HF Antenna Cookbook

Technical Application Report

11-08-26-001 March 2001

Radio Frequency Identification Systems

SCBA033

Contents

Figures

Edition One – March 2001

This is the first 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 and should be used in conjunction with:

Tag-it™ S6000 and S6500 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.

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HF Antenna Cook Book

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Abstract

During the past 2 years it has become clear that with each application of smart labels, a new antenna system has to be designed. 'Off the shelf' HF Antennae are not available for every application and therefore each antenna may 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 Tag-it™ 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 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 the techniques can be used.

This compilation is to assist the RF Engineer to build antennas for Tag-it™ HF frequency transponders. Experimentation to fine-tune the individual antenna design, in order to meet a particular application requirement, may be required by the RF Engineer.

1 Construction Details

There are two constructional methods of HF Antenna design discussed in this book both are produced from using either copper tape or copper tube.

1.1 Copper Tape

Adhesive copper tape is available in a number of widths. As a general rule, as the size of the antenna increases, the width of the tape should increase to keep the antenna resistance and 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.

Copper-backed tape is available with conductive and non-conductive adhesive. It is recommended to use **non-conductive** variety because it is much cheaper. All the folded joints should be **soldered** as shown in Figure 1. For the best results, the corners of rectangular antennas should be at 45º

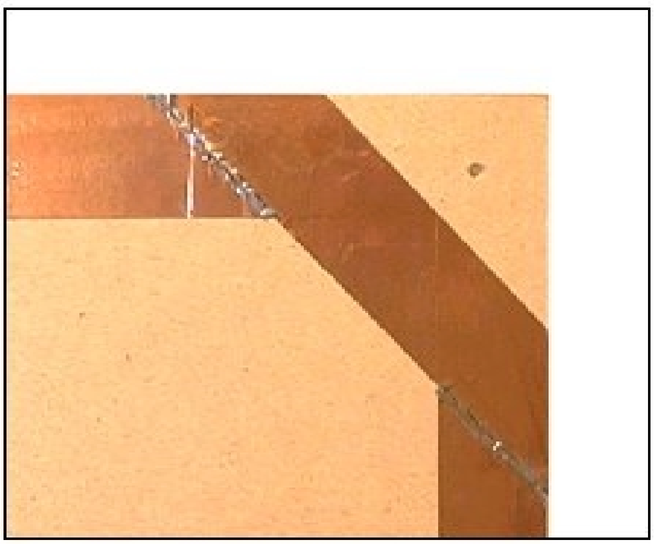


Figure 1. Copper tape folded and soldered

1.2 Copper Tube

As with copper tape antennae, as the size of the antenna increases, the diameter of the tube should be increased to reduce the resistance and 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 square loop 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

The copper antenna requires tuning and to accomplish this the antenna side opposite the transmitter feed needs to be cut, so as to achieve a minimum 30mm separation to prevent unwanted capacitive coupling.

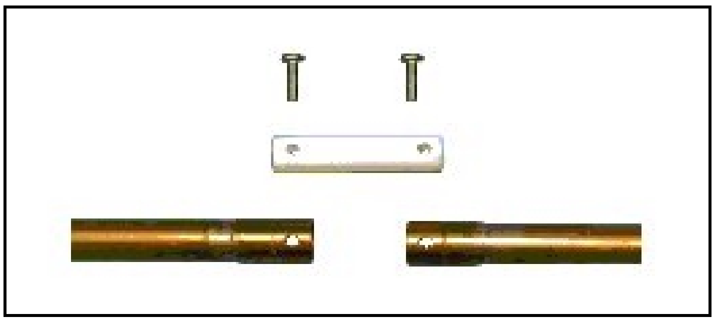


Figure 2. Picture showing copper tube and the joining material

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 50mm (2") long x 12mm (½") to insert between, maintaining the 30mm separation. Insert the PTFE or Tufnol rod into the straight connectors and drill a 3.2mm (1/8") 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.

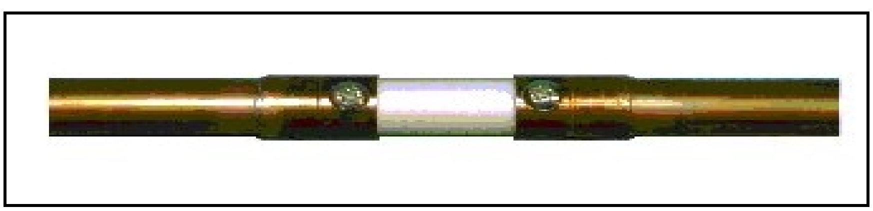


Figure 3. Assembled Copper Tube end

2 Copper Tube Antenna (500mm x 500mm)

This type of construction produces an antenna, which is self-supporting, easily constructed and tuned giving a read range of approximately 600 - 700mm.

