NOWTrak™ RFID Antenna Theory of Operation
and Specification for 50Ω Matched Antenna
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Introduction:

This document will explain the Theory of Operation of a mifare® 50Ω Matched Remote Antenna. Additionally, this document will specify what the final operating requirements of the Antenna will be and give some practical examples of the elements used in successful antennas.

Theory of Operation:

The mifare® System transmits energy to the Passive RFID TAG via the Transformer Principle. A changing magnetic field created via the Operating Frequency of 13.56 MHz, induces power into the coupled Passive TAG. When the Passive TAG is sufficiently close to the Antenna to be coupled with enough energy, the TAG Powers-up and is clocked with the 13.56 MHz Carrier Frequency from the Antenna. At this point, there exist two points, (the Reader Antenna, and the TAG), which can transmit and receive communication with each other.

The Communication Structure is a Half Duplex, (only one side communicates at a time), Reader-Talks-First, (RTF), arrangement.

Antenna to TAG Communication:

The communication from the Antenna to the TAG is accomplished using 100% Amplitude Shift Keying, (ASK), Pulse-Pause Modulation with a Modified Miller Coding. The Data Transmission takes place @ 1/128 of the 13.56 MHz Carrier Frequency, (105.9 kHz, 105,937.5 Hz). At this Data Transmission rate, each Bit Frame is 9.44 μsec long. The Modification of the Miller Coding ensures maximum energy transmission to the TAG during Communication Modulation.

TAG to Antenna Communication:

The communication from the TAG back to the Antenna is accomplished using the principal of Load Modulation. The change in the Load, (energy consumption) of the TAG as it transmits can be picked up as a change in the Reactive Effect of the Coupling. This effect can be used to communicate from the TAG to the Reader. The TAG generates the Sub-

Carrier Frequency of 1/16 the Carrier Frequency, (847.5 kHz). The TAG uses Both Side Bands, (Double Side Bands), which results in increased robustness in the TAG to Antenna Half of the communication. These two Side Bands appear @ (13.56 MHz – 847.5 kHz) and (13.56 MHz + 847.5 kHz), (12.71 MHz and 14.41 MHz respectively). The Manchester Coded Bit Frame consists of 8 cycles of the Sub-Carrier Frequency, (8 x 1/847.5 kHz = 9.44 μsec). This Bit Frame length translates to the same Data Transmission Rate, (105.9 kHz), as the Antenna to TAG Half of the communication. It is the TAG to Antenna Half of the communication that demands a very well designed Receiving Circuit to enjoy overall design robustness.

RFID Transponder (Tag):

The RFID Transponder exists in a thin Disk shaped (Button) embodiment. The Tag requirements are as listed below:

RFID Specifications:

1. 13.56 MHz Frequency Operation
2. 1 kByte Nominal Memory (736 Bytes useable)
3. 6 mm Nominal Read Range when coupled with properly designed antenna
4. mifare® compatible design or equivalent

Physical Size:

7 mm maximum disk diameter
2 mm maximum disk thickness

Remote Antenna:

The Remote Antenna must be a cylindrical configuration with the below listed features:

