TEXAS INSTRUMENTS

Series 2000 **LF** Antenna Design Guide

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Radio Frequency Identification Systems

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Edition 1 – March 2003

This is the first edition of this **LF Antenna Design Guide**

It contains details on how to develop custom antennas for use with the following products:

RFM-003B, RFM-104B, RFM-007B, RFM-008B RF Modules and the MicroReader
(Note: The S2510 reader incorporates the RFM-007B)

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PREFACE

Read This First

About this Manual

This **LF Antenna Design Guide** Application Note **(11-06-21-068}** is written for the sole use by TI*RFID Customers who are engineers experienced with TI*RFID and Radio Frequency Identification Devices (RFID).

Regulatory and safety notes that need to be followed are given Section XX.

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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LF Antenna Design Guide

J.A.Goulbourne

Abstract

This document describes how to design and develop custom antennas suitable for attaching to Texas Instruments' Low Frequency (LF) Radio Frequency (RF) modules and readers. It looks at the matching circuits of the standard RFMs and details the antenna requirements for each one.

The issues of reader inductance and Q are examined, together with wire selection, tail construction and the use of external capacitance in bringing an antenna to resonance.

1 Why Custom Antennas may be Required

There are many reasons why custom built antennas may be required:

- special sized antennas are needed
- the antennas have to be built into structures/ equipment e.g. doors
- very large antenna are required e.g. road loops
- small antennas are needed (for localized reading).
- the antenna is for the microreader

A further reason may be to get increased read distance but the reader antenna is just one factor amongst many that dictates reading distance. In order of importance these factors are:

- The size and shape of the transponder's antenna.
- The size and shape of the reader's antenna
- The electrical noise in the environment
- The transmitter power (limited by legislation)
- Metal in the environment

Warning:

Increasing the antenna size doesn't automatically lead to an increase in a tag's reading performance – **it may reduce.**

The tag's signal must always be 6 dB stronger than any electrical noise to ensure a successful read.

As an reader's antenna size increases, more ambient noise is picked up and a tag may have to move closer to the antenna to make sure its signal is still the strongest.

Result – shorter reading distance

Texas Instrument' antennas are optimized and, size for size, a custom antenna design is unlikely to give a greater read range.

2 Standard Antennas

Because different RF Modules require antennas with different inductances, Texas Instruments have three categories of antennas available:

2.1 27 µH Inductance Antennas

These antennas are used with the RFM-104B, RFM-007B and RFM-008B RF modules.

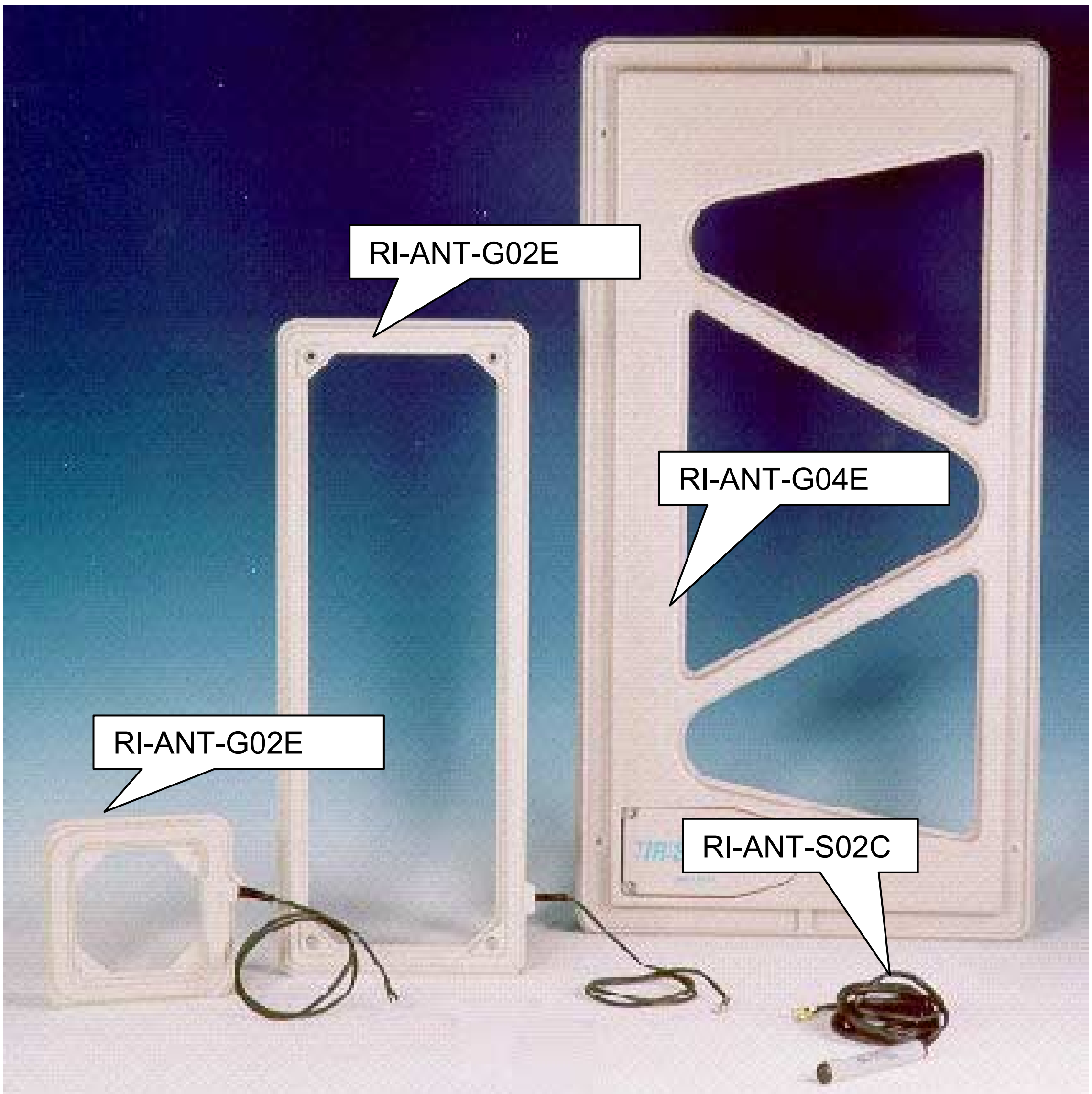

Figure 1. Standard Antennas

The RI-ANT-G01E, RI-ANT-G02E antennas have 1m tails and are nominally 27 µH and when connected to the appropriate RF Module can be tuned to resonate at 134.2 kHz. The RI-ANT-G04C antenna is provided with no tail and is nominally 26 µH. If 2.5 mm^2 (14 SWG) wire is used, a 4m (12') tail can be added and still be capable of being tuned to resonance.

Information:

The antenna tail is an integral part of the RF Module's matching circuit. Changing the length of the tail changes the performance. This topic is dealt with in a later section

2.2 47 µH Inductance Antenna

The MicroReader requires an antenna with a self inductance of 47 µH. The following antenna is available:

Figure 2. MicroReader Antenna (47 µH)

2.3 116 µH Inductance Antenna

The RFM-003B module requires an antenna with a self inductance of 116 µH and the following antenna is available:

Figure 3. Mini-RFM Antenna (116 µH)

Historically, the Mini-RF Module was intended for hand-held readers and so the antenna is supplied with a 100 mm (5”) tails.

3 Fine Tuning Antennas.

The antenna and feed cable are all part of an LC antenna matching circuit on Series 2000 readers. Changing any part has an impact on the total system, e.g. lengthening the feeder cable. Each module requires antennas of a certain Inductance to ensure the matching circuit is correct and, because of manufacturing tolerances, each antenna must be fine tuned in its final positions before a system is commissioned,. Each module has provision for this tuning.

3.1 Tuning to Resonance @ 134.2 kHz

Texas Instrument’s LF RFID system operates at 134.2 kHz and any antenna must be fine-tuned to resonate at that frequency for optimum performance.

$$f_{(134.2\ \text{kHz})} = \frac{1}{2\pi\sqrt{LC}} \qquad [1]$$

Equation [1] is the formula that determines at what frequency the antenna circuit resonates and you can see how either the Capacitance (C) or the Inductance (L) can be varied to arrive at the required frequency (f). Some RF modules tune to resonance by varying the capacitance, whilst the RFM-104B and the Remote Antenna Tuning Boards both vary the inductance.

