TEXAS INSTRUMENTS

HF Antenna Cookbook

Technical Application Report

11-08-26-001 Jan 2004

Radio Frequency Identification Systems

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Edition Two – Jan 2004

This is the second edition of this **Technical Application Report** called **HF Antenna Cookbook.**

It contains descriptions of how to build and tune antennas for use at 13.56MHz which can be used in conjunction with:

S4100, S6350, S6400, and S6500 Series Readers

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PREFACE

Read This First

About this Manual

This Technical Application Report 11-08-26-001 is designed for use by TI-RFID partners who are engineers experienced with TI-RFID and 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:

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HF Antenna Cook Book

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Abstract

During the past years it has become clear that with each application of smart labels then a new antenna system has to be designed. A few off the shelf HF Antennae are available but many antennae have to be designed from scratch, in order to meet the system requirements.

The 'HF Antenna Cook Book' is the result of this need to build different antenna systems and has been written to show the RFID Engineer how to design various HF antennas for use with Texas Instruments Tag-it™ and ISO 15693 transponder inlays. The descriptions within this document are based on actual designs which have been completed at Texas Instruments RFID laboratories and used to demonstrate antenna configurations during various trials that have subsequently taken place.

The document is full of pictures and constructional details for a variety of antennae operating at 13.56MHz and which are primarily matched to the characteristics of Texas Instruments' RFID readers. This is not an exhaustive list of antenna types that could be used, but it does offer the RF antenna design engineer an insight into some of them that have been used.

Note:

Because antenna loops may be slightly different in size to those shown in this document, and because of component tolerances, the RF Engineer may have to fine-tune individual antenna designs to achieve the correct matching.

1 Construction Details

An antenna loop can be constructed from any conductive material but in this note, three common methods involve using either copper PCB tracks, copper tape or copper tube.

1.1 Copper Tape

Adhesive copper tape is available in a number of widths and with conductive and non-conductive adhesive. It is recommended to use the **non-conductive** type because it is much less expensive. As a general rule, as the size of the antenna increases, the width of the tape should increase to keep the antennae inductance to a minimum.

For example to build a 150mm x 150mm (6" x 6") antenna - 10mm wide tape would be satisfactory but for a 1m x 1m (40" x 40") antenna 50mm (2") tape is required. The backing board must also be stiff enough, for the size of antenna, to prevent the tape rippling or stretching when applied.

All the joints should be **soldered** as shown in Figure 1 with minimum overlap, to avoid adding parasitic capacitance. For the best results, the corners of rectangular antennas should be at 45º

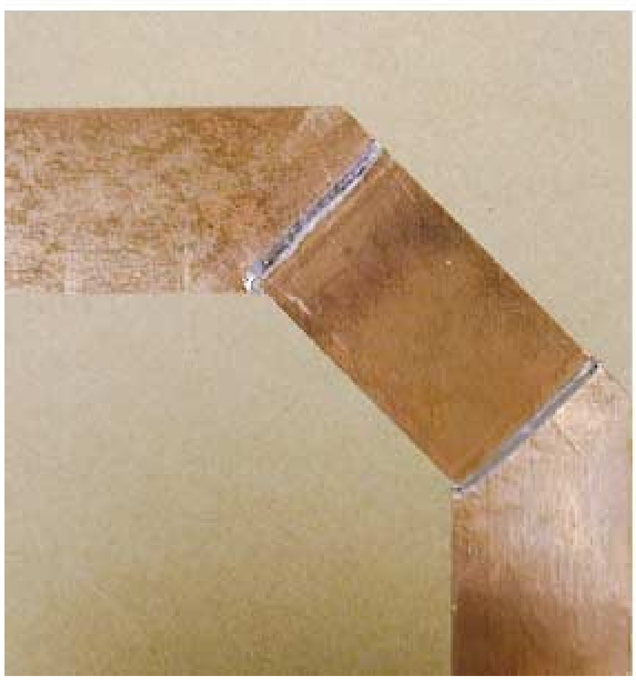

Figure 1. Soldered Antenna Corners

1.2 Copper Tube

As with the copper tape antennae, as the size of the antenna increases, the diameter of the tube should be increased to reduce the inductance of the antenna. The smallest antennas can be made with copper shielded coax cable e.g. RG 405, whereas a 500mm x 500mm (20" x 20") loop requires 15mm (½") Ø copper tube, whilst larger loops should use 22mm (¾") Ø tube.

To construct a rectangular copper antenna you can either bend the tube at 90˚, or use 90˚ solder fittings. Copper tube antennas have the additional advantage of being self-supporting and because of their rigidity, the **matching characteristics** are **unlikely to change** (as can happen with ones constructed from wire).

1.2.1 Mounting tuning components

Where a tube antenna has to be cut to attach tuning components, you should maintain a minimum 10mm separation to prevent unwanted capacitive coupling.

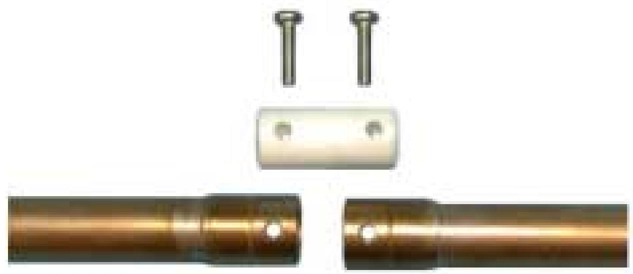

Figure 2. Picture showing copper tube and the joining material

A recommended method to achieve this is to solder straight joint connectors to each end of the copper loop and cut a PTFE or 'Tufnol' (resin bonded paper) rod 30mm (1.2") long x 12mm (½") to insert between, maintaining the 10mm separation. Insert the PTFE or Tufnol rod into the straight connectors and drill a 4mm (3/16") hole through the tube and the rod at each end. Then taking a M4 tap, tap the holes to take a M4 (3/16") screw. These screws hold both the ends of the loop in place but also provide an easy method to attach the tuning components, see Figure 3 below.

Figure 3. Assembled Tube with Damping Resistor

2 Copper Tube Antenna (500mm x 500mm)

This type of construction produces an antenna, which is self-supporting, easily constructed and when tuned gives a read range of approximately 650 mm (26”).

