HyperLynx® 3D EM

RFID Tag Design Quick Start Guide

Software Version 15.2

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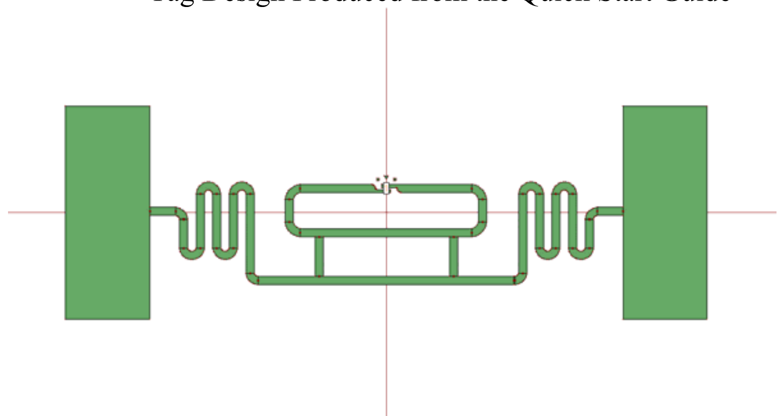
Introduction

Purpose of Guide

This manual is intended as a quick guide reference for using Mentor Graphics IE3D as the design tool for a RFID tag design. It does not replace the manual but rather shows the detailed steps and key strokes required to design a RFID tag based upon a set of requirements. It is expected that as the designer gains experience he will no longer need this quick start guide but rather will use the primary manual as his reference tool.

Tag Design Produced from the Quick Start Guide



Reference Files

These are files, provided by Mentor Graphics IE3D that can be used during the RFID Tag design process. They are the foundation of a reference library suite that the tag designer will develop to simplify future designs.

1. Reference Loops

   Two reference loop designs are provided, one for each of two different die attach methods. The first is a strap design in which the die is attached to a small substrate that then provides attachment pads. These pads then allow connection to the antenna via some conductive adhesive. The second is a direct Flip Chip attachment, in which the die is directly attached to the antenna. Both designs are resonant at 915MHz with typical RFID I.C. parameters so they can be used a starting point for a RFID tag design. These designs are intended as a starting point only. They **will require layout modification** to exactly match any particular process and will require inductance adjustment to match antenna and particular die specification. The following are the file names for these two designs:

   - Ref 1mm Loop Strap.geo
   - Ref 1mm Loop FC.geo

2. Reference IC Representations

   There are multiple manufactures of RFID Tag chips and each has their own set of electrical characteristics. Typically the characteristics are specified as parallel Resistance and Capacitance. When designing a RFID tag it is necessary to convert these impedances to Series Equivalents in order to determine the conjugate match of the antenna. This can be accomplished with the following equations:

   $\mathrm{Rchip}_{\mathrm{Series}} = R_S / (1+(\omega R_S C_S)^2$ $\quad\quad$ $\mathrm{Xchip}_{\mathrm{Series}} = -J\omega C_S R_S^2 / (1 + (\omega R_S C_S)^2$

   In IE3D, however, has a method to convert the parallel R and C values into frequency depended series impedances for use in the tag design. This is accomplished with **IE3D Modua Module**. Modua allows the creation of a model, via an included schematic capture, of the parallel parameters and then specify the component values. It will then be attached to the antenna geometry post processing to determine the conjugate match.

   The designer still must address the fact that a strap will add some parasitic capacitance but this can be accounted for by having two Modula modules, one for a strap and one for flip chip attachment. As a rule of thumb you can add approximately .1pF of capacitance to a strap design using the same IC as a flip chip.

   So again as a starting point for a future reference design suite, this guide has provided two reference designs, one for a strap based design and another for a flip chip design. These are not representative of any particular IC but rather typical of generic RFID devices. As with the Reference Loops they **will require modification** to exactly match any particular IC. The following are the file names for these two designs:

   - **Ref IC Z1 Strap.sp** *Modua Module with values entered for a strap*
   - **Ref IC Z1 FC.sp** *Modua Module with values entered for a Flip Chip*

3. Reference Tag Designs
   Provided are two tag designs used for evaluation in this guide. The first is the final output product of the design from this guide. It can be used to compare the results obtained during the example exercise. The second is a reference tag used for the substitution method of determining tag sensitivity. The file names are as follows:
   - **Eng Design Ref.geo** *The expected design geometry resulting from following this guide*
   - **Golden Ref.sp** *The output of a reference tag that has been characterized for performance*

   It should be noted that the Golden Ref.sp is not a real tag but given as an example for this guide. The tag designer is required to select and characterize his own reference tag.
4. Reference Geometries
   One file is provided but the designer will add additional requirements as he becomes familiar with his typical requirements. These files are intended to be used as common geometries that can be imported into new designs. They will save the designer the time required to construct them on his own. The file name of the file provided is as follows:
   - **1mm Meandering.geo** *Pre constructed geometries for use in new designs*

Section Definitions

This guide is divided into the following sections. The intent of each is also described.

1. Introduction
2. Requirements
   The requirements are divided into two sub sets. The first is typical from a market driven specification. The second however, is the engineering interpretation of those marketing requirements. The engineering requirements are primarily used for the tag design while the marketing requirements will be used to qualify tag performance.
3. IE3D Setup and Additional Background
   Opening an IE3D session and preparing the initial parameters. Also information concerning the actual manufacture of a RFID tag to use as background for the IE3D settings.
4. Initial Design Layout
   This section details the how to construct the initial tag layout using IE3D M-Grid (Geometry layout editor). The objective is to converge upon a fundamental design that will prove concept and allow final optimization.
5. Tag Optimization
   This is the modification of the Initial Design that will meet the Engineering Requirements.
6. Tag Qualification
   This is the final simulations that confirm the tag will meet marketing application and operational frequency requirements.

Requirements

Typical requirements are driven by customers and come from marketing to solve a particular customer need. The designer must take these requirements and extract a set of engineering requirements that represent the actual design requirements. The following is a typical set of marketing requirements and an attempt to place engineering requirements that will reflect the same. This is not an exhaustive list and is to be used only as an example. The actual requirements and engineering interpretation will vary from company to company and from designer to designer.

Marketing Requirements

1. Size — 1 inch (25.4mm) x 3 inch (76.2mm)
2. Mechanical — Z-Axis of tag to be flat within 5microns (thickness)
3. I.C. — Die, Company #1 (R_P= 1500ohms C_P=.87pF)
4. Operational Bands — US, Europe, China
5. Application — Plastic Bottle, 1mm thick, without metalized label
6. Read Range — 2 meters minimum
7. Polarity of Operation — Bottles aligned in a vertical manner
8. Miscellaneous — Alternate operation of tag on corrugate and free space

Engineering Requirements

1. Mechanical
   - Size as specified, 24.4mm x 76.2mm
   - Flip Chip Design to insure flatness
   - Minimum Trace Width = 1mm, from existing process and manufacturing tolerances.
   - Trace Height = .005mm, from existing process
   - Trace Composition = Copper from existing process
   - Substrate Layer Thickness = .06mm
2. Electrical
   - IC characteristics, from the Zealand#1 die
     a. R_P = 1500Ω, as specified
     b. C_P = .87pF, since the process will be flip chip there is no need to add .1pF parasitic capacitance
   - Trace Conductivity = 4.7 e7, per copper specifications
   - Relative Permeability = 1
   - Loss Tangent for Dielectric and Permeability = 0
   - Relative Dielectric Constants and material thickness
     a. Plastic 2.9 @ 1mm
     b. Corrugate, 1.2 @ 3.2 mm
     c. Substrate, 2.9 @ .06 mm
3. Bandwidth

   The requirements specify free space operation in the US (902 – 928 MHz), Europe (866 MHz) and China (a subset of the two). To cover these bands of operation the frequency bandwidth must be greater than (860 - 928) MHz = 62 MHz. The requirements also require operation applied to both 3.2mm of corrugate and 1mm of plastic. Operation on any non free space dielectric has the effect of shifting the bandwidth down to a lower center frequency. Since the dielectric constant of plastic is much larger than that of corrugate we can assume that if the tag functions on plastic it will also function on corrugate. An engineering estimation of the shift due to 1mm of plastic is around 50 MHz. If this shift is added to the free space requirements we see a new minimum bandwidth requirement of 62 MHz + 50 MHz = 112 MHz.

   Another consideration when determining the bandwidth is the manufacturing tolerances of the die, its attachment method and the antenna itself. An engineering estimate of this shift is up to +/-20 MHz. When this tolerances is added to minimum as calculated above the engineering requirement for bandwidth become BW = 112 MHz + 40 MHz = 152 MHz.

   Also since it is known that the effects of additional dielectric are to move the center frequency of the bandwidth, it can be stated that the lower corner frequency of the free space bandwidth should be the lowest specified operational frequency. In this case it is 860 MHz. The following therefore become the engineering bandwidth requirements.

   - BW = 150 MHz
   - $F_{L(\text{Free Space})}$ = 860 MHz
4. Turn-On Sensitivity

   The turn on sensitivity is the amount of attenuation a reference RFID reader and antenna pair can accept and still power the tag at a reference distance. A typical distance that a tag is tested to determine this parameter is 1 foot. In addition in order to remove the effects of the tag backscatter (tag to reader communication) a circulator network is utilized to insure that the response is only due to the forward attenuation path (reader to tag communication). For example if a tag could accept 28 dB of attenuation in transmit power from reader in free space at 1foot and still be read, then the tag is considered a 28 dB tag. The Golden Ref Tag as included in this guide can be assumed to have been characterized on this type of test system to yield a Turn-On-Sensitivity and non attenuated read range on a reference setup as follows:

   Golden $\text{Ref}_{\text{T-O-S}}$ = 30 dB

   Golden $\text{Ref}_{\text{READ RANGE}}$ = 4 meters *(See Tag Qualification at the end of this guide for Read Range Definition)*

   This number can be related to read range with the following equation:

   $\mathbf{RR = R_{REF} * 10^{\Delta dB/20}}$ (where ΔdB is the attenuation at T-O-S at the reference distance)
   if $\mathbf{R_{REF} = 1}$ **foot(.3048m)** then $\mathbf{RR = .3048 * 10^{\Delta dB/20}}$ **meters**

   It can be calculated from the above equations that the new design will require a minimum of 30-6 = 24dB to read at 2 meters. From this we can then specify that the match for the new design to provide adequate turn-on-sensitivity must be within 6dB of the golden ref in free space for both free space and when applied to the specified plastic. The following are requirements can now be deduced.

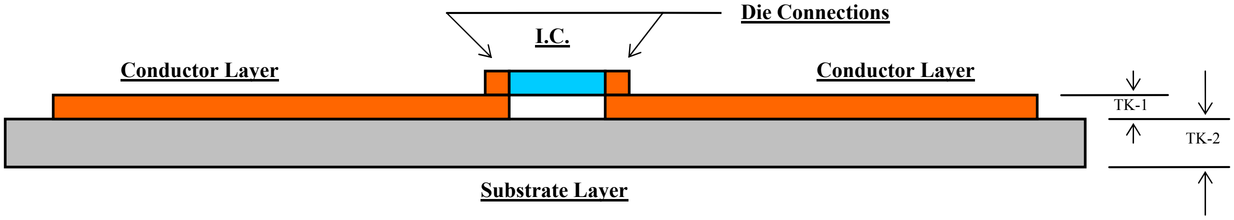
   - Maximum Free Space Mismatch = 6 dB from the Free Space Golden Ref Design
   - Maximum Free Space Variation over the 150 MHz bandwidth = /- 3 dB, *our definition of bandwidth.*
   - Maximum On Plastic Mismatch = 6 dB from the Free Space Golden Ref Design.
   - Maximum On Plastic Variation over the 150 MHz bandwidth = +/- 3 dB, *our definition of bandwidth.*
   - Maximum Delta dB between Free Space and Plastic over the entire user band = -3 dB, *desired characteristic*.
5. Backscatter Sensitivity

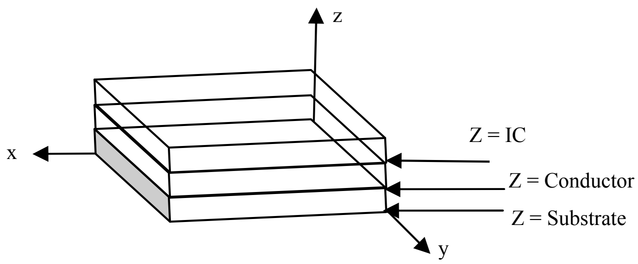
   This was not specified in the requirements and as such will not be included in the engineering specifications. It is however a parameter that is sometimes an issue.
   - BS, not specified

IE3D Setup and Additional Background

RFID Tag Construction

A typical RFID tag is comprised of four main components as shown in the following figure. The physical properties of each component must be defined in IE3D in order to get an accurate performance simulation.





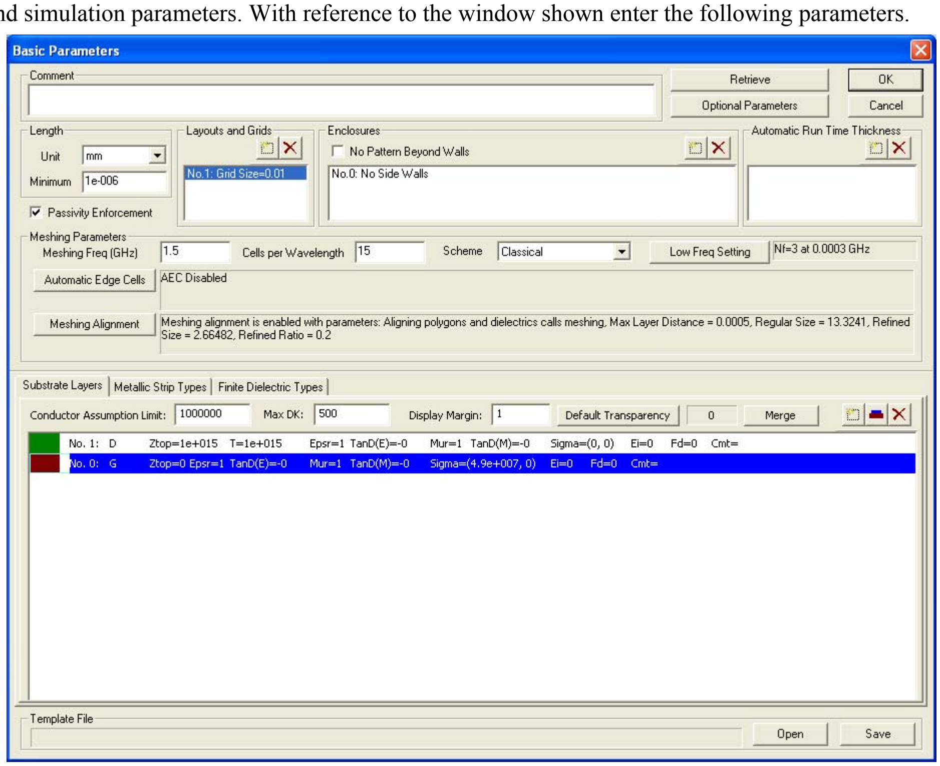
Opening IE3D

To start the design, accomplish the following;

1. Select the IE3D Program Manager **“ie3dpm” Icon** on the computer to be used for simulations
2. Select “MGrid” option from the ie3dpm menu list.
3. Select **“File” and “New”** to enable the ***Basic Parameter*** Window

Initial Basic Parameters

IE3D “**Basic Parameters**” is where the RFID tag’s substrate and conductor layer properties are defined as well as some drawing and simulation parameters. With reference to the window shown enter the following parameters.



1. Basic Drawing Parameters

Some basic drawing parameters are defined under ***Basic Parameters*** for this design the values chosen are as follows;

Enter,	Unit of Length =	**mm**
Enter,	Minimum Length =	**1e-006**
Enter,	Layouts and Grids =	**.01**

2. Basic Simulation Parameters

Some basic simulation parameters are defined under Basic Parameters. They are of concern as they affect both the speed and accuracy of the simulation. The basic simulation parameters are as follows;

Enter,	Meshing frequency =	**1.5GHz**	to cover all frequencies
Enter	Cells per Wavelength =	**15**	initially
Check the	Scheme of	**Classical**	typically for tag designs

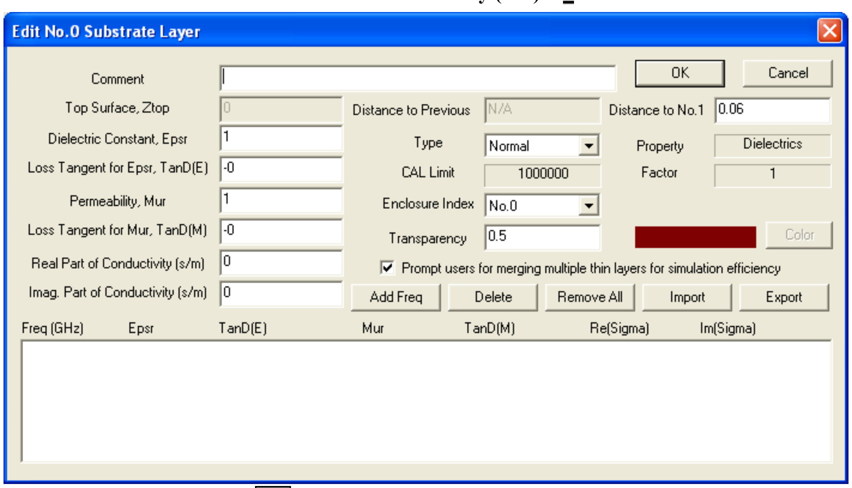
3. Substrate Layers

The substrate layer is the material that the conductor is applied to. It typically consists of some type of plastic with a defined dielectric constant as well as other mechanical and electrical properties. Initially IE3D requires the thickness and the specified dielectric constant to start the design. To enter the properties, select the ***Substrate Layer Tab*** and enter the parameters as shown in the following table.