3.1.1 The RFM-104B Module

The RFM-104B (standard) RF module is shown in Figure 4

Figure 4. The RFM-104B RF Module

RFM-104B modules use a variable inductor to fine tune antennas. A representation of the circuit is shown in Figure 5.

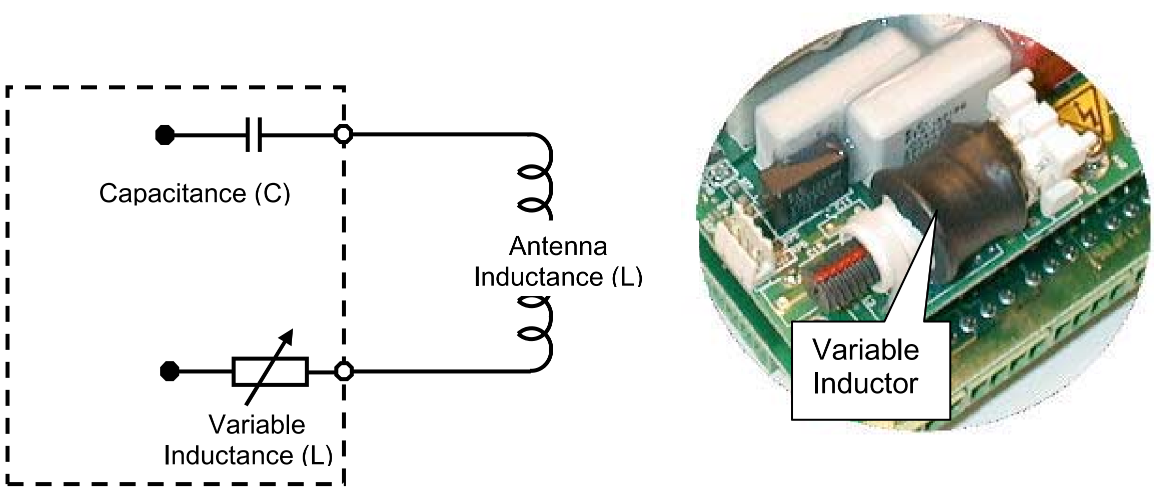

Figure 5. Inductance Fine-Tuning

3.1.2 RFM-003B and RFM-007B Modules

The RFM-003B (Mini-RFM) and the RFM-007B (Power RFM) are shown in Figure 6

Figure 6. RFM-003B and RFM-007B Modules

The RFM-003B and RFM-007B modules both use capacitance tuning (using jumpers) for the fine tuning. This circuit is represented in Figure 7.

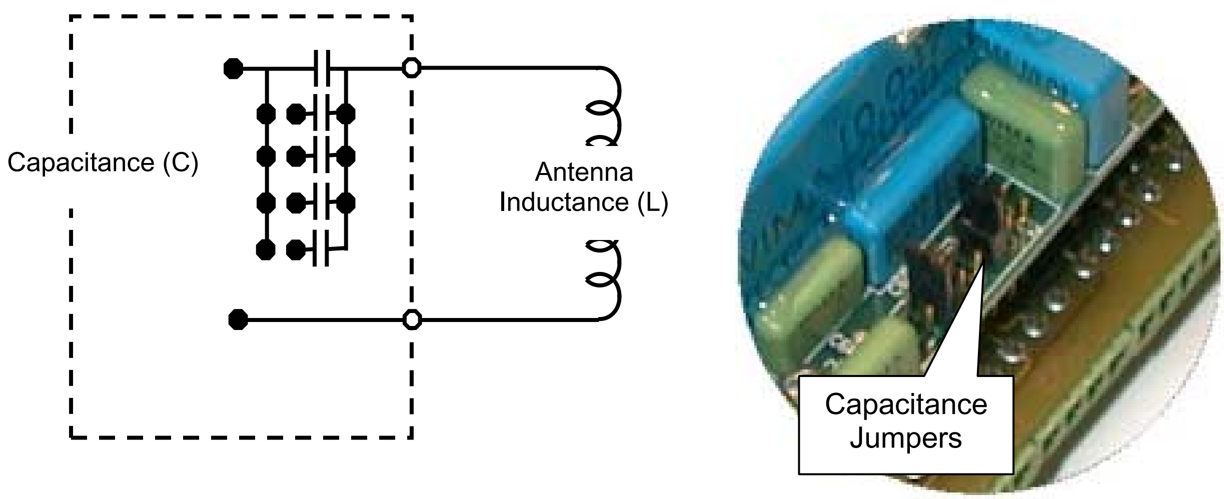

Figure 7. Capacitance Fine-Tuning

3.1.3 The RFM-008B Tuning Board

The RFM-008B (Remote Antenna) Module's resonant components have been taken off the RF Module and attached to a separate tuning board. In this way it is possible to have cable runs of up to 120 m (400') between the RF Module and the tuning board.

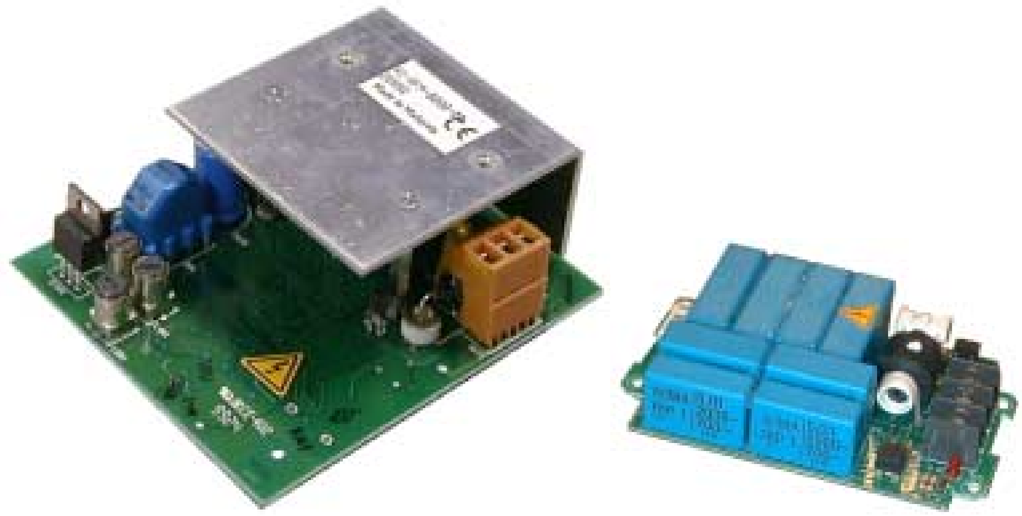

Figure 8. RFM-008B RF Module and ACC-008A Tuning Board

The board has a wide range of capacitance, which can be selected using on-board jumpers. This arrangement allows for antennas with inductances from 12 to 80 µH to be connected and fine tuned by a variable inductor.

3.1.4 The STU-MRD1 MicroReader.

This reader is shown in Figure 9.

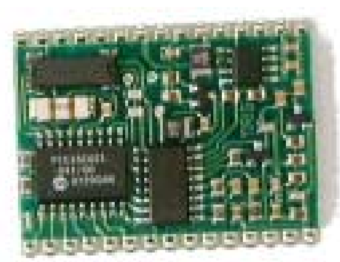

Figure 9. The MicroReader

Unlike the other RF modules already described which need high Q antennas for optimum performance; the MicroReader is designed for low Q antennas. Antenna Q is described in more detail in later sections but in general, low Q antennas are more tolerant of miss-tuning and the presence of metal. If MicroReader antennas have an inductance close to 47 µH, then fine tuning is rarely necessary.

