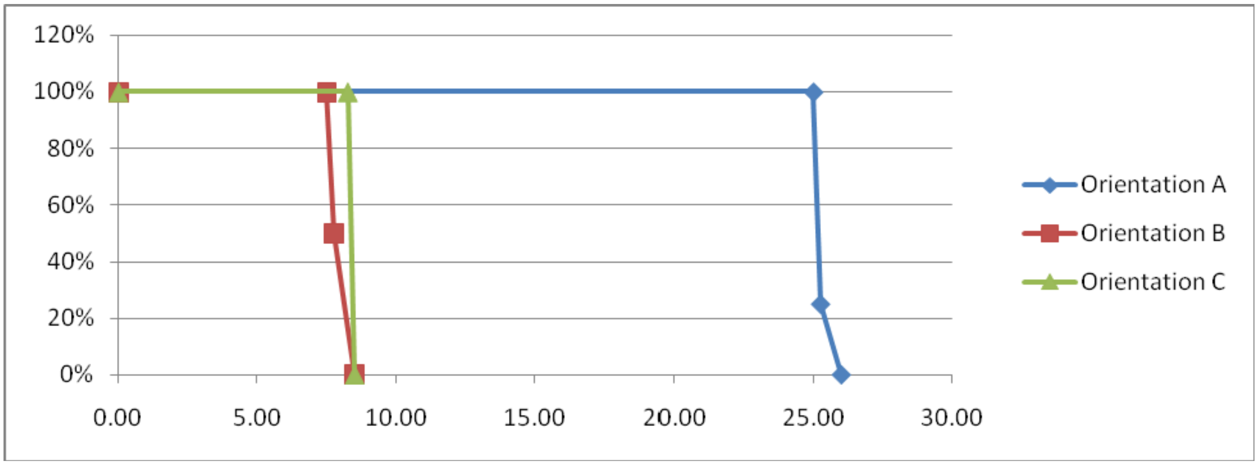


Figure 22 – Signal Power: 32.5 dB



Discussion

As can be seen from graphs 4-6, where the tag orientation is constant while power setting is variable, the tag orientation played a major role in its performance. Orientation A exhibited the best results being read at a distance of 25.5 ft from the antenna at the maximum signal power setting. Orientations B and C, however, displayed far less range at the same power settings as A. Orientation B was only able to read at up to 33% and 46% of orientation A at signal power settings of 32.5 and 24 dB while orientation C was only able to read up to 35%, 20%, and 33% of Orientation A at the three power settings.

This dramatic change in performance can be attributed to the antenna geometry embedded in the tag. The antenna is designed such that it becomes energized with the signal sent out by the reader through the antenna. The tag then uses this energy to send out information stored on its chip. However, the amount of energy that the tag antenna is able to take depends on two variables – the signal strength and amount of flux through it. Since we are trying to describe the discrepancies in tests with the same strength but different orientations, flux can be the only culprit.

The amount of energy that the RFID tag can withstand depends on the flux though its antenna. If the antenna does not receive enough flux, the tag will not be able to transmit its information to the reader. The amount of flux that the antenna receives only changes with tag orientation since the tag is directly in front of the antenna at all times with a constant signal strength. That being said, the amount of flux that the antenna receives is directly proportional to its cross-sectional area perpendicular to the direction of the signal. At orientation A, this area is at its maximum, therefore explaining why it has the greatest read range. Orientations B and C have significantly reduced cross sectional areas perpendicular to the signal source. Orientation C actually has a significantly smaller amount than B does. This area difference is the reason that Orientations B and C have read ranges as small as 20% of Orientation A at the same signal strength.

Another characteristic that was observed during the testing was the amount by which the read range decreased while reducing the signal strength. By changing the signal power strength from 32.5 to just 20 dB, the read range at Orientation A dropped from 25.5 ft to 5 ft. This range reduction is over 80% from only a 38.5% reduction in signal power. Similar observations can be made at the other orientations.

This is a strange phenomenon that cannot be fully explained at this time. Generally, signal strength in a multi-directional antenna is inversely proportional to the range at which it is being tested. This is obviously not the case here. However, it is important to note that the antenna used was one-directional, not multi-directional. Another explanation might be that the lower power settings are not strong enough to fully energize the antenna. This could be the case if the antenna provided for testing was not properly matched to the reader.

Additionally, it should be observed from the data that signal power settings below 20 dB cannot provide enough read range for the students' short range testing. Any power setting below 20 dB will result in a read range of less than 4 feet for any tag orientation. This, of course, would not be sufficient for testing within the test apparatus proposed by the students. However, both Orientations A and B were able to have 100% read efficiency within 3-4 ft at this power level. This setting is recommended as a minimum for their testing.

Other observations were also made during the test procedure that affected the tag performance. These included the position of the tag with respect to the reader antenna and physical obstructions located near the tag. When the performance testing was performed, it was noted that the maximum read range at all efficiencies could only be observed when the tag was in a narrow window of space. This window was approximately a 2 by 2 ft square that was directly in front of the reader antenna for all orientations. This can be attributed to two factors – signal transmission range and tag antenna to signal orientation.

The transmission range could explain this situation depending on the curvature of the signal. Many antennas emit a signal in a spherical shape (multi-directional), but this is probably not the case with this directional antenna. The shape could be more elliptical, having a greater degree of curvature at its end. Such a degree in curvature would explain the small window in which efficiency consistently remained at its maximum.

The curvature of the signal also affects the amount of flux through the tag when it is outside this small window. This occurs because the signal does not remain perpendicular to the tag antenna when outside this window, even if the tag orientation remains unchanged. If one continues to move the tag outside this window, the orientation to the signal can effectively change. If testing is being performed originally in orientation A, it can cross between A and C if moved horizontally or between A and B if moved vertically. This behavior may explain the data from Figure 2 where Orientation B is has a greater range with the lower signal setting. Perhaps in that test, the tag was not being held perfectly at Orientation B. It may have been held so that it was partially in Orientation A and the flux was increased resulting in a higher read range.

Lastly, obstructions of any kind seemed to interfere with the read range of the tags. If the hand that was holding the tag was covering part of the tag antenna, the range would decrease as a result of reduced flux. This also occurred when aluminum foil was present. Although not part of the original intent of the tests, aluminum was introduced to see if a change in range would occur. Range disappeared completely when the tag was enveloped in the foil, but it also decreased noticeably when the foil was placed next to or in front of the tag.

Recommendations for future testing:

1. When long range tests are to be performed, make sure that it is done in a very spacious room. The read range of the tags at maximum signal power is greater than 25 feet, so a room with up to 30 feet of test range should be sufficient. Since such tests will probably not occur in a room with a desktop computer, be sure to bring a laptop computer.
2. If short range tests are to be performed, it is suggested that a signal power setting of no less than 20 dB be selected. This is because the NXP tags were proven from the data to be unreadable at 100% efficiency at such signal settings. The short range distance that led to this suggestion is based on the 4 ft x 4 ft aluminum testing structure proposed by the students. It was determined that the tags were to be read at 100% efficiency within the structure in order to gather accurate data when compared with the interference materials.
3. During the MercuryOS setup and subsequent testing, leave the Query screen in the "hide raw" mode. This can be viewed (Yagi .ppt) as a small button in the upper right hand corner of the screen. It will be in the correct mode when this button says "show raw" This allows the tester to see the tag being read in real time. While in raw mode however, reads are not continuously counted. The computer creates a new line every cycle. Previous reads will be separate from each other and will be scrolled up the screen as the read cycles increase. This makes quantifying the data very difficult, if not impossible.
4. While testing and taking data, one wants to eliminate as many sources of error as possible:

   A. During testing, keep the tag directly in front of the reader antenna at all times. This ensures that the tag antenna is receiving the proper amount of signal flux through it. This is important because of the radius of curvature of the signal that is transmitted from the reader antenna. Once a tag is moved slightly out of this direct window, the orientation of the signal to the tag antenna effectively changes because they are no longer perpendicular. This can decrease the range if at Orientation A, extend the range of C, or do either to the range of B. If, for some reason, the tester cannot place the tag directly in front of the reader antenna, the tester should keep the tag in the same location between the tests with and without interference materials.
   B. If one is going to test the difference in performance of a tag with and without interference materials, it is important to maintain the same tag orientation throughout those tests. This is again due to the tag antenna to signal orientation. This importance is backed up by the test data from this experiment. It clearly shows significant range differences between orientations due to the amount of flux through the tag antenna.
   C. Do not perform performance tests with interference materials on the edge of the read range for the signal settings chosen. Carrying out tests in such a manner may exaggerate test results. This is due to the sharp decline in read efficiency at the read range edge. As can be seen from the data graphs, the range in which read efficiency changes from 100%-0% is on the order of one foot. Testing a tag on such an edge may produce 100% efficiency without a material, but with the interference it may not

read the tag at all. If the tag is moved well within the edge (1-2 ft), testing with the interference will most likely produce quantifiable results.

D. Try to avoid any nearby objects that are not meant to be part of the test. Obstructions made noticeable differences in read efficiencies during this experiment. This included human hands that were holding the tag too closely (covering parts of the antenna). If the tag is to be placed on a pedestal for long range tests, ensure that the pedestal does not block the tag antenna from the signal. Also, when aluminum foil was placed near the tag, it made changes in read efficiency. Test the changes in read efficiency while in the aluminum based test apparatus to see if it has a large effect on results during the short range tests.
E. After recording data from performance tests without the interference materials, compare results with the data table in the reference section of this report. If your results are not comparable (short), troubleshoot the test setup to identify any issues that may be causing this discrepancy.
F. Lastly, attempt to use the same tag in performance tests with and without interference materials. Small variations in the antennas during manufacturing may have an effect of the read range of the tags. Switching tags between tests could produce inaccurate results.

Data table from experiment:

Signal Power (dBm)	Orientation A		Orientation B		Orientation C	
	Efficiency	Range (ft)	Efficiency	Range (ft)	Efficiency	Range (ft)
20	0%	5.00	0%	5.00	0%	1.75
	25%	4.25	25%	4.00	50%	1.25
	100%	4.00	100%	3.25	100%	1.00
	100%	0.00	100%	0.00	100%	0.00
24	0%	20.00	0%	9.25	0%	4.00
	50%	18.00	50%	7.50	50%	3.00
	100%	16.00	100%	2.00	75%	2.75
	100%	0.00	100%	0.00	100%	0.00
32.5	0%	26.00	0%	8.50	0%	8.50
	25%	25.25	50%	7.75	100%	8.25
	100%	25.00	100%	7.50	100%	0.00
	100%	0.00	100%	0.00		

Figure 23

Quick reference for setting signal power for a given test range:

Test Range (ft)	***Signal Setting (dBm)***
< 4	20
4 - 14	21 - 24
14 - 23	25 - 32.5

Figure 24

Mercury4 operating system instructions power point presentation:

Yagi-How-to.ppt

Depiction of the Orientations:

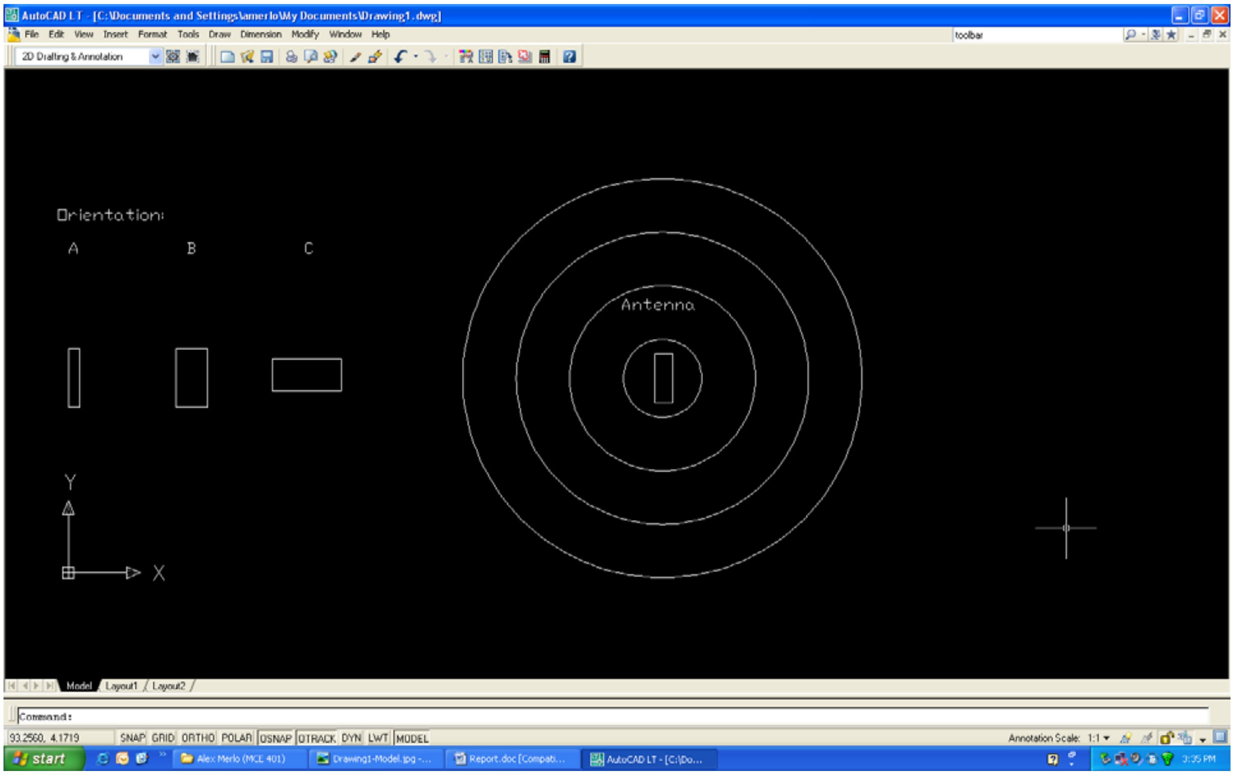


Figure 25

Electrical Properties of Materials

During the testing of RFID tag performance, interference proved to be one of the most important limiting factors. Even though environmental interference was the main setback during the testing of tags, in this section we refer to the different electrical properties of materials that would interfere with the signal.

An important material characteristic is the dielectric strength. Dielectric strength is a measure of the electric strength of insulating materials at certain power frequencies (48 Hz to 62 Hz), or the measure of dielectric breakdown resistance of a material under an applied voltage. The applied voltage just before breakdown is divided by the specimen thickness to give the value in kV/mm. The surrounding medium can be air or oil. The thickness dependence can be considerable; all values are reported at specimen thickness. Many factors influence the values:

- Thickness, homogeneity, and moisture content of the test specimen
- Dimensions and thermal conductivity of the test electrodes
- Frequency and wave form of the applied voltage
- Ambient temperature, pressure, and humidity
- Electrical and thermal characteristics of the ambient medium

Also, when an insulating plastic is subjected to a voltage, some portion of the resultant current will flow along the surface of the plastic molding, if there is another conductor or ground attached to the same surface. Surface resistivity is a measure of the ability to resist that surface current. It is measured as the resistance when a direct voltage is applied between surface mounted electrodes of unit width and unit spacing. Reported in Ohm - sometimes called ohms per square.

Similar to surface resistivity, materials also exhibit volume resistivity. It occurs when an electric potential is applied across an insulator, the current flow will be limited by the resistance capabilities of the material. Volume resistivity is the electrical resistance when an electric potential is applied between opposite faces of a unit cube. It is measured in Ohm-cm. Volume resistivity is affected by environmental conditions imposed upon the material. It varies inversely with temperature, and decreases slightly in moist environments. Materials with volume resistivity values above 1088 Ohm-cm are considered insulators. Partial conductors have values of 1033 to 1088 Ohm-cm.

Another very important electrical property of materials is called the relative permittivity. The relative permittivity of an insulating material is the ratio of capacitance of a capacitor (in which the space between and around the electrodes is entirely and exclusively filled with the insulating material in question) to the capacitance of the same configuration of electrodes in a vacuum. In AC dielectric applications, good resistivity as well as low energy dissipation are desirable characteristics. The dissipation of electrical energy results in inefficiencies in an electronic component and causes heat build-up in the plastic part which acts as a dielectric.

In an ideal dielectric material, such as a vacuum, there is no energy loss to dipole motion of the molecules. In solid materials, such as plastics, the dipole motion becomes a factor. A measure of this inefficiency is the relative permittivity (formerly called dielectric constant). It is a dimensionless factor derived by dividing the parallel capacitance of the system with a plastic material by that of an equivalent system with a vacuum as dielectric. The lower the number is, the better the performance of the material as an insulator.

Finally we encounter dissipation factor and arc resistance. The dielectric loss angle of an insulating material is the angle by which the phase difference between applied voltage and resulting current deviates from $\pi/2$ radians, when the dielectric of the capacitor consists exclusively of the dielectric material. The dielectric dissipation factor tan(d) of an insulating material is the tangent of the loss angle d. In a perfect dielectric, the voltage wave and the current are exactly 90° out of phase. As the dielectric becomes less than 100% efficient, the current wave begins to lag the voltage in direct proportion. The amount the current wave deviates from being 90° out of phase with the voltage is defined as the dielectric loss angle. The tangent of this angle is known as the loss tangent or dissipation factor. A low dissipation factor is important for plastic insulators in high frequency applications such as radar equipment and microwave parts – smaller values mean better dielectric materials. A high dissipation factor is important for welding applications. Both relative permittivity and dissipation factor are measured using the same test equipment. Test values obtained are highly dependent on temperature, moisture levels, frequency and voltage.

When an electric current is allowed to travel across an insulator's surface, the surface will damage over time and become conductive. Arc resistance is a measure of the time in seconds required to make an insulating surface conductive under a high voltage, low current arc. In other words, the arc resistance is the elapsed time in which the surface of a plastic material will resist the formation of a continuous conducting path when subjected to a high voltage and low current arc under specific conditions.

MATLAB

Testing and Data Analysis

In order to determine the performance of the RFID tag, a reader and antenna were provided by the sponsor, Tyco Electronics (M/A Com). The detection of backscattering signal of the tags is measured by an online reader interface. This interface is very useful in determining the amount of times the tags are read, but it presents the challenge of storing and analyzing the acquired data. In order to facilitate the analysis of data, a template for recording the necessary data has been created to be used in combination with a Matlab program.