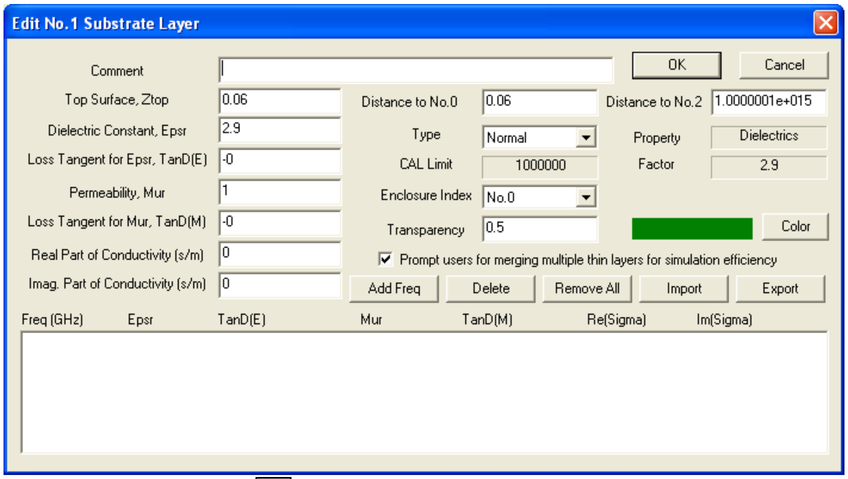
Substrate Layers Parameters (Red entries are different from the default of a new design)

Relative Dielectric Constant	Dielectric Loss Tangent	Relative Permeability	Permeability Loss Tangent	Conductivity Sigma Real, Imaginary	Comments
1	0	1	0	0,0	Ground Plane
2.9	**0**	**1**	**0**	**0,0**	Substrate Layer
1	**0**	**1**	**0**	**0,0**	Infinite Layer, exists after file save

Double Click on the	**No. 0 G** substrate data
Enter	**Real Part of Conductivity (s/m) = 0**



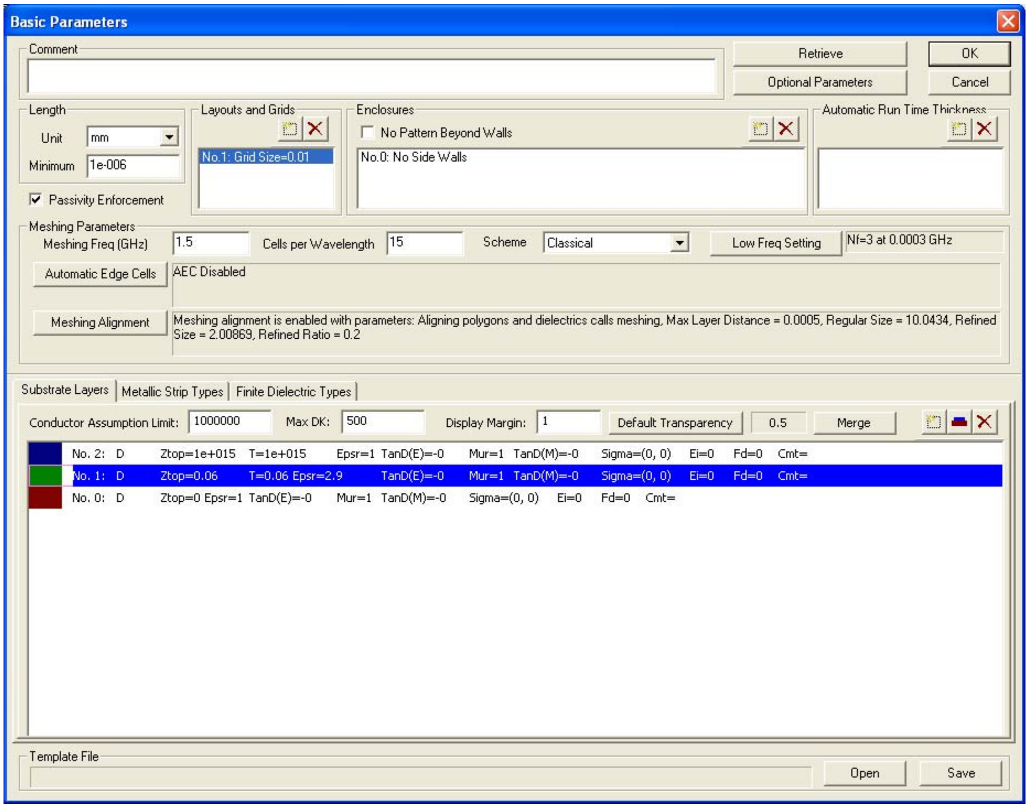
Click	**OK** (Edit No.0 Substrate Layer)
Double Click on the	**No. 1 D** substrate data
Enter	**Dielectric Constant, Epsr = 2.9**
Enter	**Top Surface, Ztop = .06**



Click **OK** (Edit No.1 Substrate Layer)

The following shows the IE3D Basic Parameter Window with the Substrate Layer defined for this RFID tag design.

- Note, Layer No. 2 is at 1 e+15mm from the ground plane. This layer is added by IE3D when the design is saved.
- Notice the ground plane has a conductivity of 0,0 (i.e. ground plane not used for tag designs).

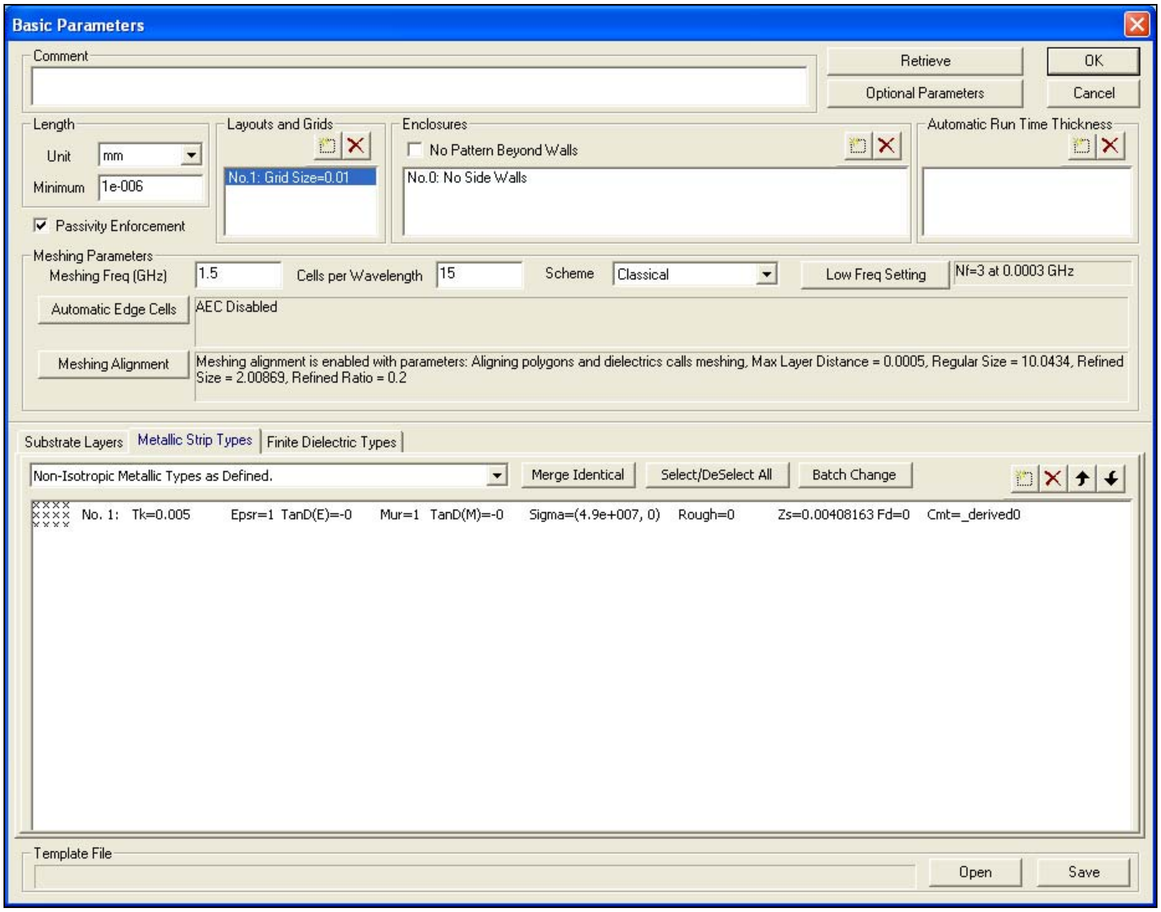


4. Metallic Strip Types

The conductor layer of the RFID tag is the electron path of the antenna that collects energy from the RF Field. It is typically made of either copper or aluminum but can also be of other conductors. For purposes of the initial design the Relative Dielectric Constant and Permeability are assumed to be “1”. The conductivity and thickness however need to be entered to reflect the design. To enter the properties, select the ***Metallic Strip Types Tab*** and enter the parameters as shown in the following table.

Metallic Strip Type Parameters (Red entries are different from the default of a new design)							
	Thickness	Relative Dielectric Constant	Dielectric Loss Tangent	Relative Permeabilit y	Permeabilit y Loss Tangent	Conductivity Sigma Real, Imaginary	Comments
1	**.005**	**1**	**0**	**1**	**0**	**4.9e+007**	**Copper, default values**

The following shows the IE3D Basic Parameter Window with the Metallic Strip Types defined for a particular RFID tag design. Notice the conductivity is the default value for copper.



Exiting the Basic Parameter Window

To Exit the Basic Parameter Window and start the design accomplish the following:

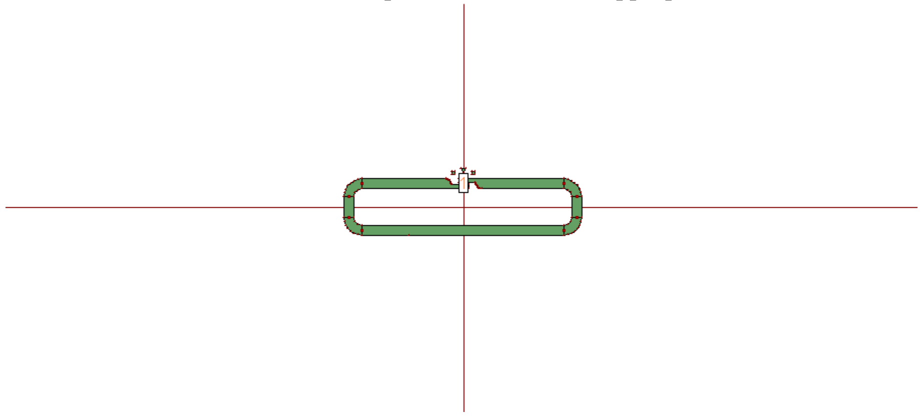
1. Select **<u>“OK”</u>** to accept the Basic Parameters
2. Select **<u>“File” and “Save As” Design Example</u>** to enable M-Grid

Initial Design Layout

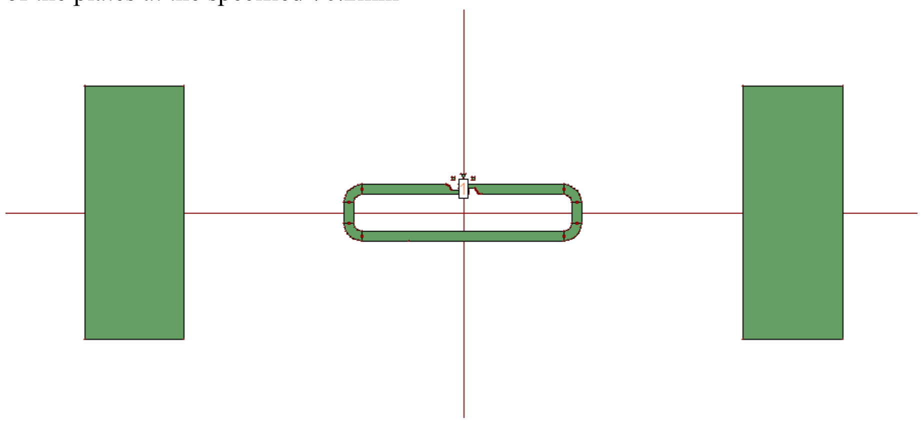
The initial dipole can be lain out with M-Grid (Mentor Graphicss' CAD Package) or with Auto Cad as a DXF file and then imported via IE3D. It can also be any external CAD program supported by ADIX. The following is a suggested sequence for laying out the initial tag geometry. If the user chooses to use the M-Grid package, Appendix C outlines the exact key strokes for this approach.

Initial Loop Design

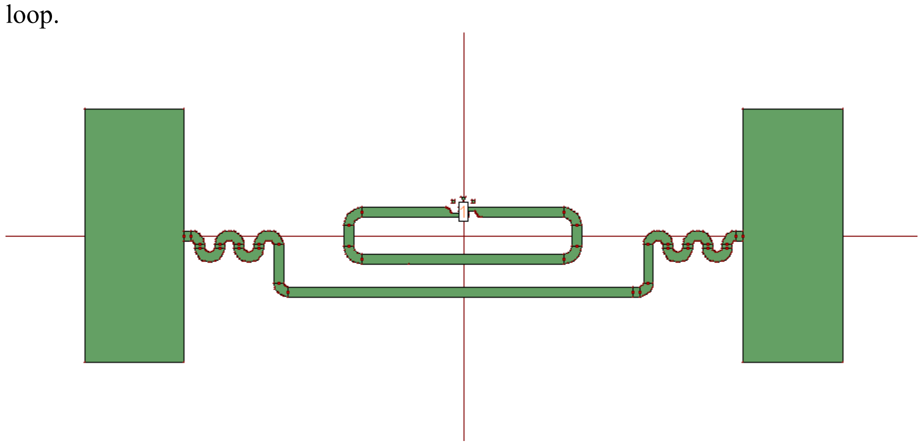
1. Convert on one of the reference loop DXF files into the appropriate format.



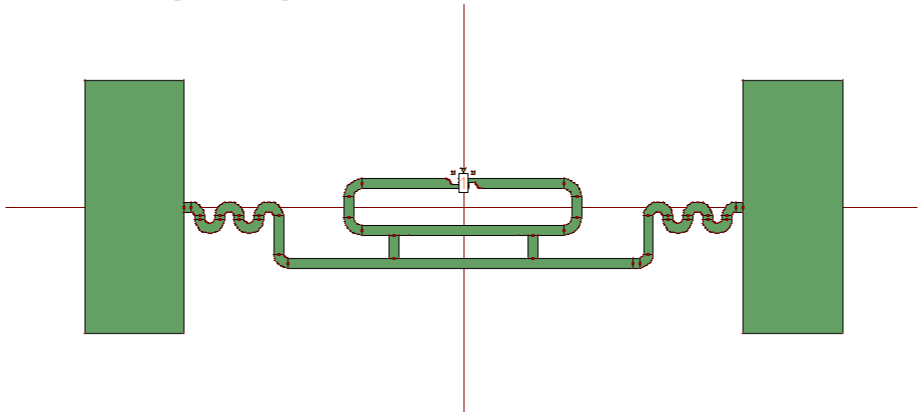
2. Add Capacitance Plates (10mm x 25.4mm) to each end of the proposed design with the outer extremes of the plates at the specified 76.2mm



3. Create a Meandered Dipole that runs from the middle of the capacitance plates to the just under the loop.



4. Connect the loop to the dipole as shown.

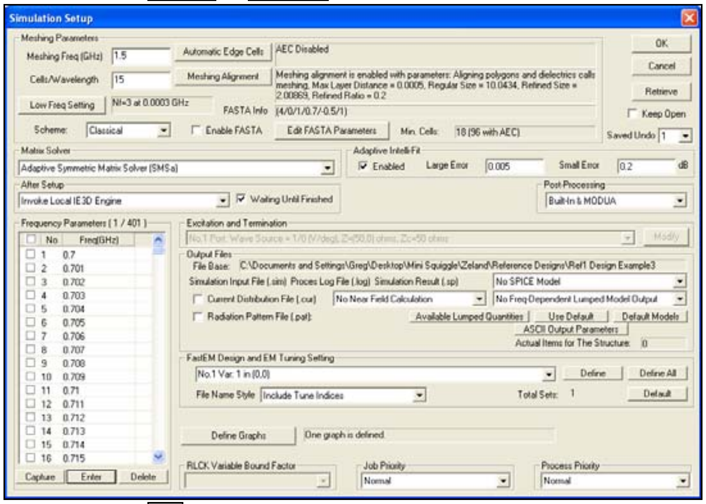


5. Import the file into IE3D as a GEO file.
6. Continue with the tag design at the next section

Tag Optimization

1. Simulation of "Design Example.geo"

Select **Process** --- **Simulate**



Select **OK** (Simulate)

2. Adjust Meandering Inductance

Increase Inductance

Select **Open** --- **Initial Design Example**
Select **Edit** --- **Select Vertices** ALT-S
Select **Left side of top half of the meandered loops** (as shown in example)
Select **Right side of top half of the meandered loops**
Select **Edit** --- **Move Objects** SHFT-M
Left Click Mouse
Enter **X-Position = 0** and **Y-Position = +2**
Select OK (Move Object Offsets to Original)
Select File --- Save As --- Initial+M
Select Process --- Simulate
Select OK (Simulation Setup) Step #1 for Screen Image

Reduce Inductance

Select **Open** --- **Initial Design Example**
Select **Edit** --- **Select Vertices** ALT-S
Select **Left side of top half of the meandered loops** (as shown in example)
Select **Right side of top half of the meandered loops**
Select **Edit** --- **Move Objects** SHFT-M
Left Click Mouse
Enter **X-Position = 0** and **Y-Position = -2**
Select OK (Move Object Offsets to Original)
Select File --- Save As --- Initial-M
Select Process --- Simulate
Select OK (Simulation Setup) Step #1 for Screen Image

