Tag Designs and Techniques Used in HF RFID Item Level Tracking

The choice and placement of a RFID[1] tag on a product requires an investigation to determine optimal performance. Tags come in many sizes and shapes and their placement is dictated by the product size and the tags orientation with respect to the interrogator antenna. The tag size will often be a performance issue with use on small products and may also require reorientation of the product and the interrogator antenna which may not be an available option. The current technology of HF tags is focused on the mass production of low cost paper thin tags that have maximized read range performance perpendicular to the broad plane of the tag. These tags are 2D in nature and vary in size dependant upon layout and the chip capacitance of the RFID chip chosen. An alternative tag that incorporates a ferrite core offers other options in that it allows for maximum read range normal to the small aperture of its geometry. Incorporating both these tag designs for use within the RFID architecture allows for flexibility of product placement and orientation while maintaining optimum performance.

A RFID system[i] consists of a host system and RF components (Figure 12). The RF components consist of an interrogator (reader and antenna) and tags. The purpose of the interrogator is to communicate to the tags in the field and to also (for passive systems) power the tag through the transmitted RF signal. The interrogator is responsible for;

1. Protocol
2. Tag power
3. Reading tag information
4. Writing tag information
5. Ensure message delivery and validity to host system

The tags are placed on products which the user desires to track. The tag has the capability of storing a unique ID number or user programmed data and can communicate this information to the interrogator. The tag design dictates the limiting parameters of the RFID system such as read range and product orientation.

Two tags currently available are the ferrite core tag (FC) and the planar tag (PC). The FC has been outshined today by the lower cost and paper thin profile of the PT. The FC design incorporates a wire coil that is wound around a ferrite material as shown in Figure 1. This type of design resembles that of the common ferrite core inductor and has a 3D footprint. The inductance of either the PT or the FC is designed to resonate with the internal capacitance of the RFID IC. The ICs available for HF RFID are most commonly offered with a capacitance of 23pF and models with 97pF are also available. The Q of the inductors/coils in these designs must be adequate to provide both efficiency and functionality within the system. The Q is directly related to read range performance but should not be so high as to limit the required system bandwidth or manufacturability of the product.

---

[1] ISO 18000-3 Mode 1 (ISO 15693 – 13.56 MHz)

The resonant frequency of the parallel combination of the IC capacitor and coil inductance is given by:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Knowing the resonant frequency and capacitance the inductor is determined by:

$$L = \frac{1}{4\pi^2 f_o^{\,2} C} \tag{2}$$

One can observe from the equation that coil inductance (L) is inversely related to the chip IC capacitance (C) such that (for a constant f_o) increasing C will decrease L. The intent of the 97pF cap offering by the IC manufacturers was to provide tag producers the option of offering a smaller tag. The smaller tag though will not achieve the same read range (R) since its induced voltage (V_{Tag}) is a function of the tag size and magnitude of the magnetic field strength dictated by[ii]:

$$V_{Tag} = 2\pi f_o NQB(S\cos\alpha) \tag{3}$$

where:

N = number of windings in tag coil
Q = Tag quality factor
B = magnetic field strength
S = area of tag coil
α = tag orientation angle

The magnetic field strength (B) is that generated by the interrogator antenna (IA) and given by:

$$B = \frac{\mu_0 I N a^2}{2r^3} \tag{4}$$

where:

I = IA coil current
N = number of windings in IA coil
a = radius of IA coil
μ_0 = permeability of free space
r = distance from IA

It is also worth noting from equations (1) and (2) that in order to double the read range the current in the IA generated by the reader must be cubed. Since power is proportional to the square of the current it requires the reader power be multiplied by a factor 64 to achieve twice the read range ($P \propto r^6$).

There are pros and cons of the PT and FC designs and one may offer a solution that the other does not. The average cost of the HF PT today is on the order of $0.35 range in high quantities (>500k). Assuming the same quantities the FC which has only a few manufacturers at this time is found to be available in the $3.00 range. With dedicated automated robot assembly the FT is expected to drop below $1 but is not expected to ever be as low as the PT design. In addition to cost, the FT design has a non planar format that one may consider a detriment for external placement but FT designs can be relatively thin (<0.1”). The FC relies upon a ferrite and wound coil that can not achieve the high tolerance of the printed/etched PT. This results in a lower yield or requires a tuning process that may account for the majority difference in cost. Other factors affecting cost, on a lesser degree, are the larger number of required components in the FC (ferrite, wire coil and protective housing). It may be worth noting that the FC with its housing is more mechanically robust than the PT and could be removed from the product without damage. The chip connection to the etched/printed coil of the flexible PT is prone to failure after being removed from the product. Since the FT can be reused it may be a justification for its higher cost.