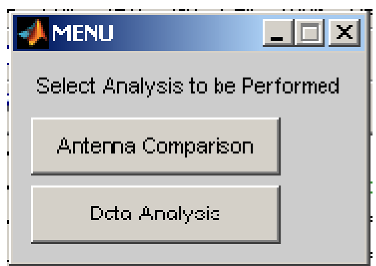
Certain parameters have been determined as variables in the testing of tags: Material, Distance from Reader, Number of Reads, and Orientation to the Antenna. In the M-file, all these parameters have been taken into account, providing the user with multiple options in the analysis of the data.

When executed, the Matlab program provides the user with two main functions to be performed: Antenna Comparison and Data Analysis. The Antenna Comparison is a main feature that allows the user to test the reading performance of the multiple antennas used in a particular project. In our particular case, we are able to test the tags with up to three antennas (not simultaneously). This feature allows us to determine which antenna is working more efficiently in terms of distance. Once the feature is selected, the program displays a new menu box, where the user can select the number of antennas to be tested. Once the amount of antennas is selected, the command window prompts for the tabulation of the readings. The number of readings, in terms of distance for each antenna, is inputted into the command window, and the Matlab program automatically graphs the data acquired. This graph is used to determine the efficiency of the antenna in terms of distance.

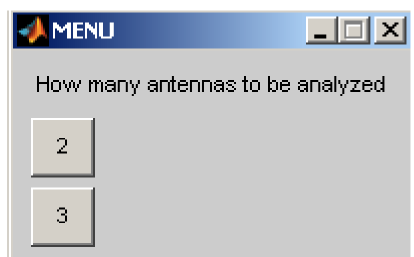
On the other hand, if the user decides to analyze only the data collected by a specific antenna, he or she can select Data Analysis on the initial menu box. Once the box is selected, another menu box appears in order to narrow down the specific parameters of the test. This box provides two options: Horizontal or Perpendicular orientation relative to the Antenna. After the orientation is selected, a new menu box appears which requests the user to specify the two materials used for the testing. In our previous conceptual design, we determined that three main classifications of materials would be used – Polymer, Aluminum and Steel. Once selected, the Command Window will ask the user to input the recordings for each material. Once this information is collected, the M-file will then analyze and graph the data, providing the user with a graphical interpretation of the test conducted. This kind of program provides a semi-automation process to the testing apparatus in order to determine the performance effects on the tags based on Material, Distance, Orientation and Antenna particularly used in the testing.

Program Description

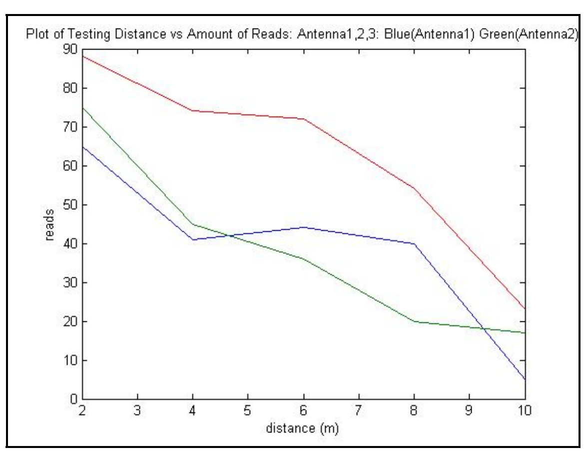
The analysis of the data acquired during the testing is inputted and analyzed in Matlab. A user-friendly program has been created to provide the user with different options to perform specific analysis. The first menu bar enables the user to select between Antenna Comparison and Data Analysis.



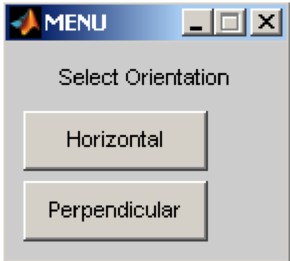
If Antenna Comparison is selected, the following menu box will appear:



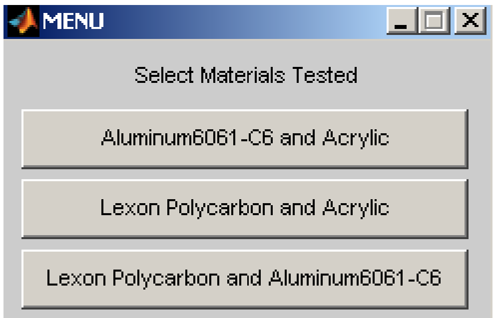
Based on the selection, the command window will request the data collected. In this particular example, three antennas were tested.



When Data Analysis is selected, a new menu box appears in order to specify the orientation at which the tag is tested.



Once the orientation is selected, a new menu box appears, to specify the materials used in the testing.



Once the materials used are selected, the command window will request the data collected for each. In this case, a horizontal orientation was used and Aluminum 6061-C6 and Acrylic were the test materials. After the information is run through the program, it automatically generates a graph in terms of distance from the antenna, number of reads at the specific position, and time elapsed.

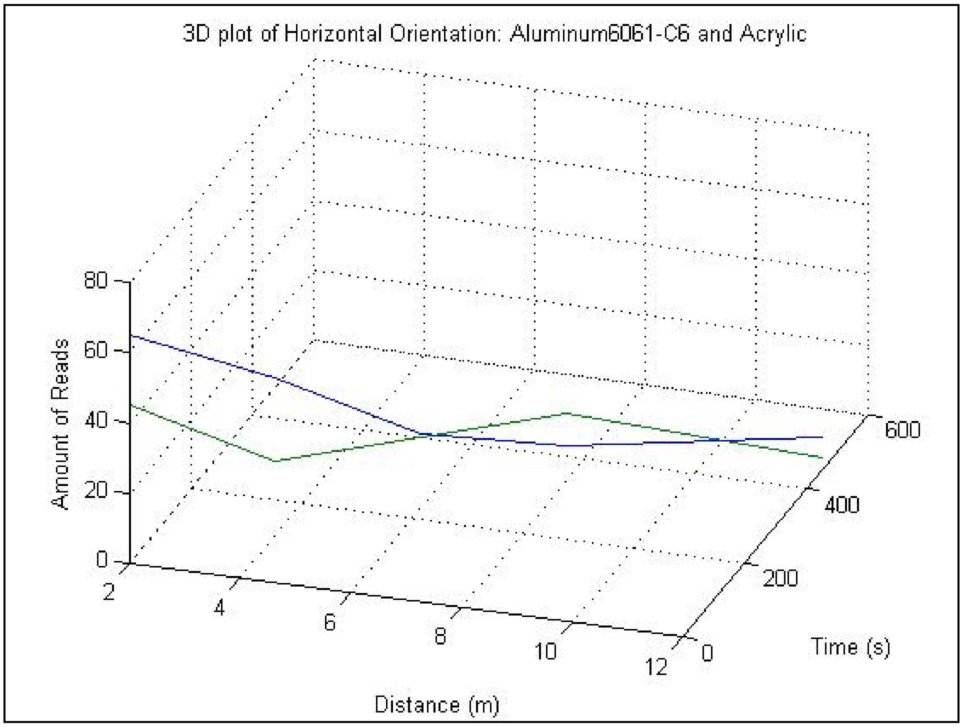


Figure 26

Also, once the user hits enter one more time, a 2D graph will appear on the screen, taking into account only the amount of tag reads and distance from the antenna.

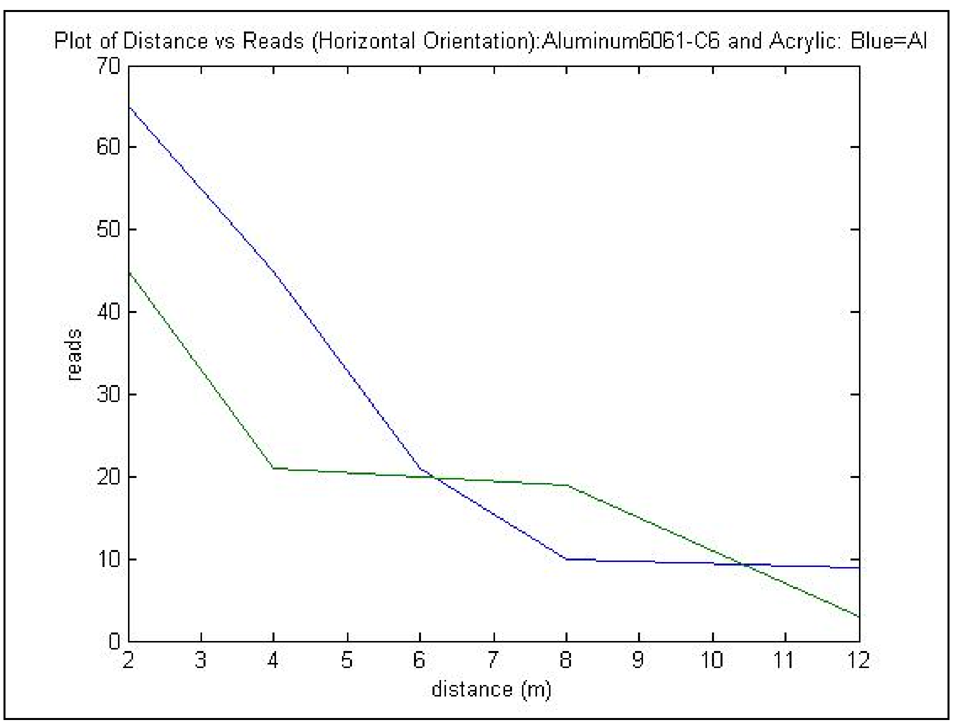


Figure 27

Improvements to the Matlab code

The Matlab code provides the user with the ability to analyze data obtained through testing. Even though the M-File serves as a practical and critical tool, a few modifications could be made in order to create a wider range of possibilities for future testing. Currently, the M-File is able to analyze and graph a specific set of collected data, which limits the user in terms of data analysis. This alteration can be performed by modifying the acquisition of the data through the Matlab program. The user should be able to select the number of data points for the program, and it could automatically generate an array with the number of data points inputted. This array should be encoded into the program as a variable, making the graphing commands a function (1:N), where N represents the amount of data points. Once this expression is correctly set in crucial locations throughout the code, it will perform the specific command from 1 through N number of data points.

Redesign

The completion of our project allowed us to evaluate our build and future design considerations. Our final Gamma design was severely limited by a lack of funding. To turn the design into a marketable product there should be changes to our final deliverable. This is, however, a level at which we would not want to exceed, in order to keep the product affordable as well. Our final frame would use corner support brackets rather than anchors to secure each joint. This would be done for two reasons. The brackets would use only T-slot nuts and bolts to be mounted. This eliminates the need on the production end to countersink for the anchors. The second reason is that the corner supports provided a much stronger joint. The anchors used are far stronger than any requirements, as seen in the evaluation section. However, the corner supports have two bolts per member being joined and allows for a factor of safety, in case the joint is not attached properly. The final design would also include casters to support the frame and allow for portability and maneuverability. This concept was not implemented in the final assembly due to cost restrictions. As the frame would remain lightweight, eight casters, four on each rigid side, would keep the frame well balanced and easy to move in a workspace. The rolling capability would also support in easy folding of the frame into a storage position.

Other concept considerations were developed once the project was completed. The shields are currently mounted with two screws and hang from the frame. The seams are then tapped and sealed to ensure a perfect anechoic environment. If there were more time for the project, a more efficient way of mounting the shields would be employed. The shields need to have the ability to be quickly removed and reattached. The current method is slow and laborious. Snap fittings, quick release buttons, or even Velcro have been considered as a solution. This improvement would once again increase the user-friendly features of the device. If more time were available, we would have liked to investigate the potential of other shields. A number of companies produce shields, geometric damping materials, and electronic RF noise inhibitors. One ideal option is the use of transparent shields. This would make the chamber even more versatile. The chamber can be used to house other testing devices and create an anechoic environment for many test procedures. With the transparent shields or the use of transparent shields for windows, the user could monitor the tests within the chamber. Another consideration for the last design phase would be the implementation of automated testing device. Within the chamber, we would like to have dual-axis motion devices that would move the tag in a specific orientation through a range of determined distances from the antenna. Finally, one complete user interface program that can log and analyze the data would be ideal for operation. The programming would be very intensive and permission and support from the manufacturer of the reader would be necessary to bridge their software.

Frame Improvements

There are several improvements that could be made to make our frame stiffer and more rigid. The addition of two sets of hinges on either side of the collapsible bars in the lower part of the chamber would stiffen the bars that attach to the non-collapsible part of the frame. Also, using stronger stainless steel joints (Appendix) would create a more efficient collapsing unit. These joints would also prevent the manufacturer from having to drill holes in the hinges. At the location where the collapsing bars attach to the frame, we would like to use parallel connectors (Appendix) to limit the movement of the arms to a single plane with little horizontal stress movement. The use of stronger T-slot connectors at all immovable joints would make the attachments much more secure and rigid. There would be corner plates (Appendix) and tee plates (Appendix) which would limit movement of the long T-slot members during movement of the entire apparatus. To add mobility to our apparatus, we would add casters with locking brakes (Appendix), so that one could easily move the unit from a room to a storage area. The addition of two sets of H-shaped bars that easily detach before moving and reattach to stiffen the frame would also help. This could be done using pegs or screws without heads in the existing slots of our frame. One H-bar would be put in place on the lower frame under the shield that acts as the chamber floor. The other H-bar would be placed at the top of the chamber and be put in place before the shield that acts as the roof of the chamber is reattached. The two H-bars would be installed parallel to the folding members of the frame. These improvements could be easily implemented with additional money in our budget.

Maintenance

1) Check all connections on frame while shields are detached prior to and after moving the unit.
2) Check to make sure that the antenna is fastened securely in place.
3) Check all electrical connections every time the unit is moved or shields are detached.
4) Checks to make sure shields are attached correctly. Attach with screws, making sure they are tight.
5) Check shields for punctures, ripped foil backing, and check tape on outer edges of shields. Re-tape if necessary.
6) The chamber must be completely sealed to ensure that there is no leakage of background RF waves into the chamber.

There is very little maintenance that must be done to our testing apparatus. The frame and the shields are made of aluminum and will not rust or wear very much. The moveable parts are hinges and do not require any lubrication.

Additional Considerations

Societal and Ethical Impact

The effects of RFID tags on today's society stem from three major issues – the potential invasions of personal privacy, the potential health hazards of exposure to RF waves, and the possible pollution of landfills by RFID systems that are no longer in service.

RFID systems have gained popularity and notoriety in recent years. The driving force behind the rapid development of RFID technology has been the rise of pervasive commerce, which has been called the quiet revolution. Pervasive commerce uses technologies such as tracking devices and so-called smart labels embedded with transmitting sensors and intelligent readers to gather information about key areas where consumers live and work and collect the information in data processing systems.

To collect this data, retailers have a choice of four categories of RFID systems. Electronic article surveillance systems (EAS) are generally used in retail stores to sense the presence or absence of an item. Products are tagged and large antenna readers are placed at each exit of the store to detect unauthorized removal of an item. Portable data capture systems, have the option of using portable RFID readers, which allows this system to be used in a variety of settings. Networked systems use fixed position readers, which are directly connected to a centralized information management system, while transponders are placed on people or movable items. Positioning systems are used for automated location identification of tagged items (e.g. vehicles, etc.).

The previously mentioned RFID systems allow businesses and corporations to have real-time access to inventory information; it also provides much more information about the buying habits of consumers. RFID technology also enables retailers and corporations to peek into the lives of consumers in ways that, until recently, were not possible. Products embedded with RFID tags can continuously transmit information ranging from an electronic product code (EPC) identifier, to information about the item itself, such as consumption status or product freshness. Data processing systems read and compile this information and can link the product information with a specific consumer. The composite consumer information gathered in this way is far superior and more invasive than data that could be obtained from scanning bar codes, or loyalty cards. Frequent shopper cards link consumers to their purchases, but this information is limited and gives retailers only a narrow view of a consumer's in-store purchasing trends. In contrast, RFID systems enable tagged objects to speak to electronic readers over the course of the life cycle of a product. From production through disposal, all segments of the product's life give retailers and outside institutions a very intrusive view of consumer's attitudes and purchasing behavior.

A major determining factor for the future of RFID technology is its cost. At present, the technology is still too expensive to be used by retailers on a large scale. The cost of an electronic tag is 30 cents, but that price is expected to fall to as little as 3 cents in the next three years. Until the cost per chip is below a penny, RFID tags will not be widely used by retailers. The sensors to read the tags will cost retailers about one thousand dollars each. Despite this cost, many retailers are willing to pay the price for the insight RFID tags provide into the lives of consumers. As demand for enhanced means of tracking products and consumer profiling increases, RFID systems are being developed with larger memory capacities, larger reading ranges, and faster processing capabilities. The RFID market is growing rapidly, and is projected to reach annual sales of $10 billion within the next 10 years. IDTechEx, which analyzes and tracks the RFID industry, believes that more than 585 billion RFID tags will be delivered by 2016.

An example of current large-scale implementation of RFID technology systems is a very ambitious five-year project by the 3M Corporation, which is now under way in Bermuda, an island nation with 21 square miles of land, 63,000 inhabitants, and 47,000 vehicles. Each vehicle will, upon registration or inspection, receive a windshield sticker embedded with an RFID tag. To maintain some level of consumer privacy, the system will use encrypted-code RFID tags that store no personal data. According to the government, the system will only identify vehicles and not drivers. The system will be able to perform such functions as automatic generation of citations, validation of commercial vehicle registration, and issuance of violations for commercial trucks operating in restricted areas during rush hour without a permit, officials said. A system of fixed readers will be established to verify vehicle registration and compliance, and officers will also use tripod-mounted and handheld readers to screen vehicles at random locations. The system is expected to generate over $11 million in lost fees from unlicensed and uninsured vehicles, and reduce the portion of non-compliant vehicles to less than 1 percent, according to officials. How would the citizens of Rhode Island react to such a system being implemented? What would be the reaction of such a system being installed at URI, with all students and faculty having an RFID tag embedded in their parking permits?

Political and Ethical Impact

RFID systems, like all new technologies, can be considered a double-edged sword, meaning that they can be used for both positive and negative purposes, whether intended or unintended. In the future, RFID technologies will present many privacy and safety implications that society in general is currently unaware of, some of which are obvious and some of which are not. RFID tags can be read without the individual's knowledge or consent, and new high-gain antennas can greatly increase the distance at which these tags can be read. The short read distance is the only defense that the RFID industry has against the argument that the tags can used to track the movement of people, or otherwise intrude on personal privacy. As chip sizes decrease and read distances increase, the potential for abuse of this technology will raise many privacy issues in human society. RFID technology has long since made its debut in popular culture – Figure 1 shows the size of the tracking and identification tag from the movie *Mission Impossible,* made in 1996.