3. Adjust Coupling Points

Tighten Coupling

Select **Open** --- **Initial Design Example**
Select **Edit** --- **Select Vertices** ALT-S
Select **Left Side Vertical Coupling Trace** (as shown in example)
Select **Edit** --- **Move Objects** SHFT-M
Left Click Mouse
Enter **X-Position = -1** and **Y-Position = 0**
Select OK (Move Object Offsets to Original)
Select **Right Side Vertical Coupling Trace** (as shown in example)
Select **Edit** --- **Move Objects** SHFT-M
Left Click Mouse
Enter **X-Position = 1** and **Y-Position = 0**

Select	OK (Move Object Offsets to Original)	
Select	File --- Save As --- Initial+C	
Select	Process --- Simulate	Step #1 for Screen Image
Select	OK (Simulation Setup)	

Loosen Coupling

Select	**Open** --- **Initial Design Example**	
Select	**Edit** --- **Select Vertices**	ALT-S
Select	**Left Side Vertical Coupling Trace** (as shown in example)	
Select	**Edit** --- **Move Objects**	SHFT-M
Left Click Mouse		
Enter	**X-Position = 1** and **Y-Position = 0**	
Select	OK (Move Object Offsets to Original)	
Select	**Right Side Vertical Coupling Trace** (as shown in example)	
Select	**Edit** --- **Move Objects**	SHFT-M
Left Click Mouse		
Enter	**X-Position = -1** and **Y-Position = 0**	
Select	OK (Move Object Offsets to Original)	
Select	File --- Save As --- Initial-C	
Select	Process --- Simulate	Step #1 for Screen Image
Select	OK (Simulation Setup)	

4. Adjust Loop Inductance

Increase Loop Inductance

Select	**Open** --- **Initial Design Example**	
Select	**Edit** --- **Select Vertices**	ALT-S
Select	**top half of the loop** (as shown in example)	
Select	**Edit** --- **Move Objects**	SHFT-M
Left Click Mouse		
Enter	**X-Position = 0** and **Y-Position = .5**	
Select	OK (Move Object Offsets to Original)	
Select	File --- Save As --- Initial+L	
Select	Process --- Simulate	Step #1 for Screen Image
Select	OK (Simulation Setup)	

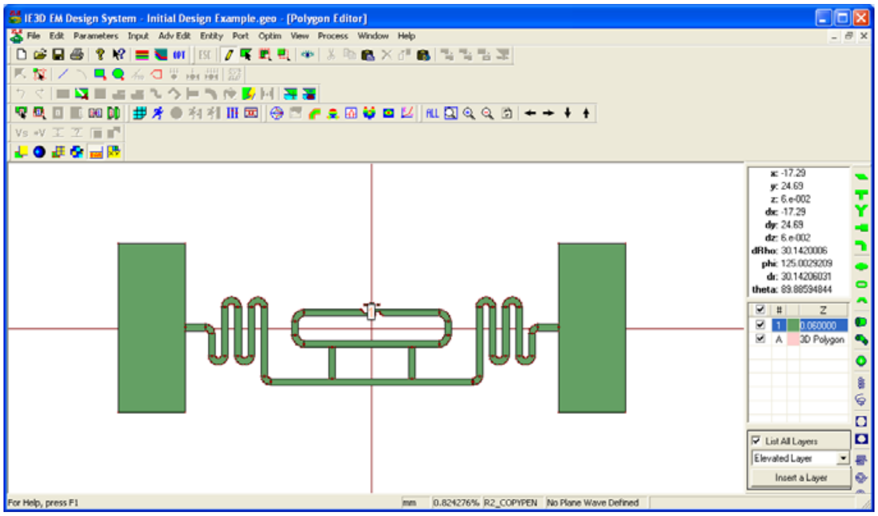
Reduce loop Inductance

Select	**Open** --- **Initial Design Example**	
Select	**Edit** --- **Select Vertices**	ALT-S
Select	**top half of the loop** (as shown in example)	
Select	**Edit** --- **Move Objects**	SHFT-M
Left Click Mouse		
Enter	**X-Position = 0** and **Y-Position = -.5**	
Select	OK (Move Object Offsets to Original)	
Select	File --- Save As --- Initial-L	
Select	Process --- Simulate	Step #1 for Screen Image
Select	OK (Simulation Setup)	

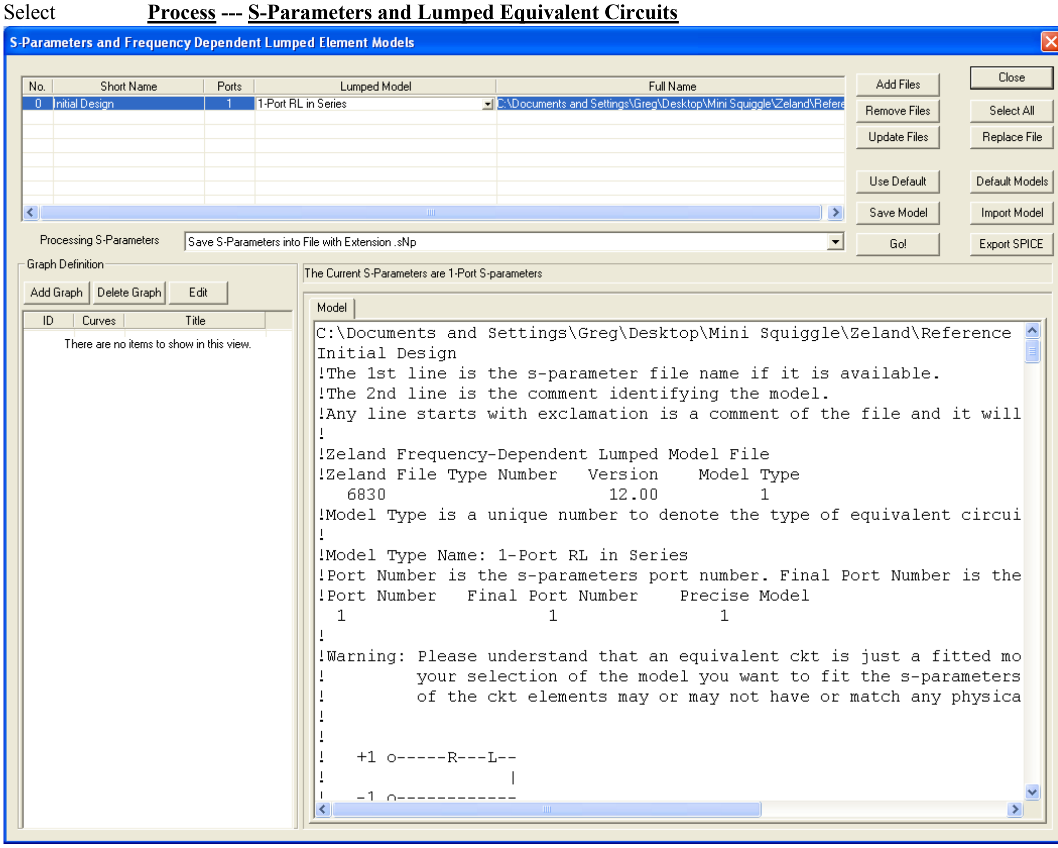
5. Conjugate Match Factor

Open Design Variation Files

Select	**File** --- **Open** --- **Initial Design Example.geo**



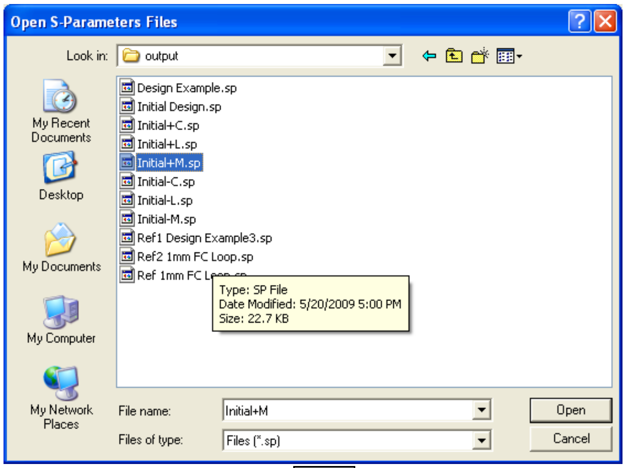
Select **Process** --- **S-Parameters and Lumped Equivalent Circuits**



Dbl Click On Space under **"Short Name"**

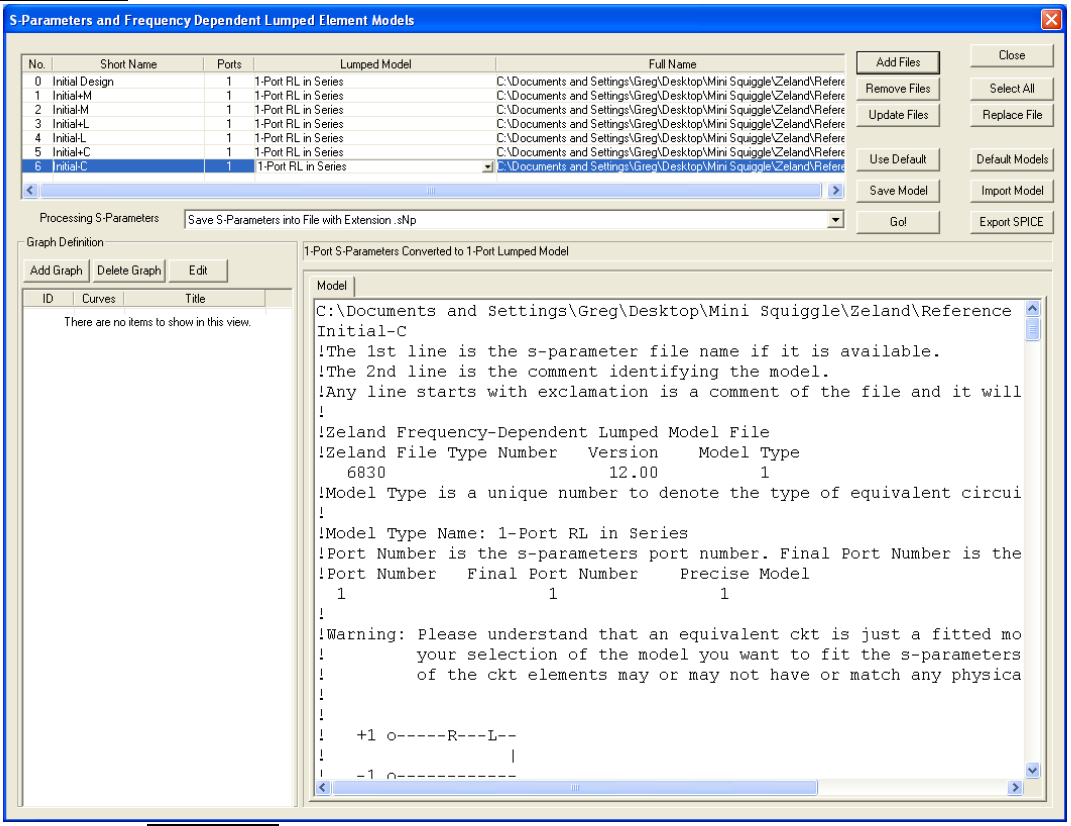
Enter **Initial Design**

Click **Add Files**



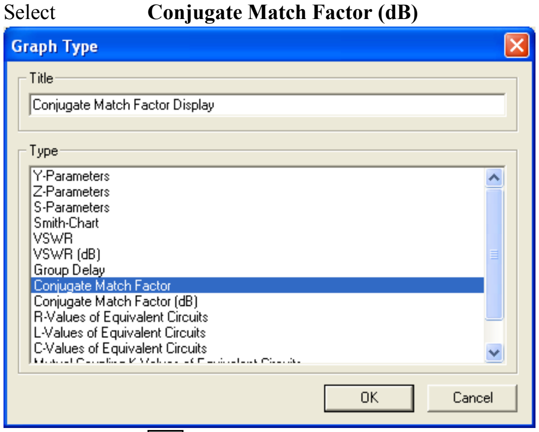
Enter **Initial+M.sp** --- **OPEN** (Open S Parameter Files)
Click **Add Files**
Enter **Initial-M.sp** --- **OPEN** (Open S Parameter Files)
Click **Add Files**
Enter **Initial+L.sp** --- **OPEN** (Open S Parameter Files)
Click **Add Files**
Enter **Initial-L.sp** --- **OPEN** (Open S Parameter Files)
Click **Add Files**
Enter **Initial+C.sp** --- **OPEN** (Open S Parameter Files)
Click **Add Files**
Enter **Initial-C.sp** --- **OPEN** (Open S Parameter Files)

Define Graph

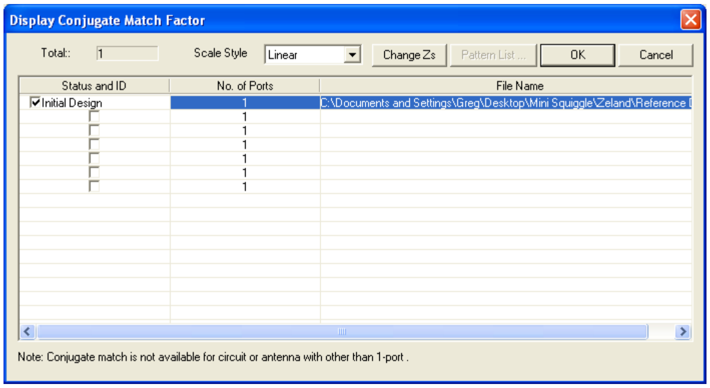


Click **ADD GRAPH** Plot 0

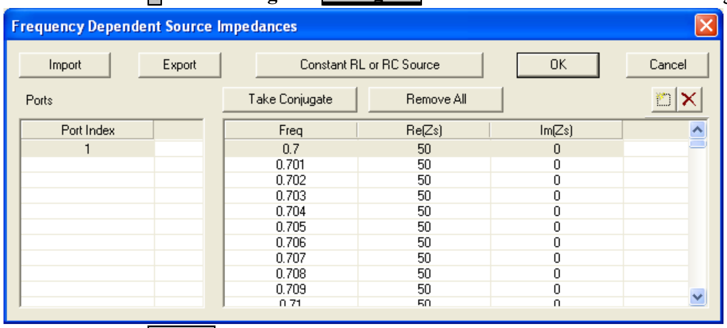
Select **Conjugate Match Factor (dB)**



Select **OK** (Graph Type)

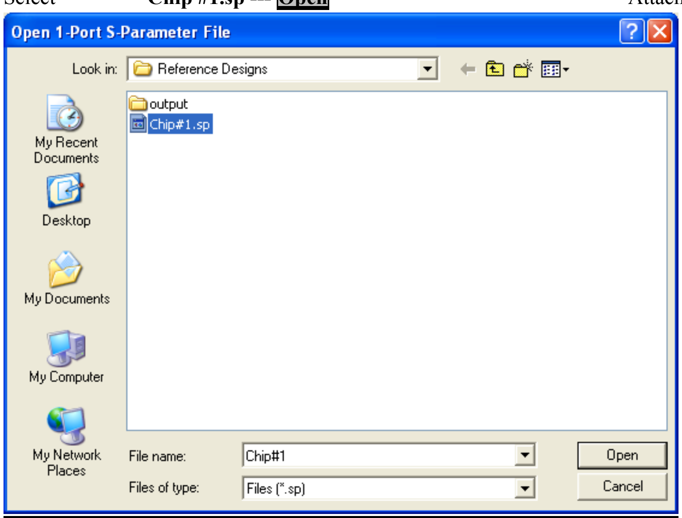


Check √ **Initial Design --- Change Zs** Initial Design Plot

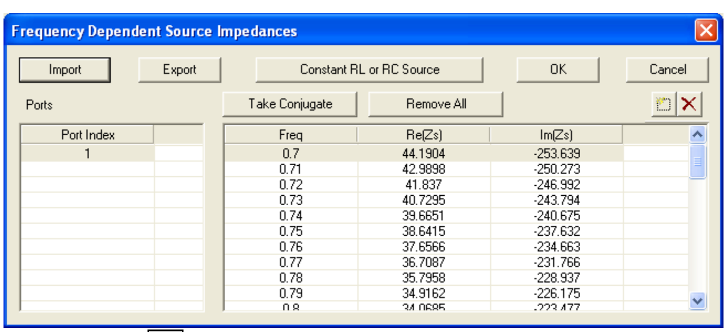


Select **Import**

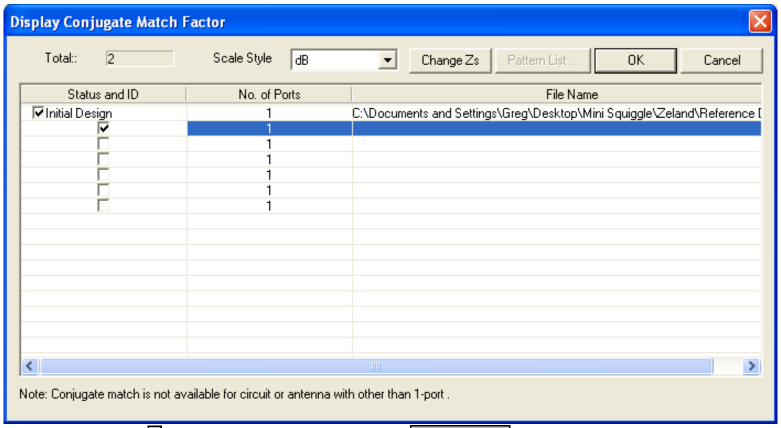
Select **Chip #1.sp --- Open** Attach chip parameters



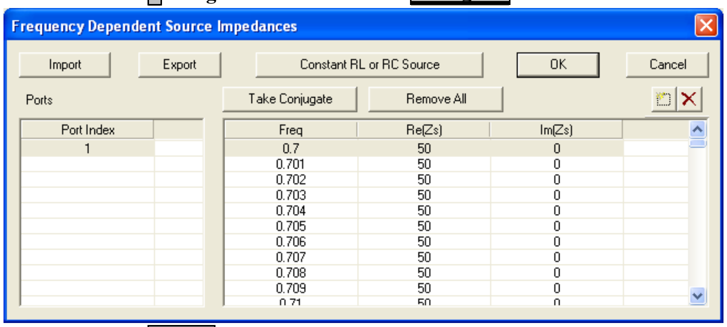
Select **Open** (Open 1=Port S-Parameter Designs



