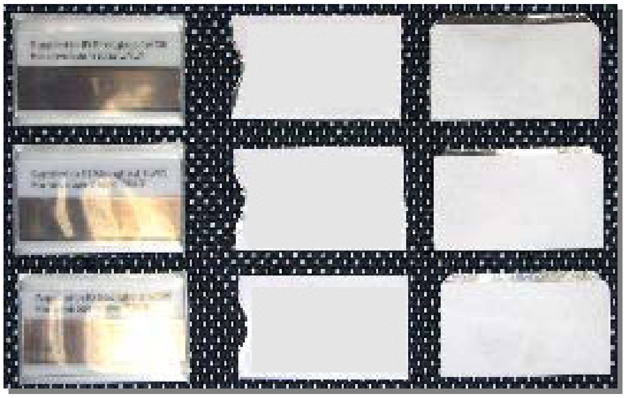
2009

Introduction:

360°RF has been retained to independently perform attenuation testing on supplied sample badge shields over the following frequencies: 13.56 MHz and 800-1000 MHz.

Supplied to 360°RF:

Three each of the following (as shown at the right, left to right):



- **RFID Tags:** Electronic Product Code (EPC) Gen-2
- **Portrait shields**
- **Landscape shields**

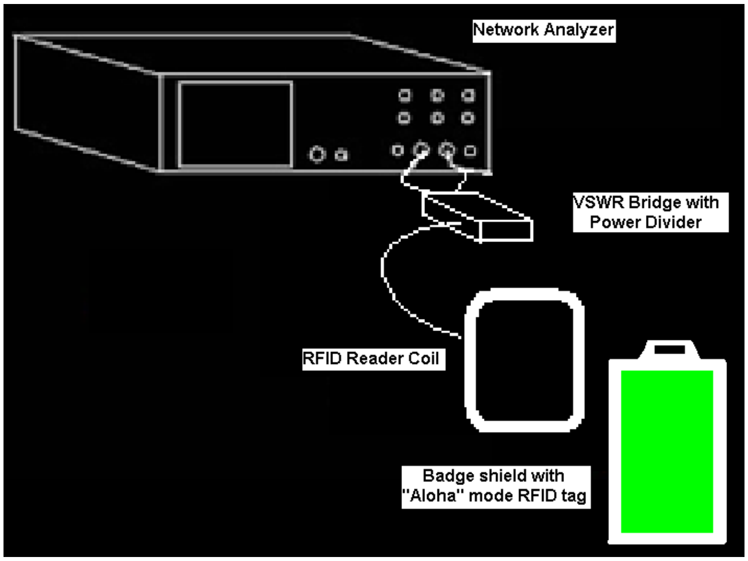
Test Equipment

- Rohde & Schwartz FSL Analyzer w/VSWR Bridge & Power Divider
- 13.56 Loop Antennas, 435 and 915 MHz Dipole-Emulation Antenna (Log Periodic)
- Hewlett Packard 8753A Vector Network Analyzer (VNA)
- Replica EPC Gen-2 Antennas

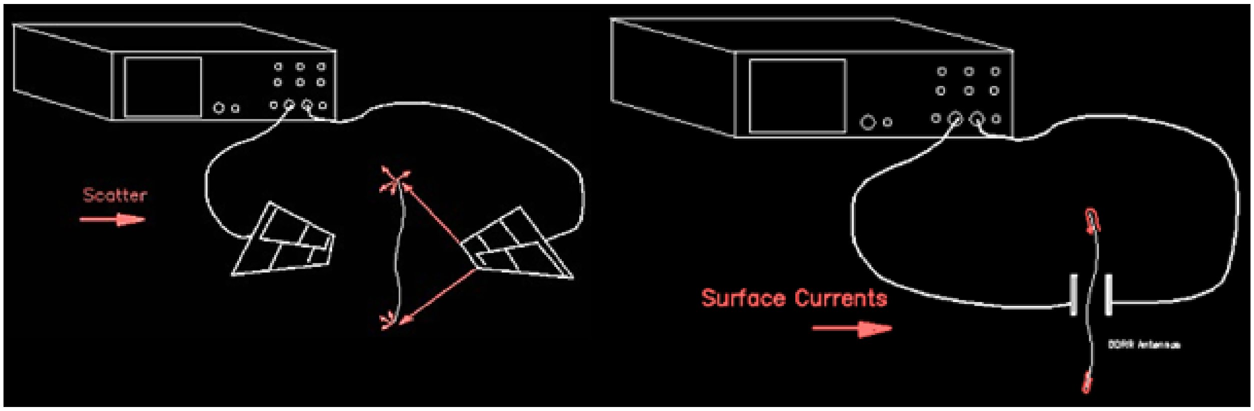
The return loss of the test antenna was monitored with the analyzer, its built-in tracking generator, and a resistive bridge, which allowed observing the precise effects of a test shield sample between the reader and a badge. Further, the HP8753A VNA was used to measure the attenuation between an emulated badge reader antenna and replica EPC Gen-2 antennas.

Test Equipment Setup for Test Antenna Frequency Response Measurements

The effect upon the frequency response of the test antenna was measured using the test setup shown below with the R&S FSL analyzer.

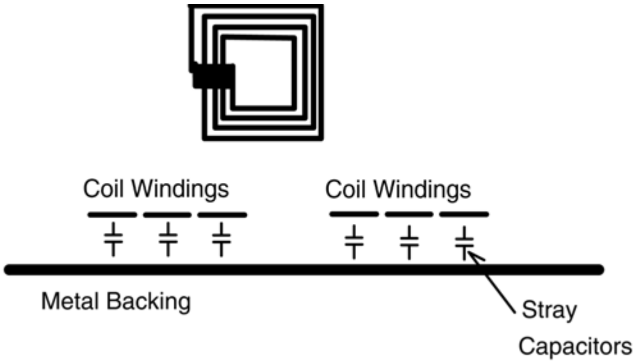


The following test setup, again with the R&S FSL analyzer, was used to measure the isolation that a shield provided between two test antennas.



For the above tests, we used our precision proprietary log periodic antennas for the 915 MHz measurements, which are representative of the performance from 800 through 1000 MHz. A set of specially designed loop antennas were utilized for the 13.56 MHz measurements.

Notes:
In the drawing at right, note that as a metallic surface approaches the tag, the capacitance effects shorts out the turns in the tag's antenna. When the tag is excited with a swept signal, there is a strong response at 13.56 MHz. As the metal tray approached the tag, the frequency response rose to 16.4 MHz. The proximity of the metallic tray retunes the coil in the RFID tag by “shorting-out” the coils.



Thus, the effect of the metal tray was to make the tag go from a strong 13.56 MHz response to a weak 16.4 MHz response. The read range went from 5 to 6-inches in open air at 13.56 MHz, to 1/4th inch at 16.4 MHz. This ~1/4" range would be the maximum range, regardless of power and other variables. For example, with very high power, the power source alone would create enough noise to jam efforts to read the tag.

