![TEXAS INSTRUMENTS]

RF430FRL15xH NFC and ISO/IEC 15693 Sensor Transponder Practical Antenna Design

Christian Buchberger, Kostas Aslanidis

ABSTRACT

The TI RF430FRL15xH ISO/IEC 15693 NFC Sensor Transponder is an NFC Tag Type 5 device operating at 13.56 MHz (HF band). Depending on the application communication distance requirements, the antenna geometry can be adjusted. The device gives the flexibility to be used in combination with various antenna geometries.

The scope of this document is a short practical guidance on antenna design basics.

Figure 1. RF430FRL152HEVM

MSP430 is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

RF430FRL15xH NFC and ISO/IEC 15693 Sensor Transponder Practical
Antenna Design

1

Contents

List of Figures

List of Tables

1   RF430FRL15xH NFC and ISO/IEC 15693 Sensor Transponder

1.1   Transponder Overview

The RF430FRL15xH device is a 13.56-MHz transponder chip with a programmable 16-bit MSP430™ low power microcontroller. The device features embedded universal FRAM nonvolatile memory for storage of program code and user data such as calibration and measurement data. The RF430FRL15xH supports communication, parameter setting, and configuration through the RF-compliant interfaces: ISO/IEC 15693, NFC Tag Type 5 (T5T) (draft version) and ISO/IEC 18000-3 and the contacted SPI or I^2C. Sensor measurements can be supported by the internal temperature sensor and the onboard 14-bit sigma-delta analog-to-digital converter (ADC), an external digital sensor can be connected through SPI or I^2C interface.

The RF430FRL15xH devices are optimized for operation in fully passive (battery-less) or single-cell battery powered (semi-active) mode to achieve extended battery life in portable and wireless sensing applications.

FRAM is a nonvolatile memory that combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash, all at lower total power consumption.

For details on the device family, refer to the corresponding product folders:

www.ti.com/product/RF430FRL152H

www.ti.com/product/RF430FRL153H

www.ti.com/product/RF430FRL154H

Figure 2 shows a typical application diagram for these transponders.
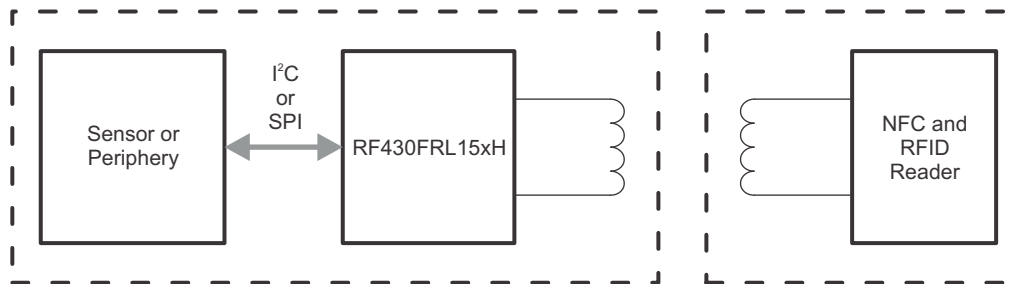
Figure 2. Typical Application

Figure 3 shows the functional block diagram of the transponder.
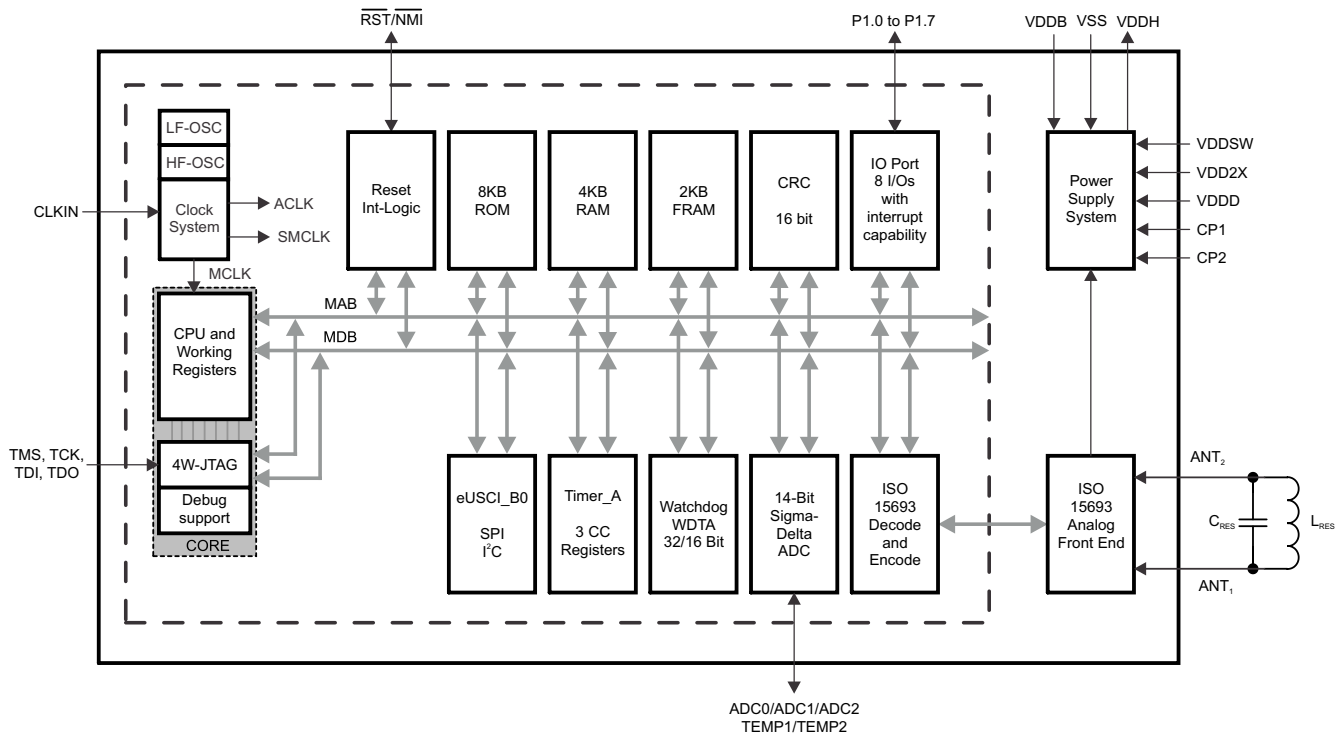
Figure 3. RF430FRL15xH Functional Block Diagram

Figure 4 shows the typical connections to the transponder for an example application.
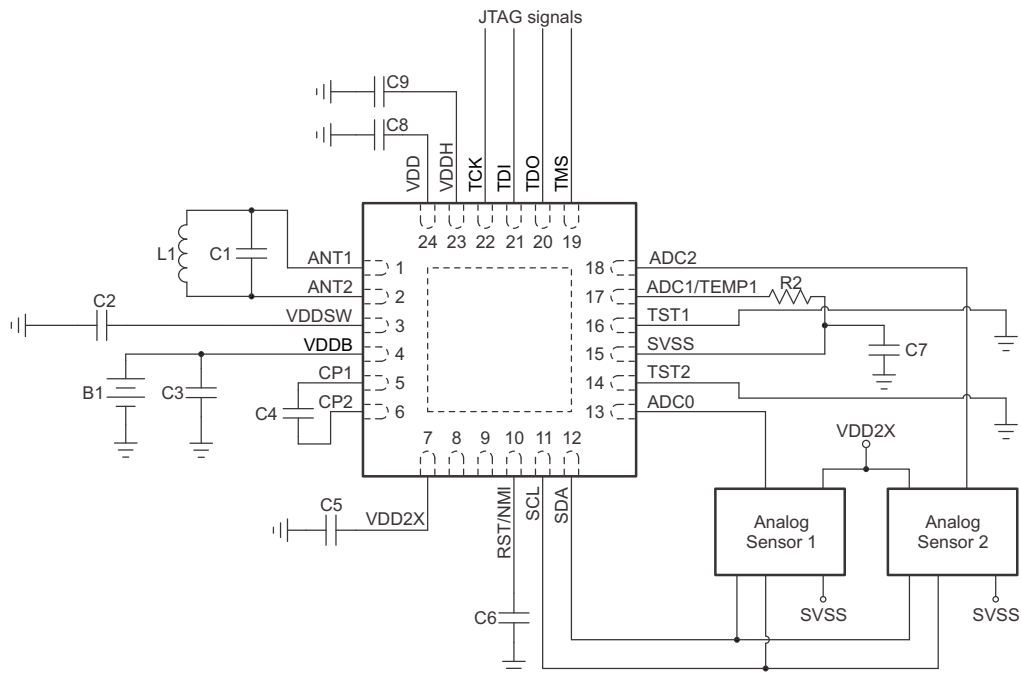
Two analog sensors connected through I²C, supplied by VDD2X (≈3 V)