Select **OK**

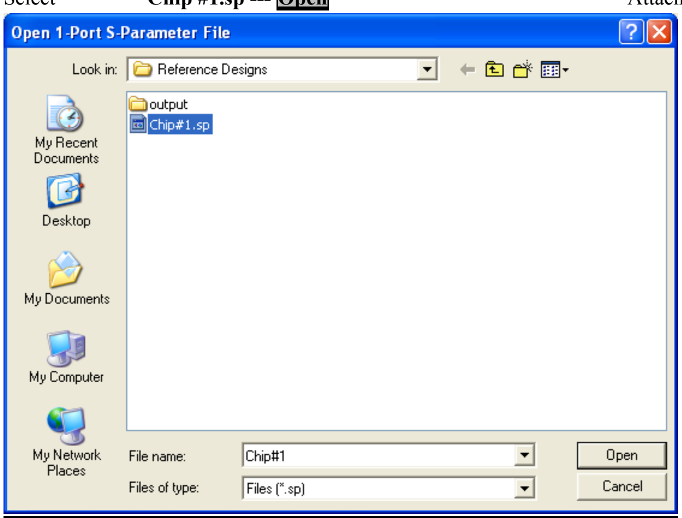


Check **√ Design Modification #1 --- Change Zs** Initial+M Plot



Select **Import**

Select **Chip #1.sp --- Open** Attach chip parameters



Select **OK**

Check **√ Design Modification #2 --- Change Zs** Initial-M Plot
Select **Import**
Select **Chip #1.sp --- Open** Attach chip parameters
Select **OK**

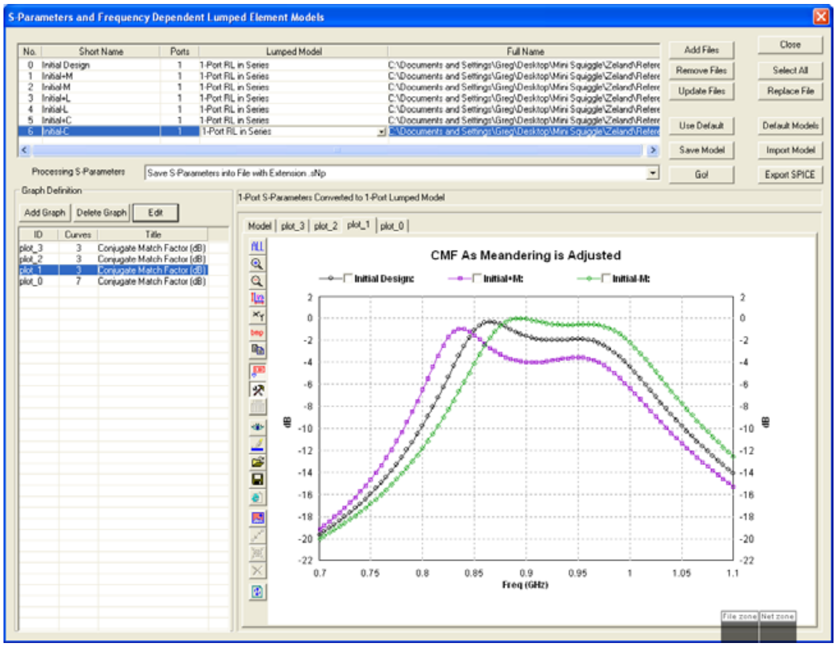
Check **√ Design Modification #3 --- Change Zs** Initial+L Plot
Select **Import**
Select **Chip #1.sp --- Open** Attach chip parameters
Select **OK**

Check **√ Design Modification #4 --- Change Zs** Initial-L Plot
Select **Import**

Select	**Chip #1.sp --- Open**	Attach chip parameters
Select	**OK**	
Check	√ **Design Modification #5 --- Change Zs**	Initial+C Plot
Select	**Import**	
Select	**Chip #1.sp --- Open**	Attach chip parameters
Select	**OK**	
Check	√ **Design Modification #6 --- Change Zs**	Initial-C Plot
Select	**Import**	
Select	**Chip #1.sp --- Open**	Attach chip parameters
Select	**OK**	
Select	**OK** (Display Conjugate Match Factor)	
Select	**plot_0**	All Data on plot_0
Click	**ADD GRAPH**	plot_1
Select	**Conjugate Match Factor (dB)**	
Select	**OK** (Graph Type)	
Select	√ **Initial Design** and the **First Two Alt Designs**	
Select	**OK** (Display Conjugate Match Factor)	
Select	**plot_1**	Initial Design and +/- Meander
Click	**ADD GRAPH**	Plot 2
Select	**Conjugate Match Factor (dB)**	
Select	**OK** (Graph Type)	
Select	√ **Initial Design** and the **Second Two Alt Designs**	
Select	**OK** (Display Conjugate Match Factor)	
Select	**plot_2**	Initial Design and +/- Loops
Click	**ADD GRAPH**	Plot 3
Select	**Conjugate Match Factor (dB)**	
Select	**OK** (Graph Type)	
Select	√ **Initial Design** and the **Second Two Alt Designs**	
Select	**OK** (Display Conjugate Match Factor)	
Select	**plot_2**	Initial Design and +/- Coupling

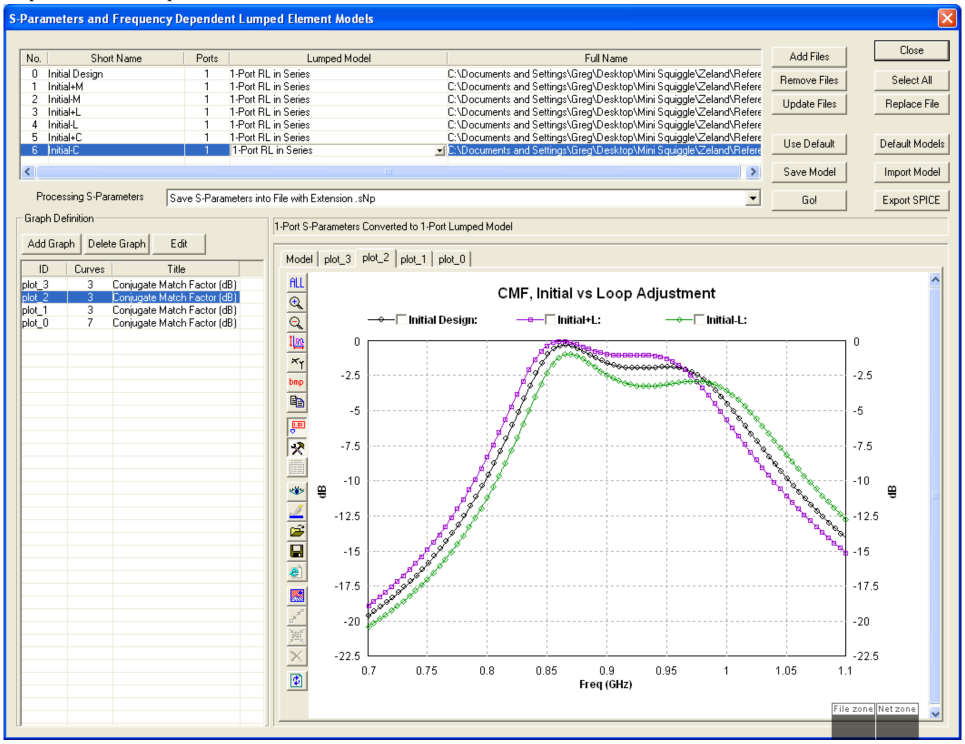
Meandering Adjustment

The graph below shows the effect of adjusting the Meandering inductance of the tag. Observe that the primary effect is frequency shift of the low frequency resonance. Also note that even though the frequency-shift of the higher resonance is less, its amplitude is affected more. In general it can be stated that meandering inductance adds effective length to the tag. As such more inductance will move the resonance of the dipole to a lower center frequency. The effects on the higher frequency resonance are a result of the mutual coupling between the dipole and loop.


S-Parameters and Frequency Dependent Lumped Element Models
CMF As Meandering is Adjusted
Initial Design
Initial+M
Initial-M
Freq (GHz)
dB

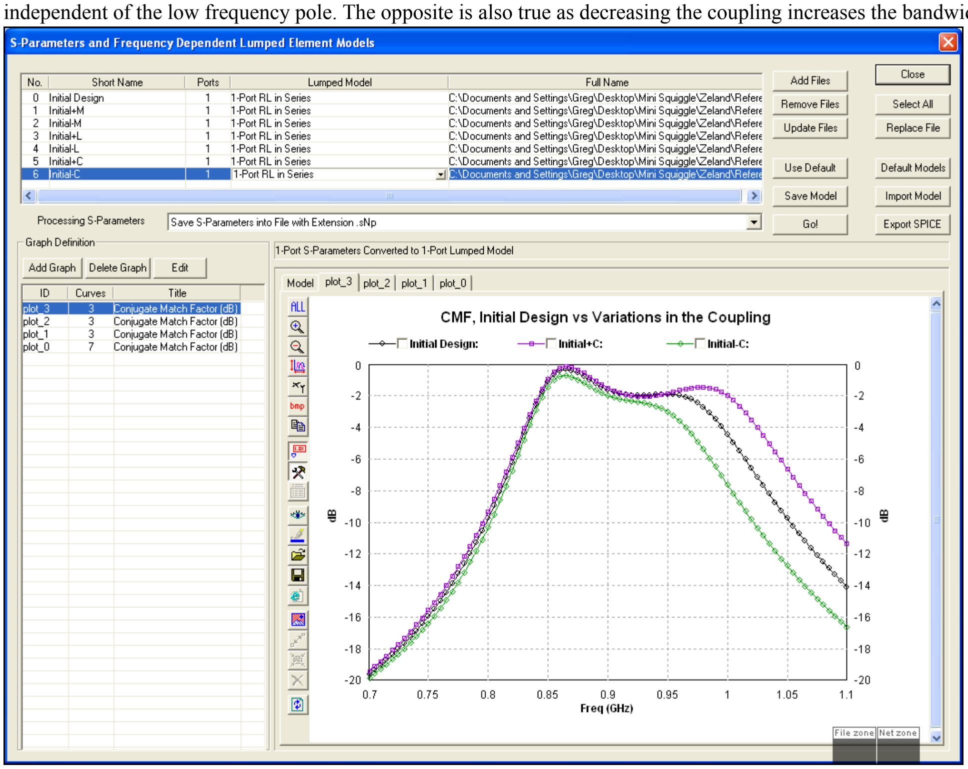
Loop Adjustment

The graph below shows the effect of adjusting the resonating loop inductance, of the tag. Observe that the primary effect is movement of the high frequency resonance with a much smaller effect upon the low frequency pole. Also notice however, the amplitude effects upon both resonances.



Coupling Points

The graph below shows the effect of adjusting the coupling between the dipole and the resonating loop of the tag. Observe that the primary effect is bandwidth. Increasing the coupling reduces the bandwidth by moving the high frequency resonance independent of the low frequency pole. The opposite is also true as decreasing the coupling increases the bandwidth..

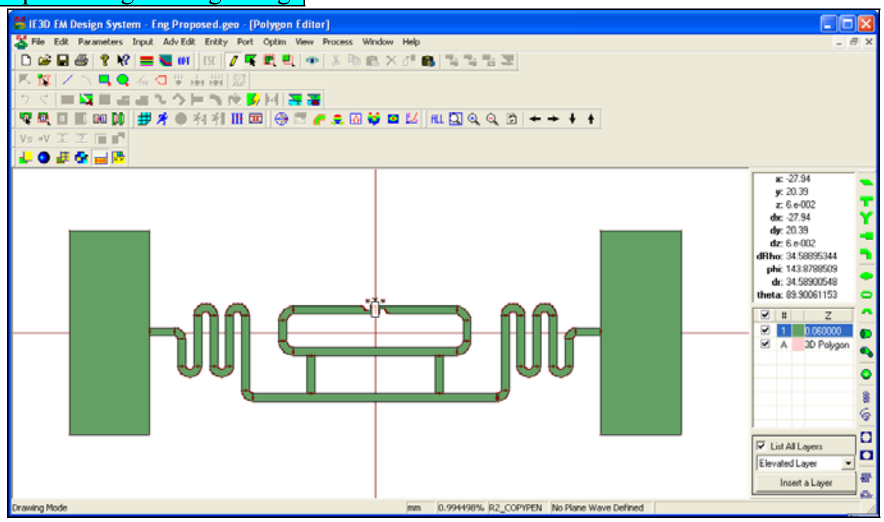


6. Optimize to Engineering Requirements

From the tag design variations it is observed that the flattest free space design is the Initial-M. This design is flat across the band to within .5dB. The bandwidth however is only ~ 90MHz. From the engineering requirements we are looking for ~150MHz so it is clear that we need more bandwidth. To obtain adequate bandwidth the coupling needs to be altered. As such the Initial+C design is selected as a starting point for this design.

Starting from the Initial+C design the meandering can be adjusted to position the low frequency resonance to the low frequency requirements as stated in the product specification, 860MH. The loop size can then be adjusted to balance the resonant peaks. Following this process, the design below was achieved.

Proposed Engineering Design

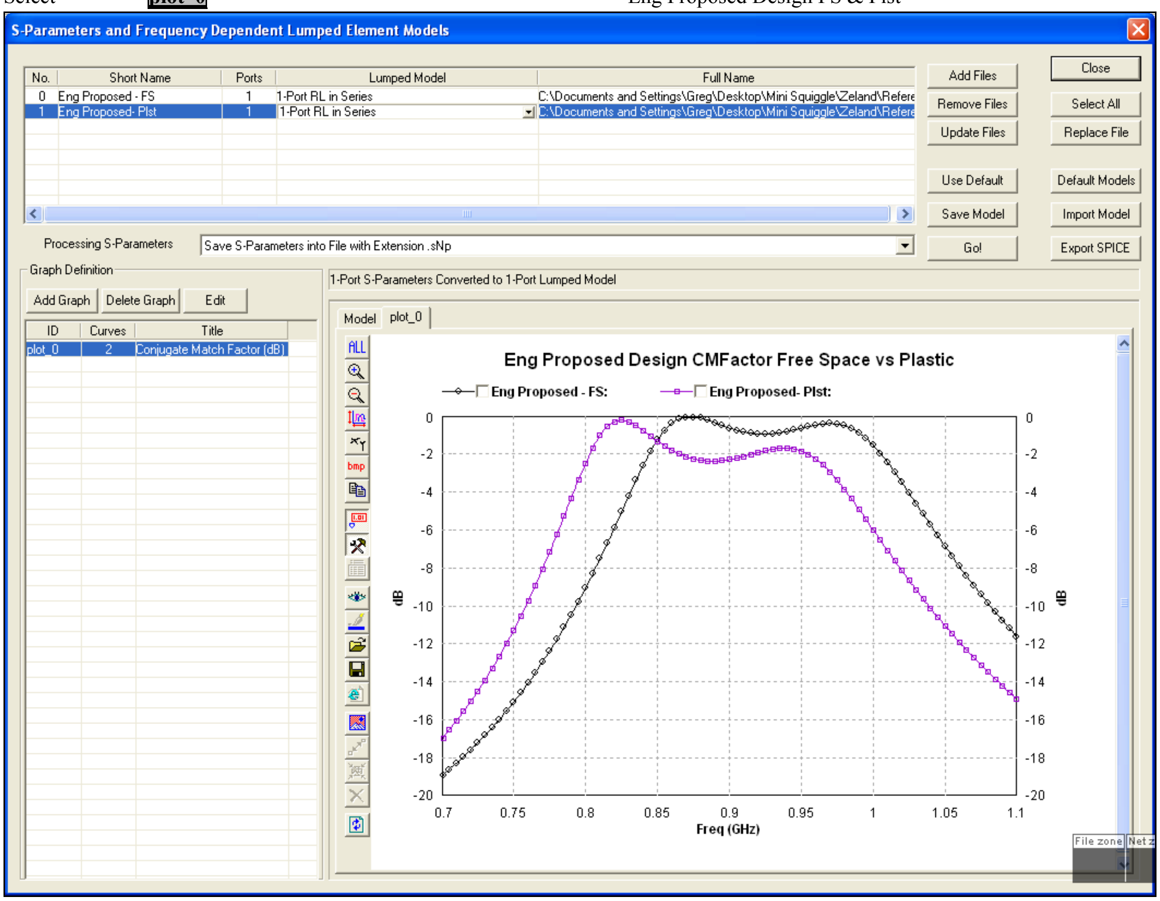


Simulation, Proposed Engineering Design

Select	**File** --- **Open**	CTR-O
Select	**Eng Proposed Design.geo** --- **OPEN**	
Select	**Process** --- **Simulate** --- **OK** (Simulation Setup)	
Select	**File** --- **Save As** --- **Eng Proposed Design.geo**	
Select	**Parameters** --- **Basic Parameters**	
Dbl Click	**No 1. D (Substrate Layer)**	
Enter	**Top Surface Ztop = 1.06**	1mm for bottle + .06 for substrate
Click	**OK** (Basic Parameters)	
Select	**Edit** --- **Select All** --- **Polygons**	
Edit	**Change Z-Coordinate**	SHFT-Z
Enter	**New Z-Coordinate = 1.06**	
Click	**OK** (Change Z-Coordinates of the Selected Objects)	
File	**Save As** --- **Eng Proposed-P.geo**	

Frequency Response Plots, Proposed Engineering Design

Select	**File --- Open**	CTR-O
Select	**Eng Proposed Design.geo --- OPEN**	
Select	**Process --- S-Parameter and lumped Equivalent Circuit**	
Dbl Click	**Space below Short Name**	
Enter	**Eng Proposed – FS**	
Click	**Add Files**	
Enter	**Eng Proposed – P.sp**	
Select	**Open**	
Dbl Click	**Second Space below Short Name**	
Enter	**Eng Proposed – Plst**	
Click	**ADD GRAPH**	plot_0
Select	**Conjugate Match Factor (dB)**	
Select	**OK** (Graph Type)	
Select	√ **Eng Proposed -FS** and the **Eng Proposed – Plst**	
Select	**Import**	
Select	**Chip #1.sp --- Open**	Attach chip parameters
Select	**OK**	
Select	**OK** (Display Conjugate Match Factor)	
Select	**plot_0**	Eng Proposed Design FS & Plst



Compliance Matrix, Proposed Engineering Design

	BW MHz	Max Turn On Mismatch over F.S. BW (dB)	Max Turn On Variation over F.S. BW (dB)	Max Turn On Mismatch over On Plastic BW (dB)	Max Turn On Variation over On Plastic BW (dB)	Max Turn On Delta FS to Plastic (dB)
Simulation	**150**	**-1**	**-1**	**-2.4**	**-2.3**	**-2.4**
Eng Requirements	**150**	**-6**	**-3**	**-6**	**-3**	**-3**

Tag Qualification

Compliance Matrix

The following parameters meet / fail specification as shown:

	Parameter	*Specification*	*Pass*	*Fail*	*Comments*
•	Size	25.4 mm x 76.2mm	√		by design
•	Flatness	less than 5microns	√		by FC design
•	Copper Thickness	.005mm	√		by process
•	Trace Width	1mm	√		by design
•	Trace Composition	Copper	√		by process
•	Trace Conductivity	4.7 e7	√		by definition
•	Substrate Thickness	.06mm	√		by process
•	IC (Rp=1500Ω Cp=.87pF)	Company #1		√	by design
•	Relative Permeability	1	√		by definition
•	Loss Tangent	0	√		by definition
•	Relative Dielectric Constants				
	Plastic	2.9	√		by definition, 1mm
	Corrugate	1.2	√		by definition, 3.2mm
	Substrate	2.9	√		by definition, .06mm
•	Polarity of Operation	Vertical	√		by application process
•	Application	FS, Corrugate, Plastic	√		by design
•	Operational Frequencies	US, Europe, China	√		per Eng Requirement Acceptance
•	Read Range	2 meters minimum	√		3.0 meters, see Below for details
•	Back Scatter	NA	√		See Below for details

Read Range

The read range as specified in the marketing document is the measurement of the distance that the tag can be read with a RFID reader. There is no industry standard definition for read range but in later years it is starting to become accepted that read range is the distance where a tag responds to most of the frequencies in the band rather than at a point where is only responds to a few.