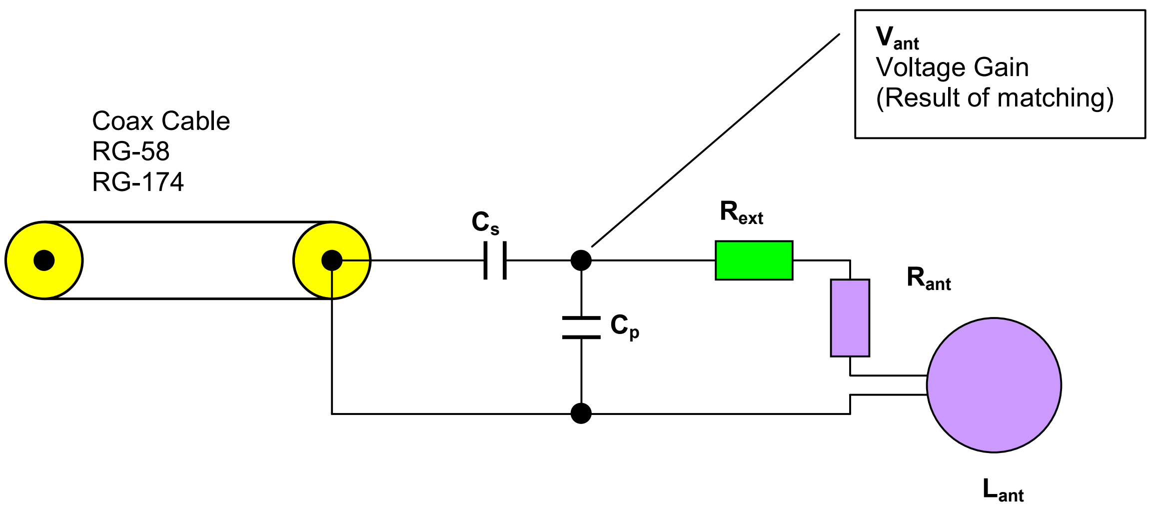
RFID Electrical Specifications:

1. 13.56 MHz Magnetically Coupled Operation
2. 6 mm Nominal Read Range
3. Connectable to Reader Board via 50Ω Impedance “Radio Guide”, (RG), cable ranging in length from 1m to 30m.
4. Convenient and Field Terminable Connection, (SMA Preferred)
5. Bi-Polarity Status LED on top of cylinder for ease of display. Green color in forward polarity, red in reverse

Physical Size:

1. 12mm Nominal Threaded Barrel for present upgrade capability
2. 1mm Thread Pitch
3. 30mm maximum cylinder length
4. Cable potting must be Strain Relieved and esthetically pleasing

Below is a schematic of the Antenna Elements required for a 50Ω Remote Antenna:



There are 5 Basic 50Ω Remote Antenna Elements:

- Coaxial Cable
- Series Capacitor C_s
- Parallel Capacitor C_p
- External Resistance R_{ext}
- Antenna Coil (L_{ant} and R_{ant})

Design Step Chronology:

1. Select/Design Antenna Coil with correct geometric parameters

Use Equation Aid:

$$L_{ant} = 2 \bullet l_1 \left[\ln\left(\frac{l_1}{D_1}\right) - K \right] N_1^{1.8}$$

where:

L_{ant} = Antenna Coil Inductance (nH)
l_1 = Length of one Loop of Antenna Coil (cm)
D_1 = Effective Diameter of Conductor in Antenna Coil (cm
K = 1.07 for Circular Antennas
N = Number of Turns of Antenna Coil
ln = Natural Logarithm Function

2. Empirically Measure L_{ant} and R_{ant} using Impedance Analyzer (e.g HP 4195)

3. Determine R_{ext} such that Antenna Quality Factor = 35

   Use Equation Aid:

$$R_{ext} = \frac{2\pi f L_{ant}}{Q} - R_{ant}$$

   where:

   Q = Antenna Quality Factor
   f = Carrier Frequency (13.56 MHz)
   R_{ext} and R_{ant} are Resistances in Ω's per Schematic above

4. Find C_p such that the Real Part of the Antenna Resonant Circuit, (Tank Circuit), Impedance, (Z_{tank}), is 50Ω.

   Use Equation Aid:

$$C_p = \frac{1}{(2\pi f)^2 L_{ant}} \bullet \left(1 - \sqrt{\frac{R_{ext} + R_{ant}}{Z_T}}\right)$$

where:

Z_T = Antenna Impedance = 50Ω (by Design Intent)
Other Variables as before

5. Find C_s such that it offsets completely the Imaginary Part of the Antenna Resonant Circuit Impedance, (Z_{tank}).

6. This will produce a Matched Antenna of Quality Factor Q = 35, with an Impedance of $50\Omega\angle 0^\circ$

50Ω Remote Antenna Examples:

Below is a Spreadsheet Layout of 5 Antennas design with different Coils ranging from 300 nH to 1500 nH:

The R_{ant} is a ratio of that from a known Antenna with R_{ant} increasing linearly as a function of the number or turns, (N_1).