Conventional RFID readers do not scan frequency, they expect the tag to be at 13.56 MHz. At 13.56 MHz, the tag was virtually unreadable even when placed against the reader. In normal use, we were unable to get hits on the tag. However, 360°RF was able to get a single hit only after numerous attempts with unconventional techniques, tags, and placement. That one hit was achieved using a proprietary tag on the backside of the holder with a reader on the corner of that tag. This bypassed the spacing from the plastic lid putting the reader in intimate contact with the tag.

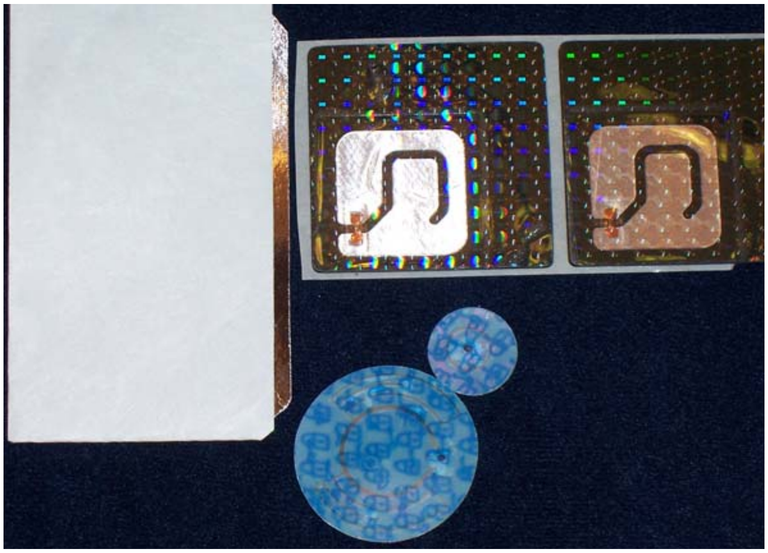
This detuning effect reduces the tag's response signal about 30 dB or 99.9% lower. Thus, placing the <u>shielding material only below the tag</u>, reduces the tag's signal about 30 dB.

800 To 1000 MHz Test Results

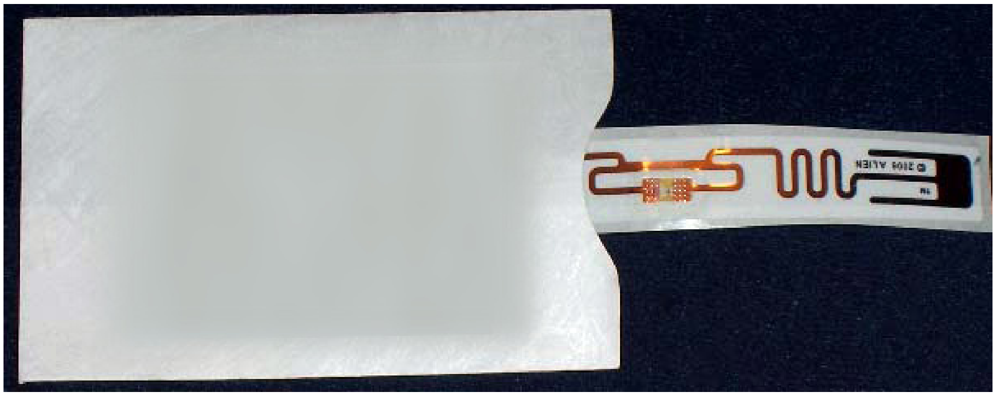
When a tag was completely within either type of envelope and located close to the Reader antenna, the tag antenna response was not detectable using our test setup emulating a conventional reader. The following paragraphs describe test results for various types of tags.

Dipole type tags

Dipole type tags are used at 435 MHz, 915 MHz, and 2.4 GHz. 435 MHz tags are quite large and far too large for badge type use. Even 915 MHz dipole tags are marginal in badge applications.

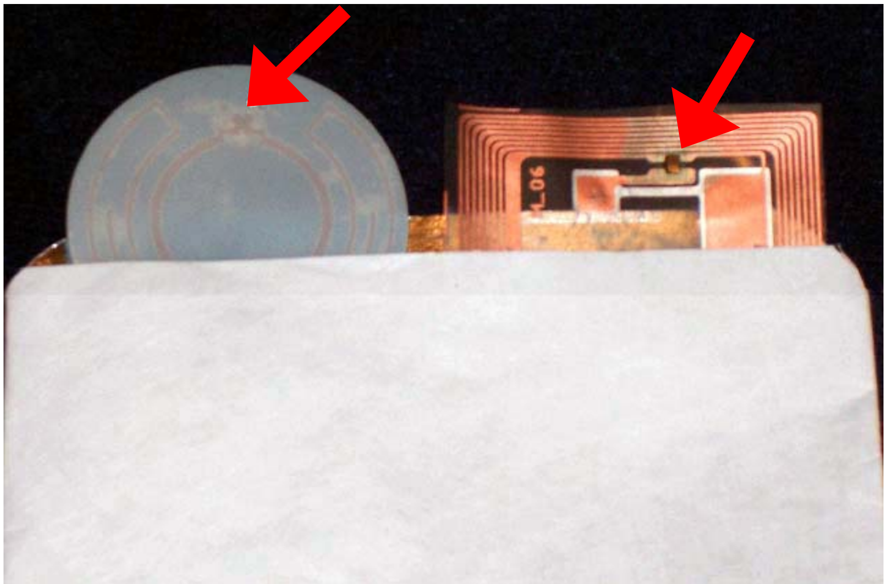


In the following photo, about 40% of a 915 MHz dipole tag has been placed inside the shielding envelope. Detection range was reduced 50%, but the tag was still quite detectable. If the tag is inserted about 60% so that the chip area is under the shielding, the tag is no longer detectable.



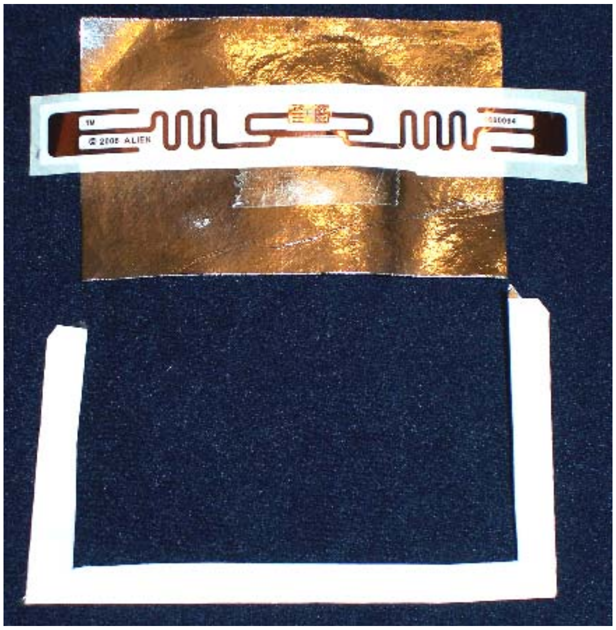
Round Tags

When partially inserted, shielding effectiveness again depended on the relative position of the chip. When just portions of the loop were in the envelope, detection range was reduced, but the tag was detectable. If more than 50% of the loop and the chip area were in the envelope, the tag was not detectable.