Figure 28 *Mission Impossible* Movie Tracking and ID tag.

Compare this to the new Hitachi mu-chip, which has dimensions of only 0.4 x 0.4 millimeters, as shown below (Figure 2) on a human fingertip. Hitachi's mu-chips are in production today, and were already used to prevent ticket forgery and counterfeiting at last year's Aichi International Technology Exposition.

Figure 29 Hitachi mu-chip RFID tag.

These new RFID chips have a 128-bit read-only memory (ROM) for storing a unique 38-digit number. Hitachi used semiconductor miniaturization and electron beam technology to write data on the chip substrate and achieve the new smaller size. RFID powder, as its name might suggest, is even smaller than the mu-chip, each tag measuring a miniscule 0.05 x 0.05 mm in size. This makes the powder ideal for applications such as paper currency and gift certificates. Figure 3 shows RFID powder next to a human hair.

Figure 30 RFID powder next to a human hair

The potential for abuse of civil rights by law enforcement institutions and individuals should be quite apparent. If a person attends a political protest, for example, and police sprinkle these tags on people in the form of a powder, they would, with a powerful enough reader, be able to track those individuals. This could also be a potential health hazard, as no one knows what effects the RFID powder may have if it is inhaled.

Some RFID tags are very difficult to remove because they are very small, less than a half a millimeter square and thinner than a sheet of paper. The tags may also be hidden or embedded within a product so that consumers cannot remove them. A consumer should retain control over his or her product choice and privacy with regard to his or her use of the product. One new technology coming to market soon will allow essentially irremovable RFID tags to be printed on a product.

As of 2005, the Euro (€) notes have contained RFID tags, present in all paper currency denominations of 5 € and up. They were put in place for the purpose of tracking financial transactions. These are shown in Figure 4.

Figure 31 RFID tags implanted in the Euro currency

Similarly, there is an RFID tag in the new series of American 20 dollar bills, in President Andrew Jackson’s right eye. Figure 5 shows a set of $20 bills after being microwaved to destroy the RFID tags.

Figure 32 Burned RFID tags in $20 bills

These RFID tags were put in place to make currency more difficult to counterfeit and also as a countermeasure to drug traffickers and others moving money out of the country illegally. Using RFID tags in larger notes is understandable, but a drug dealer trying to move large amounts of money out of the country would probably not use $20 bills. One conclusion that can be drawn is that they rather serve the purpose of government tracking of citizens.

All United States passports issued after October 2006 contain RFID tags. Security experts have warned that this may actually make it easier for criminals or terrorists to pick Americans out of a crowd at airports. Privacy advocates worry that in the future, someone with a portable reader will be able to scan a house and read the signals from tags embedded in products. This could potentially set people up for specifically targeted break-ins and robberies. The US military is beginning to use RFID tags to keep track of hardware and clothing in supply logistics systems. They are currently used to track materials and equipment in for operations in Iraq and Afghanistan. Military security experts have expressed great concern that RFID tags could be used by the enemy to track American troop locations or to set off roadside bombs using the tag signals.

Fortunately, the RFID tags used in passports can be covered with aluminum foil so that the tag cannot be arbitrarily read by anyone with a reader. This creates some level of security for citizens. It is also very hard to detect RFID tags when they are sewn into clothing or implanted in flesh, as the human body is mostly water, and fluids make signal transmission more difficult.

However, implantation in human flesh itself opens up another enormous ethical debate over whether or not human beings ought to be tracked and treated in the same manner as commercial products. It could be well-argued, for instance, that implanted RFID tags would prove to be lifesaving and indispensable in such cases as tracking of kidnapping victims and fugitives of the law, whose locations may otherwise be extremely difficult or impossible to determine. A legitimate counterargument is that sub dermal implantation, depending on who the subject is and at what stage in their life the procedure is done, would violate the most basic and universal concepts of human rights and personal privacy. It is therefore essential to maintain open public discussion and debate and produce legislation for determining what sorts of restriction are to be imposed on the producers, consumers, and government institutions involved in RFID tag technologies. This should be considered crucial for upholding the notion of democracy for which the United States is known.

Health and Ethical Impact

There is ongoing research on the possible effects on human health of radio frequency waves emitted by RFID readers. Radio frequency, microwave and radio wave radiation compose specific sections of the electromagnetic spectrum. Radio frequency radiation is in the non-ionizing portion of the electromagnetic spectrum. Non-ionizing radiation includes the lower frequencies in the electromagnetic spectrum such as ultraviolet and visible light, infrared, microwave, and radio wave. These are shown below.

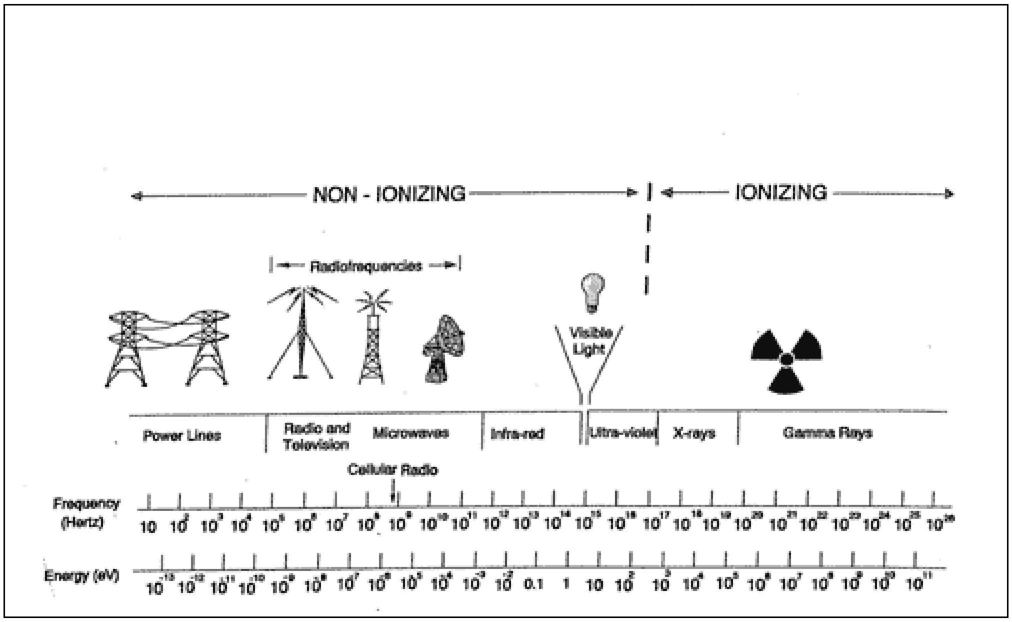


Figure 33 The Electromagnetic Spectrum

Ionization is a process by which electrons are stripped from atoms and molecules. This process can produce molecular changes that can lead to damage in biological tissue, including long-term effects on DNA molecules. The energy levels associated with radio frequency (RF) radiation are not great enough to cause ionization of atoms and molecules. Electromagnetic radiation consists of waves of electric and magnetic energy moving together, radiating through space at the speed of light. Different forms of electromagnetic energy are categorized by their wavelengths and frequencies. The RF portion of the electromagnetic spectrum is generally defined as that section where electromagnetic waves have frequencies in the range of about 3 kilohertz (kHz) to 300 gigahertz (GHz).

These various types of radiation affect the human body in different ways. Ionizing radiation, containing a tremendous amount of energy and penetrating power, will cause changes in the body's molecular system. Non-ionizing radiation operates at much lower frequencies and is not believed to be as harmful to the human body as ionizing radiation. Exposure to non-ionizing RF radiation may produce serious adverse biological effects. As high frequency RF radiation penetrates the body, the exposed molecules move and collide with one another causing friction and heat. This is known as the thermal effect. If the radiation is powerful enough, the tissue or skin can be heated and burned. The health effects may or may not be reversible, depending on variables such as the particular tissue or organ that is exposed, the intensity of the radiation, the frequency and the duration of the exposure, the environmental temperature and humidity, and the body's ability to dissipate the heat. There is substantial scientific data that links microwave radiation to negative health effects. Microwave radiation may cause, for example, eye and testicular damage. The federal Occupational Safety and Health Administration (OSHA) standard for electromagnetic radiation is based on data demonstrating that the power density necessary to produce cataracts was approximately 100 mW/cm^2, to which a safety factor of 10 was applied. A maximum permissible level of 10 mW/cm^2 was established. Unfortunately, there is not yet an OSHA standard for a low frequency radio frequency microwave or radio wave radiation. Table 2 shows the FCC limits for maximum permissible exposure.

(A) **Limits for Occupational/Controlled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	$(900/f^2)$*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(B) **Limits for General Population/Uncontrolled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

Figure 34 FCC Limits for Maximum Permissible Radiation Exposure

Exposure to low frequency non-ionizing RF radiation penetrates the skin and causes molecular collisions similar to those caused by high frequency RF radiation. Changes in learned behavior have been linked to exposure to RF frequencies below 10 MHz. The effects on the central nervous system due to exposure at lower frequencies are instantaneous and cannot be time averaged, contrary to exposure to higher frequency radiation. Human exposure to the field produced by the RFID reader causes a current to be induced and flow in the body, which results in tissue damage. RF exposures are directly linked to absorption and distribution of RF energy in the body, and the absorption and distribution are strongly dependent on body size and orientation and on incident radiation frequency and polarization. The Specific Absorption Rate (SAR) is defined as the rate of energy absorption per unit of mass of tissue, measured in watts per kilogram. A rise in body temperature of about 2.2 degrees Celsius is taken as the limit of endurance; a limit of an increase of 1 degree Celsius is used as the basis for determining the limit for human exposure. This is based on a specific absorption rate of 4 W/kg, then divided by 10 to give a further margin of safety, for a final limit of 0.4 W/kg. Because the two frequencies overlap in the band between 100 kHz and 10 MHz, both types of effects need to be considered in this range. The latest scientific research indicates a relationship between exposure to microwave radiation and birth defects such as Down syndrome and central nervous system damage.

Environmental Impact

The impact on the environment from our RFID tag testing system is considered to be fairly minimal. The system operates in the 902-928 MHz range, which is a safe range because exposures can be time averaged. Our system is also equipped with shields that not only limit RF exposure to people operating the system, but also block potential RF interference signals. Another advantage of our system is that all components can be quite easily recycled. The frame itself is made of T6061-T5 aluminum, the hinges and fasteners are zinc and steel, and the RF shielding is made of aluminum foil, nylon sheets, and cardboard. There already exist infrastructures and procedures in the United States for safe reuse and/or disposal of these materials. All electronic components of our system are valuable and can be recycled. One of the more innovative uses of RFID tags is its implantation into high tech electronics such as RFID systems themselves, to make sure that they are properly recycled. The components of our system are quite valuable; as such they should be recycled. If not the plastic, precious metals, and solders will surely have a detrimental effect on the environment. As the prices of metals and other commodities rise, economics will dictate that more and more materials will be recycled, because it makes both economic and environmental sense.

Conclusions

RFID analysts predict the tagging of food, books, drugs, tires, tickets, passports and visas, livestock, baggage, and many other items. Civil liberties advocates claim that the capabilities of RFID systems could eventually lead to the conditions of a police state such as that envisioned in George Orwell's famous novel *1984*. Other critics of RFID systems envision a seamless network of millions of RFID antennas placed around the globe in airports, seaports, highways, distribution centers, warehouses, retail stores, and consumers' homes, all of them constantly reading, processing, and evaluating consumers' behaviors and purchases. In addition to undermining a consumer's ability to enjoy a lifestyle of anonymity and privacy, critics say that information gathered by RFID readers could be used by governments for surveillance or monitoring the activities of their citizens beyond what should be allowed by law, or also misused by hackers, criminals, and the like. Implantation in humans and animals in addition to products can also result in questionable practices. However, the advantages of RFID technology are also many. They include great reductions in the costs of manufacturing, delivery, and logistics, resulting increased efficiency for firms in almost all industries, and new, more effective methods of marketing based on a new wealth of information about consumer behavior. Benefits in the areas of public and personal safety and security are also numerous, with notable applications in crime prevention, new methods of theft deterrence and retrieval of goods, new approaches to national security, and modern improvements in military and law enforcement efficiency and effectiveness.

Certainly there will be no shortage of moral and ethical issues to keep in mind and interests to balance throughout the current and future cycles of development and implementation of new RFID technologies and systems.

Conclusions

Our RFID system design is ready for the commercial market, and it can be employed by any industry that uses RFID technology or by college students testing RFID tags, as a lab assignment for the first time. The system is completely self-contained, with a built in anechoic chamber, reader, antenna, and computer program to acquire and analyze the data in order to rate the performance of any RFID tag. Our system is safe – the reader operates in the safest part of the electromagnetic spectrum, 902-928 MHz. If anyone is exposed to RF radiation, that exposure can be time-averaged because the effect is not instantaneous and a current is not produced in the body, only a small rise in body temperature will occur. The chamber is completely shielded to prevent anyone using the system from exposure to RF radiation emitted by the reader. Included with the system is a preventative maintenance list that stresses safety for the user and care for the shields that make up the anechoic chamber. Our RFID system is portable, so it can be used to train first time users of RFID technology at different locations, or be moved to different parts of a warehouse or labs to minimize cost to schools and industry. At an open market price of $1000 our design is thousands of dollars cheaper than any RFID system with an anechoic chamber.

Next steps for this project may be to see if a redesign of the system might make it cheaper and easier to move, as well as easier to assemble and disassemble after moving the unit. This was a question posed to us by Mr. Bill Levy, the Vice President of Engineering at Stanley-Bostich.

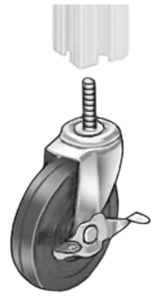
References

Tipler, A. Paul. *Physics for Scientists and Engineer: Electricity and Magnetism*. 5th Edition. Freeman/Worth. 2007

wipo.int	World Intellectual Property Organization
www.technovelgy.com	Technovelgy LLC – Where science meets fiction
www.prisonplanet.com	Alex Jones' Prison Planet
www.RFIDwizards.com	Industry Wizards.Com
www.powerprivacy.com	Practical How-To Privacy Guidance
www.cwa-union.org	Communication Workers of America, AFL-CIO, CLC
www.RFIDsb.com	RFID Switchboard
epic.org	Electronic Privacy Information Center
www.RFIDjournal.com	RFID Journal – The World's RFID Authority
www.who.int	World Health Organization
www.alternativefreedom.org	Alternative Freedom – Law, Technology, Art, Revolution
www.fcc.gov	Federal Communications Commission
en.wikipedia.org	Wikipedia – The Free Encyclopedia
www.motorola.com	Motorola, Inc. Worldwide
www.news.com	C|Net News – Technology News
www.wired.com	Wired.com – Technology News
www.physorg.com	PhysOrg.com – Science, Physics, Tech, Nano, News
RFIDnas.com	RFID News, Applications, and Sources
www.safetycenter.navy.mil	Naval Safety Center