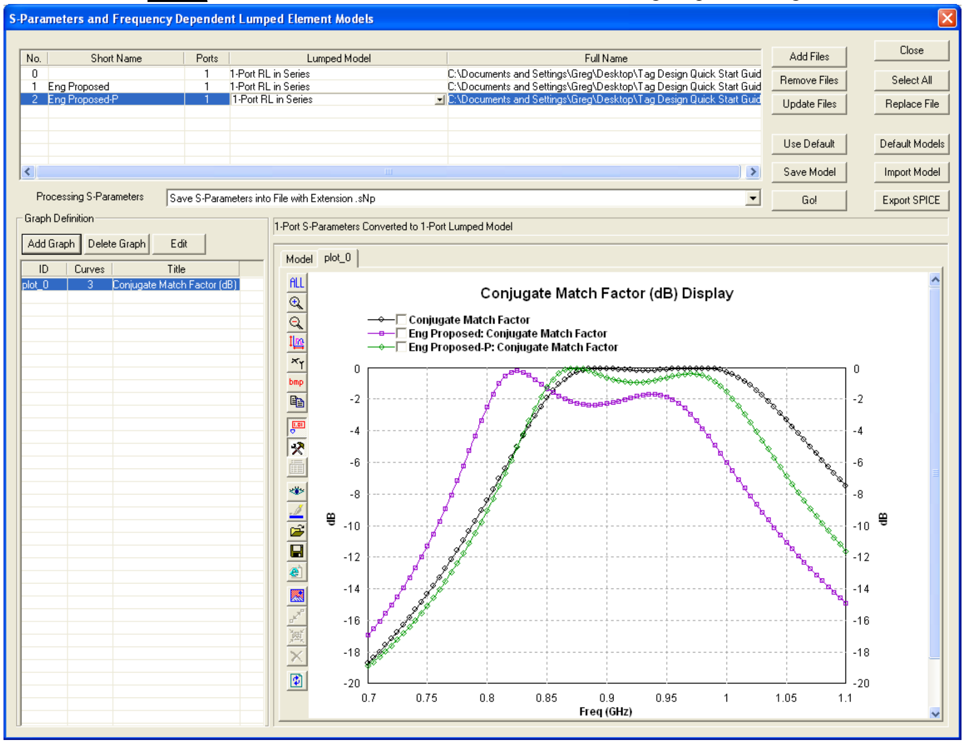
To further complicate the read range issue, it can be seen that read range is a system parameter rather than a tag specification. If however, we calculate read range based upon a Substitution Method using Turn-On-Sensitivity (dB) relative to a characterized Golden Reference Tag we can quantify a fairly reproducible metric of read range.

Given	$\mathbf{RR = R_{REF} * 10^{\Delta dB/20}}$	
And the	Golden Ref Characteristics	RR = 4 meters
From Substitution we get	2 meters = 4 meter * $10^{\Delta dB/20}$	
Division yields	$(2/4) = 10^{\Delta dB/20}$	
Log of both sides	Log10 (2/4) = ΔdB/20	
Multiplication yields	20 * Log 10 (2/4) = ΔdB	
Subtraction yields	ΔdB = 20 * Log10 (2/4) = 6dB	
So for 2 meters the	Design Example Tag must be within 6dB of the Golden Reference	

So to verify read range we can plot the golden reference CMF vs. Frequency and compare at the frequencies of concern to the Design Example for both in Free Space and on Plastic.

Select	**File --- Open**	CTR-O
Select	**Golden Ref.geo --- OPEN**	
Select	**Process --- Simulate**	
Select	**File --- Save --- Golden Ref.geo**	
Select	**Process --- S-Parameter and lumped Equivalent Circuit**	
Dbl Click	**Space below Short Name**	
Enter	**Golden Ref – FS**	
Click	**Add Files**	
Enter	**Eng Proposed.sp and Eng Proposed-P.sp**	
Select	**Open**	
Dbl Click	**Second Space below Short Name**	
Enter	**Eng Proposed - FS**	
Dbl Click	**Third Space below Short Name**	
Enter	**Eng Proposed - Plst**	
Click	**ADD GRAPH**	plot_0
Select	**Conjugate Match Factor (dB)**	
Select	**OK** (Graph Type)	
Select	√ **Golden Ref - Eng Proposed -FS** and the **Eng Proposed – Plst**	
Select	**Import**	
Select	**Chip #1.sp --- Open**	Attach chip parameters

Select **OK**
Select **OK** (Display Conjugate Match Factor)
Select **plot_0** Eng Proposed Design FS & Plst



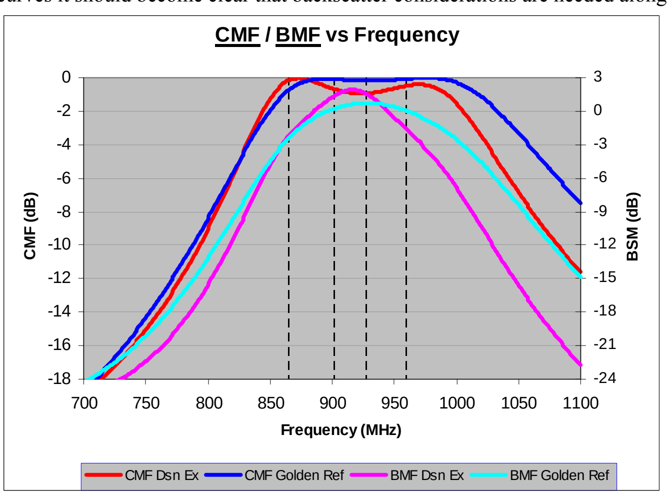
As can be observed from the results of the following plots, the Design Example is in the worst case 2.5 dB below the Free Space CMF of the Golden Reference Tag. As such we can calculate the read range as follows:

RR = 4 meters * **10$^{(27.5\text{-}30)\text{ dB}/20}$**

RR $_{\textbf{(Design Example)}}$ **= 3.0 meters**

Backscatter

Backscatter was not specified in the requirements for this design. IE3D however, incorporates a new module to help predict the tag backscatter *(see appendix B).* The following plot shows the backscatter along with the Conjugate Match Factor of the Design Example and the Golden Reference. As can be seen the backscatter bandwidth does not track the CMF bandwidth. In these two designs the backscatter BW is centered about the CMF bandwidth. This is the optimal situation for a RFID tag design. From these curves it should become clear that backscatter considerations are needed along with sensitivity to properly design a RFID tag.

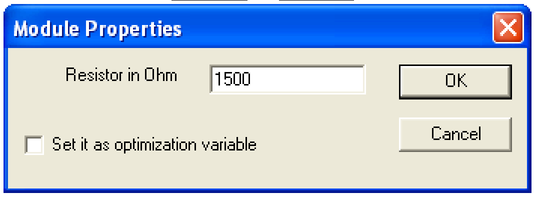


<u>Appendix A</u>

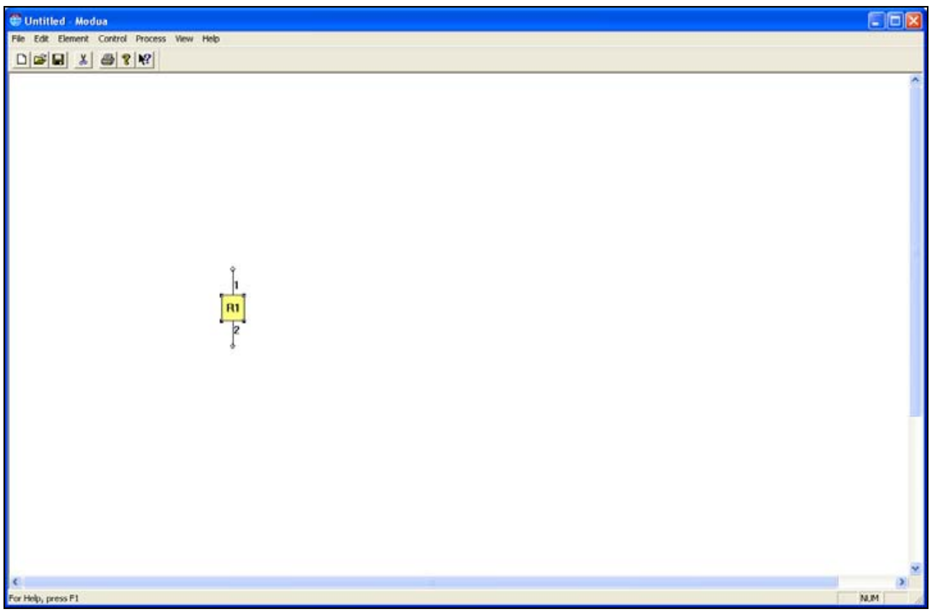
<u>RFID Tag Design, IC Modeling using Modua</u>

<u>Enter Parallel Resistance</u>

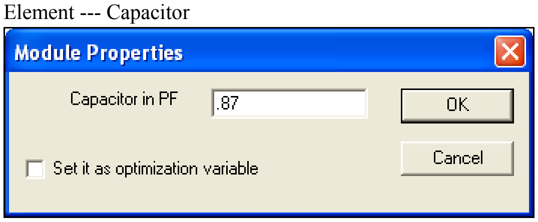
Open **Zealand Program Manager**
Dbl Click on **Modua**
Select **<u>Element</u>** --- **<u>Resistor</u>**



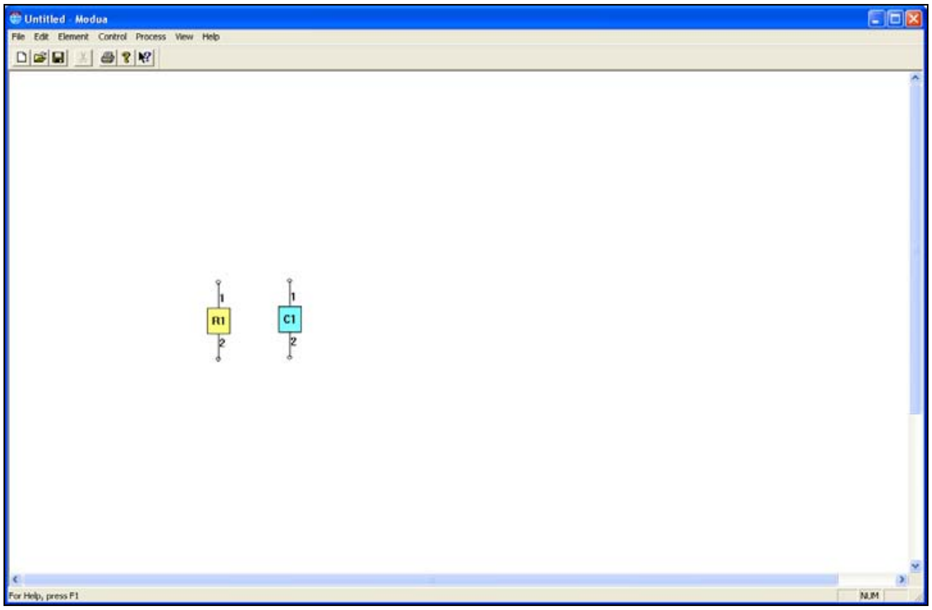
Enter --- 1500
Click OK
Place R1 as shown
Left Click to locate Resistor



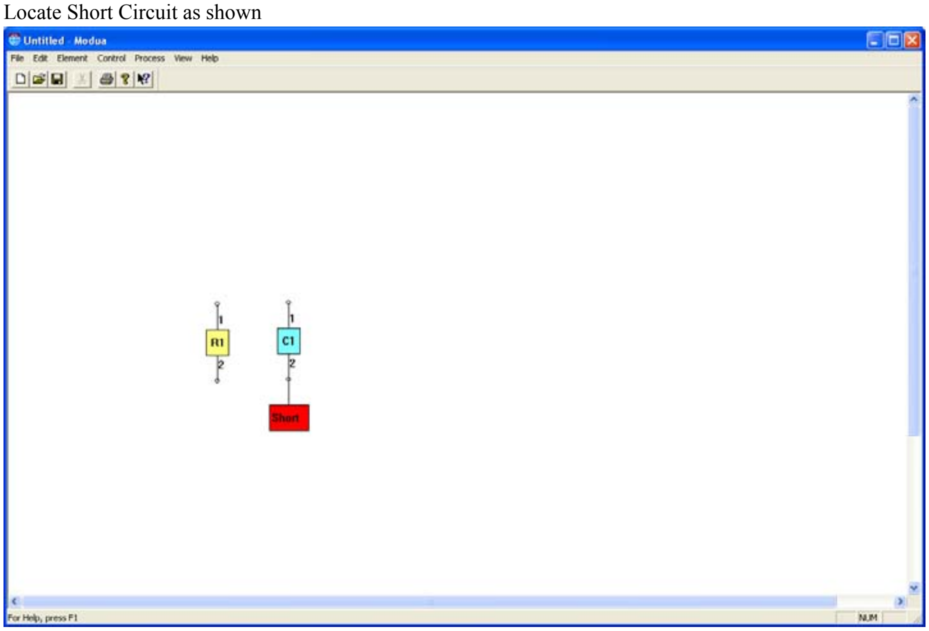
Click away from R1 to deselect
Element --- Capacitor



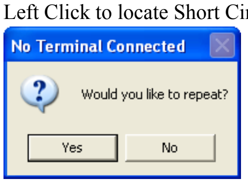
Enter --- .87
Click OK
Place C1 as shown
Left Click Mouse to locate Capacitor



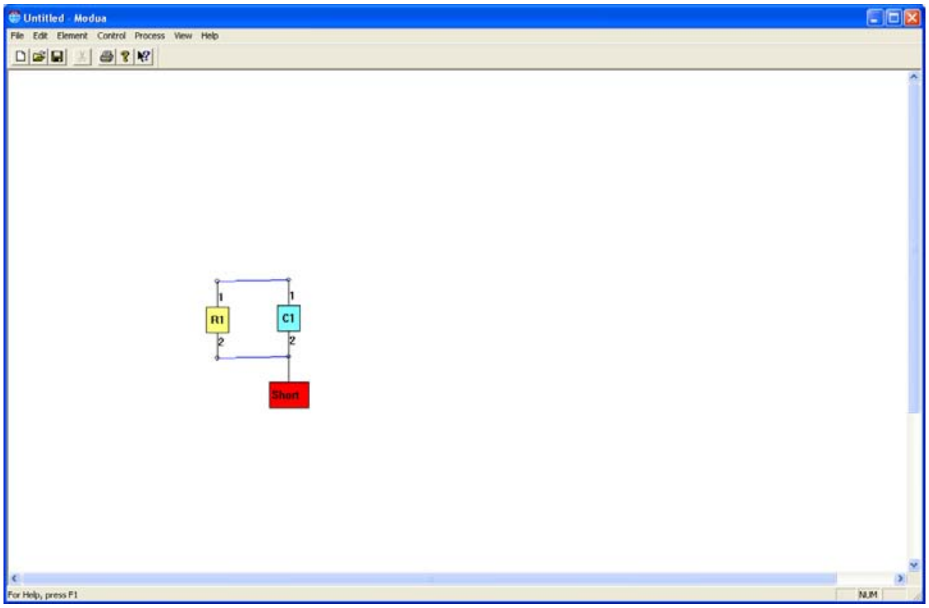
Click away from C1 to deselect
Element --- Short Circuit
Locate Short Circuit as shown