Maximum coupling occurs when the FC axis is perpendicular (Figure 2) with the IA and for the PT when its broad face is parallel (Figure 3). For optimum read performance the orientation and distance of the tag to the IA and other tags are critical. As the tag deviates off of the maximum coupling orientation (Figures 4 and 5) the coupling level to the IA decreases and approaches zero when they are 90° to that of there maximum orientation. Stacking PTs in close proximity such that the broad faces are parallel also degrades performance. The same is true for the FC when they are stacked along a common axis. The mutual coupling of the tags influences the inductance value of the coils and shifts the resonant frequency of the tags LC circuit which results in degraded performance. It is worth noting that there is not a noticeable reduction in read range until either tag design is rotated beyond 45° to that of the normal and that a reduction to half the max read range only occurs beyond 80°.

Tests were recorded on various tags designs and are summarized in Table 1. Tests performed with 1 Watt (RF output) reader and a 240x340mm IA. PT dimensions are that of etched/printed copper coil (antenna inlay). The FC read heights are referenced to bottom of core. The read range represents the average of 5 randomly chosen tags and there was shown to be less than a ±0.25” fluctuation among similar tags in measurements. All tags incorporate identical RFID ICs (internal capacitance = 23pF) from the same manufacturer.

Table 1 – Tag Design vs. Read Range

Tag Type	**Size (inches)**	**Max Read Range (inches)**
PT	3.0 x 1.8	18.5
PT	0.6 x 1.3	8
PT	0.3 x 1.2	4
FC	0.125 dia x 0.7 long	8
FC	0.250 dia x 0.7 long	12
FC	0.250 dia x 1.8 long	16.5
FC	0.500 dia x 1.8 long	18.5
FC	0.6 x 0.3 x 0.08	9.5
FC (metal design)	0.6 x 0.3 x 0.08	9.5

Tests were also performed on FC tags with the 97pF IC and the identical ferrite rod. Tags with this higher capacitance required a lower inductance (less turns) in order to achieve resonance and were found to have a read range that was 20% lower than their counterparts with the lower internal capacitance.

The FC is suitable for applications with very narrow products and the PT can be placed on the bottom side of a product without causing a tilt in the product placement. The footprint of the FC, even though considered 3D, has the advantage of a better fit to most products. Measurements also indicate the PT has a longer read range relative to the PT with a similar max dimension. Systems with IAs embedded in shelf below product (Figure 6) or IAs in bookend orientations (Figure 7) are commercially available. One can see from Figure 6 and 7 how the product and orientation dictate which tag is optimal for each application. A stent product with a PT applied to the bottom of the product for use with the shelf system is shown in Figure 8. When placed on the shelf the PT is placed in close proximity to the IA and will couple well. Hanging product as shown in Figure 9 uses a FC and as well couples well with the IA in the bookend orientation that is also in close proximity. Note for each case that neither the PT nor FC could be substituted for one another without jeopardizing performance.

Another functionality of the FC is that it can be designed to work over metal and achieve identical read performance. We were pleasantly surprised to find this the case for the formation of eddy currents in the metal was thought to cause losses. We have experienced read performance of systems incorporating IAs tuned over metal much lower and believed the tags would also exhibit degraded performance. Versions of a PT that work over metal are available though have poor read ranges and are not as thin as their non metal counter parts. In practical environments with metalized products one must have an understanding of both the tag and IA performance to fully evaluate the overall performance. Even though we have a tag that performs in proximity of metal there may be significant IA degradation when placed in close proximity to large metal objects. Metal detunes the match of the IA and also acts as a shield which reduces the signal reaching the tag both of which significantly degrade read performance. Tags which are designed to function on metal generally will not function when sandwiched between metal. It is possible to design a system with the proper IA and tag for use with either all metal or all non metal products. Designing a single system to do both metal and non metal products will have limitations in performance. In practice we have found that one must give up performance to achieve functionality with dual metal/non metal systems.