4 Antenna Design

Making antennas for S2000 Series readers is straight-forward. Only two characteristics need to be controlled - Inductance and antenna Q

For an antenna to function correctly with a particular RF Module, the parameters must match those in Table 1

RF Module	Inductance (µH)	Inductance Range (µH)	Q
RI-RFM-104B	27	26 ~ 28	100
RI-RFM-007B	27	25.5 ~ 28.5	100
RI-ACC-008B	27	12 ~ 80	60 ~ 120
RI-STU-MRD1	47	46 ~ 48	20
RI-RFM-003B	116	115 ~ 117	200
RI-STU-S251B	27	26 ~ 27.9	100

Table 1. RF Module Antenna Characteristics

4.1 Determining Self Inductance

The unit of measurement for inductance is the Henry (H). The values for Series 2000 antennas are in the micro-Henry (µH) range

4.1.1 By Calculation

For S2000 Series readers, antenna inductance can be calculated using the software utility “ADU.exe” (Antenna Design Utility). This program is available from your local Texas Instruments RFID representative and is shown in Figure 10.

Note:

Because of the different characteristics of various wire types, some experience with this program is required. By modelling and then constructing different sized loops, you can determine what offsets are required for the wire you are using, to get the exact inductance

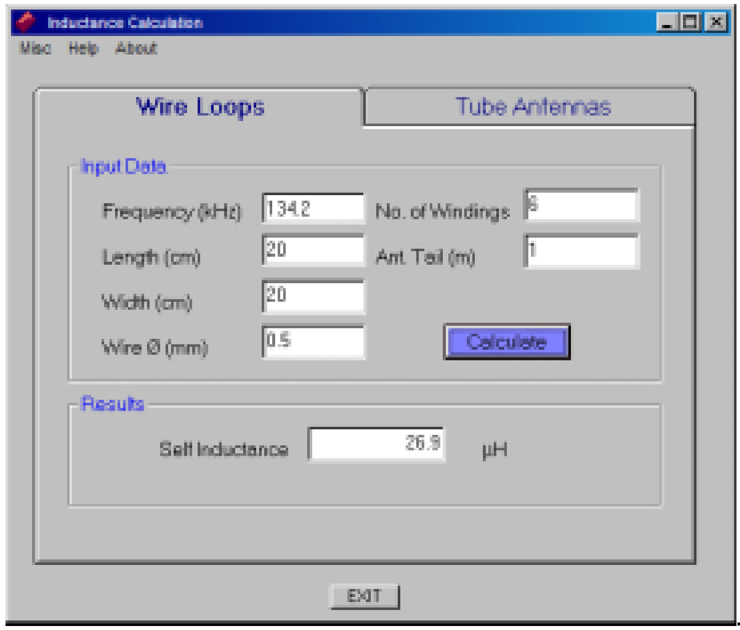

Figure 10. "ADU.EXE" Screen

The length and width of an antenna and the wire size can be specified and by adjusting the number of windings (or the size) you can decide what size antenna will give you the correct inductance.

4.1.2 By Measurement

Relatively low cost LCR (Inductance, Capacitance and Resistance) meters are available that will measure the inductance of a loop accurately enough for our purposes.

Figure 11. LCR Meter

These meters normally measure the inductance at 1 kHz (not 134.2 kHz) but providing that the meter has a resolution of 0.1 µH, they can be used

4.2 Antenna Q

The Q value of an antenna is a measure of the efficiency. For the same input power, high Q antennas have a much greater RF output than lower Q antennas.

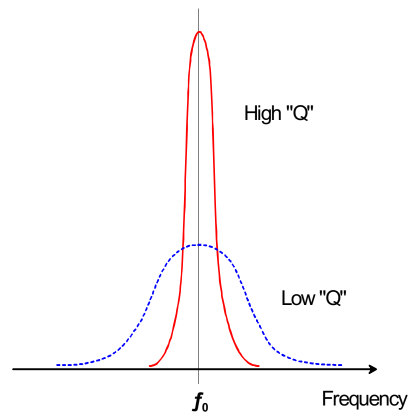

Figure 12. High Q Vs. Low Q

A high Q antenna also serves as a filter ignoring signals outside its bandwidth but high Q antennas are more effected by the presence of metal than low Q ones.

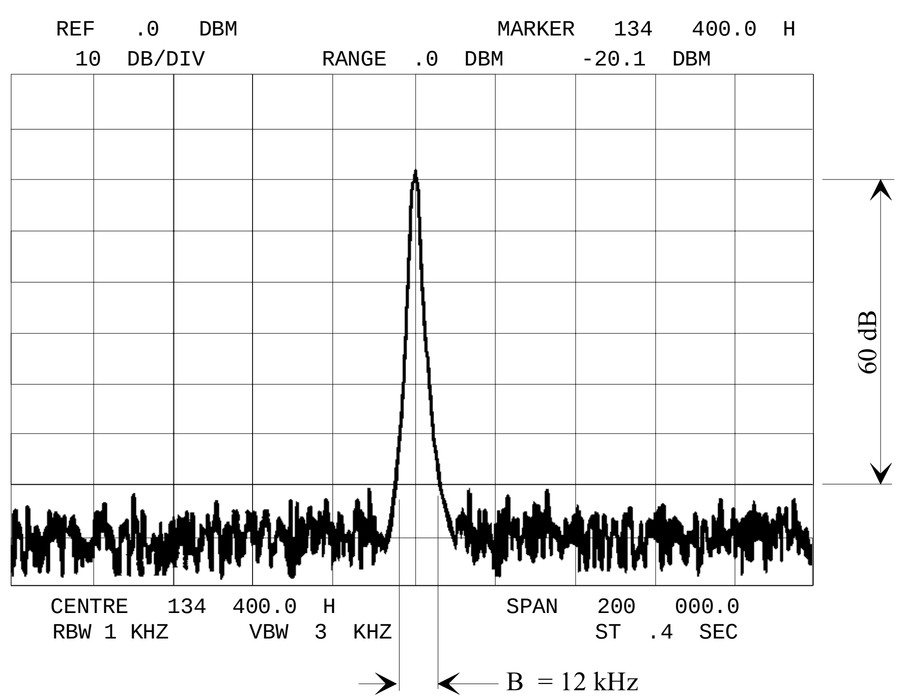

Figure 13. LF System Spectrum

Which is why the MicroReader, which was designed for applications such as vehicle immobilizer systems (where the antenna is around the lock barrel) and hotel door locks, requires low Q antennas.

4.2.1 Determing the Antenna's Q Value

4.2.1.1 By Measurement

Q values are normally measured using a signal generator and a spectrum analyzer. A signal is fed into the antenna circuit and the peak amplitude of the resulting output is detected by a spectrum analyzer.[f_0] (this should be around 134.2 kHz). The frequency of the input signal is then raised until a 3 dB drop in the amplitude of the spectrum analyzer signal is detected [f_2]. The frequency of the input signal is then reduced until the signal is at the -3 dB point on the low side [f_1]. Then using formula [2] the Q can be determined

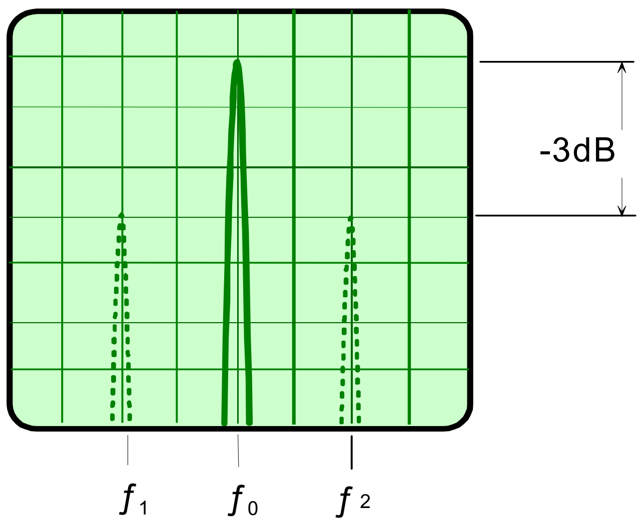

Figure 14. Spectrum Analyzer Screen

$$Q = \frac{f_0}{f_1 - f_2} \qquad [2]$$

4.2.1.2 By Calculation

This is method depends on the accurate measure of the series resistance of the antenna but even when read by an LCR meter will give an adequate approximate value.

$$Q = \frac{2\pi f L}{R} \qquad [3]$$

Example 1. RI-ANT-G01E antenna,

Where:

f = 134200 Hz (134.2 kHz)
L = 0.000027 H (27 µH)
R = 0.2 Ohms

Q = (2 * 3.142 * 134200 * 0.000027)/ 0.2 = 114

Example 2. MicroReader antenna,

Where:

f = 134200 Hz (134.2 kHz)
L = 0.000047 H (47 µH)
R = 2.4 Ohms

Q = (2 * 3.142 * 134200 * 0.000027)/ 2.4 = 16.5

4.3 Controlling the Antenna's Q

We have seen from Equation [3] that the resistance (R) controls the Q. When R is low, an antenna has a high Q and when R is high, the Q is low.