Figure 4. Copper Tube Antenna 500mm x 500mm

The antenna loop is constructed from 15mm (½") Ø copper tube, which is bent into the form shown in the figure above. It is also acceptable to use soldered right angle connectors but the sharper corners will slightly change the value of the resonance matching capacitance. The loop ends are connected together using PTFE or Tufnol rod giving 10mm separation. The tube ends are drilled and tapped through into the PTFE or Tufnol rod to take M4 (3/32") screws. This fixing also holds the PTFE or Tufnol rod in place and allows easy attachment of the resonance tuning components.

Figure 5. Resonance Tuning Components

2.1 Matching Components

The resonance tuning of the antenna to 13.56 MHz is achieved by using mica capacitors approximating to 100pF. The fixed element comprises of 68pF with a 20 ~ 80pF variable mica capacitor; all connected in parallel. A 4K7Ω, 20 Watt thick film resistor, adjusts the Q of the antenna (see Figure 6).

Figure 6. Thick Film Damping Resistor

2.1.1 Gamma matching the Antenna

The antenna is matched to 50 Ohms, the output impedance of the Reader's transmitter, using the "Gamma" matching method.

At the signal feed point of the antenna, usually opposite the tuning point, a clearance hole is drilled through the copper tube to accept a SMA solder spill bulkhead jack (the hole on the inside of the tube will have to be enlarged to accept it).

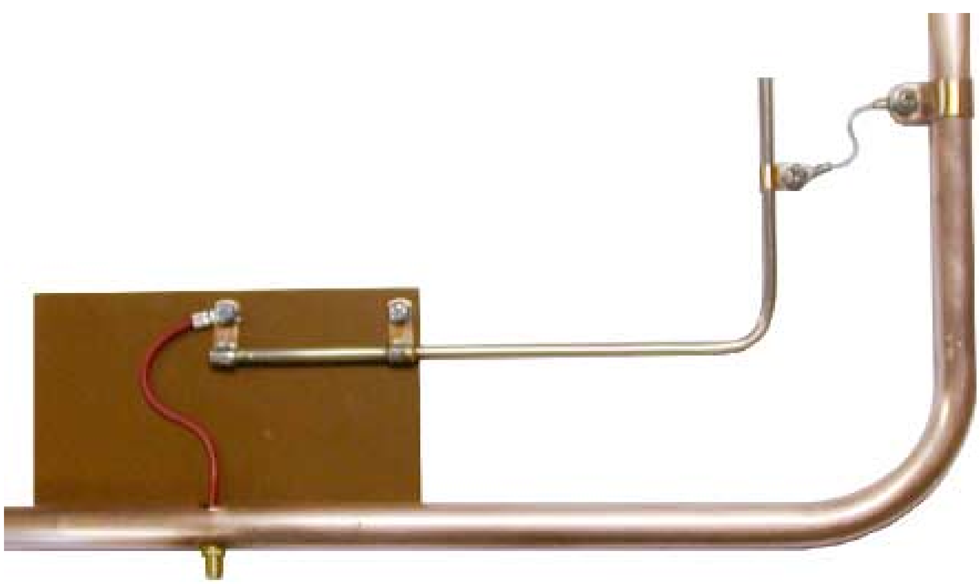

Figure 7. Gamma Matching Arm

A wire link (shown red in Figure 7) is soldered to the SMA connector center lug before it is inserted into the copper tube. The outer of the SMA Connector is at ground potential when it is fitted to the copper tube.

The other end of the wire link is connected (either soldered or by a crimp connector) to a matching arm constructed from 5mm (3/16") Ø copper / nickel automotive brake pipe. The copper / nickel pipe is attached to the main tube by using a Tufnol plate which is screwed into the main tube. The Tufnol plate should be wide enough to ensure that the copper / nickel pipe has a 30mm gap between it and the main tube to reduce induced capacitance effects.

A ‘tap’ is made from two copper clamps, one 5mm and the other 15mm in size; connected together by a solid wire soldered to each of them.

In order to match the antenna to the reader output impedance of 50 ohms and a VSWR of 1:1.0, the antenna is attached to an MFJ HF / VHF SWR Analyzer, Model MFJ-259.

Using an iterative process, change the position of the tap along both tubes, adjusting the tuning variable capacitor to find where the 50 Ohms @ VSWR 1:1.0 point is. Once the tap position is found secure the clamps (it may be necessary to change the fixed capacitor should the variable capacitor not be able to tune the antenna) and the antenna is ready for action.

3 Tape Antenna (1000 mm x 600 mm)

This large antenna (39” x 24”) is constructed from 50mm (2") wide copper tape on 12 mm (½”) thick Medium Density Fiberboard (MDF). Other non-metallic base materials can be used but should be rigid enough to prevent bending that can crease or stretch the tape. Plastic materials have the added advantage of not absorbing moisture in damp conditions.

Copper-sided tape is available with conductive and non-conductive adhesive. This antenna was made using the **conductive** type but the lower cost, **non-conductive** type can be used. Corners should be at 45º and soldered, with minimum overlap of the tape (to avoid creating capacitance). See Figure 1.

