ISO15693 (Tag-It™ HF-I) Transponder Antenna Design

Application Note

Literature number: 11-08-26-013

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Revision 0 – August 2010

This is the first edition of this **ISO15693 Tag-It™ HF-I Transponder Antenna Design** Application Note.

It describes how to create suitable antenna inductors (coils) for use with the following products:

Tag-It™ HF-I Plus Transponder IC, Tag-It™ HF-I Pro Transponder IC, and Tag-It™ HF-I Standard Transponder IC

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PREFACE

Read This First

About this Manual

This **Application Note (11-08-26-013)** is written for the sole use by TI's RFID Customers who are engineers experienced with Radio Frequency Identification Devices (RFID).

Conventions

Certain conventions are used in order to display important information in this manual, these conventions are:

WARNING:

A warning is used where care must be taken or a certain procedure must be followed, in order to prevent injury or harm to your health.

CAUTION:

This indicates information on conditions, which must be met, or a procedure, which must be followed, which if not heeded could cause permanent damage to the system.

Note:

Indicates conditions, which must be met, or procedures, which must be followed, to ensure proper functioning of any hardware or software.

Information:

Indicates conditions, which must be met, or procedures, which must be followed, to ensure proper functioning of any hardware or software.

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Tag-It™ HF-I (ISO15693) Transponder Antenna Design Application Note

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Abstract

With the introduction of the Tag-it™ HF-I Transponder Plus, Pro and Standard ICs as part of TI's 13.56 MHz product family, which is based on the ISO/IEC 15693 standard for contactless integrated circuit cards (vicinity cards) and the ISO/IEC 18000-3 standard for item management.

These transponder ICs provide the basis for the design of a multitude of inlay shapes and sizes, which can then be as consumable or reusable smart labels or tags in markets requiring quick and accurate identification of items, such as:

- asset tagging
- electronic ticketing
- anti-counterfeit prevention
- distribution logistics and supply chain management
- building access badges
- express parcel delivery
- airline boarding pass and baggage handling

User data is written to and read from memory blocks using a non-volatile EEPROM silicon technology. Each block is separately programmable by the user and can be locked to protect data from modification. Once the data has been 'locked', then it cannot be changed. (with the exception of the Pro IC)

To give some examples, information about delivery checkpoints and timing, place of origin/destination, pallet assignments, inventory numbers and even transportation routes can be coded into the transponder. Multiple transponders, which appear in the Readers RF field, can be identified, read from and written to by using the **U**nique **Id**entifier (UID), which is programmed and locked at the factory.

To build a complete transponder, the Tag-it HF-I Transponder ICs have to be made part of a resonant circuit with an external antenna and possibly a tuning capacitor. This application note explains how to design suitable antenna coils for the three Texas Instruments ISO15693 Transponder ICs currently available.

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CHAPTER 1

Introduction

This chapter introduces you to the related IC reference documents that are also required reading for the tag designer.

Topic **Page**

1 Related Documents

1.1 Tag-It™ HF-I Plus (2k bit) IC Reference Guide

http://focus.ti.com/lit/ug/scbu046/scbu046.pdf

1.2 Tag-It™ HF-I Plus Extended Commands and Options

11-09-21-052 (December 2005)

1.3 Tag-It™ HF-I Pro (256 bit with PWW and Kill) IC Reference Guide

http://focus.ti.com/lit/ug/scbu045/scbu045.pdf

1.4 Tag-It™ HF-I Pro Extended Commands and Options

http://focus.ti.com/lit/ug/scbu008/scbu008.pdf

1.5 Tag-It™ HF-I Standard (256 bit) IC Reference Guide

http://focus.ti.com/lit/ug/scbu047/scbu047.pdf

1.6 Tag-It™ HF-I Standard Extended Commands and Options

http://focus.ti.com/lit/ug/scbu002/scbu002.pdf

1.7 ISO/IEC 15693-1 Contactless Integrated Circuit Cards – Vicinity Cards

Part 1: Physical Characteristics

1.8 ISO/IEC 15693-2 Contactless Integrated Circuit Cards – Vicinity Cards

Part 2: Parameters for Air Interface Communications at 13.56MHz

1.9 ISO/IEC 18000-3 Radio Frequency For Item Management

Part 3: Parameters for Air Interface Communications at 13.56MHz

1.10 ISO/IEC 10373-7 Identification Cards – Test Methods

Part 7: Vicinity Cards

CHAPTER 2

Important Parameters

This chapter highlights the important design parameters that must be used while designing finished transponders with the Tag-It™ HF-I ICs.

Topic **Page**

2 General Descriptions, Operating Conditions, Mechanical Characteristics

2.1 Plus, Pro and Standard IC – General Descriptions

The Tag-it™ HF-I Plus, Pro and Standard Transponder ICs are low power, full duplex Transponder ICs for use with passive contactless identification systems. These transponder ICs are designed to operate with a 13.56 MHz carrier frequency. The ISO15693 and 18000 standards define, for some communication parameters, several modes in order to meet different international radio regulations and different application requirements. Therefore, communication between the reader and the transponder (Down-Link communication) takes place using ASK modulation index between 10% and 30% or 100% and data coding (pulse position modulation) '1 out of 4' or '1 out of 256'.

According to ISO/IEC 15693-2, Up-Link communication (Transponder to Reader) can be accomplished with one subcarrier (ASK modulation) or with two subcarriers (FSK modulation). Both modes, ASK and FSK, can operate with either a high or low tag data rate. The transponder answers in the mode it was interrogated from the reader and supports all communication parameter combinations.

Up- and Down-Link are frame synchronized and CRC check sum secured. Each Tag-it™ HF-I transponder has a 'unique' address (UID) stored in two blocks, which are factory-programmed and 64 bits long (=2^{64} different addresses). This can be used for addressing each transponder uniquely and individually for a one-to-one exchange between the reader and the transponder. A mechanism to resolve collisions of a multiplicity of transponders (Anti-Collision) is also implemented. This special feature allows multiple transponders to be read simultaneously and offers the capability to inventory in a very short time a large number of transponders by their unique address, provided they are within the reader operating range.

The **A**pplication **F**amily **I**dentifier (AFI) and the **D**ata **S**torage **F**ormat **I**dentifier (DSFID), which are optional in the ISO15693, are both supported by the Tag-it™ HF-I Plus IC. The Pro and Standard ICs only support the AFI.

Besides the ISO15693 defined functionality, the Tag-it™ HF-I Transponder ICs support a range of additional specific functions, providing additional application flexibility for the customer. The reference guides (shown in Section 1 of this document should be referenced for those details)

> **NOTE:** The Tag-it™ HF-I **Plus** Transponder IC has no integrated resonance capacitor (only internal parasitic capacitance) it is recommended to build an additional capacitor as part of the antenna or to use an external component. The **Pro** and **Standard** IC's **do** have an integrated capacitor (similar to other manufacturers) and can integrated onto a coil with no external capacitor if the antenna coil design is done correctly, however – for special cases, an external tuning capacitor may have to be used to achieve a resonant circuit at the required frequency.

2.2 Plus IC – Operating Conditions

Table 1. Plus IC Recommended Operating Conditions

Parameter	Symbol	Note	Min	Nom	Max	Unit
Operating Temperature	TA		-40		+85	°C
Carrier Frequency	fTX			13.56		MHz
Antenna Input Voltage	VANT	@ fTX unmodulated	2.5		Vlim	V
Impedance of LC circuit	Z		6.5		15.5	kOhm

Table 2. Plus IC Electrical Characteristics

Parameter	Symbol	Note	Min	Nom	Max	Unit
Input Capacitance	C_{IN}	@ $2V_{RMS}$		2.4		pF
Operating Supply Current	ICC	VANT=min			50	uA
Uplink Modulation Index	M_{PICC}	VANT<7V	0.1		0.3	
Limiter Clamping Volt.	Vlim				10	V
Data Retention	tDRET	55°C	10			Years
Write & Erase Endurance	W&E	Ta=25°C	100 000			Cycles

NOTE: For highest possible read-out coverage we recommend operating the reader at a modulation depth of 20% or higher.