Figure 4. Example Application Circuit

4   *RF430FRL15xH NFC and ISO/IEC 15693 Sensor Transponder Practical*   SLOA217A–April 2015–Revised July 2015
        Antenna Design   *Submit Documentation Feedback*

Copyright © 2015, Texas Instruments Incorporated

2 RF Interface

The RF communication interface (see Figure 5) is based on ISO15693 and supports the NFC T5T (draft version) specification. It supports data rates 1-out-of-4 and 1-out-of-256 for reader-to-tag communication and 26 kbit/s for tag-to-reader communication.
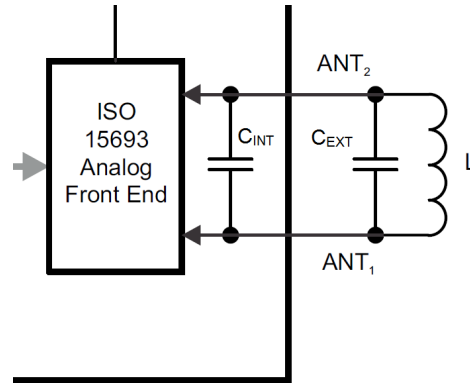
Figure 5. RF Interface Module With Antenna

The interface from the RF module to the outside world is the antenna connection. The two pins ANT1 and ANT2 can be connected to an external antenna. The antenna dimensions and parameters depend on the basic application requirements, including:

- communication distance
- available space
- antenna technology

The on-chip resonance capacitor (C_{INT}) has a typical value of 35 pF with a tolerance of ±10%.

A resonance circuit is generated using the external antenna (inductance L), the on-chip resonance capacitor (C_{INT}), and if necessary an external capacitor (C_{EXT}).The additional external resonance capacitor (C_{EXT}) can be added to allow antenna inductance variation for lower inductance antennas (L < 3.8 µH) (see Figure 10). The resonance frequency is calculated using following formula:

$$f_{res} = \frac{1}{2 \times \pi \times \sqrt{L \times C}}$$

where

- L = Antenna inductance
- C = Total resonance capacitance (C = C_{INT} + C_{EXT})
- f_{res} = Resonance frequency   (1)

3 RF430FRL152HEVM

The product family of the RF430RL15xH devices includes the RF430FRL152H, RF430FRL153H, and the RF430FRL154H variants. This evaluation and development platform uses the RF430FRL152H device.

The RF430FRL152H EVM is an evaluation and development platform for the RF430FRL152H device.

The development board allows the developers to design and test their systems and become familiar with the ISO/IEC 15693 and NFC T5T protocol.

For test purposes, an onboard antenna is available on the evaluation and development platform. This antenna is connected to the RF430FRL154H pins ANT1 and ANT2. The two 0-Ω resistors (R27 and R31) can be removed to disconnect the onboard antenna if an external antenna is used.

Additional information on the target board can be found at http://www.ti.com/tool/rf430frl152hevm.

3.1 RF430FRL152HEVM Schematic

Figure 6 shows the EVM schematic. All RF430FRL152HEVM design files can be found at
http://www.ti.com/tool/RF430FRL152HEVM.
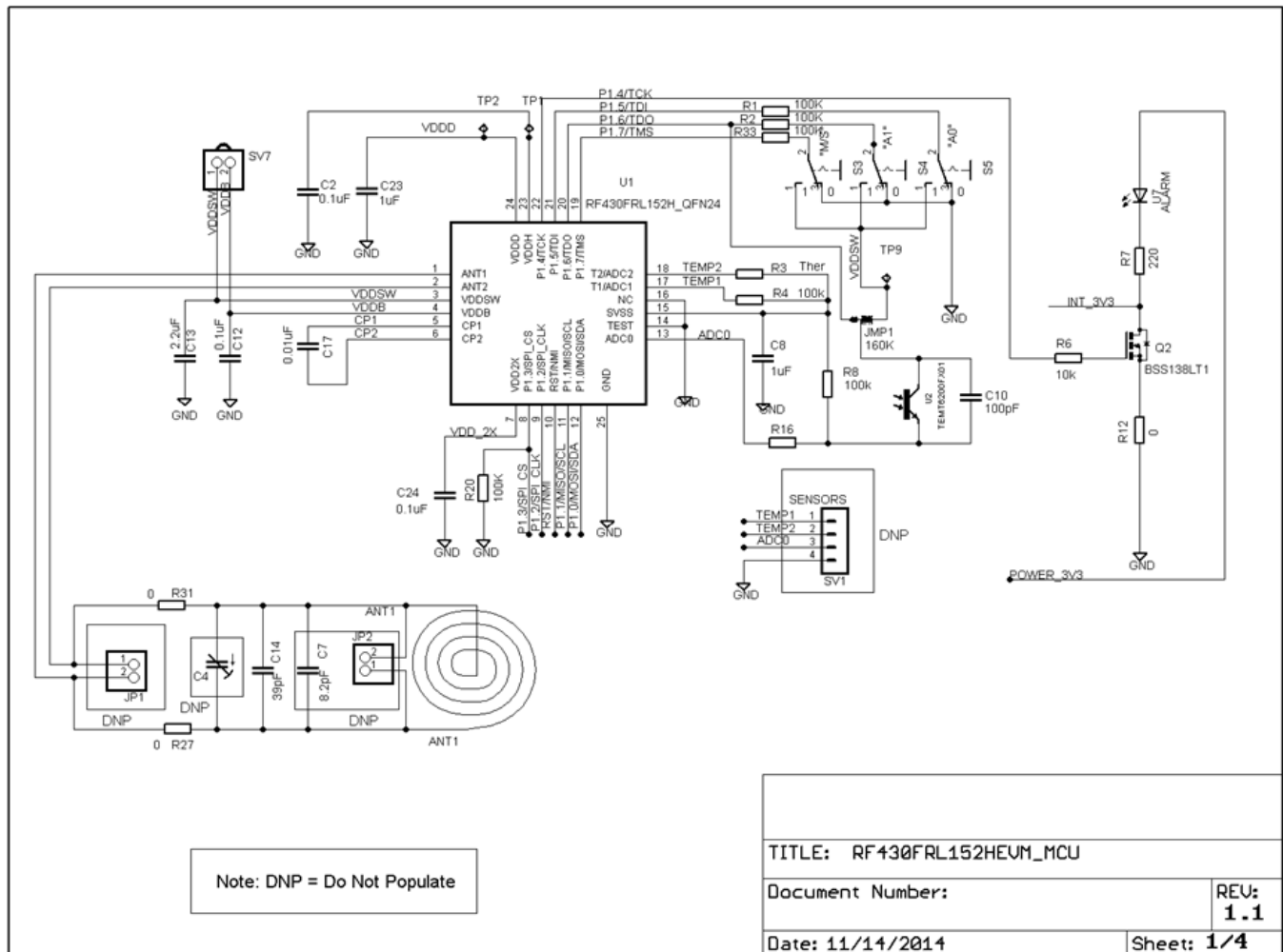
Figure 6. RF430FRL152H EVM Reference Schematic

4 Internal Resonance Capacitor

An on-chip resonance capacitor (C_{INT}) has been implemented. The C_{INT} is connected parallel to the
antenna pins ANT1 and ANT2 to generate a resonance circuit with the antenna (coil) that is connected to
the ANT1 and ANT2 pins.