	L (H)	Rant (Ohms)	Rext (Ohms)	Cp (F)	Cs (F)
L1	300.0E-9	0.10	0.630	403.7E-12	58.2E-12
L2	450.0E-9	0.15	0.945	260.8E-12	46.8E-12
L3	600.0E-9	0.20	1.261	190.4E-12	40.2E-12
L4	900.0E-9	0.30	1.891	121.0E-12	32.5E-12
L5	150E-8	0.50	3.151	67.0E-12	25.0E-12

All of the Antenna Sets from above, (L1, L2, L3, L4, and L5) have an Impedance $Z_T = 50\Omega\angle 0°$.

Due to the efficiency of matching the Antenna Load with the Source, we experience an Antenna Voltage Gain over the Supply Voltage V_s. The Gain is a result of the Voltage Divider:

$$V_{ant} = \frac{Z_{tank}}{Z_T} \bullet V_s$$

where:

- V_s = The Reader Board Antenna Circuit Supply Voltage
- V_{ant} = The Voltage across the Antenna and Parallel Capacitor
- Z_{tank} = Tank Circuit impedance
- Z_T = Antenna Total Impedance = 50Ω

The Table below shows the Gain as a function of the Coil Inductance:

	L (nH)	Ztank (Ohms)	Ztotal (Ohms)	Vant Gain (V)
L1	300	207.636	50.000	4.153
L2	450	255.952	50.000	5.119
L3	600	296.546	50.000	5.931
L4	900	364.437	50.000	7.289
L5	1500	471.737	50.000	9.435

How does this Gain help us? The Power the Antenna draws is the same over all of these Antennas because the Impedance is the same as seen by the point of connection to V_s. The other part of this design is to attempt to generate the greatest magnetic field to enhance the Read Distance.

The Magnetic Field in Amps/m is defined by:

$$H = \frac{N1 \bullet i_{ant}}{2 \bullet r}$$

where:

H = Magnetic Field Strength in (A/m)
N_1 = Number of Turns of Antenna Coil
i_{ant} = Current through Antenna Coil in (A)
r= Radius of Antenna Coil in (m)

We know the number of Turns to create the Antenna Coil from previous exercise. We know the geometric form factor (r). We can find the I_{ant} from knowledge of the V_{ant} Gain and Z_{ant}, which comes from the element values.

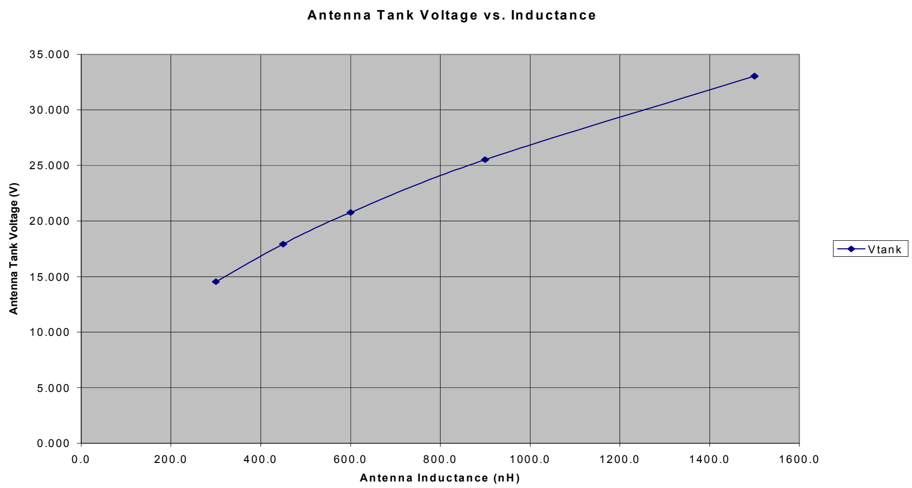
In the above Antenna Examples, the table of Coil Inductance as a function of Magnetic Filed Strength is shown below:

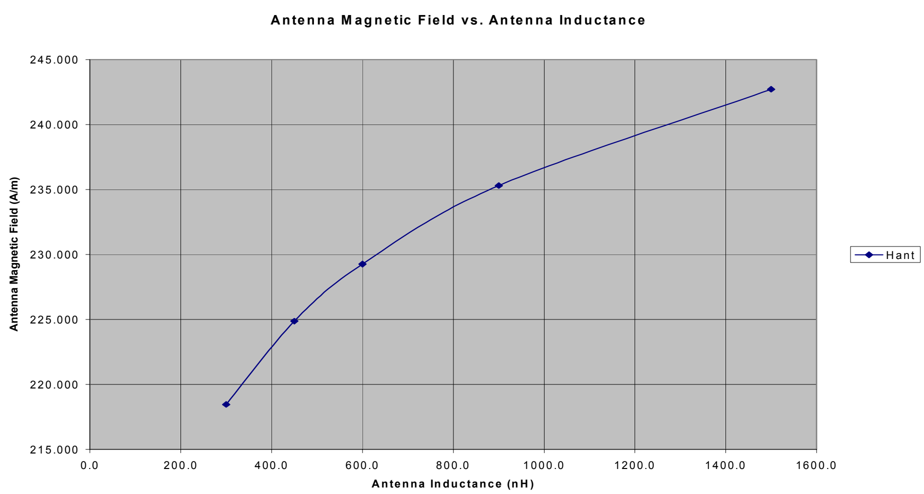
L (nH)	H (A/m)	fR (MHz)
300	218.000	14.460
450	224.000	14.690
600	229.000	14.890
900	235.000	15.240
1500	242.000	15.870

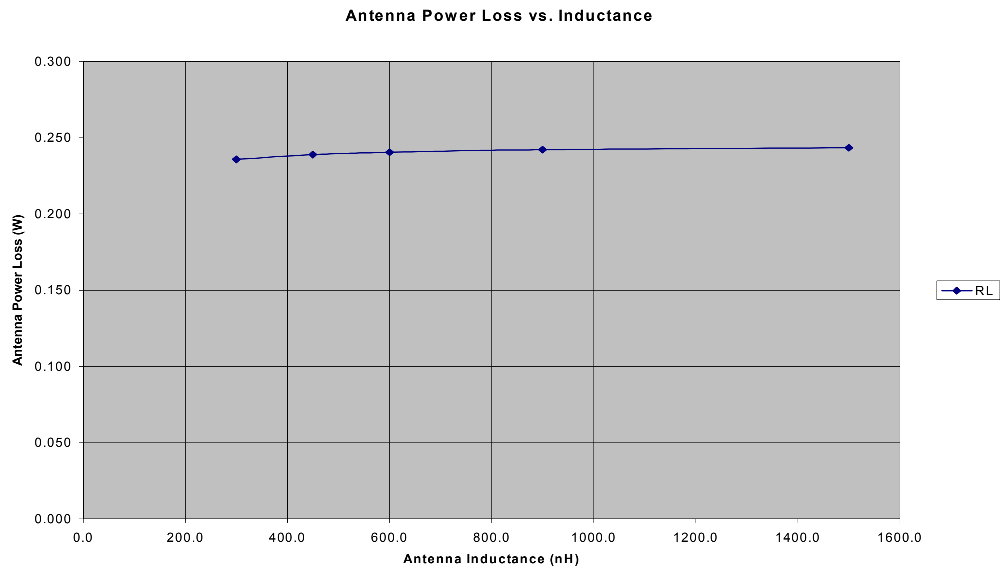
The Magnetic Field Strength goes up as the Antenna Coil Inductance goes up. Also shown above is the Tank Circuit Resonance Frequency. This also goes up as the Antenna Coil inductance goes up.