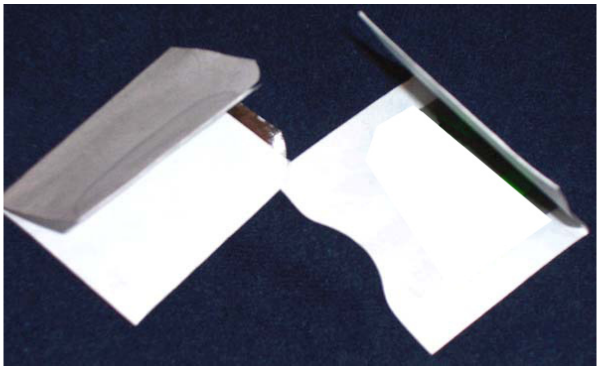
Degraded Envelopes

With the edges completely removed, and just the top and bottom foils over the tags, the shielding was still 100% effective at 915 MHz; see the photo at right. The effective power level for this measurement was -10 dBm from the FSL analyzer.

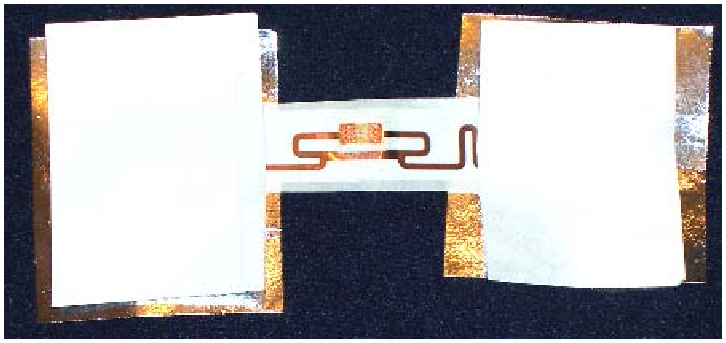


When only one side of the foil was used and the tag simply placed on top, shielding was still quite good. If the tag was 'curled up a bit', a short range detection could sometimes be seen, but shielding effectiveness was still quite good; see the photo at left.

One way the envelope could be degraded to the point where dipole or loop type tags could be read is by repeatedly folding the envelope in the middle until the aluminum foil cracks. If the aluminum foil broke completely along the fold, then electrically it would look like the photo below and lose shielding. However, the envelope would have to be folded literally hundreds of times to break the foil in this manner.



If the shield was cut in the middle leaving the chip area exposed, detection range was reduced 50-75%, but the tag could still be detected; see the photo at right. This would be analogous to the “distressed” envelope that has been folded in half so many times that the foil has broken between each half of the envelope (as noted above).



13.56 MHz Test Results

Test results for 13.56 MHz generally followed those found at 915 MHz; when the shield covered the majority of the tag's antenna area including the chip, the tag could not be detected. The effective power level used for the 13.56 MHz tests was -10 dBm. Test antennas were specially-designed loops.

Effects of Shields Upon Tag Detection Due to Detuning of Badge Antenna

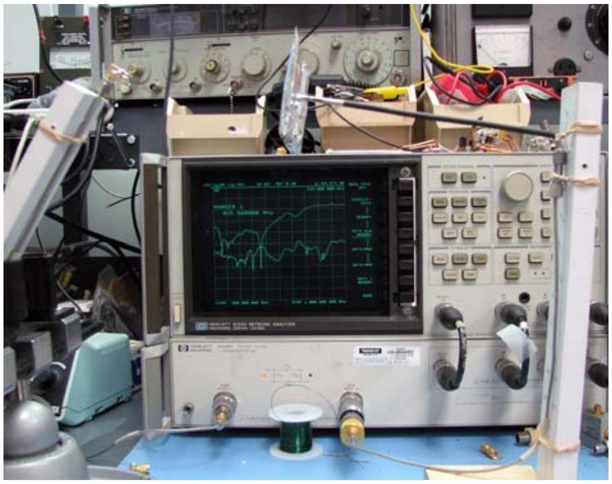
360°RF evaluated the effect of the shielding envelopes upon a badge. The following photos show several antennas that were fabricated for these measurements that emulate disclosed EPC Generation 2 RFID antennas used for secure applications. See the photo below (excerpted from public domain design disclosures).

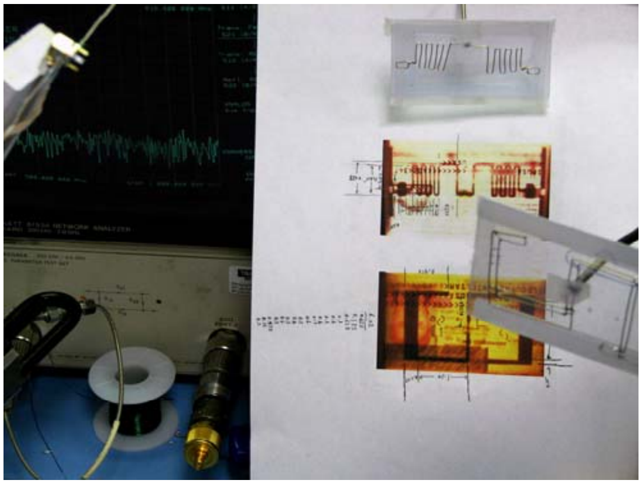
Design-1 (below) and Design-2 (right) RFID antennas

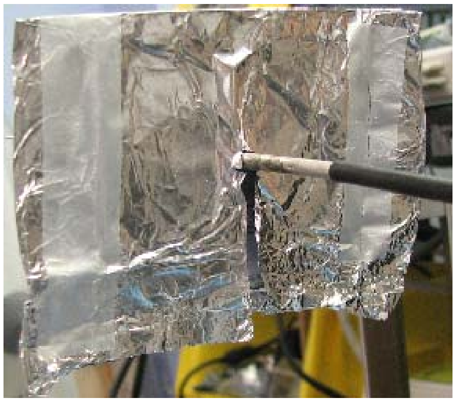
To simulate and evaluate attenuation effectiveness within a shield, we built copies of these antennas and inserted them into supplied shielded envelopes/ sleeves.

Each of the simulated badge antennas were built from copper wire placed within two sheets of clear acetate plastic (to simulate the badge material itself). The acetate plastic was found to detune the antennas slightly, reducing the resonant frequency by 1% to 2%. Each antenna was then tuned for lowest return loss at 915 MHz when sandwiched within the plastic sheets.