2.3 Plus IC – Mechanical Characteristics

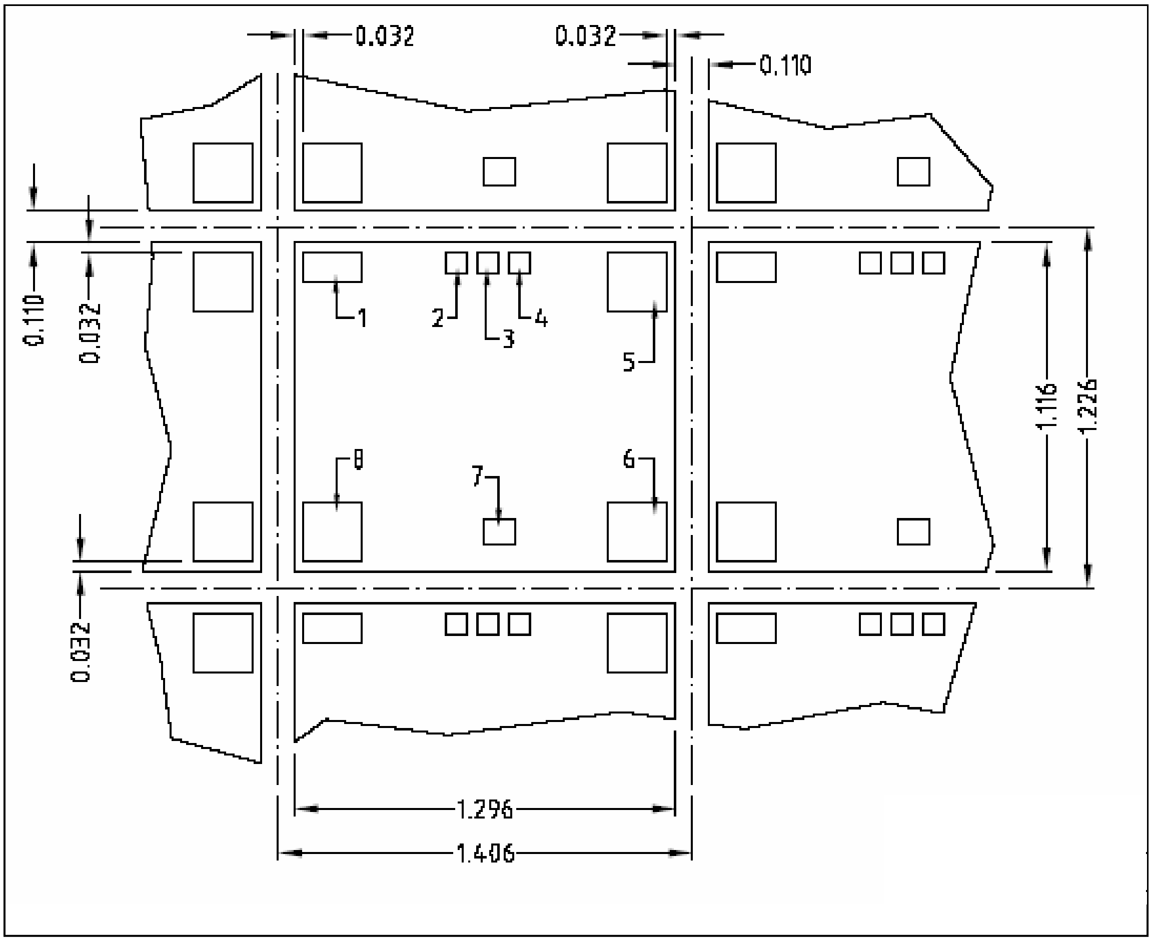
Table 3. Plus IC Mechanical Die Specification

Parameter	Value
Antenna Pad size	Pad 1: 100*200µm, Pad 5, 6, 8: 200*200µm
Test pad size	Pad 2, 3, 4: 50*70µm,
GND Test pad	Pad7: 90*90µm
Bond pad metallization material	ALCu0.5 %
Bond pad metallization thickness	0.95µm
Bond & Test Pad location	Table 6
Die dimension (including scribe line)	1406 * 1226µm +/- 15µm
Die dimension (excluding scribe line)	1296 * 1116µm +/-15µm
Top side passivation material	SiNi
Passivation thickness	1.1µm

Table 4. Plus IC Antenna and Test Pad Locations

Pad No	Name	LLCx[µm]	LLCy[µm]	URCx[µm]	URCy[µm]
1	ANT1	32	984	232	1084
5	ANT2	1064	884	1264	1084
6	ANT2	1064	32	1264	232
8	ANT1	32	32	232	232
Test pad					
2	TDI	518	1014	568	1084
3	VCCA	623	1014	673	1084
4	TDO	728	1014	778	1084
7	GND	645	90	735	180

Figure 1. HF-I Plus Antenna and Test Pad Locations



2.4 Pro and Standard IC – Operating Conditions

Table 5. Pro and Standard IC Recommended Operating Conditions

Parameter	Symbol	Note	Min	Nom	Max	Unit
Operating Temperature	TA		-40		+85	°C
Carrier Frequency	fTX			13.56		MHz
Antenna Input Voltage	VANT	@ fTX unmodulated	2.5		Vlim	V
Impedance of LC circuit	Z		6.5		15.5	kOhm

Note: For highest possible read-out coverage we recommend to operate readers at a modulation depth of 23% or higher.

Table 6. Pro and Standard IC Electrical Characteristics

Parameter	Symbol	Note	Min	Nom	Max	Unit
Input Capacitance	C_{IN}	@ $2V_{RMS}$	-10%	23.5	+10%	pF
Operating Supply Current	ICC	VANT=min			25	uA
Operating Supply Current	ICC	Programming			35	uA
Uplink Modulation Index	M_{PICC}	VANT<7V	0.1		0.3	
Limiter Clamping Volt.	Vlim				10	V
Data Retention	tDRET	55°C	10			Years
Write & Erase Endurance	W&E	Ta=25°C	100 000			Cycles