By selecting the correct wire type we can vary the Q.

4.3.1 Wire Selection.

At RF frequencies, the behavior of an AC current through a wire is different from the flow through a DC circuit. What might be considered a low resistance wire in a DC circuit can become high impedance when in an AC circuit because of the 'Skin Effect'.

4.3.1.1 Skin Effect

At RF frequencies e.g. 134 kHz, when a signal passes through a wire, eddy currents at the centre of the wire inhibit flow and the current tends to flow close to the circumference (skin) of the wire. This is the 'Skin Effect' and the higher the frequency, the thinner the depth of the skin through which the current flows.

$$\text{Skin depth(mm)} = \frac{2}{\sqrt{\frac{f}{1000}}} \qquad [4]$$

So, at 134.2 kHz, we get a skin depth of:

Depth = 2 / (sq root (134200/1000)) = 0.173 mm (0.007")

4.3.1.2 Litze Wire

Because a low resistance is required for high Q antennas, Texas Instruments use Litze Wire in their antennas. Litze wire uses multiple (e.g. 120) individually insulated (lacquered) wire stands, covered in silk to make up the wire. As each strand is twice the skin depth, total current flow occurs in each strand and for a particular wire size, eddy currents are eliminated. Result – low impedance wire and, because there is only a thin silk outer layer, multiple windings are kept as close together as possible.

Figure 15. Litze Wire (3 sizes)

Litze wire has its disadvantages though:

- It is expensive
- It is more brittle and liable to break if vibration is present.
- It is more difficult to work

One re-occurring issue is when a standard antenna connector breaks off. The temptation is to strip off the silk and crimp a new connector onto the copper wire. Unfortunately, you are crimping onto the insulating lacquer, and the antenna will no longer work effectively. When using Litze wire, the insulating lacquer has to be burnt off in a solder pot.

Tip 1:

If just the wire is put into the solder pot, solder flows up the wire by capillary action and the wire swells at the end and is too large for the connector. Always lightly crimp the terminating connectors onto the wire before putting into the pot.

Tip 2:

Commercially available solder pots are rated at 320 ºC (608 ºF) but struggle to reach that temperature. Some have space for an additional heating element. Buy a spare set and add the extra element.

4.3.1.3 Other Wires Used in Antenna Construction

Smaller antennas e.g. RI-ANT-G02C tend to have very strong RF fields but the field falls away rapidly, whereas larger antennas have a less intense field close to the antenna and the field strength falls off less rapidly. Litze wire will bring increased performance to small loops and ferrite cored antennas but has limited advantages as antennas get larger. Texas Instrument's large gate antenna (RI-ANT-G04C) does not use Litze wire but 'oxygen free' low resistance 'Jumbo' Hi-Fi speaker cable.

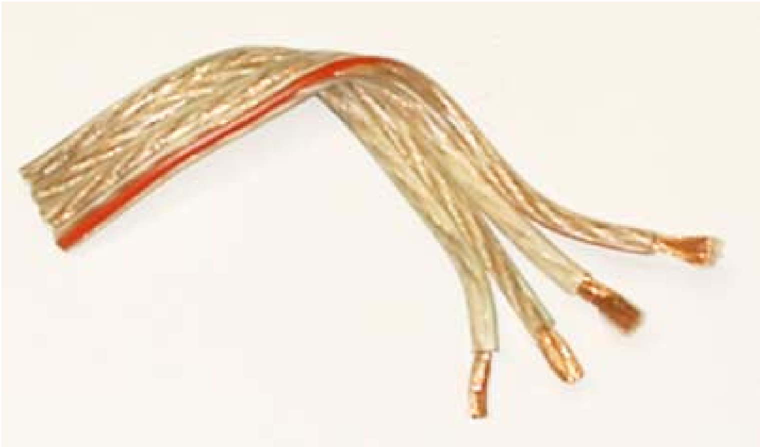

Figure 16. 'Jumbo' Oxygen Free Hi-Fi Wire

This multi-stranded wire is a good substitute for Litze wire for larger sized antennas. It is available in a variety of forms e.g. figure-of-eight, or 4 core (as shown)

For road loops, a tough wire is required, and 'Coil End Lead' wire is used. This wire can withstand a wide temperature range and the thick rubber insulation protects

Figure 17. Road Loop Wire

against damage when in a road surface. Its core is multi-stranded and tinned.

For low Q antennas e.g. for the MicroReader, we use lacquered transformer wire.

Figure 18. Transformer Wire

The increased resistance of this wire enables us to create low Q antennas.

4.4 Antenna Size

It has already been mentioned that, in electrically noisy situations, large antennas can have less reading range than smaller ones

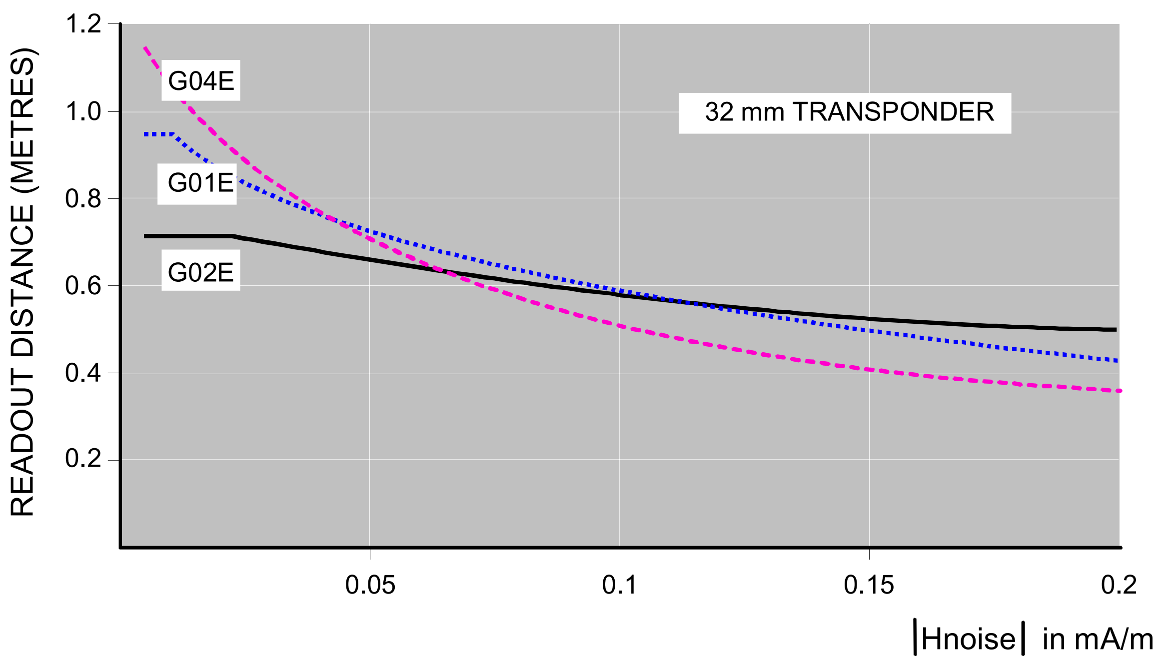

Figure 19. Reading Range Reduction due to Noise

From Figure 19, we can see how in low noise conditions, the largest antenna (RI-ANT-G04E) has the greater range but as the noise increases, has the shortest reading distance.

Not shown in Figure 19 is the stick antenna (RI-ANT-S01C). This antenna does not have a long range but because of its small area, it picks up much less ambient noise and is often used below roller conveyor systems.

4.4.1 Antenna Size vs. Inductance

There is no such thing as 'half a turn' when constructing multi-winding antennas, so although you may require a particular sized antenna, you could have to compromise on shape. The dimensions of Texas Instrument's own standard antennas are dictated by the number of windings required to achieve an inductance of 27 µH.