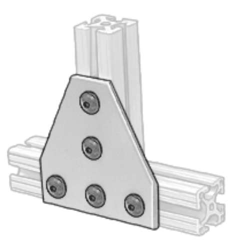
Appendix

Casters

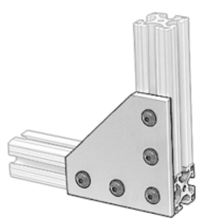


Parallel Pivots

Tee plate connector

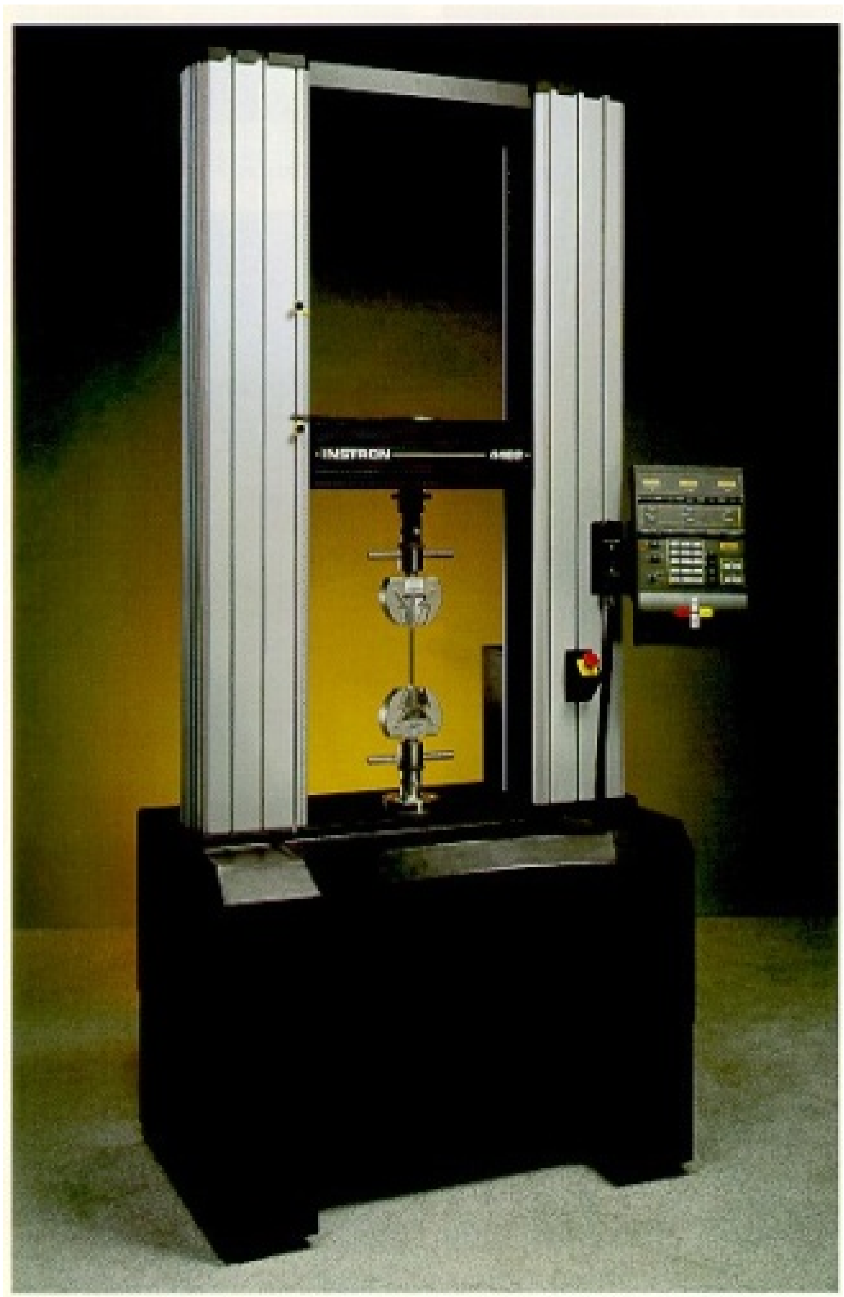


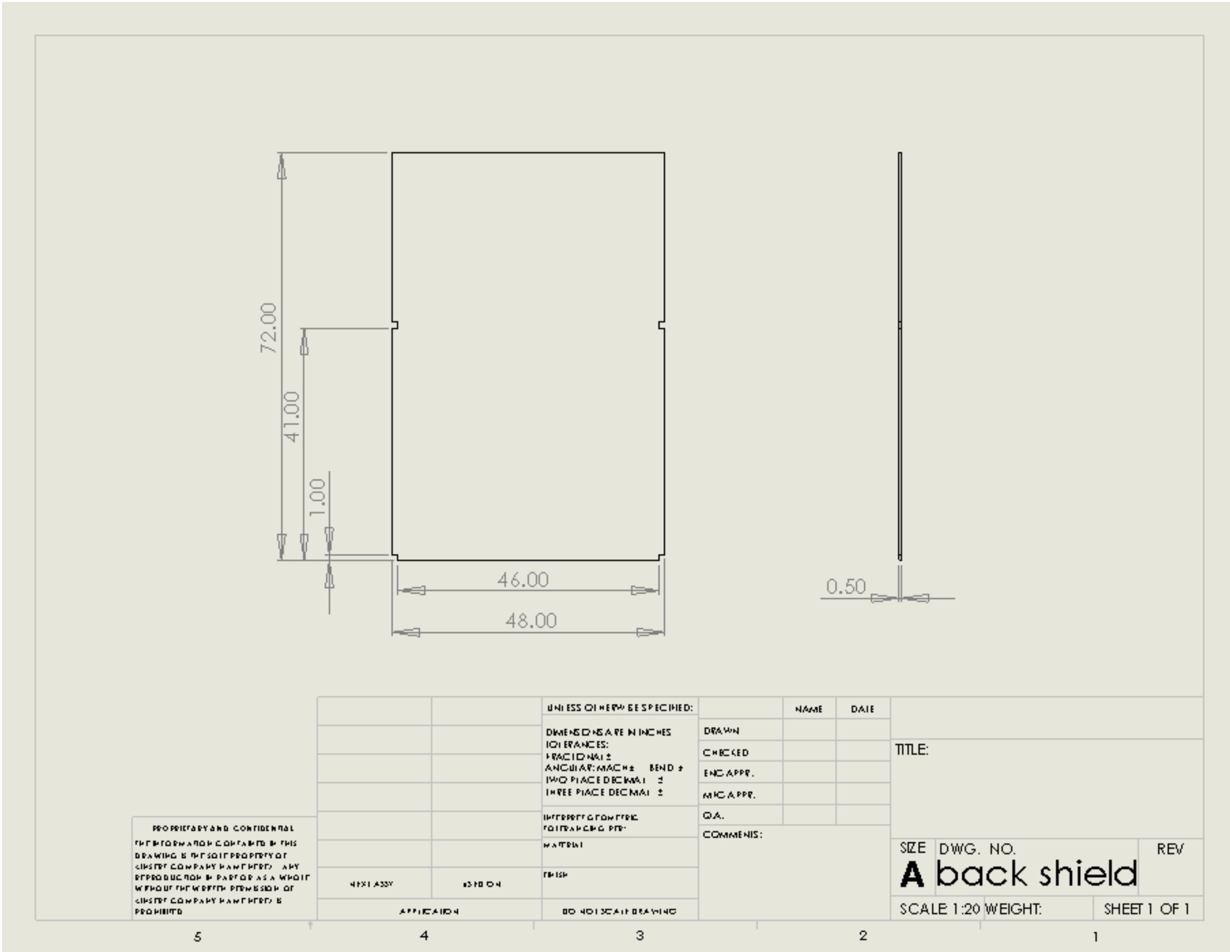
Corner plate connector



Stainless steel 1 ½ inch hinge

Instron Testing Machine





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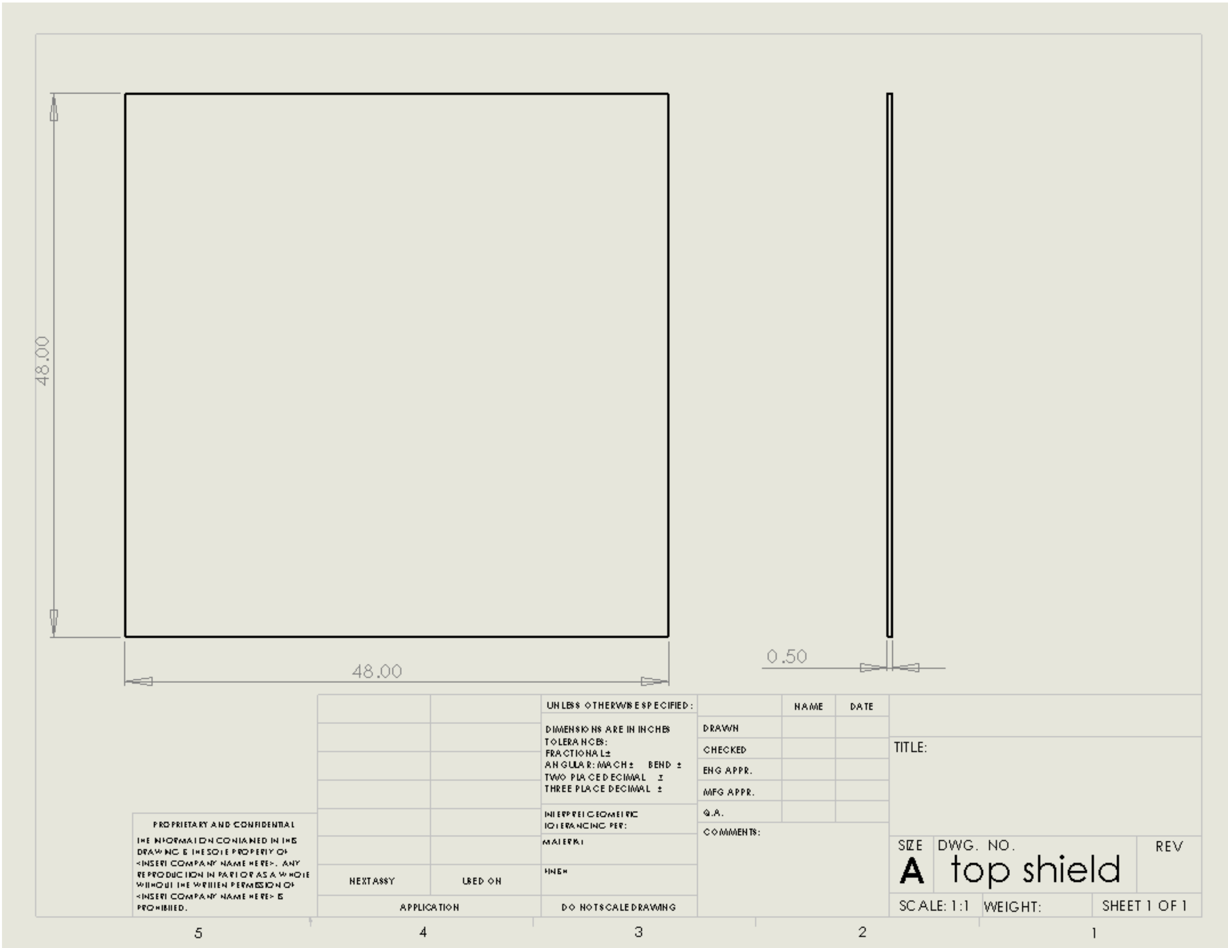
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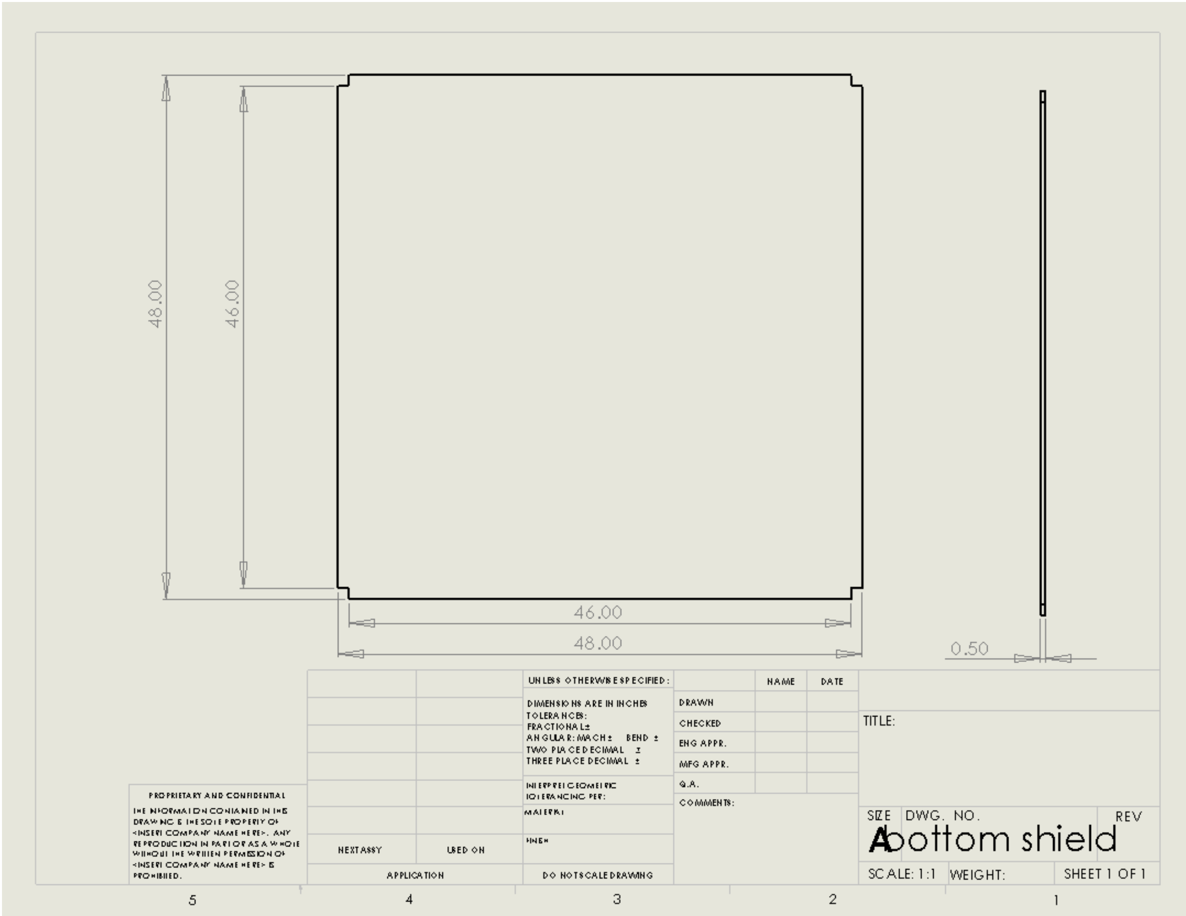
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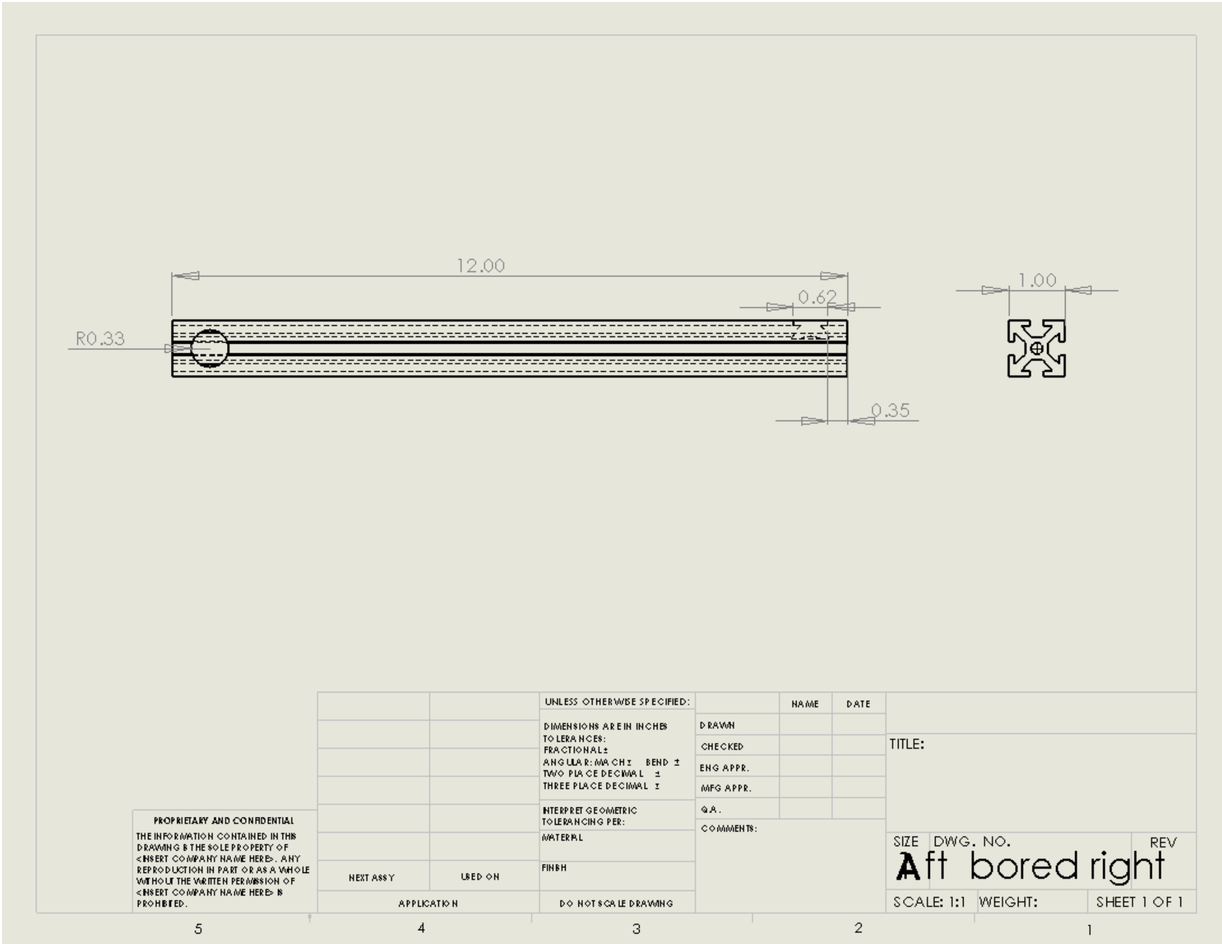
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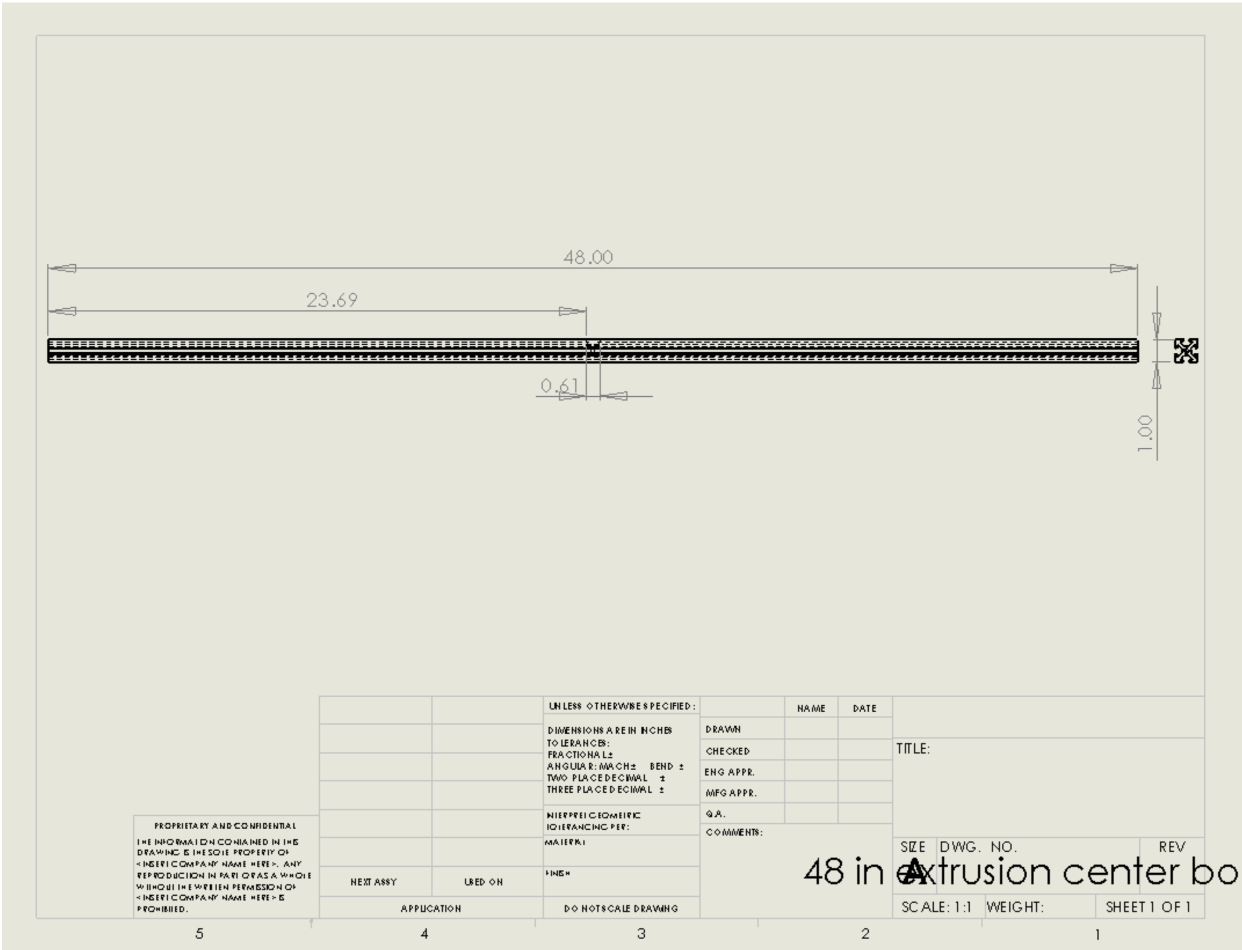
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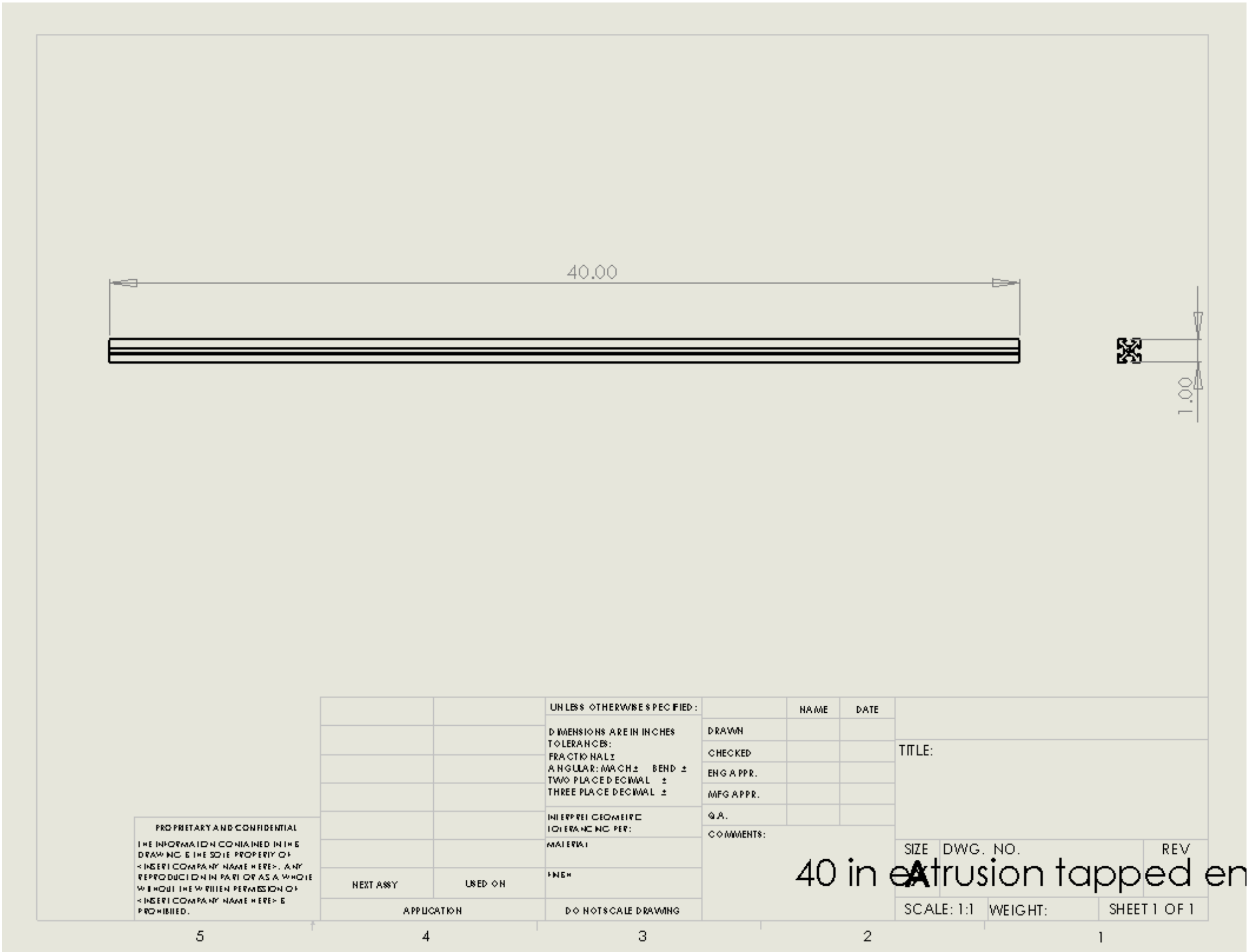
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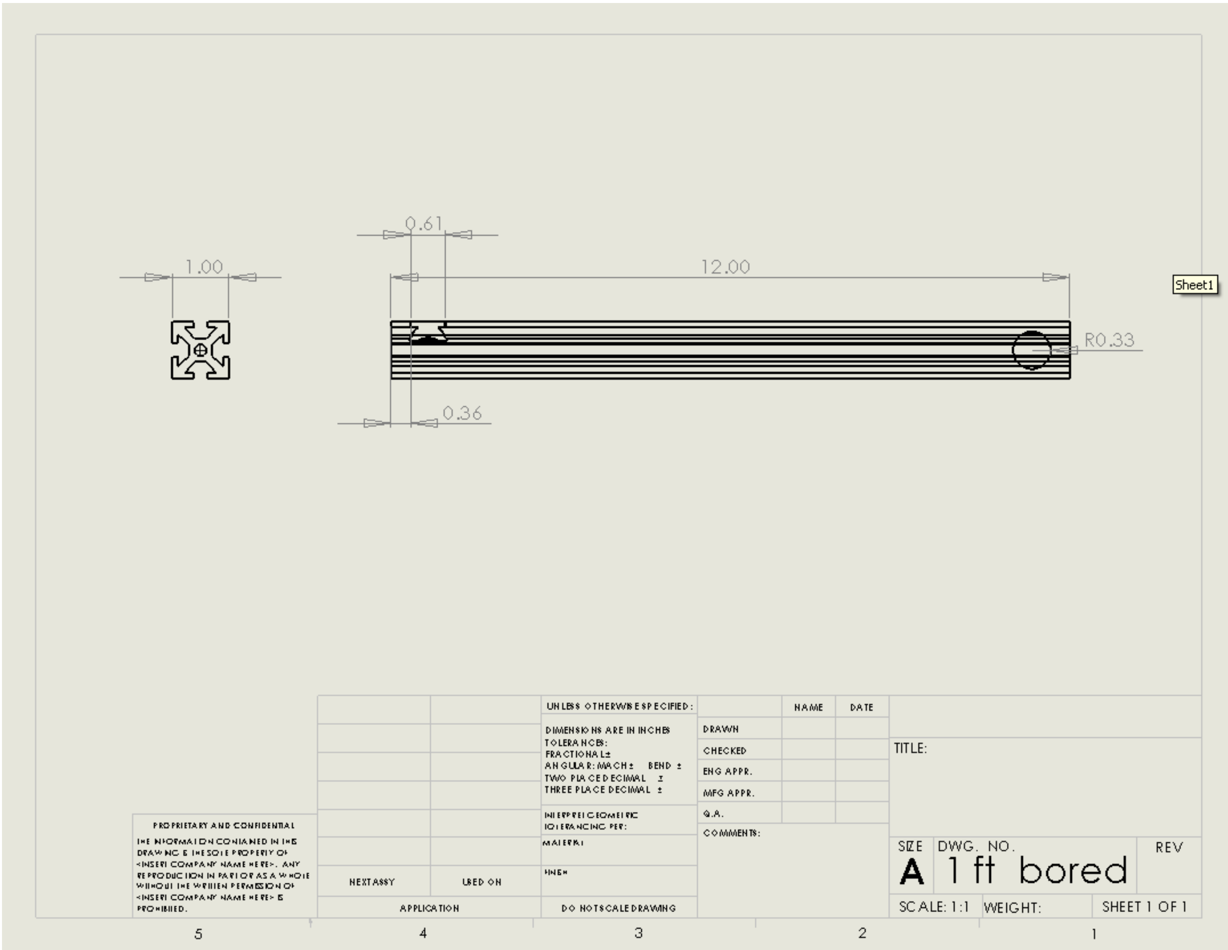