2.5 Pro and Standard IC – Mechanical Characteristics

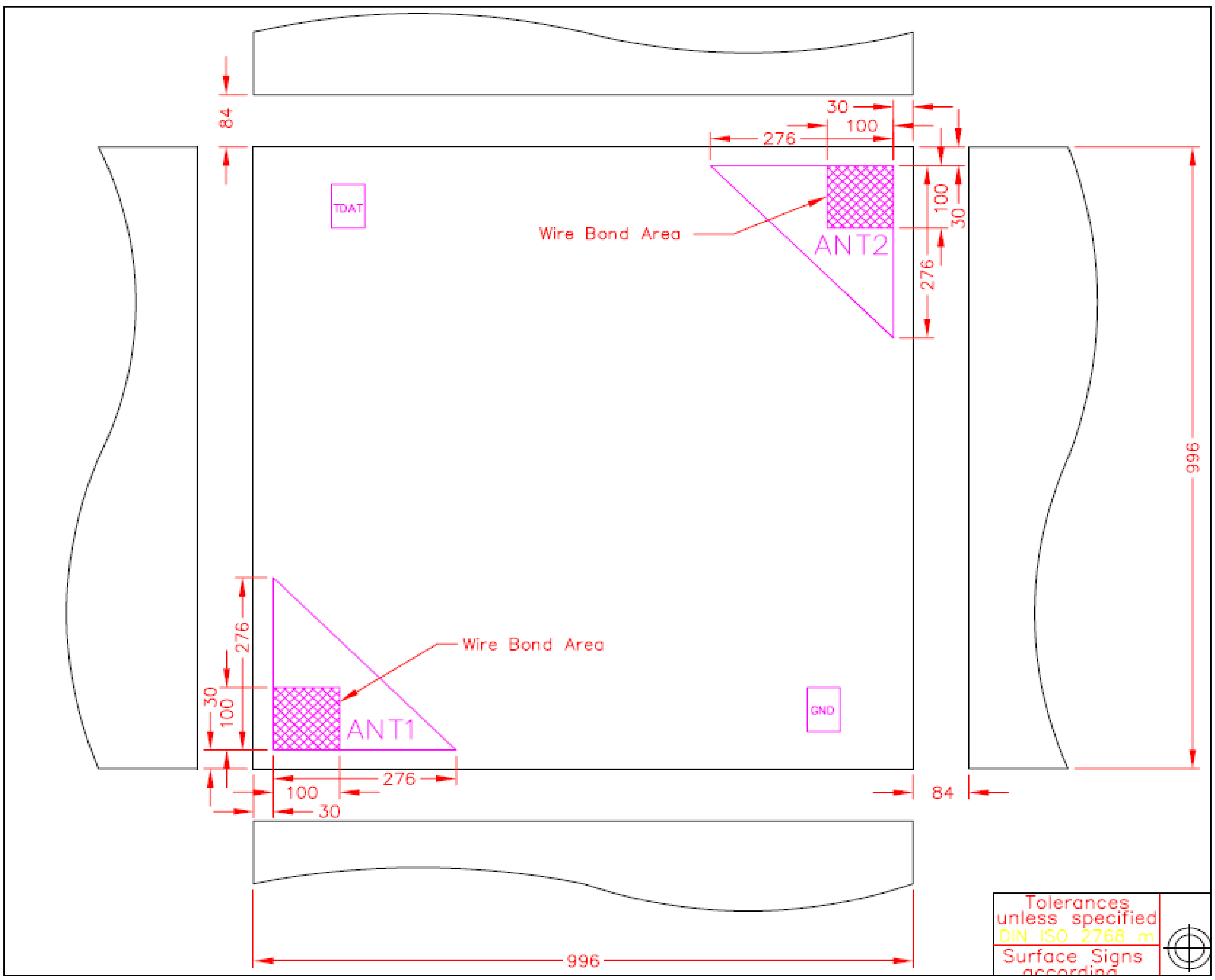
Table 7. Pro and Standard IC Mechanical Die Specifications

Parameter	Value
Bond pad metallization material	ALCu0.5 %
Bond pad metallization thickness	0.95µm
Bond & Test Pad location	Table 9
Die dimension (including scribe line)	1080 * 1080µm +/- 15µm
Die dimension (excluding scribeline)	996 * 996µm +/-15µm
Top side passivation material	SiNi
Passivation thickness	1.1µm

Table 8. Pro and Standard IC Antenna and Test Pad Locations

Pad No	Name	LLCx[µm]	LLCy[µm]	URCx[µm]	URCy[µm]
1	ANT1	30	30	n.a.	n.a.
2	ANT2	n.a.	n.a.	966	966
Test pad					
3	TDAT	118	866	168	936
4	GND	836	60	886	130

Figure 2. HF-I Pro and Standard Antenna and Test Pad Locations



CHAPTER 3

Antenna Calculations

This chapter details the methods that can be used to design antenna coils for the Texas Instruments Tag-it™ HF-I Plus, Pro and Standard ICs.

Topic **Page**

3 Antenna Calculations

The Tag-It™ HF-I Plus, Pro and Standard ICs all have the same basic circuit configuration as shown in Figure 3. The Plus IC differs from the Pro and Standard ICs in that it has a smaller internal capacitance which makes the coil requirement different and an external capacitor required to meet the recommended operating impedance of the completed circuit; however the calculation and method used for design are identical. Examples for both methods are covered in the subsequent section of this document.

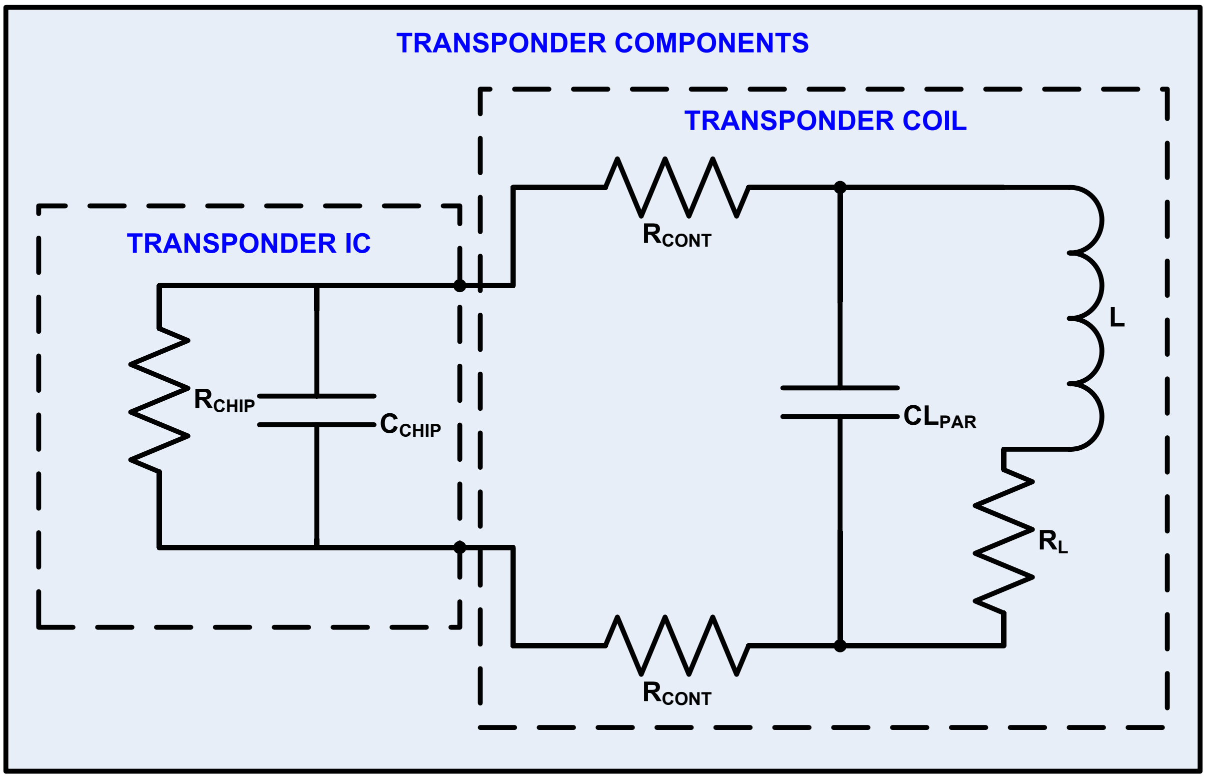


Figure 3. Transponder Equivalent Circuit

R_{CHIP} = IC Input Impedance (will vary according to applied input voltage)

C_{CHIP} = IC Input Capacitance (For Plus ≈ 2.4pF, for Pro and Standard ≈ 23.5pF)

R_{CONT} = Pad/assembly contact resistance (should be low and controlled)

CL_{PAR} = Parasitic capacitance of antenna coil (can be calculated)

R_L = Series resistance of antenna (Depends on tag trace width, length and thickness)

L = Antenna Inductance (For Plus ≈ 3.6uH, for Pro and Standard ≈ 5.86uH)

3.1 Calculating the Inductance of a Resonant Circuit

The resonant frequency of an LC circuit is given by the following formula:

$$f_{RES} = \frac{1}{2\pi\sqrt{L_R * C_{TOT}}}$$

where C_{TOT} is the sum of all capacitances parallel to L_R

If the total capacitance is known the true inductance L_R of the antenna coil can be calculated and verified using the following relationship:

$$L_R = \frac{1}{4\pi^2 * f_{RES}^{\;2} * C_{TOT}}$$

3.2 Required Inductance Needed Calculation for Pro and Standard IC Antenna

The following example shows how to calculate the true required inductance needed, based on the given specifications in the IC reference documents.

Two scenarios have to be considered during calculation:

Scenario 1: All capacitances are at their maximum value, resonant frequency is at minimum value. This scenario yields the maximum inductance possible for use with the transponder IC.

Scenario 2: All capacitances are at their minimum value, resonant frequency is at maximum value. This scenario yields the minimum inductance possible for use with the transponder IC.