Table 1. Internal Resonance Capacitor[1]

MIN	TYP	MAX
31.5 pF	35 pF	38.5 pF

[1] C_{INT} = 35 pF ±10% on-chip resonance capacitor (C_{INT})

The input impedance of the device is not constant. The value varies with the input voltage, the activation of the rectifier, and the RF limiter of the device (see Figure 7).

Figure 7. RF430FRL152H EVM Internal Resonance Capacitor Values

5   Antenna

An external antenna can be connected to JP1 on the RF430FRL152HEVM (pins 1 and 2 on the device). These pins are parallel to the internal resonance capacitor C_{INT} to generate the resonance circuit.
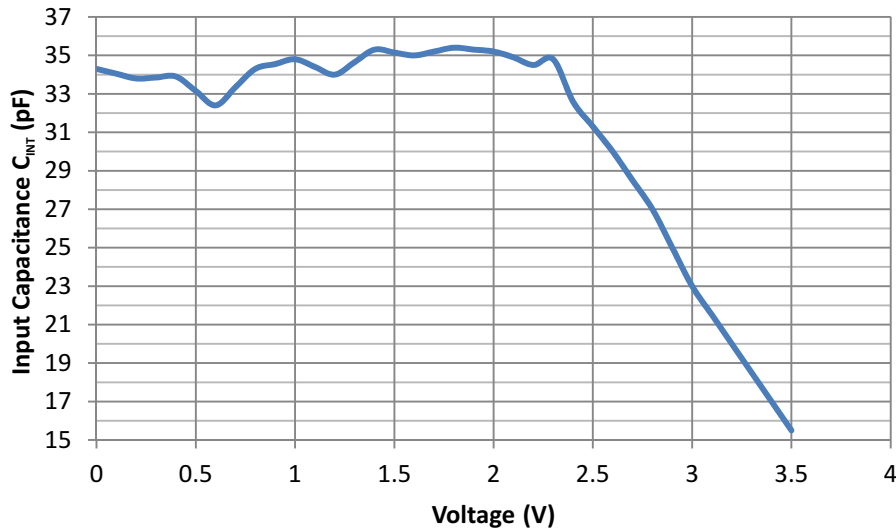
Depending on the antenna inductance, an additional external resonance capacitor parallel to C_{INT} can be used.

5.1   *Onboard Antenna Inductance*

The onboard antenna inductance has a typical value of 1.8 µH. The etched antenna tolerances are typically in the range of ±2% (see Table 2).

Table 2. Onboard Antenna Inductance

MIN	TYP	MAX
	1.8 µH	

5.2   *External Antenna Inductance Range Without External Capacitor*

Theoretically, the antenna inductance can have any value within the logical range of the L/C ratio.

If no external capacitor is used, and assuming a $f_{res} \approx 13.7$ MHz, the C_{INT} tolerances must be considered for the calculation of the antenna inductance (see Table 3).

Table 3. Antenna Inductance ($f_{res} \approx 13.7$ MHz)

MIN	TYP	MAX
3.57 µH (at C_{INT} = 38.5 pF)	3.85 µH (at C_{INT} = 35 pF)	4.28 µH (at C_{INT} = 31.5 pF)

Note: In this calculation, antenna tolerances are not considered. Normally these are in the range of ±2%.

5.3 External Antenna Connection

On the RF430FRL152HEVM, it is possible to disconnect the "onboard" antenna and connect an external antenna.

The modifications to the board are as follows (see Figure 8):

- Remove R27 and R31 (green)
- Connect an external antenna to the two antenna pins at JP1 (blue)
- Use capacitors parallel to the external coil or antenna to adjust it to the resonance frequency
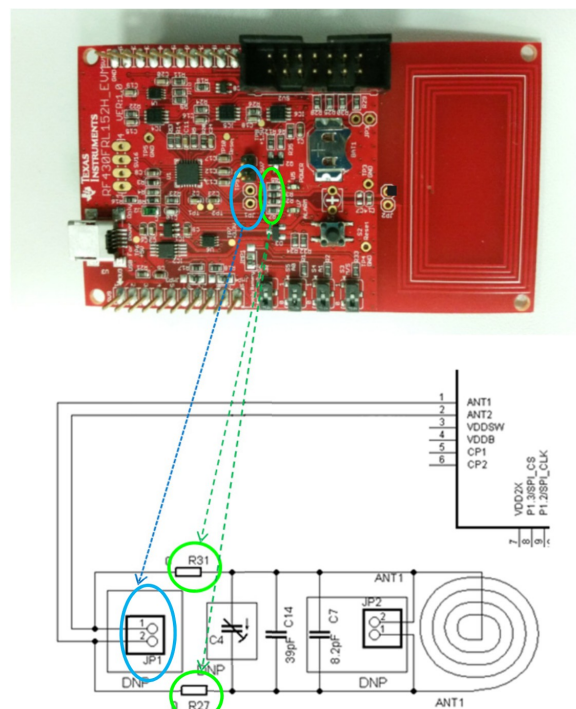

Figure 8. Evaluation Module Antenna Connection

5.4 Antenna Resonance Circuit

Figure 9 shows the basic input circuit of the RF430FRL15xH. The (onboard) antenna (L) with the internal parallel capacitor (C_{INT}) generates a resonance circuit at the desired frequency.
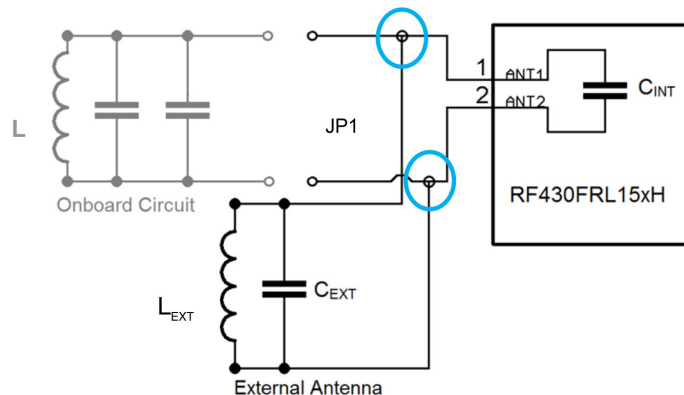

Figure 9. EVM Antenna Connection

If an external antenna is used, L_{EXT} is connected at JP1 on the RF430FRL152HEVM as described in Section 5.3. If there is no intention to use external capacitance C_{EXT}, the inductance of the coil has to be chosen as described in Section 5.2.

Depending on the antenna inductance, an additional external resonance capacitor C_{EXT} may be added parallel to L_{EXT}. When calculating the corresponding C_{EXT} value, the internal capacitance C_{INT} has to be taken into account. The sum of the parallel capacitors is the value for the total resonance capacitance.

$$C_{res} = C_{INT} + C_{EXT}$$

During the development phase, it is recommended to use an external adjustable (trimming) capacitor for fine-tuning. This will help to eliminate component tolerance and board parasitics. For production, the value of this variable capacitor can be measured and replaced by an external fixed capacitor with the same value (or combination of several capacitors).