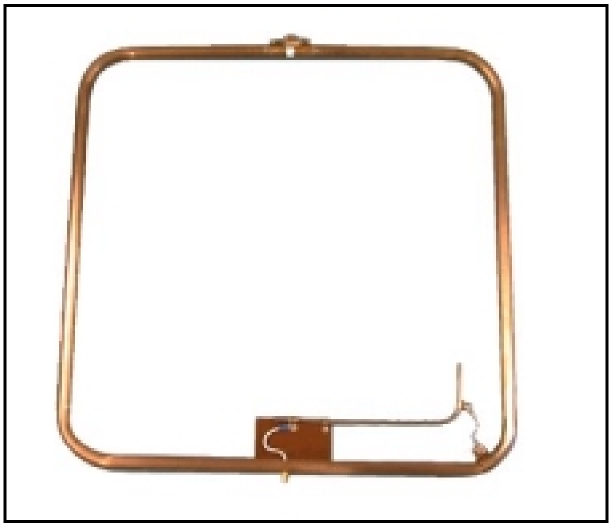


Figure 4. Copper Tube Antenna 500mm x 500mm

The antenna loop is constructed from 15mm (½") Ø copper tube, which is bent into the form shown in Figure 4 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 30mm separation. The tube ends are drilled and tapped through into the PTFE or Tufnol rod to take M4 (3/16") screws. This fixing also holds the PTFE or Tufnol rod in place and allows easy attachment of the resonance tuning components.

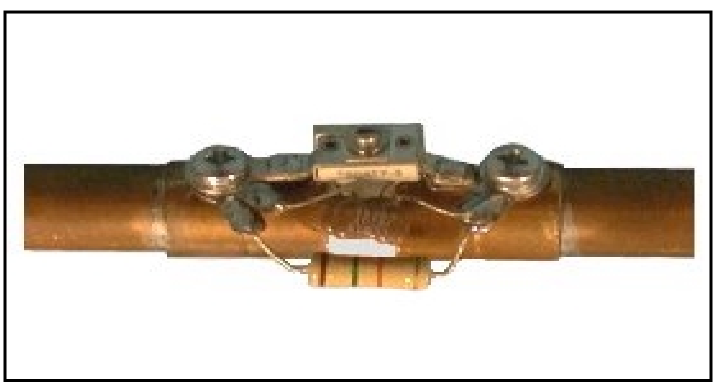


Figure 5. Resonance Tuning Components

The resonance tuning of the antenna to 13.56 MHz is achieved by using mica capacitors approximating to 100pF. The fixed element comprises of 82pF + 10pF with a 5 ~ 30pF variable mica capacitor; all connected in parallel. A 15KΩ, 2 Watt resistor, adjusts the Q of the antenna.

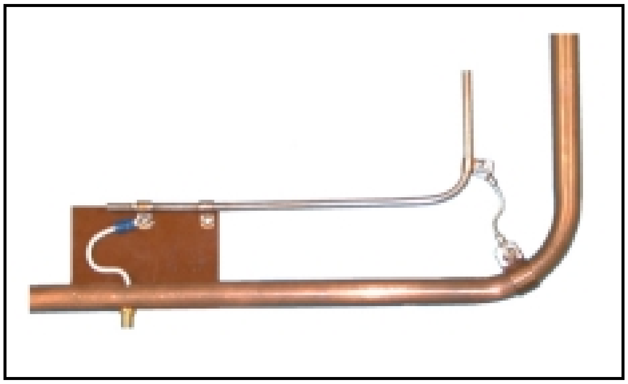


Figure 6. Gamma Matched Antenna

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 circuit, 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 enlarged to accept it).

A wire link (shown white in Figure 6) 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.