3.3 Scenario 1

The value of inductance used must be such that the nominal resonant frequency can still be achieved (using the Pro and Standard IC as an example), and is given by:

$$L_{R(MAX)} = \frac{1}{4\pi^2 * f_{RES(MIN)} * C_{TOT(MAX)}}$$

$$L_{R(MAX)} = \frac{1}{4\pi^2 * 12.80\,\mathrm{MHz}^2 * 25.85\,\mathrm{pF}} = 5.986875\,\mu\mathrm{H}$$

$$L_{R(MAX)} \cong 5.99\,\mu\mathrm{H}$$

3.4 Scenario 2

$$L_{R(MIN)} = \frac{1}{4\pi^2 * f_{RES(MAX)} * C_{TOT(MIN)}}$$

$$L_{R(MIN)} = \frac{1}{4\pi^2 * 14.44\,\text{MHz}^2 * 21.15\,\text{pF}} = 5.749578\mu\text{H}$$

$$L_{R(MIN)} \cong 5.75\mu\text{H}$$

The nominal inductance is simply the average of the minimum and maximum values calculated above, and is given by:

$$L_{R(NOM)} = \frac{L_{R(MAX)} + L_{R(MIN)}}{2}$$

$$L_{R(NOM)} = \frac{5.986875\mu H + 5.749578\mu H}{2}$$

$$L_{R(NOM)} = 5.868227\mu H$$

The above matches the reference guide for these ICs and if we repeat the same calculations holding the resonant frequency at 13.56MHz and only vary the capacitance to stated minimum and maximum values, we yield two more values of $L_{R(MIN)}$ and $L_{R(MAX)}$. If we add those two together and insert into the $L_{R(NOM)}$ calculation, we get an even tighter hold on what the nominal inductance should be.

$$L_{R(NOM)} = \frac{L_{R(NOM_1)} + L_{R(NOM_2)}}{2}$$

$$L_{R(NOM)} = \frac{5.868227\mu H + 5.927319\mu H}{2}$$

$$L_{R(NOM)} = 5.897773\mu H$$

3.5 Required Inductance Calculation for Plus IC Antenna Coil

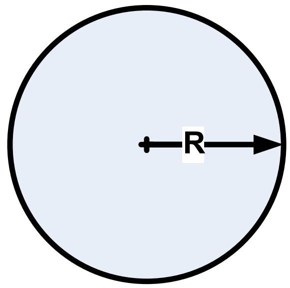
The Plus transponder IC is a bit different as it will require an external capacitor to get the same resonance. This is because the input capacitance is approximately one-tenth of the Pro or Standard IC. However, this allows for a wider range and if necessary a smaller inductance to be used, so the designer has more flexibility to create custom transponders using this IC. It also allows the designer using a rigid substrate for the coil to create one tag coil design and all three TI Tag-It™ HF-I IC's and adding capacitance to the coil circuit when the Plus IC is used.

Here the exercise is the same as seen previously with the Pro and Standard IC's, with the exception of the need to add an external parallel capacitance to match the IC to the coil being used.

3.6 Calculating the Coil Inductance Based on Particular Form Factors

More prevalent now is the case where an application demands a smaller or very custom form factor transponder that is not available off the shelf from Texas Instruments RFID Systems. This guide was written specifically for these cases. Here now we will cover shapes/styles that seem to be most popular and accommodate most applications. It is important to realize that the following three equations are specifically for round wire coils. This style of coil would be commonly used in the air core wire wound loops found in small encapsulated transponders being used today in a variety of applications. The several formulas after that are for flat and ferrite rod core styles. These examples will show how to get suitable inductance values needed for the ICs. It is important to note that the following formulas are meant as a reference to get results that spark development, and the designer may find through their own efforts, using locally sourced materials, that inductance calculations vary somewhat from actual construction, so they must not be discouraged if there are some differences noted.

3.6.1 Circular Wirewound Coil (example construction later in document)



$$L_{CIRCLE} \approx N^{1.9} R \mu_0 \mu_r \left[\ln\left(\frac{8R}{a}\right) - 2 \right]$$

N: number of turns

a: wire radius

μ_0: relative permeability of free space (1.256 x 10^{-6} H/m)

μ_r: relative permeability of the medium (usually ~1)

R: Radius of the circle

Example Inductance Calculation:

For 20mm diameter wirewound transponder coil, let:

N = 11.5 turns

a = 0.0127cm (30AWG wire)

μ_0 = 1.256 x 10^{-6} H/m (12.56 x 10^{-9}, for unit change to cm)

μ_r = 1

R = 1 cm

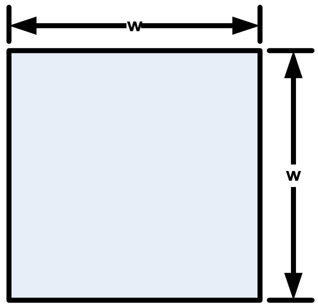
$$L_{CIRCLE} \approx (11.5^{1.9})(1)(12.56 * 10^{-9})(1) \left[\ln\left(\frac{8(1)}{0.0127}\right) - 2 \right]$$

$$L_{CIRCLE} \approx (1.301115 * 10^{-6})[\ln(629.92) - 2]$$

$$L_{CIRCLE} \approx (1.301115 * 10^{-6})[4.445595]$$

$$\boxed{L_{CIRCLE} \approx 5.784228 \mu H}$$

3.6.2 Square Wirewound Coil



$$L_{SQUARE} \approx N^2 \frac{2\mu_0\mu_r w}{\pi}\left[\ln\left(\frac{w}{a}\right) - 0.774\right]$$

N: number of turns

w: length of one side

a: wire radius

μ_0: relative permeability of free space (1.256×10^{-6} H/m)

μ_r: relative permeability of the medium (usually ~1)

Example Inductance Calculation:

For 2.54cm^2 wirewound square transponder coil, let:

N = 8 turns

w: length of one side

a = 0.0127cm (30AWG wire)

μ_0 = 1.256×10^{-6} H/m (12.56×10^{-9}, for unit change to cm)

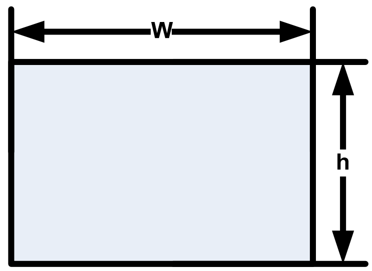
μ_r = 1

$$L_{SQUARE} \approx 8^2 \frac{2\mu_0\mu_r 2.54}{\pi}\left[\ln\left(\frac{2.54}{0.0127}\right) - 0.774\right]$$

$$L_{SQUARE} \approx 20.3097[4.524317367]$$

$$\boxed{L_{SQUARE} \approx 5.88\mu H}$$

3.6.3 Rectangular Wirewound Coil



$$L_{REC} = N^2 \frac{\mu_0 \mu_r}{\pi}\left[-2(w+h)+2\sqrt{h^2+w^2}-h\ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right)-w\ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right)+h\ln\left(\frac{2h}{a}\right)+w\ln\left(\frac{2w}{a}\right)\right]$$

N: number of turns

w: width of rectangle

h: height of the rectangle

a: wire radius

μ_0: relative permeability of free space (1.256 x 10^{-6} H/m)

μ_r: relative permeability of the medium (usually ~1)

<u>Example Inductance Calculation</u>:

For 2.1cm x 1cm wirewound rectangular transponder coil, let:

N = 11 turns

w: 2.1cm

h: 1cm

a = 0.0127cm (30AWG wire)

μ_0 = 1.256 x 10^{-6} H/m (12.56 x 10^{-9}, for unit change to cm)