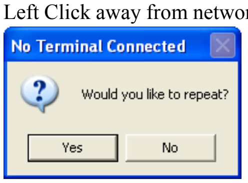
Left Click to locate Short Circuit



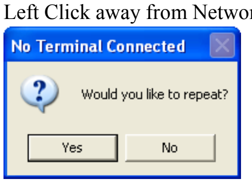
Click No
Element --- Connection
Left Click top of R1
Left Click top of C1
Left Click bottom of R1
Left Click bottom of C1



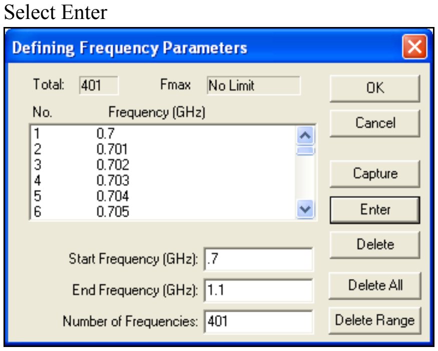
Left Click away from network



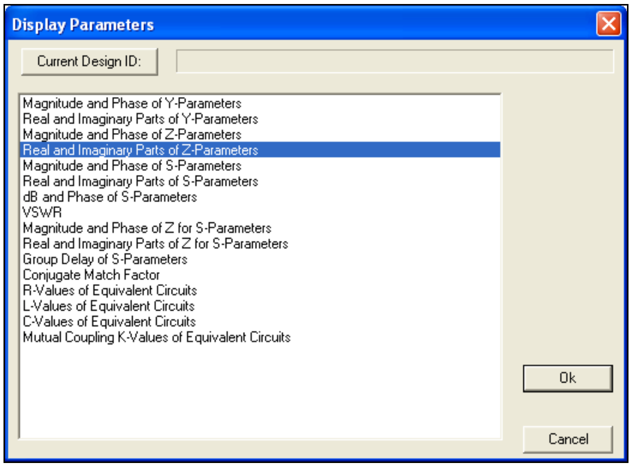
Click No
Element --- Port
Right Click to Position Port Orientation as shown
Left Click to Locate Port
Left Click away from Network to deselect



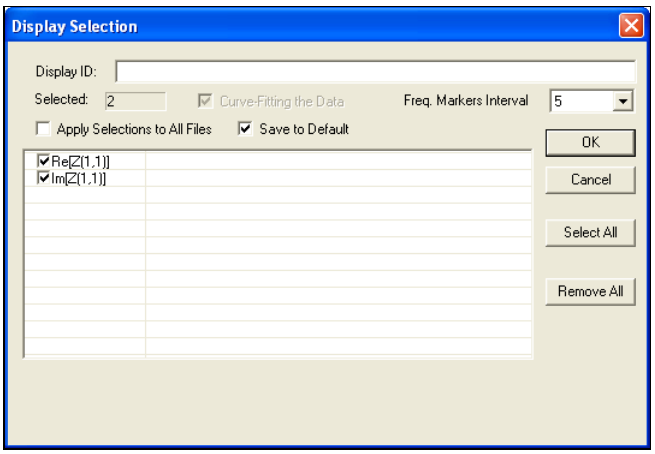
Click No
Process --- Simulate
Enter --- Start Frequency = .7
Enter --- Stop Frequency = 1.1
Enter --- Number of Frequencies = 401
Select Enter



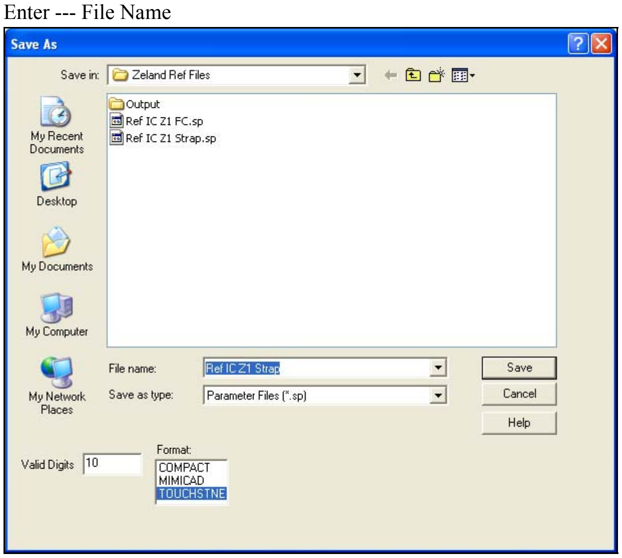
Select OK
Control --- Define Display Data
Click --- Real and Imaginary Parts of Z-Parameters



Click OK



Click OK
File --- Save S-Parameters
Enter --- File Name



Select Save
Close Modua

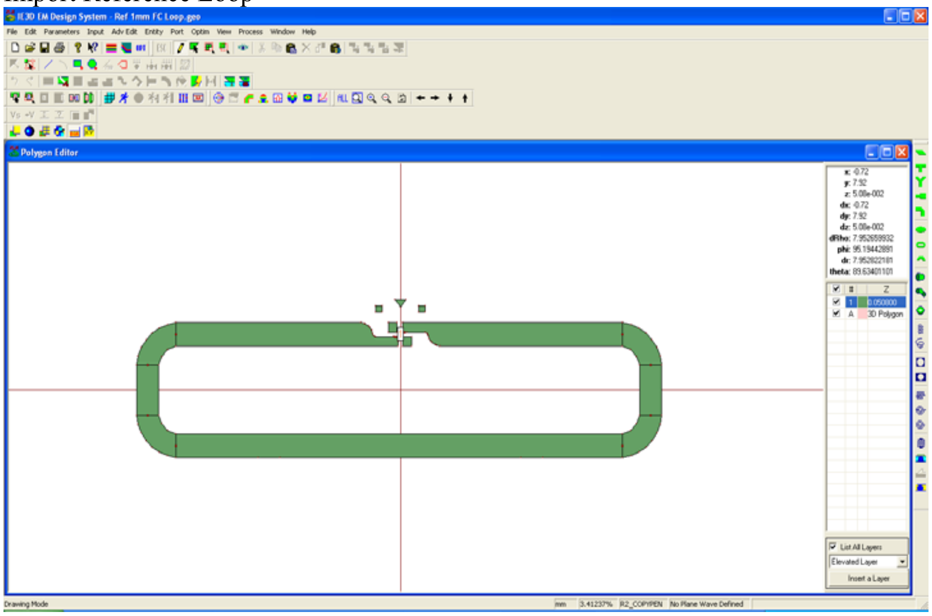
Appendix B
RFID Tag Design, Back Scatter Module

Appendix C

RFID Tag Design, Layout using M-Grid

Initial Loop Design

1. Import Reference Loop

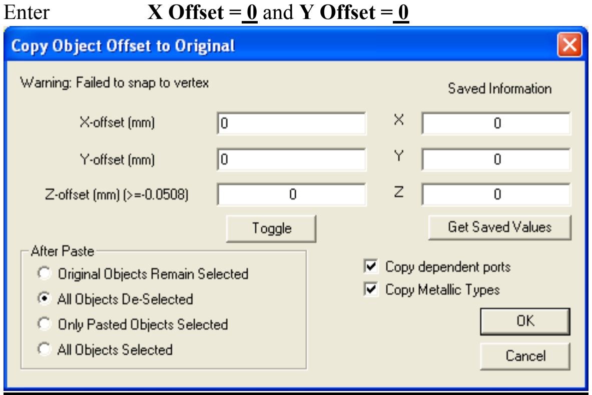


Copy "Ref 1mm Loop FC.geo" file

Select **File** --- **Open** then select **Ref 1mm Loop FC.geo**
Select **Edit** --- **Select All** --- **Polygons**
Select **Edit** --- **Copy** CTR-C

Save "Ref 1mm Loop FC.geo" file to Design Example.geo file

Select **File** --- **Open** then select **Design Example.geo**
Select **Edit** --- **Paste** CTR-V
Enter **X Offset = 0** and **Y Offset = 0**

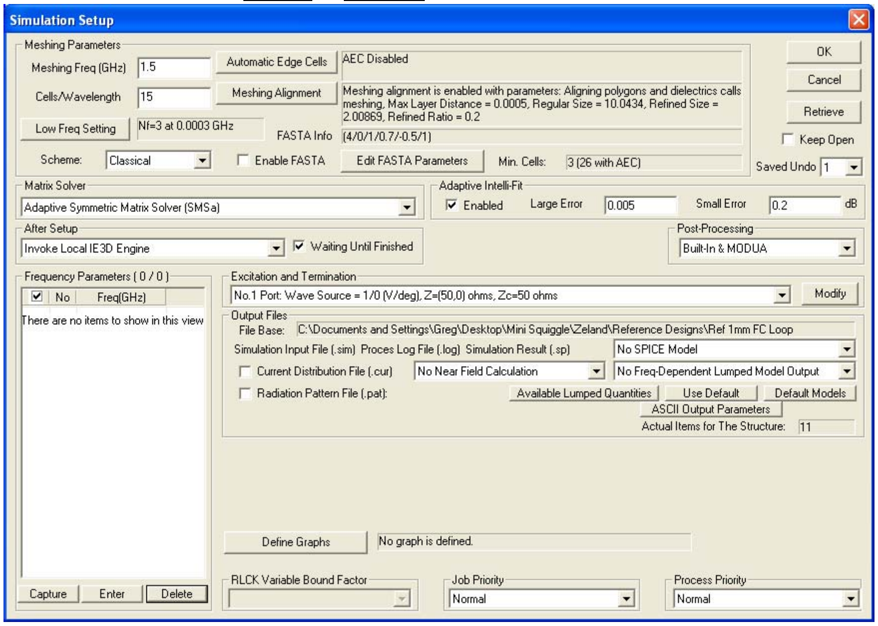


Select **OK** (Copy Object Offset to Original)
Select **ALL** to view the entire structure
Select **File** --- **Save** (Design Example.geo)

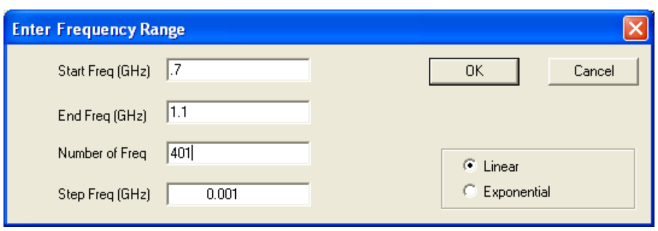
2. Simulation of “Design Example.geo”

Start Simulation

Select **Process** --- **Simulate**



Select **Enter** (Frequencies)



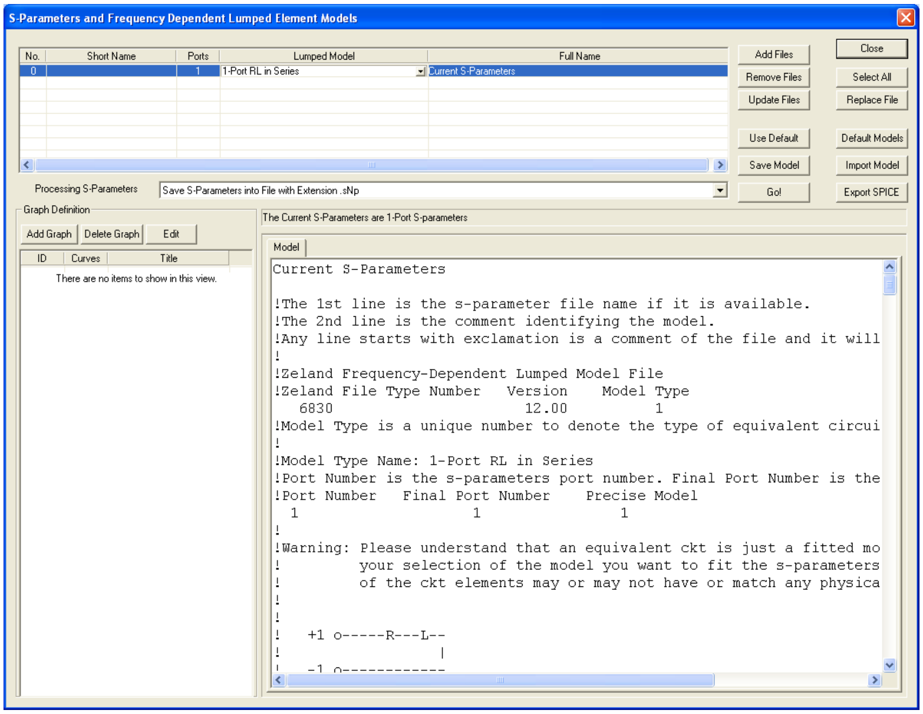
Input **Start Freq (GHz) = .7** --- **End Freq (GHz) = 1.1** --- **Number of Freq = 401**

Select **OK** (Enter Frequency Range) --- **OK** (Start Simulation)

Apply IC Electrical Parameters

The simulation excites the geometry with a 50 ohm source. The following post process attaches a conversion file (***Ref IC Z1 FC.sp***) to the simulation that converts the 50 ohm source to the proper impedances that reflects the particular IC that is used. See Appendix QS-RFID TAG-A for additional information about creating this file.

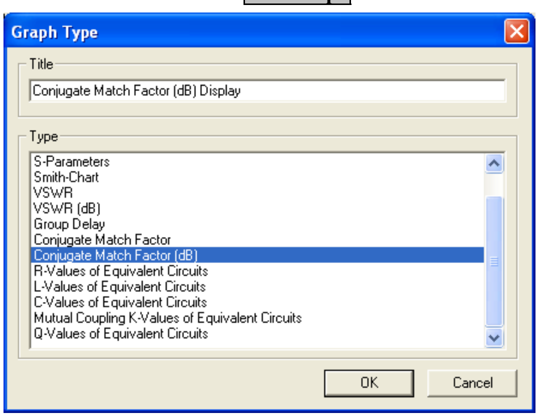
Select **Process** --- **General Lumped Equivalent Circuit**



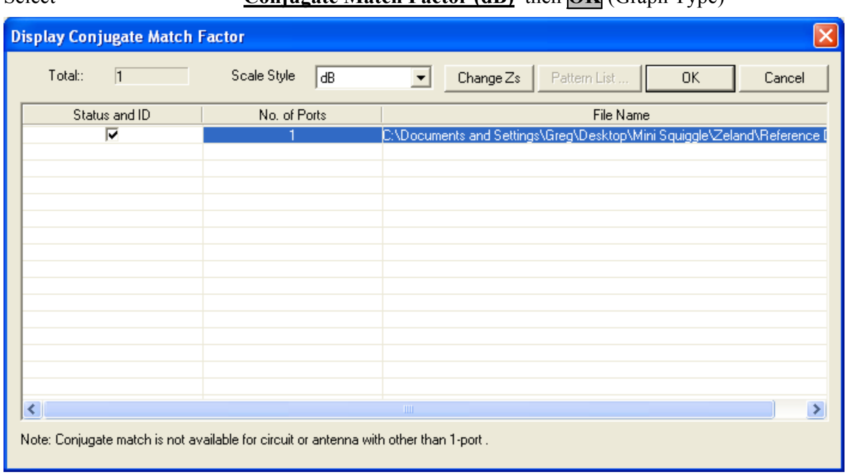
Click Cell under **Short Name**

Enter **"Loop"**

Select **Add Graph**

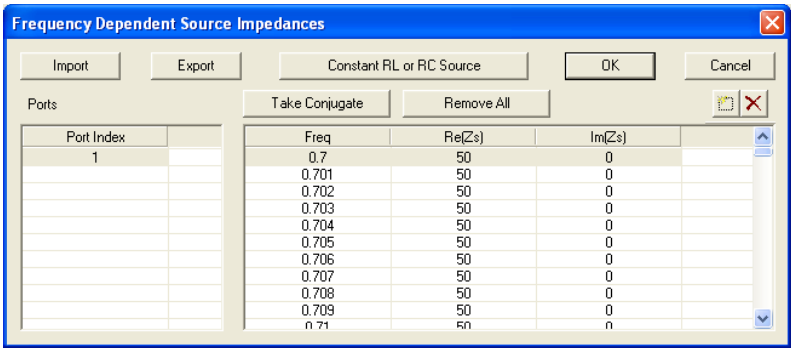


Select **Conjugate Match Factor (dB)** then **OK** (Graph Type)

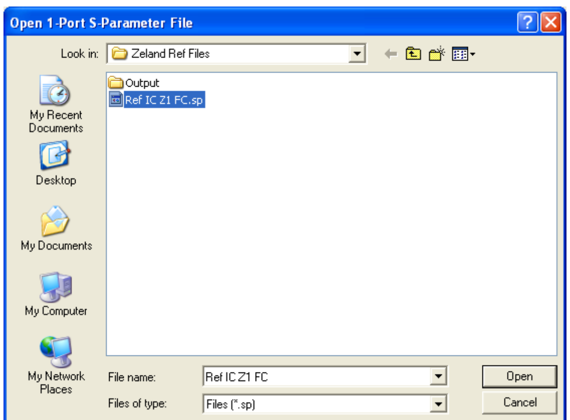


Check √ under **Status and ID**

Select **Change Zs**



Select **Import**



Select **<u>Ref IC Z1 FC.sp</u>** --- **Open** (Open 1-Port S-Parameter File)

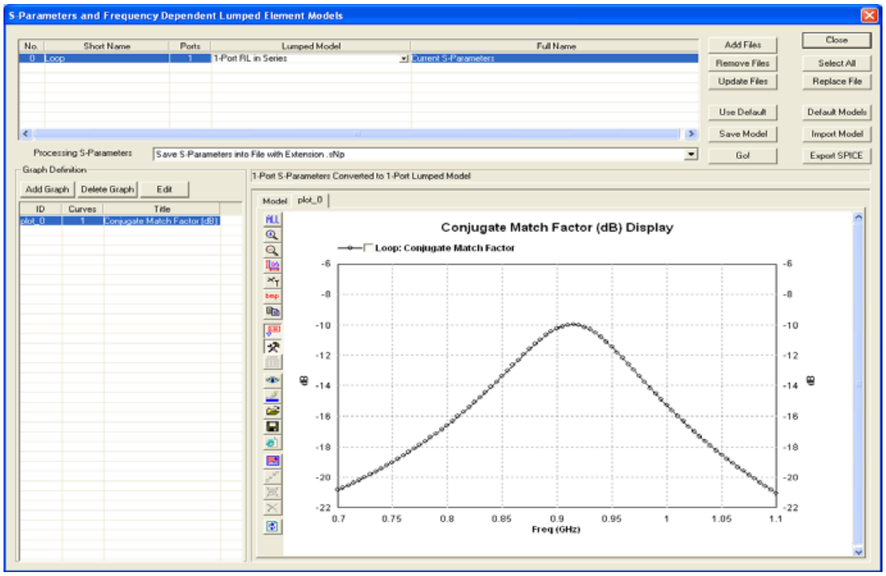
Display Conjugate Match Factor Graph

The Conjugate Match Factor is a parameter that measures the quantity of power applied to the chip. It is based upon the maximum available power transfer and is given in units of dB. As such 0dB indicates that all of the available power is transferred while 3dB indicates that one half of the available power is lost due to mismatch.