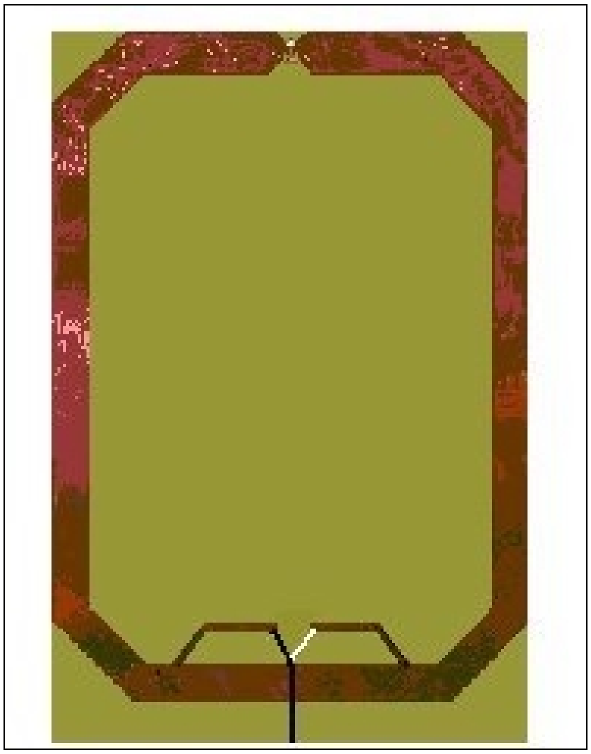
The other end of the wire link is connected (either soldered or by a crimp connector) to a matching arm constructed from 5mm (3/16") Ø copper / nickel automotive brake pipe. The copper / nickel pipe is attached to the main tube by using a Tufnol plate which is screwed into the main tube. The Tufnol plate 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 (550mm x 800mm)



Antennas can be readily made from self-adhesive copper tape adhered to wood or plastic panels. The antenna shown below uses Medium Density Fibreboard (MDF) and 50mm (2") wide copper tape. When using tape, the size and any calculations are based on the centerline dimensions - the actual outside dimensions of this antenna are 600mm x 850mm (23½" x 33½"). The corner overlap joints are soldered as shown in Figure 1.

Figure 7. Tape Antenna (550mm x 800mm)

3.1 Tape Antenna tuning circuit

As shown in Figure 8, the Tape antenna is made resonant at 13.56 MHz by using capacitance of the value approximately 80pF (72pF fixed mica and 2 ~ 12pF variable capacitor) across the ends of the loop. A 22KΩ resistor is used to adjust the antenna Q.

Figure 8. Tape antenna tuning components

3.2 Tape antenna T Matching

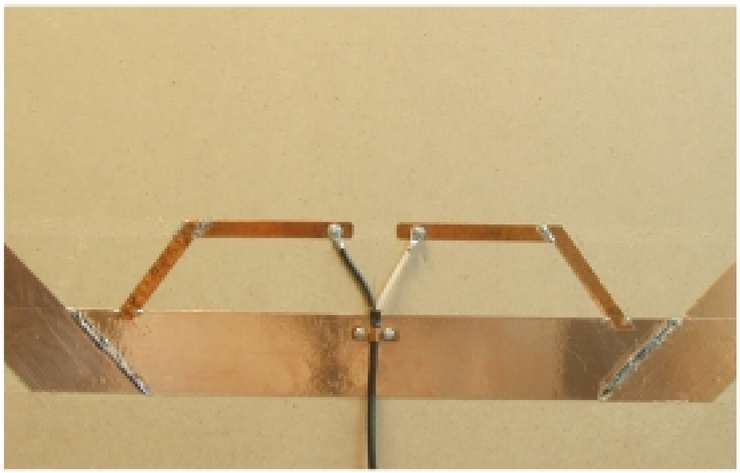


Figure 9. Tape antenna T matching

The tape antenna is matched to 50 Ohms, the output impedance of the Reader's transmitter, by using either the Gamma or 'T' matching technique. In Figure 9 we show a 'T' matched copper tape antenna, where it can be seen the two 10mm (½") tape arms connecting the screen and core of the coax cable to equally distant points on the loop to tap the inductance.

3.2.1 Method to locate the matching point

Using an MJF analyzer set to 13.56MHz and with a long leaded coaxial cable you move the ends outward from the center feed point of the antenna until you find the VSWR 1:1.0 and 50 Ohm position along the 2" wide tape antenna. At each iterative placement of the feed cable the antenna variable tuning capacitor will have to be adjusted.