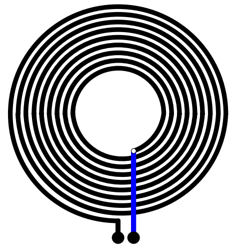
μ_r = 1

$$L_{REC} = 0.483 * 10^{-6}\left[-1.54812 - 0.4598152 - 3.123714 + 5.059 + 12.1825994\right]$$

$$L_{REC} = 0.483 * 10^{-6}\left[12.10995\right]$$

$$\boxed{L_{REC} = 5.858\ \mu H}$$

3.6.4 Flat Spiral Air Core Coil (from Nikola Tesla)



$$L_{SPIRAL} = \frac{(0.397)(aN^2)}{8a + 11b} \text{ for cm, } \quad L_{SPIRAL} = \frac{R^2 N^2}{9R + 10L} \text{ for in.}$$

N : number of turns

a : mean radius of the coil $(r_i + r_o)/2$

b : depth of coil (outer radius minus inner radius) (in cm)

r_o : outer radius of the spiral (in cm)

r_i : inner radius of the spiral (in cm)

R: Radius of coil (in inches)

L: Length of coil (in inches)

Example Inductance Calculation:

For 8.5mm (OD) flat spiral transponder coil, let:

N = 12 turns

a : 0.788

b : 0.125

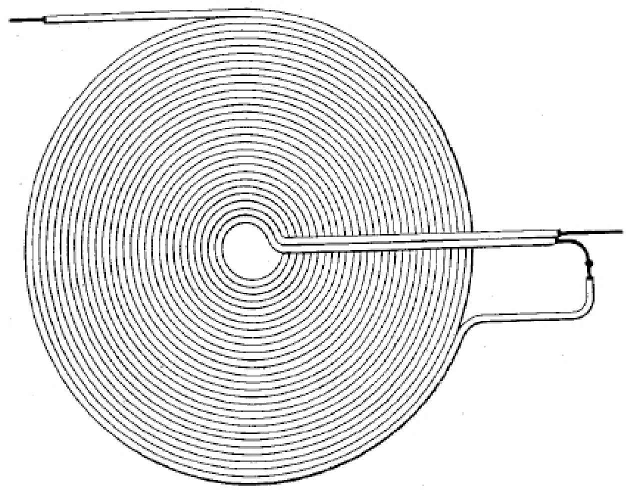
r_o : 0.85 (in cm)

r_i : 0.725 (in cm)

$$L_{SPIRAL} = \frac{(0.397)(0.788 * 12^2)}{(8 * 0.788) + (11 * 0.125)}$$

$$\boxed{L_{SPIRAL} = 5.866 \mu H}$$

3.6.5 Flat Spiral Bifilar Air Coil (from Nikola Tesla)



This Bifilar coil is from Nikola Tesla's United States patent 512,340 of 1894. Tesla explains that in some applications (which he does not specify) the self-inductance of a conventional coil is undesired and has to be neutralized by adding external capacitors.

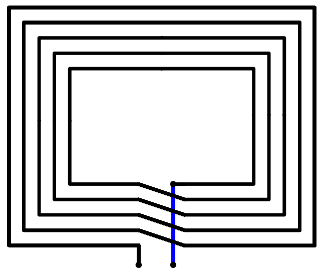
The bifilar coil in this configuration has increased self-capacitance, thereby saving the cost of the capacitors. It is notable that this is not the kind of bifilar winding used in non-inductive wire wound resistors where the windings are wired anti-series to null out self-inductance.

These bifilar coils can be explained solely on the basis of their electrical activity. A bifilar coil is capable of holding more charge than a single wound coil. When operated at resonance, the distributed capacitance of the bifilar coil is able to overcome the counter electromotive force (emf) normal to coils - inductive reactance.

This type/style of winding might be useful for the Tag-It HF-I Plus silicon where external capacitance is needed versus the Pro or Standard requirements, but the author has not experimented with this yet.

3.6.6 Flat Rectangular Air Core Coil

There are many complicated formulas for this type of coil. Below is almost same formula as the wire wound coil, but instead here we must take the dimensions from the center trace to center trace for the height and width as this is best approximation for first calculation of the coil.



$$L_{REC} = N^2 \frac{\mu_0 \mu_r}{\pi}\left[-2(w+h)+2\sqrt{h^2+w^2}-h\ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right)-w\ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right)+h\ln\left(\frac{2h}{a}\right)+w\ln\left(\frac{2w}{a}\right)\right]$$

N: number of turns

w: width of rectangle (**from center trace**)

h: height of the rectangle (**from center trace**)

a: (trace thickness)

μ_0: relative permeability of free space (1.256 x 10^{-6} H/m)

μ_r: relative permeability of the medium (usually ~1)

<u>Example Inductance Calculation</u>:

For flat rectangular air core coil, let:

N = 11 turns

w: 2.1cm

h: 1cm

a = 0.0127cm (30AWG wire)

μ_0 = 1.256 x 10^{-6} H/m (12.56 x 10^{-9}, for unit change to cm)

μ_r = 1

$$L_{REC} = 0.483 * 10^{-6}[-1.54812 - 0.4598152 - 3.123714 + 5.059 + 12.1825994]$$

$$L_{REC} = 0.483 * 10^{-6}[12.10995]$$

$$\boxed{L_{REC} = 5.858\ \mu H}$$

3.6.7 Ferrite Core Coil

Ferrite core transponders have superior performance over flat coils, and in more orientations. The **61**, **67, and 68** type material is best for the 13.56MHz frequency of operation, and each one has separate data sheet. The designer should experiment with each type to determine best material for their application. The magnetic length is the most difficult part of this calculation, and the designer should realize that the distance between the turns also has a great effect on the resulting inductance. In the example built, the turns were closely wound, and if the turns are spaced to cover the length of the rod, more turns would have been needed.
http://www.fair-rite.com/newfair/materials.htm

$$L_{FERRITE} = \left(\frac{N^2 * \mu_0 * \mu_{ROD} * r_{ROD}{}^2 * \pi}{l_{ROD}} \right) * \frac{l_m}{l_{ROD}}$$

N = number of turns

μ_0 = permeability of vacuum

μ_{ROD} = relative permeability of the ferrite rod (67 material = 18)

r = radius of the ferrite rod

l_{ROD} = length of rod

l_M = magnetic path length (circumference * # of turns/2)

Example Inductance Calculation:

For ferrite rod core coil, using Fair-Rite 3067990881 material, let:

N = 14.25

μ_0 = 1.256 x 10^{-6} H/m (12.56 x 10^{-9}, for unit change to cm)

μ_{ROD} = relative permeability of the ferrite rod (67 material = 18)

r = 0.20

l_{ROD} = 3

l_M = 8.95

$$L_{FERRITE} = \left(\frac{14.25^2 * \mu_0 * \mu_{ROD} * 0.04 * \pi}{3} \right) * \frac{8.95}{3}$$

$$\boxed{L_{FERRITE} = 5.74 \mu H}$$

3.7 Measuring the True Inductance of an Antenna Coil

Measuring the antenna coils true inductance with a network analyzer or impedance analyzer is considered to be the proper method. Both methods can be employed and the resulting calculations should match, giving a high degree of confidence to the developer. The coil should be measured at the operating frequency of 13.56MHz with a network analyzer. The Smith Chart format on a network analyzer will provide the inductance, the resistance and the inductive reactance in complex notation (R + *j* X_L).

When using an impedance analyzer, the coil should be measured at two frequencies, 13.36MHz and 13.76MHz. The magnitude values measured can be used to calculate the true inductance and capacitance of the coil using the following formulas:

$$L_R = \frac{1}{2\pi} * \frac{(f_1^2 - f_2^2)(|Z_1| * |Z_2|)}{(f_1^2 * f_2 * |Z_1|) - (f_2^2 * f_1 * |Z_2|)}$$

and

$$C_{LR} = \frac{1}{2\pi} * \frac{(|Z_1| * f_2) - (|Z_2| * f_1)}{(f_1^2 - f_2^2) * |Z_1| * |Z_2|}$$

3.7.1 Construction and Measurement Example

Using the calculation example from Section 3.6.1 (Circular Wirewound Coil), it was determined that a coil made in this manner would have about 5.78uH of inductance. This fits within the range of use for the Tag-It™ HF-I Pro and Standard IC. Now we will show how to construct this coil and then measure it properly using a network analyzer.