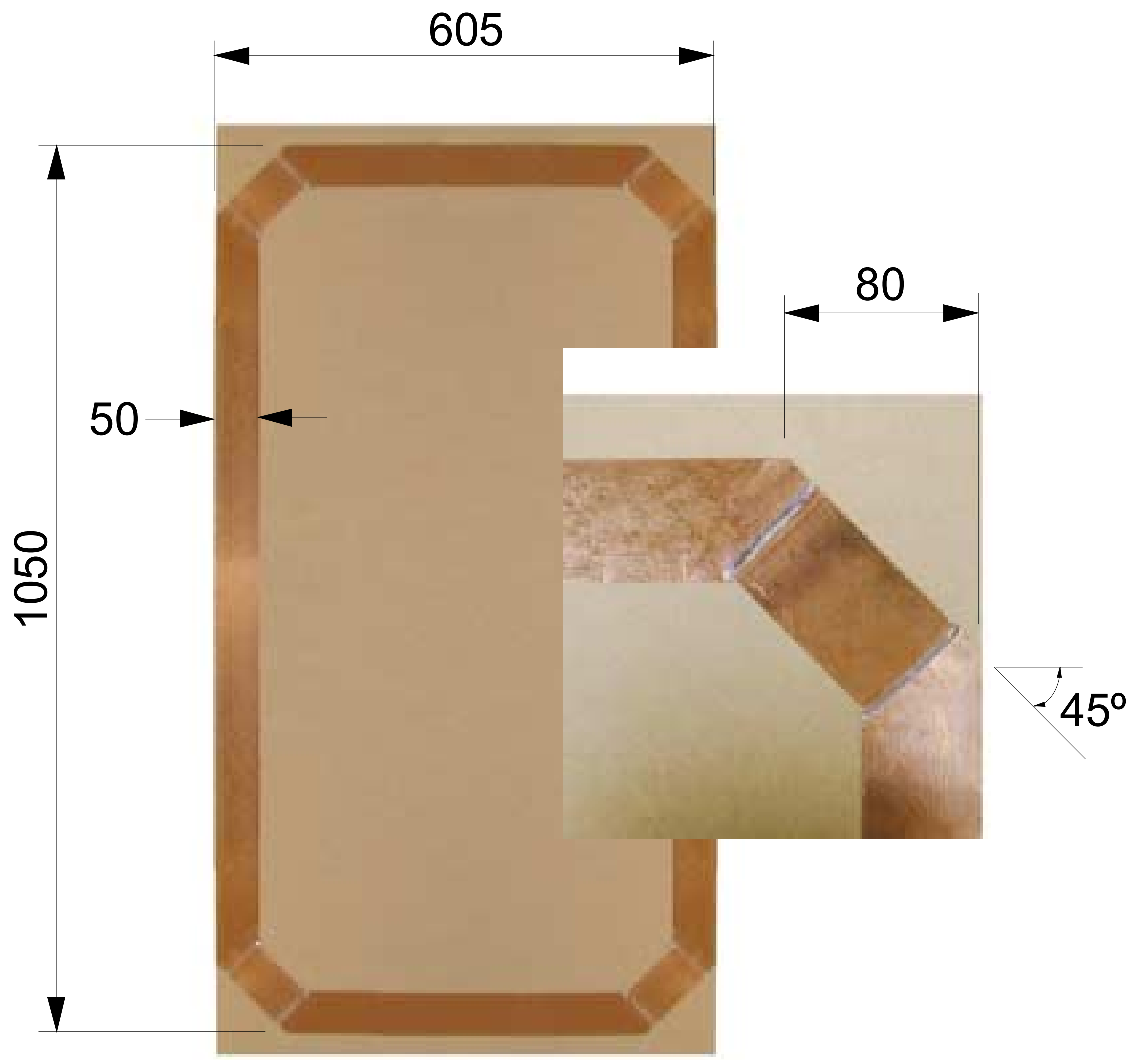

Figure 8. Soldered Copper Tape Main Loop

3.1 Tuning to Resonance

The main loop is cut at the top centre to form a 12 mm (½") gap, and if the inductance is now measured it will be about 2.2 µH. We have to add capacitance across the gap to make the loop naturally resonant of 13.56 MHz to satisfying equation. The required capacitance is 63 pF

Rather than use a fixed value capacitor, we will use a variable (10 to 80 pF) mica capacitor, to allow for tuning the antenna. The capacitor legs are modified to allow them to be soldered to the tape

Figure 9. Variable Mica Capacitor

For fine tuning, a multi-turn air gap variable capacitor is used.

Figure 10. Air Gap Variable Capacitor

The one shown in figure 10 has a range 3 to 15 pF

3.2 Damping the Q

To reduce the Quality factor (Q) of the antenna, a 10K x 20 W thick film resistor is soldered across the gap. The resistor is modified by bending back one leg and soldering it to the heat sink.

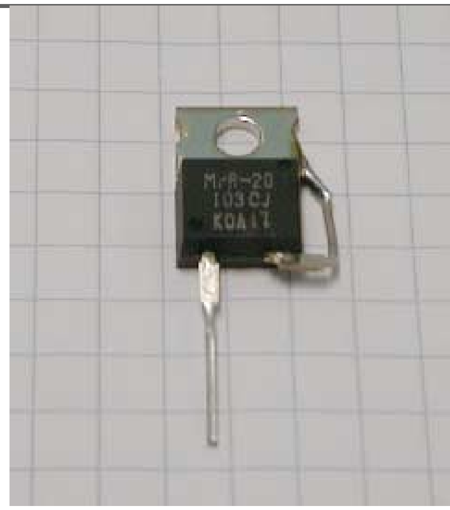

Figure 11. 10K Thick Film Resistor

The resistor is adequate for a reader configured to output up to 6W. If greater outputs are required, higher performance components must be used.

These components are shown soldered in position in figure 12. Note that the resistor's heat sink is bolted to the tape to ensure good heat transfer. .

Figure 12. Resonant Capacitors and Damping Resistor

WARNING:

High voltages exist at this point when the antenna is transmitting. Touching any of these components can result In RF burns or shock.

3.3 Matching the Loop to 50 Ohms

To achieve optimum performance the RG58 coax cable connecting the reader to the main loop should be a ¼ wavelength (3.63m) long and although we now have a main loop that will resonate at 13.56 MHz, it will not be at 50 Ohms impedance.

We will be using ‘T’ matching to ‘tap’ the main loop to give the correct 50 Ohm impedance.