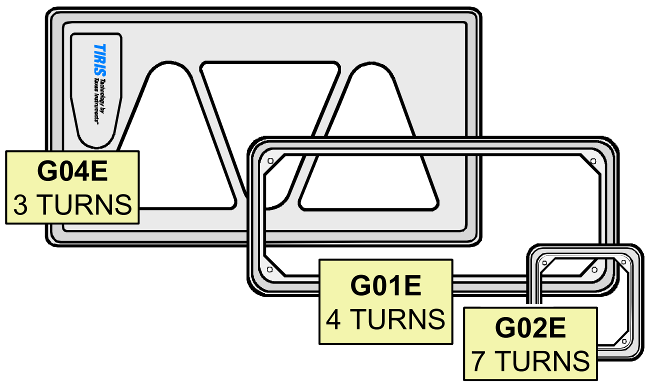

Figure 20. Windings Vs. Inductance

If we consider single turn loops, the approximate sizes to achieve 27 µH Inductance are:

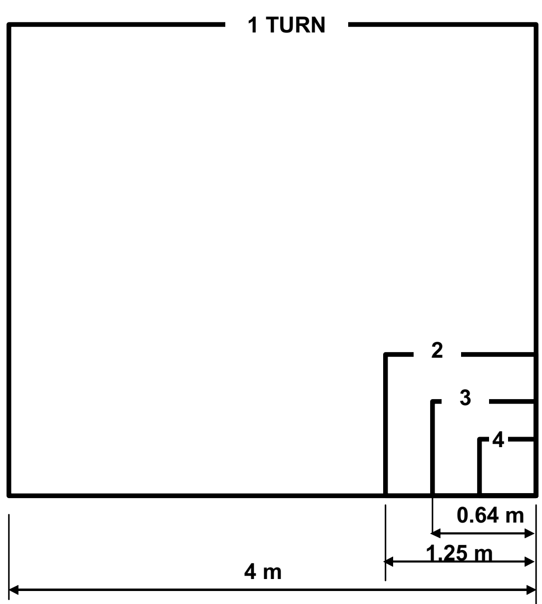

Figure 21. Single Loop Vs. 27 µH Inductance

4.4.2 Adapting a non 27µH Antenna

If you have to produce a loop to a particular size and the inductance is not 27 µH, there are 3 ways to allow you to adapt that loop to a reader.

1. Changing the shape of the loop. If the loop is made squarer, the inductance gets less. Making the loop narrower increases the inductance.
2. Use the Remote Antenna RF module. The Tuning Board for this RF Module allows antennas from 12 to 80 µH to be connected. If the antenna is high Q though (not a lower Q road loop), not all inductances can be accommodated as the higher voltages may exceed the rated values of the matching capacitors. See the Remote Antenna RFM manual – (11-06-21-047).
3. Use external capacitance to change the RF Modules matching circuit.

4.4.2.1 Using External Capacitance

In our internal matching circuit, the on-board capacitance is calculated to exactly balance the inductance of the antenna and to create a circuit that resonates at 134.2 kHz. If the inductance value is not the expected value though, we can modify the capacitance by adding external capacitors, either in series or parallel, to effectively increase or decrease that capacitance and maintain balance. We sometimes have to do this for our standard antennas when they have to be mounted close to metal (if the inductance has decreased below 25.5 µH) or when a long tail has been added (the inductance now exceeds 28.5 µH)

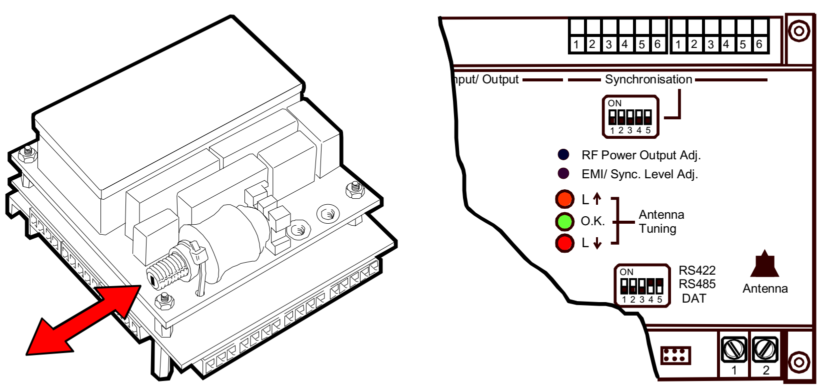

Figure 22. Out of Tune Conditions

If either the tuning core comes completely out or the top tuning LED on the S251B reader is lit then the inductance is too high and capacitance has to be added in series (to reduce total capacitance). If though, you cannot increase the inductance enough by turning the core inwards, or the bottom tuning LED on the S251B is lit, the inductance is too low and external capacitance must be added in parallel. Table 2 shows the capacitor values required for a particular inductance.

Inductance Too High (SERIES)		Inductance Too Low (PARALLEL)	
Inductance (µH)	Capacitance (µF)	Inductance (µH)	Capacitance (µF)
54.0	0.051	25.5	0.003
51.0	0.064	25.0	0.004
48.0	0.067	24.5	0.005
45.0	0.076	24.0	0.007
43.0	0.089	23.5	0.008
41.0	0.100	23.0	0.009
40.0	0.110	22.5	0.010
39.0	0.120	22.0	0.012
38.0	0.130	21.5	0.013
37.0	0.140	21.0	0.015
36.0	0.160	20.5	0.017
35.0	0.180	20.0	0.018
34.0	0.200	19.5	0.020
33.5	0.220	19.0	0.022
33.0	0.230	18.5	0.024
32.5	0.260	18.0	0.026
32.0	0.280	17.5	0.028
31.5	0.310	17.0	0.031
31.0	0.350	16.5	0.033
30.5	0.400	16.0	0.036
30.0	0.470	15.5	0.038
29.5	0.560	15.0	0.042
29.0	0.700	14.5	0.045

Table 2. External Capacitance Values

Note:

The values in this table are calculated and because of component tolerances, may not be exactly right for a particular reader.

The values in Table 2 assume that high voltage (1000 ~ 2000 VDC) polypropylene capacitors are used. When high Q antennas are in use be careful not to exceed the manufacturer's ratings for these capacitors, because as frequency increases the AC voltage capability of these capacitors reduces.

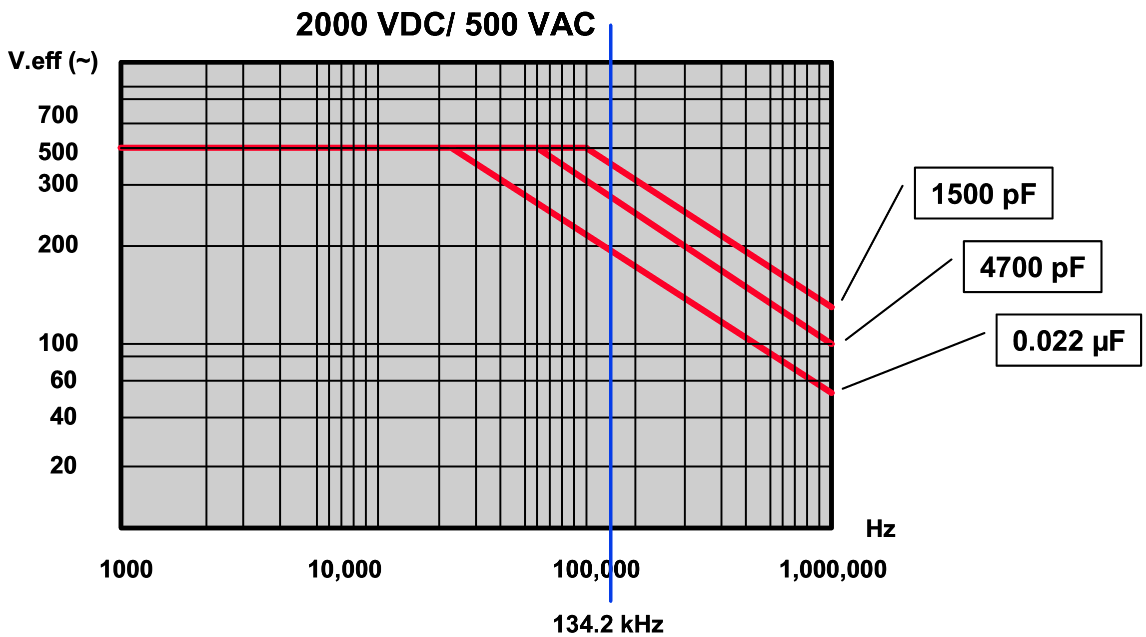

Figure 23. Polypropylene Capacitor De-rating

When designing an antenna that has to be a set size and by varying the number of turns, the antenna can have an inductance too low or too high, always opt for 'too low'.