First, a coil is wound with 30AWG (~0.24mm) magnet wire around a 20mm bobbin form 11.5 times to create the coil. The enamel from the ends is removed to allow for electrical contact.

A network analyzer with a fixture as shown in Figure 4 is calibrated with a center frequency of 13.56MHz to the ends of the alligator clips to remove any unwanted or stray capacitance or inductance from entering the measurement. The span should be more than 2MHz, but this is not critical. A marker should be set for 13.56MHz to yield the measured value of the coil at the desired frequency. Using the network analyzer for this task also allows for the impedance value of the coil to be captured.

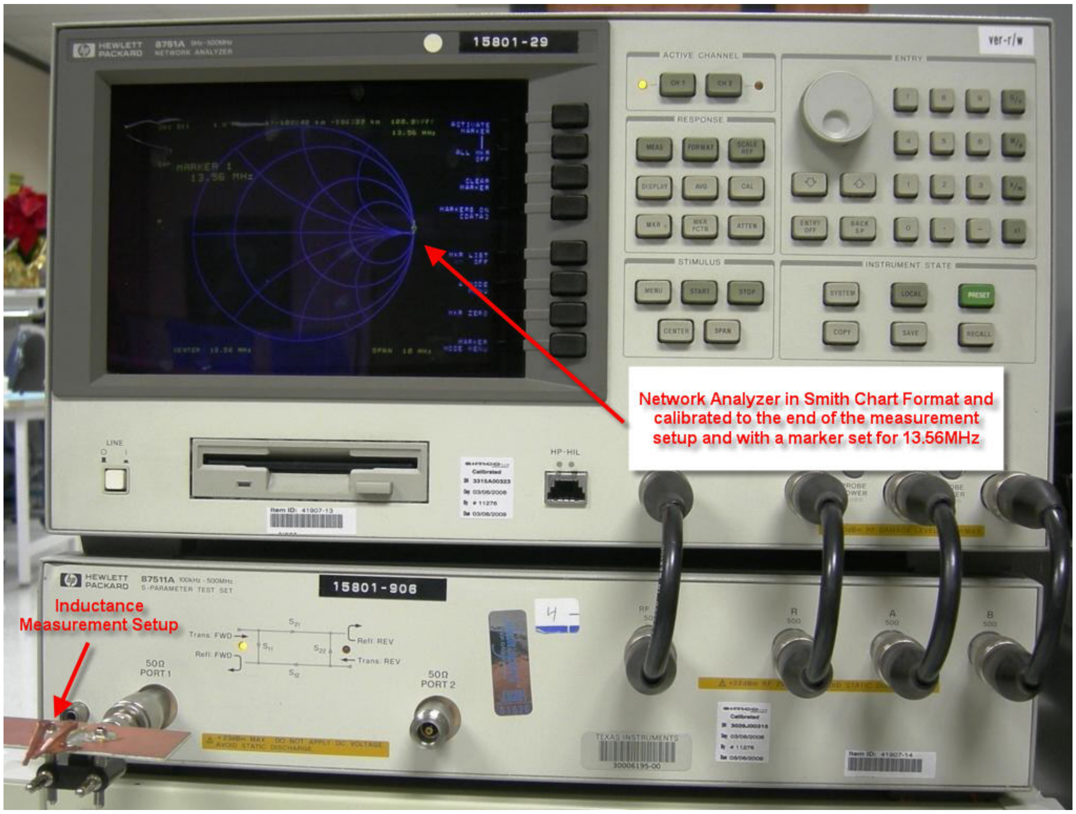


Figure 4. Inductance Measurement Fixture

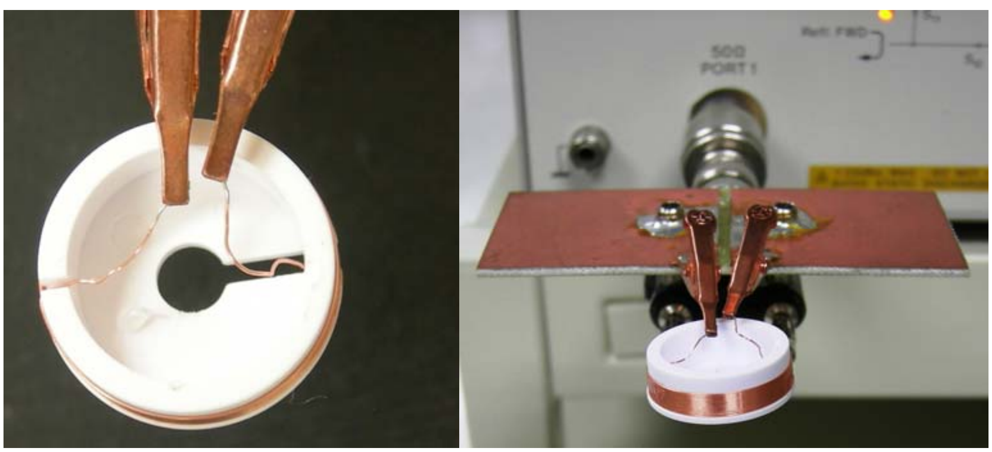


Figure 5. Measuring the Inductor with the Fixture

3.8 Results

The measurement results of this exercise were closely consistent with the calculation. The inductor shown in Figure 5 measured 5.77uH at 13.56MHz and the impedance of the coil was 11+j493.

3.9 Using the Results

The measurement results gave a measured value of 5.78uH. Using the chart below, we should be able to predict the resulting resonant frequency of the transponder. In this example, the coil was around 5.78uH and the transponder IC should be close to 23.5pF. So we can predict that the tag should come in somewhere close to 13.75MHz. We can also roughly predict the Q of the transponder since the impedance was also captured. In this case, the impedance was 11 +j493, since Q=X_L/R, then we can say the Q should come in at ≤ 45.

4*pi	fres	fres^2	Ctot	L
39.4384	12.80E+06	1.638400E+14	25.85016000E-12	05.98684E-06
39.4384	12.85E+06	1.651225E+14	25.70328000E-12	05.97428E-06
39.4384	12.90E+06	1.664100E+14	25.55640000E-12	05.96213E-06
39.4384	13.00E+06	1.690000E+14	25.40952000E-12	05.90470E-06
39.4384	13.05E+06	1.703025E+14	25.26264000E-12	05.89360E-06
39.4384	13.10E+06	1.716100E+14	25.11576000E-12	05.88290E-06
39.4384	13.15E+06	1.729225E+14	24.96888000E-12	05.87260E-06
39.4384	13.20E+06	1.742400E+14	24.82200000E-12	05.86268E-06
39.4384	13.25E+06	1.755625E+14	24.67512000E-12	05.85315E-06
39.4384	13.30E+06	1.768900E+14	24.52824000E-12	05.84401E-06
39.4384	13.35E+06	1.782225E+14	24.38136000E-12	05.83526E-06
39.4384	13.40E+06	1.795600E+14	24.23448000E-12	05.82690E-06
39.4384	13.45E+06	1.809025E+14	24.08760000E-12	05.81892E-06
39.4384	13.50E+06	1.822500E+14	23.94072000E-12	05.81134E-06
39.4384	13.55E+06	1.836025E+14	23.79384000E-12	05.80414E-06
39.4384	13.56E+06	1.838736E+14	23.67635000E-12	05.82434E-06
39.4384	13.60E+06	1.849600E+14	23.64696000E-12	05.79732E-06
39.4384	13.65E+06	1.863225E+14	23.50008000E-12	05.79090E-06
39.4384	13.70E+06	1.876900E+14	23.35320000E-12	05.78486E-06
39.4384	13.75E+06	1.890625E+14	23.20632000E-12	05.77922E-06
39.4384	13.80E+06	1.904400E+14	23.05944000E-12	05.77396E-06
39.4384	13.85E+06	1.918225E+14	22.91256000E-12	05.76909E-06
39.4384	13.90E+06	1.932100E+14	22.76568000E-12	05.76462E-06
39.4384	13.95E+06	1.946025E+14	22.61880000E-12	05.76053E-06
39.4384	14.00E+06	1.960000E+14	22.47192000E-12	05.75684E-06
39.4384	14.05E+06	1.974025E+14	22.32504000E-12	05.75355E-06
39.4384	14.10E+06	1.988100E+14	22.17816000E-12	05.75065E-06
39.4384	14.15E+06	2.002225E+14	22.03128000E-12	05.74815E-06
39.4384	14.20E+06	2.016400E+14	21.88440000E-12	05.74605E-06
39.4384	14.25E+06	2.030625E+14	21.73752000E-12	05.74435E-06
39.4384	14.30E+06	2.044900E+14	21.59064000E-12	05.74306E-06
39.4384	14.35E+06	2.059225E+14	21.44376000E-12	05.74217E-06
39.4384	14.40E+06	2.073600E+14	21.29688000E-12	05.74169E-06
39.4384	14.44E+06	2.085136E+14	21.15000000E-12	05.74958E-06
39.4384	14.45E+06	2.088025E+14	21.15000000E-12	05.74162E-06

CHAPTER 4

Transponder Construction

This chapter details construction techniques for HF-I IC based transponders.