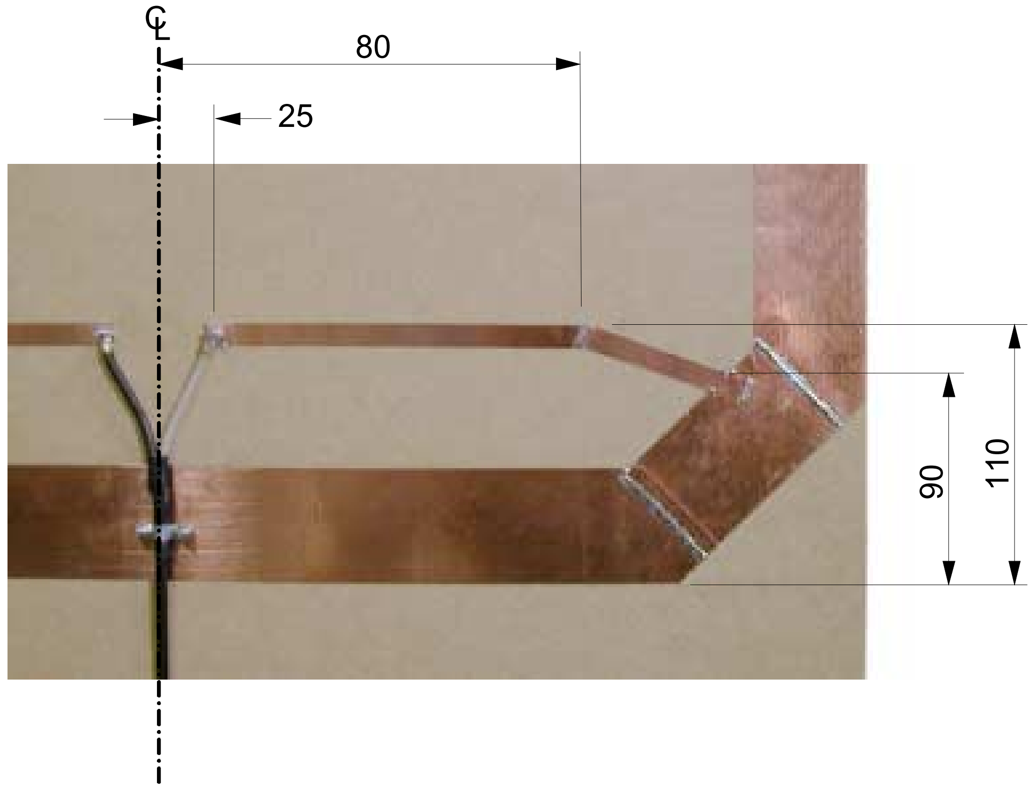

Figure 13. Dimensions of Matching arms

Using 12 mm wide copper tape, construct the matching arms EXACTLY as shown in figure 13. The RG58 coax cable is split into two wires (screen & core) which are terminated with eyelets and bolted to the matching arms. The cable is given extra security by using a small saddle to bolt it to the antenna. All matching arm joints are soldered

3.4 Tuning

The antenna is now complete and must be tuned.

Figure 14. Completed Antenna

Tuning is best done using a Voltage Standing Wave Ratio (VSWR) meter. The meter is connected between the antenna cable and the Reader. The capacitance is adjusted until a minimum needle deflection is achieved. This indicates that the antenna is close to 50 Ohms and little, or none, of the signal is being reflected because of a miss-matched antenna

Figure 15. VSWR Meter

3.5 Adding a Common Mode Choke

It is also recommended that a common mode choke is added to the coax cable. This can help increase reading reliability and the elimination of reading holes

Figure 16. Common Mode Choke

Pass the coax cable 8 times through the Ferroxcube (Philips) 4C65 grade ferrite ring core and secure with cable ties

4 Copper Tube Antenna (1 m x 1 m)

This antenna loop is constructed from 22 mm (0.87”) Copper water pipe, using 90º corner joints. The loop dimensions are measured tube centre to tube centre. There is a 20 mm gap between the tubes at the bottom, with a PTFE rod spacing piece bolted in place. This construction can be seen clearly in Figure 19