The test setup is shown below. We used a resonant half-wave dipole antenna to simulate the Reader's antenna, mounted on a length of plastic material and suspended above the plastic support such that there was no noticeable detuning effect caused by the plastic support upon the dipole. The test Badge antenna was then suspended approximately 12 inches from the dipole antenna. The path loss from the dipole antenna to the badge antenna was then measured using the VNA. Because the simulated Badge antennae had a feedline in the center

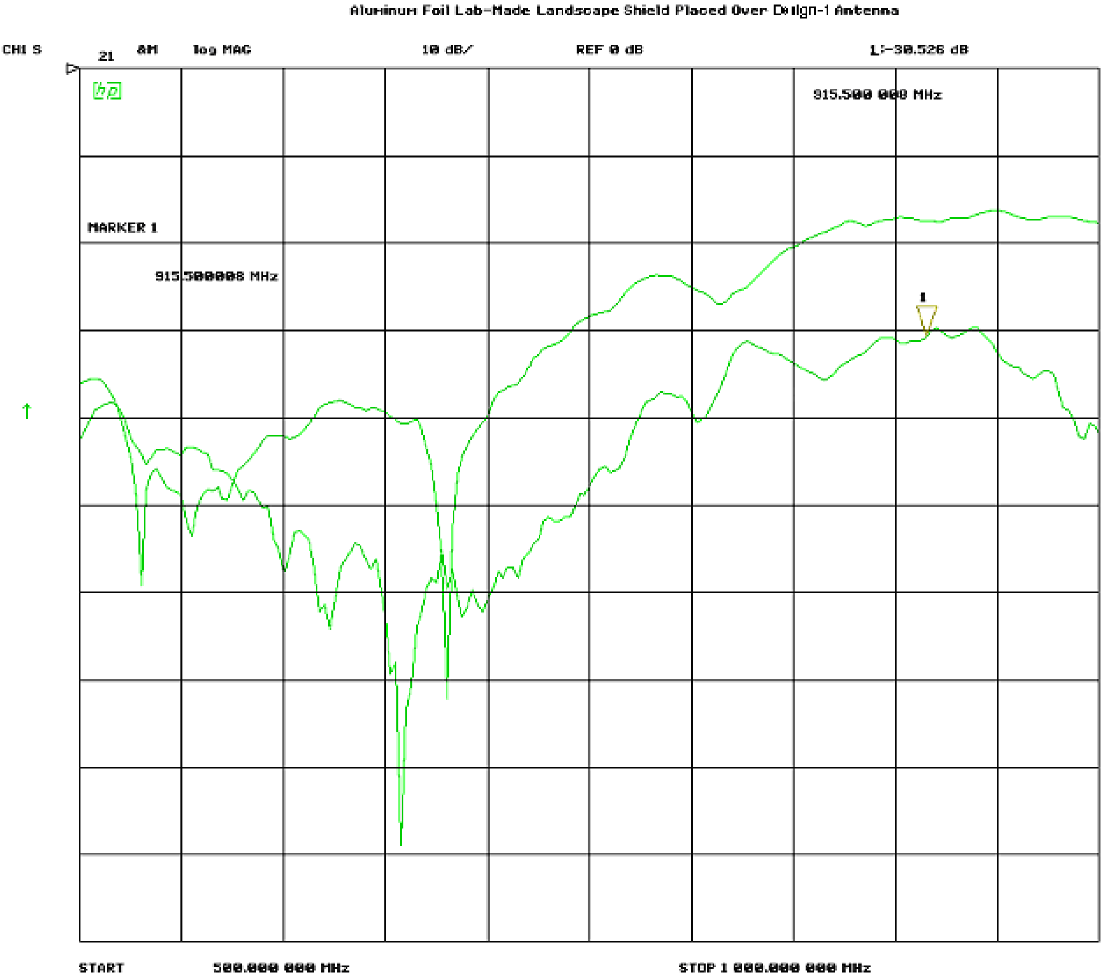




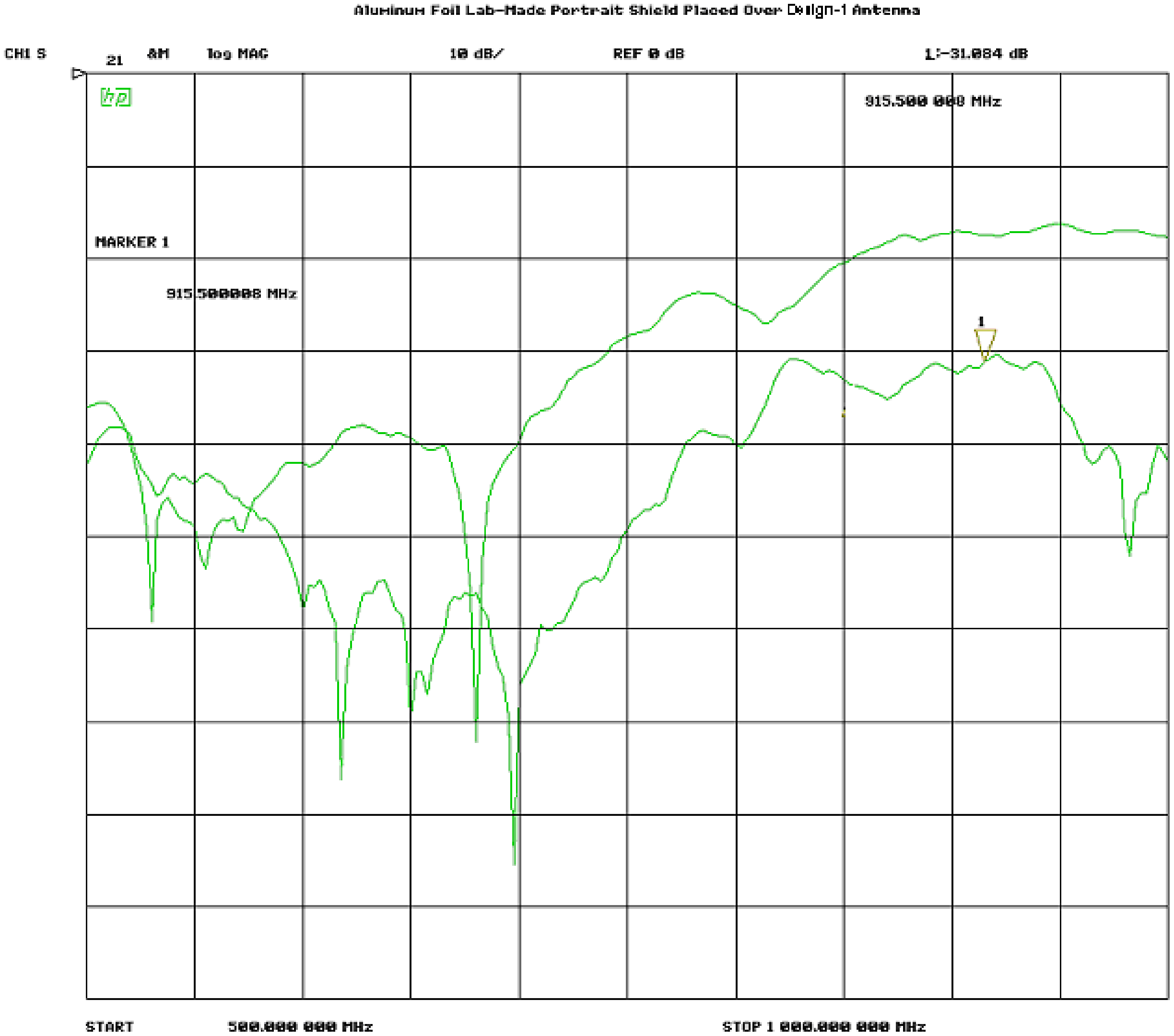


of the “Badge”, we simulated the shielded envelopes by wrapping each antenna with a shield made from aluminum foil with the appropriate edge open to simulate either type of envelope. The foil was folded over on the closed edges and taped shut. Where the feedline protruded through the back of the foil “envelopes”, the feedline sheath was insulated to prevent contact with the foil “envelope”, thus more-closely simulating the actual shielding envelopes. The photo at right illustrates the concept (Landscape foil shield placed over the Design-1 badge antenna).