The recommended operating resonance frequency (f_{res}) is about $f_{res} \approx 13.7$ MHz for optimal performance according to Section 8. For stable operation, make sure that the resonance frequency, including all of the tolerances, stays between 13.56 MHz and 13.7 MHz. Using resonance circuits tuned outside of that range results in performance degradation.

Figure 10 shows the inductance and capacitance values to generate resonance at 13.7 MHz.
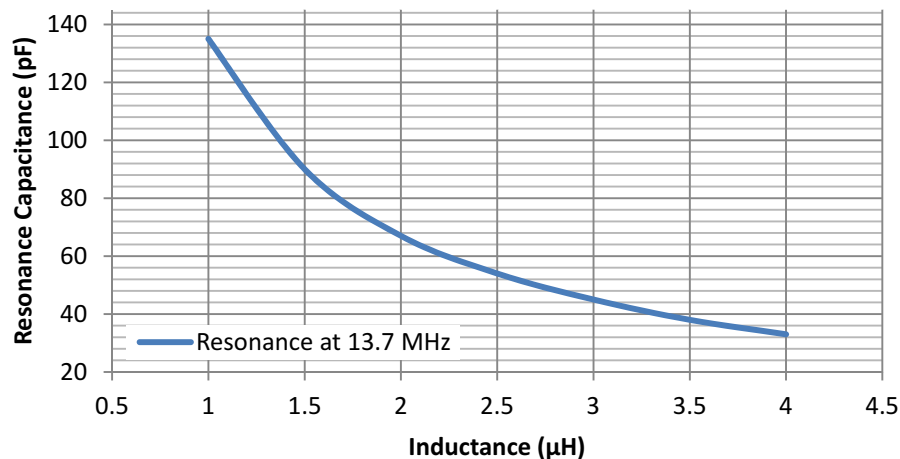
Figure 10. Inductance vs Resonance Capacitance Values

The passive quality factor (Q) of the resonance circuit should be Q < 50. In case of a higher Q, an external resistor parallel to the inductor L_{ext} can be added to reduce Q. A suitable value could be in the range of 10 kΩ to 20 kΩ.

Note: In this document, parasitic capacitances from the layout and the connections are not considered.

6 Reading Performance With Different External Antennas

Depending on the application, the antenna size may be restricted. To give an overview of how different antenna sizes can change the performance of the system, some example measurements of the reading distance are given.

The TRF7970A EVM, a fully integrated NFC/RFID transceiver with an onboard PCB antenna, is used as reference reader (http://www.ti.com/tool/trf7970aevm) (see Figure 11).
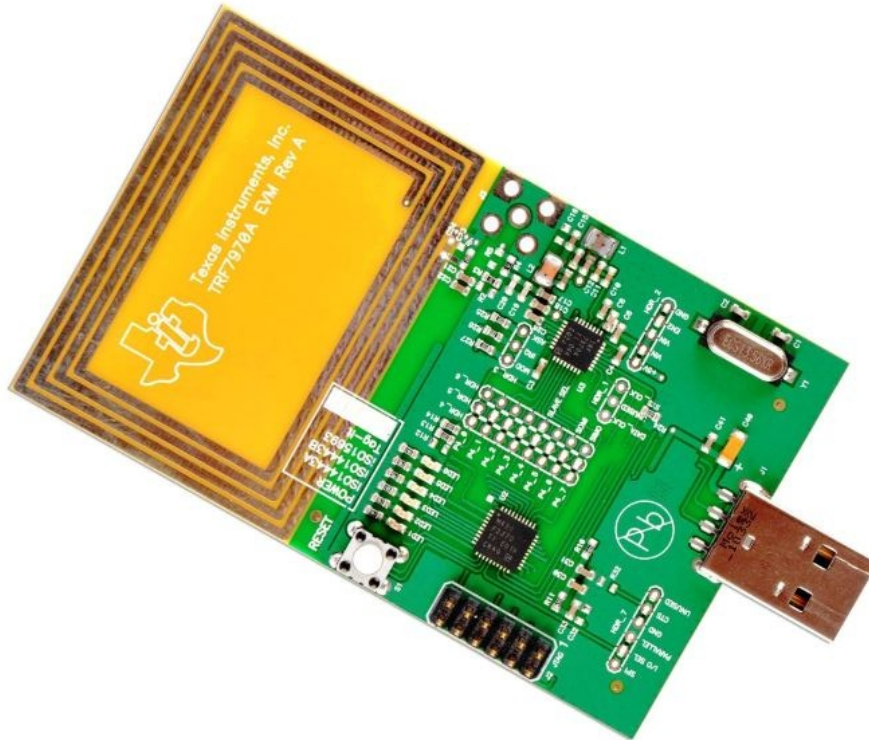

Figure 11. TRF7970A EVM, Reference Reader

Figure 12 through Figure 14 show the different antennas that were used on the RF430FRL15xH side.
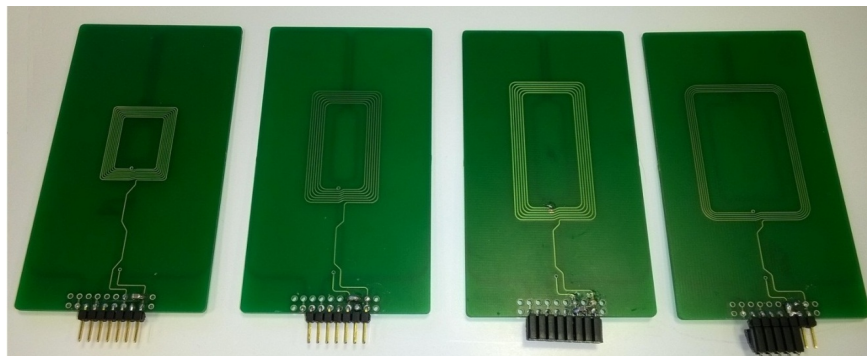

Figure 12. ISO Class 6, ISO Class 5, ISO Class 4, ISO Class 3 Antennas

Figure 13. 3DC15HF-0003K and SDTR1103-HF2-0002K Premo Coils

Figure 14. 3D15 (88 8035 82) and MS32 ka (88 8036 10) Neosid Coils

The antennas were tuned to a resonance frequency of f_{res} = 13.7 MHz in all cases using external tuning capacitors parallel to the inductors. Table 4 lists the inductances and the corresponding capacitance values to achieve 13.7-MHz resonance.

Table 4. Tuning Capacitor Values

Antenna	Inductance	Total Resonance Capacitor
ISO Class 3	2.4 µH	56 pF
ISO Class 4	2.4 µH	56 pF
ISO Class 5	2.4 µH	56 pF
ISO Class 6	2.4 µH	56 pF
SDTR1103-HF2-0002K	2 µH	68 pF
3DC15HF-0003K	3 µH	45 pF
3D15 (88 8035 82)	3.25 µH	41 pF
MS32 (88 8036 10)	2.1 µH	64 pF

Table 5 lists the performance results using TRF7970AEVM as reference reader. The communication distance described in Table 5 and Table 6 gives the range at which the reader and the tag can communicate and exchange data. The charging distance is larger. Place the reader and the tag antenna parallel to each other for the best performance.

Table 5. Maximum Communication Distance

RF430FRL152H External Antenna	Maximum Communication Distance (cm)
RF430FRL152H EVM (onboard antenna)	9.5
ISO Class 3	6.5
ISO Class 4	7.5
ISO Class 5	8
ISO Class 6	8.5
3DC15HF-0003K	4.5
SDTR1103-HF2-0002K	3.5
3D15 (88 8035 82)	5
MS32 (88 8036 10)	3.5

NFC enabled mobile phones can also be used to read the RF430FRL15xH. Table 6 lists the reading distances using different mobile phones and the RF430FRL15xH with an external ISO Class 6 antenna.