With certain orientations of metal to the tag there is no significant degradation to performance. This was observed when tracking products with foil (metal) lined internal packaging (Figure 10). When the PT was placed orthogonal to the plane of the metal and placed on the bottom of product (PT sandwiched between IA and product) no degradation in performance was noticed with the use of the standard PT. The placement of a PT on the broadside of the product had poor performance regardless of IA orientation for the adjacent product would shield signal. It is also worth noting that the FC metal design performance degraded much faster with rotation when the displacement angle positioned the metal plane between the IA and tag.

A study was performed to identify the optimum tag and location for the stent product shown in Figure 6. Stents and coils were identified to be an ideal product to track based upon their cost, limited shelf life and magnitude of product offerings. They are relatively high cost ($1000 – $2500) items that vary in a multitude of different diameter and lengths. The specific stent chosen was unique in that it was the narrowest of the stent product offerings encountered. It has been found that these products tend to have the same depths (10”) but vary in both height (10” – 12”) and width (0.5” – 1.0”). This product was also chosen for it was found to include foil lined packaging (Figure 12) which would present a challenge to performance.

We have found that stents are stored in an orderly fashion in numerous formats of which the bookshelf orientation appeared to be most prominent and in all cases the product label was always facing out. This format became even more challenging in that it restricts the use of both the PT and FC on the broad face (sandwiching of tags between metal planes significantly degrades performance). It therefore only left the narrow edges for tag placement. There were many FCs found to fit but only one PT was found with a narrow width.

Tag placement of the PT was chosen to be on the bottom horizontal surface positioned in the center. This placed the tag directly over and in close proximity to the IA. The FC was placed along the vertical surface at various positions from top to bottom. We focused on the center for it was considered a practical location for it would perform the same if the product was positioned upside down. Test results with a production shelf system (multiplexed IAs in a planar shelf – Figure 11)[2] indicated that 100% read performance was achieved with the shelf both fully and partially populated with product. Further tests were performed with the product leaning at various angles and the system performed at 100% except for the case where the product was beyond 60° of normal and this only could occur practically if only a few products were on the shelf. Fortunately the manufacturer of the system provides a bookend insert to prevent this from occurring.

With the advent of commercially available cost effective multiplexed IA systems 100% read of numerous tags has been guaranteed in many practical applications. With an understanding of tag orientation and proximity effects different tag formats will offer the flexibility to achieve an optimal solution in a wide range of applications. In addition it has also been proven that products with metalized packaging can be successfully read if properly tagged.

[2] Storage Cabinet with Improved RFID Antenna System – US patent application 20070046552

Ron Marino is currently the Chief RFID Architect at Stanley-InnerSpace and is responsible for development and verification of all RFID products and applications. Stanley-InnerSpace had purchased the rights of patents and technology from RAM Engineering & Consulting, Inc whom he was previously the owner/president. Ron had been a consultant in the RFID field for 8 years and has 10 patents issued and numerous publications. Prior to his involvement in consulting he was the Manager of Research and Development for Radio Frequency Systems and while with RecepTec LLC developed one of the first Satellite Radio (Sirius and XM) antennas for mobile reception. He has been in the RF/Antenna field for over 28 years and is a senior member of the I.E.E.E. Ron was born in New York City and received his B.S.E.E. from the Pennsylvania State University in 1981. He is a Senior member of the I.E.E.E. and can be contacted at ron.marino@ieee.org.