From Table 2, if the inductance is just too high e.g. 30 µH, a 0.47µF capacitor in series is required. If the inductance is just too low e.g. 22.5 µH, a 0.010 µF capacitor in parallel can be used. The smaller capacitor is 10 times less expensive and much easier to fit in parallel across the antenna terminals

Figure 24. Polypropylene capacitors (0.01 µF & 0.47 µF)

4.5 Antenna Tails

The antenna tail serves only to allow the antenna loop to be separated from the RF module and the longer the tail, the greater the losses that are introduced. For every metre length of the tail, approximately 0.5 µH inductance is added. If we assume that the standard antenna has an inductance of 27 µH and the upper limit that is allowed with the on-board capacitance/ variable inductance is 28.5 µH, then we can add around 3 m of extra wire and still tune to resonance.

Unfortunately, adding the extra tail also adds extra resistance and we have seen how as the R increases, the Q drops. To minimize the added resistance, the recommended wire for this tail is twin 2.5 mm^2 'Jumbo' speaker cable.

Caution

An unshielded antenna tail can pick up noise – the longer the tail, the more potential for noise. Do not run the tail with other cables, especially power cables.

4.5.1 Tail Construction

Of the other points about the tail we need to pay attention to when designing our own antennas, the most important is to keep the two conductors tight together.

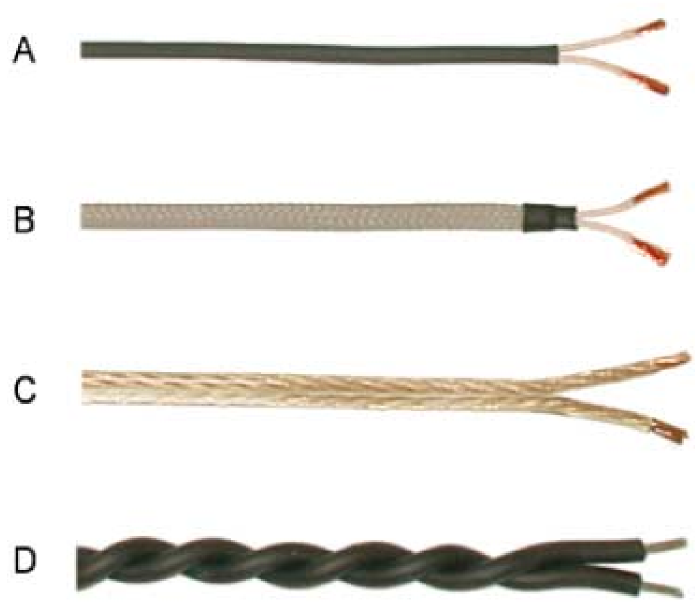

Figure 25. Antenna Tail Construction

Texas Instrument's antennas use heat shrink (method A) to hold the two Litze wires together but plastic braid (method B) is a less expensive substitute. Method C relies on the figure-of-eight construction of the 'Jumbo' Hi-Fi wire but the method will always have a join in the wires between the loop and tail and cannot be recommended for moist or wet conditions. For road loops method D is preferred and the twist is achieved by using a portable electric drill. The disadvantage of this method is that it increases the resistance and inductance because of the extra wire.

4.6 Ferrite Cored Antennas

Ferrite cored antennas, like Texas Instrument's stick antennas (RI-ANT-S01C and RI-ANT-S02C) provide a strong localized RF field and perform well in noisy environments. They are easy to construct but do need the correct grade of ferrite for the core – Texas Instruments recommend Philips 3F3 grade. Figure 26 shows the design of a small, 60 mm (2.4") long antenna.

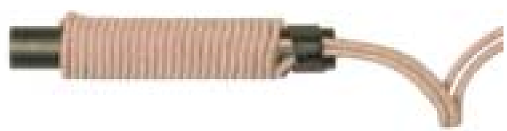

Figure 26. Ferrite Cored Antenna

5 Other Antennas

5.1 Field Lines

Texas Instruments LF system uses the magnetic (H) field to transfer energy to the transponder. When a current moves through an antenna it generates field lines similar as those shown in Figure 27.

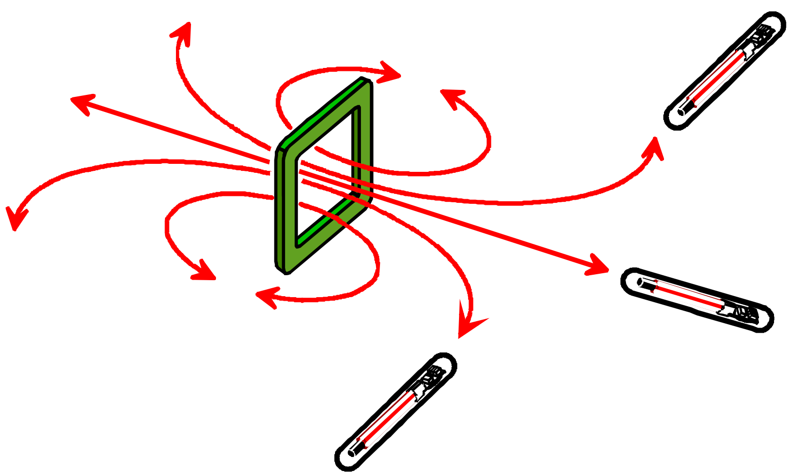

Figure 27. Field Lines

The result is that in different parts of the field, the tag couples better and receives the charge-up energy, while in other parts of the field no energy transfer takes place.

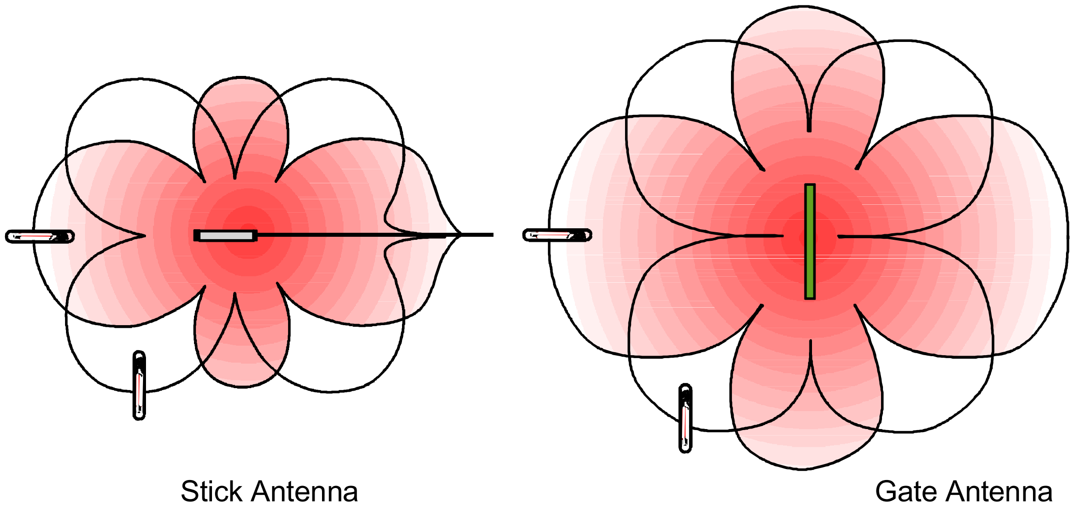

Figure 28. Antenna Field patterns

The result is the field patterns shown in Figure 28.

5.2 Opposing Antennas (In-Phase)

When two individual antennas are connected to the same RF module, they act as one antenna but can greatly increase the reading range. If they are connected in-phase the field patterns are the same as from a single antenna but a tag can be detected across a greater width – double the normal range from a single antenna.