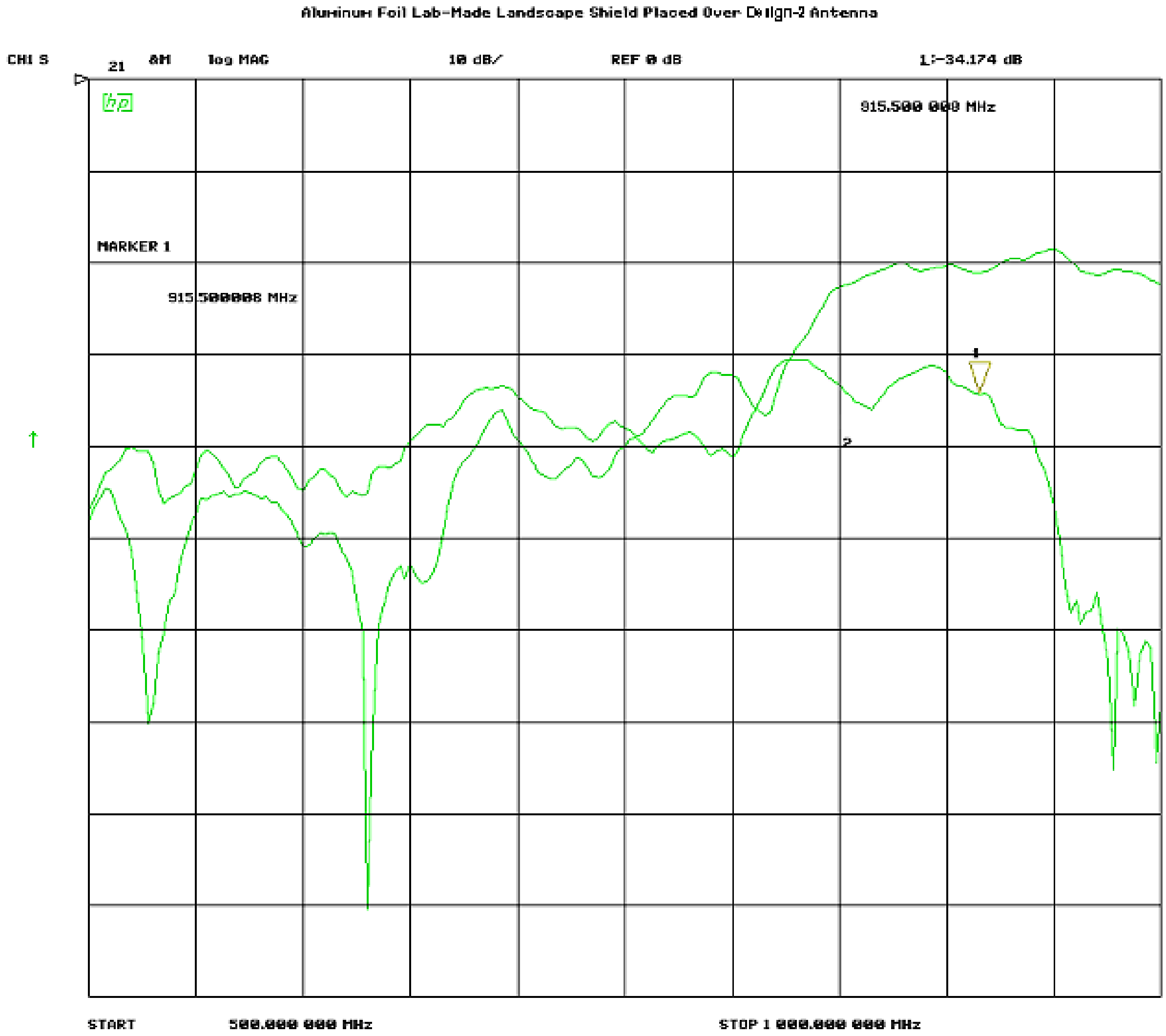
The four following plots show the measured attenuation for each antenna at a spacing of about 6 inches, when placed within the provided shielded envelopes (two plots for each antenna, one for each envelope type). The top trace in each plot is the reference path loss without the shielding envelope; the difference between the top trace and lower trace is the measured path loss in decibels. The maximum measured attenuation over 800-1000 MHz was about 30 dB with an antenna within a supplied envelope shield.



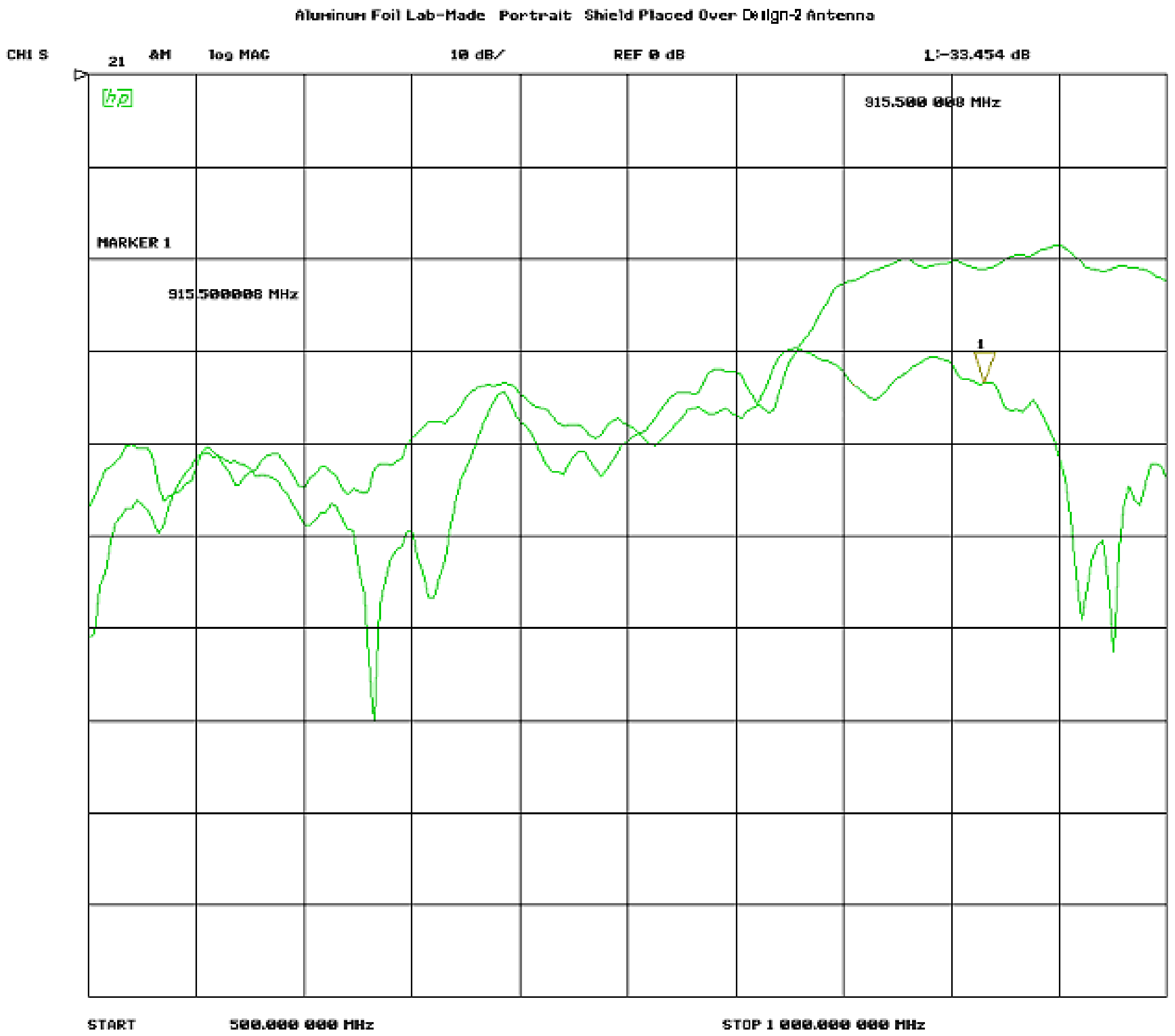
The plot above shows the transmission loss of the Design-1 RFID badge antenna with the aluminum foil Landscape shield. At 915 MHz the attenuation appears to be approximately 14 dB.