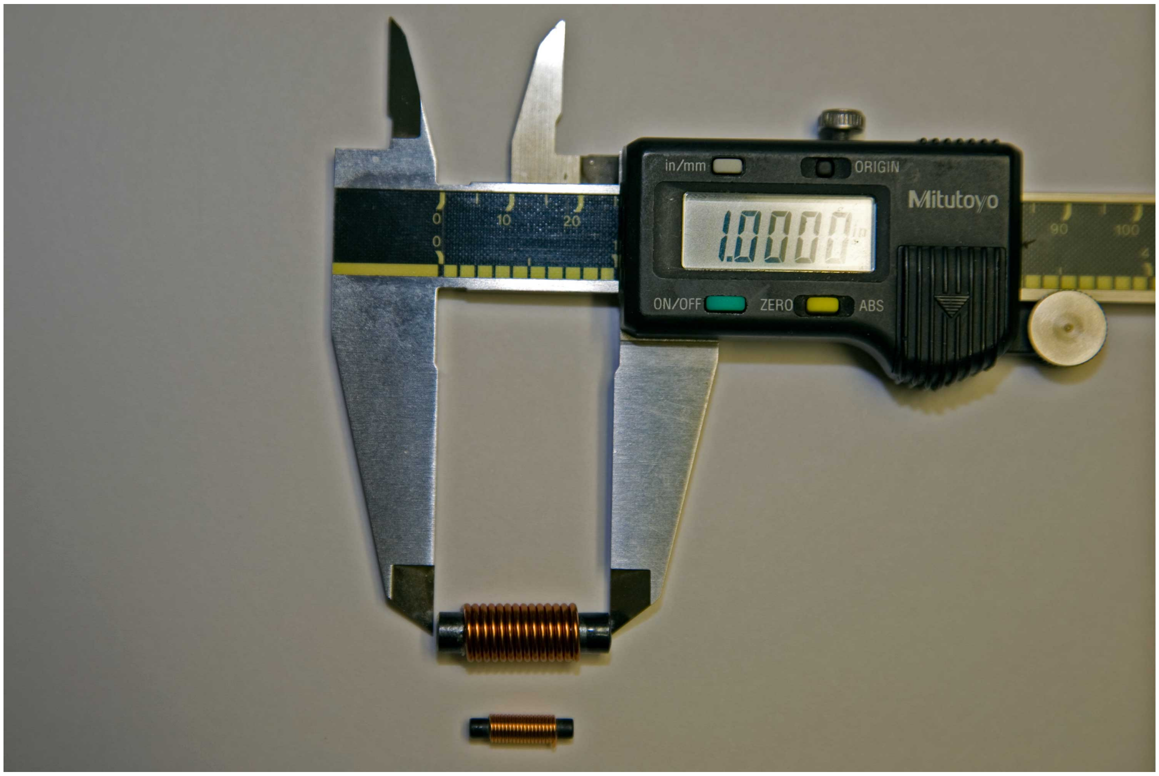

Figure 1
Ferrite Core Tags

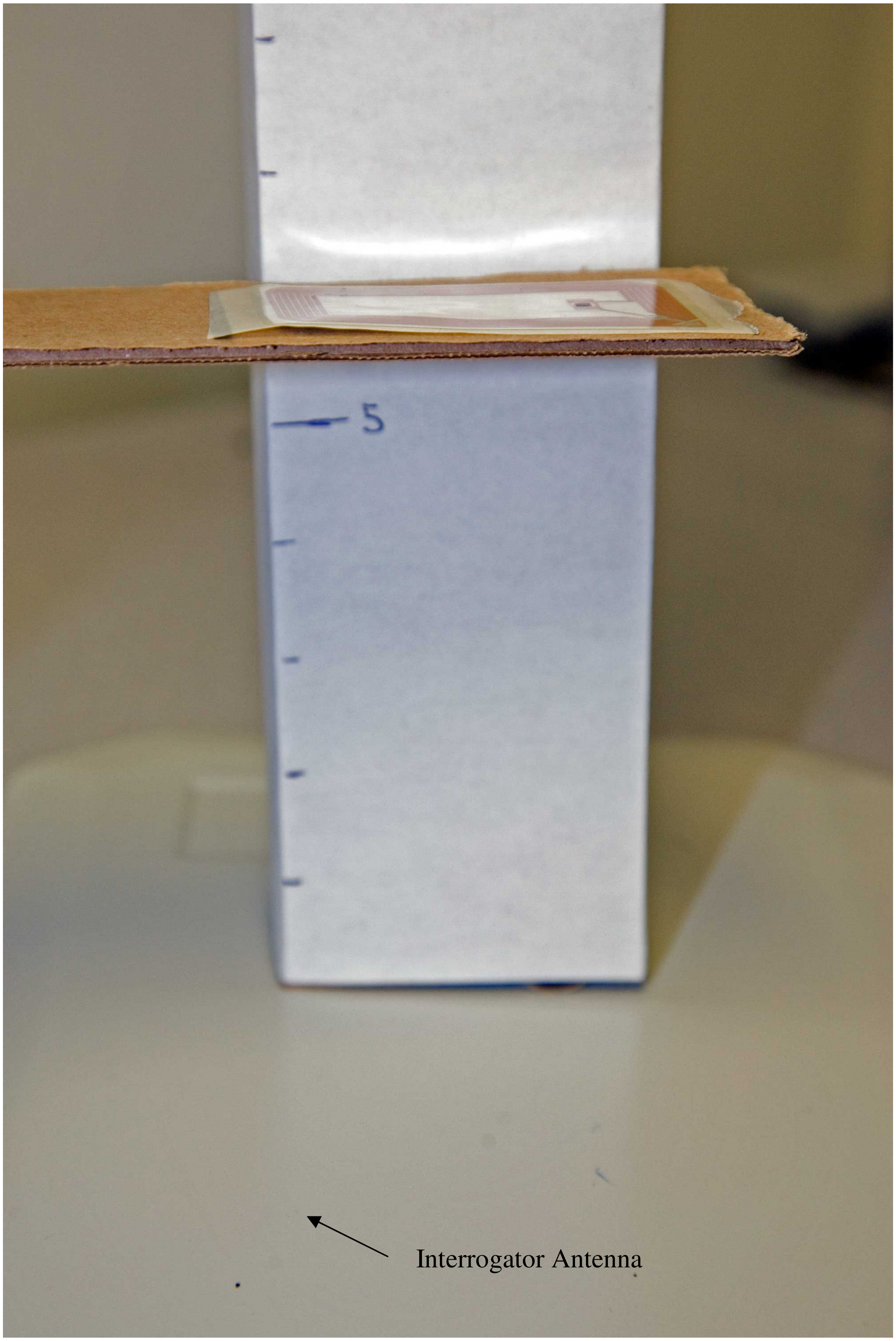

Figure 2
Planar Tag – Optimal Orientation