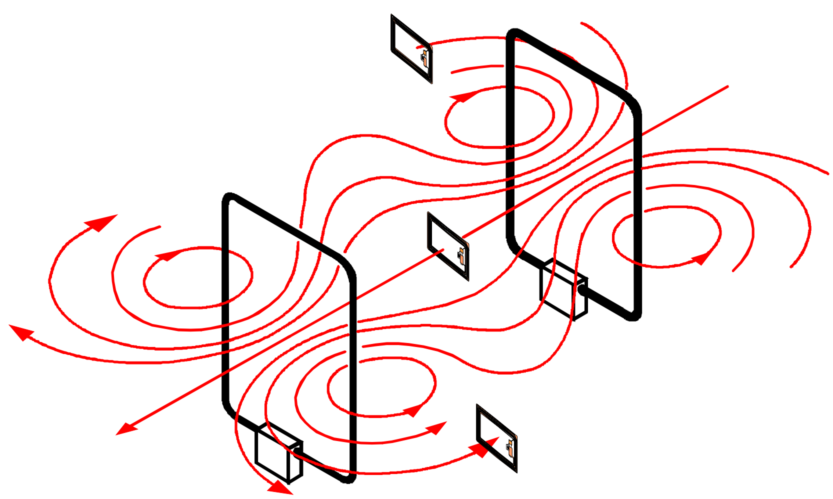

Figure 29. Opposing Antennas (In-phase)

If standard antennas are used, they are connected in parallel and appear as a single 13.5 µH antenna. This means they have to be used with the Remote Antenna RFM. A better approach is to make two antennas that are 54 µH (double inductance). When these antennas are connected in parallel, they appear as 27 µH inductance and can be used with standard RF module.

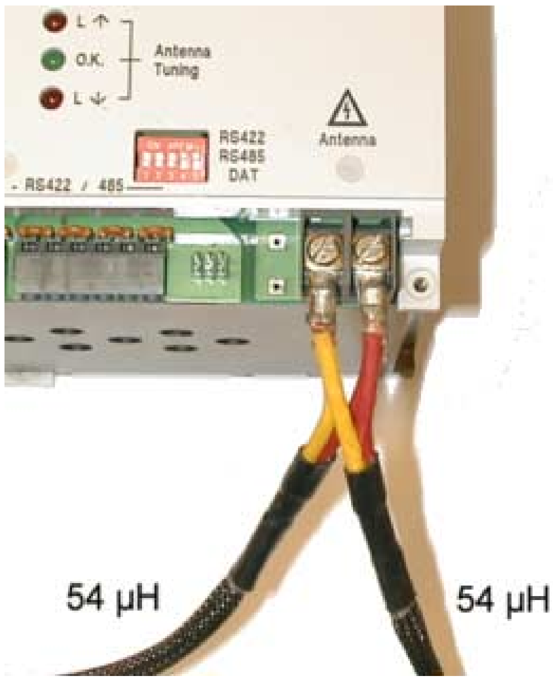

Figure 30. Two 54 µH Antennas Connected in Parallel (In-Phase)

Note:

Do not make your double inductance antennas too large. As both loops are connected to the same reader, they pick up twice the electrical noise. Also if more than one tag is in the field at once i.e. at each antenna, you may not get a response.

5.3 Opposing Antennas (out-of-phase)

When two double inductance antennas are connected to the same RF Module but out-of-phase (swap over one pair of connectors, or turn one antenna 180º), the RF field is changed.

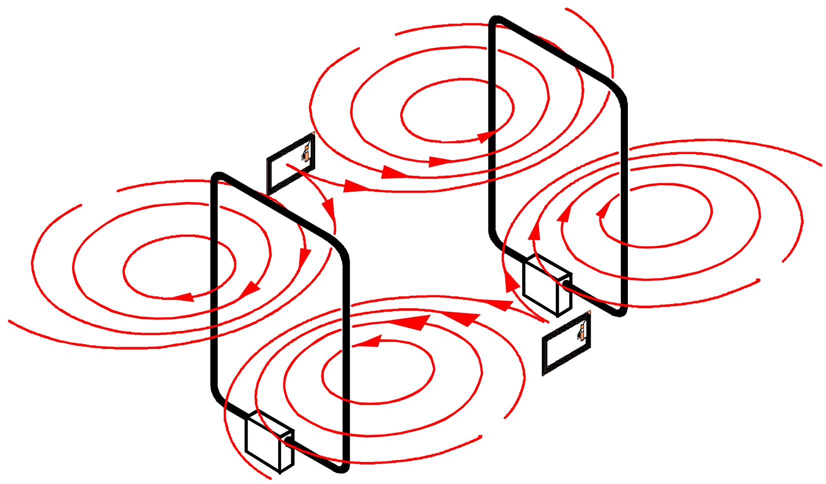

Figure 31. Opposing Antennas (out-of-phase)

This arrangement is very useful for access control gates, where the badge is always worn at right angles to the antenna. Changing the field means it will read across the width without a hole. This technique is used for livestock applications, where the electronic ear tag is normally in the same orientation as the badge.

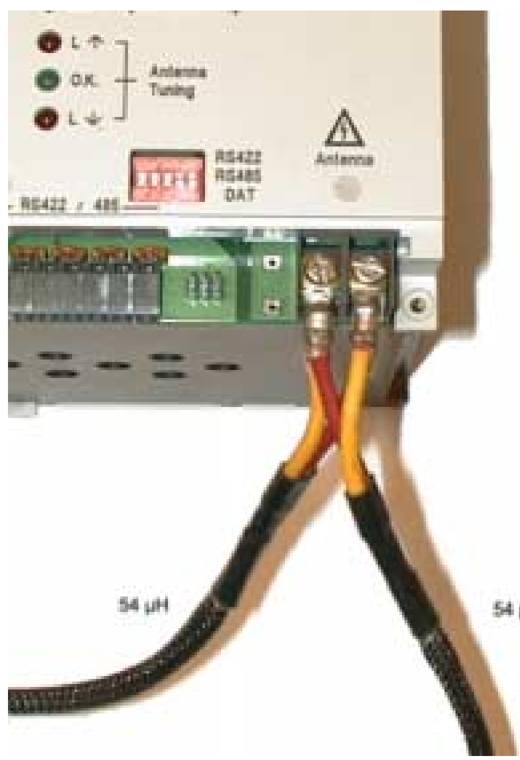

Figure 32. Two 54 µH Antennas connected in Parallel (out-of-phase)

5.4 Noise Canceling Antennas

When antennas have to operate in an environment with homogeneous noise (not coming from any one direction), noise canceling antennas may help to restore some performance. These antennas have multiple loops that are equal and opposite and any (homogeneous) signal arriving at all loops is cancelled, whereas the tag signal will arrive at one loop and be received.

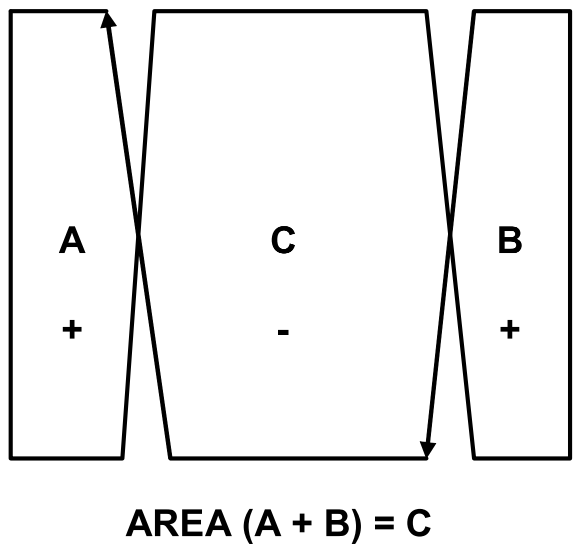

Figure 33. Noise Canceling Antenna

These antennas (and the more simple figure-of-eight antenna) are only used where noise is a problem, as under normal conditions, their read performance is less.

Appendix A – MicroReader Antenna Designs

Because of the Micro-reader's modest power output and the requirements for antennas to perform next to metal, certain constraints have been imposed by design on antenna construction.