The plot above shows the transmission loss of the Design-1 badge antenna with the aluminum foil Portrait shield. At 915 MHz, attenuation appears to be approximately 14 dB.



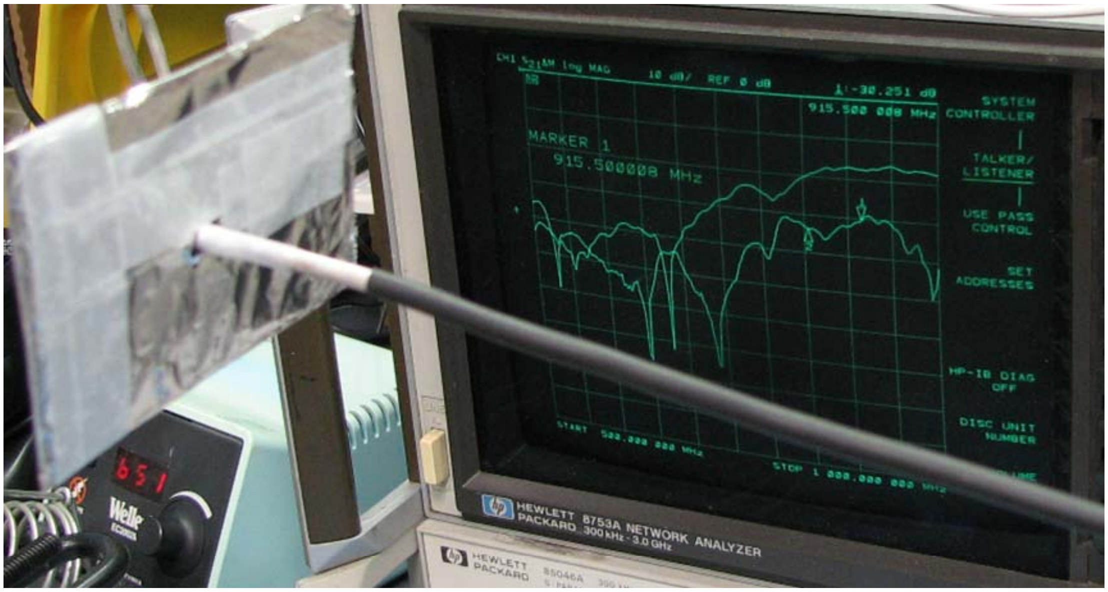
The plot above shows the transmission loss of the Design-2 RFID antenna with the aluminum foil Landscape shield. At 915 MHz the attenuation appears to be approximately 13 dB.



The plot above shows the transmission loss of the Design-2 RFID antenna with the aluminum foil Portrait shield. At 915 MHz, the attenuation appears to be approximately 12 dB.

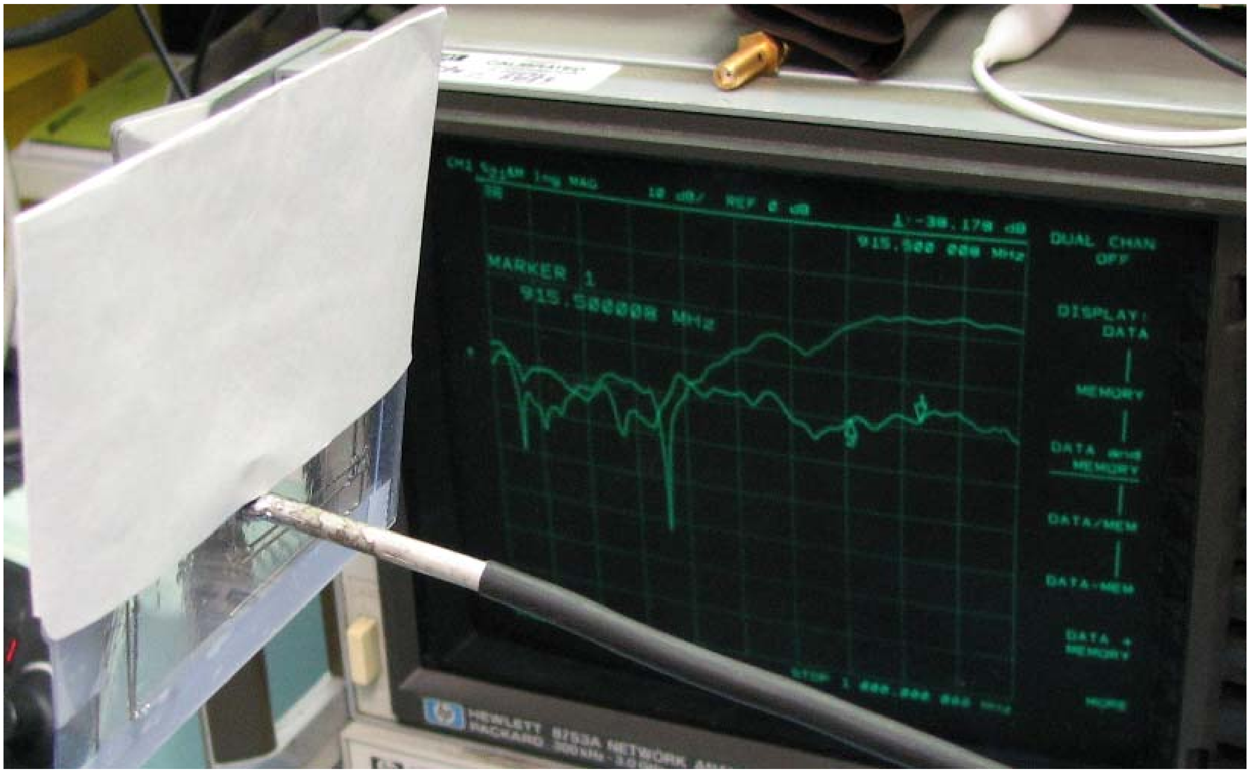
To summarize, the aluminum foil simulated shielded-envelopes showed a maximum of about 14 dB attenuation and as low as 12 dB.