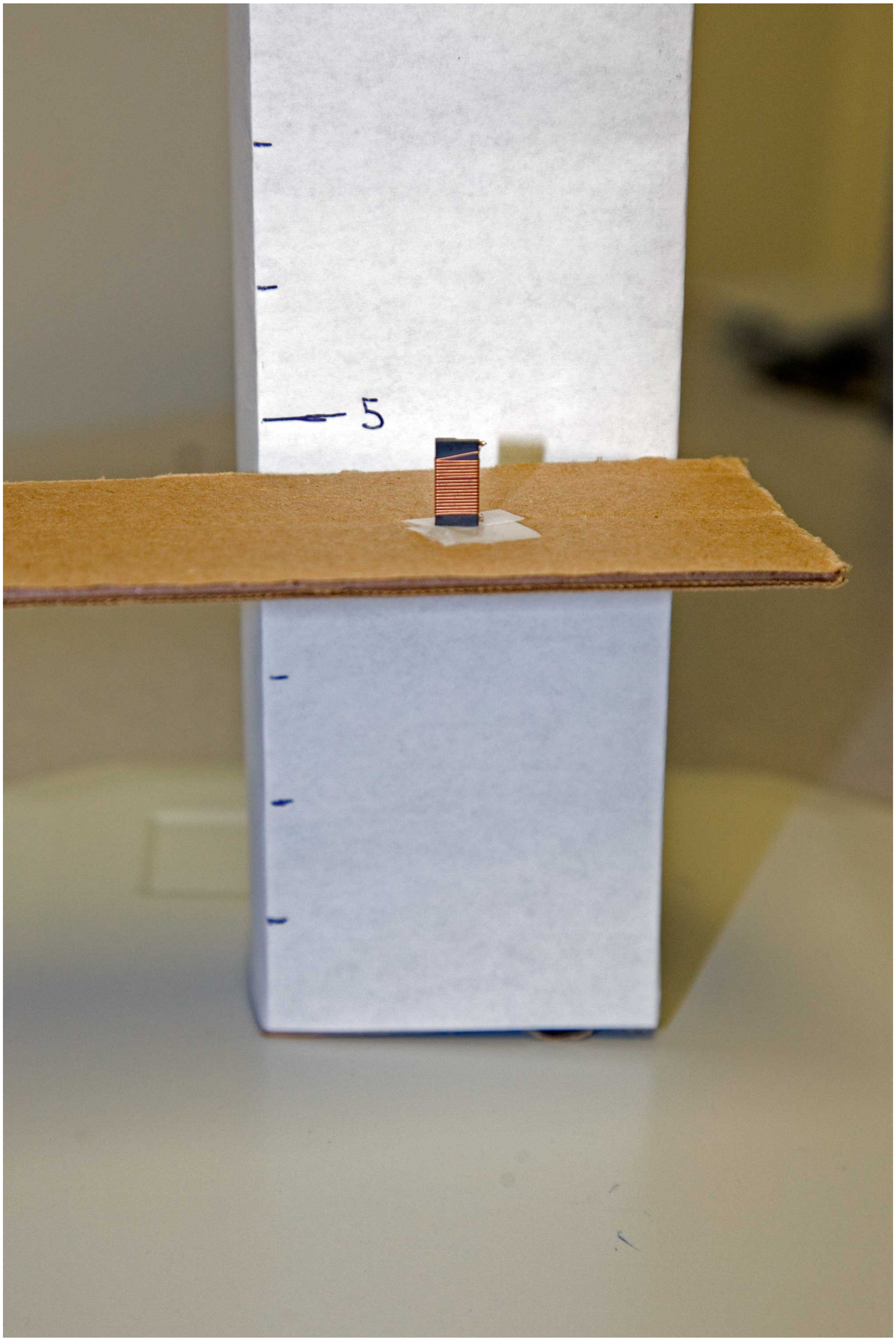

Figure 3
Ferrite Tag - Optimal Orientation

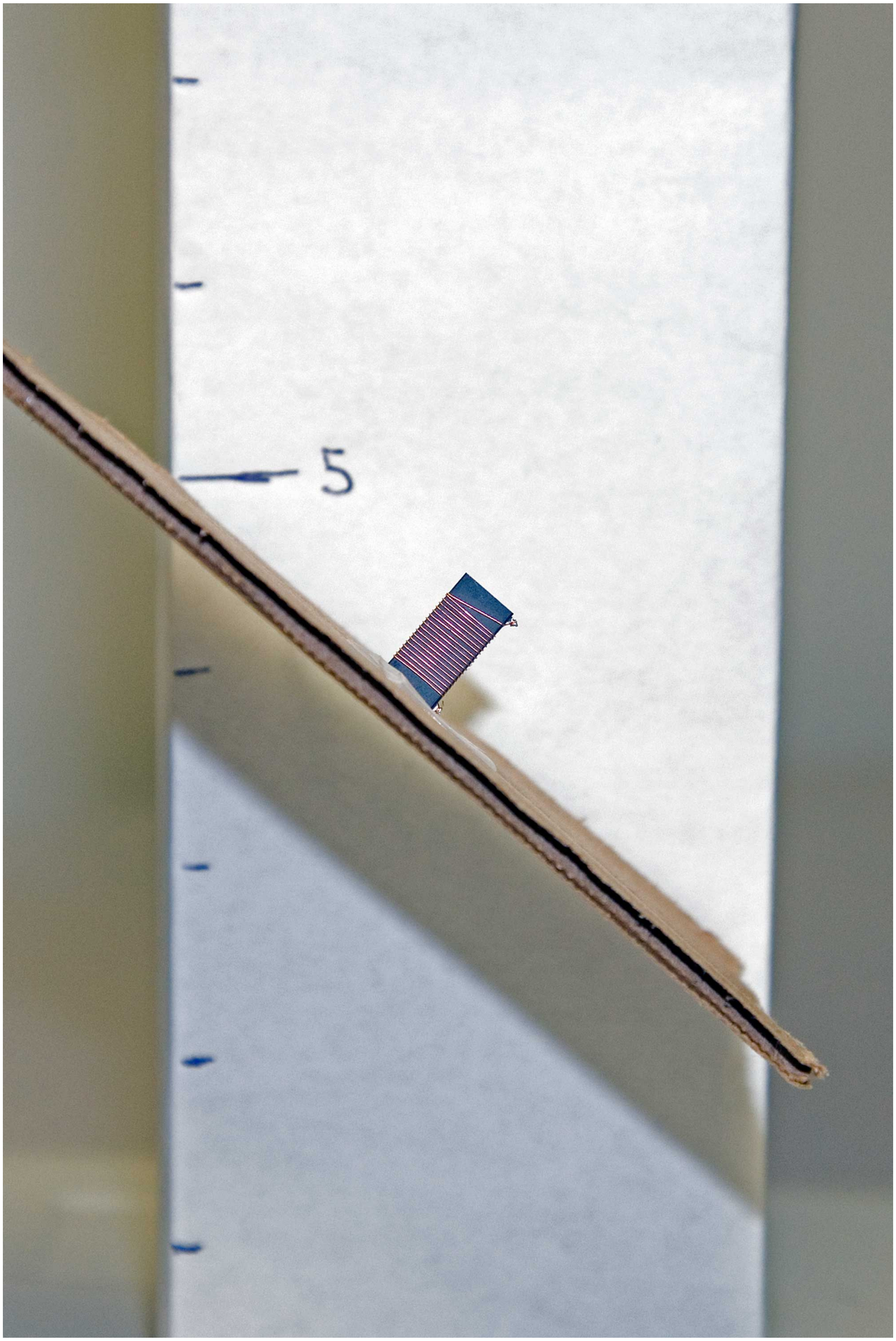

Figure 5

Ferrite Tag Orientation with Rotation

Figure 6