Table 6. Mobile Phones Communication Distance Using RF430FRL15xH With ISO Class 6 Antenna

NFC Enabled Mobile Phone	Communication Distance (cm)
Nokia Lumia 830	3
HTC One M8	2.5
Samsung Galaxy S3	3.5
Samsung Galaxy S5	4

7 Antenna Quality Factor

7.1 Basics

The quality factor of a resonance circuit antenna gives a quantification of how well the antenna behaves in the frequency spectrum given its resonance frequency. A higher Q factor results in a narrow band behavior. If the operational band of the antenna is too narrow (high Q), information can no longer be received or transmitted due to the limited bandwidth (BW) and communication MAY fail. On the other hand, if the operational band is too wide (low Q), the system performance decreases due to lower RF field leading to lower power supply and communication fails caused by noise due to large BW.

The antenna Q factor can be calculated using the following formulas:

$$BW_{3dB} = f_2 - f_1$$

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

where

- BW_{3dB} is the 3-dB bandwidth of the antenna
- f_2 is the upper frequency
- f_1 is the lower frequency
- f_{res} is the desired resonance frequency (in this case, f_{res} = 13.7 MHz).   (2)

7.2 Setup and Measurement

To calculate the Q Factor, the resonant frequency and bandwidth must be measured. That can be done using a spectrum analyzer with tracking generator (such as the R&S FSP) in combination with a special text fixture. The test fixture should consist of a pickup coil connected to the input of the spectrum analyzer and a larger coil connected to the output of the spectrum analyzers tracking generator as shown in Figure 15.

Spectrum analyzer setup:

- All measurements must be done with the antenna connected to the rest of the system (including the evaluation board and IC). Otherwise, internal and parasitic capacitance are ignored.
- Connect test fixture to analyzer. In Figure 15, connect the large coil (red connector) to output of tracking generator, and connect the small pickup coil (blue connector) to the input channel.
- Place the device under test (DUT) on top of the fixture and center and align it horizontally to the pickup coil.
- Enable tracking generator output, center to the expected inlay frequency (13.6 MHz) with a span in the range of 1 to 5 MHz. If there is no resonance curve to be seen, adjust the span and reference level. A vertical scale of 1 to 3 dB/div is recommended.
- Use markers to determine and measure the 3-dB bandwidth of the resonance curve. (–3 dB from the resonance peak in both negative and positive f-direction).
- The quality factor can now be calculated using the formulas in Section 7.1. See Section 7.3 for an example.

NOTE: Temperature, humidity, and proximity of metals or organic materials affect the resonant frequency and Q of antennas.
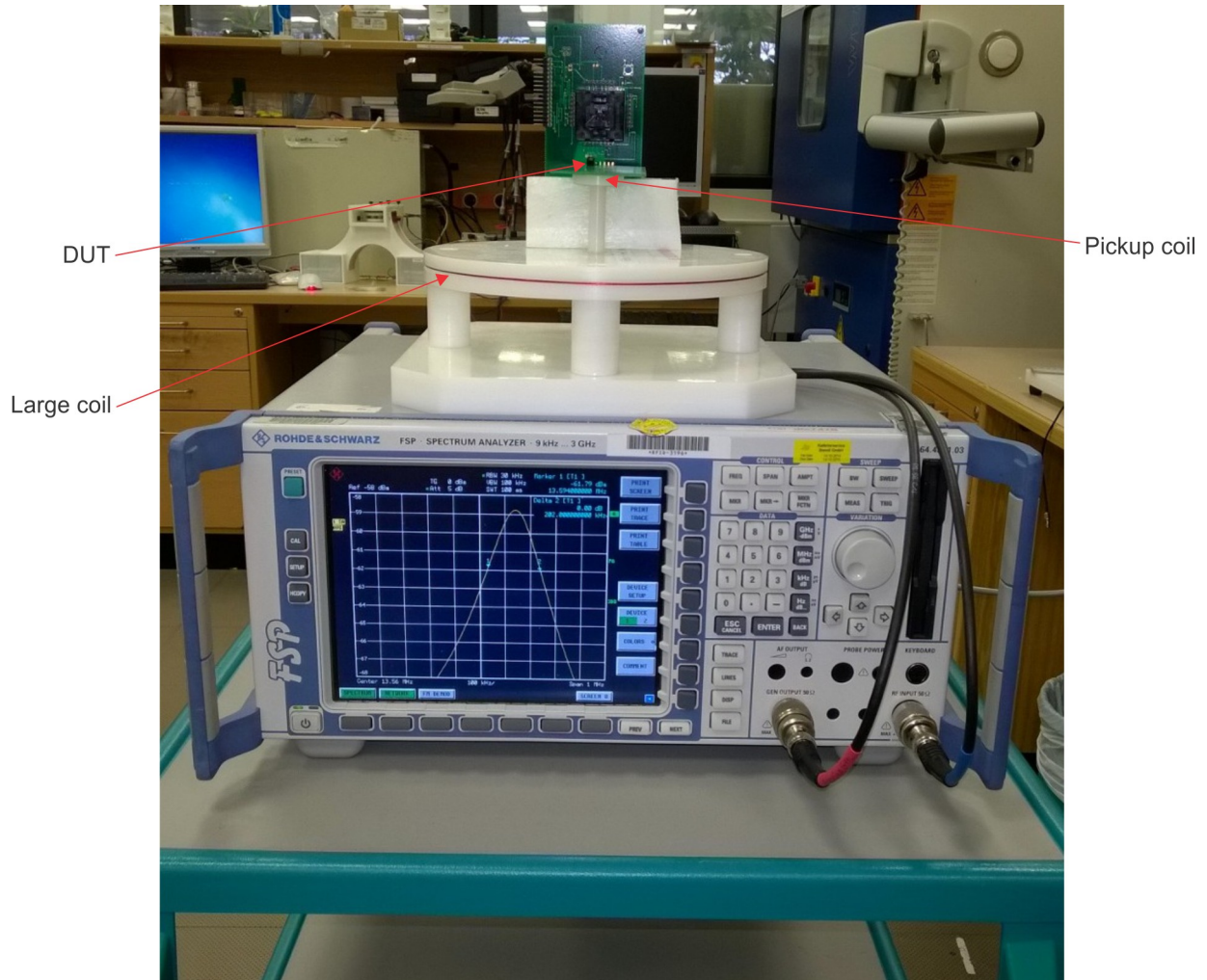

Figure 15. Resonant Frequency and Q Factor Measurement Setup
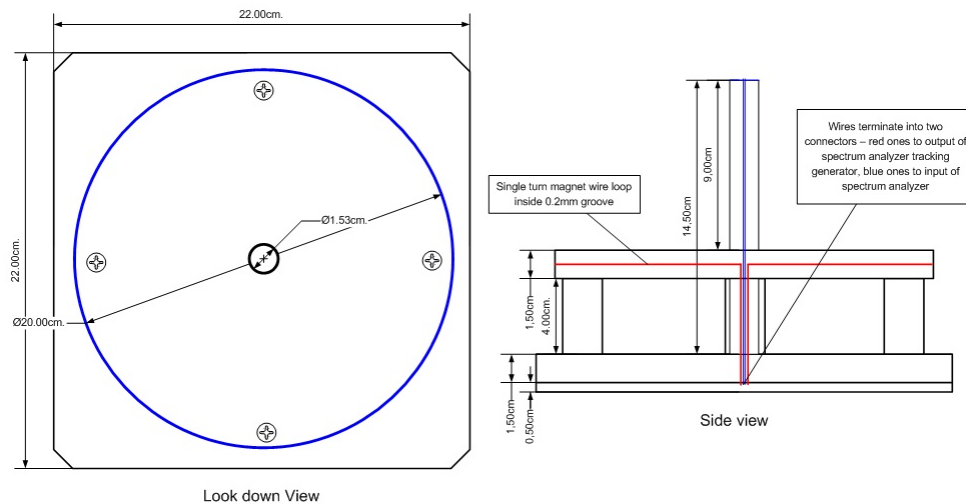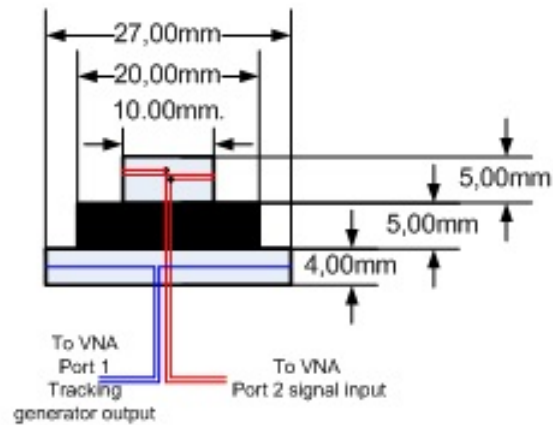
7.2.1 Test Tool