4 Twin Loop Antenna (2 x 500mm x 500mm)

This arrangement allows the antenna to be placed either side of a conveyor and be driven by one reader. In this example the side loops are 600mm apart but could be wider (e.g. 1m) and still read vertical Tag-it™ transponders all the way across, between the side loops. The two side loops are connected in parallel and at the matching point; the inductance is 0.7µH and is half the inductance of each of the two separate loops.

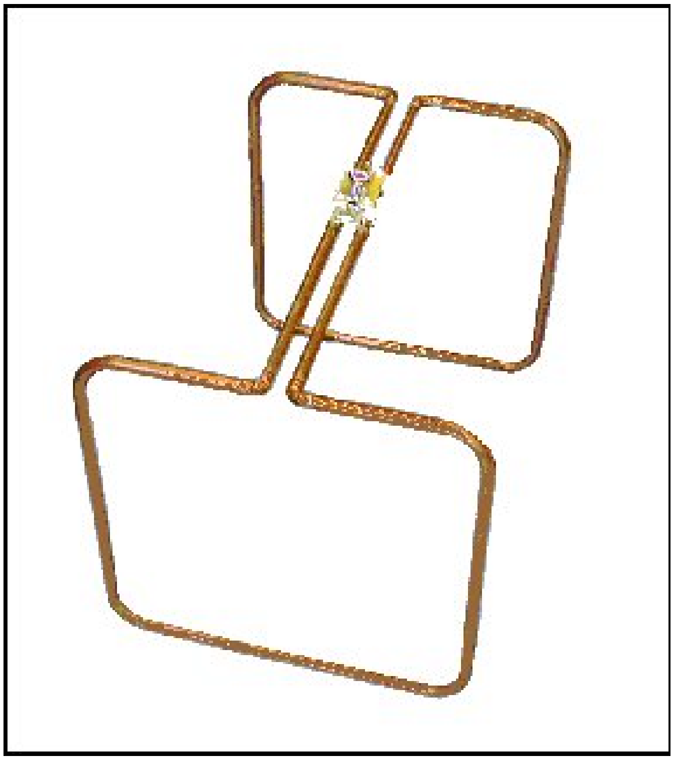


Figure 10. Twin-loop Antenna

In Figure 10 you will note that the tuning and matching circuits are positioned at the top of the antenna structure. This makes it possible to tune the antenna from above.

The antenna is also transformer matched using a BALUN (**BAL**anced **UN**balanced Transformer) to eliminate any common mode noise.

4.1 Twin loop Matching & Tuning Circuit with BALUN

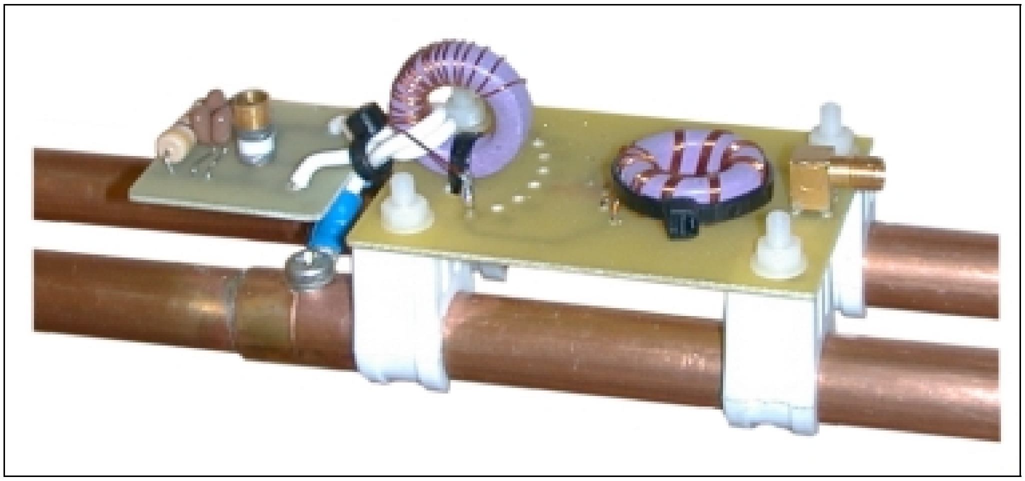


Figure 11. Tuning circuit

The PCB on the left hand side of Figure 11 above you will see from the antenna screws, wires passing through the toriodal ferrite core and back to the small board with the resonance tuning capacitors and damping resistor situated on it. This is equivalent to two turns on the secondary side of the ferrite transformer toroid. The total capacitance is 174 pF (comprising 100 pF + 33 pF, fixed mica capacitors and a 2 - 12 pF air gap variable capacitor). The 47KOhm, 2 Watt resistor reduces the Q.