Stent Product Orientation

Figure 7
Hanging Product

Figure 8
Stent Tagging

Figure 9
Hanging Product with Ferrite Tag

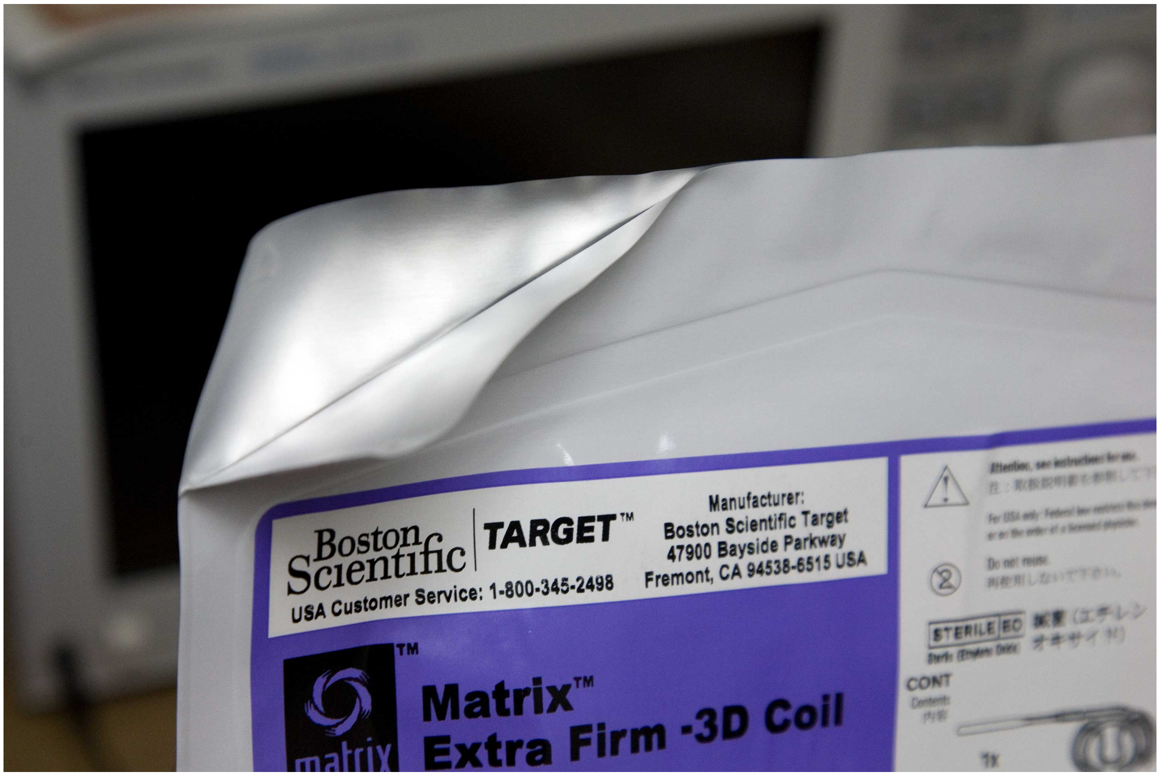

Figure 10