- The antenna Q factor must be less than 20
- The inductance must be between 46 ~ 48 µH
- The maximum recommended size is 200 mm x 200 mm

The Q factor of an antenna is a measure of its effectiveness, unfortunately, the higher the Q the more easily the antenna is de-tuned by proximity to metal. The micro-reader is designed for antennas with a Q factor less than 20. If the Q factor exceeds 20:-

- The output capacitors may receive over-voltage and long term damage could result.
- The antenna may still be resonating when the response from the tag is received. Without built-in damping, the data may not be received correctly.
- The antenna may be de-tuned by metal when in situ.

Increasing the resistance has the effect of reducing the Q factor and is why in the following designs high resistance wire is used, or extra resistance added.

The table below lists the parameters of four antennae that meet the design rules and whose constructions are described in detail in later sections.

Antenna	Size (mm)	Turns	Q	L (µH)	Range (mm) 32 mm Tag	Notes
1	10Ø	n/a	17	47	40	Off-the-shelf Inductor
2	40Ø	28	14	47	110	Automotive lock barrel size
3	75Ø	15	18	47	160	General purpose antenna
4	200 x 200	8	20	47	270	Largest size recommended.

Table 3. MicroReader Antenna Designs

Antenna 1

This antenna is built from a standard inductor and the resistance reduced by a series resistor

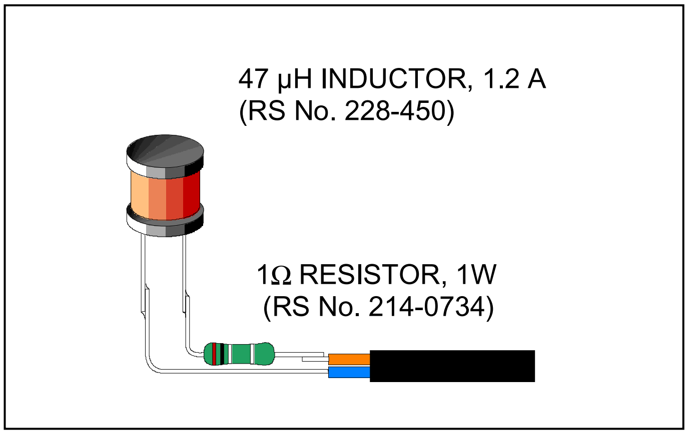

Figure 34. MicroReader Antenna 1

Antenna 2

This antenna is constructed on a 40 mm diameter plastic tube former.

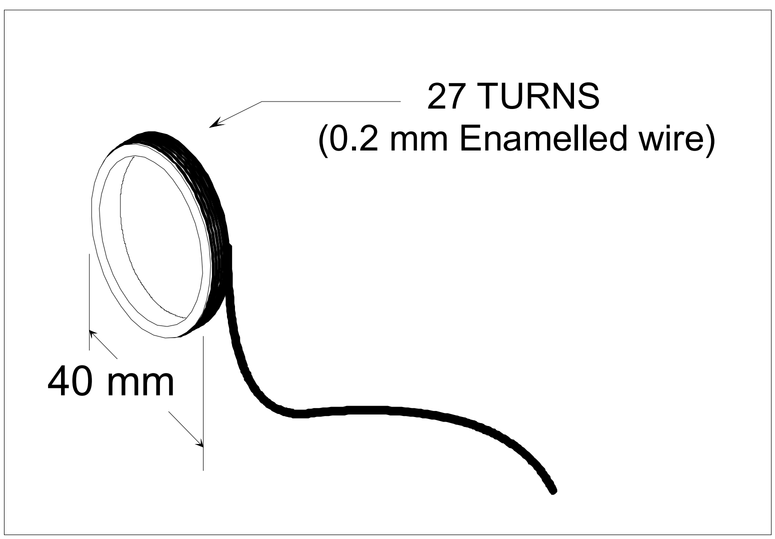

Figure 35. MicroReader Antenna 2

Antenna 3

Antenna three is 75 mm in diameter and formed around a slice of plastic water pipe.

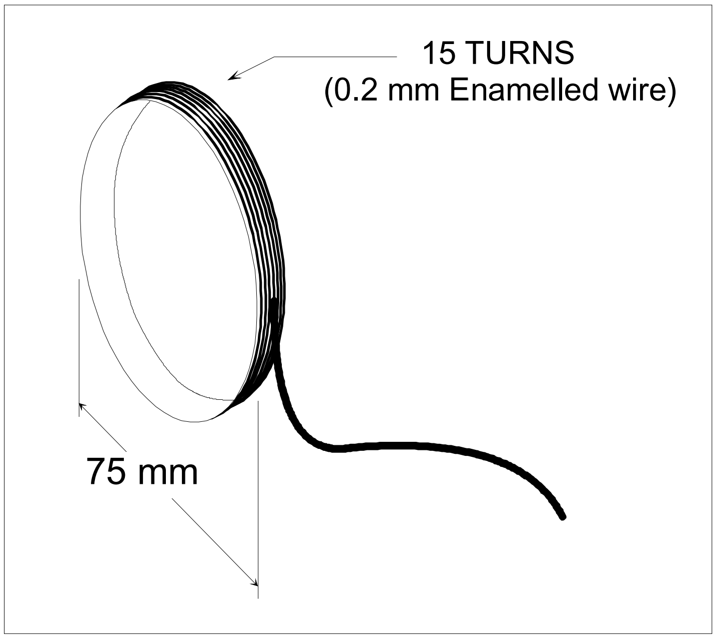

Figure 36. MicroReader Antenna 3

Antenna 4

This antenna is constructed around a 6 mm thick MDF former.

Tip:

For such antennas, double sided Scotch tape will retain the thin wire in position during winding.

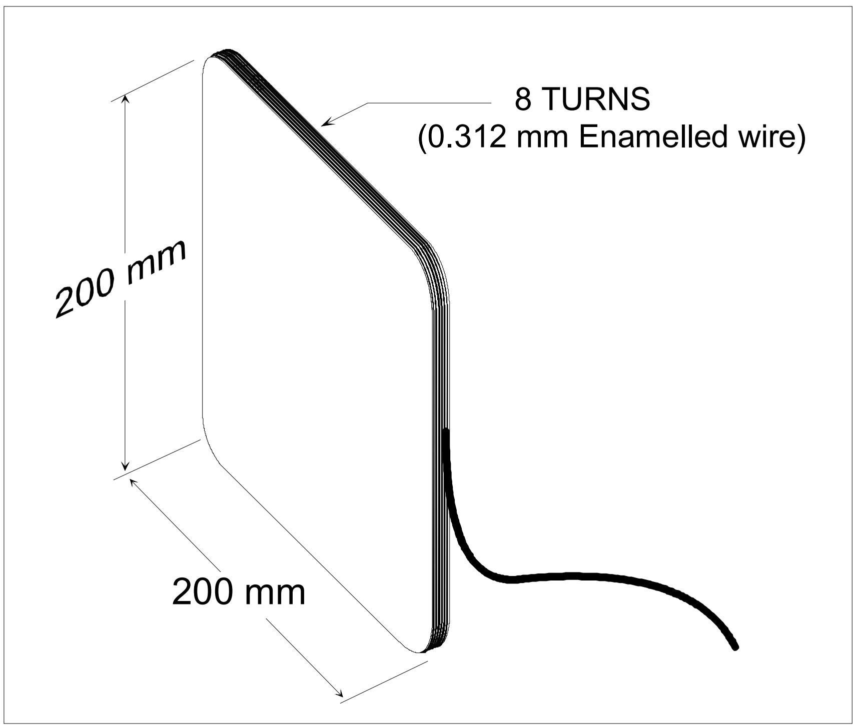

Figure 37. MicroReader Antenna 4

Appendix B. Contacts

Litze wire

Rudolph Pack +49 2261 53185
Gummersbach
Germany

http://www.pack-feindraehte.de/packE.html

The Deeter Group +44 1494 450020
High Wycombe
UK

http://www.deeter.co.uk/litz.htm

New England Electric Wire Corp +1 603 838 6625
Boston, USA

http://www.newenglandelectricwire.com/litzwire.shtml

Yu Seung Electronics Co Ltd +82 41863 8100
Korea
http://www.yuseung.com/frame.html

Ferrite

Ferroxcube (was Philips)

http://www.ferroxcube.com

Delton-Hawnt (UK distributor for Fair-rite & Ferroxcube) +44 121 7645669
UK

http://www.deltron-hawnt.com/magnetics/portfolio.shtml