Topic **Page**

4 Transponder Construction

While the examples in this document are hand built specifically for this document so a company engineer can use as references, it should be made clear that the manufacture of production transponders in volume should be done with machinery once a stable process for a given company or entity is conceived, designed, controlled and qualified. This leads to the highest quality and subsequent yield of product. The success of these sorts of efforts of course equate directly to a higher profitably for the transponder manufacturing company.

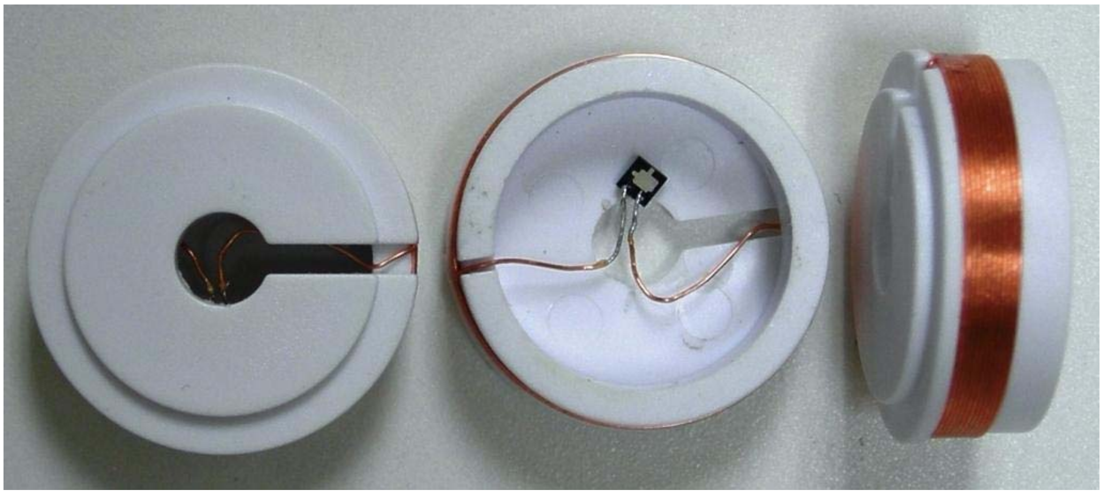


Figure 6. Handbuilt 20mm transponder examples

(NOTE: packaged TI Tag-It™ HF-I Standard Silicon (IC packaging from Chang Feng SmartCard) http://www.cfsmart.com.cn/english/index.asp)

4.1 Recommendations

If packaged die (solderable) are not to be used in the transponder construction, a suitable epoxy or film should be used to connect the bare die to the tag antenna. It is the responsibility of the designer to investigate what works best in his/her application and follow our recommendations in the handling of the silicon. Companies that supply this sort of material are Emerson & Cuming, Zymet and Delo. Please follow the links below for more detailed information about this.

http://www.emersoncuming.com/docs/proddocs/2005IMAPSInterconnectTechnologiesForRFIDAssembly.pdf

http://www.emersoncuming.com/prodgeneric.asp?region_id=1&sub_cat_id=1&prodtype_id=6&cat_id=3

http://www.zymet.com/p-adh-anstrp-ei.php

http://www.delo.de/index.php?level=2&id=2&leaf=21&lang=en

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CHAPTER 5

Transponder Measurement and Testing

This chapter details measuring and testing of Tag-It HF-I IC based transponders.

Topic **Page**

5 Transponder Measurement and Testing

There is what seems to be an infinite amount that could be written on this particular subject, however for the sake of brevity in this document and to allow the reader to get to the point – the most straightforward method is presented here.

5.1 Recommended Test Setups

The ISO10373-7 Test Specification details hardware and methodology that can be used to satisfy ISO15693-1 specification. These documents specifically refer to a full size (ISO7810 size/ID-1 or credit card size) transponder.

These documents, while accurate and great to reference, do not encompass all the other shapes and sizes that are desired and in use today in the asset tracking and item management application space.

For simple frequency and Q-factor measurement a spectrum analyzer with tracking generator is required. (for example: **Agilent 4402B)**

Any other calibrated spectrum analyzer which supports the frequency range can be used. (50 Ω or 1MΩ impedance)

Spectrum analyzer setup steps:

1. Connect fixture to analyzer. Red connector to output of tracking generator the blue connector to input channel.
2. Place a reference unit on top of the fixture (as shown in Figure 7)

   Note: (Inlay has to be centered and flat. Temperature and humidity <u>will</u> impact frequency and Q of inlay.)
3. Enable tracking generator output, center to the expected inlay frequency (i.e. 13.56MHz) with a span of 2 MHz.
4. At about –60dBm reference level with a vertical scale of 1 dB/div the resonance curve should be seen.
5. The inlay frequency can be read at maximum.
6. View bandwidth by enabling the N dB 3 points through the peak search menu (as shown in Figure 7).
7. The quality factor is calculated by dividing the resonant frequency by the measured bandwidth. (i.e. in Figure 7, the Q of the tag is ~41)