Figure 16. Test Tool

Figure 17. Small Test Tool (optional)

7.3   *Example*

The values that Figure 18 shows are:

f_1 = 13.594 MHz

f_2 = 13.796 MHz

BW_{3dB} = f_2 − f_1 = 202 kHz

Alternatively, set the marker settings to read the delta between them directly.

With our resonance frequency given as f_{res} = 13.7 MHz, the quality factor of the antenna (or DUT) is:

$$Q = \frac{f_{res}}{BW_{3dB}} = \frac{13.7 \text{ MHz}}{202 \text{ kHz}} = 67.8$$
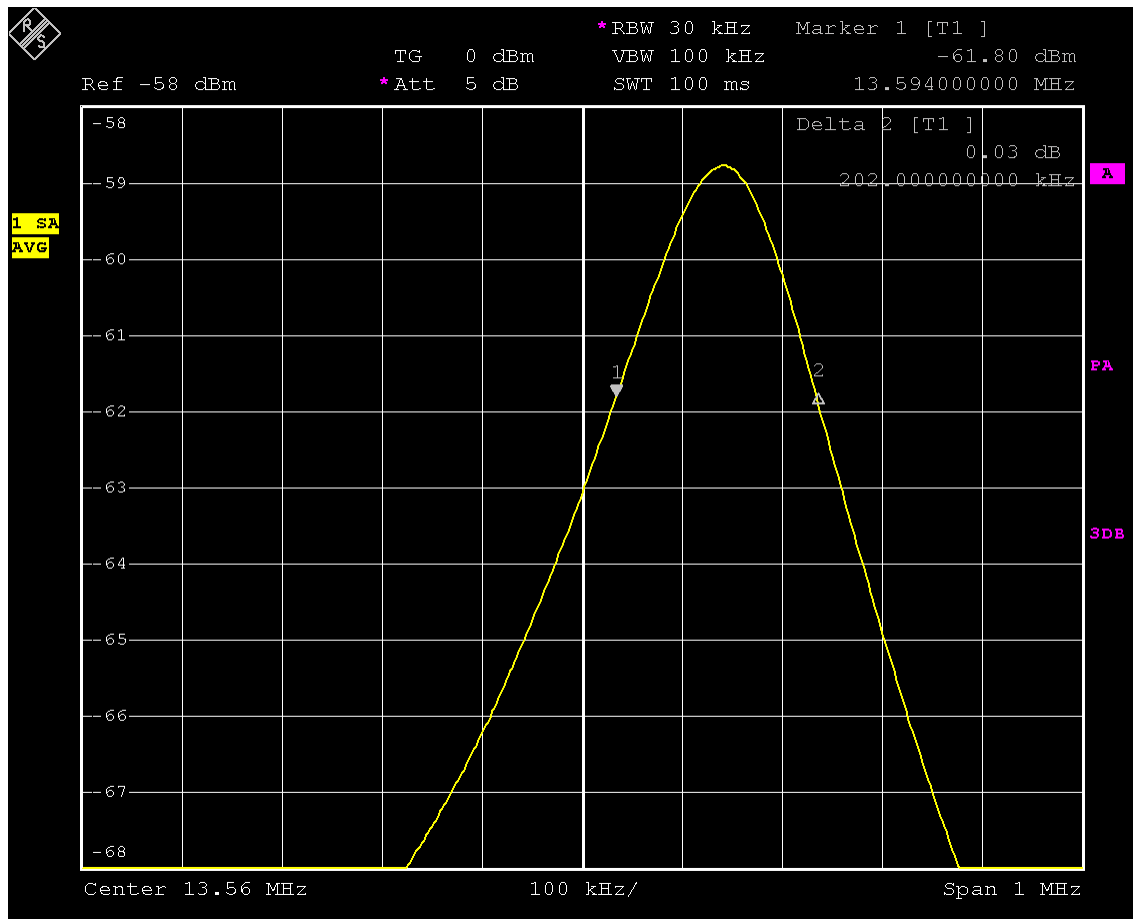
(3)

Figure 18. Antenna Q-Factor Measurement

8   Resonance Frequency Detuning

The resonance frequency (in combination with a stable quality factor) should be tuned for the best communication distance between the reader and the transponder. Variations of the resonance frequency will cause performance degradation.

The variations normally come from the tag's internal capacitor tolerances, antenna parameters, connections and external influences such as metallic or organic objects in close proximity.

Table 1 gives the internal resonance capacitor tolerances of the RF430FRL15xH IC. For practical reasons, it is recommended to compensate all the tolerances using an external capacitor connected between ANT1 and ANT2. During the development phase, an adjustable capacitor can be used to fine tune to achieve a maximum communication distance. This capacitor can be replaced with a fixed value for the final product. It is difficult to compensate the resonance frequency variations caused by unpredictable external influences in advance as these are not known. In these cases a special antenna design may be used to reduce the influences.

Figure 19 shows an example of influence of a detuned ISO Class 6 antenna on the RF430FRL152H tag over the communication distance using the NFC Reader TRF7970AEVM.
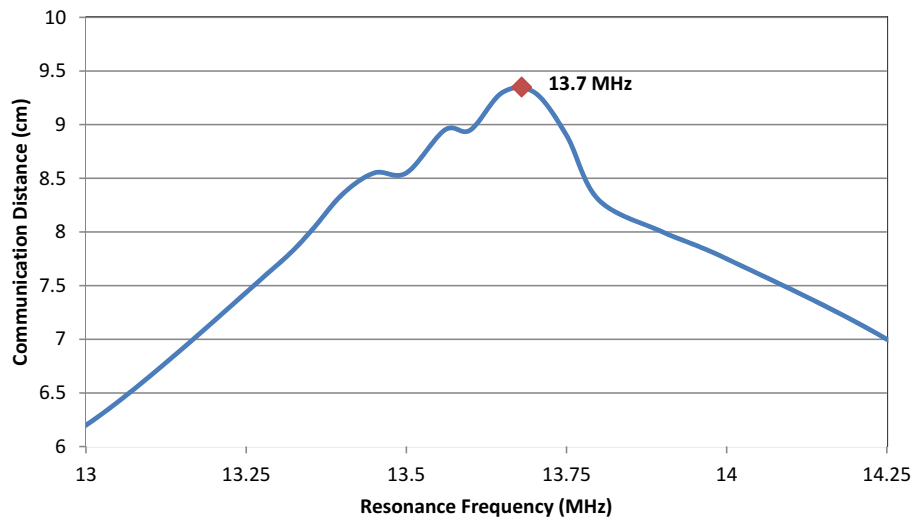
Figure 19. Communication Distance vs Resonance Detuning

9 Rectangular Antenna Inductance Calculation Examples

Calculation of the antenna inductance is very complex. For engineering purposes, there are some simplified formulas that use certain assumptions to get a good estimation of the inductance. There are various simplified formulas with different assumptions. These assumptions must be considered when choosing the formula.