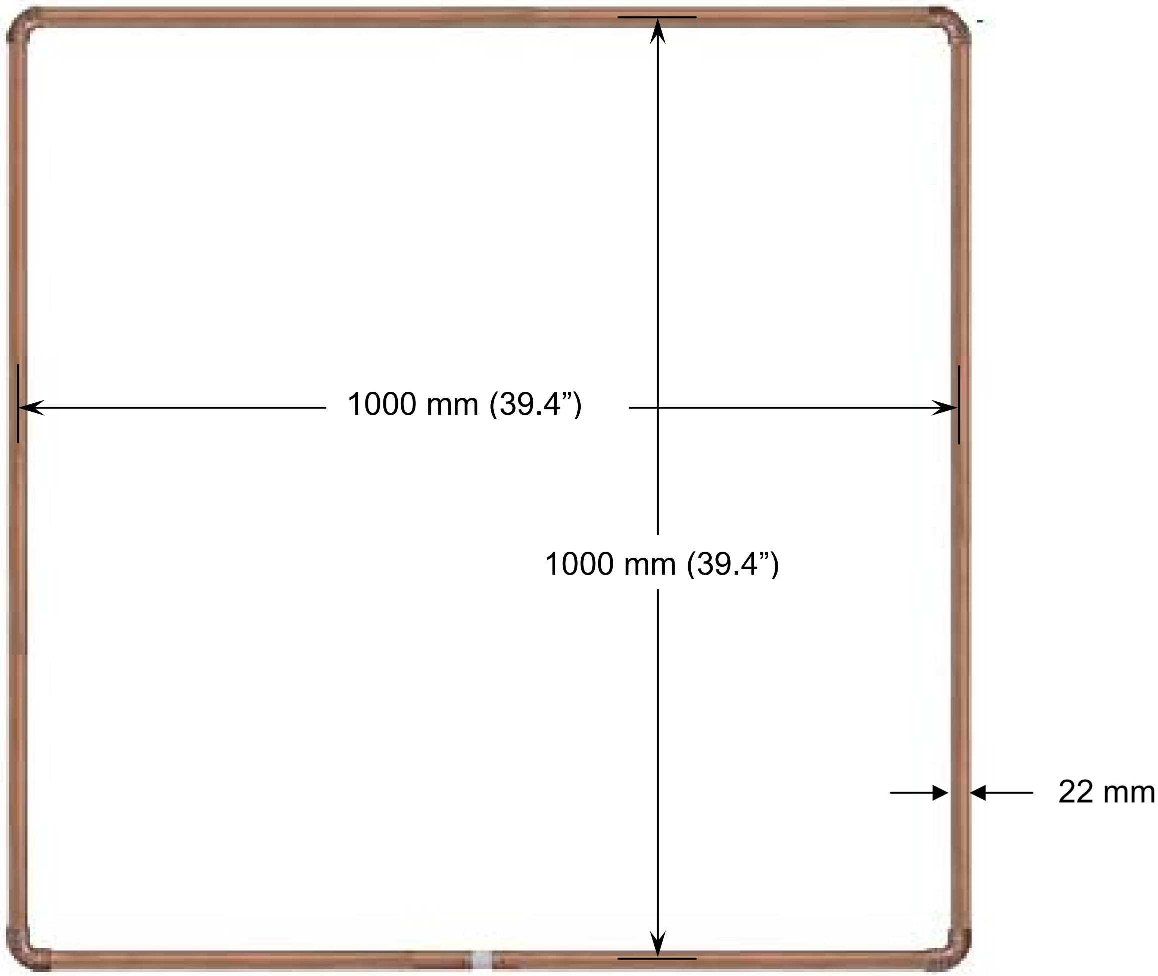

Figure 17. The 1 m Loop with Spacer

This antenna is capacitance matched and the artwork for a suitable matching board is reproduced in Figure 18

4.1 Matching Circuit Layout

You should check that the artwork has not been distorted by your printer. The 4 drill holes on the circle for the SMA connector should be 5 mm (0.197”) apart

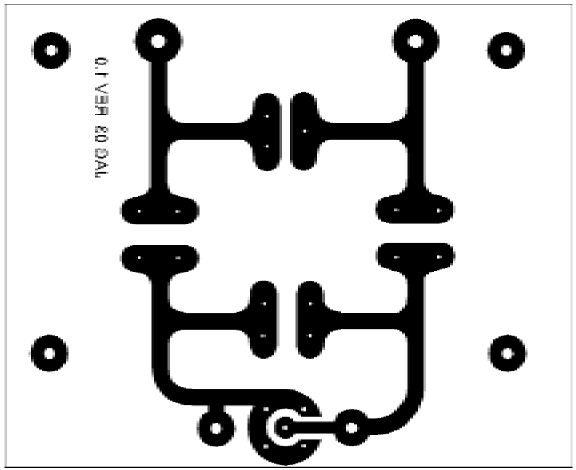

Figure 18. Artwork for Matching Board

4.2 Matching Components

There is a thick film 10 K resistor across the gap to reduce the antenna Q. It is bolted to the tube as a heat sink, instead of positioned on the board. The two series capacitors are 47 pF mica, while the parallel one is 220 pF. There is an additional parallel variable capacitor for the fine tuning. This is an air-gap 3 ~ 15 pF capacitor. (see Figure 10)

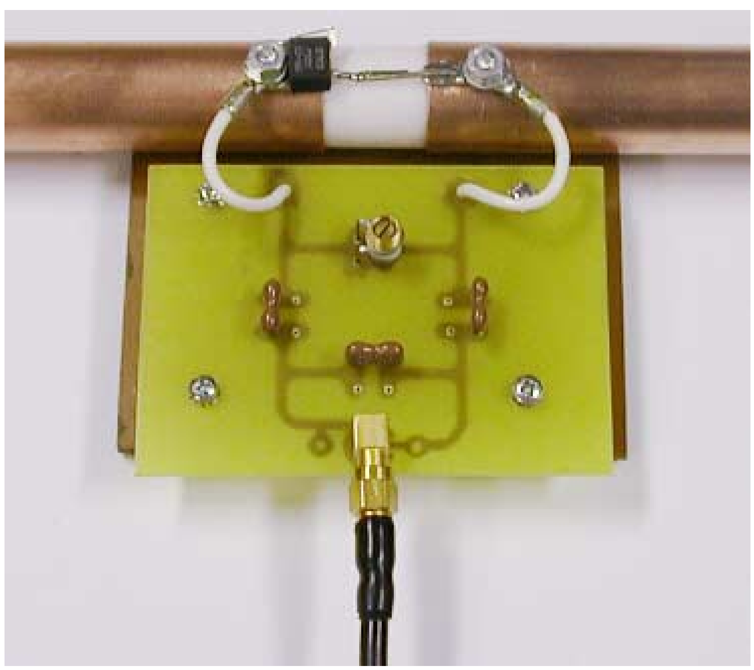

Figure 19. 1 m × 1 m Antenna Matching Circuit

5 Double Loop Antenna

This antenna is designed to read across a conveyor system. It is constructed from 15 mm (0.6”) water pipe and because the two loops are connected in parallel, the antennas are locked in-phase with each other and give a strong field between them. This is ideal if inlays are traveling parallel to the antenna.

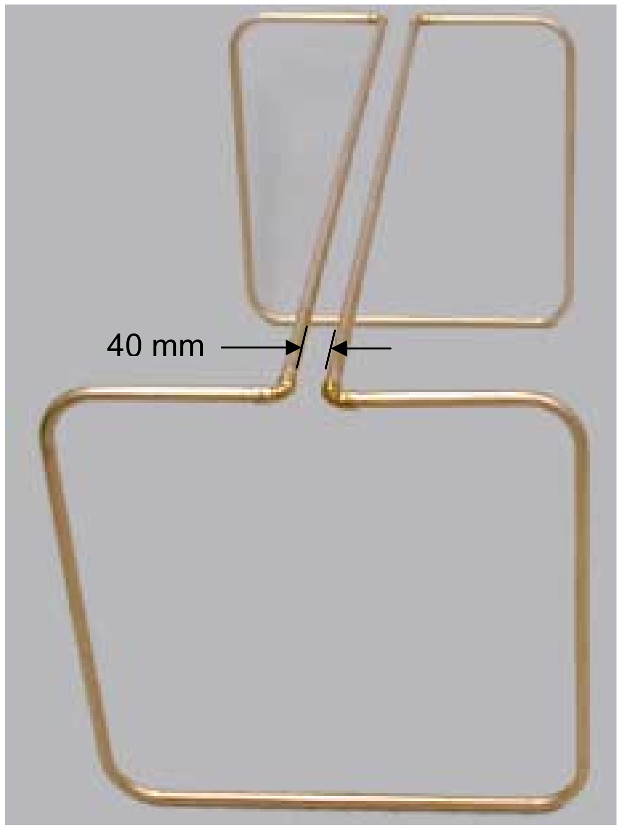

Figure 20. Double Loop Antenna

Each loop is 500 mm × 500 mm (centre to centre) and they are 1 m (39.4”) apart. Clinch nuts are used to allow easy connection of the transformer matching circuit. The cross tubes are 40 mm apart to limit capacitance coupling