Select **OK** (Frequency Dependent Source Impedance)

Select **OK** (Display Conjugate Match Factor)

Select **Plot 0** (S-Parameters and Frequency Dependent Lumped Element Models)


S-Parameters and Frequency Dependent Lumped Element Models
Conjugate Match Factor (dB) Display
Loop: Conjugate Match Factor
Freq (GHz)

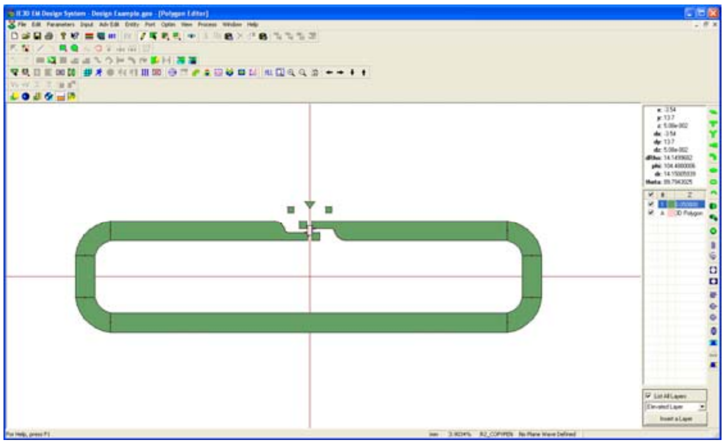
3. Preliminary Loop Adjustment
   - Adjust the Loop Diameter as necessary achieve a resonance at highest required frequency
   - Repeat Simulation to observe Conjugate Match Factor (dB) Display
   - Continue to adjust and verify until desired Loop Frequency Response is achieved.
   - When desired results are obtained save the file as “Design Example.geo”

Initial Dipole Layout

1. Dimensional Reference Plane

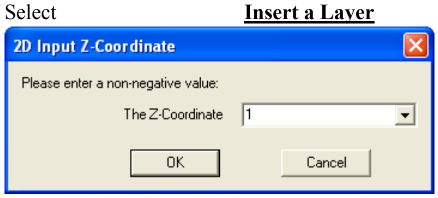
Return to Polygon Editor

Select **Close** (S-Parameters and Frequency Dependent Lumped Elements)
Select **Window** --- **Display Polygon Editor**

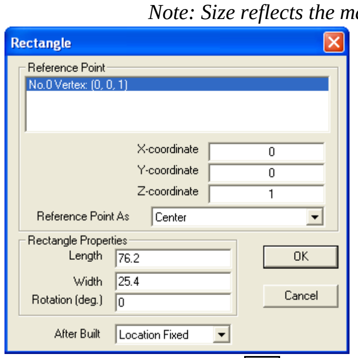


Insert Dimensional Reference

Select **Insert a Layer**

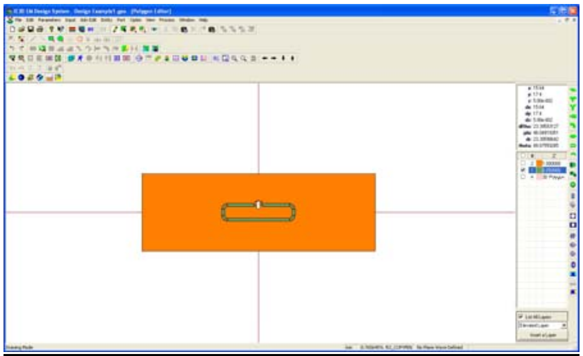


Enter **The Z-Coordinate = 1**
Select **OK** (2D Input Z-Coordinate)
Click **#2 Z-Axis**
Select **Entity** then **Rectangle**
Enter **Length = 76.2** --- **Width = 25.4** --- **X-coordinate = 0** --- **Y coordinate = 0**
Note: Size reflects the maximum size of the tag for reference



Select **OK** (Rectangle)

Select **#1 Z-Axis**



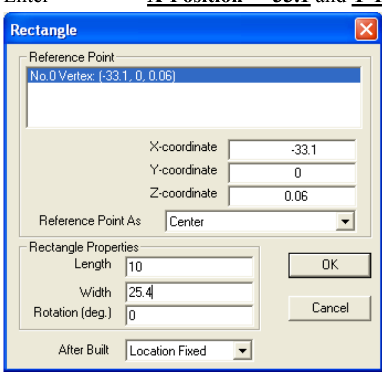
Select **File --- Save**

2. Dipole Construction

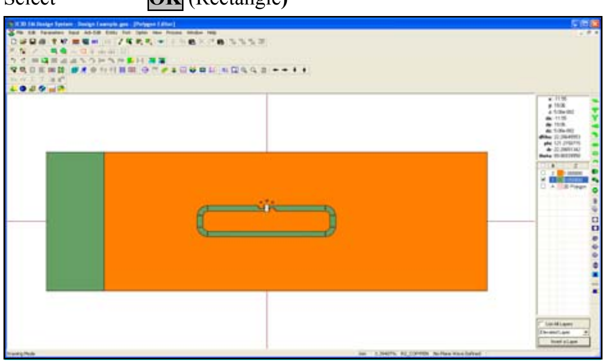
Left End Capacitance Plate

Place a 10mm x 25.4mm capacitance plate on the left end of the tag.
X position calculated from: X = Tag Width/2-(half the width of the plate)

Select **Entity** then **Rectangle**
Enter **Length = 10** and **Width = 25.4**
Enter **X-Position = -33.1** and **Y-Position = 0**



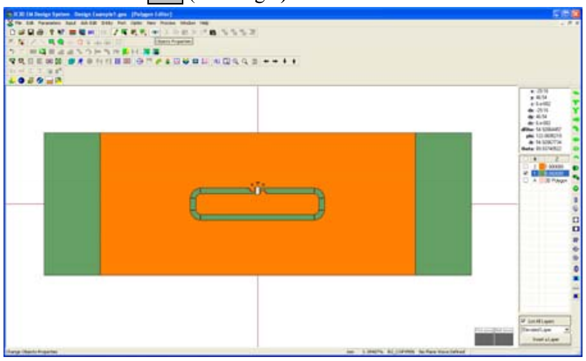
Select **OK** (Rectangle**)**



Right End Capacitance Plate

Repeat the left end capacitance plate process to enter the right end capacitance plate as follows:

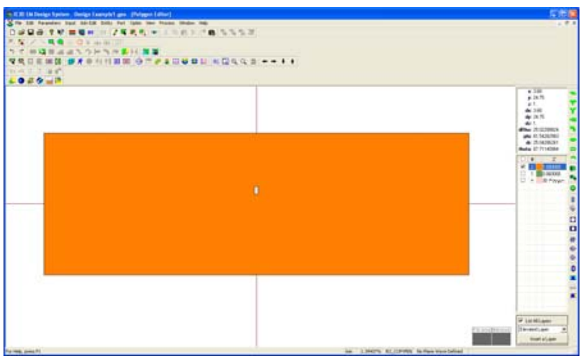
Select	**Entity** then **Rectangle**
Enter	**Length = 10** and **Width = 25.4**
Enter	**X-Position = 33.1** and **Y-Position = 0**
Select	**OK** (Rectangle**)**



Verify Geometry is contained within Dimensional Reference

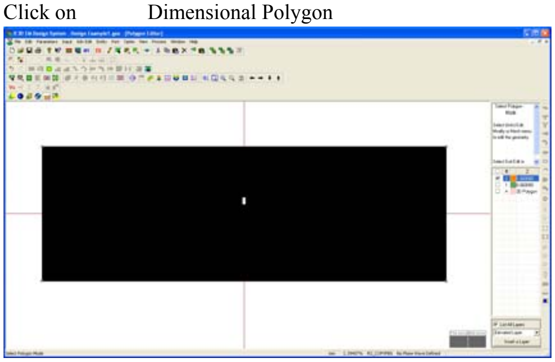
No Green should be visible if the tag outer extremes are within the size requirements.

Click	**Z-Coordinate = 2**

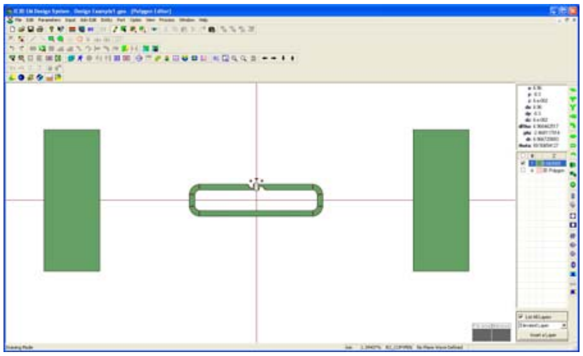


Delete Dimensional Reference

Select	**Edit --- Select Polygon**	CTR-L
Click on	Dimensional Polygon	



Select	**Edit --- Delete**	DLT

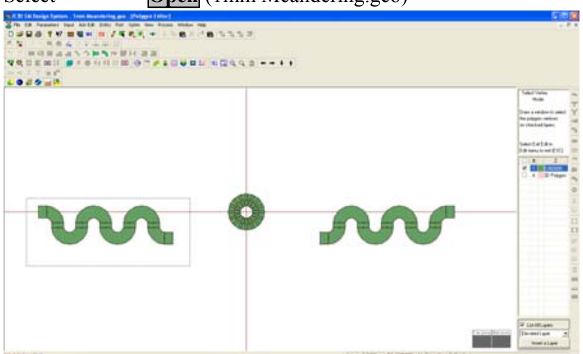


Select **File** --- **Save** CTR-S

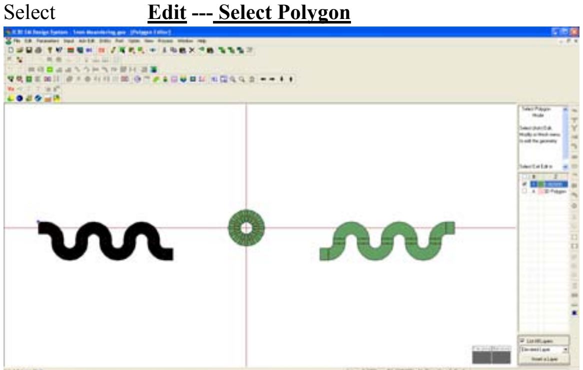
Left Dipole Meandering

Often a RFID tag will require additional inductance to achieve the desired location of the resonances. A typically used method is a trace called meandering. This guide has created reference files that contain 1mm meandering to save the designer the effort of creating them new each time a new tag is lain out.

Select **File** --- **Open**
Select **Ref Design Folder** – **1mm Meandering.geo**
Select **Open** (1mm Meandering.geo)

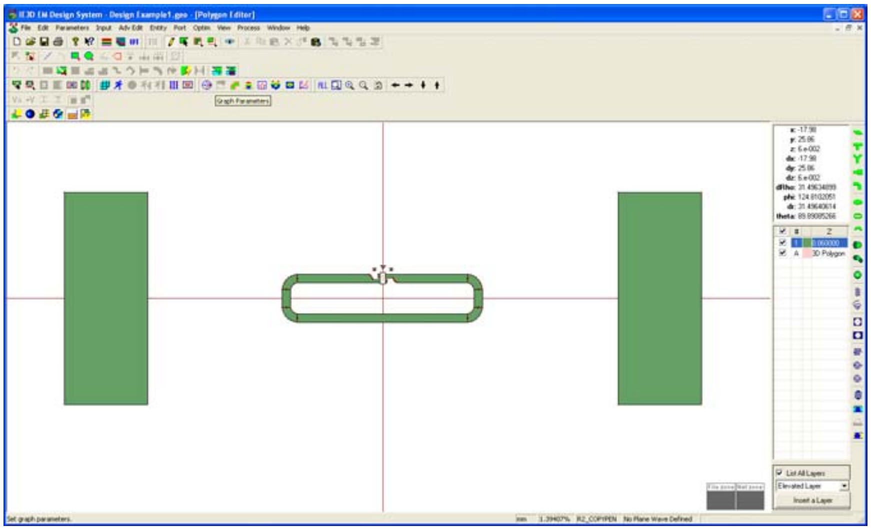


Select Edit – Select Polygon Group SHFT-Y
Press & Hold Left mouse button and drag a rectangle around geometry as shown
Select **Edit** --- **Select Polygon** CTR-L



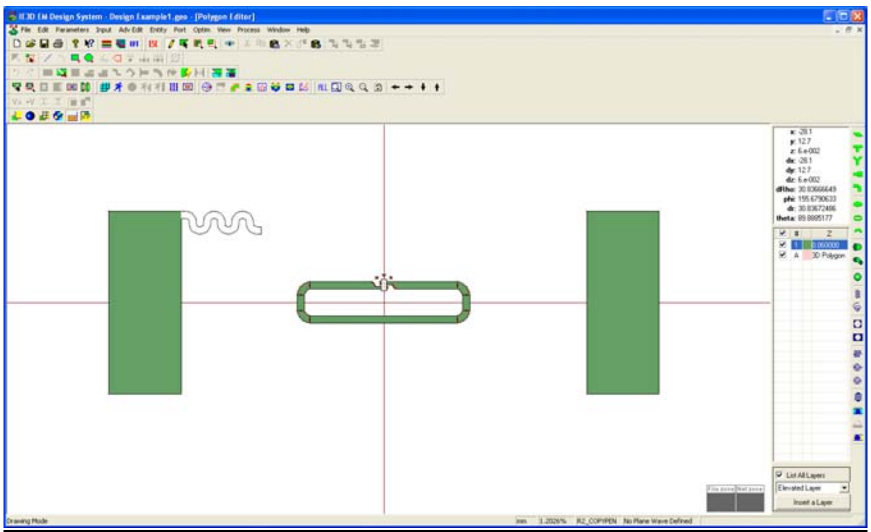
Press **Tab or Shift Tab until the upper left vertex is selected**,
(This will allow direct connection with the Design Example tag geo)

Select Edit --- Copy CTR-C
Select File – Open
Select **Design Example.geo** --- **Open** (Design Example.geo)



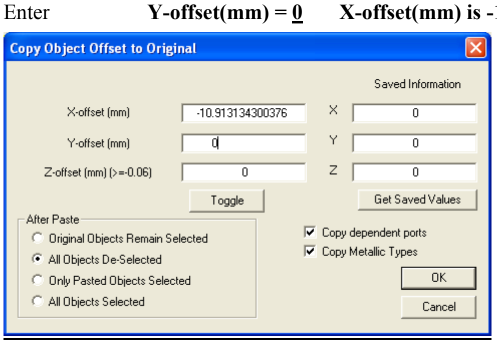
Select   **<u>Edit</u>** then **<u>Paste</u>**   CTR-V

Locate   **Meander Geometry to the upper right corner of the left capacitance plate**
The vertex should snap to the upper right corner

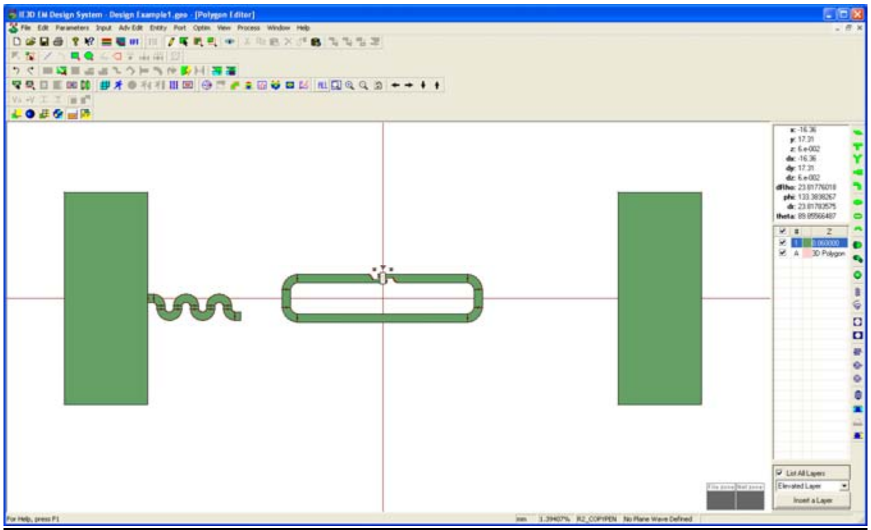


Click   **The left mouse button**

Enter   **Y-offset(mm) = <u>0</u>**   **X-offset(mm) is -10.913134300376** by default



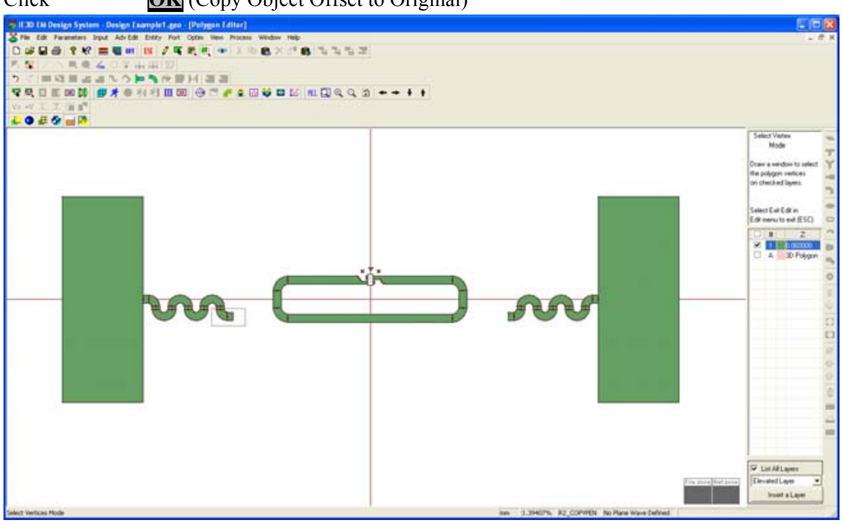
Click   **OK** (Copy Object Offset to Original)



Right Dipole Meandering

Using the same procedure as for the Left Dipole Meandering import the right dipole meandering.