Figure 20. Rectangular Antenna Coil

Equation 4 [1] estimates the inductance value of a rectangular coil such as Figure 20 shows.

$$L := N^P \times \frac{u0}{\pi} \times \left[-2(w+h) + 2\sqrt{h^2+w^2} - h \times \ln\left(\frac{h+\sqrt{h^2+w^2}}{w} \right) - w \times \ln\left(\frac{w+\sqrt{h^2+w^2}}{h} \right) + h \times \ln\left(\frac{2 \times h}{a} \right) + w \times \ln\left(\frac{2 \times w}{a} \right) \right]$$

(4)

Where,

N = Number of turns

w = Average width of the rectangle

h = Average height of the rectangle

hout = Outer height

wout = Outer with

hin = Inner height

win = Inner width

a = Trace width

μ0 **=** Permeability of the medium

P = Correction factor

[1] From http://emclab.mst.edu/inductance/rectgl/

Best experience using the average values for the parameters w and h (see Figure 21). It is calculated as:

$$h := \frac{hout - hin}{2} \qquad w := \frac{wout - win}{2}$$

(5)

The correction factor P is given in the literature as:

Wired: 1.8 to 1.9

Etched: 1.75 to 1.85
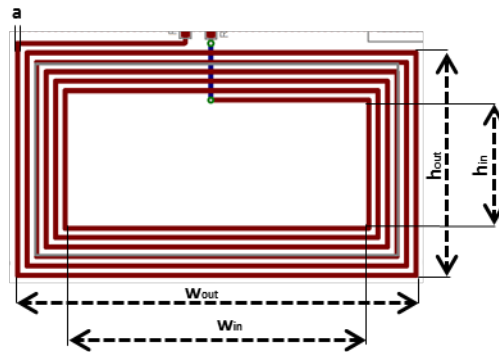
Printed: 1.7 to 1.8

Further antenna calculation methods can be found on various websites including:

http://emclab.mst.edu/inductance/rectgl/

http://emclab.mst.edu/inductance/

Figure 21. Antenna Geometry

9.1 RF430FRL152H EVM Onboard Antenna

The following example shows the calculation for the RF430FRL152HEVM onboard antenna (see Figure 22).
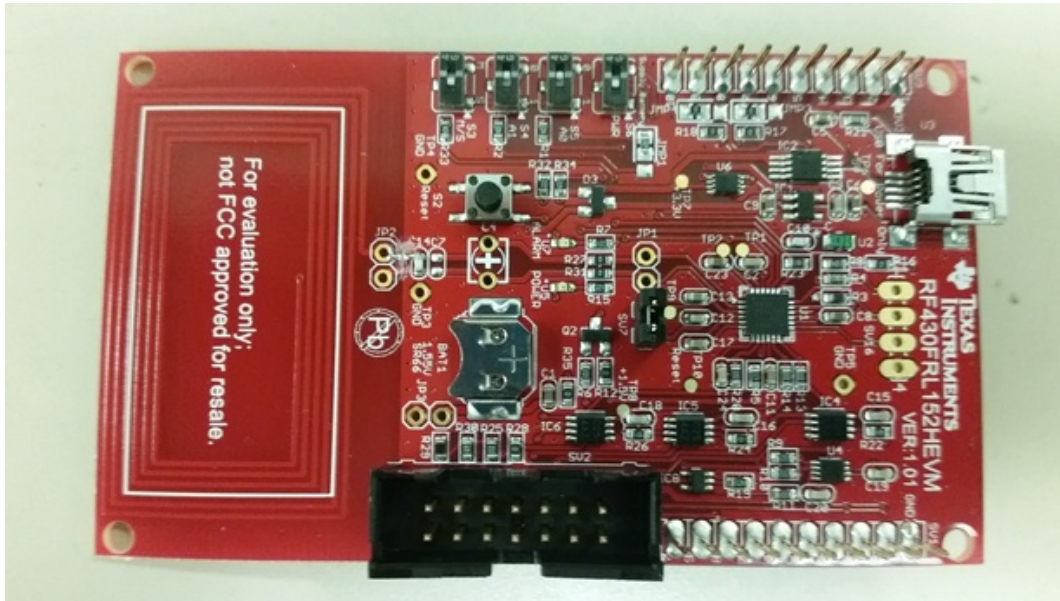

Figure 22. RF430FRL152H EVM

N: 6

w: 37 mm

h: 19 mm

hout: 25 mm

wout: 43 mm

hin: 13 mm

win: 31 mm

a: 0.5 mm

P: 1.8

Measured L = 1.8 µH

Calculated value with **P = 1.8**

$$L := N^P \times \frac{u0}{\pi} \times \left[-2(w+h) + 2\sqrt{h^2+w^2} - h \times \ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right) - w \times \ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right) + h \times \ln\left(\frac{2\times h}{a}\right) + w \times \ln\left(\frac{2\times w}{a}\right) \right]$$

$$L = 1.776 \times 10^{-6} \tag{6}$$

9.2 ISO10373-6 Reference Antenna Class 1

The following example shows the calculation for an ISO Class 1 antenna (see Figure 23).

Figure 23. ISO 10373-6 Reference Antenna Class 1

N: 4

w: 69 mm

h: 39 mm

hout: 42 mm

wout: 72 mm

hin: 36 mm

win: 66 mm

a: 0.5 mm

P: 1.9

Measured L = 2.3 µH

Calculated value with **P = 1.9**

$$L := N^P \times \frac{u0}{\pi} \times \left[-2(w+h) + 2\sqrt{h^2+w^2} - h \times \ln\left(\frac{h+\sqrt{h^2+w^2}}{w} \right) - w \times \ln\left(\frac{w+\sqrt{h^2+w^2}}{h} \right) + h \times \ln\left(\frac{2 \times h}{a} \right) + w \times \ln\left(\frac{2 \times w}{a} \right) \right]$$

$$L = 2.307 \times 10^{-6} \tag{7}$$

9.3   *ISO 10373-6 Reference PICC 6 Antenna*

The following example shows the calculation for an ISO Class 6 antenna (see Figure 24).
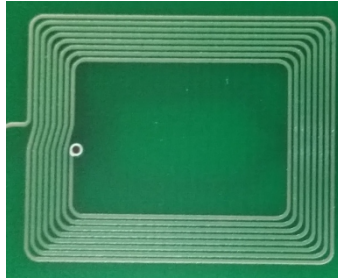

Figure 24. ISO 10373-6 Reference Antenna Class 6

N: 8

w: 69 mm

h: 39 mm

hout: 19.5 mm

wout: 24.5 mm

hin: 13.5 mm

win: 18.5 mm

a: 0.3 mm

P: 1.85

Measured L = 2.3 µH

Calculated value with **P = 1.85**

$$L := N^P \times \frac{u0}{\pi} \times \left[-2(w + h) + 2\sqrt{h^2 + w^2} - h \times \ln\left(\frac{h + \sqrt{h^2 + w^2}}{w} \right) - w \times \ln\left(\frac{w + \sqrt{h^2 + w^2}}{h} \right) + h \times \ln\left(\frac{2 \times h}{a} \right) + w \times \ln\left(\frac{2 \times w}{a} \right) \right]$$