We further measured the attenuation if the foil was wrapped completely around the badge antenna; the following photo is of that test setup. It can be seen from the screen of the VNA that the attenuation is still in the 12 - 14 dB range, no better than the simulated shielded envelopes. This indicates that there is some RF energy being picked up on the semi-rigid coax sheath of our test antennas, allowing RF energy leakage to the antennas inside the shielded envelopes. Therefore, our test setup above may be presumed to be providing “worst case” results.

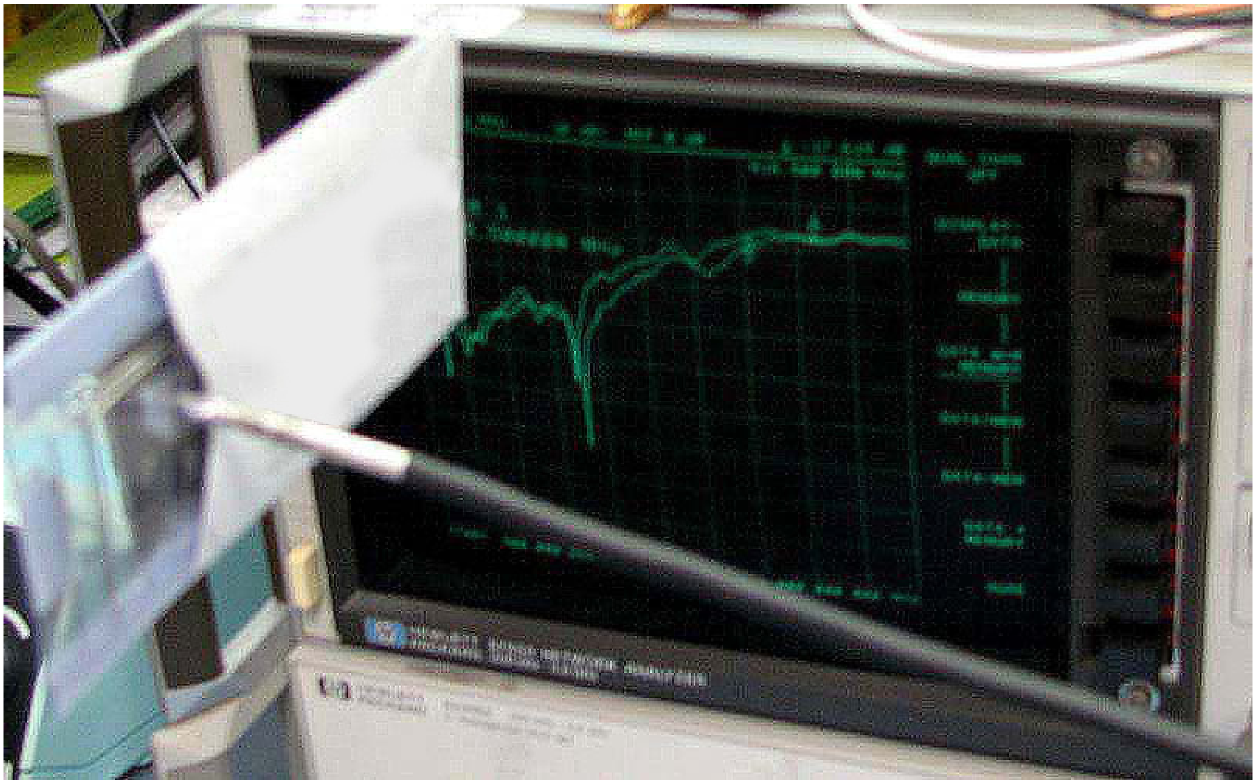


Above, the PC "badge" antenna has been entirely wrapped with aluminum foil with only the feedline protruding through a hole in the foil. Note that the transmission loss is approximately 14 dB.

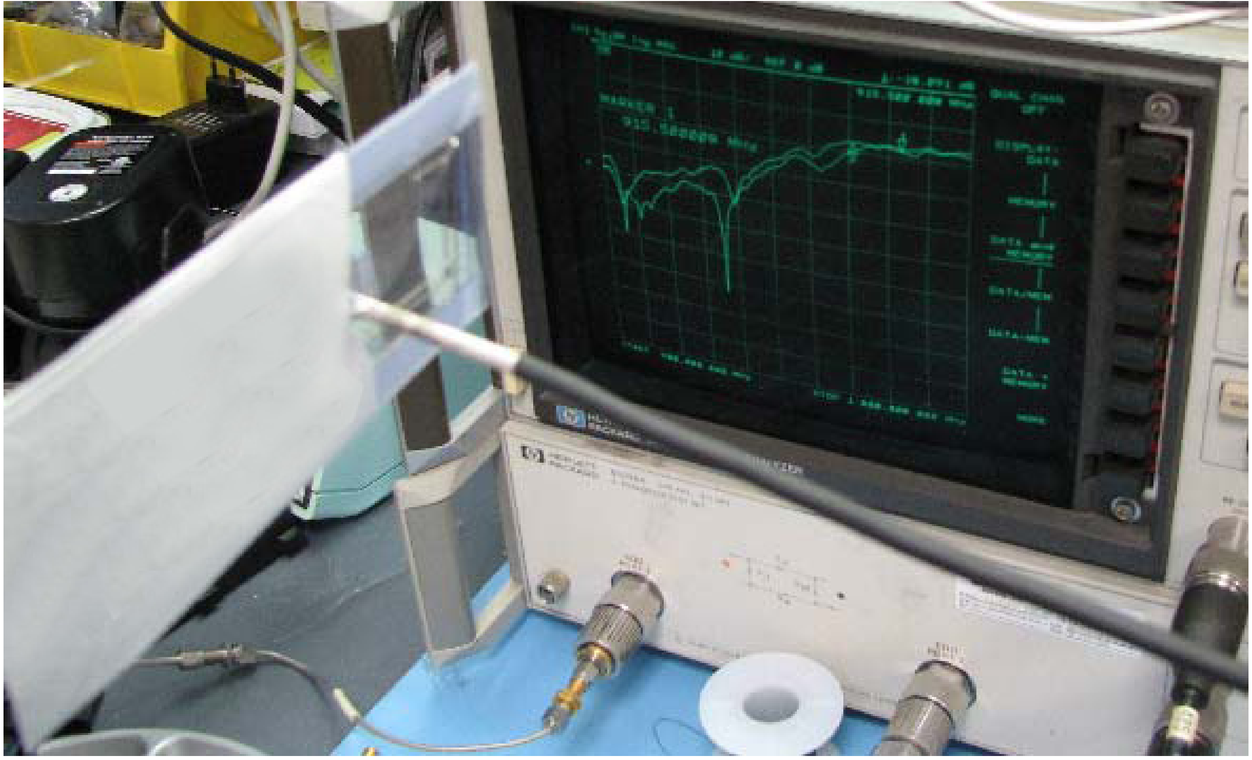
We next tried the supplied shielding envelopes, placed over the Design-1 RFID badge as far as they would go without tearing the envelope to clear the feedline; see the following photos.