On the primary side of the antenna matching / tuning toroid core are 19 turns of 0.5mm (24 AWG) enameled wire. These are linked to the Reader transmitter / receiver through a 50 Ohm matching Balun shown on the right hand side of Figure 11.

Note:

A 2 Watt 47KΩ powder oxide resistor of this value also adds 32 pF capacitance.

4.2 Antenna / Transmitter Matching with BALUN

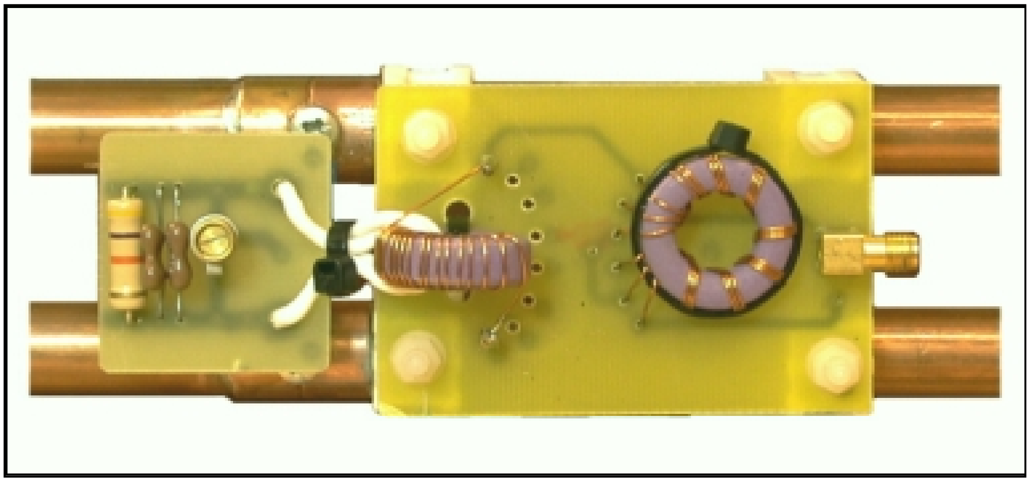


Figure 12. Antenna Transmitter Matching using a BALUN

The Balun converts an **unbalanced** load to a **balanced** load and is primarily used to remove common mode noise associated with multiple antennas that have different ground potentials.

The Balun shown to the right of Figure 12 is a trifilar winding of 1:1 ratio and it is **important** to keep the **sets of three wires tightly wound together** and **evenly spaced** about the ferrite toroid.

4.2.1 How to construct a Matching Balun

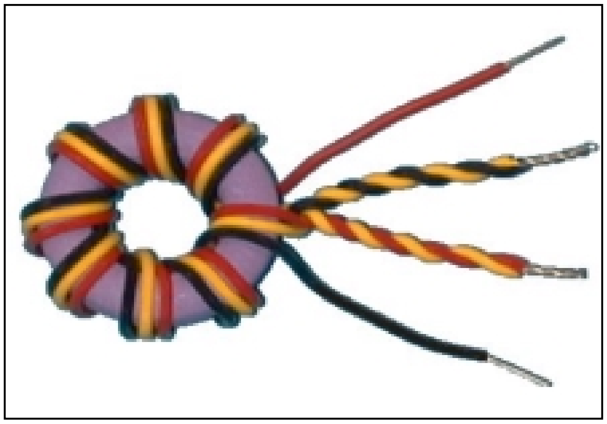


Figure 13. Example BALUN Matching Network

The three wires are wound on this toroid to form a **balun** in the following manner (I have used colors to describe this method).

Three wires are colored Red, Yellow and Black and are all wound together and evenly distributed around the ferrite toroid as shown in Figure 13.

When this is complete you will have 6 ends. Keep one end of the Red and Black wires away from the rest. Twist the other end of the Red wire with a Yellow wire and join the ends together to make one connection. Twist the other end of the Black wire together with the other Yellow wire and join the ends together to make one connection. You should now have 4 wires: 1 Red; 1 Red / Yellow; 1 Black / Yellow; 1 Black. The single Red is connected to the Reader's cable coax core and the Black / Yellow combination wire is connected to the screen. The Yellow / Red combination wire and Black cables are not polarized and can be connect to the antenna matching toroid.