$$L = 2.282 \times 10^{-6} \tag{8}$$

9.4   *Temperature Patch Application Example*

In this application example, the RF430FRL152H is used as a temperature sensor. It is mounted on a small (3-cm diameter) round PCB that includes all external capacitors necessary for operation as well as a printed inductor loop used as antenna (see Figure 25). To measure the temperature, the RF430FRL152H gathers information from an external temperature sensor. For more information, refer to the application report *Battery-Less NFC/RFID Temperature Sensing Patch* (SLOA212).
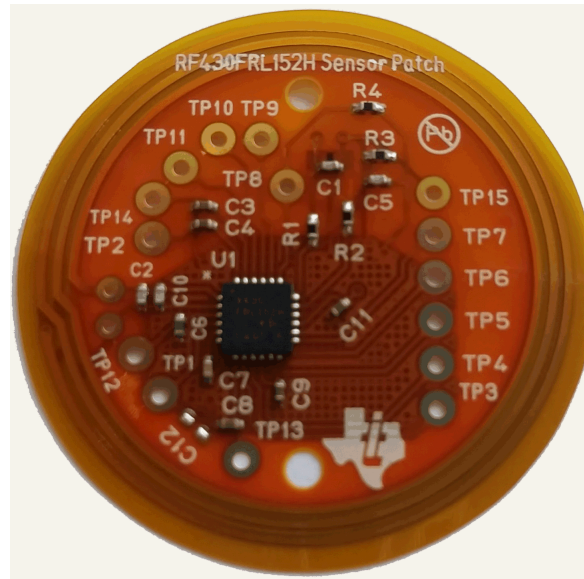

Figure 25. Temperature Patch

Using the TRF7970A EVM as reader device, the maximum reading distance is 8 cm.

Equation 9 (from http://emclab.mst.edu/inductance/circular/) estimates the inductance of a small circular coil.

$$L = N^2 * R * \mu o * \mu r \ [\ln\left(\frac{(8R)}{w+t}\right) - 2]$$

(9)

Where,
  L = Inductance
  N = Number of turns = 5
  R = Radius of coil = 15 mm
  μo = Electromagnetic permeability = 1.2566370614…×10^{-9} H/mm
  μr = Relative permeability = 0.9996
  w = Trace width = 0.540 mm
  t = Trace thickness = 0.035 mm

The calculated and measured inductance values of the temperature patch antenna (Figure 25) are:

$$L = 5^2 * 15 * 1.2566 * 0.9996 \left[\ln\left(\frac{(8*15)}{0.540+0.035}\right) - 2\right] * [H]$$

(10)

L =1565.432 * 10^{-9} [H]

(11)

Calculated value: L = 1.56 μH

Measured value: L = 1.49 μH
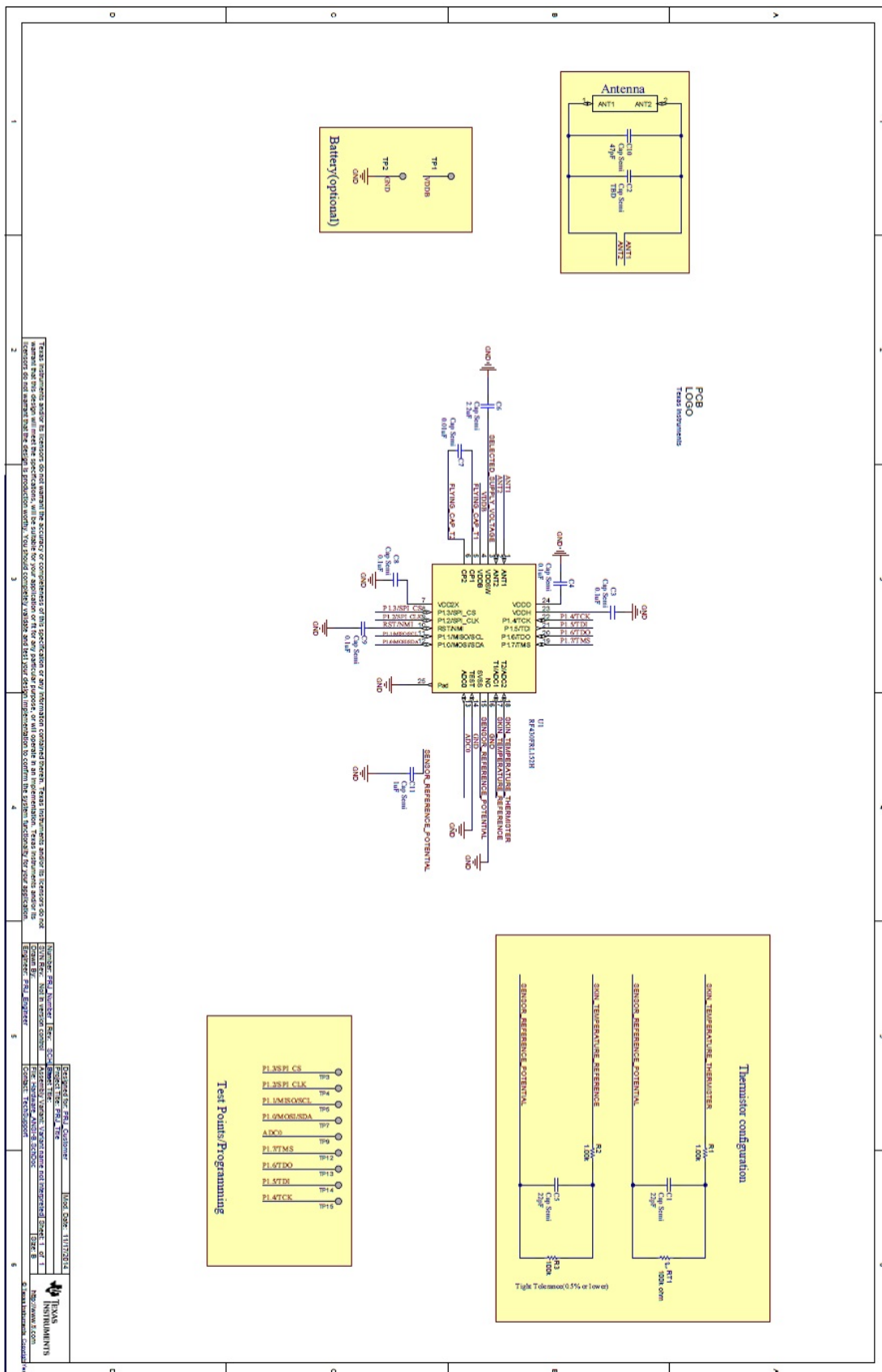
Figure 26. Temperature Patch Board Schematic

9.5 Antenna References

Neosid Pemetzrieder GmbH & Co. KG (http://www.neosid.de)
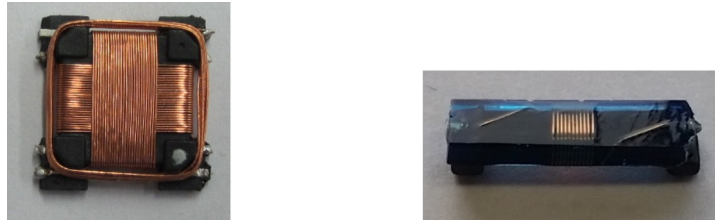

Figure 27. Neosid 3D15 (88 8035 82) and MS32 (88 8036 10)

Premo (http://www.grupopremo.com)

https://www.grupopremo.com/en/548-nfc-antennas

Figure 28. Premo 3DC15HF-0003K and SDTR1103-HF2-0002K

Revision History

Changes from April 30, 2015 to July 20, 2015   **Page**

- In Table 4, *Tuning Capacitor Values*: changed column heading from "Add External Capacitor" to "Total Resonance Capacitor"; switched "3DC15HF-0003K" and "SDTR1103-HF2-0002K" in first column...................................... 11
- Replaced Figure 25, *Temperature Patch*, with a new image 21
- Deleted former Figure 26, *Temperature Patch Board Layout*; renumbered all following figures............................ 21
- Added calculation for antenna inductance (from the paragraph that starts "Equation 9 shows how to calculate..." through "Measured value: L = 1.49 μH") 21

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have *not* been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		