The photo above shows the Landscape envelope placed over the Design-1 RFID badge antenna down to the feedline; notice that the attenuation on the VNA now shows approximately 20 dB, significantly higher than the earlier plots.



The photo above shows the portrait envelope slipped over the Design-1 RFID badge antenna to the feedline; note that the VNA now shows almost no attenuation at all.



The photo above shows the attenuation with the shielded portrait envelope slipped over the Design-1 RFID badge antenna from the other side compared to the previous photo; again, the VNA shows almost no attenuation.

The above tests demonstrate an electromagnetic principle of closely-coupled antennas and nearby objects of the same approximate size: the object, itself, acts much like an antenna and couples the energy that it intercepts to other nearby objects; in this case, the Design-1 RFID badge antenna. The reason for the relatively large amount of attenuation seen with the Landscape envelope is because the envelope is covering both dipole elements of the Design-1 RFID badge antenna, thus causing a cancellation of RF energy being received by the antenna itself. In the prior tests using the aluminum foil “envelope”, the foil intercepted and transferred a significant portion of RF energy to the badge antenna within the envelope. Return loss plots of the shielded badge antennas showed that with the foil envelopes completely encasing the badge antennas, the antenna were detuned to the point where their resonant frequency was shifted below 500 MHz, leaving a return loss at 915 MHz of virtually zero dB; that is, the antennas should have been almost totally inefficient and incapable of receiving any 915 MHz RF energy to the feedline.

However, our earlier tests described at the beginning of this report showed that when the feedpoint of the antenna is exposed (or rather, incompletely shielded), then the antenna will still pick up significant amounts of RF energy and transfer it to the feedline.

The Effect of Reader Transmitter Power and Antenna Gain

Experiments with compatible readers were reported to be unable to read the supplied EPC Gen. 2 tags with the shielding envelopes (portrait or landscape) over the tags. However, at significantly higher output power, or with higher gain antennas, it may be possible to obtain reads, particularly if the tag is able to operate efficiently when its antenna's resonant frequency is radically shifted due to being shielded within the envelope (e.g., 915 MHz tags read at below 500 MHz). The foil-lined envelopes cause severe detuning of the tag’s antenna and essentially shield the tag’s microcontroller from the reader, thus reducing the possibility of a successful tag read.

Most readers on the market today have adjustable output power levels, some as wide as +5 dBm to the legal limit of +30 dBm. Some, intended for short range applications, have a lower maximum output power capability. The maximum allowable Effective Radiated Power is +36 dBm (four watts). This can be achieved by a combination of transmit power plus antenna gain; for example, if the reader’s maximum output power capability is +23 dBm, then an antenna with gain of 13 dBi may be used. Or, if the reader is capable of +30 dBm output power, the antenna gain may be as high as 6 dBi.

Many readers claim a read range from 20 to 30 feet, depending upon their set transmit power and internal receiver sensitivity. A distance of 10 meters (32.8 feet) will present a path loss of about 52 dB at 915 MHz. Halving this distance drops the path loss by about 6 dB. A shielded envelope providing 30 dB of signal attenuation effectively will reduce the maximum read distance from 10 meters to approximately 0.3 meters, or about 1 foot. To double this distance, it would be necessary to increase transmit power or antenna gain by four times.

However, other issues come into play with passive (battery-less) RFID tags: their operation depends upon receiving sufficient RF power from the tag reader so as to “power on” the tag’s internal circuitry. Thus, the actual maximum distance between reader and tag may be very much less than path loss calculations might indicate, since the received RF power at the tag must be strong enough to turn on the tag’s circuitry.

Readers on the market are available with a built-in 6 dBi circularly-polarized antenna. Circular polarization is commonly used so that tags may be read in any orientation. The 6 dBi antenna gain effectively doubles the maximum read distance; i.e., commonly-claimed read distances when the Reader is equipped with a 6 dBi circularly-polarized antenna are 30 feet whereas most Readers with lower- or unity-gain antennas list a read range of 10 to 20 feet. Still other readers are available with "high-gain" linearly-polarized antennas but those are intended for applications such as within a warehouse, where the orientation of the tag can be controlled as a product is moved through the reader's interrogation area.

The purpose of these high-gain, linearly-polarized antennas is to increase the read distance, both so that more tags may be read as well as to increase the time during which a tag is present within the interrogation area of the reader (due to the longer read range). They are generally not practical for the case of a badge-type tag worn by a person since the orientation of the badge, with respect to the reader's antenna, cannot be controlled or anticipated. Linear polarization means either horizontal or vertical polarization, such as a badge with a dipole antenna being worn horizontally or vertically.

If the reader antenna, and the tag antenna, are cross-polarized (for example, the reader's antenna is vertically-polarized whereas the badge's antenna is horizontally-polarized), then the attenuation between the two increases by 20 or more dB, resulting in a corresponding decrease in read distance.

In contrast, the attenuation between circular polarization and either horizontal or vertical polarization is, at worst, only 3 dB. Thus, readers intended for badge identification use will more often be equipped with a circularly-polarized antenna.

The ultimate limitation is that regardless what antenna gain or transmitter power is used by the reader, it is limited, by law, to +36 dBm (4 watts).

In the case of a hostile interrogator, a 6 dBi circularly-polarized antenna can be contained in a package roughly 11” by 1.5” thick such as within a briefcase. Two such antennas might be fit within carry-on luggage, increasing the gain by 3 dB. A determined hostile interrogator would also not be limited in available transmit power; it would be possible, for example, to build or buy amplifiers to increase the reader's transmit power by as much as 10 dB (ten times).

A 6 dBi-gain linearly-polarized yagi antenna for 915 MHz would have 6 elements and be about 24 inches long and 7 inches wide although only an inch or so thick. An 11 dBi yagi antenna would have 13 elements and be about 4-1/2 feet long (and also about an inch thick). This size antenna would clearly not be feasible for a hostile to carry around who intends to surreptitiously interrogate tags, although the 6 dBi circularly-polarized antenna certainly would fit within a briefcase or even a backpack.

Conclusion

We found that the shielded envelopes readily provide between 12 and 14 dB attenuation when an antenna is placed inside the envelope and connected to the outside world through a coaxial cable. It can be expected that a badge, without such a feedline, will be shielded significantly better, 30 dB or more. Generally speaking, any metal foil based shielding envelope should exhibit the above noted effects due to inclusion within a conductive metal foil.