Select	**File --- Open**	
Select	**Ref Design Folder – 1mm Meandering.geo**	
Click	**Open** (1mm Meandering.geo)	
Select	**Edit --- Select Polygon Group**	SHFT-Y
Press & Hold	Left mouse button and drag a rectangle around the right side meandering	
Select	**Edit --- Select Polygon**	CTR-L
Press	**Tab or Shift Tab until the upper right vertex is selected**, (*This will allow direct connection with the Design Example tag geo)*	
Select	**Edit --- Copy**	CTR-C
Select	**File --- Open**	
Select	**Design Example.geo --- Open** (Design Example.geo)	
Select	**Edit** then **Paste**	CTR-V
Locate	**Meander Geometry to the upper left corner of the right capacitance plate** The *vertex should snap to the upper left corner*	
Click	**The left mouse button**	
Enter	**Y-offset(mm) = 0** **X-offset(mm) is 10.913134300376** by default	
Click	**OK** (Copy Object Offset to Original)	



Select	**File --- Save**	CTR-S

Dipole Connection

Connect the two meandered lines together

Select **Edit --- Select Vertices** ALT-S

Select **The inside quarter radius of the left side meandering**

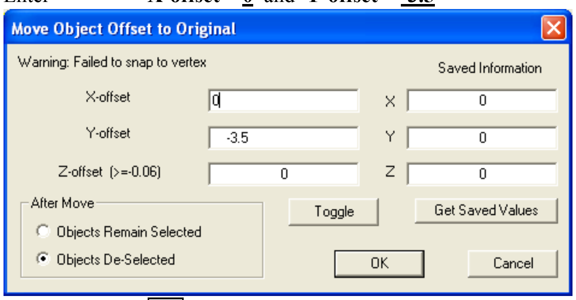
Press the left mouse button and drag a rectangle around the geometries as shown

Select **The inside quarter radius of the right side meandering**

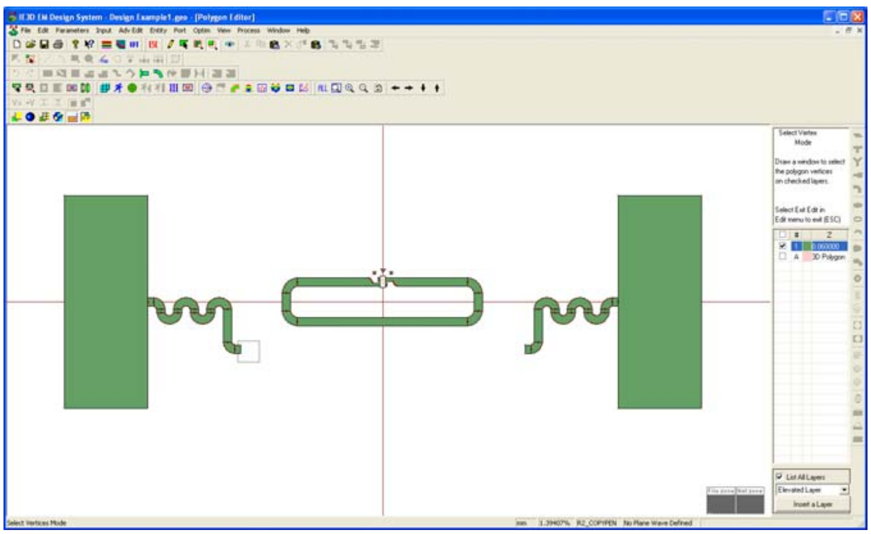
Press the left mouse button and drag a rectangle around the opposite geometries that are shown

Select **Edit --- Move Objects** SHFT-M

Enter **X-offset = 0** and **Y-offset = -3.5**



Select **OK** (Move Object Offset to Original)



Select **Edit --- Select Vertices** ALT-S

Select **The bottom right most two vertices on the left side meandering.**

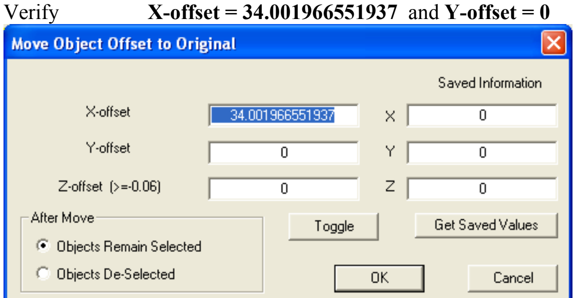
Press *the right mouse button and drag a rectangle around the geometries as shown*

Select **Edit --- Move Object**

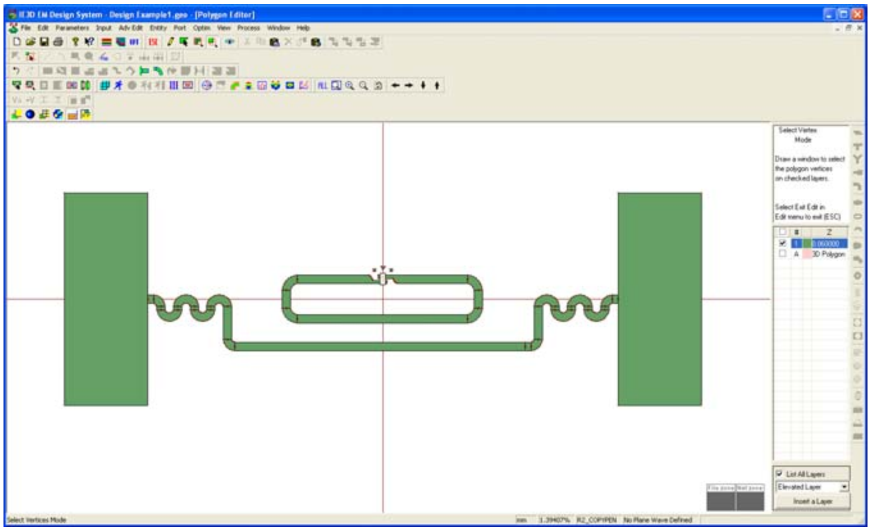
Move **The selected objects to their right side meandering corresponding vertices**

Object will snap to the opposite vertices

Verify **X-offset = 34.001966551937** and **Y-offset = 0**



Select **OK** (Move Object Offset to Original)

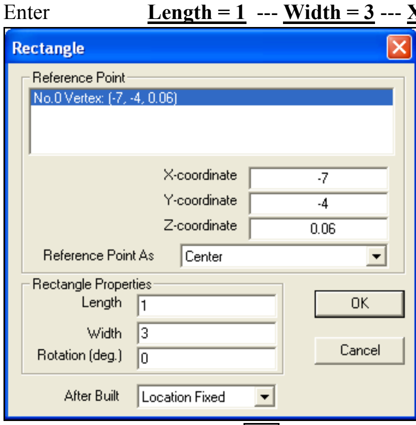


Loop Coupling Points

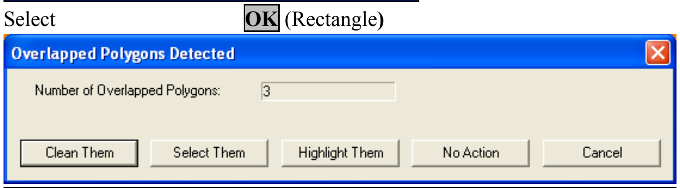
Couple the dipole to the loop

Select **Entity** then **Rectangle**

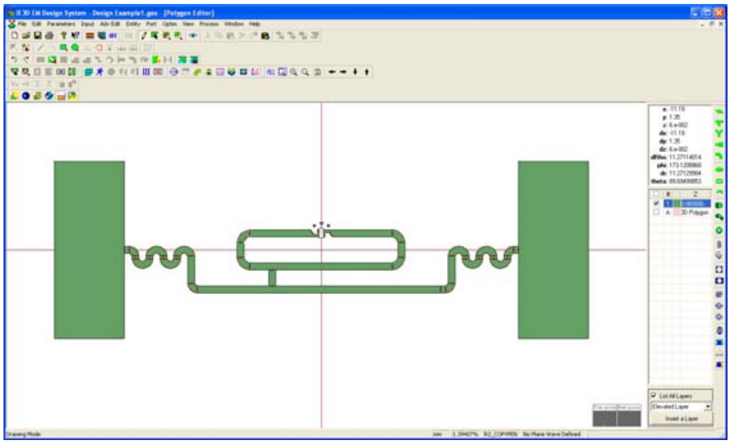
Enter **Length = 1** --- **Width = 3** --- **X-Position = -7** --- **Y-Position = -4**



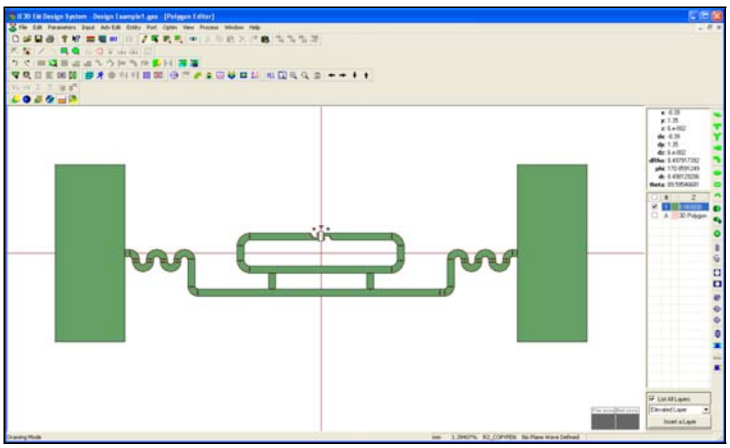
Select **OK** (Rectangle**)**



Select **Clean Them**



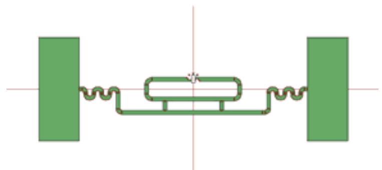
Select	**Entity** then **Rectangle**
Enter	**Length = 1** --- **Width = 4** --- **X-Position = 7** --- **Y-Position = -4**
Select	**OK** (Rectangle**)**
Select	**Clean Them**



Select **File** --- **Save** CTR-S

Appendix D
RFID Tag Design, Finite Dielectrics

Appendix E
RFID Tag Design, Optimizer



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12.2. If a claim is made under Subsection Mentor Graphics will defend or settle, at its option and expense, any action brought against Customer in the United States, Ca Mentor Graphics may, at its option and expense, (a) replace or modify the Product so that it becomes noninfringing; (b) procure for Customer the right to continue using the Product; or (c) require the return of the Product and refund to Customer any purchase price or license fee paid, less a reasonable allowance for use.

12.3. Mentor Graphics has no liability to Customer if the action is based upon: (a) the combination of Software or hardware with any product not furnished by Mentor Graphics; (b) the modification of the Product other than by Mentor Graphics; (c) the use of other than a current unaltered release of Software; (d) the use of the Product as part of an infringing process; (e) a product that Customer makes, uses, or sells; (f) any Beta Code or Product provided at no charge; (g) any software provided by Mentor Graphics' licensors who do not provide such indemnification to Mentor Graphics' customers; or (h) infringement by Customer that is deemed willful. In the case of (h), Customer shall reimburse Mentor Graphics for its reasonable attorney fees and other costs related to the action.

12.4. THIS SECTION **INFRINGEMENT** IS SUBJECT TO SECTION **LIMITATION OF LIABILITY** ABOVE AND STATES THE ENTIRE LIABILITY OF MENTOR GRAPHICS AND ITS LICENSORS FOR DEFENSE, SETTLEMENT AND DAMAGES, AND CUSTOMER'S SOLE AND EXCLUSIVE REMEDY, WITH RESPECT TO ANY ALLEGED PATENT OR COPYRIGHT INFRINGEMENT OR TRADE SECRET MISAPPROPRIATION BY ANY PRODUCT PROVIDED UNDER THIS AGREEMENT.

13. **TERMINATION AND EFFECT OF TERMINATION.** If a Software license was provided for limited term use, such license will automatically terminate at the end of the authorized term.

13.1. Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement immediately upon written notice if Customer: (a) exceeds the scope of the license or otherwise fails to comply with the licensing or confidentiality provisions of this Agreement, or (b) becomes insolvent, files a bankruptcy petition, institutes proceedings for liquidation or winding up or enters into an agreement to assign its assets for the benefit of creditors. For any other material breach of any provision of this Agreement, Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement upon 30 days written notice if Customer fails to cure the breach within the 30 day notice period. Termination of this Agreement or any license granted hereunder will not affect Customer's obligation to pay for Products shipped or licenses granted prior to the termination, which amounts shall be payable immediately upon the date of termination.

13.2. Upon termination of this Agreement, the rights and obligations of the parties shall cease except as expressly set forth in this Agreement. Upon termination, Customer shall ensure that all use of the affected Products ceases, and shall return hardware and either return to Mentor Graphics or destroy Software in Customer's possession, including all copies and documentation, and certify in writing to Mentor Graphics within ten business days of the termination date that Customer no longer possesses any of the affected Products or copies of Software in any form.

14. **EXPORT.** The Products provided hereunder are subject to regulation by local laws and United States government agencies, which prohibit export or diversion of certain products and information about the products to certain countries and certain persons. Customer agrees that it will not export Products in any manner without first obtaining all necessary approval from appropriate local and United States government agencies.

15. **U.S. GOVERNMENT LICENSE RIGHTS.** Software was developed entirely at private expense. All Software is commercial computer software within the meaning of the applicable acquisition regulations. Accordingly, pursuant to US FAR 48 CFR 12.212 and DFAR 48 CFR 227.7202, use, duplication and disclosure of the Software by or for the U.S. Government or a U.S. Government subcontractor is subject solely to the terms and conditions set forth in this Agreement, except for provisions which are contrary to applicable mandatory federal laws.

16. **THIRD PARTY BENEFICIARY.** Mentor Graphics Corporation, Mentor Graphics (Ireland) Limited, Microsoft Corporation and other licensors may be third party beneficiaries of this Agreement with the right to enforce the obligations set forth herein.

17. **REVIEW OF LICENSE USAGE.** Customer will monitor the access to and use of Software. With prior written notice and during Customer's normal business hours, Mentor Graphics may engage an internationally recognized accounting firm to review Customer's software monitoring system and records deemed relevant by the internationally recognized accounting firm to confirm Customer's compliance with the terms of this Agreement or U.S. or other local export laws. Such review may include FLEXlm or FLEXnet (or successor product) report log files that Customer shall capture and provide at Mentor Graphics' request. Customer shall make records available in electronic format and shall fully cooperate with data gathering to support the license review. Mentor Graphics shall bear the expense of any such review unless a material non-compliance is revealed. Mentor Graphics shall treat as confidential information all information gained as a result of any request or review and shall only use or disclose such information as required by law or to enforce its rights under this Agreement. The provisions of this Section **REVIEW OF LICENSE USAGE** shall survive the termination of this Agreement.

18. **CONTROLLING LAW, JURISDICTION AND DISPUTE RESOLUTION.** The owners of certain Mentor Graphics intellectual property licensed under this Agreement are located in Ireland and the United States. To promote consistency around the world, disputes shall be resolved as follows: excluding conflict of laws rules, this Agreement

shall be governed by and construed under the laws of the State of Oregon, USA, if Customer is located in North or South America, and the laws of Ireland if Customer is located outside of North or South America. All disputes arising out of or in relation to this Agreement shall be submitted to the exclusive jurisdiction of the courts of Portland, Oregon when the laws of Oregon apply, or Dublin, Ireland when the laws of Ireland apply. Notwithstanding the foregoing, all disputes in Asia arising out of or in relation to this Agreement shall be resolved by arbitration in Singapore before a single arbitrator to be appointed by the chairman of the Singapore International Arbitration Centre ("SIAC") to be conducted in the English language, in accordance with the Arbitration Rules of the SIAC in effect at the time of the dispute, which rules are deemed to be incorporated by reference in this section. This section shall not restrict Mentor Graphics' right to bring an action against Customer in the jurisdiction where Customer's place of business is located. The United Nations Convention on Contracts for the International Sale of Goods does not apply to this Agreement.

19. **SEVERABILITY.** If any provision of this Agreement is held by a court of competent jurisdiction to be void, invalid, unenforceable or illegal, such provision shall be severed from this Agreement and the remaining provisions will remain in full force and effect.

20. **MISCELLANEOUS.** This Agreement contains the parties' entire understanding relating to its subject matter and supersedes all prior or contemporaneous agreements, including but not limited to any purchase order terms and conditions. Some Software may contain code distributed under a third party license agreement that may provide additional rights to Customer. Please see the applicable Software documentation for details. This Agreement may only be modified in writing by authorized representatives of the parties. Waiver of terms or excuse of breach must be in writing and shall not constitute subsequent consent, waiver or excuse.

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