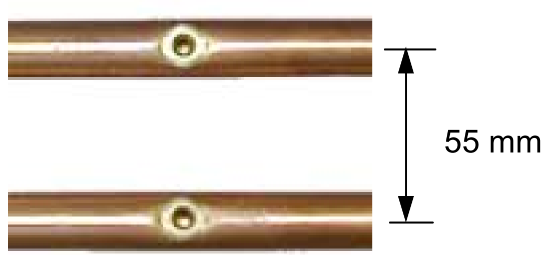

Figure 21. Clinch Nuts

5.1 The Matching Board

The antenna is transformer matched and has an additional BALUN. The artwork for the matching board and component positions are shown below.

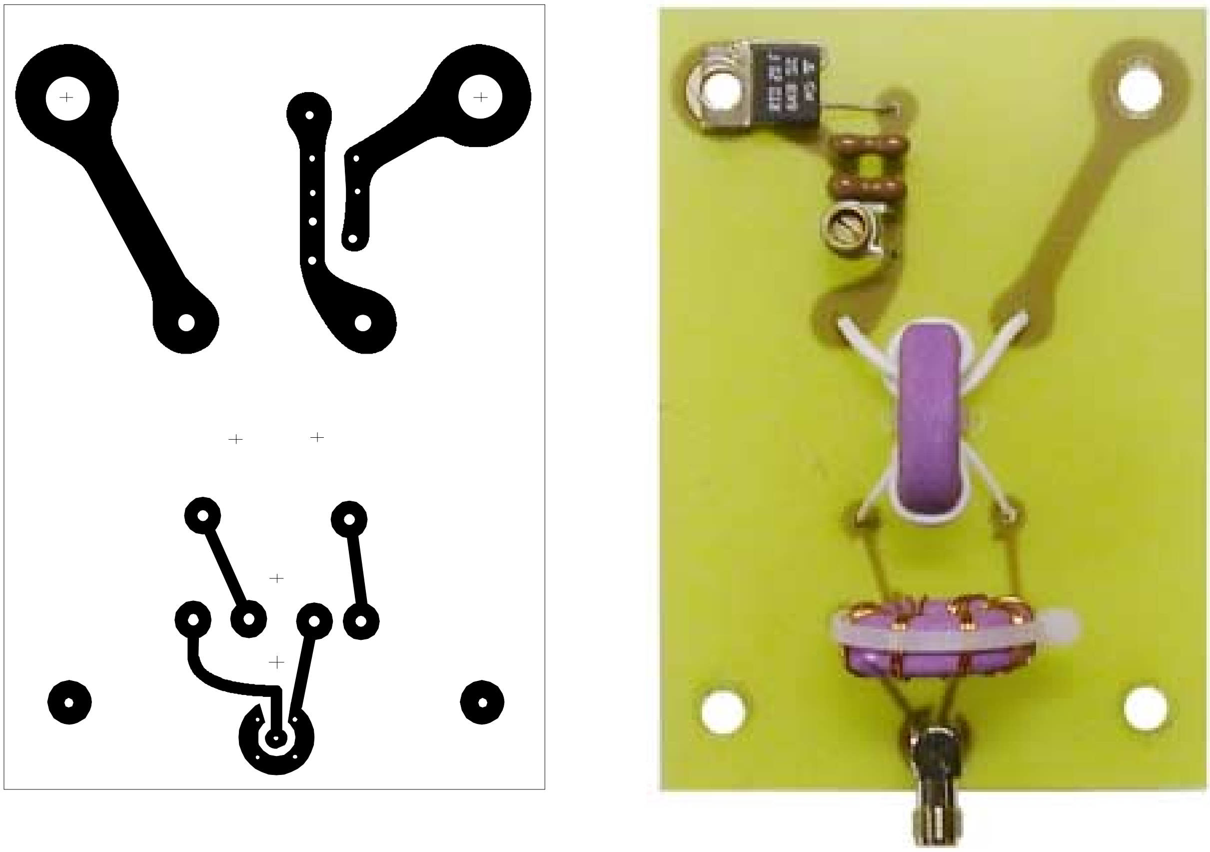

Figure 22. Artwork and Completed Board

5.2 Matching Components

A modified 6K8 Ohm thick film resistor reduces the antenna's Q to 22 and the 82 pF+ 6.8 pF mica capacitors and a 3 ~ 15 pF air-gap variable capacitor adjust the resonant frequency to 13.56 MHz.

50 Ohm matching is achieved using a toroid transformer, with 3 windings on the antenna side and 11 windings on the coax cable side. The **BAL**anced **UN**balanced (BALUN) transformer is optional.

Note:

If the BALUN is left out, the capacitor values may need changing slightly and the number of windings on the coax side may have to be changed.

5.3 Winding the BALUN

The BALUN is trifilar wound. The illustration uses 3 different coloured wires to show how it is wound – normally 0.5 mm (24 AWG) lacquered copper wire is used.

A B C D

Figure 23. How to Wind The BALUN

The toriod material is important and the recommended Ferroxcube grade is 4C65 (or equivalent). Three equal lengths of wire (around 300 mm) are carefully wound around the toriod as shown. The two outer wires are separated out and the middle wire of each set is connected to the inner wire of the other set. A is connected to the coax centre core, while C is connected to the coax screen. B & D connect to the transformer – they are not polarized.

Figure 24. Matching Board Connected

6 Small Antenna 1 (40 mm × 30 mm)

This antenna is designed for lower power readers based on Texas Instruments ASIC (200 mW), the S4100 Multi-function Reader, the S6400 reader board, or the S6350 Multi-protocol reader

6.1 Circuit Layout

The antenna uses a printed circuit and the artwork for the board is given in the figure below.