Note:

It is important that the correct grade of ferrite is used in the construction of these elements and we recommend Philips 4C65 grade or Siemens K1 material.

5 Small Round Antenna

This antenna can be used to create a hand held wand by attaching it to a wooden or plastic pole. You can then use it to swipe down the outside stacked boxes, which have a Tag-it™ smart label attached.

Figure 14. Small Round antenna

The small round antenna shown in Figure 14, is constructed by bending 5mm Ø copper nickel brake pipe tube into a circle of 150mm internal diameter.

The Reader coax feeder cable has a separation between the inner (signal) and screen (earth) of 80mm and the cable ends are soldered directly onto the copper nickel pipe. This position is found by using the MJF Analyzer as described in Section 3.2.1

The pipe is cut at the tuning end and a Tufnol rod spacer inserted. The pipe and the Tufnol spacer are then drilled and tapped to fix the ends. The tuning components are then soldered to the copper nickel pipe, in this case the values are a total of: Capacitance: 330pF + (10 ~ 60pF) variable with a damping resistance of 47KOhm across them as shown below. It is possible to bend the pipe around a former and then using tie wraps secure the antenna to it.

Figure 15. Small Round Antenna Tuning circuit

6 Spiral Antenna

6.1 Spiral Antenna construction details

This antenna is wound around a wooden or plastic former and creates a strong RF field for reading objects passing through the centre. One use might be to read a box of closely spaced envelopes, each containing a Tag-it™ transponder.

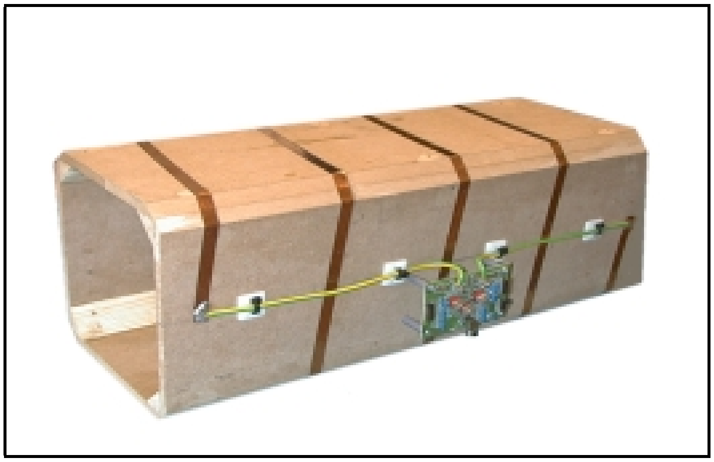


Figure 16. Spiral Antenna

Spiral wound 10mm copper tape is used for the antenna. The former is 180mm x 180mm (7" x 7") with the windings 95mm (3.7") apart and at an angle of approximately 8º to the vertical. The ends of the spiral are brought together at the centre and matched with a capacitive matching circuit.

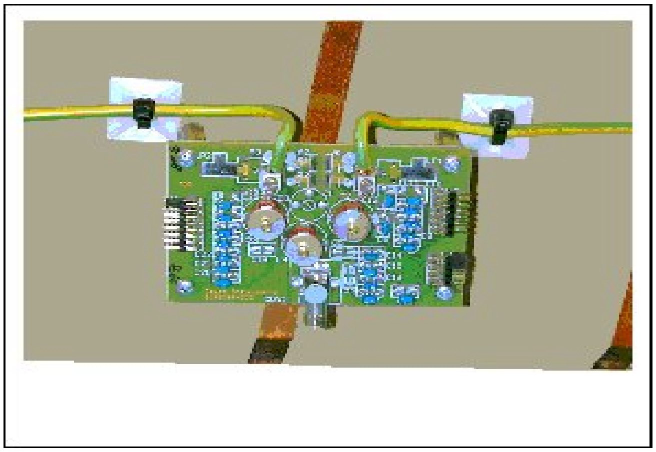


Figure 17. Capacitive matching Board

System Integrators are advised that scaling up this type of antenna is not recommended because the inductance becomes too high for easy matching.

7 Conclusion

Figure 18. 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 18. This Read gate uses all the techniques within this document and comprises of 3 antennae allowing readings of Tag-it™ transponder smart labels in all orientations as they pass through.

Note:

It is important to note that when each antenna is made and tested that it is tested for emissions against the European Specifications EN 300 330, EN 300 683 and the US FCC CFR47 Part 15.

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

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