$$BW = f_2 - f_1$$

$$Q = \frac{f_{RES}}{BW}$$

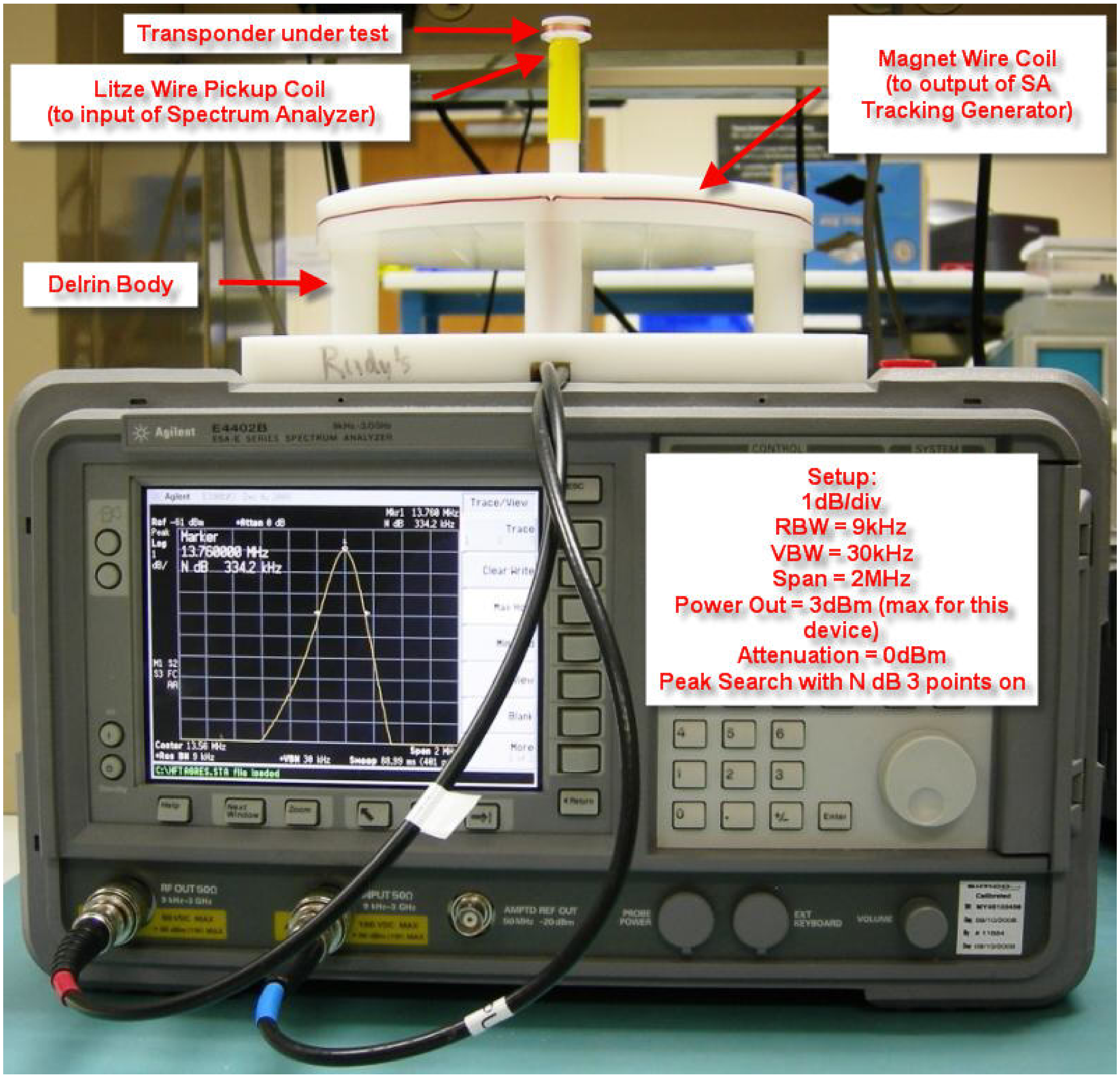

Figure 7. Frequency and Bandwidth Measurement Fixture

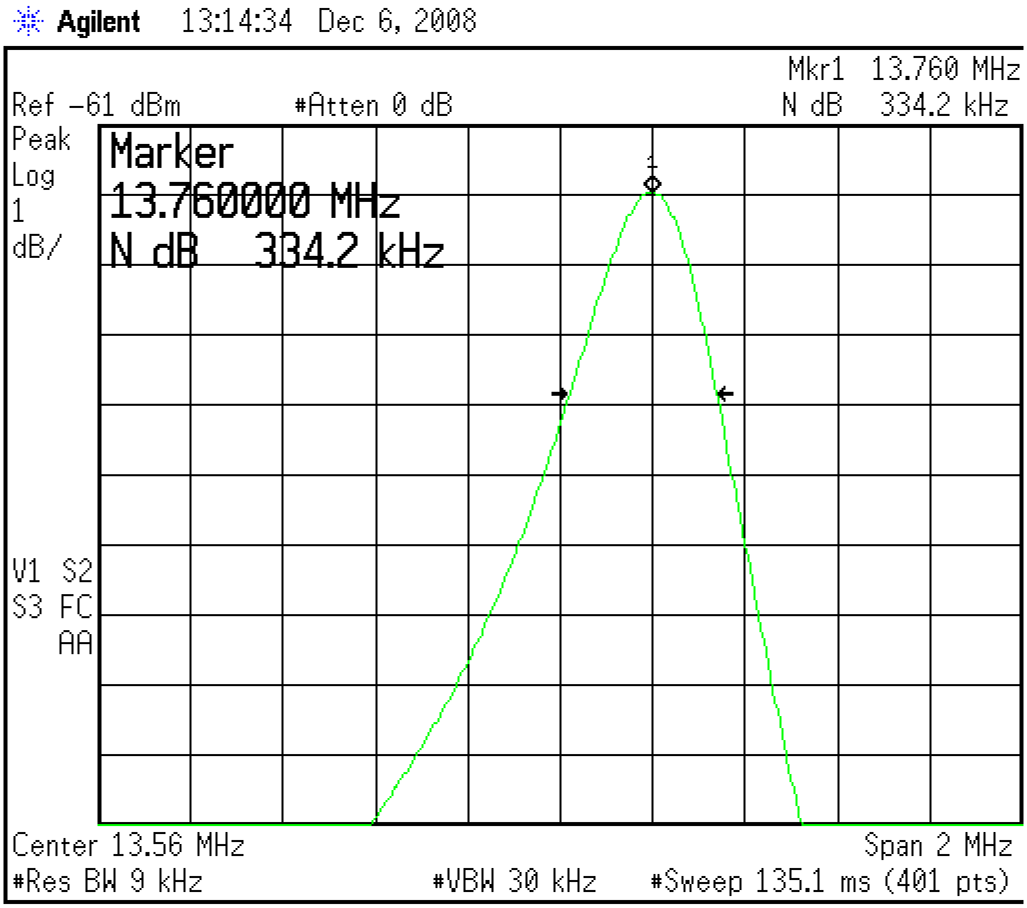

Figure 8. Spectrum Analyzer Measurement Screen 1

As shown in Figures 7 and 8, the tag that was just constructed (shown in Figure 6) exhibits resonance at 13.76MHz, with a Q of 41.17295. This falls exactly within or close to the predictions we were able to make earlier in Section 3.9, as we said we should be resonant around 13.75MHz and have a Q of less than 45.

5.2 Activation Field Strength Testing

A fixture similar to the one shown in Figure 9 should be constructed and calibrated to for accurate, repeatable activation field strength testing.

Figure 9. Activation Field Strength Test Fixture

The fixture shown in figure 9 was calibrated by using a calibrated EMCO 7405-902 near field pickup coil and a spectrum analyzer, in conjunction with the performance factor for the probe. http://www.ets-lindgren.com/manuals/7405.pdf

Activation field strength for the five samples constructed for this paper was ~108dBuA/m. This is consistent with and better than transponders of similar size, mostly due to the Q of the tag.

In the ISO10373-7 specification, another calibration coil is specified, which is a single turn coil that is contained within an ISO7810 ID-1 card outline. This coil also allows for a direct conversion from the $V_{Pk\text{-}Pk}$ measured to H_{RMS} through the formula below, which might be handy in the event one does not have a spectrum analyzer to measure the field with.

$$H_{(RMS)} = 1.1 * V_{Pk-Pk}$$

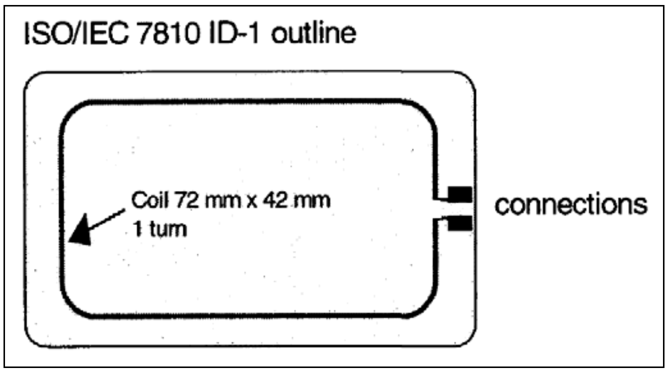

Figure 10. Calibration Coil Layout

This coil has a corner radii of 5mm, and a track width of 500µm. The inductance of this coil is approximately 200nH and follows the formula for rectangular inductors found earlier in the document. The open circuit calibration factor for this coil is 0.32$V_{(RMS)}$ per A/$m_{(RMS)}$. This is equivalent to 900$mV_{(Pk\text{-}Pk)}$ to A/$m_{(RMS)}$.

Appendix A - Terms & Abbreviations

A list of the abbreviations and terms used in the various TI manuals can now be found in a separate manual:

TI-RFID Product Manuals – Terms & Abbreviations

Document number 11-03-21-002