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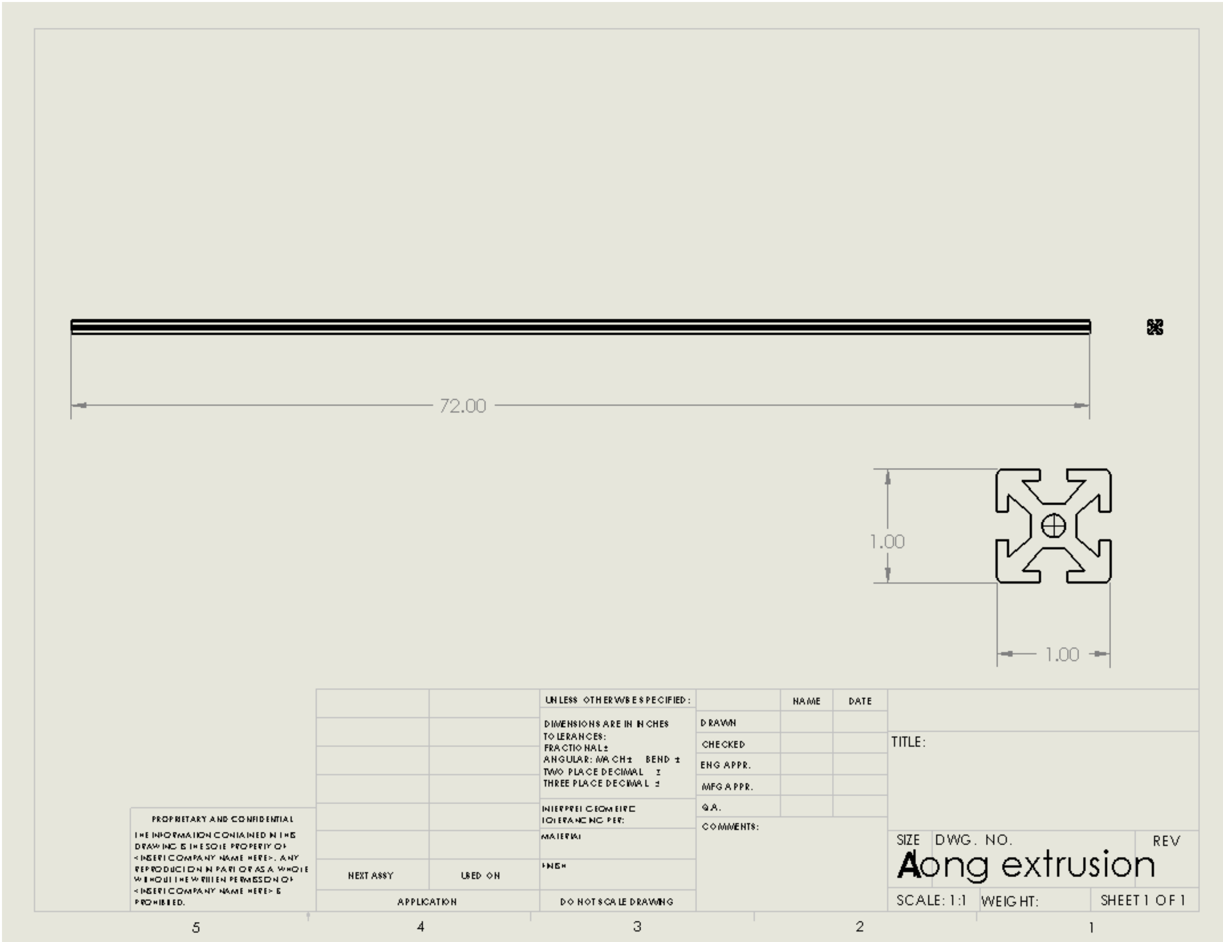
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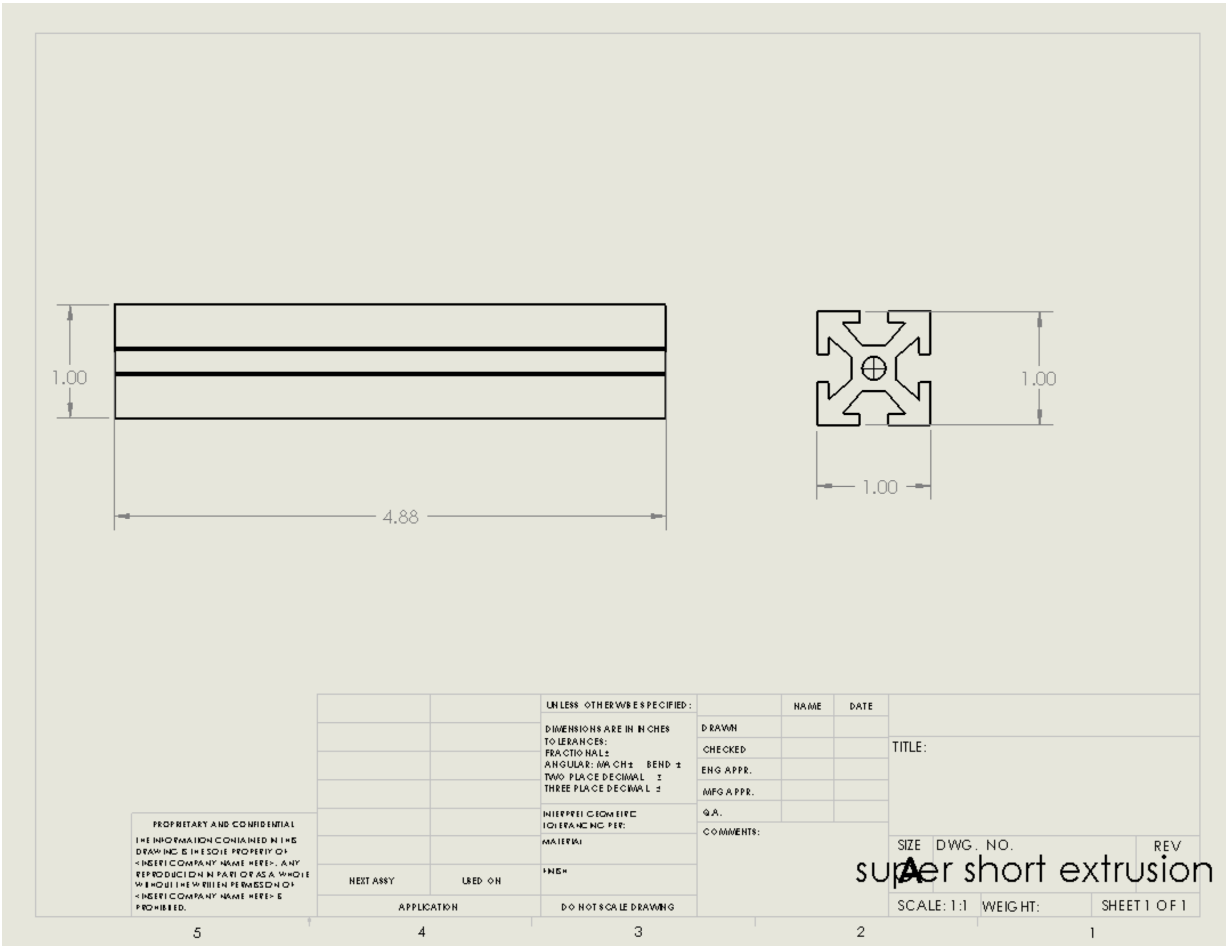
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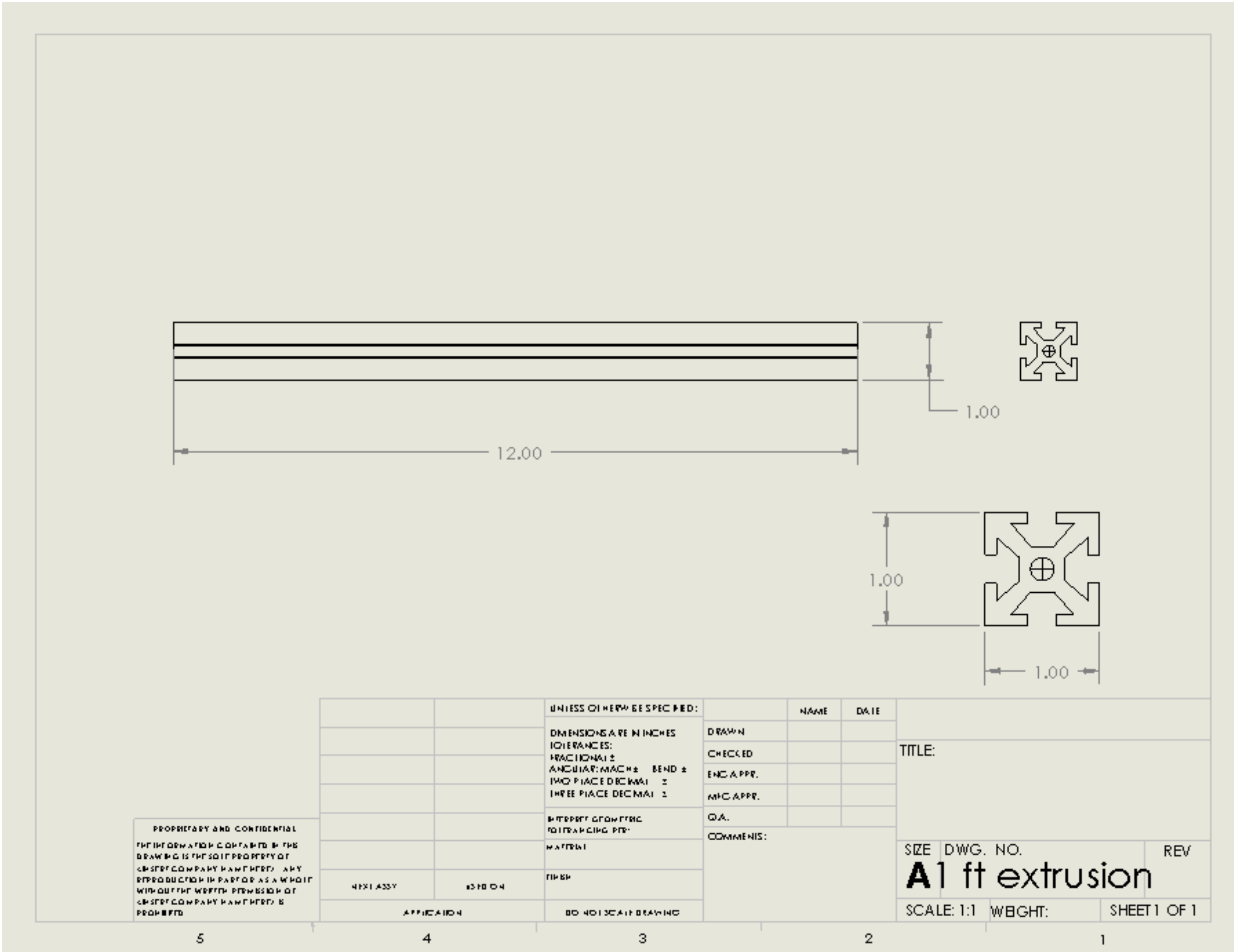