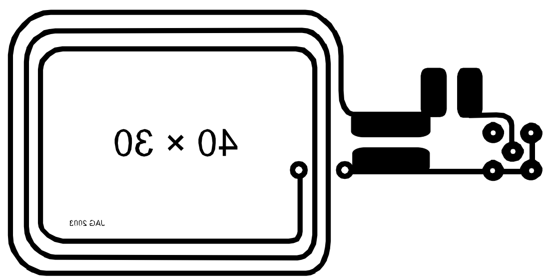

Figure 25. 40 mm × 30 mm Antenna Artwork

If this artwork is used, check that it has not been 'scaled' by your printer by measuring the holes for the SMA connector. The distance between centers for the outside pins should be 5 mm.

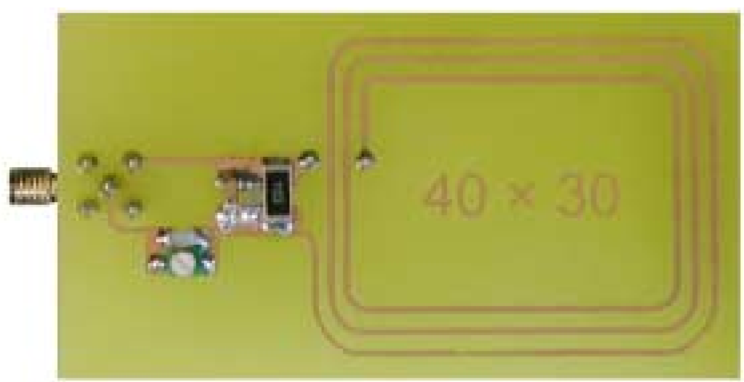

Figure 26. Completed Antenna

6.2 The Matching Components

Across the parallel pads are a 10K Ohm, 1W resistor to reduce the Q to 27 and 177 pF (150 pF + 6 to 30 pF variable,100V) resonance adjusting capacitance. In series is 33 pF (10 pF + 5 to 30 pF variable, 100V) capacitance to match the antenna to 50 Ohms. The SMA connector is optional as the coax cable could be solder directly to the pads to reduce cost.

7 Small Antenna 2 (50 mm × 30 mm)

This antenna is designed for lower power readers based on Texas Instruments ASIC (200 mW), the S4100 Multi-function Reader, the S6400 reader board, or the S6350 Multi-protocol reader

7.1 Circuit Layout

The antenna uses a printed circuit and the artwork for the board is given in the figure below.

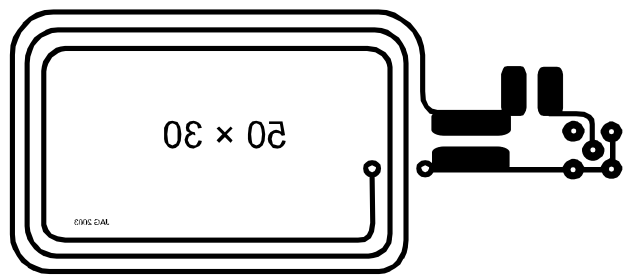

Figure 27. 50 mm × 30 mm Antenna Artwork

If this artwork is used, check that it has not been 'scaled' by your printer by measuring the holes for the SMA connector. The distance between centers for the outside pins should be 5 mm.

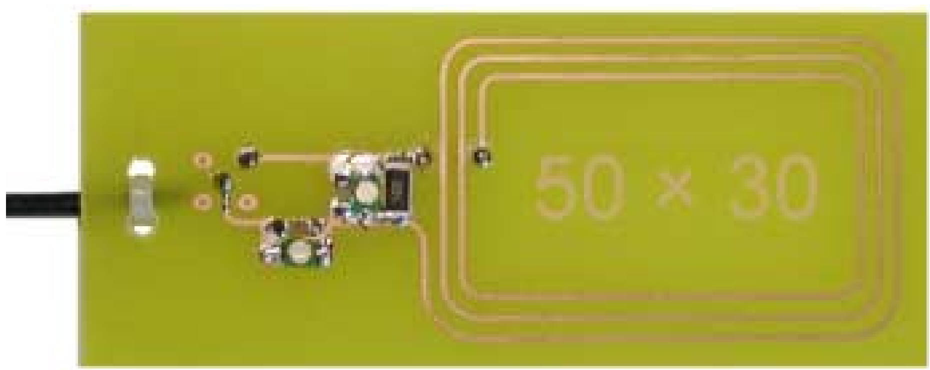

Figure 28. Completed Antenna

7.2 The Matching Components

Across the parallel pads are a 10K Ohm, 1W resistor to reduce the Q to 22 and 148 pF (120 pF + 6 to 30 pF variable, 100V) resonance adjusting capacitance. In series is 31 pF (10 pF + 6 to 30 pF variable, 100V) capacitance to match the antenna to 50 Ohms. The SMA connector is optional and in the figure above, the coax cable is soldered directly to the pads to reduce cost.

8 Small Antenna 3 (60 mm × 30 mm)

This antenna is designed for lower power readers based on Texas Instruments ASIC (200 mW), the S4100 Multi-function Reader, the S6400 reader board, or the S6350 Multi-protocol reader

8.1 Circuit Layout

The antenna uses a printed circuit and the artwork for the board is given in the figure below.

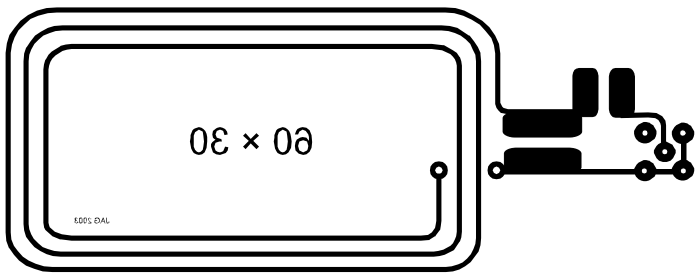

Figure 29. 60 mm × 30 mm Antenna Artwork

If this artwork is used, check that it has not been 'scaled' by your printer by measuring the holes for the SMA connector. The distance between centers for the outside pins should be 5 mm.