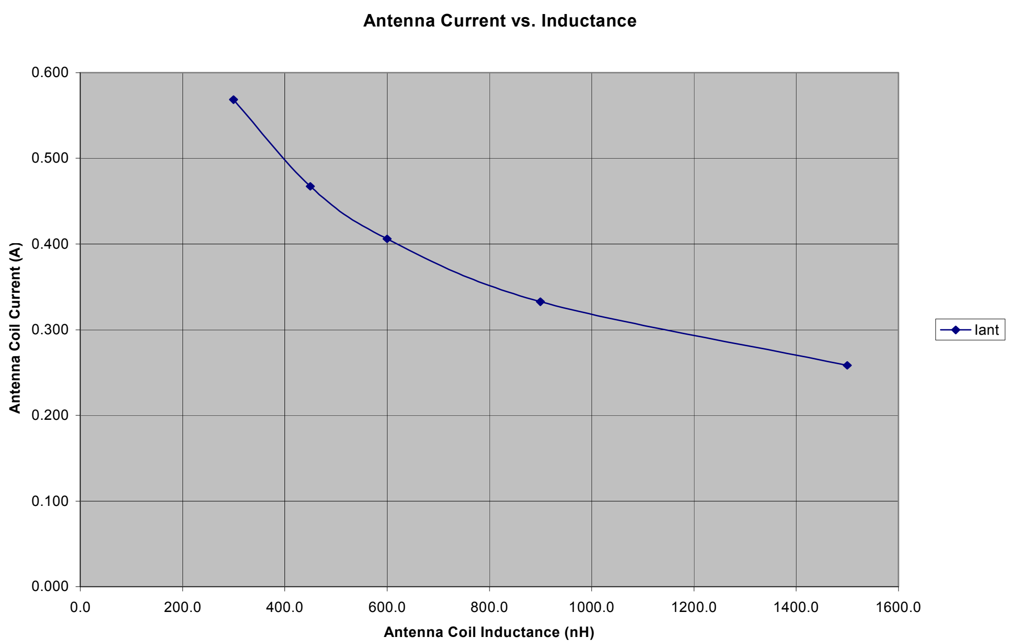
Subject to the designer, the optimum Antenna Coil Inductance must be selected. At the same Source Power Levels, it appears that the larger Antenna Inductance is preferred due to the increase in Magnetic Field Strength, unless the Higher Antenna Gain Voltages or the increase in Tank Resonant Frequency offset this gain. As is typical in engineering, some value of Antenna Coil Inductance is selected as a compromise of several factors.

To demonstrate some of the parameters from above examples in a graphical form, below are attached several interesting graphs of the Antenna Parameters as a Function of Antenna Coil Inductance:



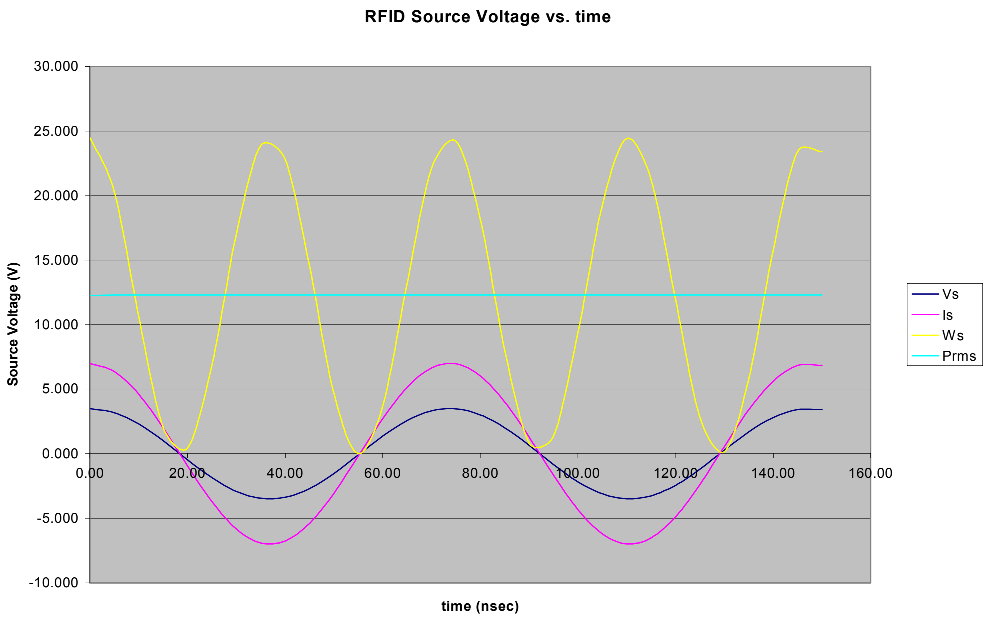



Antenna Power Loss vs. Inductance
Antenna Power Loss (W)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
Antenna Inductance (nH)
RL


Antenna Current vs. Inductance
Antenna Coil Current (A)
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
Antenna Coil Inductance (nH)
Iant

Notice again, that the Power is Constant, the V_s Gain increases, the Magnetic Field Strength increases, and the current through the Inductor drop as the Antenna Coil Inductance increases.

The graph below shows these Voltage, Current, and Power as function of time:



The magnitudes are skewed such that all parameters can appear on one graph.

The examples are presented to add extra substance to the design methodology steps. From above, the first and key step is to select a desired Antenna Coil Inductance with the correct geometry. From there, everything else is constrained by such parameters as the Quality Factor, the Total Impedance etc.

Once the Antenna Coil is selected, there are no remaining Degrees of Freedom. The designer doesn't have any other elemental decisions to make.

Antenna Basic Elements:

We saw the 5 basic Antenna Elements from the above schematic. Four of the five have been covered in terms of their design selection. The element, which has yet to receive attention, is the Antenna Transmission Cable. Below is a table of Antenna Cable Type versus Transmission Losses in dB, (decibels).

For review, recall that a Power decibel is just a Base 10 Logarithmic Ratio:

$$dB = 10 \bullet \log \frac{P_{out}}{P_{in}}$$

Gains in dB are described by positive decibels. Losses are described by negative decibels. In this manner, the Total Gains and Losses are added and subtracted instead of multiplied and divided, making the math easier, despite a tendency towards confusion with dB's. The Loss for the Cable is listed @ a Frequency of 13.56 MHz

Coaxial Cable Type	dB per 100 feet	Efficiency (%)
RG-58	-1.652	68.4
RG-174	-3.058	49.4

In this case, there is a penalty to pay for the smaller more manageable cable. The 68.4% efficiency of the RG-58 is consistent with early testing @ ATMI Packaging, Inc. over 100 ft. RG-174 will probably be adequate if the runs can be kept below 100 feet. The equivalent length of RG-174 for a 1.652 dB Loss is 54 feet, (1.652/3.058 x 100' = 54').

Previous testing shows that we would be OK to run 54 feet of RG-174 Coax Cable to the Remote Antenna. Final operation will be empirically determined.

NOWTrak™ 50Ω Antenna Design Specifications:

Mechanical Specifications:

- 12mm Diameter Threaded Cylinder x 1mm Pitch
- 1.6” in Overall Height
- Flats at top of Antenna Cylinder for Wrench Insertion
- SMA Coax Cable Termination to be Stain Relieved and Potted at Antenna Top
- Antenna Body to be constructed of ABS, or PBT, PE or other acceptable plastic

Electrical Specifications:

- $50\Omega\angle 0^\circ$ Impedance
- Coax Cable termination w/ SMA Connector
- Comply w/ FCC, CE and ISO 14443A

Functional Specification:

- Read Range of 6mm nominal, (+/- 2mm) w/ 8mm mifare™ Passive TAG