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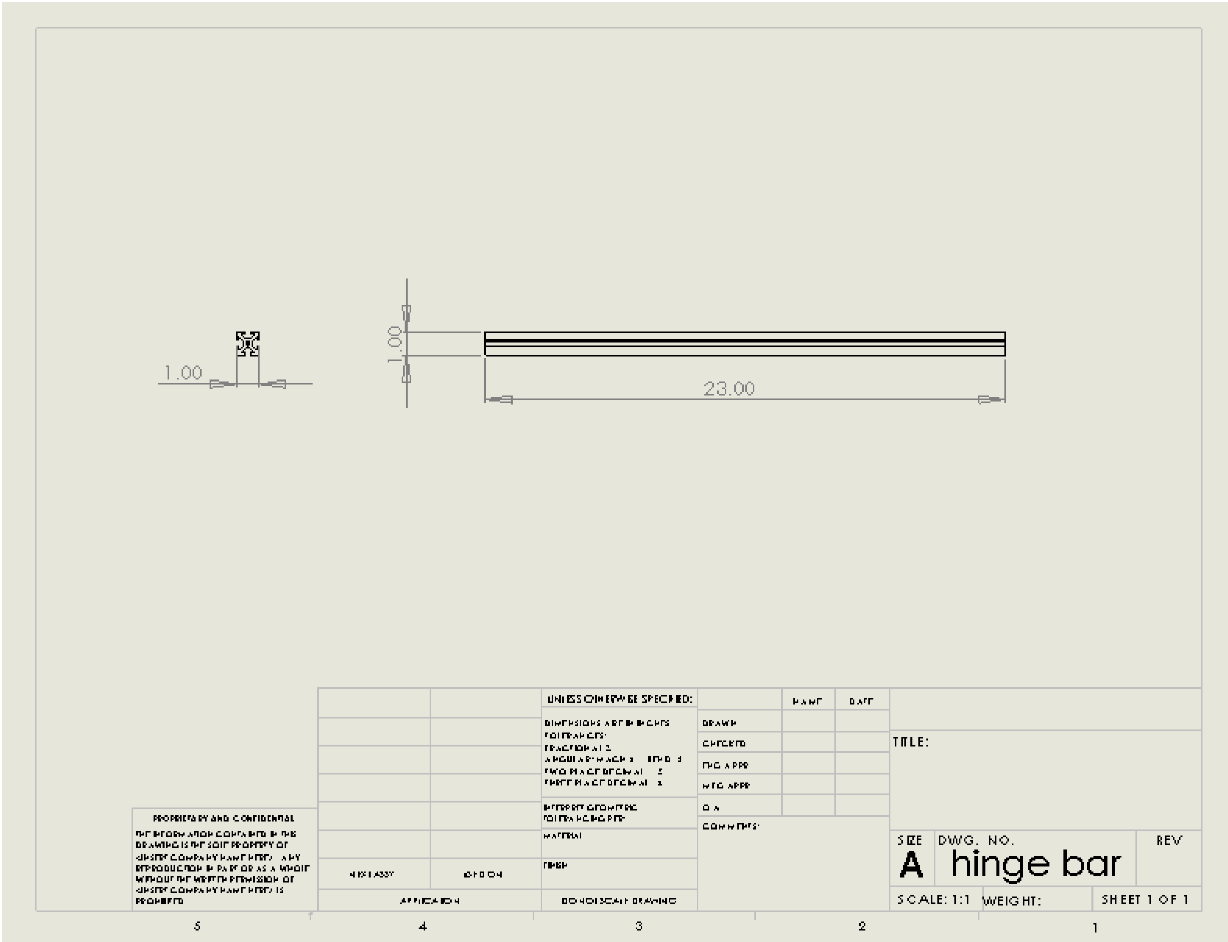
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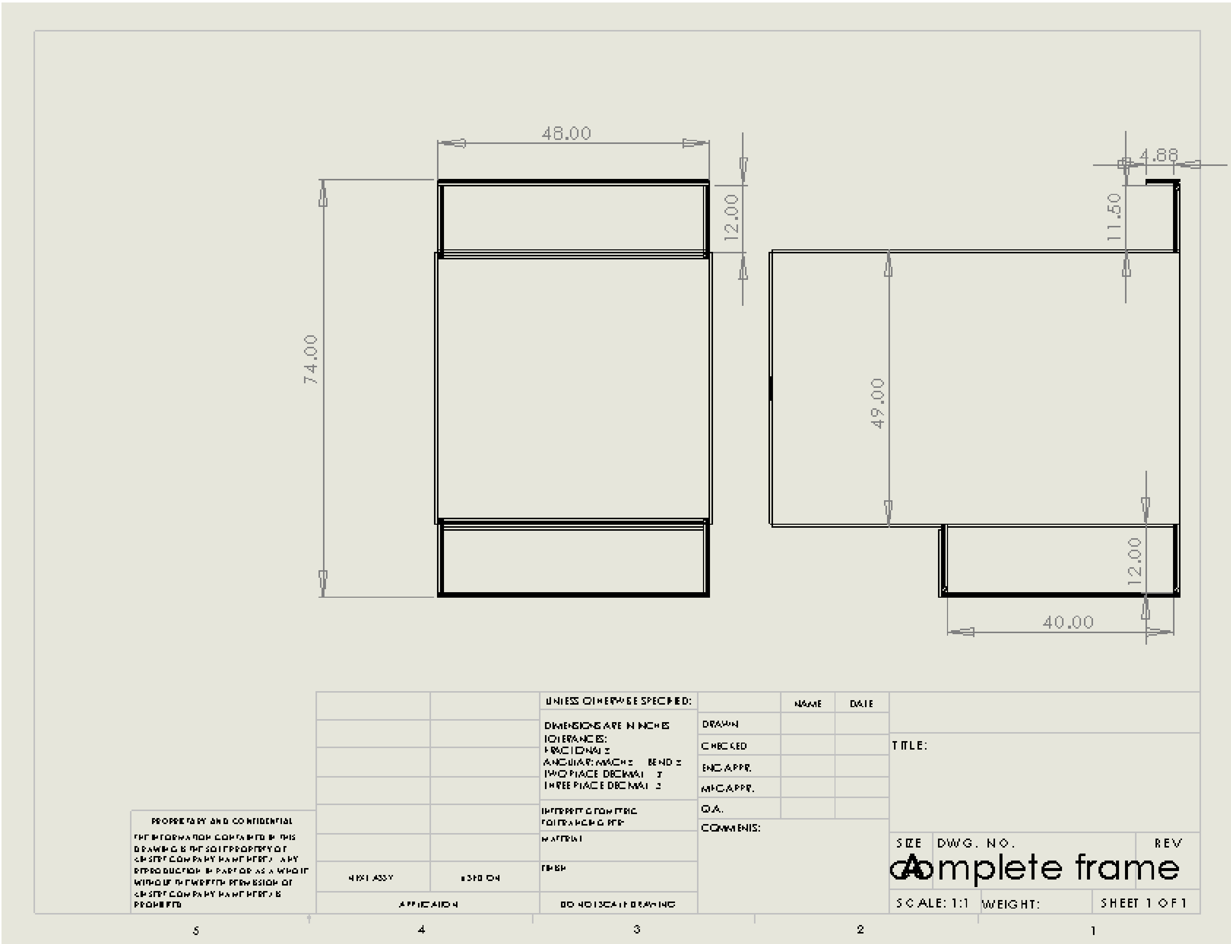

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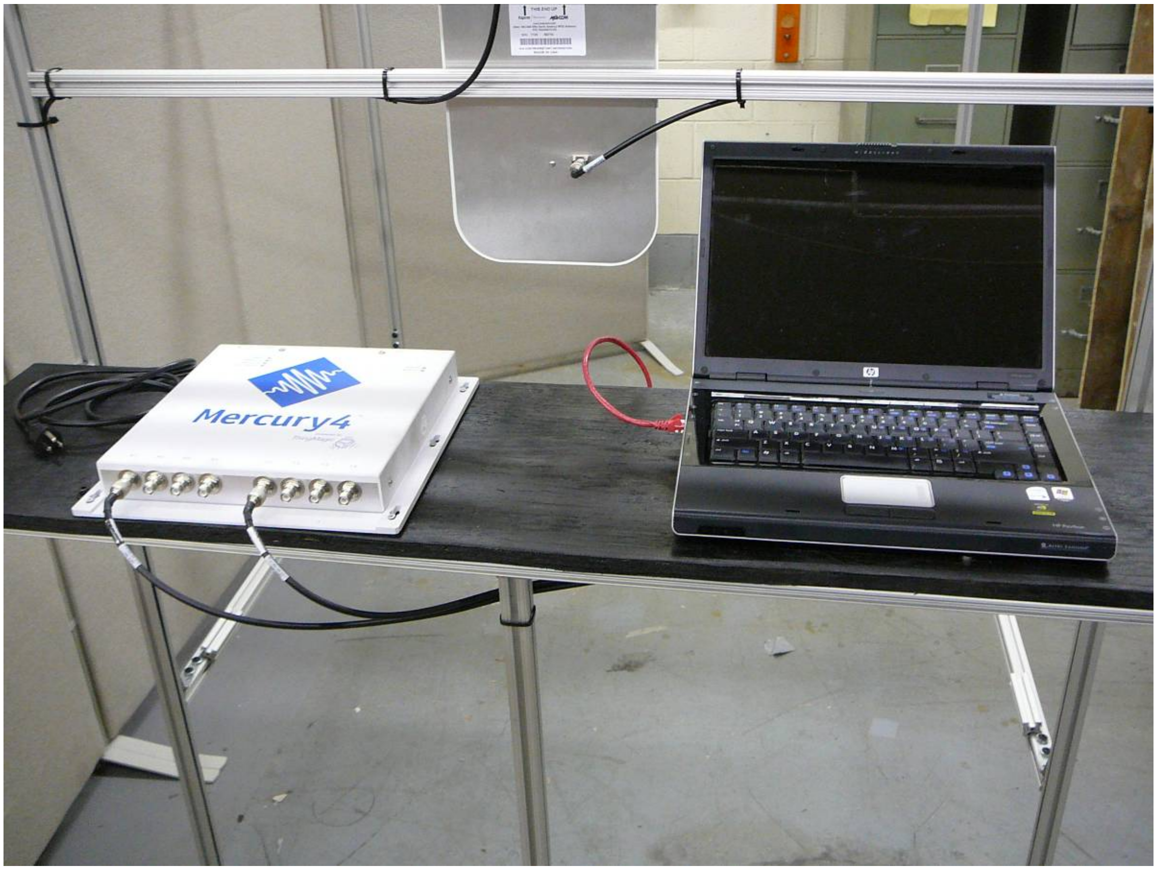
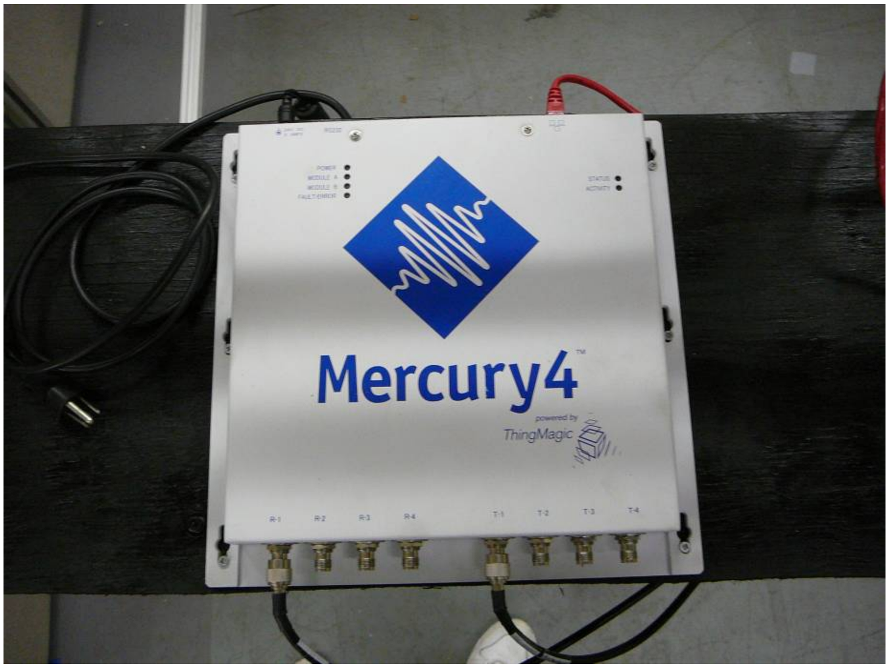
Test apparatus in expanded form, showing collapsible T6105-T5 Aluminum extruded frame and steel hinges, antenna, and support shelf for PC and ThingMagic reader.

Test apparatus in collapsed form, showing galvanized steel hinge mechanisms and reduced floor footprint.

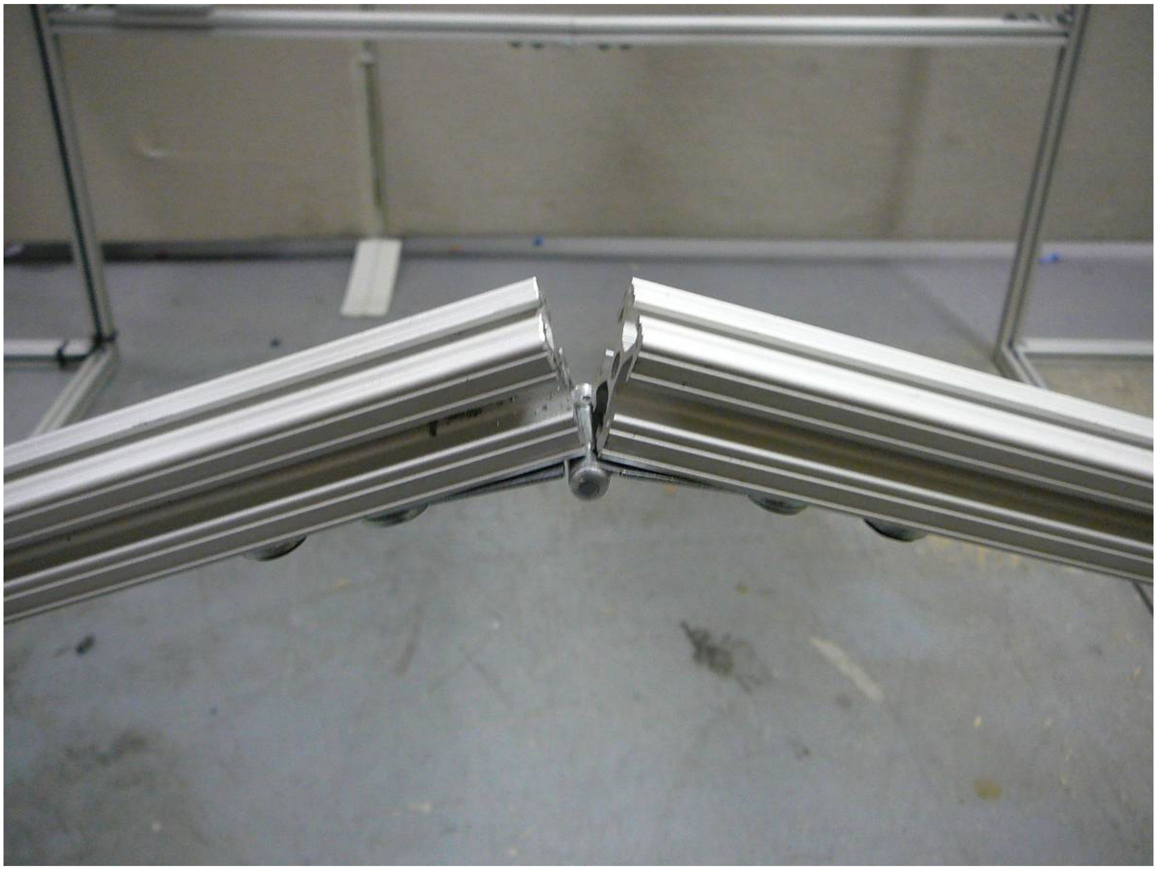


Test bench setup with ThingMagic tag reader and a PC for data acquisition and analysis through MATLAB.

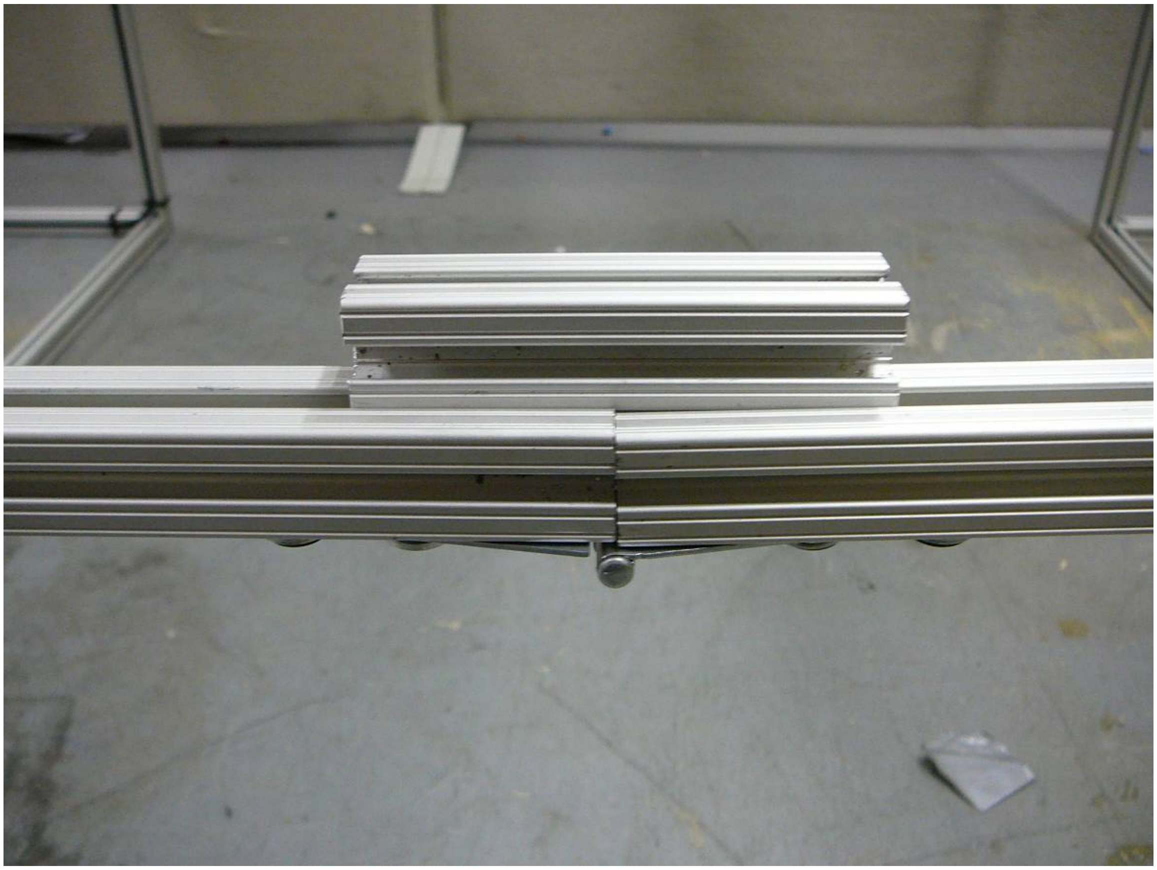


The ThingMagic tag reader as mounted on test shelf and connected to antenna and PC.