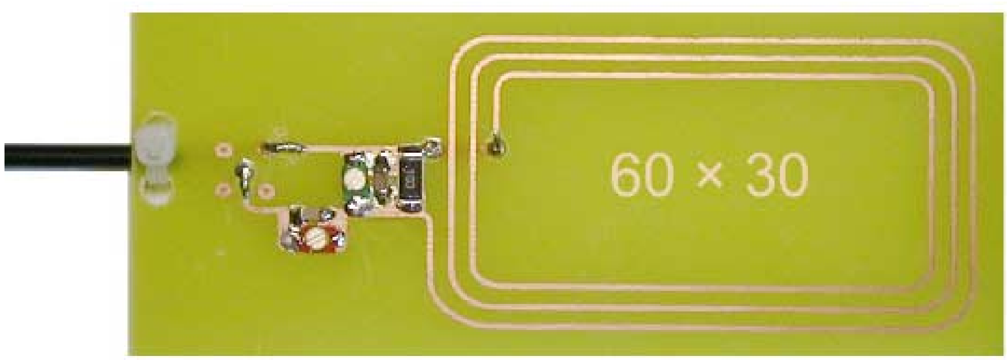

Figure 30. Completed Antenna

8.2 Matching Components

On the rear of the board, a wire link is inserted to complete the loop. Across the parallel pads are a 10K Ohm, 1W resistor to reduce the Q to 21 and 132 pF (100 pF + 10 pF + 6 to 30 pF variable, 100V) capacitance for the resonant frequency adjustment. In series is 27 pF (10 pF + 5 to 20 pF variable, 100V) capacitance to match the antenna to 50 Ohms. The SMA connector is optional and in the figure above, the coax cable is soldered directly to the pads to reduce cost.

9 Small Antenna 4 (150 mm × 100 mm)

This antenna is designed for lower power readers based on Texas Instruments ASIC (200 mW), the S4100 Multi-function Reader, the S6400 reader board, or the S6350 Multi-protocol reader (125 mW).

9.1 Circuit Layout

The antenna uses a printed circuit and the artwork for the board is given in the figure below.

Figure 31. 150 mm × 100 mm Antenna Artwork

If this artwork is used, check that it has not been 'scaled' by your printer by measuring the holes for the SMA connector. The distance between centers for the outside pins should be 5 mm.

Information:

Antennas are measured center track to center track, so the outside dimensions are actually 155 mm x 105 mm

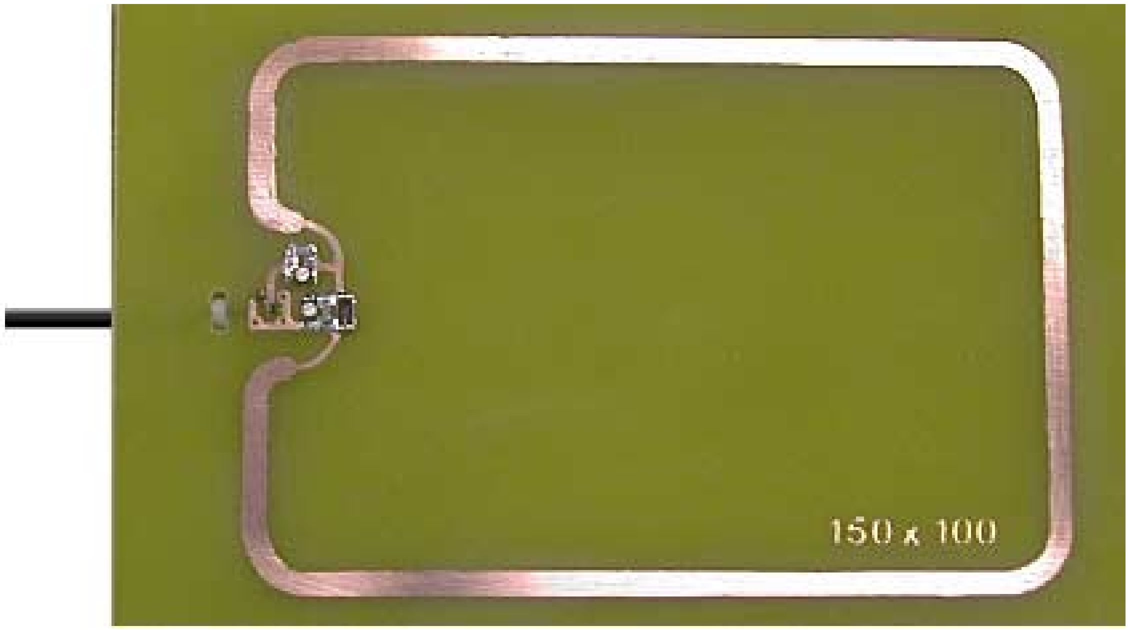

Figure 32. Completed Antenna

9.2 Matching Components

Across the parallel pads are a 10K Ohm, 1W resistor to reduce the Q to 27 and 305 pF (180 pF + 100 pF + 6 to 30 pF variable, 100V) capacitance for the resonant frequency adjustment. In series is 32 pF (22 pF + 6 to 30 pF variable, 100V) capacitance to match the antenna to 50 Ohms. The SMA connector is optional and in the figure above, the coax cable is soldered directly to the pads to reduce cost.

With an S6350 reader (125mW) reader, the reading distance for the credit card sized inlay is 230 mm (9”)

10 Conclusion

Figure 33. Roller Conveyor Read Gate

In this document we have attempted to show the RF Antenna design engineer some of the ways in which you can build HF antennae for numerous applications. Once you have become proficient in the design and construction of these antennae you will be able to build a Read gate as shown above in Figure 31. This Read gate uses many of the techniques within this document and comprises three antennas, allowing the reading of smart labels, irrespective of their orientation, as they pass through it.

References

Transmission Line Transformers by Jerry Sevick, W2FMI. ISBN 1-884932-66-5

Practical Antenna Handbook by Joseph J. Carr. ISBN 0-07-012026-9