Foil Lined Packaging

Figure 11
RFID Management Inventory Product

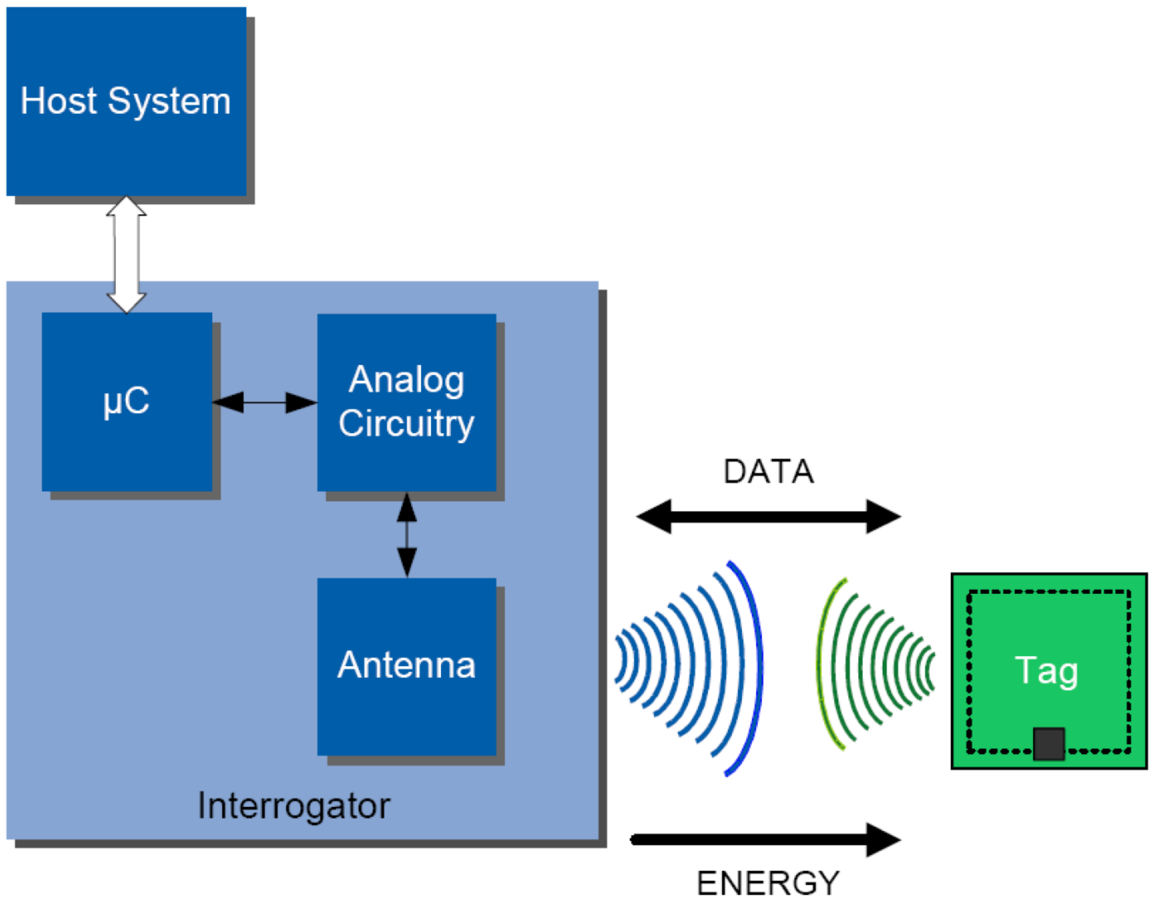

Figure 12
RFID System Components

References

[i] Infineon, Chip Card & Security ICs, SRF 55V02P Short Product Information Ref.: SRF55V02P_ShortProductInfo_2007-06.doc

[ii] Microchip, Youbok Lee, "RFID Coil Design (AN678)", 2002