The antenna (rear) as mounted to test apparatus frame showing connections to PC and tag reader.



Close-up view of galvanized steel hinge mount on test apparatus, for collapsibility and easy storage.



Close-up view of hinge with aluminum cross lock mechanism, to ensure stability and support during testing.

Close-up view of hinge mechanism in top corner of frame. One dimension folds for storage, the other remains fixed.

TruProtect™ is a patented product that brings it all together: EMI/RFI shielding, insulation, radiant barrier, sound reduction, fire retardant, mold and mildew retardant, hail damage reduction—all of this while being environmentally friendly.

RF Shielding

	Frequency	1/2 " TruProtect Attenuation (dB)	1" TruProtect Attenuation (dB)
Tested on TruProtect using conductive 5 mil Al tape front and back. All layers of Al in the panel are electrically connected. Testing preformed by R.A. Mayes, Inc., Franktown, Colorado.	200 KHz, Magnetic Field	25	25
	200 KHz, Electrical Field	80	100
	1 MHz, Electrical Field	80	100
	10 MHz, Electrical Field	80	100
	80 MHz, Electrical Field	100	100
	400 MHz, Plane Wave	>90	100
	700 MHz, Plane Wave	100	100
	1 GHz, Plane Wave	100	100
	10 GHz, Plane Wave	100	100

Hail Damage Protection

Tested according to UL 2218 Class 4 hail test.	Test summary indicates 50% less surface damage and 100% less structural damage in comparison to a roof without TruProtect.

Insulation

ASHRAE Handbook - data conversion	R-value of 6 for 1/2"; R-value of 12 for 1"
ASTM C 1363-97: Thermal Performance Test	Thermal resistance Rs 1.61 (hr.ft.sq.)/Btu
	R-value of 1.61 for 1/2"; R-value of 2.89 for 1"
ASTM E903: Hemispherical Spectral Reflectance	81.5% Solar Reflectance
ASTM E408-71: Total Emittance Test	.02 Emittance: .98 Reflectance

Fire Retardant

ASTM E84-04: Surface Burning Characteristics	Class A Fire Rating: Flame Spread Index = 25
	Class A Smoke Rating: Smoke Developed Index = 20

Noise Reduction

ASTM E90: Sound Transmission Loss Test	Thickness 1/2": STC - 19; OITC - 15
	Total assembly thickness 8": STC - 51; OITC - 35
NRC: Noise Reduction Coefficient	0.6 for both 1/2" and 1" TruProtect thickness
CAC: Ceiling Attenuation Class	38 for 1/2"; 43 for 1" TruProtect thickness

Mold, Mildew, and Fungus Retardant

ASTM D-3273-94: Resistance to Growth of Mold	TruProtect scored a perfect 10.

Installation

Sizes	Panels: 4' x 8' x 1/2" and 4' x 8' x 1" Ceiling tiles: 2' x 4' x 1/2"
Weight	17 pounds per 4' x 8' x 1/2" sheet
Busting strength	450 pound
Equipment required	No special safety clothing or equipment required.

Environment Friendly

TruProtect is made of 65-70% recycled products.
The active ingredient in the V-769 Fire Retardant is a very stable aqueous organic solution. It is non-regulated by the DOT and carries an HMIS rating of 1-0-0. Carcinogenicity: None of the components in this material are listed by IARC, NTP, or OSHA. It is listed as a non-hazardous product. The V-816 Fungal Coating contains three unique fungal barriers representing less than 4% of the total formulation. The fungicide carries an FDA approval/compliance under FCA 21CFR 178.300. The antimicrobial agent is non-hazardous, has no toxic effects, no ecological concerns, and no hazardous decomposition. It is widely used in the medical field. The third fungal barrier is an aqueous pigment dispersion with no hazardous ingredients. The combination of all three barriers gives long-term protection.

Made in the USA

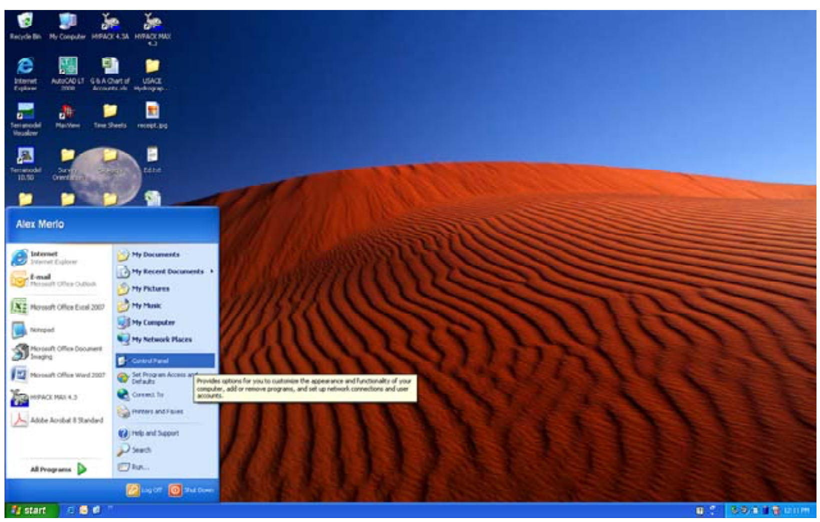
www.truprotect.com • 806.281.9698 •

MiLyn, LLC • 5507 10th Street • Lubbock, TX 70416 •

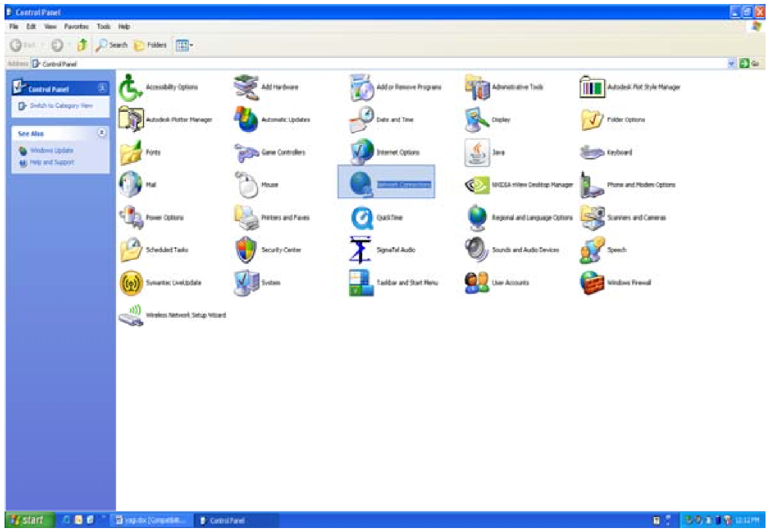
TruProtect Specifications for RF Shielding

Mercury4 / Yagi for Dummies

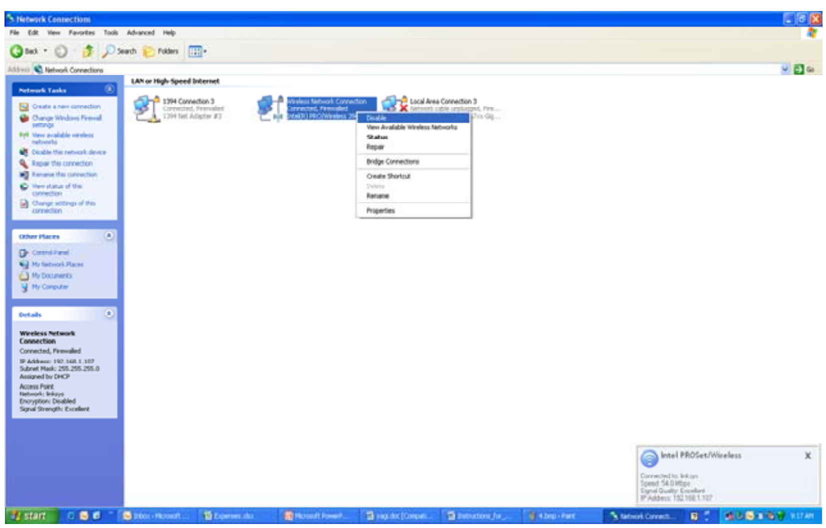
Begin by selecting the **Start** button. Find and select the **Control Panel**.



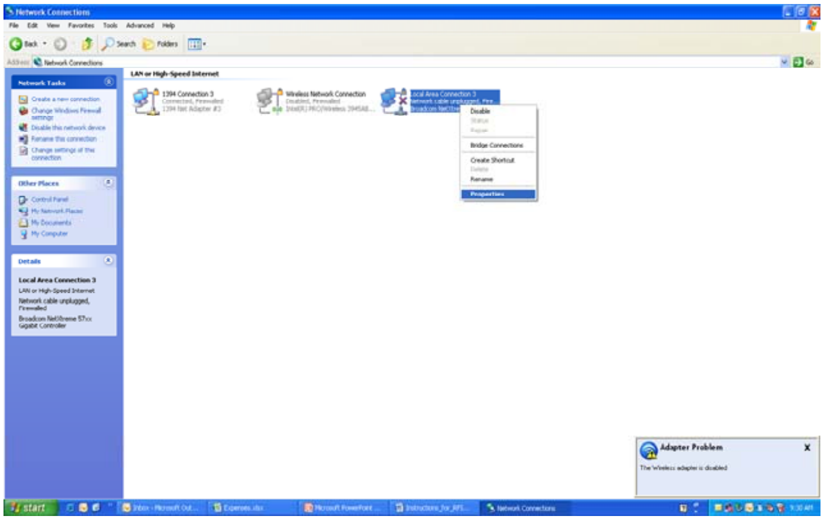
Find and select the **Internet Connections** Icon.



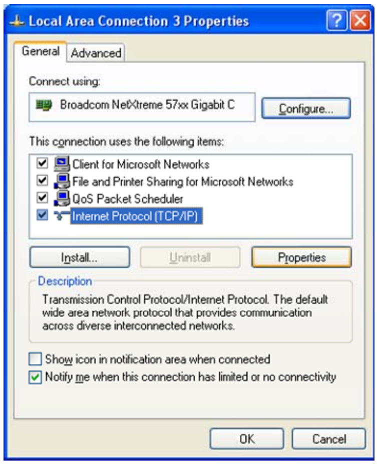
Right click on the **Wireless Internet Connection** and disable it.



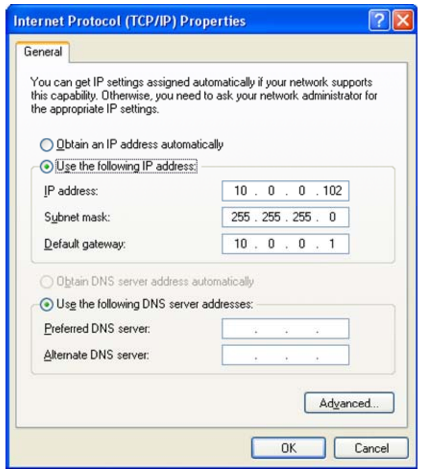
Right click on the **Local Area Connection** icon and select properties.



Choose the Internet Protocol (TCP/IP) and click the **Properties** button.



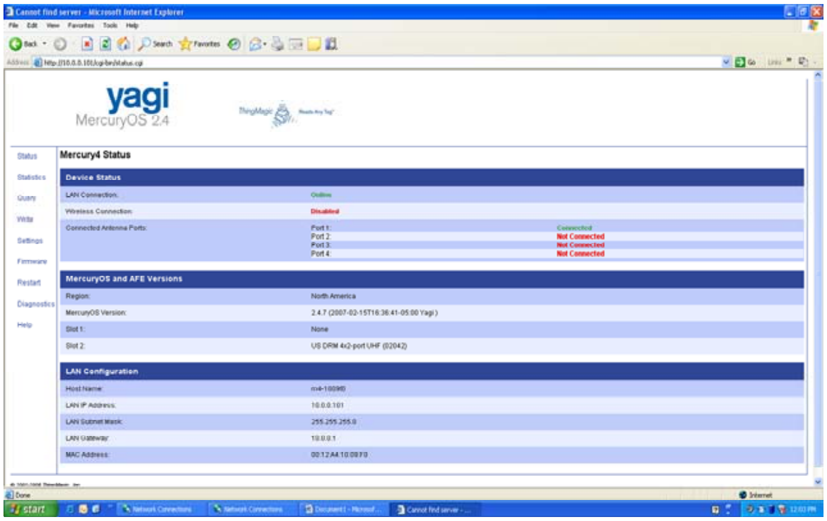
Change from the “Obtain an IP address automatically” option to “Use the following IP address:” and enter the following IP address, Subnet mask, and Default gateway.



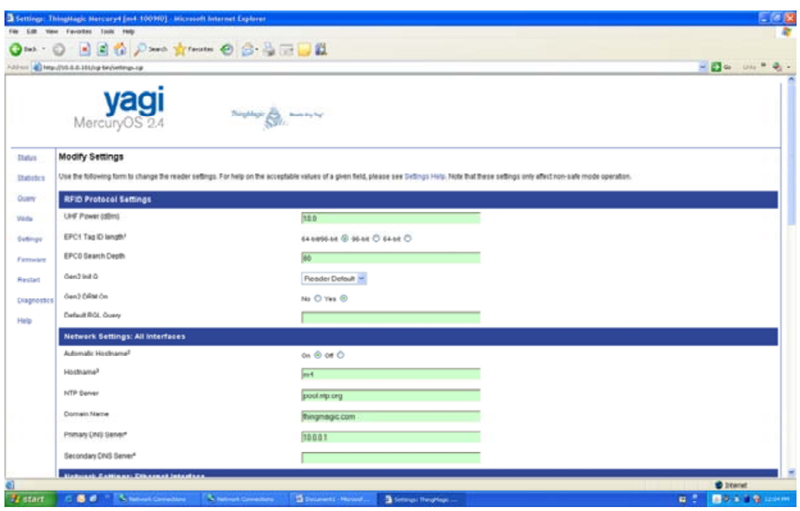
Open Internet Explorer and enter http://10.0.0.101/cgi-bin/status.cgi into the web address.

User Name: web
Passoword: radio

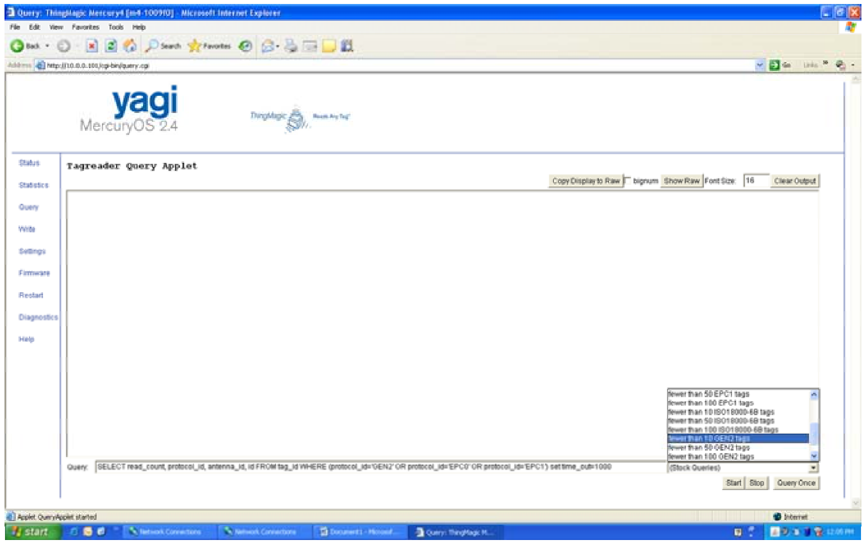
This is the MercuryOS status screen. Make sure that the antenna is labeled as connected in this status page before you begin testing. If it is not, check your co-axial connections.



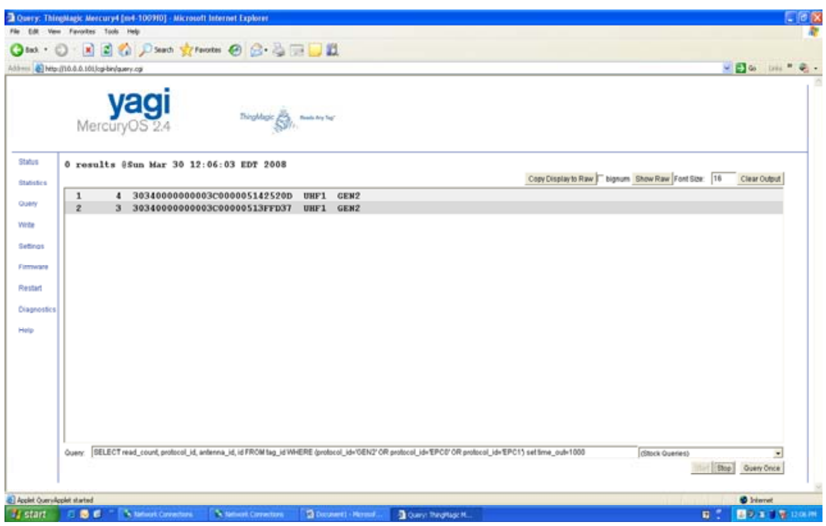
- Before you begin, ensure that you are utilizing the correct UHF Power setting for your testing range.
- Select the Settings option from the side menu. Change the value and press enter. Wait for the page to reload.
- The power setting ranges from 1 – 32.5 (dBm). Refer to the tag performance document as a guide.



- To begin Testing, select the Query page from the side menu.
- Select the proper tag from the list (Gen 2 for NXP tags).



- Testing can be carried out in two modes: Press **Query Once** to obtain one reading or press **Start** to begin a continuous reading.
- This is an example of a continuous test performed with 2 tags. Tests are best viewed while not in **Raw Mode** as was done in this example. (Continued on next slide)



Note the background color changes on the information for tag 2. These color changes signify a reading in which the reader did not read the tag.

One can verify that the reader did not read the second tag during once cycle by comparing the read count of both tags. In the second column of the tag information, one can see that the first tag was read at 100% efficiency (4 times) while the second tag was only read at 75% efficiency (3 times).

If the reader continues to not see the tag, this color will progressively become darker until it reaches a very dark grey.

1	4	30340000000003C000005142520D	UHF1	GEN2
2	3	30340000000003C00000513FFD37	UHF1	GEN2

Matlab code

```
K = menu('Select Analysis to be Performed','Antenna Comparison','Data Analysis');
if K== 1;
  Numberofantennas=menu('How many antennas to be analyzed', '2','3');
  if Numberofantennas == 1
  colormap
   %Data Entry for Antenna1
    distance1=input('Initial Tag Distance from Antenna ');
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
    reads1=input('Amount of Reads at distance 1 from Antenna1 ');
    reads2=input('Amount of Reads at distance 2 from Antenna1 ');
    reads3=input('Amount of Reads at distance 3 from Antenna1 ');
    reads4=input('Amount of Reads at distance 4 from Antenna1 ');
    reads5=input('Amount of Reads at distance 5 from Antenna1 ');

    %Data Entry for Antenna2
    disp('Input Collected Data for Antenna2')

    r1A2=input('Amount of Reads at distance 1 from Antenna2 ');
    r2A2=input('Amount of Reads at distance 2 from Antenna2');
    r3A2=input('Amount of Reads at distance 3 from Antenna2');
    r4A2=input('Amount of Reads at distance 4 from Antenna2');
```

```
    r5A2=input('Amount of Reads at distance 5 from Antenna2');
  %Equalities for Antenna 1
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
    Reads1=[reads1,reads2,reads3,reads4,reads5];
    y1=Reads1;
  %Equalities for Antenna 2
    x2=x1;
    Reads2=[r1A2,r2A2,r3A2,r4A2,r5A2];
    y2=Reads2;



   plot(x1,y1,x2,y2)
   xlabel('distance (m)');
   ylabel('reads');
   title('Plot of Testing Distance vs Amount of Reads: Antenna1,2: Blue=Antenna1')



elseif Numberofantennas == 2

  %Data Entry for Antenna1
    distance1=input('Initial Tag Distance from Antenna ');
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
```

```
    reads1=input('Amount of Reads at distance 1 from Antenna1 ');
    reads2=input('Amount of Reads at distance 2 from Antenna1 ');
    reads3=input('Amount of Reads at distance 3 from Antenna1 ');
    reads4=input('Amount of Reads at distance 4 from Antenna1 ');
    reads5=input('Amount of Reads at distance 5 from Antenna1 ');
%Data Entry for Antenna2


    r1A2=input('Amount of Reads at distance 1 from Antenna2 ');
    r2A2=input('Amount of Reads at distance 2 from Antenna2 ');
    r3A2=input('Amount of Reads at distance 3 from Antenna2 ');
    r4A2=input('Amount of Reads at distance 4 from Antenna2 ');
    r5A2=input('Amount of Reads at distance 5 from Antenna2 ');
%Data Entry for Antenna3
    r1A3=input('Amount of Reads at distance 1 from Antenna3 ');
    r2A3=input('Amount of Reads at distance 2 from Antenna3 ');
    r3A3=input('Amount of Reads at distance 3 from Antenna3 ');
    r4A3=input('Amount of Reads at distance 4 from Antenna3 ');
    r5A3=input('Amount of Reads at distance 5 from Antenna3 ');
%Equalities for Antenna 1
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
    Reads1=[reads1,reads2,reads3,reads4,reads5];
    y1=Reads1;
%Equalities for Antenna 2
    x2=x1;
    Reads2=[r1A2,r2A2,r3A2,r4A2,r5A2];
    y2=Reads2;
```

```
%Equalites for Antenna 3
    x3=x1;
    Reads3=[r1A3,r2A3,r3A3,r4A3,r5A3];
    y3=Reads3;



  plot(x1,y1,x2,y2,x3,y3)
  xlabel('distance (m)');
  ylabel('reads');
  title('Plot of Testing Distance vs Amount of Reads: Antenna1,2,3: Blue(Antenna1)
Green(Antenna2)');


end
end


if K == 2;
n=menu('Select Orientation','Horizontal','Perpendicular');


%Horizontal Direction
if n == 1;
        m=menu('Select Materials Tested', 'Aluminum6061-C6 and Acrylic', 'Lexon
        Polycarbon and Acrylic','Lexon Polycarbon and Aluminum6061-C6')


    if m == 1;
        %Sets up the time vector
        time=input('time elapsed');
        T=0:.25*time:time
        distance1=input('Initial Tag Distance from Antenna ');
```

```
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
    reads1=input('Aluminum: Amount of Reads at distance 1 from Antenna ');
    reads2=input('Aluminum: Amount of Reads at distance 2 from Antenna ');
    reads3=input('Aluminum: Amount of Reads at distance 3 from Antenna ');
    reads4=input('aluminum: Amount of Reads at distance 4 from Antenna ');
    reads5=input('Aluminum: Amount of Reads at distance 5 from Antenna ');
    %Polymer Information
    disp('Input Polymer Acquired information')
    acrylic1=input('acrylic: Amount of Reads at distance 1 from Antenna ');
    acrylic2=input('acrylic: Amount of Reads at distance 2 from Antenna ');
    acrylic3=input('acrylic: Amount of Reads at distance 3 from Antenna ');
    acrylic4=input('acrylic: Amount of Reads at distance 4 from Antenna ');
    acrylic5=input('acrylic: Amount of Reads at distance 5 from Antenna ');
    %Parameters Definition
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
    Reads1=[reads1,reads2,reads3,reads4,reads5];
    y1=Reads1;
    %Equalities for Antenna 2
    x2=x1;
    Reads2=[acrylic1,acrylic2,acrylic3,acrylic4,acrylic5];
    y2=Reads2;
pause
    %Creates a 3D plot
```

```
plot3(x1,T,y1,x2,T,y2)
    xlabel('Distance (m)');
    ylabel('Time (s)');
    zlabel('Amount of Reads');
    title('3D plot of Horizontal Orientation: Aluminum6061-C6 and Acrylic')
grid on
    pause
%Creates a 2D plot
    plot(x1,y1,x2,y2)
    xlabel('distance (m)');
    ylabel('reads');
    title('Plot of Distance vs Reads (Horizontal Orientation):Aluminum6061-C6 and Acrylic: Blue=Al')


  %Steel and Polymer
    elseif m == 2;
    %Sets up the time vector
    time=input('time elapsed');
    T=0:.25*time:time
    %Acquires the distances
    distance1=input('Initial Tag Distance from Antenna ');
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
    reads1=input('Lexon Polycarbon: Amount of Reads at distance 1 from Antenna ');
```

```
reads2=input('Lexon Polycarbon: Amount of Reads at distance 2 from Antenna ');
reads3=input('Lexon Polycarbon: Amount of Reads at distance 3 from Antenna ');
reads4=input('Lexon Polycarbon: Amount of Reads at distance 4 from Antenna ');
reads5=input('Lexon Polycarbon: Amount of Reads at distance 5 from Antenna ');
%Polymer Information
disp('Input Polymer Acquired information')
Acrylicreads1=input('Acrylic: Amount of Reads at distance 1 from Antenna ');
Acrylicreads2=input('Acrylic: Amount of Reads at distance 2 from Antenna ');
Acrylicreads3=input('Acrylic: Amount of Reads at distance 3 from Antenna ');
Acrylicreads4=input('Acrylic: Amount of Reads at distance 4 from Antenna ');
Acrylicreads5=input('Acrylic: Amount of Reads at distance 5 from Antenna ');
%Parameters Definition
Distance1=[distance1, distance2,distance3,distance4,distance5];
x1=Distance1;
Reads1=[reads1,reads2,reads3,reads4,reads5];
y1=Reads1;
%Equalities for Antenna 2
x2=x1;
Reads2=[Acrylicreads1,Acrylicreads2,Acrylicreads3,Acrylicreads4,Acrylicreads5];
y2=Reads2;
pause
%Creates a 3D plot
plot3(x1,T,y1,x2,T,y2)
xlabel('Distance (m)');
ylabel('Time (s)');
zlabel('Amount of Reads');
title('3D plot of Horizontal Orientation: Lexon Polycarbon vs Acrylic')
```

```
grid on
    pause
    %Creates 2D plot
    plot(x1,y1,x2,y2)
    xlabel('distance (m)');
    ylabel('reads');
    title('Plot of Testing Distance vs Amount of Reads(Horizontal Orientation): Lexon
Polycarbon and Acrylic: Blue=Lexon')
    grid on
    pause
%Aluminum vs Steel
    elseif m == 3;

    %Sets up the time vector
    time=input('time elapsed');
    T=0:.25*time:time
    %Acquires the Distances
    distance1=input('Initial Tag Distance from Antenna ');
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
    Lreads1=input('Lexon Polycarbon: Amount of Reads at distance 1 from Antenna ');
    Lreads2=input('Lexon Polycarbon: Amount of Reads at distance 2 from Antenna ');
    Lreads3=input('Lexon Polycarbon: Amount of Reads at distance 3 from Antenna ');
    Lreads4=input('Lexon Polycarbon: Amount of Reads at distance 4 from Antenna ');
    Lreads5=input('Lexon Polycarbon: Amount of Reads at distance 5 from Antenna ');
```

```
    %Aluminum information
    reads1=input('Aluminum6061-C6: Amount of Reads at distance 1 from Antenna ');
    reads2=input('Aluminum6061-C6: Amount of Reads at distance 2 from Antenna ');
    reads3=input('Aluminum6061-C6: Amount of Reads at distance 3 from Antenna ');
    reads4=input('Aluminum6061-C6: Amount of Reads at distance 4 from Antenna ');
    reads5=input('Aluminum6061-C6: Amount of Reads at distance 5 from Antenna ');
    %Equalities
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
    Reads1=[lreads1,lreads2,lreads3,lreads4,lreads5];
    y1=Reads1;
    %Equalities for Antenna 2
    x2=x1;
    Reads2=[reads1,reads2,reads3,reads4,reads5];
    y2=Reads2;
    pause
%Creates a 3D plot
plot3(x1,T,y1,x2,T,y2)
    xlabel('Distance (m)');
    ylabel('Time (s)');
    zlabel('Amount of Reads');
    title('3D plot of Horizantal Orientation: Lexon Polycarbon vs Aluminum6061-C6')
grid on
    pause
%Creates a 2D plot
    plot(x1,y1,x2,y2)
    xlabel('distance (m)');
```

```
        ylabel('reads');
        title('Plot of Distance vs Amount of Reads(Horizontal Orientation):Lexon Polycarbon and Aluminum6061-C6: Blue=LP')
    end
%Perpendicular Orientation
  elseif n == 2;
    m=menu('Select Materials Tested', 'Aluminum6061-C6 and Acrylic', 'Lexon Polycarbon and Acrylic','Lexon Polycarbon and Aluminum6061-C6')


    if m == 1;
        %Sets up the time vector
        time=input('time elapsed');
        T=0:.25*time:time
        distance1=input('Initial Tag Distance from Antenna ');
        distance2=input('Second Tag Distance from Amtenna ');
        distance3=input('Third Tag Distance from Antenna ');
        distance4=input('Fourth Tag Distance from Antenna ');
        distance5=input('Final Tag Distance from Antenna ');
        reads1=input('Aluminum: Amount of Reads at distance 1 from Antenna ');
        reads2=input('Aluminum: Amount of Reads at distance 2 from Antenna ');
        reads3=input('Aluminum: Amount of Reads at distance 3 from Antenna ');
        reads4=input('aluminum: Amount of Reads at distance 4 from Antenna ');
        reads5=input('Aluminum: Amount of Reads at distance 5 from Antenna ');
        %Polymer Information
        disp('Input Polymer Acquired information')
        acrylic1=input('acrylic: Amount of Reads at distance 1 from Antenna ');
        acrylic2=input('acrylic: Amount of Reads at distance 2 from Antenna ');
        acrylic3=input('acrylic: Amount of Reads at distance 3 from Antenna ');
```

```
    acrylic4=input('acrylic: Amount of Reads at distance 4 from Antenna ');
    acrylic5=input('acrylic: Amount of Reads at distance 5 from Antenna ');
    %Parameters Definition
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
    Reads1=[reads1,reads2,reads3,reads4,reads5];
    y1=Reads1;
    %Equalities for Antenna 2
    x2=x1;
    Reads2=[acrylic1,acrylic2,acrylic3,acrylic4,acrylic5];
    y2=Reads2;
pause
    %Creates a 3D plot


plot3(x1,T,y1,x2,T,y2)
    xlabel('Distance (m)');
    ylabel('Time (s)');
    zlabel('Amount of Reads');
    title('3D plot of Horizontal Orientation: Aluminum6061-C6 and Acrylic')
grid on
    pause
%Creates a 2D plot
    plot(x1,y1,x2,y2)
    xlabel('distance (m)');
    ylabel('reads');
    title('Plot of Distance vs Reads (Horizontal Orientation):Aluminum6061-C6 and Acrylic:
Blue=Al')
```

```
%Steel and Polymer
    elseif m == 2;
    %Sets up the time vector
    time=input('time elapsed');
    T=0:.25*time:time
    %Acquires the distances
    distance1=input('Initial Tag Distance from Antenna ');
    distance2=input('Second Tag Distance from Amtenna ');
    distance3=input('Third Tag Distance from Antenna ');
    distance4=input('Fourth Tag Distance from Antenna ');
    distance5=input('Final Tag Distance from Antenna ');
    reads1=input('Lexon Polycarbon: Amount of Reads at distance 1 from Antenna ');
    reads2=input('Lexon Polycarbon: Amount of Reads at distance 2 from Antenna ');
    reads3=input('Lexon Polycarbon: Amount of Reads at distance 3 from Antenna ');
    reads4=input('Lexon Polycarbon: Amount of Reads at distance 4 from Antenna ');
    reads5=input('Lexon Polycarbon: Amount of Reads at distance 5 from Antenna ');
    %Polymer Information
    disp('Input Polymer Acquired information')
    Acrylicreads1=input('Acrylic: Amount of Reads at distance 1 from Antenna ');
    Acrylicreads2=input('Acrylic: Amount of Reads at distance 2 from Antenna ');
    Acrylicreads3=input('Acrylic: Amount of Reads at distance 3 from Antenna ');
    Acrylicreads4=input('Acrylic: Amount of Reads at distance 4 from Antenna ');
    Acrylicreads5=input('Acrylic: Amount of Reads at distance 5 from Antenna ');
    %Parameters Definition
    Distance1=[distance1, distance2,distance3,distance4,distance5];
    x1=Distance1;
```

```
Reads1=[reads1,reads2,reads3,reads4,reads5];
y1=Reads1;
%Equalities for Antenna 2
x2=x1;
Reads2=[Acrylicreads1,Acrylicreads2,Acrylicreads3,Acrylicreads4,Acrylicreads5];
y2=Reads2;
pause
%Creates a 3D plot
plot3(x1,T,y1,x2,T,y2)
xlabel('Distance (m)');
ylabel('Time (s)');
zlabel('Amount of Reads');
title('3D plot of Horizontal Orientation: Lexon Polycarbon vs Acrylic')
grid on
pause
%Creates 2D plot
plot(x1,y1,x2,y2)
xlabel('distance (m)');
ylabel('reads');
title('Plot of Testing Distance vs Amount of Reads(Horizontal Orientation): Lexon Polycarbon and Acrylic: Blue=Lexon')
grid on
pause
%Aluminum vs Steel
elseif m == 3;

%Sets up the time vector
```

```
time=input('time elapsed');
T=0:.25*time:time
%Acquires the Distances
distance1=input('Initial Tag Distance from Antenna ');
distance2=input('Second Tag Distance from Amtenna ');
distance3=input('Third Tag Distance from Antenna ');
distance4=input('Fourth Tag Distance from Antenna ');
distance5=input('Final Tag Distance from Antenna ');
Lreads1=input('Lexon Polycarbon: Amount of Reads at distance 1 from Antenna ');
Lreads2=input('Lexon Polycarbon: Amount of Reads at distance 2 from Antenna ');
Lreads3=input('Lexon Polycarbon: Amount of Reads at distance 3 from Antenna ');
Lreads4=input('Lexon Polycarbon: Amount of Reads at distance 4 from Antenna ');
Lreads5=input('Lexon Polycarbon: Amount of Reads at distance 5 from Antenna ');
%Aluminum information
reads1=input('Aluminum6061-C6: Amount of Reads at distance 1 from Antenna ');
reads2=input('Aluminum6061-C6: Amount of Reads at distance 2 from Antenna ');
reads3=input('Aluminum6061-C6: Amount of Reads at distance 3 from Antenna ');
reads4=input('Aluminum6061-C6: Amount of Reads at distance 4 from Antenna ');
reads5=input('Aluminum6061-C6: Amount of Reads at distance 5 from Antenna ');
%Equalities
Distance1=[distance1, distance2,distance3,distance4,distance5];
x1=Distance1;
Reads1=[lreads1,lreads2,lreads3,lreads4,lreads5];
y1=Reads1;
%Equalities for Antenna 2
x2=x1;
Reads2=[reads1,reads2,reads3,reads4,reads5];
```

```
        y2=Reads2;
        pause
    %Creates a 3D plot
    plot3(x1,T,y1,x2,T,y2)
        xlabel('Distance (m)');
        ylabel('Time (s)');
        zlabel('Amount of Reads');
        title('3D plot of Horizantal Orientation: Lexon Polycarbon vs Aluminum6061-C6')
    grid on
        pause
    %Creates a 2D plot
        plot(x1,y1,x2,y2)
        xlabel('distance (m)');
        ylabel('reads');
        title('Plot of Distance vs Amount of Reads(Horizontal Orientation):Lexon Polycarbon
and Aluminum6061-C6: Blue=LP')
    end
  end
  end
```